Article 78

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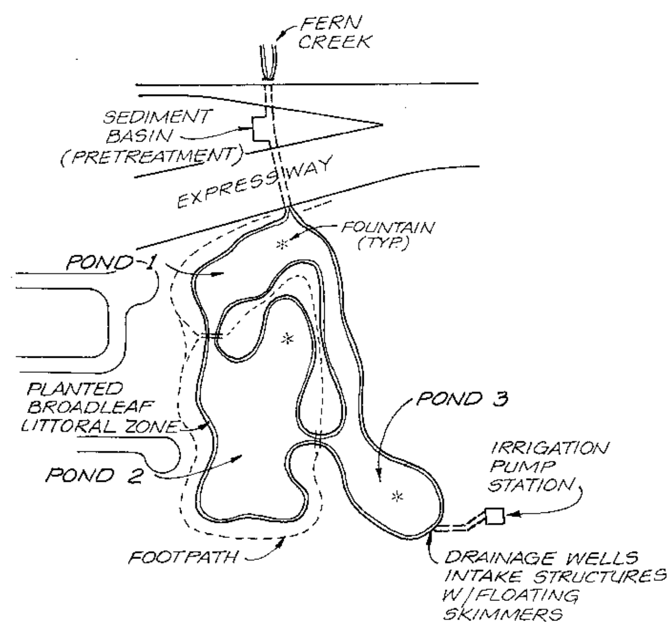
Influence of Groundwater on Performance of Stormwater Ponds in Florida

Stormwater quality treatment and flood control can be difficult in Central Florida. Flat topography and a high water table make it very difficult to separate stormwater from groundwater. A common stormwater management approach in this low-relief environment has been to construct regional ponds or wetlands. These are typically excavated below the water table to provide the required pool storage for pollutant removal. Weirs above the pool are used to create additional storage needed to protect residents from flooding caused by the intense rainfall for which the region is noted. Many regional ponds serve very large drainage areas—from one to two square miles in size. Consequently, the regional ponds are located "on-line" and are fed by base and storm flow from canals and ditches.

Several concerns have been raised about the performance of regional ponds and wetlands in such environments. First, will a regional pond's performance decline because the permanent pool is supplied by groundwater rather than stormwater? And, second, since groundwater is a more significant component of a regional pond's water budget, will the ponds prove effective in removing pollutants during dry weather conditions? Some intriguing answers to these questions have emerged from three recent monitoring studies in Central Florida.

In the first study, Kevin McCann and Lee Olson investigated the pollutant removal performance of a retrofit pond located in Orlando, Florida. The retrofit, known as Greenwood, was truly a "deluxe" model of a pond system. Greenwood consisted of a sediment basin that pre-treated runoff before entering a three-cell pond system with broad wetland benches. More than 13 acres in area, the pond had many innovative design features such as water reuse (for landscaping irrigation), four fountains to aerate deeper pools, and skimmers near the outlet (see Figure 1). The entire system was extensively landscaped, including a riverine floodplain and broadleaf marsh, creating a park area with a trail network for passive recreation. The pond had a drainage area of some 572 acres where land use was more than 50% residential, and a water quality treatment volume of 1.25 watershed inches. Like many Florida ponds, it was formed by excavating well below the normal water table (Table 1).

Figure 1: Schematic of the Greenwood Pond System (McCann and Olson, 1994)



The Greenwood pond had a unique water budget. The pond actually discharged into the Flordian aquifer through drain wells. The drain wells and low topographic position of the pond created a positive gradient for groundwater movement, thereby "attracting" groundwater inflows from an area five times greater than its "surface runoff" watershed. As a result, groundwater inflows dominated the water budget of the pond, with 46.7% of the total outflow from the pond estimated to be groundwater seepage. Of the remaining outflow, about 75% was from stormflow and 25% from surface baseflow.

McCann and Olson sampled flow and pollutant concentration at three stations above and below the pond during 11 storm events and eight baseflow periods. Pollutant removal was computed based on the reduction of mass loads during both storms and dry weather for the entire pond system. For the sediment basin, removals were based on the mean of storm EMC reductions. Results are shown for the sediment basin and the entire pond system in Table 2.

Table 1: A Comparison of Design Features: St. Joe's Creek and Greenwood Stormwater Quality Facilities

Criteria	St Joe's Creek	Greenwood
Drainage Area	1,280 acres	527 acres
Surface Area	25 acres	13 acres
Treatment Volume	0.25 watershed inches (estimated)	1.25 watershed inches (estimated)
Detention Storage?	YES, unspecified	YES, 243 acre-feet
Cells	One cell, but fill area may have created a two-cell system	Three cell design
Average Pool Depth	1.15 feet average, maximum of 5 feet	5.1 feet
Design Features	Primarily a flood detention pond with a "shallow pool" 24 hour detention	Broad wetland benches, water reuse, aeration fountains, sediment pretreatment basin, and extensive pondscaping
Monitoring Effort	6 storms, 16 baseflow samples	11 storms, 8 baseflow samples
Removal Calculation	Median storm load reduction	Load reduction
Baseflow as % of Total Flow	30% (estimated)	24.6%
Groundwater Influence?	Yes, 38.5% of outflow was due to groundwater inflow	Yes, 46.7% of outflow was due to groundwater inflow
Excavated to Groundwater?	YES	YES
Baseflow Residence Time	8 days	23 days
Location	On-line, below stream elevation	On-line, below stream elevation

In general, the sediment basin was only marginally effective as a pretreatment device, probably due to its relatively small size. About 14% of incoming sediment was retained in the trap during storm events. The sediment basin also exhibited mediocre performance in removing nutrients and metals, with removal of most of these parameters falling within a range + or – 15%. During dry weather periods, no major change in pollutant concentration was reported as they passed through the sediment basin.

The pond system, on the other hand, showed excellent removal capability for many parameters. Sediment, for example, was removed at a 68% rate, which is nearly identical to the national median removal rate for wet ponds. Total and soluble phosphorus forms were removed at the impressive rates of 62% and 77%, respectively. Removals of copper, lead and zinc all fell within a 60 to 70% range. Surprisingly, the Greenwood pond was not effective in removing any form of nitrogen, with a net outflow of about 10% for total nitrogen over the study period. Poor nitrogen removal was attributed to high nitrogen concentrations in groundwater inflow to the pond that exerted a strong influence on the nitrogen budget of the facility. As noted earlier, nearly half of the pond's water budget was due to groundwater inflow, rather than stormflow or surface baseflow. Water quality sampling within the pond revealed a system that was only mildly eutrophic, as indicated by both low chlorophyll a levels (7.3 ug/l) and deep secchi-depth readings (5.1 feet).

The reported removal rates for Greenwood, however, may underestimate the potential pollutant reduction that can be achieved by such a facility. This is evident when the outflow concentrations from the pond are more closely examined (see Table 3). Sediment and nutrient concentrations in the outflow of Greenwood Pond were about 50% lower than the national mean from other ponds and wetlands. This may suggest that Greenwood's removal capability may have been limited by the relatively low concentrations of stormwater pollutants entering the facility.

Whereas the Greenwood pond might be termed a deluxe pond, the St. Joe's pond investigated by Kantrowitz and Woodham (1995) was clearly an economy model. Located on the West Coast of central Florida, a shallow pool was formed during the construction of a large detention pond designed for flood control (see Figure 2). The pond served a 1,280 acre watershed, was nearly 25 acres in surface area and was fed by a channelized creek (median dry weather flow 1.7 cfs). The pond was excavated four to eight feet below the creek's bed, and had a dry weather residence time of about eight days. The average depth was only 1.15 feet, and much of the pond's surface area has gradually been colonized by aquatic plants. Despite its large surface area, the St. Joe's pond had a modest water quality treatment volume (an estimated 0.26 watershed-inches). A ridge of fill material, left over during construction, divided the pond into two cells during baseflow periods.

Performance monitoring of St. Joe's pond began shortly after it was constructed in 1989. Kantrowitz and Woodham sampled six storm events, computing removal efficiency on the basis of median storm load removal. In addition, 16 pre- and post- construction baseflow samples were collected to examine the pond's influence in modifying water quality in St. Joe's creek. Removal rates were calculated separately, and are shown in Table 4.

St. Joe's pond was moderately effective at removing nutrients during storms, with phosphorus removal ranging from 40 to 50%, and removal of nitrogen forms ranging from two to 40%. While sediment removal was very low during storms (7%), this reflects the fact that median inflow concentrations were a mere 16 mg/l and probably could not be reduced much further. St. Joe's pond was moderately effective in removing biological oxygen demand (49%), and many trace metals (chromium>zinc>copper>lead). Consistent with other studies, the pond exported both dissolved solids and chlorides during storm events. Kantrowitz and Woodham reasoned that much of the removal could be attributed to dilution (i.e., higher storm runoff concentrations mix with lower baseflow concentrations stored within the pond). Although the investigators did not measure the quality of groundwater inflows, it is likely that they contributed to the dilution effect.

Table 2: Pollutant Removal Capability of the Greenwood Pond System

Stormwater Pollutant	Removal Rate % Sediment Basin [a]	Removal Rate % 3 Cell Pond [b]
Total Suspended Solids	12.8	68.3
Total Dissolved Solids	(-6.8)	(-147.8)
Total Phosphorus	(-11.4)	61.5
Ortho-phosphorus	(-7.4)	76.7
Total Nitrogen	3.7	(-11)
Total Kjeldahl Nitrogen	0.3	(-10.3)
Nitrate-Nitrogen	16.0	(-13.2)
Ammonia-Nitrogen	(-100)	(-10.2)
Cadmium	26	n.d.
Lead	9.6	59.7
Zinc	(-5.9)	68.9
Copper	18.6	58.9

[a] Removal based on the mean of storm EMC reductions.
[b] Removal based on the reduction of mass load during both storms and dry weather for the entire pond system.

St. Joe's pond performed even better during dry weather conditions (Table 4) with five to 15% higher removal rates recorded for sediment, oxygen demand, nutrients and several metals. These findings suggest that settling, uptake and adsorption were acting to remove pollutants in the four to eight days that it took for baseflow to travel through the pond. Wetland vegetation was also thought to play a key role in promoting pollutant removal in St. Joe's Pond during baseflow conditions, as removal efficiency improved when wetland plant cover increased.

The fact that groundwater-influenced ponds can reduce concentration of pollutants in stormwater and baseflow does not necessarily imply that they will

Table 3: Comparison of Outflow Concentrations for Greenwood Pond System with National Mean of Stormwater Wetland Outflow Concentrations (all units in mg/l)

Pollutant Type	Greenwood Baseflow Outflow Concentration	Greenwood Stormflow Outflow Concentration	National Mean Stormflow Outflow Concentration *
Total Suspended Solids	6.7	5.9	32
Total Phosphorus	0.09	0.10	0.19
Ortho-phosphorus	0.029	0.03	0.08
Total Nitrogen	0.95	0.98	1.63
Total Kjeldahl Nitrogen	0.78	0.79	1.29
Nitrate	0.17	0.18	0.35

* Source: article 64; all units in mg/l

always reduce the mass export of pollutants, particularly when they attract large groundwater inflow. For example, monitoring of a groundwater-influenced wet pond in Central Florida revealed a sharp differences in removal efficiency, depending on whether pollutant load or concentration reduction were used as the measure of the pond's removal capability (Wanielista *et al.*, 1988). Specifically, the research done on Angel Pond confirmed that pollutant load reduction was negative over the study period, despite the fact that the pond recorded positive reductions in sediment, metal and coliform concentrations during stormwater runoff and dry weather flow events. The negative load removal was attributed to the migration of pollutants from groundwater to the pond, which comprised over 75% of the pond's water budget (Wanielista *et al.,*1988).

The three regional pond studies offer several lessons to the design engineer. First, designers should strive to keep the normal pool elevation above the water table elevation. This can act to reduce the influence of groundwater on the pond's water budget. As a practical target, groundwater should probably supply no more than a quarter of stormwater quality pond's total water budget. Second, designers should not rely on groundwater dilution alone for stormwater treatment. Indeed, depending on local groundwater quality, it is possible for groundwater to magnify rather than dilute some pollutants (particularly nitrogen). Therefore, designers should maximize internal features that can provide greater physical and biological treatment of stormwater. As was discovered in Greenwood pond, longer flow paths, greater residence times, higher treatment volumes and wetland plantings are essential in physical treatment for stormwater in high groundwater areas.

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Figure 2: Schematic of the St. Joe's Pond and Flood Control Facility (Kantrowitz and Woodham, 1995)

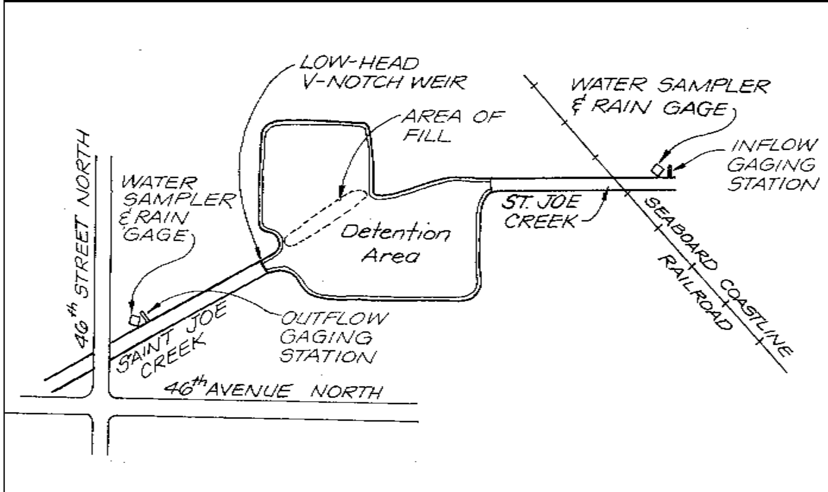

Table 2: Pollutant Removal Rates for St. Joe's Pond (Kantrowitz and Woodham, 1995)

Pollutant	Stormflow (%)	Baseflow (%)
Total Suspended Solids	7	45
Total Dissolved Solids	(-28)	17
BOD	49	65
Total Phosphorus	40	45
Ortho-phosphorus	52	51
Nitrate + Nitrite	23	36
Ammonia	40	83
Total Chromium	255	0
Total Copper	52	38
Total Lead	60	82
Total Zinc	48	50
Chloride	-28	27

Pollutant removal rates for storm events were adjusted to account for intervening drainage area and were based on median storm load removal. Baseflow removal computed by comparing pre-construction and post-construction baseflow loads.

References

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