Article 65

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Irreducible Pollutant Concentrations Discharged From Stormwater Practices

Load reduction has traditionally been the criteria used to evaluate the performance of urban stormwater management practices. Simply put, the mass of stormwater pollutants entering a practice are compared against the mass leaving it (over a suitable time frame), and a percent removal efficiency is quickly computed. While load reduction is a useful criteria to compare the relative performance of different practices, it does have some limits. For example, it tells us very little about the concentration of pollutants leaving the practice. Outflow concentrations can be of considerable interest to a watershed manager. For example, is there a background level or irreducible concentration of stormwater pollutants discharged downstream that represents the best that can be achieved with current technology?

The concept of irreducible concentrations has been explicitly recognized for some years in process models used to design of wastewater treatment wetlands (Kadlec and Knight, 1996; Reed, 1995). The consensus of expert opinion is that surface flow wastewater wetlands cannot reduce sediment and nutrient concentrations beyond the rather low levels indicated in Table 1, no matter how much more surface area or treatment volume is provided.

Figure 1 illustrates the effect of an irreducible concentration on the treatment efficiency of a hypothetical stormwater practice. When incoming pollutant concentrations are moderate to high, for example, an increase in a treatment variable (such as area or volume) will result in a proportional reduction in the concentration of a pollutant leaving the practice (line A). If, however, the incoming pollutant concentration approaches the irreducible concentration, (denoted as C-star), it is not possible to change the outflow concentration very much, regardless of how much additional treatment is provided (line B). Indeed, when the incoming concentration is equal to or falls below the irreducible concentration, it is possible to experience negative removal, i.e., an increase pollutant concentration as it passes through the practice (line C).

Why do irreducible concentrations exist? To begin with, they often represent the internal production of nutrients and turbidity within a pond or wetland, due to biological production by microbes, wetland plants and algae. Some of these internal processes inevitably return some pollutants back into the water column, where they may be displaced during the next storm event. In other cases, the irreducible concentration may simply reflect the limitations of a particular removal pathway utilized in a stormwater practice. For example, a practice that relies heavily on sedimentation for removal can have a relatively high C*. This is evident in the settling column data presented in Figure 2 developed by Grizzard *et al.* (1986). When sedimentation is the sole removal pathway, the removal rates for a range of pollutants eventually become asymptotic, no matter much more detention time is provided.

Does a C* exist for pollutants controlled by urban stormwater practices? Two recent studies suggest that irreducible concentrations do indeed exist. In the first study, Kehoe and his colleagues systematically analyzed the quality of stormwater in a series of 36 stormwater ponds and wetlands located in the greater Tampa Bay, Florida area. Researchers characterized the sediment, metal and dissolved oxygen content of water discharged from stormwater wet ponds (N=24) and pond/wetland systems (N=12) over a two-year period. Grab samples were collected from each site one to three days after storms occurred to represent post-storm discharges.

A summary of the study results are shown in Table 2 for the wet ponds and pond/wetland systems. Outflow TSS levels were remarkably consistent, at slightly less than 10 mg/l. Dissolved oxygen levels tended to be more variable, with slightly lower oxygen levels reported in wetland systems than ponds. Similarly, pH levels of pond/wetland systems were slightly more acidic than pond systems, presumably due to the greater amount of organic matter that accumulated in the wetlands. The

Table 1: Irreducible Concentrations in Wastewater Wetlands and Stormwater Management Practices

Water Quality Parameter (mg/l)	Wastewater *(Kadlec and Knight 1996)*	Wastewater *(Reed 1995)*	Stormwater Practices *(this study)*
Total Suspended Solids	2 to 15	8	20 to 40
Total Phosphorus	0.02 to 0.07	0.5	0.15 to 0.2
Total Nitrogen	1.0 to 2.5	1.0	1.9
Nitrate-Nitrogen	0.05	0.00	0.7
TKN	1.0 to 2.5	1.0	1.2

Figure 1: Effect of the Irreducible Concentration on Treatment Variables

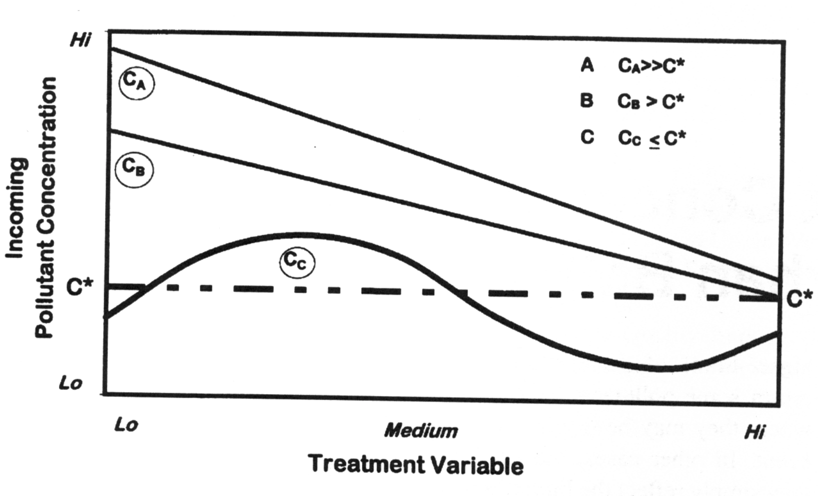
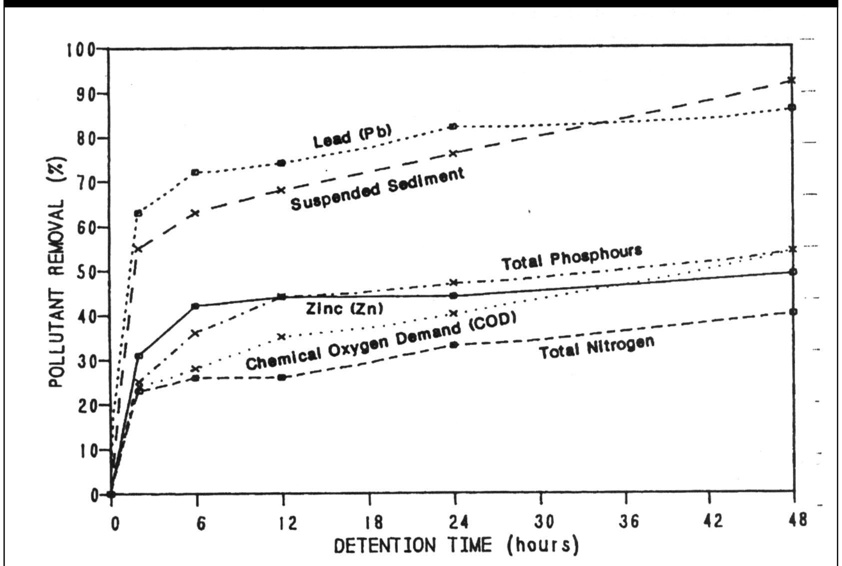


Figure 2: Removal Rate vs. Detention Time for a Series of Stormwater Pollutants (Grizzard *et al.*, 1986)



majority of the monitoring data was for the metals (cadmium, chromium, copper, lead, nickel and zinc). While detection limit problems complicated the metal analysis, most metals were occasionally detected in pond outflows, sometimes at levels exceeding Florida metal criteria.

In the second study, this author analyzed published event mean concentrations (EMCs) in the outflows of 42 stormwater practices that had been subject to intensive performance monitoring. These post-NURP stormwater practice monitoring studies were conducted in many geographic regions (FL, TX, WA, MN, WI, MD, VA, CT, CO and New Zealand), and encompassed four broad types of practices: stormwater ponds, wetlands, filtering systems, and grassed channels. For each type of practice, a group mean and standard deviation was computed based on the mean storm outflow concentrations of sediment and nutrients reported in each individual study (N ranged from three to 16) The results of the analysis are shown in Tables 3 to 6. Unlike the earlier study, these concentrations represent mean storm outflow concentrations (i.e., the partial or full displacement of runoff from the stormwater practice).

As can be seen in the tables, stormwater practice outflow concentrations exhibit a rather remarkable consistency within and among the four groups of stormwater practices, as typified by the fairly narrow range in both the computed mean and standard deviation. Interestingly, very little difference was observed in the group means of stormwater ponds and wetlands, particularly for most forms of nitrogen and phosphorus. In general, mean outflow concentrations were slightly lower for filtering systems, and somewhat higher for grass channels (this may reflect the mediocre performance of grass channels, as described in article 116). The one nitrogen form that did exhibit considerable variability in mean outflow concentrations among the four practice groups was nitrate-nitrogen. Nitrate outflow concentrations were greatest for filtering systems, intermediate for wet ponds and grassed channels, and lowest for stormwater wetlands. At the same time, total nitrogen concentrations were very consistent among the four groups of stormwater practices (1.6 to 1.9 mg/l). This result suggests that the four practice groups may differ in their internal rates of nitrification (that produces nitrate) and denitrification (that eliminates nitrate).

Based on this analysis, a preliminary estimate of the "irreducible" concentration of pollutants in stormwater practice outflows is suggested in Table 1. In general, the nutrient values are in the same range as those previously developed for wastewater wetlands, although the sediment concentrations are approximately two to four times higher.

Implications

The apparent existence of irreducible pollutant concentrations after stormwater treatment has several important ramifications for urban watershed managers. For example, an irreducible concentration can represent a real threshold for cumulative watershed impacts. The data suggests that a background storm phosphorus concentration of 0.10 to 0.15 mg/l is probably the lowest concentration that can be achieved through stormwater treatment, even when stormwater practices are widely applied and maintained. For some sensitive lake regions, this phosphorus level may still be too high to effectively prevent the onset of eutrophication.

Another ramification of irreducible concentrations relates to multiple stormwater practice systems. Some communities require that a series of practices be con-

structed to achieve a load reduction target of 80 or 90% removal. The existence of an irreducible concentration suggests that there are some practical limits to improving treatment efficiency with additional stormwater practices after a certain point. Quite simply, if the first practice reduces the pollutant concentration to near the irreducible concentration, it is not likely that a second or third practice will result in any further improvement.

Lastly, the existence of irreducible concentrations can help to interpret some of the notorious variability frequently seen in stormwater practice pollutant removal monitoring data. In many cases, the removal rate for a practice changes with each storm event. Some practices also exhibit wide variability in pollutant removal rates, even when their treatment volumes are similar. In both cases, a mediocre percentage pollutant removal may simply be a result of incoming pollutant concentrations that are very close to the irreducible concentration (and consequently, cannot be reduced much further). Consequently, investigators may want to look closely at their mean inflow concentrations before they assume poor performance is due to poor design or inadequate sampling.

While the concept of an irreducible concentration is an intriguing one, more outflow monitoring is needed to definitively characterize it for many stormwater practices. In particular, data are lacking on outflow concentrations for several key stormwater pollutants, such as bacteria and hydrocarbons. Based on these two studies, however, it is clear that there is a limit to stormwater treatment efficiency. Although the limit remains relatively low, both managers and regulators should keep it in mind when devising watershed protection or restoration programs.

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Note: The Center has developed more extensive statistics on the irreducible concentrators of a greater number of stormwater practices in its 2000 update of the national stormwater treatment database, which is available from the Center.

Table 2: Water Chemistry of Stormwater Pond and Wetlands in Tampa Bay, Florida (Kehoe, 1993 and Kehoe *et al.,* 1994)

Parameter (Units)	**Stormwater Ponds** N = 24 (236)	**Pond/Wetlands** N = 12 (83)
TSS (mg/l)	8.8 ± 11.4	9.1 ± 12.1
DO (mg/l)	5.7 ± 2.8	4.1 ± 3.8
pH	7.2	6.7 ± 0.9
Cadmium* (µg/l)	3 ± 6	6 ± 7
Chromium* (µg/l)	12 ± 26	5 ± 3
Copper* (µg/l)	16 ± 25	10 ± 10
Lead* (µg/l)	12 ± 28	BDL
Nickel* (µg/l)	9 ± 36	BDL
Zinc* (µg/l)	37 ± 73	33 ± 30
Water temperature (°C)	22.8	23.7

Notes: Grab samples taken 1 to 3 days following storm
Means plus or minus one standard deviation
N = Sites sampled (Total Samples all Sites)
BDL = Below detection limits
* Wide standard deviations may reflect detection limit problems for metals

Table 3: Mean Storm Outflow Concentrations From Stormwater Wetlands (Leersnyder, 1994; Rushton, 1995; Urbonas *et al.,* 1994; Oberts 1990, 1992; OWML, 1988, 1990; Athanas *et al.,* 1989; Martin, 1988; City of Baltimore, 1988; Barten, 1988; and Reinelt *et al.,* 1990.)

Parameter	**N**	**Concentration (mg/l)**
Total Suspended Solids	15	32 ± 25.8
Total Phosphorus	16	0.19 ± 0.13
Ortho-Phosphorus	14	0.08 ± 0.04
Total Nitrogen	11	1.63 ± 0.48
Total Kjeldahl Nitrogen	11	1.29 ± 0.43
Nitrate-Nitrogen	11	0.35 ± 0.28

Notes: Group means plus or minus one standard deviation

Table 4: Mean Storm Outflow Concentrations From Wet and Extended Detention Ponds (Urbonas *et al*., 1995; Oberts and Osgood, 1989; Yousef *et al.,* 1989; City of Austin, 1990; Stanley, 1994; Martin, 1988; and Dorfman *et al*., 1989)

Parameter	**N**	**Concentration (mg/l)**
Total Suspended Solids	11	35.0 ± 19.0
Total Phosphorus	11	0.22 ± 0.12
Ortho-Phosphorus	6	0.08 ± 0.04
Total Nitrogen	11	1.91 ± 0.56
Total Kjeldahl Nitrogen	11	1.21 ± 0.36
Nitrate-Nitrogen	11	0.70 ± 0.36

Notes: Group means plus or minus one standard deviation

Table 5: Storm Outflow Concentrations From Stormwater Filtering Systems (Sand Filters and Compost Filters) (Horner, 1995; City of Austin, 1990; Bell, 1995; CSF, 1994)

Parameter	N	Concentration (mg/l)
Total Suspended Solids	10	19.3 ± 10.1
Total Phosphorus	10	0.14 ± 0.13
Ortho-Phosphorus	ND	–
Total Nitrogen	6	1.93 ± 1.02
Total Kjeldahl Nitrogen	6	0.90 ± 0.52
Nitrate-Nitrogen	6	1.13 ± 0.55

Notes: Group means plus or minus one standard deviation

Table 6: Storm Outflow Concentrations From Grass Drainage Channels (Harper, 1987 and Dorfman et al., 1989)

Parameter	N	Concentration (mg/l)
Total Suspended Solids	5	43.4 ± 47.0
Total Phosphorus	5	0.33 ± 0.15
Ortho-Phosphorus	3	0.16
Total Nitrogen	5	1.74 ± 0.71
Total Kjeldahl Nitrogen	5	1.19 ± 0.41
Nitrate-Nitrogen	5	0.55 ± 0.29

Notes: Group means plus or minus one standard deviation
The limited number of studies available limits the accuracy of the estimates

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