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Effect of Development on Water Quality in the South Fork of the Forked Deer Watershed, Western Tennessee

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Abstract—This study investigates the relationship between development and growth in the South Fork of the Forked Deer Watershed and its effect on surface water quality in the South Fork of the Forked Deer River. This study was conducted in the hopes of establishing a sense of how current development might be impacting water quality in a traditionally rural west Tennessee setting. Overall, as development has taken place in the South Fork Watershed, no appreciable change in water quality was observed. Outcomes from this study are contradictory to what is commonly found in the literature. Efforts from the EPA and the State of Tennessee in regards to curtailing the impact on the environment usually associated with development might be sufficient enough to negate current impacts of sprawl in the study area.

Introduction

The links between urban development and resulting environmental impacts to surface and ground waters have long been shown (Hall et al., 1999; Ren et al., 2003; St-Hilaire et al., 2016). Previous studies have correlated urban growth and related land-use changes with a decrease in the quality of surface waters (Aichele, 2005; Tu et al., 2007; Tu, 2011). This study focuses on a single watershed in Tennessee, the South Fork of the Forked Deer River, and the effects of urbanization of the adjacent areas have on surface water quality, both temporally and spatially. Overall, the statistical approach used in this study did not reveal any appreciable influence of land-use changes on surface water quality, contradictory to expectations based upon previous studies.

According to the U.S. Census Bureau, the United States, the third most populous nation on Earth, currently has a population of over 323 million people and continues to grow at a rate of approximately 2.6 million people per year (U.S. Census Bureau, n.d.). Urban sprawl is the most common form of expansion used to support this continued population growth (Hamidi and Ewing, 2014). One of the fastest growing regions of the U.S. is the southeast (Johnson, 2012), where it is estimated that continued urban expansion could add an additional 125,000 km^2 of developed land (an increase of 42%) by 2060 (Hamidi and Ewing, 2014). Not only is southeastern expansion expected to continue, it is also suggested that urban growth will be particularly rapid in the state of Tennessee through the year 2030 (White et al., 2009). One of the environmental outcomes associated with sprawl and urban development due to physical changes made to the landscape is the negative impact on water quality, such as nutrient enrichment and increased concentration of dissolved solids.

For example, many previous studies have shown a direct correlation between increased development in watersheds and higher concentrations of indicators of degrading water quality, such as dissolved ions (Ca and Mg) or dissolved solids (Interlandi and Crockett, 2003; Aichele, 2005; Tu et al., 2007; Liu et al., 2009; Tran et al., 2010; Tu, 2011, 2013). In a study by Interlandi and Crockett (2003), the authors reported that the observed increase in dissolved solutes found in the Schuylkill River, southeastern Pennsylvania, correlated with the amount of urban sprawl that had occurred in that watershed. Tu et al. (2007) focused on Boston and the increasing amount of sprawl that had occurred in the surrounding suburbs. The authors reported that significant correlations between pronounced urban sprawl indicators in the eastern Massachusetts area and water quality indicators had been established. For example, sodium, magnesium, and calcium levels as well as specific conductivity (SC) all had significantly positive correlations with population density and the percent of developed land-use. In a series of papers by Tu (2011, 2013) the relationships between land-use changes and water quality indicators across northern Georgia, USA were investigated. In both studies, Tu reported that, in general, lower amounts of forested area and higher amounts of developed area lead to a more pronounced concentration of water quality indicators in surface waters. The main difference between the two articles is that the 2013 study focused on the use of Geographic Weighted Regression (GWR) as opposed to the use of Ordinary Least Squares Regression (OLS). Based on results from GWR, Tu described the importance of the modification of best management practices for different watersheds. The variation in best management practices was based on the premise that there are significant and varying relationships between water quality indicators and land-use variables because the level and source(s) that affect surface water may not be constant across an area.

To a large extent, the focus of previously-mentioned sprawl-related analyses have emphasized regions that encompass sizeable study areas, or numerous watersheds, or areas that house large populations. However, since sprawl is predicted to have a prominent impact on Tennessee in the foreseeable future

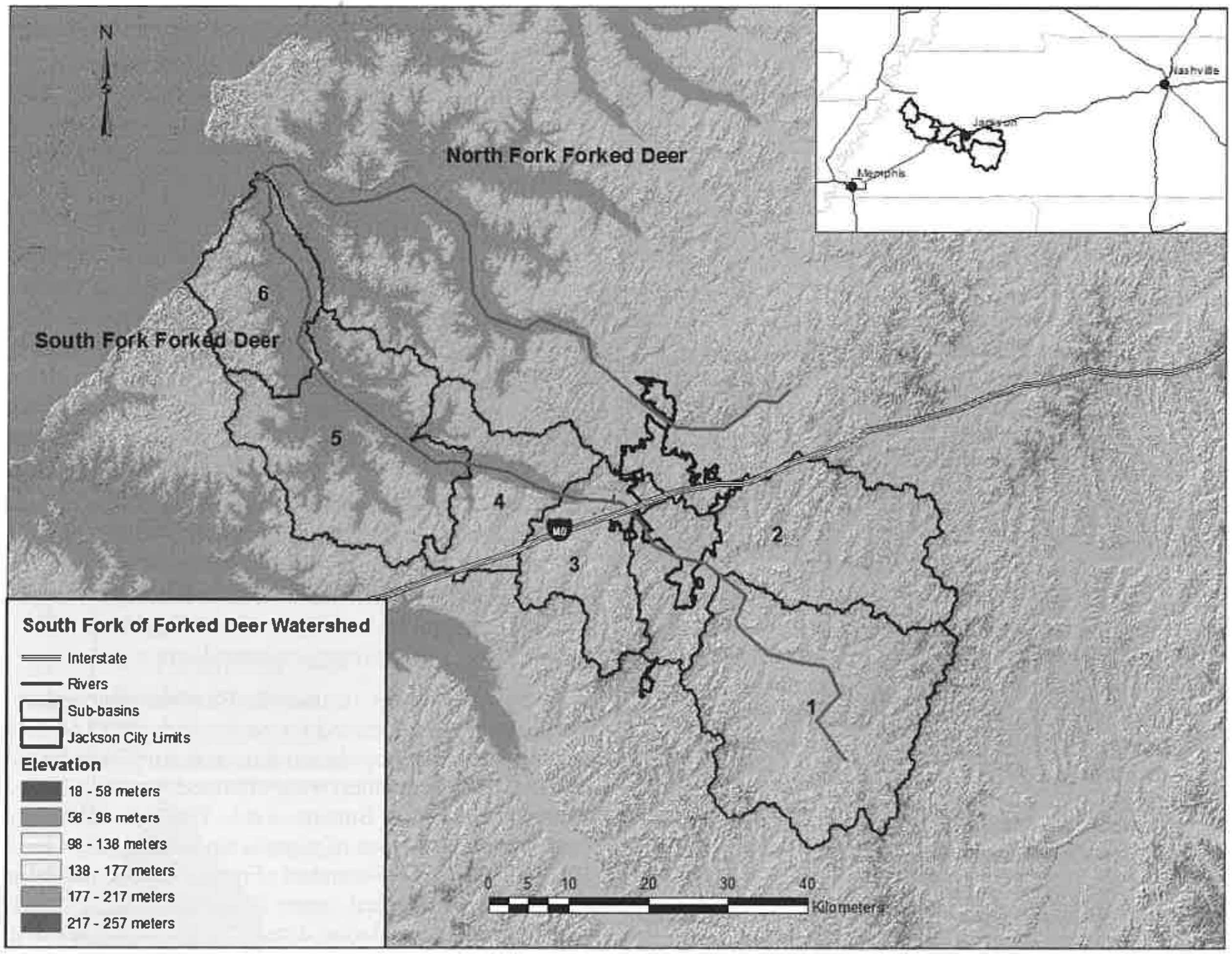

FIG. 1. Base map showing the location of the SFFD watershed and the defined sub-basins ((a) red outline) indicated by numbered areas within the SFFD watershed); and the location of Jackson urban area ((b) black outline). GIS data was derived from the National Map ("U.S. Geological Survey - National Hydrography Dataset," n.d.).

(White et al., 2009), and with the majority of future urban growth predicted to occur in areas with populations of less than 500,000 (Cohen, 2006), a study on current water quality trends in west Tennessee was warranted. The objectives of this study were to (1) establish that the chosen study area has similar characteristics in development and population growth as previous studies while focusing on a region with a smaller watershed, a smaller land area and a lower population. And to (2) identify any spatial or temporal changes to water quality associated with growth and development by making sub-basin comparisons of water quality indicators.

Study area

The South Fork of the Forked Deer (SFFD) River Watershed is located in west Tennessee and incorporates portions of eight different counties: Madison, Haywood, Chester, Crockett, Henderson, Lauderdale, McNairy, and Dyer. The SFFD Watershed encompasses more than 1,000 square miles and is divided into six sub-basins (Fig.1). The six sub-basins were defined based on major hydrologic boundaries (i.e. sub-basins 1 and 2 are defined by a divide between the North Fork and the South Fork of the Forked Deer River); areas drained by major tributaries; and/or convenient splits to divide the area into approximately equal areas. The methods used to define the sub-basins correspond to the National Hydrography Dataset sub-basin divisions ("U.S. Geological Survey - National Hydrography Dataset," n.d.). The largest portion of the SFFD Watershed (nearly 32%) can be found in Madison County. Jackson, TN, the largest and most populated city in the watershed (~67,000 inhabitants), is also located in Madison County (Tennessee Department of Environment and Conservation, 2002). As noted in Fig. 1, the southern half of Jackson, TN is included in sub-basin two, and because of this, nearly 42% of the estimated total population of the SFFD Watershed is located there.

What makes the SFFD Watershed ideal for a review on water quality is the possible influence of development on surface water and that the South Fork of the Forked Deer River (SFFD) is on the Tennessee Department of Environment and Conservation's (TDEC) 303(d) list as required by the Clean Water Act. The 303(d) list is an inventory of surface water bodies in Tennessee that exceed or may exceed surface water quality standards established by TDEC (Division of Water Pollution Control, 2004). Streams or lakes included on the 303(d) list are in violation of one or more water quality standards and are considered to be negatively impacted due to the input of pollutants or other water quality indicators.

TABLE 1. Statistical Summary of Land-use and Population Changes in Individual Sub-basins of SFFD Watershed for "2000" and "2010"

	"Sub-basins"					
Land-use & Population	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	Basin 6
Dev.$_{2000}$	58.23	64.10	27.58	28.45	55.67	28.39
Dev.$_{2010}$	59.18	65.27	28.19	29.03	56.02	28.92
Undev.$_{2000}$	469.95	401.95	161.23	149.00	240.40	114.46
Undev.$_{2010}$	497.73	402.04	161.40	149.18	240.99	114.66
Ag.$_{2000}$	282.04	238.78	108.22	132.96	324.67	177.18
Ag.$_{2010}$	280.62	235.68	107.49	132.26	323.65	176.39
Pop.$_{2000}$	17,580	47,694	7,275	4,759	11,052	6,980
Pop.$_{2010}$	23,242	46,747	16,116	5,682	12,630	7,939

All land-use indicators are figured in km^2

According to the 2002 303(d) list from TDEC's website (Tennessee Department of Environment and Conservation, n.d.), the SFFD has been continuously on the 303(d) list since 2002. In 2004, TDEC implemented a more precise classification of surface water impairment which then placed SFFD on the highest listed impairment, a Category 5. A review of listed pollutant sources in the SFFD from all available 303(d) lists (2002–2016) include:

- Non-irrigated Crop Production
- Channelization
- Undetermined Pathogen Source / Undetermined Fecal Source
- Discharges from MS4 area
- Dredge Mining
- Sand/Rock/Gravel Mining
- Land Development
- Municipal Point Source

Data and methods

Percentages of land-use and land cover change in the SFFD Watershed were calculated based on maps produced by The National Land Cover Database (NLCD) applicable to 2001 and 2011 (Homer et al., 2007, 2015). Production of the NLCD originated from the Multi-Resolution Land Characteristics (MRLC) consortium. The MRLC is an assembly of federal agencies who basically work together for the purpose of producing detailed public domain land-use information for the nation ("Multi-Resolution Land Characteristics Consortium (MRLC)," n.d.). The NLCD for 2001 and 2011 are both based on a system that defines land-use for the conterminous United States on a 16-class scheme provided at 30 meters of resolution. Land-use maps for the SFFD watershed were loaded into GIS software where the NLCD land-use classification types were then combined and aggregated into three different categories of land-use indicators: developed, undeveloped, and agriculture (Fig. 2). The aggregated categories were calculated by combining the NLCD classes as follows:

- *Developed* – Developed (open space); Developed (low intensity, medium intensity, and high intensity);
- *Undeveloped* – Barren land; deciduous forest; evergreen forest; mixed forest; shrub/scrub; grassland/herbaceous; and
- *Agricultural* – hay/pasture; cultivated crops.

The areal extent (square km) for the aggregated land-use categories were calculated for each sub-basin (Table 1).

Census block population data and corresponding shapefiles (TIGER/Line shapefiles) were obtained from the 2000 and 2010 census (US Census Bureau, n.d.). This information was then used in the production of population density maps for 2000 and 2010 in the SFFD Watershed (Fig. 3). Population estimates for the SFFD Watershed were determined by multiplying the census derived population density by the total area of each sub-basin and the percentage of the area of each census block located within the SFFD watershed, as determined using GIS software. By utilizing this method, the estimated population of each sub-basin and census block in the SFFD Watershed for 2000 and 2010 was determined (Table 1).

Water quality data for the SFFD Watershed was obtained from the Environmental Protection Agency's (EPA) STORET Central Warehouse (EPA, n.d.) and directly from the Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control, Jackson, TN, Environmental Field Office. Water quality indicators included in this study are alkalinity (Alk), dissolved oxygen (DO), hardness (Ca + Mg), pH, total suspended solids (TSS), turbidity, settleable solids (SS), nitrate + nitrite ($NO_2 + NO_3$), total phosphorous (TP), ammonia + organic nitrogen (KN), total organic carbon (TOC), ammonia (NH_3), and conductance. Since test results for specific conductance and conductivity were reported with nearly equal representation they were combined and renamed conductance.

The water quality indicators can be broadly split into three predominant, yet interrelated categories: soil and bedrock controlled (e.g., hardness, alkalinity, and pH); runoff related (e.g., TDS; conductance; TSS; SS; and turbidity); and biologically controlled (e.g., DO; nitrate/nitrite; TP, KN, TOC, and ammonia) (Drever, 1988). The soil and bedrock controlled parameters alkalinity (carbonate and bicarbonate), hardness (dissolved Mg and Ca cations), and pH are derived from soil and bedrock conditions (i.e., weathering reactions) in the surrounding watersheds (Drever, 1988; Crittenden et al.,

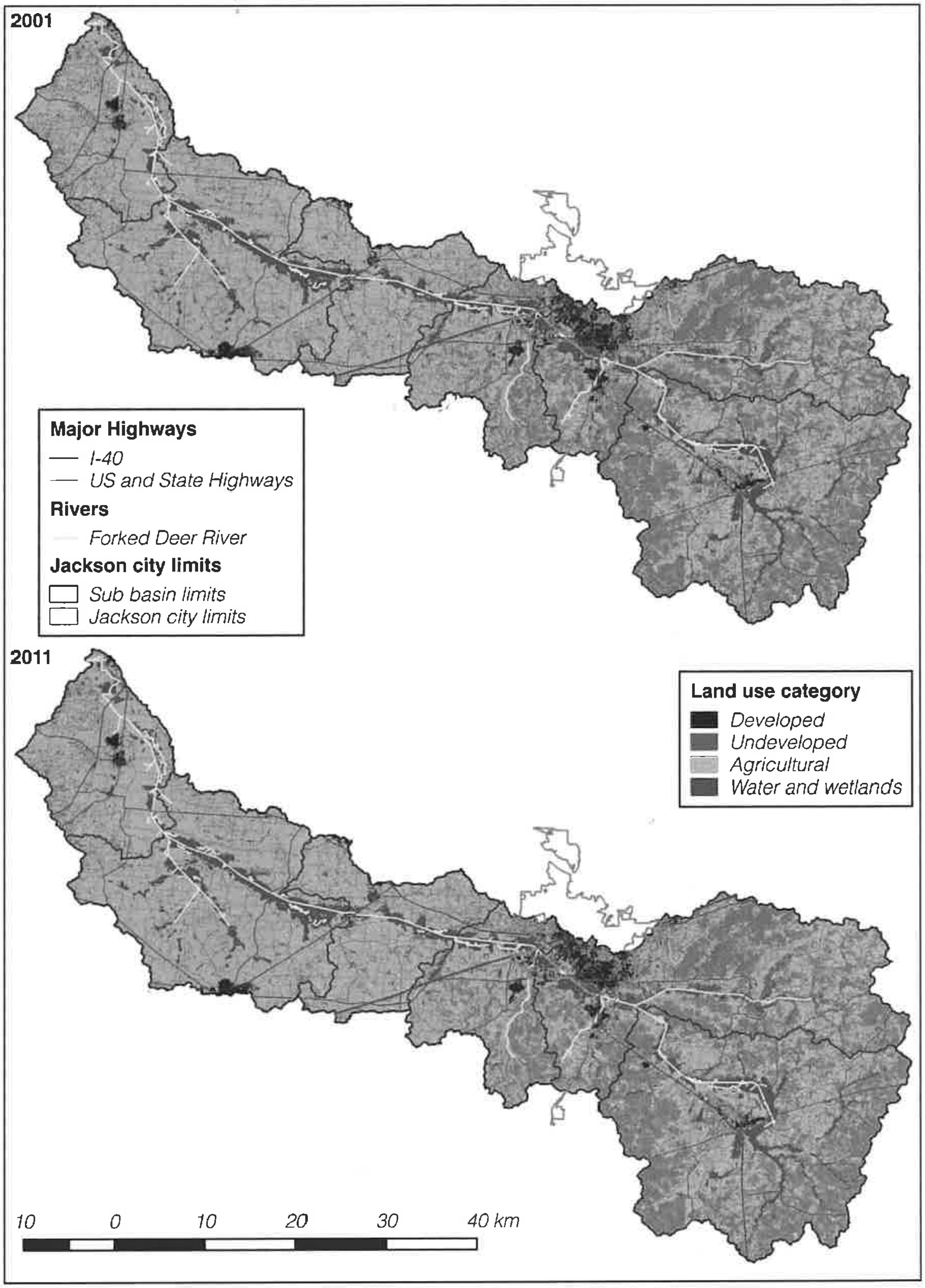

FIG. 2. Reclassified land-use maps for 2001(a) and 2011(b) ("Multi-Resolution Land Characteristics Consortium (MRLC)," n.d.).

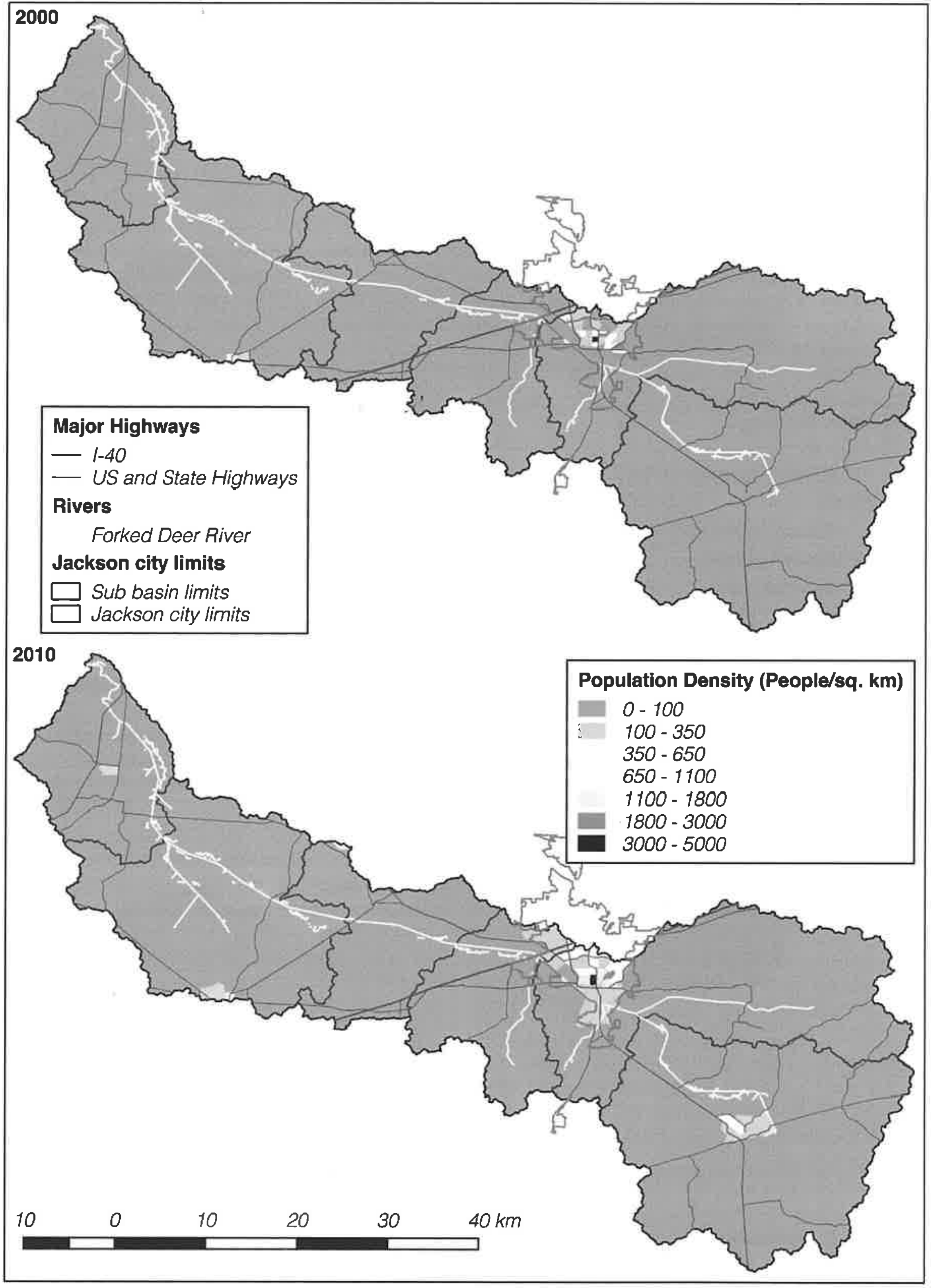

FIG. 3. Population density per census block for 2000 (a) and 2010 (b) in the SFFD watershed (U.S. Census Bureau, n.d.).

2012). Alkalinity provides an important buffer for acidity (i.e., stream water pH) and toxicity of metallic compounds (e.g., copper and aluminum), essential for healthy biological activity. Generally, concentrations of alkalinity exceeding ~20 mg/L is considered optimal for aquatic life. Additionally, hardness provides important nutrient material for the growth of exoskeletons of arthropod species. Large variations in pH can be related to changes in organic matter decomposition,

TABLE 2. Statistical summary of water quality indicators for "2000" and "2010"

WQI	Mean	Median	n 2000	Mean	Median	n 2010
Alk	18.7	18.50	82	17.22	17.00	82
DO	8.80	9.03	81	8.94	8.55	79
Ca+Mg	19.95	20.00	83	19.23	18.00	82
pH	6.88	6.91	80	6.99	7.02	80
TSS	55.26	23.50	82	41.35	31.00	83
Turbidity	42.54	19.40	71	35.88	25.00	83
SS	0.31	0.30	82	0.19	0.20	83
NO_2+NO_3	0.52	0.45	83	0.35	0.31	82
TP	0.15	0.09	82	0.13	0.11	78
KN	0.19	0.12	72	0.32	0.25	78
TOC	3.91	3.10	59	3.20	3.00	70
NH_3	0.06	0.02	82	0.07	0.04	78
Conductance	79.09	80.00	79	70.62	71.00	80

N = Total number across all sub-basins

photosynthesis, and man-made causes, such as acidic rain. Acidification of surface water can lead to the leaching of metals (e.g., Alk and Cu) and toxicity for aquatic life.

Runoff related water quality parameters, such as TSS, SS, turbidity, TDS, and conductance can be related to influx of runoff water from agricultural land, roadways, and addition of dissolved ions from waste treatment and/or acidic mine drainage (Mallin et al., 2009). Additionally, the causes of changes in conductance and TDS overlap with hardness and alkalinity. Changes in TSS and turbidity can impair water quality for aquatic life and potentially constrict stream channels leading to increased risk of flooding.

The biologically controlled parameters are generally related to improper wastewater disposal, input from agricultural runoff, and/or land-use changes in riparian zones (Dubrovsky et al., 2010; Crittenden et al., 2012). This group of parameters includes important nutrients (nitrate/nitrite; TP, KN, and ammonia); DO; and TOC (derived from natural sources of decaying organic matter and synthetic sources, such as pharmaceuticals). Nitrogen (nitrate, nitrite, and ammonia) can cause health problems, particularly to the elderly and TOC provides a quick, accurate assessment of pollution potential in wastewaters. Dissolved oxygen (DO) can be related to biological activity (e.g. respiration and decay of organic matter), changes in land-use (e.g., cleared land may provide an input of excessive organic matter), stream conditions (e.g., turbulence and channelization), and the loss of riparian zones (e.g., can lead to increase in water temperature and decrease in DO) (Wilcock et al., 1995). In addition to these issues, increased nutrient load into surface waterways can cause algal blooms and eventually lead to eutrophication (Bricker et al., 2008).

Datasets obtained from the EPA and TDEC were combined and reviewed. Many of the data collection dates contained results from only a small number of water quality indicators and were thus not applicable. In order to maintain data consistency, water quality indicators from 2000, 2001, and 2002 were grouped together and reported as water quality indicators representing "2000". This procedure was then repeated for water quality indicators from 2010, 2011, and 2012. These indicators were then grouped together and reported as water quality indicators representing "2010". According to data collection dates, water quality samples were often sporadic and incomplete between 2003 and 2009 and thus were not considered for statistical analysis. Following the previously mentioned data management procedures, sufficient water quality data was derived for all sub-basins with the exception of sub-basin three. No water quality data was gathered for the 3rd sub-basin; a statistical summary of water quality indicators can be found in Table 2. With land-use data, population data, and water quality data organized in order to generally represent "2000" and "2010", statistical analysis could thus proceed.

All water quality data were entered in IBM's Statistical Package for the Social Sciences (SPSS) version 22 and checked for normality. Since it was determined that the data were not normally distributed, nonparametric statistical procedures were employed (Helsel, 1987). For the purpose of this study, all differences with P values <0.05 are considered significant; all differences with P values <0.10 are considered weakly significant. Statistical comparisons of water quality data were made between individual sub-basins utilizing the Kruskal-Wallis H test for both "2000" and "2010" data. In instances where test results were significant, pair-wise comparisons were employed in order to determine in which sub-basins the significant relationships had occurred. Wilcoxon signed ranked tests were employed in order to determine any significant changes over time (2000–2010) in water quality within each individual sub-basin.

Results

As previously stated, the purpose of this study is two-fold. First, establish that growth and development in the SFFD Watershed has similar characteristics with studies that provide statistical evidence of a relationship between urban sprawl and negative impacts on water quality (Interlandi and Crockett, 2003; Tu et al., 2007; Tu, 2011, 2013). The establishment of this relationship will provide a platform for the second objective of this study that focuses on changes in water quality over space and time. Upon closer examination, similarities between the study area and aforementioned journal articles concerning population growth, urban development, and land-use change can be expressed.

For example, the study area in Interlandi and Crockett's 2003 article is the Schuylkill River watershed that includes Philadelphia's urban population of just over three million. The authors explain that even though population has increased by nearly 20% per decade over the last 30 years in the Schuykill watershed, the Philadelphia area lost several thousand inhabitants over the same time period. The majority of population growth occurred in the surrounding rural counties. This is the same pattern that has occurred in the SFFD watershed over a 10-year time frame, though on a smaller scale. Referring to Table 1, sub-basin 2 is the only sub-basin that lost population over the study period. The largest city in the study area, Jackson, TN, is located in this basin and has experienced population growth trending in the northern portion of the city. While people are moving out of the southern part of the city in sub-basin 2, populations in all other sub-basins have experienced positive growth with sub-basins 1 and 3 showing significant growth.

Tu and others (2007) describe a situation where a large urban center, Boston, MA, is experiencing substantial sprawl in

TABLE 3. Statistical Summary of Cumulative Land-use and Population Changes Across SFFD Watershed for "2000" and "2010"

	"Sub-basins"						
Land-use & Population	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	Basin 6	Net Change (+/-)
Dev.$_{2000}$	58.23	122.33	149.91	178.36	234.04	262.42	
Dev.$_{2010}$	59.18	124.45	152.64	181.67	237.69	266.61	4.19
Undev.$_{2000}$	496.95	898.90	1060.13	1209.13	1449.53	1563.99	
Undev.$_{2010}$	497.73	899.77	1061.18	1210.36	1451.35	1566.01	2.02
Ag.$_{2000}$	282.04	518.82	627.04	760.00	1084.67	1261.85	
Ag.$_{2010}$	280.62	516.29	623.79	756.05	1079.70	1256.08	-5.76
Pop.$_{2000}$	17,580	65,274	72,549	77,308	88,360	95,340	
Pop.$_{2010}$	23,242	69,988	86,104	91,787	104,416	112,355	17,015

All land-use indicators are figured in km^2

the outskirts of this heavily populated area. The study area described by Tu and others not only includes a large populated urban zone, it is also a region with a large amount of agriculture and forested lands. Tu's 2011 and 2013 journal articles also describe study areas of large population centers surrounded by vast amounts of forested and agricultural spaces. These studies focus on the northern Georgia area including the city of Atlanta. Tu explains that the northern Georgia study area's growth has predominantly occurred through the development of agricultural or forested areas. Again, the same pattern of growth is occurring in the SFFD watershed at a smaller level. Table 3 displays the area (square km) of agricultural lands has decreased while the amount of developed and undeveloped land has increased across the study area.

In addition, graphical representations of the relationships between water quality indicators and changes in land-use and population in the study area also provide evidence of the similarities between previously mentioned studies and the SFFD watershed. Figures 4, 5, and 6 display the relationship between increasing percentages of developed lands, agricultural lands, a decrease in undeveloped lands and water quality indicators for 2000 and 2010; the same information for increased population is also given in Figure 7. Graphs for population change, developed, undeveloped, and agricultural land express a clear relationship between these land-use changes and an increase in total hardness, alkalinity, and conductivity. Based on the range of data (i.e. little scatter in measurements for each sampling event) the authors chose the aforementioned runoff and

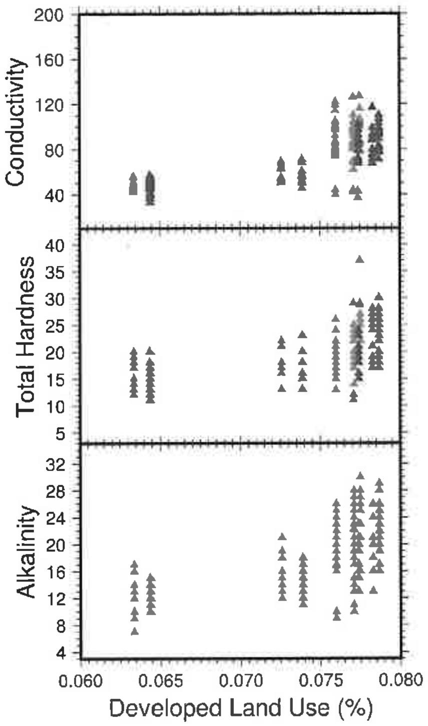

FIG. 4. Developed land-use versus water quality indicators. Red triangles indicate samples from 2000(a) and blue triangles indicate samples from 2010(b).

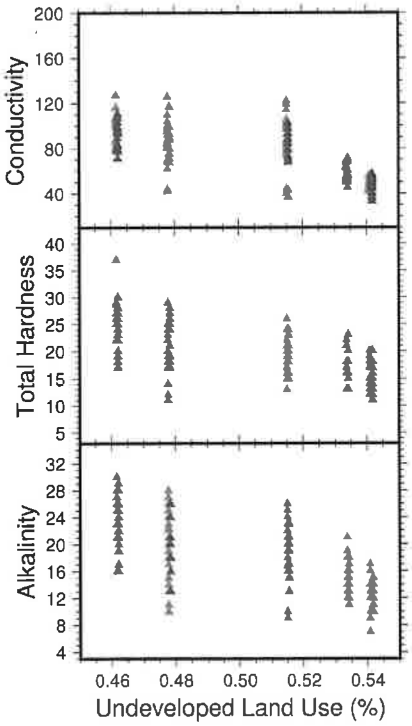

FIG. 5. Undeveloped land-use versus water quality indicators. Red triangles indicate samples from 2000(a) and blue triangles indicate samples from 2010(b).

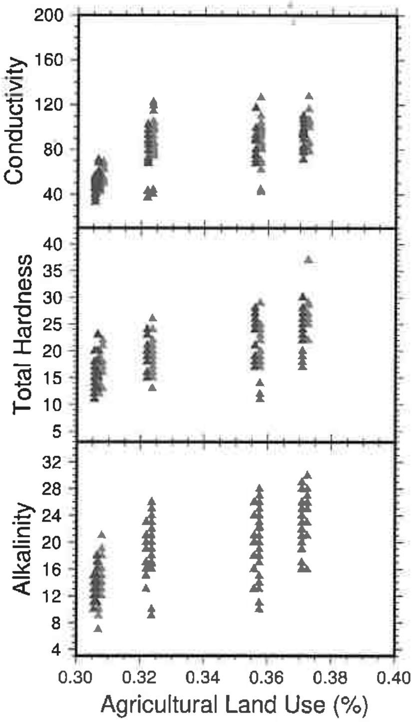

FIG. 6. Agriculture land-use versus water quality indicators. Red triangles indicate samples from 2000(a) and blue triangles indicate samples from 2010(b).

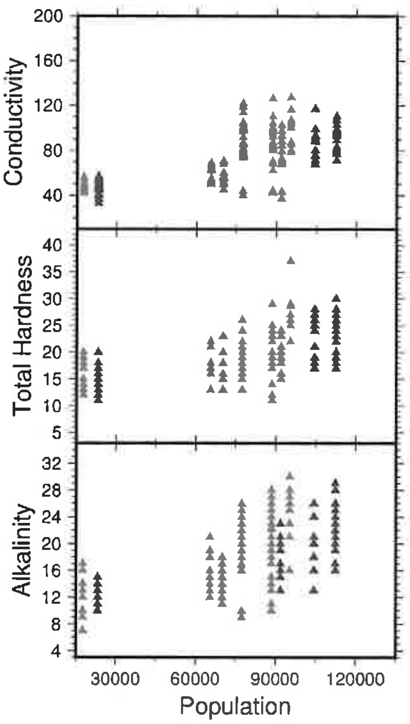

FIG. 7. Population versus water quality indicators. Red triangles indicate samples from 2000(a) and blue triangles indicate samples from 2010(b).

weathering related indicators to display time dependent trends. Using these three particular water quality indicators (WQI) follows the spirit of Tu's (2011) study where he specifically chose three WQI's according to availability of data.

Graphs for land-use indicators, population, and WQI's can be explained as follows: as the total population increases or the percent of developed land and agricultural land increases and the amount of undeveloped land decreases, the amount of each of these water quality indicators also increases. These findings are consistent from 2000 to 2010. While these outcomes may not carry the same statistically significant results when compared to findings of the aforementioned studies, they do add to the body of evidence explaining the similarities between sprawl and water quality. This presented information should now serve as a proxy for the relationship between sprawl and water quality; as sprawl increases this should have a negative impact on water quality in the SFFD watershed.

In order to test whether any significant changes in water quality had occurred across the SFFD watershed, a Kruskal-Wallis test (non-parametric ANOVA) was employed. The null hypothesis for the Kruskal-Wallis test was that the mean rank of water quality indicators is consistent across all sub-basins. A significant result indicates that the mean rank of a water quality indicator is significantly different between one or more sub-basins. If the *P* value of the statistic is less than .05 we will reject the null hypothesis of no difference. Statistical analyses produced from Kruskal-Wallis indicated that differences in six different water quality indicators for "2000" were significant (Table 4):

Alk, χ^2 $(4 = 34.76, p = 0.000)$,
Ca+Mg (hardness), χ^2 $(4 = 37.66, p = 0.000)$,
TSS, χ^2 $(4 = 16.97, p = 0.002)$,
NO_2+NO_3, χ^2 $(4 = 30.01, p = 0.000)$,
TP, χ^2 $(4 = 19.83, p = 0.001)$,
Conductance χ^2 $(4 = 38.97, p = 0.000)$.

Pair-wise comparisons were run to determine between which sub-basin(s) the significance had occurred (Table 5). In general, significance in water quality indicators occurred between upstream sub-basins (1 & 2) and downstream sub-basins (4, 5, & 6) with the exception of Ca+Mg (hardness) which showed significance between sub-basins 4–6 and 5–6. For 2010, Kruskal-Wallis tests indicated that differences in eight different water quality indicators were significant (Table 4):

Alk, χ^2 $(4 = 57.38, p = 0.000)$,
Ca+Mg (hardness), χ^2 $(4 = 52.05, p = 0.000)$,
TSS, χ^2 $(4 = 18.97, p = 0.001)$,
Turbidity, χ^2 $(4 = 12.87, p = 0.012)$,
NO_2+NO_3, χ^2 $(4 = 28.70, p = 0.000)$,
TP, χ^2 $(4 = 51.12, p = 0.000)$,
KN, χ^2 $(4 = 23.54, p = 0.000)$,
Conductance χ^2 $(4 = 54.35, p = 0.000)$.

In addition, two other water quality indicators exhibited weak significance ($p < 0.1$), SS (0.09) and TOC (0.06). Pair-wise comparisons for "2010" (Table 5) revealed that significance between water quality indicators all occurred between upstream sub-basins (1 & 2) and downstream sub-basins (4, 5, & 6).

The Wilcoxon Signed Rank test (non-parametric T-test) was also run in order to determine if any significant changes in water quality had occurred within each sub-basin between "2000" and "2010". The null hypothesis for this test is that the mean rank of water quality indicators is consistent within each individual sub-basin. A significant result indicates that the mean rank of a water quality indicator changed significantly over time (2000–2010). If the *P* value of the statistic is less than 0.05 we

TABLE 4. Kruskal-Wallis Water Quality Indicators SFFD Watershed Sub-basins

	Sub-basins							Sub-basins					
WQI 2000	1	2	4	5	6	α	WQI 2010	1	2	4	5	6	α
Alk	14.17	26.92	45.17	47.38	66.73	***.000***	Alk	15.96	30.04	45.09	56.17	64.76	***.000***
DO	41.50	47.04	42.90	38.76	34.45	0.732	DO	39.43	41.00	32.42	41.00	43.54	0.752
Ca+Mg	16.04	31.21	43.13	44.04	75.18	***.000***	Ca+Mg	17.06	33.04	41.42	58.67	63.45	***.000***
pH	51.20	46.29	31.98	39.22	45.73	0.151	pH	47.43	36.13	29.96	32.00	45.72	0.112
TSS	24.42	37.46	36.04	49.41	59.91	***0.002***	TSS	29.17	37.25	38.04	63.54	48.70	***0.001***
Turbidity	31.42	33.17	31.67	41.17	47.91	0.178	Turbidity	33.75	40.29	35.46	62.79	44.07	***0.012***
SS	26.32	40.42	40.67	47.56	46.45	0.137	SS	32.67	42.04	39.25	52.92	47.46	**0.09**
NO_2+NO_3	14.38	26.54	48.63	49.23	58.77	***.000***	NO_2+NO_3	24.40	28.92	48.00	56.58	54.93	***.000***
TP	24.04	22.71	48.46	48.46	51.32	***0.001***	TP	17.48	22.64	41.50	62.08	55.98	***.000***
KN	41.17	31.08	33.42	39.42	40.59	0.579	KN	26.00	30.59	34.95	60.79	47.54	***.000***
TOC	33.85	26.10	29.70	30.55	30.11	0.904	TOC	27.20	36.22	31.78	49.13	36.98	**0.058**
NH_3	37.63	34.00	36.57	50.92	43.68	0.119	NH_3	37.09	26.73	38.60	54.88	40.28	**0.053**
Conductance	10.82	20.41	49.25	44.20	60.18	***.000***	Conductance	14.95	27.42	46.96	54.91	61.50	***.000***

Bold and ***Italicized*** = p <.05 Significant, **Bold** = p <.1 Weakley Significant

will reject the null hypothesis of no difference. Significance levels from signed-rank tests of water quality indicators reveal that the majority of tested indicators within sub-basins did not significantly change over time. Specifically, results from Wilcoxon Singed-Rank test indicated that no significant changes in water quality had occurred in sub-basins 1, 2, and 4 with significant changes identified only for SS in both sub-basin 5 ($p = 0.039$) and sub-basin 6 ($p = 0.036$). Weak significance of SS ($p = 0.067$, $p = 0.095$) and KN ($p = 0.092$, $p = 0.074$) was also observed in sub-basins 2 and 4 while weak significance of NO_2+NO_3 ($p = 0.091$, $p = 0.050$) and KN ($p = 0.080$, $p = 0.052$) occurred in sub-basins 5 and 6. Outcomes from previous statistical procedures indicate that significant changes between sub-basins were not strongly influenced by any substantial changes of water quality within the sub-basins over time, but were probably caused by the cumulative effect of pollutants in the SFFD River flowing downstream.

Discussion

Through the use of graphical representation and listing similarities between the study area and aforementioned studies on the effect of sprawl and water quality a conclusion can be drawn on the possible influence of development on water quality in the SFFD watershed. By using the previously mentioned studies as proxy evidence, we can say that urban growth in the SFFD watershed should have a negative impact on water quality. The traditional means of assessing this relationship

TABLE 5. Pair-wise Comparisons from Kruskal-Wallis H Test for 2000 and 2010

WQI 2000	Significance between sub-basins							
Alk	1-4 (.003)	1-5 (.001)	1-6 (.000)			2-6 (.001)		
Ca+Mg	1-4 (.014)	1-5 (.010)	1-6 (.000)			2-6 (.000)	4-6 (.002)	5-6 (.004)
TSS		1-5 (.031)	1-6 (.003)					
NO_2+NO_3	1-4 (.001)	1-5 (.000)	1-6 (.000)			2-6 (.014)		
TP	1-4 (.037)	1-5 (.040)		2-4 (.022)	2-5 (.024)	2-6 (.040)		
Conductance	1-4 (.000)	1-5 (.001)	1-6 (.000)	2-4 (.006)	2-5 (.050)	2-6 (.000)		
WQI 2010								
Alk	1-4 (.008)	1-5 (.000)	1-6 (.000)			2-6 (.000)		
Ca+Mg	1-4 (.037)	1-5 (.000)	1-6 (.000)			2-6 (.004)		
TSS		1-5 (.001)						
Turbidity		1-5 (.006)						
NO_2+NO_3		1-5 (.001)	1-6 (.000)		2-5 (.044)	2-6 (.021)		
TP		1-5 (.000)	1-6 (.000)		2-5 (.000)	2-6 (.001)		
KN		1-5 (.000)	1-6 (.014)		2-5 (.014)			
Conductance	1-4 (.001)	1-5 (.000)	1-6 (.000)		2-5 (.046)	2-6 (.000)		

Adjusted Significant Values

would be through the application of a correlation analysis; however, this process was not possible due to a low number of samples (N=10). Because we had one measure of data representing population and land-use for "2000", one for "2010" in each sub-basin, and several measures of data representing water quality indicators in each sub-basin we had no way to make comparisons without decreasing the total number of observations. A procedure was tried where the means of each water quality indicator for "2000" and "2010" were computed for each sub-basin, and then differences between those means were determined. In addition, differences between land-use indicators and population for "2000" and "2010" within each sub-basin were also established. The differences, or changes, in each sub-basin from 2000 and 2010 were then used to run a correlation analysis; however, because of the low N we did not feel that the analysis provided statistically valid conclusions. Using a larger sample size would result in more accurate statistical outcomes (Hinkle et al., 2003) when performing a correlation. When a small sample size is used in the application of a correlation, the results may be too easily influenced. Basically, when using a small sample size for correlation it is easy to fail to reject the null hypothesis when use of a larger sample size would find that the null hypothesis is rejected (Rogerson, 2008), thus the use of proxy data and graphical representation to establish a correlation.

In order to determine changes in water quality over space and time throughout the SFFD watershed, Kruskal-Wallice and Wilcoxon Signed Rank tests were employed. Results of the Kruskal-Wallis test indicated that a few water quality indicators were significantly different between the sub-basins. In these instances the significance occurred between upstream sub-basins and downstream sub-basins. This may indicate that significance levels were generally due to increased concentrations of water quality indicators flowing downstream. Wilcoxson Signed Rank test was then performed to determine if any changes in water quality over time might have impacted results from the Kruskal-Wallis tests. Results of the Wilcoxson test indicated that only SS was significantly different from between 2000 and 2010 and this occurred only in sub-basins 5 and 6. These results indicate that as growth and development is occurring in the study area, no appreciable changes in water quality have occurred over the timeframe of available data.

The lack of water quality changes related to land-use changes in the study area are contradictory to previous studies and the expectations of the authors. The reasons for the lack of negative water quality response may be related to a variety of factors. For instance, only minor changes in riparian cover and channelization have occurred within the site, which have the potential to affect multiple parameters. Additionally, improved agricultural best practices (e.g. no till farming and controlled applications of fertilizers) may limit the runoff of soil and/or fertilizer derived nutrients within the watershed. Finally, stormwater and wastewater influx into the SFFD may be well controlled and sufficient for the increased development and population growth.

Conclusions

In the SFFD watershed, even though population, developed land, and undeveloped land have increased and the amount of agricultural land has decreased, water quality has not significantly changed. Upon examination of Table 2 it is clear that the mean values of many of the water quality indicators have gotten better even though development and growth increased during the time of study. A number of explanations might provide a reason for this seemingly contradictory find, based on examination of presented literature. The state of Tennessee and the city of Jackson have implemented many programs to curtail the impact on water quality due to growth and development. For example, general storm water permits, multi-sector storm water permits, and local agricultural best management practices have been in place since the 1980s. In addition, the ("Aquatic Resource Alteration Permit (ARAP) - TN.Gov," n.d.) and the ("NPDES Municipal Separate Storm Sewer System (MS4) Program - TN.Gov," n.d.) for small municipal separate storm systems were both in place long enough in order to have a positive impact on water quality in the study area.

These results are not exclusive. For example Aichele (2005) found that 14 watersheds in Oakland County, MI, displayed evidence of considerable urban development. As a result, measures of urbanization were found to be highly positively correlated with some water quality indicators such as dissolved solids, potassium, and specific conductance. Overall, Aichele explains that the majority of the negative impacts on water quality normally associated with urban growth were not apparent. He indicates that these outcomes might be due to improved storm water management practices and changes in patterns of urban expansion.

Future studies on water quality in the SFFD watershed might include a longer study period. Additional data that covered a longer time frame might grant greater clarity in interpreting these specific statistical outcomes (i.e. the current outcomes might change based on a longer trend with more data). This would alleviate the need for proxy data to serve as a substitute for correlation analyses. Being able to compare water quality samples from specific points with more land-use change and population change information would allow for more data points and hence provide the opportunity to perform other correlation analysis. Another possible endeavor into the study of water quality in the SFFD watershed might be to focus on just two or three sub-basins within the water shed. Or, initiate a comparison with a small nearby basin that has also undergone dramatic land-use changes during roughly the same time period as the SFFD.

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