Coles Creek Watershed:
Flow and Fisheries Monitoring, 2016-2018

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1.0 Background and Objectives

The city of Charlottetown has developed a municipal water wellfield in the Coles Creek watershed at Miltonvale PEI (hereafter the Miltonvale well field). The Canadian Rivers Institute at the University of Prince Edward Island and at INRS was contracted by the Province of PEI to begin monitoring Coles Creek in 2016 in order to: 1) establish baseline flow data for Coles Creek, and changes to flow post-pumping, and 2) to quantify the fish community and productivity of Coles Creek. The report represents a summary of the pre-pumping data starting in June 2016 and the results subsequent to periodic pumping that began in 2017 and 2018. Summer low flow and fall fish endpoints are the major items under study during this period.

2.0 Coles Creek Description, Pumping, Flow and Temperature, Monitoring

2.1 Coles Creek Watershed

Coles Creek is a relatively small 13 km^2 watershed that is considered part of the North River watershed, though technically it is a distinct watershed in its own right as it drains directly into the North River estuary. Coles Creek land use is heavily dominated by agricultural activity (67% of land area) with 14% forests, and less than 2% wetland, mostly in the form of ponds. Portions of the headwaters are significant degraded with little or no riparian cover or gravel substrate. However, much of the intermediate and downstream reaches have mature riparian cover with excellent habitat for brook trout. As a small coastal watershed, Coles Creek has a maximum elevation of about 70 m. Coles Creek has no substantive permanent tributaries, most of the flow into the stream is derived from groundwater input that emerges either in, or in very close proximity to the stream (<50 m). This simplifies biological monitoring as most tributaries are ephemeral and fish habitat outside of the main stem of the stream is negligible to non-existent.

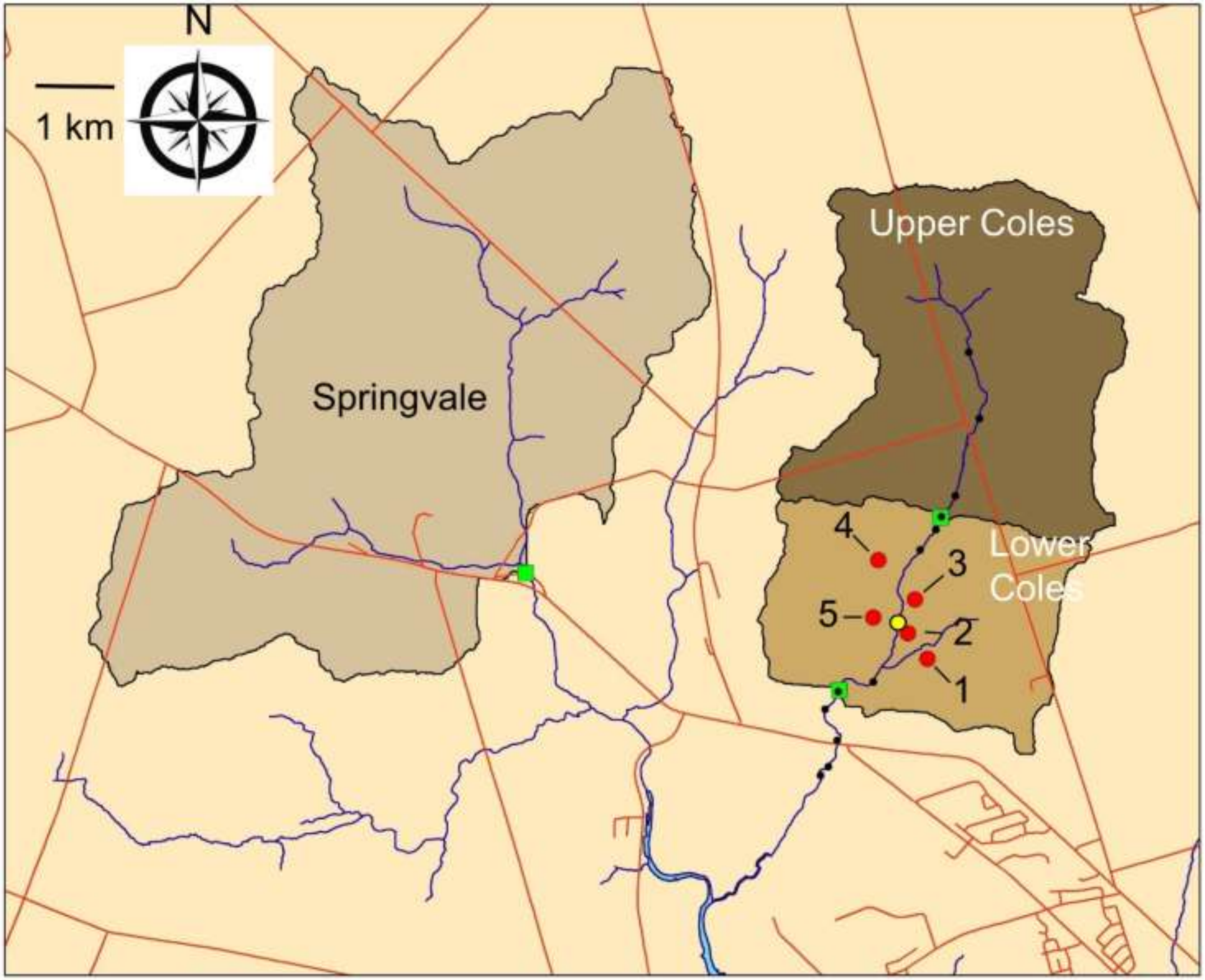

Figure 1. Springvale, Upper Coles, and Lower Coles sub-watersheds. Lower Coles includes the Upper Coles area. Red circles represent the City of Charlottetown wells. Green square are the UPEI flow measurement stations. The yellow circle is the ECCC hydrometric station. Black dots represent the start of electrofishing reaches and a temperature logger was place at each station. Number 1-5 are the well designations.

2.2 Miltonvale wellfield pumping

Pumping of Coles Creek began in 2017. No record of the date, or month, or approximation thereof when pumping started has been provided by the City of Charlottetown other than during 2017, though presumably it was late 2017. It was reported that test pumping was periodic, and water may or may not always have been removed from the watershed in 2017. The only data provided was the total volume of water pumped during 2017 and this was 17,303 m^3. Assuming this occurred across at least three months, and was continuous (likely not), this would represent just less than 3% of the permitted 4.77 m^3/min permitted (1050 igm, 6869 m^3/d). Pump flowmeters became operational in 2018 and daily flows have been provided by the City of Charlottetown since then. Pumping was not consistent due to technical difficulties with pumps for much of 2018. Coles Creek was either not pumped, or volumes were negligible for most of January and February 2018 (Figure 2). Pumping was periodic, most often several days of no pumping, interspersed with pumping at rates below 10% of the permitted maximum flow for several days until July 2018. Pumping ramped up in July to about 25% of the permitted maximum, though interspersed with periodic days of no pumping. The longest period of uninterrupted pumping in 2018 was from July 30 until August 18. The maximum rate of pumping was reached on August 16 and was 90% of the permitted maximum for that day only. The highest month of pumping was August with an average of 1.65 m^3/min (35% of 4.77 m^3/min permitted). Taken as a 30 day daily running average, the highest average pumping rate ended on August 22 and was 1.77 m^3/min, representing only 37% of allowable pumping rate over those 30 days. Pumping again declined precipitously to low levels for September and through fall 2018 was characterized by several days of high pumping, followed by weeks of no pumping.

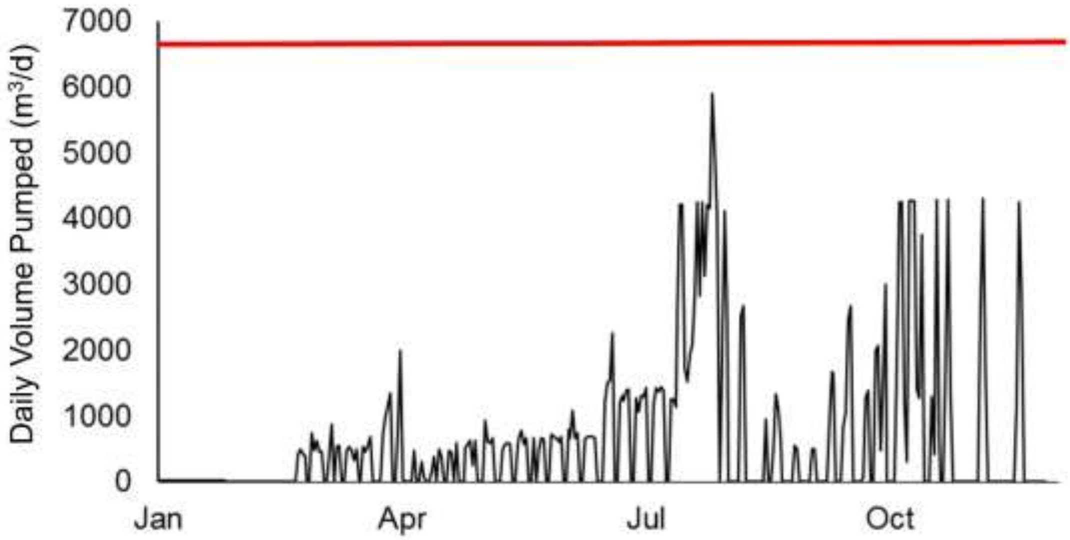

Figure 2. Miltonvale wellfield daily pumping volume in 2018. Red line indicates maximum allowable of 6,869 m^3/d.

2.3 Flow monitoring from 2016-2018

In order to monitor flow pre- and post-wellfield operation, two stilling wells, or permanent stream level loggers were installed in June 2016, above (Upper Coles) and below (Lower Coles) the wellfield (Figure 1). An additional station was also established in an adjacent branch (Springvale) of the North River Watershed. The watershed areas above the flow stations were 0.58, 0.98, and 1.50 km^2 for Upper Coles, Lower Coles, and Springvale Branch of the North River, respectively. Ongoing manual flow measurements were conducted at the stilling well locations approximately every two weeks for flow calibration. Due to minor variations in flow-water height (stage) curves (rating curves) that can cause inaccuracies at low flow levels, rating curves are recalculated at least every year (typically from winter to winter as significant changes in patterns were observed to occur during winter floods). A three-parameter rating curve in the form of Flow = C x (stage –a)^B was used as it minimizes and normalizes residuals between observed and estimated flow, particularly at low flow conditions. Changes to the flow-stage relationship often occurred during winter when large rain/snowmelt events cause significant erosion.

Estimated flows (every half hour) calculated from the rating curve at the time of manual flow collection compared well with the directly measured flows (Appendix I).

A continuous hydrograph from June 2016 to December 2018 was constructed using daily average flows from Upper and Lower Coles Creek and the Springvale Branch of the North River, near old Route 2 (Figure 3A). Typically the Springvale Branch has the highest flows, followed by Lower Coles, followed by Upper Coles in proportion with the sub-watershed area. Monthly average flows allow an evaluation of flow patterns between years (Figure 3B). These patterns are remarkable in the differences between years in terms of spring and fall flows. Lower Coles has been shown for illustration purposes (Figure 3B), the seasonal pattern between the three locations was virtually identical. The hydrographs are most consistent in the late summer low flow period. September is most commonly the month with the lowest mean flow.

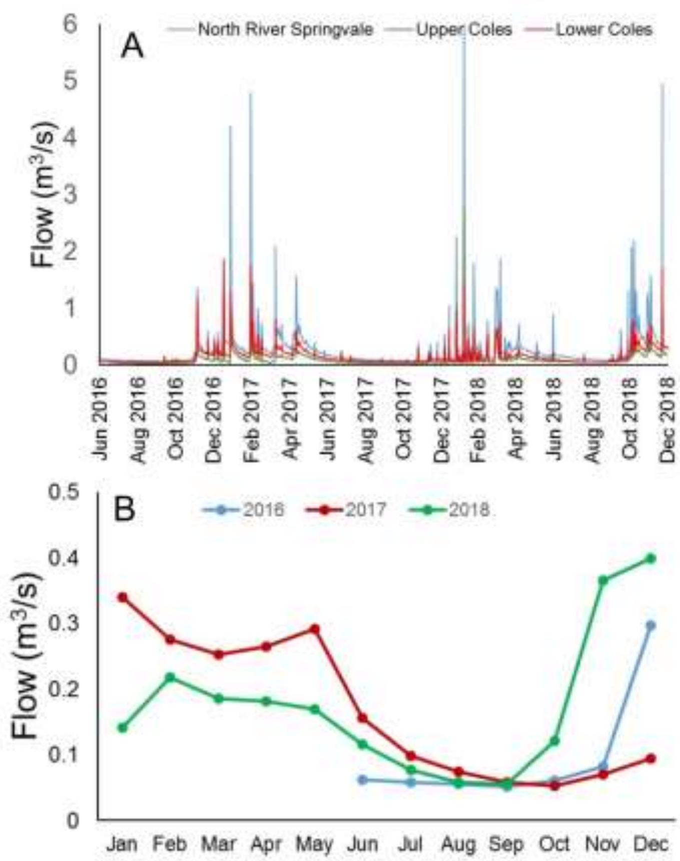

Figure 3. Flow patterns in Upper Coles Creek, Lower Coles Creek, and the Springvale branch of the North River showing A) daily average flow, and B) mean monthly flow of Lower Coles Creek.

The only exceptions to this were in 2017 for which October was the lowest flow month for all three stations. August is also typically very similar in flow to October, and is most consistently low from year to year due to consistently low precipitation, and for the purposes of this report will also be considered as the low flow month.

2.4 Flow alteration

Given the limited record of flow in Coles Creek, alternative methods were devised to estimate flow deviation due to pumping of the wellfield. The first method is a comparison of flow between the Coles Creek stations and the Springvale Branch of the North River. As flow in adjacent watersheds is generally closely correlated, any deviation from this relationship (taking 2016 and 2017 as the baseline) can be thought to represent the rate of extraction from the stream itself. There are a number of caveats and assumptions to this method. Firstly, this assumes that the Miltonvale wellfield does not result in extraction in the nearby Springvale Branch of the North River. While some effect is certainly possible, with one small subwatershed in between the two, there is relative confidence in considering this as negligible. Secondly, it assumes that the relationship between any two streams is linear. This is not universally true, but will be approximately true in two closely adjacent watershed of similar size over a restricted range of flow. As the relative size of two watersheds vary, the relationship in daily mean flows becomes more curvilinear as larger watersheds can yield more flow per watershed area at high flows. Collinearity between years is also presumed, however, particularly in the scenario up pumping. The volume amount removed from a stream by pumping will depend on the annual rechanrge and subsequent flow of that stream (baseflow) at any given time and will not likely be constant. However, for the purposes of a general estimation of extraction, this method may provide the only way to obtain a measured estimate outside of groundwater models. The method also assumes most flow in the low flow months will be baseflow, which is certainly known to be the case for PEI. Small rain events can be inconsistent between watersheds and tend to distort or add variability to the relationships, thus rain events should be removed when using this technique to best represent extraction effects on baseflow.

As August was the month with the highest and only consistent pumping, and August was the best month in terms of low rainfall and overall stability of flow, this relationship was examined for August only in 2018 (Figure 4). Only two days of flow data were removed due to small rainfall events over the three years examined. There was a clear downward translation of the Upper Coles-Springvale relationships in August 2018 as compared to 2016 and 2017(Figure 4). The volume (as flow) removed from the stream is represented by the downward translation of the line. The magnitude of this translation was estimated using the 2017 and 2018 data only as these had the most similar flow regime in the Springvale Branch. While the 2016 relationship was collinear to 2017, the much lower flows encountered in 2016 caused some lack of linearity between the pre and post-pumping data (Figure 4a). Using 2017 baseline flow only, the two lines show virtually identical slope and thus provide the most reliable estimate of flow reduction in Coles Creek (Figure 4b). The flow variance was estimated using difference between the ANCOVA least square means (at the average for Springvale) for the two lines and was 0.017 m^3/s (the categorical variable, year, was significantly different and the interaction term indicated no significant difference in slope).

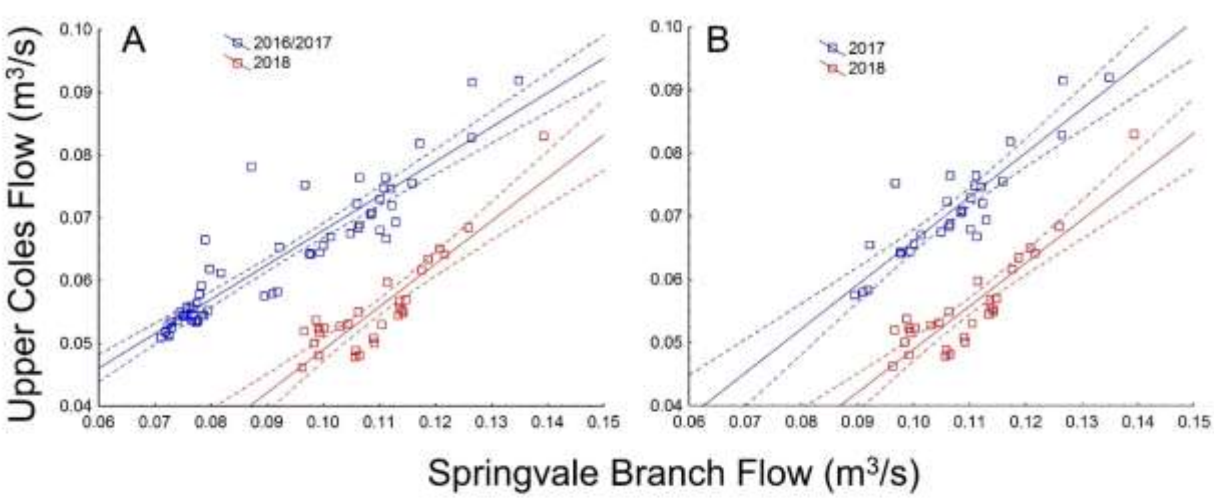

Figure 4. Upper Coles-Springvale Branch flow relationships A) including 2016 data, and B) not including 2016 data.

This analysis shows a 24% drop in Lower Coles 2018 flow from 2017 levels. The stream flows in the months of August and September in 2016, 2017, and 2018 are lower than historical average estimated from the long term stream flow monitoring data in the Dunk River (Figure 5). Thus, the reduction of stream flow by the groundwater extraction in the lower flow scenario of 2018 is expected be higher than an 'average' year. The flow removal from the stream pumping at 66% of permitted capacity at Hw 2 was estimated from the groundwater model to be 0.01 m^3/s in an average year (Qing Li, Environment Water and Climate change, personal communication). Some deviation is not surprising as the groundwater model assumes hydrogeological layers as equivalent porous media on the macroscale while actual flow into the stream is largely from discrete springs that may be differentially impacted depending the that strata they are derived from. Also, the stream flow reduction by the individual wells of the five production wells are varies by the factors of distance between the stream and the wells, local hydrogeology, and pumping rate. Models were estimated with the pumping rate being equal when in fact well number 2, closest to the stream has the highest pumping capacity and the greatest actual pumping rates. Further stream flow and groundwater level monitoring under varied (actual) pumping conditions from five wells will help to understand degree of impacts by the individual wells and can be used to refine the models.

Given the assumption of a relatively constant rate of removal from the stream, the percentage removal is dependent on the actual year to year flow in the stream. Thus, a second method is proposed wherein the annual flow of the stream is hindcast based on a watershed with a longer flow record. These are generally larger watersheds that have longer flow records, and given the above mentioned issues with non-linearity in flow from watersheds of differing areas, this presents challenges. However, this non-linearity is generally induced by rain events. To dampen this effect, monthly flows can be used. The year-and-a-half of Lower Coles Creek data was related to two watersheds West River and Dunk River on the basis on monthly averages (Winter River was excluded for the obvious issues with City of Charlottetown water extraction). The West River produced unsatisfactory variation at low flows (inconsistency in actual vs. ECCC flow data in this river has been observed before by the investigators) resulting in poor correspondence of estimated and actual flows in Coles Creek. When this method was used with the Dunk River ECCC data, it produced a tighter fit, particularly at low flow (Appendix II). Actual vs. estimated flows in Coles Creek for August data matched closely using the Dunk River data.

This allows examination of the question of what is ‘normal’ flow in Coles Creek. Unfortunately this question cannot be answered conclusively as flows on PEI appear to be in a state of change (Figure 5). Unquestionably there have been six consecutive years of relatively lower August flow in PEI. Additional measured flow data collected in year previous to this study at a location 100 m downstream of the present Lower Coles Flow monitoring station provided by the province confirm a large drop in Coles Creek August flow in 2012 as was expected from the Dunk River data. While a significant data quality issue has been observed in these data for previous years (an instantaneous 40% flow drop after year 3), these data still serve to illustrate the general trend. This raises the question as to whether this is abnormal, or is it the new normal? In the context of 40 years of August flow from the Dunk River (with which the estimated Coles Creek flows are directly proportional), flows on PEI are decreasing during this month as there is a statistically significant downward trend from 1961 (Figure 5) driven by the post 2011 low August flows. While it would be natural to suggest climate change, our preliminary models of flow related to climate change suggest that flow in early- to mid-summer will actually be higher and not lower (though year-to-year variability may be higher), so this is opposite to anticipated climate trends (St-Hilaire unpublished data) and such a precipitous drop in flow for half a decade would not necessarily be expected. While this does not preclude climate change, as models can be wrong, it does suggest that other climactic oscillations may be responsible. For example, the Pacific oscillation may be involved, though we could find no evidence of such, and this would largely effect summer conditions. The baseflow conditions in August are largely established the previous fall and winter, and years previous may also impact this. Clearly winter snowfall is not a factor since the highest recorded snowfall on PEI occurred in 2014-2015 during the current low flow period. Further investigation of this will be conducted using the Wilmot River flow model that has been constructed. This method does however provide another basis for determining expected flow in a given period. While observed and expected flows were quite close in 2016 and 2017, considerable deviation was observed in 2018 consistent with pumping in Coles Creek. Considerable caution should be applied to this as 2018 Dunk River flow data were provisional and the model may only be accurate within the lower range of flows in 2016 and 2017 that is was calculated for.

The relationship used for this model almost certainly becomes non-linear over a wider range of flows. This assumption will be tested with Springvale Branch flows (as there is no pumping) in future. However, certainly with two consecutive fall periods with high flow/recharge in 2018, and now 2019, an increase in August flows back to mean levels is expected. Improvement in this relationship may be achieved by using modelled base flows.

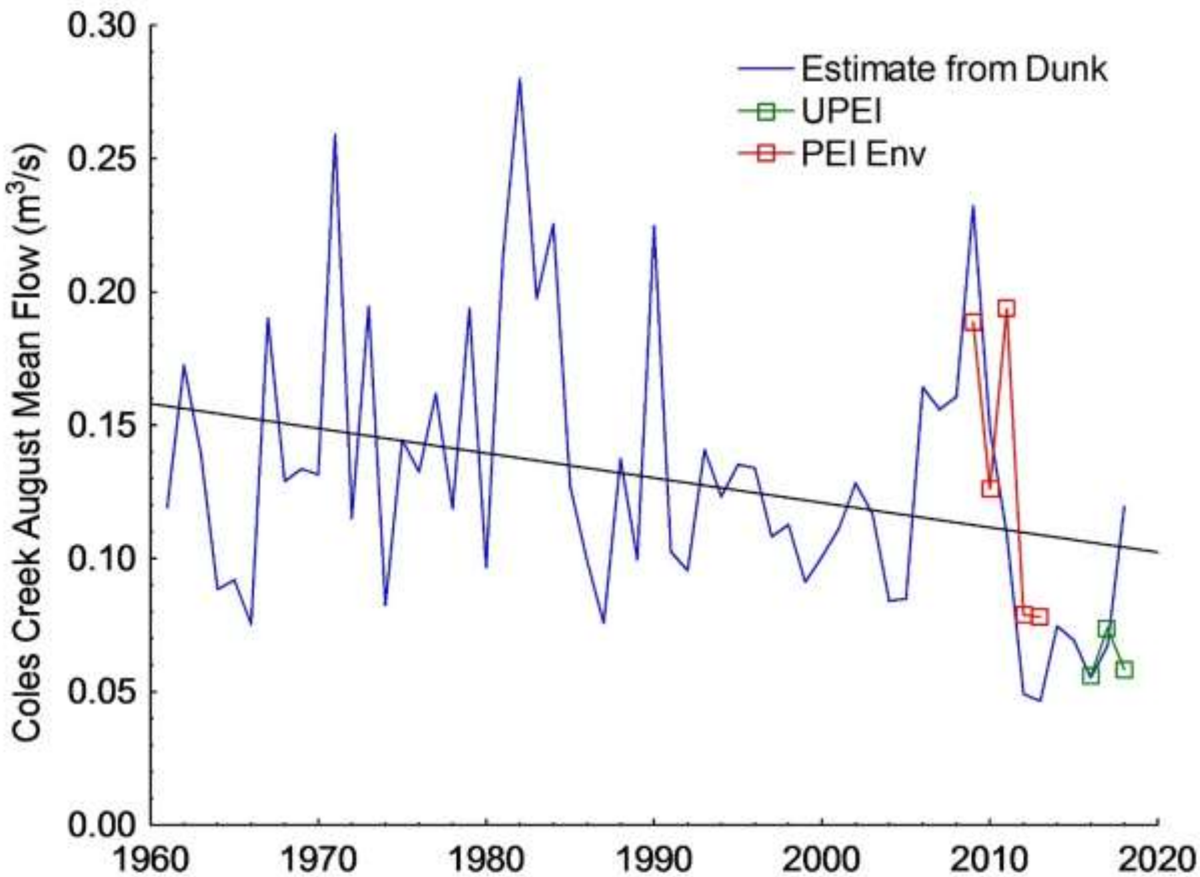

Figure 5. Simulated and actual Coles Creek mean August flow based on Dunk River historic records. Green points are from the current study, red points were provided by the PEI Department of Environment, Water and Climate.

2.5 Coles Creek Temperature

As PEI streams are fed by groundwater, particularly during low flow periods, increases in temperature might be expected as a result of flow reduction due to groundwater extraction. This is particularly critical in light of climate changed-induced warming in future. Water temperature has been collected on the stilling well pressure loggers since 2016. However, as these logger are in the banks (to differing degrees), they reflect a muted or average representation of temperature. To obtain a better estimate of longitudinal temperature changes in Coles Creek, an additional 14 temperature loggers were placed in Coles Creek at the lower end of electrofishing reaches, and at the two stilling wells. Loggers (Hobo tidbit) were placed inside ABS pipe housings and logging was started in June 2018.

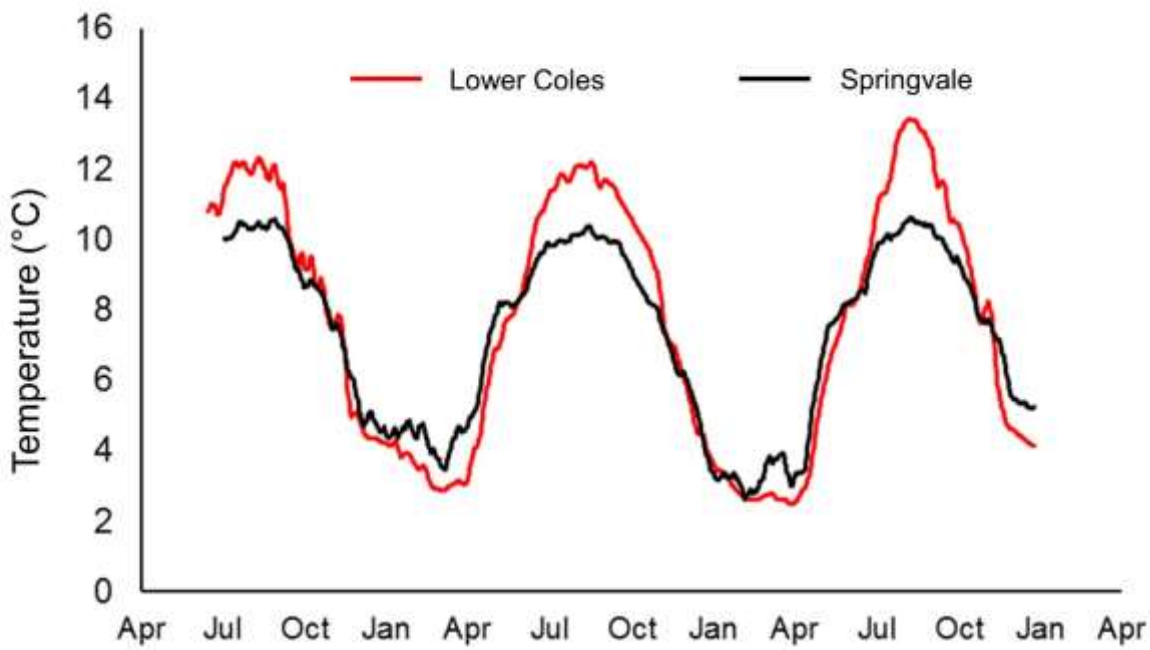

Figure 6. Temperature profile from level loggers in stilling wells over the duration of the study.

Data from the Lower Coles temperature logger is shown with reference to the Springvale logger temperature to take account of year to year variability (Figure 6). August mean temperature at the Springvale branch was 10.4, 10.2, and 10.5°C in 2016, 2017, and 2018, respectively. August mean temperature for Lower Coles was 12.1, 12.0, and 13.2°C, over the identical periods. Given very consistent temperatures in the Springvale branch from year to year, it would appear that there was an approximately

1ºC temperature increase in Lower Coles Creek. This corresponds with the period of highest levels pumping at the wellfield and was not apparent in July and September means (Figure 6), strongly suggesting an effect of pumping.

The longitudinal gradient conducted on Coles Creek temperature indicates that the warmest water is coming from the headwaters (Figure 7A). This is not surprising given the almost complete absence of riparian zones/shade and two ponds in the upper system. However, this gradient also demonstrates the importance of groundwater inputs in cooling this stream, and July and August temperatures indicate a drop from almost 20°C to 13ºC as the stream reaches the wellfield. There was about a 1°C increase into the lower reaches from July to September which is not surprising given fewer springs and more open area between the wellfield and Hw 2. August data suggested that most of the stream temperature increase observed at Lower Coles came after the wellfield. By November when brook trout spawn, temperature was uniformly 5-7ºC throughout the stream. Stream temperature loggers also capture more of the daily variation than stilling well loggers and this can be up to 4ºC in a given day (Figure 7B). This also demonstrates that the maximum temperature reached was 19.1°C in late July. The stream loggers are more representative of what a fish would be exposed to than the stilling well loggers.

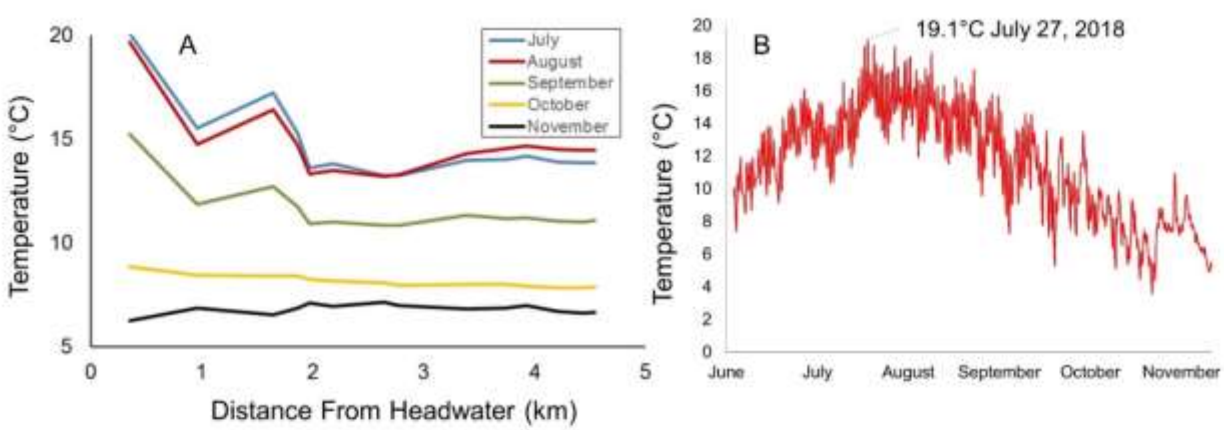

Figure 7. A) Temperature profile of Coles Creek from the headwater to the lowest downstream electrofishing reach in 2018 and, B) Half-hourly temperature in Lower Coles Creek in 2018

While temperature tolerance can vary with strain, temperature duration, and acclimation, the longstanding general guideline followed for brook trout has been that for growth, the weekly average temperature must not exceed 19°C, and for survival, temperature must not exceed 24ºC for any period of time (Brungs and Jones 1977). A more recent study demonstrates that brook trout growth rate declines precipitously from its optimum at 16ºC to nearly zero at 22°C (Chadwick and McCormick 2017). Heat shock protein and plasma cortisol start to increase appreciably at 20ºC. Certainly the upper portion of Coles Creek is above 20°C for much of the summer and has few brook trout. Temperatures in Lower Coles have not reached the point where avoidance or adverse physiological effects would be expected. However, with increased pumping in future combined with warmer years and climate changes, temperatures are in the range where adverse effects might be possible in the near future. While rainbow trout have the same general guidelines regarding temperature as brook trout in the Brungs and Jones (1977) report, they are often considered as being more high temperature tolerant than brook trout, and elevated temperature may favour rainbow trout over brook trout. Rainbow trout have been observed to have higher growth rates at 20°C than at 15ºC, suggesting a higher thermal optimum (Viant et al. 2003). Agriculture has certainly been a factor implicated in the success of rainbow trout invasions on PEI (Roloson et al. 2018).

3.0 Coles Creek fisheries monitoring

3.1 Annual electrofishing surveys.

Electrofishing surveys were conducted September 26-30 in 2016, October 3-11 in 2017, September 20-October 10 in 2018. While efforts are made to complete this as close to the end of September as possible, periods of rain, as was frequent in 2018, delayed sampling. Three-pass electrofishing was collected on 12 study reaches of Coles Creek each year and reaches were identical from year-to-year. Reaches were estimated at 50 m and exact length was later determined from the start and stop GPS (mean reach length 52 m). Evaluation of electrofishing pass data showed that there was a declining rate of return with each pass and that the total proportion of fish captured would be ~85%.

The numbers of rainbow trout and brook trout 1+ and YOY (as well as less commonly occurring species) were counted and length measured (YOY discrimination are checked later using annually established length distribution cutoffs). Weights of each fish were also recorded. In 2016, YOY were weighed from each location en masse but were individually weighed in 2017 and 2018. Fish were then returned to the stream alive. A total of four species were collected in Coles Creek, threespine stickleback (*Gasterosteus aculeatus*), brook trout (*Salvenlinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), and Atlantic salmon (*Salmo salar*). Stickleback were most prominent in the uppermost and lowermost reaches, and we have not evaluated these data further. Only one Atlantic salmon post-smolt was captured in the lower reaches in 2016 and again in 2017. In 2018, two Atlantic salmon juveniles were captured in the lower reaches. This suggests that salmon have been spawning in lower Coles, through spawning activity was likely very limited. Lower Coles Creek does have large cobble substrate, and taken together with the presence of Salmon, can be considered to be potential Atlantic salmon spawning habitat.

For the purposes of fish monitoring, four stream reaches (Figure 1) were delineated based on habitat features (van den Heuvel et al. 2017). Those areas were, moving downstream, Headwater (2 electrofishing reaches), Upper Coles (4), Pond Bed (3), and Below Pond (3). Brook trout density per unit area data showed that only the Headwater reach had significantly different density as compared to the other three reaches and this is not surprising given high temperature and poor habitat (Figure 8A, 8B). Brook trout density and biomass are relatively similar in the remainder of the stream, though the old pond bed is generally the poorest of these. With the exception of the Headwater, all reaches of Coles Creek have shown declines in brook trout density and abundance between 2016 and 2018. Rainbow trout biomass and density is generally about half of that for brook trout (Figure 8C, 8D). However, the pattern between years for rainbow trout is not consistent with both increases and decreases occurring.

Despite this observed drop, Coles Creek salmonid density and biomass is high as compared to other streams in the region. A summary of electrofishing surveys in 32 streams in Canada, mostly in the Atlantic provinces, showed that the highest salmonid biomass recorded was the Margaree River with 5.47 g/m^2 (Randall et al. 2017). In this current study, all reaches below the Headwater have ranged between 4 and 8 g/m^2, suggesting it remains high relative to other streams. A study of the West, Pisquid and Cross Rivers on PEI showed mean salmonid densities (42 reaches; single pass electrofishing, biomass not collected) of 0.046, 0.028, and 0.12 individuals/m^2, respectively (Roloson et al. 2018). Coles Creek brook trout density averaged 0.25 individuals/m^2 for the first pass, again suggestion very high brook trout productivity in this system. However, another study of nearly 70 watersheds on PEI found brook trout density to average 0.78 individuals/m^2, similar to the numbers found for Coles Creek (Guignion et al. 2010). Coles Creek below the Headwaters ranges from 0.2 to 0.8 individuals/m^2, again, suggesting quite high density with regards to other areas of PEI and the Maritimes.

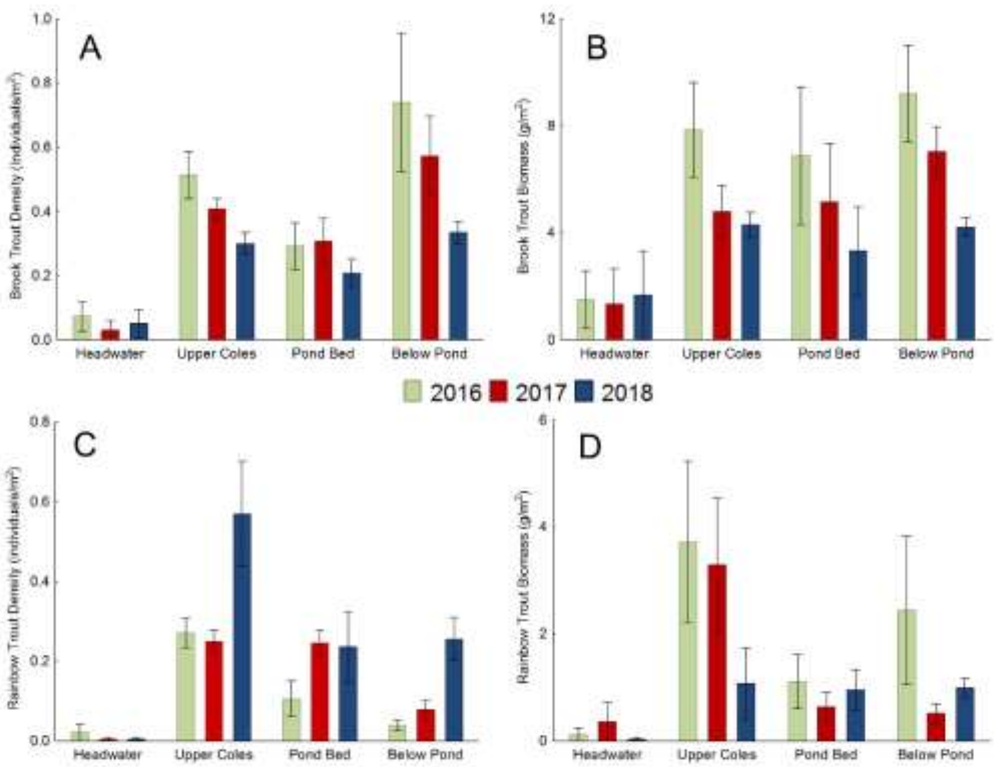

Figure 8. A) brook trout density, B) brook trout biomass, C) rainbow trout density, and D) rainbow trout biomass in Coles Creek electrofishing surveys

It is considered quite unlikely that the drop in brook trout numbers and biomass was associated with the Miltonvale pumping. Some drop in brook trout numbers was already seen from 2016 to 2017 when there was virtually no pumping. The most intense pumping in 2018 was constrained to August and while flow declines are evident, there is no reason to believe that this resulted in fish movements at this point based on preliminary tagging/tracking data (see below). Densities have decreased similarly throughout the stream, and the upper region of the stream is expected to be less impacted in terms of flow reduction. There are a number of potential reasons for this decrease. Coles Creek has had six years of historically relatively low flow, and this may have led to a decline in numbers. Evaluation of YOY density shows that the overall density change is driven by YOY density (Figure 9). This evaluation reveals another observation, rainbow trout YOY density has steadily increased between 2016 and 2018. In the lower reaches of the stream, rainbow trout YOY were virtually absent in 2016, and abundance has been steadily increasing since then. Areas of the stream have also had some removal of woody debris, removing habitat for larger brook trout, though the intensity of those removals have been relatively low and not consistent throughout the stream. The YOY density is likely very dependent on sea-run brook trout spawning. Decreases in sea-run brook trout number or size can influence the YOY density without the influence of any stream-based factors at all. At present, it is inconclusive as to the factors influencing brook trout declines and further years of monitoring will show whether the trend is ongoing. However, on the basis of a changing system irrespective of water extraction, it becomes challenging to attribute effects to this activity, and thus other means of fish population assessment will be required.

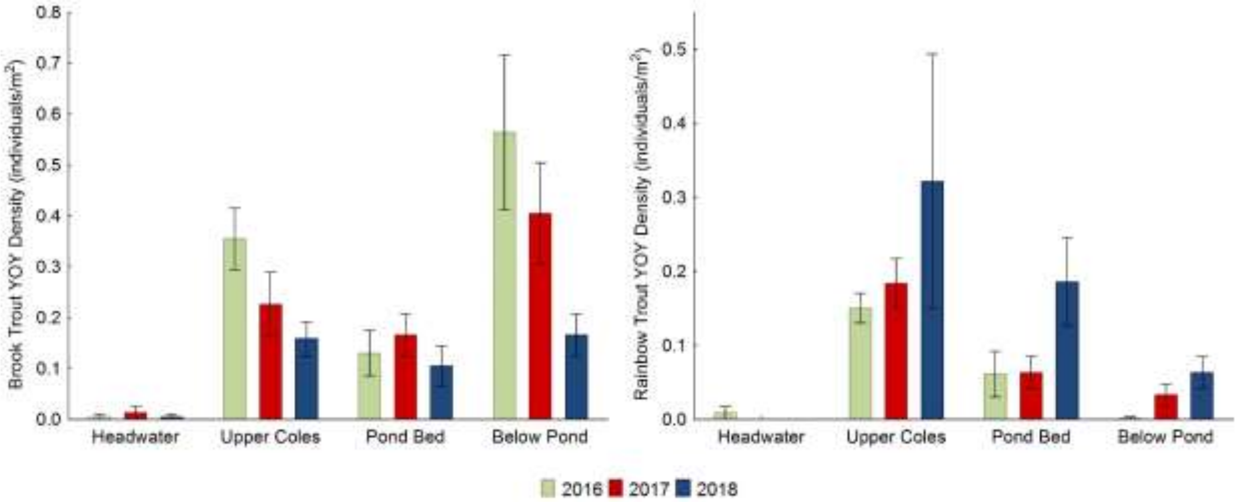

Figure 9. Brook trout and rainbow trout YOY densities in electrofishing surveys

3.2 Preliminary tagging study

Brook trout (1+) were tagged with 23 mm passive integrated transponder (PIT) tags in June 2018 in order to examine whether they would leave parts of the steam during summer. The second reason for this effort was to document micro habitat of brook trout for future hydraulics/habitat simulations. Two reaches were chosen, both of about 150 m in length, one adjacent to the wellfield, and the other in Upper Coles in the region of the stilling well. Fish were tracked through the summer every month using a mobile PIT tag reader (fixed antennas were also present at the ends of the study reaches). While full results have yet to be evaluated, some results are obvious based on the preliminary assessment of these data. Firstly, of the approximately half of the fish that were detected post tagging, relatively few left the study reach, thus pumping/temperature in 2018 had little or no effect on trout movement. Secondly, brook trout showed high fidelity with regards to region of the stream, and with the use of cover. One brook trout was detected under the same small log 5 times over a number of months. The technique demonstrated high potential to examine potential avoidance behaviour by brook trout during the summer months. In hindsight, future studies of this nature (in 2020) would include a location further downstream that would be more impacted by flow and temperature. The drawback of this method is that YOY brook trout are too small to tag, though other methods such as visual elastomer implants may be used. Trout locations in the stream, along with detailed stream bed profiles will allow hydraulic simulations of habitat in future, e.g. how much habitat is lost at simulated flow levels.

3.3 Redd surveys

Redd surveys were conducted in 2016 and 2018 by walking the stream to identify and document the location of redds. The 2016 study was conducted by Hilary Shea for Cornwall and Area Watershed Group (CAWG) and the 2018 study was conducted by UPEI staff. A survey was done in 2017 by Holland college students with CAWG, however, for various reasons these data were discarded for the present study as being incomplete and unreliable. The redd surveys showed 55 redds in 2016 and 46 redds in 2018. Redd surveys found that brook trout spawn over almost the entirety of Coles Creek (Figure 10) with the exception of the Headwater region. Two redds in 2016 were considered possible salmon redds and one redd in 2018. It is likely that the uppermost salmon redd in 2016 was a large brook trout redd as no salmon have ever been caught in this area, and the habitat for spawning is not suitable. However, the presence of salmon in the lower reached does speak to the accuracy of the salmon redd identification in the lower reaches. The watershed group has found that Coles Creek has the highest redd counts of any of the tributaries of the North River and certainly numerous sea run brook trout have been observed spawning. Overall, results to date do not indicate any potential effect on brook trout spawning in 2018.

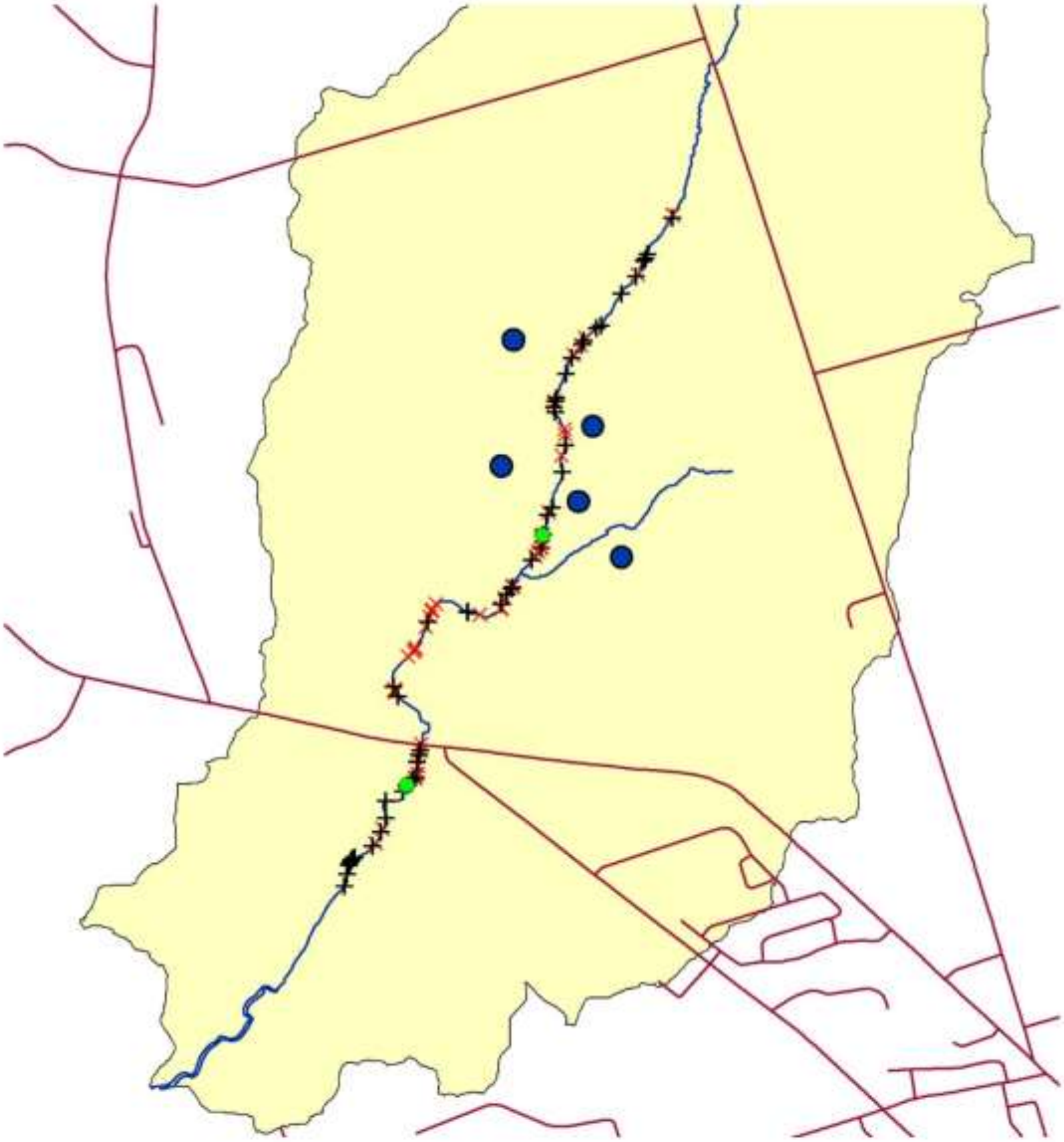

Figure 10. Redd locations in 2016 (black +) and 2018 (red x). Green circles indicate potential Atlantic salmon redds. Blue circles indicate the wellfield.

4.0 Future work

Going forward, this monitoring will evolve into a Ph.D. (starting September 2019) study that will:

- Continue to measure flow and fisheries for at least three year post-pumping using the sites and method described here.
- Characterize the groundwater flux into the stream, including in stream upwelling with either thermal remote sensing, piezometers or direct stream bed temperature measurement.
- Continue to characterize brook trout spawning areas, but also conduct spring rainbow trout redd surveys.
- Expand on the tagging study to examine summer fish movement under a full pumping regime.
- Conduct habitat simulations using Coles Creek from hydraulic models.

5.0 Conclusions

1. Substantive, biologically relevant flow deviations could be detected based on a short pumping period in August 2018.

2. Coles Creek is experiencing an extended period of historically low flows.

3. Brook trout biomass has shown a decreasing trend, but there have been no changes in spawning.

4. Rainbow trout YOY are increasing throughout the stream.

5. No observed effects on fish can be attributed to the observed flow changes.

6. Flow deviations likely resulted in a 1 degree temperature change in the lower river and temperatures in the lower river reach 19ºC. Based on this, temperature changes pose the greatest risk to brook trout based on present knowledge.

6.0 Recommendations

1. Given the delays in establishing pumping in Coles Creek, and additional year of study, or more is warranted.

2. With the observed, and possible more severe temperature changes consideration should be given to compensatory stream mitigation of the effects of pumping. The upper regions of the stream could benefit significantly from the establishment tree cover in riparian zones. Restoration of the upper reaches has the potential to more than compensate for impacts of flow reduction on temperature. This would also lead to the creation of additional habitat in Coles Creek suitable for brook trout.

References

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Appendix I
Estimated vs. measured flow

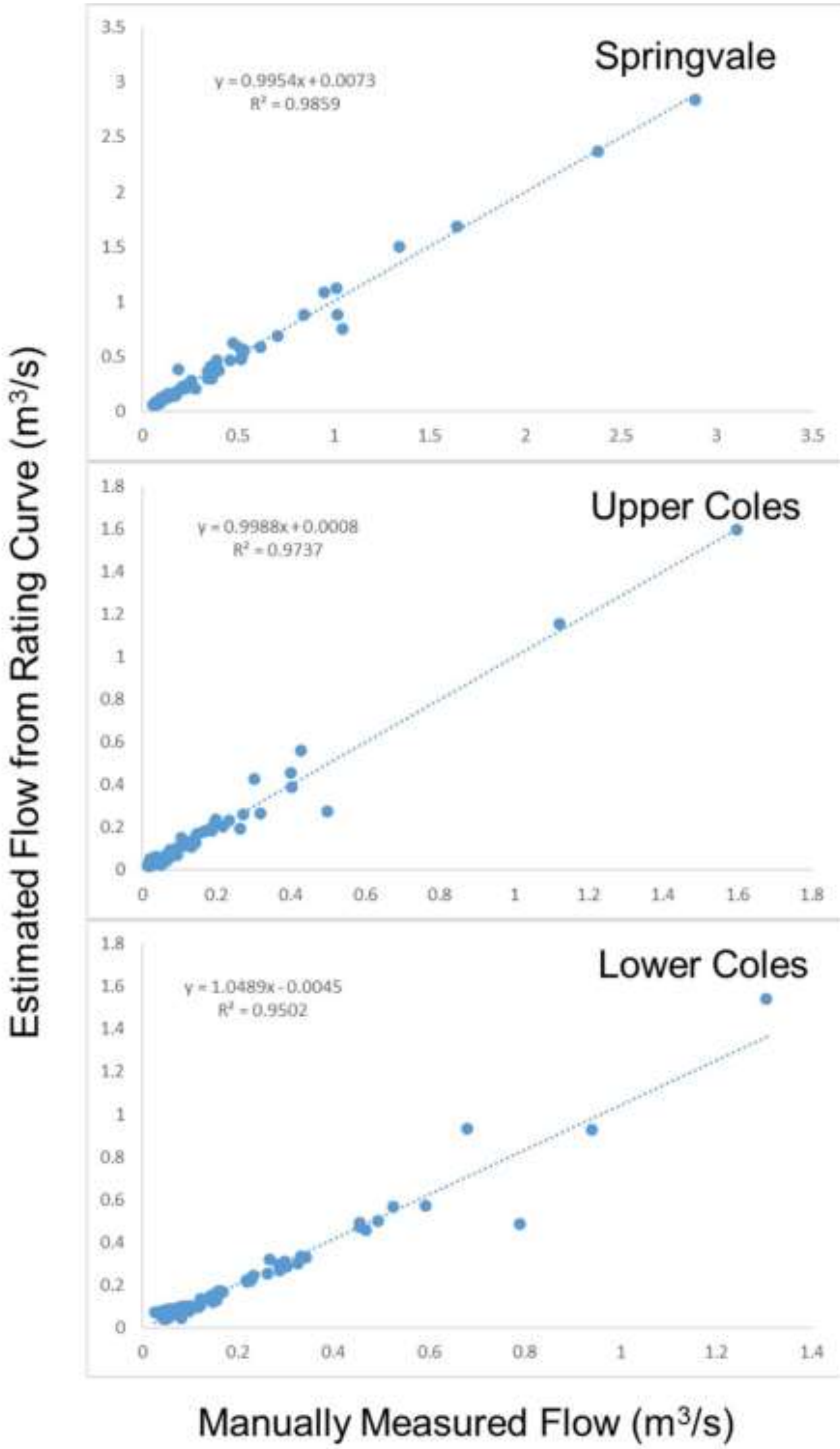

Figure 11. Estimated vs. manually measured flow from 2016 to 2018. n=83 measurements for each location.

Appendix II
Coles Creek Flow Hindcast Model

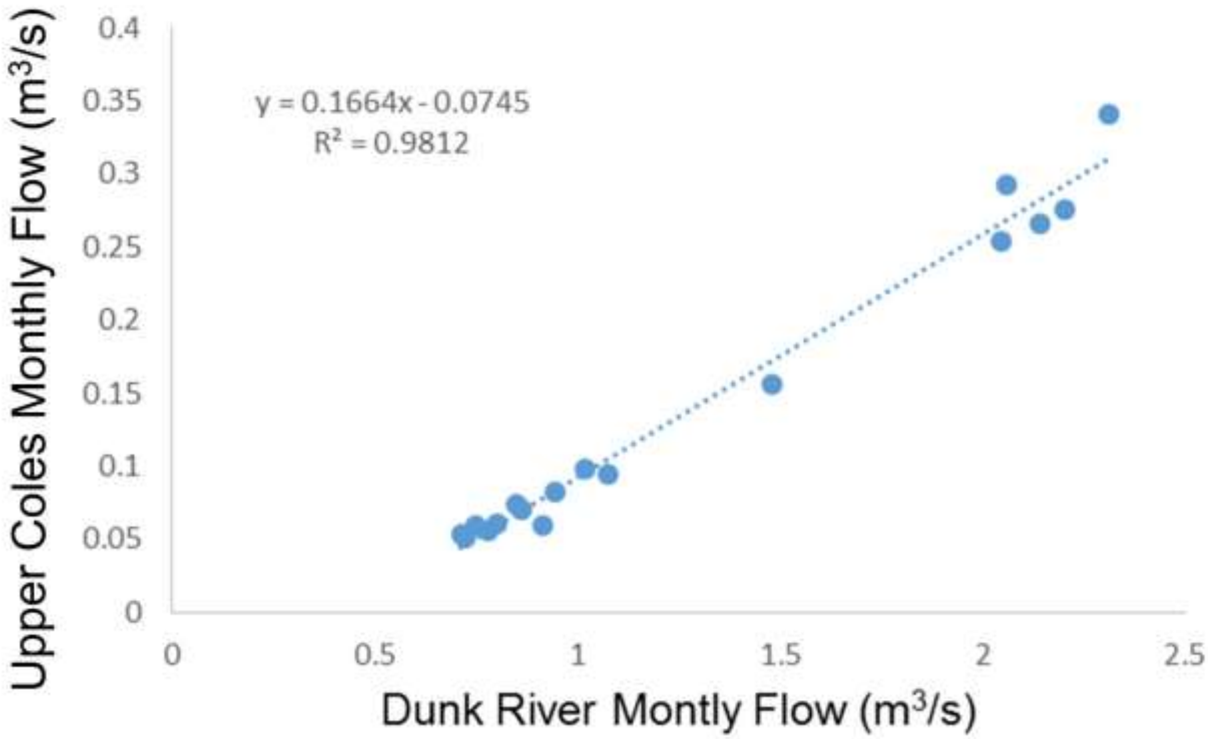

Figure 12. Lower Coles monthly mean flow from June 2016 to December 2017 vs. Dunk River Monthly mean flow over the same period.