Article 79

# The Environmental Impact of Stormwater Ponds

Stormwater ponds are one of the most effective techniques for providing channel protection and pollutant removal for urban streams. However, persistent concerns have been raised about the possible secondary environmental impacts produced by ponds. This article reviews available data on the negative impacts of stormwater ponds on downstream water temperature regimes, downstream dry weather water quality, downstream bedload movement, downstream trophic shifts, upstream fish passage, upstream channel degradation, and destruction of riparian cover and wetlands. The article concludes by suggesting design and “fingerprinting” techniques that can be used to avoid or mitigate these environmental impacts.

Stormwater ponds are among the most adaptable, effective and widely applied stormwater treatment practices in developing areas. The popularity of stormwater ponds can be attributed to their proven ability to attenuate flows from design storms; economies of scale compared to other types of stormwater practices (Wiegand *et al.*, 1986); high urban pollutant removal capability (Schueler and Helfrich, 1989); longevity, particularly in comparison to other types of stormwater practices (MDE, 1991); community acceptance (UWLI, 1987); and effect on adjacent land prices (Schueler, 1987).

In recent years, many communities have adopted regional stormwater pond policies to achieve maximum stormwater benefits at the watershed scale at minimum cost. Individual ponds serve areas ranging in size from 50 to 500 acres, and are located within the larger watershed using hydrology simulation models.

However, large stormwater pond systems have recently come under increased scrutiny from state and federal environmental regulatory agencies in the mid-Atlantic region. In many cases, pond designers must obtain both a Section 401 (water quality certification) and/or Section 404 (wetland) permit prior to construction. In an increasing number of cases, permits for pond construction are denied or are issued with rigorous conditions. The most common impacts cited are wetland disturbance, downstream warming, and the sacrifice of upstream stream reaches. Other frequently cited negative impacts of ponds include the creation of barriers to fish passage, poor quality of pond effluent, downstream shifts in stream trophic status, and loss of forests in the floodplain.

To date, very limited research has been conducted on the environmental impacts of stormwater ponds. Typically, the severity of impacts attributed to ponds has been inferred from limnological research studies on the effects of larger impoundments and reservoirs on large river systems (for an excellent review, see Ward and Stanford, 1979 and Petts, 1984). In these systems, impoundments are a “serial discontinuity” and have a pervasive and persistent impact on aquatic life downstream. How well does this paradigm apply to the case of urban stormwater ponds? For a number of reasons, it may not apply totally.

First, stormwater ponds are typically located in first and second order headwater streams, as opposed to larger rivers. Second, stormwater ponds tend to be extremely shallow (five to 10 feet), and thus experience only weak stratification. Impoundments, on the other hand, may be from 15 to 150 feet deep, and exhibit very strong seasonal stratification. Third, and most importantly, urban streams differ in many important characteristics from more natural systems. Urbanization profoundly changes the hydrology, morphology, water quality and ecology of streams, and the severity of these changes is directly related to the degree of watershed imperviousness (see article 1).

## Environmental Impacts Associated With Stormwater Ponds

This article presents some new research data on the severity of secondary impacts of stormwater ponds. In addition, several design techniques are suggested to minimize secondary impacts.

The range of potential environmental impacts that ponds can exert is shown in schematic fashion in Figure 1. Ponds can have both positive and negative impacts on the local and downstream environment, as discussed below.

### *Alteration on Downstream Temperature Regime*

It has been recognized for many years that urban streams tend to be warmer than undisturbed streams (Pluhowski, 1970). A recent study of headwater streams in the Maryland Piedmont confirmed the existence of a “heat island effect” in urban streams (Galli, 1991). The increase in urban summer stream temperatures from an undeveloped reference stream baseline (denoted as the

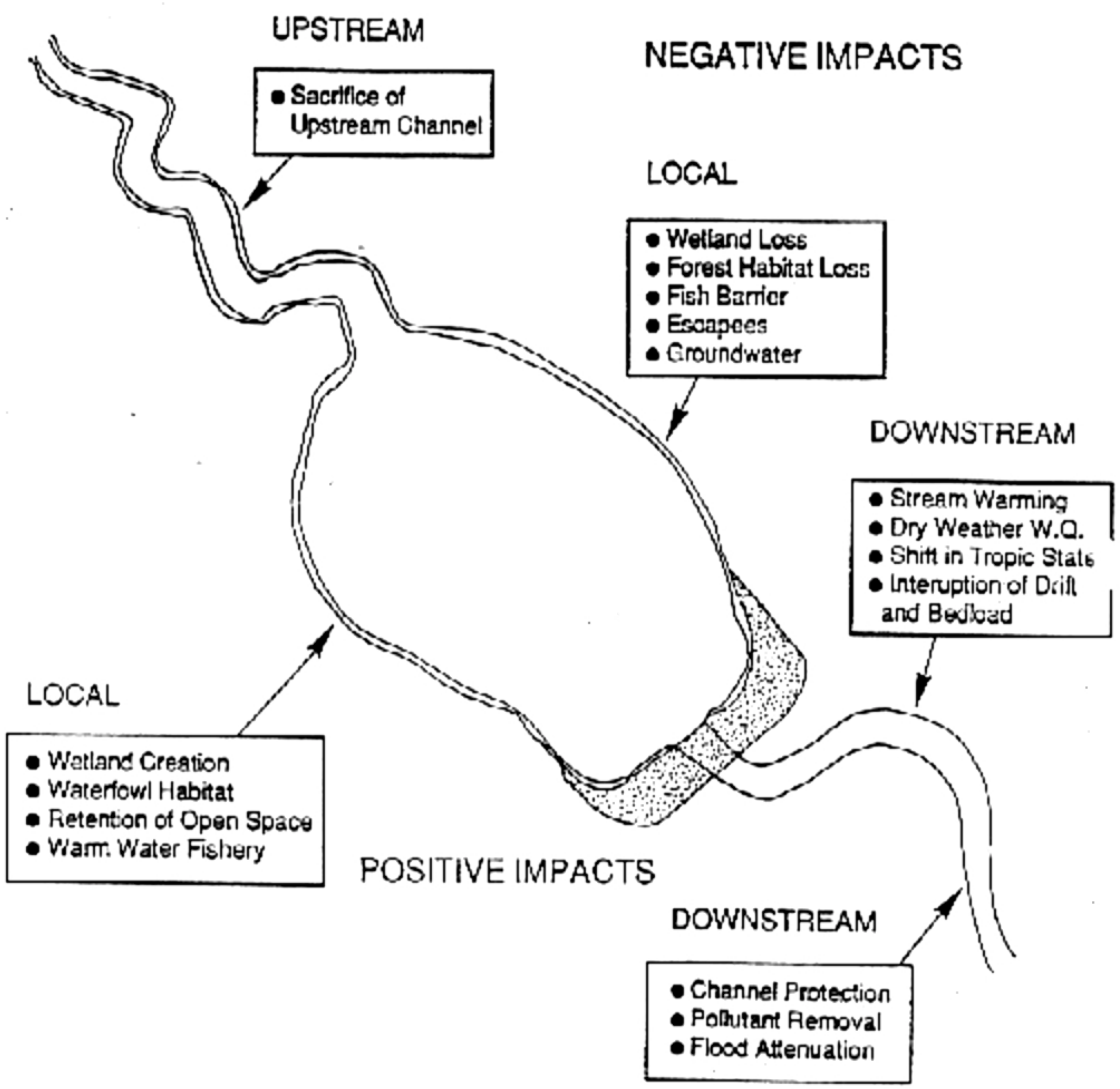


**Figure 1: Schematic of the Positive and Negative Impacts of Ponds**

watershed Delta-T) is a direct function of watershed imperviousness (Table 1). The summer mean Delta-T for a highly developed headwater stream was 8.6 degrees Fahrenheit, with no statistical difference between baseflow and stormflow conditions. A maximum instantaneous Delta-T of 16.2 degrees F was observed during the hottest portion of the summer.

Stormwater ponds can amplify the warming effect noted for urban streams. The permanent pool of ponds acts as a heat sink during the summer months, and discharges warmer waters during both storm and baseflow conditions (Schueler and Helfrich, 1988). The magnitude of this effect can be characterized by the pond delta-T, which expresses the change in water temperature upstream and downstream of a pond. The mean summer delta-T for the Countryside wet pond in Maryland was 9.5 degrees F with an instantaneous maximum of 15.1 degrees F (Table 2 and Figure 2). A similar Delta-T was reported by Galli (1988) for the Rolling Acres wet pond. The magnitude of a wet pond Delta-T appears to be a direct function of the size of the permanent pool in relation to the contributing watershed area. For example, a shallow pond system that had a much smaller permanent pool had a correspondingly smaller mean summer Delta-T (Table 2).

No pond system was found to be thermally neutral, even for ponds that did not have a permanent pool. For example, the Tanglewood extended deten-

### Table 1: Effect of Watershed Imperviousness on Stream Temperatures
### Delta-T Values for Six Headwater Streams in the Maryland Piedmont
### Continuous Observations -- April to September, 1989

| Stream Name | Area (acres) | Flow (a) (cfs) | Impervious (percent) | Mean (b) Delta-T | Max (b) Delta-T |
|---|---|---|---|---|---|
| Lakemont | 400 | 0.9 | > 1.0 | 0$^0$F | 0$^0$F |
| Countryside | 165 | 0.25 | 12 | 1.9 | 9.4 |
| Oak Springs(c) | 140 | 0.11 | 18 | 2.4 | 8.4 |
| Fairland Ridge | 25 | 0.05 | 25 | 3.7 | 12 |
| Tanglewood | 195 | 0.26 | 30 | 5.1 | 15.1 |
| Whiteoak Trib | 225 | 0.35 | 60 | 8.6 | 16.2 |

(a) Measured dry weather baseflow
(b) Delta-T computed as the change in summer mean water temperatures from an undisturbed natural reference stream to a geographically similar urban stream over an identical time interval
(c) The temperature regime of the Oak Springs site was influenced by the presence of a farm pond 100 feet upstream of sampling site.

### Table 2: Effect of Stormwater Pond Systems on Downstream Water Temperatures
### Delta-T Values for Four Maryland Pond Systems
### Continuous Observations -- April to September, 1989

| Pond Name | Pond System | Mean Delta-T | Max Delta-T | Max Temp of Pond Effluent |
|---|---|---|---|---|
| Fairland | Dry "Infilter" (a) | 2.5 $^0$F | 7.6 $^0$F | 77.7 $^0$F |
| OakSprings | ED Shallow Marsh (b) | 3.2 | 8.7 | 77.7 |
| Tanglewood | Dry ED Pond (c) | 5.3 | 10.9 | 81.9 |
| Countryside | Wet Pond (d) | 9.5 | 15.1 | 82.6 |

(a) Infiltration trenches provide 0.25 inches/impa of WQ storage
(b) 3 acre Dry 24 hr ED Detention w/ 500 foot rip-rap pilot channel
(c) 1 acre shallow wetland (mean depth 18 inches with 24 hr ED)
(d) 1.5 acre pond (mean depth 6 feet) with pond release 2.5 feet below normal pool elevation.

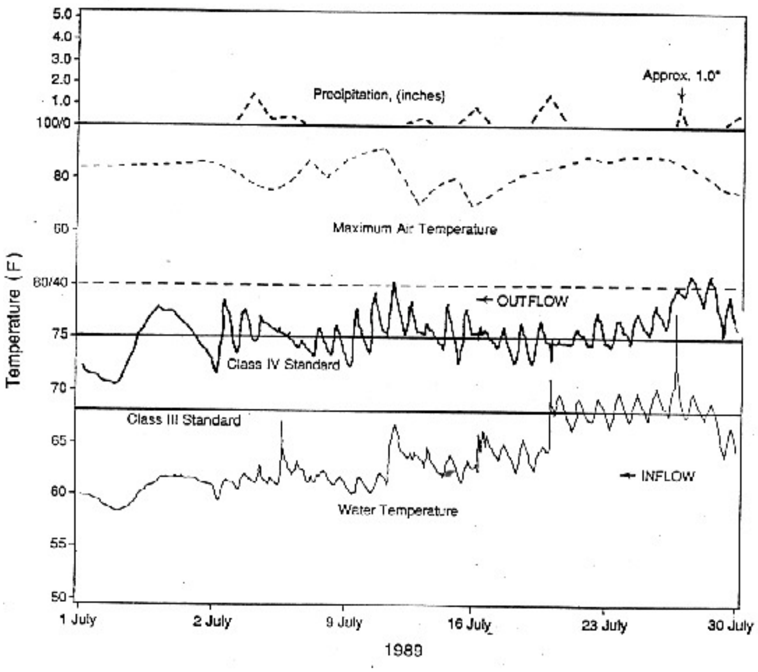


**Figure 2: Upstream and Downstream Summer Temp Profiles of a Wet Pond**

tion dry pond had a mean and maximum Delta-T of 5.1 and 15.1, respectively. The high Delta-T was attributed to warming within the unshaded, rip-rap pilot channel. The lack of riparian cover and the thermal properties of rip-rap and concrete pilot channels can impart significant heat to baseflow and runoff in dry detention ponds. Galli (1991) observed average Delta-T's ranging from one to three degrees F per 100 feet (maximum eight degrees F per 100 feet) for rip-rap pilot and outfall channels.

The impact of stream warming is especially significant for cool- or cold-water streams. Stream temperature is one of the central organizing features of aquatic communities, and affects the rates of detrital processing, respiration, and bacterial growth, as well as the timing of reproduction, molting and drift for aquatic organisms. For some species, stream warming can be lethal. Salmonoid species, such as trout, are exceptionally sensitive to stream warming (Galli and Dubose, 1991). Stream warming also fundamentally alters macroinvertebrate species composition (particularly so for stoneflies and caddisflies), as well as diatom, periphyton and fungal associations of streams.

### *Poor Water Quality of Pond Effluent*

Although most ponds reduce urban pollutant concentrations during storms over the long term (although not necessarily during every storm event), their discharge during dry weather periods can be a concern. Ponds are typically weakly stratified but are hyper-eutrophic systems that can become partially or totally anoxic in the summer months (Galli, 1988).

Dissolved oxygen levels discharged from surface and mid-depth release ponds can be hypoxic but are seldom anoxic. About 1% of dissolved oxygen measurements in pond discharges in the Maryland suburbs were below 5.0 mg/l, with a minimum reading of 3.4 mg/l (Galli, 1991). Recovery is usually quite rapid and occurs within a few hundred feet below the pond.

Dissolved oxygen, however, can be a serious problem in ponds that release water from the bottom of the pool. Galli (1988) reported a minimum DO level of 1.7 mg/l at the Rolling Acres wet pond. Deep release ponds also often discharge extremely carbon-rich effluent that can coat the stream substrate and increase the benthal oxygen demand during low flows.

### *Barrier to Downstream Movement of Bedload*

Ponds are excellent traps for silt, sand and coarser-grained gravels and cobbles that comprise the bedload of the stream. Because of the limits of gravity settling, ponds are much less effective at trapping fine silts and clays (Schueler and Lugbill, 1990). Thus, ponds tend to totally block the downstream movement of extremely coarse-grained particles, while at the same time exporting a steady supply of fine-grained particles downstream. Galli (1988) provides some evidence that this process can lead to embedding of downstream substrates, with a consequent reduction in habitat value.

### *Downstream Shift in Stream Trophic Status*

Ward and Stanford (1979) contend that impoundments create a strong shift in the trophic status of the downstream community. This is often manifested in reduced detrital processing of leaf litter (i.e, the shredding of leaf litter into bacterially rich fine particles) and increased scraping of microbial slime on rocks and filtering of fine organic particles from the water column. This paradigm has been confirmed for wet ponds (see Table 3). A much greater proportion of shredders was found above the pond, whereas a greater proportion of collectors and scrapers was found below it. This presumably reflects differences in the size of carbon fractions utilized by aquatic insects as they are modified by the pond.

Table 4 provides additional conclusions as to the changes in aquatic insect communities above and below the Rolling Acres wet pond, as abstracted from Galli (1988).

## Table 3: Macroinvertebrate Community Trophic Structure Upstream, Downstream and Within a Wet Stormwater Pond Rolling Acres Wet Pond, Maryland, April to December, 1985

| Primary Functional Trophic Category | Riffle Upstream Of Pond | Riffle Downstream Of Pond | Littoral Area Within Pond (a) |
|---|---|---|---|
| | % of benthic community | | |
| Shredders | 55.8 | 1.1 | 0.5 |
| Collector-Gatherers | 6.5 | 15.7 | 13.6 |
| Collector-Filterers | 12.0 | 26.0 | 0.0 |
| Scrapers | 13.4 | 43.4 | 0.6 |
| Predators | 12.3 | 13.8 | 85.3 |

(a) benthic samples only
(b) percentage based on lumped individuals within each category for eight sampling surveys.

## Table 4: Other Changes In the Benthic Community Upstream and Downstream of the Rolling Acres Wet Pond Reported by Galli (1988)

- Riffle substrates below the pond were finer grained, more heavily embedded and contained higher mass of CPOM and FPOM than upstream substrates.
- Greater mass of detrital carbon was evident below the pond than above the pond.
- Detrital carbon below the pond was much finer-grained in size, as typified by the high percentage of collector/filter species.
- Periphyton density was greater above the pond than below it; however, algal species below the pond tended to be associated with eutrophic conditions.
- Leaf pack processing rates were sharply lower below the pond than above the pond
- Macroinvertebrate density was similar above and below the pond; however, the standing crop was slightly lower, and species diversity was sharply lower below the pond.
- Several pollution-sensitive taxa were eliminated below the pond, including all Ephemeroptera, Plecoptera, and Odonata. Non-insect forms predominated below the pond (tubificid worms and snails).

**Table 5: Summary of Useful Techniques to Reduce Pond Impacts**

| Site Problem | Recommended Pond Fingerprinting Techniques |
|---|---|
| Need to Avoid an Existing Wetland | • Perform wetland delineation before locating pond<br>• Select pond system with minimal permanent pool<br>• Adjust pond configuration ("donut pond")<br>• Install parallel pipe system to divert runoff around wetland to pond site further downstream<br>• Construct a sequence of ponds around the wetland |
| Need To Preserve Mature Forest or Habitat Area | • Select pond system with micropool<br>• Configure pond to minimize the removal of specimen trees<br>• Limit the area of disturbance<br>• Mandate tree protection measures during construction<br>• Plant native tree and shrubs to replicate habitat functions lost due to pond |
| Concern About the Thermal Impact of a Permanent Pool on Downstream Fishery | • Split 50-75% of cooler baseflow above pond and bypass it around the permanent pool<br>• Select pond system with minimal permanent pool<br>• Use the infilter pond<br>• Preserve existing shade trees, plant fast-growing shade trees along the shoreline/stream valley<br>• Align pond in north-south direction<br>• Avoid excessive rip-rapping and concrete channels that rapidly impart heat to runoff<br>• Utilize deep-water release in the permanent pool |
| Need to Protect Stream Reach Above Pond From Urban Stormflows | • Install parallel pipe system along the upstream reach to convey excessive stormflows<br>• Install plunge-pools at terminus of storm drains to reduce runoff velocities<br>• Use bio-engineering techniques and checkdams to stabilize the stream reach |
| Concern About Pond Effluent | • Locate pond release within a foot of normal pool elevations<br>• Dilute pond effluent during severe pond drawdowns and draining operations<br>• Maximize reareation within riser, barrel and outfall |

### *Sacrifice of Upstream Channels*

A frequent concern of large ponds is that they provide no effective control for their tributary drainage, and thereby sacrifice the entire network of upstream channels. The extent of this sacrifice is closely related to the size and imperviousness of the contributing watershed to the pond.

### *Influence of Ponds on the Fish Community*

Ponds are usually a final barrier to resident fish migration, and can prevent the recolonization of fish when upstream populations are severely impacted. Given the frequent stressors in degraded urban streams, it is quite likely that upstream fish populations may eventually become extinct. What is less appreciated is the influence that ponds have on downstream fish populations. Most larger ponds eventually establish a modest warm-water fish community due to the unregulated introduction of fish species by local fisherman. Typically, the fish community is quite similar to that of a farm pond, with the exception of some exotic species such as goldfish and koi. During storms, many of these warm-water species are washed downstream. Cummins

(1990) has documented at least seven species of pond “escapees” that have become well established within the urban Anacostia stream network.

*Disturbance of Non-Tidal Wetlands and Forests*

Typically, the best location for a wet pond is at the lowest elevation of a development site, stream valley or floodplain. These same areas are likely to be wetlands and/or forest habitat. The traditional approach has been to construct an embankment across the stream to obtain the needed storage for a permanent pool, which can result in the complete inundation and eventual destruction of the wetland. In suburban Maryland, construction of stormwater ponds has been cited as the greatest single source of urban wetland destruction in the last two decades (MDE, 1987). In most cases, at least a portion of a proposed pond site will be considered as a wetland under the currently accepted unified federal method for wetland delineation (WTI, 1989), particularly if it is located on a perennial stream.

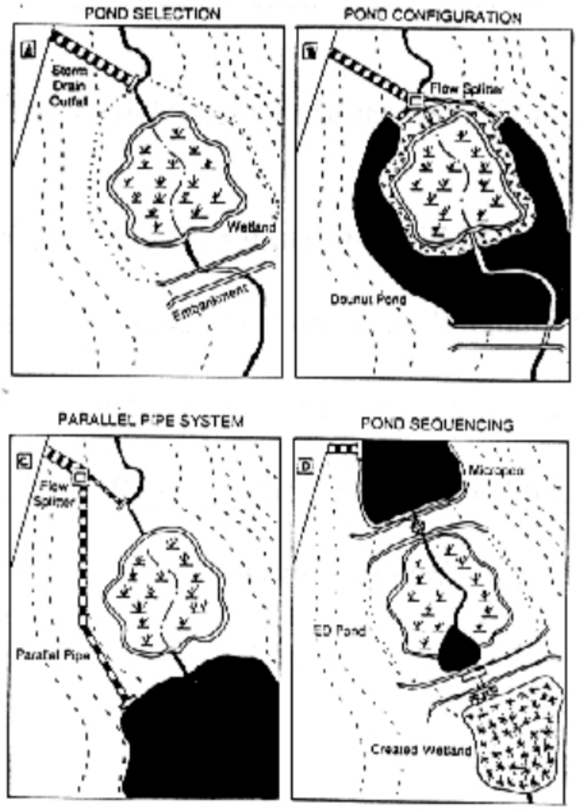
Non-tidal wetlands play an important role in maintaining the hydrology and water quality of urban streams. At the same time, uncontrolled stormwater severely degrades the quality of non-tidal wetlands. Thus, a pond siting strategy that seeks to totally avoid wetlands is self-defeating. A more realistic strategy is to fingerprint ponds above, around, or below wetlands, and in some cases, substitute stormwater wetlands for low quality natural wetlands.

## Minimizing the Secondary Impacts of Ponds

This section presents techniques for reducing or eliminating secondary impacts from stormwater ponds. These techniques include the selection of an appropriate pond system, fingerprinting, special pond design features, artificial wetland creation, and alternative conveyance. The techniques are summarized in Table 5.

*Selecting the Right Pond System*

The first step to reduce secondary pond impacts is to perform a careful field analysis of the development site and the stream prior to choosing a pond design. A complete delineation of wetlands, forest habitats and infiltration potential should be performed prior



**Panel A.** Existing natural wetland is severely impacted by upstream stormwater inputs and frequent inundation.
**Panel B.** Existing wetland is protected by berm; stormwater bypassed to the two arms of the wet pond.
**Panel C**. Excess stormwater diverted around natural wetland to a more favorable location via a parallel pipe system.
**Panel D.** Stormwater penetrated before it reaches wetland, where temporary extended detention is provided. A downstream stormwater wetland is created to compensate for impacts to the existing wetland.

**Figure 3: Techniques for Fingerprinting a Stormwater Wetland Around a Natural Wetland**

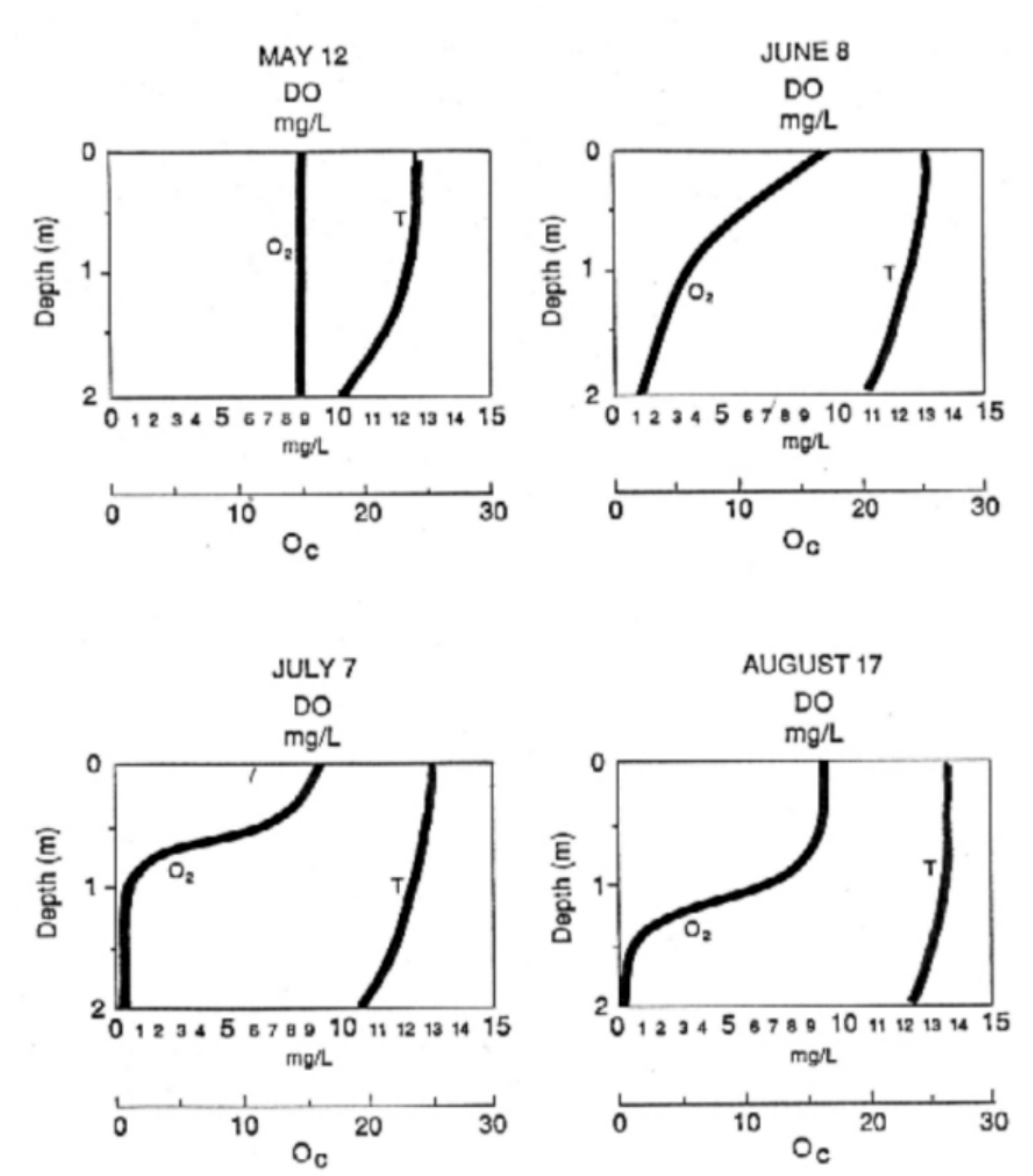


**Figure 4: Profiles of Oxygen and Temperature in an Eight-Foot Deep Hypereutrophic Wet Pond in Maryland in the Summer**

to any pond design. The stream evaluation should assess the temperature regime (cold, cold/cool, cool or warm water), as well as a biological survey to determine if any sensitive indicator organisms are present, such as trout.

In temperature-sensitive watersheds, the ED micropool pond is recommended since it is expected to have the smallest pond delta-T. Ponds that employ a deep permanent pool, or a large shallow marsh should generally be avoided in trout streams. The ED micropool design is also an excellent choice for fingerprinting a pond around a high quality wetland or a quality forest habitat.

*Pond Fingerprinting*

Pond fingerprinting is a broad term that refers to a series of techniques that can reduce the potential environmental impacts of ponds. Figure 3 illustrates several fingerprinting approaches that can minimize the impact of ponds on existing wetland areas.

Traditionally, ponds are located by constructing an embankment across the stream valley to create the required storage volume for a permanent pool. This results in the complete inundation and destruction of the wetland area. Designers should select a pond design that does not have a permanent pool. While this eliminates the need for a destructive permanent pool, it can cause a major hydrologic change to the existing wetland, due to the greater frequency of inundation or water level fluctuation.

A second option is to create a “donut” pond configuration (shown in Panel B). In this option, a flow splitter is installed at the terminus of the stormdrain system. At the same time, a berm is created around the existing wetland. A permanent pool is then excavated along the outside perimeter of the berm to provide the required storage. The flow splitter controls the flow to the entire system. The stream’s baseflow is directed through the wetland to maintain its original hydrology; however, all stormflow is routed to the two upper arms of the permanent pool. The donut can sharply reduce impacts to the wetland.

A third option involves installing a parallel pipe system to divert stormflows around the existing wetland to a permanent pool situated further downstream (Panel C). Once again, a flow splitter is installed at the terminus of the storm drain to divert the stormflows and send the existing baseflow into the wetland to maintain its hydrologic regime.

A fourth fingerprinting option involves pond sequencing, i.e., employing a series of smaller pools and wetland areas along the stream valley, rather than a single large permanent pool. One such scheme is shown in Panel D. In this option, a three-cell pond system is used to obtain the total storage requirement, involving (a) a small permanent pool cell above the wetland, (b), a ED micropool cell within the wetland, and finally, (c), a created wetland cell below the existing wetland.

### *Engineering Solutions to Reduce the Pond Delta-T*

A number of pond design techniques can be employed to reduce the magnitude of the delta-T of a pond. First, it is very important to shade pilot and outfall channels, using fast-growing riparian species such as willows and red-maple. The use of exposed rip-rap and concrete surfaces in ponds should be kept to a minimum.

Second, the volume of permanent pools should be reduced, with a greater reliance on extended detention storage. Pools can be aligned in a north-south direction, where possible. A portion of the incoming baseflow can also be split out above the pool and bypassed entirely around the pool area. This has been done with some success at the Rolling Stone pond in Maryland, but the bypass pipes and flow splitters do require constant maintenance.

Deepwater releases from ponds have been suggested as a method for reducing the delta-T. However, the value of the deep-water release is extremely limited for ponds less than 10 feet deep, as shown in Figure 4. The plot shows the profiles of oxygen and temperature in an eight foot deep hypereutrophic wet pond in Maryland in the summer. While oxygen concentrations exhibited sharp stratification from top to bottom, the vertical stratification of water temperature was much less pronounced. The maximum temperature difference between the surface and bottom of the pond was less than five degrees F (it should also be noted that pond surface temperatures are often two to three degrees F higher than what is observed at the point of outflow for any pond with an underwater release). The Rolling Acres pond had a deep water release six feet below the pond surface, yet still experienced significant delta-T (Galli, 1988). Moreover, the oxygen and carbon concentrations discharged from the pond was of very poor quality during the summer months.

### *Alternative Conveyance to the Pond*

The sacrifice of upstream reaches can be mitigated to some extent by the use of parallel pipe systems. In these systems, excess stormwater runoff is split from the storm drain before it is discharged into the stream, and is piped in a direction parallel to the stream before it is returned to the stream. Excess runoff is roughly defined as all storm flow runoff volumes from the six month storm up to the two-year event. A number of parallel pipe systems have been constructed in the Maryland suburbs, and most appear to be working effectively to protect sensitive stream reaches (see article 150).

### *Wetland Creation*

Stormwater ponds have the potential to create additional areas of emergent and high marsh wetland. Contrary to popular belief, the potential quality and functional value of these artificially created wetland systems can be quite high. In actual practice, many stormwater wetlands have little diversity or structure, since they have uniform depth, and overemphasize the use of non-local emergent plants. Recent stormwater pond designs borrow heavily from experiences gained in wetland restoration, and emphasize complex shapes, irregular micro-topography, wetland mulch, and greater attention to the more diverse “high marsh” zone (Schueler, 1991).

### Concluding Thoughts: The Relative Importance of Primary and Secondary Impacts

Stormwater ponds remain the preferred and practical option for mitigating the impacts of uncontrolled stormwater runoff on streams and distant receiving waters. However, when ponds are designed and located with no regard for the immediate environment, they can produce a diverse array of potential negative impacts in sensitive streams. Consequently, designers should carefully assess the potential impact of stormwater ponds, and utilize pond fingerprinting to help reduce these impacts.

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