Agriculture in Jordan Lake Watershed

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Land Use and Agricultural Practices

The National Land Use Land Cover Dataset (NLCD) provides land cover information from Landsat satellite data (https://www.mrlc.gov/nlcd2011.php), which is then transformed into maps created by the Multi-Resolution Land Characteristics (MRLC) Consortium. There are 16-class land cover classifications nationally. Data used to classify land use in Jordan Lake watershed from 1992 – 2011 suggest an increasing urbanizing land use. In 1992, land use in Jordan Lake watershed was classified as 62% forest, 22% agriculture, 11% urban, and 5% other. Ten years later (2001) the watershed consisted of 49% forest, 23% agriculture, 19% urban, and 9% other. The latest land use analysis in 2011 showed that there was not much change from 2001-2011: 46% forest, 22% agriculture, 21% urban, and 11% other. This was primarily due to a slowing in growth caused by the Great Recession. Taken together, this 20 year period in the Jordan Lake watershed indicates that there is increasing urbanization and decreasing forestation, whereas agriculture has remained consistent at less than 25% of the total land area. These land use changes have significant implications for water quality.

The NLCD suggests that the vast majority of the agricultural land is in pasture and hay, but an on-the-ground agricultural survey of producers in Jordan Lake watershed suggested otherwise. Agricultural fields were randomly selected and 650 were useable for further characterization (Osmond and Neas, 2007). The total number of agricultural acres enumerated was 5218.2 acres. The average field size ranged from less than 1 acre to a maximum size of 70 acres; the mean was 8.0 acres per field and a standard deviation of 8.5 acres. No fields were enumerated in Durham County because all segments had become urban.

Although the majority of the agricultural land use is pasture or hay, there is cropland in Jordan Lake watershed. During the survey, sampled fields in four counties (Chatham, Forsyth, Randolph, and Wake) had 100% of the surveyed agricultural land use in pasture and hay, while cropland was found in five counties: Alamance (75% hay/pasture, 25% cropland); Caswell (70% hay/pasture, 30% cropland); Guilford (61% hay/pasture, 39% cropland); Orange (62% hay/pasture, 38% cropland), and; Rockingham (45% hay/pasture, 55% cropland). No agricultural land use was found in Durham County. The type of agriculture has profound implications for nutrient and sediment loss.

Sediment losses from agricultural lands were determined to be low (~1.5 T/ac) due to pasture and hay land uses and a predominance of conservation tillage used on croplands (Osmond and Neas, 2007). All counties were under the tolerable soil loss levels as defined by USDA-Natural Resources Conservation Service.

Nutrient (nitrogen (N), phosphorus (P) and potassium (K)) application rates were collected and analyzed (Osmond and Neas, 2007). We used a tool, Nitrogen Loss Estimation Worksheet (NLEW) to estimate relative N losses for cropland only, as it did not estimate N losses for pastures (Osmond et al., 2001). In almost half of the counties (Alamance, Forsyth, Guilford, and Rockingham) the amount of fertilizer N applied was less than the crop N needed based on NC state N rate recommendations. When N applied was greater than N needed (Caswell, Chatham, Orange, Randolph, and Wake), the amount of excess N was generally negligible. This analysis did not include pastures, many of which were either not fertilized or under fertilized. If pastures had been included in the analysis, the amount of N under fertilization would be even greater for all counties, indicating that there is significant N under fertilization from the agricultural sector of Jordan Lake watershed.

Phosphorus application rates should be based on soil test results, although when organic nutrient sources are applied, excess P is almost always added. There were 74 fields to which organic fertilizer was applied and 17 of these fields had soil test levels of very high. For fields testing very high for P, the primary organic application source was biosolids (57%), followed by dairy (44%) and finally poultry litter (5%) (Osmond and Neas, 2007).

Five of the nine counties in the survey had average soil test levels of High and one had Very High; thus on average, no additional P was needed for adequate crop growth. Four of the counties had average soil test levels of Medium, suggesting that P additions were still needed. Overall, 65 percent of all agricultural fields sampled tested Low and Medium for P indicating that P was needed. Phosphorus application rates on these fields averaged 24 lb ac^{-1} yr^{-1}, which is lower than needed (Osmond and Neas, 2007). Thirty-five percent of sampled fields tested High or Very High for P indicating that P was not needed; despite the soil test results, farmers applied on average 71 lb ac^{-1} yr^{-1}. This discrepancy on P application was due to farmers continuing to apply P to tobacco and organic applications of biosolids and animal waste.

Since pasture represented almost 50% of all agricultural land use in Jordan Lake watershed (Osmond and Neas, 2007), animal type and stocking rate were important. Cattle were the predominant species grazing on pasture. Four of the counties had appropriate stocking rates, (~ one cow per 2-acres per year or 0.5 cattle), whereas Alamance, Chatham, Forsyth, Guilford, Randolph, and especially Orange had cattle stocking rates above this threshold.

Multiple studies in North Carolina have demonstrated that riparian buffers can reduce agricultural nutrient and sediment losses (see North Carolina Riparian Buffer References at the end of this report). Significant riparian buffers existed next to streams in the agricultural landscape of Jordan Lake watershed (Osmond and Neas, 2007; Table 1). Some counties, such as Wake and Forsyth, had most of their agricultural fields buffered; only 8 % of the acreage is not buffered. One county, Caswell, had more than 50% of its agricultural fields not buffered. These results suggested that some counties have greater potential for buffer installation than others.

Table 1. Number of Acres and Percentage of this Area with no Buffers by County

County	Total Ag Acres	No Buffers – Acres Affected	% Ag Fields Not Buffered
Alamance	1206.3	313.6	26
Caswell	165.6	99.2	60
Chatham	544.0	200.2	37
Forsyth	60.5	4.9	8
Guilford	1983.0	699.8	35
Orange	595.9	84.7	14
Randolph	93.0	41.7	45
Rockingham	524.4	184.4	35
Wake	45.5	3.5	8
Total	5218.2	1632.0	31

Taken as a whole, the Osmond and Neas (2007) agricultural survey suggested that producers in the Jordan Lake watershed were minimizing environmental impact of nutrient and soil losses from agricultural fields due to: 1) the types of cropping systems used, 2) under fertilization of most crops as nutrient inputs were generally below recommended levels, and 3) use of best management practices, primarily buffers and conservation tillage. Overall, the data suggested that nutrient and sediment losses from agricultural activities would be minimal.

Finally, relationships between land use and annual stream water concentrations and loads of total nitrogen (TN) and phosphorous (TP) were explored to characterize the vulnerability of water bodies to nutrient pollution as a function of land use under different climatic conditions (Tasdighi et al., 2017). Jordan Lake watershed has a very robust water quality data set, both temporally and spatially, that made this characterization possible and more conclusive. Multiple linear regression (MLR) models were used across 23 subbasins within Jordan Lake watershed in North Carolina between 1992 and 2012 to explore land use-water quality relationships.

Strong and significant relationships were determined between land use and water quality in Jordan Lake Watershed, Haw subbasin (Tasdighi et al., 2017). Urban land and wastewater treatment plants were dominant factors in the multiple linear regression models developed between components of land use and water quality. Percentage of urban land use and wastewater treatment plant capacities showed significant ($p < 0.01$) positive correlations with annual concentrations and loads in all models. Wastewater treatment plant capacity was a significant factor in all models. McSwain et al. (2014) measured very low losses of nutrients in suburban watersheds where there was no presence of wastewater treatment plant discharge thus bolstering Tasdighi’s work that suggests the major contributor of TN in Jordan Lake urban watersheds is wastewater treatment plants. Agriculture was negatively correlated with TN in almost all years. Agricultural subbasins include some agricultural lands but also many forested areas; therefore as agricultural subbasin size increased, TN and usually TP loads declined due to dilution from the forested areas, although the correlation between % agriculture and TP was positive in some years. Likewise as urban subbasins size increased, the effect and intensity of wastewater treatment plants also increased.

Analysis of covariance was used to explore the impact of inter-annual precipitation variations on land use-water quality relationships. Significant difference ($p < 0.01$) was determined between models developed for urban land use with TN or TP loads based on annual precipitation (Tasdighi et al., 2017). Climate variability showed an important influence on land use-water quality relationships. Comparing the performance of the models developed based on loads and concentrations, loads better captured the effects of precipitation variations on the land use-water quality relationships versus concentrations. In general, the effects of the urban land on water quality were higher during dry years. This finding conforms to intuition since pollutant loadings from diffuse sources are typically insignificant due to low surface runoff during dry years.

As part of the above analysis, the Soil and Water Assessment Tool (SWAT) was used to model sources of nutrients (data not shown). In the Haw subwatershed of the Jordan Lake, it was estimated that wastewater treatment plants were the major source of TN (64%), followed by agriculture (22%), urban (11%), and forest (3%). Missing in the TN estimates, however, is contributions from the airshed, which some scientist have estimated as upwards of 30% of the TN load. Estimates for TP sources were as follows: agriculture (51%), urban (25%), wastewater treatment plants (12%), and forest (12%). It should be noted that much of the water from the Haw by-passes Jordan Lake proper so it is not clear if these analyses are appropriate for Jordan Lake proper.

Nutrient Loading Studies

The objective of a recent water quality monitoring project was to document the effectiveness of a combination of livestock exclusion fencing and nutrient management implemented on a beef cattle pasture and nutrient management on crop land. Monitoring sites were located in the Jordan Lake watershed. The quantity and quality of discharge from two predominantly pasture and two predominantly cropland watersheds were monitored for ~3.5 years prior to and following implementation of the exclusion fencing and nutrient management in the pasture treatment watershed and nutrient management in the cropland treatment watershed, while the other watersheds (control) remained unchanged and then monitoring post-treatment for ~3.5 years. Water quality monitoring included collection of flow-proportional samples during storm events and analyzing them for total Kjeldahl (TKN), ammonia (NH_3-N), and inorganic (NO_x-N) nitrogen as well as total phosphorus (TP) and total suspended solids (TSS). In addition, land use information was collected.

In the pasture treatment watershed, the excluded stream corridor was intentionally minimized by constructing the fenceline about 10 feet from the top of the streambank on either side and limiting it to the main stream channel only. Nutrient management consisted of discontinuing biosolids and fertilizer P applications, while applying approximately 70 lb N ac^{-1}, which is less than recommended N.

Losses of nutrients from pasture watersheds were much greater than expected (Table 2; Line et al. 2017), although TSS losses were much lower than expected. Average nutrient losses were: TN loss of 6.1 lb ac^{-1} yr^{-1}, TP of 2.8 lb ac^{-1} yr^{-1}, and TSS of 312 lb ac^{-1} yr^{-1}. Post-conservation practice implementation generally had greater nutrient losses due to increased rainfall and greater runoff during the monitoring period. Prior pasture studies from North Carolina (Table 2) demonstrated that the loads measured were similar across North Carolina piedmont watersheds.

Table 2. Pasture watersheds in Jordan Lake watershed and measured metrics: duration of sampling, rainfall, water discharge, runoff % and total loads of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS).

Site	Dur.	Rain[1]	Discharge	Runoff	TN	TP	TSS
	yr	in/yr	in/yr	%	------lb ac/yr------		
Pre-Conservation Practice Implementation Period							
Past-cont	3.77	35.71	4.65	0.15	4.15	1.96	244
Past-treat	3.77	35.71	6.69	0.22	6.33	3.28	433
Post-Conservation Practice Implementation Period							
Past-cont	3.76	37.60	7.72	0.20	6.55	2.88	302
Past-treat	3.76	37.60	8.70	0.23	7.42	2.86	272
Related Studies							
Pasture[3]	3.30	28.50	7.40	0.26	5.98	3.84	128
Pasture[4]	1.70	46.30	7.83	0.17	4.54	1.26	377

It is significant that many pastures are underfertilized (Osmond and Neas, 2007) in this watershed, including the pastures monitored in this work. It is clear that nutrients from cattle excrement (or any animal excrement) deposited on the surface has the potential to be lost from agricultural lands. The use of conservation practices in this watershed demonstrated statistically significant reductions in TN (37%), TKN (34%), NH_3-N (54%), TP (47%), and TSS (60%) loads in the treatment relative to the control watershed following conservation practice implementation, while storm discharge and NO_x-N loads were not significantly different (Line et al., 2017). These data show that even a relatively narrow exclusion corridor implemented on only the main stream channel can significantly reduce the export of TN, TP, and TSS from beef cattle pastures.

The cropland was a 3-crop, 2-yr rotation (corn, wheat, and soybeans). Nutrient management was implemented in October 2012 when wheat was planted. However, because the pre-treatment water quality monitoring began with soybean planting in 2009, the post-treatment period was begun with soybeans in 2013. Soil samples collected in the fall of 2013 and 2015 were analyzed by the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) and indicated that the treatment watershed had very high levels (> 100 index) of P and K; no additional P or K was needed for any of the three crops produced. No N fertilizer was applied to the soybeans, while N fertililzer rates were appropriate for wheat. Only corn was overfertilized by about 30 lb N ac^{-1}. The farmer was willing to reduce his N rate in 2014 to 120 lb ac^{-1} but not in 2016, when he overapplied N by approximately 80 lb N ac^{-1}. On average, the same amount of yearly N was applied (150 lb ac^{-1}) during the pre-conservation practice implementation period (2008-2012) and the post-conservation practice implementation period (2012-2016). Meanwhile, on his own, the farmer reduced the amount of P fertilizer by half. The P application rate was 15 lb P_2O_5 ac^{-1} $crop^{-1}$ in the post-BMP period (2012-2016) and 30 lb P_2O_5 ac^{-1} $crop^{-1}$ in the pre-BMP period (2008-2012).

Losses of nutrients from cropland watersheds were much lower than expected (Table 3), as were TSS losses. Average nutrient losses were: total: TN loss of 5.2 lb ac^{-1} yr^{-1}, TP of 0.4 lb ac^{-1} yr^{-1}, and TSS of 82 lb ac^{-1} yr^{-1}. Post-conservation practice implementation generally had greater nutrient losses due to increased rainfall and greater runoff during the monitoring period.

Table 3. Cropland watersheds in Jordan Lake watershed and measured metrics: duration of sampling, rainfall, water discharge, runoff % and total loads of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS).

Site	Dur.	Rain[1]	Discharge	Runoff	TN	TP	TSS
	yr	in/yr	in/yr	%	-----lb ac/yr-----		
Pre-Conservation Practice Implementation Period							
Crop-continuous	3.44	32.52	3.70	0.11	3.19	0.29	258
Crop-treatment	3.44	32.52	2.64	0.08	5.49	0.19	8
Post-Conservation Practice Implementation Period							
Crop-continuous	2.77	36.81	5.71	0.16	6.62	0.90	470
Crop-treatment	2.77	36.81	3.74	0.10	5.56	0.35	16

Nutrient losses in cropland watersheds ranged from 3.2 to 6.6 lb TN ac^{-1} yr^{-1}, 0.2 to 0.9 lb TP ac^{-1} yr^{-1}, and 8 to 470 lb TSS ac^{-1} yr^{-1}. Cropland TN and TSS losses were slightly lower than pastures, while TP losses were as much as 10 fold lower. Nutrients and sediment increased during the post-conservation practice implementation period by as much as 3 fold due to greater rainfall, which indicates that rainfall is a major driver to nutrient and sediment losses.

The only parameter that showed a reduction due to nutrient management was TP, but it was not significant but rather suggestive. As mentioned above, P rates were reduced but not N rates even though we focused on reducing N application rates. Obtaining fertilizer rates were essential to understanding these results. Thus, linking land use behavior is critical to explaining water quality results: TP loads declined but TN did not (Osmond et al., 2012).

Nutrient losses from pastures were tied less to applied nutrients than the livestock themselves (Line et al., 2017) and loads can be reduced by around 50% by managing livestock access to streams and minimizing applied nutrients. Nutrient losses from cropland can be reduced through judicious application of nutrients. Finally, the low intensity of agriculture in association with forested areas and the low total amount of agriculture reduces overall nutrient losses that will be possible from agricultural lands (Tasdighi et al., 2017).

Economics and Farmer Attitudes

A water quality trading (WQT) program is one of the main policies suggested to address water quality issues, especially in the face of a rapidly growing urban sector that requires options to reduce its delivery of nutrients. Jordan Lake watershed is no exception and explicit rules were approved enabling new development to buy nutrient reduction credits from the agricultural section (North Carolina Department of Environmental Quality, 2017). Although a WQT program is appealing in theory, it has thus far failed to prove feasible in several attempts in the United States and Jordan Lake Watershed.

An economic analysis of WQT was performed using net returns of 20 years, and amortized at a 4.6% discount rate (Motalebbi et al., 2016a). The Soil and Water Assessment Tool (SWAT 2012) model (Arnold et al. 1998) was used in the Jordan Lake watershed in order to predict the amount of TN and TP loads in three scenarios, control-years (1997-2001), current BMP practices (2012), and TN and TP loads after installing buffers in addition to the already installed BMPs.

Recent work by Motalebbi et al. (2016a) in the Jordan Lake watershed found that WQT programs may not always be the most applicable approach when all factors (e.g. wedges) that diminish the chance of WQT program's success were analyzed. Implementing WQT programs requires knowledge that comes from a well-defined model that includes as many implementation wedges as appropriate. For example, adding four wedges (baseline, transaction cost, trading cost, and trading ratio) reduced the amount traded by three quarters and society's welfare by 84% in Jordan Lake watershed. In the end, results indicated that the four wedges marginalized the market in Jordan Lake watershed, but did not make trading unviable by themselves. The total amount of supply of agricultural lands is inadequate to keep up with demand, rendering the market unviable overall. Thus, when applied to the Jordan Lake program, the framework clearly shows that the traditional nutrient trading program will not be feasible or address nutrient management needs in any meaningful way.

Ninety farmers selected randomly were interviewed in Jordan Lake watershed using a semi-structured interview clustered around five thematic areas: regional agricultural, farm operation and history, regional water quality issues, conservation practices, fertilizer decision-making, and water quality trading. Interviews lasted between 30-40 minutes (O'Connell et al., 2017). A demographic survey was also used to collect information on age, sex, education, farm size, land ownership, farming status, and income information.

These data were then used to determine farmer interest in the program. An additional problem with WQT in Jordan Lake watershed was the large adoption premium for this program (Motalebbi et al., 2016b). The adoption premium is the amount that farmers require over and above direct adoption costs to participate. In another recent study, farmers were asked at in-person interviews about their willingness to accept a payment to adopt a particular conservation practice (riparian buffers) in order to generate and sell credits. Farmers' willingness to accept a payment was compared to their direct cost of participation, which allowed estimation of the adoption premium. On average, the adoption premium more than doubled the cost of purchasing credits. Even without the adoption premium, modeled results suggested that within 2 years of a trading program (riparian buffer installation), costs for purchasing agricultural credits would be too expensive relative to urban nutrient abatement at the development site (Motalebbi et al., 2016a).

The survey demonstrated that farmers in Jordan Lake watershed are ageing but they have a deep sense of history and knowledge of their communities, awareness of environmental problems, and a solid track record for conservation practice adoption (O'Connell et al., 2017). Specifically, farmers have a strong and enduring record of conservation practice implementation, as well as frequent collaboration with state and federal programs related to conservation. The majority of farmers (93%) with cropland reported using conservation tillage. They also demonstrated widespread use of public cost-share with nearly 80% of farmers using publicly subsidized conservation programs and planning or implementation support. In addition, water quality issues of Jordan Lake were well-known; 82% of participants were aware of water quality problems in Jordan Lake. Very few farmers (18%) viewed the issues as unimportant or not a problem.

When farmers were asked about establishing a riparian buffer, 43% answered "yes", 20% answered "no", and the remaining 37% offering many reservations or answered "maybe" (O'Connell et al., 2017). Then farmers were then asked about the WQT program in Jordan Lake watershed. Of the 90 farmers interviewed, 26% were willing to participate, 40% were unlikely to participate, 32% were unwilling to participate and 1 person declined to respond. Notably, of the 26% willing to participate in the program, 15 out of 24 farmers were ineligible for participation in the WQT program because they had already implemented buffers, or they lacked streams on their properties. Thus, only 9 individuals, or 10% of people interviewed, were both eligible and willing to engage in WQT. Farmers unwilling or unlikely to participate in the Jordan Lake WQT program reached these conclusions despite reporting very high rates of conservation practices use on their farms and general knowledge of water quality problems in Jordan Lake. These findings suggest that the reason is pervasive skepticism of the WQT program itself. Just as with the group of farmers who were willing to participate, we found that farmers' decision-making was influenced by not only financial and environmental considerations, but a sense of fairness; the farmers believed that the development community should meet their own pollution reduction goals.

Conclusions

A large and diverse body of recent agricultural research exists in the Jordan Lake watershed that allows us to make some conclusions concerning the water quality problem and possible solutions. Overall the data suggest that agricultural land use has been stable, while forested areas are being transformed to urban areas. Based on Tasdighi et al. (2017) analysis, this will increase nutrient loads even more due to both the actual urban area and the increased potential use of wastewater treatment plants unless there is aggressive urban nutrient abatement plan and upgrades made to wastewater treatment plants.

About 60% of the agricultural land use is pasture or hay (Osmond and Neas, 2007) and farmers typically under apply nutrients. Nitrogen is underapplied and generally P is underapplied except for organic sources of nutrients (particularly biosolids from wastewater treatment plants) and tobacco, of which there is less and less. Erosion is well controlled in this watershed and many streams (~60%) are already buffered. The largest nutrient losses are derived from pasture lands due to animal excrement but research indicates that these losses can be reduced by ~50% through the use of a narrow (10-ft) exclusion fence and nutrient management. Additional nutrient losses may also be derived from reducing phosphorus applications on fields that do not need more (e.g. nutrient management) but since this represents the minority of agricultural lands, it is doubtful that any real water quality reductions will be realized.

Water quality trading is a regulatory framework in the Jordan Lake watershed and is viewed as useful in solving nutrient over-enrichment of Jordan Lake. A number of different types of studies (land use-water quality relationship analysis, economic, and social) conducted recently suggest otherwise. The results of land use-water quality relationship analysis suggest that nutrient trading might not be an effective policy for improving the water quality in the Jordan Lake (Tasdighi et al., 2017) for two reasons: 1) agriculture is less than 25% of the land area but the dominant factor in TN generation in Jordan Lake Watershed appears to be the urban sector (wastewater treatment plants) and, 2) agriculture is low intensity. Due to the characteristics of agricultural production determined from several studies (Osmond and Neas, 2007; Line et al., 2016; O'Connell et al., 2017), it appears that there is already significant conservation practices on agricultural lands. There is some possibility of adding more exclusion fencing for livestock and reducing applied P on soils testing High or Very High. The recent economic and social analyses in Jordan Lake watershed indicated financial and human constraints limiting the potential for trading (Motalebbi et al., 2016a & b; O'Connell et al., 2017). First, only 22% of the entire land area is agricultural and ~60% is already buffered. Due to the scarcity of agricultural lands, it would take approximately only two years of urban new development trading needs before it would be cheaper to build larger stormwater structures after which the entire trading market would collapse (Motalebbi et al., 2016a). In addition, it appears that farmers would need premiums over and beyond current market prices, thus making these trades even more prohibitive (Motalebbi et al., 2016b). It appears that WQT as a policy strategy will have little use and even less effect; this policy should be revisited.

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