Acknowledgements

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2.0 WHY STORMWATER MATTERS - THE IMPACTS OF DEVELOPMENT

Historically, stormwater has been viewed as strictly a drainage (flooding) issue, a waste to be disposed, and has generally been routed to the nearest discharge location, infiltrated with little or no pretreatment, or conveyed directly to receiving waters as channel-flow. This chapter describes how this type of stormwater management greatly alters the natural hydrology and water quality of a watershed. Rhode Island started moving away from this approach with the stormwater manual developed in 1993, which required water quality treatment and quantity control. The goal of this manual is to not only address water quality and quantity issues, but also to require that designers maintain a site’s pre-development hydrology. In the sections below, stormwater runoff is defined and water quality and quantity issues related to stormwater are discussed, as well as methods for preventing and mitigating stormwater impacts.

2.1 WHAT IS STORMWATER RUNOFF?

Stormwater runoff is precipitation that washes over the land (i.e., runs off) and discharges to nearby streams, lakes, wetlands, estuaries and other waters. Stormwater runoff is a part of the hydrologic cycle, which is the distribution and movement of water between the earth’s atmosphere, land, and waterbodies (see Figure 2-1). Water that does not runoff includes the following: (a) atmospheric evaporation; (b) transpiration or uptake by plants, which in combination with evaporation, is referred to as evapotranspiration; and (c) infiltration into underlying soils, which is responsible for groundwater recharge. Thus, stormwater runoff is essentially the remaining water after evapotranspiration and infiltration.

Land development has a profound influence on the quality of the waters of Rhode Island. To start, land development dramatically alters the local hydrologic cycle. The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the native soil that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff. In addition, the construction process exposes soils to rainfall, which increases the potential for erosion and sedimentation.

Additional impacts occur after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces interrupt infiltration mechanisms by not allowing rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in Figure 2-2, which shows the increase in runoff (along with a decrease in groundwater recharge) as a function of site imperviousness. As can be seen by the relative size of the arrows, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre
A parking lot can produce 16 times more stormwater runoff each year than a one-acre meadow (Schueler, 1994).

**Figure 2-1 Hydrologic Cycle**

While adding impervious area on a small residential lot might not seem significant, the cumulative effect of several such increases in site imperviousness throughout a watershed can drastically change the hydrology and overall ecological health of the whole system. Studies have shown that once impervious cover in a watershed reaches between 10 and 25 percent, ecological health is greatly stressed. Some studies have shown that water resources health is impacted at percentages as low as 5 to 7 percent. At 25 percent impervious cover and greater, stream stability decreases, habitat disappears, water quality declines, and biological diversity dwindles (NRDC, 1999). Development not only increases runoff quantity, but can also introduce new sources of pollutants from everyday activities associated with residential, commercial, and industrial land uses (CTDEP, 2004). When it rains, stormwater flowing over pavement and disturbed areas carries these pollutants directly into nearby wetlands and surface waters, either by direct runoff or via storm drains, bypassing any treatment that would naturally occur when rainwater infiltrates into the ground.
To put these thresholds into perspective, typical imperviousness in medium-density residential areas ranges from 25 to nearly 60 percent (SCS, 1986). Table 2-1 indicates typical percentages of impervious cover for various land uses according to TR-55. While most watersheds are developed with land uses of varied intensity, significant residential, commercial and industrial development suggests an expanse of impervious cover that exceeds ecological stress thresholds.

Table 2-1 Typical Amounts of Impervious Cover Associated with Different Land Uses

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Percent Impervious Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial and Business District</td>
<td>85%</td>
</tr>
<tr>
<td>Industrial</td>
<td>72%</td>
</tr>
<tr>
<td>High Density Residential (1/8 ac zoning)</td>
<td>65%</td>
</tr>
<tr>
<td>Medium-High Density Residential (1/4 ac zoning)</td>
<td>38%</td>
</tr>
</tbody>
</table>
### 2.0 WHY STORMWATER MATTERS - THE IMPACTS OF DEVELOPMENT

#### 2.2 DEVELOPMENT AND STORMWATER IMPACTS

Stormwater from urban development can cause severe impacts to downstream waters and waterways. These impacts can be broken down into four types, which include:

- Impacts to Natural Stream Channels;
- Impacts to Water Quality;
- Impacts to Receiving Waters; and
- Impacts to Aquatic Habitat.

The following discussion lists and describes these impacts to illustrate why effective stormwater management is needed to address and mitigate them.

#### 2.2.1 Impacts to Natural Stream Channels

As pervious meadows and forests are converted into less pervious urban soils or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, there are changes to both stream flow and geometry.

##### 2.2.1.1 Changes to Stream Flow

Urban development disrupts the natural water cycle and tends to alter watershed response to precipitation events. Watershed response becomes “flashier,” and runoff is “intensified,” meaning:

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Percent Impervious Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium-Low Density Residential (1/2 ac zoning)</td>
<td>25%</td>
</tr>
<tr>
<td>Low Density Residential:</td>
<td></td>
</tr>
<tr>
<td>1 ac zoning</td>
<td>20%</td>
</tr>
<tr>
<td>2 ac zoning</td>
<td>12-16%</td>
</tr>
<tr>
<td>3 ac zoning</td>
<td>8%</td>
</tr>
<tr>
<td>5 ac zoning</td>
<td>5-8%</td>
</tr>
<tr>
<td>10 ac zoning</td>
<td>2.4%</td>
</tr>
</tbody>
</table>

Source: Adapted from USDA Soil Conservation Service, 1986 and the Scituate Reservoir Watershed Greenspace Protection Strategy (DEM, 2008).
**Increased Runoff Volumes**
Replacement of natural features (e.g., woodlands) with buildings, pavement and lawns can dramatically increase the total volume of water running off into streams of developed watersheds.

**Increased Peak Runoff Discharge Rates**
Increased runoff volumes result in increased peak discharges. Peak discharges for a developed watershed can be two to five times higher than those for an undisturbed watershed.

**Greater Runoff Velocities**
Impervious surfaces, compacted soils and storm sewers are more hydraulically efficient than natural landscapes and increase the speed at which rainfall runs off land surfaces within a watershed.

**Reduced Time of Concentration**
As runoff velocities increase, runoff takes less time to reach streams or other waterbodies.

**Increased Frequency of Bank-Full and Near Bank-Full Events**
Increased runoff volumes and peak flows increase the frequency and duration of flows that lead to degradation of (i.e., widen and deepen) stream channels. The bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975).

**Increased Flooding**
Increased runoff volumes and peaks increase the frequency, duration and severity of flows that overtop stream banks and cause flooding. An example of severe flooding in Rhode Island occurred in the Pocasset River Watershed in 2001. This watershed has lost approximately 700 acres of wetland since 1939, much of which was floodplain loss. As a result, in the highly urbanized and industrial areas of Johnston and Cranston, there is now little natural floodplain storage so during heavy periods of rain, flooding occurs on private properties (Wetland Functions and Values Brochure, DEM, 2008). Another example of severe flooding occurred in October 2005, during which many evacuations were necessary, mainly along the Pawtuxet, Pocasset, Woonasquatucket, and Blackstone Rivers. Damages in Rhode Island from this storm event totaled to $1.6 million (NCDC, 2008).

**Lower Dry Weather Flows (Base Flow)**
Stream base flow (i.e., the typical level of stream flow during dry weather) is derived primarily from groundwater input. Loss of groundwater recharge due
to impervious surfaces artificially lowers the groundwater table and consequently lowers base flow.

The change in post-development peak discharge rates that accompany development is profiled in Figure 2-3.

Figure 2-3 Stream Flow Hydrographs Before and After Development (MDE, 2000)

2.2.1.2 Changes to Stream Geometry

The changes in the rates and amounts of runoff from developed watersheds directly affect the morphology, or physical shape and character, of streams and rivers. Some of the impacts due to urban development include:

Stream Widening and Bank Erosion

Stream channels widen to accommodate and convey the increased volumes and rates of runoff and higher stream flows from developed areas. More frequent small and moderate runoff events undercut and scour stream banks causing steeper banks to slump and collapse during larger storms. A stream can widen many times its original size due to post-development runoff.
2.0 WHY STORMWATER MATTERS - THE IMPACTS OF DEVELOPMENT

Streambed Downcutting
Streams may also deepen to accommodate higher flows and become less stable. When streams downcut, their bottom widths may decrease (i.e., become narrower). Loss of width narrows flow and increases flow velocity, triggering further channel erosion at the toe of the bank.

Loss of Riparian Trees
Increased flows undercut stream banks and cause them to slump. Trees that protect the banks are exposed at the roots and may eventually topple over.
Root systems support soil structure. Unanchored stream banks erode away more easily.

**Sedimentation of Channel Beds**

When upstream channels erode, sediment particles are carried and deposited downstream. The deposits replace the natural streambed with shifting sands, silts and muck.

![Source: R. Claytor File Photo](image)

**Increased Floodplain Elevation**

Floodplains are areas adjacent to streams that become inundated during peak storm events. A stream’s floodplain can be increasingly isolated from the normal channel with more intense development and increased runoff volume. Increases become more acute when building and filling occurs in floodplain areas where it may displace floodwaters and directly elevate the floodplain.

![Figure 2-4 Changes to a Stream’s Physical Character Due to Watershed Development](image)

The increase in stormwater runoff can be too much for the natural drainage system to handle. As a result, the drainage system is often "improved" to rapidly collect runoff and
quickly convey it away (using curb/gutters, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, lakes, wetlands, estuaries, or near-shore bays.

2.2.2 Impacts to Water Quality

Development concentrates and increases the amount of nonpoint source pollutants. As stormwater runoff moves across the land surface, it picks up and carries away both natural and anthropogenic pollutants, depositing them into Rhode Island’s streams, rivers, lakes, wetlands, coastal waters and marshes, and groundwater. Stormwater pollution is one of the leading sources of water quality degradation in Rhode Island – as evidenced in the 2008 Rhode Island list of impaired waters prepared pursuant to Section 303(d) of the Federal Clean Water Act, urban runoff and stormwater discharges are a significant cause of impairment to the state’s waterbodies (DEM, 2008). Water quality impacts are numerous, and common pollutants found in stormwater runoff are listed and described below. Table 2-2 summarizes the major stormwater pollutants and their effects.

2.2.2.1 Sediment (Suspended Solids)

Sources of sediment include particles that are deposited on impervious surfaces and subsequently washed off by a storm event, as well as the erosion of streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997). Additionally, significant quantities of sediments are deposited in waterways as a result of winter sanding of roadway surfaces and the infrequent maintenance of catch basins by state and municipal public works departments.

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, ponds, and bays. Turbidity resulting from this sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems and smothering benthic organisms. In addition, sediment transports many other pollutants including nutrients, trace metals and hydrocarbons to water resources. High turbidity due to sediment increases the cost of treating drinking water and reduces the value of surface waters for industrial and recreational use. Sediment also fills ditches and small streams and clogs storm sewers and pipes, causing flooding and property damage. Sedimentation can reduce the capacity of reservoirs and lakes, block navigation channels, fill harbors and silt estuaries.

2.2.2.2 Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, reservoirs, and bays (known as eutrophication). Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, sewage (e.g., from wastewater treatment facilities, overflows, and faulty on-site wastewater treatment systems), animal waste (both domestic and feral), organic
matter, detergent, and streambank erosion. Data from studies across the country suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer et al., 1997; Waschbusch et al., 2000; Bannerman et al., 1993). Nutrients are of particular concern to ponds, lakes, and estuaries and are a major source of degradation in some of Rhode Island’s waters because they promote weed and algae growth in lakes, streams and estuaries. Algae blooms block sunlight from reaching underwater grasses and deplete oxygen in bottom waters. In addition, nitrification of ammonia by microorganisms can consume dissolved oxygen, while nitrates can contaminate groundwater supplies.

### 2.2.2.3 Pathogens

Pathogen levels in stormwater runoff routinely exceed public health standards for water contact recreation and shellfish harvesting. Some stormwater sources of fecal contamination include cesspools and failed OWTSs, sanitary and combined sewer overflows, and illicit connections to the storm drain system. Other sources include pet waste and urban wildlife. Pathogens are a leading contaminant in many of the waters of Rhode Island and have led to many beach and shellfishing bed closures in recent years. For example, the Department of Health discourages swimming, surfing and other full body contact activities at Easton’s Beach, Atlantic Beach Club Beach, and Scarborough State Beach for a minimum of 24 hours after heavy rainfall due high levels of harmful bacteria from nearby stormwater drains (DOH, 2008).

### 2.2.2.4 Organic Matter

When organic matter decomposes in a waterbody, the process consumes dissolved oxygen (DO) in the water. As organic matter is washed off by stormwater, dissolved oxygen levels in receiving waters can be rapidly depleted. If the DO deficit is severe enough, fish kills may occur and aquatic life can weaken and die. In addition, oxygen depletion can affect the release of toxic chemicals and nutrients from sediments deposited in a waterway. All forms of organic matter in urban stormwater runoff such as leaves, grass clippings and pet waste contribute to the problem. In addition, there are a number of non-stormwater discharges of organic matter to surface waters such as sanitary sewer leakage and septic tank leaching.

### 2.2.2.5 Toxic Pollutants

Besides oils and greases, urban stormwater runoff can contain a wide variety of other toxicants and compounds including heavy metals such as lead, zinc, copper, and cadmium, and organic pollutants such as pesticides, PCBs, and phenols. These contaminants are of concern because they are toxic to aquatic organisms and can bioaccumulate in the food chain. In addition, they also impair drinking water sources and human health. Many of these toxicants accumulate in the sediments of streams and lakes. Sources of these contaminants include industrial and commercial sites, urban surfaces such as rooftops and painted areas, vehicles and other machinery, improperly disposed household chemicals, landfills, hazardous waste sites and atmospheric deposition. According to the 2006 Section 305(b) Report State of the
State’s Waters (DEM, 2006), toxicants were at elevated levels in 70% of the total acreage of lakes and 44% of the total miles of rivers assessed.

2.2.2.6 Thermal Impacts

As runoff flows over impervious surfaces such as asphalt and concrete, it increases in temperature before reaching a stream or pond. Water temperatures are also increased due to shallow ponds and impoundments along a watercourse as well as fewer trees along streams to shade the water. Since warm water can hold less DO than cold water, this “thermal pollution” further reduces oxygen levels in depleted urban streams. Temperature changes can severely disrupt certain aquatic species, such as trout and stoneflies, which can survive only within a narrow temperature range.

2.2.2.7 Trash and Debris

Considerable quantities of trash and other debris are washed through storm drain systems and into streams, lakes and bays. The primary impact is the creation of an aesthetic “eyesore” in waterways and a reduction in recreational value. In smaller streams, debris can cause blockage of the channel, which can result in localized flooding and erosion.

Table 2-2 Effects of Stormwater Pollutants

<table>
<thead>
<tr>
<th>Stormwater Pollutant</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediments—Suspended Solids, Dissolved Solids, Turbidity</td>
<td>Stream turbidity</td>
</tr>
<tr>
<td></td>
<td>Habitat changes</td>
</tr>
<tr>
<td></td>
<td>Recreation/aesthetic loss</td>
</tr>
<tr>
<td></td>
<td>Contaminant transport</td>
</tr>
<tr>
<td></td>
<td>Filling of fresh and estuarine water bodies, and freshwater and coastal wetlands</td>
</tr>
<tr>
<td>Nutrients—Nitrate, Nitrite, Ammonia, Organic Nitrogen, Phosphate, Total Phosphorus</td>
<td>Algae blooms</td>
</tr>
<tr>
<td></td>
<td>Eutrophication</td>
</tr>
<tr>
<td></td>
<td>DO depletion</td>
</tr>
<tr>
<td></td>
<td>Ammonia and nitrate toxicity</td>
</tr>
<tr>
<td></td>
<td>Recreation/aesthetic loss</td>
</tr>
<tr>
<td>Pathogens—Total and Fecal Coliforms, Fecal Streptococcus (Enterococci), Viruses, E.Coli</td>
<td>Ear/Intestinal infections</td>
</tr>
<tr>
<td></td>
<td>Shellfish bed closure</td>
</tr>
<tr>
<td></td>
<td>Recreation/aesthetic loss</td>
</tr>
</tbody>
</table>
Stormwater Pollutant | Effects
--- | ---
Organic Matter—Vegetation, Sewage, Other Oxygen Demanding Materials | DO depletion
Odors
Fish kills
Toxic Pollutants—Heavy Metals (cadmium, copper, lead, zinc), Organics, Hydrocarbons, Deicing Salt, Pesticides/Herbicides | Human & aquatic toxicity
Bioaccumulation in the food chain
Thermal Pollution | DO depletion
Habitat changes
Trash and debris | Recreation/aesthetic loss

Concentrations of pollutants in stormwater runoff vary considerably between sites and storm events. Typical average pollutant concentrations in urban stormwater runoff in the Northeast United States are summarized in Table 2-3.

Table 2-3 Average Pollutant Concentrations in Urban Stormwater Runoff (All Land Uses)

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Units</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>mg/l</td>
<td>54.5</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>mg/l</td>
<td>0.26</td>
</tr>
<tr>
<td>Soluble Phosphorous</td>
<td>mg/l</td>
<td>0.10</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>mg/l</td>
<td>2.00</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>mg/l</td>
<td>1.47</td>
</tr>
<tr>
<td>Nitrite and Nitrate</td>
<td>mg/l</td>
<td>0.53</td>
</tr>
<tr>
<td>Copper</td>
<td>μg/l</td>
<td>11.1</td>
</tr>
<tr>
<td>Lead</td>
<td>μg/l</td>
<td>50.7</td>
</tr>
<tr>
<td>Constituent</td>
<td>Units</td>
<td>Concentration</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>----------</td>
<td>---------------</td>
</tr>
<tr>
<td>Zinc(^1)</td>
<td>(\mu g/l)</td>
<td>129</td>
</tr>
<tr>
<td>BOD(^1)</td>
<td>mg/l</td>
<td>11.5</td>
</tr>
<tr>
<td>COD(^1)</td>
<td>mg/l</td>
<td>44.7</td>
</tr>
<tr>
<td>Organic Carbon(^2)</td>
<td>mg/l</td>
<td>11.9</td>
</tr>
<tr>
<td>PAH(^3)</td>
<td>mg/l</td>
<td>3.5</td>
</tr>
<tr>
<td>Oil and Grease(^4)</td>
<td>mg/l</td>
<td>3.0</td>
</tr>
<tr>
<td>Fecal Coliform(^5)</td>
<td>Colonies/100 ml</td>
<td>15,000</td>
</tr>
<tr>
<td>Fecal Streptococcus (Enterococcus)(^5)</td>
<td>Colonies/100 ml</td>
<td>35,400</td>
</tr>
<tr>
<td>Chloride (snowmelt)(^6)</td>
<td>mg/l</td>
<td>116</td>
</tr>
</tbody>
</table>

Source: Adapted from NYDEC, 2001; original sources are listed below.

\(^1\)Pooled NURP/USGS (Smullen and Cave, 1998)
\(^2\)Derived from National Pollutant Removal Database (Winer, 2000)
\(^3\)Rabanal and Grizzard, 1996
\(^4\)Crunkilton et al., 1996
\(^5\)Schueler, 1999
\(^6\)Oberts, 1994

mg/l = milligrams per liter
\(\mu g/l\) = micrograms per liter

### 2.2.3 Impacts to Receiving Waters

Rhode Island enjoys an abundance of water resources that support vital uses such as drinking water, recreation, habitat and commerce, among others. The state has approximately 1,498 miles of rivers, 20,917 acres of lakes and ponds, and approximately 15,500 acres of shrub swamps, marshes, bogs and fens as well as close to 72,000 acres of forested wetlands. Estuaries, including Narragansett Bay and the coastal ponds, cover 156 square miles. Underlying the state are 22 major stratified drift (sand and gravel) aquifers as well as usable quantities of groundwater in almost all other locations from the bedrock aquifers (DEM, 2008).

These water resources are impacted by both hydrologic and water quality aspects of stormwater runoff, as were discussed above. The sensitivity of the range of water types...
is described below. Table 2-4 summarizes the effects of urbanization on these receiving environments.

2.2.3.1 Groundwater

As land development occurs, impervious surfaces preclude the natural infiltration of rainwater, thereby reducing the recharge rate. This results in a lowering of the water table. Ultimately, development can lead to a depletion of aquifers, reduced baseflows for streams and rivers, and increased concentrations of other pollutants derived from urban runoff in groundwater. Aquifer levels and clean groundwater are very important in Rhode Island, where as of September 2005, there were 647 public wells in the state, with approximately 30% of the state’s residents depending on wells for drinking water (DEM, 2006).

One potential remedy for this “de-watering” impact is to collect stormwater runoff and to infiltrate it to help restore (or enhance) natural recharge rates. It is possible to collect and infiltrate enough stormwater to match the natural (pre-development) recharge rates. This is a viable option to mitigate and compensate for other sources of water consumption and groundwater de-watering, such as groundwater withdrawals for drinking water and irrigation purposes.

However, the infiltration of stormwater raises some important water quality issues. As discussed previously, stormwater is commonly degraded with a broad range of pollutants collected from the land surface or accompanying precipitation. Secondly, aquifers can be highly permeable and, therefore, very susceptible to contamination. Thus, depending on the land use, stormwater can require significant pre-treatment prior
to infiltration to protect the quality of groundwater resources. This may be accomplished with certain stormwater BMPs that provide effective treatment. Wellhead protection areas that have been delineated showing the specific groundwater contribution areas require the highest level of protection to ensure a safe drinking water supply. Infiltration issues are discussed further in Chapters Three and Five.

2.2.3.2 Freshwater Streams, Ponds, Wetlands, and Estuaries

There are numerous streams (perennial and intermittent), ponds, wetlands, and estuaries throughout Rhode Island. They provide important aquatic habitat for a broad range of fish, amphibian, mammal and bird species, and as recreational resources for humans. In addition, surface water provides approximately 70% of the drinking water in Rhode Island. The Scituate Reservoir alone provides more than 50% of the state’s residents with drinking water (DEM, 2008).

Stream flow is derived from overland runoff and baseflow from groundwater, which discharges into streambeds. If baseflow is continuous throughout the year, the stream is perennial. If groundwater elevations fall below the natural stream bed elevation, the stream is intermittent. In either case, stream ecosystems are very dependent upon the maintenance of natural groundwater levels and corresponding groundwater discharges to the streams.

Each stream ecosystem is adapted to its natural flow regime, which is a mixture of surface runoff events and groundwater baseflow. Stormwater management practices associated with land development within watersheds can significantly alter the timing and rates of surface flow and groundwater discharge, thereby impacting stream ecosystems. In some cases, naturally occurring perennial streams may dry up seasonally in a developed watershed, significantly altering the habitat. Similarly, water quality impacts caused by increased nutrients and sedimentation can significantly impact stream ecosystems. Finally, streams, particularly small first- and second-order streams, are especially susceptible to increased channel erosion associated with altered hydrology and land development.

Ponds provide unique habitats and are also sensitive to stormwater discharges within their watersheds. Eutrophication is a common problem in freshwater ponds, and is the result of excessive phosphorus loading, which can cause excessive weed or algal growth and ultimately can cause depleted oxygen levels, fish kills, and noxious odors. Although both phosphorus and nitrogen contribute to excessive plant growth, phosphorus is the limiting nutrient of freshwater pond environments. Common sources of phosphorus include phosphate-containing cleaners or detergents, human and animal waste, and lawn fertilizers.

Wetlands provide a broad range of habitat and recreational values. They too are susceptible to impacts from stormwater in terms of both hydrology and water quality changes. Wetlands are defined and entirely dependent upon surface and near surface hydrologic conditions (water levels to within 12 inches of the surface of the ground), which support hydrophytes (wetland vegetation) and hydric soils. Similar to the other
freshwater resource areas discussed above, wetlands are very sensitive to water level changes and to alterations in water inputs. Therefore, stormwater must be managed within the watersheds to wetlands in a manner that minimizes impacts to natural flow regimes. Wetlands are also susceptible to pollutant loading increases, particularly phosphorus.

### 2.2.3.3 Coastal Waters

Coastal waters are valuable for the support and propagation of fish, shellfish, and other marine life, and serve as a very significant commercial and recreational resource for humans. Coastal water quality issues include eutrophication, damage to wildlife habitat (including sedimentation), and bacterial/viral pollution of swimming beaches and shellfish harvesting areas. Sediments cause physical damage, including decreased water clarity and smothering of benthic habitat. Nutrients (typically nitrogen for coastal environments) cause eutrophication, which results in excessive algae growth, depleted DO levels, and foul odors.

**Table 2-4 Effects of Development on Receiving Waters**

<table>
<thead>
<tr>
<th>Receiving Environment</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands</td>
<td>• Changes in hydrology and hydrogeology</td>
</tr>
<tr>
<td></td>
<td>• Increased nutrient and other contaminant loads</td>
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<td>• Changes in atmospheric inputs through increased air emissions to the urban airshed</td>
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<td>• Compaction and destruction of wetland soil</td>
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<td>• Changes in wetland vegetation</td>
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<td>• Changes in or loss of habitat</td>
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<td>• Changes in the community (diversity, richness, and abundance) of organisms</td>
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<td></td>
<td>• Loss of particular biota</td>
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<td>• Permanent loss of wetlands</td>
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<tr>
<td>Lakes and Ponds</td>
<td>• Impacts to biota on the lake bottom due to sedimentation</td>
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<td></td>
<td>• Contamination of lake sediments</td>
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<td>• Water column turbidity</td>
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<td>• Aesthetic impairment due to floatables and trash</td>
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<td>• Increased algal blooms and depleted oxygen levels due to nutrient enrichment, resulting in an aquatic environment with decreased diversity</td>
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<td></td>
<td>• Contaminated drinking water supplies</td>
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<tr>
<td>Receiving Environment</td>
<td>Impacts</td>
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| Estuaries             | - Sedimentation in estuarial streams and submerged aquatic vegetation beds  
                          - Altered hydroperiod of brackish and tidal wetlands, which results from larger, more frequent pulses of fresh water and longer exposure to saline waters because of reduced baseflow  
                          - Increased algal blooms and depleted oxygen levels due to nutrient enrichment, resulting in an aquatic environment with decreased diversity  
                          - Turbidity  
                          - Bio-accumulation  
                          - Scour of tidal wetlands  
                          - Short-term salinity swings in small estuaries caused by the increased volume of runoff which can impact key reproduction areas for aquatic organisms  
                          - Alteration of salt marsh vegetation communities caused by freshwater inputs; increased occurrence of invasive species such as *Phragmites australis* |

Source: Adapted from WEF and ASCE, 1998.

### 2.2.4 Impacts to Aquatic Habitat

Along with changes in stream hydrology and morphology, the habitat value of streams may diminish due to development. Aquatic habitat impacts include those in the following sections:

#### 2.2.4.1 Degradation of Habitat Structure

High velocity flows scour channels and may wash away entire biological communities. Stream bank erosion and the loss of riparian vegetation reduce habitat for fish and other aquatic life, while sediment deposits may smother bottom-dwelling organisms.

#### 2.2.4.2 Loss of Pool Riffle Structure

Streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with “riffles” or shoals of shallower, fast-flowing water. These pools and riffles provide valuable habitat for fish and aquatic insects. As a result of the increased flows and sediment loads from urban watersheds, the pools and riffles disappear and are replaced with more uniform, and often shallower, streambeds that provide less varied habitat and may fail to support a native diversity of species.
2.2.4.3 Reduced Base flows

Urbanization reduces the groundwater recharge and consequently the base flow to streams. Loss of flow stresses habitat and may eliminate many species. During periods of drought, streams may dry up completely, extirpating even the hardiest plants and animals.

2.2.4.4 Increased Stream Temperature

Pavement tends to absorb light energy as heat. Precipitation over pavement absorbs the heat as it runs off into nearby streams and raises stream temperature. Increased temperatures can reduce DO levels and disrupt the food chain. Some aquatic species such as certain trout can only survive within a narrow temperature range.

2.2.4.5 Changes in Water Chemistry

In addition to causing changes in temperature and DO, stormwater contributes other pollutants such as heavy metals, petroleum products, road salts, and excess nutrients to receiving water bodies, which may adversely affect aquatic organisms. In estuarine systems, stormwater inputs may significantly alter salinity levels, which can cause shifts in plant and animal species composition.

2.2.4.6 Decline in Abundance and Biodiversity

Loss of habitat and habitat variety reduces abundance and diversity of organisms.