Article 95

Technical Note #64 from Watershed Protection Techniques. 1(4): 210-213

Performance of Gravel-Based Wetland in a Cold, High Altitude Climate

A recent study by John Reuter and his colleagues provides new insights about the performance of stormwater wetlands in tough climates. The study team investigated the nutrient removal capability of a small wetland in the high altitudes of the Lake Tahoe Basin of California. The average precipitation in this mountainous region is a scant 20 inches a year, much of which is in the form of snowfall. The spring melt of the snowpack produces a sharp increase in runoff. The summers are hot and dry, and produce little runoff during the short growing season. Fall rainstorms are also important part of the water balance.

The mountainous region has granititic soils that are very poor in nutrients. Consequently, the region's exceptionally clear mountain lakes are highly oligotrophic, and are very sensitive to nutrient enrichment. As a result, communities have taken stringent measures to limit nutrient inputs into their sensitive lakes, including stormwater treatment options. Prior studies have shown that the ability of stormwater wetlands to remove nutrients can decline in the winter months especially when runoff is dominated by snowmelt (Oberts, 1994). The climate of the Lake Tahoe region presents a difficult challenge for removing nutrients through conventional stormwater wetland designs.

The study is intriguing not only for its location, but for its design. Most stormwater wetland designs have followed the traditional "impoundment" model. In this model, a site is excavated to form a very shallow pool, and emergent wetlands are rooted in the sediment. The primary pollutant removal mechanisms involve settling, and the adsorption of pollutants to sediments, detritus or plant stems. Actual pollutant uptake by the wetland plants themselves is incidental. In the Tahoe study, the stormwater wetland was designed using the "underground" model, which has been extensively used for the treatment of wastewater. In this design, runoff is directed into a gravel layer in which the wetland plants are rooted. Consequently, the wetland plants can directly take up pollutants from their roots, and the gravel medium also acts as an effective filtering mechanism (Figure 1).

The Tahoe stormwater wetland treated the runoff produced from a 2.5 acre recreational area, most of which was a fertilized ballfield (i.e., no impervious cover). The wetland was rather small (0.16 acres in size), composed of transplanted cattails that had not become fully established during the course of study. The bottom of the wetland was sealed with a liner, and filled with a three foot deep layer of fine gravel. Runoff was introduced into the gravel layer in a perforated pipe; outflow were collected by means of perforated pipe located in a standing well. Thus, runoff had to pass through the entire gravel filter before leaving the wetland. In general, the gravel layer was anaerobic (no oxygen), except for the top few inches. The bottom of the gravel layer was "inoculated" with muck from an adjacent wetland to introduce denitrifying bacteria into the system.

The stormwater wetland was monitored over a 18-month period, which included two winters. Most of the flow during the sampling period was generated by snowmelt, although the largest single runoff event was associated with a Fall thunderstorm. Incoming nutrient concentrations were fairly low in comparison with other urban runoff datasets-averaging 0.05 to 0.30 mg/l for nitrate, 0.5 to 1.5 mg/l for TKN, and 0.15 to 0.25 for total phosphorus. The sampling design did not permit the

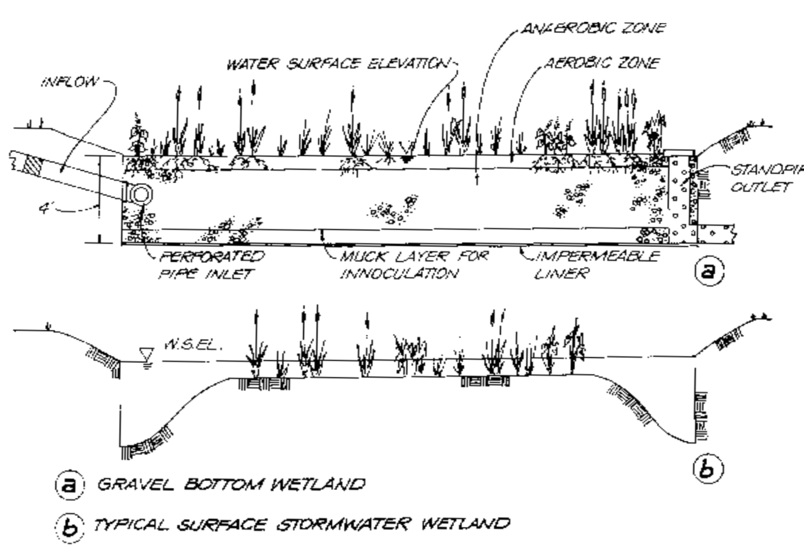

Figure 1: Comparison of Gravel-Based and Surface Stormwater Wetlands

Table 1: Estimated Pollutant Removal Performance of the Lake Tahoe Gravel Stormwater Wetland (Reuter *et al.*, 1992)

Water Quality Parameter	Mean storm removal (%)
Suspended sediment	80 to 88
Particulate phosphorus	44 to 47
Soluble reactive phosphorus	-28 to -41
TKN	-3 to -14
NH_4	-53 to -58
Nitrate	85 to 87
Total iron	80 to 88
Souble iron	72 to 78

direct measurement of runoff volumes entering and existing the wetland, so the performance estimates were based solely on the change in nutrient concentration through the wetland. The results are shown in Table 1.

The gravel-based stormwater wetland proved to be very effective in removing particulate pollutants, such as sediment, iron and particulate phosphorus. Nutrient removal, however, was much more complex. Consider the nitrogen dynamics in the wetland. Soluble nitrogen forms, such as nitrate were removed at a high rate. Evidently, the anaerobic conditions in the wet gravel layer created ideal conditions to promote the denitrification process (the bacterial conversion of nitrate into nitrogen gas).

The wetland was not effective in removing organic nitrogen (TKN), and actually acted as a net source (-3 to -14% removal). The authors speculated that the source of the excess organic nitrogen was cattail detritus. On a positive note, the wetland did act as a sink for organic nitrogen under three conditions (1) during the warmer months, (2) when organic nitrogen concentrations in incoming runoff were high or (3) incoming runoff volumes were relatively low. The stormwater wetland also exhibited poor removal of ammonia (-53 to -58%), which was thought to be due to the mineralization of organic nitrogen in the gravel. Ammonium removal due to the nitrification process (bacterial conversion of ammonium into nitrate-nitrogen) was generally not possible since this process requires aerobic conditions in the gravel layer that were seldom present.

Phosphorus removal in the wetland was also mixed. Particulate phosphorus (PP) was consistently trapped in the gravel layer, resulting in average removal rates of 44 to 47%. Greater PP removal was observed in the summer than the winter. On the other hand, the wetland was a net exporter of soluble reactive phosphorus (average SRP removal rates of negative 28 to 41%). The wetland did remove soluble phosphorus during the growing season, but tended to export dilute levels (0.03 to 0.09 mg/l) through the winter months. The authors concluded that a key source of SRP was the unwashed gravel used to form the wetland bed, and predicted that performance would improve as this internal load was gradually washed out.

Reuter and his colleagues were generally encouraged by the monitoring results, and predicted greater efficiency when the wetland vegetation became fully established, and if it were regularly harvested. They consider gravel based wetlands as a useful stormwater practice for smaller development projects in the mountainous West where spring snowmelt runoff dominates the water-balance. It would seem that the gravel-based wetland bed is a concept that could be transferred to coastal areas where nitrogen control is often a management priority. A two-cell wetland design that includes a drained sand layer cell (to promote aerobic conditions) that feeds into a gravel-based wetland cell (to promote anaerobic conditions) might provide higher and more reliable removal of all the nitrogen forms. Further testing of gravel-based stormwater wetlands in more humid and benign climates are warranted.

—TRS

References

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