VIRGINIA WATER RESOURCES RESEARCH CENTER

The Stroubles Creek Watershed: History of Development and Chronicles of Research

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Acknowledgments

This document compiles past and contemporary research reports on the Stroubles Creek watershed. Acknowledgements are due to many Virginia Tech faculty/students and larger community members who have studied the Stroubles Creek for nearly one hundred years. The development of this comprehensive report was made possible by a National Science Foundation Research Experiences for Undergraduates (NSF REU) program funding (Grant No. 0649070) which provided summer internship support to two co-authors of this report, i.e., Ms. Stephanie DiBetitto (University of Vermont) and Ms. Tiffany Sprague (James Madison University). Others who made significant contributions to this report include Dr. Gene Yagow (VT Biological Systems Engineering Department), Dr. James Campbell (VT Geography Department), Ms. Llyn Sharp (VT Geosciences Outreach), Dr. Vinod Lohani (VT Engineering Education), Ms. Tara McCloskey and Ms. Erica Adams (Geography Department Graduate Students), and Ms. Erika Karsh a volunteer summer research assistant from Oberlin University.

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Disclaimer

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Summary

According to available documents, Virginia Tech faculty and students have studied the Stroubles Creek for nearly one hundred years. The Stroubles Creek Watershed Initiative was launched in 1999. The major goal of the Initiative was to provide research, educational, and service-learning opportunities to Virginia Tech students. A secondary goal was to compile historic information on watershed development and water quality of the creek. This report is the culmination of ten years (1999 – 2009) of work by many students on the Stroubles Creek Watershed.

Stroubles Creek originates from three springs in the Town of Blacksburg, Virginia. These springs form streams that flow through the Town, Virginia Tech campus and merge to form the Virginia Tech Duck Pond. The stream below the Duck Pond dam is known as the Stroubles Creek. It flows through Virginia Tech farms, rural areas in Montgomery County, and eventually drains into the New River. The whole watershed system is situated within the Mississippi River Basin.

Stroubles Creek watershed is divided into two sections - the Lower Stroubles Creek watershed and the Upper Stroubles Creek watershed. The Upper Stroubles Creek watershed contains parts of the Town of Blacksburg and Virginia Tech's main campus. The Lower watershed contains areas below the Duck Pond (including Virginia Tech farms) and parts of Montgomery County. This report mostly focuses on the streams that flow through the Town of Blacksburg and Virginia Tech's central campus, i.e., the Upper Stroubles Creek watershed. The Upper Stroubles Creek watershed has been experiencing land use changes since it was first settled in 1740 and the establishment of Virginia's first land grant college in 1872. The accelerated land development, as a result of Town growth and increased University enrollment, has adversely impacted the watershed and its streams and continues to this date.

The report is comprised of three sections. The first section documents the history of watershed development. The second section documents chronicles of water studies conducted on the creek since 1914. This section includes abstracts of various water quality studies and synthesis of those studies for chemical, physical and biological parameters, and provides a summary of the stream corridor survey that shows stream environmental conditions in 2001. The third section documents changes in watershed land use for the period 1973 to 2008 using various geospatial technologies. This report also contains a comprehensive list of published and unpublished documents related to the Stroubles Creek watershed. Furthermore, Appendix 1 documents historic population data, Appendix 2 documents location of various study sites, and Appendix 3 documents raw water quality data extracted from various reports.

The authors hope this report presents a historic perspective of the watershed to curious minds and also serve as a useful guide for future studies, watershed restoration efforts and sustainable development of the watershed

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Introduction

Stroubles Creek is a freshwater second order stream flowing15 kilometers (9.2 miles) from the Town of Blacksburg, through Virginia Tech's campus, and then into the New River. The New River flows north to the Kanawha River, which in turn flows to the Ohio River. The Ohio River merges into Mississippi River. The 14,336 acre Stroubles Creek watershed (VAW-N22R) is a sub-watershed of the New River Watershed.

The watershed is divided into two sections, the upper and lower watersheds. The dam at the lower portion of Virginia Tech's Duck Pond acts as the line of demarcation for the two sections. This report focuses on the Upper Stroubles Creek watershed which is impacted by urbanization from both the Town of Blacksburg and Virginia Tech's Central Campus (Figure 1).

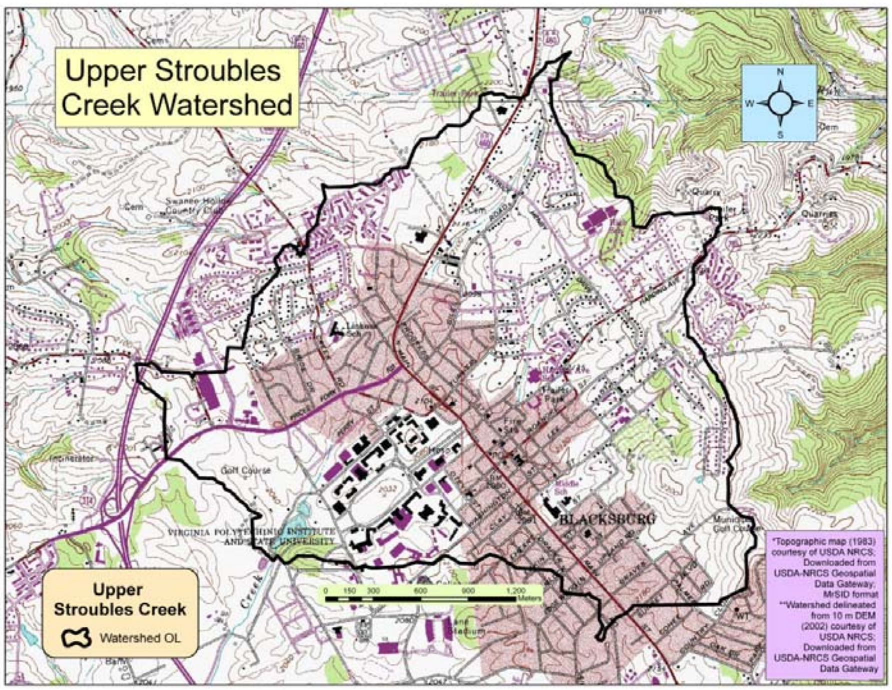

Figure 1. The Upper Stroubles Creek Watershed (Topomap Source: USDA 2009)

The boundaries of the Upper Stroubles Creek watershed encompass 1,975 acres. Three natural springs – Town, Keister-Evans and Spout, located in the northern part of the Town of Blacksburg, constitute the headwaters of Stroubles Creek. Figure 2 shows one of the three natural springs, Spout Spring. Spout Spring is the headwaters of one of three branches that converge on Virginia Tech's Campus to form the Main Branch. The Main Branch merges with the Webb Branch, also spring originating, to form the Virginia Tech Duck Pond. As Town and Campus development has progressed, major portions of the upper stream have been covered and diverged underground (Figures 3 and 4) with very few sections actually day-lighted (located above ground). Figure 5 shows the sections of the stream which are still located above ground.

Figure 2. Spout Spring - Clay & Wharton Streets (Source: Parece 2009)

Figure 3. Section culverted underground, Progress Street at Rescue Squad (Source: Parece 2009)

Figure 4. Section culverted underground, Draper & Washington Streets
(Source: Parece 2009)

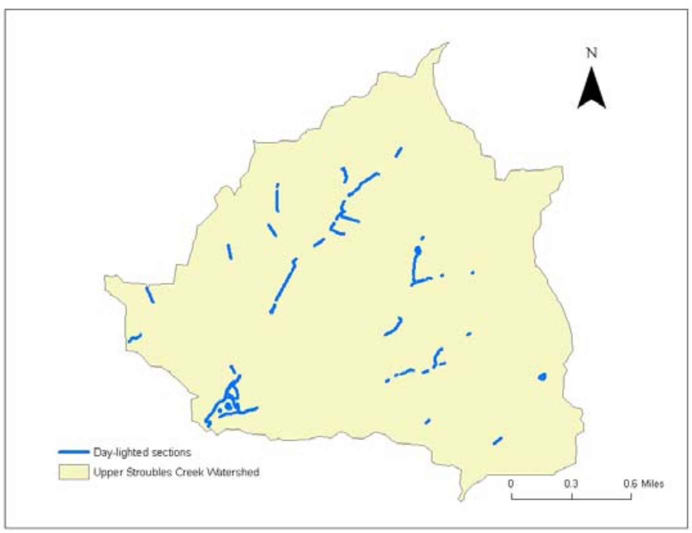

Figure 5. Daylighted sections of stream (Source: Town of Blacksburg 2007)

Stroubles Creek's streambed is composed of alluvial-floodplain deposits of stratified unconsolidated silt, clay and sand with lenses and beds of cobbles and pebbles. The watershed is classified by dolomite and limestone formations; sink holes, and natural springs. Land use in the entire Stroubles Creek watershed is 40% forest, 29% agriculture, 19% urban, 12 % unknown, and 0.24% water (Younos and Walker 2002).

History of Watershed Development

Stroubles Creek has been experiencing anthropocentric changes since it was first settled in 1740 by the Draper's Meadow Community. This area was chosen for settlement because of fertile land located on the plateau between the Allegheny and Blue Ridge Mountains (Blacksburg 2009a). The three springs feeding Stroubles Creek provided a vital water source for the community. By 1798, this pristine land became the Town of Blacksburg – a sixteen block 38- acre square grid (Figure 6).

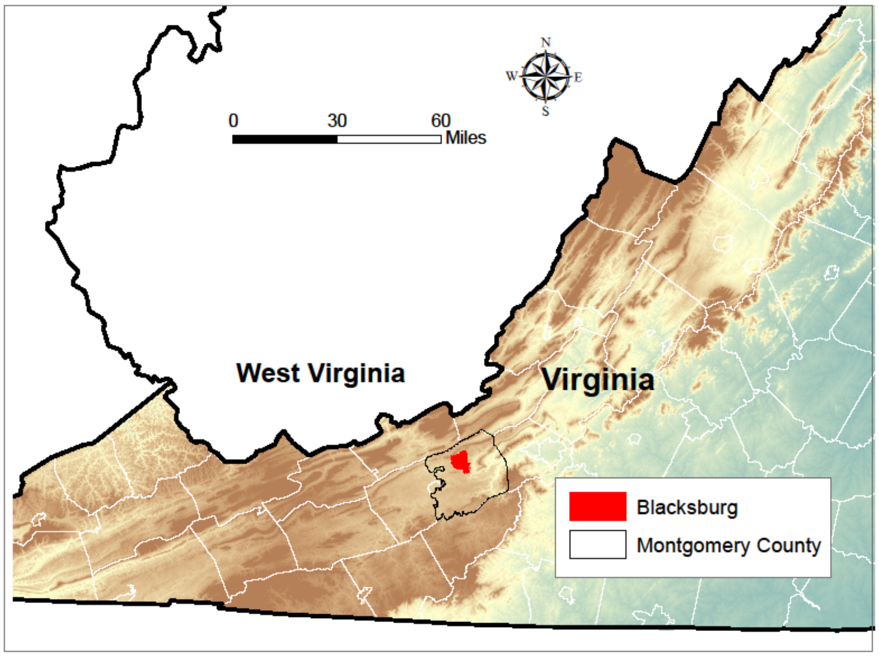

Figure 6. Town of Blacksburg Reference Map (Blacksburg 2007)

In 1851, the Town's Methodist community opened the Preston and Olin Institute, a seminary for boys (Preston and Olin 2009), and by 1860 the population of Blacksburg had grown to 460 people (Hedgepeth et al. 1998). In 1864 a surveyed map was completed of the area (Figure 7). This map shows the original stream channels in blue, the outline of what was considered the watershed in black, and the major road through the area in red.

Figure 7. 1864 Surveyed Map of Upper Stroubles Creek
(Source: Virginia Tech Newman Library Archives)

In 1872 the Preston and Olin Institute in Blacksburg was purchased by the Virginia General Assembly and turned into the Virginia Agricultural and Mechanical College. The college grew independently from Blacksburg but was to become the driving force behind urbanization in the town.

In 1896, the college's name was changed to the Virginia Agricultural and Mechanical College and Polytechnic Institute (currently known as Virginia Polytechnic Institute and State University or Virginia Tech), becoming a four- year higher education institute.

Stroubles Creek flowed along the Institute's agricultural experiment station which grew wheat, hay, an orchard and horticulture gardens.   The stream often flooded in the spring months (Kinnear 1972). In 1937, the field was enlarged to 1.2 million ft^2 as a Drillfield constructed for the use of the school's cadet corps (Figure 8). This event marked an even greater change in the Stroubles Creek stream channel, as the main branch of the stream was culverted under the drillfield (Roanoke Times 1928).

At the same time, a dam was constructed where the Webb and Main branches merged to make a small on-campus pond larger for the cadet corps' recreational use in winter (Figure 9). This area, now known as the Duck Pond, is fed from both branches (Figure 8). At present, the pond operates as a stormwater management facility for urban runoff from portions of the University's campus and the town of Blacksburg (Younos and Walker 2002).   But stormwater runoff has created sedimentation problems in the Duck Pond and has led to repeated dredging in 1950, 1960, 1986 (Hoehn and Woodside 1988).

Figure 8. 1937 Aerial Photo of Drillfield and Duck Pond
(Source: Jim Campbell 2009)

Figure 9. Dam below the Duck Pond (Source: Parece 2010)

Urbanization in Blacksburg has dramatically increased since 1845, although the changes within the community have been most prevalent for the past 100 years. An increase in population after World War II caused an influx in both town population and University enrollment, and increases in Town population even to this date mirror increasing enrollment at the University (Figure 10). From 1950 to 1960, the population increased from 3,358 to 7,070, a 110.5% change. From 1960 to 1980, a second population boom occurred with a 333% increase (from 7,070 to 30,638 people). From 1980 to 2008, population growth continued, albeit more gradually, with the percent change from 2000 to 2008 at 14.3% (Figures 11 and 12). Also see Appendix 1.

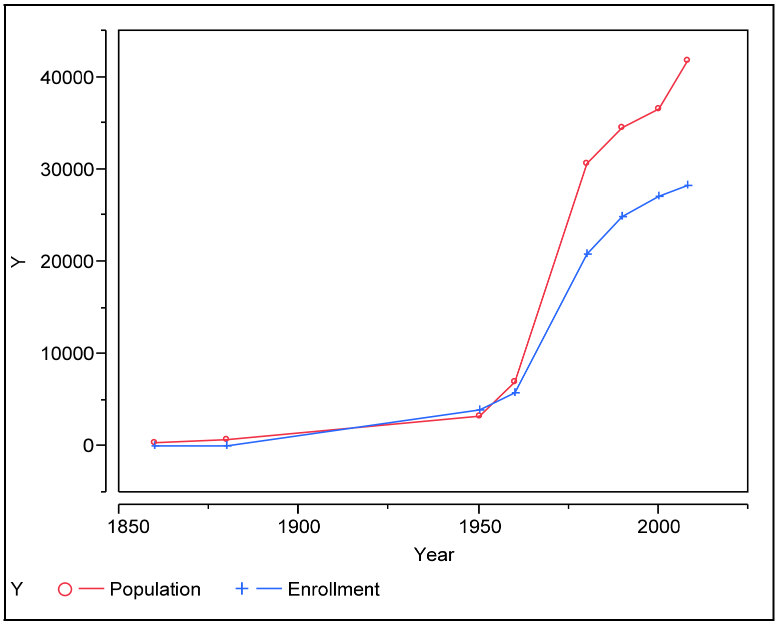

Figure 10. Town Population versus School Enrollment (Virginia Tech 2009a)

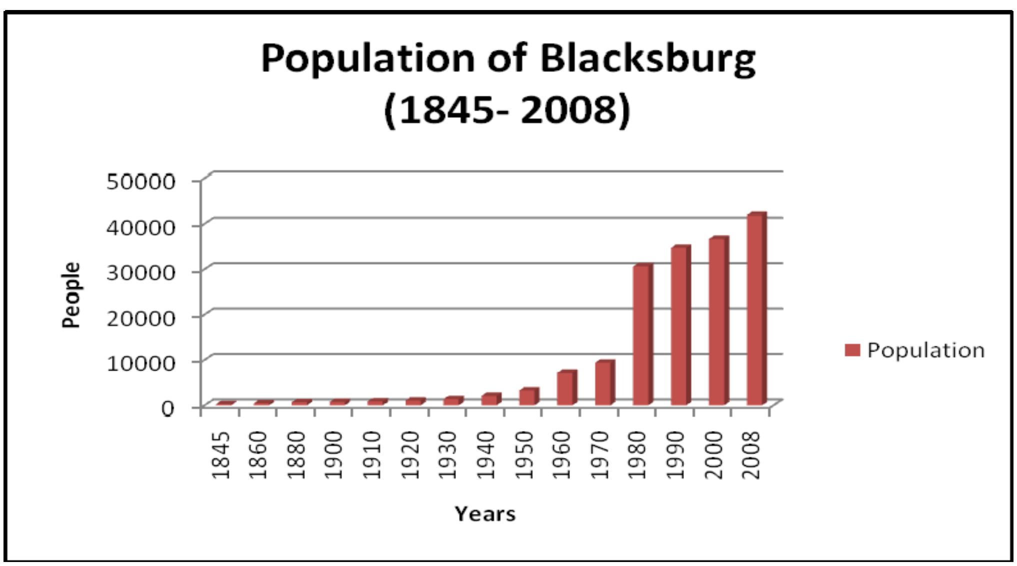

Figure 11. Population Change in Blacksburg, 1845 to 2008 (Blacksburg Partnership (Source: Blacksburg Partnership 2008).

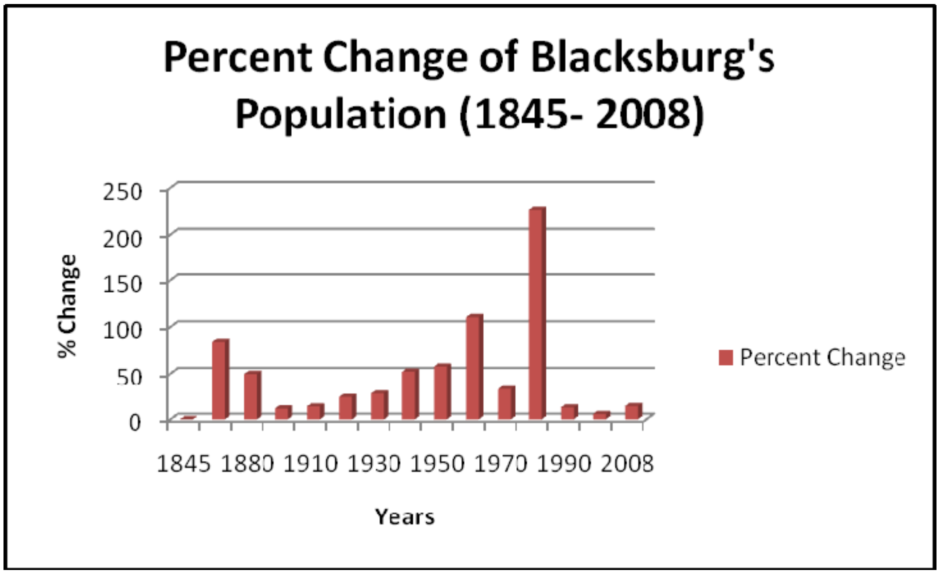

Figure 12. Percent Population Change in Blacksburg, 1845- 2008
(Source: Blacksburg Partnership 2008)

As the population of the Town and University enrollment increased, the Town's boundaries also grew, eventually encompassing the entire Virginia Tech Campus (Figure 13). In 1768, the Town was 38 acres and with the last expansion, in 2004, the Town comprised 12,606 acres (Blacksburg 2009b).

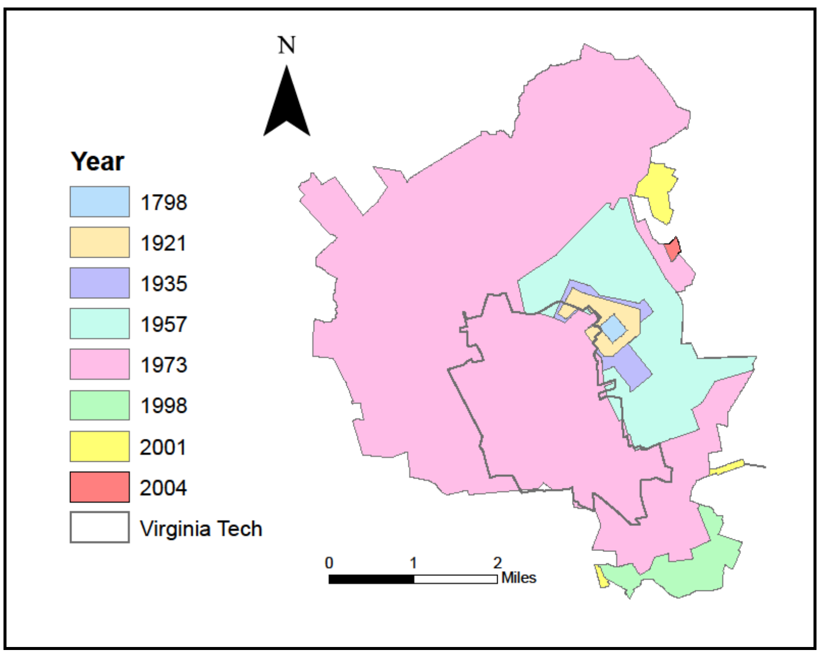

Figure 13: Expanding Town area and boundaries
(Blacksburg 2009b; Virginia Tech 2009b)

Until the 1900s, urbanization was not an issue within the watershed due to a low population density, few university buildings, and a small downtown area. But since that time, the watershed experienced land use changes from land development in the Town, and urbanization along with crop and animal production on Virginia Tech's campus. Although Blacksburg has been highly urbanized for several decades, Figures 14 and 15 demonstrate that urbanization has become more intensive in the past 20 years. Figure 14 is the land-use plan for Blacksburg from 1991 and Figure 15 is the projected land-use plan for 2046 (which was completed in 2006). Figure 14 shows that in 1991, the prevalent land-use types, with the exception of the University, were Agricultural/Open/Vacant (represented by green) and Low Density Residential/Open (represented by yellow). This Figure also shows that in 1991, the land-use types were categorized into only seven different types, including the University.

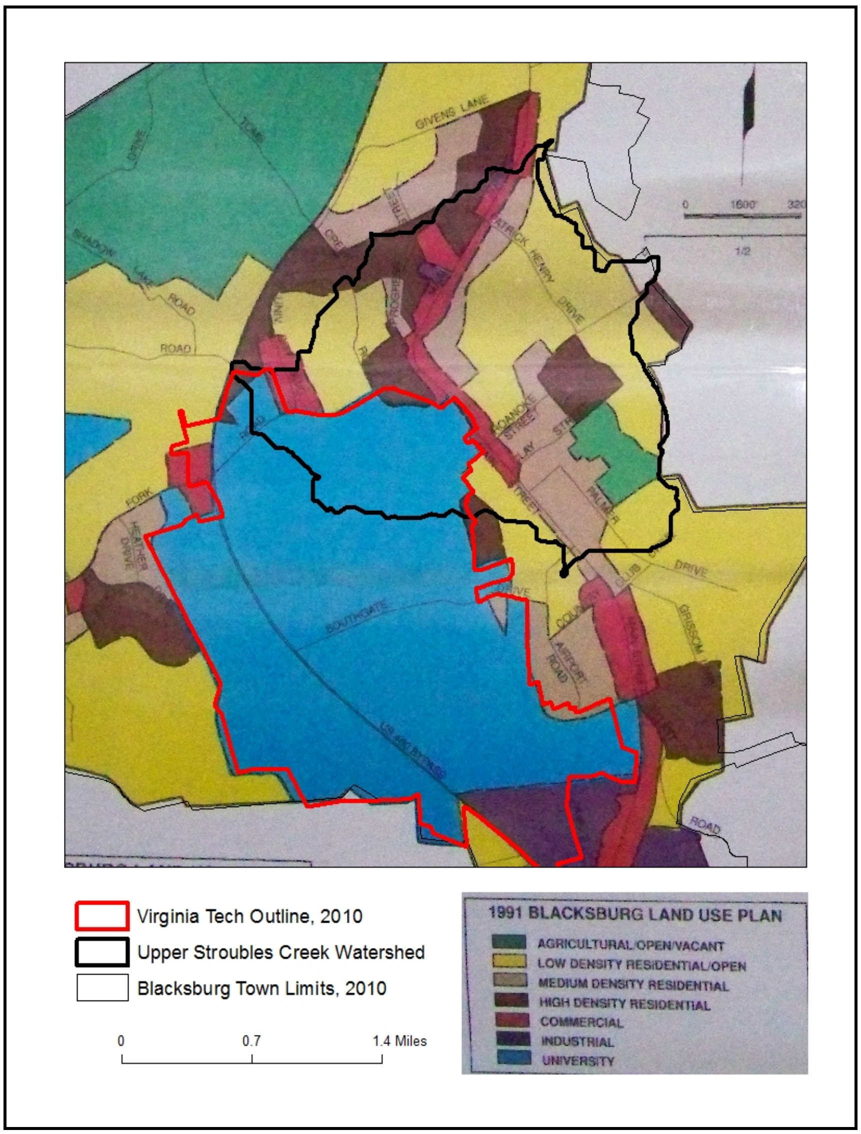

Figure 14. 1991 Land-Use Plan (Blacksburg 1991)

Figure 15 demonstrates that land-use evaluation and classification is more complex than in 1991, as the land-use types are now divided into eleven different categories, four of which correspondence to residential density categories. Agricultural/Open/Vacant is now absent in the land-use and has been replaced by Very Low Density Residential. The majority of the land-use type in the Town represents the different density levels of residential use (63.6%). Of this residential use, the Town has divided the residential classification into four different density categories – high (10 or more dwellings per acre), medium (up to 10 dwellings per acre), low (up to 4 dwellings per acre) and very low (up to one dwelling per acre) (Blacksburg 2006).

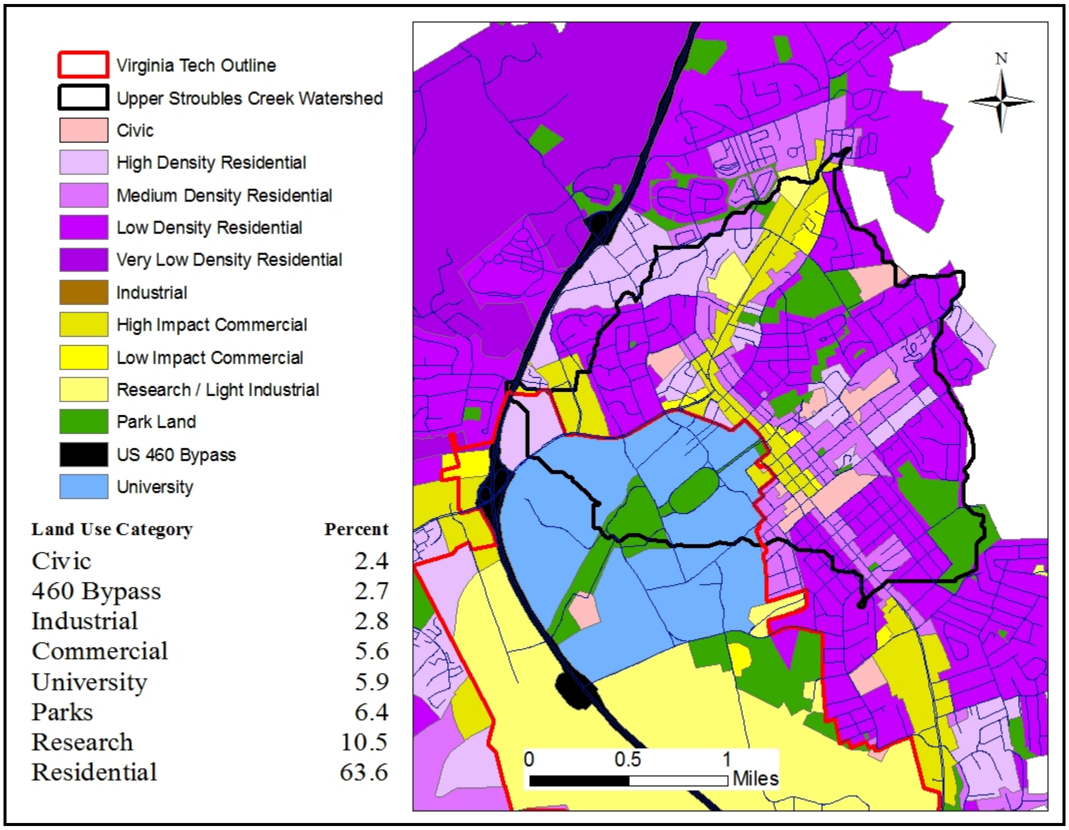

Figure 15. Land-use Plan 2046 (Blacksburg 2006)

Today, Town of Blacksburg and Virginia Tech are the major contributors to the changing stream quality of Stroubles Creek, especially in regards to increasing impervious surface cover and stormwater runoff.   In 1995, after an intense flood event, the Town recognized the need for a new stormwater planning designs (Hayes et al. 1995).

Over time, several activities and incidents have contributed to water pollution in Stroubles Creek. From the 1800s to the 1930s coal mining wastewater contaminated the lower part of the watershed.   From 1970 to 1978, chemical waste generated in Virginia Tech's Davidson Hall's chemistry laboratories was directly discharged into the Duck Pond. As a result, toxic substances are considered a potential hazard in the sediment deep within the Duck Pond. In January 1985, kerosene was spilled in the Duck Pond

(Knocke 1985). And on December 15, 2006, 50 to 80 gallons of fuel oil was released into the stream from a 275 gallon above-ground storage tank spill at a local Hardware Store. During the investigation of this spill, a whitish/gray flocky substance on the bottom of the stream was identified. However, since petroleum floats, it was concluded that the substance was not related to the spill. The source of this substance remained unknown but with speculation that it could be related to a leaking sewer or stormwater runoff (Steering Committee 2007).

In the early 1970s when the Clean Water Act was passed, the Virginia Department of Environmental Quality (DEQ) began monitoring the stream. However, DEQ monitoring was conducted in the lower portion of the stream, about 4.5 miles downstream from the Duck Pond (discharge point for old wastewater treatment plant). In 1996 and 1998, the DEQ classified lower Stroubles Creek, which extends 4.5 miles downstream of the Duck Pond as benthically impaired, and included this section in the 303(d) list of impaired waters (Commonwealth of Virginia, 1998). In 2002, the stream was included in the total maximum daily load (TMDL) list of impaired waters (303d list). A TMDL study of the impaired segment was completed in 2003 which identified sediment as the major cause of impairment (BSE 2003). In 2006, a TMDL implementation plan (IP) for the Stroubles Creek was completed (Stroubles Creek Steering Committee 2006). The TMDL IP identified critical areas in the watershed that cause impairments and proposed watershed restoration strategies. At present, several stream restoration projects are underway.

Water Supplies and Wastewater Treatment Facilities

Before World War II, the Town of Blacksburg depended on natural springs for its water supplies. After the post WW II population boom, for several years the Town and University experienced water shortages. The Town explored possible development of the springs and wells to supplement water supplies, but eventually determined that the New River was the only practical water supply. In 1950, a special Act of the legislature created the Blacksburg-Christiansburg-VPI Water Authority, and the Authority was chartered by the State Corporation Commission on September 15, 1956 (Virginia Division of Legislative Services 2010). The capacity of the existing water treatment plant is 12.5 million gallons per day (MGD), with a current average treatment volume of 7.5 MGD from which over 3.0 MGD is delivered to Blacksburg and Virginia Tech (Blacksburg 2010).

The increased population also resulted in high volumes of sewage from the Town and the University. The original septic system located immediately downstream from the Duck Pond could no longer handle the sewage volume, so in 1948 a new sewage treatment plant was constructed about 4.5 miles downstream from the Duck Pond. The second and current wastewater treatment facility went into operation in 1978 at a design capacity of 6.0 MGD average flow. The facility was expanded to 9.0 MGD average flow in 1996 (Blacksburg 2010). Twenty-two wastewater discharge pumps are used to collect wastewater from the town neighborhoods and Virginia Tech in a central location below the Drillfield, and then wastewater is transported by gravity from Blacksburg to the Sanitation Authority for treatment. Treated wastewater is discharged into the New River.

Chronicles of Water Studies

Researchers began studying Stroubles Creek as early as 1914. These studies covered different parameters and varying locations throughout the watershed. The following paragraphs summarize these studies in chronological order. Some of these reports are available in Virginia Tech Newman Library. Other sources are mostly unpublished reports. This documentation is by no means a complete coverage of research as many more unpublished reports may be available at various academic departments.

Figure 16 shows the various research sites which are also documented in Appendix 2. Sections following Figure 16 include abstracts of research reports and study results under the subcategories of chemical and physical parameters, biological parameters, and stream environmental condition. Raw quality data are documented in Appendix 3.

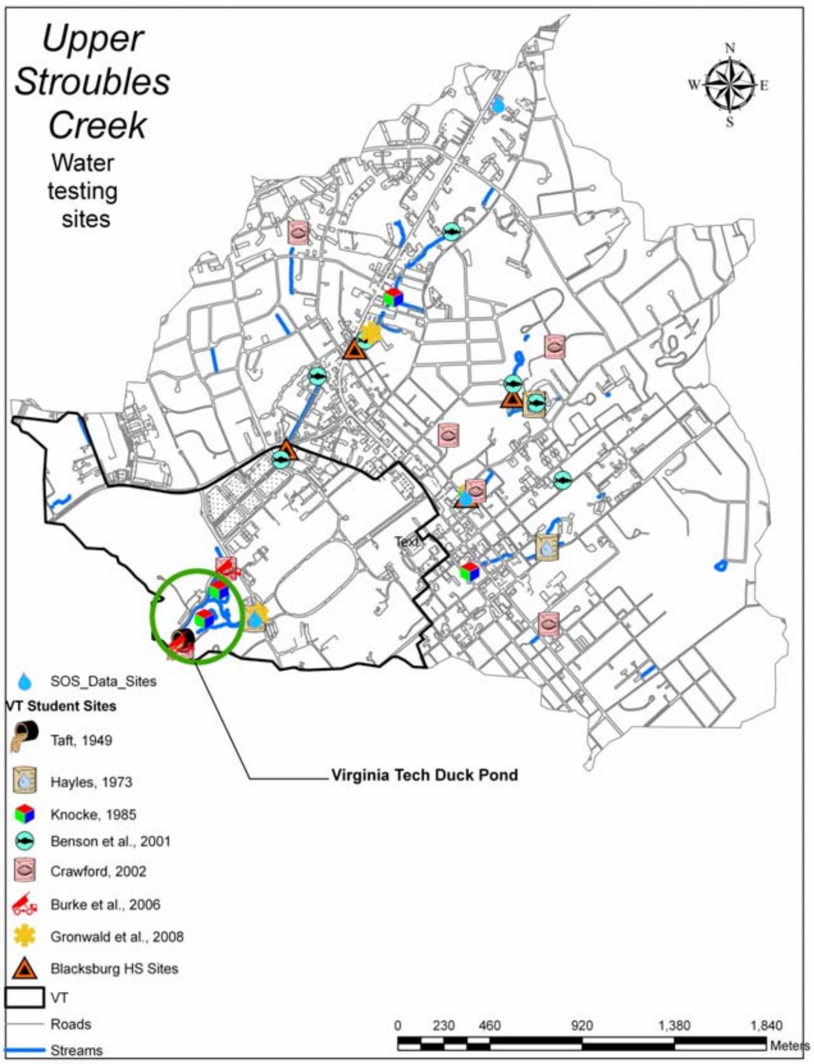

Figure 16. Research Sites in the Upper Stroubles Creek Watershed, 1949 – 2008

Abstracts of Research Reports

"A Study of the Self- Purification of Stroubles Creek" (Sutton, Jr. 1914)
In 1914 Lee Edward Sutton, Jr., completed his Bachelor of Science degree with his thesis in Bacteriology on Stroubles Creek's ability to purify itself. His report linked stream pollution to horse waste, privies, pastures, cultivated fields, coal- mining activities and the Virginia Tech septic tank, all of which drained into the stream. High bacteria concentrations were observed through 25 water samples (24 from the stream and one from the tap). At this time, *Bacillus coli* (present in raw sewage) were the most plentiful bacteria in the water sampled. Sutton also concluded that the geologic formations through which Stroubles Creek flows, karst and limestone terrain, is not porous therefore water is not filtered on its way downstream. Sutton further noted that larger amounts of bacteria occur in winter and spring months.

"*To Determine the Rate and Degree of Recovery of Stroubles Creek after Diversion of Poorly Treated Sewage, Blacksburg, Virginia"* (Taft 1949)
Walter D. Taft, Jr. completed his Master of Science in Sanitary Engineering with research on the chemical parameters of Stroubles Creek. In July of 1948, a new sewage treatment plant was implemented in Blacksburg preventing raw sewage from being discharged directly into the stream. During the summer months (June 22 to August 31, 1948), Taft studied 3 sites below the duck pond dam, 100 feet, 500 feet and one mile). Though the areas were not specifically located above the duck pond, the water flowing into the study sites was coming from upstream. He found that water quality recovered after implementation of the new sewage treatment facility immediately in the Upper Stroubles Creek portion of the stream. There was an increase in dissolved oxygen and pH and decreases in biochemical oxygen demand, carbon dioxide, and decrease bicarbonate alkalinity (Younos 1999). The self-purification of the stream bellow the point of pollution did not begin until early August. These results from this research are compared to results from future research later in this paper.

"Biological and Chemical Monitoring of Three Streams in the Area of Blacksburg, Virgina" (Hayles 1973)
Hayles completed her research for a Master of Science degree in Zoology by assessing chemical and biological data to assess stream quality of three streams (Stroubles, Tom's and Cedar creeks) over a one year. She concluded that those Stroubles Creek areas tested below the Sewage Treatment Plant had increased concentrations of phosphate, nitrate, chloride, total organic nitrogen, and biological oxygen demand. One site located on the corner of Greenhouse Road and South Gate Drive on the Virginia Tech Campus found fuel oil, flyash and chromium in the water and resulted in low macroinvertebrate diversity above and below the pollution source (Younos 1999).

"Assessment of Pollutant Loads to the Virginia Tech Duck Pond" (Knocke 1985)
Dr. William Knocke compiled reports of students from several departments at Virginia Tech to complete an overall assessment of pollutant loads delivered to the Virginia Tech Duck Pond during both dry and wet weather events. His goal was to identify the

pollution source and design an improvement system to fix and maintain the quality of the pond for the future.

"Virginia Save Our Streams (SOS 1992- present)"
Save Our Steams a non-profit organization that conducts regular assessment of benthic macroinvertebrates in the Stroubles Creek. Data is mostly collected by volunteers and students. The SOS data summarized in this report was provided by Ms. Llyn Sharp and Dr. Gene Yagow.

"Fish Survey of Webb and Central Branches of Upper Stroubles Creek, Blacksburg, Virginia" (Benson and Younos 2001)
This survey assessed water quality, instream habitat and determined the composition of fish biota in the Upper Stroubles Creek watershed. General chemical parameters (i.e. pH, dissolved oxygen, alkalinity and conductivity) and a fish count at seven locations were taken, four on the Webb branch and three on the Central Branch. Conclusions were made that the Webb Branch water quality was poor due to the existence of only one tolerant fish species (Blacknose Dace), diversity was nonexistent, and that chemical parameters (pH, dissolved oxygen, alkalinity and conductivity) increased when moving down stream. The Central Branch was not tested for fish (too narrow and shallow) because most likely none exist in this location.

"Biological Physiochemical Assessment of Stroubles Creek: Winter Condition" (Crawford and Younos 2002)
Crawford performed studies on both chemical parameters and biological conditions (macroinvertebrates) in Stroubles Creek. Her work contributed to the ongoing work of the Stroubles Creek Corridor Assessment and analyzed stream quality impairments resulting from land use changes in Blacksburg. Areas within the upper watershed (urban areas) were concluded to show impaired water quality.

"E. Coli and Sediment Monitoring for the Virginia Tech Duck Pond in Blacksburg, Virginia" (Burke et al. 2006)
This research monitored the relationship between E. coli, total suspended solids and nutrients flowing into the Duck Pond versus those flowing out of the duck pond. Bacteria and nutrient levels decrease as the water exits the Duck Pond. A better understanding of nutrient loading and fecal contamination to the Duck Pond was observed by looking at the baseline readings of sampling locations. E. coli, sediment, phosphorous, and nitrogen concentrations are higher when entering the Duck Pond than when exiting. Ms. Katie Perkins an undergraduate researcher under Dr. Younos was the team leader for this study.

Blacksburg High School (2007, 2008, 2009)
Ms. Patricia Colatosti, the AP Environmental Science teacher, at Blacksburg High School provided data collected by BHS students during the 2007, 2008 and 2009 school years. All sampling locations are within the walking distance to BHS and within the Upper Stroubles Creek watershed.

"Water Quality Assessment of a Mixed Land Use Watershed" (Gronwald et al. 2008) This report and testing was accomplished during a National Science Foundation and the Virginia Tech Research Experience for Undergraduates during the summer of 2008. The test performed on Stroubles Creek measured general chemical parameters and heavy metals at base flow and after an intense storm event. The report concluded base flow chemical concentrations were higher because the pollutants were diluted during storm events. The report concluded that benthic impairment results from large sediment and nutrient concentrations. Also, E. coli, nitrates (from lawns), and physical impairment (pipe outfall, inadequate buffers) cause stream water quality alterations.

Synthesis of Water Quality Studies

Chemical and Physical Parameters

Taft's data (1949) was averaged to show the values of the three sites. During the summer months of 1949, the temperature (23.13˚C, 22.3˚C, 22.04˚C) and pH (7.55, 7.43, 7.6) showed little fluctuation between sites1, 2 and 3 (Figure 17). Dissolved oxygen was lowest at site 2 (3.75 mg/L) and highest at site 1 (7.55 mg/L). Nitrites and nitrates tested in all location are relatively low, with site 3 revealing the lowest level at 0.04 mg/L and site 1 at the highest level - 1.99 mg/L (Figure 18). Chlorides were the highest at site 2 (63.25 mg/L) and lowest at site 3 (24.25 mg/L). Alkalinity was highest at site 2 (219.2 mg $CaCO_3$/ L). The number of coliforms was calculated by the probable number of organisms/mL of water sampled. Site 2 contained the greatest number of coliforms with a probable 484,381.1 organisms/mL where site 1 had the least estimating 772.5 probable organisms/mL (Figure 19).

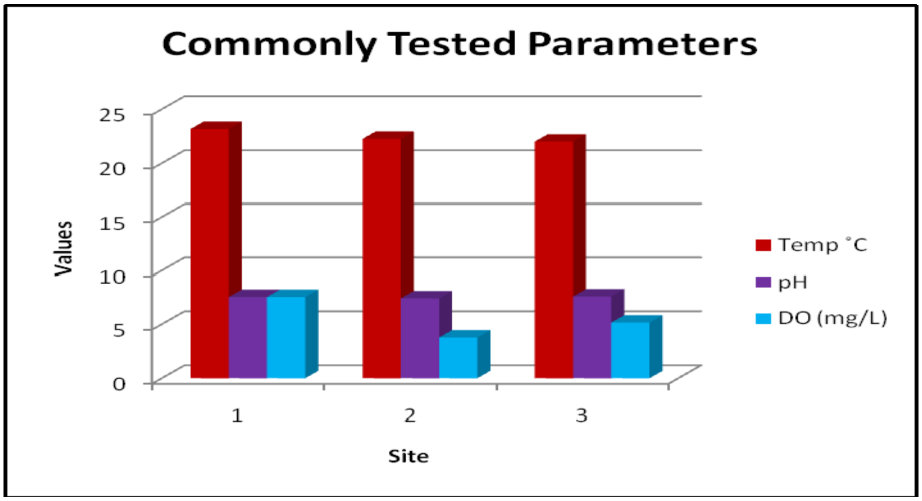

Figure 17. Commonly Tested Parameters in Summer Months (Taft 1948)

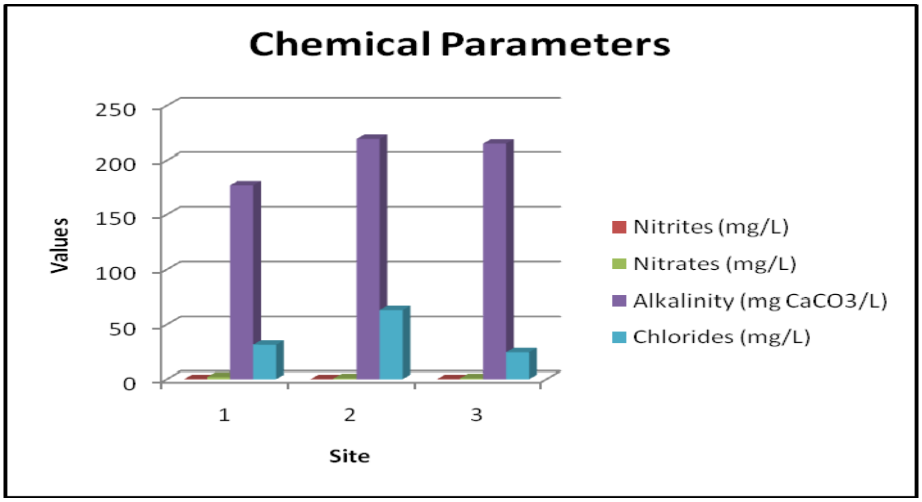

Figure 18. Chemical Parameters in Summer Months (Taft 1948)

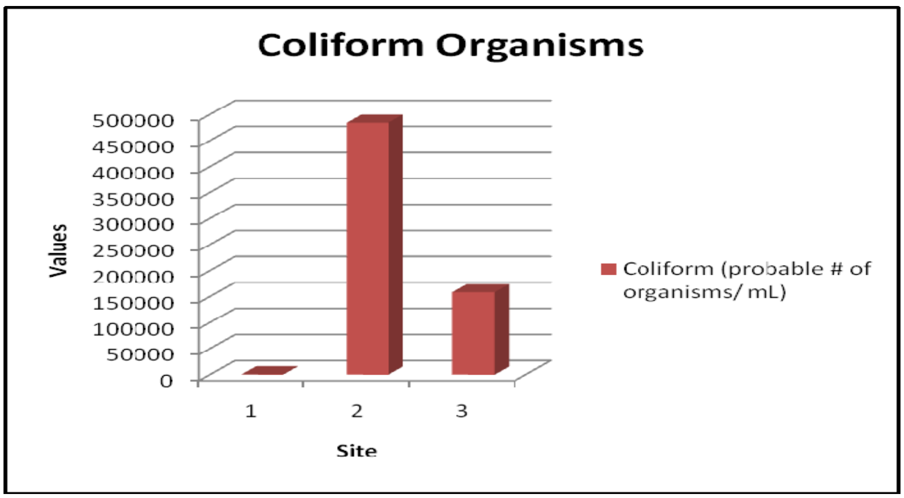

Figure 19. Coliform Findings in Summer Months (Taft 1948)

Hayles (1973) conducted her studies from August 1971 to August 1972. Hayles studied 11 sites within the Stroubles Creek watershed with site 1 (Clay St., 175'N of Corner of Clay and Wharton) located near the original headwaters of Spout Spring. The average alkalinity in the year of testing at site 1 was 225 mg $CaCO_3$/ L (Figure 20). The pH was 7.3, chloride concentration in the water was 13 mg/L and nitrates were 2.1 mg/L. The percent of saturated dissolved oxygen was 88%, biochemical oxygen demand (BOD) was 1.2 mg/L, total oxygen content was 5.8mg/L and COD was 5.2 mg/L. No total Kjeldahl nitrogen (TKN) was detected. Chromium was also tested at a location on Virginia Tech campus that no longer exists (Corner of Greenhouse Rd. and Southgate Dr.). The location was tested 3 times over the course of a year and contained an average chromium concentration of 10.6 mg/L (Figure 21).

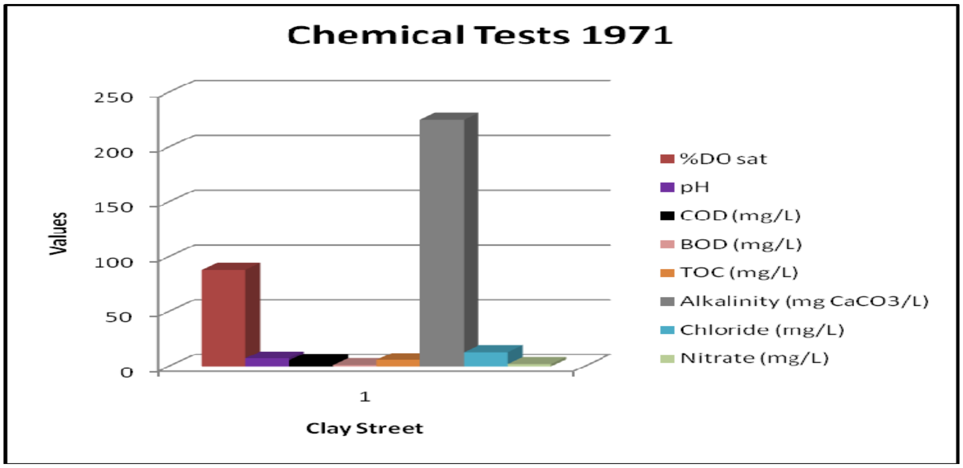

Figure 20. Chemical Testing on Clay Street (Hayles 1973)

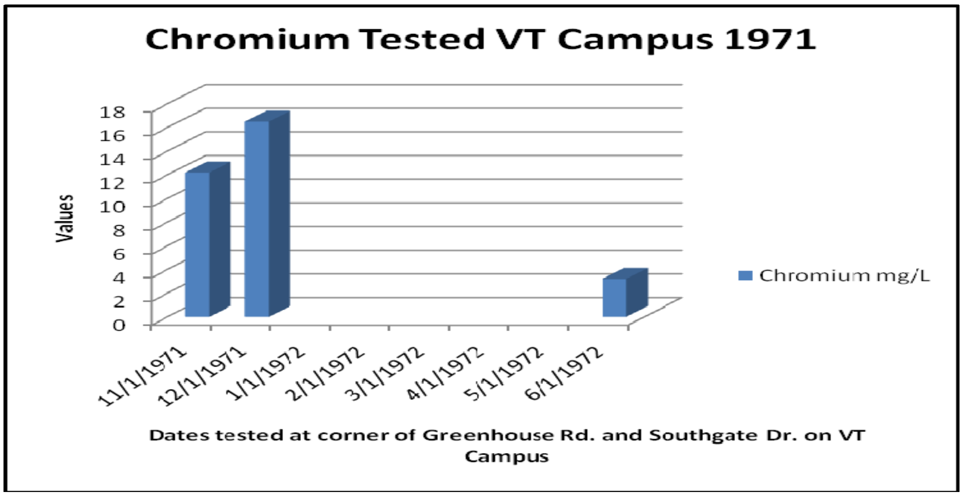

Figure 21. Chromium Tested on Virginia Tech Campus (Hayles 1973)

Knocke (1985) prepared "An Assessment of Pollutant Loads to the Virginia Tech Duck Pond." Samples were taken at 4 locations in the upper watershed during both dry and wet weather events. Dry weather conditions revealed that both temperature and pH varied most between the Fire station site and Ewald Clark site with 22˚C and 15˚C and an 8.6 pH and a 7.9 pH (Figure 22). The highest BOD was 5.3 mg/L at site by the Hoy Funeral Home and the highest TOC was 3.62 mg/L at Ewald Clark site. The total phosphorous (TP) was lowest at the fire station (0.05 mg/L), highest at Hoy Funeral (0.14mg/L) but not tested at Northview. TKN was relatively low at all locations though highest at Hoy Funeral with 0.84 mg/L. Alkalinity was similar at Ewald Clark, Hoy Funeral and Northview (272, 262, 270 mg$CaCO_3$/ L), it was slightly lower at the fire station with 232 mg $CaCO_3$/ L (Figure 23). Conductivity ranges from 450 to 490 µmhos (1µS/cm = 1 µmho/cm) for all four site locations.

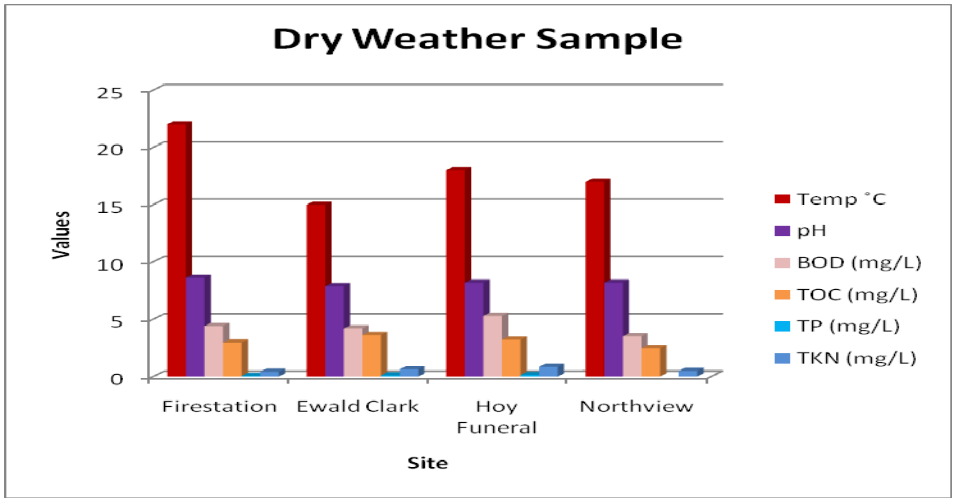

Figure 22. Dry Weather Chemical Data (Knocke 1985)

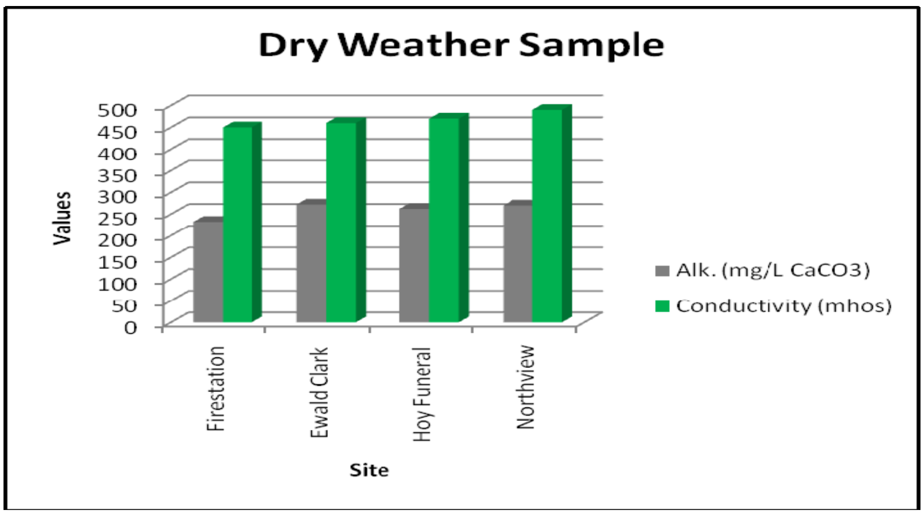

Figure 23. Alkalinity and Conductivity during Dry Weather Event (Knocke 1985)

During wet weather conditions (storm events) the BOD, TKN and TP were measured and averaged over the duration of the 2-hour storm event (Figure 24). BOD was 40 mg/L at all site locations except Hoy Funeral Home where it was 30 mg/L, increasing over all amounts from dry weather events. TKN increased to 5.31 mg/L at the fire station, 3.43 mg/L at Ewald Clark, 5.95 mg/L at Hoy Funeral and the largest increase at Northview to 50.4 mg/L. TP was measured at prepeak in addition to composite samples taken. Prepeak conditions did not show significant change from dry event samples, though from prepeak to composite samples there was a definite increase. The highest increase occurred at Ewald Clark: dry conditions and prepeak conditions are equal with 0.11 mg/L (Figures 22 and 23) though composite readings show 2.15 mg/L after the storm event. Conductivity increased at all site locations at the prepeak of the storm (range of 590 to

610 µmhos) and either went back to the dry weather amount or remained higher when samples were taken after the course of the storm period, Northview had only a composite sample taken (Figure 25). However, Northviews composite sample resulted in 1,280 µmhos, a difference of 790 units from the dry weather sample taken. Suspended solids (SS) from prepeak to when composite samples were taken increased drastically. The greatest change is seen in Hoy Funerals prepeak SS at 64 mg/L to a composite reading of 1,698 mg/L.

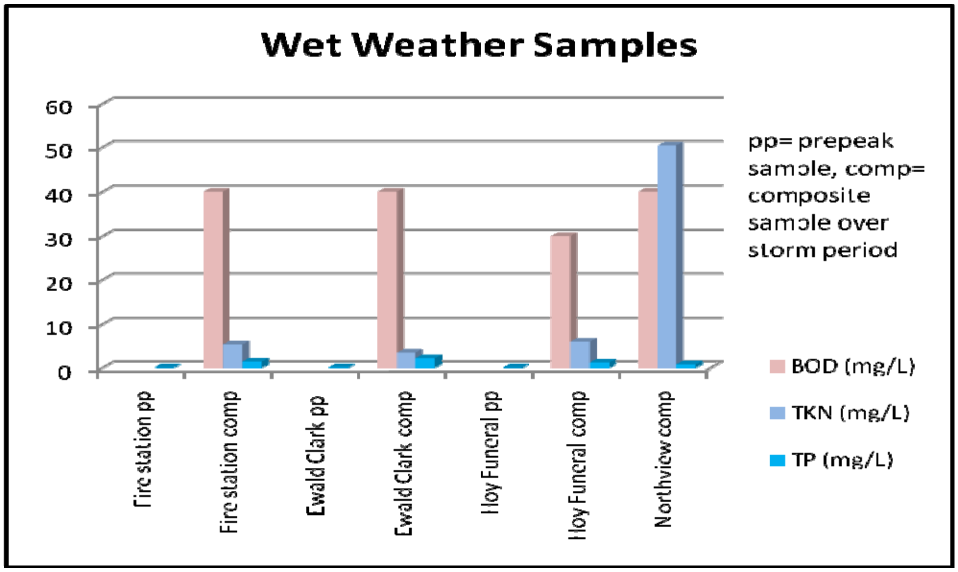

Figure 24. Chemical Data Wet Weather Event (Knocke 1985)

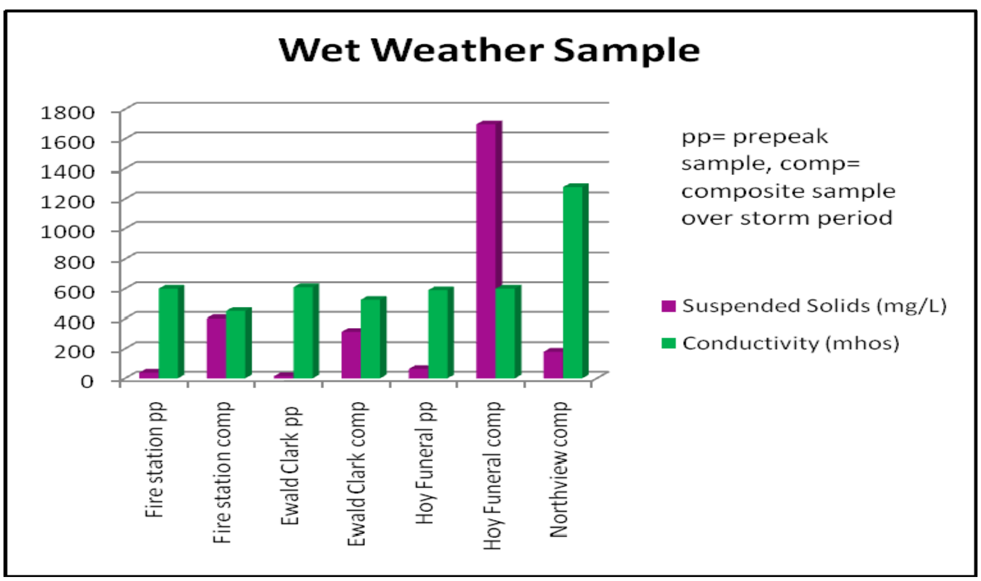

Figure 25. Suspended Solids and Conductivity Wet Weather Event (Knocke 1985)

Benson and Younos (2001) completed a "Fish Survey of Webb and Central Branches of Upper Stroubles Creek" and also tested the water for dissolved oxygen (DO), pH, alkalinity, and conductivity on seven locations (4 on Webb Branch, 3 on Central Branch see Appendix I). DO was highest (10.28 mg/L) at C3 (Figure 26). The lowest DO (7.48 mg/L) was found at W1. The pH was also lowest (7.5) at W1 and highest (8.3) on Virginia Tech campus before Webb branch runs under a parking lot. Alkalinity and conductivity are the highest at C2 with 270 mg$CaCO_3$/ L and 540 µS (Figure 27). Alkalinity and conductivity are lowest at C3 with 110 mg$CaCO_3$/ L and 250µS.

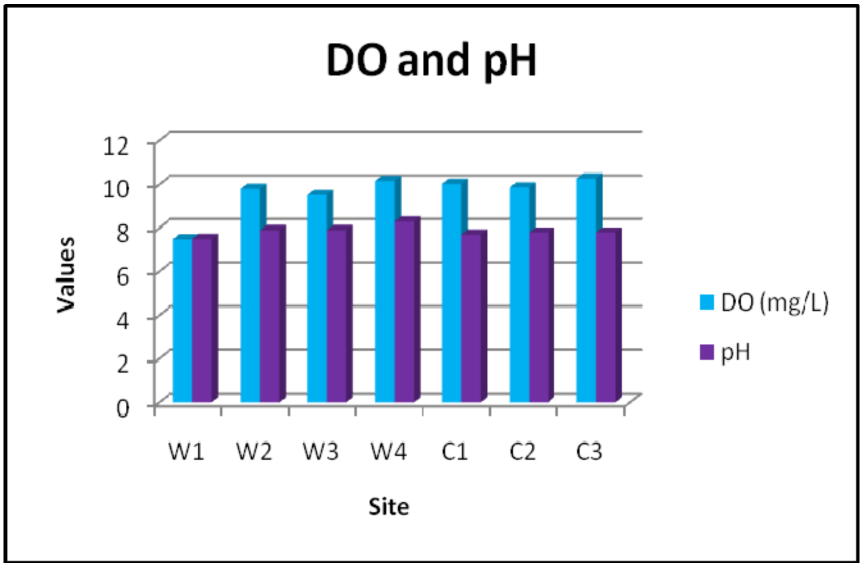

Figure 26. Dissolved Oxygen and pH Webb and Central Branch (Benson and Younos 2001)

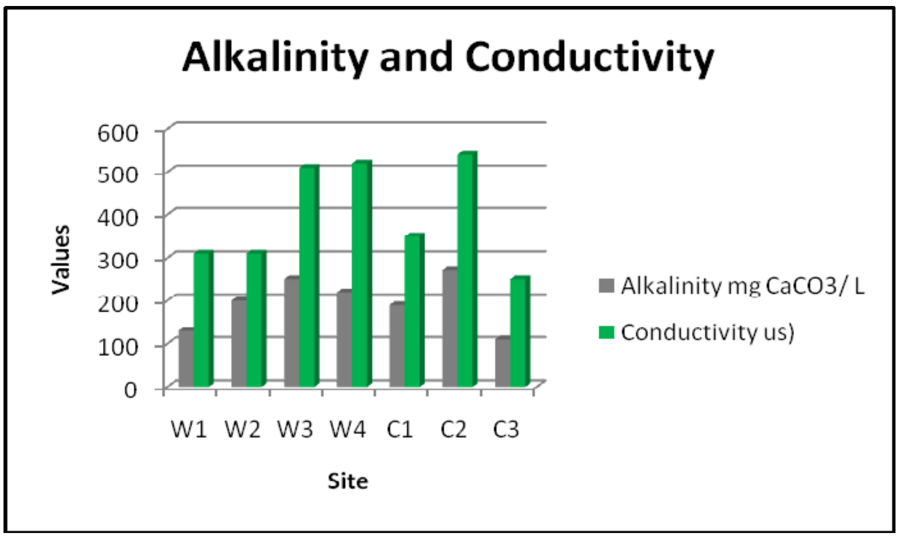

Figure 27. Alkalinity and Conductivity Webb and Central Branch (Benson and Younos 2001)

Crawford and Younos (2002) completed a "Biological and Physiochemical Assessment of Stroubles Creek: Winter Conditions" on 6 sites within the upper watershed. Results are averaged over the month of March 2002. The temperature at the sites ranged from 11˚C to 13.4˚C (Figure 28). DO was 9mg/L at sites 1, 3, 5 and 6, differing at site 2 at 9mg/L and site 4 with 8mg/L. A pH of 9 was the highest at site 1 and lowest at sites 2 and 6 with a pH of 7.4. The percentage of dissolved oxygen was lowest at site 2 at 65% and highest at sites 3 and 5 with 85% (Figure 29). Conductivity was highest at site 1 with 890 µS making it 780 units higher than the lowest value of 110 µS at site 6. Alkalinity was not consistent, in descending order from site 1 to 6 results showed 288, 51, 47, 101, 78 and 40 $mgCaCO_3$/ L. Results varied between sites for total suspended solids (TSS) from site 1 having 1 mg/L to site 3 containing 411 mg/L. E. coli and fecal coliform findings are lowest at site 1 with 20 cfu/100mL of E.coli and 40 cfu/100mL of fecal coliform (Figure 30). The second lowest results were found at site 6 with cfu/mL of E.coli and 960 cfu/mL of fecal coliform. Site 2 contained the greatest amounts of E.coli and fecal coliform with 5,000cfu/mL of E. coli and 6,400cfu/mL of fecal coliform.

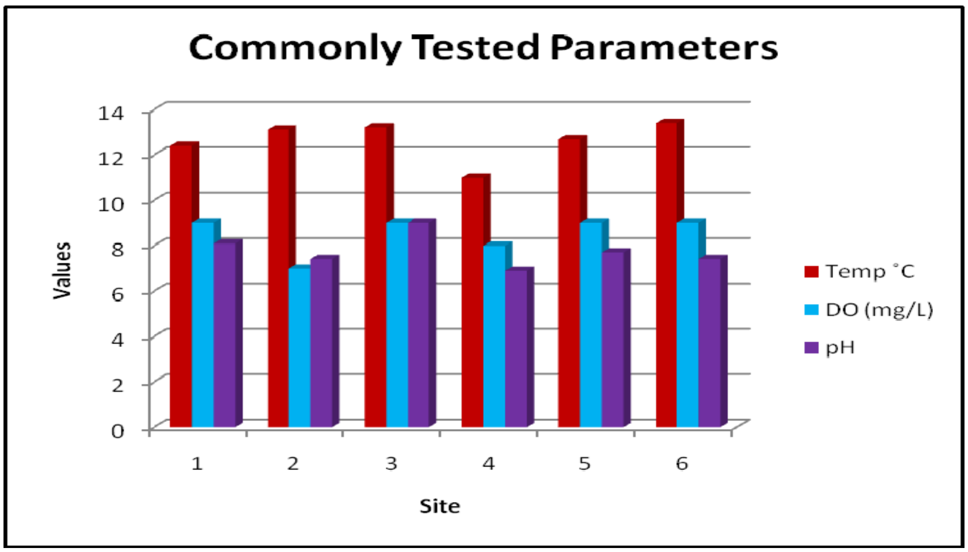

Figure 28. Commonly Tested Parameters Winter Conditions
(Crawford and Younos 2002)

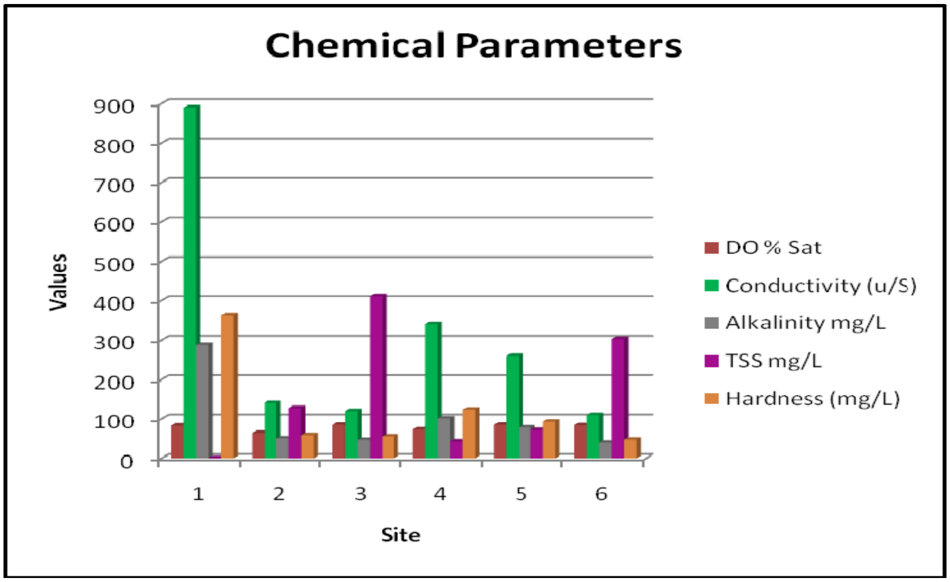

Figure 29. Chemical Parameters Winter Conditions (Crawford and Younos 2002)

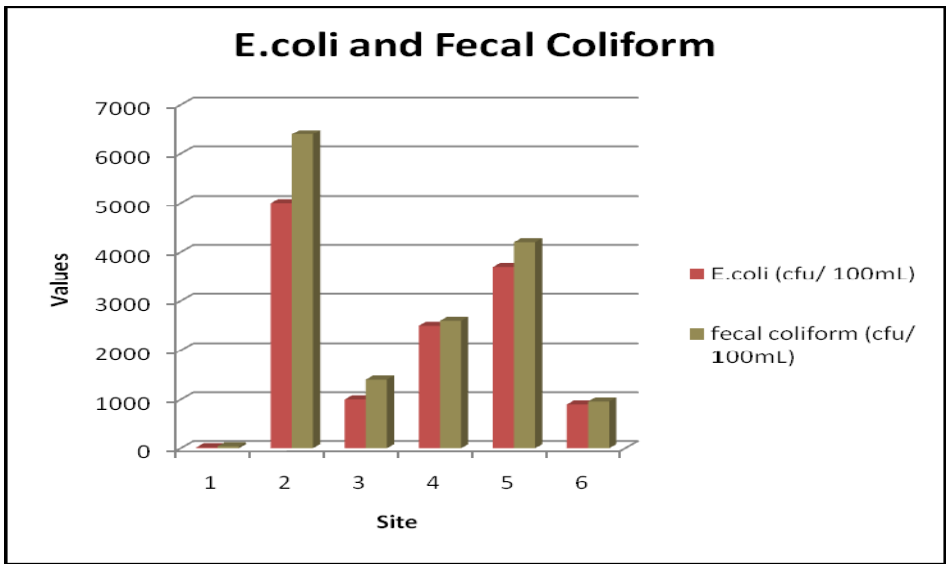

Figure 30. E.coli and Fecal Coliform Findings Winter Conditions
(Crawford and Younos 2002)

Burke, et al (2006) researched E.coli and sediment loading in the Duck Pond. The Webb and Central Branches at locations prior to entering the Duck Pond were measured. Average conditions for February, March and April, 2006 were used to analyze conditions (Figure 31, 32). Temperature at Webb and Central Branches were 11.8˚C and 11.9˚C. The pH at central branch was 9.5 and 11.9 at Webb (Figure 31). TSS for Central Branch was 22.4mg/L, 16mg/L more than the amount at Webb Branch. Phosphate levels were higher at Webb Branch with 0.63mg/L. Central Branch had a higher concentration of nitrates with 1.38mg/L. E.coli concentration was significantly higher in Webb Branch compared to Central branch (Figure 32).

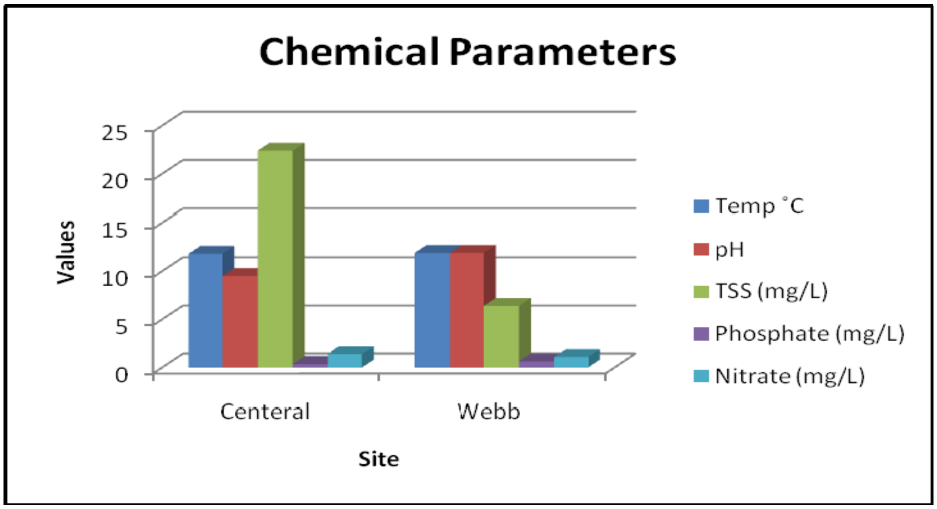

Figure 31. Chemical Parameters Webb and Central Branch (Burke et al. 2006)

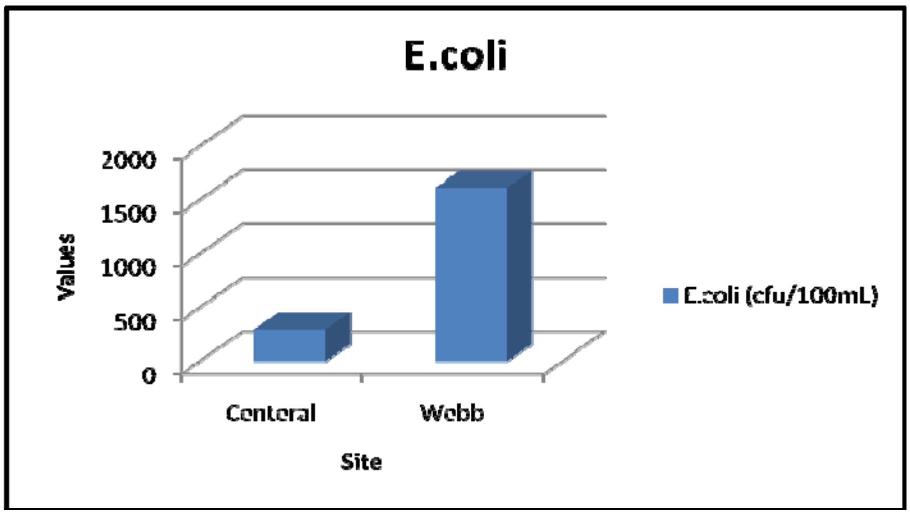

Figure 32. E.coli in Webb and Central Branch (Burke et al. 2006)

Blacksburg High School students tested 4 locations within Upper Stroubles Creek over the three years (2007- 2009). This data was averaged by year (Figures 33 - 40).

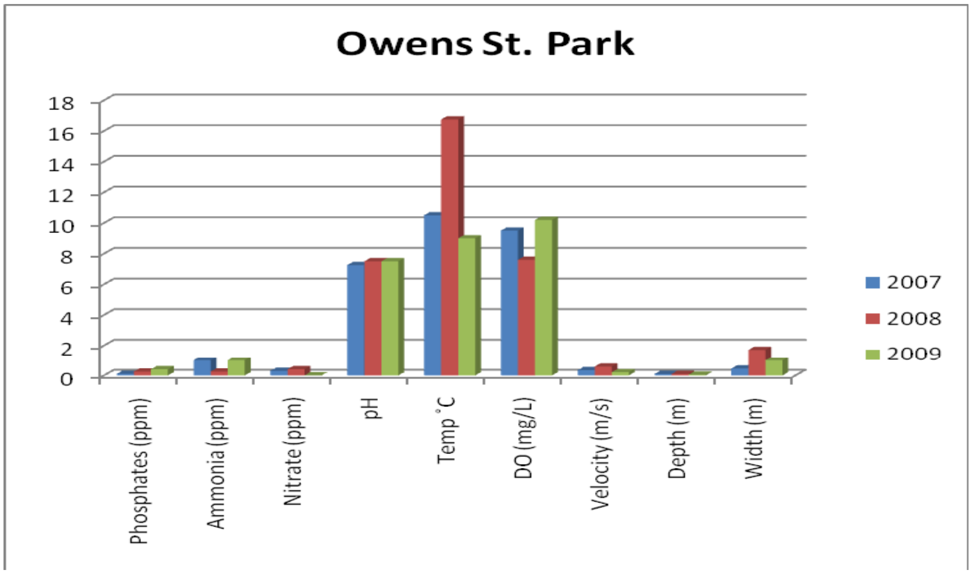

Figure 33. Owens St. Park Chemical Data

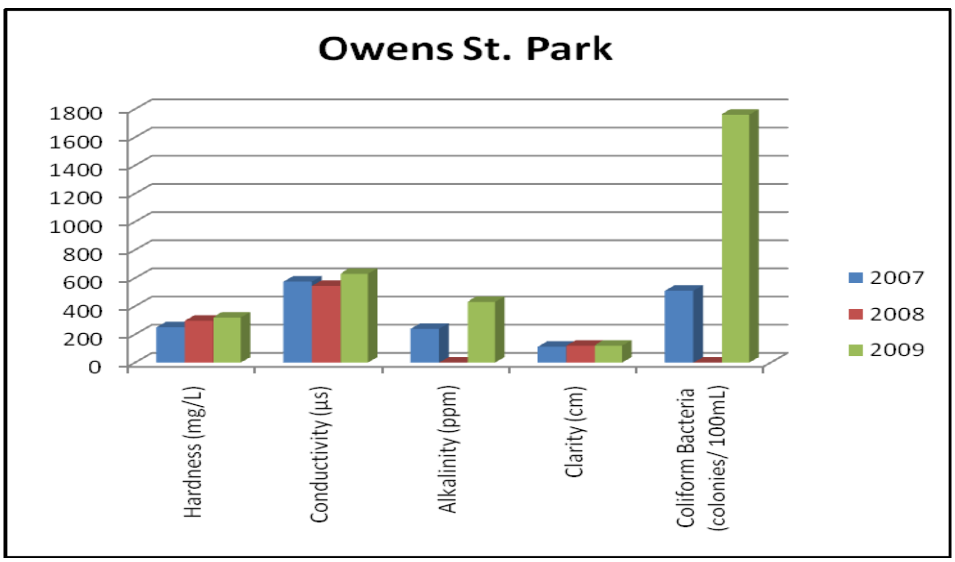

Figure 34. Owens St. Park Chemical Data

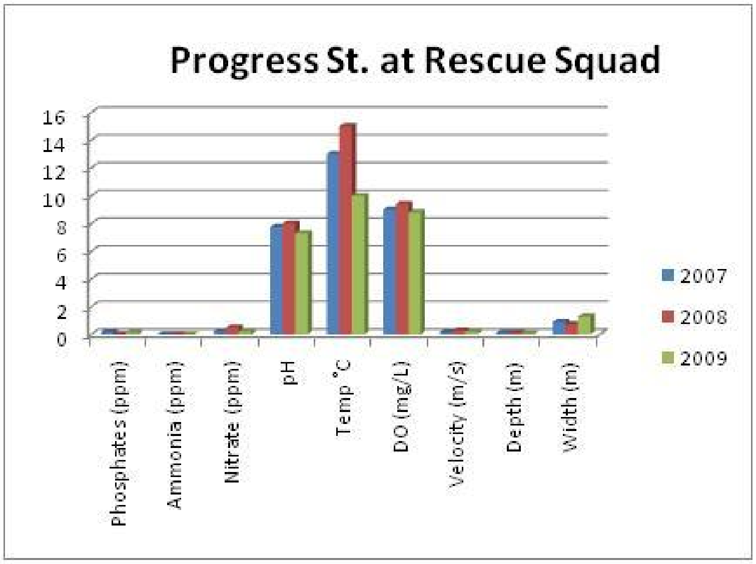

Figure 35. Progress St. at Rescue Squad

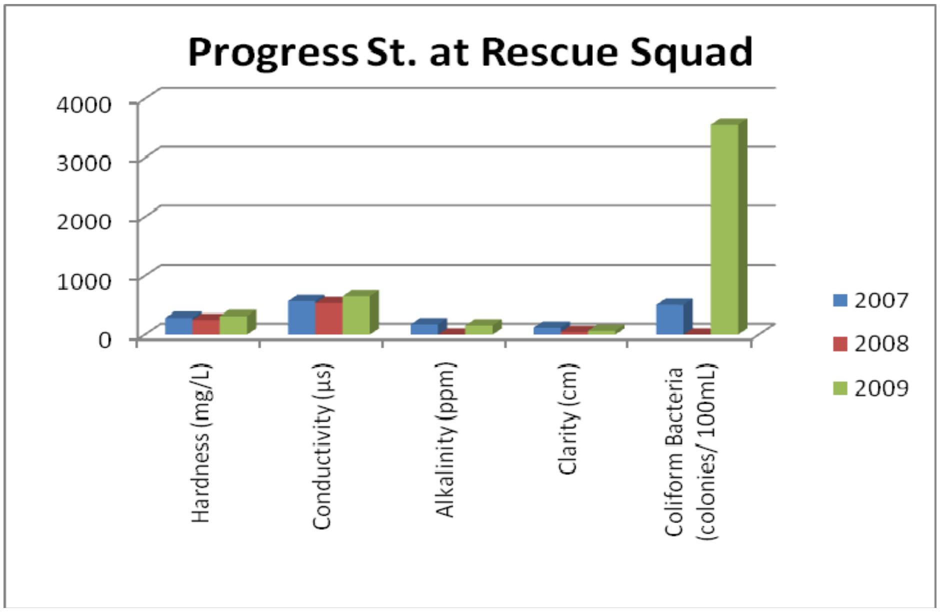

Figure 36. Progress St. at Rescue Squad

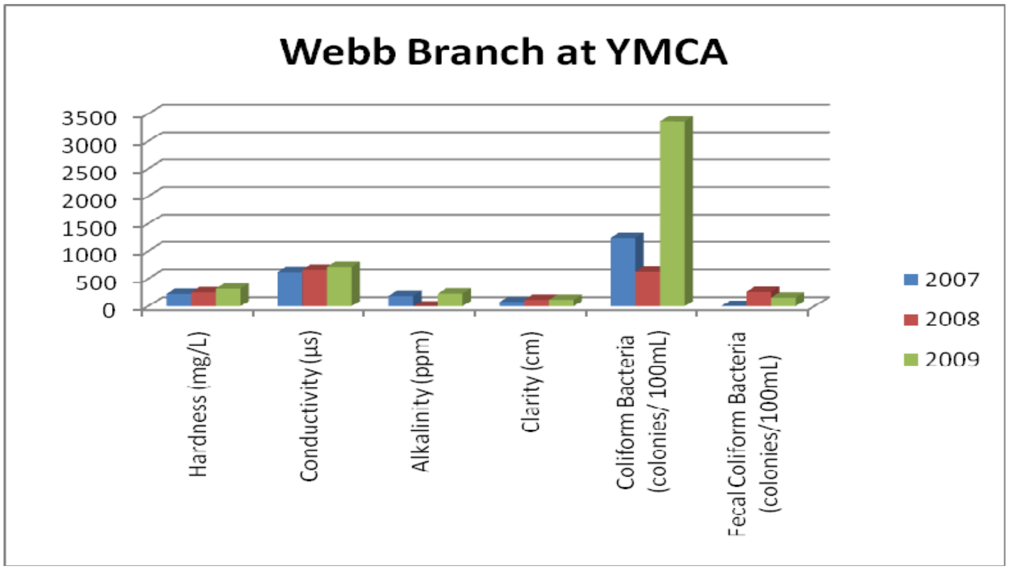

Figure 37. Webb Branch at YMCA

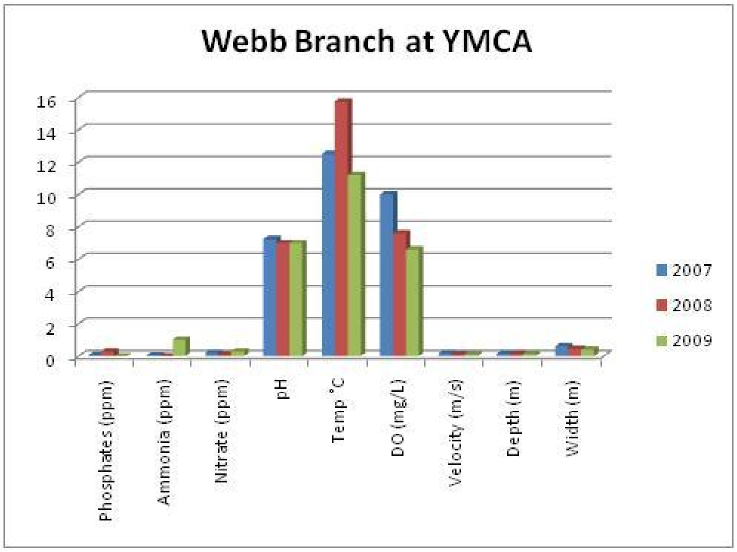

Figure 38. Webb Branch at YMCA

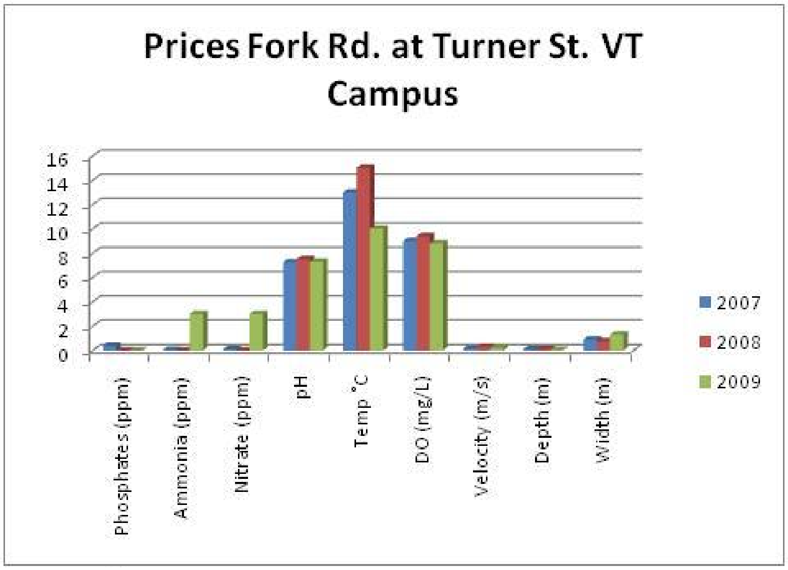

Figure 39. Prices Fork Road at Turner Street, Virginia Tech Campus

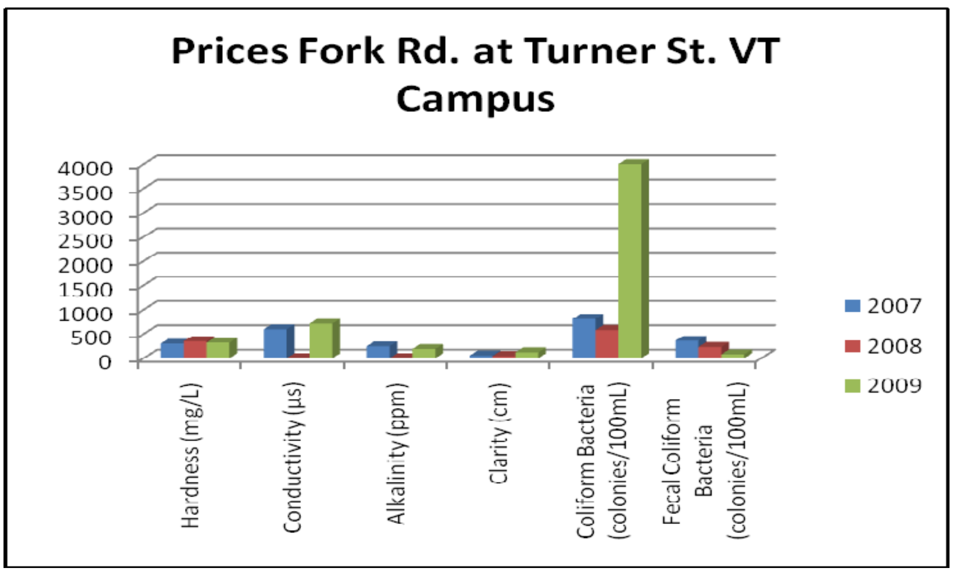

Figure 40. Prices Fork Road at Turner Street, Virginia Tech Campus

The 2008 National Science Foundation Research Experience for Undergraduates (NSF REU) research team compiled the report "Water Quality Assessment of a Mixed Land Use Watershed." The group tested 4 sites within the upper watershed during June 2008. Data was averaged for testing conducted on June 2, June 9, June 19, and June 22, 2008. Chemical parameters and heavy metals were tested during base flow and at intense storm events. Results are shown in Figures 41 to 46.

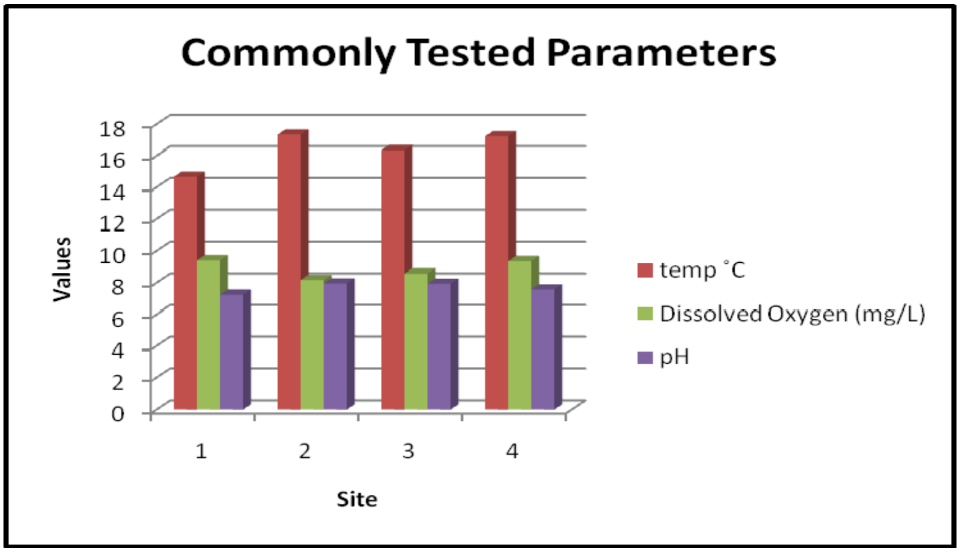

Figure 41. Diagnostic Parameters (Gronwald et al. 2008)

At base flow nitrate was highest at site 3 with 2.638mg/L and lowest at site 2 with 1.62mg/L (Figure 42).

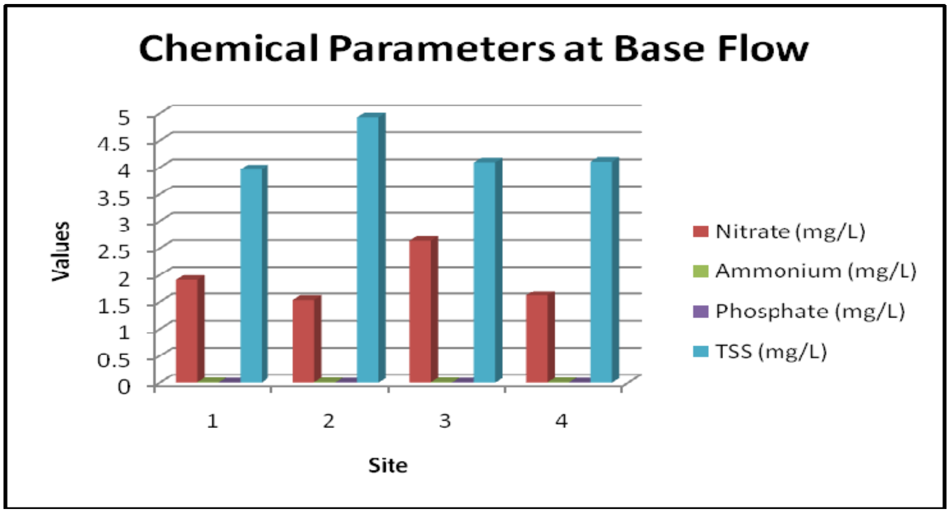

Figure 42. Chemical Parameters Base Flow (Gronwald et al. 2008)

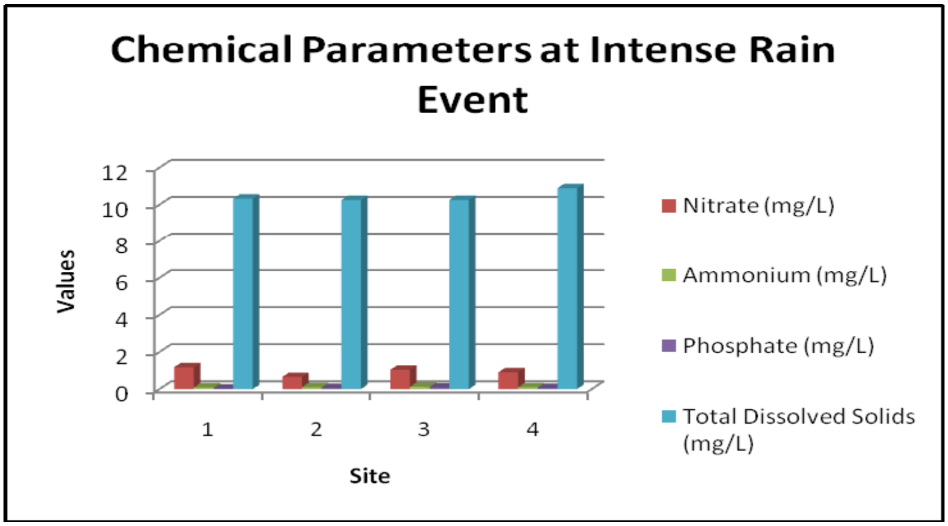

Figure 43. Chemical Parameters Intense Rain Event (Gronwald, et al. 2008)

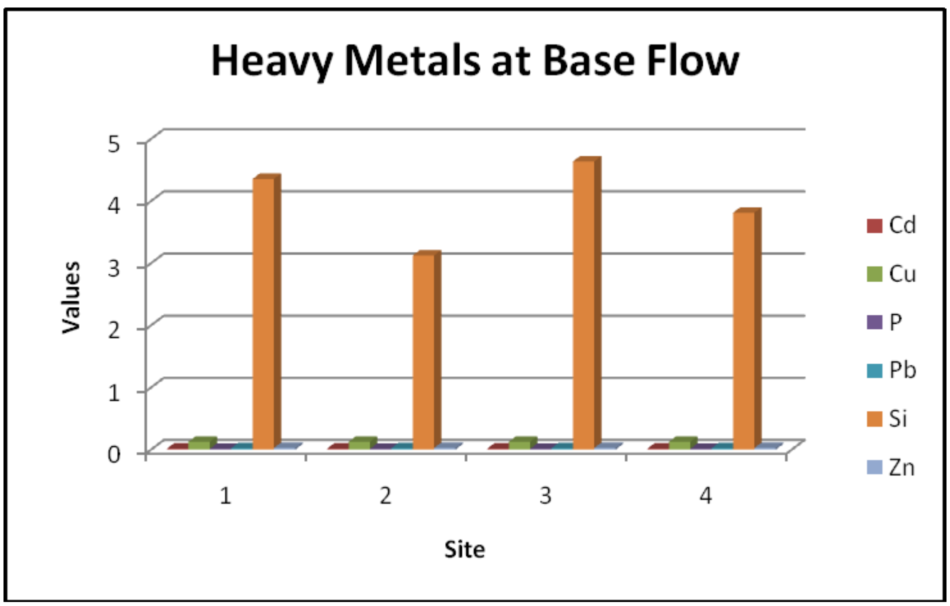

Figure 44. Heavy Metals Base Flow (Gronwold et al. 2008)

All heavy metals were below the detectable limit at all locations before and after storm events, except for silicon (Si) (Figure 44, 45). Si decreases at storm events, having higher concentrations during base flow. The biggest decrease occurs at site 3, Si at base flow is 4.636mg/L and at the intense storm event it drops to 0.0643mg/L.

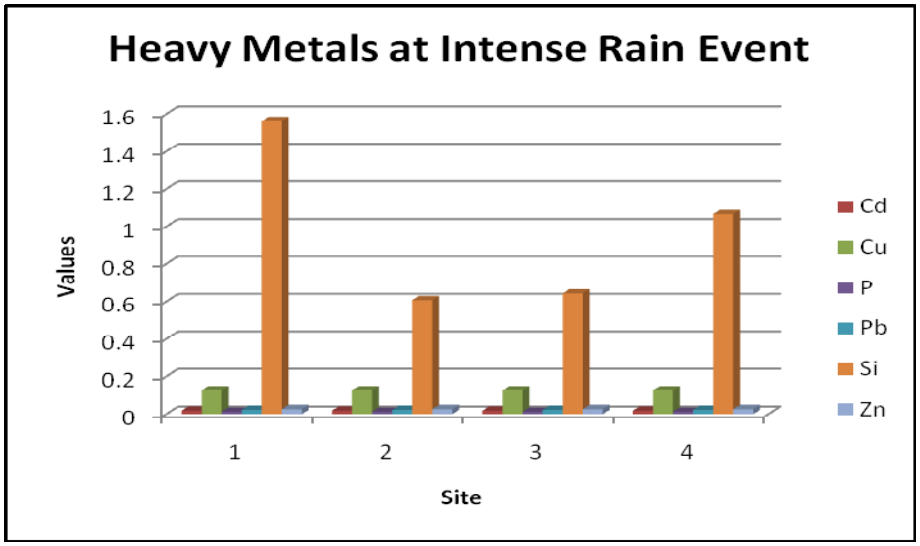

Figure 45. Heavy Metals Intense Rain Event (Gronwold et al. 2008)

E. coli was tested in two locations within the upper watershed without regard to weather condition (base flow, intense storm event). At site 3 E. coli was 3,650cfu/100mL and at site 4 E. coli was 1,290cfu/100mL (Figure 46). The Virginia standard for surface water for E. coli is 235cfu/100mL both sites exceeded this standard.

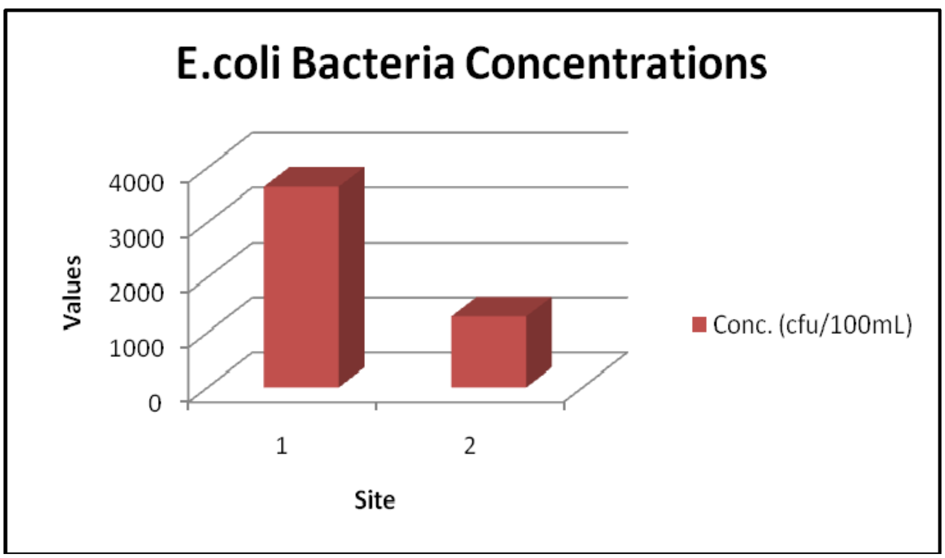

Figure 46. E.Coli Bacteria Concentrations (Gronwald et al. 2008)

Biological Parameters
Hayles (1973) recorded biological data for years 1971 to 1973. The scale of "Diversity Indices" used in her report is ranked from less than 1 to greater than 3 where <1 indicates heavily polluted water, 1-3 indicates moderately polluted water and >3 indicates non-polluted water based on macroinvertebrate results. Sites 1, 3, and 7 were classified as moderately polluted (Table 1). Site 8 was heavily polluted with an average diversity index of .98. The macroinvertebrate with the highest percent composition was the Diptera, totaling 61 species at site 3 (Table 2). Macroinvertebrates with the least percent composition were Odonata. Plecoptera and Megaloptera were not detected in any Taxa data samples. Non-insects have a higher percent composition than macroinvertebrates at each site location.

Table 1. Macroinvertebrates Diversity Index, 1971

Site	Oct	Dec	Feb	April	June	Aug	Average
1	2.6	1.25	2.41	2.07	1.64	1.83	1.97
3	2.56	1	1.24	1.96	1.59	-	1.67
7	1.62	1.37*	0*	1.34	0.99	1.92	1.21
8	0.7	1.33	0.92*	-	-	-	.98

*= 5 or less macroinvertebrates in sample, -= substrate not recovered from stream

Table 2. Percent Composition by Taxa of Macroinvertebrates at Each Site, 1971

Taxa	Ephemeroptera	Odonata	Coleoptera	Tricoptera	Diptera	Non-insects
1	3	<1	<1	<1	31	67
3	<1	0	1	<1	61	37
7	1	0	0	0	43	56
8	<1	0	0	0	56	84

Virginia Save Our Streams (VASOS) has tested the Stroubles Creek since the early 1990s. During 1990s, the ratings were based on the Issak Walton League of America rankings but in 1998 rating method was switched to using Multimetric Index score. Table 3 shows date, location and Index of Biotic Integrity ratings for two sites. The Multimetric Index score incorporates the type of organisms, number of organisms, and the amount of organisms per sample. This system considered anything less than 11 poor, from 11 to 16 fair, from 17 to 22 good, and greater than 22 excellent. The most common rating at both locations is in the range of fair to poor conditions.

Table 3. SOS Data Dates, Location and Ratings for Upper Stroubles Creek

Date	Location	Rating Index
10/19/1998	Webb St.	11
2/12/1999	Webb St.	6
2/17/1999	Webb St.	6
4/16/1999	Webb St.	11
8/04/1999	Webb St.	4
6/29/2000	Webb St.	11
2/24/2001	Webb St.	12
3/16/2002	Webb St.	Rained Out
10/5/2002	Webb St.	4
10/20/2002	Webb St.	11
2/18/2002	Webb St.	6
4/17/2003	Webb St.	11
6/13/2003	Webb St.	<11
6/30/2004	Webb St.	11
2/25/2005	Webb St.	12
12/2/2005	Fire Station	2
3/17/2006	Webb St.	Rained Out
3/17/2006	Fire Station	5
3/24/2006	Fire Station	5
10/06/2006	Webb St.	4

Benson and Younos (2001) conducted fish survey of Webb and Central Branches of Upper Stroubles Creek. Highest numbers of fish (240) were observed at the Webb Branch. - site 2. No fish was observed in the Central Branch.

Table 4. Number of Fish Counted in Webb and Central Branch Sites, 2001

	W1	W2	W3	W4	C1	C2	C3
# of Fish	0	240	3	17	0	0	0

Stream Environmental Conditions

The Stroubles Creek Corridor Assessment (SCCA) was implemented in 2001 as an activity of the Stroubles Creek Watershed Initiative (SCWI) that was launched in 1999 (Younos et al. 2003). The SCCA was conducted by a team of undergraduate students (service-learners) under the guidance Raymond deLeon (graduate student) and Dr. Younos (project advisor). The SCCA objective was to document stream problems and to provide data for watershed restoration efforts. The Stroubles SCCA protocol design was based on Maryland Department of Natural Resources, DNR protocols and the U.S. Environmental Protection Agency guidelines for assessment of wadeable streams. The three ecological components of the protocol design are watershed characteristic survey, biological assessment and physiochemical assessment. Student team included those with educational and experience backgrounds in environmental sciences, wildlife, biology, and forestry. Porter and Roessler (2001) summarized the “Stroubles Creek Stream Corridor Assessment” results after the SCCA was completed. Out of the 225 segments analyzed in the SCCA, 33 segments were within the upper watershed limits (25 Webb Branch segments, 8 Central Branch segments). Table 5 shows a summary of environmental conditions in Webb Branch and Central Branch of the Stroubles Creek in 2001.

Table 5. Physical Conditions on Webb and Central Branches (Porter and Roessler 2001)

Environmental Conditions	Webb Branch			Central Branch		
	# of Sites	Length (ft.)		# of Sites	Length (ft.)	
Channel Alteration	47	1,327		9	375	
Erosion	27	1,293		1	25	
Exposed Pipes	11	137		6	39	
Pipe Outfall	# of Sites	Evidence of Discharge		# of Sites	Evidence of Discharge	
	46	21		6	0	
Fish Barriers	# of Sites	Total Blockage	Unknown Blockage	# of Sites	Total Blockage	Unknown Blockage
	16	14	2	5	5	0
Inadequate Buffer	# of Sites	Left length (ft.)	Right length (ft.)	# of Sites	Left length (ft.)	Right length (ft.)
	25	4,250	4,250	7	1,160	1,160
Construction	2			0		
Trash	33			2		

de Leon and Younos (2002) classified all physical conditions found on Upper Stroubles Creek in an article titled “Integrating Student Service Learning and University Knowledge into Watershed Management Programs: The Stroubles Creek Watershed Case Study” which was published in the Journal of American Water Resources Association (JAWRA). Table 6 is excerpted from the JAWRA article. The environmental problems found at the Stroubles Creek watershed are ranked by their percent severity, 1 being the most severe and 5 being the least severe. The most commonly found problem is pipe outfall which is seen 57 times, though it is primarily ranked as minor in severity with 39%. The second most observed problem is channel alteration which is classified at 8% in a 1 severity rating. The most severe physical problem occurring on the watershed is in or near stream construction with a 50% 1 severity, though it is only observed at 2 site locations on the stream (least occurring problem). Inadequate buffers are the second most severe problem which are seen 33 times and are ranked as 27% with a 1 severity rating.

Table 6. Physical Conditions Ranked by Severity and Frequency Observed (de Lean and Younos 2002)

Specific Conditions	Number of Times Observed	Percent Severity Rating					
		1	2	3	4	5	u*
Pipe Outfall	57	0%	5%	11%	32%	39%	14%
Channel Alteration	49	8%	8%	49%	22%	10%	2%
Trash Dumping	36	3%	0%	6%	22%	69%	0%
Inadequate Buffer	33	27%	21%	21%	21%	9%	0%
Erosion Site	31	3%	16%	35%	26%	19%	0%
Unusual Condition	23	0%	9%	9%	17%	22%	43%
Fish Barrier	21	14%	10%	10%	19%	48%	0%
Exposed Pipe	15	0%	13%	40%	13%	27%	7%
In or Near Stream Construction	2	50%	0%	50%	0%	0%	0%
Total Problems Found on 33 Sites	267						

*u- unknown

Long-Term Changes in Watershed Land Use

In this section, historical aerial photos and geospatial technologies were used to determine long-term land use changes in the Stroubles Creek watershed. Aerial photos for Blacksburg/Virginia Tech area are available since 1937. With the advent of satellites, remote imagery has been available for this area since 1963 and LiDAR imagery in 2005. Portable GPS units allow for instant on the ground measurements. Using the most recent geographic information system and remote sensing tools, analyses on land cover changes, impervious surface cover, and stream channel alterations can be accomplished.

Methods of Analysis

Watershed Delineation from Historical DEMs

A 10-meter DEM was downloaded for Montgomery County, VA (USDA 2009) and projected in North American Datum 1983 (NAD 83) and Universal Transverse Mercator Zone 17 North (UTM 17N). A 1:24 000 1983 topographic SID mosaic of Montgomery County, VA (USDA 2009) was used to guide the vector shape file pour point directly below the Duck Pond on Virginia Tech's campus. Using the Spatial Analyst/Hydrology tools in ArcToolbox, the Upper Stroubles Creek Watershed and flow accumulation paths were delineated. This watershed delineation was used as the Upper Stroubles Creek Watershed boundary for the remainder of the study. Light Detection and Ranging (LiDAR) data (Blacksburg 2005) was processed in the provided projection, NAD 83, Virginia StatePlane South Zone. Using ArcGIS, a DEM was created from the LiDAR elevation points using the Natural Neighbor interpolation method. A flow accumulation layer was generated from this newly created DEM by the same process as previously described. ESRI's ArcGIS version 9.2 was used in the GIS analysis.

Field-Derived Watershed Delineation from GPS Readings

Using Garmin E-trex® GPS units, elevation readings were collected throughout the town of Blacksburg and on Virginia Tech's central campus. To maintain consistency in the comparative analysis, each GPS unit was spatially referenced to NAD 83, UTM 17N. Collecting points was accomplished by randomly walking the watershed. In some instances, due to safety issues, elevations readings were obtained by driving, and in those instances, one meter was subtracted from the elevation readings prior to analysis in GIS. Using the MapSource® program provided with the E-trex® unit, the files were downloaded onto a laptop and saved as a .gdb file. The MapSource® program was set to the NAD 83 reference system. Using GPS Utility, which was also set to NAD 83 UTM 17N, each waypoint .gdb file was converted to a vector shapefile (.shp, .shx, and .dbf) to allow for analysis in GIS. To eliminate 'over-weighting' of points that were close together, points within five meters of each other were integrated. A DEM and flow accumulation layer was created by the same methodology as used to process the LiDAR data.

Utilizing GPS technology to develop a DEM is done so with uncertainty, as vertical accuracies of civilian GPS units can range from ±77 meters 95 percent of the time (Thuston, Moore & Poiker 2003). Therefore, the field-derived DEM and flow accumulation layers should be used as only a guide to understanding the current watershed conditions.

Orthoimagery Interpretation

Aerial photographs of Blacksburg for 1937 and 1971 were compiled and digitally scanned by Dr. J.B. Campbell. Additionally, spatially referenced (NAD 83 UTM 17N) orthoimagery for 2000 and 2008 were downloaded for Montgomery County, VA (USDA 2009).

The images retrieved from Dr. Campbell did not include spatial reference information, and as a result, were georeferenced using ESRI ArcMap's Georeferencing toolbar by collecting ground control points (GCPs). The 1:24 000 topographic SID mosaic of Montgomery County, VA (1983), downloaded from the USDA Geospatial Data Gateway with the NAD 83, UTM 17N spatial reference, was used as a base map for GCP collection. Twenty to thirty control points were collected per image, using road intersections as the main basis for a majority of the GCPs. Once the same road intersection was identified in both the aerial photo and the topographic SID, a control point was collected on the photograph and the corresponding X and Y coordinates were recorded from the topographic SID. The Link Table of control points for the orthoimagery was manually edited with the appropriate X map and Y map coordinates recorded from the spatially referenced topographic SID. GCPs were collected throughout the entire image to ensure an even distribution of georeferencing 'weight'. Per the guidance of Dr. Campbell, control points with the highest residual were deleted with the goal of keeping twelve to fifteen control points. Furthermore, a root mean square error (RMSE) below three (ideally below two) was desired, and thus deleting control points with a high residual resulted in a decrease in the RMSE for the different images. The Link Table in Georeferencing Toolbar calculated the residuals for the control points and the RMSE for the total GCPs collected, allowing for ease in determining which control points to keep and delete for each image. A first-order linear transformation was used to georeference the aerial photographs due to the low number of control points collected, to decrease processing time, and to reduce possible distortion errors with areas that were not in close proximity to GCPs.

Land cover was analyzed for 1937, 1971, 2000, and 2008 using ESRI's ArcMap. An empty polygon shapefile was created in ESRI's ArcCatalog and referenced to NAD83, UTM 17N for each year studied. A "Land_Use" text field was added to the attribute table of each year's empty shapefile, which was updated as either forest, urban, agriculture, or open water; an "Area" float field was also added so as to calculate the different land cover areas in acres. Once the appropriate imagery year, corresponding empty polygon shapefile, and Upper Stroubles Creek Watershed boundary (derived from the 10 meter DEM that was downloaded from the USDA Geospatial Data Gateway) were imported in ArcMap, an edit session of the year's empty shapefile was started using the

Editor Toolbar. New features were created by digitizing boundaries around the different land cover classes; only those lands that fell within the Upper Stroubles Creek Watershed boundary were digitized. Using the 'merge' feature of the Editor Toolbar, similar land class polygons were merged so as to be labeled in the same class and to allow for appropriate area calculations in the shapefile's attribute table. The 'snapping' feature of the Editor Toolbar allowed for vertex, edge, and end snapping of both the land cover shapefile and the watershed boundary shapefile to reduce and eliminate the presence of slivers between land cover classes and between land cover classes and the watershed boundary. Keeping the slivers to a minimum allowed for more accurate calculation of land cover area for each orthoimage. Once the land cover was digitized for the entire Upper Stroubles Creek Watershed, the edits were saved and the editing session was closed.

The land cover classes used in this investigation were based on the principal of Anderson Level I classification (Anderson et al. 1976). Anderson Level I classification contains nine land cover classes: urban or built-up land, agricultural land, rangeland, forest land, water, wetland, barren land, tundra, and perennial snow or ice. After a preliminary investigation of the land cover types in the Upper Stroubles Creek Watershed, it was determined that only urban land, agricultural land, forest land, and water were necessary to classify the land cover within the watershed boundary. Anderson Level II classification was used to define the characteristics of each land cover type. Agricultural lands were defined as cropland and pasture, orchards, groves, vineyards, nurseries, and ornamental horticultural areas, confined feeding operations, and other agricultural land. Water was defined as streams and canals, lakes, reservoirs, and bays and estuaries. Urban land included residential, commercial and services, industrial, transportation, communications, utilities, industrial and commercial complexes, mixed urban or built-up land, and other urban or built-up land. Forested land was defined as deciduous, evergreen, and mixed forested land.

Based on the previous definitions, specific land cover examples were needed to help define an urbanized area and forested land cover. For example, a farm house located in the middle of an agricultural plot was not digitized as an urbanized area, but rather the entire agricultural plot, including the farm house, was digitized and labeled as agricultural. On the other hand, urbanized land in this study did include a wide variety of differing land cover characters. For example, a recreational field, grocery store with parking lot, graveyard, and a house with a grassy yard and trees were all equally considered urbanized land cover. Difficulty arose in defining an urbanized land area with dense trees versus that of forested land cover. Patchiness in the canopy cover and surrounding land areas were the defining features in distinguishing forested lands from urbanized lands containing heavy tree presence.

Additionally, the watershed boundary extended beyond the boundaries of the scanned historical aerial photographs provided by Dr. Campbell. In the upper and right hand portion of the watershed boundary, an unconventional method of heads-up digitizing took place due to the lack of imagery backdrop in which to digitize land cover. Hard copies of orthoimagery for the appropriate years were available for the missing area gaps in the watershed boundary; these hard copies were used to determine the land cover classes present in the watershed boundary gaps. Thus, in ArcMap, the proper land cover class was digitized in the gap areas based on the observations of the aerial photograph hard copies. While not typical, this method was possible due to the broad definitions of the land cover classes and the relatively simple outline of the watershed boundary.

As a result, the percent of land cover for the four land classes were determined by dividing the area of each land cover class by the total area of the Upper Stroubles Creek Watershed boundary. Since this was done for multiple years through time, land cover change analysis was possible.

It should be cautioned that the percent land cover, and ultimately the change in land cover through time, was based on the discretion of the photographic interpreter. Therefore, the definition of forested lands, for example, could be altered for a different user, which has the effect of changing land cover percentages. Also, due to the historical nature of the photographs, the differences between open urbanized grassy fields and agricultural lands was based on the interpreter, and has the possibility of being incorrect in relation to what the land cover truly was during that time period. Consequently, land cover results should be used as a guide to what land types were observed in Upper Stroubles Creek Watershed over time, and should not be taken as exactly accurate.

Temporal Changes in Watershed Land Use

Land Cover Changes through Time Urbanization in Upper Stroubles Creek

Settled initially as an agricultural area, the Upper Stroubles Creek Watershed has seen an increase in lands dedicated to urbanization. Figures 47 through 54 are a series of aerial photos and land cover digitization using remote sensing techniques for the time periods 1937, 1971, 2000, and 2008.

Analysis of these photos reveals that between 1937 and 1971, urban land cover increases 194%, while agricultural lands decrease by 60%. Urbanization expansion continues into the 2000s – urban land cover increases 41% between 1971 and 2008, while agricultural land cover decreases 93%. Within approximately the past ten years, urbanization has expanded 5% and agriculture has reduced 60%, indicating the increasing trend in development in an already urbanized watershed (Table 7).

Table 7. Land cover area (acres) of Upper Stroubles Creek Watershed, 1937 – 2008

Year	Urban	Agriculture	Forest	Open Water
1937	459	1508	0	8
1971	1348	597	24	7
2000	1815	118	35	8
2008	1900	40	30	9

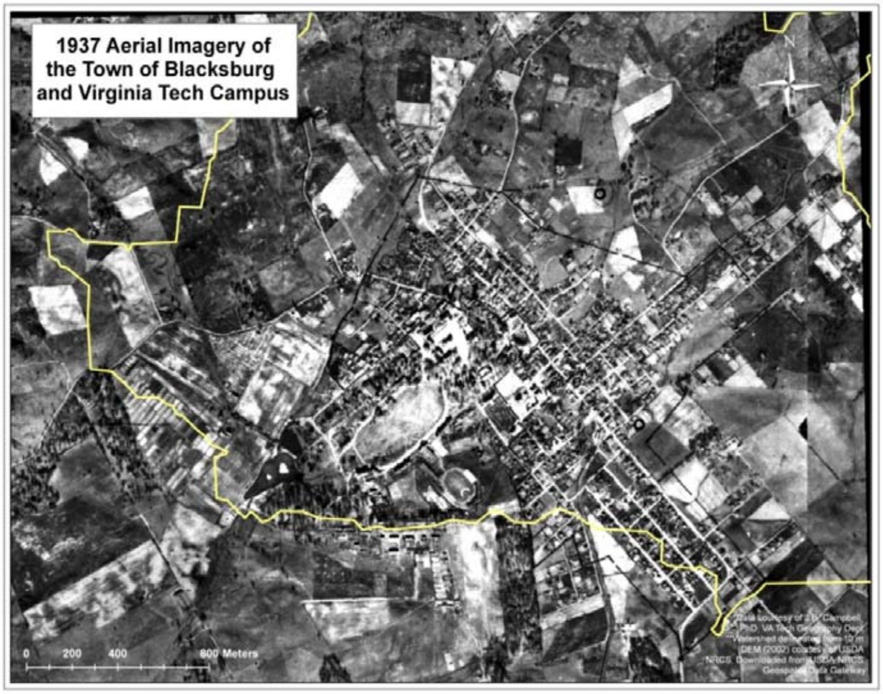

Figure 47. 1937 aerial image of Blacksburg and Virginia Tech's central campus

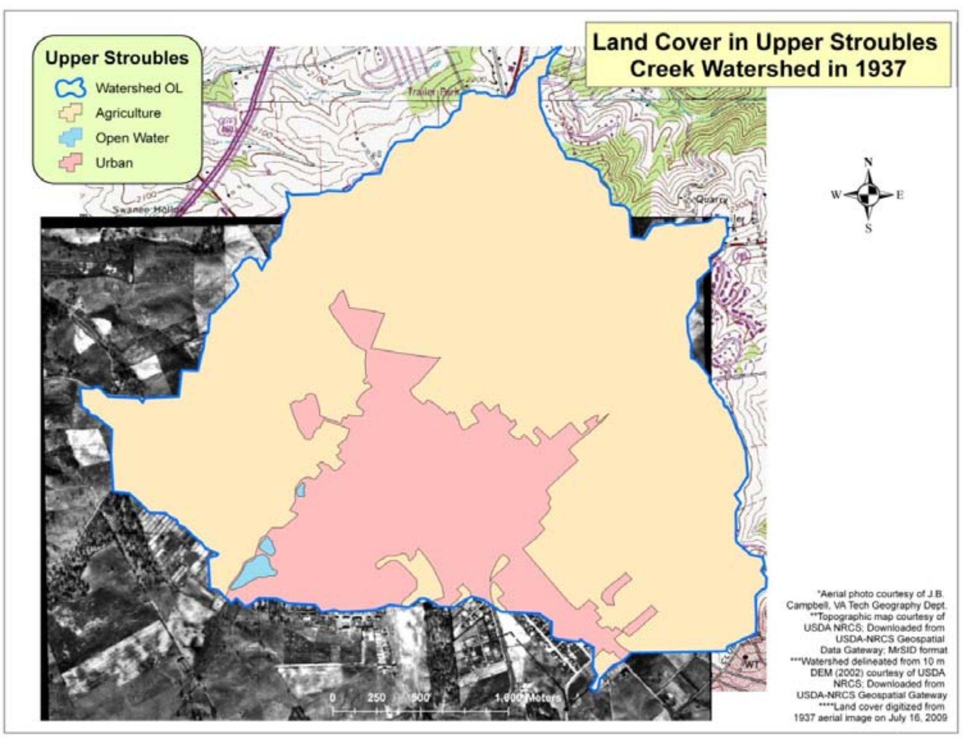

Figure 48. 1937 land cover type

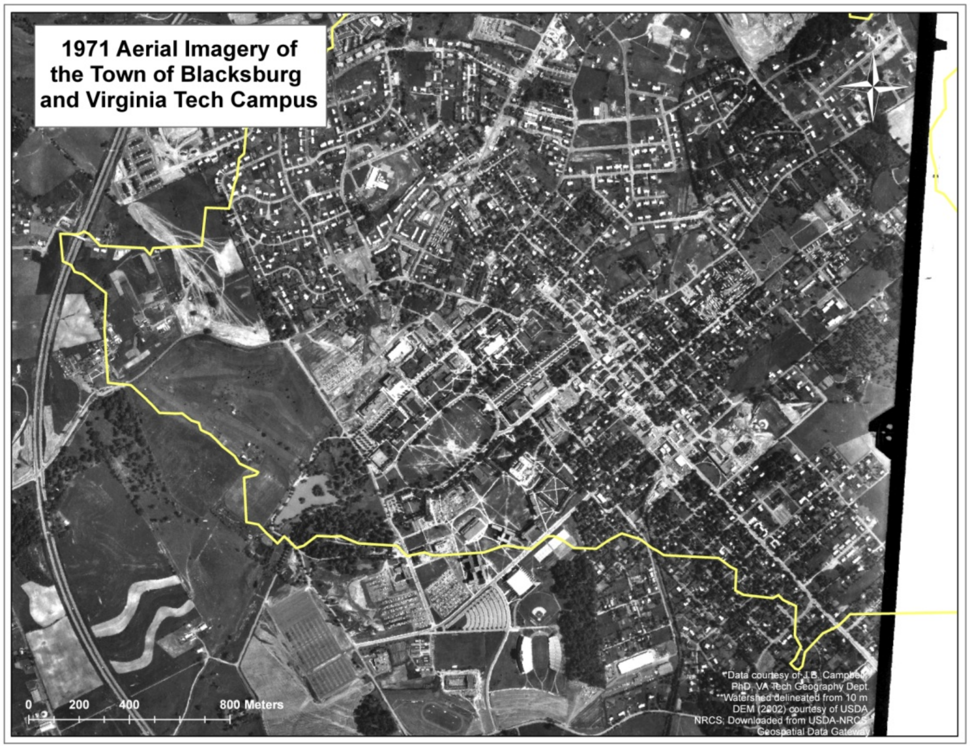

Figure 49. 1971 aerial image of Blacksburg and Virginia Tech's central campus

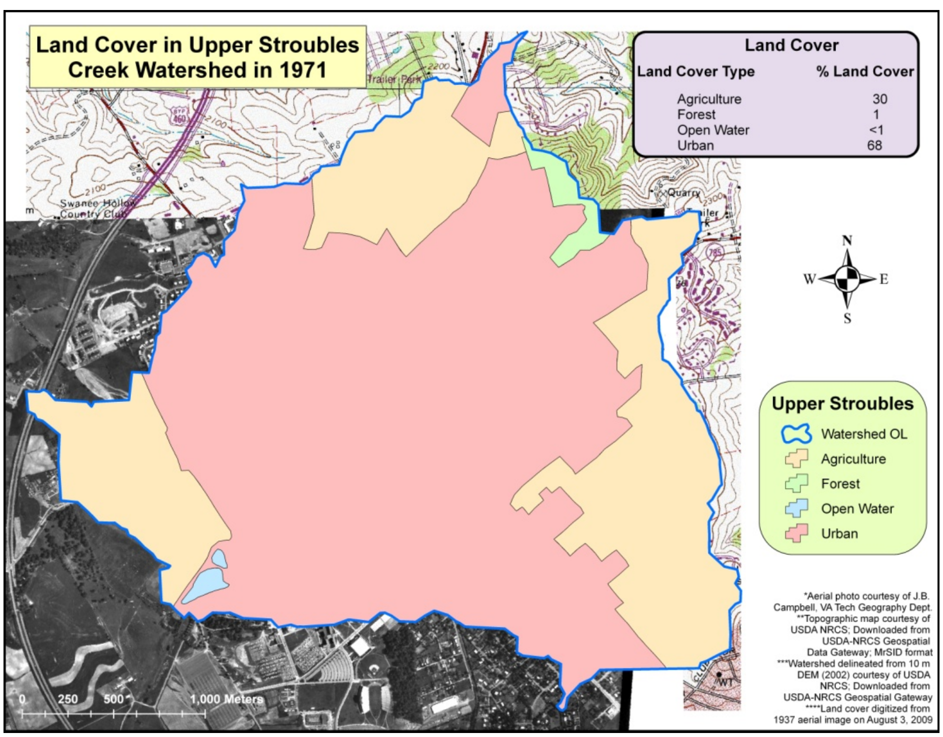

Figure 50. 1971 land cover type

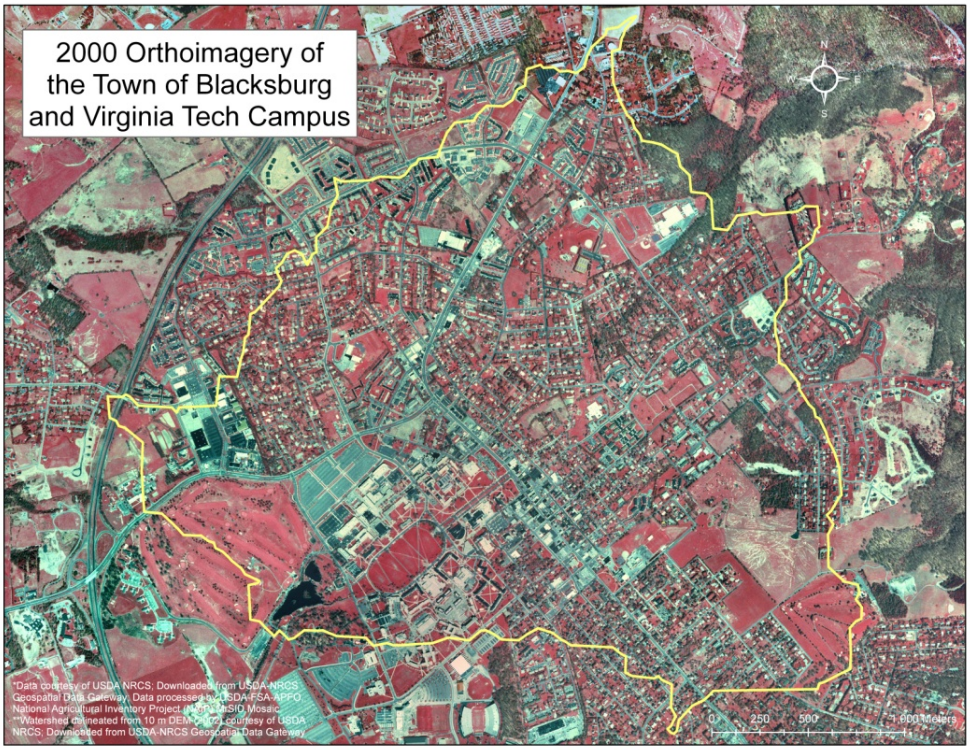

Figure 51. 2000 aerial image of Blacksburg and Virginia Tech's central campus

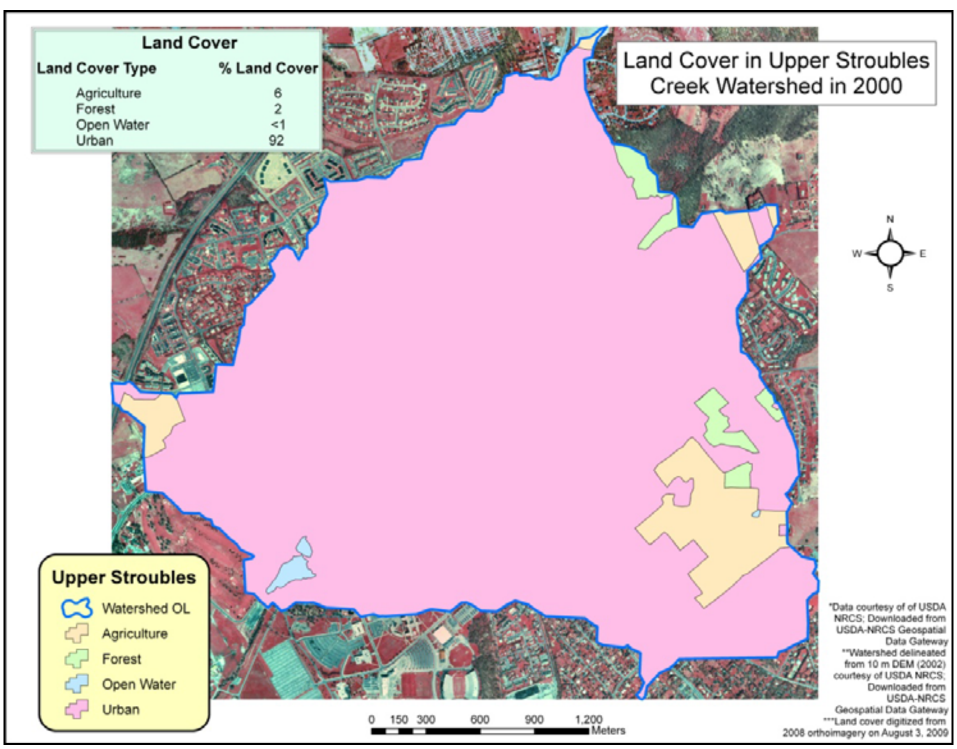

Figure 52. 2000 land cover type

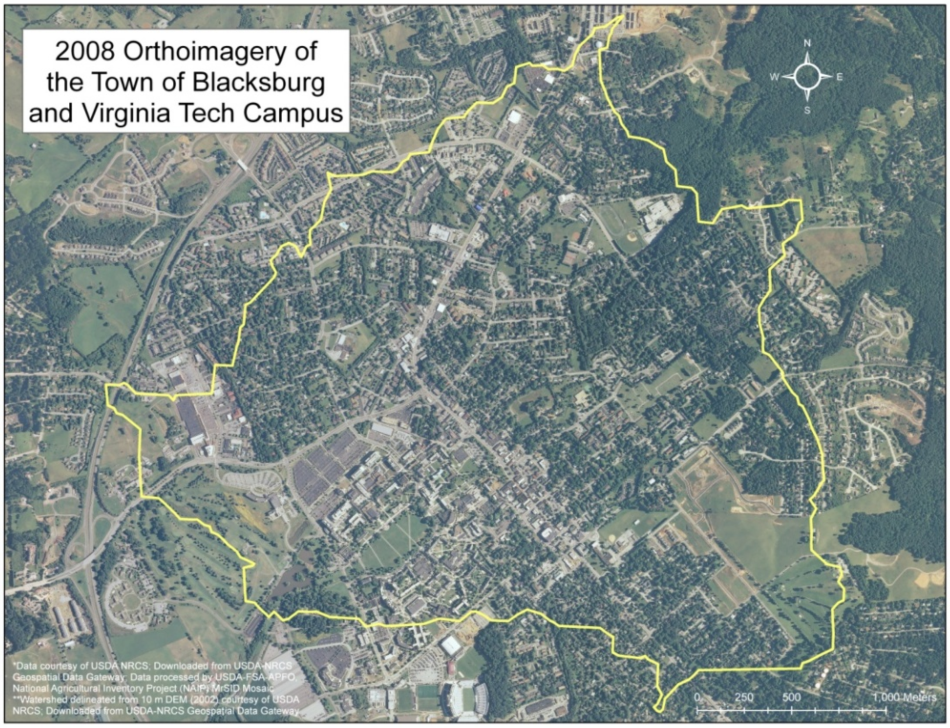

Figure 53. 2008 aerial image of Blacksburg and Virginia Tech's central campus

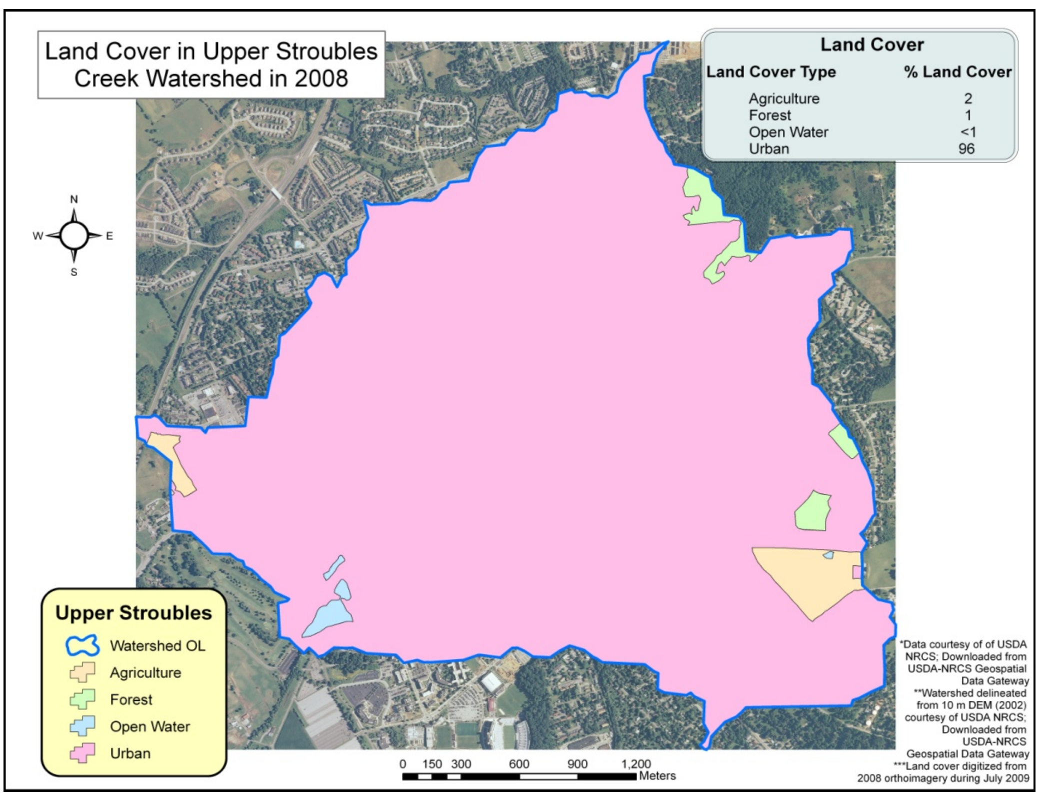

Figure 54. 2008 land cover type

At present, the Upper Stroubles Creek Watershed is dominated by urban land cover to such an extent that the amount of land cover dedicated to forest and agricultural lands is virtually nonexistent. Furthermore, omniscient urbanization is not a recent development in this region. Analyzing the NLCD Retrofit Change Product (MRLC 2008), from 1992 to 2001, 90% of land cover remains urbanized, 3% remains forested, 4% remains agriculture; 2% changed from forested to urban, and 1% changed from agricultural to urban (Figure 55). In this product, urbanization includes grassed lawns, recreational fields, and urbanized vegetative cover (MRLC 2008).

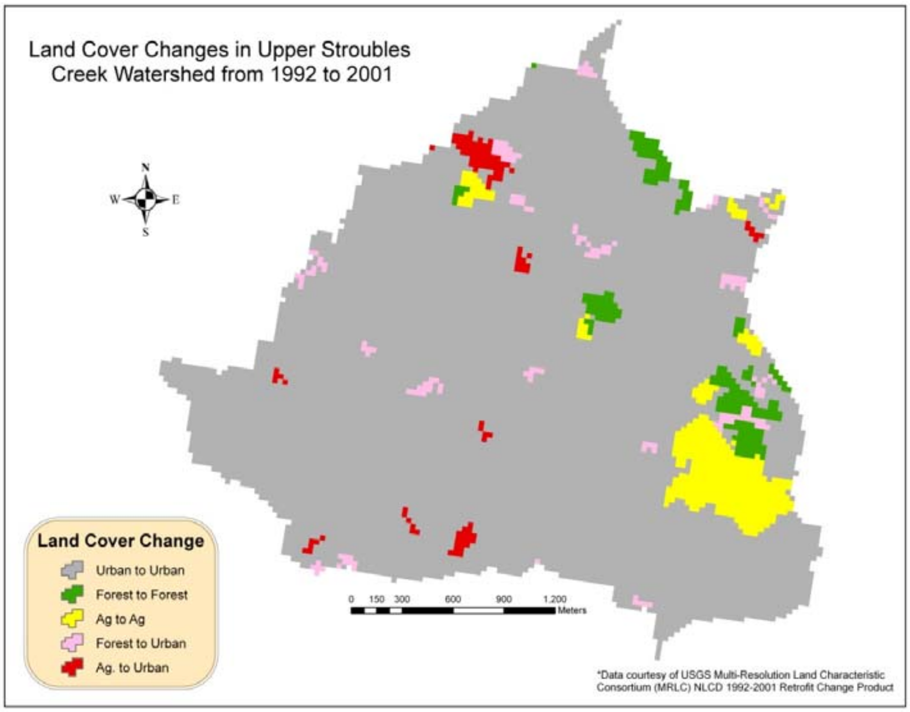

Figure 55. Land cover changes in Upper Stroubles Creek Watershed, 1992 – 2001

According to the 2004 NASS survey (USDA 2009), 85% of the land cover in Upper Stroubles Creek Watershed is agri-urban, and the other 15% is ranges from fifteen to fifty percent cultivated (Figure 56). These two data sources confirm that urbanization is wide spread in this watershed, yet a fair majority of the urbanization is open space, low and medium development.

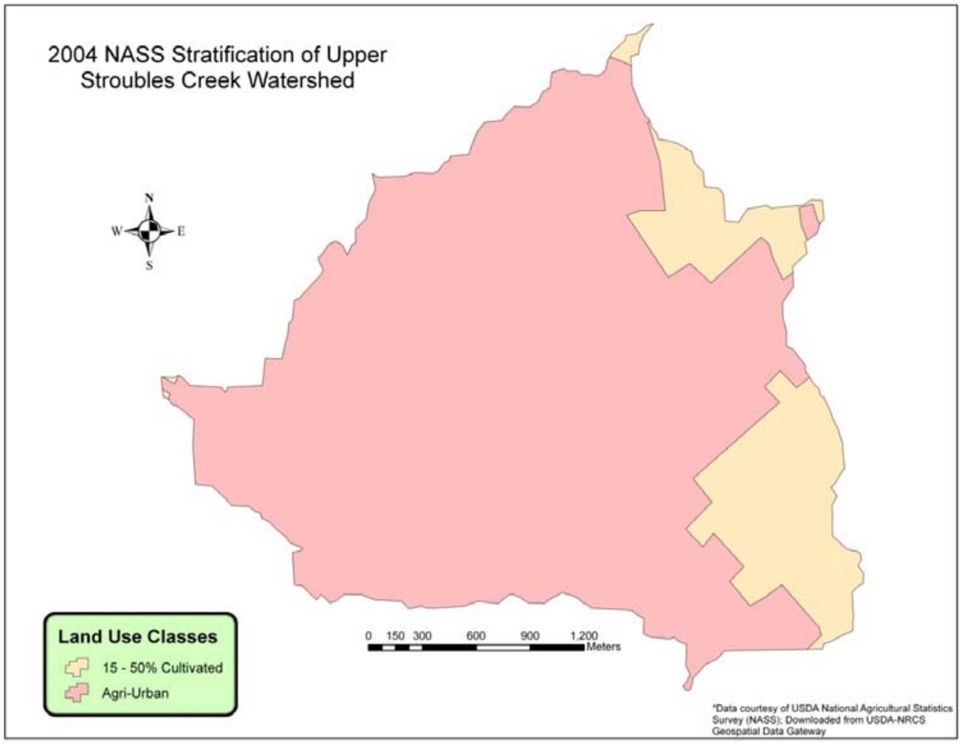

Figure 56. Land cover Upper Stroubles Creek Watershed (Source: USDA National Agricultural Statistics Survey (NASS) 2004).

Impervious surface cover and canopy density cover products of the NLCD reveal widespread urbanization trends in the Upper Stroubles Creek Watershed (USGS 2008). According to the canopy density product, 85% of the 30 meter by 30 meter grid cells within the watershed contains fifty percent or less canopy density cover. 74% of these grid cells contain zero percent canopy density cover further indicating the pressuring effects of urbanization (Figure 57). Analysis of the impervious surface cover in the thirty meter by thirty meter resolution of this layer reveals that 65% of these 30 m x 30 m grid cells have 50% or less impervious surface cover, whereas only 35% of the grid cells contain greater than fifty percent impervious surface cover, once again indicating the effects of low and medium intensity development within the watershed (USGS 2008) (Figure 58).

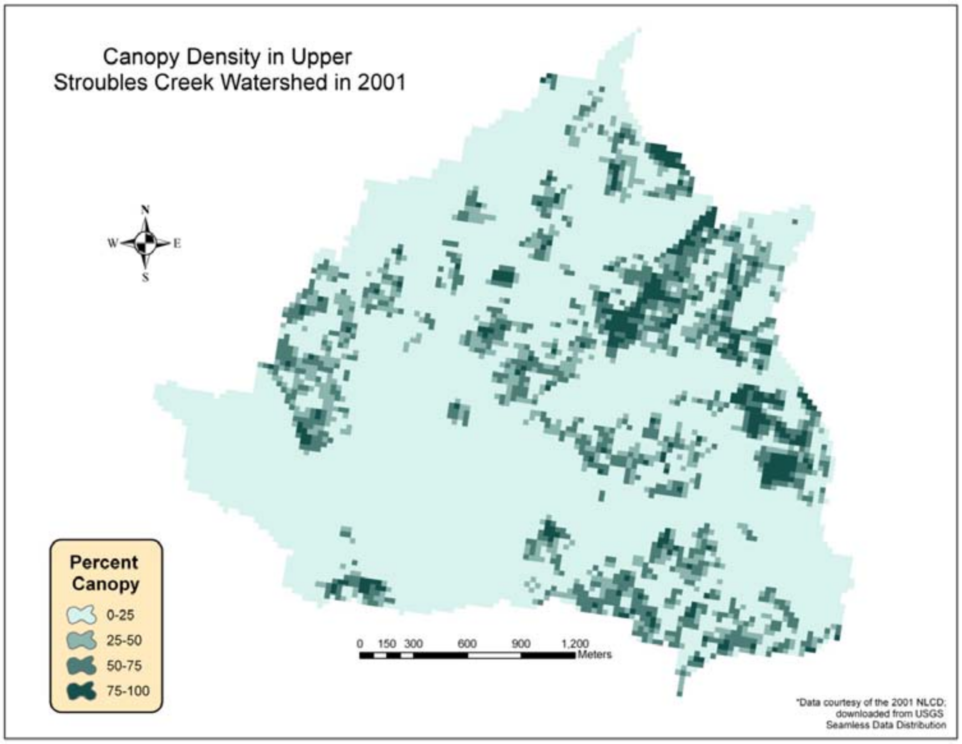

Figure 57. Canopy density in Upper Stroubles Creek Watershed (NLCD 2001)

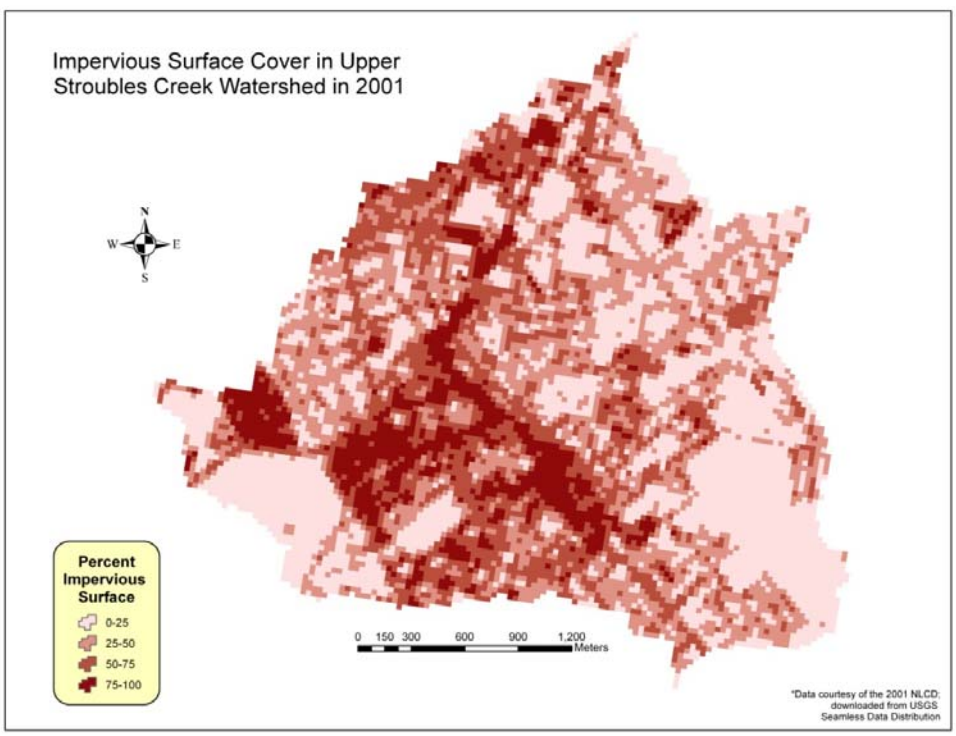

Figure 58. Impervious surface cover in Upper Stroubles Creek Watershed (NLCD 2001)

The trend of urbanization within this watershed has continued into the new century. Over the past ten years, a portion of the golf course on Virginia Tech's campus progressed from open space development to high development and impervious surface cover. Figures 59 through 62 demonstrate this development from 2000 through 2008. Figure 59 shows just the golf course. Figures 60 and 61 reveal the construction of the Oak Lane Community (right photo - lower left), and the beginnings of the construction of the Inn at Virginia Tech (right photo - upper right). Figure 62 shows the end results. Even in a watershed region of high urbanization, more intense development is possible on areas of open space and low urbanization.

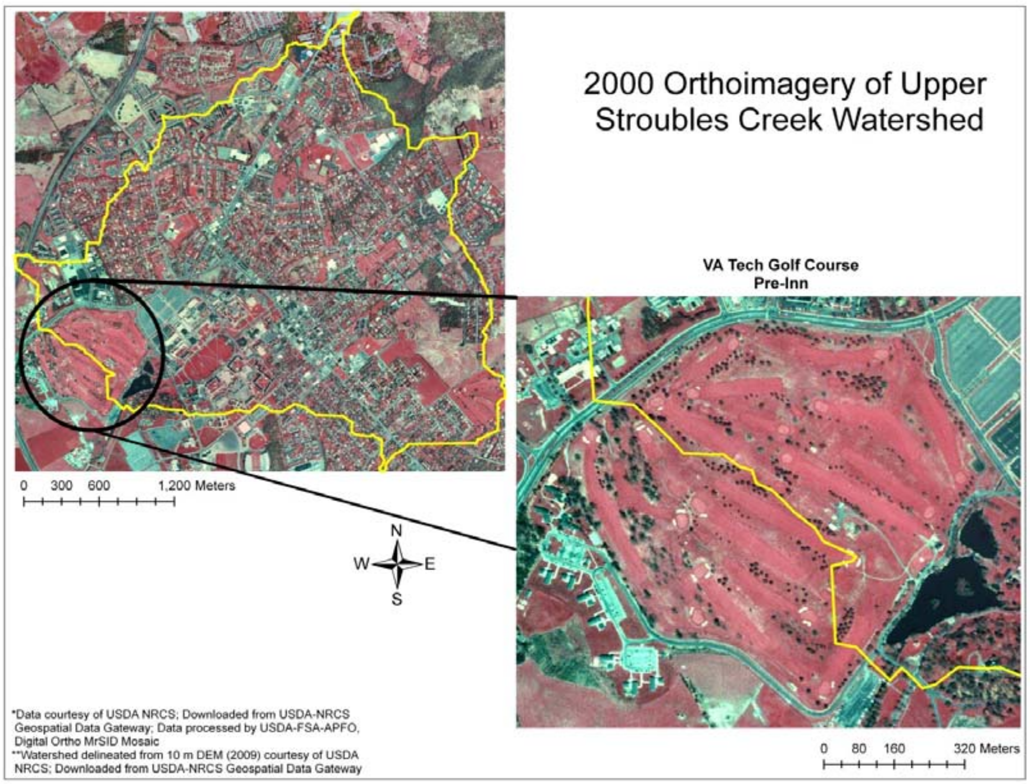

Figure 59. Orthoimagery of the Virginia Tech golf course, 2000.

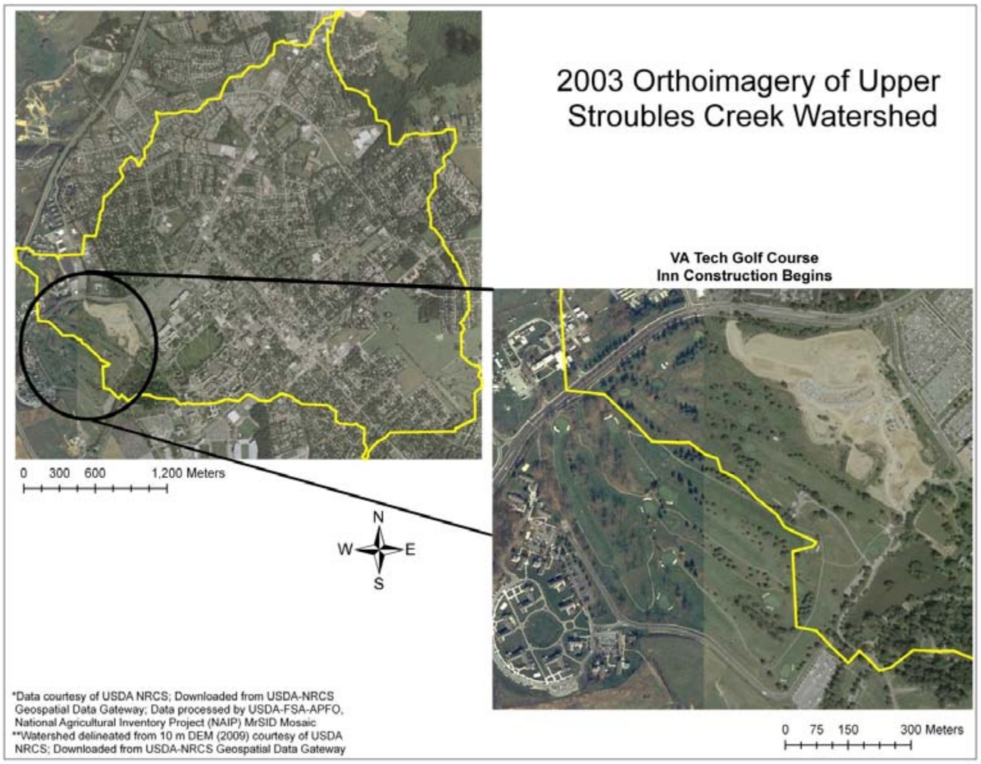

Figure 60. Orthoimagery of the Virginia Tech golf course, 2003.

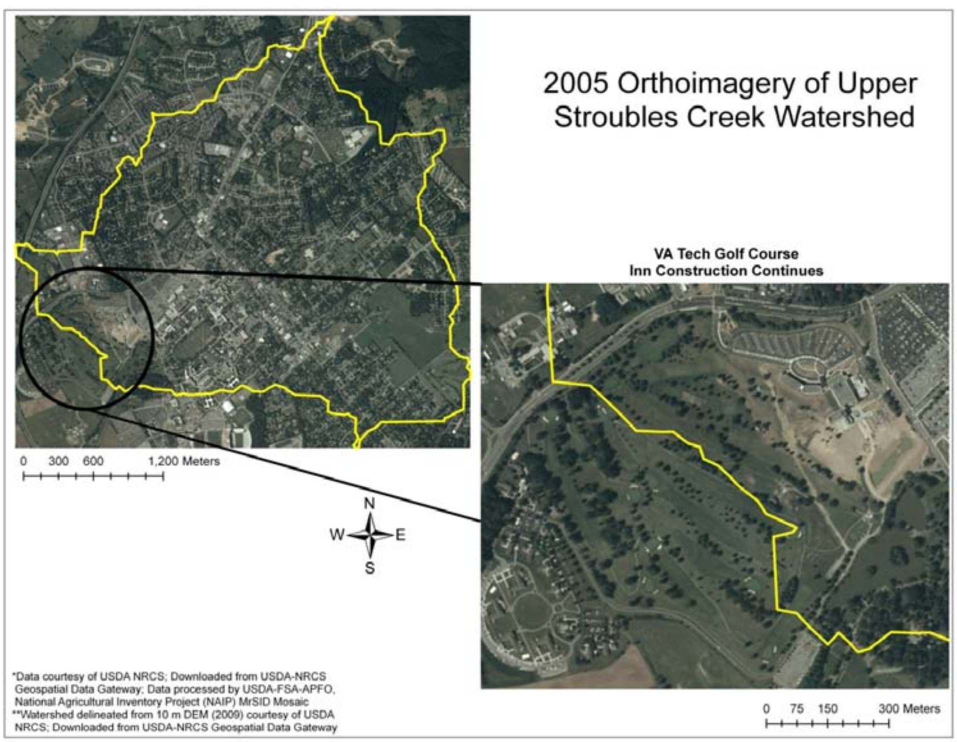

Figure 61. Orthoimagery of the Virginia Tech golf course, 2005

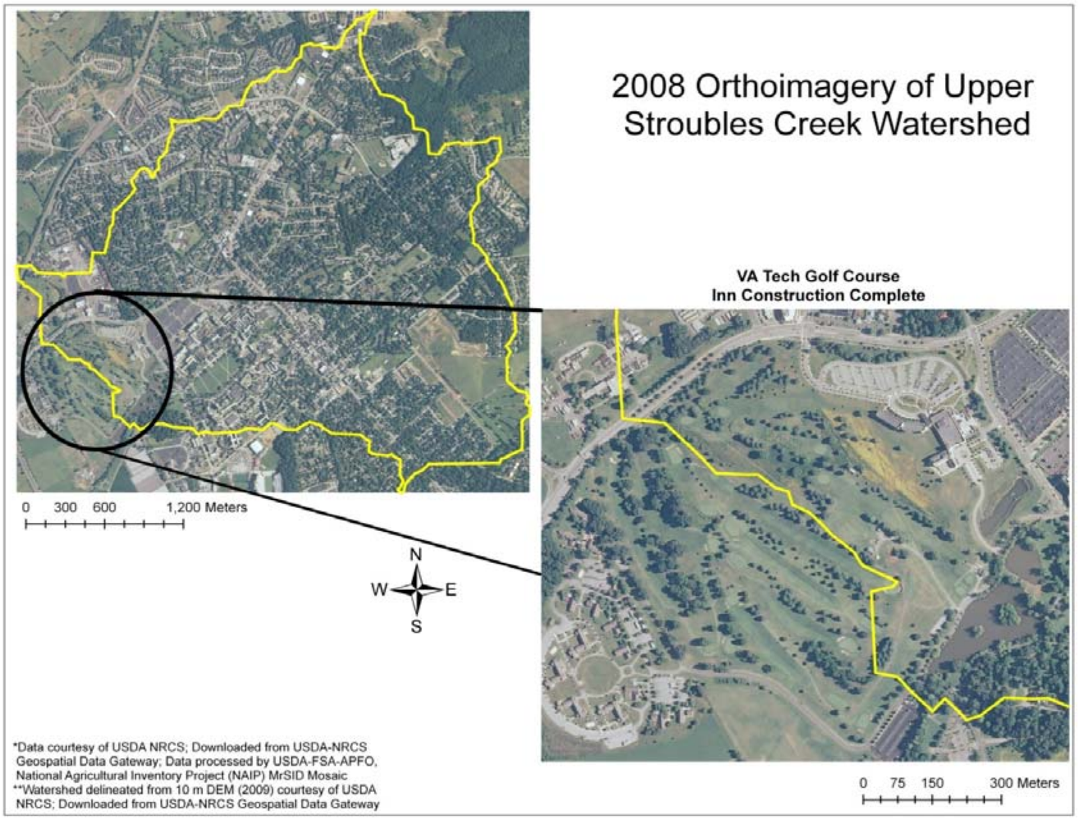

Figure 62. Orthoimagery of the Virginia Tech golf course, 2008

Development in the Upper Stroubles Creek watershed is not limited to that on Virginia Tech's Campus. As seen in Figure 63, the most current imagery (2008) is "out-of-date." A housing development, Fiddler's Green, is in the process of being developed in the last space of agricultural land remaining. The only saving grace for some of this agricultural land is that in 1991, Katherine Hoge entered into an engagement with the Town of Blacksburg, in which thirty-two acres of her land was placed into a conservation easement. According to Andrew Warren, Zoning Administrator for the Town, this type of conservation easement is the only one of its kind in Blacksburg. Additionally, Warren has indicated that a violation of the easement occurs if the thirty-two acres were to be abandoned or become fallow, therefore indicating that this area must remain active agriculture in the future. In an article discussing the easement, it is reported that the land has been recently bought by Jim and Heather Cowan and that the land will remain ninety percent agricultural with organic farm management practices (*Collegiate Times*, November 19, 2008). Additionally, a second lake is going to be constructed on the property (increasing open water in the Upper Stroubles Creek Watershed), which will act as a migratory bird habitat. Ironically, one of the selling points of trying to bring buyers to Fiddler's Green is the close location to the easement and the beauty of being located near the horse farm.

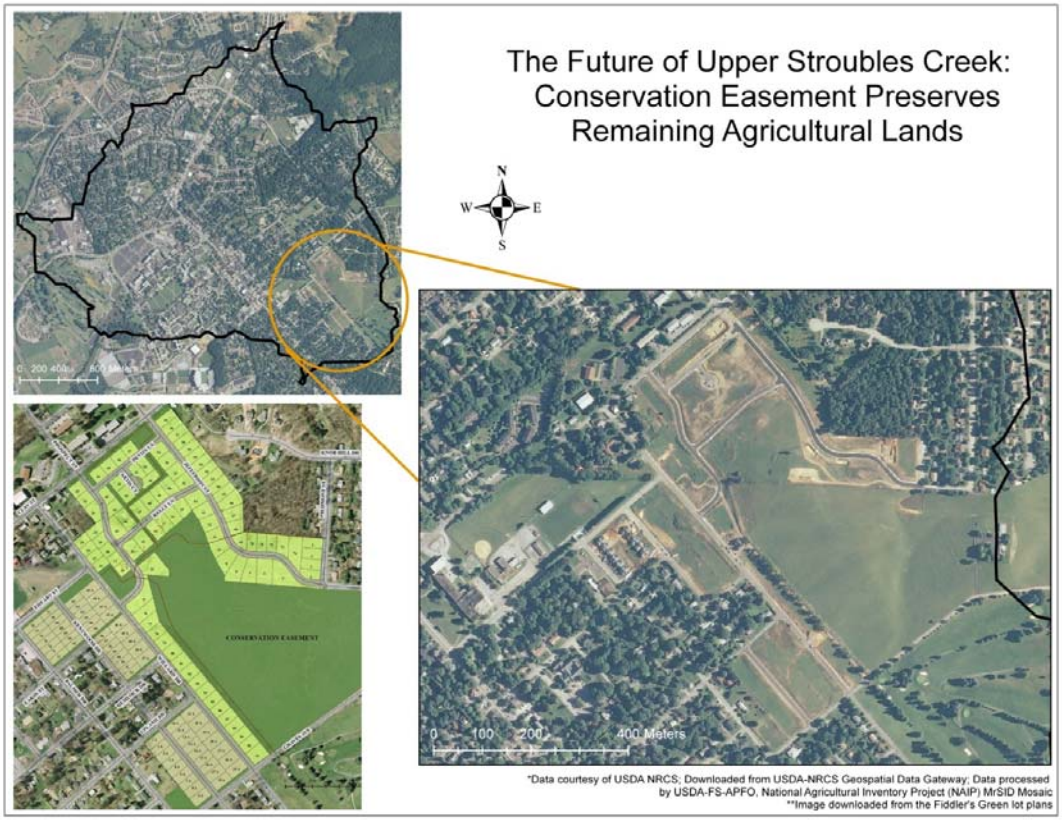

Figure 63. The Hoge Conservation Easement and Fiddler's Green Development, 2008

Watershed analysis using Digital Elevation Models

Comparison of the flow accumulation layers of the 2002 DEM and 2005 LiDAR data layers reveals similarities (Figure 64). This is important for a few reasons: (1) these results support that urbanization was so widespread by the time these technologies were available to analyze changes in the Upper Stroubles Creek watershed, and that more recent land cover changes such as urbanization are not significant enough to change the movement and flow path of water between 2002 and 2005; (2) abnormalities in the data are not present, giving credibility to the data layers used in this study; and 3) this interpolation is a defensible method for establishing a DEM.

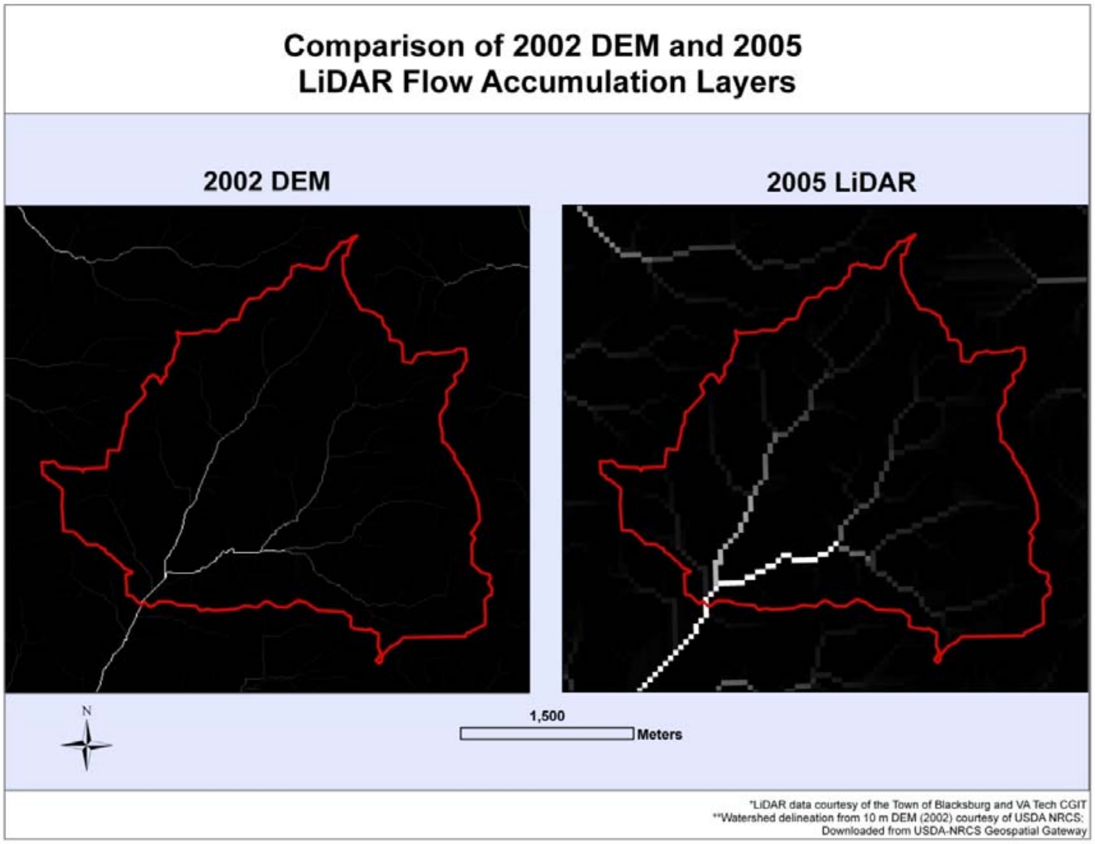

Figure 64. Flow accumulation comparison, 2002 DEM and 2005 LiDAR DEM.

Field-Derived DEM

The collection of GPS points allowed a present day digital elevation model (DEM) to be developed to analyze the effects of urbanization on elevation, and ultimately watershed delineation. Over 15, 000 GPS readings were obtained in the Town and on the University's campus (Figure 65).

A disparity does exist between the GPS and LiDAR derived flow accumulation layers (Figure 66). This disparity can be attributed to (1) developmental changes altering the flow and movement of water within the watershed, (2) error associated with the elevation readings of the GPS device, and (3) an unsystematic collection of GPS points throughout the watershed area. Due to time limitations, inability to get onto private property, other inaccessible areas and safety, GPS readings were not collected uniformly throughout the entire town and campus. This resulted in "weighting" issues in developing a surface raster and flow accumulation layer.

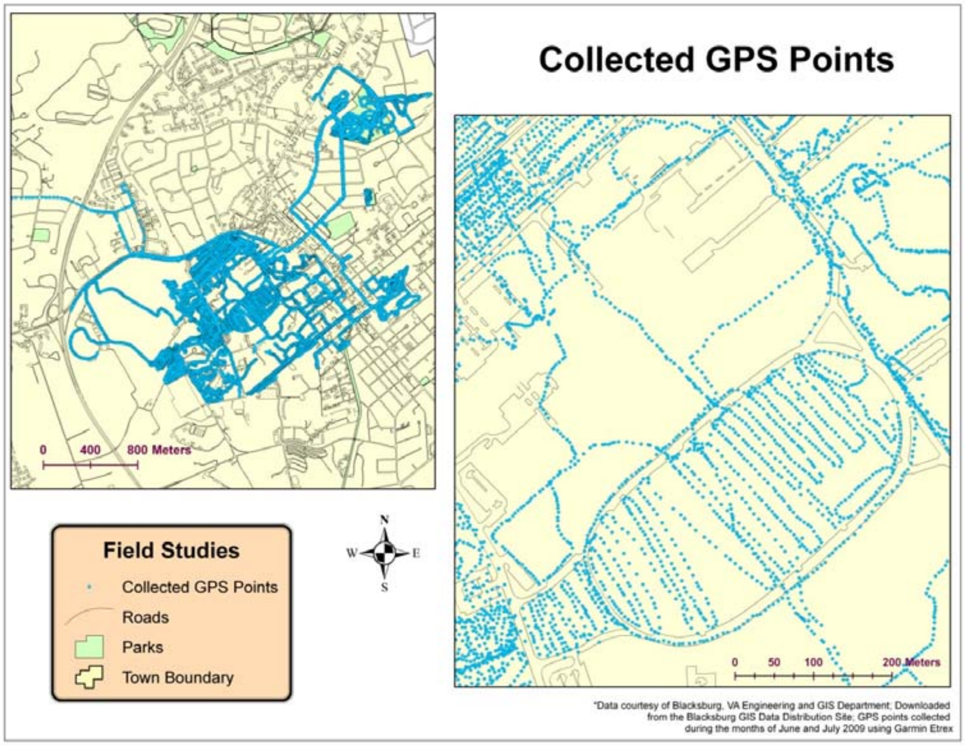

Figure 65. GPS points collected using Garmin E-trex® GPS units, 2009

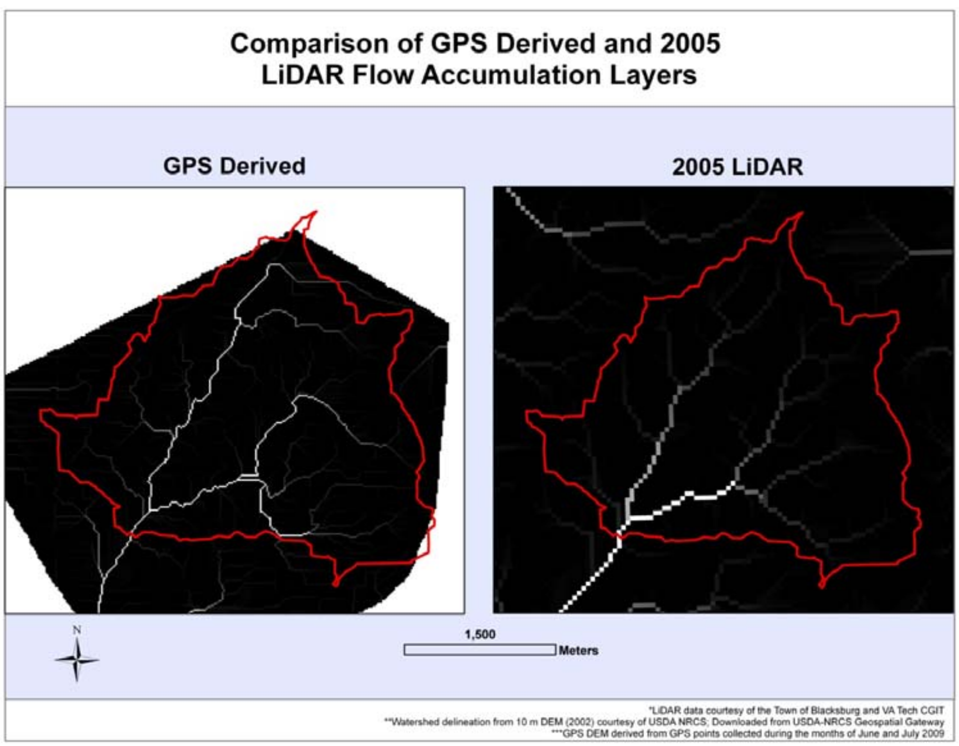

Figure 66. Flow accumulation comparison, GPS DEM and 2005 LiDAR DEM.

Finally, a comparison of the stream channels delineated from a USGS DEM from 1963 and the stream channel layer from the Town of Blacksburg is found in Figure 67. 1963 delineation clearly shows the original 4 branches, 3 from their origins in the springs, and in 2005, only the day-lighted portions remain.

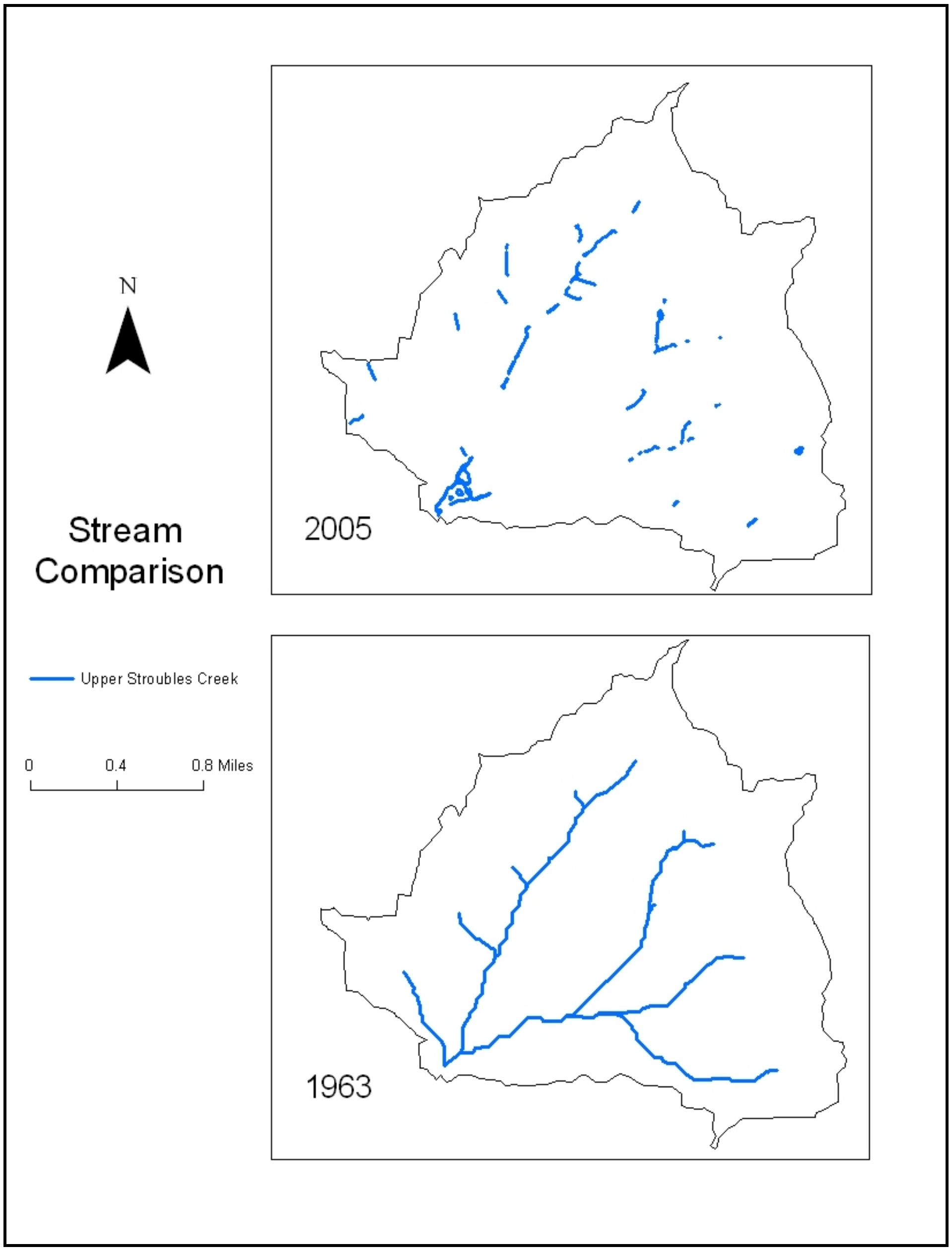

Figure 67. Stream Channel Changes, 1963 – 2005

Conclusion

Historic water quality data and analysis of the series of aerial photos, satellite imagery and field investigation allowed for compilation of information from and comparison of long-term land use changes in the Upper Stroubles Creek watershed. This data compilation allowed an assessment of continued urbanization and its long-term impacts on the health of the Upper Stroubles Creek watershed.

At present, urbanization is the leading land use type in the Upper Stroubles Creek watershed. The urban development has increased areas of physical disturbance and depleted the ecosystem health throughout the watershed. As revealed through orthoimagery analysis, mass urbanization in the watershed began in the 1970s and has continued to present. Today, less than 40 acres of land cover in the watershed is dedicated to agriculture, whereas agriculture land use was predominant prior to 1970.

The Webb Branch of the Stroubles Creek experiences greater adverse environmental conditions because of the more extensive urbanization imposed at this branch. The Central Branch is almost entirely culverted underground. Degradation of this Central Branch is also caused by increased urban stormwater runoff generated by impervious surfaces that continue to contribute pollutants and sediment into the stream.

On the positive side, the TMDL implementation plan for the watershed has been completed. The Town and Virginia Tech are collaborating on several watershed restoration projects and serious consideration is given to low impact development projects within the Town and the Virginia Tech campus. Large expanses of open space on Virginia Tech's central campus, along with the large number of recreational parks throughout the Town of Blacksburg, shows significant progress for implementing low impact development and maintaining open space throughout the watershed.

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Appendix 1

Population Data, Town of Blacksburg (1845-2008)

Year	Population (people)	Percent Change (%)	Source
1845	250	0	Worsham, 1997
1860	460	84	Hedgepeth et al., 1998
1880	688	49.5	Garnett, 1935
1900	768	11.6	Worsham, 1997
1910	875	13.9	Garnett, 1935
1920	1095	25.1	Garnett, 1935
1930	1400	27.8	Worsham, 1997
1940	2130	57.1	Worsham, 1997
1950	3358	57.7	Blacksburg Partnership
1960	7070	110.5	Blacksburg Partnership
1970	9384	32.7	Blacksburg Partnership
1980	30638	226.5	Blacksburg Partnership
1990	34590	12.9	Blacksburg Partnership
2000	36573	5.7	Blacksburg Partnership
2008	41796	14.3	US Census

Appendix 2

Upper Stroubles Creek Past Report Study Site Locations

Report	Site Description		Year(s) & detail
"Biological and Chemical Monitoring of Three Streams in the Area of Blacksburg, VA" (Hayles, 1973)	Clay St., 175'N of Corner of Clay St. and Wharton St. (Site 1)		1971- 1972
" "	Behind Georgetown Apartments on Owens St. (Site 3)		1971-1972
" "	Corner of Greenhouse Rd. and South Gate Dr., Virginia Tech, stream underground .25mi. before site (Site 7)		1971-1972
" "	Bridge on Greenhouse Rd. crossing Stroubles Creek at end of drill field, Virginia Tech, stream underground .75mi. before site (Site 8)		1971-1972
"Assessment of Pollutant Loads to the Virginia Tech Duck Pond: (Knocke, 1985)	Fire station		1981
" "	Ewald Clark		1981
" "	Hoy Funeral		1981
" "	Northview		1981
Save Our Streams	Longitude	Latitude	1992*-2005*, Webb Branch
	-80˚24' 45"W	37˚14'56"N	
" "	Longitude	Latitude	1992*-2005*, John Randolph House
	-80˚30' 14"W	37˚10'51"N	
" "	Longitude	Latitude	1992*-2005*, 30' below John Randolph House
	-80˚30' 12"W	37˚10'55"N	
" "	Longitude	Latitude	1992*-2005*, Central Branch
	-80˚25' 32"W	37˚13'33"N	
" "	Longitude	Latitude	1992*-2005*, Fire

	-80˚24' 50"W	37˚13'53"N	Station
"Fish Survey of Webb and Central Branches of Upper Stroubles Creek, Blacksburg, Virginia" (Benson et al., 2001)	Behind 809 Giles Rd. below area with heavy machinery, exposed dirt and erosion. Muddy and silt substrate, vegetated banks		2001, Webb Branch (W1)
" "	Main St. behind Wade's Supermarket (under building), no riparian buffer, fish barriers and concrete/ gabion banks. Silt and gravel substrate		2001, Webb Branch (W2)
" "	Webb St. between Papa John's and Hardware Store. Heavily urbanized, little riparian buffer, trash, erosion, pipe outfall. Silt and gravel substrate		2001, Webb Branch (W3)
" "	Virginia Tech Campus, Webb branch before flowing under parking lot, some riparian buffer and pipe outfall. Mostly muddy and silt substrate		2001, Webb Branch (W4)
" "	Owens Rd., grassy park across from apartments with a lot of aquatic vegetation, some trash and muddy substrates		2001, Central Branch (C1)
" "	Behind Owens Rd. apartments, some trash, a lot of aquatic vegetation. Muddy substrate		2001, Central Branch (C2)
" "	Next to fire station, gabion banks, gravel and pebble substrate		2001, Central Branch (C3)
"Biological Physiochemical Assessment of Stroubles Creek: Winter Condition" (Crawford, 2002)	Longitude	Latitude	2002, Webb Branch Headwaters (Site 1)
	-80˚24' 53.8"W	37˚14'34.7"N	
" "	Longitude	Latitude	2002, Webb Branch Urban landscape (biological testing) (Site 2)
	-80˚25' 25"W	37˚14'2.8"N	
" "	Longitude	Latitude	2002, Webb Branch Entering the duck pond (Site 3)
	-80˚25' 38.2"W	37˚13'40.7"N	
" "	Longitude	Latitude	2002, Central Branch

	-80˚24' 32.6"W	37˚14'17.3"N	Headwaters (Site 4)
“ ”	Longitude	Latitude	2002, Central Branch Urban Landscape (biological testing) (Site 5)
	-80˚24' 48"W	37˚13'54"N	
“ ”	Longitude	Latitude	2002, Central Branch Entering Duck Pond (Site 6)
	-80˚24' 32.7"W	37˚13'33"N	
E.Coli and Sediment Monitoring for the Virginia Tech Duck Pond in Blacksburg, VA (Burke et al., 2006)	Central Branch (before the duck pond)		2006
“ ”	Webb Branch (before the duck pond)		
Blacksburg High School	Owen’s St. Park		2007- 2009
“ ”	Progress St. at Rescue Squad		2007- 2009
“ ”	Webb Branch at YMCA		2007- 2009
“ ”	Prices Fork Rd. at Turner St., Virginia Tech Campus		2007- 2009
“Water Quality Assessment of a Mixed Land Use Watershed” (Gronwald et al., 2008)	Longitude	Latitude	2008, Webb Branch behind YMCA (Site 1)
	W80 25.164	N37 14.315	
“ ”	Longitude	Latitude	2008, Central Branch behind Fire Station (Site 2)
	W80 24.818	N37 13.895	
“ ”	Longitude	Latitude	2008, Central Branch above Duck Pond (Site 3)
	W80 25.526	N37 13.558	
“ ”	Longitude	Latitude	2008, Webb Branch above Duck Pond (Site 4)
	W80 25.638	N37 13.675	

*Not all parameters and/or years are tested for the same number of years

Appendix 3

Water Quality Data

Average data from June, July and August (Taft, 1949)

Site	DO mg/L	pH	Temp ˚C	Nitrites Mg/L	Nitrates mg/L	Alkalinity mg $CaCO_3$/ L	Chlorides ppm	Coliform probable # of organisms/mL
1	7.55	7.55	23.13	0.04	1.99	177	31.2	772..5
2	3.75	7.43	22.3	0.04	0.79	219.2	63.25	484381.1
3	5.15	7.6	22.04	0.08	0.8	214.8	24.25	158300

Site 1 (Hayles, 1973)

Site	% DO sat	Cl mg/L	pH	COD mg/L	BOD mg/L	TOC mg/L	Alkalinity mg $CaCO_3$/ L	TKN mg/L	Chloride mg/L	Nitrate mg/L
1	88	0	7.3	5.2	1.2	5.8	225	0	13	2.1

Chromium Tested (mg/L) on specific Dates at Site 7 (Hayles, 1973)

Site	11/2/1971	12/14/1971	6/14/1972
7	12.2	16.5	3.2

Dry Weather Samples (Knocke, 1985)

Site	Temp ˚C	pH	BOD mg/L	TOC mg/L	TP mg/L	TKN mg/L	Alkalinity mg $CaCO_3$/ L	Conductivity mhos
Fire station	22	8.6	4.4	2.96	0.05	0.42	232	450
Ewald Clark	15	7.9	4.2	3.62	0.11	0.63	272	460
Hoy Funeral	18	8.2	5.3	3.21	0.14	0.84	261	470
Northview	17	8.2	3.5	2.47		0.49	270	490

Wet Weather Samples, 4/23/1981 (Knocke, 1985)

Site	Sample Type *	Suspended Solids mg/L	Conductivity mhos	BOD mg/L	TKN mg/L	TP mg/L
Fire Station	Pp	39	600			0.07
Fire Station	comp	403	450	40	5.32	1.41
Ewald Clark	Pp	15	610			0.11
Ewald Clark	comp	314	525	40	3.43	2.15
Hoy Funeral	Pp	64	590			0.05
Hoy Funeral	comp	1698	600	30	5.95	1.16
Northview	comp	180	1280	40	50.4	0.75

*pp- prepeak sample, comp= composite sample over storm period (2 hours)

Chemical Parameters Tested (Benson et al., 2001)

Site	Alkalinity mg $CaCO_3$/ L	Conductivity µS	DO mg/L	pH
W1	130	310	7.48	7.5
W2	200	310	9.8	7.9
W3	250	510	9.51	7.9
W4	220	520	10.17	8.3
C1	190	350	10.03	7.7
C2	270	540	9.87	7.8
C3	110	250	10.28	7.8

Chemical Parameters Tested, Average March 2002 (Crawford and Younos)

Site	Temp ˚C	DO mg/L	pH	E. Coli cfu/100mL	Fecal Coliform cfu/100mL
1	12.4	9	8.1	20	40
2	13.1	7	7.4	5000	6400
3	13.2	9	9	1000	1400
4	11	8	6.9	2500	2600
5	12.7	9	7.7	3700	4200
6	13.4	9	7.4	900	960

Chemical Parameters Tested, Averages Feb, March and April 2006 (Burke et al., 2006)

Site	Temp ˚C	pH	TSS mg/L	Phosphates mg/L	Nitrate mg/L	E.coli cfu/100mL
Central	11.8	9.5	22.4	0.35	1.38	293.75
Webb	11.9	11.9	6.4	0.63	1.09	1609.91

Blacksburg High School Chemical Parameters Tested, 2007, 2008, 2009 (annual average)
Owen's St. Park

Years	Phosphate ppm	Ammonia ppm	Nitrate ppm	pH	Temp ˚C	DO mg/L	Velocity m/s	Depth m	Width m
2007	0.1	1	0.3	7.25	10.5	9.5	0.34	0.09	0.45
2008	0.25	0.25	0.4	7.5	16.75	7.6	0.58	0.094	1.71
2009	0.4	1	<.2	7.5	9	10.2	0.21	0.05	1

Years	Hardness mg/L	Conductivity µs	Alkalinity ppm	Clarity cm	Coliform Bacteria cfu/100mL	Fecal Coliform
2007	250.5	575	240	112.5	510	
2008	297.5	545		120		
2009	320	630	430	120	1760	

Blacksburg High School Chemical Parameters Tested, 2007, 2008, 2009 (annual averaged - Progress St. at Rescue Squad

Years	Phosphate ppm	Ammonia ppm	Nitrate ppm	pH	Temp ˚C	DO mg/L	Velocity m/s	Depth m	Width m
2007	0.155	0	0.2	7.75	13	9	0.15	0.1	0.9
2008	0	0	0.5	8	15	9.4	0.28	0.102	1.74
2009	0.1	0	0.2	7.3	10	8.8	0.2	0.06	1.3

Years	Hardness mg/L	Conductivity µs	Alkalinity ppm	Clarity cm	Coliform Bacteria cfu/100mL
2007	290	575	180	120	510
2008	255	540		45	
2009	320	660	160	67	3560

Webb Branch at YMCA

Years	Phosphate ppm	Ammonia ppm	Nitrate ppm	pH	Temp ˚C	DO mg/L	Velocity m/s	Depth m	Width m
2007	0.075	0.05	0.2	7.25	12.5	0.175	0.15	0.09	0.61
2008	0.3	0	0.1	7	15.75	0.155	0.152	0.094	0.46
2009	0	1	0.3	7	11.2	0.12	0.14	0.05	0.4

Years	Hardness mg/L	Conductivity µs	Alkalinity ppm	Clarity cm	Coliform Bacteria cfu/100mL
2007	225	620	190	79.5	1250
2008	255.5	660		120	630
2009	320	710	230	120	3360

Prices Fork Rd. at Turner St., Virginia Tech Campus

Years	Phosphate ppm	Ammonia ppm	Nitrate ppm	pH	Temp ˚C	DO mg/L	Velocity m/s	Depth m	Width m
2007	0.375	0.05	0.1	7.25	13	9	0.15	0.1	0.9
2008	0	0		7.5	15	9.4	0.28	0.102	0.74
2009	0	3	3	7.3	10	8.8	0.2	0.06	1.3

Years	Hardness mg/L	Conductivity µs	Alkalinity ppm	Clarity cm	Coliform Bacteria cfu/100mL
2007	300	595	245	53.75	810
2008	350			45	580
2009	320	710	190	120	4000

2008 REU NSF Results Average for 6/2, 6/9, 6/19. 6/22, 2008 (Gronwald et al., 2008)

General Parameters Tested

Site	Temp ˚C	DO mg/L	pH	E. Coli Bacteria Concentrations cfu/100mL
1	14.66	9.39	7.23	
2	17.33	8.17	7.95	
3	16.34	8.57	7.93	3650
4	17.22	9.34	7.57	1290

Chemical Parameters Tested at Base Flow

Site	Nitrate mg/L	Ammonium mg/L	Phosphate mg/L	TSS mg/L
1	1.91	<0.008731	<0.04034	3.962
2	1.534	<0.008731	0.005	4.929
3	2.638	<0.008731	0.005	4.092
4	1.62	<0.008731	0.006	4.106

Chemical Parameters Tested at Intense Rain Event

Site	Nitrate mg/L	Ammonium mg/L	Phosphate mg/L	TSS mg/L
1	1.181	0.091	0.023	10.33
2	0.655	0.101	0.051	10.251
3	1.042	0.124	0.088	10.257
4	0.905	0.905	0.062	10.891

Heavy Metals at Base Flow

Site	Cd	Cu	P	Pb	Si	Zn
1	<0.018416	<0.126289	<0.013233	<0.02266	4.355	<0.02644
2	<0.018416	<0.126289	<0.013233	<0.02266	3.124	<0.02644
3	<0.018416	<0.126289	<0.013233	<0.02266	4.636	<0.02644
4	<0.018416	<0.126289	<0.013233	<0.02266	3.812	<0.02644

Heavy Metals at Intense Rain Event

Site	Cd	Cu	P	Pb	Si	Zn
1	<0.018416	<0.126289	<0.013233	<0.02266	1.562	<0.02644
2	<0.018416	<0.126289	<0.013233	<0.02266	0.0607	<0.02644
3	<0.018416	<0.126289	<0.013233	<0.02266	0.643	<0.02644
4	<0.018416	<0.126289	<0.013233	<0.02266	1.066	<0.02644

Save Our Streams Raw Data (1998- 2006)

Site	Date	Rating	Air Temp ˚C	Water Temp ˚C	pH	DO ppm	% DO saturated	Turbidity cm
Webb St	10/19/1998	F11		19.4				
Webb St	2/12/1999	P6		10				
Webb St	2/17/1999	P6		10				
Webb St	4/16/1999	F11		8.3				
Webb St	8/4/1999	U4		18.3				
Webb St	6/29/2000	F11		20				
Webb St	2/24/2001	F12		6.1				
Webb St	3/16/2002	R.Out						
Webb St	10/5/2002	U4						
Webb St	10/15/2002			12	7~8	4~8	37~74	0~40

Webb St	10/20/2002	F11						
Webb St	2/18/2003	P6						
Webb St	4/17/2003	F11						
Webb St	6/13/2003	P(<11)						
Webb St	3/27/2004		18	12.5	8.5	6		65
Webb St	6/30/2004	F11						
Webb St	2/25/2005	F12						
Central	10/4/2005		22	20	8.5	2		33
Central	10/4/2005		23	18	8.0	3.5		33
Central	10/4/2005		24	20	8.0	6.8		33
Fire Station	12/2/2005	U2						
Webb St	3/17/2006	R.Out						
Fire Station	3/17/2006	U5						
Fire Station	3/24/2006	U5						
Webb St	10/6/2006	U4						
Webb St	10/16/2006			12	7~8	4~8	37~74	0~40
Webb St	3/28/2008		18	12.5	8.5	6		65

Benthic Macroinvertebrates of Stroubles Creek, March 28, 2001 (Trumbo et al., 2001)

Species	Scientific Name	Resistence	Ecology
Riffle Beetle Adult	Colteoptera Elmidae	Very Sensitive	Prefers well aerated, flowing water
Caddisfly Larva	Tricoptera Hydropsychid	Very Sensitive	Needs moderate to fast flowing waters
Hellgramite (or Dobsonfly)	Megaloptera Corydalida nigronia	Very Sensitive	Needs Coarse rubble bottom streams, quite waters and a pH b/t

			4.4- 8.8
Bettle Larva	Colteoptera Elmidae	Very Sensitive	
Planarian	Planariidae	Very Sensitive	Needs well oxygenated water, prefers alkaline to acidic pH
Mayfly	Ephemerptera Oligoneuridae Heptageniida	Very Sensitive	Moderate to slow moving shallow streams, needs DO at 5ppm or more, pH range of 5.5 to 8.3 (alkaline)
Clams and Mussels	Unionda Corbiculidae	Somewhat Sensitive	Prefer alkaline water and water high in CaCO2, stable cobbles, gravel and sand necessary
Cranefly	Diptera Tipula	Somewhat Sensitive	Live in or beneath algal scum, percolating or flowing water, sandy, gravely or loamy stream beds
Crayfish	Decapoda Cambaridae	Somewhat Sensitive	Wide range of temps, pH and CO2 levels, shallow waters
Lunged Snail		Not Sensitive	
Leech		Not Sensitive	
Aquatic Worm	Ogligochoeta Lumbriculidae+ Tubificida Tubificidae	Not Sensitive	Cold water, low DO, found in mud and debris substrate
Midge Fly Larva	Diptera Chironmida	Not Sensitive	Prefers sluggish streams, low oxygen conditions (responsible for the red coloration from hemoglobin) pH of 4.5- 8.5
Black Fly Larva	Diptera Simuliidae	Not Sensitive	Prefers firm substrates in fast moving waters