Stormwater Quality Management in Rhode Island

Elizabeth A. Scott
University of Rhode Island

Follow this and additional works at: http://digitalcommons.uri.edu/ma_etds
Part of the Environmental Indicators and Impact Assessment Commons, Natural Resources Management and Policy Commons, and the Oceanography and Atmospheric Sciences and Meteorology Commons

Recommended Citation

This Thesis is brought to you for free and open access by the Marine Affairs at DigitalCommons@URI. It has been accepted for inclusion in Theses and Major Papers by an authorized administrator of DigitalCommons@URI. For more information, please contact digitalcommons@etal.uri.edu.
STORMWATER QUALITY MANAGEMENT IN RHODE ISLAND

BY

ELIZABETH A. SCOTT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
IN
MARINE AFFAIRS

UNIVERSITY OF RHODE ISLAND
1989
ABSTRACT

This study documents the threat that uncontrolled "urban" stormwater runoff poses to surface water quality and the inadequacy of existing regulations governing land use development in preventing further water quality degradation resulting from "urban" runoff. The study applies recent research findings from the Nationwide Urban Runoff Program and the experience of other state regulatory programs in evaluating management alternatives and proposing a strategy for Rhode Island.

The documented impacts of "urban" stormwater runoff on water quality, including exceedances in criteria for copper, lead, and coliform, and eutrophication, support the need for stormwater quality management. This need is made more evident by a review of existing regulations.

Local authority to enact stormwater quality requirements is limited as, the legal basis under the zoning ordinance is uncertain and the subdivision ordinance, while providing adequate legal authority, applies to subdivisions, only. At the state level, no comprehensive policy or guidelines have been adopted under the Freshwater Wetlands (FWW) regulations. The Coastal Resources Management Council (CRMC) has adopted stormwater quality requirements which apply to only certain
areas within their jurisdiction. At present, there are no federal regulations governing stormwater runoff.

A comprehensive and consistent approach to stormwater quality management requires adoption of uniform applicability and design criteria, and consistent performance standards.

Of the three management alternatives evaluated in this study, the approach entailing the establishment of stormwater quality management requirements as mandatory provisions of the FWW and CRMC programs, as complements to the federally mandated National Pollution Discharge Elimination System program requirements is preferred.
PREFACE

This thesis incorporates the findings of an advisory committee organized by the Rhode Island Department of Environmental Management (RIDEM) to develop technical specifications and guidelines for stormwater management and soil erosion control. The Stormwater Management and Erosion Control Committee, composed of engineers, scientists, and planners, met from October 1986 through January 1988. The author, a Sr. Environmental Scientist with the RIDEM, served as chairperson and staff to the Committee. The author's role in preparation of the stormwater management technical guidelines for use in Rhode Island involved the review of published documents, synthesis of this information into technical reports and recommendations, presentation of this material to the Committee for their review and discussion, incorporation of Committee members' comments into the proposed guidelines and lastly, compilation of the Committee's findings into a final report. Through this process, the Committee members lent their expertise in integrating the most recent scientific and technical information on stormwater management with sound engineering and planning practices. A list of the Committee members is provided in Appendix A.
The Committee's recommendations address major aspects of stormwater management programs, including identification of preferred control measure designs, implementation of the technical guidelines, the definition and applicability of minimum design criteria, site plan requirements, facility design guidelines and procedures, and maintenance, inspection and enforcement considerations.


The author received technical assistance from several individuals. William Keating, an engineering graduate student intern with the RIDEM performed many case study calculations using various proposed procedures and design alternatives, and also plotted values for the figure presented in Chapter 4. Eugene Driscoll of E.D. Driscoll and Associates, a consultant to RIDEM provided assistance in performing computer modelling analyses necessary in developing the wet basin design procedure. Finally, Stephen Davis, with the United States
Department of Agriculture Soil Conservation Service provided technical assistance and advice throughout the process of developing the technical guidelines for stormwater management.
CONTENTS

ABSTRACT ................................................................. ii
PREFACE .............................................................. iv

Chapter

I. INTRODUCTION .................................................. 1

II. URBAN STORMWATER RUNOFF AS A POLLUTION SOURCE ....... 9
   Introduction ....................................................... 9
   Pollutant Characteristics of "Urban" Stormwater Runoff ... 10
   Pollutant Form and Its Significance ................. 21
   Receiving Water Impacts .................................. 26
   NURP Screening Procedure for Copper, Zinc and Lead .... 30
   Comparison Between Urban Runoff Concentrations of Conventional Pollutants and Water Quality Standards ... 35
   Conclusions ..................................................... 39

III. STATUTORY AUTHORITY FOR STORMWATER QUALITY
     MANAGEMENT IN RHODE ISLAND ..................... 42
    Introduction ............................................... 42
    Municipal Authority ..................................... 43
   Zoning Ordinance ......................................... 43
   Subdivision Ordinance ................................ 47
   State Authority ............................................ 49
   Rhode Island Freshwater Wetlands Act ............. 49
   Rhode Island Coastal Resources Management Council ... 55
   Federal Authority ......................................... 58
   Rulemaking under the Federal Water Pollution Control Act .... 58
   Water Quality Act of 1987 ............................ 61
   Proposed Rules for NPDES Stormwater Permits .... 64
   Interpretation of Section 402(p) Requirements .... 69
   Conclusions ................................................... 70

IV. GUIDELINES FOR STORMWATER QUALITY
    CONTROL MEASURES ........................................ 73
   Introduction ............................................... 73
   'Form and Function' in Stormwater Management .... 74
   Pollutant Removal Efficiencies .......................... 81
Dry Detention Basins.................................82
Extended Detention Basins..........................82
Wet Detention Basins.................................84
Lake Ellyn, Chicago, IL..............................84
Geddes Pond and Pittsfield Retention Area, Washtenaw Co., MI......86
Westleigh Pond, Washington, DC.....................86
METRO Facility, Seattle, WA........................87
Unqua Pond, Massapequa, NY........................89
Ann and Hope Detention Basin, Seekonk, MA...89
Infiltration Devices.................................90
Summary of Case Study Findings.....................91
Preferred Stormwater Quality Control Measures........94
Design Guidelines for Wet Detention Basins.....96
Design Guidelines for Extended Detention Dry Basins..............104
Additional Design Considerations for Wet Basins and Extended Detention Dry Basins......107

V. SURVEY OF EXISTENT STATE STORMWATER MANAGEMENT PROGRAMS...............113
   Introduction........................................113
   Maryland Stormwater Management Program........114
   Wisconsin Model Construction Site
      Erosion Control and Stormwater Management Ordinance.........117
   New Jersey Stormwater Management Act.........................121
   Summary of Stormwater Management Approaches..............125

VI. STORMWATER QUALITY MANAGEMENT ALTERNATIVES FOR RHODE ISLAND..................130
   Introduction........................................130
   Definition of "Comprehensive and Consistent"............131
   Essential Elements of Stormwater
      Quality Management Programs........................132
      Applicability Criteria............................132
      Design Criteria..................................138
      Performance Standards..............................140
   Alternative Stormwater Quality Management
      Strategies for Rhode Island.........................144
      Alternative One: NPDES Permit Requirements
         for Urban Stormwater Runoff........................145
         Description of Management Approach..............145
         Strengths and Weaknesses........................147
      Alternative Two: State Level Stormwater
         Quality Management.............................149
         Description of Management Approach..............149
         Strengths and Weaknesses........................151
      Alternative Three: Local Level Stormwater
         Quality Management..............................153
         Description of Management Approach..............153
         Strengths and Weaknesses........................155
CHAPTER I

INTRODUCTION

New residential and commercial developments are appearing across the rolling landscape of Rhode Island's rural areas at a rate unprecedented in recent history. The number of building permits issued annually in Rhode Island nearly tripled from 2,422 to 7,147 permits in the time period from 1982 to 1986 (RI Builders Association, unpublished). This growth is an indicator and an element of the strong economy the State of Rhode Island has enjoyed in recent years. The state's prosperity is not without cost, however. Where and how development takes place directly affects the quality of the state's surface and ground water resources. To ensure a continuation of the quality of life Rhode Islanders are accustomed to, development must occur in full recognition of our land and water resources' carrying capacity.

Of the many consequences of growth, congestion is probably the most obvious. More subtle are the environmental changes occurring over a period of time and in response to an area's overall development pattern. Development affects the quality and quantity of stormwater runoff, with increased
flooding and water quality degradation likely products of uncontrolled runoff.

Central to these changes are the hydrologic alterations accompanying the transition from forest or open fields to urban uses. As the imperviousness of a site increases with the construction of buildings and paved areas, the volume of rainfall infiltrating into the soil and recharging groundwater supplies is significantly reduced. Consequently, the volume of runoff generated on a given site increases. Because water flows more quickly over impermeable surfaces the peak rate of runoff is also increased.

These hydrologic changes may be evident in various forms. An increase in the frequency with which a stream overflows its banks and a broadening in the area affected by floodwaters are examples. Increased frequency of ponding on streets served by stormwater drainage systems may also reflect the effect of increased development and an exceedance of the drainage system's capacity. Flooding conditions may also be exacerbated by a reduction in stream and channel capacity due to sedimentation. Soil erosion caused by uncontrolled runoff and sand applied to roadways as a deicing agent are sources of sediments deposited into waterways. The sediments may carry pollutants, formerly bound within the soil profile, creating water quality problems.

Changes in land use activities from forest or open fields to urban uses typically result in adverse effects to receiving
waters. As runoff passes over the land's surface, substances previously deposited on the surface are "picked up" and carried into low lying areas, such as wetlands, and/or streams, rivers, or lakes. Significant levels of lead, zinc, iron, copper, phosphorus, nitrates, coliform bacteria, sodium, chloride, and hydrocarbons have been found in stormwater runoff from urban areas (U.S. EPA, 1983; Hoffman et al., 1984b; Oakland et al., 1983).

To evaluate the importance and control of runoff derived pollution, this thesis addresses two related hypotheses. The first, that uncontrolled stormwater runoff from urbanized areas threatens the quality of surface waters and the second, that existing federal, state, and local regulations governing land use development are inadequate to prevent further water quality degradation resulting from new sources of urban runoff. Operationally, these hypotheses are examined by the following two questions: Does runoff from urbanized areas present a threat to surface water quality? Are Rhode Island's regulations governing land use development and stormwater runoff adequate to protect the state's waters from new sources of urban runoff?

Findings from the analysis of these questions identify the need for stormwater quality management in Rhode Island. Resolution of this issue is achieved by addressing the following questions: What runoff control measures are effective in removing pollutants commonly found in runoff from
urbanized areas? How should regulatory programs be structured to ensure a comprehensive and consistent approach to stormwater quality management? How can this approach be implemented in Rhode Island? In answering these questions, the thesis critically evaluates alternatives and proposes a strategy for implementation of a stormwater quality management policy for Rhode Island.

Chapter II examines the results of the Nationwide Urban Runoff Program (NURP), as well as, other independent investigations in Rhode Island and elsewhere, to document "urban" stormwater runoff as a pollution source. Through analysis of these data, the type and range of pollutant concentrations found in runoff from urban areas, the variability of these pollutant concentrations, and the potential impacts to surface water quality and uses of these waters are documented. The implications for designing stormwater runoff control measures effective in removing pollutants and for accurately predicting pollutant loads from unmonitored sites are discussed.

Chapter III addresses the second question regarding the adequacy of Rhode Island's existing regulations governing land use development and stormwater runoff in protecting the state's waters from new sources of urban runoff. To support the second hypothesis, the statutes and regulations upon which the pertinent programs are based, are evaluated to determine (1) whether the legal authority is adequate to establish
stormwater quality management requirements and (2) what requirements have been established. Emphasis is placed on those regulatory programs affecting land use development projects.

The author recognizes that significant water quality impacts have and continue to occur due to existing urban stormwater discharges. A separate analysis would be necessary to evaluate the environmental importance and social feasibility of controlling them. The approach examined here, is to prevent further water quality degradation due to new sources of uncontrolled urban runoff. This can be accomplished by first establishing stormwater quality management requirements at new development projects including highways.

This position is supported by the U.S. Environmental Protection Agency (U.S. EPA) in comments presented in its proposed rules for defining stormwater point sources subject to the National Pollution Discharge Elimination System (NPDES) requirements (53 FR 49445, December 7, 1988). U.S. EPA recognized that opportunities to implement some type of control to reduce pollutants in municipal separate storm sewer discharges was limited by the scarcity of land for controls, the high cost of retrofitting and institutional constraints. Furthermore, U.S. EPA stated that areas of new development offer municipalities a more practicable opportunity to reduce pollutants in stormwater discharges.
Having identified the need for stormwater quality management in Rhode Island, Chapter IV begins the analysis of information upon which development of a management strategy appropriate for Rhode Island is based. Results from NURP sponsored studies and other independent investigations are analyzed to address the question regarding which runoff control measures are effective in removing pollutants commonly found in runoff from urbanized areas. Effectiveness is determined by a measure's pollutant removal efficiency as documented in the case studies reviewed. Basic principles of stormwater quality management are discussed, including design features which enhance the processes responsible for runoff borne pollutant removal. Based upon the case studies' findings, conceptual guidelines for the design of wet basins and extended detention dry basins are presented.

The stormwater management programs established by Maryland, Wisconsin, and New Jersey are reviewed in Chapter V. This survey of state regulatory programs provides a framework for formulation of an implementation strategy for Rhode Island.

Two related questions are examined in Chapter VI. How is a comprehensive and consistent stormwater quality management program structured? How can it be implemented in Rhode Island? In addressing these questions, the scientific and technical information presented in previous chapters is synthesized in the context of Rhode Island's institutional and
political setting to evaluate how a stormwater quality management approach can be structured so as to minimize the potential water quality impacts from new sources of "urban" runoff. Evaluated in detail in Chapter VI is the adoption of applicability criteria, design criteria, and performance standards as essential components of a stormwater quality management program.

Implementation of this structured approach within Rhode Island's existing regulatory framework is analyzed. Three alternatives for the establishment of a stormwater quality management program in Rhode Island are evaluated. The legal and administrative constraints of each alternative are evaluated relative to the objective of minimizing the impact of "urban" stormwater runoff on surface water quality.

This evaluation of stormwater quality management policies in Rhode Island considers selected aspects of a complex problem. For example, although the importance of establishing comprehensive flood management policies in Rhode Island is recognized, this topic is not addressed by this thesis. In addition, a truly comprehensive stormwater quality management program entails a planning component to, as noted above, identify existing sources, and characterize discharges and their pollutant loads. Also included in a comprehensive program are a public education and technical assistance component, for example, to encourage proper disposal of used oil and establish technical guidelines; and a regulatory
component to address existing and new sources of urban runoff. This thesis will address only the regulatory component affecting new sources.

The author recognizes that viable programs are dependent upon not only adequate legal authority, but also financial and administrative capabilities to implement these programs. In formulating a strategy for establishment of a stormwater quality management program, these factors are considered however they are not addressed in detail. Issues of enforcement, while critical to an effective program, will not be included in this thesis.
CHAPTER II

URBAN STORMWATER RUNOFF AS A POLLUTION SOURCE

Introduction

The purpose of this chapter is to document urban stormwater runoff as a pollution source, one that threatens the quality of the state's waters and the continuance of the beneficial uses enjoyed. The presence of pollutants in stormwater runoff is not in itself an indication of water quality problems. This information must be analyzed in the context of the environment to which it is discharged to determine the potential impact to water quality and/or beneficial uses.

It is the author's intent to review selected literature documenting urban runoff characteristics and its effect on receiving water quality. My hypothesis is that uncontrolled stormwater runoff from urbanized areas threatens the quality of surface waters.

The most comprehensive database on urban stormwater runoff is that collected under the Nationwide Urban Runoff Program (NURP) sponsored by the United States Environmental Protection Agency (U.S. EPA). The twenty-eight NURP projects were conducted separately at the local level, but centrally
reviewed, coordinated, and guided by U.S. EPA. All of the projects involved one or more of the following elements: characterizing pollutant types, loads, and effects on receiving water quality; determining the need for control; and evaluating various alternatives for the control of stormwater pollution.

Although there were no NURP project sites located in Rhode Island, analysis of the NURP data has proven the transferability of the results, for planning purposes, to other geographical areas of the United States (U.S. EPA, 1983). The large size of the NURP database renders the pooled results particularly useful in describing pollutant concentrations representative of urban stormwater runoff.

**Pollutant Characteristics of "Urban" Stormwater Runoff**

Many factors are thought to affect the composition and concentration of pollutants in urban stormwater runoff. Perhaps the most influential factor is the land use or activity occurring at a site. However the site's topography and soil type, the storm's duration and 'flush phenomenon', runoff flow rates, the length of the antecedent dry period, and seasonal variations are also thought to influence runoff's pollutant characteristics (U.S. EPA, 1983; Gupta et al., 1978; Hoffman et al., 1985; 1984a; 1983; 1982). These factors can be important in explaining variability observed from site to
site, or during the course of a storm event or between storms at any particular site.

The Nationwide Urban Runoff Program has adopted the following constituents as "standard pollutants" characterizing urban runoff: Total Suspended Solids (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Soluble Phosphorus (SP), Total Kjeldahl Nitrogen (TKN), Nitrite-Nitrate Nitrogen (NO$_2$,-N), Copper (Cu), Lead (Pb), and Zinc (Zn). Petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and coliform bacteria are not included as "standard pollutants" by NURP, however are included in this evaluation of runoff borne pollutants.

The NURP data were analyzed and reported as event mean concentrations. Results from runoff monitoring studies are often reported as flow weighted or event mean concentrations (EMC), because it is a way to normalize the variability which occurs over the course of a storm event. The EMC can be defined as the constituent mass discharge divided by the total runoff volume.

The median event mean concentration was selected by NURP investigators to compare data from the individual sites, as the median has been proven to be a more robust measure of central tendency than the mean for data exhibiting lognormal distributions (U.S. EPA, 1983). Table 2-1 lists the site EMC median concentrations for the "standard pollutants": The 'mixed' land use category is represented by urban areas having
### TABLE 2-1

**MEDIAN EMCS FOR ALL NURP PROJECTS BY LAND USE**

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Mixed</th>
<th>Commercial</th>
<th>Nonurban/Open</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TSS (mg/l)</strong></td>
<td>101</td>
<td>67</td>
<td>69</td>
<td>70</td>
</tr>
<tr>
<td><strong>BOD (mg/l)</strong></td>
<td>10.0</td>
<td>7.8</td>
<td>9.3</td>
<td>--</td>
</tr>
<tr>
<td><strong>COD (mg/l)</strong></td>
<td>73</td>
<td>65</td>
<td>57</td>
<td>40</td>
</tr>
<tr>
<td><strong>TP (ug/l)</strong></td>
<td>383</td>
<td>263</td>
<td>201</td>
<td>121</td>
</tr>
<tr>
<td><strong>SP (ug/l)</strong></td>
<td>143</td>
<td>56</td>
<td>80</td>
<td>26</td>
</tr>
<tr>
<td><strong>TKN (ug/l)</strong></td>
<td>1900</td>
<td>1288</td>
<td>1179</td>
<td>965</td>
</tr>
<tr>
<td><strong>NO$_2$+N (ug/l)</strong></td>
<td>736</td>
<td>558</td>
<td>572</td>
<td>543</td>
</tr>
<tr>
<td><strong>TCu (ug/l)</strong></td>
<td>33</td>
<td>27</td>
<td>29</td>
<td>--</td>
</tr>
<tr>
<td><strong>TPb (ug/l)</strong></td>
<td>144</td>
<td>114</td>
<td>104</td>
<td>30</td>
</tr>
<tr>
<td><strong>TZn (ug/l)</strong></td>
<td>135</td>
<td>154</td>
<td>226</td>
<td>195</td>
</tr>
</tbody>
</table>

(Source: U.S. Environmental Protection Agency, 1983, p. 6-12.)
no predominant land use type, such as an area having residential, commercial and perhaps, industrial uses adjacent to one another. The 'commercial' category includes results from industrial sites monitored by NURP. The two categories were combined because the latter was typified by modern industrial parks which more closely resemble commercial sites than industrial sites in their pollutant loading characteristics. With the exception of zinc, the median pollutant concentration of runoff from the residential sites monitored is generally higher than in runoff from the commercial or mixed urban sites.

Other studies have indicated the strong influence of land use on runoff quality (Hoffman et al., 1984b; 1983). NURP investigators set out to determine the extent to which site categorization by land use could be used to predict concentrations of pollutants at unmonitored sites. The site EMC medians and their upper and lower 90 percent confidence limits were evaluated to determine the existence of statistically significant differences between categories of land use. Overlapping confidence limits were interpreted by the NURP investigators to represent no statistical difference between site medians.

The analysis identified differences in site EMC medians for different land use categories at certain locations, however the differences were neither widespread nor consistent among the sites (US EPA, 1983). Based upon this approach,
the NURP investigators concluded that if urban land use category effects are present, they are eclipsed by individual storm variabilities. While not widely supported by many of the previous studies having much smaller data sets, the findings of at least one other study support this conclusion (Helsel et al., 1979).

Although no consistent statistical differences were found in the data for different urban land use categories, the investigators did find statistically significant differences between nonurban and urban categories (US EPA, 1983). The median pollutant concentrations resulting from the pooling of all urban categories were also presented as appropriate for characterizing urban stormwater runoff for planning purposes (US EPA, 1983). The site median EMCs for the median urban site and for the 90th percentile urban site, in addition to the median EMCs for nonurban/open sites are given in Table 2-2.

One sees significant differences between dissolved nutrient concentrations representative of rural runoff and those typical of urban runoff concentrations. Omernik (1981) as cited in Mills et al. (1985) reports a soluble phosphorus concentration of 6 ug/l for forested watersheds in the eastern United States. The site median EMC for the median urban site reported by NURP is twenty times this value, and the concentration for the 90th percentile urban site is seventy times this value.
<table>
<thead>
<tr>
<th>Constituent</th>
<th>Median Urban</th>
<th>90th percentile Urban</th>
<th>Median Nonurban</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (mg/l)</td>
<td>100</td>
<td>300</td>
<td>70</td>
</tr>
<tr>
<td>BOD (mg/l)</td>
<td>9</td>
<td>15</td>
<td>--</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>65</td>
<td>140</td>
<td>40</td>
</tr>
<tr>
<td>TP (ug/l)</td>
<td>330</td>
<td>700</td>
<td>120</td>
</tr>
<tr>
<td>SP (ug/l)</td>
<td>120</td>
<td>210</td>
<td>30</td>
</tr>
<tr>
<td>TKN (ug/l)</td>
<td>1500</td>
<td>3300</td>
<td>960</td>
</tr>
<tr>
<td>NO$_2$+NO$_3$-N (ug/l)</td>
<td>680</td>
<td>1750</td>
<td>540</td>
</tr>
<tr>
<td>TCu (ug/l)</td>
<td>34</td>
<td>93</td>
<td>--</td>
</tr>
<tr>
<td>TPb (ug/l)</td>
<td>144</td>
<td>350</td>
<td>30</td>
</tr>
<tr>
<td>TZN (ug/l)</td>
<td>160</td>
<td>500</td>
<td>195</td>
</tr>
</tbody>
</table>

(Source: U.S. Environmental Protection Agency, 1983, pp. 6-31, 6-43)
Although not included in NURP's "standard pollutants", fecal and total coliform are common constituents of urban stormwater runoff (US EPA, 1983; Oakland et al., 1983; Mallard, 1982). Fecal and total coliform are used as indicators of the presence of sewage and ideally are correlated with the number of disease causing pathogens, bacteria, and viruses in a water sample. Contamination of receiving waters by these biological constituents can be potentially harmful to humans via direct contact (e.g. swimming) or consumption (e.g. drinking water or shellfish consumption).

In general, storm runoff is a hostile environment for fecal indicator organisms and pathogens because they require high nutrient levels and warm temperatures for growth. In addition, the population may be adversely affected by the chemical constituents of runoff (Mallard, 1982). A survey of studies monitoring fecal and total coliform densities in urban stormwater runoff samples indicates fecal coliform counts on the order of 1,000 coliform per 100 ml and total coliform counts of tens of thousand coliform per 100 ml are common (Mallard, 1982).

Seasonal variations are found with runoff borne concentrations of these pathogens and bacteria due to the affect of temperature on growth and survival of the organisms. The final NURP report summarized the results of data collected at 17 different locations under warm and cold weather
conditions. The reported median EMC during the cold weather months was 1,000 organisms/ml whereas the median EMC at the same sites during the warm months was 21,000 organisms/ml (US EPA, 1983). No comparable differences in urban activities were noted to account for these seasonal variations.

The NURP results have provided valuable information on the characteristics of runoff from generic urban areas. Due to the variability observed in the data no consistent differentiation was discerned between land use types. Nor has the analysis of NURP data provided insight into the density of land use or degree of site imperviousness likely to produce the runoff pollutant concentrations cited by the studies. However, investigations by Dennis (1986) indicate a seven to ten times increase in the total phosphorus concentration of runoff from a low density residential area (minimum 2 acre lot size) after construction was completed and the site's disturbed areas were stabilized as compared with runoff from a forested area.

As an indication of the broader spectrum of pollutants found in urban stormwater runoff, a list of the more frequently detected priority pollutants detected in the NURP samples was constructed and is presented in Table 2-3. The most commonly detected priority pollutants in urban runoff samples were copper, lead, and zinc. Other frequently detected inorganics include arsenic, chromium, cadmium, nickel and cyanide.
### TABLE 2-3

FREQUENCY OF DETECTION AND RANGE OF DETECTED CONCENTRATIONS FOR SELECTED PRIORITY POLLUTANTS BASED UPON 121 NURP SAMPLE RESULTS

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Frequency of Detection (%)</th>
<th>Frequency of Detections/Frequency</th>
<th>Range of Detected Concentrations (ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pesticides</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>α-Hexachlorocyclohexane</td>
<td>20</td>
<td>21/106</td>
<td>0.0027T-0.1M</td>
</tr>
<tr>
<td>γ-Hexachlorocyclohexane</td>
<td>15</td>
<td>15/100</td>
<td>0.007-0.1M</td>
</tr>
<tr>
<td>Chlordane</td>
<td>17</td>
<td>7/42</td>
<td>0.01L-10</td>
</tr>
<tr>
<td>α-Endosulfan</td>
<td>19</td>
<td>9/49</td>
<td>0.008-0.2</td>
</tr>
<tr>
<td><strong>Metals and Inorganics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>52</td>
<td>45/87</td>
<td>1-50.5</td>
</tr>
<tr>
<td>Cadmium</td>
<td>48</td>
<td>44/91</td>
<td>0.1M-14</td>
</tr>
<tr>
<td>Chromium</td>
<td>58</td>
<td>47/81</td>
<td>1-190</td>
</tr>
<tr>
<td>Copper</td>
<td>91</td>
<td>79/87</td>
<td>1L-100</td>
</tr>
<tr>
<td>Cyanides</td>
<td>23</td>
<td>16/71</td>
<td>2-300</td>
</tr>
<tr>
<td>Lead</td>
<td>94</td>
<td>75/80</td>
<td>6-460</td>
</tr>
<tr>
<td>Nickel</td>
<td>43</td>
<td>39/91</td>
<td>1-182</td>
</tr>
<tr>
<td>Zinc</td>
<td>94</td>
<td>88/94</td>
<td>10-2400</td>
</tr>
<tr>
<td><strong>Polycyclic Aromatic Hydrocarbons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chrysene</td>
<td>10</td>
<td>11/109</td>
<td>0.6T-10M</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>16</td>
<td>17/109</td>
<td>0.3T-21</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>12</td>
<td>13/110</td>
<td>0.3T-10M</td>
</tr>
<tr>
<td>Pyrene</td>
<td>15</td>
<td>16/110</td>
<td>0.3T-16</td>
</tr>
</tbody>
</table>

* Number of times detected/number of acceptable samples

# M = presence of material verified but not quantified

L = Actual value is known to be greater than value given

T = Value reported is less than criteria of detection

(Source: U.S. Environmental Protection Agency, 1983, pp. 6-47 - 6-49)
It should be noted that the pollutants listed in Table 2-3 represent total pollutants, and that particulate and soluble fractions have not been differentiated. The significance of pollutant form will be discussed in a later section of this chapter. The NURP report (US EPA, 1983) points out that the sites from which these samples were collected are representative of residential, commercial, and mixed urban land uses, and not heavy industrial sites.

A review of the findings of Hoffman et al. (1984a; 1982) and Latimer et al. (1986) affords a more detailed evaluation of petroleum hydrocarbons, polycyclic aromatic hydrocarbons and heavy metals detected in stormwater runoff from an interstate highway, and commercial and heavy industrial sites.

Latimer et al. (1986) monitored runoff from a commercial site into a stormwater detention basin during spring and summer storm events to evaluate the effectiveness of the basin in removing petroleum hydrocarbons (PHC), polycyclic aromatic hydrocarbons (PAHs), and suspended solids. Runoff from the commercial site's parking lot as influent to the basin was monitored during two storm events. The results were reported as flow weighted mean concentrations and are presented in Table 2-4. The PAHs reported here represent the sum of particulate and dissolved fractions.

Hoffman et al. (1984a) reported storm flow-weighted means of PAH concentrations in runoff collected from residential, commercial, industrial, and highway land uses. The results
### TABLE 2-4

PETROLEUM HYDROCARBON, POLYCYCLIC AROMATIC HYDROCARBON, AND SUSPENDED SOLID CONCENTRATIONS IN RUNOFF FROM A COMMERCIAL SITE

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PHC</td>
<td>400 ug/l</td>
<td>818 ug/l</td>
</tr>
<tr>
<td>PAHs</td>
<td>1.17 ug/l</td>
<td>0.58 ug/l</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>61.4 mg/l</td>
<td>35.9 mg/l</td>
</tr>
</tbody>
</table>

(Source: Latimer et al., 1986, p. 550)
for selected high molecular weight polycyclic aromatic hydrocarbons are presented in Table 2-5. The results observed for individual PAHs relative to land use indicate urban runoff loading factors to generally follow the relationship: residential equal to commercial but less than industrial which is equal to highway. No direct relationship between the discharge of PAH urban runoff discharges with rainfall amounts or length of antecedent dry periods were found (Hoffman et al., 1984a).

**Pollutant Form and Its Significance**

Differentiation of soluble and particulate forms of pollutants in urban runoff is necessary to further refine the analysis of potential water quality and beneficial use impacts. Many forms of contaminants are unavailable to affect aquatic organisms and water quality (Lee and Jones, 1980). As a result, a pollutant's form may greatly influence the type of receiving water impact effected. Long term impacts may be caused by suspended solids and pollutants associated with these solids (U.S. EPA, 1983). Pollutants settling out of the water column may become concentrated in sediments and adversely affect aquatic habitat and/or subsequently be made available for resuspension in the water column and biological uptake. The long term impacts associated with nutrients introduced into a waterbody with a long residence time is good example of the latter process. In certain aquatic systems,
TABLE 2-5
RANGE OF STORM FLOW-WEIGHTED MEANS OF PAH CONCENTRATIONS IN URBAN RUNOFF (ng/l)

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenanthrene</td>
<td>13 - 120</td>
<td>10 - 1200</td>
<td>340 - 9100</td>
<td>480 - 1100</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>480 - 870</td>
<td>110 - 720</td>
<td>1100 - 8200</td>
<td>590 - 2800</td>
</tr>
<tr>
<td>Pyrene</td>
<td>190 - 650</td>
<td>56 - 540</td>
<td>910 - 5400</td>
<td>35 - 2000</td>
</tr>
<tr>
<td>Benz(a)anthracene</td>
<td>37 - 170</td>
<td>10 - 280</td>
<td>230 - 8400</td>
<td>500 - 700</td>
</tr>
<tr>
<td>Number of storms</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>monitored</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: Hoffman et al., 1984a, supplemental materials, Appendix I)
the recycling of nutrients from the sediments to the overlying waters results in a self-perpetuated eutrophication problem regardless of nutrient source control efforts in the contributing watershed. Researchers at two NURP sites (Lake George, New York and Lake Quinsigamond, Massachusetts) found urban runoff to be a primary source of phosphorus and cause of accelerated eutrophication (U.S. EPA, 1983).

A survey of sediment quality in Mashapaug Pond, a small urbanized lake in Rhode Island found relatively high concentrations of both metal and organic pollutants (Quinn et al., 1986). Sediment samples were collected from four stations within the pond. The highest concentration of total saturated hydrocarbons, polycyclic aromatic hydrocarbons, and lead were found in sediments adjacent to a stormwater drainage system discharge point. The qualitative distribution of the hydrocarbons indicated that the major sources were used crankcase oil and/or other used lubricating oils. These findings supported the results of earlier research (Latimer, 1984) regarding the types of hydrocarbons found in urban stormwater runoff. While the authors could not form conclusive statements on the chemical contamination of fish resulting from the contaminated sediments, they found the possibility of contamination of deposit feeders and bottom feeding organisms to be great (Quinn et al., 1986).

Often times long term water quality impacts are manifested during critical periods, such as, summer low flow
periods or the sensitive life cycle stage of an organism. On the other hand, short term water quality impacts associated with urban stormwater runoff discharges occur during and following a storm event. Typically these impacts are the result of sharp peaks in pollutant concentrations. Exceedance of fecal coliform levels established to protect beneficial uses such as bathing and shellfish harvesting are frequently violated in waters subject to urban runoff discharges (U.S. EPA, 1983). Ambient criteria for acute concentrations of toxics may also be exceeded during this time period.

Pollutant form also has implications on the type of treatment that will be most effective in removing pollutants from urban runoff. A high association of pollutants with particulates or percentage of pollutants in the particulate fraction would indicate the potential success of measures using physical settling to remove runoff borne pollutants. Whereas filtering and uptake by vegetation are approaches to reduce soluble pollutant concentrations.

Urban stormwater runoff samples collected from four sites (suburban residential, commercial, heavy industrial, and interstate highway) were analyzed for selected polycyclic aromatic hydrocarbons and particle size (Hoffman et al., 1984a). The investigators found the percentage of high molecular weight PAHs associated with particulate matter to vary from storm to storm. However, in general, the high
molecular weight polycyclic aromatic hydrocarbons (HMW PAHs) are largely associated with particulate matter, averaging 79% to 93% of mean storm loads. The HWM PAHs were mostly enriched on two different particle sizes, larger particles with diameters ranging between 125 and 250 um and the smaller size with diameters less than 45 um. Two sources of PAHs in urban runoff were suggested by the investigators, (1) asphalt abrasion particles which is the source of the larger, heavier particle sizes and (2) atmospheric fallout which is the source of smaller particles (Hoffman et al., 1984a). It is unknown whether hydrocarbons become incorporated onto particles or are merely adsorbed to the surfaces. This study by Hoffman et al. did not evaluate the chemistry of the different sized particles, per se.

NURP has reported approximate particulate fractions of 50% for copper, 50% for zinc, and greater than 90% for lead (U.S. EPA, 1983). Correlations between heavy metal and suspended solids concentrations in runoff collected from an interstate highway during a storm event on October 25, 1980 generally support these findings (Hoffman et al., 1985). The highest correlations were found between suspended solids and iron, lead, and copper, as follows: 0.90, 0.89, and 0.85, respectively.

The NURP findings are corroborated by another independent study conducted in New York State. Samples were collected under varying meteorological conditions from the water column
of Weston's Mill Pond, a water supply/recreation reservoir exposed to substantial inputs of highway runoff (McIntosh et al., 1980). The investigators found the highest concentrations of lead occurred after a period of heavy rainfall and that the particulate fraction accounted for 80 - 96% of the total lead present.

Soluble phosphorus as a percentage of total phosphorus quantified in samples collected from different land use types under the NURP studies ranged from 21% - 40% (U.S. EPA, 1983). The inverse of this relationship indicates that 60 - 79% of phosphorus was in particulate form. Other pollutants with a high particulate matter association include bacteria (100% particulate) and COD which is predominately in particulate form (Schueler and Bley, 1987).

The results of this analysis indicate that excellent reductions in urban runoff discharges of sediments, HMW PAHs, lead, bacteria, and COD can be expected by physical settling; whereas, moderate removal rates may be expected for copper and phosphorus. Physical settling may be expected to result in negligible removal of pollutants found primarily in soluble form, such as nitrates.

**Receiving Water Impacts**

There are many factors which may influence the effect of a pollutant source with a given flow and concentration on receiving water quality. Among these factors are stream or
lake hydrology, rainfall, urban site characteristics, the location and areal extent of urban areas relative to upstream drainage area, and for metals, the total hardness as calcium carbonate (CaCO₃) of the receiving water. To further define water quality impacts, resulting in-stream concentrations must be evaluated in the context of the receiving water's designated (beneficial) use and the water quality standards established to protect those uses.

Surface waters in the United States are classified according to the most sensitive beneficial use achievable. Therefore, if a particular body of water is of adequate quality to support bathing and recreational activities, and fish migration, it is assigned a classification based upon the more sensitive use, in this case, bathing and recreation. A brief description of Rhode Island's Water Use Classification System further identifies the relationship between these "beneficial uses" and water quality classes. Class A waters are identified as suitable for use as a drinking water supply; Class B waters suitable for use as a drinking water supply with appropriate treatment and for primary contact recreation, such as bathing; and Class C waters suitable for non-contact secondary recreational activities, such as fishing or boating (RIDEM, Division of Water Resources, 1988).

To protect these beneficial uses, class specific criteria have been adopted by the U.S. EPA and individual states for many conventional pollutants, such as dissolved oxygen, and
total and fecal coliform. In addition, the U.S. EPA and many states, including Rhode Island, have adopted criteria to protect aquatic life from toxic substances. The U.S. EPA's Quality Criteria for Water, otherwise known as the "Gold Book" (U.S. EPA, 1986) sets numerical values for acute (short term) and chronic (long term) levels of toxic substances, based upon extensive bioassay studies (45 FR 79318, November 28, 1980; 50 FR 30784, July 29, 1985). Unlike the standards established for conventional pollutants, these ambient criteria for toxic substances are not differentiated according to the water classification system. Rhode Island's water quality standards specify that ambient pollutant concentrations in waters designated as suitable for fish and wildlife habitat shall not exceed the state's Ambient Water Quality Guidelines for the protection of aquatic organisms from chronic effects (including Classes A, B, C, SA, SB, and SC). Whereas, the acute criteria are applicable to waters suitable for fish migration only, (that is, Class D).

Comparison of these standards with undiluted stormwater runoff discharges is one way to screen the potential impacts of runoff to water quality and beneficial uses. Caution should be exercised in using water quality criteria exceedances as the only benchmark for determining water quality problems. The standards are designed to protect certain designated uses, however there are shortcomings in the system. For example, Rhode Island has not adopted
numerical values for nutrients in surface waters, although the regulations state that nutrients will not exceed the site-specific limits necessary to control accelerated or cultural eutrophication (RIDEM, Division of Water Resources, 1988).

To assess the potential impact of a given pollutant discharge where no water quality standards are established, it is necessary to refer to values found in literature.

The water quality criteria and standards adopted by U.S. EPA and states assume continuous exposure of pollutants. It is probable that these standards are a conservative measure for assessing the effects of urban stormwater runoff discharges which are characterized by intermittent flow and highly variable pollutant concentrations. The Nationwide Urban Runoff Program has developed estimates for concentration levels resulting in adverse effects when exposures occur intermittently at intervals typical of urban runoff discharges (U.S. EPA, 1983).

The results of a generalized screening procedure utilized by NURP to compute the probability distribution of in-stream concentrations of copper, lead, and zinc from urban runoff relative to three different target concentrations will be discussed. The three target concentrations include the U.S. EPA's maximum concentration for protection of aquatic life, and two values recommended by NURP to assess threshold effects and significant mortality of the most sensitive species from urban runoff discharges.
Observed urban runoff concentrations of fecal and/or total coliform will be compared with ambient water quality criteria. Where there are no water quality standards for a pollutant of concern different screening techniques will be used. For nutrients, typical urban runoff concentrations will be compared with U.S. EPA's recommended ambient nutrient concentration standards.

**NURP Screening Procedure for Copper, Zinc, and Lead**

The screening procedure developed by the NURP investigators was designed to examine the concentration characteristics of the storm pulses occurring in streams, given the variability of the relevant processes involved. Stream and runoff flow rates, runoff borne pollutant concentrations, the duration of storm/runoff events, and stream velocity were factored into the analysis to estimate the frequency and magnitude of pollutant concentrations in the in-stream pulses produced (U.S. EPA, 1983).

The analysis was performed on a national scale, therefore, values believed to be typical for the eight geographical areas delineated were used as input values for the screening analysis. For the area which includes Rhode Island, the following values were used: event average rainfall intensity, mean 0.04 in/hr, average number of events/yr, 110; average runoff flow rate, mean event 5 cfs/sq mi; stream flow
rate, mean 1.75 cfs/sq mi; and stream total hardness, 50 mg/l (U.S. EPA, 1983).

Other input variables include the drainage area ratio (DAR) expressed as the stream drainage area upstream of the urban input divided by the urban area contributing runoff. It is designed as a measure of the location of the urban area relative to the headwaters of the receiving stream. A range of site median pollutant EMCs were used in the analysis; this discussion will present results for the average and 90th percentile site conditions, only. The screening procedure assumes the upstream concentration of the pollutant of concern equals zero, therefore the summaries show the effect of urban runoff only.

The NURP report (U.S. EPA, 1983) compared the calculated frequency and magnitude of pollutant concentrations resulting from urban runoff discharges with various in-stream target concentrations as a way of evaluating expected water quality impacts. One set of in-stream target concentrations used were the maximum ambient concentrations adopted by the U.S. EPA in 1980 for protection of freshwater aquatic life (45 FR 79318, November 28, 1980). These ambient criteria have since been amended (50 FR 30784, July 29, 1985) with fairly significant changes in the criteria for copper, lead, and zinc. These changes will be discussed in detail below. As noted previously, the ambient criteria assume continuous exposure of pollutants and, therefore are
likely a conservative measure for assessing the effects of urban stormwater runoff discharges.

The second set of target concentrations used are the "effects levels" adopted by NURP as an estimate of the concentration levels likely to result in adverse effects when exposures occur intermittently at intervals typical of urban runoff discharges (U.S. EPA, 1983). The threshold level represents the value likely to result in mortality of the most sensitive individuals of the most sensitive species. The significant mortality level represents the value likely to result in mortality of 50 percent of the most sensitive species (U.S. EPA, 1983).

A summary of the results of this screening procedure is presented in Table 2-6. The screening analysis indicates that the greatest number of in-stream target concentration exceedances will occur with copper, followed by lead, and then zinc. The effect of urban area size and location relative to the stream's headwaters is brought out in this analysis. Generally speaking the smaller the drainage area ratio (DAR), the more frequently in-stream concentrations will be violated for an urban runoff discharge of a given quality.

The 1986 edition of the EPA Water Quality Criteria consist of both acute and chronic concentrations for pollutants. Acute criteria are represented by a 1-hour average concentration which is not to be exceeded more than once every 3 years on the average. The chronic criteria is
TABLE 2-6
APPROXIMATE FREQUENCIES OF EXCEEDANCES OF IN-STREAM TARGET CONCENTRATIONS BY URBAN RUNOFF DISCHARGES ON AN ANNUAL BASIS

<table>
<thead>
<tr>
<th></th>
<th>Average Site (35 ug/l)</th>
<th>90th Percentile Site (90 ug/l)</th>
<th>90th Percentile Site (350 ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>COPPER</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target Concentrations</td>
<td>12 ug/l</td>
<td>20 ug/l</td>
<td>50 ug/l</td>
</tr>
<tr>
<td>DAR = 10</td>
<td>50 X</td>
<td>20 X</td>
<td>2 X</td>
</tr>
<tr>
<td>DAR = 100</td>
<td>3 X</td>
<td>1 X</td>
<td>&lt;1 X</td>
</tr>
<tr>
<td>Average Site (135 ug/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAR = 10</td>
<td>22 X</td>
<td>5 X</td>
<td>2 X</td>
</tr>
<tr>
<td>DAR = 100</td>
<td>1 X</td>
<td>&lt;1 X</td>
<td>--</td>
</tr>
<tr>
<td>90th Percentile Site (350 ug/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAR = 10</td>
<td>50 X</td>
<td>33 X</td>
<td>10 X</td>
</tr>
<tr>
<td>DAR = 100</td>
<td>10 X</td>
<td>2 X</td>
<td>&lt;1 X</td>
</tr>
<tr>
<td><em>LEAD</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target Concentrations</td>
<td>74 ug/l</td>
<td>150 ug/l</td>
<td>350 ug/l</td>
</tr>
<tr>
<td>DAR = 10</td>
<td>100 X</td>
<td>7 X</td>
<td>1 X</td>
</tr>
<tr>
<td>DAR = 100</td>
<td>17 X</td>
<td>7 X</td>
<td>1 X</td>
</tr>
</tbody>
</table>
TABLE 2-6 - Continued

<table>
<thead>
<tr>
<th>Target Concentrations</th>
<th>EPA Max</th>
<th>Threshold Effect</th>
<th>Significant Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 ug/l</td>
<td>380 ug/l</td>
<td>870 ug/l</td>
</tr>
</tbody>
</table>

**ZINC**

Average Site (165 ug/l)

| DAR = 10  | 5 X | <1 X | -- |
| DAR = 100 | <1 X | -- | -- |

90th Percentile Site (450 ug/l)

| DAR = 10  | 33 X | 12 X | 2 X |
| DAR = 100 | 3 X  | <1 X | <1 X |

Note: DAR = Drainage Area Ratio
X = "times"

(Source: U.S. Environmental Protection Agency, 1983, pp. 7-14 - 7-16.)
represented by a 4-day average concentration which is not to be exceeded by a numerical value given by a logarithmic equation more than once every 3 years on the average. Table 2-7 presents ambient criteria for copper, lead, and zinc assuming a receiving water hardness of 50 mg/l as CaCO$_3$ for freshwater systems.

Comparing both the acute and chronic levels established under the Water Quality Criteria revised in 1986 with the maximum criteria adopted by U.S. EPA in 1980, with a few exceptions, one sees an overall decrease in acceptable stream concentrations. It is likely that the chronic criteria (established to protect uses associated with Classes A, B, C, SA, SB, and SC) will be exceeded at a far greater frequency than determined in NURP's screening analysis.

**Comparison Between Urban Runoff Concentrations of Conventional Pollutants and Water Quality Standards**

The prevalence of water quality problems associated with coliform bacteria is suggested by the NURP report's concluding statements regarding coliform bacteria. It states that coliform bacteria levels in urban runoff are generally high and can be expected to exceed water quality criteria during and immediately following storm events in many surface waters, even those providing high degrees of dilution. Because the organisms eventually die off, the water quality problems associated with elevated concentrations of coliform bacteria
<table>
<thead>
<tr>
<th></th>
<th>FRESHWATER</th>
<th></th>
<th>SALTWATER</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute (ug/l)</td>
<td>Chronic (ug/l)</td>
<td>Acute (ug/l)</td>
<td>Chronic (ug/l)</td>
</tr>
<tr>
<td>Copper</td>
<td>9.2</td>
<td>6.5</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Lead</td>
<td>34</td>
<td>1.3</td>
<td>140</td>
<td>5.6</td>
</tr>
<tr>
<td>Zinc</td>
<td>47</td>
<td>*</td>
<td>170</td>
<td>58</td>
</tr>
</tbody>
</table>

Note: These criteria assume a receiving water hardness of 50 mg/l CaCO₃.

* The Water Quality Criteria for zinc states that the concentration should not exceed 180 ug/l at any time for freshwaters with a hardness of 50 mg/l as CaCO₃.

(Source: U.S. Environmental Protection Agency, 1986, pp.)
discharged intermittently are typically of limited duration. Despite these mitigating factors, elevated coliform counts can significantly affect surface waters' use.

The primary water quality factor considered by RIDEM the state's shellfish beds is coliform levels. Based upon coliform counts, waters may be opened, conditionally or permanently closed to shellfish harvesting for direct human consumption. Rhode Island's water quality standards for fecal and total coliform in saltwater are presented in Table 2-8.

The reported fecal coliform median EMCs for the 17 locations sampled was 1,000 organisms/ml during the cold weather and 21,000 organisms/ml during the warm weather months (U.S. EPA, 1983). Seasonal fluctuations aside, the median values far exceed the water quality standards for Class SA and SB waters.

Rhode Island has not adopted numerical standards for nutrients, however the water quality standards do state that "nutrients shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication..." (RIDEM, Division of Water Resources, 1988). National criteria are referenced here to evaluate nutrient concentrations relative to the potential for accelerated eutrophication. The Water Quality Criteria (U.S. EPA, 1986) establishes the level of 0.05 ug/l of total phosphorus for any stream at the point where it enters any lake or reservoir. This value is established to prevent the development of biological nuisances
TABLE 2-8
RHODE ISLAND'S WATER QUALITY STANDARDS FOR Fecal AND TOTAL COLIFORM FOR SALTWATER

Class SA

**Total Coliform** - Not to exceed a median most probable number (MPN) of 70 organisms/100 ml and not more than 10% of the samples shall ordinarily exceed an MPN of 330 organisms/100 ml for 3-tube decimal dilution.

**Fecal Coliform** - Not to exceed a median value of 15 organisms/100 ml and not more than 10% of the samples shall exceed a value of 50 organisms/100 ml.

Class SB

**Total Coliform** - Not to exceed a median value of 700 organisms/100 ml, and not more than 10% of the samples shall exceed a value of 2300 organisms/100 ml.

**Fecal Coliform** - Not to exceed a median value of 50 organisms/100 ml, and not more than 10% of the samples shall exceed a value of 500 organisms/100 ml.

(Source: RIDEM, Division of Water Resources, 1988).
and to control accelerated or cultural eutrophication. When compared with the median site event mean concentration for total phosphorus (as P) of 0.33 mg/l, it is evident that urban runoff discharges may potentially lead to accelerated eutrophication. Runoff from urbanized areas has been cited as the cause of excessive weed growth or algal blooms in many urban ponds in Rhode Island (RIDEM, Office of Environmental Coordination, 1988b).

There are no water quality criteria for TSS, BOD or COD relating to protection of beneficial uses or aquatic life. However, the NURP program found suspended solids contributions from urban runoff to be roughly an order of magnitude or greater than those from secondary treatment plants (U.S. EPA, 1983). Similarly, based upon the median site EMC median concentrations quantified, NURP found urban runoff discharges of both BOD and COD to be comparable in magnitude to secondary treatment plant discharges on an annual load basis.

Conclusion

This review of selected literature documenting urban runoff pollutant characteristics and its effect on receiving water quality provides conclusive evidence in support of my hypothesis that uncontrolled stormwater runoff from urbanized areas threatens the quality of the surface waters. Stormwater runoff from urbanized areas has been found to contain significant concentrations of conventional pollutants, heavy
metals, petroleum and polycyclic aromatic hydrocarbons, as well as detectable concentrations of a number of priority pollutants.

While no statistically significant differences were discerned in pollutant concentrations of runoff from different urban land use categories, the NURP investigators did find the pollutant characteristics of runoff from non-urban/open sites to differ significantly from urban sites. Analyses of the concentration characteristics of storm pulses occurring in streams based upon EMCs of copper, lead, and zinc in runoff from the median urban site indicated that frequent exceedances in ambient standards for copper and lead were likely.

The potential for water quality problems related to the discharge of conventional pollutants in concentrations typically present in urban stormwater runoff was also documented. A comparison between typical urban runoff concentrations of coliform bacteria and water quality standards established by the RIDEM for the purposes of protecting primary contact and consumptive uses of the state's saltwaters suggests the occurrence of frequent standards violations. An evaluation of typical total phosphorus concentrations in urban runoff relative to U.S. EPA's water quality criterion for total phosphorus indicated that such discharges were likely to accelerate the eutrophication process. Finally, urban runoff discharges of solids, biological oxygen demand, and chemical oxygen demand were
found to be comparable to and/or roughly an order of magnitude greater than secondary treatment plant discharges on an annual basis.

This literature review has also documented the significance of the pollutants' chemical form with respect to selection of control practices that will be most effective in removing pollutants from urban runoff. Significant reductions in pollutants found predominantly in particulate form or having high associations with particles, such as sediments/solids, hydrocarbons, lead, chemical oxygen demand, and bacteria are possible via physical settling. Physical settling can also be expected to provide moderate removal of pollutants composed equally of particulate and soluble fractions, such as phosphorus and copper, and negligible removal of pollutants found predominately in soluble form.
CHAPTER III

STATUTORY AUTHORITY FOR STORMWATER QUALITY MANAGEMENT
IN RHODE ISLAND

Introduction

There is presently no comprehensive authority to control urban stormwater runoff discharges to protect the quality of Rhode Island's surface waters. However, the installation of stormwater management structures may be required by any one of several existing regulatory programs. In most cases, the legal authority to establish stormwater quality management requirements for the purposes of enhancing water quality is not explicitly stated, but rather included under broadly stated mandates. This chapter will examine the legal authority of applicable local, state, and federal laws to control runoff from urbanized areas for the explicit purpose of enhancing or protecting water quality. Emphasis will be placed on those regulatory programs affecting new development projects including highways. The objective of this analysis is to document that the existing patchwork of regulatory programs governing stormwater quality management in Rhode
Island is inadequate to provide comprehensive and consistent protection of the state's surface waters.

The specific statutes to be included in this review are the zoning enabling legislation (RI G.L. 1956, as amended, Chapter 45), subdivision zoning legislation (RI G.L. 1956, as amended, Section 45-23), Rhode Island's Freshwater Wetlands Act (RI G.L. 1956, as amended, Sections 2-1-18 through 2-1-25), Rhode Island's Coastal Resources Management Act (RI G.L. 1956, as amended, Sections 46-23), and relevant sections of the Federal Water Pollution Control Act as amended in 1987 otherwise known as the Water Quality Act of 1987. Rules and regulations pertinent to implementation of stormwater quality management requirements and in particular, definitions of areas of jurisdiction, and specific requirements will be examined, where relevant.

**Municipal Authority**

**Zoning Ordinance**

Zoning statutes and ordinances come within the class of legislation authorized under the police power of the state, which establishes the state's sovereign right to enact laws for the protection of the health, safety, morals, and welfare of its citizens. The state enabling legislation then grants local authorities the power to enact and to amend zoning regulations (RI G.L. 1956, as amended, Chapter 45). It specifically allows city and town councils to regulate and
restrict the types and locations of buildings, to determine the percentage of the lot that may be occupied and to prohibit or limit the uses of land in areas subject to flooding.

The establishment of zoning districts allows for the delineation of geographic areas where certain uses or activities, such as commercial or industrial activities, are permitted. The enabling legislation requires that the regulations be applied uniformly to all property located within the district so as to avoid discrimination which would represent a denial of equal protection of the law. Any regulatory action which imposes inequalities must be shown to be neither unreasonable nor arbitrary.

The zoning enabling legislation states that regulations must be designed to promote the public health and general welfare; to facilitate the adequate provision of transportation, water, sewerage, schools, parks and other public requirements. In addition, reasonable consideration must be given to the character of the district and with a view to conserving the value of buildings.

In establishing land use control regulations designed to protect water quality, special districts or zones may be delineated within a municipality's comprehensive plan and zoning ordinance, and specific requirements established to accomplish this purpose. Zoning ordinances routinely place restrictions on the types of development allowed in an area, establish minimum lot sizes to ensure a low density of
development, and establish setback requirements from the resources to be protected.

The zoning enabling legislation does not specifically authorize municipalities to establish zoning districts and requirements to protect environmental quality. Therefore, the enactment of more detailed site conditions or requirements to accomplish this purpose, such as stormwater quality management requirements brings with it greater uncertainty in the face of a legal challenge. In considering the legal viability of stormwater quality management requirements enacted under the zoning ordinance, several issues arise.

As the local government has no authority other than that granted it by the enabling legislation, it is imperative for the municipality to demonstrate that it is acting within its legal bounds. A test of the legitimacy of any restrictions established under police power is the existence of a reasonable relationship between the exercise of such powers and the public health, safety, morals, and general welfare (Town of Glocester v Olivo's Mobile Home Court, Inc., 300 A2d 465, (1973)). However, even if the town can prove that its action has a clear public purpose and is reasonable, the courts may require a demonstration that sufficient consideration was given to both the environmental and non-environmental ramifications of the action (Uchtmann and Seitz, 1979). A limitation on use of property which is not reasonably related to the stated objectives of the police
power is confiscation and a violation of the Fourteenth Amendment of the U.S. Constitution; representing a taking of property without just compensation. This is perhaps the most contentious issue raised by the use of zoning regulations to protect water quality.

Referring directly to the authority granted municipalities in the zoning enabling legislation, it could be argued that the control of stormwater runoff as a pollution source is within the purposes of promoting public health and welfare. This argument would be particularly cogent with respect to the maintenance of high quality waters valued as a source of drinking water, shellfish harvesting area, or recreational resource. Additionally, the argument may be extended to relate the impact of water quality degradation upon reduced property values within the town. Properties most affected by water quality degradation are obviously waterfront parcels or property having deeded access to ponds or lakes. For example, if the surface water is allowed to become choked with nuisance aquatic weeds or excessive algae blooms, the benefits of owning waterfront property, such as swimming and boating access are drastically reduced - negatively affecting property values. In rural areas, reductions in a town's income from property taxes due to lowered property values could be particularly damaging to its overall budget and ability to function.
Few towns in Rhode Island have enacted zoning ordinances aimed specifically at preserving environmental quality and, as yet, the legal authority of municipalities to do so has not been challenged directly. One court decision regarding conformity to enabling legislation may have set a precedent potentially influential in any subsequent litigation, however. The court has ruled (Lincourt v. Zoning Board of Review, 201 A.2d 482; American Oil Co. v. City of Warwick, 351 A.2d 577) that local zoning ordinances may not change or enlarge upon the specific authority contained in the state enabling act, and the jurisdiction thereby conferred can neither be expanded nor diminished.

Rhode Island's zoning enabling legislation does not contain language which explicitly authorizes municipalities to protect water, or even environmental quality. Lacking specific authority, a municipality's ability to legally defend its authority to enact stormwater quality management requirements under the zoning ordinance is uncertain.

**Subdivision Ordinance**

The state subdivision enabling legislation grants municipalities the power to adopt, modify, and amend rules and regulations governing and restricting the subdivision of land, for the purposes of promoting the general health, safety, morals, or general welfare of the community (RI G.L. 1956, as amended, Section 45-23-2). The rules and regulations are to
be designed to promote safety from fire and other dangers, to prevent overcrowding of land, to secure an appropriate allotment of land area in new developments for all requirements of community life, to conserve natural beauty and other natural resources, to furnish guidance for the wise and efficient expenditure of funds for public works and to facilitate the adequate, efficient, and economic provision of recreation and other public utilities (RI G.L. 1956, as amended, Section 45-23-3).

The enabling legislation lays out a fairly broad mandate for towns in regulating the subdivision of land. Relative to authorizing the establishment of stormwater quality management requirements at subdivisions, the key phrases include "to conserve natural beauty and other natural resources, to furnish guidance for the wise and efficient expenditure of funds for public works; and to facilitate the adequate, efficient, and economic provision of recreation and other public utilities." It could be argued that requiring the construction of control measures providing water quality enhancement of runoff generated at a subdivision achieves these objectives. No Rhode Island case law was found testing municipalities' authority to enact such requirements under subdivision ordinances.
State Authority

Rhode Island Freshwater Wetlands Act

In its declaration of intent, the Freshwater Wetlands Act recognizes the value of swamps, marshes, and other freshwater wetlands in moderating floodwaters, recharging groundwaters, and providing highly valuable wildlife habitat and recreational areas (Section 2-1-18 of RI G.L. 1956, as amended). The declaration of intent continues that it is the Act's intention to preserve and regulate the use of such swamps, marshlands and wetlands to protect them from random, unnecessary, and/or undesirable drainage, excavation, filling, encroachment or other form of disturbance or destruction. It is further stated, that the statute is enacted in the best public interest and essential to the health, welfare, general well being of the general populace and protection of property and life during times of flood or other disaster affecting water levels or water supply.

Based upon these stated intentions, the Act establishes that it is the public policy of the State of Rhode Island to preserve the purity and integrity of the swamps, marshes and other freshwater wetlands and that in the exercise of the police power they are to be regulated. To achieve this end, the Act requires that approval from the Rhode Island Department of Environmental Management (RIDEM) be obtained prior to the initiation of any activity potentially affecting a freshwater wetland.
The statute's definition of freshwater wetlands is unusually comprehensive and particularly significant in that it explicitly states those areas governed by the Act. Vegetation, hydrologic characteristics, and distance from specific features are used to define freshwater wetlands. Included in the definition of freshwater wetlands are marshes, swamps, bogs, ponds, rivers, river and stream flood plains and banks, areas subject to flooding or storm flowage, emergent and submergent plant communities in any body of freshwater and that area of land within 50 feet of the edge of any bog, marsh, swamp or pond. Minimum acreages are placed on the definition of certain wetland areas, as follows: all bogs, marshes greater than one acre, swamps greater than three acres, and ponds greater than a quarter acre. Riverbank is further defined as that area of land within 200 feet of the edge of any flowing body of water ten feet or wider and within 100 feet of the edge of any flowing body of water less than ten feet wide during normal flow (RI G.L. 1956, as amended, Section 2-1-20).

Broadly interpreted, the statute's intention of preserving and regulating the use of wetland areas to protect them from random, unnecessary, and/or undesirable forms of disturbance or destruction could be found to provide a mandate sufficient to establish regulations to protect the quality of these wetland areas. Given that the statute's definition of wetland areas includes ponds, lakes, rivers and streams, this
could be further defined as authorization to preserve and regulate the use of wetlands to protect water quality. Certainly, the maintenance of water quality is necessary for the protection of wetland areas' cited values, that is, wildlife habitat and recreation.

In adopting regulations to implement the Freshwater Wetlands Act, RIDEM adopted the declarations of intent and public policy set forth in the Act as the administrative findings and policy upon which the regulations are based. In addition, RIDEM enumerated several other findings as further basis of the regulations. RIDEM's recognition that "alteration of wetlands may adversely affect water quality and diminish the uses of water bodies through sedimentation and other causes" creates the foundation for establishing regulations designed to protect water quality (RIDEM, 1981). Another finding potentially affecting the area governed by the regulations states that "alterations within wetland areas, or within the drainage basin surrounding wetland areas, often reduce the ability of wetlands to prevent flooding."

Included in the regulations' definition of alteration are the following terms pertinent to stormwater runoff management: drain installation, drainage discharge, directing effluents or surface water flows into or out of, or otherwise changing the character of any freshwater wetland. The regulations further state that activities conducted outside of wetland areas as defined, will be considered wetlands alterations "if
such activities directly affect the ability of the wetland to
moderate flooding, provide wildlife habitat, recharge the
groundwater supply, or provide recreation" (RIDEM, 1981).

At first glance, this statement appears to significantly
increase the regulations' area of jurisdiction. However, upon
further examination, it also appears to limit the RIDEM's
authority to regulate detrimental activities occurring outside
wetland areas, if the regulations are enacted for any purpose
other than those stated. Furthermore, the regulations do not
require that the applicant prove that such activities will not
directly affect the wetland's stated functions or values. It
is implied, therefore, that the onus is on RIDEM to prove that
such activities will detrimentally affect a wetland area. In
the case of stormwater management requirements placed on an
activity occurring outside of a wetland area, RIDEM would be
required to prove that the activity would result in water
quality degradation and that as a result the wetland's ability
to provide wildlife habitat or recreation was adversely
affected.

The regulatory program establishes two procedural steps;
first, a preliminary determination of the Freshwater Wetlands
Act's applicability to a proposed project and second,
determination of whether the proposed activity constitutes a
significant alteration of the wetland requiring adherence to
formal application procedures. If the proposed activity is
found to result in insignificant alterations to the wetland,
RIDEM may stipulate that certain conditions be met in granting approval of the project to ensure that no significant alterations do occur as a result of the project.

The formal application procedure, which is delineated in Section 2-1-22 of the Act, is set forth in detail in Sections 5.00 through 8.00 of the rules and regulations. The regulations also set forth the policy by which an application for approval to alter a freshwater wetland will be denied. Included in the actions representing random, unnecessary and/or undesirable destruction of freshwater wetlands is reduction in the use assigned to that class of water quality as defined in Rhode Island Water Quality Regulations for Water Pollution Control (RIDEM, 1979). Reduction of the ability of any wetland tributary to a public water supply to remove pollutants from surface water is also considered as "destruction of freshwater wetlands".

The review criteria used in evaluating a site plan of a proposed project are outlined in Section 7.00 of the regulations. Any projects involving changes in the drainage and/or runoff characteristics (including any piping of streams or storm drainage) of an area must analyze the anticipated effects of such changes. Specifically, the flows resulting from a 10-year frequency storm event are to be analyzed to determine if any net increase in runoff is indicated. If increases are evident, the engineer must evaluate the effect on peak discharges with specific reference to local flooding.
problems. A formal application will be required, if significant increases in flooding are evident. The regulations state that the use of percolation structures, holding ponds, etc., to contain and/or detain on-site, the additional runoff resulting from the proposed work is considered a desirable design feature (RIDEM, 1981).

As evidenced in this review of Section 7.00, there is no mention that projects involving changes in the drainage and/or runoff characteristics (inherent in most development projects) must analyze the water quality effects of such changes. Water quality impacts associated with projects subject to the wetlands regulations, however, are covered in Section 7.05 of the rules and regulations. More specifically, the RIDEM Wetlands Section is required to request a review of the impact of water quality by the RIDEM Division of Water Resources, where substantial question concerning the impact of a proposed alteration on the water quality of a wetland exists.

In conclusion, while it appears that the freshwater wetlands law and regulations establish the authority to regulate the use and alteration of wetland areas (including drainage discharges thereto) to protect water quality, there are no guidance or criteria established for this purpose. In fact, by referring issues of substantial water quality impact to the Division of Water Resources, it would appear that it is not the regulations' intent to address these issues directly. Based upon the analysis presented, the authority
to establish stormwater management requirements designed to protect water quality would appear to be limited to those projects located within 50 feet from swamps, marshes, bogs, or ponds; 100 feet of streams less than 10 feet wide; and 200 feet of streams greater than 10 feet wide. These requirements would not apply to projects potentially affecting water quality but located outside the wetland area unless it could be proven that discharges from these projects would directly affect the wetland areas' ability to provide wildlife habitat or recreational opportunities.

Rhode Island Coastal Resources Management Council

In enacting the legislation creating the Coastal Resources Management Council (CRMC), the state legislature gave recognition to the value of the state's coastal resources as a rich variety of natural, commercial, industrial, recreational and aesthetic assets. The preservation and restoration of ecological systems were to be the primary guiding principles upon which environmental alteration of the coastal resources was to be measured, judged and regulated (RI G.L. 1956, as amended, Chapter 23). The CRMC was created to undertake the comprehensive and coordinated long term planning and management of the state's coastal resources. In establishing the council's powers and duties, Section 46-23-6 of the Act specifies certain basic standards and criteria, around which all plans and programs will be
developed. Included are the need and demand for various activities and their impact upon ecological systems; water quality standards set by the Department of Health (since taken over by the Department of Environmental Management); and consideration of contiguous land uses and transportation facilities. The Act specifically authorizes the CRMC to adopt regulations necessary to implement its various management programs.

In establishing the Coastal Resources Management Program, the CRMC specified the geographic areas under its jurisdiction and the activities and alterations requiring a CRMC assent. With respect to land areas, the CRMC's jurisdiction includes shoreline features and areas contiguous to shore features. Contiguous areas are defined as extending inland 200 feet from the coastal feature (Coastal Resources Management Program as amended June 28, 1983, Section 100.1). The activities and alterations requiring a CRMC assent are specifically listed in the program and include residential, commercial, and industrial structures; point discharges of runoff; and construction of public roads, bridges, parking lots, etc. All tidal waters and coastal ponds have been assigned to one of six use categories, as follows.

Type 1 Conservation Areas
Type 2 Low-Intensity Use
Type 3 High-Intensity Boating
Type 4 Multipurpose Waters
Type 5 Commercial and Recreational Harbors

Type 6 Industrial Waterfronts and Commercial Navigation Channels

The program sets forth findings, goals, and policies pertinent to each category. With respect to runoff from developed areas, the most restrictive language pertains to discharges to Type 1 and 2 waters. The policy governing use of Type 1 waters recognizes runoff from developed areas as a potential major source of pollutants and, therefore requires that any new or enlarged point discharges of runoff to these waters demonstrate that no reasonable alternative exists and that no significant adverse impact to the receiving waters will result. The criteria go on to state that cumulative impacts of runoff are of particular concern in Type 1 waters.

Relative to Type 2 waters, the program's policies recognize the potential impact of runoff to poorly flushed estuaries and establishes the same criteria as applies to Type 1 waters to specifically defined estuaries in Rhode Island. Although not explicitly requiring runoff control measures, the policies governing use of Type 4 waters which encompass large expanses of open water in Narragansett Bay recognize the need to maintain good water quality in the Bay.
Federal Authority

Rulemaking under the Federal Water Pollution Control Act

In 1972, amendments to the Federal Water Pollution Control Act (FWPCA) prohibited the discharge of any pollutant to navigable waters from a point source unless the discharge was authorized by a National Pollution Discharge Elimination System (NPDES) permit. As defined in the 1972 statute, point sources of pollution included "...any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation or vessel or other floating craft from which pollutants are or may be discharged" (33 USC 1362).

In adopting rules to implement the FWPCA, U.S. EPA reasoned that stormwater runoff was more appropriately treated as a nonpoint source of pollution rather than a point source, despite the fact that urban runoff is frequently collected and conveyed via drainage ditches or conduits. In 1973, U.S. EPA issued its first stormwater regulations exempting stormwater discharges uncontaminated by industrial or commercial activity (38 FR 13530, May 22, 1973).

The first legal challenge to U.S. EPA's stormwater regulations was made by the Natural Resources Defense Council which questioned U.S. EPA's authority to exempt any point sources from the NPDES permit requirements (NRDC v Train, 396
F Supp. 1393, (D.D.C. 1975); 568 F.2d 1369 (D.D.C 1977)). The U.S. District Court held that U.S. EPA could not lawfully exert this authority, however also reaffirmed the agency's discretion to determine which pollution sources were to be covered by the NPDES program.

Through a series of proposed regulations (41 FR 11307, March 18, 1976; 45 FR 33290, 44 FR 32854, June 7, 1979; May 19, 1980; 49 FR 37998, September 26, 1984), several public comment periods, and a second law suit (NRDC v. EPA, 673 F.2d 392 (D.C. C. 1980), U.S. EPA formulated stormwater regulations ranging widely in scope and requirements. Initially, U.S. EPA proposed a comprehensive permitting program for all stormwater discharges, including urban separate storm sewers, with only rural runoff uncontaminated by industrial or commercial activity (including agricultural runoff) exempted. Discharges of runoff from industrial and commercial areas were required to submit the then-existing individual permit applications, including testing requirements imposed on wastewater dischargers. This series of rulemaking actions ended with a settlement in which U.S. EPA agreed to change the regulations.

The proposal by U.S. EPA would significantly narrow the definition of stormwater point sources to conveyances of stormwater contaminated by process wastes, raw materials, toxics, hazardous pollutants or oil and grease. In addition, the application requirements for discharges from commercial
and industrial areas were revised thus, limiting the testing requirements to conventional parameters only.

Following a public comment period on this proposal, U.S. EPA finalized the stormwater regulations on September 26, 1984 (40 CFR 122.26). The scope of "stormwater point sources" was again redefined; the 1984 rule broadened the definition to include channelized conveyances of runoff located in urbanized areas as defined by the Bureau of Census (populations of 50,000 or greater), in industrial and commercial areas, or as designated by the Director (49 FR 37998, September 26, 1984). Group I discharges, defined as runoff discharged from industrial or plant associated areas, were required to submit Forms 1 and 2C, and the NPDES Application Form, including certain sampling and testing data.

Based upon comments received from industry and trade representatives objecting to the scope of testing requirements, U.S. EPA proposed changes to these final regulations on March 7, 1985 (50 FR 9362). Under these regulations, U.S. EPA proposed issuance of general permits to groups of like industries. Under these general permits, an industry included in a "group" would be exempt from the individual Group I application requirements (including the testing requirements). The approach relied upon voluntary, written commitments by trade associations to submit quantitative data from selected representative Group I sources (50 FR 9362, March 7, 1985).
After evaluating the comments received on the proposed rules issued on March 7, 1985, U.S. EPA decided to re-open the public comment period to provide additional information and issues on the process and procedures to be employed in implementing the group application option for Group I applicants. This cycle of rulemaking actions undertaken by U.S. EPA was interrupted by consideration of the stormwater issue by Congress in the course of reauthorizing the Clean Water Act. In fact, because of significant changes made by provisions of the Water Quality Act of 1987, U.S. EPA requested that the regulations (40 CFR 122.26, promulgated on September 26, 1984) be remanded for further rulemaking. On February 12, 1988 (53 FR 4157), U.S. EPA published a notice which deleted Section 122.26 pursuant to the Court of Appeals' remand.

Water Quality Act of 1987

The Water Quality Act of 1987 (33 USC 1251) was signed into law on February 4, 1987. The issue of stormwater is addressed in Section 405 of the statute. This section amends the Federal Water Pollution Control Act by adding Section 402(p) which requires U.S. EPA to promulgate regulations establishing permit application requirements for stormwater discharges associated with industrial activity and discharges from large municipal separate storm sewer systems (serving a population of 250,000 or more) by February 4, 1989.
Regulations establishing permit requirements for discharges from medium municipal separate storm sewer systems (serving a population of greater than 100,000 but less than 250,000) must be promulgated by February 4, 1991.

Section 402(p) further requires that permits for large municipal separate storm sewer discharges and stormwater discharges associated with industrial activities be submitted by no later than February 4, 1990. Whereas February 4, 1992 is the deadline for submittal of permits for medium municipal separate storm sewer discharges. Permits for other stormwater discharges cannot be required until October 1, 1992, unless a permit for the discharge was issued prior to the enactment of the Water Quality Act of 1987, or U.S. EPA or an NPDES State determines that a discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

Section 402(p)(3) is meant to clarify permit application requirements for stormwater discharges. Discharges associated with industrial activity must meet all of the applicable provisions of Sections 402 and 301 (relating to the control of priority pollutants) including technology and water quality based standards. For discharges from municipal separate storm sewer systems, the Act allows for the issuance of system- or jurisdiction-wide permits, requires the prohibition of non-storm water discharges into the storm sewers, and requires the use of controls to reduce the discharge of pollutants to the
maximum extent practicable, including management practices, control techniques and systems, design and engineering methods, etc.

Under Section 402(p)5 of the Water Quality Act of 1987, U.S. EPA in consultation with states is to conduct studies for the purpose of identifying stormwater discharges or classes of discharges for which permits are not required prior to October 1, 1992. Once identified, the nature and extent of pollutants in such discharges are to be determined, and procedures and methods established to control these stormwater discharges to the extent necessary to mitigate impacts on water quality. Section 402(p)6 sets October 1, 1992 as the deadline for U.S. EPA to promulgate regulations based upon the Section 402(p)5 studies, identifying stormwater discharges for which permits will be required to protect water quality. Stormwater discharges identified under these studies are to be regulated under a comprehensive program to be established by these regulations, which, at a minimum, establishes priorities, requirements for state stormwater management programs, and expeditious deadlines. A final provision of the Act relevant to the stormwater issue is Section 503 which amends Section 502(14) to exclude agricultural storm water discharges from the definition of point source.
Proposed Rules for NPDES Stormwater Permits

On December 7, 1988, U.S. EPA issued proposed rules establishing NPDES permit application requirements for stormwater discharges associated with industrial activity, and discharges from large and medium municipal separate storm sewer systems (53 FR 49416, December 7, 1988). The proposed NPDES requirements apply to separate storm sewer systems and are focused primarily on cities meeting the population criterion.

The proposed regulations provide that no NPDES permit is required for stormwater discharges associated with industrial activities entering any municipal separate storm sewer system, unless otherwise required under Section 402(p)(2)(E). For discharges associated with industrial activities entering a municipal system serving a population of less than 100,000, no permit will be required prior to completion of studies mandated under Section 402(p)5 (53 FR 49430, December 7, 1988).

The proposed rule issued on December 7, 1988 defines the scope of "activities associated with industrial activities" (53 FR 49430, December 7, 1988). Legislative history provides insight into Congress' intention with respect to what activities should be included (Vol. 132 Cong. Rec. H 10932, H 10936 (daily edition October 15, 1986); Vol. 133 Cong. Rec. H 176 (daily edition January 8, 1987). As explained by several members of Congress, the term was meant to apply if
a discharge was "directly related to manufacturing, processing or raw materials storage areas at an industrial plant." U.S. EPA has based the regulatory definition on that described by Congress; relying upon the Standard Industrial Classification codes for clarification. Included in the proposed definition of facilities which generate and discharge stormwater associated with industrial activity are the manufacturing and mineral industries; certain landfills and hazardous waste sites; transportation facilities which have vehicle maintenance shops, material handling facilities, equipment cleaning operations and airport deicing operations; and facilities classified as general building contractors and heavy construction contractors (53 FR 49431, December 7, 1988). This last category is comprised of clearing, grading and excavation activities except operations that result in the disturbance of less than 1 acre total land area which are not part of a larger common plan of development or sale, or that are designed to serve single family residential projects including duplexes, triplexes or quadraplexes, that result in the disturbance of less than 5 acres total land area which are not part of a larger common plan of development or sale.

The December 7, 1988 rule provides two application approaches for discharges associated with industrial activities, individual or group permits. U.S. EPA proposes modifications in the individual permit application requirements found under the 1984 regulations. Specifically,
the permit application requirements reduce the amount of quantitative data required and exempt discharges which contain entirely stormwater from certain reporting requirements of Form 2C. The proposed approach would rely more on descriptive information for assessing impacts of the stormwater discharge.

The group application option for discharges associated with industrial activities would establish a regulatory procedure whereby a representative entity, such as a trade association, may submit a group application to the Office of Water Enforcement and Permits in which quantitative data from certain representative members of a group of industrial facilities is supplied (53 FR 49435, December 7, 1988). This information would be used to develop models for individual permits or general permits for use by U.S. EPA Regions and NPDES States. As proposed by U.S. EPA, this process would not directly result in the issuance of permits, per se.

Distinct permit application requirements are proposed for construction activities, as a subset of discharges associated with industrial activities (53 FR 49441, December 7, 1988). Under the proposal, such facilities would be required to submit a narrative describing the nature of the construction activity; proposed measures, including best management practices to control pollutants in runoff during and after construction; and other site specific information related to construction activities and hydrological changes expected. As such, no quantitative data requirements will be imposed on
construction activities. Categorized as a discharge associated with industrial activities, runoff from construction sites discharging to municipal separate storm sewer systems would not be subject to the NPDES permit requirements. For example, runoff from a subdivision discharged to the drainage system of an existing road or a road built by a developer for a municipality is, under U.S. EPA's proposal, discharging to a municipal storm sewer.

In mandating that permits for municipal separate storm sewers require controls to reduce the discharge of pollutants to the maximum extent practicable (Section 402(p)(3)), Congress envisioned a shift from the traditional end-of-pipe approach towards comprehensive stormwater management programs (Vol. 132 Cong. Rec. S 16425, daily edition Oct. 16, 1986). The application requirements proposed in the December 7, 1988 rule are meant to apply to large and medium municipal storm sewer systems, and any other municipal system required to obtain a permit as designated by U.S. EPA or an NPDES state under Section 402(p)(2)(E).

U.S. EPA's intent is to develop permit application requirements that will lead to development of site-specific stormwater management programs. The proposed strategy for implementation of the permit program is very comprehensive (53 FR 49450, December 7, 1988). Included in its requirements are identification and characterization of significant sources of pollutants, assessment of water quality impacts,
descriptions of proposed control measures and approaches proposed for implementation of measures, estimates on the effects of control measures on discharges' pollutant characteristics and on receiving waters. Additionally, U.S. EPA is proposing that the permit application requirements include an analysis of legal authority and financial capabilities of municipalities to establish stormwater management programs. In the detailed requirements for municipal stormwater management programs, U.S. EPA has included measures to reduce pollutants in runoff from commercial and residential areas, from discharges associated with industrial activities, and from construction sites. The proposed rule also details requirements for measures to control illicit discharges.

In the near future, U.S. EPA intends to issue a final rule codifying numerous provisions of the Water Quality Act of 1987 into EPA regulations. Included in this codification action, will be the statutory authority of Section 402(p)(2)E for U.S. EPA or NPDES states to designate storm water discharges for a permit on a case by case basis if it is determined that the discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. Any available water quality or sampling data may be used in making this determination. Factors to be considered are the location and
size of the discharge, the quantity and nature of pollutants discharged, as well as any other relevant information.

**Interpretation of Section 402(p) Requirements**

At the present time, there are no regulations governing the issuance of new NPDES permits for stormwater discharges in effect, as the regulations (40 CFR 122.26) promulgated on September 26, 1984 were vacated and remanded for further rulemaking by U.S. EPA. The proposed regulations issued on December 7, 1988 are guided by provisions of the Water Quality Act of 1987 and past rulemaking experience. In Rhode Island, only the City of Providence meets the population criterion set forth in the Water Quality Act in defining municipal separate storm sewer systems subject to the NPDES permit application requirements. And under the proposed rule, only those discharges associated with industrial activities directly entering the state's surface water would be required to comply with the Act's requirements. As a delegated NPDES state, Rhode Island is provided broad discretion under Section 402(p)(2)(E) in designating additional stormwater discharges subject to the NPDES program requirements, however this would affect only existing discharges and, thus would not address control of stormwater runoff from new land use (and highway) development projects. Lastly, it appears that studies required under Section 402(p)(5) may result in regulations establishing comprehensive stormwater management programs and
more broad coverage of stormwater discharges governed by the Water Quality Act requirements. However, the deadline for promulgation of these regulations is nearly four years away.

Conclusions

The existing patchwork of regulatory programs governing stormwater quality management in Rhode Island has been shown to be inadequate to provide comprehensive and consistent protection of the state's surface waters from new sources of urban runoff. Stormwater quality management requirements for new land use developments may be imposed at the state and local level, however, generally the legal authority is not explicitly stated nor is there an overall policy establishing uniform standards and specifications.

At the local level, the lack of specific authority to enact zoning ordinances for the purposes of protecting environmental quality places any stormwater management requirements promulgated for this purpose on uncertain terms in the face of a legal challenge. The subdivision enabling legislation, on the other hand, appears to provide adequate authority for municipalities to enact stormwater management requirements as a condition of a subdivision approval, although again, it is not explicitly stated.

The Rhode Island Freshwater Wetlands Act and regulations appear to establish the authority to regulate the use and alteration of wetland areas (including drainage discharges
thereeto) to protect water quality. However, it is this author's interpretation that explicit authority is limited only to those activities occurring within the legally defined wetland area. Not included under this authority are those projects occurring outside the wetland area potentially having adverse impacts on the wetland's water quality. The regulations' lack of guidance or criteria governing stormwater quality management and its referral of significant water quality issues to another division of RIDEM indicate that it was not the regulation's initial intent to address these issues directly.

The Coastal Resources Management Council's policy governing the management of coastal waters recognizes runoff from developed sites as a potentially significant source of pollution to areas designated for conservation and low-intensity use. CRMC has jurisdiction over activities occurring within 200 feet of coastal features statewide, however its policies require stormwater quality management only in those areas described.

Finally, at the federal level, the Water Quality Act of 1987 establishes stormwater quality requirements under the NPDES program. The proposed NPDES permit application requirements would affect a relatively small subset of land use development projects in Rhode Island. Only the City of Providence meets the population criterion for inclusion of municipal separate storm sewer systems under the NPDES permit.
requirements. These requirements are likely to have only limited impact on land use development projects with the possible exception of redevelopment projects. The second group affected by the proposed regulations are storm sewers associated with industrial activities, including construction sites. These NPDES requirements, however, are limited only to those discharging directly to surface waters. Representing a major loophole, is the exemption of any land use development projects discharging directly to an existing municipal separate stormwater system, regardless of the population served.

The inclusion of other stormwater discharges under the NPDES program as a result of Section 402(p)(5) studies could lead to comprehensive stormwater quality management, however the mandated time frame for promulgation of these regulations is nearly four years away. Furthermore, if the history of U.S. EPA's rulemaking with respect to NPDES permit application requirements for stormwater runoff is any indication, no speedy resolution of these issues can be expected.
CHAPTER IV

GUIDELINES FOR STORMWATER QUALITY CONTROL MEASURES

Introduction

Detailed technical guidelines for the design of runoff control measures form the foundation of any stormwater quality management program. This chapter presents information on the effectiveness of stormwater control measures in removing runoff borne pollutants. Research undertaken by the author in preparation of Rhode Island Department of Environmental Management (RIDEM) report entitled, "An Evaluation of the Effectiveness of Stormwater Control Facilities in Providing Water Quality Enhancement" was drawn upon in writing this section. Based upon these research findings and other considerations, such as groundwater protection and facility maintenance, recommendations are made as to the measures most appropriate for use in Rhode Island.

Pollutant removal efficiency appears to be highly dependent upon many different factors, control structure design being particularly significant (U.S. EPA, 1983; Woodward-Clyde Consultants, 1986). This thesis presents conceptual design features found to be influential in the pollutant removal process. Research and materials
incorporated into the RIDEM Office of Environmental Coordination (OEC) (1988a) report entitled "Recommendations of the Stormwater Management and Erosion Control Committee Regarding the Development and Implementation of Technical Guidelines for Stormwater Management" prepared by the author in coordination with the Committee were drawn upon in writing this section of the chapter. In addition to the findings of NURP and other stormwater management investigations, the guidelines and preferred technologies of states and localities with established stormwater management programs were reviewed.

'Form and Function' in Stormwater Management

The design of stormwater control facilities is dependent upon the purpose they are intended to serve. Flood control facilities are designed to replace the natural storage lost through development and to moderate development-related increases in runoff peak discharges. The temporarily stored runoff is discharged from flood control basins at a specified rate, often set at the site's pre-development peak rate of runoff. The outflow structure of flood control basins is designed to completely drain the collected runoff, to ensure adequate storage capacity for subsequent storm events. Dry detention basins are commonly used for flood control purposes.

The primary design criteria for flood control measures is the peak rate of runoff or peak discharge. Detention basin design criteria are most often expressed in terms of control
of the peak discharge from a specified frequency storm event. The National Weather Service has analyzed rainfall data and determined regional rainfall characteristics associated with different frequency storm events. For example, the expression of rainfall conditions based upon the 2-year frequency, 24 hour duration storm event represents the extreme 24 hour rainfall depth condition likely to occur once in two years.

To prevent streambank erosion and channel scouring, stormwater flood management structures are typically designed to control increases in the 2-year, 24 hr frequency storm event peak discharge and runoff volume. Whereas, to prevent nuisance flooding, increases in the 10- or 25-year frequency storm event would be controlled. Maximum flood protection is provided with detention basins designed to treat the peak discharge of the 100-year storm event.

Basin designs which accommodate the natural storage lost through development can be effective in reducing peak discharges however, typically the timing characteristics of runoff and storage release are very different than exist naturally (Lakatos and Kropp, 1982). A potential consequence of the altered timing is increased flooding downstream resulting from the simultaneous arrival of multiple stormwater discharges located upstream in the same drainage basin. While dry detention basins are generally effective in mitigating the potential for localized flooding, they are typically very ineffective in enhancing the water quality of runoff.
Because dry basins are designed for complete drawdown of the temporarily stored runoff and have relatively high outflow rates and thus short detention times, the processes effective in reducing pollutant loads are not activated. The effectiveness of dry basins to provide water quality enhancement is further reduced by the scouring action of inflowing runoff upon basin substrate resulting in resuspension of previously deposited materials.

Several processes are influential in the reduction of runoff borne pollutant loads in stormwater control facilities including sedimentation, chemical flocculation and transformation, and biological uptake. A description of these processes further explains why the design of conventional dry detention basins is not conducive to the removal of runoff borne pollutants.

Pollutant removal efficiency appears to be highly correlated with the length of time a parcel of stormwater runoff is detained in a facility and subject to the previously mentioned pollutant removal mechanisms. The longer a parcel of water is maintained in the basin, generally, the greater the pollutant removal efficiency expected.

Gravitational settling of pollutants occurs when the average velocity in the basin, as related to its outflow rate, is less than the critical settling velocity of the particles (Barfield et al., 1981). Analysis of particle settling test results conducted by NURP projects and a similar set of tests
by Whipple and Hunter (1981) were analyzed to derive information on particle settling velocities of urban stormwater runoff (Driscoll, 1988). The results of this analysis indicate that the median settling velocity of particles in urban runoff is 1.5 ft/hr (Driscoll, 1982; 1988).

The poor pollutant removal rates of a basin with an outflow rate far exceeding this median settling velocity and the excellent pollutant removal rates for a basin with an outflow rate equal to a small fraction of this median settling velocity is testimony to the significance of basin outflow rates (Driscoll, 1988).

In his evaluation of the NURP data, Driscoll did not report the particle diameter associated with this median settling velocity. However, the analysis of seven stormwater samples collected from commercial areas as part of the Metropolitan Washington Council of Governments NURP study indicated that over 80 percent of the particles were less than 35 microns in diameter (MWCOG, 1983). These fine particles, having greater surface area per unit mass, than larger particles, provide more binding sites for adsorption of organic and inorganic pollutants. This coalescing of larger particles with smaller particles is also known as chemical flocculation. This process may entail soluble pollutants becoming adsorbed onto particles.

Biological uptake of pollutants is related to the metabolism of microorganisms primarily in the form of
bacteria, digesting organic matter (Harrington, 1986); as well as, uptake by aquatic plants and phytoplankton.

Runoff monitoring studies document pulses in runoff flow rate and pollution concentration over the course of a rain event (Hoffman et al., 1985). The first sharp and generally, greatest increase in runoff flow rate is referred to as the 'first flush'. Many runoff borne pollutants exhibit corresponding peaks in concentration during the 'first flush' of storm events (Hoffman et al., 1985; 1982). Hoffman et al. (1985) found peaks in pollutant concentrations to generally occur during high flow rates when the transportation of runoff contaminants is most efficient.

In their monitoring of runoff from a commercial area, Hoffman et al. (1982) found that settleable solids accounted for 66.7% of the total solids and that hydrocarbons associated with these solids accounted for 63.5% of the total. In the samples following the first flush, the importance of settleable solids in the samples became less important (Hoffman et al., 1982). An examination of a first flush sample to determine the influence of particle size on the hydrocarbon concentrations observed confirmed the significance of settleable solids to first flush effluents (Hoffman et al., 1982). These investigators' research also indicates that the discharge of runoff borne pollutants is supply limited as opposed to transport limited (Hoffman et al., 1983).
The implication for the treatment of stormwater runoff is that the majority of pollutants can be 'captured' if the facility is designed to provide prolonged detention of the first flush. This volume of runoff is relatively small as compared with flood control storage volumes and is assumed to be on the order of the volume of runoff generated from a 1-year frequency storm event.

Water quality enhancement may be achieved by a variety of stormwater control measures, including wet basins; extended detention dry basins; infiltration devices, such as basins, trenches, and dry wells; and vegetative control measures, among others (Schueler, 1987). Wet basins are designed to maintain a permanent pool of water, creating conditions conducive to physical settling, and chemical and biological interactions. Additionally, maintenance of a permanent pool of water reduces the scouring action of incoming flows upon bottom sediments and subsequently, the resuspension of deposited pollutants.

Extended detention dry basins differ from conventional dry detention basins, in that, the collected stormwater is metered out at a much slower rate than is required for flood control purposes. As a result, greater physical settling of pollutants is possible. Although more effective than dry detention basins in removing pollutants, extended detention dry basins are still subject to scouring and subsequent resuspension and discharge of previously settled sediments and
pollutants. The use of aquatic vegetation in either type of basin can have beneficial effects on pollutant removal efficiencies through biological uptake and physical trapping of pollutants (Schueler, 1987).

Infiltration measures depend upon seepage of collected runoff into the surrounding soil profile and occasionally, biological uptake of pollutants as the primary means of evacuation and treatment of runoff. Infiltration devices are true volume reduction measures as the amount of runoff discharged to surface water is either partially or completely reduced. Finally, vegetative control measures, such as grassed swales and filter strips, provide pollutant removal benefits through biological uptake, sedimentation, and in many cases, infiltration into the underlying soil. While these measures are recognized as viable alternatives for stormwater quality management, they will not be addressed by this thesis.

The technology for stormwater management measures providing flood control benefits is fairly well established due to a longstanding recognition of the flooding problems associated with land use development. This is not the case with stormwater controls providing water quality enhancement, however. The findings of recent stormwater management investigations in concert with the efforts of government regulators have provided considerable guidance in the design of control measures effective in reducing runoff borne pollutant loads.
Pollutant Removal Efficiencies

The purpose of this analysis is twofold. The first objective is to determine the type of pollutants that can be effectively removed by stormwater quality control facilities and the second is to identify a range of pollutant removal rates characteristic of the particular stormwater facility design. A case study approach is used to focus the discussion on particular design features influencing pollutant removal efficiencies.

Various arithmetic and statistical methods have been used by investigators to calculate pollutant removal efficiencies for stormwater control facilities. The basic formula for determining a facility's pollutant removal rate, expressed as a percentage is:

\[
1 - \frac{\text{Output pollutant load}}{\text{Input pollutant load}} \times 100
\]

The 'long term removal efficiency' approach was selected by the Nationwide Urban Runoff Program as the primary method for reporting project results (U.S. EPA, 1983). The long term removal efficiency rate is calculated by summing total mass loadings into and out of the facility as measured over the entire monitoring period. While the term does not allow analysis of seasonal and/or storm based variations in pollutant removal efficiencies, it serves as a sound planning guide.
Pollutant removal estimates for eight facilities have been compiled and are presented in Table 4-1.

**Dry Detention Basins**

The poor pollutant removal capability of dry basins is evidenced by the monitoring results from Whispering Heights Basin and Lake Ridge Pond (Table 4-1). Negligible reduction in pollutants was observed at the latter site, whereas the former site actually exhibited an increase in total suspended solids loads. These basins' poor performance was attributed to both short detention time and resuspension of previously deposited materials (Dally et al., 1983; MWCOG, 1983). It was noted that one of the first storms monitored at the Whispering Heights structure exhibited positive removal efficiencies, which was attributed to the absence of deposited materials from previous storms (Dally et al., 1983). The substrates of both structures were poorly vegetated and therefore prone to scour and erosion.

**Extended Detention Dry Basins**

The effect of extended detention upon pollutant removal rates is made obvious by comparing the conventional dry detention basin removal efficiencies with those from a dry basin retrofitted to provide extended detention (Table 4-1). The outlet of Stedwick Pond was retrofitted to provide a detention period of up to 24 hours. The removal rates for solids and pollutants found primarily in particulate form
### TABLE 4-1
POLLUTANT REMOVAL RATES FOR SELECTED STORMWATER CONTROL FACILITIES

<table>
<thead>
<tr>
<th>TSS</th>
<th>O&amp;G</th>
<th>TSP</th>
<th>TP</th>
<th>NO$_2^-$</th>
<th>NO$_3^-$</th>
<th>TKN</th>
<th>COD</th>
<th>TCd</th>
<th>DCD</th>
<th>TPb</th>
<th>DPb</th>
<th>Tzn</th>
<th>D2n</th>
<th>TCr</th>
<th>TCu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Dry Detention Basins

A  - 81

B  - 14 <20 <10 0 -10

#### Extended Detention Dry Basins

C  - 64 1 <15 10 30 84 57

#### Wet Detention Basins

D  - 20 -10 -156 -34 -81 23 -64 -91 -131

E  - 81 71 54 27 35 26

F  - 87 60 90 45 87 -132 81 78

G  - 44 25 22 33 12 32 33

H  - 89 63 15 89 49 6 58

Note: Pollutant removal rates are expressed as percentages

Description of Case Examples:

A  - Whispering Heights, Bellevue, WA (Dally et al., 1983)
   Note: Designed to provide flood control only

B  - Lakeridge Pond, Washington, DC (MWCOG, 1983)

C  - Stedwick Pond, Washington, DC (U.S. EPA, 1983)
   Note: Retrofitted to provide extended detention of up to 24 hrs.

D  - METRO Facility, Seattle, WA (Dally et al., 1983)
   Note: Facility design included baffle system oil/water separator


F  - Lake Ellyn, Chicago, IL (Hey and Schaefer, 1983)

G  - Pittsfield Retention Area, Washtenaw Co., MI (Akeley, 1980)

   Note: Removal rates based upon 5 day sampling period, Feb. 22-26, 1979; snow melt is only contributing inflow.
(Total Suspended Solids and Total Lead) are significantly greater than observed for the conventional dry basins. Other factors contributing to the improved removal rates, in addition to the extended detention period are a paved channel at the pond's bottom and establishment of vegetation along the pond bed. Both features reduced scour and resuspension of settled particles, (MWCWG, 1983). Despite the use of vegetation at Stedwick Pond, removal of pollutants in soluble form, such as soluble phosphorus and nitrite-nitrate, was poor.

**Wet Detention Basins**

Lake Ellyn, Chicago, IL

Lake Ellyn, studied in the Chicago NURP project is a natural body of water receiving both stormwater flows and base flows. The lake functions as a stormwater control facility, however, unlike most wet basins, it has a residence time of approximately nine months (Hey and Schaefer, 1983). The Lake Ellyn study reported some of the highest overall removal efficiencies of any of the studies reviewed (Table 4-1). Both particulate and dissolved forms of pollutants exhibited significant reductions. The long term removal rates for TSS, Nitrite-Nitrate, Total Phosphorus, Total Lead, Total Zinc and copper are particularly notable. The investigators attributed Lake Ellyn's excellent performance as a control device to four features, (1) its long residence time, (2) the location of the
main inlet at the extreme opposite end of the lake from the outlet, (3) sufficient depth so that wind induced turbulence does not resuspend bottom deposits, and (4) a substantial lake surface to depth ratio which promotes a high degree of reaeration in the upper layers (Hey and Schaefer, 1983).

Anoxic conditions at the sediment-water interface appear to be in part responsible for the observed reduction in nitrates and related increase in NH$_3$. In the absence of oxygen, the oxidation of metals and the reduction of nitrates is favored, thus producing NH$_3$. Another chemical reaction apparent within the hypolimnion is the complexing of lead deposits with chloride resulting in an increase in the dissolved lead concentrations. Although the outlet baseflow concentration of dissolved lead (DPb) were somewhat similar to both inlet baseflow and stormflow concentrations, the outlet stormflow concentrations were four to five times greater (Hey and Schaefer, 1983).

Reductions in total phosphorus and dissolved phosphorus loads were attributed to sedimentation and uptake in phytoplankton and aquatic vegetation. The true reduction in these pollutants is probably less than quantified as a portion of the dissolved phosphorus was discharged from the lake as suspended algal material. The investigators were unable to quantify the dissolved phosphorus fraction tied up in suspended algal material (Hey and Schaefer, 1983). The
suspended phosphorus fraction was thought to have been deposited in the lake sediments.

**Geddes Pond and Pittsfield Retention Area, Washtenaw Co., MI**

The Southeastern Michigan Council of Governments monitored two wet basins, Geddes Pond and Pittsfield Retention Area in Washtenaw County, Michigan. The preliminary results of these studies were reviewed for this thesis and are presented in Table 4-1. Geddes Pond was sampled during a five day sampling period where snow melt was the only contributing inflow (Akeley, 1980). High removal rates were observed for Total Suspended Solids, Total Phosphorus, Total Cadmium and Copper. In sharp contrast to these pollutant removal efficiencies, are those from the Pittsfield Retention Area, sampled during the summer months. The author related this difference to the larger particle size of pollutants deposited on snow in comparison to that contained in stormwater runoff (Akeley, 1980). Relative to the removal efficiencies observed at Lake Ellyn, the Pittsfield Retention Area pollutant removal rates are poor. The reference report did not specify site characteristics or the detention time provided in the facility, therefore no analysis of the facility's performance is possible.

**Westleigh Pond, Washington, D.C.**

Westleigh Pond was monitored by the Metropolitan Washington Council of Governments (1983) as part of the
Nationwide Urban Runoff Program (U.S. EPA, 1983). The maintenance of a permanent pool of water contributes to the substantial pollutant removal rates observed at Westleigh Pond (Table 4-1). In particular, removal rates for Total Suspended Solids, Total Soluble Phosphorus, and Total Phosphorus were significant (U.S. EPA, 1983). The pond had substantial emergent vegetation along the shoreline and there was also evidence of significant biological activity within the water profile. The relatively high removal rates for soluble phosphorus and modest reduction in nitrates is primarily attributable to biological uptake. By contrast, physical settling appears to be the primary mechanism for removal of organic nitrogen and organic phosphorus (MWCOG, 1983).

A multivariate regression model performed by MWCOG (1983) indicated that removal efficiencies for most particulate pollutants increase sharply as the size of storm increases.

METRO Facility, Seattle, WA

The poor performance of the METRO wet detention basin in Seattle, WA is in sharp contrast to the previously discussed wet basins (Table 4-1). A significant factor in the negligible or negative pollutant removal rates observed at the METRO facility is its short detention time, averaging 1-3 hours (Dally et al., 1983). Other factors contributing to the poor pollutant removal performance reported for this facility are poor sampling design, inadequate facility design, and poor
facility maintenance. The low TSS removal rate was thought to be associated with incomplete sampling of the inflow which allowed the majority of the first flush to bypass the sampler. The negative removal rate for oil and grease was attributed to the under design and poor maintenance of the two oil and water separator baffle structures incorporated into the METRO pond design. The investigators found that with high stormwater runoff flows, the separators overflowed releasing the accumulated petroleum hydrocarbons (Dally et al., 1983).

The data for lead, cadmium, and zinc suggest a substantial transformation from the particulate to the soluble fractions have occurred in the wet basin. The investigators observed that the increased levels of free ionic metals in the outflow could be a function of in situ chemical digestion, however concluded that it was more likely the result of significant contributions in the unmonitored "dry" flow from a nearby bus maintenance facility (Dally et al., 1983).

The researchers found the first flush effect to be most evident for particulate pollutants; such as total suspended solids, grease and oil and lead (Dally et al., 1983). There was no similar effect observed with total phosphorus, zinc or cadmium loads. The greatest particulate pollutant removal efficiencies occurred during storms exhibiting the most distinct first flush characteristics. Furthermore, this effect was greatest for pollutants exhibiting the most dramatic first flush loading pattern.
Unqua Pond, Massapequa, NY

Removal efficiencies for total and fecal coliform bacteria and fecal streptococci were quantified for eleven storm events surveyed at Unqua Pond as part of the Nationwide Urban Runoff Program (Long Island Regional Planning Board, 1982). Reductions in total coliform exceeded 95 percent for five of the eleven events monitored and ranged between 46 and 92 percent for the remaining storms. For fecal coliform, removal efficiencies ranged from 57 to 99 percent, whereas for fecal streptococci, removal rates of between 56 to 99 percent were observed (LIRPB, 1982). The retention of runoff for sufficient periods of time to allow settling of suspended particles and adsorbed pollutants, and bacterial die-off were mechanisms viewed as influential in the bacterial loading reductions observed at this site.

Ann and Hope Detention Basin, Seekonk, MA

Removal rates for hydrocarbons were quantified for a detention basin serving a commercial parking lot. The detention basin was originally designed as a flood control device, however during the time period in which it was monitored, a permanent pool of water was present (Latimer, personal communication). The inflow and outflow of the detention basin were monitored during two storm events, one in the spring and the other in the summer. Taking into account both storm events and including soluble and
particulate species, the overall removal efficiency for petroleum hydrocarbons was 67% and for PAHs was 54% (Latimer et al., 1986). The investigators found fairly significant differences in the individual storm pollutant removal efficiencies. This was attributed to physical differences in the two storms as well as antecedent dry conditions. Seasonal variations in the treatment efficiency for organic constituents due to increased biological activity during the warmer months was also noted as a probable factor in the observed differences.

**Infiltration Devices**

Two infiltration trenches were monitored by the Metropolitan Washington Council of Governments (1983). These investigators report removal rates for total suspended solids and total zinc to be on the order of 50 and 48 percent, respectively. Whereas, increases in total phosphorus and total nitrogen loads were observed. This poor performance was related to the insignificance of the biological removal mechanism within the coarse gravel of the trench monitored (MWCOG, 1983).

The primary means for evacuation of collected runoff in most infiltration devices is by seepage into the surrounding soil profile. As a result, no surface outlet is installed. Sampling of groundwater beneath recharge or infiltration facilities provides an indication of the pollutant reduction
occurring as runoff flows through the soil profile, as well as the potential for groundwater contamination from use of such control measures.

The Long Island Nationwide Urban Runoff Program project monitored the quality of stormwater runoff discharged to six recharge basins as well as, the quality of groundwater underlying these basins (LIRPB, 1982). The results of these studies indicate that the recharge basins were effective in removing bacteria, total lead and total chromium from stormwater before it reached the water table. This was not the case with nitrates and chlorides, however. Study results indicate little or no removal of these constituents as the stormwater moves through the unsaturated zone beneath the recharge basin (LIRPB, 1982). The shallowest depth to groundwater found at the Long Island study sites was 22 feet.

Similar findings were reported from a study performed in Florida (Wanielista, 1986), whereby nitrate was present in both the saturated and unsaturated groundwater zones. By contrast, other nutrients and heavy metals appeared to be either retained in the soil profile or taken up by vegetation. These findings have relevance to all stormwater control devices constructed in highly permeable soils.

Summary of Case Study Findings

These case studies have proven instructive in illustrating the relationship between certain design features
and the removal of pollutants. They have also demonstrated the variability in pollutant removal performance of similar control measure designs. These finding suggest a certain degree of site specificity in control measure performance and may also reflect the variability in runoff borne pollutant discharges between sites and/or storms.

The results of dry detention basin monitoring studies exemplify the negligible reduction in pollutants expected under non-quiescent conditions. The cited examples also documented the problems associated with the resuspension of deposited materials.

The effect of extended detention periods upon pollutant removal efficiencies was well illustrated by the Stedwick Pond example. Substantial reductions in solids and particulate pollutants were observed at this site - likely the result of design features which extended the detention period and reduced bottom scour. With the exception of total zinc, which typically consists of fairly high dissolved fractions, removal of dissolved pollutants in the extended detention dry basin was poor. This finding suggests that the conditions created by the extended detention basin were not conducive to the processes effective in removing dissolved fraction pollutants, that is, biological uptake, chemical transformation and adsorption.

The high removal rates for pollutants in solid or particulate form observed at the wet detention basins serve
to document the positive relationship between maintenance of a permanent pool and sedimentation. Wet basins were also found to be very effective in reducing bacterial contaminant loads. The substantial trap efficiencies for pollutants present in both particulate and dissolved forms (such as, Total Kjeldahl Nitrogen, Total Phosphorus, Total Copper, Total Chromium, Total Cadmium, Petroleum Hydrocarbons, and Polycyclic Aromatic Hydrocarbons) suggest that the wet detention basin design is also favorable for settling of smaller particles, chemical flocculation, and/or biological uptake. Finally, the wet basins surveyed demonstrated relatively high removal rates for dissolved nutrients, that is, total soluble phosphorus and nitrates. This finding is perhaps misleading in that, removal of these specific forms of nutrients was related to biological uptake, in the case of phosphorus, and chemical transformation in the case of nitrates. In both cases, the pollutants were not removed from the system but altered.

Lastly, the evaluation of infiltration devices indicates the potential for substantial removal of pollutants in particulate form and certain dissolved fraction pollutants. Negligible reductions in nitrates, chlorides, and other pollutants with poor soil attenuation properties are expected as a result of the infiltration process.

The case study approach has documented the effect of various removal mechanisms and design features in both the
type of pollutants removed and the degree to which this is accomplished. Obviously the pollutant removal rates cited will not always be achieved by any one stormwater control facility design at any one point in time. The studies reviewed indicate significant variability in stormwater control measures' pollutant removal performance can be expected as a function of changing site conditions, including storm intensity and weather conditions.

**Preferred Stormwater Quality Control Measures**

Basins designed to maintain a permanent pool of water appear to be the most effective means of reducing pollutant loads to surface waters without compromising the quality of groundwaters. The prolonged 'reaction time' for physical settling, chemical flocculation, and biological uptake in addition to the reduction in scouring action of incoming flows upon the basin substrate are major factors contributing to the pollutant removal efficiency of wet ponds. From the perspective of achieving maximum pollutant removal efficiency, wet basins are the preferred control measure for water quality enhancement purposes.

Extended detention dry basins designed to reduce bottom scour appear to be capable of substantially reducing solids and particulate pollutants. However, they are less effective in reducing pollutants in dissolved or soluble form. In some cases, the level of treatment provided by extended detention
dry basins may be sufficient to protect receiving water quality. However, where the introduction of nutrients to a waterbody may lead to accelerated eutrophication, the use of extended detention dry basins alone does not appear to be adequate to protect water quality.

The available data on infiltration devices indicate substantial reductions in both particulate and dissolved forms of pollutants are possible, with the exception of nitrates, chloride, and other highly soluble pollutants poorly attenuated in soils. Because of the potential for groundwater contamination, a cautionary flag is raised with the use of infiltration devices to treat runoff from sites expected to contain these pollutants.

The primary means of stormwater evacuation from infiltration systems is percolation into the surrounding soil. Infiltration systems are dependent upon the maintenance of high infiltration rates for their effective performance, therefore it is important that they be sited in relatively porous soils and be kept free of sediment and substances that clog the soil. The groundwater contamination and siting considerations are likely to present certain limitations on the use of infiltration devices.

Perhaps the most pertinent conclusion to be drawn from this case study is the significance of facility design and maintenance on pollutant removal efficiency. The following sections outline conceptual design criteria for wet basins and
extended detention dry basins, the two most broadly applicable stormwater quality control measure designs. The case study findings, and design criteria and technical guidelines established for existent stormwater management programs in other states serve as the basis for these criteria. More detailed technical specifications will not be included here, as they may be found elsewhere as noted previously in this chapter.

**Design Guidelines for Wet Detention Basins**

Wet basins are designed to permanently store the volume of runoff generated from a given frequency storm event or water quality design storm. The outlet of a wet basin is designed to maintain the specified control volume while discharging stormwater in exceedance of this volume. Therefore, the water in the basin will be exchanged as new stormwater runoff flows in and overtops the outlet orifice.

Pollutant removal efficiency is related to the time in which a parcel of stormwater runoff is detained in the basin and is subject to physical settling and biological uptake. The detention time for a given parcel of stormwater is related to the volume of the permanent pool, the mean rainfall volume, duration of the storm event, the interval between storms, and the elevation of the lowest outfall orifice.

In most cases, stormwater control measure design procedures presently in use by other states are appropriate
for use in Rhode Island. However in the case of wet basins, no well established procedure applicable to Rhode Island's conditions was available. Through personal communication with one of the members of U.S. EPA's NURP project team, Eugene Driscoll (E.D. Driscoll and Associates), a wet basin design procedure for use in Rhode Island was developed and reported by the author in the recommendations of the Stormwater Management and Erosion Control Committee (RIDEM OEC, 1988a). The procedure is presented in the following section. The design procedure's simplicity and ability to relate storage volume requirements to the amount of runoff generated on a particular site and desired pollutant removal efficiency rates lends itself to broad applicability.

Rainfall data is collected by the National Weather Service (NWS) at nine stations around the state, in addition to the stations maintained by the University of Rhode Island, the Providence Water Supply Board, the Narragansett Bay Commission and others. The U.S. EPA maintains a computerized data base of NWS rainfall data for most areas around the country. Using the computer model (SYNOP) documented in the NURP Data Management Procedures Manual as cited by U.S. EPA (1983), the U.S. EPA is capable of determining the longterm mean rainfall volume, intensity, duration, and interval between storms. This analysis has been performed for seven precipitation stations in Rhode Island, as shown in Table 4-2.
TABLE 4-2
PRECIPITATION STATISTICS FOR RHODE ISLAND

<table>
<thead>
<tr>
<th>Location</th>
<th>Years of Record</th>
<th>Mean Volume (in)</th>
<th>Mean Intensity (in/hr)</th>
<th>Mean Storm Duration (hr)</th>
<th>Mean Delta* (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woonsocket</td>
<td>17</td>
<td>0.38</td>
<td>0.103</td>
<td>5.95</td>
<td>73.82</td>
</tr>
<tr>
<td>T.F. Green Airport</td>
<td>35</td>
<td>0.39</td>
<td>0.050</td>
<td>6.72</td>
<td>74.94</td>
</tr>
<tr>
<td>Providence</td>
<td>5</td>
<td>0.43</td>
<td>0.062</td>
<td>7.11</td>
<td>81.87</td>
</tr>
<tr>
<td>Newport</td>
<td>33</td>
<td>0.53</td>
<td>0.134</td>
<td>5.45</td>
<td>98.73</td>
</tr>
<tr>
<td>Newport</td>
<td>15</td>
<td>0.40</td>
<td>0.137</td>
<td>5.37</td>
<td>84.74</td>
</tr>
<tr>
<td>Fort Adams</td>
<td>3</td>
<td>0.29</td>
<td>0.077</td>
<td>5.62</td>
<td>71.10</td>
</tr>
<tr>
<td>Block Island</td>
<td>35</td>
<td>0.39</td>
<td>0.055</td>
<td>6.63</td>
<td>83.80</td>
</tr>
</tbody>
</table>

* Delta is the time duration between mean storm events

(Source: RIDEM OEC, 1988, p. 18)
A model was developed for U.S. EPA which relates the solids removal efficiency rate to the ratio of the wet basin storage volume to runoff volume (Woodward-Clyde Consultants, 1986). The model is based upon analysis of the Nationwide Urban Runoff Program data using a basic probabilistic method developed by DiToro and Small (Hydroscience, 1979; DiToro and Small, 1979). The basis of the approach is the relationship between the physical settling of solids and associated pollutants under both quiescent and dynamic removal conditions and detention time as determined by basin storage capacity and surface area relative to the mean rainfall volume, duration of the storm event, and the interval between storms.

This model was applied to rainfall data collected at T.F. Green Airport in Warwick, Rhode Island to generate a plot relating solids removal efficiency to the ratio of detention basin storage volume to runoff volume for a series of detention basin depths (Figure 4-1). The T.F. Green Airport rainfall data was thought to be fairly representative of conditions in Rhode Island and therefore was used in this analysis. Modelled after the approaches developed for the State of Maryland (Harrington, 1986) and the Federal Highway Administration (Versar, Inc., 1986), this plot serves as the foundation of the wet basin design procedure developed for use in Rhode Island (Table 4-3).

Typically, the volume of runoff generated on a given site is determined by the Technical Report - 55 (TR-55) Method
Figure 4-1 - Long Term Solids Removal Efficiency as a Function of the Ratio of Volume of Basin/Volume of Runoff
(Source: UDDEM OEC, 1958, p.19)
TABLE 4-3

PROCEDURE TO DETERMINE WET BASIN VOLUME REQUIREMENTS

1. Define the area covered by impervious surfaces, including roadways, driveways, parking lots, buildings, rooftops, etc.
   \[ A = \text{area of impervious surfaces} = \text{______ ft}^2 \]

2. Determine the volume of runoff requiring water quality treatment by multiplying the square feet of impervious surfaces by the mean event rainfall volume of 0.4 inches.
   \[ VR = \text{Volume of runoff} = (A)(0.4 \text{ in})(\text{ft}/12 \text{ in}) = \text{______ ft}^3 \]

3. Determine the ratio of basin volume to runoff volume, \( VB/VR \) from the performance curves (Figure 4-1), entering at the desired percent solids removal and average depth.
   \[ D = \text{Average Depth} = \text{______ ft} \]
   \[ \% = \text{Percent removal} = \text{______} \]
   \[ VB/VR = \text{volume ratio} = \text{______} \]

4. Determine the required water storage volume for the permanent pool of water in the wet basin by multiplying the volume of runoff requiring water quality treatment by the volume ratio.
   \[ VB = \text{basin volume} = (VB/VR)(VR) = \text{______ ft}^3 \]

5. Determine the additional storage volume required for sediment accumulation.
   \[ SV = \text{sediment accumulation storage volume} = \text{______ ft}^3 \]

6. Determine the total wet basin storage volume capacity needed for the permanent pool of water and solids accumulation by adding the two volume requirements.
   \[ TV = \text{total wet basin volume} = (VB) + (SV) = \text{______ ft}^3 \]

7. Determine the preferred basin surface area by dividing the basin volume by the average depth.
   \[ \text{Basin surface area} = TV/D = \text{______ ft}^2 \]

8. Convert the average depth \( D \) and total volume \( TV \) requirements to physical basin dimensions based on the length to width and side slope ratios.
   \[ \text{Length to width ratio} = \text{______} \]
   \[ \text{Side slope ratio} = \text{______} \]
   \[ \text{Basin depth} = \text{______ ft} \]
   \[ \text{Basin length at the surface} = \text{______ ft} \]
   \[ \text{Basin length at the bottom} = \text{______ ft} \]
   \[ \text{Basin width at the surface} = \text{______ ft} \]
   \[ \text{Basin width at the bottom} = \text{______ ft} \]
Land use, soils, and slope are factors considered in the determination of runoff volumes. Control of stormwater runoff for water quality purposes is primarily concerned with the washoff of pollutants from impervious surfaces. Although pollutants may accumulate on pervious surfaces, such as lawns or fields, typically the rate of overland flow and thus pollutant discharge is significantly less than on impervious surfaces such as pavement due to natural infiltration.

A simplified approach to runoff volume determination is recommended for the design of wet basins. Because the treatment of runoff for water quality purposes is primarily concerned with impervious surfaces, the wet basin design procedure is based upon the area of impervious surfaces at the development site, as specified in Step 1 (Table 4-3). The second step in determining the volume of runoff requiring water quality treatment is to multiply the area of impervious surfaces by the mean event rainfall volume of 0.4 inches.

This approach assumes that no runoff is generated from the pervious surfaces at the development site and that 100 percent of the rainfall hitting the impervious surfaces generates runoff. In reality, as reflected in the designation of runoff coefficients and curve numbers for various land use types, it is likely that impervious surfaces provide minimal infiltration or ponding of runoff and that pervious surfaces generate a modest volume of runoff. It is assumed that the
respective overestimation and underestimation of runoff are offset by one another.

The required storage volume for the wet basin's permanent pool of water is determined in steps 3 and 4 of the procedure. Using the performance curve (Figure 4-1), the volume ratio is determined given a specified percent removal efficiency and average depth. Because the design procedure is based upon the removal of pollutants under both dynamic and quiescent conditions, both basin volume and surface area are critical factors. The average depth is selected as a means of relating basin volume to surface area. The average depth therefore, does not necessarily represent actual depth. The permanent pool storage volume requirement is calculated by multiplying the volume ratio by the previously determined volume of runoff requiring water quality treatment.

The total basin volume is determined by adding the storage capacity needed for sediment accumulation to the permanent pool storage requirements. This is accomplished in step 6 of the wet basin design procedure. Details of the procedure to determine solids storage requirements are given in "Recommendations of the Stormwater Management and Erosion Control Committee Regarding the Development and Implementation of Technical Guidelines for Stormwater Management" (RIDEM OEC, 1988a). Where stormwater management objectives include flood control, the flood storage requirements may be added to these storage volumes. The last step in the wet basin design
procedure is the conversion of the basin volume requirements to physical dimensions, given length to width and side slope ratios. These and other design specifications which enhance pollutant removal capacity of both wet basins and extended detention dry basins are addressed in the last section of this chapter.

Design Guidelines for Extended Detention Dry Basins

Fundamental design features of extended detention dry basins include determination of the runoff volume to be controlled and the time period in which runoff will be detained. These basins are designed so that the volume of runoff generated by a given frequency storm event is 'metered out' at a rate which results in a specified detention period for that parcel of water.

Unlike the wet basin design procedure, no site specific analysis of extended detention dry basin performance given Rhode Island rainfall conditions has been undertaken. Therefore, a more generic design criterion is recommended. The 1-year frequency 24 hour duration storm has been selected as the generic "water quality control" design storm. This frequency storm event represents the commonly occurring, short duration rainfall event, and in most cases would encompass the "first flush" of longer duration, less frequently occurring rain events. Research results indicate that these runoff volumes are likely to have the highest pollutant loads
(Hoffman et al., 1985; 1982). Precedence for selection of the one-year 24 hour storm has been set by the Federal Highway Administration (Versar Inc., 1986) and the State of New Jersey (NJ DEP, 1986).

The efficiency with which smaller diameter particles (particles with settling velocities less that 7 ft/hr) are removed via physical settling or biological uptake is dependent upon the amount of time the parcel of water is detained in the basin and other factors. By specifying a minimum detention time or requiring that permanent storage be provided for a given volume of runoff, enhanced pollutant removal capabilities are achieved.

The detention period can be defined as the time difference between the center of mass of the inflow hydrograph and the center of mass of the stormwater detention basin outflow hydrograph. Various column settling experiments have determined the pollutant removal efficiency associated with certain detention times. A summary of these research findings follows:

- 6 to 12 hours (Metropolitan Washington Council of Governments, 1983) Based upon the analyses of stormwater samples collected from 7 commercially developed areas. The study found 65% of the sediment removal occurred within the first 6 hours.

- 16 and 32 hours (Whipple and Hunter, 1981) Based upon the results of column settling experiments on samples
collected from 5 urbanized areas. The data for suspended solids, hydrocarbons, and lead indicate that most of the sedimentation was accomplished in 16 hours. All five samples exhibited suspended solids settling of approximately 70% of the initial concentration after 32 hours, whereas lead and hydrocarbons were reduced by 65% and 60% respectively over the same time period. BOD_5 and phosphate reductions ranged from 20 - 50% and 30 - 60%, respectively.

24 hours (Harrington, 1986) Based upon analysis of the NURP results comprised of samples collected and analyzed nationwide; represents the largest and most varied data set considered. This detention time on average is expected to remove greater than two-thirds of the sediments, total nitrogen, total phosphate and trace metals contained in runoff.

The 6 to 12 hour detention time recommended by the Metropolitan Washington Council of Governments (MWCOG) (1983) is based upon a small number of samples, all of which were collected from commercial areas. The MWCOG study found a positive correlation between concentration of runoff-borne pollutants and rate at which pollutants are removed. Given this correlation, samples collected from commercial areas may be expected to have higher than normal pollutant removal efficiencies because runoff from commercial areas has relatively high pollutant concentrations. The 6 to 12 hour
period therefore, would not provide an adequate time period for the removal of pollutants from less concentrated runoff.

The detention periods of 16 and 32 hours found by Whipple and Hunter to result in significant pollution reduction are based upon laboratory settleability experiments on stormwater samples collected in urbanized areas. A detention period of 24 hours for all urban uses is intermediate between those detention periods experimentally found to allow significant pollutant reductions in runoff from residential and more intensive urban uses, and appears to be reasonable as a generally applicable detention time.

Based upon an analysis of these findings, the recommended minimum detention time for significant removal of particulates/sediments is 24 hours. The 24 hour detention time is based upon the largest and most varied data set.

**Additional Design Considerations for Wet Basins and Extended Detention Dry Basins**

The following design criteria are drawn from the analysis and interpretation of the Nationwide Urban Runoff Program results (U.S. EPA, 1983; Woodward-Clyde Consultants, 1986) and the experience of other states with established stormwater programs (Harrington, 1986; MWCOG, 1983; NJ DEP, 1986; NVPDC, 1987). The criteria have been selected based upon their ability to enhance the effectiveness of stormwater management basins in removing runoff-borne pollutants. Other design objectives, such as, prevention of groundwater contamination.
minimization of mosquito propagation, ease of maintenance, and creation of safe and aesthetically pleasing facilities are recognized as equally important design considerations. However, they are not addressed in detail by this thesis.

Basins designed to achieve a specific solids removal efficiency based upon storage volume and/or detention time requirements will not operate as designed if the facility receives groundwater inflows. These inflows reduce storage capacity and decrease the effective detention time of collected stormwater runoff. Furthermore, the intermingling of groundwater and concentrated runoff introduces the potential for groundwater contamination. For these reasons, the bottom of stormwater detention basins (including wet basins) should not intercept the seasonal high groundwater table.

The maintenance of a permanent pool of water may be infeasible in excessively well drained soils, specifically those having saturated infiltration rates greater than 0.52 inches/hr (Harrington, 1986). Where wet basins are proposed in highly infiltrative soils, impervious materials, such as compacted silt or clay should be used to ensure proper basin functioning and maximum water quality benefits. The secondary benefits associated with the installation of an impervious layer include increased protection of groundwater quality by preventing the infiltration of contaminated runoff.
The purpose of specifying basin geometry criteria is to enhance the pollutant removal capabilities of the basin by encouraging the sedimentation of particles and to prevent short circuiting. A length to width ratio of 3:1 is recommended to encourage the creation of "plug flow" conditions within the basin (Schueler, 1987). Under these conditions, vertical stratification in the basin is prevented and sedimentation is enhanced. The basin inlet and outlet should be located so as to maximize travel distance and prevent "the short circuiting" of collected runoff.

Given a specified permanent or temporary storage volume requirement, it is preferable to maximize the basin's surface area rather than its depth. There are several reasons for this recommendation. Most obviously, shallow basins represent less of a public safety hazard than do deep basins. Additional benefits are related to enhanced water quality and reduced mosquito propagation potential. The Nationwide Urban Runoff Program results indicate a positive correlation between solids removal performance and surface area. Mosquito larval development is favored in stagnant waters. By maximizing surface area, the potential for wind generated surface turbulence is increased thereby discouraging larval development.

In determining a range of acceptable basin depths, considerations must be given to providing adequate water depth to avoid the resuspension of sediments and particles. And on
the other hand, the depth should not be so great as to enhance thermal stratification and the formation of anoxic conditions in the bottom waters of the basin. Schueler (1987) recommends a range of depths between 2 and 8 feet; intermediate depths are probably most desirable from a water quality perspective.

Maryland's experience with stormwater management has shown that basins having both shallow and deep areas exhibit enhanced pollutant removal capabilities (Harrington, 1986). Shallow areas along the perimeter of basins and/or at its entrance allow for the growth of aquatic plants; while deeper sections provide the storage capacity needed for temporary or permanent storage of runoff and sediments.

Aquatic plant growth is beneficial from a water quality perspective in that vegetation may act as pollutant traps. Nutrients and many heavy metals are predominately in dissolved form and therefore are not significantly reduced through the sedimentation process. The removal rates of these pollutant components are enhanced through biological uptake. The presence of aquatic plants may also enhance sedimentation of particulates, as well. For these reasons, limited use of aquatic plants within the stormwater management facility is recommended. Plant removal may be an essential element of a management plan to prevent storage capacity reduction and pollutant recycling.

The dissipation of inflow velocities is important in preventing scouring of the basin bottom and resuspension of
settled particles. The installation of inflow velocity dissipators in all basins is recommended to reduce inflow velocities and thus prevent scouring of the basin bottom.

To prevent erosion of the basin bottom and to ensure a complete "dry-out", the use of a pervious low flow channel within all dry detention basins is recommended. Pervious channels such as riprap, gabions or dense vegetative linings are suitable for this purpose and may also promote the interaction of runoff with soil and vegetation. Such interaction may increase the sorption of pollutants to particulates (NJ DEP, 1986). Based upon the experience of stormwater management in New Jersey, the use of impervious materials such as concrete is not recommended as it tends to increase flow velocities and decrease detention time.

Elevated risers are recommended as the outlet design for both wet basins and extended detention dry basins. For wet basins, the orifice should be placed at an elevation which will allow for the storage of sediments and the maintenance of a permanent pool of water. The riser should be fitted with a trash rack to prevent clogging and with a manually operated orifice at its base so that the basin can be completely drained for maintenance purposes. The use of oil/water separators or skimmers should be considered only where frequent maintenance of the structure is possible.

The outlets of pipes are points of critical erosion potential. Stormwater which is transported through man-made
conveyance systems at design capacity generally reaches a velocity which exceeds the capacity of the receiving channel or area to resist erosion. To prevent scour at stormwater outlets, a flow transition structure is recommended to absorb the initial impact of the flow and reduce the flow velocity to a level which will not erode the receiving channel or area.
CHAPTER V

SURVEY OF EXISTENT STATE STORMWATER MANAGEMENT PROGRAMS

Introduction

The review of existent regulatory programs related to the control of urban stormwater runoff discharges to Rhode Island's waters in Chapter III documented the lack of a comprehensive, or even consistent statewide approach to stormwater quality management. In this chapter, the stormwater management programs of three states, Maryland, Wisconsin, and New Jersey are reviewed. Research and materials written by the author in preparation of the Rhode Island Department of Environmental Management report entitled, "Implementation of Stormwater and Erosion and Sediment Control Measures - A Survey of Existing Regulatory Programs" was drawn upon in writing this chapter.

The purpose of this survey is to evaluate various approaches taken to address the water quality threats posed by stormwater runoff from developing areas. How these states have created and implemented their regulatory programs will prove insightful in development of a stormwater management strategy for Rhode Island. Of particular interest are the statutory authority and stated
goals or objectives creating and guiding the regulatory programs, the level of government authorized to implement the program, the types of land use development projects affected, and the water quality enhancement requirements imposed at these sites.

**Maryland Stormwater Management Program**

The adoption of Stormwater Management Subtitle 08.05 in 1982 by the Maryland legislature created the authority to control stormwater runoff in order to reduce stream channel erosion, pollution, siltation and sedimentation, as well as local flooding. The stated goal of the legislation is to maintain pre-development runoff characteristics as nearly as possible on land developed for residential, commercial, industrial and institutional use.

The statute sets forth requirements for the establishment of stormwater programs at the county and/or municipal level by July 1, 1984. The Maryland Department of Natural Resources was made responsible for development of rules and regulations establishing uniform criteria and procedures to be used in implementing the stormwater management programs. In addition, the statute places the Department of Natural Resources responsible for the review of all state and federal activities subject to the rules and regulations.
A model ordinance was developed by the Maryland Department of Natural Resources to provide guidance in specifying the minimum content of the local ordinances (MD DNR, 1984b). Maryland's regulations (MD DNR, 1982) outline minimum criteria which require that the post development peak discharge of runoff for the 2-year frequency storm event or 2- and 10-year frequency storm events (specified on a county-by-county basis according to regional hydrologic and hydraulic characteristics) be maintained at a level less than or equal to that of the pre-development peak discharge. This is to be accomplished through the installation of stormwater management measures that control the volume, timing, and rate of runoff, and are to be designed according to the standards and specifications outlined by the Department of Natural Resources.

Furthermore, the Maryland Department of Natural Resources has specified an order of preference for use of stormwater management practices in the development of stormwater management plans (MD DNR, 1984b). The order is as follows: on-site stormwater infiltration, flow attenuation by use of open vegetated swales and natural depressions, stormwater retention structures (or wet basins) and lastly, stormwater detention structures. The regulations state that selection of one or more of these practices will be determined according to site conditions only.
The Department of Natural Resources has developed detailed standards and specifications for the design of infiltration systems (MD DNR, 1984a). Whereas, the regulations (MD DNR, 1984b) specify that if detention or retention structures are used, facilities serving more than one development, referred to as off-site structures, must consider the following:

1) The contributing drainage area will not exceed 400 acres, unless otherwise approved;

2) A permanent pool of water will be maintained or a 24 hour detention period for detaining and releasing the volume of runoff from a 1-year frequency storm will be provided;

3) Increases in peak discharges for the 2- and 10-year frequency storm events resulting from development will be managed;

4) No discharges are allowed to Class III Natural Trout Waters unless authorized by the Department of Natural Resources; and

5) Velocity dissipation devices will be required at the outfall of all detention or retention structures.

Exempt from the requirements of the local stormwater management ordinances are all agricultural activities, additions or modifications to existing single family residential structures, developments not disturbing more than 5000 square feet, residential developments of single
family houses on 2 acres or greater and those activities which are determined to be regulated under specific state laws which provide for stormwater management. All state and federal activities disturbing more than 5000 square feet of land are reviewed by the Department of Natural Resources in compliance with the established regulations.

**Wisconsin Model Construction Site Erosion Control and Stormwater Management Ordinance**

In May 1984, the Wisconsin legislature passed Wisconsin Act 416 requiring the Wisconsin Department of Natural Resources (WIDNR) to prepare a state construction site erosion control and stormwater runoff control plan and model ordinance. All state agency construction activities are required to comply with the ordinance's provisions. Additionally, the ordinance was meant to serve as a model for local adoption, although this is not mandatory. The criteria which specify when stormwater controls are necessary and what types are required are described below.

The stormwater management requirements were designed to achieve two goals; the control of runoff borne pollution loading rates and the maintenance of existing levels of infiltration (WI DNR, 1986). The legislation defines the types of land development or land disturbing activities which are subject to these provisions of the model ordinance. They are as follows:

1) All subdivisions, certified surveys or other
residential developments with a gross aggregate area of 5 acres or more or the construction of houses or apartment buildings on the same;
2) All subdivisions, certified surveys or other residential developments with a gross aggregate area of 3 acres or more with at least 1.5 acres of impervious surfaces;
3) All industrial developments with a gross aggregate area of 0.2 acres or more;
4) All commercial developments with a gross aggregate area of 1.0 acre or more;
5) All non-residential, non-commercial and non-industrial developments with a gross aggregate area of 3 acres or more; and
6) All other developments likely to result in stormwater runoff excluding the safe capacity of existing drainage facilities or receiving bodies of water, causing channel erosion; increasing water pollution by scouring or transportation of particulate matter; or endangering downstream property.

The general requirements stipulate the control of post development runoff volumes resulting from a 1-year design storm ranging in duration from 0.5 hrs to 24 hrs to predevelopment runoff volumes (WI DNR, 1986). Complete control of one year storm volumes was chosen as the basis of
these general requirements because of the documented water quality benefits directly related to water volume reductions. The WIDNR cited the receiving water fishery problems associated with frequent "flashy" storms and the resulting long-term accumulation of toxic materials in the receiving water sediment and benthic organisms. It was reasoned that this level of control would also provide significant control of larger, but less frequent storms.

The specific procedures to be followed in designing stormwater controls are outlined in a manual of practice to be prepared by the Wisconsin Department of Natural Resources.

The model ordinance specifies requirements to limit significant runoff volumes and pollutant discharges from sites having special development characteristics (WI DNR, 1986). Among these special provisions are requirements for drainage from non-industrial medium sized paved parking lots and storage areas. Those sites with impervious areas ranging from 5,000 to 500,000 square feet are required to collect the runoff and discharge into one or more grit chambers and/or oil and grease traps designed and constructed to remove all particles greater than 100 microns in size.

The ordinance requires subsequent treatment in one or more infiltration devices to treat runoff for the set of 1 year design storms (WI DNR, 1986). A vertical distance of
three feet from the high water table mark and the bottom of
device is required. If an infiltration device cannot be
used because site conditions do not meet this criterion, the
model ordinance requires construction of one or more wet
detention basins. These basins must have a surface area of
at least 3% of the drainage area and maintain a permanent
pool depth of at least 3 feet.

For all non-industrial paved parking lots and storage
areas having surface areas greater than 500,000 square feet
the ordinance requires that the runoff be treated
in one or more wet detention basins which subsequently
discharge to one or more infiltration devices (WI DNR, 1986).
The detention basin specifications are the same as those
described above; infiltration devices must be designed to
treat the discharge from the detention basin based on the
set of 1-year design storms.

The ordinance also requires the pretreatment of runoff
from industrial sites (WI DNR, 1986). Specifically, for
sites less than 100,000 square feet in area, the runoff must
be discharged to one or more grit chambers or oil and grease
traps. Furthermore, the ordinance requires that these
devices be cleaned at least once every three months and that
the pumped liquids be discharged to a licensed wastewater
treatment plant. Additional requirements are stipulated for
industrial sites of more than 100,000 square feet and for
runoff from large industrial roofs.
In attempts to provide flexibility to the site developer and local planners and managers, alternatives to the runoff volume control requirements are provided for single residential lots. The alternative control measures stipulate that roof drainage from these sites will be discharged to either pervious surfaces with an overland flow distance of at least 15 feet before the discharge reaches an impervious surface or an infiltration device. Additionally, this alternative specifies that all driveways must slope to adjacent lawns to the extent practicable.

**New Jersey Storm Water Management Act**

The New Jersey Storm Water Management Act (New Jersey Public Law 1981 Chapter 32) was enacted in 1981 as an amendment of and supplement to the Municipal Land Use Law. Under the legislation all municipalities are required to adopt stormwater management ordinances and plans contingent upon the availability of 90% state funding for planning. By law, the New Jersey Department of Environmental Protection is required to establish a list ranking municipalities according to their need for stormwater management planning. Highest priority was given to communities that are relatively underdeveloped and experiencing development pressures; whereas, urban communities, and rural and agricultural communities not experiencing development pressure were given low priority.
A model ordinance prepared by the Department of Environmental Protection, establishes minimum general standards for preventive measures applied to the site plan review process (NJ DEP, 1984). As stated in the regulations (NJ DEP, 1983), the site plans are to be conceptually designed to provide a reduction in artificially induced flood damage and to minimize increases in storm water runoff from any new land development contributing to this; to reduce erosion from any development or construction project and the impacts of development of stream erosion; to induce water recharge where natural storage and geologically favorable conditions exist; to prevent an increase in nonpoint source pollution and minimize development related increases in runoff for this purpose; to maintain the integrity of stream channels for their biological functions; and finally, to maintain the adequacy of existing and proposed culverts and bridges, dams and other structures.

The stormwater management planning process has been divided into two parts; phase one is targeted at preventive measures to be included in the site plan or subdivision review process. The second phase involves a more comprehensive plan which considers alternative preventive techniques in conjunction with remedial stormwater management measures, and the siting of regional facilities.

The minimum standards set forth in the model ordinance (NJ DEP, 1984) apply to major developments in compliance
with the established goals. Major developments are defined as those sites that will ultimately cover one or more acres of land with additional impervious surfaces or any construction of the following:

1) feed or holding lots which provide for a specified number of animals;
2) pipelines, storage or distribution systems for petroleum products or chemicals;
3) storage, distribution or treatment facilities for liquid waste, excluding Individual Sewage Disposal Systems;
4) solid waste storage, disposal or incineration
5) quarries or mines
6) land application of sludge or effluents;
7) storage, distribution or treatment facilities for radioactive waste.

The flood and erosion control standards for detention require that post development runoff volumes and rates be controlled so that the peak runoff does not exceed that from the site prior to development for 2-, 10- and 100-year storms. These design storms are defined as either 24 hour storms or as the estimated maximum rainfall for the estimated time of concentration, depending upon the runoff calculation method used. Regardless of the present condition, for the purposes of calculating runoff, all lands are assumed to be in good condition unless the land is in
agricultural use, and then conservation treatment is to be assumed.

For the purposes of providing water quality enhancement, all plans must provide control of a 1-yr, 24 hr frequency storm or a storm of one and a quarter inches of rainfall in two hours. The model ordinance specifies the practices that may be used to control the water quality design storm; specifically, they are extended detention dry basins, wet basins, and infiltration devices. Dry detention basins are to be designed so that not more than 90% of the specified design storm is evacuated prior to 36 hours for all non-residential projects or 18 hours for all residential projects. Retention time is considered a brim-drawdown time and therefore begins at the time of peak storage.

The water quality requirements for wet detention basins are satisfied by maintaining a permanent volume in exceedance of three times the volume of runoff produced by the specified water quality design storm. Finally, infiltration practices may be used to fulfill the water quality requirement provided they produce zero runoff from the design storm and allow for complete infiltration within 72 hours.

In all cases, single or multiple staged outlets are to be designed so that the discharge rate does not exceed that generated by runoff from the pre-development site condition. Additionally, criteria have been developed for the
construction of detention basins in flood plains; the specifics of these standards will not be elaborated here.

Summary of Stormwater Management Approaches

One commonality among the three state programs reviewed was the adoption of legislation for the sole purpose of managing stormwater runoff from developing areas and specific recognition of pollution control or water quality protection as an objective. Both Maryland and New Jersey statutes specify a number of objectives, including flood control. The legislative initiatives are significant in that, they indicate the states' commitment to address the specific water quality problems posed by urban stormwater runoff. This observation is in striking contrast to the regulatory programs controlling stormwater runoff discharges in Rhode Island, as described in Chapter III. An inherent weakness of the Rhode Island programs is the lack of specific legal authority to regulate stormwater runoff discharges for water quality protection purposes.

New Jersey opted to enact its stormwater management legislation as an amendment of and supplement to its municipal land use law. This approach appears to build upon an existing governance structure and perhaps serves as a good model for legislative initiatives in Rhode Island. One alternative for implementation of water quality enhancement requirements in Rhode Island is to expand upon the existing
regulatory programs created to enforce flood control measures.

Each state has chosen a unique approach for implementation of their stormwater management programs. Maryland's statute takes advantage of its strong county government structure in mandating the establishment of local programs. The statute preserves the Department of Natural Resources' review authority over applicable state and federal activities, however. Because state, county, and municipal stormwater management programs are all governed by the same set of standards and specifications, the potential for contradictory or inconsistent requirements is mitigated.

Wisconsin, on the other hand, has established mandatory requirements for state agency activities only. However, a model ordinance was drafted with the intent of providing guidance to those local communities voluntarily choosing to adopt stormwater management ordinances. Finally, New Jersey's stormwater management strategy relies solely upon the establishment of local programs as required by the legislation. However this requirement was contingent upon the availability of state funds, so that only those towns ranked as a high priority would receive funds and be expected to establish programs in the immediate future.

Unlike the Rhode Island Freshwater Wetlands and Coastal Resources Management Council programs, the jurisdiction of the three stormwater management programs described here is
not limited by certain geographical limits. The regulations apply to all development projects as defined in the regulations, regardless of their geographic location. Maryland's requirements are by far the most encompassing, with applicability to all development projects disturbing more than 5000 square feet (with the exception of renovations to existing single family residences or the construction of single family homes on 2 acres or more). A regulatory program of this magnitude, in terms of the number of permit applications processed, is possible when implemented at the county or municipal level. One might expect a similar program implemented at the state level to be administratively infeasible.

Wisconsin's applicability requirements have attempted to discern potential differences in stormwater runoff characteristics and pollutant loads from varying urban land use categories. The stormwater requirements apply to low to moderate density residential development with aggregate areas of 5 acres or more, whereas 3 acres is the criterion for more dense residential developments (50% imperviousness). At the other end of the spectrum are industrial developments, subject to the stormwater requirements if the aggregate area is 0.2 acre or more.

New Jersey's program is clearly intended to address the water quality problems arising from the more significant nonpoint sources of pollution, such as quarries, mines,
liquid and solid waste facilities, and livestock operations. It appears that urban development projects (that is, industrial, commercial, or residential sites) were viewed as less of a water quality threat, as only projects creating an acre or more of impervious surface are subject to the regulations.

Each state has established stormwater quality management design criteria, commonly based upon the one-year frequency storm event, as well as detailed standards and specifications for the various control measures. Therefore, regardless of the control measure alternative selected for use on a site, a uniform standard is applied to the determination of the volume of runoff treated. The standards and specifications for the different control measure alternatives establish further requirements to achieve water quality enhancement of runoff.

A potential shortcoming of these regulatory programs is an inconsistency in the pollutant removal rate achieved from site to site depending upon the control measure used. Fairly uniform performance can be expected for flood control measures designed to maintain a particular runoff peak discharge, based upon a specified frequency storm event. However, the same does not hold true for stormwater quality management measures designed according to a specified water quality design storm event. Although practices may be designed to treat similar volumes of runoff, differing
pollutant removal mechanisms and design features affect removal rates so that one can not expect all practices or control measures to perform equally.
CHAPTER VI

STORMWATER QUALITY MANAGEMENT ALTERNATIVES
FOR RHODE ISLAND

Introduction

Previous chapters have documented "urban" runoff as a pollution source and described the inadequacy of existing regulatory programs in preventing further water quality degradation resulting from new sources of urban runoff. This information has clearly established the need for a stormwater quality management policy which strives to minimize the impact of "urban" stormwater runoff on the quality of Rhode Island's surface waters. This objective may be achieved, in part, by preventing further water quality degradation from new sources of "untreated" stormwater runoff discharges - the focus of this thesis.

This chapter evaluates various alternatives for establishment of a stormwater quality management program in Rhode Island. Two related questions are addressed. How is a comprehensive and consistent stormwater quality management program structured? How can it be implemented in Rhode Island?
The process of environmental policy formulation strives to achieve stated public policy objectives by integrating available scientific and/or technical information with the setting's political, economic, legal, and institutional realities. Towards that end, the scientific and technical information presented in previous chapters will be synthesized in the context of Rhode Island's institutional and political setting to evaluate how a comprehensive and consistent approach to stormwater quality management can be structured so as to minimize potential impacts from new sources of "urban" runoff. Implementation of this structured approach to stormwater quality management within the framework of Rhode Island's existing regulatory programs is analyzed. The legal and administrative constraints of the various management alternatives are evaluated relative to the objective of minimizing the impact of "urban" stormwater runoff on surface water quality.

Definition of "Comprehensive and Consistent"

To achieve the objective of minimizing "urban" stormwater runoff impacts on surface water quality, a comprehensive and consistent management approach is necessary. In the context of this thesis, the term "comprehensive" refers to the inclusion of all land use development projects generating pollutants potentially causing water quality problems, regardless of geographic location. The term "consistent"
refers to a coherent plan for the application of stormwater quality control requirements through the establishment of performance standards and uniform design criteria.

As an academic study, this thesis has chosen to define a "comprehensive and consistent" stormwater management approach in relatively narrow terms - not included in this analysis are flood control considerations or the water quality problems posed by existing urban stormwater runoff discharges.

**Essential Elements of Stormwater Quality Management Programs**

A comprehensive and consistent approach to stormwater quality management entails establishment of three essential program elements. These program elements are applicability criteria, design criteria, and performance standards.

Clearly, definition of these criteria and standards must reflect available scientific and technical information, in addition to administrative considerations and Rhode Island's unique political setting.

**Applicability Criteria**

In the context of this thesis, applicability criteria establish standards upon which to determine which land use development sites are subject to stormwater quality management requirements. Two information sources are reviewed in determining the most appropriate applicability criteria for use in Rhode Island. The available scientific information
documenting urban runoff pollutant characteristics and potential water quality impairment are reviewed first. Secondly, the thesis evaluates the applicability criteria of the proposed NPDES permit requirements and the existent state stormwater management programs.

NURP and other monitoring studies have documented that runoff from residential, commercial, and industrial sites contains significant concentrations of pollutants. These data indicate that discharges of runoff from urbanized areas may result in short and/or long term impacts to surface water quality. NURP investigators found the pollutant loads of runoff from urban and non-urban/open sites to be statistically significant. However, no statistical differences were differentiated between urban land use types. Furthermore, with the exception of one study which evaluates residential development relative to total phosphorus loads (Dennis, 1986), the available scientific information has not documented the density or areal extent of land use development or degree of site imperviousness likely to generate the pollutant concentrations or water quality impairments observed.

One may look to the applicability criteria of the proposed NPDES permit requirements for separate stormwater discharges, and existent state stormwater management programs for further guidance in establishing appropriate criteria for Rhode Island.
As federally mandated regulations, the NPDES permit requirements for stormwater discharges are likely to be very influential, ultimately, in setting the course for stormwater quality management initiatives nationwide. In Rhode Island, the Department of Environmental Management has been delegated authority to implement the NPDES program. Even as a delegated state, Rhode Island is obligated to follow federally mandated standards and guidelines. Although only proposed NPDES permit requirements for stormwater discharges have been issued by U.S. EPA, the requirements' broad applicability warrant their discussion.

As proposed by U.S. EPA, construction sites are covered under the category of separate storm sewers associated with industrial activities (53 FR 49441, December 7, 1988). The NPDES requirements would apply to all clearing, grading, and excavation activities except those disturbing less than 1 acre of total land area, or that are designed to serve single family residential projects including duplexes, triplexes, or quadruplexes on 5 acres or less, and in either case, not part of a larger common plan of development or sale. The NPDES applicability criterion affects only those stormwater drainage systems discharging directly to surface waters. Therefore, any land use development project discharging directly to an existing municipal separate stormwater system would be exempt. This provision of the proposed NPDES program represents a
major loophole and will be discussed in greater detail in a later section of this chapter.

Compared to the applicability criteria established by existing state stormwater management programs, the NPDES applicability criteria are of intermediate stringency. Maryland's stormwater management requirements are by far the most encompassing in terms of the projects affected; with all development projects disturbing more than 5000 square feet subject to the regulations (MD DNR, 1984b; MD DNR, 1982). The regulations exempt renovations to existing single family residences or the construction of single family homes on 2 acres or more from the requirements. Primary responsibility for implementation of these requirements rests with county and city governments.

Wisconsin has attempted to tailor its applicability requirements in a way which discerns potential differences in site imperviousness and the stormwater runoff characteristics of varying urban land use categories (WI DNR, 1986). The applicability criteria vary depending upon the areal extent of the given urban land use type. For example, stormwater quality management requirements apply to low to moderate density residential sites having aggregate areas of 5 acres or more, to more dense residential sites (having 50% site imperviousness) with aggregate areas of 3 acres or more, to commercial sites with aggregate areas of at least one acre, and to industrial sites with aggregate areas of at least 0.2
acres. As a practical consideration, one might expect the number of permit applications to be less under Wisconsin's criteria as opposed to those adopted by Maryland. Primary responsibility for program implementation rests with the state.

The primary focus of New Jersey's program is quite different than the two previously described, and most likely attributable to the more industrialized and urbanized nature of its landscape. The New Jersey stormwater management program is clearly intended to address the water quality problems arising from the more significant nonpoint sources of pollution, such as quarries, mines, liquid and solid waste storage and treatment facilities, and livestock operations. As for urban development projects such as, industrial, commercial, or residential sites, the requirements apply only if an acre or more of impervious surface is created (NJ DEP, 1983).

Unlike the proposed NPDES permit requirements, Maryland, Wisconsin, and New Jersey exercise jurisdiction over all applicable land use projects regardless of whether stormwater is discharged directly into surface waters or indirectly via public drainage systems. These state programs are also dissimilar to Rhode Island's Freshwater Wetlands and Coastal Resources Management Programs in that the applicable land use development activities are regulated regardless of geographic location or distance from potentially affected surface water
resources. In other words, there are no geographical constraints placed on their statutory authority to regulate certain activities.

The final definition of applicability criteria must balance the need to regulate those stormwater runoff sources discharging significant pollutant loads with Rhode Island's institutional, political, and economic constraints. The scientific database does not provide definitive guidance in establishing these criteria. Relying on the public policy database, one finds varying levels of applicability criteria proposed or required. Given the inevitable influence of the NPDES permit requirements for stormwater runoff on future management initiatives in Rhode Island, the applicability criteria should be at least as stringent as those proposed for construction sites by U.S. EPA. The question then becomes whether Rhode Island should follow the lead of Maryland and Wisconsin in establishing more stringent criteria. Institutional and administrative considerations must be factored into this decision. For example, at what level of government will the primary responsibility for program implementation rest.

Given that the majority of Rhode Island municipalities lack full time planning and engineering staff, it may not be realistic to expect most municipalities to assume primary responsibility for implementation of a stormwater quality management program. Furthermore, unlike Maryland, there is
no county level government in Rhode Island. For the purposes of selecting an appropriate set of applicability criteria for use in Rhode Island, one may assume that primary responsibility for program implementation will rest at the state level. Maryland's criteria, implemented at the state level, could prove administratively burdensome and thus unworkable. Based upon these considerations, the proposed NPDES applicability criteria for construction sites appear to provide a reasonable initial benchmark for establishment of stormwater quality management requirements in Rhode Island.

Design Criteria

Critical to the creation of a consistent stormwater quality management program is the establishment of design criteria and standards. Typically, design criteria specify the volume of runoff to be treated and provide for detailed specifications for the design and installation of acceptable control measures. The specification of a design storm event, ensures that a uniform standard is applied to all sites for determining the volume of runoff to be treated. Runoff monitoring studies document the occurrence of pollutant loading maxima over the course of a storm event, with the first flush representing the first and often greatest peak in pollutant loads (Hoffman et al., 1985). A primary objective of water quality design criteria is to ensure that the most concentrated runoff volumes, that is the first flush of larger
storms, is captured by the treatment device. It is likely that control measures that are designed to handle runoff volumes generated from a 1-year, 24 hour frequency storm event will also capture the first flush of larger storms. Therefore, as a generic criterion to be applied to the design of stormwater quality control measures, the 1-year, 24 hour frequency storm event appears to be scientifically sound. Precedence for establishment of this design storm event is provided by several existing stormwater management programs, including Maryland, New Jersey and Wisconsin.

Analysis of the Nationwide Urban Runoff Program results has brought about the creation of a second generation of control measure design criteria and procedures. A model relating solids removal efficiency rate to the ratio of the wet basin storage volume to runoff volume has been developed (Woodward-Clyde Consultants, 1986). The basis of the approach is the relationship between the physical settling of solids and associated pollutants under both quiescent and dynamic removal conditions and detention time as determined by basin storage capacity and surface area relative to the mean rainfall volume, duration of the storm event, and the interval between storms. This model was applied to rainfall data collected at T.F. Green Airport in Warwick, Rhode Island to generate a plot relating solids removal efficiency to the ratio of detention basin storage volume to runoff volume for a series of detention basin depths (Figure 4-1). This plot
serves as the foundation of the wet basin design procedure developed for use in Rhode Island. Design calculations are based upon a mean event rainfall volume of 0.4 inches.

In conclusion, two design criteria are recommended for use in Rhode Island. The 1-year, 24 hour frequency storm event is appropriate as the "generic" design storm event. In the case of wet basins, however, the design criteria and procedure developed using Rhode Island specific rainfall conditions are recommended. As more detailed analyses result in more refined and sophisticated design criteria and procedures, such as the wet basin design procedure, consideration should be given to their use.

In addition to the "design storm event" specifications, stormwater management regulations typically define acceptable practices or measures and provide detailed standards and specifications for each. These design standards ensure maximum pollutant removal efficiencies and achievement of other environmental, public welfare and safety objectives. These have not been addressed in detail by this thesis as they may be found elsewhere (RIDEM OEC, 1988a).

**Performance Standards**

Relative to stormwater quality management, the primary goal of performance standards is to establish a minimum pollutant removal efficiency to be achieved by an individual or group of runoff control measures. A performance standard
would be used to complement the design criteria and standards described above. The need for performance standards as an essential element of stormwater quality management is illustrated by reviewing the overall findings of the case studies presented in Chapter IV.

Available data indicate that control measure pollutant removal efficiency is significantly affected by design and maintenance. Substantial reductions in pollutants loads have been observed for control measures incorporating design features which enhance physical settling, chemical flocculation, and biological uptake, and prevent the resuspension and discharge of deposited pollutants. More specifically, the case study presented in Chapter IV found reductions in sediments and pollutants associated with particulates (such as hydrocarbons, lead, bacteria, and chemical oxygen demand) largely attributable to physical settling. Whereas removal of pollutants found in soluble form, such as nitrates, chlorides, and zinc or those in composite form, such as copper and phosphorus were more likely accomplished by chemical flocculation and physical settling, or biological uptake. Available data suggest that the more soluble pollutants exhibiting poor soil attenuation properties, such as nitrates and chlorides, are most effectively controlled via source reduction techniques.

The survey of control measure pollutant removal performance, however also suggests that given treatment of a
specified volume of runoff, not all control measure designs may be expected to perform equally well. For example, conventional dry detention basins were found to have poor removal rates for all pollutants, whereas wet basins exhibited substantial reductions in both particulate and dissolved pollutants. Therefore, regulations based solely upon control of a certain frequency storm event may not necessarily be achieving uniform pollutant removal efficiencies from site to site.

Maryland and Wisconsin's stormwater management programs illustrate attempts by the regulator to gain greater control over the control measure alternative used; with preferences likely based upon expected pollutant removal efficiencies as well as the achievement of other public policy goals and objectives. Because control measure suitability can be limited by site specific conditions, such as soil type, depth to groundwater, and the contributing drainage area (Harrington, 1986; Schueler, 1987), it is advantageous to maintain as much flexibility in control measure selection as possible. Additionally, it is desirable from the regulator's perspective to place the burden of proof on the applicant that the selected control measure will meet regulatory objectives.

Performance standards provide an alternative way to structure regulatory requirements so that flexibility in control measure selection is maintained while ensuring uniform pollutant removal efficiencies. The primary goal of
performance standards is to establish a benchmark for control measure performance; in this case, a minimum pollutant removal efficiency. The burden of proof is placed upon the applicant to design control measure(s) which meet the minimum pollutant removal rate.

Maryland's Chesapeake Bay Critical Areas Program has applied performance standards to land use developments taking place in a particular class of land use. The 10% Rule requires that stormwater control practices be capable of removing pollutant loads generated from the development site to a level at least 10% below the load generated at the site prior to development. This standard is applied to a "keystone pollutant"; total phosphorus has been selected as the "keystone pollutant" having met the criteria established for pollutant selection. These criteria require that the "keystone pollutant" exhibits a well defined adverse affect on water quality and exists in composite form, that is, the particulate and soluble fractions being in roughly equal proportions. By removing the keystone pollutant, the Chesapeake Bay Critical Areas Program expects simultaneous removal of other important pollutants (Schueler and Bley, 1987).

Alternatively, total solids could be used as the pollutant of concern - based upon established correlations between total solids and other pollutants, one could estimate the removal of other pollutants having particulate fractions.
This method however, would not be effective for controlling soluble pollutants, such as nitrates, as the removal of solids provides no basis for their removal. Selection of the specific performance standard for use in Rhode Island should be done after careful consideration of all relevant factors, including those discussed above. These may be structured as uniform statewide standards, or defined according to receiving water quality conditions or to watershed characteristics.

**Evaluation of Alternative Stormwater Quality Management Strategies for Rhode Island**

The previous section described the objectives and essential elements of a comprehensive and consistent stormwater quality management program. This section addresses the second question posed by this chapter: How can a stormwater quality management program be implemented in Rhode Island? Three alternatives for implementation of stormwater quality management requirements governing land use development projects are reviewed.

The first alternative evaluates implementation of stormwater quality management requirements under the NPDES program, as proposed by U.S. EPA and administered by the RI Department of Environmental Management. The other two management alternatives consider state initiated stormwater quality management programs intended as complements to the federally mandated NPDES program requirements. The second alternative considers a stormwater management program which
vests primary authority for program implementation with the relevant state agencies. Specifically, alternative two entails implementation of stormwater quality management requirements as mandatory provisions of the Freshwater Wetlands and Coastal Resources Management Council programs. Finally, the third alternative evaluates an approach whereby the NPDES program requirements are complemented by local stormwater management programs.

Alternative One: NPDES Permit Requirements for Urban Stormwater Runoff

Description of Management Approach

The Water Quality Act of 1987 establishes stormwater quality requirements under the National Pollution Discharge Elimination System program. Because of the widesweeping changes set forth in the statute, U.S. EPA requested that the previously adopted stormwater regulations (40 CFR 122.26) be remanded for further rulemaking. As a result, there are presently no regulations in place governing the issuance of NPDES permits for stormwater discharges.

As proposed by U.S. EPA in the new round of rulemaking, the NPDES permit application requirements would apply primarily to two categories of storm sewer discharges in Rhode Island: municipal storm sewers located in a city with population greater than 100,000 but less than 250,000, and storm sewers associated with industrial activities, including construction sites. In Rhode Island, only the City of
Providence meets the population criterion for inclusion of municipal separate storm sewer systems under the NPDES permit requirements. The legislatively mandated deadline for submittal of NPDES permits for medium municipal separate storm sewers is February 4, 1992. With relatively little open land remaining for new urban development, these requirements are likely to have only limited impact on land use development projects with the possible exception of redevelopment projects.

The second group affected by the proposed regulations are storm sewers associated with industrial activities, including construction sites. The Water Quality Act of 1987 mandates that NPDES permits for large municipal separate storm sewers (not applicable to any Rhode Island city) and storm sewers associated with industrial activity be submitted no later than February 4, 1990. These NPDES requirements, however, are limited only to those discharging directly to surface waters. Exempt from these proposed requirements are any land use development projects discharging directly to an existing municipal separate stormwater system, regardless of the population served. The implications of this exemption are discussed in greater detail in the following section.

Full implementation of the Water Quality Act's provisions, and in particular regulations resulting from Section 402(p)(5) studies could lead to a fairly comprehensive stormwater management program eventually. However, the
mandated time frame for promulgation of these potentially more comprehensive regulations is nearly four years away, with program implementation likely to occur over a much longer time period.

Strengths and Weaknesses

Once finalized by U.S. EPA, the requirements for stormwater discharges will become incorporated into the NPDES program, which in Rhode Island, is administered by the RI Department of Environmental Management (RIDEIM) Division of Water Resources. Presently, the RIDEIM has limited experience in the area of stormwater quality management, however it is responsible for many technically complex programs and can be expected to attain the expertise needed to administer the NPDES requirements for stormwater discharges given adequate training, staff, and funds. Additionally, as a federally mandated program, the NPDES program is likely to benefit from the issuance of detailed technical guidance documents by U.S. EPA. Administratively this management alternative appears to represent a feasible scenario.

To determine the NPDES program's ability to meet the objective of minimizing the impacts of stormwater discharges on surface water quality, one must evaluate what permit requirements have been proposed and which sites will be affected by the regulations. The proposed regulations define applicability criteria for construction sites, which as
discussed previously represent a reasonable benchmark for a state program. The proposed regulations also broadly define NPDES permit requirements, including a narrative describing the best management practices to be used during and after construction to control runoff. These requirements lack detail or specificity, and in themselves are inadequate. However, these broadly stated NPDES permit requirements supplemented with the very specific design criteria and performance standards described previously represent a sound basis for establishment of a state program.

The proposed NPDES regulations fall short of establishing a comprehensive stormwater quality management program which addresses land use development sites in its exemption of storm water systems discharging to municipal storm drainage systems. This provision represents a major loophole, as there is presently no regulatory mechanism to require that runoff be treated prior to its discharge into an existing drainage system. In the absence of other regulations governing stormwater management, the least cost and most probable alternative for developers will be to connect into the drainage system of an existing road or to a road built by the developer for a municipality. In either case, the project would be exempt from NPDES requirements.

Therefore, one may conclude that the proposed NPDES program requirements for storm sewer discharges are inadequate
to protect the state's waters from further water quality degradation due to new "urban" runoff discharges.

**Alternative Two: State Level Stormwater Quality Management**

**Description of Management Approach**

This alternative evaluates the establishment of mandatory stormwater quality management requirements for applicable land use development projects subject to the Freshwater Wetlands or Coastal Resources Management Council programs, as complements to the NPDES program requirements. It is assumed that the applicability criteria, design criteria, and performance standards, described previously, would be extended to projects subject to these state regulatory programs to determine where and what stormwater quality management requirements apply.

Neither Freshwater Wetlands or Coastal Resources Management Council regulations clearly define stormwater quality management criteria or standards. The analysis presented in Chapter III, however, found the statutory authority for both programs to be sufficiently broad to provide for the establishment of water quality protection requirements. Therefore, no legislative revisions are necessary to establish stormwater quality requirements as mandatory provisions of the respective programs. The intent of these revisions would be to amend existing provisions and
to add significant detail relative to stormwater quality criteria and standards.

Both state programs must include revisions to their regulations which specify applicability criteria, water quality design criteria, and performance standards, as discussed earlier. As a further measure to ensure consistency between programs, the regulations must include a reference to a design manual detailing specific standards and specifications to be universally applied in Rhode Island. These two provisions are absolutely critical to the establishment of a consistent stormwater quality management approach under this alternative.

Relative to the Freshwater Wetlands program, specific language revising the definition of a "freshwater wetlands alteration" would be necessary to expand the program's jurisdiction over activities potentially impacting water quality but occurring outside the wetland area, as defined in the statute. More specifically, the definition of wetlands alteration as it applies to activities conducted outside of wetland areas must be expanded to include such activities directly affecting the water quality of any wetland or the wetland's ability to moderate flooding, provide wildlife habitat, recharge the groundwater supply, or provide recreation. As discussed in Chapter III, the review criteria for drainage requirements, set forth in Section 7.00 of the Freshwater Wetlands regulations, specify only flood control
requirements. It is this section of the regulations that would change most substantively - with detailed water quality enhancement criteria and standards provided for in the revised regulations.

Revisions to the Coastal Resources Management Council's program would be oriented to expand stormwater quality requirements for land use development projects on land adjacent to all waters under their jurisdiction and not only Type 1 and Type 2 waters.

Strengths and Weaknesses

Alternative Two describes a stormwater quality management approach entailing the establishment of mandatory requirements for applicable development sites as provisions of two existing state programs. These state program requirements are assumed to complement the federally mandated NPDES program requirements. Both the RIDEM Division of Groundwater and Freshwater Wetlands responsible for administering the Freshwater Wetlands program, and the Coastal Resources Management Council (CRMC) staff responsible for administering CRMC regulations have experience in stormwater management. The former agency's experience is primarily in stormwater management for flood control purposes, and the latter agency's experience lies primarily in stormwater quality management. Given the technical capabilities needed to administer the existing program requirements, it is apparent that a high
degree of technical expertise in stormwater management already resides within these state programs. One might expect deficiencies in technical expertise to be corrected easily given adequate training, staff, and funds.

Implementation of the management approach described under Alternative Two would require revisions to two sets of regulations and administration of stormwater quality management requirements under three programs; that is, the NPDES, Freshwater Wetlands, and CRMC programs. Critical to the success of this approach is the adoption of uniform criteria and standards, as defined earlier in this chapter. One may expect the passage of consistent regulatory revisions to be difficult, but not completely impossible. It may be possible to tie these state regulatory program revisions into establishment of the state's NPDES program, especially in implementing those regulations resulting from Section 402(p)5 studies.

Finally, the effectiveness of this management approach in minimizing the impacts of "urban" stormwater discharges to surface water quality are discussed. Analysis of the management approach's comprehensiveness, relative to its coverage of applicable sites, follows.

A certain degree of overlap may be expected in the jurisdictions of the state initiated programs and the NPDES program with respect to those land use development projects discharging directly to surface waters. However, with regards
to the stormwater systems discharging to municipal storm drains, the state program requirements would be complementary to those of the NPDES program. With revisions to the Freshwater Wetlands regulations as described previously, the number of applicable land use development sites, that is, those meeting the 1 and 5 acre criteria, within RIDEM's jurisdiction would be significantly expanded. Similarly, revisions to CRMC's regulations would extend stormwater quality management requirements to all projects meeting the applicability criteria within their jurisdiction.

Implementation of stormwater quality management requirements as components of the NPDES, Freshwater Wetlands, and Coastal Resources Management Council permit programs is likely to capture the majority of land use development projects meeting the previously defined applicability criteria. One may conclude, therefore, that the stormwater quality management scenario presented under Alternative Two is administratively feasible and adequate to protect the state's surface waters from new sources of "urban" runoff.

Alternative Three: Local Level Stormwater Quality Management

Description of Management Approach

This alternative evaluates the establishment of municipal stormwater quality requirements, as a complement to the NPDES program requirements. Building upon the existing regulatory framework at the local level, these requirements could be
incorporated into the zoning ordinance. As discussed in Chapter III, the subdivision enabling legislation provides a more sound legal basis for implementation of stormwater quality management requirements than the zoning enabling legislation. However, the subdivision ordinance applies only to those land use development projects occurring on large, undeveloped parcels not previously platted. More comprehensive in coverage are requirements promulgated under the zoning ordinance which apply to all specified land use development projects in the municipality.

Implementation of the local component of this management alternative requires legislative revisions; that is, either revision of the state's zoning enabling legislation (RI General Laws Chapter 45, 1956 as amended) or passage of distinct stormwater quality management legislation amending the zoning enabling legislation. Given the complexity of the stormwater quality management issue, passage of distinct stormwater management legislation would allow for the inclusion of necessary detailed provisions and is preferred.

As complementary requirements to the NPDES program, the municipal stormwater management program requirements would apply to land use development projects subject to the previously described applicability criteria and discharging to municipal stormwater drainage systems. It is assumed that the design criteria and performance standards described
previously, would also be incorporated into the local program requirements.

The costs associated with the administration of this program at both the local level and at the state level with respect to the preparation of guidance documents and the review and approval of local programs must be recognized in the statute. The statute must contain a provision for the collection of application or permit fees sufficient to cover these costs.

Following the example of Maryland, the legislation should require the mandatory establishment of local stormwater quality management programs, subject to the review and approval of the RIDEM. Furthermore, the local programs should reference use of a design manual detailing specific standards and specifications to be universally applied in Rhode Island.

Strengths and Weaknesses

Alternative Three describes a management scenario whereby the NPDES program requirements are complemented by mandatory local stormwater quality management programs. Comprehensive coverage of applicable land use development sites is expected, as the former program governs discharges to surface waters and the latter applies to stormwater discharged to municipal storm drains. Not covered by this management approach are discharges to existing state drainage networks. All tie-ins to state drainage systems must be approved by the Rhode Island
Department of Transportation. Presently, there are no water quality enhancement requirements placed on tie-ins. Despite the omission of discharges to state drainage systems, the management approach described by Alternative Three is likely to adequately protect the state's surface waters from new sources of "urban" runoff.

Implementation of the local component of this management alternative is dependent upon passage of stormwater quality management legislation mandating municipalities to establish stormwater programs subject to the review and approval of RIDEM. State oversight of the content of local programs is necessary to ensure consistency among local programs. The Comprehensive Planning and Land Use Regulation Act (RI General Laws, 1956, as amended, Chapter 45-22.1) passed in 1988, establishes a precedent for such an approach in Rhode Island. This statute requires municipalities to prepare comprehensive plans which are subject to the review and approval of the Rhode Island Division of Planning.

A mandatory approach to the establishment of local stormwater quality management programs ensures a universal adoption of requirements, and thus comprehensiveness, that is not likely achieved under a voluntary approach. The history of adoption of soil erosion and sediment control ordinances is perhaps a good example of this point. The state enabling legislation (RI General Laws, 1956, as amended, Chapter 46) authorizing municipalities to adopt soil erosion and sediment
control ordinances was passed in 1980. Eight years later only 12 out of 39 municipalities in Rhode Island had adopted the model ordinance contained in the legislation (Domingoes, personal communication).

As proposed under Alternative Three, the stormwater management legislation contains several provisions which are likely to be politically unpalatable. The establishment of mandatory local programs is likely to meet opposition by municipal officials resistant to any state efforts to impose new requirements. The building and real estate industries are also likely to oppose the legislation as it may be seen as imposing requirements and fees which increase the cost of development in the state.

Assuming the legislation successfully maneuvers these political hurdles, administration of the local component of this management approach may present other more severe problems. Unlike the state regulatory programs described previously, few municipalities have any experience in stormwater quality management. Furthermore, the majority of Rhode Island municipalities lack full time planners and engineers. In fact, many of the municipalities having passed ordinances requiring the review of technical information, rely heavily upon the United States Department of Agriculture Soil Conservation Service (USDA SCS) for technical assistance. This lack of technical expertise at the local level represents
perhaps the greatest obstacle to implementation of this alternative.

Establishment of a RIDEM program to review and approve of local stormwater quality management programs also presents new challenges. RIDEM has only limited experience with reviewing local plans and programs. Generally, these efforts have not entailed the review of technical provisions as contained in stormwater quality management programs. RIDEM's technical expertise in the area of stormwater quality management would have to be expanded considerably to administer this program.

In conclusion, Alternative Three presents a comprehensive approach to stormwater quality management in Rhode Island, however the considerable opposition to legislation mandating the establishment of local programs expected, and the lack of technical expertise at the local level are likely to severely hamper its success.

**Conclusions**

Three management alternatives have been presented here. Alternative Two represents the most administratively feasible approach thought to provide adequate protection of the state's surface water quality from new sources of "urban" runoff. The stormwater quality management approach described by Alternative Two entails the establishment of stormwater quality management requirements as mandatory provisions of the
Freshwater Wetlands and Coastal Resources Management Council programs, as complements to the NPDES program requirements.

The other two management alternatives were found to be less preferable to Alternative Two. The first alternative entails establishment of the federally mandated NPDES program by the RIDEM. This approach was found to affect relatively few land use development sites subject to the 1 or 5 acre applicability criteria because of its exemption of stormwater discharges to municipal storm sewers. Adoption of the NPDES program alone would not provide adequate protection of the state's surface water quality. The management approach described by Alternative Three proposed establishment of mandatory local stormwater quality management programs as complements to the NPDES program. While this approach is comprehensive and likely to adequately protect the state's surface water quality, it is expected to be severely constrained by political and administrative hurdles.
CHAPTER VII

SUMMARY

Two hypotheses were addressed by this thesis: (1) uncontrolled stormwater runoff from urbanized areas threatens the quality of surface waters, and (2) existing federal, state, and local regulations governing land use development are inadequate to prevent further water quality degradation resulting from new sources of urban runoff. These hypotheses were operationally examined by the following questions: Does runoff from urbanized areas present a threat to surface water quality? Are Rhode Island's regulations governing land use development and stormwater runoff adequate to protect the state's waters from new sources of urban runoff?

Resulting from the analyses of these questions was the identification of the need for stormwater quality management in Rhode Island. Resolution of this issue was achieved by addressing the following questions: What runoff control measures are effective in removing pollutants commonly found in runoff from urbanized areas? How should regulatory programs be structured to ensure a comprehensive and consistent approach to stormwater quality management? How can this approach be implemented in Rhode Island?
The review of selected literature documenting urban runoff characteristics and its effect on receiving water quality in Chapter II conclusively found uncontrolled stormwater runoff from urbanized areas to threaten surface water quality. Runoff borne pollutants commonly found in significant concentrations include conventional pollutants, such as nutrients, pathogens, and oxygen demanding substances; heavy metals; petroleum and polycyclic aromatic hydrocarbons; and in lesser concentrations, a number of priority pollutants.

Both short and long term impacts to surface water quality from "urban", that is, non-rural, stormwater discharges have been documented. The short term water quality impacts are related to exceedances in ambient water quality standards. For example, the screening analyses performed by NURP investigators indicate runoff from the average "urban" site may be expected to exceed ambient water quality standards for copper three times per year and for lead once a year. Furthermore, a comparison between urban runoff concentrations of coliform bacteria and state water quality standards suggests frequent violations of these standards are likely, as well.

The documented long term water quality impacts include accelerated eutrophication rates related to stormwater discharges of nutrients; dissolved oxygen deficiencies as a secondary impact of eutrophication and/or aggravated by the discharge of oxygen demanding substances in runoff; and the
contamination of sediments by heavy metals, hydrocarbons, and/or nutrients.

Given the pollutant load from "urban" stormwater runoff and the recent surge in land use development experienced in Rhode Island, the long term quality of the state's surface waters comes into question. Are the state's surface waters adequately protected from these new sources of stormwater runoff? A review of existing federal, state, and local regulatory programs governing land use development and stormwater runoff in Rhode Island found the existing patchwork of regulations, as they are currently written, to be inadequate in protecting the state's surface waters from new stormwater discharges.

At the local level, the zoning enabling legislation does not specifically authorize municipalities to enact zoning ordinances to protect environmental quality. The authority to establish stormwater quality management requirements is subject to interpretation, and therefore uncertain. The subdivision enabling legislation appears to provide adequate authority, however it applies only to subdivisions and therefore, has limited applicability.

At the state level, the Freshwater Wetlands regulations appear to provide adequate legal authority to enact stormwater quality requirements, however no policy or guidelines have been established. Furthermore, certain provisions of the Freshwater Wetlands regulations appear to severely limit
jurisdiction over activities occurring outside of the legally defined wetland area, with regards to the imposition of water quality protection requirements. Relative to the Coastal Resources Management Council program, stormwater quality enhancement requirements have been adopted for activities occurring adjacent to Type 1 and 2 waters, only.

After a protracted rulemaking process, the U.S. EPA promulgated regulations for stormwater discharges under the NPDES program, as required by the Federal Water Pollution Control Act. However, with passage of the Water Quality Act of 1987 and substantial changes to the NPDES requirements for separate storm sewers by Congress, these regulations were remanded for further rulemaking. As a result, there are no final regulations in effect at the present time.

The establishment of detailed technical guidelines for the design and construction of runoff control measures is central to addressing the water quality problems posed by stormwater runoff. What runoff control measures are effective in removing pollutants found in runoff from urbanized areas? Wet basins, extended detention dry basins, and infiltration devices have been found to be most effective. A primary factor in pollutant removal efficiency appears to be prolonged detention of the "first flush," which represents the first sharp and generally, greatest increase in runoff flow rates. Of relevance to water quality protection is the corresponding peak in runoff borne pollutant concentrations. Through
prolonged detention, the processes effective in removing runoff borne pollutants are enhanced. These processes include physical settling, biological uptake, infiltration and, chemical flocculation and/or transformation. In addition to facility design, the review of case studies found facility maintenance to be a significant factor in pollutant removal efficiency.

Translating detailed technical guidelines for the design of stormwater control measures into properly operating facilities in the community requires carefully structured regulatory programs. How should regulatory programs be structured to ensure a comprehensive and consistent approach to stormwater quality management? This approach to stormwater quality management may be achieved through the adoption of applicability criteria, design criteria and standards, and performance standards.

Relative to the focus of this thesis, applicability criteria define land use development sites subject to stormwater quality management requirements. The criteria most appropriate for use in Rhode Island govern activities disturbing 1 acre or more of land, unless the activity is a residential development of no more than four units, then 5 acres is the applicable area of disturbance. These criteria are consistent with proposed NPDES requirements for stormwater discharges associated with construction activities. And with
respect to the criteria adopted by other states, these criteria are intermediate in stringency.

Design criteria entail the designation of design storm events, as well as, detailed engineering standards and specifications for the design and construction of measures. The 1-year, 24 hour frequency storm event is appropriate as a "generic" design storm event. Wet basins, however, should be designed in accordance with a procedure based upon NURP findings and developed for use in Rhode Island. As a complement to these design criteria, performance standards should be established to ensure uniform pollutant removal efficiency while providing needed flexibility in site design. In selecting performance standards, consideration should be given to differentiation in receiving water quality and/or specific watersheds.

How can a comprehensive and consistent approach to stormwater quality management be implemented in Rhode Island? Adoption of the NPDES program requirements alone was found to be inadequate in protecting the state's waters from new discharges of "urban" runoff. Whereas, the establishment of mandatory municipal stormwater quality management requirements as complements to the NPDES program requirements was found to be administratively infeasible and likely, politically unpalatable. Of the three management alternatives evaluated, the management approach establishing stormwater quality management requirements as mandatory provisions of the
Freshwater Wetlands and Coastal Resources Management Council programs, as complements to the federally mandated NPDES program requirements was found to be most appropriate for Rhode Island.
APPENDIX A

Members of the Stormwater Management and Erosion Control Committee:

William Arcieri, URI Department of Natural Resources
Lauren Baker-Hart, RI Department of Transportation
Daniel Baumert, USDA Soil Conservation Service
Michael Bennett, RI Department of Transportation
Hans Bergey, Providence Water Supply Board
Rich Blodgett, Providence Water Supply Board
Janne Cookman, RIDEM, Division of Fish and Wildlife
Stephen Davis, USDA Soil Conservation Service
Hank Ellis, RIDEM, Division of Groundwater and Freshwater Wetlands
Kevin Flynn, City of Warwick
Christine Volkay-Hilditch, RIDEM Division of Water Resources
Eva Hoffman, Narragansett Bay Project
Barbara Leo, RI Department of Transportation
Frank Kostka, C.E. Maguire, Inc.
Scott Millar, RI Department of Administration Division of Planning
Christopher Modisette, Providence Water Supply Board
Robert Pesce, RI Builders Association
Lynne Pike, Narragansett Bay Commission
Nick Pisani, RI Coastal Resources Management Council
Henry Sardelli, RIDEM, Division of Groundwater and Freshwater Wetlands
Henry Sherlock, Construction Industries of Rhode Island
Frederic Thaler, Gordon R. Archibald, Inc.
Robert Wakefield, URI Department of Plant Sciences
Raymond Wright, URI Department of Civil Engineering
APPENDIX B

List of Abbreviations:

- **BOD** - Biological Oxygen Demand
- **COD** - Chemical Oxygen Demand
- **DAR** - Drainage Area Ratio
- **DCd** - Dissolved Cadmium
- **DPb** - Dissolved Lead
- **DZn** - Dissolved Zinc
- **EMC** - Event Mean Concentration
- **FR** - Federal Register
- **Federal Water Pollution Control Act**
- **HMW** - High Molecular Weight
- **LIRPB** - Long Island Regional Planning Board
- **MPN** - Most Probable Number
- **MWCG** - Metropolitan Washington Council of Governments
- **NO\(_{2-3}\)\_N** - Nitrite and Nitrate Nitrogen
- **NPDES** - National Pollution Discharge Elimination System
- **NURP** - Nationwide Urban Runoff Program
- **NWS** - National Weather Service
- **O & G** - Oil and Grease
- **PAH** - Polycyclic Aromatic Hydrocarbon
- **RIDEM** - Rhode Island Department of Environmental Management
- **SCS** - Soil Conservation Service
- **SP** - Soluble Phosphorus
- **TCd** - Total Cadmium
- **TCr** - Total Chromium
- **TCu** - Total Copper
- **TKN** - Total Kjeldahl Nitrogen
- **TP** - Total Phosphorus
- **TPb** - Total Lead
- **TSS** - Total Suspended Solids
- **TZn** - Total Zinc
- **US EPA** - United States Environmental Protection Agency
BIBLIOGRAPHY


American Oil Co. v. City of Warwick. 351 A.2d 577.


Lincourt v. Zoning Board of Review. 201 A.2d 482.


Maryland. Natural Resources Article, Maryland Annotated Code (1983 replacement volume), Section 8-11A-05 et seq.


Maryland Department of Natural Resources, Water Resources Administration, Sediment and Stormwater Division. 1984a. Maryland Standards and Specifications for Stormwater Management Infiltration Practices. MDNR, Annapolis, MD.

Maryland Department of Natural Resources, Water Resources Administration. 1984b. Model Stormwater Management Ordinance.

Maryland Department of Natural Resources, Water Resources Administration. 1982. Stormwater Management Regulations, Code of Maryland Regulations 08.05.05.

McIntosh, Alan W., Joseph V. Hunter, and Patrice Krug. 1980. Input Into and Fate of Lead in a Small Reservoir. Water Resources Research Institute, Rutgers University, Brunswick, NJ.


New Jersey Department of Environmental Protection. 1983. 
Stormwater Management Regulations, N.J.A.C. 7:8-1.1 et seq.


Rhode Island. Subdivision, General Laws (1956 as amended), Chapter 45-23.


Rhode Island Builders Association. unpublished. Monthly Tabulations Sheets of Rhode Island Building Permits. Rhode Island Builders Association, Providence, RI.


Rhode Island Department of Environmental Management, Division of Water Resources. 1988. Water Quality Regulations for Water Pollution Control.


Rhode Island Department of Environmental Management, Office of Environmental Coordination. 1988b. An Assessment of Nonpoint Sources of Pollution to Rhode Island's Waters. 167 pp with appendices.


Wisconsin. Wisconsin Act 416 (1983)
