Influence of anaerobic breakdown on the selection of appropriate urban stormwater management measures

by

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Abstract:

Organic decay or "anaerobic breakdown" has played a part in many stormwater treatment decisions. Anaerobic breakdown can lead to a reduction in dissolved oxygen and pH as well as changing the partitioning of nutrients and other pollutants into a more bioavailable form. Additionally, anaerobic breakdown can lead to the production of odours, algal blooms and fish kills.

Anaerobic breakdown will occur in every waterbody given appropriate environmental conditions. However, the occurrence and extent of this process will differ between alternative waterbodies. A fundamental question in management of these waterbodies, therefore, becomes "should we consider removing every dam, wetland, lagoon, billabong, creek, and wet sump Gross Pollutant Trap (GPT), in order to stop the occurrence of anaerobic breakdown?" In considering this question, it should be remembered that anaerobic breakdown is a natural process, which cannot be stopped.

Presented in this paper is a logical approach to the issue of anaerobic breakdown based on knowledge of the risk and the consequences of its occurrence. Using this approach, decisions on waterbody health and urban stormwater management measures are based on knowledge of the system and the benefits and consequences of alternative management approaches.

In presenting this approach to the management of anaerobic breakdown, the chemical reactions and processes taking place are presented together with the drivers and effects of these drivers. It discusses the potential impacts on waterbodies, wetlands and GPTs, along with their risks. Input is provided by selected industry experts to provide a well rounded discussion.

Finally, the paper will provide advice on how this issue should be taken into account by decision makers in the design/selection of urban stormwater management measures such as GPT's and wetlands, as well as any other body of water. This paper provides a solid basis for further credible debate on this topic and will eliminate some of the wives tales, on this inconvenient, but interesting phenomenon, that is known as "anaerobic breakdown".

Introduction

Anaerobic breakdown is one of the processes resulting in the natural decay of organic substances which are those substances containing primarily carbon and hydrogen but also some other chemicals such as nutrients. The processes influencing the breakdown or decay of organic material can be categorised as:

- Aerobic;
- Anoxic; and
- Anaerobic.

Aerobic processes occur in the presence of air while anoxic processes occur under water, but in the presence of adequate air (specifically oxygen). The third category of processes are the anaerobic which occur without the presence of air (i.e. wet or under water).

Irrespective of the type of breakdown process occurring, the decay of organic material (typically grass clippings and leaves), involves breakdown of the organic material into its component elements. Hence, the carbon in the organic material will be transformed primarily to CO_2, while the hydrogen will be transformed primarily to H_2O. Both of these reactions require oxygen from local sources, which generally is the waterbody itself or available pollutants.

The breakdown or decay of organic material in any waterbody in the absence of a continual input flow of oxygenated water initially will be anoxic while there is adequate dissolved oxygen (DO) in the water. Once this readily available oxygen has been depleted, signs of anaerobic processes such as bubbles rising to the water surface will occur. Even though the initial processes resulting in the breakdown of the organic material were anoxic, anaerobic processes will occur if the waterbody becomes stagnate. Hence, the breakdown of the organic material will lead to lower DO levels as the oxygen is consumed. A secondary result of the lowering of the DO levels is the development of more acidic conditions and a lower pH.

With a reduction in DO, total phosphorus (TP) that previously may have been adsorbed to particulates (silts or sediment) is encouraged into a more aqueous phase (i.e. some pollutants change from particulate to soluble forms). This means they are more bioavailable and easier for algae to take up, potentially leading to blooms.

Furthermore, the reduction in DO in the waterbody results in Nitrates (NO_3) being transformed into Nitrites (NO_2) and then into ammonia (NH_4). This transformation decreases the oxygen within the molecule and increases the bioavailability of the nitrogen.

Finally, it should be noted that there is potential for a reduction in pH associated the decay of biological material. With this reduction in pH, metals that were previously adsorbed onto particulates (see, for example, Ball et al. 2000) may partition into a soluble phase and, as a consequence, higher dissolved metal concentrations may occur in the effluent water compared to the influent water to the GPT during low flow conditions.

Phosphorous in Stormwater

In discussing the decomposition of leaf litter, an important aspect of the discussion is the different forms that phosphorous occurs within urban stormwater systems. Shown in Tables 1 and 2 are the partitioning of phosphorous in stormwater and sewage effluent as presented by Waller and Hart (1986) and by Abustan and Ball (1995).

Table 1 - Phosphorous Partitions (after Waller and Hart, 1986)

	Soluble P	**Particulate P**	
		Organic	Inorganic
	(%)	(%)	(%)
Sewage	83	17	0
Stormwater	4.2	11.6	84.2

Table 2 - Proportion of Phosphorous Transported in a Particulate Form

Particulate Percentage	**Reference**
up to 90	Camp Scott Furphy (1988)
99	Hvitved-Jacobsen et al. (1986)
84 - 96	Ball and Abustan (1995)

As shown in these tables, the majority of phosphorous transported in stormwater runoff is in a particulate form. This high proportion of particulate phosphorous is in contrast to phosphorous in a sanitary sewer system which is transported primarily in a soluble and hence biologically available form.

In assessing the information presented in these tables it should be noted that this partitioning is based on removal of gross pollutants prior to analysis. Hence the phosphorous in gross pollutants is not considered in the partitioning. Phosphorous from this source needs to be considered herein.

Gross Pollutant Traps

Gross pollutant traps (GPTs) form a component of the treatment train (see, for example, Mouritz et al., 2006) applied to traditional stormwater drainage networks for improvement of stormwater quality prior to discharge into receiving waters. Through the collection of litter, debris and coarse sediments they reduce the quantities discharging to both the receiving waters and to downstream components of the treatment train. There are many different styles and makes of GPTs and sediment traps.

The basic purpose of a GPT is to trap pollutants being transported with the stormwater runoff thereby protecting the downstream receiving waters from the trapped pollutants. There are many different classifications into which the trapped pollutants may be categorised; these classifications include sediment, leaf litter, and anthropogenic pollutants. Ball et al. (2003) reported, if sediment is not considered, that 80% of the trapped pollutants were organic in nature and primarily leaf litter.

An assessment of the importance of phosphorous release from leaf litter can be obtained from consideration of the nutrient content of leaf litter in urban stormwater. Allison et al. (1998) reported that the phosphorous in leaf litter is in the range of 0.05-0.45% of the dry leaf weight. Additionally, Allison et al. (1998) claimed that over time up to 20% of the phosphorous in leaf litter could leach into the stormwater flow; this claim, however, is not substantiated and needs to be investigated.

Prasad et al. (1980) in a series of experiments considered leaf litter from five alternative deciduous tree species commonly found in metropolitan Toronto, Canada and found that a 48 hour period was adequate to leach most of the soluble substances from the leaf litter. They do not comment, however, on the time-frame necessary for leaching of decomposition by-products, such as phosphorous, from the leaf litter. A longer time-frame was considered by McCann and Michael (1995) in a series of experiments investigating the release rate of nutrients from Oak leaves. While it was found that phosphorous release was still occurring 28 days after the leaves were placed in water, the rate of this release was not quantified. Without quantification of the rate at which phosphorous is released from leaf litter as the result of decomposition, it is not possible to quantify whether the phosphorous released from the leaf litter results in the phosphorous concentration exceeding the assimilative capacity of the downstream aquatic environment.

It should be noted that decomposition of leaf litter occurs naturally and the downstream aquatic environment will have adjusted to accommodate this naturally occurring process; the issue is whether the implementation of a GPT will result in an anthropogenic induced change to the downstream aquatic environment. This issue can be resolved only through further research into the decomposition of leaf litter in GPTs.

Which GPTs are affected the most?

The basic purpose of a GPT is to trap pollutants being transported with the stormwater runoff thereby protecting the downstream receiving waters from the trapped pollutants. In general, holding of the trapped pollutants until removal is achieved in two main ways which are

- By containing pollutants within a wet sump (either in baskets or chambers); or
- By storing pollutants in baskets, nets or behind screens that are free draining.

A well designed wet sump GPT will remove a large range of pollutants adhered to particulates throughout the runoff event without performance being affected during the storm as well as the gross pollutants. Dry trap GPTs, catch the gross pollutants but generally collect little of the sediment. Accordingly dry traps have more oxygen, but they have almost none of the particulates and hence little of the particulate bound phosphorous.

This will influence the decomposition of the leaf litter collected and the release of phosphorous from the collected sediment. Nonetheless, a storm flush has the potential to remove decomposition products such as phosphorous from both wet sump and free draining GPTs. The difference will be the rate of decomposition which is likely to be anaerobic in a wet sump GPT and aerobic in a free draining GPTs.

Management of Anaerobic Decomposition

There are a number of management approaches which will mitigate the effects of anaerobic decomposition. These include:

- Oxygenation;
- Maintenance; and
- Post-GPT Treatment

The use of pumps, fountains, aerators, etc will all introduce more oxygen into the system, to promote aerobic breakdown, rather than anaerobic breakdown. In this situation, the pH remains constant and pollutants are less likely to change form. This is a lot easier in a wetland than a GPT, but it is physically possible in both. Wetlands with large water bodies can benefit from the action of wind to oxygenate surface waters, but this surface turbulence does not help TSS settlement.

The simple truth is that the more often a GPT is cleaned out, the less time and chance there is for anaerobic breakdown to occur. Monthly cleaning may reduce the time for decay in GPTs, whereas yearly dredging of silt/sediment/organics from a wetland will remove those nutrients from the system and minimize nutrient cycling and the potential for blooms. There is of course a cost trade off here. It is recommended to clean GPTs when they are 100% full, unless anaerobic breakdown is noted to be having some kind of undesirable impact, upon which cleaning frequency should be increased.

Run low flows through a media filter cartridge system filled with zeolite or similar media. Zeolite has a negative charge, so it attracts not only the heavy metals, but also the ammonium ions that are also positively charged. They are captured physically and chemically, and all by a natural substance that is cheap to use. For sites without much room, or for which a wetland is not desired, use of media cartridge filtration for low flows is likely to become more common.

Is it a problem?

The first thing is not to panic. It is natural and has been happening for millions of years. Man is having an impact primarily because of improvements to the drainage system have increased the transport capacity of storm flows and hence is moving the location at which the decomposition is occurring. However, by understanding the issues and how to minimize the problem, it is possible to mitigate the problems if the research determines it is necessary to do so.

On one occasion it was reported that water coming from a GPT was black. Upon inspection, this was found to be false. The water was clear. Green algae prefer oxygenated waters while black algae prefer low oxygen levels. Because the GPT had not been cleaned for 11 months, the trickle flow would have been very low in oxygen, and the natural algae found coating rocks in any urban stream were noted to be much darker in colour as a result. Of interest, when some of the rocks were lifted for inspection, there was an abundance of life that was happily living there.

"*Don't throw the baby out with the bathwater*", is a proverb that means stay focused on what is important (ie when disposing of dirty bathwater, the baby that's in it is much more important), so pay the most attention to the important things, and much less attention to the relatively unimportant things. Performance and minimal life cycle costs are the primary things of importance for a GPT. Performance, minimal life cycle costs and biological benefits are the things of importance for a wetland. Solution designers should not be drawn into thinking this is a major problem because it is not.

Both the authors have never seen a location where the installation of an effective GPT has caused any detrimental effect on the downstream waterbody. On the contrary, even a poorly performing GPT will have a net positive removal of pollutants, and a positive impact on the receiving waters. Obviously, the more effective the GPT, the less work the wetland has to do, or the more effective the wetland can be.

However, in dryer areas, with stagnant wetlands, nutrient cycling in wetlands can be a big problem. Algal blooms can be toxic, and as the algae grow it takes even more oxygen from the water further stressing any aquatic life. Likewise in dry climates, GPTs should be cleaned and left dry, or designed to drain dry, or be able to be pumped out if water quality in the GPT deteriorates to an unacceptable level.

Essentially, stormwater managers need to understand what is happening and why, and then be vigilant that there are no downstream problems as a result. In areas of low or intermittent rainfall, systems that can remain stagnant for long periods of time, need consider how to empty or aerate their water in their system.

Conclusions

Anaerobic breakdown is the natural decay of organics, and there are several potential chemical impacts that may occur as this takes place. These include low DO, low pH, form changes from particulate to soluble for some pollutants and gases given off. It was also noted that leaf breakdown occurs in both wet and dry sump GPTs.

There is always a net removal of pollutants with a GPT. Effective GPTs have more potential for anaerobic breakdown than dry traps, but aerobic breakdown will occur in dry traps.

Finally, this aspect of stormwater management is not understood well. More research is needed to understand what governs the physical processes with different stormwater management measures. CopaWater and UTS are committed to this research and hope to be able to report more on this topic in the future.

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