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Subject: Beaver Ponds as BMPs for MS4 Impervious Restoration

1. Background

Beaver (*Castor canadensis*) were abundant in the pre-colonial era of the eastern Coastal Plain of North America until the European fur trade greatly reduced the population (Correll et al, 2000). However, their reintroduction to the Coastal Plain of Maryland by the U.S. Fish and Wildlife Service in the 1970's has since increased their abundance (Correll et al, 2000).

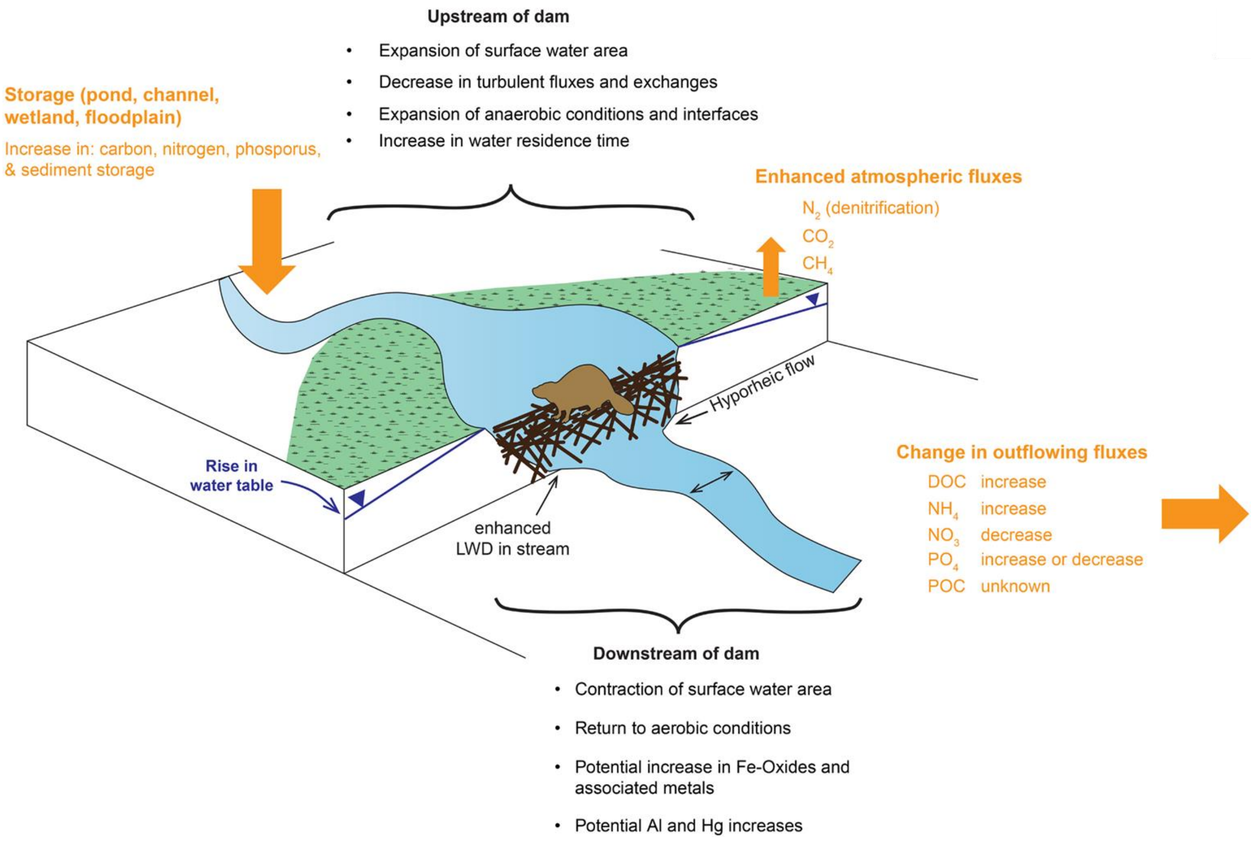

Figure 1: Conceptual model of beaver ponds and their water quality benefits. Taken from Larsen et al. (2021).

Beaver, and resultant beaver dams, are considered to have many beneficial impacts on stream hydrology and biogeochemistry. As shown in Figure 1, beaver can increase in the riparian water table and increase hydraulic storage by creating dams (Larsen et al, 2021). Beaver habitat leads to increased retention of sediment, nutrients, and particulate carbon, as well as the permanent removal of nitrogen via denitrification. Many new in-stream restoration techniques, often implemented to achieve regulatory-mandated pollution reductions, try to mimic beaver habitat and operate as de facto beaver pond analogues.

Within the State of Maryland, the potential water quality benefits of beaver are not recognized as contributing to regulatory-mandated pollution reductions. Therefore, jurisdictions lack a regulatory incentive to either encourage beaver colonization or manage and protect existing beaver habitat. Such an incentive is important, as conflicts between human and beaver habitat regularly arise. While beaver habitat often increases the groundwater table and the wetted extent of a stream system, this is not always welcomed by homeowners and can result in beaver being trapped out, with beaver dams dismantled.

If beaver ponds were a recognized BMP to improve water quality, it would assist local jurisdictions with the development of beaver habitat conservation programs via easements and adaptive management. Rather than living *on top* of nature and replicating nature's original ecosystem engineers with significant amounts of tax dollars, citizens could live *with* nature allowing tax dollars to go further, and implement more ecological restoration.

2. Beaver Studies in Anne Arundel County

One of the road blocks to using beaver ponds as a BMP is the relatively small number of studies that have investigated the water quality benefits of beaver habitat within Maryland. Indeed, the number of studies that employed a before-after-control-impact (BACI) monitoring design – a gold standard design for environmental impact assessments – is even fewer.

Within the same physiographic province, Bason et al. (2017) studied 13 beaver ponds in the Coastal Plain of North Carolina using a control-impact framework. Bason et al. (2017) observed beaver ponds to reduce nitrate concentrations by 19%, increase ammonium concentrations by 59%, and decrease sediment concentrations by 40%.

Within Anne Arundel County, two paired watersheds have been monitored by the Smithsonian Environmental Research Center since the 1970s, watersheds 101 and 102 (Correll et al, 2000). Beavers constructed a dam just upstream of the monitoring station in watershed 101, and a beaver pond was maintained from 1990 through 1996 (Correll et al, 2000). Figures 2 and 3 show the difference in the orthoimagery at the site between 1970 and 1995, with the development of the pond clearly observed. Water quality samples were collected from 1984 through 1996 in both the beaver and control watersheds and afforded a BACI assessment of the water quality benefit of beaver ponds.

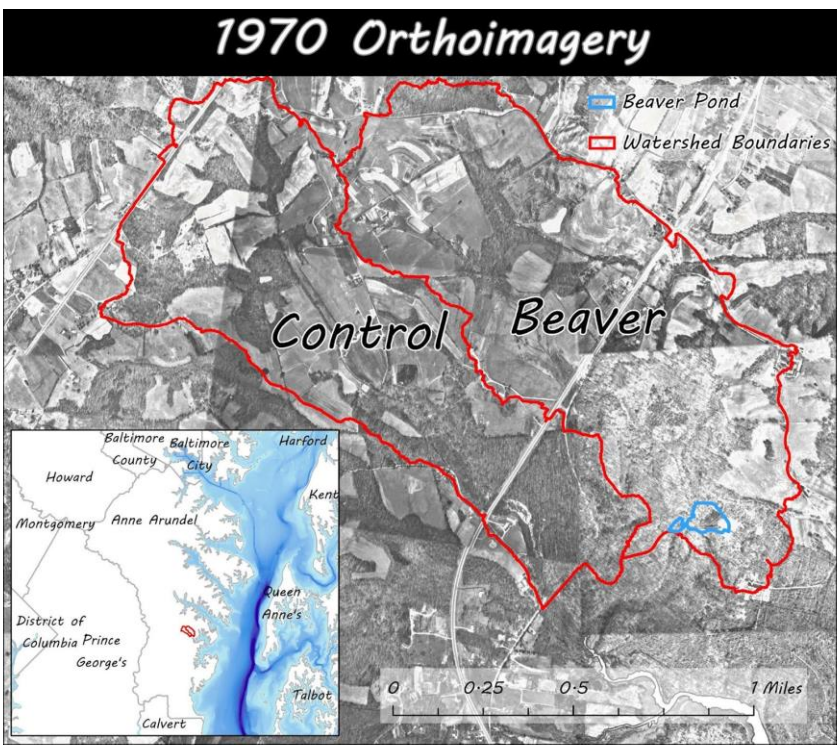

Figure 2: 1970s orthoimagery from the Correll et al. (2000) study site.

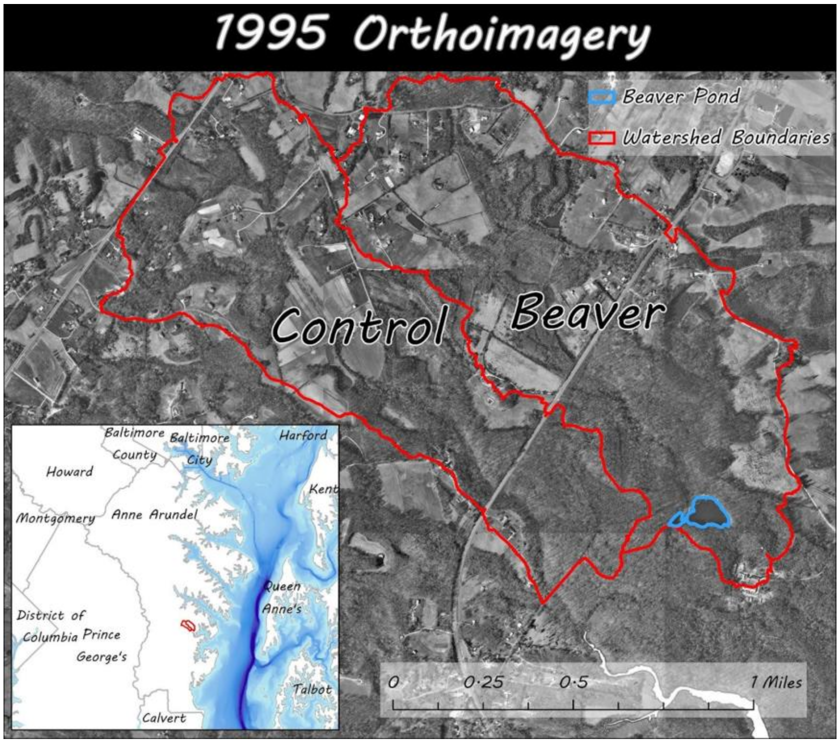

Figure 3: 1995 orthoimagery from the Correll et al. (2000) study site.

Correll et al. (2000) observed seasonal retention effects, with retention rates greatest in the summer and winter season, and negative retention rates (i.e., increases in downstream nutrients) observed during the spring season. Negative retention rates were hypothesized to be the result of higher stream flows (Correll et al, 2000). Annual discharges of total nitrogen (TN) were found to reduce by 18%, total phosphorus (TP) by 21%, and total suspended sediment (TSS) by 27% (Correll et al, 2000). Although these studies are few in number, their robust monitoring design gives confidence in the results, and demonstrates that beaver ponds have the potential to reduce nutrient and sediment discharges associated with stormwater.

3. Retention Pond Performance

Studies by both Correll et al. (2000) and Bason et al. (2017) demonstrate the sediment and nutrient reducing behavior of beaver habitat. One approach for developing a method of crediting beaver habitat is to follow similar approaches for upland stormwater retrofits. Within Maryland, upland stormwater retrofits are credited based on their retention capacity which are used to determine impervious restoration and TN, TP, and TSS reductions via pollutant adjuster curves (MDE, 2020).

To understand whether this approach could be used to credit beaver habitat, it is important to compare the performance of beaver habitat to an analogous BMP type. Consequently, we assessed retention pond and wetland basin performance data from the International Stormwater BMP Database (https://bmpdatabase.org). In a hydraulic sense, retention ponds and wetland basins are the stormwater practices that most closely resemble beaver habitat. Data from EPA Rain Zone 2 was used for comparison, as this reflects the geographical region of Maryland.

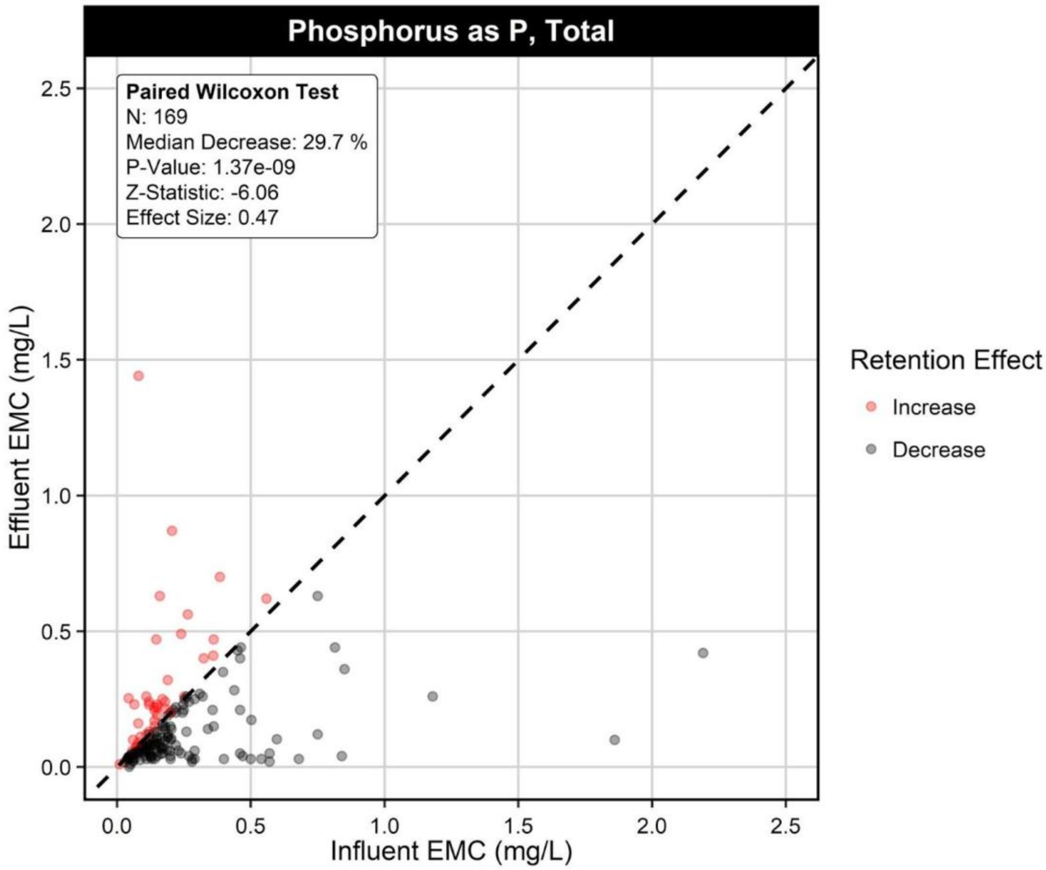

Figure 4: Total phosphorus concentrations, presented as event mean concentrations (EMCs), in the influent and effluent of retention ponds and wetlands. Data adapted from www.bmpdatabase.org.

Figures 4 through 6 show the performance of retention ponds and wetlands in reducing TP, TN, and TSS. Paired Wilcoxon tests indicated influent and effluent concentrations were statistically different. In general, retention ponds and wetland basins reduced event mean concentrations (EMCs) of TN by 11.4%, TP by 29.7%, and TSS by 61.8%.

Retention pond and wetland basin performance compares favorably to the performance of beaver ponds studied by both Correll et al. (2000) and Bason et al. (2017). However, it should be noted that unlike Correll et al. (2000) and Bason et al. (2017), data from the International Stormwater BMP Database was not assessed within a BACI framework. This means that the EMCs data represent differences in inflowing and outflowing concentrations, where studies such as Correll et al. (2000)

report changes due to beaver habitat, after using a control site to constrain any influence of exogenous variables influencing the performance evaluation. Thus, if Correll et al. (2000) were to have assessed the beaver pond by comparing inflowing and outflowing concentrations, it is likely that nutrient and sediment reductions would have been larger. Regardless, data from the International Stormwater BMP Database and Correll et al. (2000) are within the same order of magnitude, and indicates that crediting beaver habitat as retention ponds and wetland basins is justifiable.

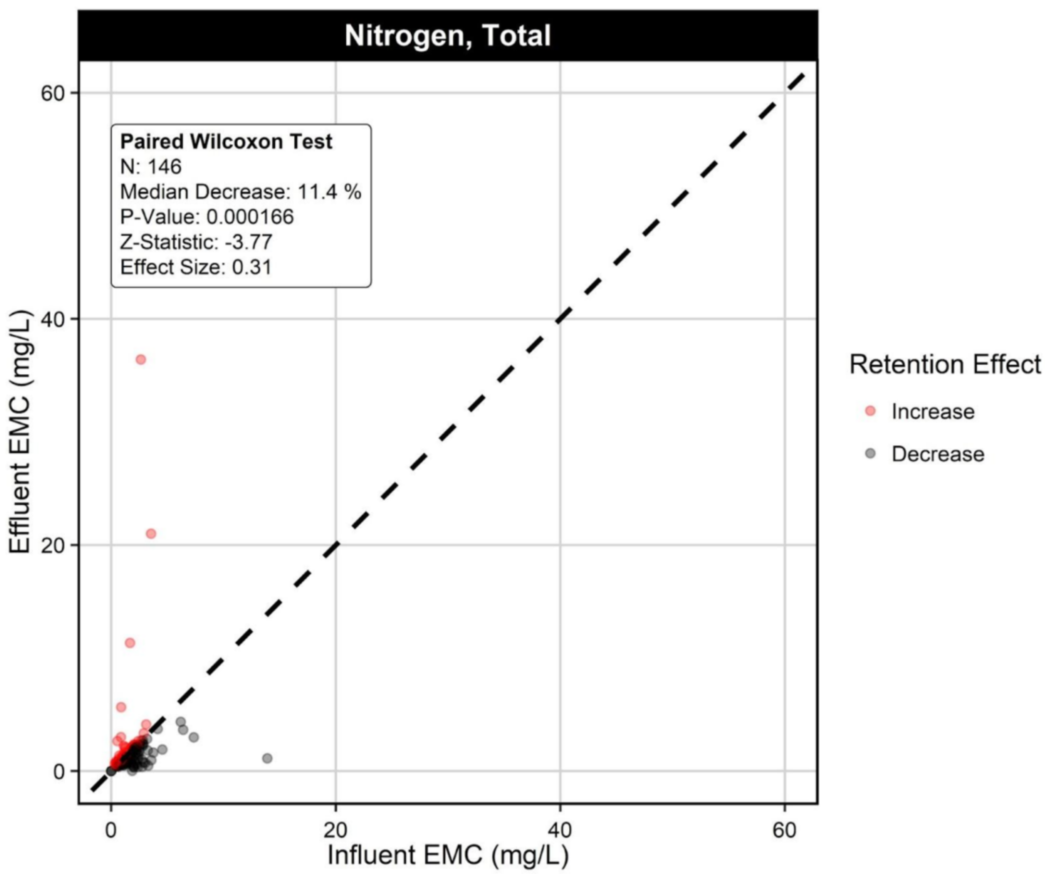

Figure 5: Total nitrogen concentrations, presented as event mean concentrations (EMCs), in the influent and effluent of retention ponds and wetlands. Data adapted from www.bmpdatabase.org.

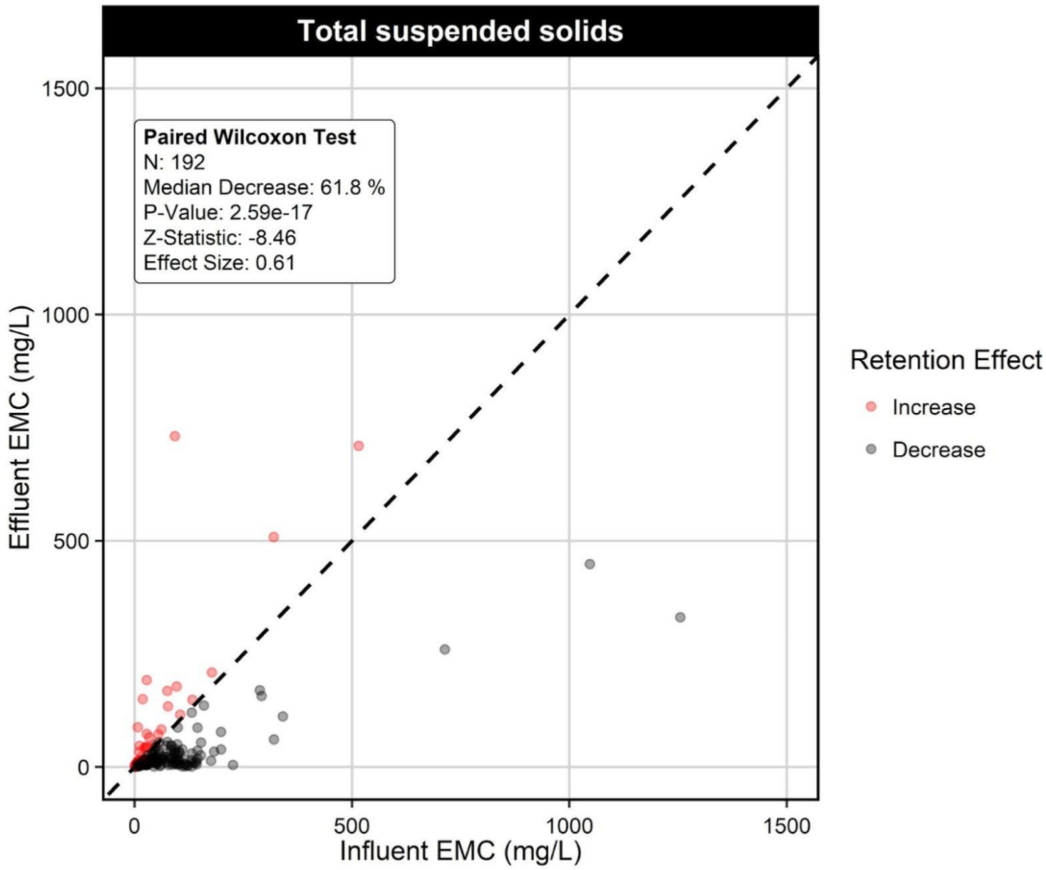

Figure 6: Total suspended solid concentrations, presented as event mean concentrations (EMCs), in the influent and effluent of retention ponds and wetlands. Data adapted from www.bmpdatabase.org.

4. Crediting Examples

As discussed in Section 3, crediting beaver habitat as retention ponds and wetland basins is justifiable. This section will demonstrate, using three beaver pond examples in Anne Arundel County, how this could be done in a practical sense.

North Cypress Creek

North Cypress Creek is a tributary that drains to the Magothy River in Anne Arundel County. As shown in Figure 7, beaver have become established within this stream, and inundation of the riparian area has occurred.

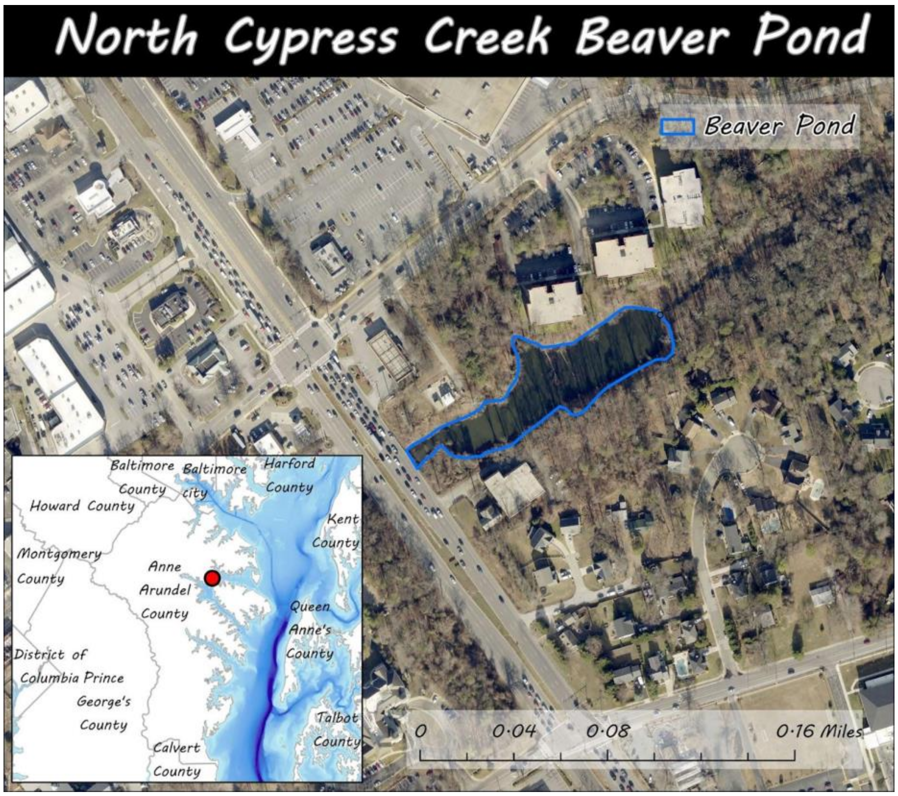

Figure 7: Map of North Cypress Creek Beaver Pond, Anne Arundel County.

Crediting beaver habitat as an upland stormwater BMP requires information on the storage capacity of the system. To achieve this, high-resolution LiDAR data was used to evaluate the beaver dam height. As shown in Figure 8, the height of North Cypress Creek beaver dam was estimated to be 2.82 ft.

To be conservative, the baseflow water surface level was assumed to be 60% of the beaver dam height, resulting in an estimate of 1.69 ft mean pond depth. Based on the estimated mean pond depth, and the 1.69 ac pond surface area, the storage volume, herein referred to as the WQv volume, is calculated to be 2.86 ac-ft.

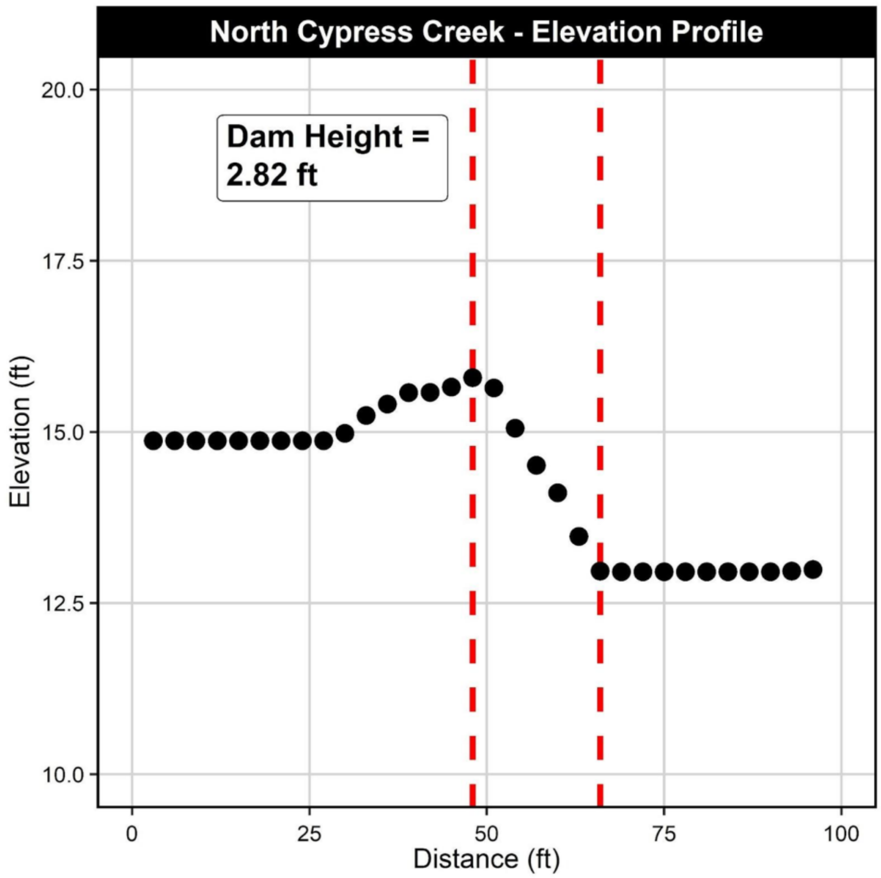

Figure 8: Beaver damn elevation profile at North Cypress Creek, Anne Arundel County.

Following MDE's stormwater design manual (MDE, 2000) and MDE (2020) MS4 crediting guidance, crediting requires the calculation of the volumetric runoff coefficient, Rv, the rainfall depth treated (inches), Pe, and the required water quality volume, WQv, where:

Rv = 0.05 + 0.009 * % Impervious Area

Pe = (WQv x12)/(% Impervious Area x Drainage Area [ac])

WQv Required = (Pe x Rv x Drainage Area [ac]) / 12

Thus, using data from the North Cypress Creek, Rv is estimated to be 0.497, WQv required is estimated to be 12.71 ac-ft, and Pe is estimated to be 0.22 in:

Rv (0.497) = 0.05+0.009*49.7 (Impervious Area)

Pe (0.22 in) = (2.86*12)/(0.497*306.9)

WQv Required (12.71 ac-ft) = (1*0.49*306.9)/12

Following MDE (2020) guidance, credited pollutant removal efficiencies were estimated to be 14.7% for TN, 23.1% for TP, and 29.4% for TSS. The theoretical stormwater restoration would therefore be the Pe (0.22 in) multiplied by the impervious area in the watershed (152.7 acres). This would result in a credit of 33.6 ac of impervious restoration.

Assuming an equivalent BMP would be $50,000 per acre restored, the theoretical value of this beaver habitat would be $1,680,000. To date, Anne Arundel County has spent a total of $22,000 to manage this pond - $12,000 for 2 water levelers, $10,000 for tree removal, and approximately $1,000 per year in annual maintenance.

Wolf Pit Branch

Wolf Pit Branch beaver pond is shown in Figure 9. Using LiDAR data, the height of beaver pond was estimated to be 1.38 ft (Figure 10). As with North Cypress Creek, the baseflow water surface level was assumed to be 60% of the beaver dam height, resulting in an estimate of 0.83 ft mean pond depth. The drainage area of this site was assessed to be 1,462 ac with 27.4% impervious in the drainage area. Based on the estimated mean pond depth, and the 2.4 ac pond surface area, the WQv volume was calculated to be 2.02 ac-ft.

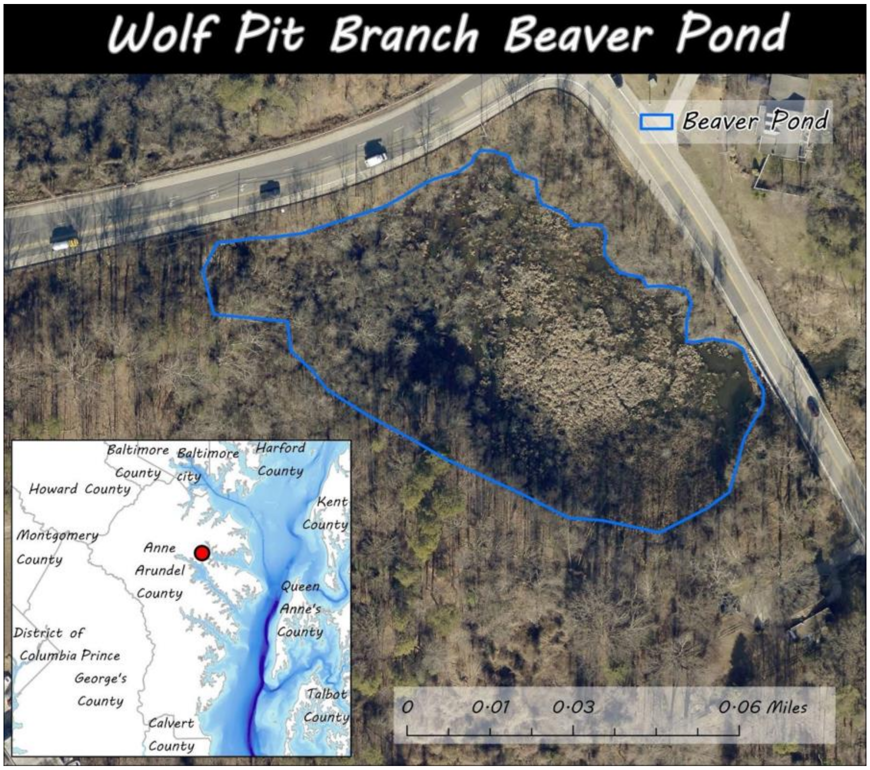

Figure 9: Map of Wolf Pit Branch Beaver Pond, Anne Arundel County.

Using data from the Wolf Pit Branch beaver pond, Rv is estimated to be 0.297, WQv required is estimated to be 36.2 ac-ft, and Pe is estimated to be 0.06 in:

Rv (0.297) = 0.05+0.009*27.4

WQv Required (36.2 ac-ft) = (1*0.297*1462.5)/12

Pe (0.06 in) = (2.02*12)/(0.297*1462.5)

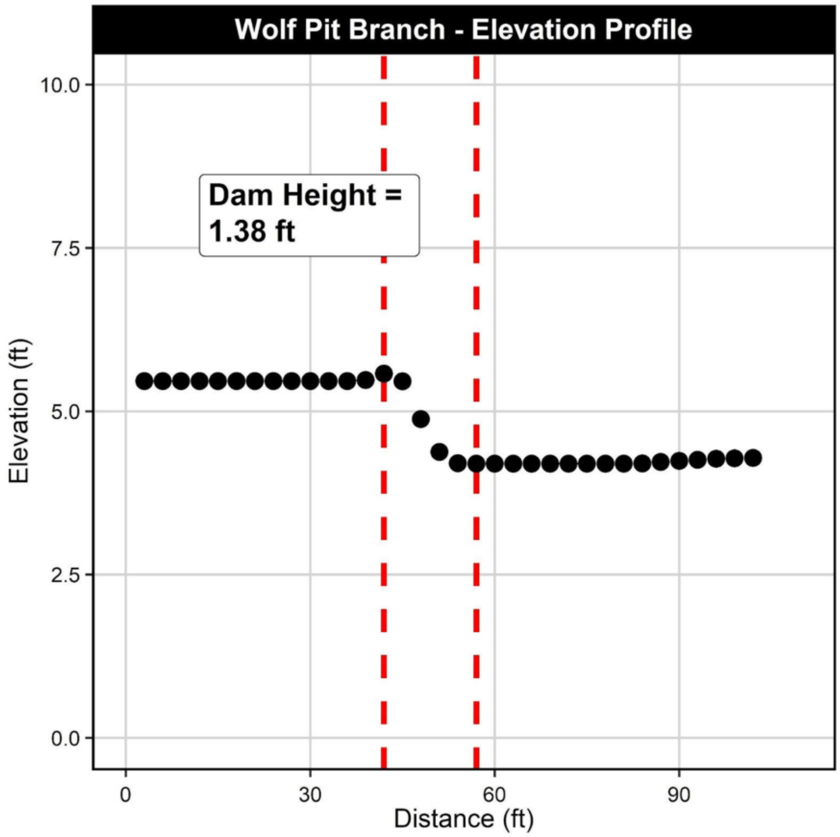

Figure 10: Beaver damn elevation profile at Wolf Pit Branch, Anne Arundel County.

Following MDE (2020) guidance, credited pollutant removal efficiencies were estimated to be 4.6% for TN, 7.3% for TP, and 9.3% for TSS. The theoretical stormwater restoration would therefore be the Pe (0.06 in) multiplied by the impervious area in the watershed (401.1 acres). This would result in a credit of 24.1 ac of impervious restoration.

Assuming an equivalent BMP would be $50,000 per acre restored, the theoretical value of this beaver habitat would be $1,205,000.

Annapolis Roads

Annapolis Roads beaver pond is shown in Figure 11. As the dam is recent, it was not reflected in the most recent orthoimagery. Based on a site visit, the dam height was reported to be 4 ft. Because this was an estimate, the baseflow water surface level was assumed to be 50% of the beaver dam height. Volume analysis of the pond was conducted via GIS, and the mean pond depth was estimated to be 0.99 ft.

The drainage area of this site was assessed to be 125.3 ac with 28.1% impervious in the drainage area. Based on the estimated mean pond depth, and the estimated 0.75 ac pond surface area, the WQv volume was calculated to be 0.74 ac-ft.

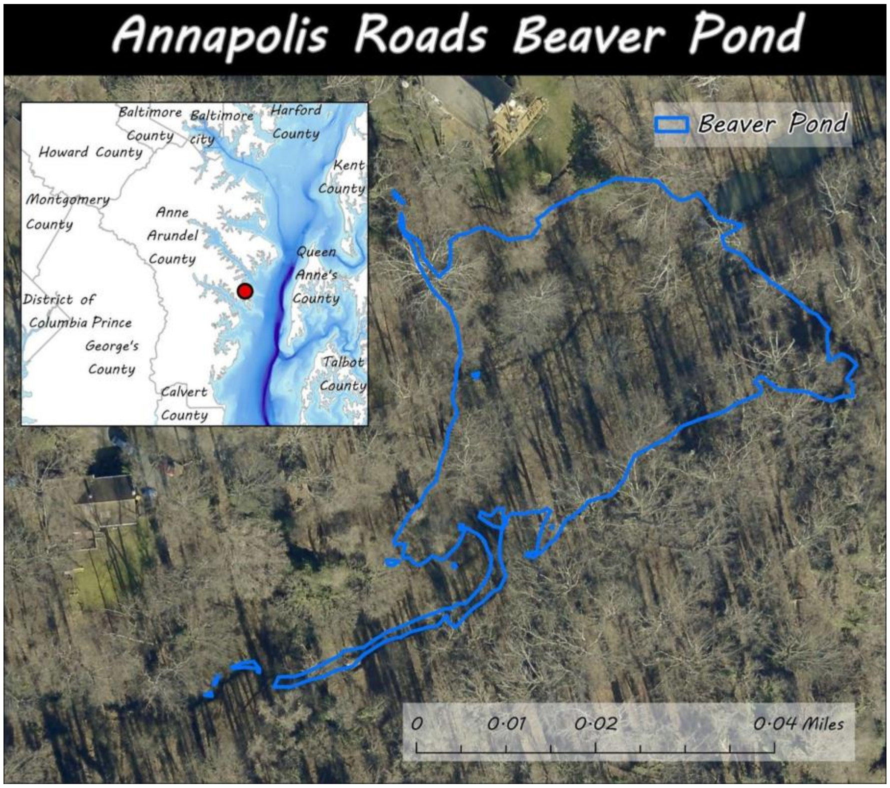

Figure 11: Map of Annapolis Roads Beaver Pond, Anne Arundel County.

Using data from the Annapolis Roads beaver pond, Rv is estimated to be 0.303, WQv required is estimated to be 3.16 ac-ft, and Pe is estimated to be 0.23 in:

Rv (0.303) = 0.05+0.009*28.1

WQv Required (3.16 ac-ft) = (1*0.303*125.3)/12

Pe (0.23 in) = (0.74*12)/(0.303*125.3)

Following MDE (2020) guidance, credited pollutant removal efficiencies were estimated to be 15.2% for TN, 23.9% for TP, and 30.4% for TSS. The theoretical stormwater restoration would therefore be the Pe (0.06 in) multiplied by the impervious area in the watershed (35.2 acres). This would result in a credit of 8.1 ac of impervious restoration.

Assuming an equivalent BMP would be $50,000 per acre restored, the theoretical value of this beaver habitat would be $405,000. To date, Anne Arundel County has spent a total of $8,000 to manage this pond using 1 water leveler. The County anticipates spending approximately $1,000 per year in annual maintenance.

5. Future Development of Crediting Approaches

Crediting beaver habitat via an upland stormwater management approach demonstrates the potential value of beaver habitat as a tool to abate stormwater issues. Allowing beaver habitat to be credited as BMP would have advantages for the State of Maryland and local jurisdictions including:

- Incentives for local jurisdictions to manage rather than remove beaver when they conflict with homeowners;
- Incentives for local jurisdictions to legally preserve existing beaver habitat using easements;
- Incentives for local jurisdictions to conserve and set aside suitable beaver habitat as conservation areas;
- Allowing natural improvement of water quality via a nature based approach; and

- Allowing restoration dollars to go further to benefit the citizens of Maryland and local jurisdictions.

Despite the simplicity and validity of this crediting approach, there are two key areas that should be developed. First, although stormwater ponds and retention basins are static in nature, beaver ponds can be more fluid in their establishment year to year. Validation of stormwater management BMPs requires inspections by local jurisdictions every 5 years validate its performance. Although beaver habitat may exist for 5 years or more, to be conservative, it is recommended that it should be valuated annually. In this case, it should be credited as an annual practice, similar to street sweeping or catch basin cleaning. This validation could take the following form:

- Development of a pattern recognition machine learning model to identify and predict beaver habitat from annual or biannual orthoimagery, trained by observations of beaver ponds throughout Maryland and constrained to only those areas that are suitable habitat for beaver; and/or
- Physical inspections of credited beaver ponds each year, taking measurements of pond surface area and dam height.

Likewise, as noted in Sections 2 and 3, although beaver ponds have water quality benefits, the limited number of regional studies means that more data should be acquired on the beaver pond performance. This is not to suggest that data should be collected to change the suggested crediting approach, rather, more data should be collected to support the suggested crediting approach. Indeed the runoff-adjustor curve proposed by Schueler and Lane (2012a; 2012b), although not ideal, present a simple way to credit upland stormwater management structures. This same concept could be applied to beaver habitat with more data.

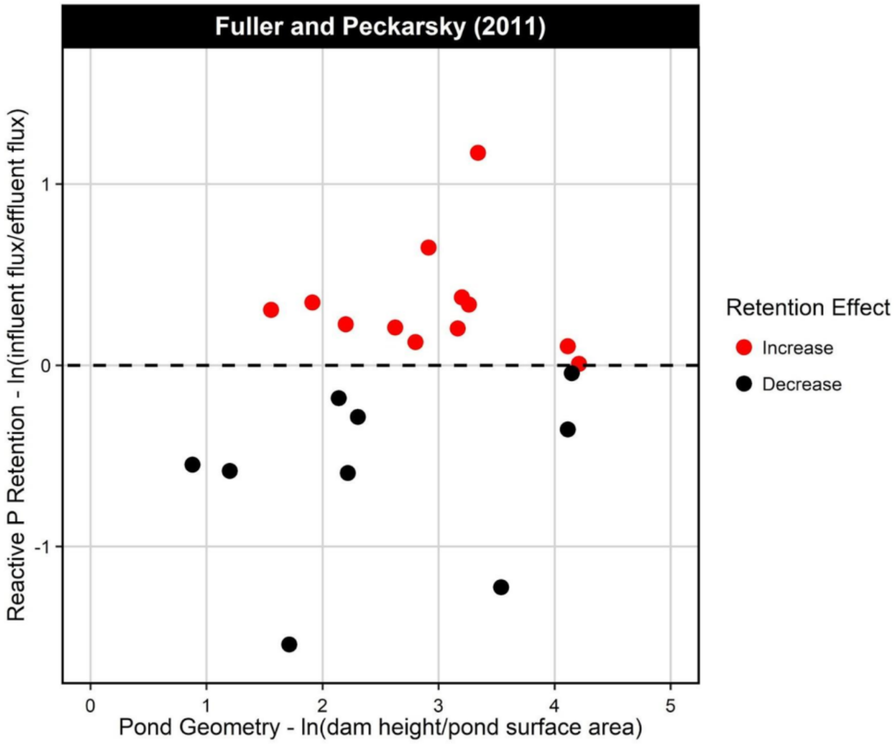

Figure 12: Pond geometry vs. reactive phosphorus retention. Data adapted from Fuller and Peckarsky (2011).

Figure 12 presents data adapted from Fuller and Peckarsky (2011), and shows the relationship between beaver pond geometry and phosphorus concentration reduction. Red points indicate a positive retention effect (i.e., downstream decrease in P) and black points indicate a negative retention effect (i.e., downstream increase in P). These data were collected from environments in the Western U.S. where background concentration of reactive phosphorus were low. It is hypothesized that the relationship between pond geometry and nutrient and sediment retention will reflect a horizontal asymptote in more disturbed systems with higher background concentrations of nutrients and sediment. This relationship may offer a refined crediting approach for beaver habitat, similar to Schueler and Lane (2012a; 2012b). It is suggested that data be collected throughout the State of Maryland measuring nutrient and sediment fluxes in and out of beaver ponds under different flow conditions, and comparing these fluxes to pond geometry.

6. References

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