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Article

Past, Present, and Future Nutrient Quality of a Small Southeastern River: A Pre-Dam Assessment

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Abstract: Riverine dams alter both the physical environment and water chemistry, thus affecting species assemblages within these environments. In the United States, dam construction is on the decline and there is a growing trend for dam removal. The Choctawhatchee, Pea, and Yellow Rivers Watershed Management Authority had initiated the permitting process for placing a reservoir dam on the Little Choctawhatchee River (LCR), a tributary to the Choctawhatchee River. The purpose of the proposed reservoir was water supply, and while the permit application has been suspended, history shows that this or related projects are likely to arise in the future. This study collected data on nutrient quality seasonally (four times) from 12 sites in the LCR watershed from October 2007 to June 2008 in order to determine pre-dam conditions and to compare these data to historical and regional information. Historical and current nutrient concentrations were elevated throughout the watershed, in most cases above suggested criteria, and indicated that water quality of the river was and continues to be nutrient rich. A future reservoir at recent levels of water quality will likely be highly eutrophic, and anthropogenic influences will further stress this ecosystem and its water quality as the urban region expands.

Keywords: Choctawhatchee; Little Choctawhatchee River; water quality; reservoir; dam; nutrients; wastewater; phosphorus; nitrogen

1. Introduction

The environmental effect of dams on riverine systems includes the degradation of habitat and river morphology [1,2] and the decline of water quality [3,4]. The number of dams being built across the United States began decreasing after the 1960s [5]. Of the 1995 dams reported in the National Inventory of Dams (NID) for Alabama, the number of dams being built has decreased in Alabama since the 1960s, with the majority of dams built being low-hazard earth dams [5] which are typically small scale farm ponds.

Riverine impoundments often impact water chemistry by increasing concentrations of nutrients [6], and decreasing levels of dissolved oxygen. Reservoirs not only increase certain chemical concentrations to harmful levels, but also reduce needed parameters to critical levels by acting as annual sinks for organic and inorganic compounds [7]. Even though a reservoir may act as a flow-through system, dams often act as large nutrient traps that slow nutrient advancement [3]. Concentrations and ratios of nutrients play a critical role in eutrophication and the development of algal blooms [8], which can be toxic to humans and animals and are often a nuisance. When nuisance algal blooms die, these can deplete the reservoir of oxygen leading to fish kills, noxious odors, and other problems associated with decaying organic matter. In addition, regional variations play a vital role in the processing of retained nutrients in reservoirs [9].

The Choctawhatchee, Pea, and Yellow Rivers Watershed Management Authority (CPYRWMA) had initiated the permitting processes for the placement of a reservoir dam on the Little Choctawhatchee River (LCR) for a drinking water supply, though the recent permit has been suspended. The need for baseline nutrient information is important when little historic data are available, so that the future nutrient status of the reservoir can be predicted. This study focused on the nutrient quality of the LCR and its tributaries. The objectives were to: (1) describe the nutrient conditions of the river over a one-year period; (2) compare nutrient data with historical and regional measurements and to nutrient criteria; and (3) discuss future water quality of a proposed reservoir, if built.

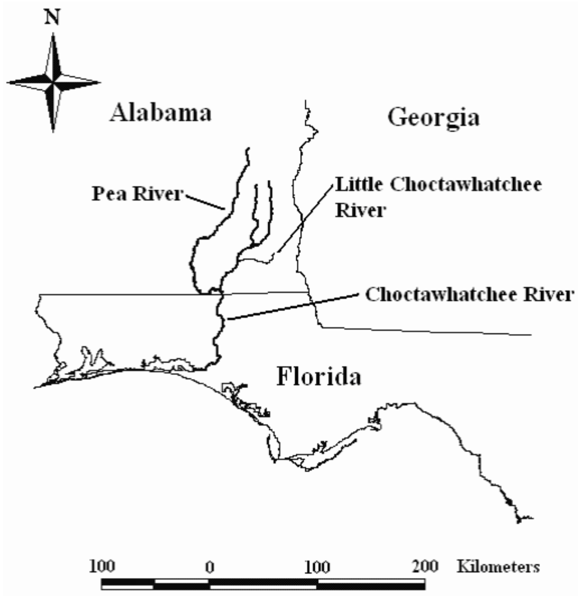
2. Materials and Methods

2.1. Study Area

The LCR is a tributary to the Choctawhatchee River located in southeastern Alabama, USA (Figure 1). The LCR system drains the northern and western sides of Dothan, AL and primarily borders the Dale and Houston County line. The watershed covers about 430 km^2 and is comprised of low-gradient streams with sand and marl bottoms. Urban development and agriculture are currently the dominate land uses within this area. Conversion of forested habitats for urbanization and agricultural purposes has caused numerous changes in stream habitats including destabilization of stream banks, increased sedimentation from eroding fields and developing areas, chemical changes from fertilizers and biocides, and alteration of light, thermal regimes, and hydrologic conditions [10].

The dam's intended location was upstream of an old power dam at Dale County Road 121, and is between Highway 123 and County Road 9 on the border of the Dale and Houston County line, near Panther and Bear Creeks [11]. The proposed reservoir of the LCR would have had a normal pool depth of 9.75 m and a normal pool area of 592 ha [11].

Figure 1. Little Choctawhatchee River near Dothan in southeast Alabama.



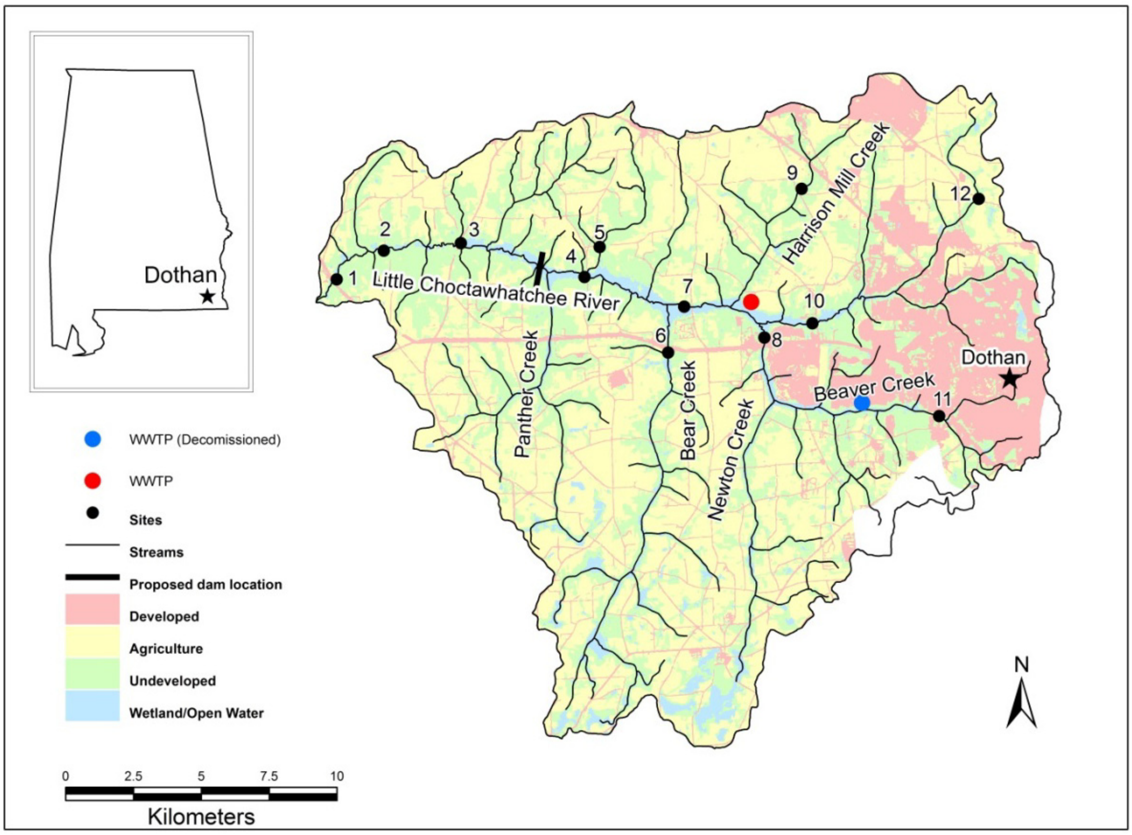
2.2. Nutrient Sample Collection and Analysis

Twelve sites were selected within the LCR watershed (six sites on the Little Choctawhatchee River and six sites on tributaries) (Figure 2). Using standard sampling protocols [12], nutrient variables were measured seasonally (four times) at each site to provide baseline nutrient data for the watershed. Nutrients measured included total phosphorus (TP), orthophosphate (OP), and nitrate (NO_2 + NO_3). All grab samples for laboratory analysis were collected at approximately 15 cm depth, in flowing water where available, in acid-washed (10% HCl) 125 mL Nalgene® narrow-mouth HDPE bottles, transported on ice to the laboratory, and analyzed within appropriate time frames [12]. Grab samples were taken in separate containers for TP (unfiltered), and OP and NO_3 (filtered, 0.45 µm). Duplicate water samples were collected for >10% of the samples for quality control. The Hach DR/2800 (Hach Company, Loveland, CO, USA) was used to measure all nutrient concentrations. All means (in our study and others referenced) were calculated from grab samples, therefore not implementing discharge to determine mean loading. Measurements under the detection limit were calculated as one half the detection limit in computing means. Total phosphorus (TP) was measured with Hach Method 8190 (Hach Company) using program 3036, with detection limits ranging from 0.02 to 1.14 mg/L P [13]. Orthophosphate (OP) concentrations were measured with Hach program 3025 PhosVer3 (Ascorbic Acid) Method 8048, with detection limits from 0.01 to 0.81 mg/L P [14]. Nitrate (NO_3) was measured using procedure 8192 [15], with detection limits ranging from 0.01 to 0.50 mg/L NO_3-N. This method converts nitrite (NO_2) to nitrate (NO_3), and actually measures NO_2 + NO_3 as N. All values found to be above detection limits were derived by diluting samples with deionized water prior to analysis [12].

2.3. Data Analysis

Box plots were used to visually compare nutrients over the entire year (four samplings) by site. Nutrient information gathered in the present study was compared to past nutrient data of the LCR found in the literature, regional data, U.S. Environmental Protection Agency (EPA) regional criteria [16], phosphorus levels considered to be eutrophic by Dodds *et al.* [17], and nitrogen levels indicative of excessive algae growth [18].

Figure 2. The Little Choctawhatchee River watershed demonstrating general land use and the twelve stream sampling sites near Dothan in southeast Alabama, USA.



3. Results

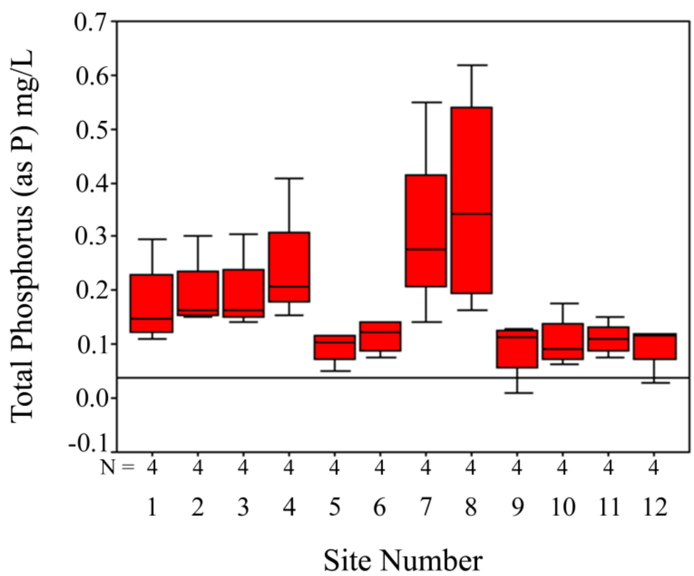
3.1. Recent and Seasonal Condition of the LCR Watershed

Total phosphorus (TP) varied from below detection limits (<0.02 mg/L P, used in mean as 0.01 mg/L P) in the summer of 2008 at site 9 to 0.62 mg/L P at site 8 during the first sampling which occurred in the fall of 2007. Of 48 samples taken at 12 sites over four seasons, only two were found to have concentrations below the U.S. EPA recommended criteria (0.0365 mg/L P) for this region, and six samples were found with a concentration below the eutrophic level as suggested by Dodds *et al.* [17] (0.075 mg/L P). Yearly TP means (using half the detection limit for numbers recorded below detection limits) by site ranged from 0.091 mg/L P at site 9 to 0.367 mg/L P at site 8, with an overall mean of 0.175 mg/L P for the entire study (mean of four sampling events over all sites) (Table 1). Total phosphorus concentrations over the entire year were much higher at sites 7 and 8 (sites below wastewater treatment plants), and lowest at sites 5, 6, 9, 10, 11, and 12 (Figure 3). The site most directly downstream of the proposed dam location (site 3) had a mean TP concentration of 0.194 mg/L P, over five times the U.S. EPA recommended criterion for rivers and streams and almost ten times the criterion for lakes and reservoirs (0.020 mg/L P) [16].

Table 1. Mean, median, variance, minimum, and maximum total phosphorus (TP), orthophosphate (OP), and nitrate (NO_3) concentrations in mg/L by season (*n* = 12) and for the year. TP recommended stream criteria: U.S. Environmental Protection Agency (EPA) [16], 0.0365 mg/L P; Dodds *et al.* [17], 0.075 mg/L P.

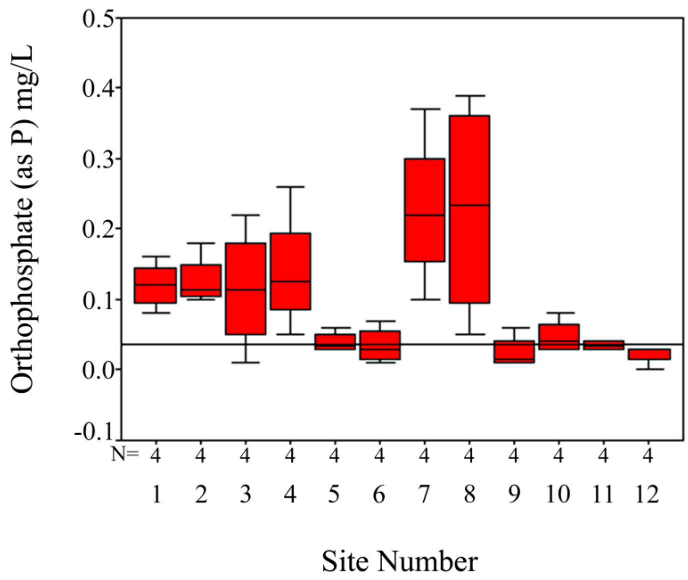
Nutrients by Season	Mean (mg/L)	Median (mg/L)	Variance (mg/L)	Minimum (mg/L)	Maximum (mg/L)
Fall (7 October 2007)					
TP	0.274	0.236	0.031	0.09	0.62
OP	0.146	0.103	0.019	0.01	0.39
NO_3	0.838	0.825	0.230	0.05	1.71
Winter (8 January 2008)					
TP	0.135	0.139	<0.001	0.10	0.16
OP	0.049	0.033	0.002	<0.01	0.12
NO_3	0.618	0.630	0.138	0.10	1.47
Spring (4 April 2008)					
TP	0.150	0.134	0.004	0.08	0.28
OP	0.100	0.096	0.004	<0.01	0.23
NO_3	0.552	0.510	0.126	0.20	1.50
Summer (29 June 2008)					
TP	0.141	0.093	0.016	<0.02	0.46
OP	0.093	0.059	0.009	0.01	0.33
NO_3	0.864	0.710	0.347	0.16	2.25
Mean/Year 2007–2008					
TP	0.1750	0.142	0.015	<0.02	0.62
OP	0.0969	0.059	0.009	<0.01	0.39
NO_3	0.7177	0.600	0.216	0.05	2.25

Figure 3. Box plot of total phosphorus (TP) concentrations (as P) in mg/L by site (4 samples/site) in the Little Choctawhatchee River watershed from October 2007 to June 2008. Reference line indicates U.S. EPA suggested criteria for TP as P (0.0365 mg/L as P).



Orthophosphate (OP) ranged from below detection limits (0.01 mg/L P, reported as 0.005 mg/L P) in the spring at site 12 and the lowest detectable limit in winter at site 3 (0.01 mg/L), to 0.39 mg/L at site 8 during fall 2007. Yearly OP means by site ranged from 0.025 mg/L at sites 9 and 12 to 0.231 mg/L at site 7 (site below a WWTP). The overall mean for all samples for the year was 0.097 mg/L (Table 1). As with TP, OP at sites 7 and 8 (both below WWTPs) was highest for the year, and lowest at 5, 6, 9, 10, 11, and 12 (Figure 4).

Figure 4. Box plot of orthophosphate (OP) concentrations in mg/L by site (4 samples/site) in the Little Choctawhatchee River watershed from October 2007 to June 2008. Reference line indicates U.S. EPA suggested criteria for TP as P (0.0365 mg/L as P).

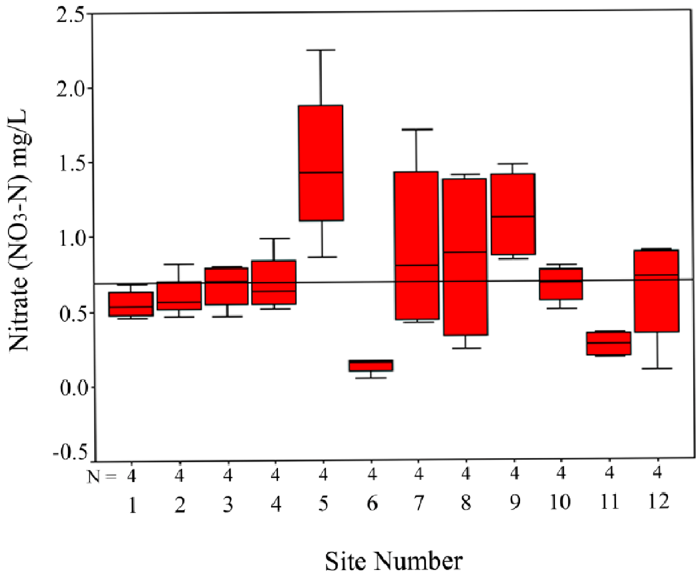


Nitrate (NO_3) was lowest during fall at site 6 with 0.05 mg/L N, and highest in summer at site 5, measuring 2.25 mg/L N (Figure 5). Yearly NO_3 means ranged from 0.128 mg/L N at site 6 to 1.490 mg/L N at site 5 (Table 1). The yearly overall mean from all sites for NO_3 for the watershed was 0.718 mg/L N (Table 1). The highest yearly means were at sites 5 and 9 while the lowest were found at sites 6 and 11. The site most directly downstream of the proposed dam location had a mean NO_3 concentration of 0.668 mg/L N, which almost exceeds the total nitrogen (TN) U.S. EPA recommended criterion for rivers and streams (0.69 mg/L N) and is almost twice the TN criterion for lakes and reservoirs (0.36 mg/L N) [16].

By season, TP mean was highest at 0.274 mg/L P during fall and lowest at 0.135 mg/L P during winter. Orthophosphate had the highest seasonal mean of 0.146 mg/L P in fall and lowest at 0.049 mg/L P in winter. The mean NO_3 by season was highest (0.864 mg/L N) in summer and lowest (0.552 mg/L N) in spring (Table 1).

Elevated TP, OP, and NO_3 were found throughout the year at sites 1, 2, 3, 4, 7, and 8 (primarily main channel sites downstream of WWTPs). Of all sites, the top five highest nutrient concentrations for all three nutrients almost always included sites 4, 7, and 8 for each sample and for means in this study. Site 8 always had high TP, and only during one sampling event did it not record the highest TP of all sites. Site 6 had the lowest NO_3 levels, except for winter sampling, where site 6 was second lowest behind site 12.

Figure 5. Box plot of nitrate (NO_3) concentrations in mg/L by site (4 samples/site) in the Little Choctawhatchee River watershed from October 2007 to June 2008. Reference line indicates U.S. EPA suggested criteria for TN as N (0.69 mg/L as P).



3.2. Comparison to Past LCR Nutrient Data

Data were retrieved from other studies on the LCR to compare these values to past and more recent conditions (Tables 2–5). These data were examined to determine whether water quality was changing throughout the watershed and at individual sites. Site 8 TP had been decreasing over time in regards to historical data, until this study indicated an increase in TP (Table 2). Total phosphorus at sites 5 and 12 appeared to be lower in this and the Geological Survey of Alabama (GSA) study [19] than in the past, while site 11 showed a substantial increase from 2007–2008 to 2009–2010 [10,19,20]. Data published by Mullen [21] from 1999 to 2003 were lower than recent findings for OP at sites 4 and 8, while most other data suggested that OP was similar to the recent findings for most sites where data were found (Table 3).

A comparison of NO_3 concentrations suggested that these concentrations have been quite high in the past (ranging from 0.17 to 4.09 mg/L) and remain so with site means in our study ranging from 0.13 to 1.49 mg/L (Table 4), and 0.3 to 2.2 mg/L in the GSA study [19]. Site 5 had elevated NO_3 concentrations for all samples in the our study, and these values were similar to results from Sawyer *et al.* [10] and Cook *et al.* [19] that found concentrations ≥ 2.0 mg/L N (Table 4). Further, nutrient data collected from multiple subwatersheds within the Choctawhatchee River basin suggested that our LCR TP concentrations were lower than most, OP concentrations were in the middle of the range, and NO_3 concentrations were somewhat similar, though all were elevated (Table 5; [10,20,22,23]).

Table 2. Minimum, maximum, and mean (if available) of total phosphorus (TP) concentrations from historical sources in chronological sampling order, with coinciding sites, along with our data.

Source	Sample Year	TP	Site 1	Site 4	Site 5	Site 6	Site 8	Site 10	Site 11	Site 12
ADEM [24]	1999	Min					0.19			
		Max					0.91			
		Mean					0.48			
Mullen (PE) [21]	1999–2003	Min	BDL	0.02		0.03	0.15	BDL		
		Max	0.22	0.18		0.12	0.24	0.13		
		Mean	0.13	0.14		0.08	0.19	0.06		
Mullen (CERS) [21]	1999–2003	Min	0.15	0.20		0.11	0.23	0.07		
		Max	0.54	0.58		0.21	0.31	0.18		
		Mean	0.29	0.32		0.17	0.26	0.13		
Sawyer *et al.* [10]	2001	Value			0.73					
Heath [20]	2004	Value							0.61	0.76
ADEM [24]	2004	Min					0.04			
		Max					0.29			
		Mean					0.18			
ADEM [24]	2005	Min					0.03			
		Max					0.26			
		Mean					0.16			
Chakravarty [23]	2006–2007	Min	0.12	0.20				0.09		
		Max	0.36	0.34				0.38		
		Mean	0.23	0.27				0.18		
Our Study	2007–2008	Min	0.11	0.15	0.05	0.08	0.16	0.06	0.08	0.03
		Max	0.30	0.41	0.12	0.14	0.62	0.18	0.15	0.12
		Mean	0.18	0.24	0.10	0.12	0.37	0.11	0.11	0.10
Cook *et al.* [19]	2009–2010	Min	BDL		BDL	BDL			BDL*	BDL*
		Max	0.13		0.06	0.05			0.74	0.04
		Mean	0.06		0.02	0.02			0.36	0.02

Notes: Value = One measurement; PE = Polyenvironmental Corporation duplicated analysis of [21]; BDL = Below detection limit; * = Exact site location varied by <5 km.

Table 3. Minimum, maximum, and mean (if available) of orthophosphate (OP) concentrations from historical sources in chronological sampling order, with coinciding sites, along with our data.

Source	Sample Year	OP	Site 1	Site 4	Site 5	Site 6	Site 8	Site 10	Site 11	Site 12
Mullen [21]	1999–2003	Min	BDL	BDL		BDL	0.08	BDL		
		Max	0.22	0.14		0.11	0.23	0.10		
		Mean	0.08	0.07		0.06	0.14	0.04		
Sawyer *et al.* [10]	2001	Value			0.11					
Heath [20]	2004	Value							0.11	0.09
Our Study	2007–2008	Min	0.08	0.05	0.03	0.01	0.05	0.03	0.03	BDL
		Max	0.16	0.26	0.06	0.07	0.39	0.08	0.04	0.03
		Mean	0.12	0.14	0.04	0.04	0.23	0.05	0.03	0.03

Note: Value = One measurement.

Table 4. Minimum, maximum, and mean (if available) of nitrate (NO_2 + NO_3) concentrations from historical sources in chronological sampling order, with coinciding sites, along with our data.

Source	Sample Year	NO_3	Site 1	Site 4	Site 5	Site 6	Site 8	Site 10	Site 11	Site 12
ADEM [24]	1999	Min					0.17			
		Max					2.56			
		Mean					1.33			
Mullen (PE) [21]	1999–2003	Min	0.82	0.72		0.90	1.12	0.98		
		Max	3.58	4.09		1.06	1.69	3.42		
		Mean	1.80	1.81		0.97	1.42	1.96		
Mullen (CERS) [21]	1999–2003	Min	0.40	0.80		0.30	1.00	0.80		
		Max	1.70	1.70		0.50	1.30	1.30		
		Mean	1.20	1.30		0.40	1.20	0.90		
Sawyer *et al.* [10]	2001	Value			2.00					
Heath [20]	2004	Value							0.30	1.10
ADEM [24]	2004	Min					0.50			
		Max					3.40			
		Mean					1.60			
ADEM [24]	2005	Min					0.29			
		Max					2.12			
		Mean					0.95			
Our Study	2007–2008	Min	0.46	0.52	0.86	0.05	0.24	0.51	0.18	0.10
		Max	0.68	0.99	2.25	0.16	1.41	0.80	0.35	0.90
		Mean	0.56	0.69	1.49	0.13	0.86	0.67	0.27	0.61
Cook *et al.* [19]	2009–2010	Min	BDL		0.7	0.3			0.1*	0.4*
		Max	5.7		2.3	1.9			3.6	1.5
		Mean	1.7		1.9	0.6			1.3	1.0

Notes: Value = One measurement; PE = Polyenvironmental Corporation; * = Exact site location varied by <5 km.

Table 5. Historical means of total phosphorus (TP), orthophosphate (OP), and nitrate (NO_3) in studies on the Choctawhatchee River watershed. Note: Our study in one watershed (LCR), others within multiple watersheds within the Choctawhatchee River drainage.

Source	Sample Year	TP	OP	NO_3	No. Sites
Mullen [22]	1999–2003	0.29	0.07	0.74	10
Sawyer *et al.* [10]	2001	0.77	0.13	0.66	49
Heath [20]	2004	0.60	0.29	0.54	44
Chakravarty [23]	2006–2007	0.24	N/A	N/A	48
Our Study	2007–2008	0.18	0.10	0.72	12 (4 seasons)

3.3. Comparison to Regional Data

Several historical regional studies were found that reported TP concentrations that could be compared to the data collected in this study (Table 5). Of other Alabama rivers studied, from 1999 to 2001 [25] and 2006 to 2007 [23], most had TP concentrations that were within 0.06 mg/L of our mean concentration, though one was half the LCR mean TP concentration and two were over four times the concentration found in our study (Table 6). A Georgia-Florida drainage study (1992 to 1996) found mean OP levels for primary agricultural streams to be 0.06 mg/L and 0.08 mg/L for urban sites [26], which was slightly lower than the mean OP concentration of 0.097 mg/L in our study.

Table 6. Mean total phosphorus (TP) concentrations of the Little Choctawhatchee River watershed (our study) *versus* those from 1999 to 2001 in selected rivers of Alabama, the Choctawhatchee River watershed from 2006 to 2007, and historical studies of rivers throughout the south and 381 U.S. riverine sites.

Rivers of Alabama	**Location**	**Mean TP Concentrations (mg/L)**
Little Choctawhatchee River drainage (our study)	(12 sites) throughout drainage	0.18
Alabama River McPherson *et al.* [25]	Claiborne, Alabama	0.09
Black Warrior River McPherson *et al.* [25]	Below Bankhead Lock and Dam near Bessemer, Alabama	0.80
Bogue Chitto Creek McPherson *et al.* [25]	Memphis, Alabama	1.07
Cahaba River McPherson *et al.* [25]	Centreville, Alabama	0.21
Chattooga River McPherson *et al.* [25]	Above Gaylesville, Alabama	0.14
Cahaba Valley Creek McPherson *et al.* [25]	Cross Creek Road at Pelham, Alabama	0.14
Pintlalla Creek McPherson *et al.* [25]	Liberty Church Road near Pintlalla, Alabama	0.15
Threemile Branch McPherson *et al.* [25]	North Boulevard at Montgomery, Alabama	0.22
Tombigee River McPherson *et al.* [25]	Below Coffeeville Lock and Dam near Coffeeville, Alabama	0.14
Choctawhatchee Watershed Chakravarty [23]	(48 sites) throughout drainage	0.24
Other U.S. Rivers		
Smith *et al.* [27]	381 U.S. riverine sites (1974 to 1981)	0.13
Spruill *et al.* [28]	Albemarle-Pamlico Basin of North Carolina and Virginia (1992 to 1995)	0.05
Kleiss *et al.* [29]	Mississippi River (1984 to 1993)	0.16
Kleiss *et al.* [29]	Yazoo River, Mississippi (1984 to 1993)	0.26
Atkins *et al.* [30]	Mobile River Basin, Alabama (1998 to 1999)	0.10

3.4. Comparison to Nutrient Criteria

Nutrient criteria were established by the U.S. EPA to control excess nutrients and associated problems. Total phosphorus levels exceeding the U.S. EPA ecoregional nutrient criterion (0.0365 mg/L as P) were found in historical data at most sites. Specifically, site 8 by the Alabama Department of Environmental Management (ADEM) [24], site 5 by Sawyer *et al.* [10], sites 1, 4, 6, 8, 9, and 10 by Mullen [21], sites 11 and 12 by Heath [20], and sites 1, 4, and 10 by Chakravarty [23] (Table 2). The mean TP concentrations of historical data ranged from almost two times to well over an order of magnitude higher than the recommended criterion. Sawyer *et al.* [10] also found elevated TP levels throughout the Choctawhatchee River watershed in 2001 (mean = 0.76 mg/L), along with Mullen [22] finding elevated levels throughout the Little Choctawhatchee (mean = 0.44 mg/L) and Choctawhatchee River (mean = 0.29 mg/L) watersheds.

All samples in our study exceeded the U.S. EPA nutrient criterion for TP except for site 9 and 12 in June 2008, in which site 9 was below the detection limit of 0.02 mg/L P. Forty four of the 48 samples collected during this study exceeded the TP nutrient criterion by two times or more, the highest TP concentration found exceeded the criterion by nearly 17 times, and the overall mean of TP exceeded the criterion by almost five times.

The mean yearly value for TP was more than two times the eutrophic level as reported by Dodds *et al.* [17]. The yearly OP mean for all samples for the year was 0.0969 mg/L, which was more than the TP level determined to be eutrophic by Dodds *et al.* [17]. The U.S. EPA ecoregional nutrient criterion for total nitrogen (TN) in streams and rivers is 0.69 mg/L N [16], meanwhile Maidment [18] reported that 0.5 mg/L NO_3-N was indicative of excess algal growth. Nitrate (nitrate + nitrite) concentrations alone in this study exceeded TN criteria limits in 20 samples, and exceeded 0.5 mg/L in 31 of the 48 samples. Eight of these NO_3 samples were almost, if not more than, twice the TN criterion. The highest measured NO_3 concentration was over three times the TN criterion, and over four times Maidment's [18] criteria. Two of the seasonal means of the 12 sites, along with the overall mean, exceeded the TN criterion as well (Table 1). In addition to NO_3 concentrations in our study exceeding U.S. EPA TN criterion levels, levels exceeding nutrient criterion were also found by ADEM [24] (site 8), Mullen [21] (sites 1, 4, 6, 8, and 10), and Cook *et al.* [19] (sites 1, 5, 6, 11, and 12) (Table 4).

4. Discussion

4.1. Recent and Seasonal Condition of the LCR Watershed

The LCR watershed has been stressed by the impacts of the surrounding urban and agricultural area. Habitat has been altered, nutrients are elevated, and mussel assemblages have been devastated [31]. Elevated levels of nutrients in an aquatic system can cause increased turbidity due to free-floating algae, the build-up of toxic cyanobacterial blooms, or unattractive dense filamentous algae that can cause odor problems and oxygen deficiency when decaying. Many of the sites (1–4, 7, and 8) measured in this study had elevated TP, OP, and NO_3 levels throughout the year. These sites have cultivated crop land percentages from 20% to 29.9% and urban developed percentages from 1% to 16% (excluding developed open areas) [32]. Developed areas do not have to make up a large percentage of a watershed to have a major impact (e.g., WWTP, industrial effluent, impervious surface runoff, *etc.*). Urbanization impacts have been shown, in this study and others (e.g., [33,34]), to yield higher concentrations of phosphorus (OP and TP), and as little as 5% urban land-use can lead to increases in OP year round [35].

Major contributors of phosphorus exist in watersheds, including WWTPs, urban storm-water, industrial discharge, livestock operations, precipitation runoff and soil erosion from croplands, runoff from lawns and gardens, and septic tank seepage near open water sources [36]. The increased concentrations of TP and OP near WWTPs were a good indication of where much of the nutrients were originating. The WWTP that released effluent into Beaver Creek (downstream of site 11) is now decommissioned, and effluent has been rerouted to the Little Choctawhatchee WWTP (upstream of site 7).

Fertilizers are one of the main sources of nitrogen compounds in water. Nitrate levels can persist in streams due to slow movement through the water table to streams [37]. These can be elevated further under drought conditions, as in this study [38], which leaves streams fed predominantly by ground water. If elevated levels of nitrogen fertilizer were applied in the past in this area, their effects could be seen for many years (up to decades) in the future [37]. Additional problem sources include release of by-products of industrial processes and sewage treatment, which occur in the LCR watershed [39]. With the possibility of impoundment of the LCR being suggested again in the future, as it has multiple times in the past, it must be noted that nutrient retention and accumulation of nitrogen may increase by many times (9 to 44) as a result of impoundment [40], and may also increase upstream from the reservoir as a result of reduced flow velocities.

In addition to high phosphorus, streams that drain agricultural catchments usually have higher nitrogen concentrations than urban and undeveloped areas [33], but similar or even higher levels have sometimes been found as a result of urbanization [41–43]. Elevated NO_3 concentrations at site 5 could be due to pastures bordering the stream and a high percentage of cultivated crops [32], though the more recent study by Cook *et al.* [19] indicated similar elevated levels throughout the LCR watershed, and corresponded with our study with the majority of NO_3 levels exceeding 0.5 mg/L in fall and summer.

4.2. Comparison to Historical Data

Historical data on nutrients were limited in the LCR watershed, but did provide some data for eight of the twelve sites. Total phosphorus concentrations measured in the past and in our study indicated that elevated nutrients levels were and remain a problem in the watershed, though more recent values reported by Cook *et al.* [19] were somewhat lower. Concentrations of all nutrients measured tended to be much higher below WWTPs than other sites in our study. Elevated nutrient levels are likely due to pressures being placed on the system from the surrounding agricultural, industrial, and urban input. As these contributions intensify with increasing population and urban expansion, these issues will grow.

4.3. Comparison to Regional Data

Other Alabama rivers studied from 1999 to 2001 [25] and 2006 to 2007 [23] had TP concentrations that were similar to our mean LCR watershed TP concentration, though two of the nine TP concentrations reported in McPherson *et al.* [25] greatly exceeded the mean LCR TP level (Table 6). Exceptions having much higher concentrations were Bogue Chitto Creek, in Dallas County, Alabama and the Black Warrior River near Bessemer, Alabama, which recorded means of 1.09 and 0.80 mg/L, respectively [25]. Nutrient levels reported by McPherson *et al.* [25], suggested that there were elevated TP levels throughout the state that were higher than ecoregional nutrient criteria and demonstrated a need for regulation of phosphorus throughout the state [23].

Berndt *et al.* [26] found that 30% of the Georgia-Florida sites reported had TP concentrations higher than 0.1 mg/L, which is the non-regulatory U.S. EPA TP goal, which poses a nuisance algal threat when exceeded. Of the 48 samples taken in our study, 40 samples (>80%), had TP concentrations exceeding the non-regulatory goal. Alabama, along with many other states, has not developed state-specific criteria and can only compare data with non-regulatory TP levels set as a desired U.S. EPA goal. Examination of other studies across the United States suggested that mean TP concentrations in the Choctawhatchee and the LCR watersheds ranged among the middle of other watersheds.

4.4. Comparison to Nutrient Criteria

The U.S. EPA ecoregional nutrient criterion for total phosphorus in streams and rivers is 0.0365 mg/L P [16]. Dodds *et al.* [17] proposed that 0.075 mg/L TP indicated a eutrophic condition for temperate streams. Of 48 samples taken in this study across the LCR watershed, only four had TP concentrations below the suggested eutrophic level that Dodds *et al.* [17] proposed, and only one of the samples taken in this study (2007–2008) was in the oligotrophic category (*i.e.*, <0.025 mg/L). With 22 of the 48 samples having at least two times the proposed eutrophic level of TP [17], and 12 sample concentrations over five times the U.S. EPA ecoregional nutrient criterion of TP, these levels suggest that if any reservoir were built it would be quite eutrophic. The U.S. EPA ecoregional nutrient criterion for total nitrogen (TN) in streams and rivers is 0.69 mg/L [16]. Nitrate (nitrate + nitrite) concentrations alone in our study exceeded TN criteria limits in 20 of the 48 samples and the overall mean.

4.5. Future Consideration of Potential Reservoir Impacts

Excess nutrient levels shown by past and more recent studies suggest that any reservoir established in the area with these reported phosphorus and nitrogen levels would be a eutrophic system. Cyanobacterial blooms, excess nutrients, and variable dissolved oxygen concentrations (with potential anoxia) and pH levels are all characteristics of eutrophic lakes [17]. Stream nutrients usually increase with land-use intensity [17,44,45], human population density [17,46], and impervious surfaces. Elevated nutrient levels usually support greater algal biomass, and have been observed in many urban streams (e.g., [47,48]). Dense algal concentrations have occurred yearly in at least one area of the watershed (site 11, Figure 6), and could also occur in any future reservoir within the system. A future reservoir on the LCR, if built, will likely be highly eutrophic, and anthropogenic influences will further stress this ecosystem and its water quality as the population in the region continues to grow.

Comparisons of watersheds to determine future eutrophic conditions can be very difficult due to spatial and temporal variables and the lack of consistent data [49,50]. Cook *et al.* [19] reported nutrient loading about 8 km downstream of the proposed dam location (current study site 1; 3776 t N/year, 82 t TP/year) and these should also be considered in the natural processes of the system prior to impoundment.

Figure 6. Photograph of Site 11 (Beaver Creek on Honeysuckle Rd.) during September 2008.

5. Conclusions

In conclusion, this study suggests that nutrients are excessive in the LCR watershed. Nutrient levels in areas not impacted by WWTPs remain in excess, with some TP levels four times greater than the U.S. EPA recommended criteria. Historical nutrient levels of the watershed were similar yet elevated, as was regional TP throughout the state of Alabama, whereas lower levels of nutrients were reported for neighboring states.

The need for additional sources of water may be extensive within the next 50 years in the "high growth scenario" in Coffee, Dale, Geneva, and Houston Counties and around the developing Dothan area [11]. Regardless, the future water quality of the proposed reservoir will need regulated nutrient levels to reduce deleterious effects. The Choctawhatchee River is one of the very few medium to large free-flowing rivers remaining in the southeastern U.S. The majority of all medium to large rivers in the United States are currently dammed, but nationwide more dams are currently being removed than built [51]. Since the times that dams were being rapidly built across the U.S. and knowledge of their impacts were lacking, it is now recognized that altering natural river systems degrades ecosystem services.

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Conflict of Interest

The authors declare no conflict of interest.

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