Title: Pigg River Water Quality Analysis – Years 2020-2021.

Introduction and Background

The Pigg River located in south central Virginia was named after an early settler John Pigg who laid claim to 400 acres of land opposite the mouth of Snow Creek (Clement 1929). When John Pigg made that claim, the river flowed through miles of forested land predominated by Chestnut, Oaks and Hickory. Since that point, the watershed has remained predominately forested land use but through time experienced an ever-increasing encroachment of land clearing for agricultural production. By best estimates in 2021, the watershed consists of 65% forest, 26% agriculture (crops and cattle) and 5% urban development (Streamstat 2011; Benham et al. 2006).

The land cover and land use (LCLU) in any watershed can be very predictive of water quality. In watersheds predominately covered by forest, river water quality is good. As a watershed becomes increasingly plagued by human alteration and economic activities, degradation follows and can be strongly correlated to disturbances (Tong and Chen 2002; Baker 2003; Buck et al. 2004). Direct quantification relating to a specific land use impact is difficult. However, generalizations exist. The model of impervious cover (Schueler et al. 2009) generalizes degrading water quality with increasing impervious surface. Sediment moving from deforested or disturbed areas into rivers can be characterized as the urban sediment cascade (Taylor and Owens 2009). The key to understanding such impacts is a quantification of ever-increasing amounts of impervious surface or tilled land surface redirecting rainfall into streams rather than infiltration back to groundwater where it was historically stored (Schueler er al. 2009). This problem is now being exacerbated by climate change (Shahady 2022b).

Specifically defining agricultural impacts becomes more difficult because these stressors are often diffuse (Stone et al. 2005; Cuffney et al. 2000). Characterizing cattle and wildlife direct deposits into rivers along with straight pipes and manure loading is difficult. Agricultural land use along with precipitation events may be driving causes for degraded water quality, but it is hard to scientifically characterize such impacts and mechanisms. Haramoto et al. (2006) demonstrated a 10- to 100-fold increase in *E. coli* concentrations following precipitation events from agricultural lands, providing evidence that agricultural land use frequently degrades water quality. Other studies support this conclusion (Stein et al. 2008; Tong and Chen 2002; Shahady 2022a). Further, Sobolewski (2016) found that lakes in catchments with extensive agricultural land use exhibit poorer water quality. Thus, common agricultureal practices are understood to degrade water quality.

An even more difficult quantification is describing risk associated with pathogens (bacteria, protozoans, viruses) flowing from agricultural fields. Using climate and epidemiological records, Rose et al. (2000) found statistical evidence suggesting a correlation between storm events and disease outbreak. Runoff of bacteria and nutrients from hillsides may be responsible for this correlation. Particularly since many pathogens can survive in a pasture or woodland environment for an extended period of time. However, the role of stream sediment to these outbreaks has been strongly implicated. It is hypothesized that sediment loading along with organic material provides a good environment for pathogens to survive until the next storm event re-suspends them back into the river environment. Pachepsky and Shelton (2011) found the survivorship of *E. coli* in sediments is much greater than in the overlying waters. Mallin et al. (2011) measured continued bacterial contamination of sediments from a sewage spill well after levels depleted in overlying water. Chen and Lui (2017) found suspended sediment transport influenced fecal coliform concentrations. Hence, we understand that pathogens can be deposited in river beds and then resuspended during storm events. This creates the concern that impacted rivers harbor extensive beds of bacteria, potential pathogens and other pollutants that will be resuspended continually as precipitation events flow through these rivers.

The concern in the Pigg River and perhaps in Leesville Lake is that exposure to pathogens entering contaminated water exposes residents to disease. While some level of exposure is assumed, the critical question is one of acceptable risk. In addition, the persistent influx of sediment and nutrients continue to degrade water quality and exacerbate this problem. At what point does the water quality entering from the Pigg River degrade Leesville Lake enough to create potential health concerns and unacceptable water quality? Thus far, our water monitoring of Leesville Lake has shown that bacterial concentrations may exceed state standards only in the upper portion of the reservoir.

This investigation was initiated in the summer of 2018 to address these concerns. It was continued in 2019 to begin determinations of the exact origins of *E. coli* contaminations at certain stations and during various stormwater flows in the river. In 2020 and now reported in 2021, we intensively studied specific areas of the watershed to quantify were the bacterial and water quality contamination emanated and if we could correlate this contamination to specific sources using molecular source tracking.

Methods

Regulatory Background and Previous Work

The Federal Section 319(h) funding for nonpoint source BMP (Best Management Practices) provides implementation for the control of pollution entering the nations rivers. Because there are no current TMDL studies or implementation plans active on the Pigg River, this is the best and current regulatory program to improve water quality on the Pigg River. This program is based on nine required elements of a NPS IP (Non-point Source Pollution Implementation Plan). Essentially the installation of things like fencing or treatment facilities that will reduce the flow of bacteria into the Pigg River. The grant requires the following elements:

1. Identify the causes and sources of groups of similar sources that will need to be controlled to achieve the load reductions estimated in the NPS IP.
2. Estimate the load reductions expected to achieve water quality standards.
3. Describe the nonpoint source management measures that will need to be implemented to achieve the identified load reductions.

4. Estimate the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement the NPS IP.
5. Provide an information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the NPS management measures that will be implemented.
6. Provide a schedule for implementing the NPS management measures identified in the NPS IP.
7. Describe interim, measurable milestones for determining whether nonpoint source management measures or other control actions are being implemented.
8. Identify a set of criteria for determining if load reductions are being achieved and progress is being made towards attaining water quality standards, and if not, the criteria for determining if the NPS IP needs to be revised.
9. Establish a monitoring component to evaluate the effectiveness of the implementation efforts.

The central aim of this continuing program is the installation of BMPs that meet the NPS IP load reductions, and to monitor and evaluate the existence of current BMPs through collaborations for NPS reductions. The lower Pigg alone contains 368 miles of stream. Pasture that adjoins those stream miles is 100 miles. Current estimates suggest that 132 miles of stream needs exclusion. So far, 5.9 miles of stream exclusion fencing has been built – only 4.4% accomplished. This activity is considered 100% effective.

Of installed measures, SL-6 (Grazing Land Protection Systems) and WP-2T (Stream Protection Systems) systems of practices are needed to control pasture runoff. The SL-6 practice includes streamside fencing, cross fencing, alternative water system(s), hardened crossing(s) when needed, and a 35-ft buffer from the stream. These systems were estimated at 20k per installation in 2008 dollars. This system is needed for 93% of the watershed.

The WP-2T practice includes stream-side fencing with a 35-ft buffer and hardened stream crossing(s), if needed. The cost of the WP-2T system was set at $13,000, which includes on average, 2,000 feet of stream exclusion fencing and one hardened stream crossing. This system will meet remaining 7%.

Two types of buffer systems are recommended - (woodland buffer filter area practice, FR-3 at $292 per acre) and (Reforestation of Erodible Crop and Pasture Land, FR-1 at $103 per acre) Finally animal waste control facilities (WP-4 at $60,000 each) for beef and dairy cattle, and loafing lot management systems (WP-4B at $50,000 each) are the recommended systems to reduce bacteria loads.

Current estimates suggest 221 of the SL-6 systems are needed and 29 of the WP-2T in this watershed. Ten acres of FR-3 and 1,899 of FR-1 are needed. WP-4 systems for Beef Cattle facilities is 7 and for dairy the need is 4. A total of 5 WP-4B systems are needed. 100% of all pastures in the watershed need management. On the residential side, 813 septic systems need repair. Other suggested fixes include RB-1 septic tank pump outs and connection to public sewer.

Virginia Total Maximum Daily Load (TMDL) Program

The Virginia Total Maximum Daily Load (TMDL) Program, which addresses waters with bacteria levels exceeding state standards, published a report in 2006 on waters around Leesville Lake (Benham et al. 2006). This report addressed bacteria levels flowing from the lake's two main tributaries, Pigg River and Old Woman's Creek. Story Creek (a tributary to Leesville Lake-Pigg River) and Upper Pigg River have been on Virginia's 303(d) list of impaired waters since 1996. Leesville Lake-Pigg River has been listed as impaired since 1998. Snow Creek (another tributary to Leesville Lake-Pigg River) and Old Woman's Creek have been listed as impaired since 2002.

The TMDL report identified three-point sources discharging bacteria into the Pigg River basin, with one located in the Story Creek watershed area. There were no permitted dischargers in the Old Woman's Creek watershed. The TMDL reporting specifies nonpoint sources as the primary source for high bacteria levels; including agriculture, land-applied animal waste, and livestock manure as the main nonpoint sources. The report also specifies that cattle and wildlife directly dumping feces into streams cause a large bacteria load. Nonpoint sources from residential areas include straight pipes, failing septic systems, and pet waste (Virginia Tech, 2006).

Pigg River and Old Woman's Creek TMDL Implementation Plan published in 2009 identifies work necessary for *E. coli* reductions in the watershed to bring violation rates below 10% per year. Majority of the need is controlling pasture runoff with livestock fencing and point source reductions. Of concern for Leesville Lake are the elevated *E. coli* concentrations in Pigg River discharge. Additionally, cattle have previously been reported in the river at the Pigg River mouth entering Leesville Lake.

The total cost-share payments for BMPs installed throughout the project period were $1,588,908. Eighteen on-site sewage disposal practices were installed in the watershed in FY13, these included replacement of 16 failing septic systems and the repair of two septic systems. A total of 38 miles of livestock stream exclusion fencing has been installed through TMDL practices, constituting 60% of the fencing goal in the TMDL implementation plan (VADEQ IP Progress Report). Funding for this program ended in 2015.

Previous Investigation

An investigation was initiated in the summer of 2018 to measure water quality conditions in the Pigg River Watershed. This river system flows into Leesville Lake in the upper reaches of the reservoir, within 5 miles of the dam for Smith Mountain Lake. This is significant because, during pump-back operations, water from the Pigg River is entrained into the fore-bay of SML. It is unclear the quantities of Pigg River flow that enters SML during pump-back but water quality measures at the tailrace during pump back suggest it is significant. Although the Pigg River supplies significant concentrations of sediment, TP and bacteria, the ultimate fate in each reservoir is poorly understood.

Another recent concern in this watershed was the removal of an obsolete power dam near Rocky Mount, Virginia. Dam removal has become a popular river improvement strategy yet how a dam is removed and reasons for the removal should be carefully considered (see review by D. Orth http://vtichthyology.blogspot.com/2017/11/trends-in-dam-removal-reversing.html). In this instance, the removal of the dam without significant sediment management in place delivered considerable loads of bacteria and turbidity to Leesville Lake. It is important to study this problem as well.

Our study of the Pigg River was initiated to begin the process of quantifying overall water quality in the watershed. Previous TMDL studies identified pasture as significant contributors in *E. coli* studies (Virginia Tech 2006). It follows that sediment and TP also associated with storm water runoff are elevated due to pasture impacts. This study outlines an initial approach to quantify these concerns in the watershed. It is our hope subsequent studies can pinpoint significant problem areas and help policy makers control point and non-point pollution in this watershed.

Study Sites and Sampling Protocols

We sampled 11 sites along the Pigg River and its associated tributaries (Figure 1). In 2020, we focused on the upper Pigg River characterizing any associated problems emanating from Rocky Mount. In 2021, we focused on the lower Pigg River looking at areas suspected as having significant agricultural inputs.

Figure 1 – Map of Pigg River Watershed. Samples were collected throughout the watershed including Lower Pigg (All Portions of the River

below Rocky Mount and Upper Pigg (All Portions of the River above Rocky Mount). We eliminated sampling on Snow Creek and Big Chestnut Creek based on earlier sampling (Figure from Virginia Tech 2006).

Each site was chosen for accessibility as we sampled water from a bridge crossing using an alpha bottle or similar container to capture a water sample. Each sample was obtained by lowering the sampling device into the flowing water bringing to the surface then recording measurements for analysis.

Figure 2 – The Pigg River as it enters Leesville Lake showing the excessive turbidity present during storm events. This is the Toshes site (Figure by permission of author).

Water was immediately transferred to acid washed bottles and stored in a cooler until TP analysis was performed. Another 100ml aliquot was transferred to a sterilized bottle for *E. coli* analysis. Remaining water was analyzed using a YSI multiprobe and Turner Turbidimeter to collect the remaining data.

Additional sites, as described subsequently, were sampled for bacterial source tracking (BST). At these sites, water was aseptically collected by directly immersing a sterile plastic bottle several inches into the river. The bottle was stored on ice and subsequently shipped overnight to a commercial firm (SourceMolecular, Miami Lakes, FL) which performed the analysis. The host species was determined using quantitiatve polymerase chain reaction (qPCR). Marker sequences were for various bacteriodes species were identified and, using appropriate primers, the sequences were amplified and quantified. A single human marker sequence was targeted, two bovine sequences (bovine 1 and 2) and a more encompassing ruminant sequence was also targeted.

Figure 3 – Area of recent deforestation in the Pigg River Watershed. This is occurring throughout the watershed (Figure by permission from Author).

Figure 4 – Area of active deforestation along the banks of the Pigg River. This activity is within the riparian corridor of the river and is adjacent to the Museville sampling site (Figure by permission from Author).

Figure 5 – Excessive buildup of timber from deforestation into bridge on Power Dam Road near Rocky Mount Virginia. Contractors are working to remove the debris (Figure by permission from Author).

2020 Sampling

Based upon areas identified in previous work as potential "hot spots" we initiated sampling to monitor these sites using both the conventional sampling that included water chemistries and Colilert *E. coli* testing with the addition of Bacterial Source Tracking (BST). A hot spot was considered a sampling station where excessive concentrations of *E. coli* were measured using the Colilert methodology. Excessive was considered over 1000 counts/100ml during low flow conditions and in excess of 2400 counts/100ml during flood conditions.

A two-tiered approach was selected for this study. Initially, we sampled above, below and directly in the hot spot during low flow conditions in the river. High flow was during periods of time where stormwater was flowing in the river. Stormwater could be identified by high turbidity (>5 NTU) in the river and appreciable rain (> 0.5 inches) in the watershed during the week preceding a sampling. Low flow sampling was designed to pinpoint exact location of bacterial contamination during non-runoff conditions. The second sampling was designed to identify contamination during a stormwater event. Several additional sampling sites along Pigg River were sampled to track the flow of contamination along the river into Leesville Lake.

Figure 6 - Sampling the Pigg River at Chestnut Hill Road crossing during a dry period for Bacterial Source Tracking (Figure by permission from Author).

Three sampling dates were selected. August 27, 2020 was our initial sampling to look at parameters in the river around the hot spot and conditions. On October 6, 2020, we sampled the river from Leesville Lake into Rocky Mount taking additional samples for BST to determine contamination in identified hot spots. We followed up this sampling again on October 22, 2020 under differing flow conditions in the same manner as the previous sampling.

Figure 7 – Removal of the Power Dam. This has created an ongoing concern about water quality in the Pigg River (Figure from review by D. Orth http://vtichthyology.blogspot.com/2017/11/trends-in-dam-removal-reversing.html).

Figure 8- late summer condition of dam on Power Dam Road after removal. Legacy sediment appear to be a continual problem. Note the discoloration of the water even during low flow conditions (Figure by permission from Author).

Figure 9 – Sampling the Pigg River by kayak following one of the storm events in early fall. Note the color of the water. This sampling method allowed direct measure of WWTP effluent (Figure by permission from Author).

Sampling Plan 2021

Building upon previous work, the focus of this study moved to the Lower Pigg River and an attempt to quantify impact in each river reach. Each reach or river segment was characterized using aerial maps and quantification of land use adjacent and directly along the river upstream from each sampling point. A land use or buffer was considered identified within 100 feet of the river bank. River segments were measured and land use identified. Using the aerial maps, forest vs. pasture or other use was easily identified. Each land use was measured and then quantified using the following criteria to determine a land use type:

- Minimal Impact - > 50% land forested and buffered along each river reach. Buffer minimum of 50 feet. Minimal impact from pasture land use
- Mixed Impact – approximately 50% of reach buffered or forested with remaining reach pasture with minimal buffer
- Significant Impact - < 25 % of reach forested or buffered – up to 75% reach pasture with minimal buffer
- Major Impact - <10% of reach forested or buffered – up to 90% reach pasture with minimal buffer

Each river segment was quantified by land use and river length between segments (Table 1)

Table 1 – River segments, land use and distance between proposed sampling sites. Sampling sites were determined by highway river crossings.

River Segment	Designated Land Use	River Distance (Miles)
Toshes to Toler	Riverine/Limnetic – Minimal Impact	3.5
Route 40 to Toshes	Significant Impact	5.2
Museville to Rt 40	Mixed Impact	5.7
Snow Creek Rd to Museville	Significant Impact	3.5
Pigg River Road to Snow Creek Road	Mixed Impact	8.3
Truevine to Pigg River Road	Significant Impact	2.2
Colonial Turnpike to Truevine	Minimal Impact	5.1
Doe Run Road to Colonial	Minimal Impact	4.7
Chestnut to Doe Run	Mixed Impact	10.2
Power Dam to Chestnut	Major Impact	4.8

2021 Study Design

Within the possible impacts along the Lower Pigg River, differing impacts were identified (Table 2). For this study, 4 designated land use impact types were studied (2 from significant, mixed use and minimal). As resources allowed, all study sites were sampled.

Table 2 – total number and river distance of each identified land use impact along the lower Pigg River between designated sampling points.

Use	Number of Reaches	Total Stream Miles
Major Impact	1	4.8
Significant Impact	3	10.9
Mixed Use Impact	3	23.3
Minimal Impact	2	9.8

All collected parameters are plotted against land use to determine impact from each designated use. The basis for this study is to determine from data the impact of buffer/land use in each segment and degradation or improvement based upon that land use to accomplish the following goals:

1. Identify areas of concern and where needed resources should be applied to improve or preserve water quality
2. Serve as a watershed management blueprint for water quality improvements based on application of agricultural BMPs.

Results

Collected data support the designation of the Pigg River as impaired (Table 3). Our bacteriological results clearly suggest the river is continually impaired for *E. coli* throughout the entire basin. Our hot spot investigation revealed that while human contamination was visible in the data, ruminants were the predominant source of bacterial impairment. Our focus on the Rocky Mount area did not warrant further investigation as the areas previously identified as concern for human waste contamination no longer exhibited human source contamination at concentrations that were concerning for our investigation.

In 2021, we monitored the river twice (Table 4) and again measured elevated *E. coli* throughout most of the basin. With these samplings, we used BST to pinpoint the source of bacterial contamination and elevated *E. coli*. Data indicated that although we were able to identify human bacterial contamination, it was not predominant or concerning. Where *E. coli* were elevated the source of this elevation appeared to be predominantly from deer. While contamination from bovine was again present in the watershed, it did not appear to be predominate source of the *E. coli* elevations. It appeared that during the higher river flows during October 6, 2021 sampling that elevated *E. coli* could be attributed deer origin. Of the measured markers, 86% at Colonial Turnpike and 94% at Chestnut Hill sites were of these origins. We know from previous studies ruminant markers become very elevated during rain events. This year's work supports the idea that Deer are the predominate source of bacterial contamination in the watershed. More data is needed to support this idea.

Associating observed contamination to a particular land use in the watershed is more difficult. During low flow conditions, as observed during the November 4, 2021, the river is not as contaminated. *E. coli* concentrations were reduced and similar contributions of host species to bacterial contamination were observed. Stormwater is clearly the driver of contamination and during the October 6, 2021 sampling we see a pattern emerge. Measures at Colonial Turnpike and Chestnut Hill were much more impaired than elsewhere in the river. Not only are the elevated *E. coli* concentrations concerning, but the input of total phosphorous above 2 mg/L is very worrisome.

Correlating this to land use identification, we see that these sections are characterized by different land use impacts (Table 1). Land use from Power Dam Road to Chestnut Hill is primarily agricultural and we see this reflected in the data. However, from this point to Colonial Turnpike we see the land use impact reduces from major to mixed and then minimal. We therefore suggest that the bed load of sediment previously contained by the power dam has moved into this section of the river following dam removal and now impacts water quality when river flows increase. Surrounding land use are not suggestive of this impact.

Table 3 – Measured Water Quality Parameters in 2020 Per Station. Units are indicated in each column.

Station	Temp C	Conductivity us/cm	DO %	DO mg/l	pH	ORP	Turbidity NTU	TP mg/l	NO3 mg/l	E. coli cfu/100 m	Human	Bovine I	Bovine II	Ruminants
Toshes	10.19	17	93.4	10.43	6.06	50.2	0.667	0.051		151	76	0	0	3790
Museville	10.12	17	98.6	11.05	6.52	47.7	0.533	0.245		201				
Snow Creek	10.04	18	104.1	11.6	6.44	47.3	0.391	0.043		114				
Truvine	10.3	17	109	12.29	6.33	75.5	0.297	0.029		111				
Leadbetter	10.97	43	101.5	11.18	7.34	25.8	0.189	0.022		123	0	0	0	0
Chestnut hill	11.13	22	98.3	10.57	6.82	38.8	0.732	0.079		411	228	0	0	2280
Memorial Park	9.86	18	97.9	11.05	7.38	22.8	0.306	0.06		214	40	0	0	11400
Furnace Creek	10.49	40	97.8	10.91	6.96	34.5	0.274	0.028		61	148	0	0	0
South Main	11.18	19	100.1	11.02	6.81	42.3	0.411	0.021		200				
Waid Park	11.37	18	104.5	11.42	6.6	71.6	0.291	0.058		250				
Powerdam Road	12.2	21	108	11.45	6.82	41	0.561	0.021		148				
Powder Mill Mouth								0.021		192	0	0	0	0
			Oct 22 2020											
Station	Temp C	Conductivity us/cm	DO %	DO mg/l	pH	ORP	Turbidity NTU	TP mg/l	NO3 mg/l	E. coli cfu/100 m	Human	Bovine I	Bovine II	Ruminants
Toshes	12.18	72	86.3	9.25	6.53	68.7	0.367	0.028		135	80	0	0	3150
Museville	12.5	69	108.1	11.52	6.18	102.5	0.554	0.028		122				
Snow Creek	12.27	44	131.1	14	6.23	103.5	0.729	0.041		131				
Truvine	12.66	74	96.5	10.22	7	67.5	0.617	0.101		770				
Leadbetter	12.97	181	95.3	10.02	7.53	42.6	0.222	0.007		205	120	0	0	0
Chestnut hill	12.55	89	93	9.88	7.1	69.5	0.48	0.1		261	624	0	0	16300
Memorial Park	11.96	74	88.9	9.58	7.18	50.9	0.095	0.021		345	80	0	550	27900
Furnace Creek	12.66	171	90.6	9.61	7.54	42.2	0.055	0.026		291	0	0	0	0
South Main	14.64	82	100.1	10.13	7.37	46.2	0.142	0.049		308				
Waid Park	12.97	181	95.3	10.02	7.53	42.6	0.183	0.026		231				
Powerdam Road	13.99	91	99.3	10.18	7.33	32.5	0.419	0.006		231				
Powder Mill Mouth	12.2	166	93.3	10	7.09	59.6	0.146	0.016		49	0	0	0	0
	Temp C	Conductivity us/cm	DO %	DO mg/l	pH	ORP	Turbidity NTU	TP mg/l	NO3 mg/l	E. coli cfu/100 m	Human	Bovine I	Bovine II	Ruminants
Toshes	14.3	38.7	94.2	9.6	6.6	51.7	1.0	0.06		302	80.0	0.0	0.0	3150.0
Museville	14.3	37.0	106.1	10.9	6.6	63.6	0.9	0.13		237	76.0	0.0	0.0	3790.0
Snow Creek	14.3	29.7	116.9	12.0	6.6	63.4	0.9	0.04		211				
Truvine	14.5	39.3	107.2	11.0	6.8	58.3	0.6	0.08		416				
Leadbetter	14.8	85.7	104.9	10.6	7.4	31.9	0.3	0.04		263	60.0	0.0	0.0	0.0
Chestnut hill	14.6	48.3	101.3	10.2	7.1	46.8	0.6	0.09		346	426.0	0.0	0.0	9290.0
Memorial Park	13.7	40.0	100.4	10.4	7.3	34.3	0.3	0.04		391	60.0	0.0	275.0	19650.0
Furnace Creek	13.9	91.3	101.6	10.5	7.4	31.9	0.2	0.02		255	74.0	0.0	0.0	0.0
South Main	15.0	43.7	104.4	10.5	7.2	39.4	0.3	0.04		323				
Waid Park	14.9	75.3	107.1	10.8	7.2	47.9	0.2	0.04		257				
Powerdam Road	16.1	47.7	109.8	10.8	7.2	37.3	0.5	0.04		309				
Powder Mill Mouth	12.2	166.0	93.3	10.0	7.1	59.6	0.1	0.02		120	0.0	0.0	0.0	0.0

Table 4 – Measured Water Quality Parameters in 2021 Per Station. Units are indicated in each column.

Station	Temp C	Conductivity us/cm	DO %	DO mg/l	pH	ORP	Turbidity NTU	TP mg/l	NO3 mg/l	E. coli cfu/100 m	Human	Bovine	Elk / Deer
Toler	16.63	54	65.2	6.33	7.12	64.2	4.32	0.041		23	0	0	0
Toshes	16.12	26	95.7	9.4	6.88	77.1	10.53	0.156		145	28	0	0
Route 40	16.06	25	95.2	9.38	6.78	86	9.24	0.09		411			
Museville	16.23	26	98.1	9.59	6.9	84.6	12.65	0.089		517	180	0	26
Snow Creek	16.12	26	107	10.3	6.88	79.7	12.85	0.123		616			
Truvine	16.19	26	97.1	9.55	6.74	89.4	21.2	0.319		2738	156	220.5	0
Colonial Turnpike	16.52	33	102	10	6.89	83	31	2.067		12098	304	3850	24700
Pigg River PO	16.93	29	105	9.6	6.96	80.6	25.5	0.889		881			
Doe Run	16.61	33	97	9.5	6.85	90	19.14	0.198		2420			
Power Dam	16.93	30	110	10.7	7	91	13.99	0.087		291			
Chestnut hill	16.99	35	106.6	10	6.98	82	19.21	0.97		5055	248	3040	52000
			11/4/21										
Station	Temp C	Conductivity us/cm	DO %	DO mg/l	pH	ORP	Turbidity NTU	TP mg/l	NO3 mg/l	E. coli cfu/100 m	Bovine	Elk/Deer	Ruminant
Toler	9.33	36	87.5	10.02	6.63	119.6	11.39	0.11		32	0	0	34.2
Toshes	5.78	23	91.6	11.43	6.84	110.4	4.036	0.079		130	35.76	0	34.7
Route 40	5.64	22	94.9	11.73	6.8	113.7	2.807	0.105		166			
Museville	5.57	22	100.4	12.02	6.87	108.6	2.538	0.069		248	0	0	36.1
Snow Creek	5.64	22	95.2	11.91	6.94	106.1	6.088	0.098		115			
Truvine	5.46	22	94.9	11.98	7.04	88.7	6.529	0.079		91	0	38.9	35.6
Colonial Turnpike	5.53	25	98.1	12.4	12.4	83.1	6.663	0.106		326	35.27	35.7	31.5
Doe Run	5.41	27	132	14.7	7.12	87.6	2.78	0.086		219			
Power Dam	5.78	24	117.4	14.7	7.02	88.5	2.003	0.051		148			
Chestnut hill	5.46	26	101.4	12.35	6.57	95.8	3.738	0.102		260	34.6	33.3	29.3

Discussion

E. coli measures in Pigg River violate state standards whenever stormwater begins flowing. Pigg River is highly impaired by *E. coli*, yet the source of this impairment is not clearly understood. Our current work attempts to answer these questions. This problem must be approached by examining the external inputs (surrounding land use and source of contamination) and internal inputs (legacy sediment contamination, stream bank erosion, and bed load from dam breach). The work from 2021 gives us some insights into these sources.

First, under low flow conditions the river is not highly contaminated. *E. coli* remains below the standard levels of impairment and the distribution of markers for host species contributing to these levels are evenly distributed and at low levels of detection. This suggests minimal levels of contamination flowing from surrounding land and no disturbance of stream bank erosion or bed load contributions. The river under these flow conditions provides water to Leesville Lake that is minimally problematic for water quality and overall health of the lake.

Yet, stormwater is very concerning. The data presented here demonstrate that under elevated flow conditions *E. coli* and Total Phosphorus (TP) elevate quickly. This highly contaminated water flows through the Pigg River eventually enters Leesville Lake, contributing to water quality problems in this system. We have established a significant relationship between turbidity and *E. coli* in this river (Figure 10), and also between turbidity and TP (Figure 11). Further, the collected data provide inferences regarding the source of problems so that changes in management may be implemented to alleviate the problem.

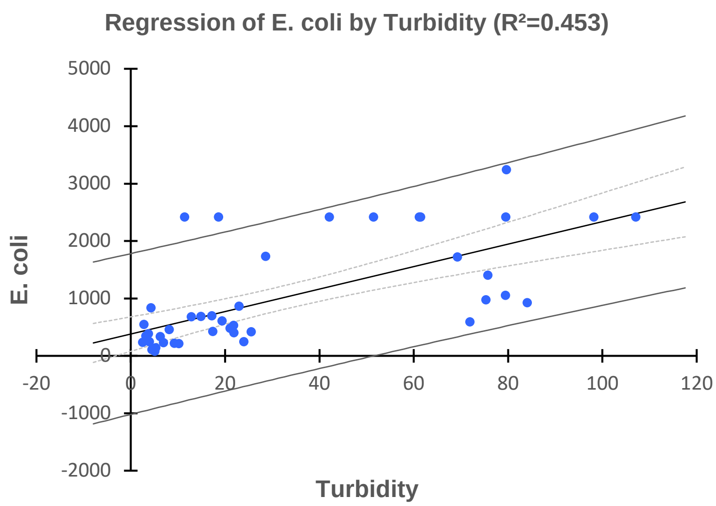

Figure 10 – regression of turbidity and *E. coli*. The relationship is highly significant (p<0.001). Lines represent 95% confidence interval.

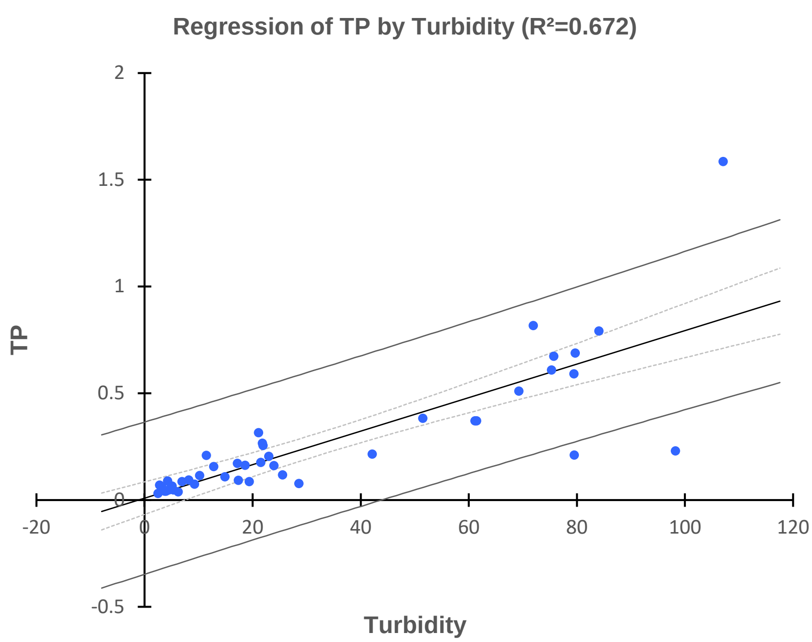

Figure 11 – regression of turbidity and TP. The relationship is highly significant (p<0.001). Lines represent 95% confidence interval.

Concerning land use, heavy agricultural development in the segment between Power Dam Road and Chestnut Hill suggest water quality impairment. We have observed a decline in water quality during storm events at this station. However, we did not observe highly elevated bovine markers when *E. coli* was markedly elevated. This suggests that concentrated land use for agriculture may not be the problem. Additionally, because *E. coli* concentrations were greater at Doe Run and Colonial Turnpike than at Chestnut Hill, without an accompanying increase in bovine markers supports the idea that current land use may not be the primary contributor to this problem.

The concern from the collected data appears to support the idea that internal sediment loading is a major source of contamination. We know legacy sediments harbor bacteria and that stormwater flow will increase levels in streams. We also know that these sediments contain high levels of TP that become resuspended when water movement increases. Sediments that were in association with the bottoms of reservoirs become even more enriched as organic material incorporates into those sediments. Thus, our data suggests that legacy sediments, particularly those associated with the former Power Dam, are major causes of impairment in the river. It is understood that the movement of these sediments is a slow and arduous process and that each storm event significant enough to resuspend these sediments will generate the pattern we observed on Oct 6, 2021; whereas when stormwater is absent, we see the pattern observed on Nov 4, 2021. As storm intensity increases, stream bank erosion and greater sediment overland flow further contributes to the observations. It is suggested that the overwhelming percentage of Deer markers in the river may be legacy bacteria contained in the sediments as these marker studies do not discriminate between living and dead cells only the presence of the genetic markers.

Although legacy sediments appear to be major or primary contributors to contamination of the Pigg River, we must acknowledge that runoff from hillsides can at times be a major contributor. In previous years we have found highly elevated *E. coli* concentrations in the most downstream regions of the Pigg River following heavy rainfalls. That region is less susceptible to sediment contributions, particularly those associated with the Power Dam legacy sediment.

Conclusions and Future Directions

Current data suggests that in-stream processes are generating the degraded water quality in the Pigg River. This conclusion is based on 2020 and 2021 data. This is a small data set and needs further study for validation. However, this conclusion is based on the following observations:

- Both elevated *E. coli* and TP concentrations strongly correlated with turbidity. Increasing turbidity generates increased concentrations of pollutants of concern.
- Turbidity increases with increased flow in the river. This is associated with precipitation. Under baseflow conditions, we do not see elevated turbidity nor concerning levels of any pollutants.

- The elevated turbidity is associated with two processes – overland flow (in particular agricultural fields) combining with loose and unprotected sediment flowing directly into the river *or* existing sediment in the river (streambanks and bedload) that become resuspended during increased flow. Highest flow (technically called bankfull) will erode the stream banks and generate more sediment in the stream.
- Inference then suggests that sediment flowing from agriculture would contain a greater proportion of bovine markers. Human markers can be assumed to be independent from stormwater flow. Deer/elk markers would be associated with forest and in this instance legacy sediments.
- Since it is unlikely that heavy sedimentation flows from forested areas that would harbor dense deer populations it is assumed that these increased markers (and *E. coli*) are from the legacy sediments.

Further study is needed to examine this hypothesis. Work underway in the watershed is focused on building riparian buffer zones. While this work is crucial to good and sound water quality protection its effectiveness will not be realized if the internal loading of pollutants continues. Understanding this relationship could help us know where to concentrate efforts in the protection and restoration of Pigg River. By knowing how water quality is degraded, the negative effects of nutrient run-off and the deleterious impacts of dam removal all contribute to observations current in the Pigg River. Work needs to occur directly in the river bed to measure these contributions as well as land use occurring throughout.

If this hypothesis is correct, as the bedload moves down river it poses an increasing threat to the health of Leesville Lake. Based on measures further from Colonial Turnpike, the river appears to mitigate these concentrations further from the source. This may be the result of better riparian buffers and general health of the stream to metabolize these problems. As this bedload moves downstream it would be an expectation that water quality would degrade.

Additionally, the use of enterococci as a contamination indicator needs to be explored along with the source tracking. Research suggests (Chacon et al 2018) that when the ratio between *E. coli* and enterococci is less than 2 the contamination is likely of animal origin. When the ratio is greater than 4, it is indicative of probable human pollution. This would be a very valuable and much less expensive tool to measure this problem in the river.

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