



## Water Quality and Runoff Trends of a Pheasant Branch Creek Tributary

*Collin Roland, Hydrologic Technician*

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### Abstract

The Pheasant Branch Conservancy protects >700 acres of ecologically sensitive land north of Middleton in Southcentral Wisconsin. In 2019, Dane County purchased a 159-acre addition to the conservancy to reduce sediment and nutrient loading to downstream waters, protect sensitive features, and enhance ecosystem services generated by the property. Dane County has implemented a four year restoration project that includes removing the barnyard, converting the cropped land to perennial vegetation, and constructing stormwater retention structures. The property includes a small, ephemeral agricultural drainage that has historically sourced high nutrient concentration waters to Pheasant Branch Creek and Lake Mendota, a eutrophic lake with a regulatory impaired status for phosphorus. The concentrations of most pollutants in runoff from this parcel have decreased since monitoring began in 2003, with the exception of dissolved inorganic nitrogen species. The observed water quality improvements are contemporaneous with construction of barnyard improvements, conservation practices, and improved nutrient management during the early 2000's and 2010's. Monitoring of runoff generation immediately before and after restoration by Dane County indicates that the restoration efforts have led to an order of magnitude decrease in runoff volume from the addition and its contributing watershed, bringing the empirical curve number down from 74 to 44. This decreased runoff volume is associated with a concomitant annual reduction in pollutant loading of approximately 5,400 pounds of sediment, 600 pounds of phosphorus, and 650 pounds of organic nitrogen. The targeted implementation of conservation practices prior to restoration led to even greater load reductions, with sediment yields decreasing from 560 lbs acre<sup>-1</sup> to 15 lbs acre<sup>-1</sup> and total phosphorus yields decreasing from 8.0 lbs acre<sup>-1</sup> to 1.6 lbs acre<sup>-1</sup>. This monitoring effort documents a >95% reduction in pollutant loading from surface runoff at the Acker Farm achieved via multiple conservation measures and subsequent restoration, providing additional constraints on the potential water quality and flood mitigation benefits of future conservation and restoration projects in other watersheds.

### Introduction

Dane County purchased the 159-acre *Acker Farm* in 2019 as an addition to the Pheasant Branch Conservancy. This property contains an ephemeral tributary to Pheasant Branch Creek and the acquisition of this property and its subsequent restoration accomplishes multiple conservation goals, including increasing water storage capacity, reducing runoff and pollutant loading to Lake Mendota, protecting sensitive springs, and expanding wildlife habitat. This restoration work is

being completed via the collaborative efforts of multiple entities, including Clean Lakes Alliance, The Nature Conservancy of Wisconsin, The Meringoff Family Foundation, Friends of Pheasant Branch Conservancy (FOPBC), and Dane County Land & Water Resources Department.

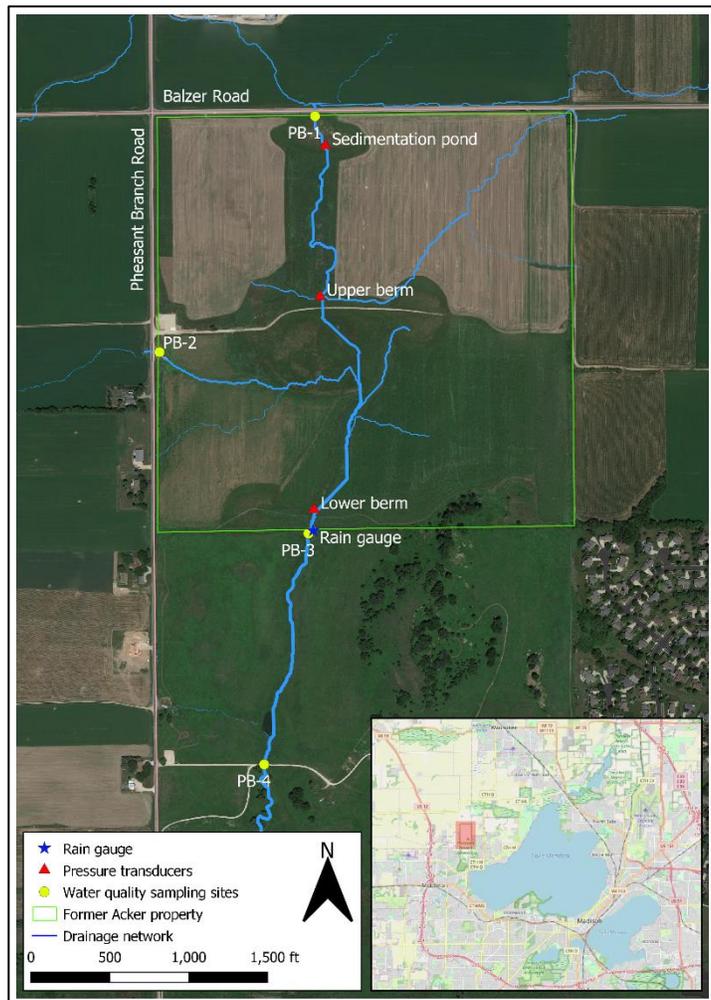
The Acker Farm and its surrounding watershed are covered dominantly by moderately-drained, type B silt loam soils underlain by glacial till, sandstone and carbonate bedrock. The watershed is moderately sloped with 3.5° average slope. Prior to purchase by Dane County, the farm was an active dairy and fields were cropped as continuous corn silage or a corn silage – hay rotation. Restoration of the Acker Farm includes reestablishment of native vegetation, demolition, removal, and regrading of the farmstead, and construction of several major storm water control structures. The crop fields are being restored to perennial vegetation in a four year [phased approach](#)<sup>1</sup> with scheduled completion in 2024. The farmstead infrastructure was removed in 2020 and three stormwater control structures were installed the same year. The [stormwater control structures](#)<sup>2</sup> include an upper sediment control basin and two downstream impoundments. Between 2003 and 2010, prior to Dane County’s acquisition of the property, several conservation practices were implemented on the Acker Farm. These practices included cover cropping, nutrient management planning, grassed waterway installation, sediment pond construction, and improved barnyard runoff management.

This report assesses trends in surface water quality, runoff generation, and pollutant loading associated with the implementation of conservation practices and restoration efforts on the Acker Farm.

## Methods

### *Pollutant concentration trends*

Surface water quality sampling has occurred intermittently for two decades at the Acker Farm. In 2003, FOPBC volunteers began collecting surface water



**Figure 1.** Site map of the Acker Farm area showing the drainage network, water quality sampling sites, and instrument locations.

grab samples at site PB-3, the surface water outlet of the Acker Farm (Figure 1). The initial sampling effort ended in 2006 and was resumed temporarily during the period 2010-2012, with the addition of sampling at site PB-4, which lies downstream of two additional sedimentation ponds. The contributing area to PB-3 and PB-4 is 393 acres and 474 acres, respectively. Sampling started again in the fall of 2019 following Dane County's acquisition of the property and has continued since. In recent years, the sampling effort expanded to include additional monitoring sites PB-1, PB-2, and PB-5 (off map), though the short period of record at these sites limits their utility for trend analyses at the present time.

During runoff generating events (snowmelt, rainfall), volunteers collect water samples via the "grab" method of dipping a sample bottle near the center of flow of the ephemeral stream. Following construction of the storm water control structure at site PB-3, sample collection occurred either at the upstream pool near the culvert inlet if the pool stage was insufficient to overtop the culvert stop logs, or from the culvert outlet if it was flowing. Samples are delivered as soon as possible to the Wisconsin State Lab of Hygiene and analyzed for total suspended solids (TSS), total phosphorus (TP), nitrate + nitrite ( $\text{NO}_3 + \text{NO}_2$ ), and total Kjeldahl nitrogen (TKN). In 2019, Dissolved Reactive Phosphorus (DRP) was added as an analyte. Trend analyses in this report are limited to sites PB-3 and PB-4. The water quality data used in this analysis are displayed in Supplemental Table S1 and publicly available via the Wisconsin Department of Natural Resources [Surface Water Information Management System](#)<sup>3</sup>.

A conventional, monotonic trend analysis of analyte concentrations was deemed inappropriate due to the long gaps in the data record<sup>4</sup>. Instead, trends were evaluated using a step trend approach. The samples were grouped into four time periods that matched natural breaks in sample collection. The sample time period groupings are 2003-07 (Group 1), 2010-13 (Group 2), 2019-21 (Group 3), and 2021-present (Group 4). A nonparametric Kruskal-Wallis test was performed on log-transformed grouped concentrations to assess whether the medians of the groups are significantly different. The Kruskal-Wallis test is the nonparametric analog to the analysis of variance and was chosen because many of the sample distributions are non-normally distributed even after log transformation. Levene's test was used to verify the homoscedasticity of the log-transformed sample distributions<sup>5</sup>. All of the sample distributions, with the exception of TSS at site PB-3, exhibit similar variances. The Dunn post-hoc test was used to assess differences between particular groups and the Holm-Bonferroni method was used to adjust the p-values to account for the influence of multiple comparisons<sup>6</sup>.

Only the most recent two time periods contain samples with DRP concentrations, and the values within each group at site PB-3 are normally distributed following removal of a single outlier from Group 4. A one-tailed t-test was used to assess whether the mean of the post-restoration samples was significantly less than the mean of the pre-restoration samples at Site PB-3, but a

similar analysis was not performed at Site PB-4 given the smaller sample size (n=3). All statistical computations were performed in the R computing environment<sup>7</sup>.

### *Runoff volume and pollutant loading*

Runoff volume was quantified at site PB-3 for a six-week period prior to restoration (9/1/2019 – 10/15/2019) by integrating a discharge record measured with a self-logging, non-vented HOBO U20 pressure transducer affixed to a U-channel post in the ephemeral stream channel. The full time series was not used because it includes intervals when the watershed was actively being regraded. Absolute pressures were recorded by the transducer at 15-minute intervals and were barometrically compensated with a record of atmospheric pressure recorded by another onsite HOBO U20 installed sub-aerially. FOPBC volunteers measured velocity transects in this stream channel using a Pygmy velocimeter during nine runoff events and the area-velocity method was used to compute a stage-discharge relationship following a power-law equation (Supplemental Figure S2)<sup>8</sup>. Post-restoration runoff volume was quantified for a three-month period following completion of the majority of restoration work (7/21/2022 – 11/2/2022) by recording the stage in the pool above the lower berm and using a stage-volume relationship to calculate the storage volume change of the pool. A two-meter resolution digital elevation model acquired via drone photogrammetry and airborne light detection and ranging was used to compute the stage-volume relationship (Supplemental Figure S3).

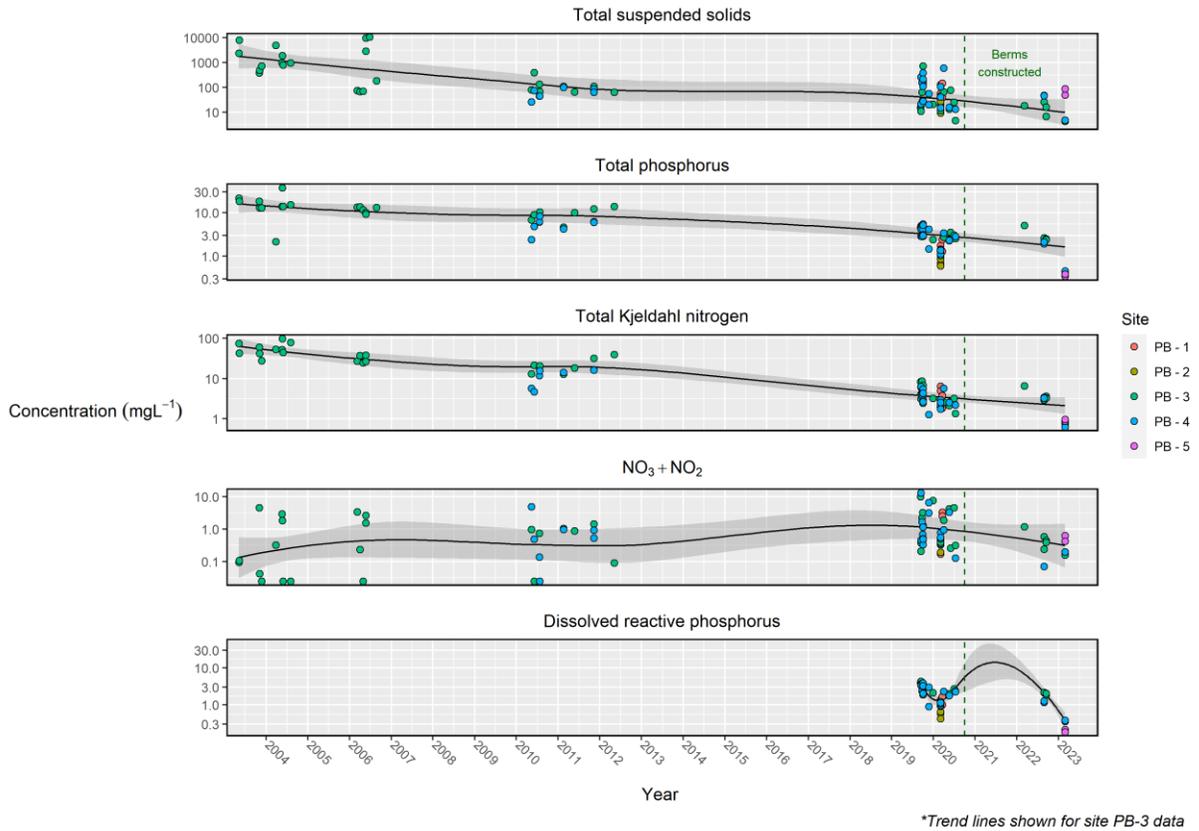
Runoff coefficients (ratio of runoff to rainfall) were computed for the pre-restoration period and post-restoration period using the computed runoff volumes and rainfall data from an onsite HOBO RG3 self-logging rain gauge. Average annual pre- and post-restoration pollutant loading was then extrapolated by multiplying the respective runoff coefficients by the [mean annual precipitation](#) and the median pollutant concentrations<sup>9</sup>. Annual load estimates were calculated for Groups 1 and 2 by multiplying their median pollutant concentrations by the pre-restoration runoff volume estimates. To isolate the impact of runoff reduction, load estimates for Groups 3 and 4 were calculated by multiplying the pre- and post-restoration runoff volume estimates by the median concentrations of the combined groups. Best-fit curve numbers were calculated using non-linear least squares regression and methodology described in USDA Technical Release 55<sup>10</sup>.

## Results

### *Pollutant concentration trends*

Visual analysis of all sample results suggests strong downward trends in TSS, TP, and TKN concentrations (Figure 1, Supplemental Table S1). Conversely, no monotonic trend is evident in the NO<sub>3</sub>+NO<sub>2</sub> samples. Considerable variability in sample concentrations is evident within the

temporal groups, reflecting the complex stochastic processes that drive non-point source surface water pollution.



**Figure 2.** Concentrations in surface water quality samples of all analyzed constituents. A LOESS regression trend line is plotted for site PB-3, and the time of construction of the storm water control features is denoted by the vertical green dashed line.

The Kruskal-Wallis tests yielded significant results for all of the groupings except for the  $\text{NO}_3+\text{NO}_2$  groups at site PB-3 and the TSS groups at site PB-4, indicating that, for the most part, there are statistically significant differences (decreases) between at least one pair of group median concentrations (Table 1, Supplemental Figure S4). At site PB-3, Dunn post-hoc test results indicate significant decreases between the median concentrations of Group 1 (2003-07) versus Groups 3 (2019-21) and 4 (2021-Present) for TSS, TP, and TKN (Supplemental Figure S4). The median concentrations of Groups 3 and 4 were also significantly lower than those of Group 2 (2010-13) for TSS and TP at site PB-3. At site PB-4, the median concentrations of Groups 3 and 4 were significantly lower than the median Group 2 concentrations for both TP and TKN (Supplemental Figure S5). The only statistically significant decrease between Group 3 (pre-restoration) and Group 4 (post-restoration) median concentrations was for  $\text{NO}_3+\text{NO}_2$  at site PB-

4. Mean DRP concentrations at site PB-3 also decreased significantly ( $p=0.045$ ) between pre- and post-restoration samples (Supplemental Figure S6).

**Table 1.** Median concentrations (mg L<sup>-1</sup>) of the analyzed constituents for each temporal group and sampling site, along with the number of samples in parentheses. Rows where the site cell is shaded blue have significant Kruskal-Wallis test results. Bolded values are significantly different ( $p\leq 0.05$ ) from the Group 1 medians, and red shaded cells are significantly different from the Group 2 medians. Group 4 medians with an \* are significantly different from the Group 3 medians.

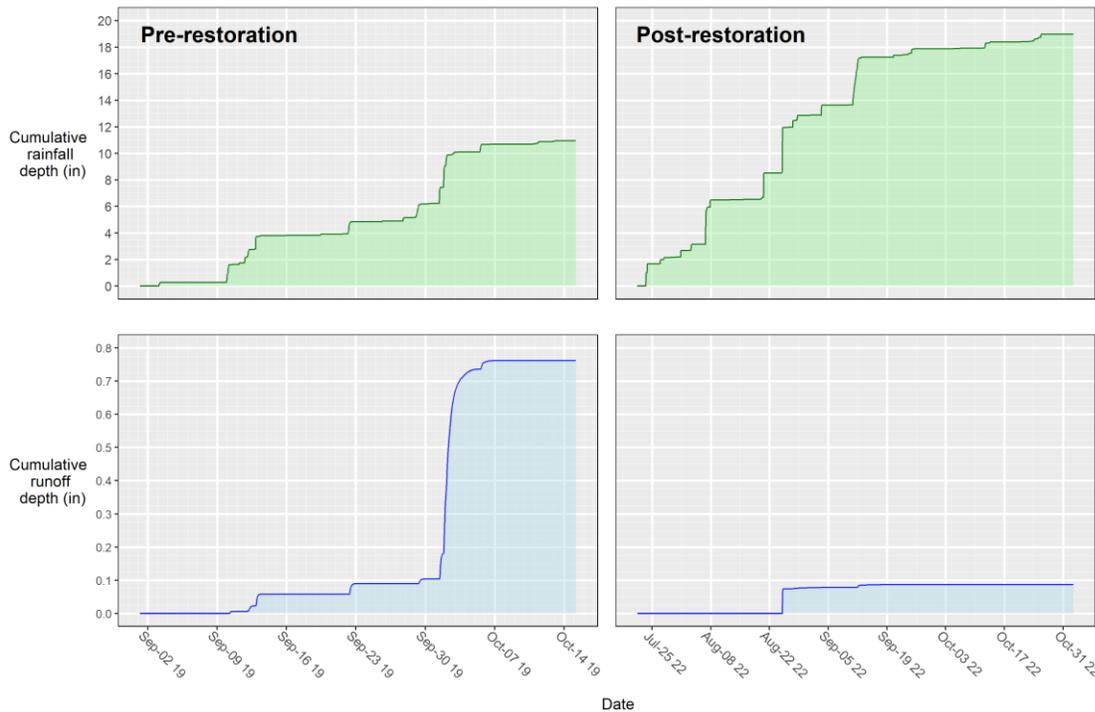
	Site	Group 1 2003-07	Group 2 2010-13	Group 3 2019-21	Group 4 2021-Present
TSS	PB-3	960.0 (17)	96.0 (8)	<b>28.0</b> (17)	<b>17.2</b> (6)
	PB-4	-	65.0 (7)	48.7 (16)	47.0 (3)
TP	PB-3	13.70 (16)	9.51 (8)	<b>3.07</b> (17)	<b>2.55</b> (6)
	PB-4	-	6.06 (7)	2.94 (16)	1.93 (3)
DRP	PB-3	-	-	2.35 (16)	1.73 (5)*
	PB-4	-	-	2.228 (15)	0.94 (3)
TKN	PB-3	43.10 (15)	19.60 (8)	<b>2.80</b> (17)	<b>3.13</b> (6)
	PB-4	-	14.10 (7)	2.93 (16)	3.26 (3)
NO <sub>3</sub> +NO <sub>2</sub>	PB-3	0.24 (15)	0.82 (8)	0.52 (17)	0.42 (6)
	PB-4	-	0.53 (7)	0.74 (16)	0.07* (3)

#### *Runoff volume and pollutant loading trends*

Eight runoff events occurred at site PB-3 during the pre-restoration monitoring interval with peak discharges ranging from 0.9 to 21 ft<sup>3</sup> s<sup>-1</sup> (Supplemental Figure S7). Rainfall events as small as 0.5 inches generated measurable runoff. In total, 10.93 inches of rain fell during the pre-restoration monitoring period and the catchment-averaged runoff depth was 0.76 inches, yielding a runoff ratio of 0.07 (Figure 3). A curve number of 74 yielded the best fit to the observed runoff depths for the eight events (Figure 4).

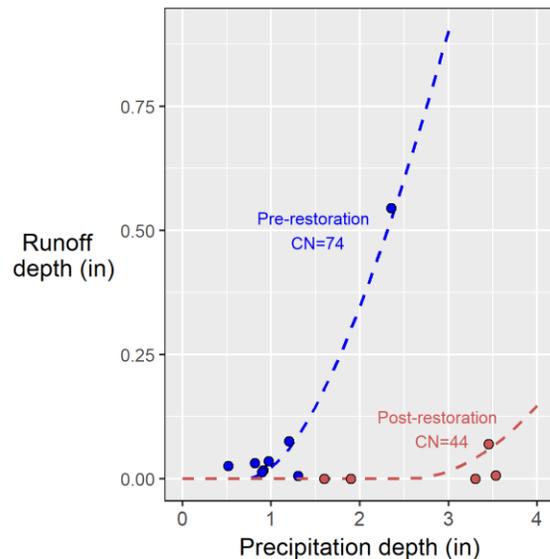
Only two runoff generating events occurred during the post-restoration period (Figure 3). The elevation in the lower pool did not crest the stop logs during either event, so the maximum pool volume associated with each runoff event was taken as the runoff volume. Runoff was generated only by rainfall events exceeding 3 inches. 19 inches of rain fell during the post-restoration

measurement period and the catchment-averaged runoff depth was 0.09 inches, yielding a runoff ratio of 0.005. The best fit curve number for the observed runoff depths was 44 (Figure 4).



**Figure 3.** Cumulative rainfall (top row) and runoff (bottom row) depths for the pre- (left column) and post-restoration (right column) analysis periods.

Extrapolating the calculated runoff ratios to the regional 1990-2020 mean annual precipitation depth (37.13 inches) results in mean annual runoff estimates of 85 acre-ft and 5.5 acre-ft for the pre- and post-restoration conditions, respectively. This decrease in runoff volume is estimated to have reduced annual TSS, TP, TKN, and  $\text{NO}_3+\text{NO}_2$  loading at PB-3 by an order of magnitude (Table 2). The reductions in pollutant concentrations associated with the implementation of multiple conservation practices are estimated to have generated even greater reductions in pollutant loading absent any quantification of temporally coincident runoff volume reductions. TSS loading is estimated to have decreased by ~90% or nearly 200,000 pounds between 2003 and 2013, and decreased by another 16,000 pounds between 2010 and 2021. Annual TP loading is estimated to have been ~3,200 lbs during the period 2003-07



**Figure 4.** Pre- and post-restoration runoff events as a function of rainfall. The blue and red dashed lines depict the runoff-rainfall relationships for the best fit curve numbers, 74 and 44.

and declined to ~640 lbs during the period 2019-21. Estimated TKN loading reductions are of similar magnitude, with a 5,000 lb or 50% reduction between 2003 and 2013 and an additional 3,800 lb reduction between 2013 and 2021. Complete loading extrapolation results are presented in Table 2.

**Table 2.** Estimated mean annual pollutant loadings and yields at site PB-3 for each temporal water quality sample grouping.

	<b>TSS load / yield (lbs yr<sup>-1</sup>, lbs yr<sup>-1</sup> acre<sup>-1</sup>)</b>	<b>TP load / yield (lbs yr<sup>-1</sup>, lbs yr<sup>-1</sup> acre<sup>-1</sup>)</b>	<b>TKN load / yield (lbs yr<sup>-1</sup>, lbs yr<sup>-1</sup> acre<sup>-1</sup>)</b>	<b>NO<sub>3</sub>+NO<sub>2</sub> load / yield (lbs yr<sup>-1</sup>, lbs yr<sup>-1</sup> acre<sup>-1</sup>)</b>
<b>2003-07</b>	220,000 / 560	3,200 / 8.0	10,000 / 25	60 / 0.14
<b>2010-13</b>	22,000 / 56	2,200 / 5.6	4,500 / 12	190 / 0.5
<b>2019-21</b>	5,800 / 15	640 / 1.6	690 / 1.7	110 / 0.28
<b>2021-Present</b>	380 / 1.0	40 / 0.1	40 / 0.1	10 / 0.02

## Discussion

Pollutant concentrations in the Acker Farm tributary to Pheasant Branch Creek have declined dramatically over the period of record, with the largest fraction of the decline taking place prior to restoration of the property. From the first period of sampling in the early 2000's to the sampling period prior to restoration, median TSS concentrations at site PB-3 decreased by 97% and median TP concentrations decreased by 78%. In samples where both TP and DRP were analyzed, DRP comprised 78±20% (±2 standard deviations) of the total phosphorus. This high percentage of bioavailable soluble phosphorus in runoff reflects high soil test-P due to legacy manure and fertilizer applications to this watershed and is in agreement with DRP fractions in other nearby streams dominated by similar agricultural land use<sup>11</sup>. The TP yields prior to 2019 were more than twice as high as mean yields from Discovery Farms plots across Wisconsin (1.98 lbs acre<sup>-1</sup>), but declined to near that value during 2019-21 period and have declined well below that value following restoration<sup>12</sup>. Estimated TSS yields during the earliest time period were near the mean yield from Discover Farms plots (667 lbs acre<sup>-1</sup>), and have since declined well below that value. The post-2013 downward trend in TSS concentrations at site PB-3 is not mirrored at site PB-4, where TSS concentrations have remained relatively consistent following dramatic declines from 2003 to 2013. The driver of this lack of improvement in suspended sediment concentrations at the downstream site is unclear, though local bank erosion or mobilization of sediments stored in the channel or retention structures are possible causes.

Median TKN concentrations decreased by 93% prior to restoration, but there was no statistically significant trend in median NO<sub>3</sub>+NO<sub>2</sub> concentrations. During the period 2003-13 total nitrogen yields at site PB-3 were well above mean yields measured at Discovery Farms plots (7.2 lbs acre<sup>-1</sup>), but declined to less than 25% of that value during the 2019-21 period. The decreased concentration of organic nitrogen in runoff likely reflects improved manure spreading practices and decreased erosion of sediment upstream of the monitoring site. While nitrogen is generally

not thought to limit algal growth in the Yahara chain of lakes, it is a major driver of eutrophication downstream in the Gulf of Mexico<sup>13</sup>.

The pre-restoration runoff coefficient (0.07) is in close agreement with the mean runoff coefficient of Discovery Farms plots (0.08), indicating that the relatively high estimated pollutant yields during the 2003-13 period are most likely caused by higher concentrations rather than larger runoff volumes. The post-restoration runoff coefficient (0.005) is substantially lower than the Discovery Farms average, but approaches the lowest reported plot values (0.01), if the calculation is modified to account for interception by the upper sedimentation pond and consequent reduced catchment area for runoff to the lower berm pool.

Monitoring of pollutant concentrations and runoff volumes at the Acker Farm demonstrates that targeted conservation practice implementation and perennial cover establishment at this site has reduced pollutant loading in surface runoff to downstream waters by >95%. Conversion to perennial cover and removal of impervious surfaces led to rapid and drastic reduction of runoff volume and pollutant loading to this small ephemeral stream.

## Limitations

There are multiple unpropagated and/or unquantified sources of uncertainty inherent to this analysis, including the uncertainty in individual sample and volume-averaged pollutant concentrations and uncertainty in the pre-restoration stage-discharge relationship and therefore the runoff volume. Additionally, the runoff ratio calculations made in this analysis are computed from relatively short time series that do not cover the full range of seasonal conditions. Stuntebeck et al., 2011 found that >80% of runoff from field plots occurred during the period January-June, indicating that this analysis might underestimate annual runoff. Curve number hydrology is most accurate for runoff events >0.5 inch and is not applicable for runoff from snowmelt or rain on frozen ground. This analysis applies the curve number approach to runoff events smaller than that threshold. Explicit quantification and propagation of uncertainty through pollutant load calculations would aid interpretation of the results presented here.

The post-restoration runoff volumes provided here may be gross overestimates of actual runoff because the pool above the lower berm has yet to overtop its culvert stop logs. The accumulated runoff instead dissipates through some unquantified partitioning of evaporation, infiltration, and leakage through the stop logs. A portion of the infiltrated water may reemerge via interflow to down gradient stream reaches. The infiltration rate in the pool footprint is expected to diminish with time as fine sediment clogs macropores in the underlying soil, which will lead to greater partitioning to evaporation and leakage. These post-restoration runoff volumes thus represent a conservatively high estimate for the analyzed time period.

## Acknowledgements

This project was developed by former Dane County Land & Water Resources Department employee Matt Diebel in collaboration with the FOPBC. Funding for sample analysis and

instrumentation was provided by the Dane County Land & Water Resources Department and samples were collected by FOPBC volunteers. Stream gaging measurements were spearheaded by FOPBC volunteer Herb Garn.

## References

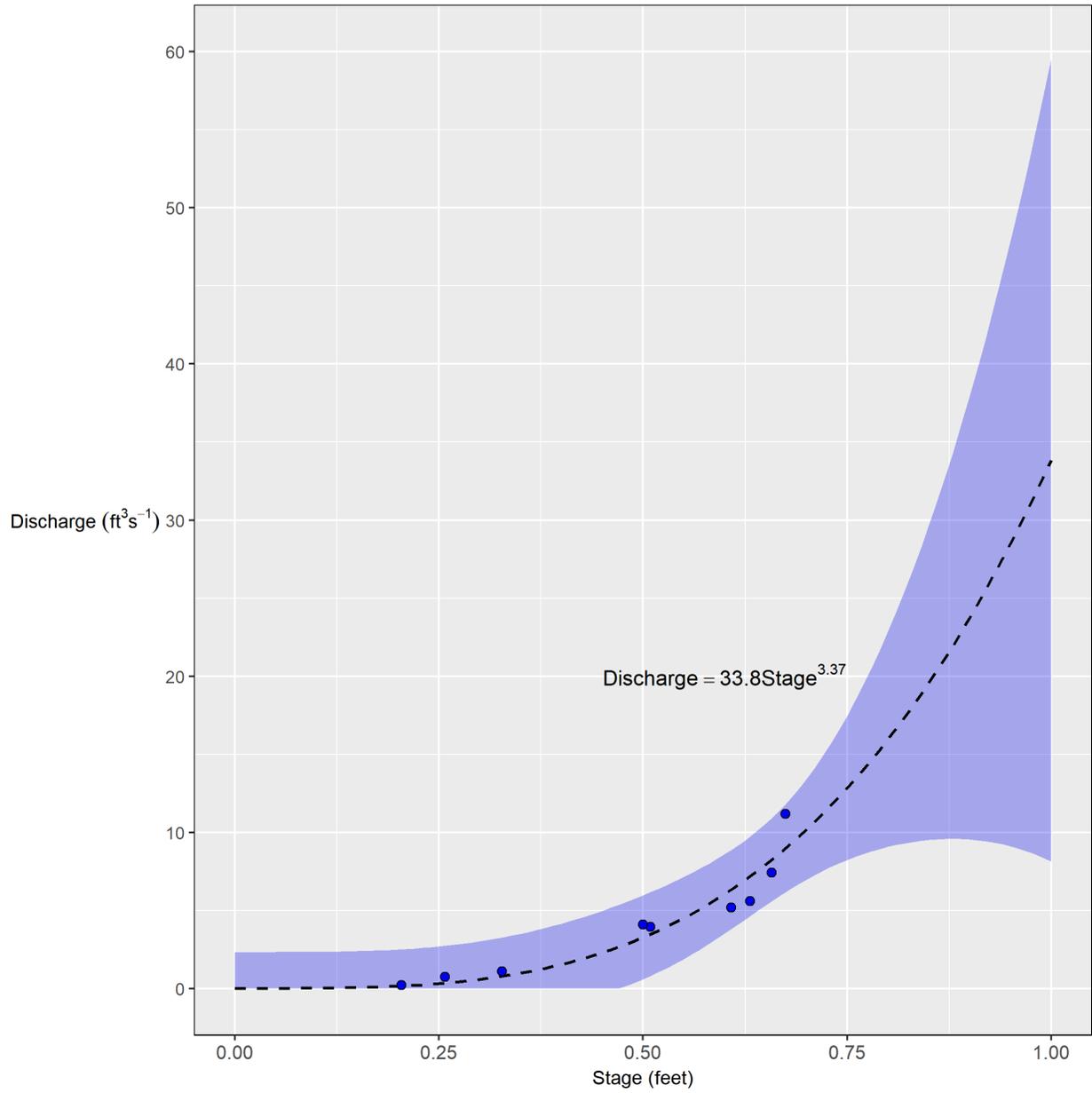
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## Supplemental

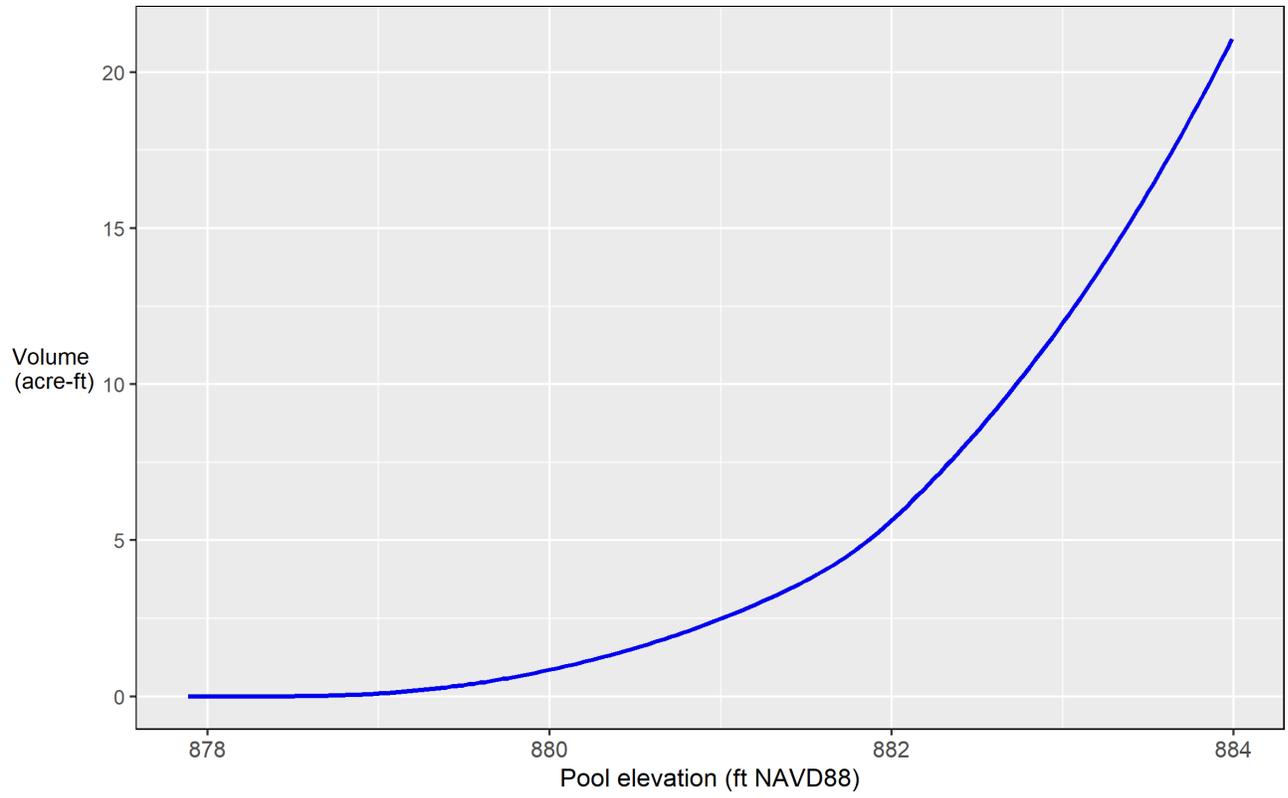
**Table S1.** Water quality sampling results.

Datetime	Site	DRP (mg L <sup>-1</sup> )	NH <sub>3</sub> (mg L <sup>-1</sup> )	NO <sub>3</sub> +NO <sub>2</sub> (mg L <sup>-1</sup> )	TKN (mg L <sup>-1</sup> )	TP (mg L <sup>-1</sup> )	TSS (mg L <sup>-1</sup> )
5/9/2003 2:30	PB - 3	-	22.6	0.096	74.2	21.6	2400
5/10/2003 22:30	PB - 3	-	-	0.108	43.1	18.4	7880
11/2/2003 11:30	PB - 3	-	20.5	4.56	59.5	18.3	385
11/4/2003 2:00	PB - 3	-	-	0.043	42.1	13	500
11/23/2003 9:00	PB - 3	-	-	0.025	27.6	12.9	720
3/26/2004 1:00	PB - 3	-	-	0.328	53.7	2.16	4940
5/21/2004 9:50	PB - 3	-	-	2.96	52.2	13.9	960
5/21/2004 17:30	PB - 3	-	-	1.87	98.5	37.7	1920
5/30/2004 12:00	PB - 3	-	-	0.025	44.6	14	803
8/3/2004 21:00	PB - 3	-	-	0.025	78.5	15.3	980
3/10/2006 16:40	PB - 3	-	-	3.38	27.3	13.6	74
4/3/2006 12:00	PB - 3	-	-	0.238	37.1	13.8	68
4/30/2006 12:45	PB - 3	-	-	0.025	24.6	11.65	70
5/24/2006 19:30	PB - 3	-	-	1.58	37.8	10.1	9530
5/24/2006 19:50	PB - 3	-	-	2.71	26.5	9.41	2870
6/25/2006 16:00	PB - 3	-	-	NA	NA	NA	10500
8/25/2006 12:45	PB - 3	-	-	NA	NA	13.12	184
5/13/2010 7:15	PB - 3	-	-	0.972	13.2	6.84	80
5/13/2010 7:40	PB - 4	-	-	4.89	5.69	2.41	26
6/5/2010 17:50	PB - 3	-	-	0.025	21.4	9.03	396
6/5/2010 18:10	PB - 4	-	-	0.498	4.69	4.8	74
7/22/2010 20:15	PB - 3	-	-	0.742	18.7	6.13	132
7/22/2010 20:30	PB - 4	-	-	0.138	11.9	6.27	45
7/24/2010 8:20	PB - 3	-	-	0.025	20.5	10.5	69
7/24/2010 8:45	PB - 4	-	-	0.025	15.7	8.33	45
2/17/2011 15:00	PB - 3	-	-	1.06	12.8	4.68	112
2/17/2011 15:30	PB - 4	-	-	0.973	14.1	4.26	100
5/25/2011 14:15	PB - 3	-	-	0.897	18.4	9.99	66
11/9/2011 10:20	PB - 3	-	-	1.44	32.1	12.4	112
11/9/2011 16:45	PB - 4	-	-	0.533	16.7	6.26	88
11/10/2011 11:00	PB - 4	-	-	0.93	16.3	6.06	65
5/6/2012 15:00	PB - 3	-	-	0.091	39.8	14.1	65
9/10/2019 8:45	PB - 3	4.02	-	10.1	8.31	4.7	15.3
9/12/2019 9:20	PB - 3	4.36	-	0.374	6.03	4.97	18.5
9/12/2019 9:55	PB - 4	-	-	13.2	6.32	2.87	258
9/13/2019 8:50	PB - 3	3.67	-	0.209	3.12	4.15	11
9/13/2019 9:45	PB - 4	3.32	-	0.456	4.12	4.19	21.3
9/22/2019 10:30	PB - 3	3.81	-	2.26	8.62	5	64.5
9/22/2019 10:45	PB - 4	2.39	-	1.67	4.15	2.82	159
9/29/2019 10:30	PB - 3	3.7	-	3.24	5.44	4.52	28

Datetime	Site	DRP (mg L <sup>-1</sup> )	NH <sub>3</sub> (mg L <sup>-1</sup> )	NO <sub>3</sub> +NO <sub>2</sub> (mg L <sup>-1</sup> )	TKN (mg L <sup>-1</sup> )	TP (mg L <sup>-1</sup> )	TSS (mg L <sup>-1</sup> )
9/29/2019 11:00	PB - 4	3.25	-	0.696	3.38	4.15	30
10/1/2019 11:45	PB - 3	2.76	-	1.32	6.9	5.01	716
10/1/2019 12:05	PB - 4	3.88	-	0.337	5.45	5.48	27.7
10/1/2019 15:45	PB - 4	3.28	-	1.16	4.31	5.24	386
10/2/2019 8:30	PB - 3	2.21	-	0.516	2.47	3.18	166
10/2/2019 9:30	PB - 4	2.07	-	0.505	2.87	3.14	218
10/2/2019 13:30	PB - 3	1.87	-	0.47	2.8	2.88	142
10/2/2019 14:00	PB - 4	2.02	-	0.494	2.64	3.01	112
11/21/2019 9:00	PB - 4	0.908	-	3.18	1.27	1.46	20.3
11/21/2019 9:30	PB - 4	3	-	6.6	1.27	4.2	56
12/29/2019 9:00	PB - 3	2.11	-	7.64	3.25	2.4	21
3/2/2020 16:00	PB - 1	0.984	-	0.174	6.48	1.3	57.6
3/2/2020 16:10	PB - 2	0.573	-	0.779	2.34	0.695	9.33
3/2/2020 16:25	PB - 3	0.919	-	0.471	1.74	1.03	11.8
3/2/2020 16:45	PB - 4	0.973	-	0.793	1.76	1.12	15.3
3/3/2020 16:08	PB - 1	1.36	-	0.445	5.02	1.75	130
3/3/2020 16:11	PB - 2	0.431	-	0.334	2.8	0.597	19
3/3/2020 16:42	PB - 3	1.07	-	0.364	1.95	1.28	42.8
3/3/2020 16:59	PB - 4	1.08	-	0.526	2.99	1.4	108
3/4/2020 15:20	PB - 2	0.662	-	0.196	1.97	0.868	27.8
3/4/2020 15:40	PB - 3	1.23	-	0.397	2.06	1.45	45.1
3/4/2020 16:00	PB - 4	1.14	-	0.565	2.53	1.36	41.3
3/19/2020 16:15	PB - 1	1.67	-	3.37	3.8	2.4	145
3/19/2020 16:30	PB - 1	1	-	2.52	1.85	1.29	39.8
3/29/2020 8:30	PB - 3	2.32	-	1.89	2.62	2.75	67
3/29/2020 8:45	PB - 4	2.31	-	0.954	5.74	3.42	600
5/17/2020 15:30	PB - 3	1.99	-	4.26	2.12	2.28	13.2
5/17/2020 16:00	PB - 4	1.81	-	3.3	2.53	2.32	15.6
5/28/2020 17:05	PB - 3	NA	-	0.265	2.7	3.53	77.3
6/29/2020 15:50	PB - 3	2.7	-	4.55	3.23	3.07	25
7/10/2020 7:45	PB - 3	2.38	-	0.32	1.36	2.54	4.6
7/10/2020 8:20	PB - 4	2.28	-	0.129	2.22	2.83	13.2
3/6/2022 9:00	PB - 3	-	-	1.19	6.61	5.11	18.4
8/25/2022 10:02	PB - 3	2.15	-	0.59	2.95	2.61	26
8/25/2022 10:17	PB - 4	1.16	-	0.0714	3.42	1.93	48.5
8/25/2022 12:50	PB - 3	2.19	-	0.246	2.97	2.65	26.4
8/25/2022 13:15	PB - 4	1.26	-	0.0713	3.26	2.13	47
9/12/2022 12:30	PB - 3	1.89	-	0.449	3.62	2.5	16
9/13/2022 10:00	PB - 3	2.05	-	0.394	3.3	2.41	6.8
2/27/2023 11:15	PB - 5	0.187	-	0.425	0.972	0.386	89.5
2/27/2023 13:45	PB - 3	0.356	-	0.16	0.768	0.449	4.4
2/27/2023 14:10	PB - 4	0.387	-	0.198	0.632	0.459	4.8
2/27/2023 15:00	PB - 5	0.215	-	0.625	0.869	0.345	49.4

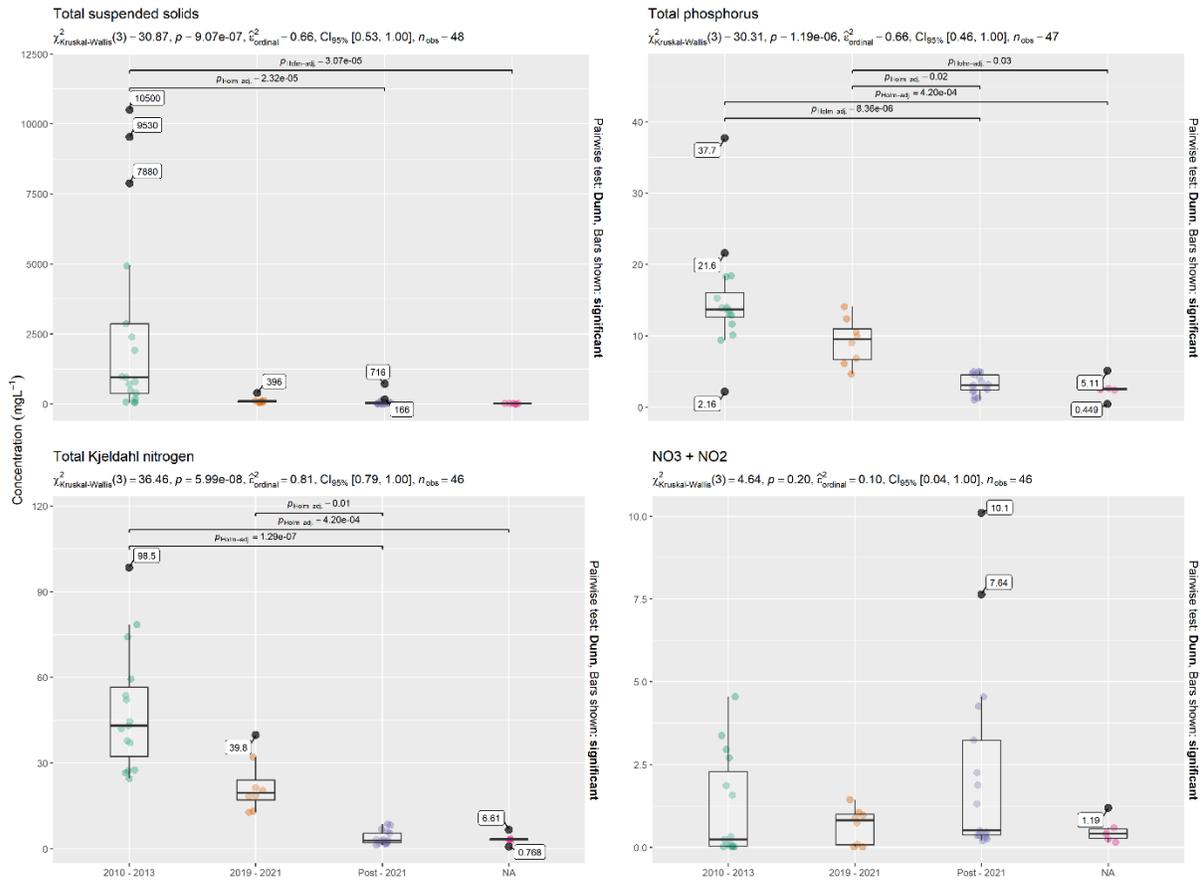


**Figure S2.** Measured stages and discharges at site PB-3 (blue circles). The best-fit equation is displayed by the black dashed line and the equation form and coefficients are shown. The blue envelope displays the 90% prediction interval.



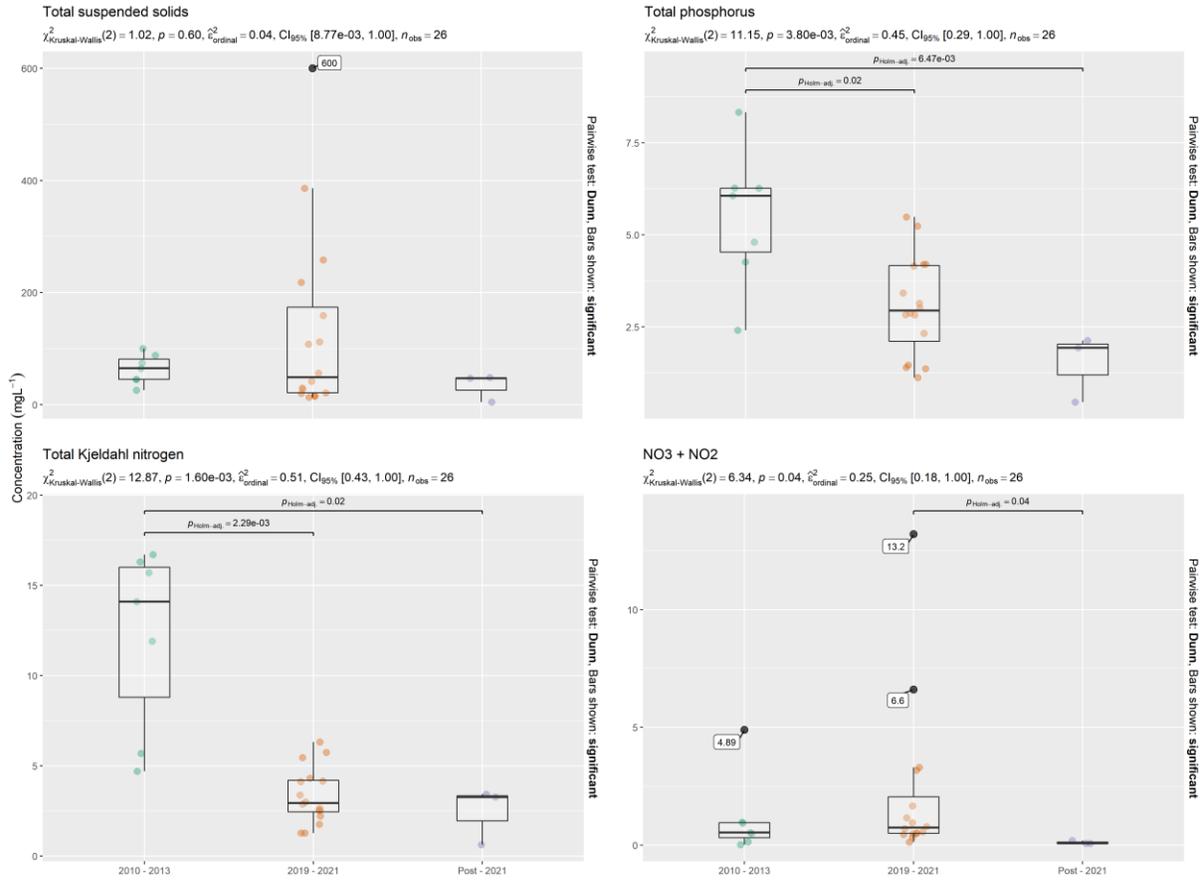
**Figure S3.** Volume in the pool above the lower berm as a function of pool elevation.

### Kruskal-Wallis Post-hoc Results for PB-3 Trends



**Supplemental Figure S4.** Boxplots, data points, and Kruskal-Wallis test results for water quality concentrations in runoff at site PB-3. Bars between groups indicate significant ( $p < 0.05$ ) Dunn post-hoc test results for differences between median concentrations. Labeled data points are outliers as determined by Tukey's method with a coefficient of 1.5. Median values are denoted by the horizontal bar within the boxplot and the 25<sup>th</sup> and 75<sup>th</sup> percentile values are represented by the extent of the box. The vertical lines extending beyond the box indicate the non-outlier minimum and maximum values.

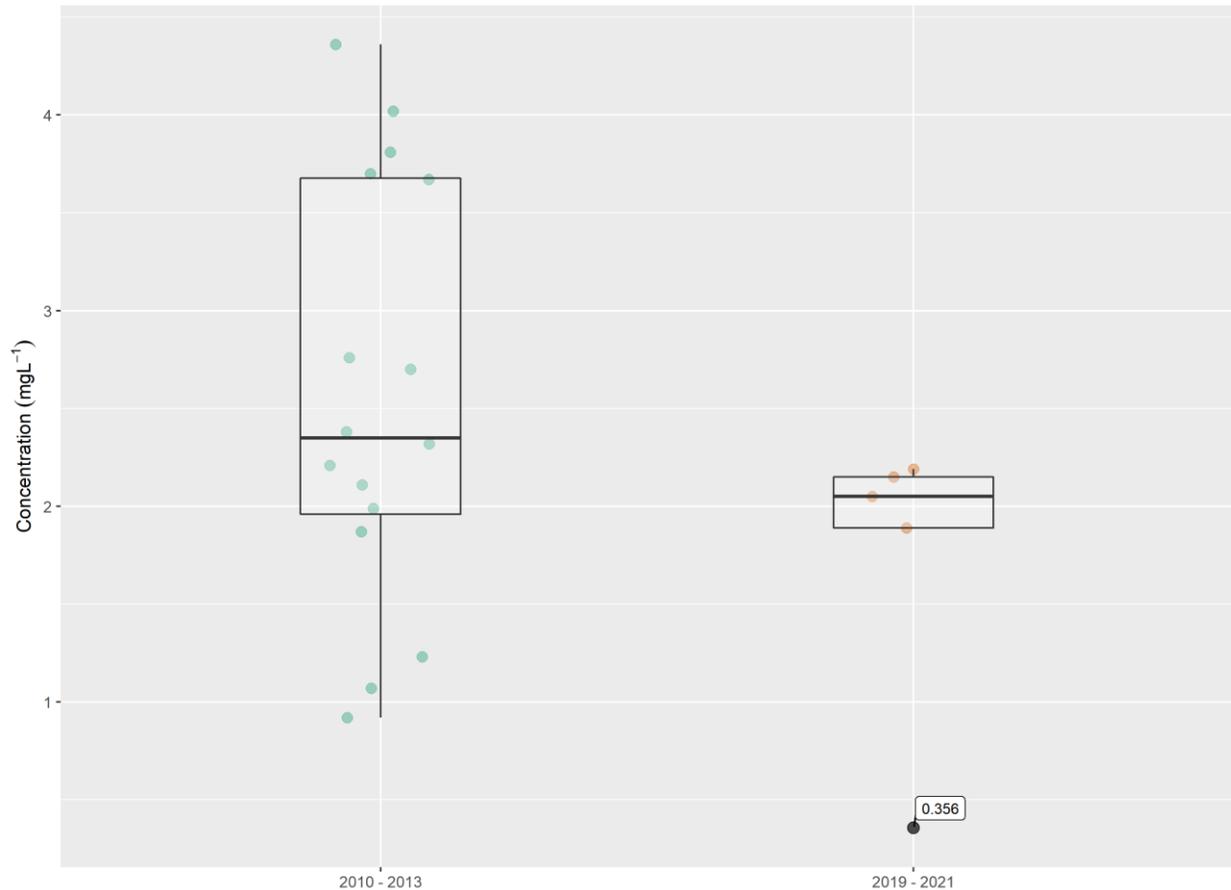
### Kruskal-Wallis Post-hoc Results for PB-4 Trends



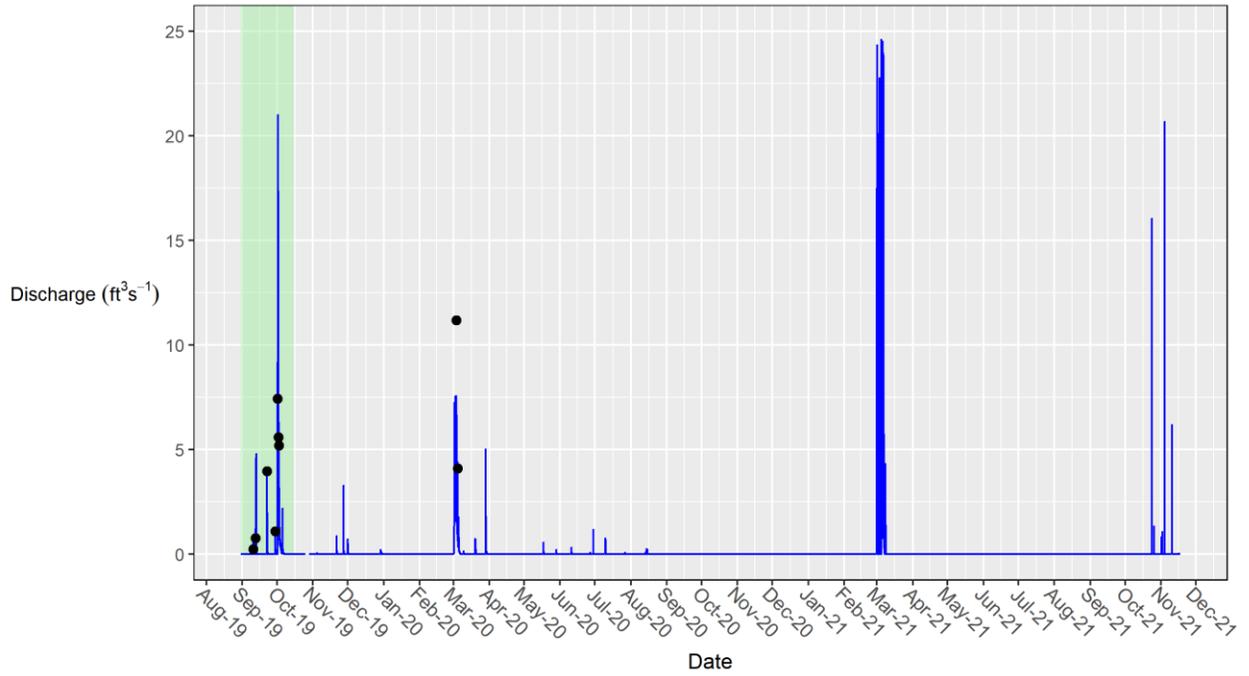
**Supplemental Figure S5.** Boxplots, data points, and Kruskal-Wallis test results for water quality concentrations in runoff at site PB-4. Bars between groups indicate significant ( $p < 0.05$ ) Dunn post-hoc test results for differences between median concentrations. Labeled data points are outliers as determined by Tukey's method with a coefficient of 1.5. Median values are denoted by the horizontal bar within the boxplot and the 25<sup>th</sup> and 75<sup>th</sup> percentile values are represented by the extent of the box. The vertical lines extending beyond the box indicate the non-outlier minimum and maximum values.

### Dissolved reactive phosphorus concentrations at PB-3

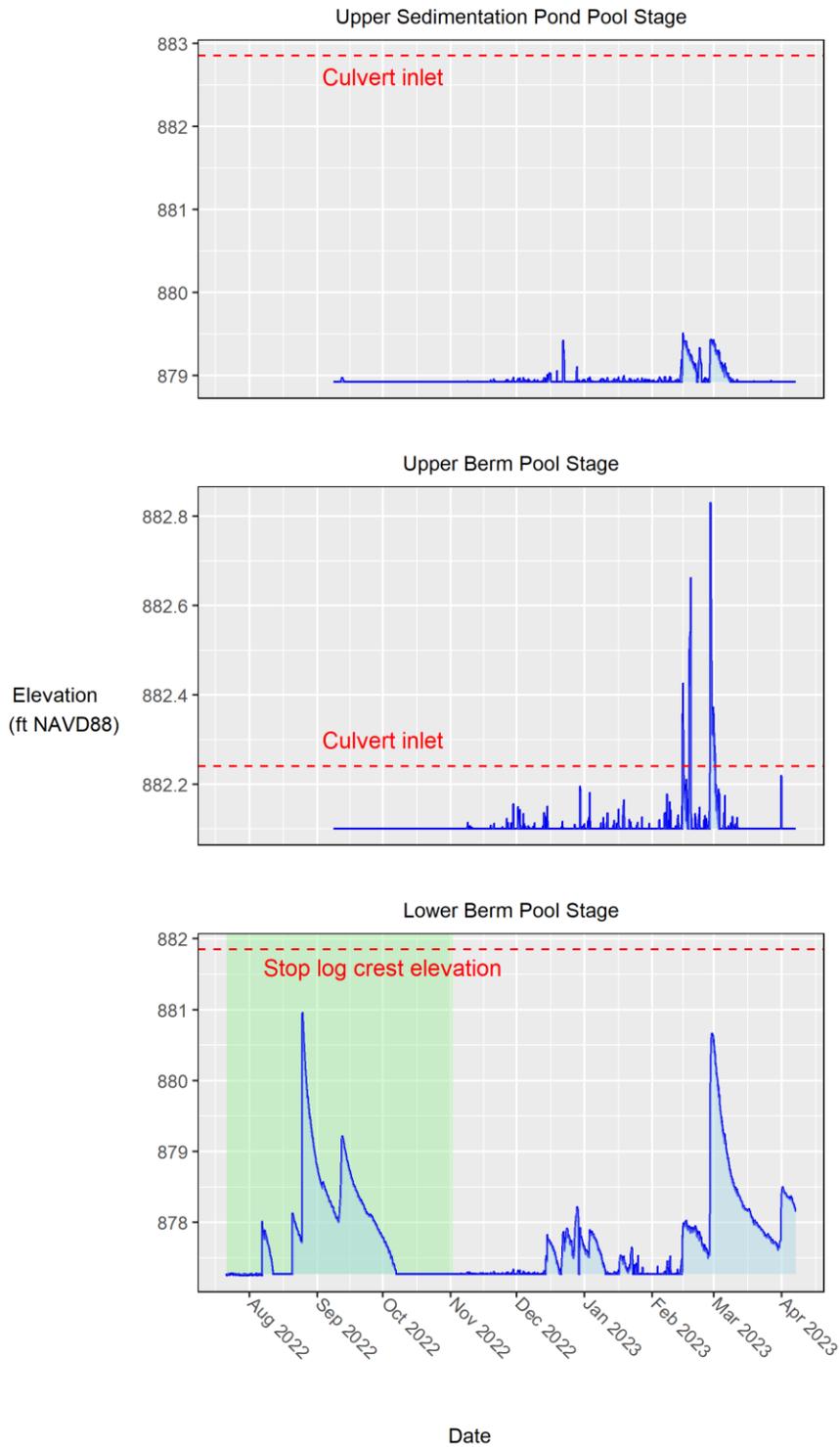
$t_{\text{Welch}}(9.38) = 1.92$ ,  $p = 0.09$ ,  $\hat{g}_{\text{Hedges}} = 0.82$ ,  $CI_{95\%} [-0.11, 1.72]$ ,  $n_{\text{obs}} = 21$



**Supplemental Figure S6.** Boxplots, data points, and T-test results (without outliers removed) for dissolved reactive phosphorus concentrations in runoff at site PB-3. Labeled data points are outliers as determined by Tukey's method with a coefficient of 1.5. Median values are denoted by the horizontal bar within the boxplot and the 25<sup>th</sup> and 75<sup>th</sup> percentile values are represented by the extent of the box. The vertical lines extending beyond the box indicate the non-outlier minimum and maximum values.



**Supplemental Figure S7.** Discharge time series at site PB-3. Field discharge measurements are shown by dots, and the period of analysis for runoff ratio and hydrograph parameters is indicated by a green rectangle.



**Supplemental Figure S8.** Stage time series at the upper sedimentation pond, upper berm pool, and lower berm pool. Pool outlet elevations are annotated with a red dashed line, and the period of analysis for the lower berm pool is denoted by a green rectangle.