Coles Creek Watershed:
Flow, Temperature, and Fish Monitoring, 2016-2020

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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-water extraction, 2) to examine temperature changes that may be caused by groundwater extraction, and 3) to quantify the fish community and productivity of Coles Creek. The report represents a summary of the pre-pumping data from 2016-2018, the results of 2018, a year of periodic pumping, and continuous pumping in 2019 and 2020. Additional data provided by the province has extended the flow monitoring period back to 2009-2020. Temperature has been collected year-around since 2016. Fish data focusses on fall redd surveys and electrofishing studies from 2016 until 2020.

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 as it drains directly into the North River estuary (Figure 1). 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.

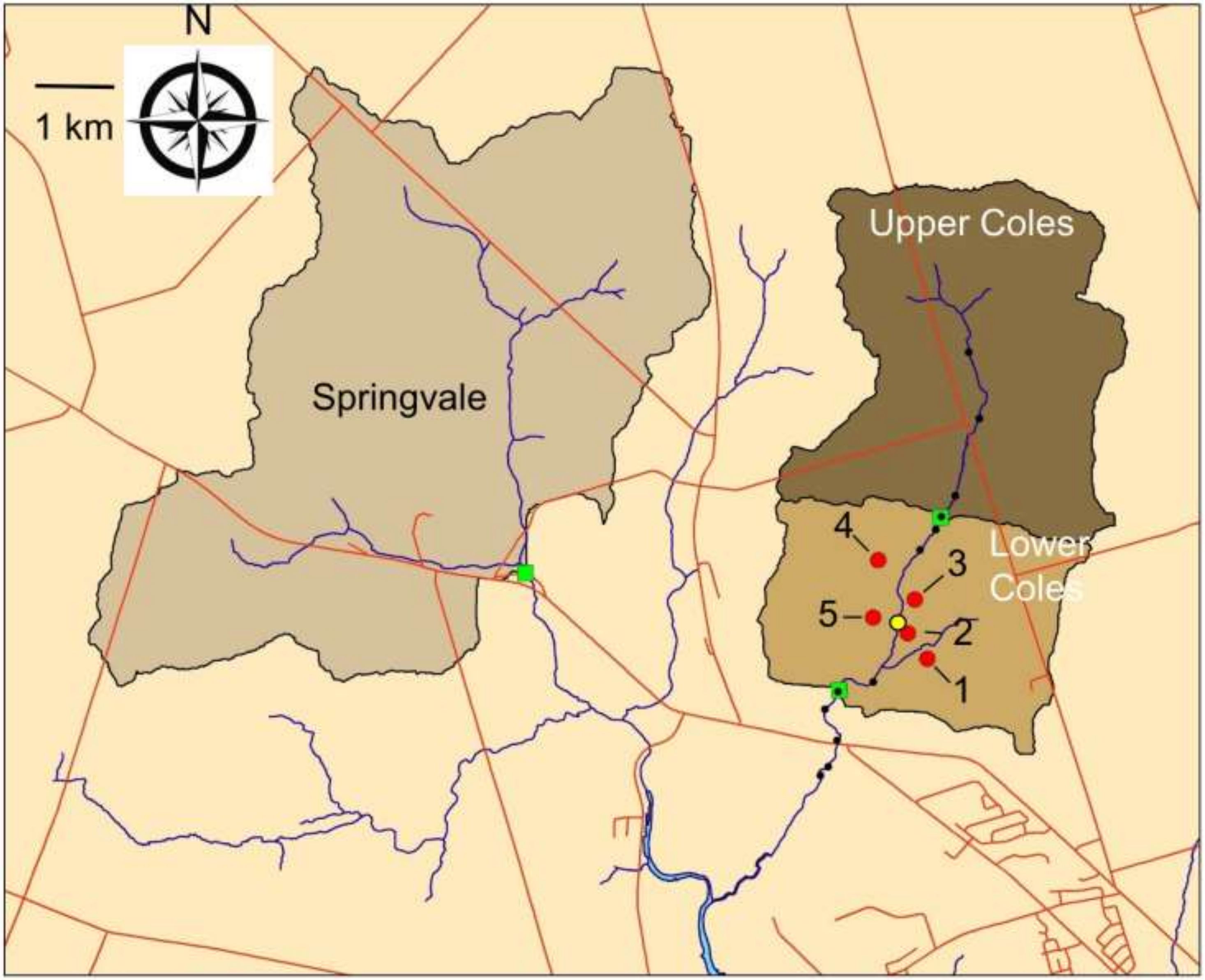

Figure 1. Springvale, Upper Coles, and Lower Coles sub-watersheds. Lower Coles includes the Upper Coles area. Red circles represent the City of Charlottetown wells. Green square are the UPEI flow measurement stations. The yellow circle is the ECCC hydrometric station. Black dots represent the start of 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 (6869 m^3/d). As water extraction was negligible in 2017, and may not have been removed from the watershed, 2017 is considered a baseline year in terms of flow and fish results presented.

Pump flowmeters became operational in 2018 and daily flows have been provided by the City of Charlottetown since then. Initially, pumping was not consistent due to technical difficulties with pumps in 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, 2018 and was 90% of the permitted maximum for that day only. Thus, the highest month of pumping in 2018 was August with an average of 1.65 m^3/min (35% of 4.77 m^3/min permitted). 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.

Uninterrupted pumping did not start until February 20, 2019 (Figure 2). Mean daily extraction was 4754 and 4966 m^3/d, for 2019 (post February 19) and 2020, respectively. This represents 69 and 72% of permitted capacity on an annual basis for 2019 and 2020, respectively. The maximum permitted extraction amount of 6869 m^3/d was only exceeded on two days in July and August 2019. Pumping became less variable in 2020 than in 2019 (Standard deviation 736 and 464 m^3/d for 2019 and 2020, respectively). However, seasonal trends due to water demand can be observed in both years with peak water extraction from June until August (Figure 2).

Water extraction has not been consistent from all five wells over time (Table 1). In 2018, as pumping was sporadic, the relative extraction from each well was only examined for a one-month period in July and August for which pumping was continuous. Pumping alternated between pumps considerably during that period. The majority (> 70%) of the water came from the two wells (4 and 5) on the west side of Coles Creek during that period. There was an initial period of variable pumping between Wells 2-5 for the first continuous month of pumping in 2019, followed by just over six months where water was pumped almost exclusively from wells 2, 4, and 5. Pumping was subsequently dominated by wells 2 and 5 until February 2020, after which a switch was made to the three pumps not being used, 1, 3, and 4. From June 2020 onward, pump 2 was half of the flow, with 1 and 3 being used to provide the remainder. While there is no consistent pattern, pumping did substantially switch from the west to the east side of the river in October 2019. Wells closer to the river may be more likely to influence flows or may do so more rapidly. Well 2, followed by well 3 are closest to Coles Creek. Certainly not all wells will influence streamflow equally.

Table 1. Relative pumping (% of daily volume) of Miltonvale Wellfield wells, numbered 1 to 5 as per Figure 1.

Period	1	2	3	4	5
July 24, 2018 to August 24, 2018	13.9	13.9	0	35.6	36.7
February 20, 2019 to March 26, 2019	0	23.6	9.3	26.4	40.6
March 27, 2019 to October 3, 2019	0	38.2	0.02	35.0	26.7
October 4, 2019 to February 7, 2020	0.5	59.2	0.4	1.4	38.5
February 8, 2020 to June 11, 2020	41.9	0.0	44.9	13.1	0.0
June 12, 2020 to December 31, 2020	24.6	49.9	25.3	0.0	0.0

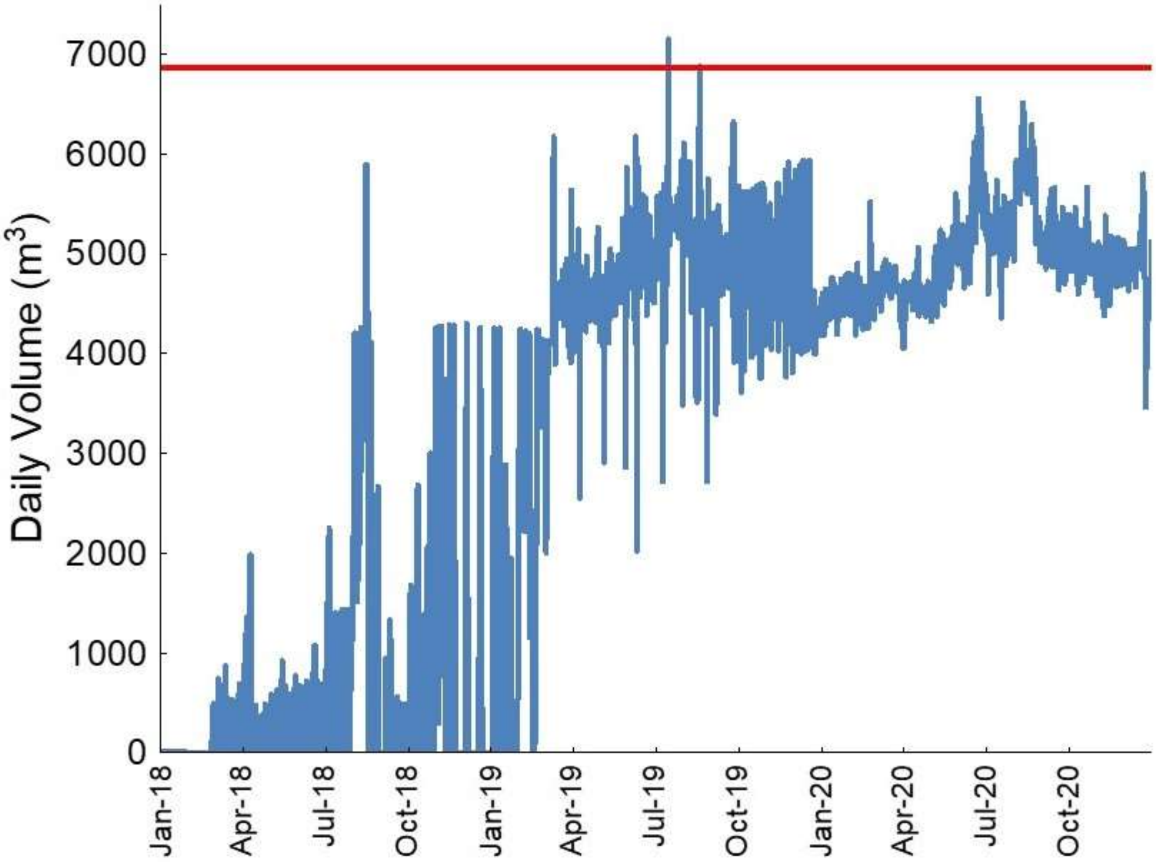

Figure 2. Daily extraction volume of the Miltonvale Wellfield from 2018-2020. Red line indicates the maximum permitted volume of 6869 m^3/day.

2.3 Flow Monitoring from 2009-2020

Historical flow data from 2009 to 2015 was made available by the Department of Environment, Energy and Climate action in 2020. The location of the stilling well was just downstream of Hw 2, less than 500 m downstream from the UPEI Lower Coles level logger. As inputs over this reach are limited to one small spring, these data are considered comparable to that of the UPEI flow data. Initially the 2009-2015 data were collected half-hourly but switched to hourly part way though the period. There were only three data gaps in these data, approximately two days of missing data in June 2010 and June 2014, and eight days of missing data in December 2011.

Data was subjected to rigorous QA/QC and subsequent recalculation as sudden shifts in flow, not explained by precipitation were initially noted. Numerous issues were identified with the data. The location for the stilling well itself is in a wider riffle, which is not typically ideal for level measurements, particularly in low flow conditions as changes in flow result in smaller changes to level than would occur in a narrower channel. Manual flow calibration data was sparse, with only 13 manual flow measurements over the entire six-year period. Three years, 2010, 2012, and 2013 had only one manual flow measure while 2011 had none. A two-parameter rather than a three-parameter rating curve had been used and while this is adequate for many purposes, this creates inaccuracies at low flow. These data had been previously split into two rating curves as there was a significant translation in the level data. Further examination showed that level translation to be due to misplacement of the logger during download (change in level over a half hour without any previous or subsequent level changes and corresponding with a noted download). A translation in level such as this occurs when the logger is not placed precisely at the same depth as when it was retrieved. More than 20 such level deviations during downloading were observed and corrected by assuming that the level change pre and post download was due to placement issues.

Post correction, one outlier was removed from the manual flow data and this resulted in a single rating curve with an r^2 of 0.98 (see methodology below). Following corrections and calibrations, data accuracy was checked by comparing calculated flow data to the manual measurements (minus the one outlier mentioned above). The slope of the regression of calculated vs. manually measured flows was 0.98 with an r^2 of 0.98 indicating excellent agreement. Due to the paucity of manual flow calibrations points, and the placement of the stilling well, there is far more uncertainty in these data than those collected subsequently. However, given the importance in having multiple year to determine historic stream flows these data are more than adequate for inclusion below.

UPEI efforts to monitor flow started in June 2016 meaning that there was only a five-month gap between the flow monitoring described above and the ongoing monitoring. Fortunately, this meant that there was no break in monitoring of the low flow months from 2009 until present. 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. Manual flow measurements were conducted at the stilling well locations at least every two weeks for flow calibration. In the fall of 2020, some perturbation occurred in the Springvale Branch of the North River due to culvert reconstruction. Changes did not occur until the installation of the new culvert in November which effectively created an upstream pond (20 cm level increase) due to an elevated area of stream bottom created in front of the culvert (which has subsequently been rectified). As the level change occurred over hours, a correction was applied to the level to account for this.

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 every year. Curve transitions are made during winter during the first thaw even (typically January or February) as this is typically when stream channel re-structuring occur in the high flow events surrounding these thaws. 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.

Monthly average flows allow an evaluation of flow patterns between years for the three UPEI flow monitoring stations (Figure 3). These patterns are remarkable in the differences between years in terms of spring and fall flows. The hydrographs are most stable/consistent in the late summer low flow period. September is most commonly the month with the lowest mean flow and this was observed at all three locations in 2016, 2018, and 2020. In 2017, October was the lowest flow month, and in 2019 August had the lowest flow at all three locations. However, August and September mean flows seldom differ by more that 10%. While August was not always the lowest flow month, it does have the lowest coefficient of variation of the annual monthly average flows (CV = 25-27% over the three locations), meaning flows in August are more consistent. For this reason, August it is chosen as the representative low flow month for further analysis. Only March is more stable than August. November has the most variable flows from year to year (CV – 91-101%).

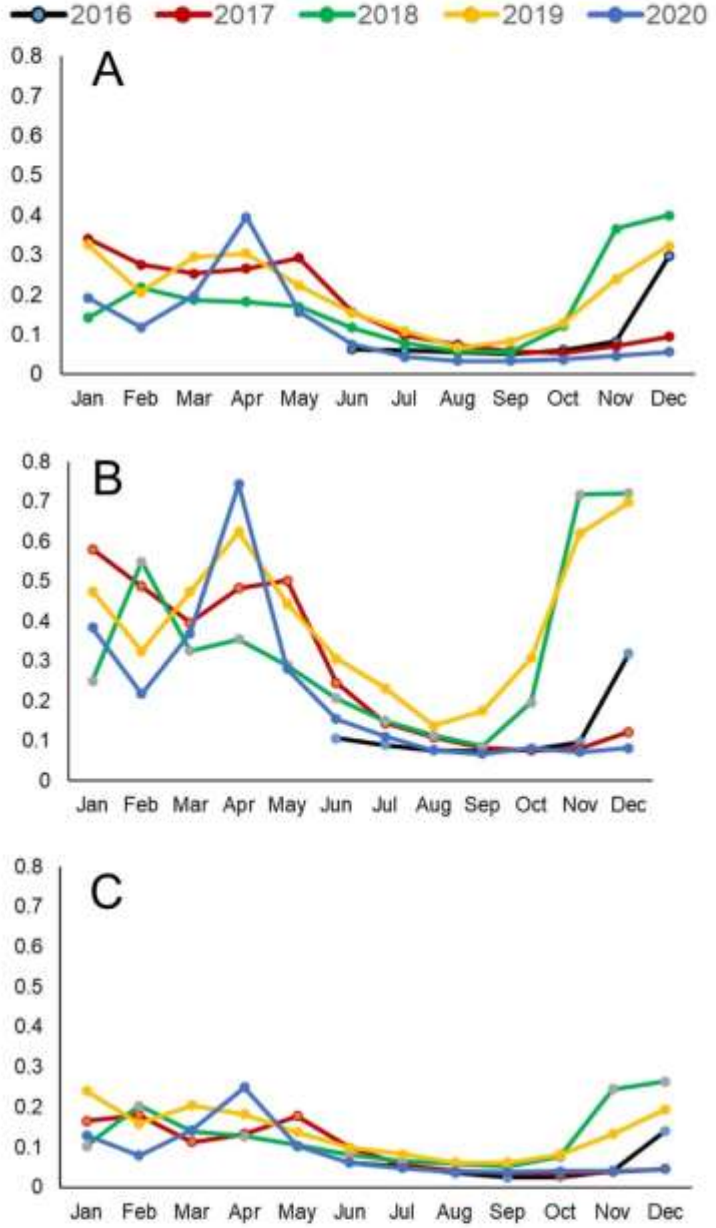

Figure 3. Monthly average flows at A) Lower Coles, B) Springvale Branch, and C) Upper Coles from 2016 until 2020.

Seasonal flow patterns can be further evaluated by examining the Lower Coles Creek dataset in its entirety from 2009 to 2020 (Figure 4). From these data, it can be observed that there were some unusually high summer flow years from 2009 until 2011 and that these years were not consistent in either the magnitude or intensity of the spring freshet. The late and very intense spring freshet in 2014 and 2015 resulted in average summer flows. Summer flows appear to be most strongly related to flow in May and June reflecting a wet spring and considerable recharge occurring during those months strongly influences low flow months. While May and August mean flows were not correlated, there was a statistically significant correlation between June and August flows (r=0.91). The lowest flow year was 2020, and these data reinforce the above conclusions as it was a dry spring, and flows would suggest little recharge occurring between May and June (bearing in mind that water extraction also influences 2020). The implication is that spring rainfall is most critical to summer flow which offers some predictive value of low flow situations.

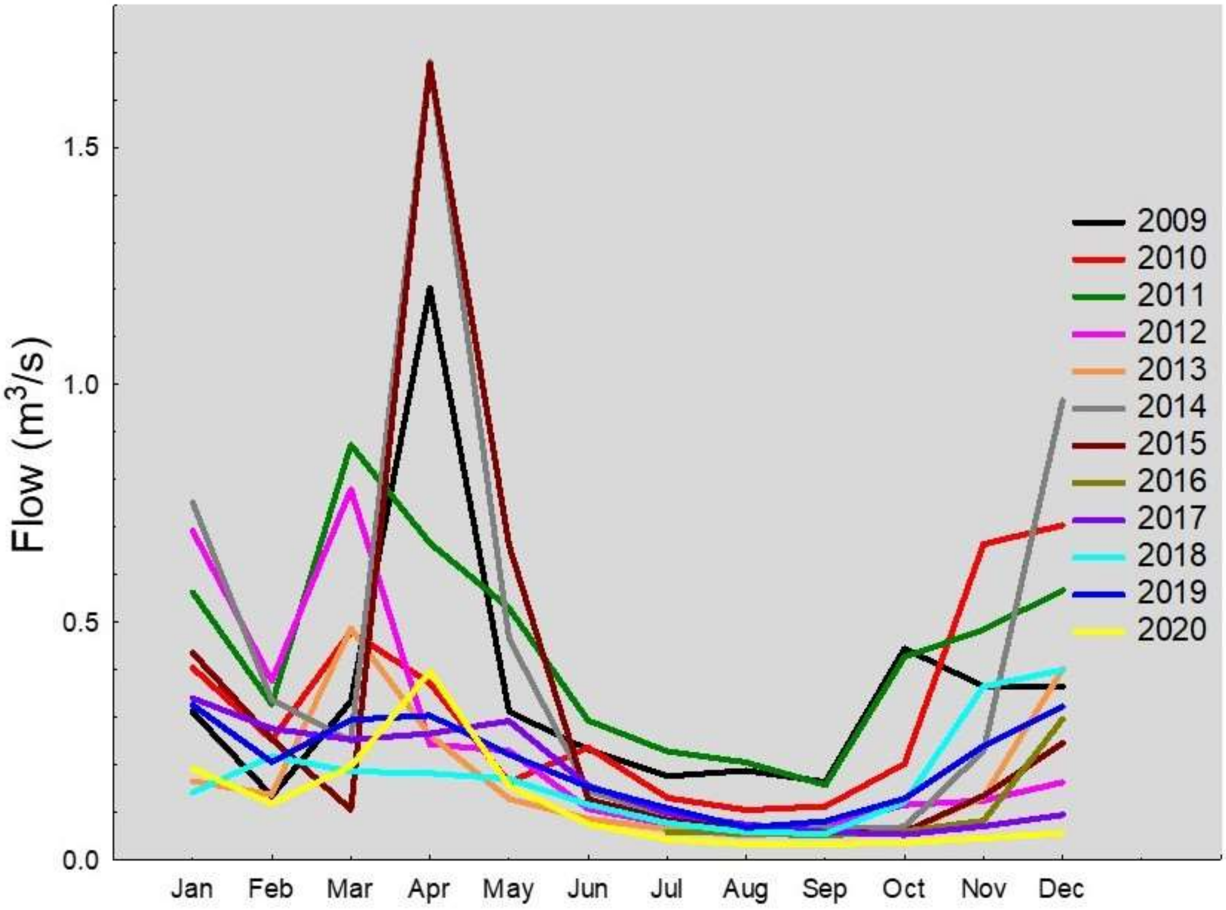

Figure 4. Monthly mean flow in Lower Coles Creek from 2009-2020.

2.4 Absolute Flow Alteration

Absolute volume of flow alteration in Coles Creek was calculated for August of the three years of pumping. In 2018, pumping was sporadic but the only period of continuous pumping started in late July, and ended in late August. So August was the only month in 2018 for which such an analysis could be conducted. Two methods of evaluating absolute flow alteration were examined, the first using the flow difference between Upper Coles and Lower Coles hydrometric station, and the second using the daily flow relationship between Lower Coles, and Springvale Branch of the North River. We will call these the ‘difference’ method and the ‘ANCOVA’ method, respectively.

For the difference method, this assumes that the groundwater extraction from the wellfield will primarily impact stream inputs between the Upper Coles and Lower Coles Flow monitoring station through reduction of spring inputs from the aquifer into the river. Daily average flows were used to calculate an average flow at each station for the month of August. In August 2016 and 2017, the upstream-downstream flow increment was 0.020 and 0.032 m^3/s, respectively (Table 2). The difference between years is not surprising as 2016 was a low flow year compared to 2017, It was observed that in the three pumping year, there was virtually no flow increase from Upper to Lower Coles stations. In 2020, there was actually a loss of flow from upstream to downstream. This is entirely possible, as with no water additions, some water can be lost to either evapotranspiration, or even to downwellings. The average flow increment of 2016 and 2017 was used as an expected upstream to downstream flow increase (0.027 m^3/s). The absolute flow lost to pumping was then calculated as the difference between the expected flow increase, and the actual flow increase or decrease from upstream to downsteam. This showed a range of absolute flow deficit values ranging from 0.019 to 0.032 m^3/s (Table 2). As the upstream to downstream August flow increase will vary between wet and dry years, this can be viewed as an approximation since there is no way to calculate what the actual expected flow increase is each year. The driest years to date, 2020 also had the highest calculated flow deficit. While this could be due to the approximation mentioned above, it is also possible the water extraction has more impact on the absolute amount not reaching the stream in a dry year vs. a wet year.

Table 2. Summary of estimates of Coles Creek August flow reduction due to groundwater extraction.

Year	Lower-Upper Coles flow difference (m^3/s)	August Deficit Lower-upper (m^3/s)	ANCOVA flow deficit
2016	0.020		
2017	0.032		
2018	0.000	0.027	0.016
2019	0.007	0.019	0.017
2020	-0.006	0.032	0.023

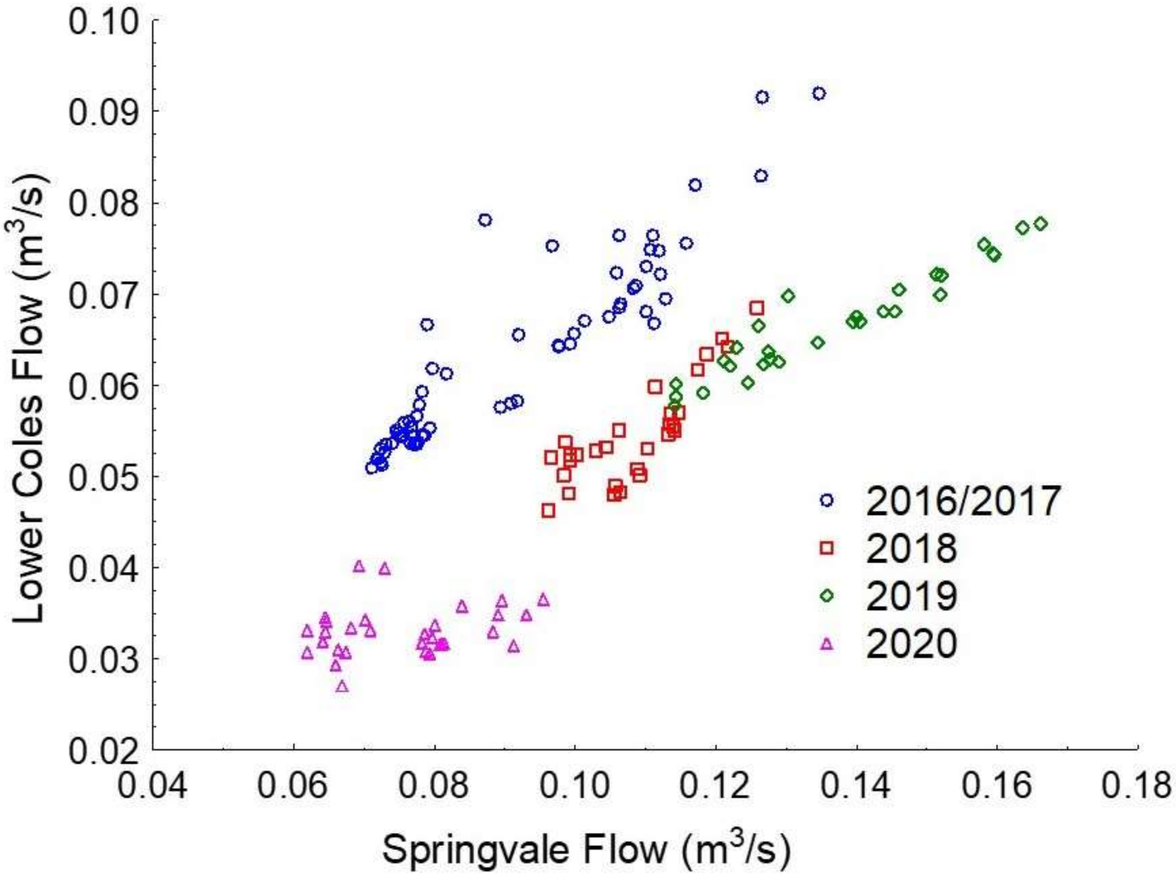

Figure 5. Lower Coles vs. Springvale Branch daily average August flows from 2016 until 2020.

The ANCOVA method utilizes the strong correlation in flows between adjacent watersheds. Baseline data are essential for this method and those were collected in 2016 and 2017. This method used daily average flows over the month of August to establish and expected flow relationship between Springvale Branch of the North River, and Lower Coles Creek. As Lower Coles Creek is expected to have less flow in-post pumping years, this can be observed as a downward translation of the line (Figure 5). Such data can be analyzed by analysis of covariance (ANCOVA), where Lower Coles Creek is the dependent variable, Springvale flow is the covariate, and the river is the categorical variable being tested. Thus, it can be statistically determined if Lower Coles Creek flows changed from expected. Furthermore, the difference in least square means (flow in Lower Coles at the average flow value for Springvale) between years can be used to determine the average flow reduction from average values (Table 2).

The flow alterations were very comparable, though consistently lower than to those found by using the difference method above. The absolute flow alternation was less variable than that estimated using the difference method, ranging from 0.016 to 0.023 m^3/s for the ANCOVA method. This is not surprising since with this method, the Springvale Branch serves as an interannual (non impacted) reference. As with the difference method, the driest year, 2020, also had the highest absolute flow alteration value, supporting the previous suggestion that this could be higher in dry years. Overall, the consistency between these two methods, and consistency from year to year, give high confidence of the range of absolute flow alteration due to water extraction.

The flow removal from the stream pumping at 66% of permitted capacity at Highway 2 was estimated from a groundwater model to be 0.01 m^3/s in an average year (Qing Li, Environment Water and Climate change, personal communication). The annual pumping estimate (66%) used for the groundwater model was marginally lower that the actual annual pumping of 69 and 72% for 2019 and 2020, respectively. However, the above estimates for actual flow reduction were for August, at a time of year when the wellfield is being pumped at greater than 80% capacity. So, the modeled value would be expected to be a low estimate based on the amount of water extracted alone.

Some additional deviation between the model and observed reduction 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 on 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 there has been varying disproportionate pumping from the various well. In 2020, almost half of the flow came from Well 2, closest to the stream, and this may have disproportionate effects.

Relative Flow Alteration

PEI flow regulations specify that 70% of monthly median flow be maintained in waterways for surface water extraction (70Q50) and 65% for groundwater extraction (65Q50). While such metrics are commonly used, their implementation is a challenge where insufficient historic data exists. The additional data from 2009-2015 incorporated herein allowed the calculation of median flows (Figure 6). While ideally, at least 20 years of data would be desired, August median flow was found to be 0.071 m^3/s in Lower Coles Creek for the 9 years between 2017 and 2019. The 9-year 70Q50 (the more stringent regulation) derived from this 0.05 m^3/s. Flows from 2020 substantially exceeded this value as only 47% of the Q50 was maintained. Coles Creek consistently exceeded the 70Q50 from May until December in 2020. In the 2018 and 2019 pumping years, the 70Q50 was maintained. Based on absolute flow reductions of approximately 0.02 m^3/s calculated above, Coles Creek would have been expected to fall below the 70Q50 in 5 of the past 12 years and fall below the 65Q50 in 4 of the last 12 years, or 41% and 33% of the time, respectively (including 2020).

The Q50 was derived with only 9 years of data, and this begs the question of what ‘normal’ flow in Coles Creek over the longer term is. The only way to address this question is to examine flows in nearby systems for which there are longer term data sets and relate them to Coles Creek flow. While the West River is the closest location, the strength of the correlative relationship, particularly with regards to low flow was inferior to that found with the Dunk River, so Dunk River was used. Given the 9 years of pre-pumping data, a simple model predicting Coles Creek monthly flow from Dunk River monthly flow was constructed using the logarithms of monthly data. While a linear relationships had a reasonable fit (r^2=0.78), examination of predicted vs. residual value observed a bias at high and low flows, the latter of which are particularly important to predict accurately. A polynomial equation explained marginally more variability (80%), however the residuals were more evenly distributed which cause less error at low flows.

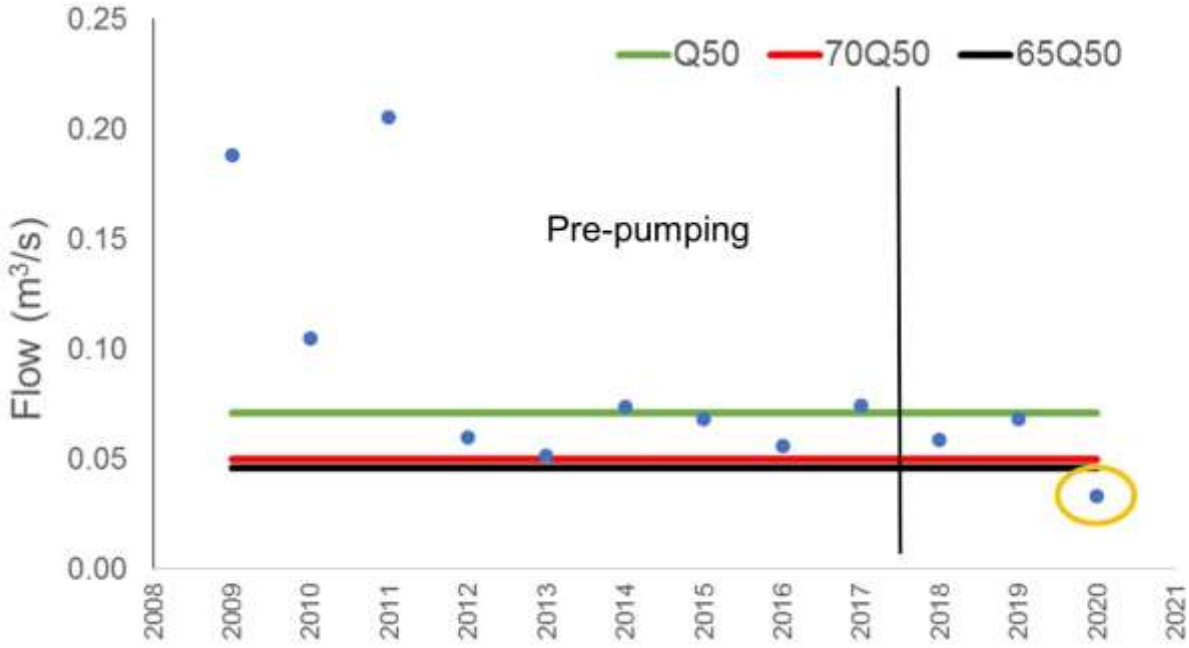

Figure 6. Median (Q50, green line), 70Q50 (red line), 65Q50 (black line) August flow at Lower Coles from 2009 until 2020. Mean August flow shown by blue circles.

Based on this analysis (Figure 7), there was a sudden downward transition of flow in August starting after 2011. The 59-year predicted August median flow was 0.13 m^3/s, almost double the 0.071 m^3/s found above for the 9-year observation period. There has been a significant reduction in flow over the 59 period (and likewise in the Dunk River from which these data are directly derived). While a recent evaluation of flow and temperature data in the Wilmot River showed no significant change in precipitation (St Hilaire et al. 2021), the data used therein only up to 2012, and most of the changes in flow occurred after this point. A complete analysis of rainfall and flow data over the periods in question would be required to examine what shifts in weather patterns are related to this change.

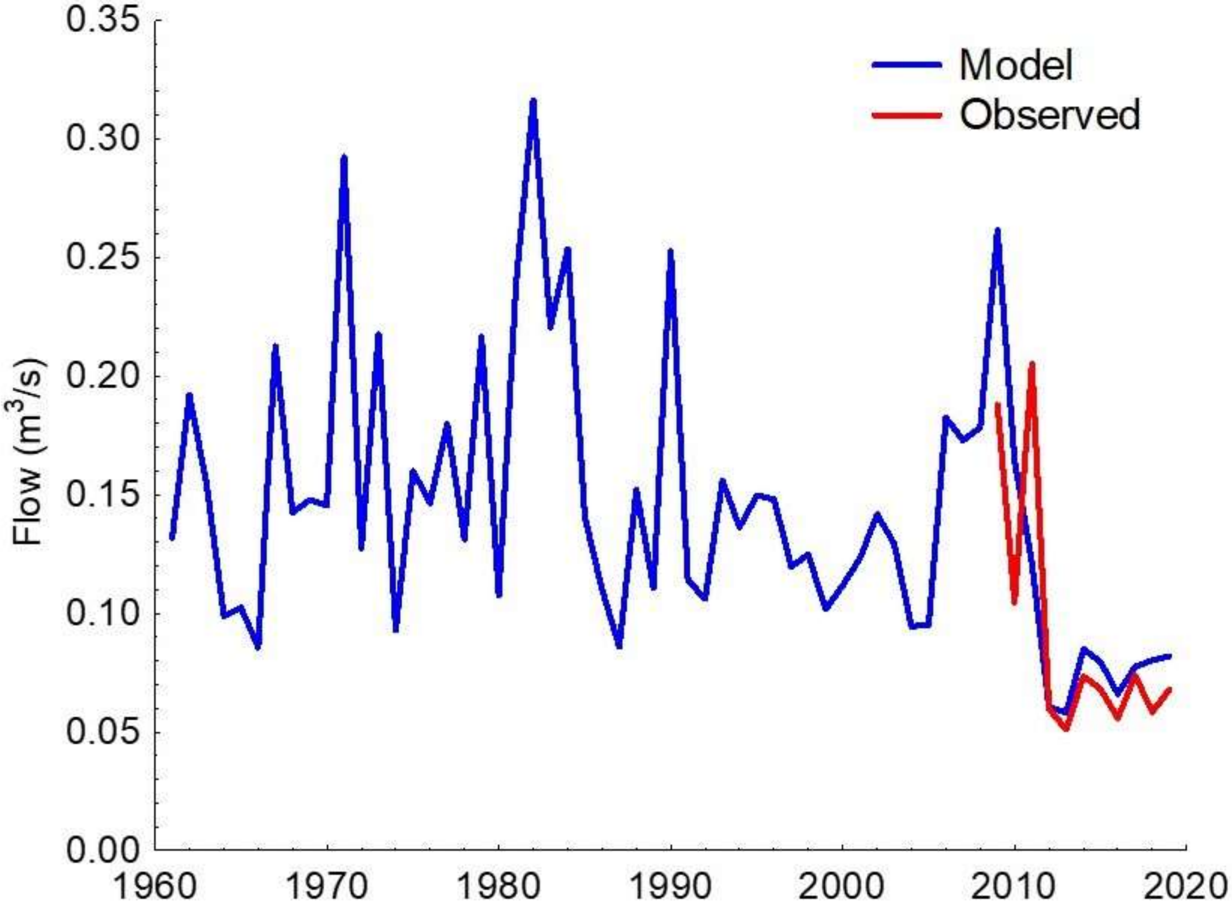

Figure 7. Hindcasting of Lower Coles Creek mean August flow using historic Dunk River data from 1961 to 2019.

Temperature change due to climate change is a gradual process, and sudden changes are unlikely to derive from hydrological implications those gradually increasing temperatures. Furthermore, a PEI model of flow related to climate change suggest that future flow in early- to mid-summer is predicted to be higher and not lower (though year-to-year variability may be higher), so the sudden decrease in flow is opposite to anticipated long-term climate trends (St-Hilaire et al. 2021). Likewise, the regional climate data used in that flow model suggests higher annual rainfall in the more pessimistic climate scenario (St-Hilaire et al. 2021). However, there are still many unknows with climate change such as what will happen to Ocean currents Atlantic Meridional Overturning Circulation (or AMOC) and the North Atlantic

Oscillation. While sudden changes in such phenomenon would dramatically affect our weather, none have been documented within the timeframe of this study that we can determine. With regards to dry summer weather in the region, the jet stream may have the highest influence. A steady west to east jet stream directly over the region means that wet fronts do not linger in the regions for long, leading to dryer conditions. Global climate models still have great uncertainties with predicting weather phenomenon such as the jet stream, and in the worst case may entirely fail to predict seasonal future weather patterns.

The hypothesis that the lower flows being observed in central PEI is influenced by cyclical local weather patterns is supported by mean August flows in the most westerly (Mill River, Carruthers) and easterly (Bear River) hydrometric stations on PEI. In the Mill River, historic low flows being experienced in central PEI are not occurring. There is a non-significant upward trend in August mean flow (Figure 8). The Bear River to the east has shown quite a substantive and statistically significant upward trend in mean August flow (Figure 8). Thus, considerably more effort is required to answer the question of what constitutes ‘normal’ flow in Coles Creek given the enormous variability across PEI.

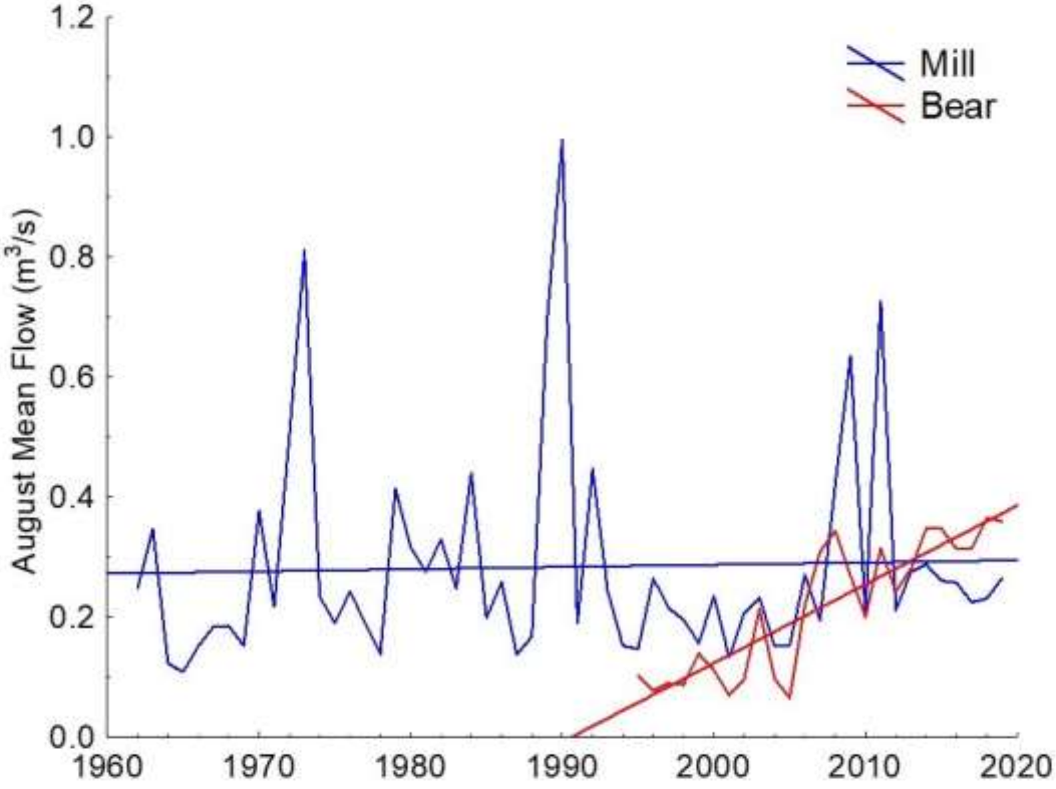

Figure 8. Mean August flow in the Mill (Carruthers) and Bear Rivers.

2.5 Coles Creek Temperature

As PEI streams are fed by groundwater, particularly during low flow periods, increases in temperature would be expected as a result of flow reduction due to groundwater extraction. This is particularly critical considering climate changed-induced warming in future. Water temperature has been collected on the stilling well pressure loggers since 2016. However, as these loggers 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 that were anchored in the stream and logging was started in June 2018. However, the stilling well temperature data has more baseline, or pre-pumping data, so will be evaluated in addition to the supplemental loggers in stream.

Stilling well logger data shows that Springvale Branch is colder in summer and warmer in winter, reflecting a larger groundwater influence in the reach of stream examined. The Springvale stilling well is place in the old highway bridge concrete channel, and as such is not in the riverbank itself as are Lower Coles and Upper Coles, and for this reason the raw data shows far more temperature fluctuations. In order to better observe the trends, a 12-day running average was applied to smooth the lines (Figure 9). The most obvious changes in temperature are observed at the summer temperature peak in July and August. Groundwater input between the Upper and Lower Coles Creek flow stations has a cooling effect on the stream. In 2016 and 2017 this was approximately a 1°C difference from upstream to downstream. This cooling starts in early July and continues through September. With some pumping occurring in 2018, this cooling decreased to approximately 0.5°C. With continuous pumping in 2019 and 2020, the cooling impact diminished further. In the driest year, 2020, Upper and Lower Coles have and identical temperature profile, reflecting the observations above that the stream lost flow between the Upper and Lower station. While the opposite effect would be expected in winter, this is not apparent. It is unclear at present when spring input might resume due to groundwater recharge. However, flow data for 2019 showed that Lower Coles flow exceeded Upper Coles for the month of September. In 2020, this was not apparent until November, suggesting that this will differ from year to year depending on the timing of the fall recharge.

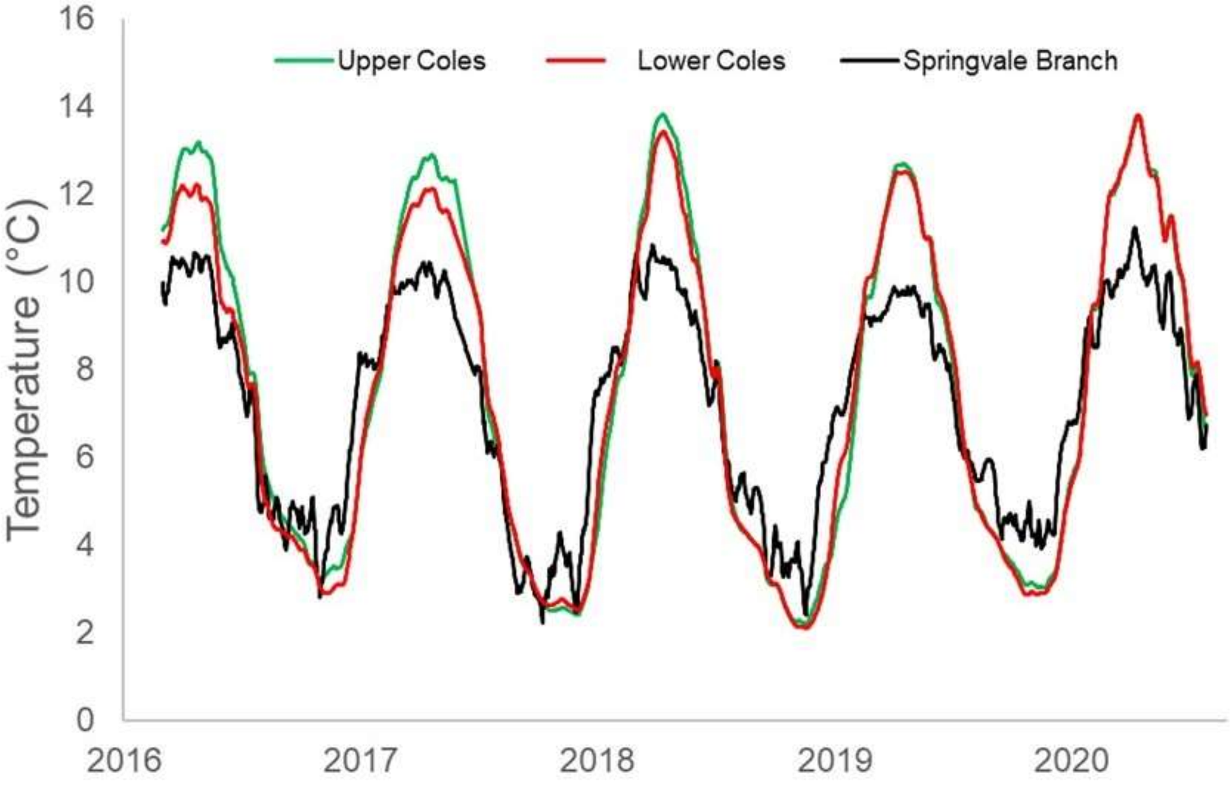

Figure 9. Temperature (12 day daily running average) in Coles Creek and Springvale Branch of the North River recorded by stilling well loggers.

The longitudinal in-stream gradient conducted on Coles Creek using Tidbit loggers also indicates that the warmest water is coming from the headwaters (Figure 10). While this is not surprising given the almost complete absence of riparian zones/shade and two ponds in the upper system (Figure 10A). The most substantive spring input is located just above the Upper Coles stilling well. Spring input in this area contributes significantly to the sharp cooling observed in those reaches, after which the stream warm gradually, particularly after passing through the wellfield area.

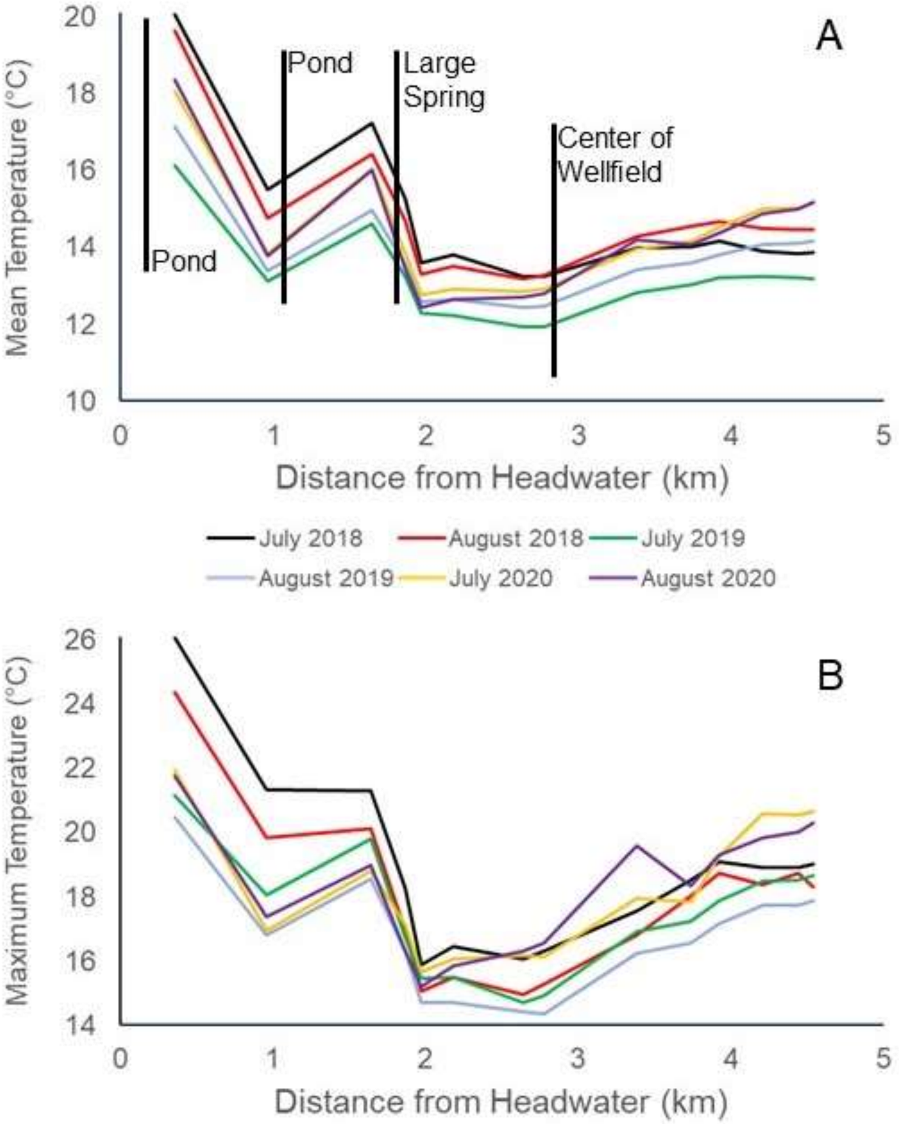

Figure 10. Mean (A) and maximum (B) temperature along Coles Creek in July and August, 2018-2020.

There were interannual temperature differences of just over two degrees in the lower reaches of the stream. The coolest year was 2019, and the warmest year 2020. While summer temperature likely contributes to this variance, summer flows will also contribute. As 2020 was the driest year, and 2019 the wettest of those examined, the results would be as expected if flow were having an influence. Each year also shows characteristics of both the flow, and the pumping regime combined. In 2018, the July and August mean temperature lines cross indicating that the lower reached became warmer in August (usually slightly cooler). This approximately 1°C temperature change is consistent with low volumes of water extraction in July, and much more water extraction in August 2018 and is consistent with reduced cooling of the stream as observed from the stilling well temperature loggers. In 2020, the rate of warming of the lower stream with distance travelled downstream was the highest as indicated by a steeper slope in the mean temperature graph (Figure 10A). There was also less of a plateau in the warming of the three lower stations in 2020, and this resulted in maximum temperatures ranging from 20.55°C to 20.65°C in all three lower reaches.

Temperature maximum in lower Coles Creek in 2020 are approaching the ideal upper range for brook trout. 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 (Brungs and Jones 1977). While daily high temperatures exceed 19°C frequently in the lower reaches, the diurnal variation is considerable, usually between 3 to 5°C from day to night. A seven-day running average in the lowest (warmest) reach in lower Coles did not exceed 17.3 ºC. The influence of the short daily maximum temperature on brook trout is unknown. Certainly, from tagging studies conducted so far (see below), brook trout do not appear to be abandoning these reaches of stream to seek thermal refugia elsewhere, though they may be able to find thermal refugia nearby given the number of springs and upwellings.

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). Thus, for periods of the summer, temperature for growth in the lower reaches will exceed optimum in a low flow year such as 2020. However, currently, YOY brook trout in the lower reaches are larger (authors unpublished data). Heat shock protein and plasma cortisol start to increase appreciably at 20ºC though again it this response is unknown for very short pulses. 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 might be expected, and this is being examined. Pumping in future combined with warmer years and higher year to year variability due to climate change could certainly lead to temperatures are in the range where adverse effects might be possible in the 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 Fish Monitoring

3.1 Redd Surveys

Redd surveys were conducted from 2016 to 2020 by walking the stream in the second week of December 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 remainder were 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. Redds found in springs adjacent to the stream were not counted here as there has not been consistent effort to examine these, so the redds presented are only in the mainstem of the stream.

Two redds in 2016 were considered possible salmon redds and one salmon redd in was identified in 2018 and 2019. No salmon redds were identified in 2020. 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 reaches in 2017-2020 does speak to the accuracy of the salmon redd identification in the lower reaches. Salmon spawning has dramatically decreased on PEI since 2018 based on redd surveys (authors unpublished data) and spawning salmon seem to become absent from more marginal habitat such as Coles Creek during this time.

Table 3. Summary of annual redd survey data.

Redd survey year	Total number of redds	Redds within 500 m of the center of wellfield
2016	42	17
2018	47	16
2019	62	33
2020	110	36

Redd surveys found that brook trout spawn over almost the entirety of Coles Creek examined, (Figure 11) though it has not been evaluated in the headwater region. Redds were even found in tidal fresh waters in 2016 and 2020, however this area was not included in the survey data presented since redd surveys did not consistently examine tidal waters. Coles Creek is showing an increase in overall brook trout redd count since pumping began (Table 3) with 2020 being the highest year observed. There was no change in the spatial distribution of redds and they are generally evenly spread over the area examined. As the influence of groundwater extraction on substrate upwelling the brook trout prefer will vary with distance from the well field, the number of redds within a 1000 m diameter circle around the center of the wellfield was examined. The general trend in this limited reach was the same as overall, redds are increased in 2019 and 2020.

There are a number of uncertainties with regards to redd counts and their interpretation. Redd counts are highly dependent on the stream conditions at the time of the survey. Low flow and clear waters improve the probability of spotting redds, and particularly smaller redds. Of the years surveyed, 2020 had the lowest December flows and the highest redd count. Survey staff experience can also play a factor, though in this was consistent from 2018 onwards. With excellent fish passage, Coles Creek has a strong sea run spawning population and thus these spawning individuals are not directly influenced by local stream conditions in summer. The fidelity of brook trout to their native stream in the region is unknown. Thus, if poor recruitment of sea-run juveniles were to occur in Coles Creek, it is unknown whether or not this would even influence the spawning biomass significantly, or if it did, how long that would take. Sea run brook trout are not thought to mature until their third summer, so it may take several years for changes to occur to the spawning biomass.

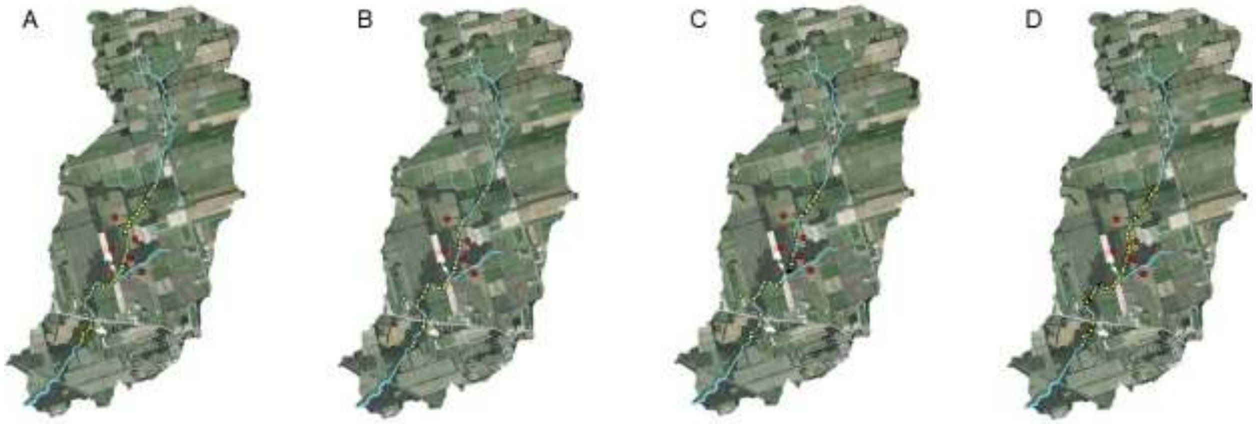

Figure 11. Redd locations observed during A) 2016, B) 2018, C) 2019, and D) 2020 Coles Creek surveys. Yellow circles show redd locations and red circles are the Miltonvale wells.

3.2 Annual Electrofishing Surveys.

Electrofishing surveys were conducted September 26-30 in 2016, October 3-11 in 2017, September 20-October 10 in 2018, Sept 26-October 4 in 2019, and September 30-October 7 in 2020. While efforts are made to complete this in as few consecutive days as close to the end of September as possible, periods of rain, as was frequent in 2018, delayed sampling. Three-pass electrofishing without barrier nets 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 directly measured. The mean length or electrofishing reaches was 60.9 m (SD=8 m). Evaluation of electrofishing pass data showed that there was a declining rate of return with each pass and that on average the total proportion of fish captured would be ~85%. Electrofishing data are raw and not corrected for estimated fish not captured.

The numbers of rainbow trout and brook trout 1+ and YOY (as well as less commonly occurring species) were counted, and weight and length measured (YOY discrimination checked later using annually established length distribution cutoffs). In 2016, YOY were weighed from each location en masse but were individually weighed for the remainder of years. Fish were 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. Four Atlantic salmon smolts were captured in 2019 and one juvenile Atlantic salmon was captured in 2020. This suggests that salmon have been regularly spawning in Lower Coles, through spawning activity was likely very limited to the one redd observed. 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.

Previous reports have examined brook trout and rainbow trout density and biomass and found them to be relatively high in Coles Creek as compared to other streams in Atlantic Canada. Given the number of years of data, the fact that every reach is unique, the full five years of data is examined herein by individual reach (Figure 12). However, as the two upper headwater reaches contain few fishes, are not in comparable habitat to the rest of Coles Creek, are impacted by summer temperature, and are distant from the wellfield and were dropped from further analysis. The use of density was again considered, however in low flow situations streams will be narrower and fish will either adjust their density to suit conditions, or potentially exist at higher density than expected as there is less stream area. Calculation of stream area also has very high uncertainty. For this reason, and because each reach is comparable to itself, absolute numbers of fish per linear meter of stream was examined herein as being more likely to reflect change.

Considerable inter-annual patterns are apparent in the abundance of the two main species examined. Brook trout YOY are most indicative life stage of the previous fall spawning and the subsequent survival. Between 2016 and 2017 (pre-pumping) there was a substantial drop in YOY Brook trout in the lower reaches (Figure 12; green lines) and in increase in the old pond bed reaches (red/orange lines). Overall, Coles Creek had the lowest abundance of brook trout YOY in 2018 (based on the average of the entire stream), with only a slight increase at some locations in 2019. However, in 2020, every single reach saw an increase in YOY brook trout numbers over 2019. Rainbow trout YOY showed generally opposite trends to brook trout YOY and they increased during the study to the highest overall average abundance in 2019, followed by a drop in 2020. This was particularly evident in the lower three reaches of the stream where there was only a single YOY in 2016 and 73 YOY by 2019. In 2020, rainbow trout decreased in 8 of the 10 reaches examined here. Increases were only found in two of the uppermost reaches in 2019. In 2020 drops in YOY rainbow trout were most apparent in the lower reaches and no rainbow trout YOY were found in two of the three lower reaches.

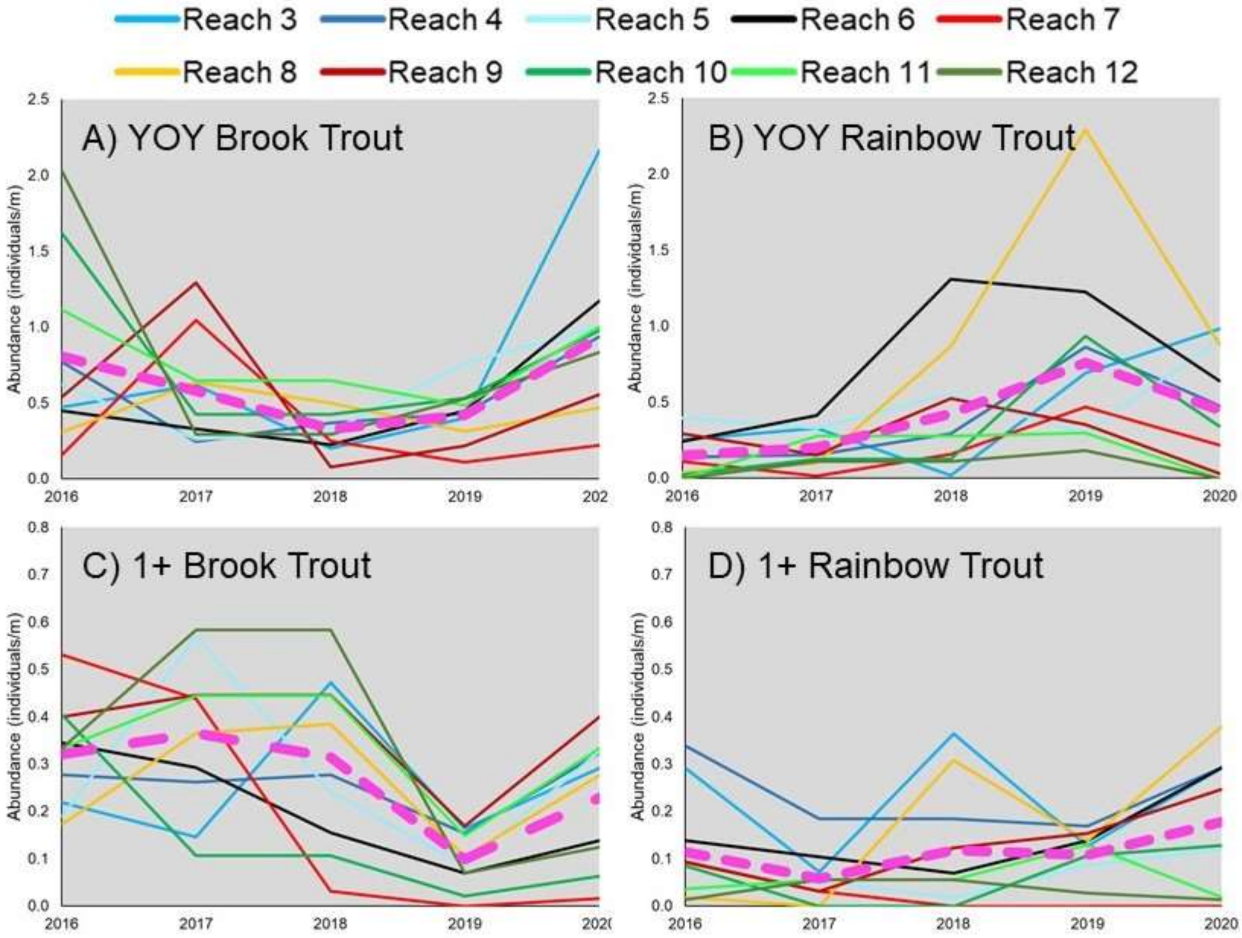

Figure 12. Rainbow trout and brook trout abundance by reach. Blue/black lines are Upper Coles, red/orange lines the old pond bed, and green lines the Lower reaches. Dashed pink line represents the annual average for all reaches.

In order to statistically evaluate the changes to brook trout and rainbow trout YOY abundance, multivariate regressions were used to examine the effects of reach (categorical), year (categorical), and YOY abundance of the potentially competing species (continuous). With brook trout YOY as the dependent variable, year or survey was the only statistically significant variable (the trend by year is shown by the pink dashed line in Figure 12). When rainbow trout YOY abundance was examined as the dependent variable, both year and reach were statistically significant. This result is not surprising given the appearance an subsequent decline of rainbow trout in the lower reaches. Overall, this suggest that year to year environmental factors, or spawning activity are influencing YOY numbers most strongly.

In Coles Creek, 1+ fish are likely dominated by two- and three-year-old fish. Many brook trout may go to sea, and larger older rainbows typically move out to the estuary as this stream is too small to sustain them. As such, a delay of one year or more is expected in the 1+ abundance of both species relative to YOY fish. While individual reach patterns were variable, stream wide averages demonstrated this delay. Brook trout YOY reached their lowest level in 2018 and 1+ brook trout followed with the lowest stream average abundance in 2019. Rainbow trout YOY reached their peak abundance in 2019, followed by 1+ rainbow trout reaching peak abundance in 2020. It would be concluded that the abundance of YOY fish in the previous year, is the greatest determinant of 1+ fish.

The multitude of confounding factors in Coles Creek make it challenging to specifically relate changes in fish abundance to causes. Firstly, the primary purpose of this study was to examine potential impacts of ground water extraction. Declines in brook trout YOY occurred before full time pumping started in 2019. The absolute numbers of YOY brook trout increased in 2020, the lowest flow year in Coles Creek to data. It might be expected that the lower reaches would change more to groundwater extraction than the upper reaches, yet upper reaches showed the same trends. At present, there appears to be little or no fish population responses to groundwater extraction from the electrofishing data (supported by redd surveys). However, impacts of the low flow in 2020 (which persisted through to December) may not be realized until 2021 or later years. Changes to sea-run recruitment that likely dominates the lower reaches of the stream, may not respond to in-stream conditions for three years.

Fish numbers in Coles Creek are exhibiting stream-wide annual variability and several factors may be causing this. There is a general inverse relationship between rainbow trout and brook trout YOY, though this is not statistically significant across the stream (possibly as there is a negative slope in the brook trout rainbow trout relationship only in the lower 7 reaches). This could mean that YOY rainbow trout compete directly with YOY brook trout. However, it could also mean that conditions that favour brook trout egg to YOY survival are different than those that favour rainbow trout survivorship. This in conceivable since brook trout are fall spawners and rainbow are spring spawners. For example, a large, late, spring freshet could benefit brook trout that are already emerged in March before the freshet by exposing food items and reducing redd sedimentation. This may be a detriment to rainbow trout as redds may be infilled with sediment if high flows occur closer to the April spawning period. Emergence trapping efforts in Coles Creek in spring 2021 have shown sediment to be a significant issue and recent efforts to examine Atlantic salmon redd oxygen demonstrate that oxygen declines during high flow events (J. Condon unpublished data). It is difficult to speculate on this without better knowledge of the spawning biomass and many of the brook trout and rainbow trout spawners will come in from sea. There is evidence that brook trout redd counts are increasing, which is consistent with the recent increases observed in YOY brook trout in 2020. However, it will not be apparent until 2021 whether the 2020 redd count increases manifest into increased YOY abundance.

Another confounding factor in this study can be stream restoration (generally brush mats) and the removal of woody debris. This practice of woody debris removal, a concept considered outdated and detrimental in most jurisdictions 4 decades ago (Warren et al. 2018), is practiced by watershed groups in Coles Creek and elsewhere on PEI. Brook trout unquestionably respond to changes in woody debris as they are dependent on it for cover, though scientific studies have not been conducted on PEI. While woody debris removal in Coles Creek has not been aggressive, it has been ongoing, and the confounding effect are not known. It is unlikely to see stream wide patterns of response from woody debris removal as this is generally only conducted in particular reaches each year. Woody debris removal did take place in the lower reaches in the past few years, and a usual response to this activity is a reduction of brook trout and dramatic increases in rainbow trout.

3.3 Tagging Study

Electrofishing studies are conducted in the fall when stream temperature is falling, and thus may not capture impacts occurring when stream temperature are highest in July and August. As temperature in the lower stream has risen due to groundwater extraction, temperature avoidance, or seeking thermal refugia may be the immediate response of brook trout. Passive integrated transponder tags were used in brook trout to examine movement between June and September 2020. The second reason for this tagging effort is to document micro habitat of brook trout for future hydraulics/habitat simulations. Three 150 m reaches were chosen to examine brook trout movement. One was in the wellfield area, a second below Highway 2, and a third in Springvale branch of the North River. Fixed antennas were present at the upper and lower ends of the study reaches to document fish entering or leaving the reach. Fish were tracked through the summer every two weeks using a mobile PIT tag reader. Currently, only the data from the mobile PIT reader has been given initial evaluation.

Of 45 brook trout tagged in Springvale branch of the North River, 18 (40%) were detected with the mobile tag reader though the summer. Only 16 brook trout were tagged in the wellfield area, and 4 (25%) were found with the mobile tag reader. Lower Coles below Highway 2 had the lowest proportion detected with only 16% (7 of 44). In all three reaches, not every fish was detected in every survey (generally less than half detected), so it is uncertain at this point if those fish are escaping detection, or temporarily leaving the reach. In Springvale and the wellfield area, the detections per survey did not increase or decrease consistently over time. In Lower Coles, detections did drop off in late August and early September. However, these numbers were too low to draw conclusions, and this was at a time when temperatures were falling. Evaluation of the fixed antenna information should determine if fish left and did not return after tagging or were coming and going.

4.0 Future Work

Going forward with the three-year extension of the present project the study objectives are:

- Continue to measure flow and fisheries for at least another three years post-pumping using the sites and method described here with a possible increase in pumping rate considered.
- Characterize the groundwater flux into the stream, including from spring temperature monitoring and 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 and emergence trap evaluation of brook trout reproductive success.
- Repeat the tagging study with a May start to examine summer fish movement under a full temperature regime.
- Conduct habitat simulations using Coles Creek from hydraulic models.
- Initiate groundwater models using provincial data in conjunction with historic flow data.

5.0 Conclusions

1. Flow deviations from expected of approximately 0.02 m^3/s were consistently detected in August from 2018 to 2020 due to groundwater extraction.

2. Coles Creek experienced an extended period of low flows for the past decade.

3. In the low flow year 2020, the Coles Creek 70Q50 was not maintained in August (and much of the year). Given current flows and pumping, August exceedances of this regulation are likely approximately 40% of years.

4. Flow deviations resulted in at least 1°C degree temperature change in the lower river and temperatures in the lower river reach 20ºC. Based on this, temperature changes pose some future risk to brook trout in light of climate change.

5. Coles Creek fish abundance data showed annual streamwide patterns rather than local patterns with drops in brook trout starting in 2016 and increases in brook trout number in 2020. Increases in brook trout YOY abundance are consistent with increases in the number of redds observed each fall.

6. Brook trout YOY abundance is inversely proportional to rainbow trout YOY abundance.

6.0 Recommendations

1. Three more years of Coles Creek monitoring are starting this year, and while this may be revealing, there are data gaps in our basic biological understanding that will preclude making further conclusions. Given an expanded project including agricultural wells, and the potential for seeking substantive matching funding from NSERC, several basic fisheries data gaps need to be examined:

i. Do rainbow trout and brook trout compete directly for resources? There is not information on this in the fisheries literature.

ii. Do spring conditions, particularly where sediment loads are high differentially affect brook trout and rainbow trout?

iii. What is the impact of woody debris on brook trout and rainbow individually, and their trout interactions.

iv. There is little site-specific or Island wide data on brook trout sea-run spawning trends. Counting traps are work intensive to manage and passive (electronic) fish counting technology may need to be examined as this technology is rapidly developing.

v. There is little understanding of the ratio of sea-run vs. resident-derived YOY in PEI streams. Preliminary investigations have shown the potential of otolith microchemistry to document this.

2. With the observed, and possible more severe temperature changes likely to be how brook trout become impacted in Coles Creek, consideration should be given to compensatory stream mitigation for the effects of pumping. The upper regions of the stream could benefit significantly from the establishment tree cover in riparian zones, though the effects of ponds on temperature may not be possible to change without their

removal. Restoration of the upper reaches has the potential to more than compensate for impacts of flow reduction on temperature and maintain Coles Creek as excellent brook trout habitat. This would also lead to the creation of additional habitat in Coles Creek for brook trout through decreases in sediment load.

3. In light of the impacts of groundwater extraction on stream temperature, it is confusing and counter-intuitive to have two stream flow regulations, one for groundwater extraction, and one for surface water extraction. Groundwater extraction will likely have greater impacts on the stream, yet the regulation is more lenient. It is recommended that the 70Q50 be adopted for both.

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