TECHNICAL REPORT

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From: Ji Yeow Law; Michelle Soupir, Iowa State University

Subject: Data analysis for Squaw Creek and East Indian Creek

Date: March 15, 2019

Attachments: Supplementary information (figures), Excel worksheets

BACKGROUND

Three years (2016-2018) of water quality monitoring was conducted in Squaw Creek and East Indian Creek, with the goal to establish baseline nitrogen (N) and phosphorus (P) loading. Iowa State University (ISU) was tasked to assist with water quality data analysis to answer the following questions:

1) Did 2016-2018 data provide sufficient information to estimate baseline nitrogen and phosphorus loading in Squaw Creek and East Indian Creek?
2) Did 2018 data reveal any interesting patterns in nitrogen, phosphorus, or *E. coli* concentrations?
3) Will continued monitoring over the next 5 years allow detection of nutrient reductions in Squaw Creek?

DATA ACQUISITION & ANALYSIS

All water quality (nitrate, total phosphorus, total suspended solid, *E. coli*) data in Squaw Creek and East Indian Creek was provided by Prairie Rivers of Iowa. In Squaw Creek, grab samples were collected in 2018, while both grab and time-weighted composite samples were collected in 2016 and 2017. For East Indian Creek, grab samples were collected in 2016, 2017, and 2018. Only samples between April 15 and October 31 were used for data analyses. Nitrate and total phosphorus sample concentrations were compared against EPA's ambient water quality criteria recommendations for total nitrogen (3.26 mg/L) and total phosphorus (0.118 mg/L) concentrations in Ecoregion VI – subecoregion 47 (EPA, 2000). Note that the total nitrogen standard was used to compare against nitrate in this analysis due to lack of environmental criteria for nitrate in natural streams.

For flow data, 15-minute frequency flow data of Squaw Creek from 2002 to 2018 was obtained from USGS WaterWatch (USGS, 2019). Watershed drainage area information was also acquired from USGS WaterWatch. Flow data for East Indian Creek was not available.

Precipitation data at Squaw Creek (coordinate: 42.02º, -93.63º) and East Indian Creek (41.95º, -93.41º) monitoring stations were obtained from PRISM (PRISM Climate Group, 2019). No differences in annual cumulative precipitation were found between these two locations during 2016, 2017, and 2018. Therefore, only precipitation data from the Squaw Creek monitoring location was used in this report. 30-year precipitation data at Squaw Creek monitoring location was also downloaded to calculate the long-term precipitation average.

Data analysis included calculation of load from the watershed and load duration curves, when possible. For load calculations, nitrate samples (grab or time-weighted event) were assumed to be representative of the period between the current and previous sample collection. Phosphorus loading analysis was not included in the report because loads would be greatly underestimated without flow-weighted water quality data. For Load Duration Curves (LDC), the sample was plotted against the daily average flow or the average event flow during the period of sample collection (2017 only, based on ISCO first and last collection time). Nitrate concentrations are typically less variable with flow during an event, and thus we assumed that a time-weighted event sample is representative of the period of flow. However, for phosphorus the highest concentrations are typically observed at highest flows, and thus time-weighted event samples underestimate the event load.

PROJECT QUESTIONS, METHODS, AND FINDINGS

Table 1: Research questions, approach/methods used, and findings;

Questions	Approach	Findings
Did 2016-2018 data provide sufficient information to estimate baseline nitrogen and phosphorus loading in Squaw Creek and East Indian Creek?	<u>Squaw Creek</u> - Load duration curve (LDC): allows assessment of nitrate concentration over a range of flow conditions in each year. This approach assumed that time-weighted nitrate concentrations (2017) were less variable during the storm events, and were comparable to the grab samples (2016-2018). Because event phosphorus samples were time-weighted, the LDC for phosphorus is less representative of the actual high flow conditions without using flow-weighted water quality data, but the analysis is provided as an approximation. - Annual nutrient loading: allows estimation of annual nitrate load in Squaw Creek, which covered two normal precipitation years (2016, 2017) and one wet year (2018). Similarly, phosphorus loading is underestimated without flow-weighted water quality data, and therefore not provided in this analysis. <u>East Indian Creek</u> - Load duration curve: LDC cannot be developed without flow data. - Annual nutrient loading: load estimation is not possible without flow data.	<u>Squaw Creek</u> 2016-2018 data was able to provide sufficient information to estimate baseline nitrogen loading, but not phosphorus. 2016 and 2017 were considered “normal” precipitation years, while 2018 was a “wet” year. A “dry” year was not observed between 2016 and 2018. The nitrate load duration curve (Fig 5) shown that nitrate loads often exceeded the EPA recommended total nitrogen (TN) load (using target concentration of 3.26 mg/L) for Ecoregion VI during medium and high flow conditions. The nitrogen loading for respective years and seasons are summarized in Fig 9. The annual nitrate loads were 17.5, 14.5, and 37.0 kg N/ha in 2016, 2017, and 2018, respectively. As expected for a wet year, 2018 had the highest annual nitrate load when compared to 2016 and 2017. The highest seasonal nitrogen loading (47 to 95% of annual loads) occurred in Q2 of each year, as higher nitrate concentrations and higher flow rates were observed during this period. The LDC was developed for phosphorus (Fig 8), but is limited in its representation of export during storm events. <u>East Indian Creek</u> LDC and annual load were not estimated.
Did 2018 data reveal any interesting patterns in nitrogen, phosphorus, or *E. coli* concentrations? **we also looked for the patterns in 2016 and 2017 data**	<u>Squaw Creek and East Indian Creek</u> - Time series plot: daily flow (only for Squaw Creek), precipitation, and temperature data are plotted with nitrogen, phosphorus, or *E. coli* concentration, respectively. This allowed us to identify how nutrient and bacteria concentrations may relate to these environmental factors. Seasonal median is included to represent typical concentrations over a range of flows.	<u>Squaw Creek</u> Nitrogen: nitrate concentrations in Q2 of each year were higher than in Q3 and Q4. Nitrate concentrations in Q3 varied by year and flow conditions. When flows were low (2017 Q3), nitrate concentrations were below the EPA recommended TN concentration (3.26 mg/L). When flows were high (2018 Q3), nitrate concentrations consistently exceeded the EPA recommended concentration. Mixed results were observed in 2016 Q3. Q4 appeared to have higher nitrate concentrations, but the lack of extended

		sampling through November/December restricted the detailed analysis during Q4. The seasonal medians of each year are presented in Fig 10. Phosphorus: total phosphorus (TP) concentrations often exceeded the EPA recommended concentration (0.118 mg/L) even during base flow conditions. Flow-weighted samples are expected to reveal higher TP concentrations during event flow conditions. During elevated base flow conditions (i.e. 2018), higher TP concentrations (also higher annual median) were observed. The seasonal medians of each year are presented in Fig 12. *E. coli*: almost all *E. coli* concentrations exceeded the recommended water quality standard (235 MPN/100 mL) for Class A1 primary contact recreation. All recreational season geometric means also exceeded recommended criteria using geometric mean (126 MPN/100 mL). As expected, *E. coli* concentrations were higher when temperature was higher in the late-Q2, Q3, and early-Q4. *E. coli* concentrations also increased during high flow conditions, which were likely due to increased runoff from manure-applied landscapes, wildlife, and resuspension of *E. coli* from streambed sediments. The seasonal medians of each year are presented in Fig 11. <u>East Indian Creek</u> Nitrogen: similar nitrate concentration patterns were observed in East Indian Creek and Squaw Creek. Nitrate concentrations in East Indian Creek were significantly correlated (Table 3) with nitrate concentrations in Squaw Creek. The seasonal medians of each year are presented in Fig 14. Phosphorus: similar phosphorus concentration patterns were observed in East Indian Creek and Squaw Creek. TP concentrations in East Indian Creek were significantly correlated (Table 3) with TP concentrations in Squaw Creek. The seasonal medians of each year are presented in Fig 16. *E. coli*: similar *E. coli* concentration patterns were observed in East Indian Creek and Squaw Creek, but they were not

		significantly correlated. There were greater variations observed in East Indian Creek. Nevertheless, higher *E. coli* concentrations were generally observed when temperature was higher in late-Q2, Q3, and early-Q4. The seasonal medians of each year are presented in Fig 15.
Will continued monitoring over the next 5 years allow detection of nutrient reductions in Squaw Creek?	The recommendation is provided through assessment of year-to-year variation observed in nutrients concentration and loading, as well as results from Minimum detectable change (MDC) analysis provided by Dan Haug.	It is very unlikely that nutrient reduction in a watershed of this size will be detected within a few year period, especially when BMPs implementation is limited and gradual. The success to detect changes is higher when the watershed size is smaller (i.e. catchment scale) or when BMP implementation is extensive. If the monitoring goal is to detect change, we recommend implementing the monitoring at the catchment scale, downstream of similar catchment areas of high and low BMP implementation. We recommend using IIHR nitrate sensors to detect trends in nitrate concentration, which may indicate if BMPs in the watershed have been effective. It is important to note that even if a decreasing nitrate trend is observed, phosphorus export patterns are different and additional monitoring would be needed. Many BMPs (e.g. nitrogen management plans, woodchip bioreactors) may only be effective in reducing nitrate and not phosphorus. For example, if manure application increased in the watershed, phosphorus concentration will likely increase, while nitrate concentrations may decrease. Crop fertilization and manure application typically occur in the late fall, after harvest. Therefore, we recommend extending the monitoring season to capture potential nitrate leaching that occurs after harvest (e.g. November 15).

Q2: April to June, Q3: July to September; Q4: October

RESULTS AND DISCUSSION

Hydrology – precipitation, water yield, and drainage ratio

Annual cumulative precipitation depth is presented in Fig 1. The 30-year (1989-2018) cumulative depth was used to determine if a particular year was a "dry", "normal", or "wet" year. A year was considered dry or wet if the annual cumulative precipitation depth is one standard deviation away from the 30-year average. The 3-year water quality monitoring effort covered 1 wet year (2018) and 2 normal years (2016 and 2017). The first half of 2016 had an average precipitation but remained dry during June. Large storm events (Aug 12: 76.7 mm; Sept 8: 64.6 mm; Sept 23: 124.8 mm) were observed between July and October, then remained dry for the remainder of the year. 2017 received more precipitation in spring and fall, but less in the summer. 2018 started off with average normal precipitation until June, then received high precipitation through the rest of the year. The outflow ratio (i.e. water yield over precipitation volume) of 2016 and 2017 are similar, while in 2018 the outflow ratio was nearly twice the previous years (Table 2).

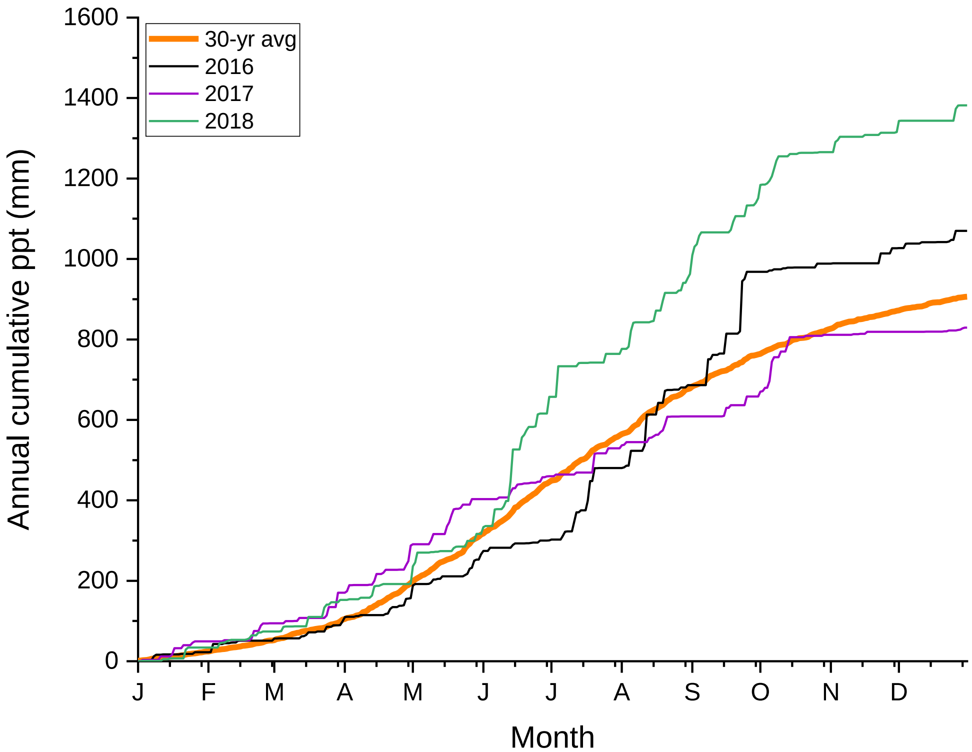

Fig 1: Annual cumulative precipitation in 2016, 2017, and 2018 as compared to the 30-year average. 2016 and 2017 represent the "normal" years; 2018 represents the "wet" year.

Table 2: Annual cumulative flow, water yield (per unit area of drainage area), precipitation, and outflow ratio of Squaw Creek.

Year	Annual cumulative flow (m^3)	Water yield (cm)	Annual total ppt (cm)	Outflow ratio
2016	9.45E+07	17.9	107.0	17%
2017	6.96E+07	13.2	82.9	16%
2018	2.54E+08	48.0	138.2	35%

The outflow volume from Squaw Creek in Q2 and Q3 of 2016 and 2018 were similar. Approximately 40% of the flow occurred during these two quarters of the year, respectively. As 2017 received more precipitation in Q2, 88% of the 2017 annual flow from Squaw Creek occurred during this period. Meanwhile, Q3 and Q4 of 2017 only contributed 6.3% and 5.9% of the annual flow, respectively, due to the low precipitation depths.

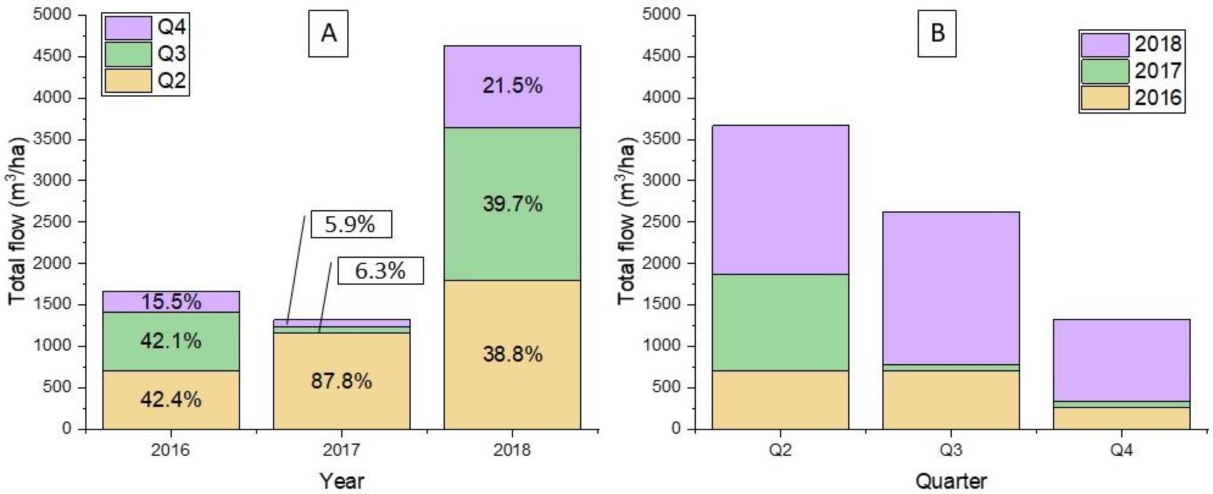

Fig 2: (a) Estimated annual flow from Squaw Creek in 2016, 2017, and 2018; (b) Estimated seasonal flow from Squaw Creek in each quarter of the year.

<u>Nitrate load duration curve (Squaw Creek)</u>

A load duration curve (LDC) is commonly used to relate pollutant loading under various flow conditions. The target load (target concentration multiply by flow) is plotted as a line (e.g. orange line in Fig 3), while the calculated sample daily loads are plotted using scattered points to represent daily pollutant loads at respective flow conditions. Lower flow exceedance % represents higher flow conditions. When a sample point is above the line (i.e. target load) in LDC, it shows that the daily load exceeds the target daily load, and vice versa.

<u>Annual comparison:</u> The 3-year sampling efforts successfully covered approximately 90% of the flow conditions in Squaw Creek. In 2016, the sampling season mainly covered medium-low to high flow conditions (0-70% flow exceedance) (Fig 3). 11 out of 14 (78.6%) of the 2016 daily loads had exceeded the target daily nitrogen load. Although 2017 was a normal precipitation year, most of the sampling occurred during low flow conditions (> 60% flow exceedance). 9 out of 22 (40.9%) of the 2017 daily loads had exceeded the target daily nitrogen load. As expected from a wet year, the sampling season in 2018 covered medium to high flow conditions (0-40% flow exceedance). Only 1 out of the 12 (8.3%) of the 2018 daily loads met the target daily nitrate load. Additional analysis by categorizing the data into four quarters will provide insight into how seasonality affects nitrate concentrations and loads.

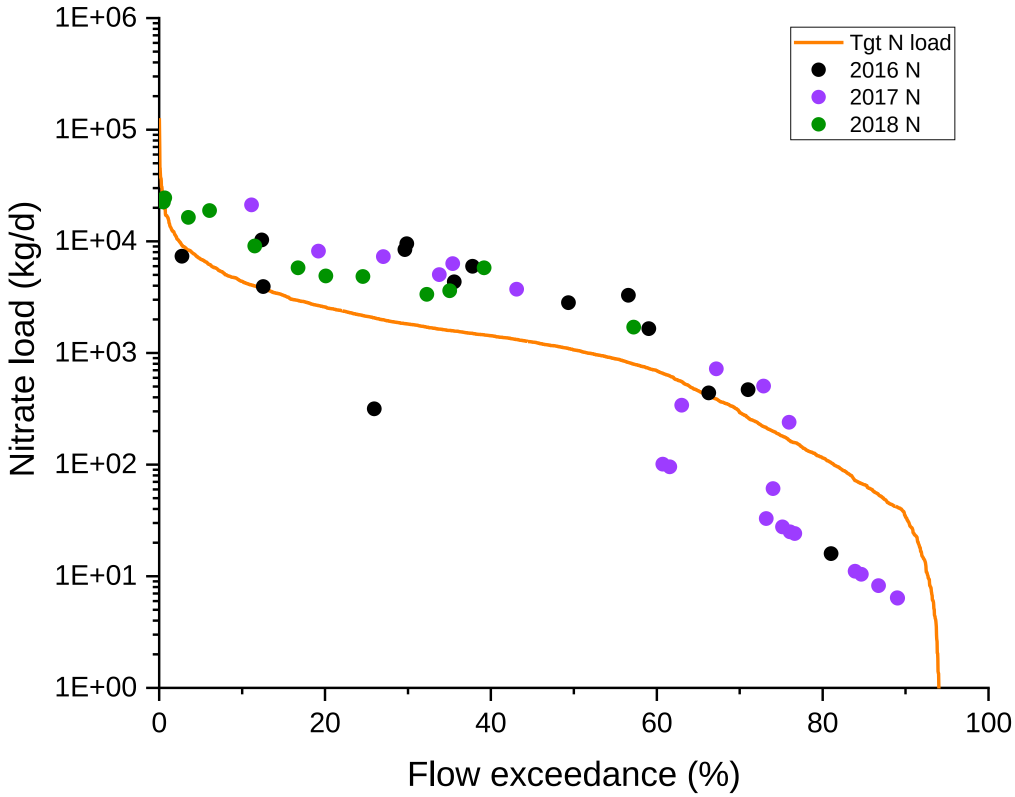

Fig 3: Squaw Creek nitrate load duration curve, categorized by sampling year (color coded: 2016, 2017, 2018). Target TN concentration is 3.26 mg/L.

Seasonal Comparison: 2016 to 2018 data were combined together, then categorized seasonally (Q1, Q2, Q3, and Q4). This comparison allowed identification of nitrate export patterns in each quarter, regardless of the year. Q1 covers January through March but no sampling was done during this period, and thus excluded in this analysis. Q2 includes samples from April to June, with medium to high flow conditions (i.e. less than 50 % flow exceedance), in general (Fig 4), which can be dependent on accumulated snow and precipitation. As Q2 consists of the planting and early growing season, higher nitrate concentrations and loads were observed during this period. None of the samples collected during Q2 met the target daily TN load. Q3 begins in July and ends in September, which covers the growing season. As nitrates are consumed by crops during this period, nitrate leaching is expected to decrease, and subsequently, lower nitrate loading was observed. Warmer temperatures also contribute to in-stream denitrification. The nitrate loads in Q3 during low flow (>70% flow exceedance) conditions met the target daily nitrogen load, but exceeded the target load during higher flow conditions. Q4, which consists of the late-growing and harvest seasons, includes October, November and December. Fall nitrogen fertilization also may occur during this period. Since the sampling season ended in late-October, Q4 only contained few data points collected in October in this analysis. Using only October data, Q4 appeared to have similar nitrate export pattern as Q3. The daily nitrate loads met the target during low flow conditions, but not during higher flow conditions. Crop fertilization and manure application typically occur late fall, after harvest. Therefore, we recommend extending the monitoring season to capture potential nitrate leaching that occurs after harvest (e.g. November 15).

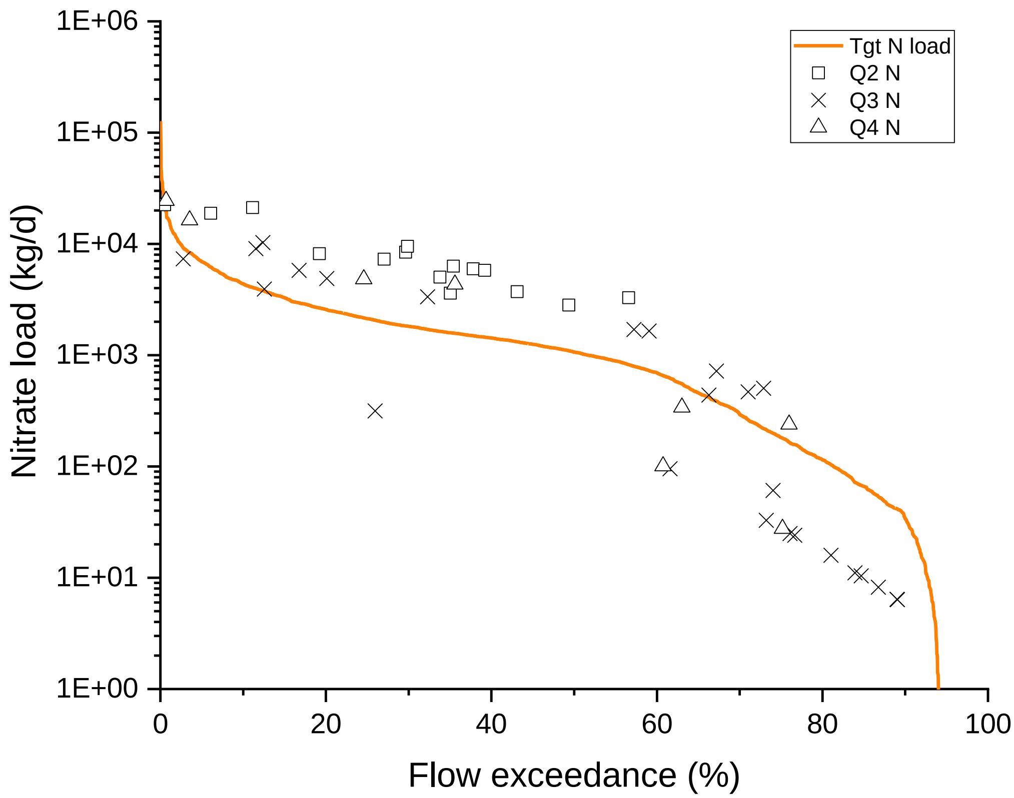

Fig 4: Squaw Creek nitrate load duration curve, categorized by sampling season (symbol coded: Q2, Q3, Q4). Q2 represents April to June; Q3 represents July to September; Q4 represents October. Target TN concentration is 3.26 mg/L.

Overall comparison: All 2016-2018 data were combined, then grouped based on years and quarters (e.g. 2016 Q2, 2016 Q3, etc.). This comparison allowed a more detailed examination of daily nitrate loads that could vary between years and seasons (Fig. 5).

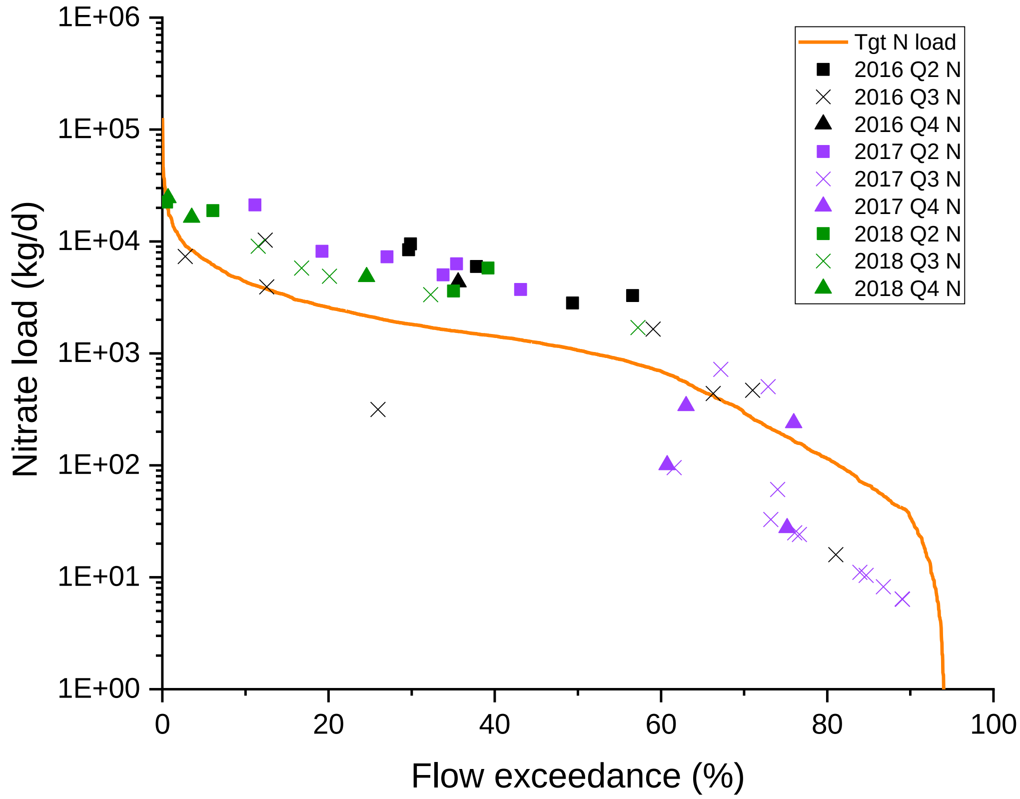

Fig 5: Squaw Creek nitrate load duration curve, categorized by sampling year (color coded: 2016, 2017, 2018) and season (symbol coded: Q2, Q3, Q4). Target TN concentration is 3.26 mg/L.

Most of the flows during 2016 Q2 fell within the medium flow range (20-60 % flow exceedance), while all daily nitrate loads were above the target nitrogen load. Meanwhile, 2016 Q3 nitrate loading pattern was less consistent regardless of the flow conditions. The extremely low nitrate load observed in 9/8/16 (i.e. the 2016 Q3 daily load at 26% flow exceedance) composite sample was due to short-term dilution resulted from the storm, and was confirmed using nitrate sensor readings from Iowa Water Quality Information System. In 2016, Q4 samples were collected during medium-high (30% flow exceedance) flow, and had higher daily nitrate load than all but one (9/28/16, which is close to Q3 period beginning on October 1) Q3 daily loads. However, note that there was only one Q4 nitrate sample collected in 2016 Q4, and thus limiting us to confirm the data consistency.

The majority of the nitrate export in 2017 occurred during Q2, which had the highest flow and highest nitrate concentration in 2017. All but one daily nitrate load (6/28/17, which is close to the Q4 period beginning on July 1) during this period exceeded the target nitrogen load. In 2017 Q3 had the lowest nitrate load compared to all other periods between 2016 and 2018 due to the extremely low flow conditions (> 70% flow exceedance) and nitrate concentrations. When stream flow was lower, the longer in-stream retention time, combined with warm summer temperatures, likely led to greater in-stream denitrification. In addition, the contribution of nitrate from tile drainage may have reduced or ceased, and thus allowing more dilution from other water sources that contain lower nitrate concentration. Nitrate loads in 2017 Q4 were slightly elevated after several storm events in the early October, but 3 out of the 4 estimated daily nitrate loads were still below the target nitrogen load.

Daily nitrate loads in 2018 Q2 were comparable to those in 2016 Q2 and 2017 Q2, which exhibited high nitrate concentrations and medium flow conditions. Meanwhile, flows during 2018 Q3 and Q4 were considerably elevated (< 40% flow exceedance), and thus increasing nitrate loads during this period. All 2018 daily nitrate loads exceeded the target nitrogen load.

Overall, the nitrate loads often exceeded the target nitrogen load at flow exceedance lesser than 60%. At low flow conditions (60-90% flow exceedance), all nitrate samples had concentrations below 3.26 mg/L, hence meeting the target nitrogen load. As discussed above, warmer temperatures, longer in-stream retention time and lower tile drainage likely explain the low nitrate concentrations observed during this period. A dry (zero-flow) period was not observed between 2016 and 2018.

<u>Phosphorus load duration curve (Squaw Creek):</u>

Since TP and nitrate concentrations were essentially analyzed from the same samples, the distribution of samples across various flow conditions (i.e. whether samples were collected during high or low flow) in each year was the same as described in the nitrate load duration curve discussion. No obvious patterns in annual phosphorus loads were found under various flow conditions, as almost all daily TP loads exceeded the target TP load (Fig 6).

**Phosphorus concentration is heavily dependent on flow conditions. Since grab samples (i.e. non flow-weighted) and time-weighted samples (2017) were used, the provided LDC for TP should only be used as a rough estimation. **

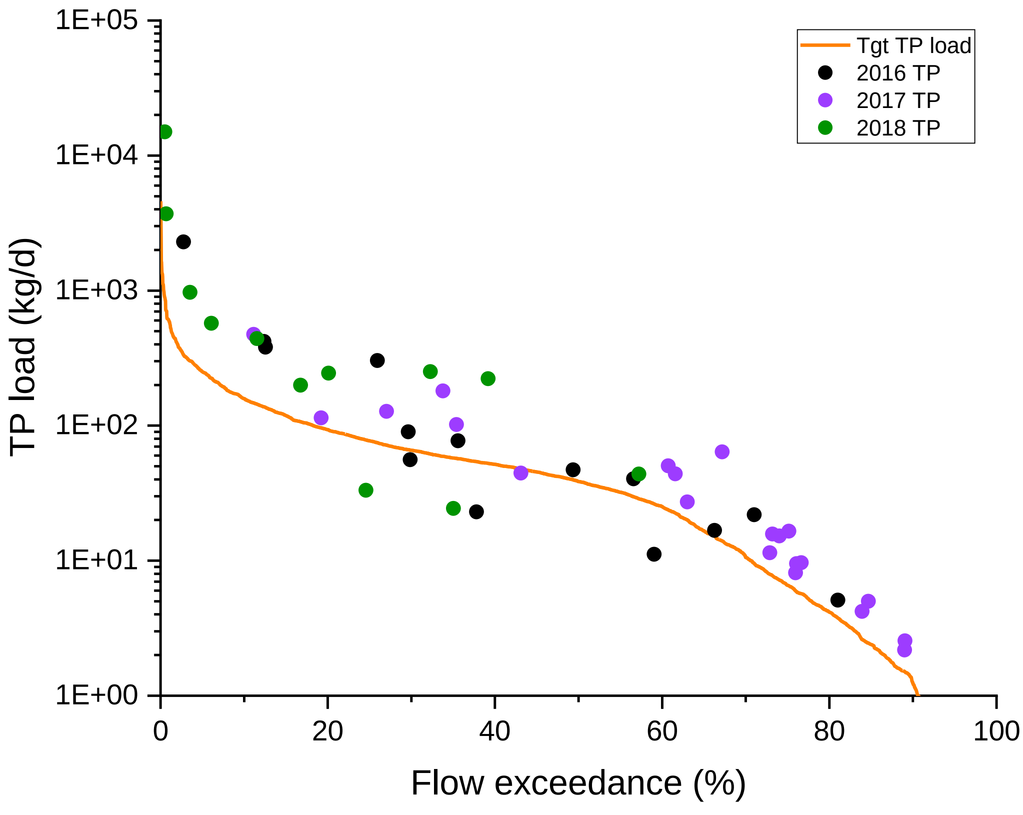

Fig 6: Squaw Creek total phosphorus load duration curve, categorized by sampling year (color coded: 2016, 2017, 2018). Target TP concentration is 0.118 mg/L.

As mentioned above, the TP and nitrate concentrations were essentially analyzed from the same samples, and therefore, the distribution of samples across various flow conditions (i.e. whether samples were collected during high or low flow) in each quarter was the same as described in the nitrate load duration curve discussion. No obvious pattern in seasonal phosphorus loads was found under various flow conditions, as almost all daily TP loads had exceeded the target TP load (Fig. 7).

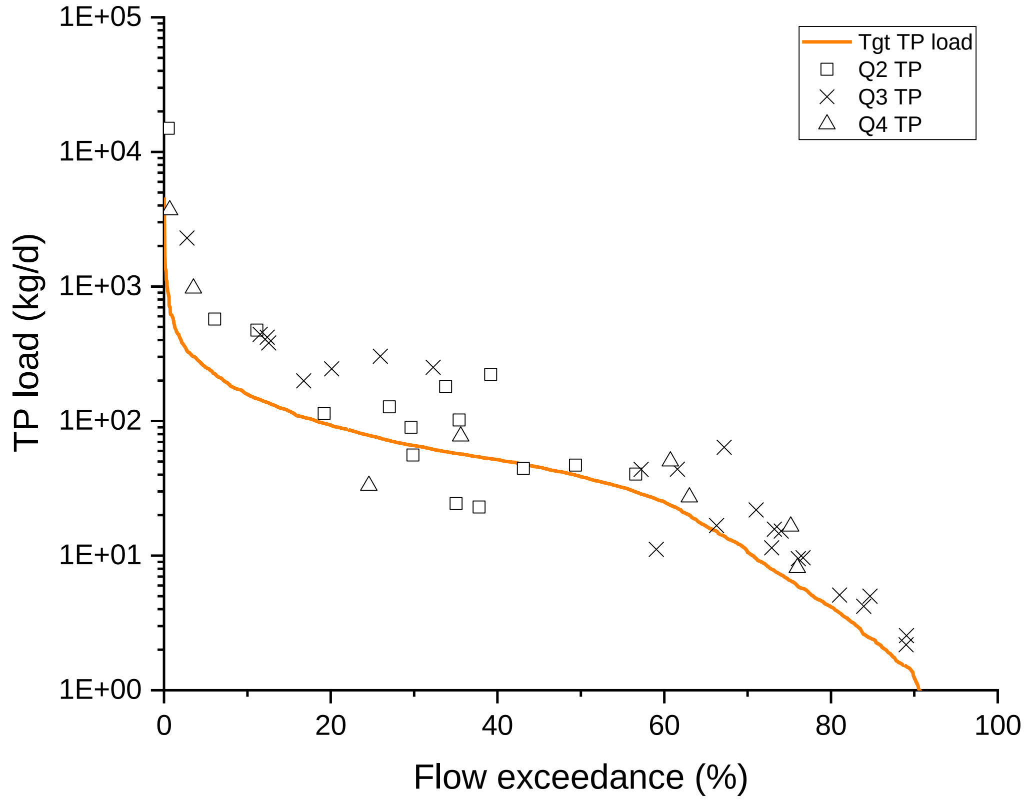

Fig 7: Squaw Creek total phosphorus load duration curve, categorized by sampling season (symbol coded: Q2, Q3, Q4). Q2 represents April to June; Q3 represents July to September; Q4 represents October. Target TP concentration is 0.118 mg/L.

Overall comparison: In general, TP concentrations tend to remain stable during base flow conditions, but can vary greatly during storm events. TP samples collected during the "rising limb" of an event hydrograph (this is also commonly known as "first flush") would have the highest concentration when compared to samples collected during other sections of the same event hydrograph. In contrast, the "falling limb" of the event hydrograph would have lower TP concentrations. Without using flow-weighted samples, the TP loads presented in Figs 5, 6 and 7 are less representative of the actual conditions, especially for the TP loads during higher flow conditions (e.g. < 40 % flow exceedance). In reality, all the "daily TP loads" on the left of Figs 5, 6 and 7 are expected to shift up (i.e. higher loads) since the TP concentrations during high flow conditions were likely underestimated. Nevertheless, there were some TP samples with exceptionally high concentrations (Fig 12), and thus suggested that those samples were collected during high flow conditions.

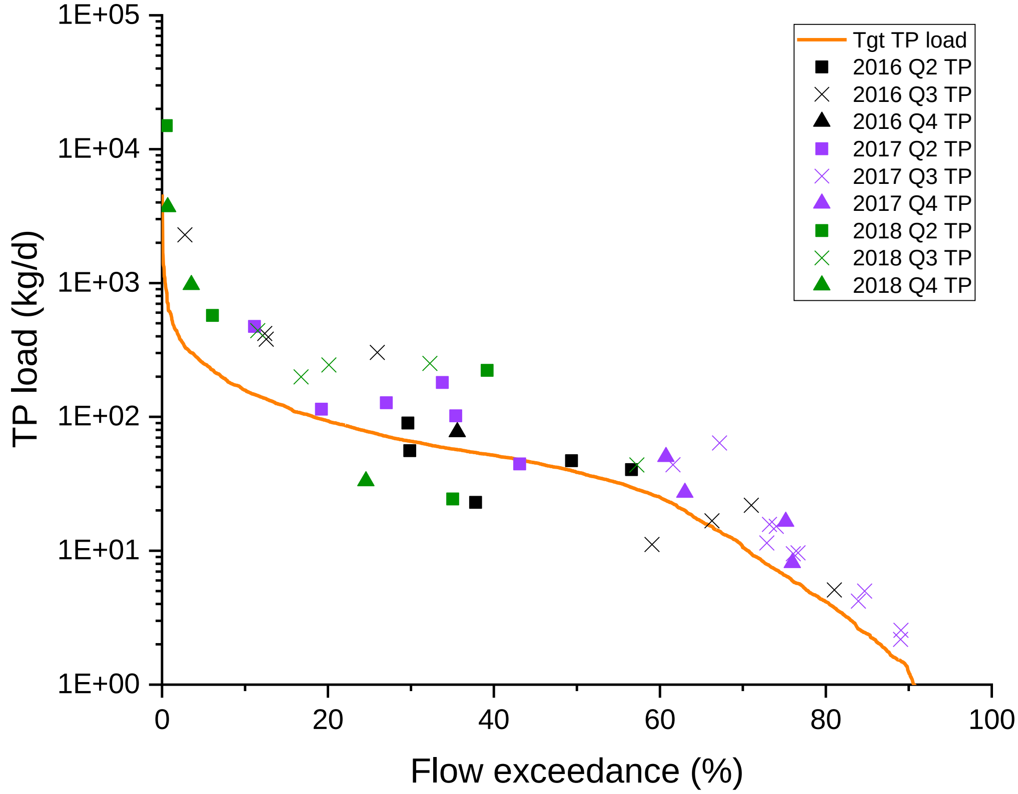

Fig 8: Squaw Creek total phosphorus load duration curve, categorized by sampling year (color coded: 2016, 2017, 2018) and season (symbol coded: Q2, Q3, Q4). Target TP concentration is 0.118 mg/L.

The LDC figures show that the majority of the daily TP loads exceeded the target daily TP loads, regardless of the years and seasons. Since fresh water systems are typically phosphorus limited, locally, Squaw Creek potentially has a greater phosphorus pollution concern than nitrate, and in-stream eutrophication may be triggered when flows are low and temperatures are warm.

Annual nitrate loading (Squaw Creek):

Based on the available data, the annual nitrate load in Squaw Creek was only estimated for the period between April 15 and October 31 of each year. The annual nitrate loads were 15.3, 15.2, and 29.3 kg N/ha in 2016, 2017, and 2018, respectively.

As shown in Fig 9, approximately half or more (43 to 96%) of the annual nitrate export occurred during Q2, when nitrate concentrations (above target concentration at 3.26 mg/L, see Fig 10) and flows (between medium and high flow range, see Figs 3-5) were higher. Although 2016 and 2017 were "normal" precipitation years, both the years had different precipitation and outflow patterns (see Figs 1 and 2, and discussion in "Hydrology" section above), and therefore, different magnitudes (by %) of nitrate export were observed in each quarter of a year. Briefly, precipitation depth in 2016 Q2 were slightly below the 30-year average, while precipitation depth in 2017 Q2 was higher than the 30-year average (Fig 1). Meanwhile, Q3 and Q4 in 2016 received more precipitation than Q3 and Q4 in 2017. Similar to the precipitation pattern, 2017 Q2 also had greater outflow volume than in 2016 Q2, while both 2017 Q3 and Q4 had lower outflow volume than in 2016 Q3 and Q4 (Fig 2). This supports the observation which showed that higher % of nitrate load were exported in 2017 Q2 than in 2016 Q2, relative to the Q3 and Q4 nitrate loads in respective years. Although 2017 Q3 and 2018 Q3 had similar outflow (by %), the higher nitrate concentration (Fig 10) observed in 2018 Q3 led to a higher nitrate export (by %) during this period. While Q4 of each year appeared to have the lowest nitrate load (by % or kg/ha), it should be noted that Q4 only included October, and higher nitrate load contribution would be expected if post-harvest season (i.e. November and December) data were included.

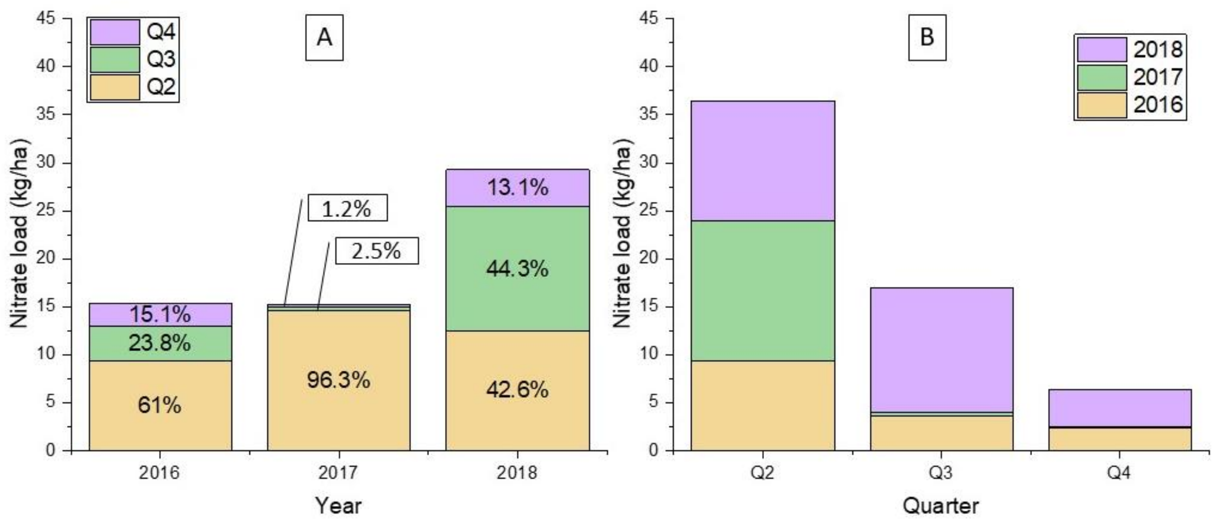

Fig 9: (a) Estimated annual nitrate loads from Squaw Creek in 2016, 2017, and 2018; (b) Estimated seasonal nitrate loads from Squaw Creek in each quarter of the year.

Temporal trends in water quality (Squaw Creek and East Indian Creek):

Squaw Creek Nitrate: As shown in Fig 10, the seasonal medians in Q2 of all years are greater than in Q3 and Q4. The 2016 Q2, Q3, and Q4 seasonal nitrate medians were 13.0, 3.4, and 9.0 mg/L, respectively. All nitrate samples in 2016 Q2 exceeded target total nitrogen concentration at 3.26 mg/L. A steep decreased in nitrate concentration from 13.0 to 3.4 mg/L was observed between 6/22/16 and 7/13/16 samples. The nitrate concentrations in Q3 were rather inconsistent, and no clear relationship was found between nitrate concentrations and antecedent precipitation depths. Nitrate concentration appeared to increase in the late-Q3 period, and continued to rise in the early-Q4, which could be due to increased nitrate leaching resulting from the largest precipitation event on 9/23/16.

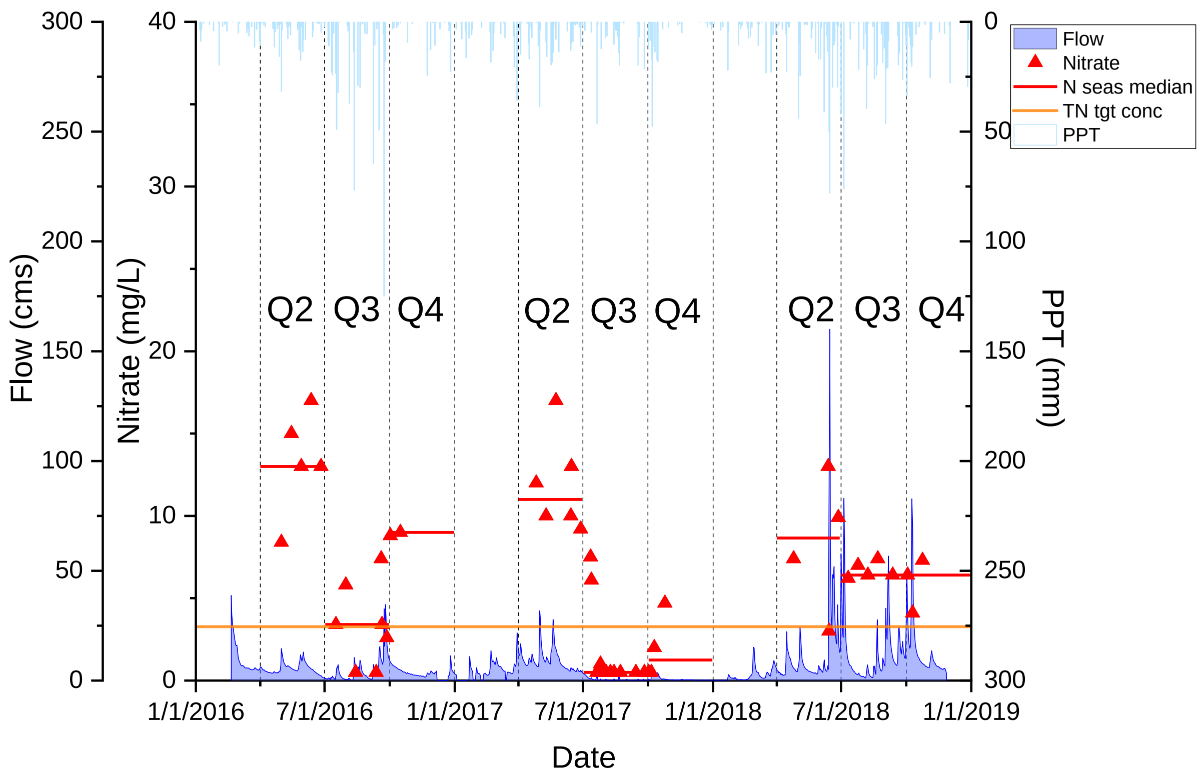

Fig 10: 2016-2018 Squaw Creek nitrate concentrations (red triangle symbol, left y-axis), seasonal nitrate median (red horizontal line, left y-axis), daily average flow (dark blue, left y-axis), and daily precipitation (light blue, inversed right y-axis). Target TN concentration is 3.26 mg/L (orange horizontal line, left y-axis).

see Figs S1-S3 for zoomed-in versions of Fig 10 in 2016, 2017, and 2018, respectively

Meanwhile, the 2017 Q2, Q3, and Q4 seasonal nitrate medians were 11, 0.5, 1.25 mg/L, respectively. All nitrate samples in 2017 Q2 exceeded target nitrogen concentration at 3.26 mg/L. The nitrate concentration decreased gradually from 9.2 mg/L (6/28/17) to 7.5 mg/L (7/12/17), 6.1 mg/L (7/13/17), then remained below 1 mg/L for the remaining of Q3 period. 2017 Q3 was extremely dry, and nitrate contribution from tile drainage was likely reduced. As mentioned in the LDC discussion, longer in-stream retention time and warmer temperatures likely resulted in greater denitrification efficiency within the stream. The nitrate concentration gradually increased again in Q3 after a fairly large storm event (47 mm) on 10/6/17.

Finally, the 2018 Q2, Q3, and Q4 seasonal nitrate medians were 8.7, 6.4, and 6.4 mg/L, respectively. All but one (6/14/18) 2018 samples exceeded the target nitrogen concentration. The large and prolonged storm events in June and July, along with potentially higher than usual legacy nitrogen from 2017 (dry year), are possibly the major contributors to the high nitrate concentrations observed in 2018 Q3 and Q4.

<u>Squaw Creek *E. coli:*</u> All but one (4/25/18) *E. coli* sample exceeded the EPA recommended water quality standard for primary contact recreational purpose (Class A1) (Iowa DNR, 2018). When assessing individual samples, the single sample maximum (SSM) criteria at 235 MPN/100 mL was used. Although DNR only requires 7 samples from recreational season (March 15-November 15) to compute the geometric mean, the *E. coli* concentration may vary on a weekly, or even daily and hourly, basis. The more accurate assessment method is to compare the 30-day geometric mean (not less than 5 samples) of *E. coli* concentration, which is recommended for recreational water quality criteria sampling (U.S. EPA, 2010). The EPA recommended standard for *E. coli* geometric mean is 126 MPN/100 mL. None of the recreational season (or annual) geometric means successfully met SSM or geometric mean criteria, and thus suggesting that Squaw Creek is pathogen impaired. The geometric means were 1794, 2804, and 2629 MPN/100 mL in 2016, 2017 and 2018, respectively. In general, the *E. coli* concentrations in each year followed a bell-shaped curve, which *E. coli* concentration began to increase from Q2, peaked at Q3, then decreased during Q4. This bell-shaped trend of *E. coli* concentration is likely a response to the temperature, dominantly. Other factors such as wildlife (e.g. waterfowls), grazing intensity, confined animal feeding operations (CAFOs) runoff, and precipitation also can affect *E. coli* concentration.

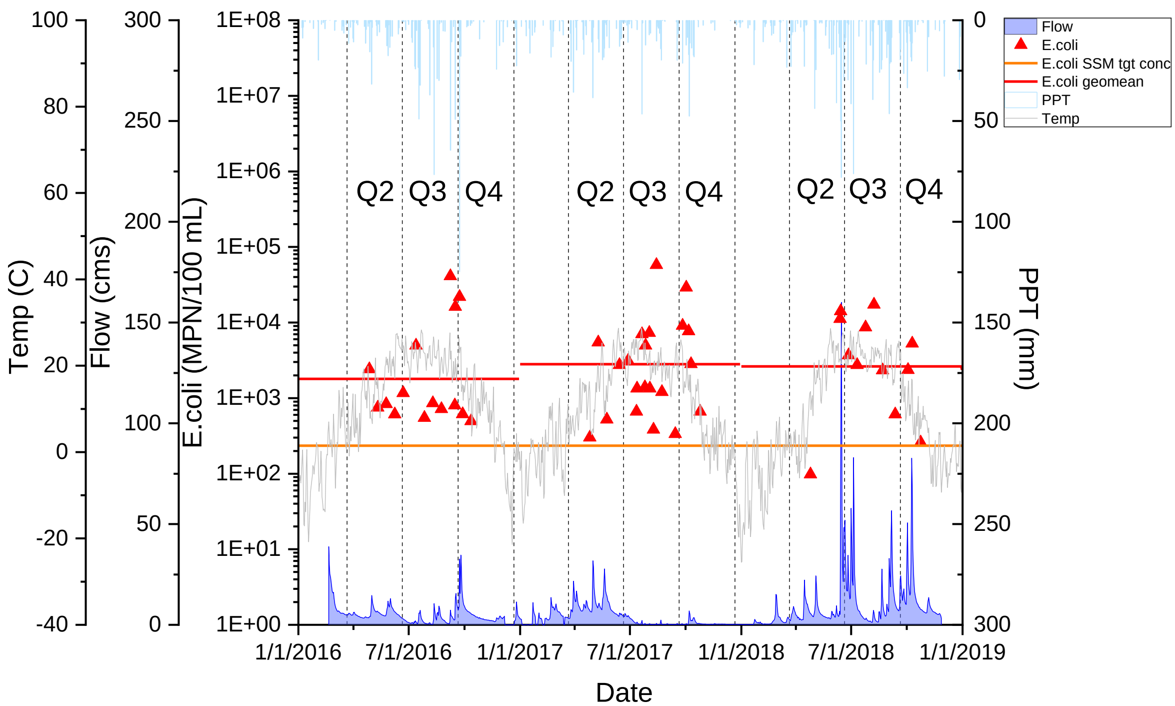

Fig 11: 2016-2018 Squaw Creek *E. coli* concentrations (red triangle symbol, left y-axis), recreational season *E. coli* geomean (red horizontal line, left y-axis), daily average flow (dark blue, left y-axis), daily mean temperature (grey, left y-axis), and daily precipitation (light blue, inversed right y-axis). SSM target *E. coli* concentration is 235 MPN/100 mL (orange horizontal line, left y-axis). Geometric mean target *E. coli* concentration is 126 MPN/100 mL (not plotted).

see Figs S4-S6 for zoomed-in versions of Fig 11 in 2016, 2017, and 2018, respectively

In 2016, *E. coli* concentration peaked in the late-Q3. The large precipitation events (9/8/16 and 9/23/16) appeared to increase *E. coli* concentration in Squaw Creek, which could due to increased runoff from manure-applied landscapes, and resuspension of *E. coli* from streambed sediments (Pandey et al., 2012).

The high *E. coli* concentrations in 2017 Q2 were possibly contributed by the higher precipitation in 2017 spring, which may contribute to greater runoff from manure-applied landscapes. Meanwhile, many of the 2017 Q3 samples had lower *E. coli* concentrations, and were collected during low flow conditions. Reduced *E. coli* source (lower input load and less resuspension from streambed) and shallower stream depth (better penetration of sunlight) may have contributed to this observation. Decreasing concentrations were observed as temperature decreased in Q4.

As shown in Figs 11 and S6, most of the *E. coli* concentrations in 2018 Q3 remained above 2018 geometric mean. This observation was likely due to the elevated flow conditions (higher manure runoff, more resuspension from streambed) in 2018 Q3. *E. coli* concentrations also appeared to decrease in 2018 Q4, similar to the observations in 2016 and 2017.

Squaw Creek Total Phosphorus: As discussed, TP samples were not flow-weighted and did not represent TP concentrations during storm events. However, the annual medians should reflect the typical TP concentrations across the range of flow. The annual medians for two normal years were 0.16 and 0.21 mg/L, respectively, in 2016 and 2017. The annual median for 2018 (wet year) was 0.45 mg/L. These high medians indicated that Squaw Creek often had TP concentrations exceeding recommended concentration of 0.118 mg/L, even during base flow conditions. Only 14.6% of the 3-year samples successfully met the recommended TP concentration.

Grab samples were collected during base flow or more than 24 hours after heavy precipitation events, while time-paced composite samples (9/8/16, 9/16/16, 9/23/16) were collected during the storm events. The TP concentrations of the storm composite samples were among the highest in 2016. The concentrations were 0.48, 0.33, and 0.81 mg/L for 9/8/16, 9/16/16, and 9/23/16 sample, respectively. Meanwhile, the 9/28/16 grab sample collected during the falling limb of the event also had third highest TP concentration (0.36 mg/L) in 2016. The 2016 seasonal medians were 0.14, 0.27, and 0.16, respectively, for Q2, Q3, and Q4. 2016 Q3 had a higher median due to the influence of high concentration composite samples collected during late-Q3.

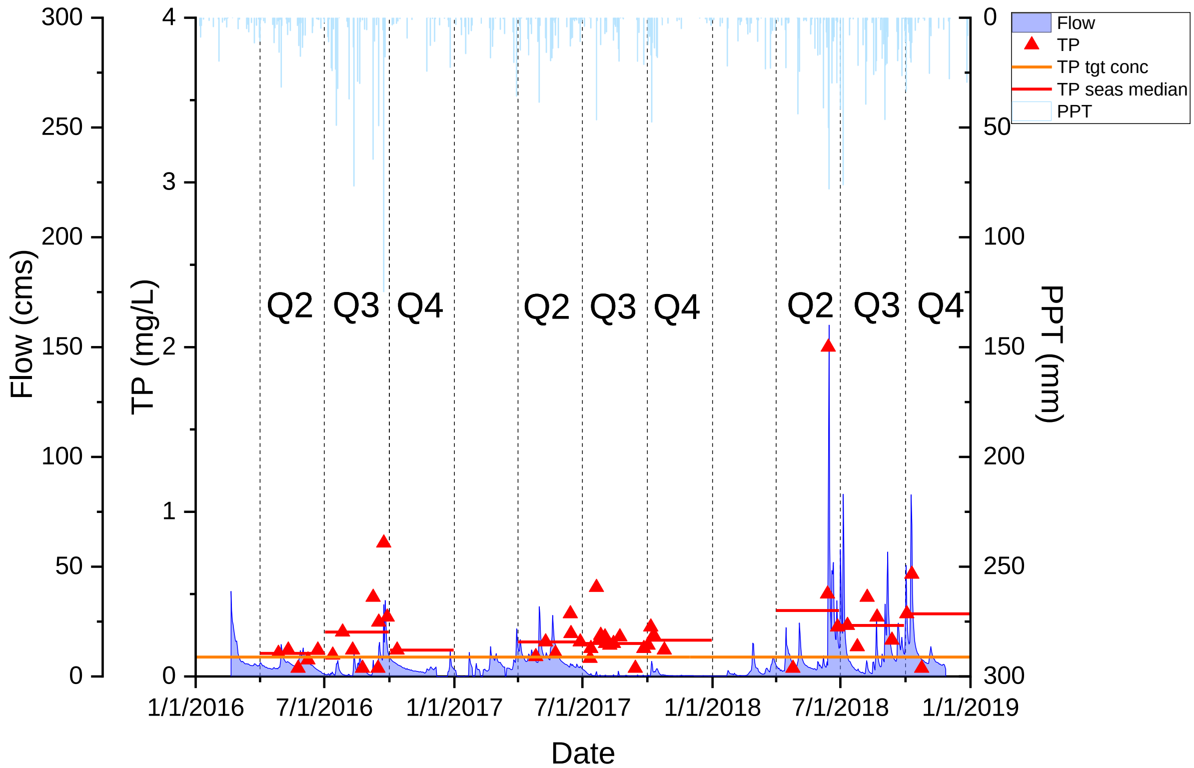

Fig 12: 2016-2018 Squaw Creek total phosphorus concentrations (red triangle symbol, left y-axis), seasonal TP median (red horizontal line, left y-axis), daily average flow (dark blue, left y-axis), and daily precipitation (light blue, inversed right y-axis). Target TP concentration is 0.118 mg/L.

see Figs S7-S9 for zoomed-in versions of Fig 12 in 2016, 2017, and 2018, respectively

The TP seasonal medians in each quarter of 2017 were rather consistent. Q2, Q3, and Q4 had seasonal median of 0.21, 0.20, and 0.22 mg/L, respectively. The 2017 sample with the highest TP concentration was collected on 7/21/17, which was one day after the second largest storm event (46.7 mm precipitation) in 2017. The lowest TP concentration in 2017 was observed in the 9/14/17 sample after a prolonged dry period in the mid-Q3. A series of precipitation events beginning 9/15/17 had appeared to re-elevate TP concentrations in Squaw Creek, and reached its peak (0.30 mg TP/L) on 10/6/17, which was the day with the largest storm event (47.6 mm precipitation) in 2017.

2018 had higher cumulative precipitation depth than an average year, and had higher TP annual median than 2016 and 2017. The seasonal medians in each quarter of 2018 were also similar. Q2, Q3, and Q4 had seasonal median of 0.4, 0.31, and 0.38 mg/L, respectively. The 3-year record highest TP concentration (2 mg/L) was observed in 6/14/18, which the sample was collected during the rising limb (peaked in 6/15/18) of the 3-year record largest event (based on daily flow rate).

<u>*Squaw Creek Total Suspended Solids:*</u> As expected for a wet year, 2018 (280 mg/L) had the highest annual median TSS concentration when compared to 2016 (27 mg/L) and 2017 (51 mg/L), Fig. 13. In 2016, Q3 had the highest seasonal median due to influence from the storm event composite samples collected in the late-Q3. It was also unclear why the 7/27/16 sample had such a high TSS concentration, even though no precipitation was observed for the previous 5 days. The Q2, Q3, and Q4 seasonal medians were 19, 260, and 27 mg/L, respectively.

In 2017, Q2 had the highest seasonal median (80 mg/L) because most of the annual flow occurred during this period (Figs 13 & S11). Meanwhile, Q3 (32 mg/L) and Q4 (34 mg/L) had similar seasonal medians as the flow conditions during these periods remained low.

2018 Q2 had the highest seasonal median due to the influence from the samples collected during the largest recorded storm event (6/14/18) in the 3-year of sampling period. The reason for the high TSS concentration observed on the 4/25/18 is unknown as no precipitation was observed in the previous 5 days. The seasonal medians for Q2, Q3, and Q4 were 441, 52, and 120 mg/L, respectively.

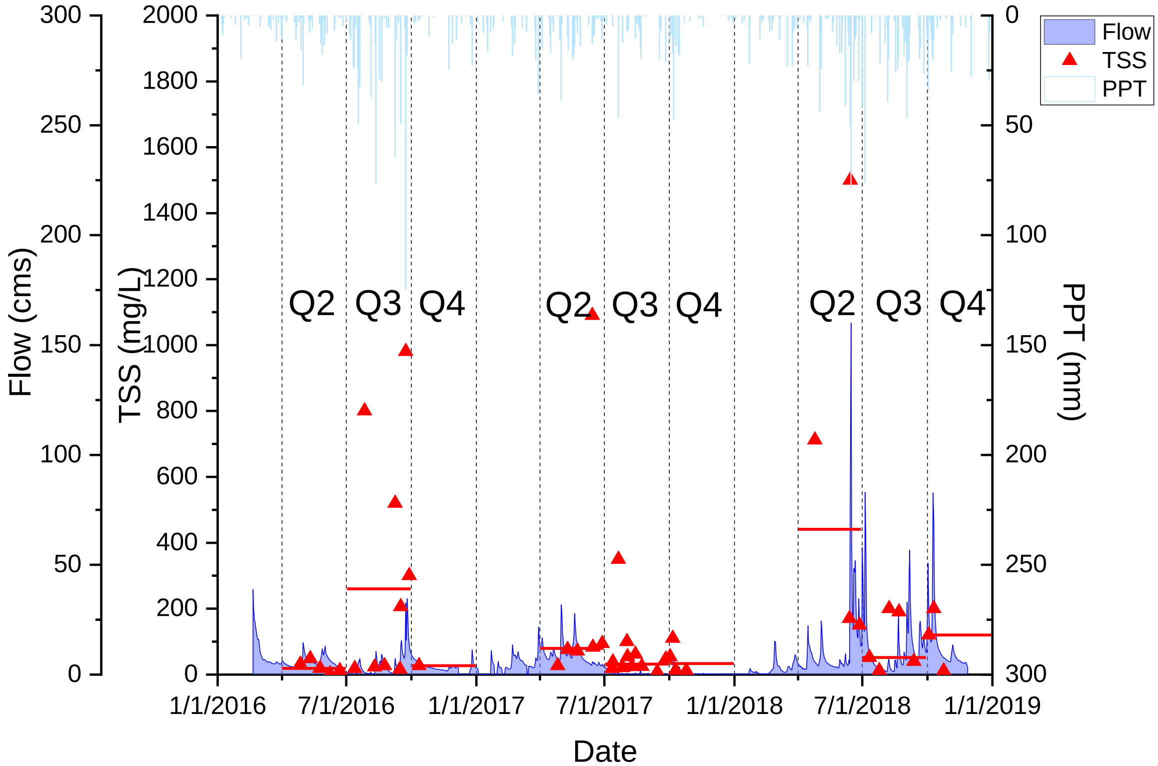

Fig 13: 2016-2018 Squaw Creek total suspended solid concentrations (red triangle symbol, left y-axis), seasonal TSS median (red horizontal line, left y-axis), daily average flow (dark blue, left y-axis), and daily precipitation (light blue, inversed right y-axis).

see Figs S10-S12 for zoomed-in versions of Fig 13 in 2016, 2017, and 2018, respectively

<u>*East Indian Creek Nitrate:*</u> The seasonal medians of Q2 in all the three monitoring years were very similar, and were higher than seasonal medians of Q3 and Q4 in its respective year (Fig 14). All the samples collected during Q2 were also above the recommended TN concentration at 3.26 mg/L. In 2016, the seasonal medians of Q2, Q3, and Q4 were 10.0, 6.8, 7.1 mg/L, respectively. Q3 and Q4 had a similar seasonal median, but note that Q4 only consisted of one sample collected on 10/12/16. Meanwhile, the seasonal medians of 2017 Q2, Q3, and Q4 were 10.0, 0.5, 3.3 mg/L respectively. Although flow data is not available in East Indian Creek, the flow data in Squaw Creek suggested that 2017 Q3 flow was extremely low. Similar to the nitrate discussion for Squaw Creek, the dry condition in East Indian Creek had allowed greater extent of denitrification to occur within the stream, and therefore, a low seasonal median nitrate concentration was observed. The storm event on 10/6/17 gradually increased the nitrate

concentration in the early-Q4. Finally, the seasonal medians of Q2, Q3, and Q4 were 11.0, 5.6, and 5.0 mg/L, respectively. None of the 2018 samples met the recommended TN concentration, which was likely due to the consistently wet conditions.

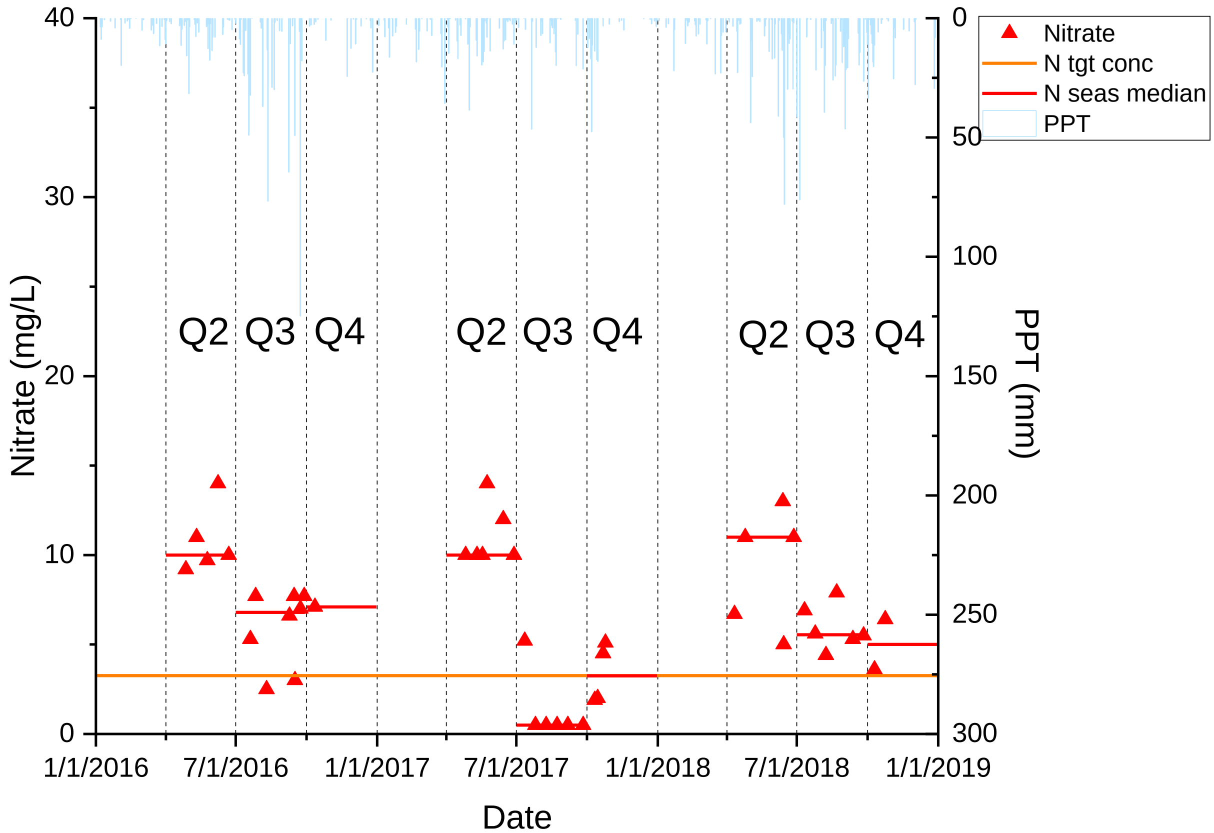

Fig 14: 2016-2018 East Indian Creek nitrate concentrations (red triangle symbol, left y-axis), seasonal nitrate median (red horizontal line, left y-axis), and daily precipitation (light blue, inversed right y-axis). Target TN concentration is 3.26 mg/L (orange horizontal line, left y-axis).

see Figs S13-S15 for zoomed-in versions of Fig 14 in 2016, 2017, and 2018, respectively

<u>*East Indian Creek E. coli:*</u> Indian Creek is also designated for primary contact purpose (Class A1) (Iowa DNR, 2018). All but three *E. coli* samples exceeded the EPA recommended single sample maximum criteria at 235 MPN/100 mL (Fig 15). The three samples that met the SSM criteria were the first or first two earliest samples collected in each year, when the water temperature was lower. The recreational season (or annual) geometric means were 1169, 1518, and 913 MPN/100 mL for 2016, 2017, and 2018, respectively. Similar to Squaw Creek, the East Indian Creek is also considered pathogen impaired as the recreational season geometric means in all years exceeded the recommended criteria for *E. coli* geometric mean (126 MPN/100 mL).

In 2016, the *E. coli* concentration peaked on 7/20/16 (9048 MPN/100 mL), and again between 9/9/16 and 9/23/16 (between 5460 and 5848 MPN/100 mL). The *E. coli* concentration quickly decreased in the early-Q4.

Typically, Q3 would have greater *E. coli* concentrations than Q2. The higher-than-average precipitation in Q2 may have contributed to the higher *E. coli* concentrations in Q2. In contrast, the lower precipitation in

Q3 may have resulted in lower *E. coli* concentration during this period. However, this inconsistent trend in *E. coli* concentration in Squaw Creek and East Indian Creek during this period makes it more difficult to draw a firm conclusion. The concentration in the Q4 appeared to be decreasing, and likely to remain low as temperature decreased for the rest of the year.

The 2018 *E. coli* concentrations peaked on 6/14/18, which was during the largest storm event (based on flow data in Squaw Creek). Most of the high concentration *E. coli* samples were collected during Q3 or early-Q4, while the latest sample collected in Q4 may indicated that the *E. coli* concentration was likely to decrease further as temperature decreased in Q4.

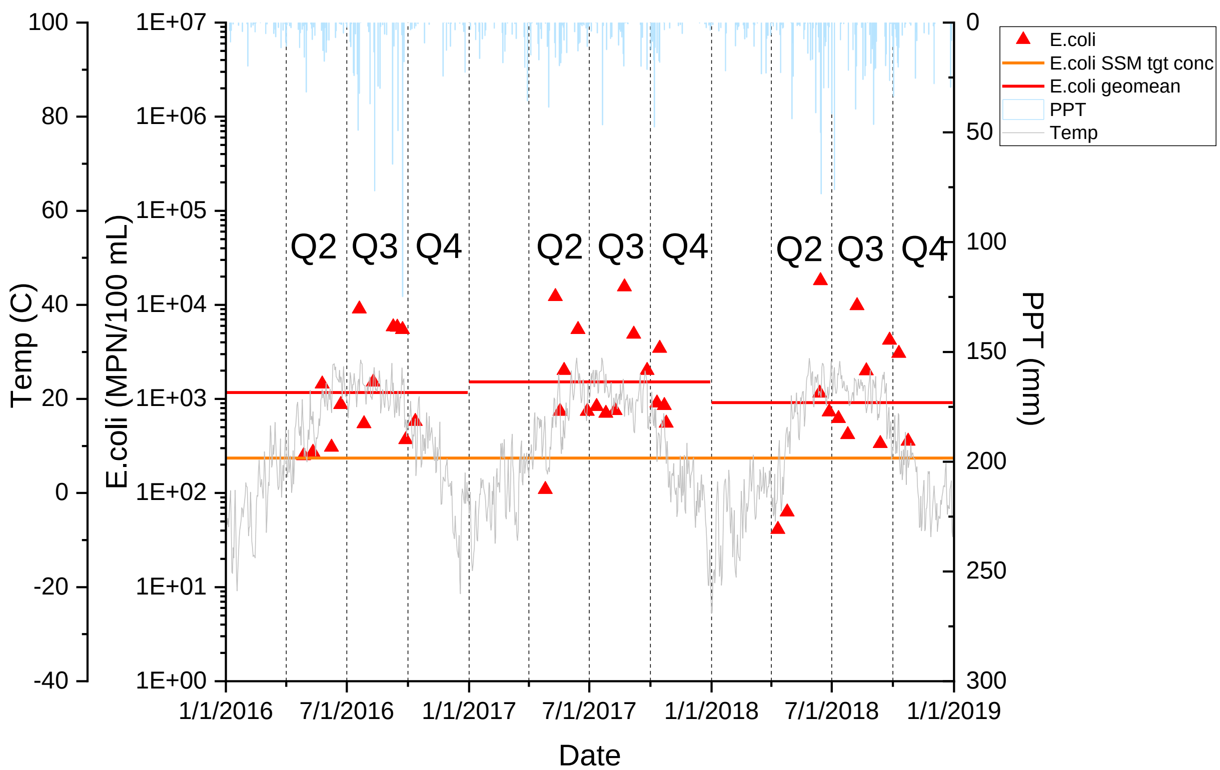

Fig 15: 2016-2018 East Indian Creek *E. coli* concentrations (red triangle symbol, left y-axis), seasonal *E. coli* median (red horizontal line, left y-axis), daily mean temperature (grey, left y-axis), and daily precipitation (light blue, inversed right y-axis). SSM target *E. coli* concentration is 235 MPN/100 mL (orange horizontal line, left y-axis). Geometric mean target *E. coli* concentration is 126 MPN/100 mL (not plotted).

see Figs S16-S18 for zoomed-in versions of Fig 15 in 2016, 2017, and 2018, respectively

<u>*East Indian Creek Total Phosphorus:*</u> As TP concentration is heavily dependent on flow, the lack of flow data in East Indian Creek posed additional challenge to provide insightful discussion on the behavior of TP concentration. Discussions on individual samples were not attempted for the reason above. Nevertheless, the following discussions were made by comparing the seasonal medians, which were assumed to represent the TP concentrations during base flow conditions in respective years and seasons. Precipitation data was also used to support the discussion.

The TP seasonal medians of Q2, Q3, and Q4 in 2016 were 0.05, 0.23, and 0.05 mg/L, respectively. The higher seasonal median observed in Q3 was likely due to the higher frequency and intensity of precipitation that occurred during the same season (i.e. wet summer). The TP seasonal medians of Q2, Q3, and Q4 in 2017 were similar. They were 0.15, 0.17, and 0.18 mg/L, respectively. No distinct pattern was found in 2017 TP data. Finally, the TP seasonal medians of Q2, Q3, and Q4 in 2018 were 0.25, 0.20, and 0.31 mg/L, respectively. The 2018 seasonal medians were fairly similar, and the slight difference in medians was contributed by the high TP concentration samples (i.e. 6/14/18, 10/10/18). Overall, TP concentrations in East Indian Creek appeared to be lower than in Squaw Creek.

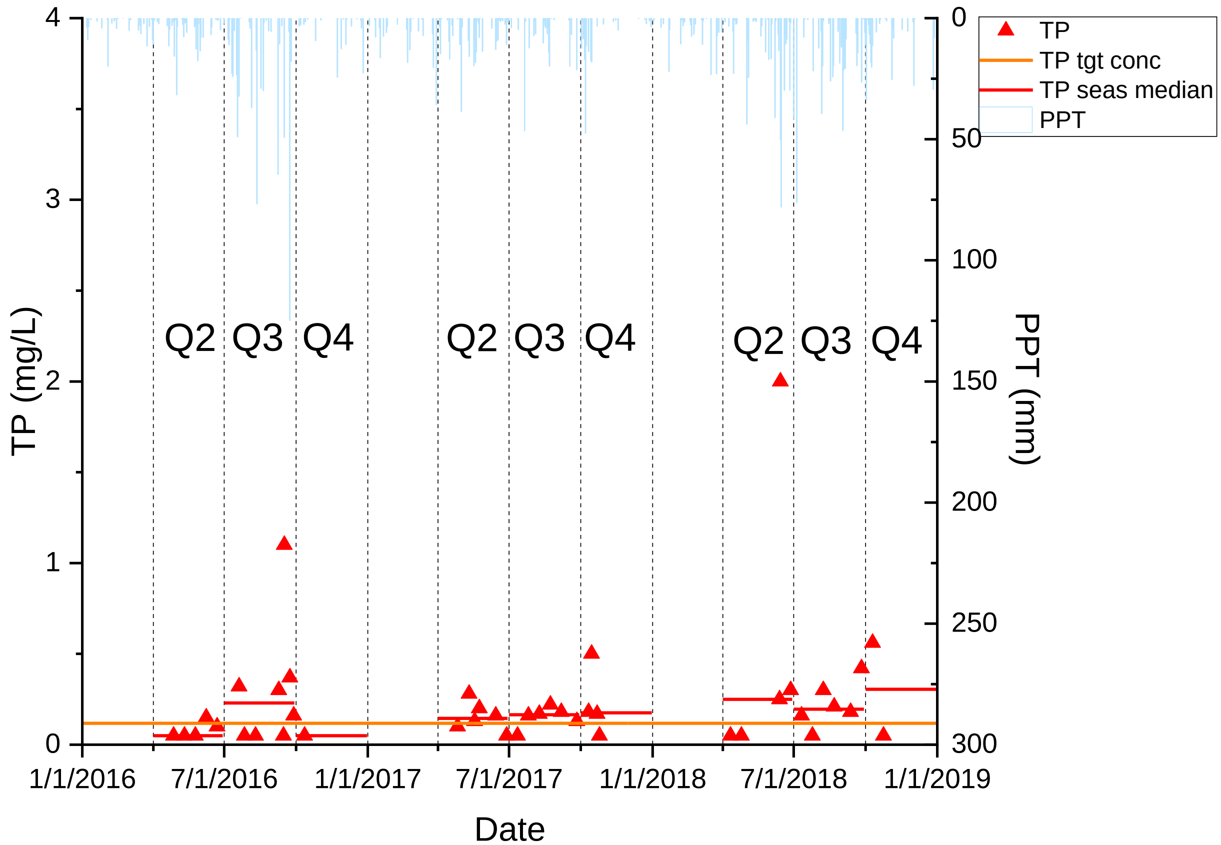

Fig 16: 2016-2018 East Indian Creek total phosphorus concentrations (red triangle symbol, left y-axis), seasonal TP median (red horizontal line, left y-axis), and daily precipitation (light blue, inversed right y-axis). Target TP concentration is 0.118 mg/L.

see Figs S19-S21 for zoomed-in versions of Fig 16 in 2016, 2017, and 2018, respectively

<u>*East Indian Creek Total Suspended Solids:*</u> As TSS concentration is heavily dependent on flow, the lack of flow data in East Indian Creek posed additional challenge to provide insightful discussion on the behavior of TSS concentration. Discussions on individual samples or seasonal medians were not attempted for the reason above. Nevertheless, the following discussions were made by comparing the annual medians, which were assumed to represent the TSS concentrations during base flow condition in respective years. The annual medians for 2016 (normal precipitation year), 2017 (normal precipitation year), and 2018 (wet year) were 31, 30, and 41 mg/L. There were less variations in the seasonal medians in each year. In overall, the TSS concentrations in East Indian Creek also appeared to be lower than in Squaw Creek.

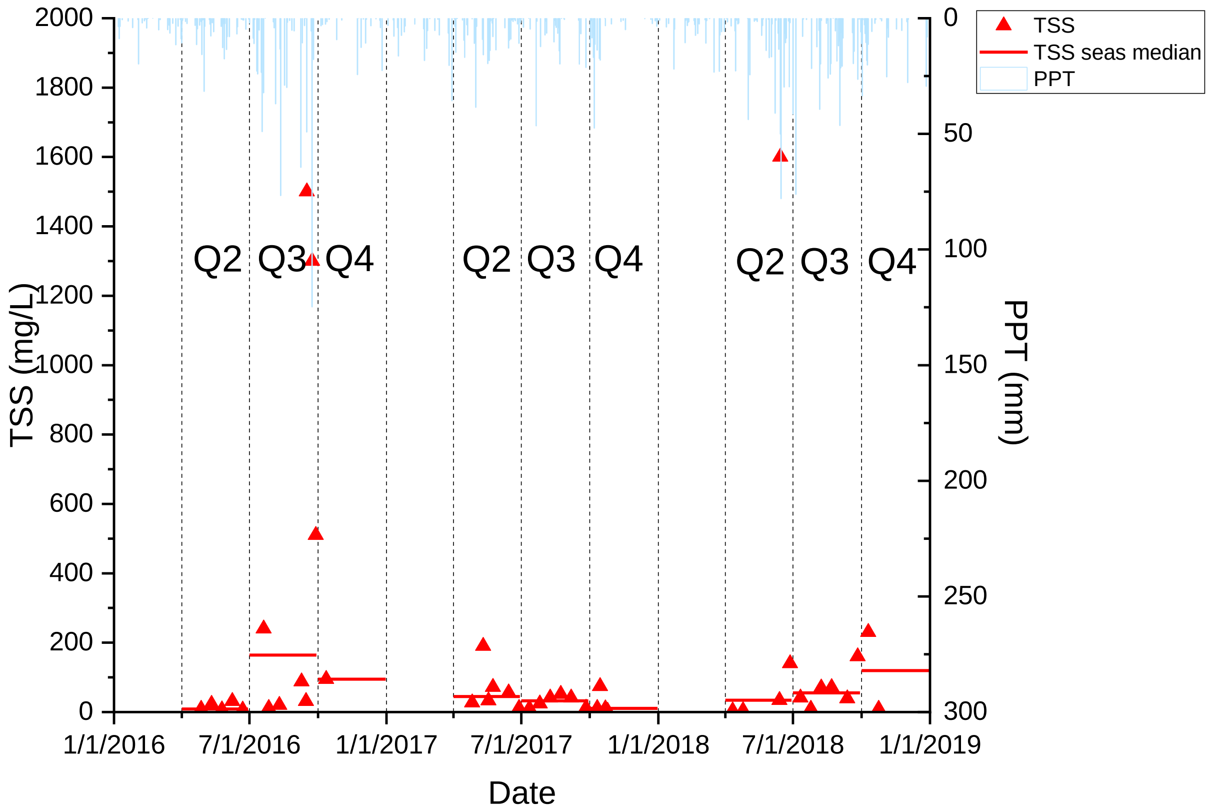

Fig 17: 2016-2018 East Indian Creek total suspended solid concentrations (red triangle symbol, left y-axis), seasonal TSS median (red horizontal line, left y-axis), and daily precipitation (light blue, inversed right y-axis).

see Figs S22-S24 for zoomed-in versions of Fig 17 in 2016, 2017, and 2018, respectively

Correlation analysis on analyte concentrations

When using alpha level of 0.01 (i.e. 1% probability of making error), we observed strong correlations between nitrate, TP, and TSS concentrations between Squaw Creek and East Indian Creek. The correlations and p-values of each analyte are presented in Table 3. No modeling effort was attempted in this analysis/report but there is a potential to develop a model to estimate nitrate, TP, and TSS concentration in East Indian Creek by using monitoring data collected in Squaw Creek. Although grab samples from East Indian Creek may still be needed from time to time to validate the model, the model would help to reduce the overall cost and time.

Analyte	Correlation	p-value
Nitrate	0.8935	0.0001
TP	0.8707	0.0001
TSS	0.6818	0.0001
E. coli	0.3671	0.0254

Table 3: Correlation of analytes between Squaw Creek and East Indian Creek

SUMMARY

The results and discussions for nitrate were reasonably reliable as nitrate concentration tend to remain fairly constant throughout an event hydrograph. Although precipitation will increase nitrate leaching, the nitrate concentration during the rising limb and falling limb of the hydrograph is not expected to change significantly, unlike *E. coli*, TP, and TSS. Meanwhile, the discussion of *E. coli*, TP, and TSS results were the best deductions based on the limited data. Approaches to improve dataset quality are suggested in the "recommendations" section below. Please refer to Table 1 for summary discussions for respective project questions.

FUTURE MONITROING RECOMMENDATIONS

Nitrate, TP and TSS sampling:

We recommend beginning annual monitoring in March (or as soon as the snow melts) to capture the period with highest nitrogen export. Phosphorus and sediment loading during this period also may be among the highest of the year due to large volume of surface runoff. In addition, we would also recommend extending the monitoring period through November to capture nutrient export during the post-harvest season, especially if there are expected fall manure and fertilizer applications in the watershed. The use of an automated water sampler (e.g. ISCO 6712) to collect flow-weighted samples also will improve the estimation of nutrient (especially phosphorus) and sediment loading.

E. coli sampling:

If accurate *E. coli* quantification is important, we would recommend using 30-day geometric mean (not less than 5 samples) approach, which allows unbiased "average" that does not over-weigh one or two samples, and thus minimizing the impact of daily and weekly variations (U.S. EPA, 2010). However, this intensive sampling approach can be cost-prohibitive. If the monitoring objective is only to determine if the streams are impaired, then the current monitoring data would be sufficient to suggest that both Squaw Creek and East Indian Creek are pathogen impaired. Collecting *E. coli* samples during same time of the day also may help to minimize the uncertainties contributed by UV light and temperature.

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