Impact of Rapid Infiltration Beds on Hydrology, Vegetation and Chemistry of a Forested Wetland

Catherine Owen Koning[1], Franklin Pierce University, Rindge NH; Jennifer Bell, Plymouth State University, Plymouth, NH

Pearly Pond, a 142-acre lake in southwest New Hampshire, has become eutrophic as a result of phosphorus loading (i.e., experiencing harmful algae blooms and decreased dissolved oxygen). Consequently, the lake does not meet its water quality goals, which include primary contact recreation and support of aquatic life (VLAP 2012). The Rindge campus of Franklin Pierce University (FPU) sits on the northern edge of Pearly Pond, and historic wastewater discharges have contributed to the phosphorus loading of this shallow lake. The University has addressed this problem through the installation of Rapid Infiltration Beds (RIBs) for tertiary wastewater treatment. However, monitoring of wetland systems indicate that these infrastructure changes may not be as effective as expected.

Since the University's establishment at this location in 1968, wastewater was treated on site and discharged directly into the surrounding wetland system (Figure 1). Thirty years of wastewater discharge exceeded the natural capacity of the wetlands to take up phosphorus. In 1998, the New Hampshire Department of Environmental Services (NHDES) classified Pearly Pond as impaired and identified wastewater as a primary source of excess phosphorus (NHDES 2010). To address this impairment, the University improved its wastewater treatment process by augmenting the chemical treatment with aluminum sulfate to remove phosphorus. In addition to this and other upgrades, the University also installed two RIBs in 2008. The RIBs are composed of mounded sand underlain by crushed stone on fractured bedrock (Figures 2 and 3). By design, RIB systems release effluent wastewater atop the mounds, then flows downward where pollutants are adsorbed to the sand, thereby leaving clean water to recharge the groundwater.

While land-based discharge systems such as RIBs are becoming more common, several studies suggest that they are not effective at removing nutrients such as phosphorus and nitrogen over the long term (Delaware Geological Survey 2014). After observing increased water levels and vegetation changes in the adjacent wetland (Northeast of the RIBs, Figure 1) in the years following their installation, we set out to test the hypothesis that Franklin Pierce University's RIBs are affecting water levels, water chemistry, and vegetation in the adjacent wetland system.

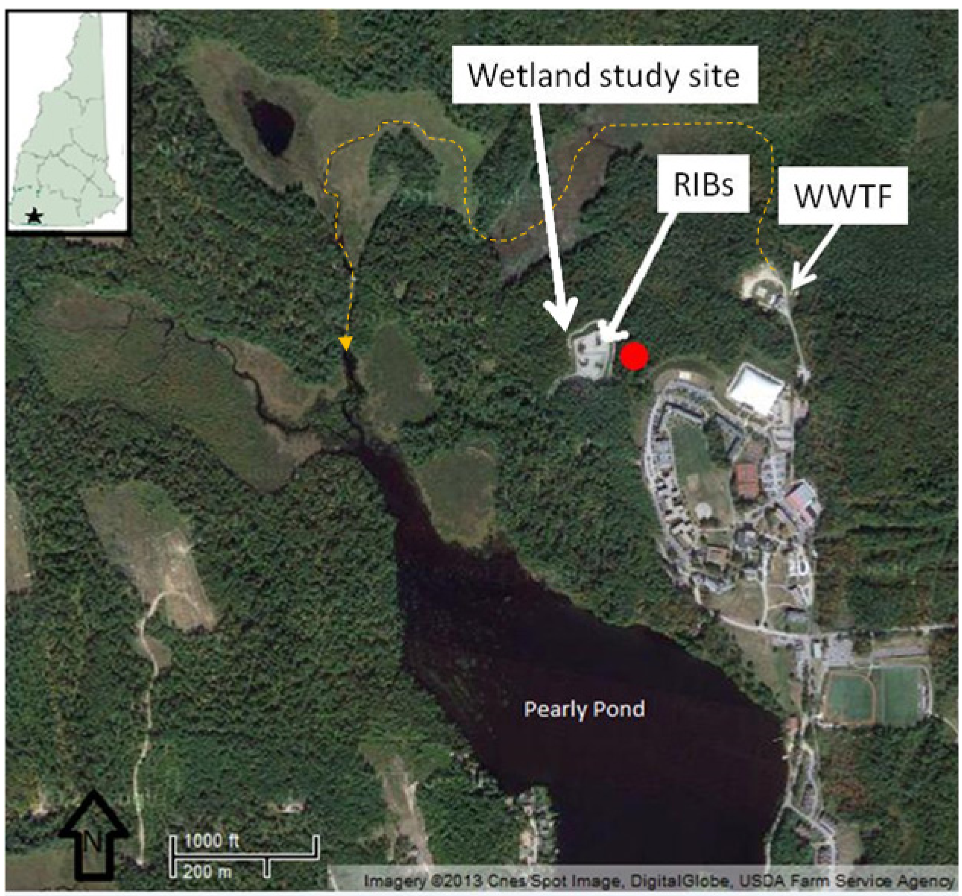

Figure 1. Study Location. Red dot marks University's official surface water monitoring location, located about 80 m southeast of the wetland study site. Orange line shows path of former effluent discharge prior to construction of RIBs.

1. Correspondence author; Email: koningc@franklinpierce.edu

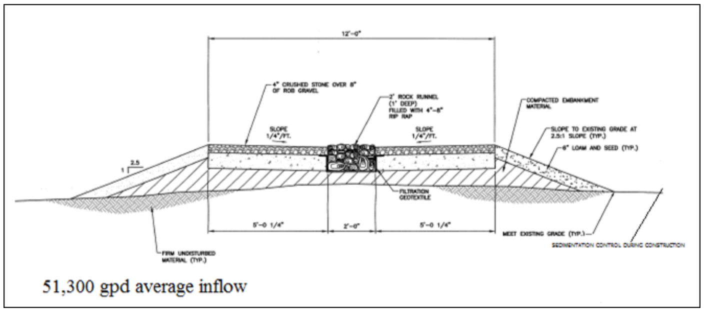

Figure 2. Schematic diagram of Rapid Infiltration Bed

Study site

The wetland is a 0.36 ha (0.9 acres) red maple–*Sphagnum* basin swamp in Rindge, NH. Its small size and geographically isolated position precluded its mapping based on aerial photography, so it is not found on the National Wetlands Inventory map. Soils in the area are Monadnock fine sandy loam, very stony, and Beckett fine sandy loam, very stony. The soil in the wetland area is mapped as Adams loamy sand; these soils are typically well-drained, 60-80" deep (NRCS Websoil survey). Underlying geology of this area consists of a Silurian metamorphic schist/quartzite, Rangeley formation, overlain with drumlins of glacial till (Lyons et al. 2006). The study area drains into Pearly Pond, which empties into Tarbell Creek, a second-order tributary of the Connecticut River.

Methods

Piezometers were installed in the wetland in 2005 and have been used to record piezometric head levels and hydraulic gradients intermittently. Water levels, water quality, and vegetation survey data from the years before the facility's installation and startup (2005, 2006, 2007) were compared to data collected after installation in 2009 (2011 and 2012).

Piezometer A is shallow (52 cm below ground) while Piezometer B is deeper (124 cm below ground). Piezometers were constructed of 3.175 cm (inside diameter) schedule 40 PVC pipes, with 30 cm screens and 0.254 cm slots. Piezometers were backfilled with native materials, and sealed at the top with 5-10 cm of bentonite. A stage gage installed in a 0.6 m deep unlined well was used to determine depth to water table. For this study, piezometric data that were collected before RIB installation (2005-2007) were compared to data collected in 2011-2012. Hydrologic data from 2011-2012 that did not have temporally corresponding data (by month) in 2005-07 were omitted from the analysis.

Specific conductance and pH were monitored and recorded three times per year in 2005 and biweekly from May to November in 2012; again, only data from the same months was used for comparison. Specific conductance and pH were measured using a YSI 30 conductivity meter and a Hanna 9025 pH meter. Surface water samples were taken from within the wetland on three occasions in 2012, stored in acid-washed bottles and frozen until analysis for total phosphorus at the University of New Hampshire water quality lab using an alkaline persulfate digestion followed by colorimetric measurement of phosphate (EPA method 365.1). One surface water sample was also taken from the wetland outflow in 2014, and analyzed at the NHDES Water Quality Lab in Concord (EPA method 365.2). In addition, water quality reports from 2008-2013 provided by FPU's wastewater treatment facility were also used to characterize the surface water taken from an area adjacent to the RIB, about 80 m southeast of the wetland (Figure 1). These samples were analyzed for total phosphorus by Eastern Analytical Inc. of Concord NH, using EPA method 365.1, as well as for pH, dissolved oxygen, total Kjehldahl nitrogen (EPA 4500N_{org} C/N) and nitrate (EPA method 353.2). Before and after data were compared statistically using a t-test in Microsoft EXCEL.

Vegetation assessments of the wetland were done in 2005 as a part of a larger study, and again in 2012 using a nested plot design. For the survey of the herbaceous layer, four 1 m^2 plots were laid out in the four cardinal directions two meters from Piezometer A. All species within the plots were identified and percent cover was estimated. The shrub layer was surveyed in four 25 m^2 plots in the same manner. Trees were surveyed in a 400 m^2 plot with Piezometer A at the center. Again, all species were identified and percent cover estimated. Diameter at breast height was measured for each tree within the 400 m^2 plot. A list of species present in the wetland before and after the RIB installation was compiled by walking through the entire wetland and recording all species until no new species were found.

Results

Piezometric head levels in Piezometer A increased from an average of 37.24 cm (std. dev. 23.53 cm) below ground to an average of 13.96 cm (std. dev. 2.38 cm) above ground after installation (Figure 4). Similarly, levels in Piezometer B increased from an average of 42.11 cm (std. dev. 50.73 cm) below ground to an average of 21.2 cm (std. dev. 3.21

Figure 3. Franklin Pierce University Rapid Infiltration Bed, south basin.

cm) above ground after installation. Annual discharge from the wastewater treatment plant did not change significantly, averaging 15.3 million gallons per year (std. dev. 0.23 MG/yr) in 2005-2007 and 15.7 (std. dev. 1.25 MG/yr) in 2011-2012. Stage gage data show high water levels, similar to those of the piezometers, in the period after RIB installation as well. Not only did head levels increase substantially, but there was far less variability in head levels in both the shallow and deep piezometers after the RIBs were installed, as indicated by the smaller standard deviation (Figure 5). Water levels increased sufficiently during the study period enough that a surface flow outlet that had rarely seen any outflow was observed to contain flow much more often. A change in precipitation could not explain this difference since annual precipitation was slightly lower in the years after installation (i.e., averaging 115.78 cm, std. dev. 26.7 cm compared to 121.9 cm, std. dev. 18.3 cm in the years before installation; Figure 4). The impact of this change in water levels on the wetland can be seen in Figures 5a and 5b.

Prior to installation, relative head levels in piezometers A and B indicated a pattern of weak recharge gradients in dry periods, alternating with weak discharge gradients in wetter periods. After installation of the RIBs, head levels were higher in Piezometer B than in Piezometer A, indicating a weak but consistent pattern of groundwater discharge gradients (Figure 4).

Water sampling in the wetland shows that specific conductance increased from an average of 50 uS (std. dev. = 6.4) in 2005-2006 to 937 uS (std. dev. = 236.9) in 2012, while pH, using the geometric mean, has also increased from an average of 3.75 (std. dev. 0.2) to 6.0 (std. dev. 0.3). Surface water samples taken directly in the wetland only in 2012 and 2014 show very high total phosphorus levels: 1.09 mg/l (std. dev. = 0.84) in 2012, and 0.207 mg/l (n=1) in 2014.

Surface water monitoring from 2006-2012 taken from an area 80 m southeast of this wetland for required monitoring shows a statistically significant increase in pH, nitrate, and dissolved oxygen, but a significant decrease in total Kjeldahl nitrogen and no significant difference in total phosphorus (Figure 6).

The wetland vegetation showed corresponding changes as well. As shown in Figure 7, the wetland was dominated by *Sphagnum* moss, facultative and facultative wetland species in 2006, but in 2012 the wetland is dominated by obligate and facultative wetland species, and the *Sphagnum* moss has been lost to inundation. The average vegetation cover in the wetland has decreased while dominance of obligate wetland plants has increased (vascular plants, excluding mosses). Table 1 lists new species that were observed after the RIB installation, including obligates *Typha latifolia* and *Lemna minor* and the invasive *Phragmites australis*. Further evidence of wetland degradation was the observation of many dead or dying trees of *Acer rubrum, Tsuga canadensis* and other species.

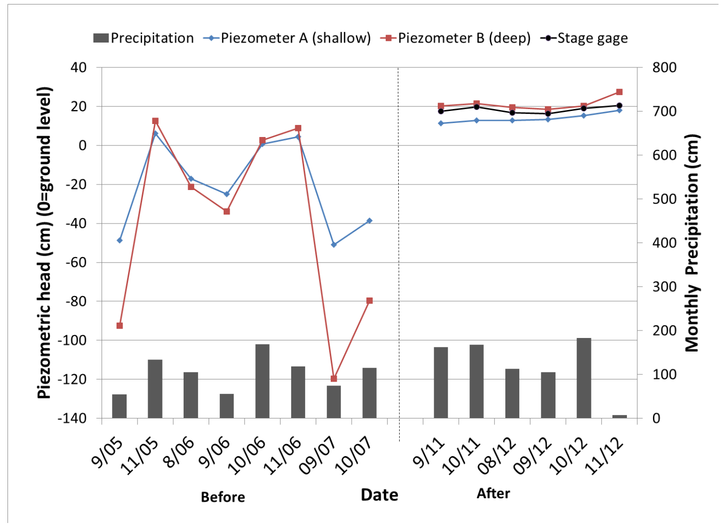

Figure 4. Wetland head levels in Piezometer A (shallow) and B (deep) before and after installation of the RIBs. Stage gage data were not available from the before period. Monthly precipitation is shown by the bars corresponding to the secondary axis.

Figure 5. Wetland from same point before RIB installation and after. Note higher water levels after and the presence of duckweed, Lemna minor) on the water's surface.

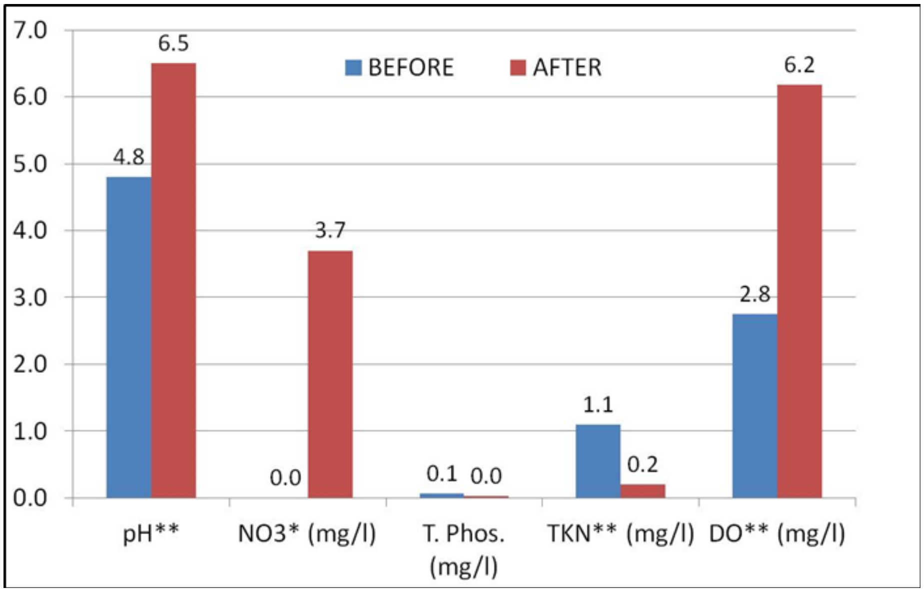

Figure 6. Water chemistry in surface water samples in adjacent wetland area before and after RIB installation. *=significant difference at p<0.01; **=significant difference at p<0.001.

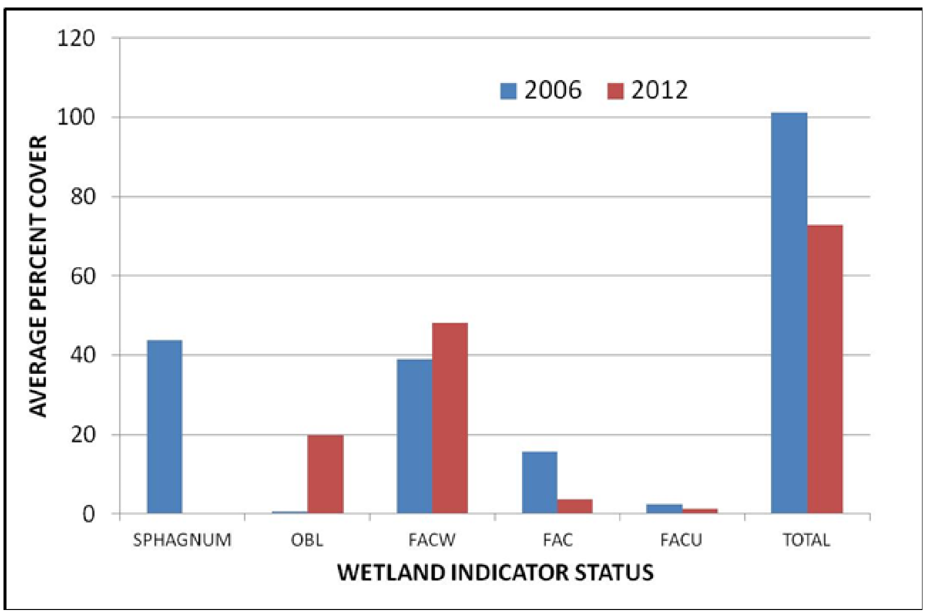

Figure 7. Wetland indicator status of plants in the wetland in 2006 (before RIB installation) and 2012 (after).

Table 1. New plant species found in the wetland after RIB installation.

Scientific name	Common Name	Wetland Indicator Status
Bidens connata	Common beggarticks	OBL
Gaultheria procumbens	Eastern teaberry	FACU
Lemna minor	Duckweed	OBL
Phragmites australis	Common Reed	OBL
Triadenum virginicum	Marsh St. John's wort	OBL
Trillium undulatum	Painted trillium	FACU
Typha latifolia	Broad-leaved cattail	OBL

Discussion

Moura et al. (2011) found that phosphorus levels in soil and groundwater tend to increase in and around RIB systems. In that study, the older systems showed a greater increase. In addition, they found large spatial variability in the phosphorus concentrations in soils around the RIBs, indicating large heterogeneity in subsurface soils. This may explain why phosphorus levels seem to be much higher in the wetland study site here, relative to the University's official shallow surface water monitoring site 80 m southeast of the wetland study site, or the differences may be an artifact of different labs used for water testing or of insufficient sample sizes. The US EPA guide to RIBs indicate that RIB systems rarely fail (EPA 2003), with most failures due to inaccurate site evaluation prior to construction. The FPU site consists of shallow soil over bedrock, necessitating a mounded system, which may have limited the effectiveness of the facility. This geologic setting is less desirable than those of the systems studied by Andres and Sims (2013). These authors found that, despite deep soils high in iron oxides and organic matter, which should favor phosphorus adsorption, the soils in the RIBs showed phosphorus saturation and surrounding groundwater showed high nitrogen and phosphorus levels. In this case, preferential flow paths allowed for faster flow and less effective treatment than was expected.

Conclusion

Water levels in the wetland have clearly increased and shifted from alternating weak groundwater recharge and discharge gradients to weak but steady discharge year-round. The wetland is now connected to adjacent wetlands by surface outflow, so what may have been a "geographically isolated" wetland has gained a more substantive surface flow connection. Elevated specific conductance and pH indicate effluent wastewater may be entering the wetland and changing water chemistry. The plant community has transitioned from a palustrine forest with a dense canopy and an understory of mostly facultative species and *Sphagnum* to a more open canopy forest with an understory of an obligate emergent and floating leaved community. New species found in the wetland included as duckweed, cattails and common reed, all of which are known to respond to very wet, high-nutrient conditions (Farnsworth and Meyerson 2003; Bastlova et al. 2004; Tulbure and Johnston 2010; Ray et al. 2014).

In light of our findings, future plans for the Franklin Pierce University system include greater efforts at phosphorus removal upstream via chemical treatment with aluminum sulfate in the wastewater treatment system, as well as the potential for iron filings to be added to the RIBs when the time comes to replace the sand, and measures to reduce overall water use on campus.

In summary, the results indicate that Franklin Pierce University's RIBs are affecting water levels, water chemistry, and vegetation in the adjacent wetland system. These changes mark a significant shift in the wetland's functions and values and its role within the larger wetland system. While the water quality problem in Pearly Pond is being addressed at a watershed scale by these RIBs and other measures, it is important to quantify the local impacts of RIBs. The potential for the local impacts of RIBs to affect the surrounding ecosystem indicate a need for continued monitoring at this location as well as others. Since RIBs clearly have the potential to alter the functions and values of adjacent wetlands, more attention should be given to site characteristics when planning the use of RIBs for water quality improvement. ■

References

Andres, A. S. and Sims, J.T. 2013. Assessing potential impacts of a wastewater rapid infiltration basin system on groundwater quality: a Delaware case study. *Journal of Environmental Quality* 42:391-404. doi:10.2134/jeq2012.0273.

Bastlová, D., Čížková, H., Bastl, M., and Květ, J. (2004). Growth of Lythrum salicaria and Phragmites australis plants originating from a wide geographical area: response to nutrient and water supply. *Global Ecology & Biogeography* 13(3):259-271. doi:10.1111/j.1466-822X.2004.00089.x

Delaware Geological Survey. 2014. Evaluation of Rapid Infiltration Basins (RIBs). http://www.dgs.udel.edu/projects/evaluation-rapid-infiltration-basin-systems-ribs. Accessed Nov. 13, 2014.

Farnsworth, E. J., and Meyerson, L. A. (2003). Comparative ecophysiology of four wetland plant species along a continuum of invasiveness. Wetlands 23(4), 750-762.

Lyons, J.B., Bothner, W.A., Moench, R.H., and Thompson, J.B., Bennett, D.S., Wittkop, C.A., and Dicken, C.L., 2006 Bedrock Geologic Map of New Hampshire(NHGS Geo-1), U.S. Geological Survey Data Series 215.

Moura, D. R., Silveira, M.L., O'Connor, G.A., and Wise, W.R. 2011. Long-term reclaimed water application effects on phosphorus leaching potential in rapid infiltration basins. Journal of Environmental Monitoring, 13: 2457-2462. DOI: 10.1039/C0EM00785D

Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. http://websoilsurvey.nrcs.usda.gov/. Accessed Nov. 13, 2014.

New Hampshire Department of Environmental Services 2010. Watershed Assessment, Tracking, and Results. Accessed Nov. 13, 2014. http://iaspub.epa.gov/tmdl_waters10/attains_waterbody.control?p_list_id=NHLAK802020103-08&p_cycle=&p_report_type=#causes

Ray, A., Mebane, C., Raben, F., Irvine, K., and Marcarelli, A. (2014). Evaluation of a combined macrophyte-epiphyte bioassay for assessing nutrient enrichment in the Portneuf River, Idaho, USA. Environmental Monitoring & Assessment 186(7):4081-4096. doi:10.1007/s10661-014-3682-0

Tulbure, M. G., and Johnston, C. A. (2010). Environmental conditions promoting Non-native Phragmites australis expansion in Great Lakes coastal wetlands. Wetlands 30(3):577-587. doi:10.1007/s13157-010-0054-6

USEPA. 2003. Wastewater Technology Factsheet. http://water.epa.gov/scitech/wastetech/upload/2003_09_30_mtb_final_rapidinfiltration.pdf.

Accessed Nov. 13, 2014.

USGS. 2003. Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Evaluation of Alkaline Persulfate Digestion as an Alternative to Kjeldahl Digestion

for Determination of Total and Dissolved Nitrogen and Phosphorus in Water. Water-Resources Investigations Report 03–4174.

Volunteer Lakes Assessment Program. 2012. Volunteer Lake Assessment Program Individual Lake Reports. Pearly Lake, Rindge, NH. http://des.nh.gov/organization/divisions/water/wmb/vlap/annual_reports/2012/documents/pearly-rindge.pdf. Accessed Nov. 13, 2014.