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Evaluating Dissolved Oxygen Regimes Along a Gradient of Human Disturbance for Lotic Systems in West-Central Florida

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Geography
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EVALUATING DISSOLVED OXYGEN REGIMES ALONG A GRADIENT OF HUMAN DISTURBANCE FOR LOTIC SYSTEMS IN WEST-CENTRAL FLORIDA

Daniel G. Hammond

ABSTRACT

Land uses dominated by human activity can have a significant effect on ecological processes. In Florida, oxygen depletion is the most common impairment in lake, stream, and coastal water bodies. The continual growth and development in Florida, along with a conversion to more human intense land uses warrants study and discussion on impacts to dissolved oxygen regimes along a gradient of human disturbance. This research study is designed to identify observable trends in dissolved oxygen regimes along a gradient of increasing human intensity.

Twenty-six stations in the Tampa Bay area were selected to represent lotic systems in west-central Florida. Data was collected quarterly, during four-day deployments, using a deployable data sonde. Grab samples for nutrients and chlorophyll-a provided antecedent data to explain observed trends. Physical components of streams, such as channelization were also taken into account. Biological integrity of streams was assessed to identify if altered dissolved oxygen regimes as a result of human land use significantly affect the health of the systems. Analysis included the use of Spearman rank order correlations to identify patterns.

Dissolved oxygen regimes were correlated with the Landscape Development Intensity Index (LDI). Nutrients, primary productivity, and physical alteration to the streambed play a significant role in understanding how land use affects dissolved oxygen regimes. Results indicate the intensity of human land use has a significant effect on dissolved oxygen regimes and has significant policy implications for Florida's Total Maximum Daily Load (TMDL) program. Diel variation in oxygen measurements may be a more appropriate indicator of impairment and stream biological integrity.

INTRODUCTION

Land uses dominated by human activity are known to have significant effects on natural communities and ecological processes within those communities (Brown and Vivas 2005). This relationship has been well documented in the literature (Brown and Vivas 2005, Allan et al. 1997, Beaulac & Reckhow 1982, Crosbie & Chow-Fraser 1999, Tsegaye et al. 2006, Ehrenfeld 1983, Richards et al. 1996, and Roth et al. 1996, among others). Similar results are presented from studies conducted in a variety of landscapes showing degradation in ecological community structure with intense human dominated land uses.

In the United States, non-point source runoff from intense human land use is the main source of lake, stream, and coastal water degradation (Tsegaye et al. 2006, Carpenter et al. 1998, USEPA 1996 & 2001). According to the U.S. Environmental Protection Agency (1996 & 2001) approximately 35 percent of river reaches in the United States violate water quality standards as a result of temporal land use/land cover changes. In Florida, this same pattern is illustrated as a result of continuing urban sprawl and intense agriculture activities that increase the human influence on Florida's natural communities. Water resources in Florida are diverse, supporting a wide array of plant and animal habitats as well as human uses such as food crops, industry, tourism, and recreation (FDEP 2008).

The Florida Department of Environmental Protection (FDEP) is charged with assessing Florida's aquatic resources to determine which waterbodies are impaired and in need of restoration. According to the FDEP (2008) Integrated Water Quality Assessment for Florida, there are currently 931 river and stream segments listed as impaired for some constituent throughout Florida. The most common impairment observed is oxygen depletion (248 waterbody segments), totaling over 2,000 miles of impaired rivers and streams out of the approximate 20,000 miles accessed (FDEP 2008). Dissolved oxygen (DO) is the main focus of this research project as it is one of the main parameters of concern in Florida and is widely recognized as a general indicator of aquatic health.

Adequate dissolved oxygen concentrations are an essential part of any healthy aquatic system. Many processes can affect the amount of DO in a system at any given time. For example, respiration, metabolism, re-aeration potential, sunlight, and nutrient loading among others can cause significant fluctuations in DO concentrations on a daily or even hourly basis. Many studies have described links between oxygen depletion and anthropogenic impacts such as urbanization (Walsh et al. 2005, Wang et al. 2003, Paul and Meyer 2001, Meyer et al. 2005). Oxygen depletion in aquatic systems has been linked to increased nutrient loading from agriculture and urban stormwater runoff, impervious land cover, and pollution (Boeder & Chang 2008, MacPerson et al 2007, Mallin et al. 2006, and NRC 2000).

It is important to understand the effect human dominated land uses have on dissolved oxygen regimes in aquatic communities, especially with the abundance of river reaches impaired for oxygen depletion in Florida and the knowledge that adequate oxygen concentrations are essential for healthy aquatic systems and normal ecological functions. This project was initiated to identify correlations between DO regimes in lotic (flowing) systems and increasing intensity of human land uses in the surrounding watershed. Research focuses on lotic systems throughout west-central Florida located in varying landscapes of human disturbance. The purpose is to determine what effect increasing intensity of human land use has on the DO regime of the stream system, and, in turn, what affect the altered system has on the ecological health of the stream. Growth and development in Florida, along with conversion to more human intense land uses warrants study and discussion on impacts to dissolved oxygen regimes along a gradient of human disturbance. This information is critical in understanding the human impact on natural communities and assisting environmental managers and urban planners in developing strategies to mitigate those impacts.

Research Design

This study design was based around the general idea that increasing intensity of human land uses has an effect on the ecological processes of natural communities. Furthermore, adverse impacts to stream ecosystems as a result of urbanization and agricultural land uses are well documented (See Literature Review section). Dissolved oxygen is used in this project as a general indicator of the overall health of a waterbody. Adequate and sufficient dissolved oxygen regimes are critical to the health of biological communities in aquatic ecosystems as well as necessary for physical processes, including the breakdown of organic material.

Figure 1 presents a basic flow diagram indicating general knowledge on the effects of intense human land uses on dissolved oxygen in stream ecosystems. As the figure indicates, increasing human activity in a watershed can alter the chemical and physical properties of a stream system leading to depletion of oxygen and decreased stream biological integrity. However, the hypothesis tested during this project revolves around the idea that human activity in a watershed may have the opposite effect on dissolved oxygen regimes than that depicted in Figure 1. Increasing intensity of human land use in a watershed results in increased DO regimes compared to those in less disturbed stream reaches likely as a result of increased nutrient inputs and therefore increased primary production. This hypothesis is tested by identifying correlations between land use, nutrients, chlorophyll-*a*, DO, and biological integrity of the stream.

Antecedent variables are expected to play an important role in understanding the effect of increasing human intensity of land use on dissolved oxygen regimes. Nutrient levels are known to affect concentrations of dissolved oxygen in waterbodies and are evaluated as a part of this project. Increased nutrient loading to a system can cause increased primary production, resulting in large diel variations in DO concentrations. This information is included to help identify correlations between intensity of land use, nutrient inputs, and resulting DO.

A critical component of this study is the accurate determination of a gradient of human disturbance. Brown and Vivas (2003 & 2005) present a Landscape Development Intensity Index (LDI); a land use based index of potential human disturbance. The index reflects non-renewable energy flow through a system and is based on the principle that ecological processes are impacted by the intensity of human dominated land uses (FDEP 2006). This method of evaluating intensity of human land use is broad enough to accurately reflect the wide range of human activities that can affect a waterbody.

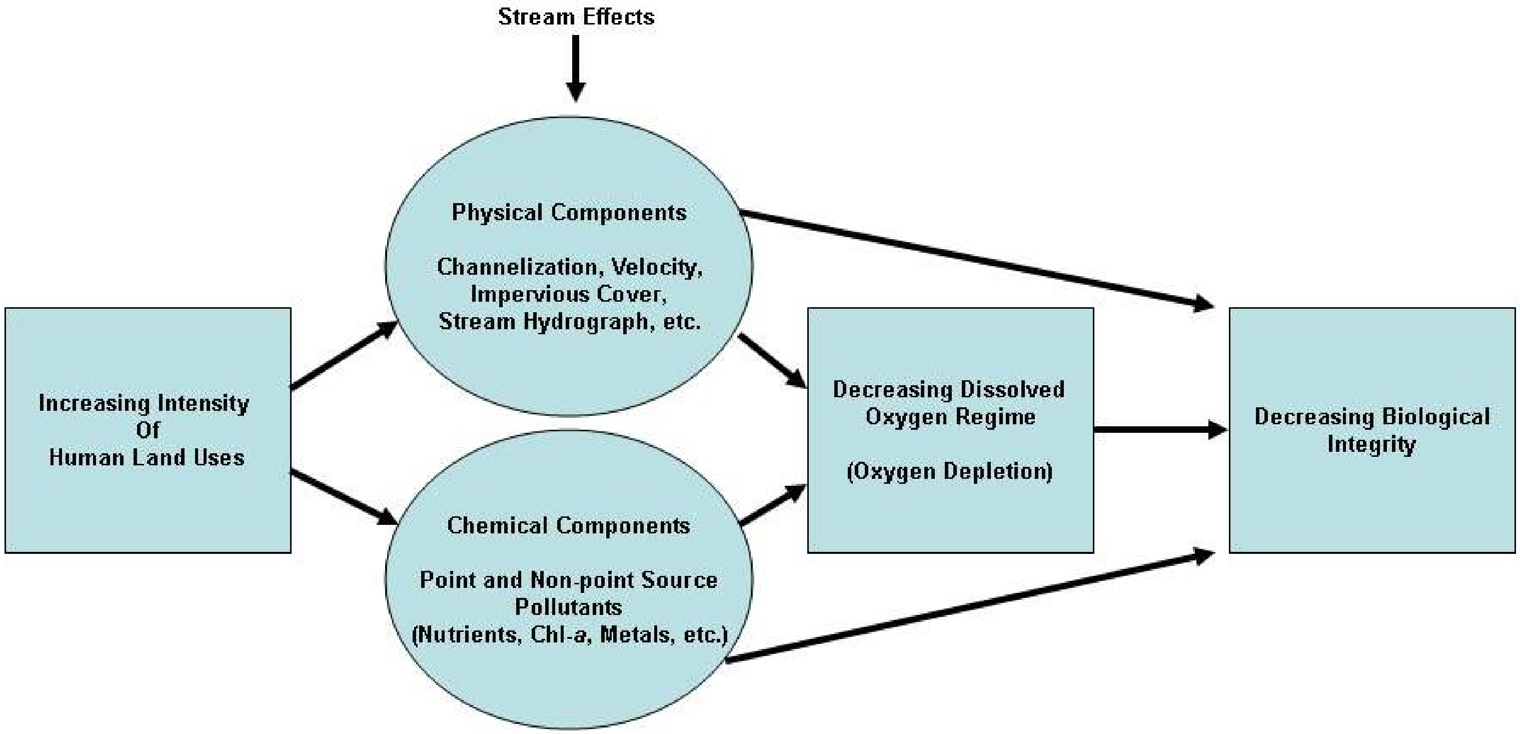


Figure 1. Basic flow diagram indicating general knowledge on how intensity of human land uses affect stream ecosystems. This diagram is meant to be specific to factors affecting dissolved oxygen concentrations and does not include all possible effects to streams.

It is important to note the LDI does not directly account for physical or chemical disturbance to a stream system. However by using non-renewable energy flow, the index reflects a gradient of human activity in a watershed that is expected to result in corresponding physical and chemical alterations to the aquatic system, thereby resulting in altered DO regimes. The LDI is an accepted and viable index of human disturbance and is used in this project to represent land uses of increasing human intensity that are likely to have some effect on streams and aquatic ecosystems.

Another important aspect of this study is to identify correlations between DO regimes and the overall health of the aquatic ecosystem. In this study, in-stream biological data are used to evaluate the biological integrity of the systems. The Stream Condition Index (SCI) was developed by the FDEP as an index of biological integrity using in-stream and riparian habitat conditions and stream macroinvertebrate assemblages. Previous studies have linked increasing LDI to decreasing SCI scores (Fore 2004 & 2007). The same framework is employed in this study, and includes DO, to identify stream effects as a result of increasing human intensity of land use and altered DO regimes.

This study identifies correlations between DO regimes and increasing intensity of human land uses. Altered DO regimes as a result of increasing human disturbance have significant effects on the overall health of aquatic systems. The research questions addressed during this study are:

- Is there a significant correlation between dissolved oxygen regimes and increasing human disturbance in west-central Florida streams?

- Do nutrient and chlorophyll-*a* data correlate to explain shifts in DO as a result of increasing human disturbance?
- Do altered dissolved oxygen regimes result in corresponding changes in biological integrity of stream systems?

This information can be valuable when refining Florida's dissolved oxygen criterion to determine when DO has been altered by the effects of human land uses, and therefore assist FDEP in focusing its Total Maximum Daily Load (TMDL) development efforts on abating the causes of those alterations.

LITERATURE REVIEW

This chapter provides a review of available literature pertaining to the effects of human disturbance on dissolved oxygen and stream integrity as it relates to the current research presented in this study. Dissolved oxygen has long been used as a primary indication of water quality standards and is an important indicator of general water body health (Wang et al. 2003 and Alexander & Stefan 1983). The presence of adequate concentrations of DO in surface waters is critical to the health and survival of aquatic ecosystems (Boeder & Chang 2008). Florida state regulations (62-32.530, F.A.C.) set a dissolved oxygen standard for freshwater systems of 5.0 mg/L. The American Fisheries Society (1979) concurs that a minimum value of 5.0 mg/L is necessary to maintain a healthy lotic ecosystem. Understanding the dynamics of DO is complex involving chemical, physical, and biological processes. Re-aeration potential, photosynthesis, and respiration have been identified in the literature as three primary factors affecting DO (Odum 1956, Schurr & Ruchti 1977, Parkhill & Gulliver 1999, and Wang et al. 2003). In healthy lotic systems, DO fluctuates near saturation varying with temperature and metabolism (Wang et al. 2003). However, oxygen concentrations depressed below saturation can indicate a water quality concern, such as increased nutrient inputs (Wilcock 1986 and Wang et al. 2003). The National Research Council (2000), Mallin et al. (2006), and MacPerson et al (2007), among others, report the catalyst for increased oxygen demand is often the result of increased nutrient loading. Low oxygen concentrations have been linked to impaired development, maturation, and increased mortality of fish as well as macroinvertebrate habitat degradation (Rounds & Doyle 1997, Cox 2003, and Boeder & Chang 2008).

Many studies have been devoted to understanding the dynamics of DO in stream systems (Odum 1956, O'Conner & Di Toro 1970, Kelly et al. 1974, Gulliver & Stephan 1984, Butcher & Covington 1995, Chaudhury et al. 1998, and Wang et al. 2003). Some of these studies have been based on models ranging from simple (Chapra & Di Toro 1991) to very complex, requiring a significant number of input parameters (Hornberger & Kelly 1972 and Edwards et al. 1978). Most modeling efforts for DO have evolved from the basic Sag equation pioneered by Streeter and Phelps (1925), which has been extensively used as a tool in stream pollution (Berkun & Aras 2007). The Sag curve shows that oxygen demand in a stream is increased at the point where some pollutant is introduced and oxygen is replenished at some point downstream indicating recovery (Streeter and Phelps 1925). While DO modeling efforts have been used to characterize stream conditions, metabolism, respiration, and photosynthesis, as well as to estimate the effects of pollutant loading, no modeling studies have been uncovered that attempt to evaluate DO along a human disturbance gradient.

The evaluation of DO in urbanizing landscapes has garnered more attention in recent years. Brilly et al. (2006) describe the complexity in characterizing the impact urbanization has on stream systems. They conclude the heavily modified concrete channel of an urbanized stream had a significant effect on the dissolved oxygen regime with oversaturation due to excessive algae growth. Wang et al. (2003) found that streams in an urban landscape had lower rates of metabolism than those in an agricultural landscape. Colangelo (2007) studied DO in the Kissimmee River, Florida showing increased DO concentrations in the post-restoration period compared to pre-restoration, which included a series of impounded reservoirs and water control structures. Boeder & Chang (2008) shows that urban streams and associated land cover changes affect the volume and timing of runoff, causing water quality impacts that can lead to low DO concentrations.

As human populations congregate in urban areas, ecological studies on the effects of urbanization on stream ecosystems are increasing. Meyer et al. (2005) and Walsh et al. (2005) describe an "urban stream syndrome" that documents the ways in which urban streams are ecologically degraded. Paul and Meyer (2001) state urbanization is second only to agriculture as the major cause of stream impairment. Walsh et al. (2005) provide a thorough review of current literature pertaining to the urban stream syndrome and indicate directions for future research to alleviate its effects. Symptoms of the syndrome include a flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology and stability, and reduced biotic richness with increased dominance of tolerant species (Paul and Meyer 2001, Meyer et al. 2005, Walsh et al. 2005). Reduced baseflow from an increase in impervious area is described as another symptom, usually compounding water chemistry problems, such as increasing diel variation in dissolved oxygen (Walsh et al. 2005). In addition, stormwater impacts have been identified as the catalyst for correlations between stream condition and catchment imperviousness (Walsh et al. 2005, Paul and Meyer 2001).

The LDI has been accepted as a viable index of human disturbance and is included as a metric calculated for the human disturbance gradient (HDG) (Fore et al.

2007). The HDG calculates disturbance based on five metrics including water quality, energy flow (LDI), and stream macroinvertebrate biologic integrity (Fore et al. 2007). The HDG uses ammonia to summarize water quality as it may be a general indicator of urbanization and agriculture (Fore et al. 2007). This study uses dissolved oxygen to summarize water quality as it is an indicator of general aquatic health and is affected by measures of disturbance used in other metrics, such as nutrients.

Mack (2006) states that the LDI uses quantified land use percentages and therefore has many advantages over more qualitative human disturbance gradients. Mack (2006) showed the LDI was positively correlated with a human disturbance gradient (Ohio Rapid Assessment Method for Wetlands) and an Index of Biotic Integrity (IBI) for a large wetland data set in Ohio. However, according to Novotny (2005), an acceptable IBI should not rely on a single stressor such as percent imperviousness because it may not represent a true cause-effect proximate relationship. Percent impervious surface has been shown to be a relatively good indicator of surface water pollution in watersheds, although this correlation breaks down in agricultural watersheds where imperviousness may be relatively unimportant (Brown and Vivas 2005). The LDI, then, is a continuous index and differs from other measures of land use intensity because it scales the intensity of activity based on non-renewable energy use, a characteristic common to all human dominated land uses (Brown and Vivas 2005).

The Landscape Development Intensity Index has also been shown to be an effective predictor of stream macroinvertebrate biological integrity (FDEP 2006). A strong correlation has been demonstrated between the LDI and the Stream Condition Index (SCI) by Fore (2004). In this study, the SCI is used to evaluate biologic integrity of the systems and is correlated with the LDI scores to determine if the same pattern observed by Fore (2004) is observed in the lotic systems used here.

Literature has shown shifts in dissolved oxygen regimes to have significant effects on the biological integrity of stream systems. Availability of oxygen has been recognized as a factor in the composition of freshwater communities affecting distribution of many species (Hynes 1960, Giller and Malmqvist 1998, Dodds 2002, and Connolly et al. 2004). Hynes (1960), Pearson and Penridge (1987) and Connolly et al. (2004) show that anthropogenic impacts can cause decreased oxygen conditions resulting in changes to community structure and in many cases a loss of diversity. Walton et al (2007) also show that urban land use has a negative association with biological integrity of streams. Jacobsen (2008) concluded that oxygen saturation was the best predictor of stream macroinvertebrate richness. Available literature has shown dissolved oxygen concentration and saturation to be significantly linked to the biological integrity of stream macroinvertebrate assemblages. This study builds on the current base of knowledge by attempting to link in-stream effects of altered DO regimes along a gradient of human disturbance.

The goal of this study is to build on the current base of knowledge by using empirical data to identify direct correlations between dissolved oxygen and rates of human disturbance. This study includes more data points over a longer period of time then previous studies and includes a measure of stream biological integrity to further identify the potential impacts of altered dissolved oxygen regimes.

MATERIALS AND METHODS

This chapter describes the methods used to evaluate dissolved oxygen regimes against a gradient of human disturbance in west-central Florida streams. The methods used to identify rates of disturbance and subsequent biological integrity of the subject streams is also provided.

Site Selection

This study focuses on west-central Florida and specifically the Tampa Bay area. The FDEP has selected approximately 350 water bodies, including streams, rivers, canals, lakes, and estuaries, throughout Florida for inclusion in a statewide water quality survey to collect data on dissolved oxygen and nutrient concentrations for the purpose of revising state water quality standards. Twenty-six waterbodies from the statewide dataset represent the lotic systems of the Tampa Bay area and west-central Florida located throughout Hillsborough, Pinellas, Manatee, Polk, and Pasco counties (Figure 2). These 26 stations make up the dataset used for this study and include all the lotic systems that were included in the statewide data set for west-central Florida.

These lotic systems vary in size from low velocity streams to large rivers. Monitoring stations are located along all of the major Tampa Bay tributaries, as well as many smaller tributaries feeding the larger systems. Station names, IDs, and coordinates are presented in Table 1. The dataset includes inland and coastal streams and provides a

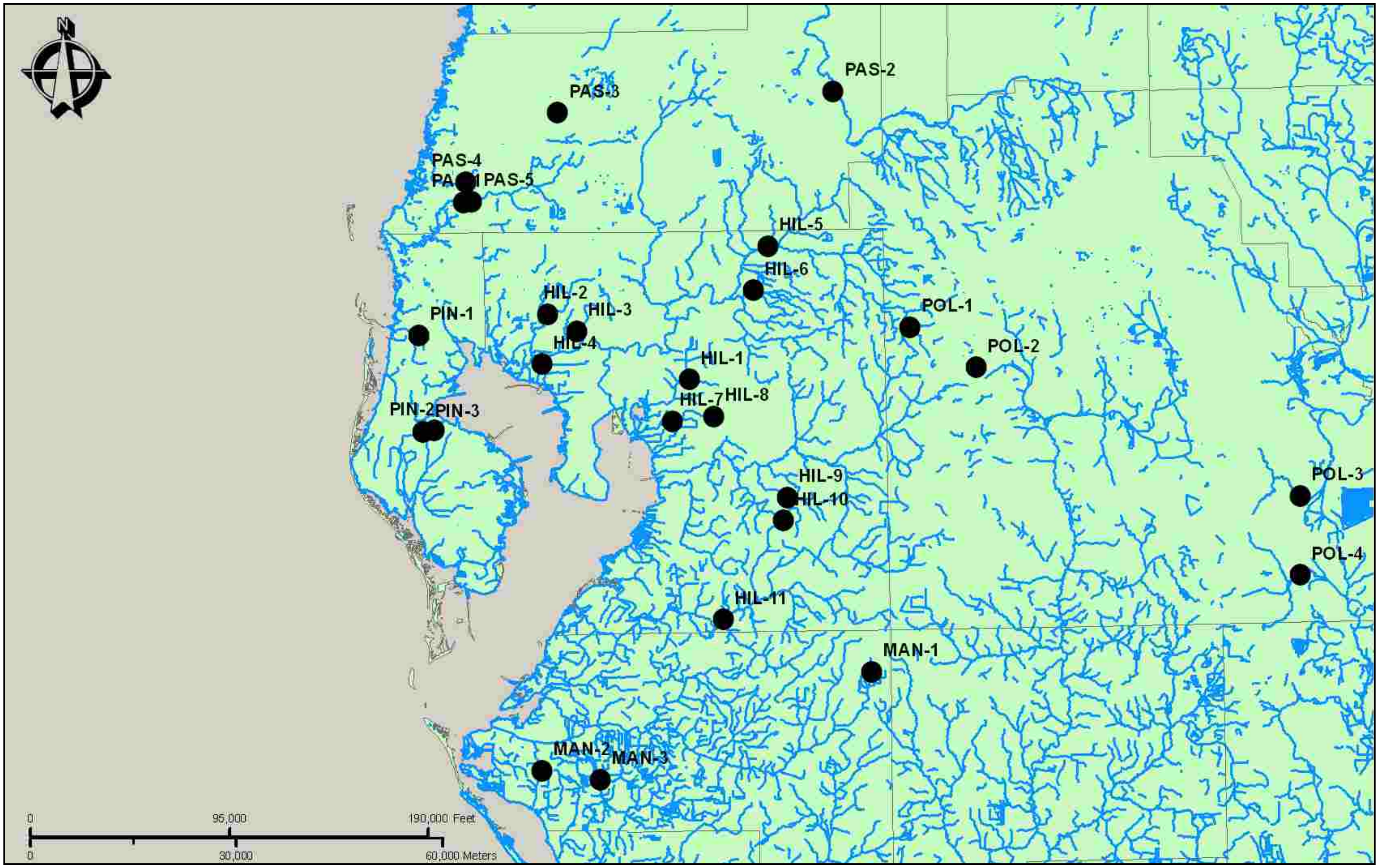


Figure 2. Monitoring Station Locations.

good representation of the diversity of lotic systems throughout west-central Florida and the Tampa Bay area. The stations are located in varying landscapes ranging from rural to agricultural to urban settings.

Table 1. Station names and locations, west-central Florida.

Station ID	Station Name	Latitude	Longitude
HIL-1	Mango Creek	27.97777472	-82.3463173
HIL-2	Brushy Creek	28.06589772	-82.55529783
HIL-3	Sweetwater Creek	28.04307258	-82.51181536
HIL-4	Sweetwater Creek	28.00033	-82.56456
HIL-5	Hillsborough River	28.15111311	-82.22626586
HIL-6	Hollomans Branch	28.09380971	-82.24892382
HIL-7	Delaney Creek	27.92374602	-82.37205405
HIL-8	Delaney Creek	27.92948	-82.31095
HIL-9	Fishhawk Creek	27.82192873	-82.20348711
HIL-10	Alafia River	27.79151012	-82.20949805
HIL-11	Little Manatee River	27.6630995	-82.30080073
MAN-1	Manatee River	27.59203278	-82.08192905
MAN-2	Wares Creek	27.468325	-82.570529
MAN-3	Williams Creek	27.455666	-82.485258
PAS-1	Anclote River	28.21324018	-82.67836345
PAS-2	Withlacoochee River South	28.35262888	-82.12632803
PAS-3	Pithlachascottee River	28.32950795	-82.53628406
PAS-4	Pithlachascottee River	28.24018407	-82.67372628
PAS-5	Anclote River	28.21465233	-82.66573936
PIN-1	Surlew Creek	28.04018	-82.74659
PIN-2	Long Branch	27.91507435	-82.72460915
PIN-3	Long Branch	27.91315148	-82.7410334
POL-1	Itchepackesassa Creek	28.04214604	-82.01752026
POL-2	Banana L Mid Stream	27.98848007	-81.92082793
POL-3	Tiger Creek	27.81206389	-81.44429611
POL-4	Livingston Creek	27.70860793	-81.44644802

Landscape Development Intensity Index (LDI)

This section presents the method for determining the gradient of human disturbance used in this study. For each stream reach, the LDI was calculated for an area that includes the station location, a 100 meter buffer on either side of the stream, and 10 km of the upstream drainage basin (zone of calculation). Brown and Vivas (2003 & 2005) and Fore (2004 & 2007) have determined this technique to adequately represent the stream reach and state that increasing buffers and upstream distances does not provide more significant results. Land uses and percent area occupied by each land use in the zone of calculation for each station were determined using 2005 Geographic Information System (GIS) land use coverage maps. Land uses were identified using the standard Florida Land Use and Cover Classification System (FLUCCS). Land uses that fall into the FLUCCS code categories of lakes and reservoirs were not included in the LDI calculation. This was done to prevent skewing the LDI calculation as these land uses do not represent a direct source of anthropogenic load to the stream (Dr. Gary Payne, personal communication). In addition, the stream itself was not included in the calculation (Dr. Gary Payne, personal communication).

As previously described, the LDI is a land use based index of potential human disturbance with values calculated spatially based on coefficients applied to land uses within watersheds, according to Brown and Vivas (2005). Coefficients are quantified using emergy use per unit area per time. Emergy is energy that has been corrected for different qualities and is expressed in units of solar emergy joule (sej) (Brown and Vivas 2005). The units for quantifying the intensity of human activity are therefore sej/ha*yr^{-1}

(empower density) (Brown & Vivas 2005 and FDEP 2006). Brown and Vivas (2003 and 2005) collected energy consumption data from billing records and literature sources for non-renewable energy sources such as electricity, fuels, fertilizers, pesticides, and water (public supply and irrigation) (FDEP, 2006). Since this index was designed to specifically measure human disturbance, only non-renewable energy sources were included in the calculation (Brown and Vivas 2003 and 2005, FDEP, 2006). Empower density of natural systems is assigned a value of 0 sej/ha*yr^{-1}. The LDI coefficients are calculated as the natural log of the empower densities on a scale from 1 to 10 (FDEP 2006). Natural lands are given an LDI coefficient of 1.0, while an LDI coefficient of 10.0 is associated with high intensity land uses (e.g. central business district or power plant) (Brown and Vivas 2003 & 2005 and FDEP 2006).

Using the land use coefficients and the percent area occupied by each land use, the LDI was calculated as follows, described by Brown and Vivas (2003 & 2005):

$$LDI_{total} = \Sigma\ (LDC_i * \%LU_i)$$

Where,
LDI_{total} = Landscape Development Intensity Index for the area of influence
$\%LU_i$ = percent of total area of influence in land use i
LDC_i = landscape development intensity coefficient for land use i

In accordance with Brown and Reiss (2006), an LDI break point of less than or equal to 2.0 was used to identify minimally disturbed reference sites and an LDI of greater than 2.0 designates areas with increasing levels of human disturbance (FDEP 2006).

Dissolved Oxygen, Nutrient, and Chlorophyll-*a* Data Acquisition

This section describes the field methodologies employed for data collection of dissolved oxygen, nutrient, and chlorophyll-*a* constituents necessary to complete this study. Dissolved oxygen, nutrient, and chlorophyll-*a* data were collected in each of the 26 lotic systems on a quarterly basis for one year between March 2005 and January 2006. During each quarter, a YSI 6600 multi-parameter data sonde was deployed in the stream and programmed to record field measurements in 15 minute intervals over a four day (96 hour) period. The sonde recorded temperature (ºC) and dissolved oxygen in mg/L as well as percent saturation. Each quarter the YSI data sondes were deployed in the same location at approximately mid-stream and mid-depth in streams and rivers with a total water depth of one meter or less and at mid-stream and a depth of one-half meter below the water surface in systems with a total water depth of more than one meter (Figure 3). Sondes were deployed with probes facing upstream and encased in PVC tubes with multiple one inch holes drilled in the tube to allow sufficient water flow over the probes. The PVC tubes were painted in camouflage for security and provided safety for the YSI from debris floating downstream (Figure 3). Data sondes were properly calibrated and verified according to manufacturer's and FDEP protocols for temperature (DEP SOP 001/01 FT 1400) (acceptance criteria +/- 0.2°C) and dissolved oxygen (DEP SOP 001/01 FT 1500) (acceptance criteria +/- 0.3 mg/L) before and after each 96 hour deployment period. Following each deployment, dissolved oxygen data were uploaded from the YSI data sonde using EcoWatch version 3.15.00 (EcoWatch) software and entered into a Microsoft Access database.

Figure 3. Typical sonde deployment structure and positioning in stream.

For each deployment period at each station the overall minimum, maximum, and mean dissolved oxygen (DO_M) values were calculated. In addition, the minimum and maximum DO values measured each day of the four day deployment were averaged to obtain average daily minimum and maximum concentrations. The average daily range of DO measurements (DO_R) was determined by subtracting the average daily maximum from the average daily minimum concentrations for each quarterly deployment. The mean DO deficit (DO_D) concentration was calculated for each station and each quarter using the following formula:

$$DO_D = (DO_M/DO_{SAT}) - DO_M$$

Where,
DO_D = mean DO deficit in mg/L
DO_M = mean DO concentration over the four day deployment period
DO_{SAT} = mean DO percent saturation over the four day deployment period

The above formula was designed for this study and is only accurate for use in this study. This is because the YSI 6600 data sonde internally compensates for temperature when calculating the percent saturation and the conversion from percent saturation and temperature to a solubility in mg/L is carried out using formulae available in *Standard Methods for the Examination of Water and Wastewater (ed. 1989)* (YSI 2002). This allows the above calculation to accurately determine the mean dissolved oxygen value, at any given time, if the percent saturation were 100 percent. Then by subtracting the observed mean oxygen concentration, the mean oxygen deficit can be derived. In addition to the above calculations, the percent of DO values that exceeded Florida's Class III fresh water dissolved oxygen standard (*shall not be less than 5.0 mg/L*) in all measurements collected over the four day deployment period for each quarter was also determined ($DO_{\% < 5}$).

During data sonde retrieval, water quality grab samples were collected for nitrate+nitrite, total Kjeldahl nitrogen, and chlorophyll-*a* (corrected for phaeophytin) each quarter. Samples were collected at the same depth as the sonde deployment. All samples were properly preserved in the field according to FDEP protocols. Samples collected for chlorophyll-*a* analysis were filtered through a GF/C glass fiber filter (DEP SOP BB-29) within 24 hours of collection and immediately frozen with dry ice for transport to the laboratory.

All field sampling was conducted according to the FDEP Standard Operating Protocols (SOP) listed below. All laboratory analyses were conducted by a certified laboratory accredited by the National Environmental Laboratory Accreditation Conference (NELAC).

FC 1000 - Cleaning/Decontamination
FD 1000 – Documentation
FQ 1000 – Field Quality Control
FS 1000 – General Sampling
FS 2100 – Surface Water Sampling
FS 2000 – General Aqueous Sampling
FT 1000-1600 – General Field Testing and Measurement

Stream Condition Index (SCI)

In order to measure and determine the potential effects of human land use on dissolved oxygen regimes, a measure of stream integrity is included in this study. Methodologies for collecting the stream biological integrity data are presented here. Biological assessment data were collected during the second and fourth deployment periods at each site to evaluate seasonal differences. At each of the 26 stations, a Stream Habitat Assessment (FDEP-SOP-001/01 Form FD 9000-6) and a Physical/Chemical Characterization Field Sheet (FDEP SOP-001/01 Form FD 9000-3) were completed. The habitat assessment is comprised of a variety of physical criteria that are independently evaluated on a numerical scale, and the component values are summed to provide a quantitative rating for a stream segment that is presumed to be proportional to the quality of the stream for native macroinvertebrates. The Physical/Chemical Characterization also provides for the delineation of various microhabitats in the stream into categories to ensure that sampling of such microhabitats is conducted in general proportion to their abundance.

Macroinvertebrate sampling was performed according to the Stream Condition Index (SCI) protocol developed by FDEP (FDEP-SOP-001/01 FS 7420) by personnel with training and experience with the SCI who have successfully passed FDEP audits for the protocol. The SCI is a standardized macroinvertebrate sampling methodology that accounts for the various microhabitats available (e.g., leaf packs, snags, aquatic vegetation, roots/undercut banks) within a 100-m segment of stream. Utilizing this methodology, twenty 0.5-m D-frame dip net sweeps were performed within a 100-m segment of the stream. The number and quality of benthic macroinvertebrate microhabitats present during the sampling event determines the number of sweeps performed within each microhabitat type. Macroinvertebrate samples are preserved in the field using 99 percent Isopropyl alcohol. The amount of alcohol used is dependent on the amount of organic material and site water present in the sample necessary to achieve a 90 percent final concentration of alcohol. Consistent with FDEP protocols, each benthic macroinvertebrate sample was sorted in the laboratory and taxonomically analyzed according to FDEP SOP-001/01 LT 7200. Macroinvertebrate identifications were made to the lowest possible taxonomic category.

Data from each invertebrate sample were used to calculate the various SCI metrics and resulting overall SCI values per the methodology for the Florida Peninsula (Table 2). For each equation in Table 2, "X" equals the number representing the count or percentage listed in the corresponding row of the left column. For calculated values greater than ten, the score is set to ten; for values calculated less than zero, the score is set to zero.

Table 2. Equations for calculating SCI metrics for peninsular Florida (range from zero to ten).

SCI Metric	Peninsula Score
Total Taxa	10(X-16)/25
Ephemeropteran Taxa	10X/5
Trichopteran Taxa	10X/7
Percent Collector-Filterer Taxa	10(X-1)/39
Long-lived Taxa	10X/4
Clinger Taxa	10X/8
Percent Dominant Taxon	10-(10[(X-10)/44])
Percent Tanytarsini	10[ln(X+1)/3.3]
Sensitive Taxa	10X/9
Percent Very Tolerant Taxa	10-(10[ln(X+1)/4.1])

It is important to note that in the fall of 2006, FDEP revised the SCI protocol by changing the range of individual macroinvertebrates required for sample analysis from 100-120 to 140-160, requiring the SCI to be determined as the average of two replicate samples, and updating the aquatic life use categories that describe the resulting SCI scores. The data acquisition effort for this study was conducted prior to the FDEP revisions to the protocol. However, the resulting SCI scores were evaluated using the revised aquatic life use categories (Table 3) to employ the most accurate and up to date information for evaluating the biological integrity of the stream systems in this study.

Every effort was made to conduct the biological monitoring during retrieval of the data sonde. If this was not possible, the monitoring was conducted within two weeks after retrieval of the sonde following a successful deployment.

Table 3. Aquatic life use categories for SCI scores, peninsular Florida.

SCI Category	SCI Range	Typical Description for Range
Category 1 (Exceptional)	71-100	Higher diversity of taxa than for Category 2, particularly for Ephemeroptera and Trichoptera; several more clinger and sensitive taxa than found in Category 2; high proportion for Tanytarsini; few individuals in the dominant taxon; very tolerant individuals make up a very small percentage of the assemblage.
Category 2 (Healthy)	35-70	Diverse assemblage with 30 different species found on average; several different taxa each of Ephemeroptera, Trichoptera, and long-lived and, on average, 5 unique clinger and 6 sensitive taxa routinely found; small increase in dominance by a single taxon relative to Category 1; very tolerant taxa represent a small percentage of individuals, but noticeably increased from Category 1.
Category 3 (Impaired)	0-34	Notable loss of taxonomic diversity; Ephemeroptera, Trichoptera, long-lived, clinger, and sensitive taxa uncommon or rare; half the number of filterers than expected; assemblage dominated by a tolerant taxon, very tolerant individuals represent a large portion or the individuals collected.

* Adapted from Fore (2004).

Data Analyses

Non-parametric Spearman rank order correlation analyses were used in this study to identify relationships among the dissolved oxygen, nutrient, LDI, and SCI data. Non-parametric statistics were used because the data do not meet the assumptions of parametric analyses (i.e. normal distribution). Analyses were run using STATISTICA version 7.1 (StatSoft, Inc 2005) software. Data was lumped together to provide an overall analysis as well as separated by quarter at each station to determine any seasonal differences.

DESCRIPTIVE RESULTS

This chapter presents the results of the raw data collection effort for all variables used in this study. The data collection effort for this project was conducted between March 2005 and January 2006. Table 4 shows station IDs and dates of data collection. Logistical issues forced the data collection to begin approximately 2 months late and resulted in the following quarterly breakdown; Quarter 1 – March-April, Quarter 2 – May–July, Quarter 3 – August–October, and Quarter 4 – November–January. During Quarter 1 data sonde malfunctions prevented collection of dissolved oxygen data from stations HIL-6 and POL-4. During Quarter 2, deployment of the data sonde at stations HIL-6 and HIL-11 occurred the first week of August, but were still included in the Quarter 2 data set. Also in Quarter 2, a sonde malfunction at HIL-7 midway through deployment resulted in only two days of useable dissolved oxygen data.

Table 4. Quarterly data collection periods, west-central Florida, 2005 – 2006.

Station ID	**Data Collection Periods**			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
HIL-1	3/18/05 - 3/22/05	6/2/05 - 6/6/05	8/25/05 - 8/29/05	12/2/05 - 12/6/05
HIL-2	3/25/05 - 3/29/05	6/9/05 - 6/13/05	9/2/05 - 9/6/05	11/17/05 - 11/21/05
HIL-3	3/11/05 - 3/15/05	6/2/05 - 6/6/05	9/2/05 - 9/6/05	12/1/05 - 12/5/05
HIL-4	3/3/05 - 3/7/05	5/19/05 - 5/23/05	8/18/05 - 8/22/05	11/17/05 - 11/21/05
HIL-5	3/3/05 - 3/7/05	5/19/05 - 5/23/05	8/18/05 - 8/22/05	11/1/05 - 11/15/05
HIL-6	---	8/1/05 - 8/5/05	10/14/05 - 10/18/05	12/16/05 - 12/20/05
HIL-7	3/18/05 - 3/22/05	5/27/05 - 5/29/05	9/2/05 - 9/6/05	12/2/05 - 12/6/05
HIL-8	3/18/05 - 3/22/05	5/27/05 - 5/31/05	9/2/05 - 9/6/05	12/2/05 - 12/6/05
HIL-9	3/4/05 - 3/8/05	5/20/05 - 5/24/05	9/2/05 - 9/6/05	11/18/05 - 11/22/05
HIL-10	3/4/05 - 3/8/05	5/20/05 - 5/24/05	9/2/05 - 9/6/05	11/18/05 - 11/22/05
HIL-11	4/22/05 - 4/26/05	8/1/05 - 8/5/05	9/30/05 - 10/4/05	1/6/06 - 1/10/06
MAN-1	4/7/05 - 4/11/05	6/9/05 - 6/13/05	9/15/05 - 9/19/05	1/6/06 - 1/10/06
MAN-2	3/11/05 - 3/15/05	5/27/05 - 5/31/05	9/2/05 - 9/6/05	1/5/06 - 1/9/06
MAN-3	3/11/05 - 3/15/05	5/27/05 - 5/31/05	9/2/05 - 9/6/05	1/5/06 - 1/9/06
PAS-1	4/8/05 - 4/12/05	6/10/05 - 6/14/05	9/8/05 - 9/12/05	12/2/05 - 12/6/05
PAS-2	3/24/05 - 3/28/05	6/9/05 - 6/13/05	8/18/05 - 8/22/05	11/11/05 - 11/15/05
PAS-3	4/8/05 - 4/12/05	6/3/05 - 6/7/05	9/8/05 - 9/12/05	12/8/05 - 12/12/05
PAS-4	4/8/05 - 4/12/05	6/10/05 - 6/14/05	9/8/05 - 9/12/05	12/2/05 - 12/6/05
PAS-5	4/8/05 - 4/12/05	6/10/05 - 6/14/05	9/8/05 - 9/12/05	12/2/05 - 12/6/05
PIN-1	3/10/05 - 3/14/05	5/19/05 - 5/23/05	8/18/05 - 8/22/05	11/11/05 - 11/15/05
PIN-2	3/11/05 - 3/15/05	5/27/05 - 5/31/05	8/19/05 - 8/23/05	11/17/05 - 11/21/05
PIN-3	3/10/05 - 3/14/05	5/27/05 - 5/31/05	8/19/05 - 8/23/05	11/17/05 - 11/21/05
POL-1	3/4/05 - 3/8/05	5/20/05 - 5/24/05	8/18/05 - 8/22/05	11/10/05 - 11/14/05
POL-2	3/4/05 - 3/8/05	5/20/05 - 5/24/05	8/19/05 - 8/23/05	11/10/05 - 11/14/05
POL-3	4/7/05 - 4/11/05	7/7/05 - 7/11/05	9/23/05 - 9/27/05	12/16/05 - 12/20/05
POL-4	---	7/1/05 - 7/5/05	9/23/05 - 9/27/05	12/16/05 - 12/20/05

Landscape Development Intensity Index (LDI)

This section shows the results of the LDI calculation effort conducted for the 26 stations in this study. LDI scores were calculated using 2005 GIS land use coverages and are presented in Table 5. Appendix A shows the raw data for each station used to calculate the index.

Table 5. Landscape Development Intensity Index scores, calculated from 2005 GIS land use coverages for west-central Florida.

Station ID	Stream Name	LDI Score
HIL-1	Mango Creek	4.15
HIL-2	Brushy Creek	5.35
HIL-3	Sweetwater Creek	6.72
HIL-4	Sweetwater Creek Tributary	7.22
HIL-5	Hillsborough River	2.59
HIL-6	Hollomans Branch	4.00
HIL-7	Delaney Creek	4.84
HIL-8	Delaney Creek	1.38
HIL-9	Fishhawk Creek	2.91
HIL-10	Alafia River	2.68
HIL-11	Little Manatee River	2.07
MAN-1	Manatee River	1.42
MAN-2	Wares Creek	7.73
MAN-3	Williams Creek	3.46
PAS-1	Anclote River	2.09
PAS-2	Withlacoochee River South	2.05
PAS-3	Pithlachascottee River	1.45
PAS-4	Pithlachascottee River	1.84
PAS-5	Anclote River	1.70
PIN-1	Surlew Creek	7.61
PIN-2	Long Branch	6.83
PIN-3	Long Branch	8.60
POL-1	Itchepackesassa Creek	5.20
POL-2	Banana L Mid Stream	7.18
POL-3	Tiger Creek	1.23
POL-4	Livingston Creek	2.29

The overall LDI scores ranged from 1.23 to 8.60 across the 26 stations. Six stations (HIL-8, MAN-1, PAS-3, PAS-4, PAS-5, and POL-3) have LDI scores less than 2.0 and are reference stations indicative of areas with minimal levels of human disturbance, according to Brown and Reiss (2006). The scores are well distributed along the LDI scale with 13 stations having a LDI score between 2.0 and 6.0, and another seven scores greater than 6.0.

The 11 Hillsborough County stations were wide ranging with LDI scores between 1.38 and 7.22. All of the West-Central Florida counties included in this study had at least one reference station (LDI < 2.0), with the exception of Pinellas County. Pinellas County is the most densely populated county in Florida (Pinellas County Government, 2009) and therefore it is not surprising that LDI scores from stations in this county indicate more intense levels of human activity.

Dissolved Oxygen

The results of the dissolved oxygen data collection effort are presented in this section. Table 6 presents the quarterly range and mean dissolved oxygen concentrations (DO_M) collected over each deployment at all stations. Eighteen of the 26 stations had overall mean dissolved oxygen concentrations (mg/L) that fell below Florida's Class III state water quality standard (5.0 mg/L) during at least one quarter. Twenty-two stations had DO concentrations that exceeded the standard at some time during the deployment during at least one quarter. DO concentrations at two stations (PAS-2 and PAS-4) exceeded the state water quality standard in all measurements, during all quarters.

Table 6. Overall quarterly range and mean dissolved oxygen concentrations, west-central Florida, 2005 – 2006.

Station ID	**Dissolved Oxygen (mg/L)**							
	Quarter 1		**Quarter 2**		**Quarter 3**		**Quarter 4**	
	DO_M (mg/L)	**Range**	**DO_M (mg/L)**	**Range**	**DO_M (mg/L)**	**Range**	**DO_M (mg/L)**	**Range**
HIL-1	6.4	5.5 - 8.0	4.2	3.5 - 6.7	3.7	2.9 - 6.5	7.5	6.0 - 8.5
HIL-2	6.8	6.3 - 7.3	6.0	4.4 - 6.6	5.8	5.2 - 6.7	6.6	5.6 - 8.0
HIL-3	5.5	4.3 - 7.2	3.7	2.9 - 5.1	5.1	3.7 - 6.4	6.4	5.4 - 7.6
HIL-4	3.0	1.9 - 8.6	0.5	-0.1 - 1.7	0.8	0.2 - 5.4	2.7	0.4 - 4.7
HIL-5	7.4	7.0 - 7.7	6.5	6.3 - 6.9	5.8	5.5 - 6.1	6.4	6.2 - 6.5
HIL-6	---	---	5.2	4.9 - 6.2	6.3	5.8 - 7.3	7.6	6.9 - 8.9
HIL-7	7.3	6.1 - 9.6	9.2	1.2 - 17.1	3.9	2.8 - 5.8	8.5	5.8 - 12.1
HIL-8	3.9	2.0 - 6.4	2.3	0.7 - 4.7	1.6	0.9 - 4.5	5.5	4.2 - 6.6
HIL-9	8.0	7.1 - 9.0	6.2	6.0 - 6.5	5.9	5.7 - 6.2	7.3	6.6 - 8.0
HIL-10	8.5	8.0 - 9.2	6.9	6.0 - 8.2	6.2	5.7 - 6.9	7.9	7.0 - 9.1
HIL-11	8.3	7.9 - 8.7	6.5	6.4 - 6.6	7.0	6.9 - 7.4	9.1	3.1 - 11.2
MAN-1	2.2	1.5 - 3.3	1.2	0.5 - 2.2	0.6	0.1 - 2.1	3.6	2.4 - 5.5
MAN-2	5.8	3.4 - 9.7	5.8	0.6 - 12.9	4.0	1.0 - 10.0	7.1	4.2 - 10.8
MAN-3	9.3	7.4 - 10.9	5.1	3.4 - 6.0	6.6	4.9 - 8.7	8.2	7.3 - 9.1
PAS-1	4.9	4.6 - 5.2	5.0	4.6 - 5.6	5.4	5.1 - 6.0	4.8	3.9 - 5.4
PAS-2	3.2	2.8 - 3.9	3.1	2.2 - 4.7	1.6	1.4 - 2.1	2.7	2.6 - 2.9
PAS-3	5.5	5.1 - 6.0	5.1	4.5 - 6.0	3.4	3.0 - 4.0	5.6	4.7 - 7.1
PAS-4	4.0	3.7 - 4.4	4.3	3.7 - 4.8	4.0	3.6 - 4.4	4.2	3.6 - 4.6
PAS-5	4.8	4.4 - 5.3	5.1	4.7 - 5.6	5.4	5.2 - 5.8	4.1	3.4 - 4.6
PIN-1	8.0	7.3 - 9.1	6.6	6.2 - 7.6	6.6	6.0 - 7.0	7.2	6.8 - 7.9
PIN-2	4.1	0.1 - 12.2	1.5	0.1 - 5.4	0.7	0.2 - 2.7	1.0	0.3 - 3.6
PIN-3	3.5	1.1 - 6.0	0.8	0.1 - 4.1	0.9	0.3 - 3.8	0.7	0.1 - 2.9
POL-1	6.7	4.7 - 8.9	4.2	3.1 - 5.8	4.2	2.0 - 6.8	6.9	5.6 - 9.1
POL-2	9.2	7.1 - 11.8	3.6	0.2 - 10.1	4.9	1.1 - 10.5	6.8	3.7 - 12.3
POL-3	5.2	4.9 - 5.6	1.9	1.7 - 2.8	2.8	2.6 - 3.0	6.0	5.4 - 6.8
POL-4	---	---	2.7	2.4 - 3.3	3.5	3.2 - 4.1	7.2	5.9 - 9.8

As expected, DO concentrations were generally higher during Quarters 1 and 4 when lower water temperatures allow for more oxygen absorption. During Quarters 1 and 4 the number of stations with mean DO concentrations below the standard was nine and eight, respectively. Quarters 2 and 3 had 13 and 15 stations, respectively, with concentrations below the 5.0 mg/L standard.

The mean DO saturation percent (DO_{SAT}), the mean oxygen deficit (DO_D), and the percentage of DO values that fell below the water quality standard ($DO_{\% < 5}$) for each quarter are presented in Table 7. The mean saturation percent ranged from 5.9 to 119.7 percent across all stations and quarters. Saturation percentages above 100 percent indicate supersaturated conditions, usually resulting from algae blooms at the time of monitoring. Both the minimum and maximum saturation percent occurred during Quarter 2. Two stations (POL-2; Quarter 1 and HIL-7; Quarter 2) had mean saturation percents above 100 percent likely indicating the presence of an algae bloom at the time of sampling.

The mean oxygen deficit ranged from -1.5 to 8.4 mg/L across all stations and quarters. Two stations (POL-2; Quarter 1 and HIL-7; Quarter 2) had negative oxygen deficits and coincide with the super-saturation conditions at the same stations, during the same sampling events. The mean oxygen deficit across quarters was very similar ranging from 3.3 mg/L (Quarter 1) to 3.8 mg/L (Quarter 3), indicating no significant seasonal difference.

Also listed in Table 7 is the percentage of DO values that exceeded the state water quality standard during each quarter. Only four stations (HIL-5, HIL-9, HIL-10, and PIN-1) did not exceed the standard in any measurements during any quarter, none of which were characterized as reference stations by the LDI scores. The mean percentage of DO values below the standard during Quarters 1 and 4 was 36.1 and 33.5 percent, respectively. Quarters 2 and 3 had a mean of 57.1 and 55.4 percent of values below the standard, respectively. This pattern is expected showing warmer summer temperatures somewhat increase the likelihood dissolved oxygen may fall below the standard.

Table 7. Mean dissolved oxygen saturation percent, mean oxygen deficit, and percentage of dissolved oxygen values below Florida's water quality standard (5.0 mg/L), west-central Florida, 2005 – 2006.

Station ID	**Dissolved Oxygen (mg/L)**											
	Quarter 1			**Quarter 2**			**Quarter 3**			**Quarter 4**		
	DO_{SAT} (%)	**DO_{D} (mg/L)**	**$DO_{\% < 5}$ (%)**	**DO_{SAT} (%)**	**DO_{D} (mg/L)**	**$DO_{\% < 5}$ (%)**	**DO_{SAT} (%)**	**DO_{D} (mg/L)**	**$DO_{\% < 5}$ (%)**	**DO_{SAT} (%)**	**DO_{D} (mg/L)**	**$DO_{\% < 5}$ (%)**
HIL-1	69.38	2.84	0.00	51.58	3.97	95.01	48.08	4.04	97.36	76.55	2.29	0.00
HIL-2	79.04	1.79	0.00	74.25	2.07	10.39	73.47	2.09	0.00	74.99	2.21	0.00
HIL-3	59.21	3.80	28.72	45.14	4.46	98.96	66.31	2.59	60.31	64.92	3.46	0.00
HIL-4	30.40	6.93	92.82	5.89	7.62	100.00	10.48	6.79	99.74	29.46	6.37	100.00
HIL-5	79.56	1.90	0.00	77.94	1.84	0.00	71.89	2.27	0.00	72.93	2.38	0.00
HIL-6	---	---	---	67.09	2.57	5.87	74.65	2.15	0.00	76.96	2.29	0.00
HIL-7	79.25	1.91	0.00	119.65	-1.51	33.20	50.31	3.90	93.80	87.44	1.23	0.00
HIL-8	42.01	5.32	82.06	29.06	5.49	100.00	20.39	6.20	100.00	56.44	4.26	14.36
HIL-9	81.80	1.79	0.00	74.64	2.12	0.00	73.85	2.10	0.00	80.25	1.78	0.00
HIL-10	89.39	1.01	0.00	84.75	1.23	0.00	78.55	1.69	0.00	88.23	1.05	0.00
HIL-11	90.92	0.83	0.00	82.36	1.39	0.00	86.35	1.11	0.00	86.08	1.48	7.63
MAN-1	25.03	6.47	100.00	14.54	6.77	100.00	7.19	7.21	100.00	34.73	6.77	88.54
MAN-2	65.78	3.02	50.13	76.30	1.82	46.35	52.08	3.66	64.14	72.49	2.68	11.86
MAN-3	97.15	0.27	0.00	61.78	3.18	30.57	80.26	1.61	0.80	79.97	2.06	0.00
PAS-1	55.03	3.97	79.95	61.30	3.17	52.91	65.54	2.82	0.00	50.74	4.63	78.40
PAS-2	36.28	5.65	100.00	37.26	5.20	100.00	20.61	6.22	100.00	30.36	6.30	100.00
PAS-3	60.47	3.59	0.00	60.08	3.37	33.77	41.60	4.79	100.00	57.20	4.22	26.75
PAS-4	45.99	4.76	100.00	51.59	4.00	100.00	48.23	4.26	100.00	45.11	5.13	100.00
PAS-5	54.90	3.97	68.78	62.27	3.09	47.49	66.54	2.74	0.00	43.61	5.25	100.00
PIN-1	87.72	1.13	0.00	81.88	1.47	0.00	85.86	1.08	0.00	84.80	1.30	0.00
PIN-2	46.68	4.73	61.48	19.59	6.21	95.10	9.56	6.69	100.00	11.70	7.69	100.00
PIN-3	36.53	6.13	86.61	9.78	7.36	100.00	11.87	6.75	100.00	7.83	8.39	100.00
POL-1	69.97	2.88	5.46	52.45	3.83	73.74	55.32	3.40	67.01	78.35	1.91	0.00
POL-2	100.07	-0.01	0.00	47.83	3.91	62.27	68.37	2.25	58.18	81.03	1.59	43.23
POL-3	59.50	3.51	10.08	23.96	5.93	100.00	34.65	5.21	100.00	62.24	3.62	0.00
POL-4	---	---	---	34.62	5.09	100.00	44.39	4.40	100.00	76.21	2.23	0.00

Nutrients and Chlorophyll-*a*

In this study nutrient and chlorophyll-*a* data are used as antecedent variables, included to help explain the observed relationships between dissolved oxygen regimes and LDI scores, representing the gradient of human disturbance. Table 8 presents the range and mean nutrient and chlorophyll-*a* data collected at all stations.

Nitrate+Nitrite (N+N) ranged from 0.002 to 1.28 mg/L across all 26 stations with a mean of 0.25 mg/L. Total Kjeldahl nitrogen (TKN), the sum of organic nitrogen and ammonia, ranged from 0.47 to 1.76 mg/L, with a mean of 1.01 mg/L at all stations. Total nitrogen (sum of nitrate+nitrite and TKN) at all stations, with the exception of station HIL-5, was dominated by TKN, indicating a predominance of organic nitrogen over other forms. Total nitrogen (TN) ranged from 0.58 to 2.05 mg/L with a mean of 1.30 mg/L at all stations. In the quarterly samples collected during this assessment, mean total phosphorus (TP) ranged from 0.06 to 0.78 mg/L with a mean of 0.27 mg/L. Mean chlorophyll-*a* concentrations (corrected for phaeophytin) ranged from a low of 0.28 to a high of 19.08 µg/L during thus study, with a mean of 2.9 µg/L.

Table 8. Mean and range values for nutrients and chlorophyll-*a*, west-central Florida, 2005 – 2006.

Station ID	**Nitrate+Nitrite (mg/L)**		**Total Kjeldahl Nitrogen (mg/L)**		**Total Nitrogen (mg/L)**		**Total Phosphorus (mg/L)**		**Chlorophyll-*a* (µg/L)**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
HIL-1	0.15	0.04 - 0.33	1.23	0.98 - 1.46	1.35	1.1 - 1.77	0.27	0.17 - 0.37	8.26	0.05 - 16.0
HIL-2	0.38	0.08 - 0.57	0.85	0.75 - 1.02	1.19	0.92 - 1.38	0.15	0.09 - 0.21	0.76	0.05 - 2.0
HIL-3	0.24	0.14 - 0.34	1.02	0.72 - 1.35	1.26	0.89 - 1.49	0.08	0.04 - 0.13	1.65	1.1 - 2.7
HIL-4	0.01	0.002 - 0.02	1.29	0.47 - 2.14	1.50	1.08 - 2.14	0.22	0.04 - 0.37	2.83	0.5 - 7.5
HIL-5	1.28	0.97 - 1.5	0.47	0.29 - 0.76	1.74	1.36 - 1.93	0.16	0.11 - 0.23	0.33	0.05 - 1.1
HIL-6	0.90	0.3 - 1.23	1.12	0.8 - 1.44	2.01	1.74 - 2.34	0.39	0.24 - 0.64	3.03	1.1 - 6.9
HIL-7	0.06	0.01 - 0.1	0.89	0.58 - 1.22	0.98	0.66 - 1.26	0.23	0.14 - 0.36	1.25	0.5 - 2.1
HIL-8	0.02	0.002 - 0.03	1.27	0.56 - 2.64	1.46	0.63 - 2.67	0.23	0.09 - 0.55	3.53	1.3 - 6.4
HIL-9	0.28	0.21 - 0.36	0.74	0.57 - 1.04	1.05	0.92 - 1.25	0.66	0.49 - 0.8	1.21	0.05 - 2.1
HIL-10	0.06	0.04 - 0.07	0.68	0.52 - 0.84	0.77	0.58 - 0.91	0.44	0.32 - 0.61	3.48	0.5 - 7.5
HIL-11	0.59	0.19 - 0.95	0.62	0.4 - 0.82	1.33	1.04 - 1.71	0.45	0.29 - 0.57	0.81	0.05 - 1.6
MAN-1	0.002	0.002 - 0.002	1.38	1.15 - 1.56	1.43	1.38 - 1.56	0.35	0.22 - 0.52	1.84	0.05 - 5.3
MAN-2	0.22	0.17 - 0.3	0.75	0.52 - 1.14	1.01	0.7 - 1.44	0.22	0.13 - 0.38	1.73	0.5 - 4.3
MAN-3	0.50	0.11 - 1.56	1.24	0.72 - 1.79	1.87	0.83 - 3.35	0.78	0.59 - 0.94	0.98	0.5 - 1.2
PAS-1	0.08	0.02 - 0.13	0.63	0.22 - 0.87	0.70	0.31 - 0.89	0.06	0.05 - 0.06	0.28	0.05 - 0.5
PAS-2	0.02	0.002 - 0.03	1.60	1.21 - 1.99	1.71	1.39 - 1.99	0.09	0.06 - 0.16	0.91	0.05 - 2.0
PAS-3	0.02	0.002 - 0.05	1.48	0.84 - 2.27	1.65	1.21 - 2.27	0.09	0.04 - 0.13	1.28	0.5 - 2.1
PAS-4	0.06	0.04 - 0.08	0.68	0.58 - 0.84	0.58	0.04 - 0.88	0.06	0.05 - 0.06	0.41	0.05 - 0.6
PAS-5	0.08	0.02 - 0.13	0.74	0.3 - 0.99	0.80	0.41 - 1.01	0.07	0.05 - 0.09	0.31	0.05 - 1.1
PIN-1	0.56	0.14 - 1.58	0.76	0.56 - 0.93	1.41	0.76 - 2.51	0.49	0.31 - 0.72	0.68	0.5 - 1.2
PIN-2	0.05	0.002 - 0.18	0.78	0.62 - 0.87	0.84	0.62 - 1.02	0.14	0.1 - 0.21	2.70	0.7 - 5.3
PIN-3	0.05	0.01 - 0.12	1.76	0.8 - 4.32	2.05	0.9 - 4.33	0.35	0.18 - 0.82	3.40	1.6 - 4.8
POL-1	0.45	0.17 - 0.63	1.20	1.03 - 1.49	1.69	1.29 - 2.12	0.46	0.37 - 0.59	7.75	4.3 - 10.7
POL-2	0.09	0.02 - 0.23	1.26	0.92 - 1.7	1.25	1.0 - 1.49	0.35	0.23 - 0.52	19.08	5.0 - 39.2
POL-3	0.08	0.02 - 0.16	0.76	0.52 - 0.94	0.85	0.68 - 0.96	0.09	0.04 - 0.16	0.93	0.5 - 1.1
POL-4	0.21	0.08 - 0.31	0.99	0.84 - 1.17	1.20	0.99 - 1.48	0.12	0.08 - 0.18	5.95	3.2 - 8.5

Stream Condition Index (SCI)

Macroinvertebrate assemblages are quantified using the Stream Condition Index (SCI) to assess the biological integrity of the stream reaches in this study. SCI scores were calculated for each stream reach twice during the sampling period (2005-2006) and results are presented in Table 9. Macroinvertebrate samples were collected once during the summer months (Quarter 2) and once during the winter months (Quarter 4). At station PIN-3, only the SCI conducted during Quarter 2 resulted in useable data.

During the summer of 2005 SCI scores ranged from a low of six (POL-1) to a high of 61 (HIL-5). Eighteen of the 26 stations assessed during the summer are categorized as “impaired” according to Fore et al. (2007). The remaining eight stations were categorized as “healthy.” SCI scores calculated during the winter months (Quarter 4) ranged from 11 (POL-1) to 71 (HIL-5) with the high and low scores occurring at the same stations as the summer scores. Fifteen stations fall in the “impaired” category, with another nine categorized as “healthy,” and one station rated as “exceptional” (Fore et al. 2007). Twelve of the stations in this study had SCI scores that fell in the “impaired” category during both of the assessments conducted.

Table 9. Stream Condition Index scores and aquatic life use categories, west-central Florida, 2005 – 2006.

Station ID	**Stream Condition Index**			
	Summer (Quarter 2)		**Winter (Quarter 4)**	
	Score	**Aquatic Life Use Category***	**Score**	**Aquatic Life Use Category***
HIL-1	16	impaired	13	impaired
HIL-2	28	impaired	35	healthy
HIL-3	44	healthy	34	impaired
HIL-4	10	impaired	25	impaired
HIL-5	61	healthy	71	exceptional
HIL-6	41	healthy	34	impaired
HIL-7	31	impaired	26	impaired
HIL-8	19	impaired	24	impaired
HIL-9	47	healthy	52	healthy
HIL-10	41	healthy	46	healthy
HIL-11	53	healthy	46	healthy
MAN-1	19	impaired	35	healthy
MAN-2	33	impaired	22	impaired
MAN-3	23	impaired	32	impaired
PAS-1	30	impaired	40	healthy
PAS-2	11	impaired	18	impaired
PAS-3	23	impaired	36	healthy
PAS-4	50	healthy	44	healthy
PAS-5	29	impaired	31	impaired
PIN-1	26	impaired	18	impaired
PIN-2	12	impaired	14	impaired
PIN-3	7	impaired	---	---
POL-1	6	impaired	11	impaired
POL-2	11	impaired	29	impaired
POL-3	39	healthy	30	impaired
POL-4	25	impaired	53	healthy

* Source - (Fore et al. 2007)

ANALYSIS AND DISCUSSION

This chapter provides the analyses of the data collection effort for this study. Relationships between intensity of human land use, dissolved oxygen, nutrients, chlorophyll-*a*, and stream biological integrity are discussed. Correlation analyses were successful in indentifying these relationships and provide insight into causative factors affecting dissolved oxygen regimes in the subject streams.

Dissolved Oxygen, Nutrients, and Chlorophyll-*a*

Correlation analysis serves to identify relationships between the variables and better understand how intensity of human land uses affects dissolved oxygen regimes in streams. Table 10 presents the Spearman rank order correlation values calculated for LDI, dissolved oxygen, and nutrient concentrations over the year long study. Significant correlations ($p < 0.05$) are in bold.

Table 10. Spearman correlations for dissolved oxygen, LDI, nutrients, and chlorophyll-*a* concentrations, west-central Florida, 2005 – 2006.

Parameter	**LDI**	**TKN**	**N+N**	**TN**	**TP**	**Chlorophyll-*a***
LDI		0.04	**0.24**	0.09	**0.32**	**0.28**
DO_{M}	0.11	**-0.33**	**0.58**	-0.01	**0.28**	-0.15
DO_{R}	**0.54**	**0.24**	-0.08	0.08	**0.29**	**0.56**
DO_{D}	-0.16	**0.27**	**-0.6**	-0.03	**-0.38**	0.09
$\mathrm{DO}_{\% < 5}$	-0.14	**0.28**	**-0.6**	-0.07	**-0.29**	0.17

Bold values indicate significant correlations ($p < 0.05$)

As the table shows, mean DO range was the only measure of dissolved oxygen significantly correlated (Spearman $r = 0.54$, $p < 0.001$) with the LDI scores when evaluated over all quarters. Diel variation in dissolved oxygen increased with increasing intensity of human land use in the surrounding watershed (Figure 4). This is not surprising as other studies have linked increased diel variation in streams to anthropogenic sources such as increased impervious area (Walsh et al. 2005). Catchment imperviousness has been linked to reduced baseflow and flashier hydrographs leading to increased diel variation in urban settings (Meyer et al. 2005 and Walsh et al. 2005). Land uses with higher LDI scores can be expected to experience higher amounts of catchment imperviousness as well as greater effects of point and non-point source runoff. Monitoring stations with LDI scores ≤ 2 (reference streams) showed diel variations generally less than 2.0 mg/L during all quarters, indicating relatively stable oxygen concentrations throughout the day and night (see Figure 4).

The other measures of dissolved oxygen in this study (mean concentration, mean deficit, and percent of exceedances) did not correlate with the gradient of human disturbance (LDI) when all stations were viewed over all quarters. As expected, mean dissolved oxygen values tend to be lower during the warmer months (quarters 2 and 3) at all stations, although viewing the measures of dissolved oxygen on a quarterly basis did not produce any significant results with respect to LDI scores.

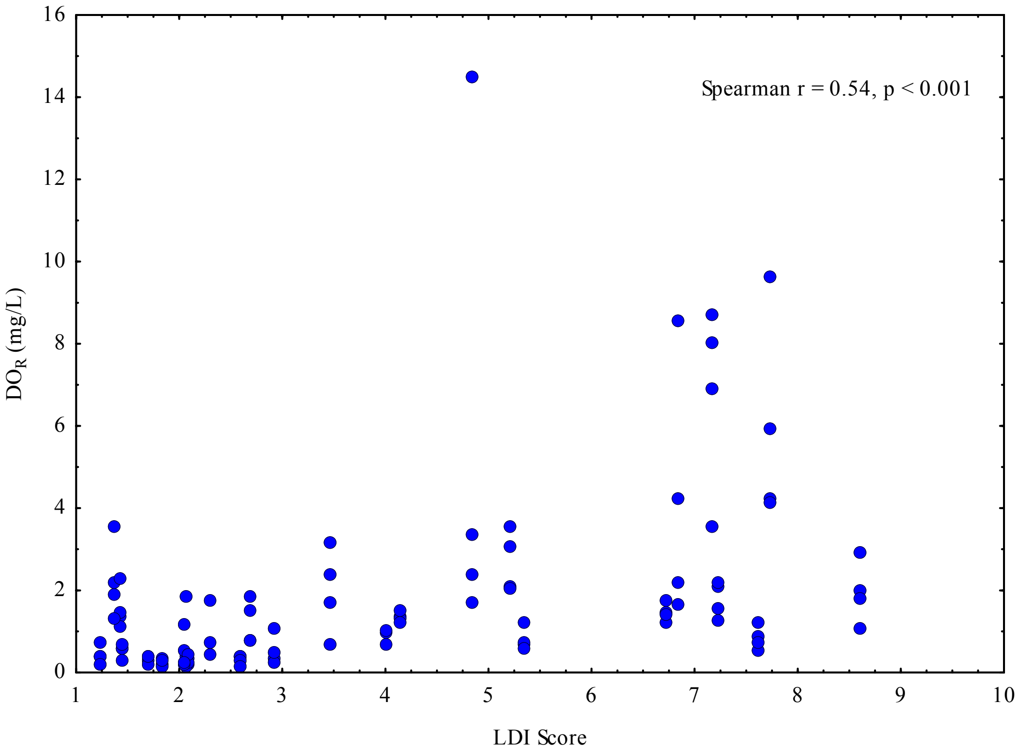


Figure 4. Mean dissolved oxygen range (DO_R) for each deployment and LDI score over all quarters.

Mean dissolved oxygen (DO_M) calculated over each four day deployment generally exceeded Florida's fresh water quality standard (5.0 mg/L) at the reference stations in this study (HIL-8, MAN-1, PAS-3, PAS-4, PAS-5, and POL-3) during most quarters (Figure 5). These stations, as determined by the LDI score, are those in areas with the least non-renewable energy consumption and exhibit natural conditions with little to no impact from human activities (Brown and Vivas 2005). The majority of the reference streams are dominated by heavy canopy cover (PAS-3, PAS-4, PAS-5, and POL-3) and reduced sunlight penetration can lead to reduced photosynthesis in the aquatic system causing lower overall dissolved oxygen values compared to more open systems (Roy et al. 2005). The data support this claim showing a significant positive correlation between LDI score and chlorophyll-*a* concentrations (see Table 10). Another of the reference stations (MAN-1), has an open canopy, but is located immediately downstream of a large groundwater fed wetland system which serves as the stream's headwaters. Groundwater wetland systems typically have low dissolved oxygen and this most likely explains the low overall mean oxygen concentration recorded at this reference station. These data indicate the natural systems identified in this study, through the use of the LDI scores, may be characterized as impacted for dissolved oxygen even though human activity and influence in these catchments is expected to be very low.

Mean dissolved oxygen values calculated from monitoring stations with high LDI scores (LDI scores 6 – 9) also exceeded the state standard on the majority of occasions (see Figure 5). Land uses represented by these LDI scores tend to indicate high intensity agriculture, medium to high density residential, low intensity commercial, and industrial (Brown and Vivas 2005). While these stations typically exhibit less canopy cover than the reference stations, the overall low oxygen concentrations (below the standard) observed during most quarters is likely the result of physical alterations to stream channels, such as channelization (described below), in areas of more intense human land use.

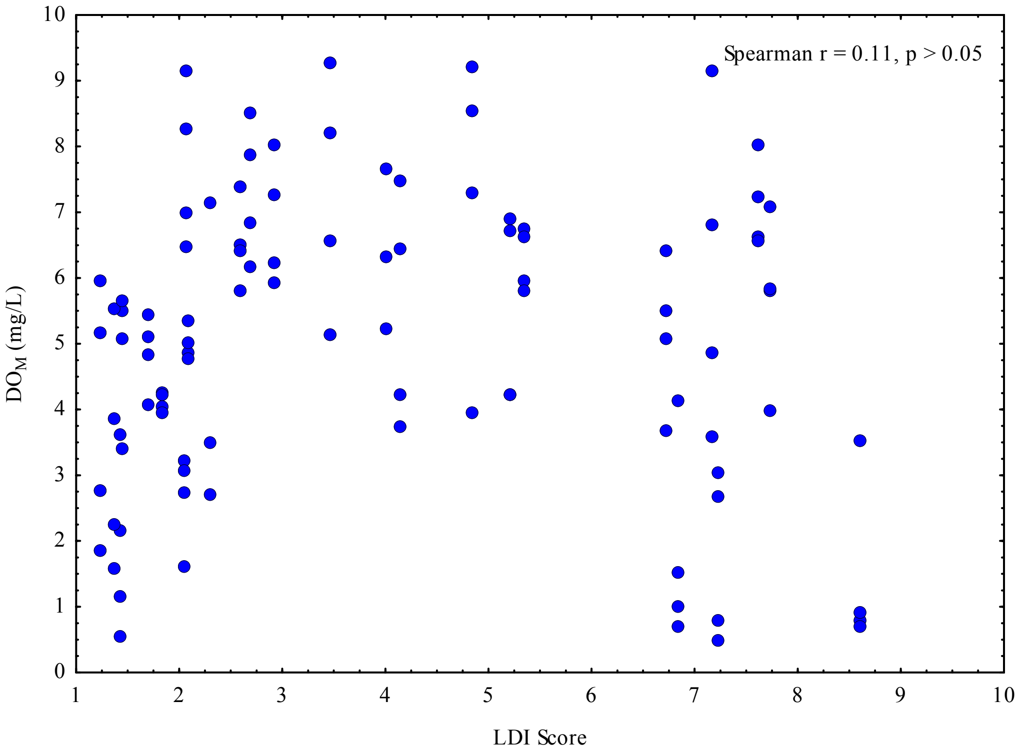


Figure 5. Mean dissolved oxygen (DO_M) values for each deployment and LDI score over all quarters.

Monitoring stations represented by LDI scores along the middle of the gradient (LDI scores 2 – 6) generally had higher mean oxygen values during all quarters than the reference or high human intensity stations. The land uses in this category tend to be dominated by agriculture including pasture, citrus and row crops (Brown and Vivas 2005). The stream systems located in agriculture dominated areas tend to have little to no canopy cover and receive direct sunlight allowing for increased photosynthesis compared to more shaded systems leading to increased overall DO. In addition, these streams are subject to increased groundwater inputs from irrigation which may be clearer allowing for less light attenuation.

An evaluation of nutrient concentrations was included in this study to determine if nutrients could help explain shifts in dissolved oxygen regimes as a result of increasing human disturbance. As previously mentioned, many studies have linked excess nutrients to anthropogenic sources and urban land uses, as well as depletion of oxygen in aquatic systems (Mallin et al 2006, MacPerson et al 2007, National Research Council 2000, Wang et al 2003, and Wilcock 1986). In this study the LDI scores were not significantly correlated with TKN (organic nitrogen and ammonia) or total nitrogen (see Table 10). Significant positive correlations ($p < 0.05$) were observed between LDI and inorganic nitrogen (N+N) (Spearman $r = 0.24$, $p = 0.01$) and TP (Spearman $r = 0.32$, $p = 0.001$). Although only a weak correlation was observed in this data set, the findings coincide with previous studies showing increased nutrient concentrations in watersheds of increasing intensity of human activity.

Measures of dissolved oxygen were significantly correlated with nutrient concentrations, with the exception of total nitrogen (see Table 10); suggesting nutrient concentrations play a significant role in the dissolved oxygen regime of an aquatic system. TKN was significantly correlated with measures of dissolved oxygen when viewing all deployments over all quarters. TKN was negatively correlated with mean dissolved oxygen and positively correlated with the DO range, oxygen deficit, and the percentage of exceedances. This is not an unexpected finding as increasing organic nitrogen leads to increased demand for oxygen and therefore reduced DO levels. The increased demand for oxygen can also explain the positive correlations between oxygen deficit and TKN (Spearman $r = 0.27$, $p = 0.006$) as well as percentage of exceedances and TKN (Spearman $r = 0.28$, $p = 0.004$).

Significant results were obtained by evaluated inorganic nitrogen with measures of dissolved oxygen. When comparing all deployments over all quarters, inorganic nitrogen showed a strong positive correlation with mean dissolved oxygen (Spearman $r = 0.58$, $p < 0.001$) (Figure 6) and strong negative correlations with mean oxygen deficit (Spearman $r = -0.60$, $p < 0.001$) and percentage of exceedances (Spearman $r = -0.60$, $p < 0.001$). The majority of nitrate+nitrite reported in this study was in the form of nitrate, indicating nitrification was occurring to breakdown toxic nitrite into nitrate. The nitrification process requires oxygen and therefore it is not surprising to find increased levels of nitrate when the availability of oxygen is also increased. The strong negative correlation between nitrate+nitrite and oxygen deficit and percentage of exceedances further indicates the presence of adequate oxygen allowing for the conversion of nitrite to nitrate. The presence of strong correlation between measures of oxygen and inorganic nitrogen does not indicate the nitrogen is in any way causing increased oxygen, but rather, the availability of oxygen allows for the breakdown of toxic nitrite into less toxic nitrate.

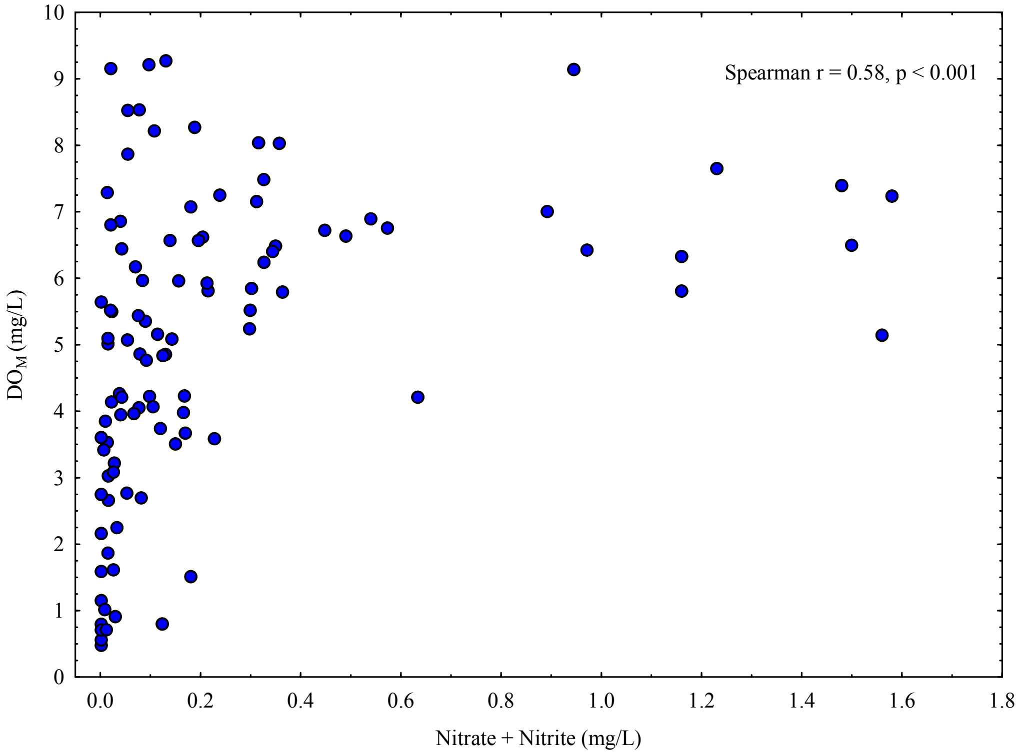


Figure 6. Mean dissolved oxygen (DO$_M$) and nitrate+nitrite values for each deployment over all quarters.

Total phosphorus (TP) was correlated with the LDI scores as well as all measures of dissolved oxygen used in this study. The mean dissolved oxygen concentration recorded over each deployment and the mean dissolved oxygen range showed a significant positive correlation with total phosphorus concentrations (Spearman r = 0.28 and 0.29, p = 0.005 and 0.003, respectively). In addition, the mean oxygen deficit and percentage of exceedances showed a significant negative correlation with TP (Spearman r = -0.38 and -0.29, p = < 0.001 and 0.004, respectively). The reason for these significant correlations is likely linked to primary production and is supported in the data. Chlorophyll-*a* concentrations were significantly correlated with TP concentrations (Spearman r = 0.32, p = 0.01). Phosphorus is generally considered to be the limiting nutrient for phytoplankton growth in freshwater systems (Hecky and Kilham 1988 and Mallin et al. 2004). Therefore it is appropriate to assume that as phosphorus concentrations observed in this study increase, the ability of phytoplankton to bloom also increases. While chlorophyll-*a* concentrations were not correlated with the overall mean oxygen values in this study, chlorophyll-*a* showed a significant positive correlation with the mean oxygen range (Spearman $r = 0.56$, $p < 0.001$). Photosynthesis during the day and respiration at night by phytoplankton communities results in large diel swings in dissolved oxygen. These variations can have a significant effect on the oxygen regime of a stream system and can help to explain the correlation between dissolved oxygen and phosphorus observed in this study.

Phosphorus and chlorophyll-*a* concentrations were also positively correlated with LDI scores (Spearman $r = 0.32$ and 0.28, $p = 0.001$ and 0.005, respectively) indicating a link between the intensity of human land use, phosphorus inputs, and subsequent increase in primary production. This relationship helps to explain the link between the diel variation (DO_R) observed and LDI scores. As the intensity of land use increases phosphorus inputs to stream systems through point and non-point sources such as agriculture and urban runoff also increase, resulting in increased primary production which, in turn, increases the diel range of dissolved oxygen values. This relationship in conjunction with the increased catchment imperviousness expected with higher LDI scores, work together to explain the observed relationship between LDI, nutrients, and dissolved oxygen.

The Role of Stream Morphology

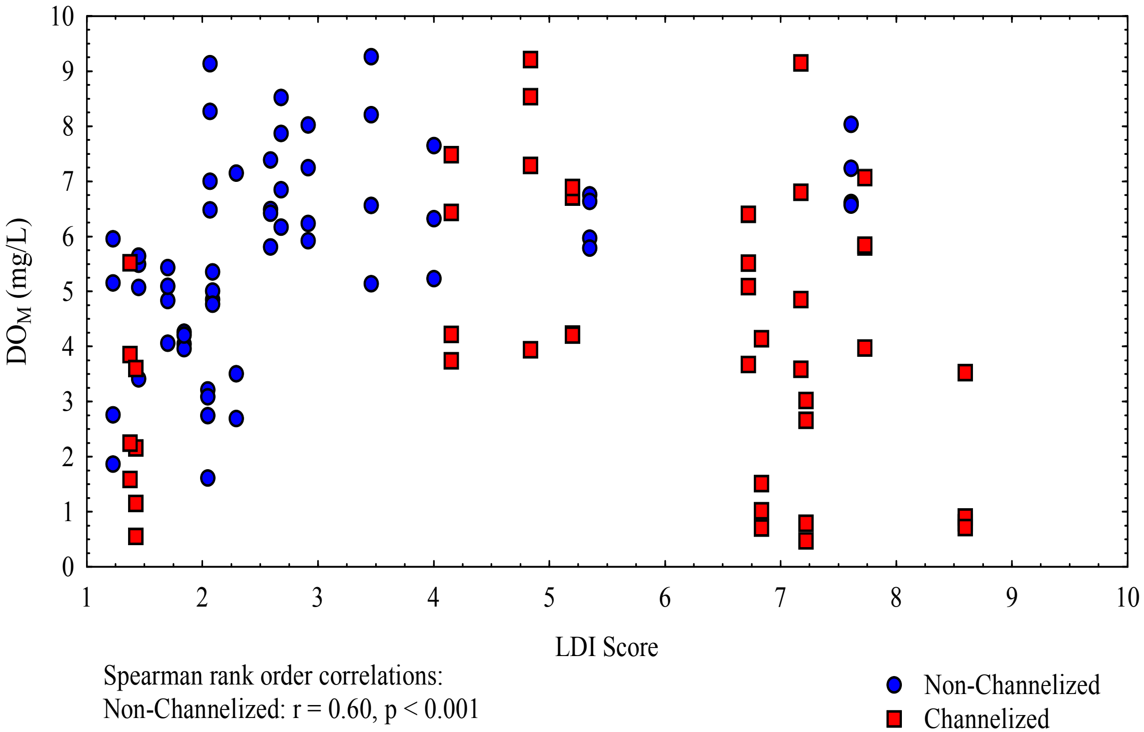
As previously explained, the calculation of the LDI score is based on non-renewable energy flow and does not directly account for physical alterations to stream systems that may occur as a result of human activity in a watershed. In fact, the stream itself is not included in the LDI calculation. Previous studies have linked altered channel morphology to degradation in water quality including dissolved oxygen (Brilly et al. 2006, Meyer et al. 2005, Paul and Meyer 2001, and Walsh et al. 2005). It is not possible for the LDI calculation to account for stream morphology other than to suggest that higher LDI scores are more likely to occur in places where the stream channel has been altered as a result of increased human activity. In order to account for differences in dissolved oxygen regimes that occur as a result of physical alterations to stream morphology, the dataset presented in this study was separated into non-channelized and channelized systems. Each subset of the data was then subjected to the same correlation analyses presented above to determine if stream morphology significantly alters the relationship between dissolved oxygen and intensity of human land uses.

Fifteen of the 26 stations fall into the non-channelized category with at least one station found in each county included in this study. Four of the six reference stations (LDI score ≤ 2.0) are non-channelized and only two stations have LDI scores above 5.0 (HIL-2 – 5.35 and PIN-1 – 7.61). Non-channelized systems tend to fall on the lower end of the LDI scale while the channelized systems tend to fall on the higher end of the scale (Table 11). Eleven of the 26 stations were channelized and included two of the reference stations (HIL-8 – 1.38 and MAN-1 – 1.42). MAN-1 is located in Manatee County, FL and drains a large tract of wetland area with little human activity. Although MAN-1 is a channelized stream at the station location, the majority of the upstream basin for which the LDI was calculated encompasses wetland areas described as freshwater marshes and wet prairies by FLUCCS (see Appendix A). Station HIL-8 is located along Delany Creek in Hillsborough County, FL and is included as a channelized stream because the system is altered to include a retention basin at the station location. However, the headwaters of Delany Creek are located just upstream of the sampling location and therefore the LDI could only be calculated for a short distance of the upstream basin and only included an approximate 96,000+ square meters of area (see Appendix A). In contrast, LDI calculations in stream systems for which the entire 10km of upstream basin can be calculated encompass 2,000,000 square meters. The area of influence for which the LDI was calculated was dominated by shrub and brushland and conifer mixed hardwood. This resulted in a channelized system (HIL-8) with one of the lowest LDI scores in this project. The rest of the channelized streams had LDI scores ranging from 4.15 (HIL-1) to 8.60 (PIN-3).

Table 11. Breakdown of LDI scores for channelized and non-channelized streams, west-central Florida, 2005 – 2006.

Non-Channelized		**Channelized**	
Station ID	**LDI Score**	**Station ID**	**LDI Score**
HIL-2	5.35	HIL-1	4.15
HIL-5	2.59	HIL-3	6.72
HIL-6	4.00	HIL-4	7.22
HIL-9	2.91	HIL-7	4.84
HIL-10	2.68	HIL-8	1.38
HIL-11	2.07	MAN-1	1.42
MAN-3	3.46	MAN-2	7.73
PAS-1	2.09	PIN-2	6.83
PAS-2	2.05	PIN-3	8.60
PAS-3	1.45	POL-1	5.20
PAS-4	1.84	POL-2	7.18
PAS-5	1.70		
PIN-1	7.61		
POL-3	1.23		
POL-4	2.29		

This exercise illustrates significant differences in the behavior of dissolved oxygen in channelized and non-channelized streams. In addition, it provides valuable insight into understanding the relationship between dissolved oxygen and the intensity of human land use. Figure 7 presents the mean oxygen concentrations and LDI scores separated into channelized and non-channelized systems, while Table 12 provides the results of correlation analyses. As Figure 7 indicates, non-channelized streams tend to be concentrated on the lower end of the LDI scale, representing areas of less intense land use. In contrast, the channelized systems in this study tend to concentrate on the higher end of the LDI scale, indicating channelized streams are more likely to be found in areas of higher intensity land use. While this result is not surprising, it is important to note as this relationship plays an important role in understanding how dissolved oxygen is affected by increasing intensity of human land use.



Spearman rank order correlations:
Non-Channelized: $r = 0.60$, $p < 0.001$
Channelized: $r = -0.15$, $p > 0.05$

Figure 7. Mean dissolved oxygen concentrations (DO_M) and LDI scores for non-channelized and channelized streams over all quarters in west-central Florida.

Table 12. Spearman rank order correlations for dissolved oxygen, LDI, nutrients, and chlorophyll-*a* concentrations in non-channelized and channelized streams, west-central Florida, 2005 – 2006.

	LDI		**TKN**		**N+N**		**TN**		**TP**		**Chlorophyll-*a***	
	Non-Chan	**Chan**	**Non-Chan**	**Chan**	**Non-Chan**	**Chan**	**Non-Chan**	**Chan**	**Non-Chan**	**Chan**	**Non-Chan**	**Chan**
LDI			-0.03	-0.19	**0.61**	0.16	**0.27**	-0.12	**0.68**	-0.07	0.13	0.03
DO_M	**0.6**	-0.15	**-0.34**	-0.19	**0.58**	**0.57**	0.07	-0.04	**0.6**	-0.07	0.09	0.01
DO_R	**0.51**	**0.3**	0.12	-0.25	0.24	0.26	0.16	-0.19	**0.41**	0.03	**0.45**	0.24
DO_D	**-0.66**	0.08	**0.26**	0.11	**-0.53**	**-0.61**	-0.05	-0.03	**-0.68**	-0.04	-0.1	-0.13
$DO_{\% < 5}$	**-0.57**	0.06	0.26	0.19	**-0.6**	**-0.57**	-0.13	0.01	**-0.5**	0.13	-0.02	-0.03

Non-Chan - Non-Channelized Stream

Chan - Channelized Stream

Bold values indicate significant correlations ($p < 0.05$)

When viewing non-channelized systems, all measures of dissolved oxygen showed strong significant correlations with LDI scores (Table 12). Mean dissolved oxygen (Figure 7) and mean dissolved oxygen range showed strong positive correlations (Spearman r = 0.6 and 0.51, respectively, $p < 0.001$), while mean oxygen deficit and percentage of exceedances showed strong negative correlations (Spearman r = -0.66 and -0.57, respectively, $p < 0.001$). The same relationship was not observed in the channelized streams. As Figure 7 shows, mean dissolved oxygen was not correlated with LDI scores for the channelized streams. The LDI only showed a significant correlation with mean oxygen range (Spearman r = 0.3, p = 0.04), similar to viewing all stations together. Two channelized systems (HIL-8 and MAN-1, described above) are outliers, with low LDI scores. However, with these two stations removed the correlation between dissolved oxygen and LDI is no more significant than with the outliers included. This indicates a much stronger relationship is evident between oxygen and intensity of human land use in streams that have not been physically altered. In non-channelized systems, as land uses become more intense with human activity the overall concentrations of dissolved oxygen increase, fluctuate closer to the saturation level, and fewer exceedances of Florida's state water quality standard are observed. The same relationship was observed for each quarter and no significant seasonal differences were identified.

The data indicate nutrients play an important role in understanding the relationship between dissolved oxygen and LDI score in the non-channelized and channelized systems. Inorganic nitrogen and total phosphorus in the non-channelized systems were positively correlated with LDI scores (Spearman r = 0.61 and 0.68, respectively, $p < 0.001$). Nutrient data collected from channelized streams were not correlated with LDI score in any case. This likely indicates the relationship between nutrients and intensity of human land use is more evident when the channel of a stream has not been altered.

Measures of dissolved oxygen showed significant correlations to nutrient concentrations, especially in the non-channelized streams. TKN (organic nitrogen and ammonia) was correlated with mean dissolved oxygen (Spearman $r = -0.34$, $p = 0.01$) and oxygen deficit (Spearman $r = 0.26$, $p = 0.048$) in the non-channelized systems, but was not correlated in the channelized streams. Inorganic nitrogen (N+N) showed a strong correlation with most measures of dissolved oxygen in both the non-channelized and channelized streams (see Table 12). These results are consistent with viewing all stations together.

Total phosphorus showed no relationship with measures of dissolved oxygen in the channelized systems, but showed strong correlations in the non-channelized streams. Total phosphorus showed a strong positive correlation with mean dissolved oxygen values and mean oxygen range (Spearman $r = 0.6$ and 0.41, $p < 0.001$ and $p = 0.001$, respectively) while exhibiting a strong negative correlation with mean oxygen deficit and percentage of exceedances (Spearman $r = -0.68$ and -0.50, $p < 0.001$, respectively). This relationship between dissolved oxygen and phosphorus concentrations is similar to that observed when viewing all stations together, although the correlations in non-channelized systems were much stronger.

As previously described, phosphorus is typically the limiting nutrient in freshwater systems and is responsible for the growth and bloom of phytoplankton and other aquatic plant communities. In the non-channelized systems phosphorus concentrations were significantly positively correlated with chlorophyll-*a* concentrations (Spearman r = 0.30, p = 0.02). As a result, the chlorophyll-*a* concentrations show a strong relationship with the diel variation (DO_R) in non-channelized streams (Spearman r = 0.45, p < 0.001) from the photosynthetic and respiratory functions of microbial and algal communities. This relationship helps to explain the correlation between the mean oxygen range, phosphorus, and chlorophyll observed in this study and may also help to explain the correlation between other measures of oxygen and phosphorus. Research indicates as algal communities produce and consume oxygen through normal metabolic processes, they typically produce more oxygen during photosynthesis than they consume during dark respiration resulting in a net increase in oxygen concentration (Platt 1981). An increase in algal community as a result of increased phosphorus inputs to streams could therefore help to explain the relationship between phosphorus and dissolved oxygen observed. The sestonic chlorophyll-*a* data used in this study only partially exhibit this relationship (see Table 12), however studies have indicated sestonic chlorophyll concentrations may not be the appropriate method to fully explore these scenarios (Morgan et al. 2006). Morgan et al. (2006) suggest biomass of filamentous algae may be a better indicator of primary production, and further research should be conducted to determine if this variable provides more significant relationships in this data set.

Stream morphology has shown to be a significant factor in identifying relationships between dissolved oxygen and human land use intensity. The non-channelized streams located throughout west-central Florida used in this project show a significant relationship between dissolved oxygen and the intensity of human land use.

Measures of oxygen, with the exception of mean dissolved oxygen range, seem to show improvement as the intensity of human land use in the surrounding watershed increases. With increasing LDI scores the overall mean dissolved oxygen value increases and the mean oxygen deficit and percent of exceedances decreases. Total phosphorus seems to pay an important role in understanding this relationship. Increased primary production as a result of increased phosphorus inputs in land uses of more intense human activity seem to account for at least some of the relationship between dissolved oxygen and LDI scores. The same relationship was not apparent in the channelized systems. The physical alteration of channelized streams (such as straight, deep, incised channels) can have significant affects on dissolved oxygen and may obscure the relationship between dissolved oxygen, nutrients, and chlorophyll-*a*. Other physical factors affecting dissolved oxygen in channelized streams were not included in this study and therefore cannot be fully explored. However, the relationships observed here indicate that nutrient inputs as well as physical alteration of the stream channel are significant factors affecting dissolved oxygen along a gradient of human disturbance.

Biological Integrity of Streams

The Stream Condition Index (SCI) is an index of biological integrity using in-stream and riparian habitat conditions and stream macroinvertebrate assemblages. The SCI was conducted at each station during quarters two and four, allowing for characterization of summer and winter macroinvertebrate assemblages. Fore (2004) has shown a significant negative correlation between the LDI score and the SCI. In-stream biological integrity is evaluated against the intensity of human land use in this study to determine if the same relationship observed by Fore (2004) is evident in this data set. The SCI is also evaluated against measures of dissolved oxygen to identify if altered oxygen regimes, as a response to intense human land use, have an effect on the biological integrity of stream systems in west-central Florida.

Table 13 presents the Spearman rank order correlations observed between the LDI, SCI, and measures of dissolved oxygen in this study. Stations were evaluated overall, as well as separated into channelized and non-channelized streams. In addition to using the overall SCI score, four of the metrics used to calculate the SCI (total taxa, sensitive taxa, percent very tolerant taxa, and percent dominant taxon) were also evaluated against the LDI score and dissolved oxygen. These metrics were chosen because they are expected to be more sensitive to effects of changes in dissolved oxygen in response to intense human land use than other metrics.

Table 13. Overall, channelized and non-channelized Spearman rank order correlations for dissolved oxygen, LDI, and biological integrity, west-central Florida, 2005 – 2006.

	SCI			**Total Taxa**			**Sensitive Taxa**			**% Very Tolerant Taxa**			**% Dominant Taxon**		
	Overall	**Non-Chan**	**Chan**	**Overall**	**Non-Chan**	**Chan**	**Overall**	**Non-Chan**	**Chan**	**Overall**	**Non-Chan**	**Chan**	**Overall**	**Non-Chan**	**Chan**
LDI	**-0.33**	-0.01	-0.17	-0.01	**0.36**	-0.15	**-0.4**	-0.05	-0.14	**0.37**	0.11	0.08	-0.09	-0.29	-0.16
DO$_M$	**0.41**	**0.37**	0.4	0.16	0.17	0.2	0.2	0.24	-0.06	-0.14	-0.13	0.16	-0.26	-0.29	-0.18
DO$_R$	**-0.43**	-0.2	0.12	-0.11	-0.17	0.03	**-0.46**	-0.14	-0.11	**0.46**	0.19	-0.03	0.18	0.24	0.05
DO$_D$	**-0.4**	-0.34	-0.29	-0.17	-0.16	-0.2	-0.2	-0.22	0.08	0.15	0.09	-0.11	0.27	0.33	0.14
DO$_{\% < 5}$	**-0.4**	**-0.39**	-0.24	-0.15	-0.26	-0.04	-0.25	-0.28	-0.01	0.19	0.14	-0.12	0.21	0.27	0.05

Non-Chan - Non-Channelized Stream

Chan - Channelized Stream

Bold values indicate significant correlations ($p < 0.05$)

SCI scores showed a significant negative correlation with the LDI (Spearman r = -0.33, p = 0.02) when viewing all stations together indicating the biological integrity of stream systems is negatively affected by increasing intensity of human land use (Figure 8). Fore (2004) reported the same relationship, however the strength of the correlation in her work was stronger (Spearman r = -0.60, p < 0.01). The reason for the weaker correlation observed in this study is unknown, but may be related to the much smaller data set used than reported by Fore (2004). Seasonality seemed to play a role in this relationship as well. The SCI showed a significant negative correlation with LDI (Spearman r = -0.4, p = 0.047) in samples collected from quarter 4 (winter) while the quarter 2 collection (summer) showed no significant relationship. The LDI score also showed a significant negative correlation with the number of sensitive taxa (Spearman r = -0.4, p = 0.003) and a positive correlation with the percent of very tolerant taxa (Spearman r = 0.37, p = 0.008). This indicates a reduction in the most sensitive taxa and increase in tolerant macroinvertebrate species in stream systems located in areas of increasing human impact. These findings coincide with other studies showing reduced biological integrity in watersheds with increased human influence (Fore 2004 and 2007). When the data set was separated into channelized and non-channelized streams, only the number of total taxa collected in non-channelized streams showed a significant correlation with LDI scores (Spearman r = 0.36, p = 0.047). The reason for the positive correlation observed is unknown, but raises interest and it may be prudent to conduct further investigation into this relationship in the future. Seasonality did not significantly affect the relationships observed in the non-channelized and channelized systems.

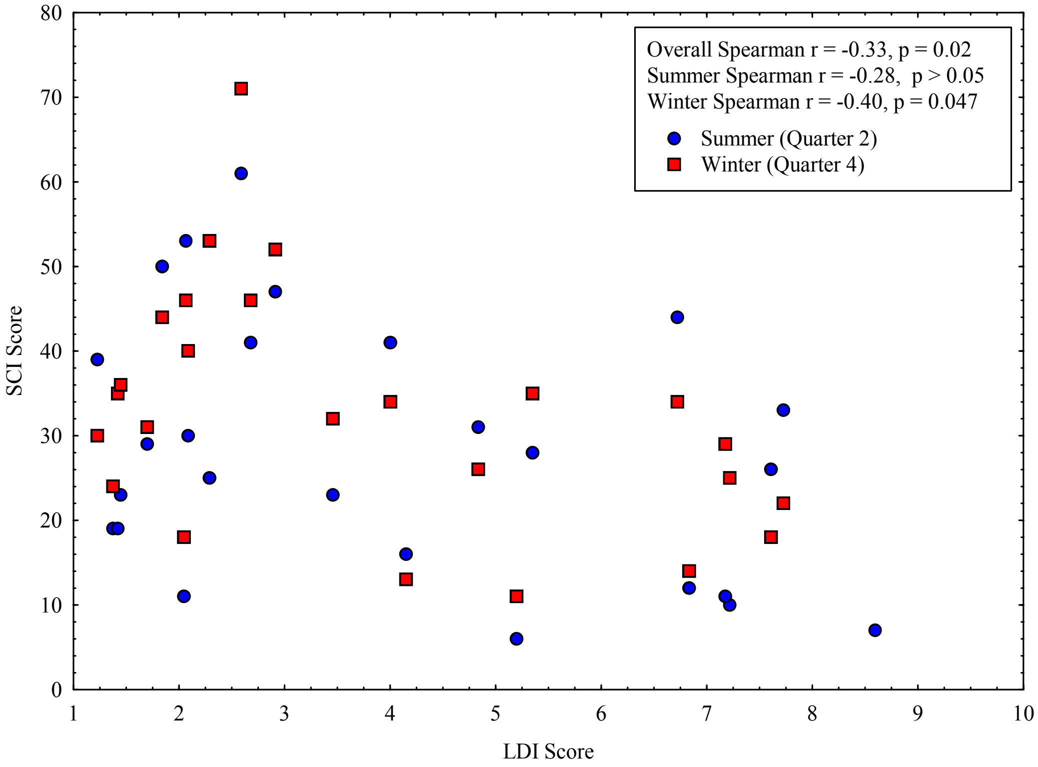


Figure 8. LDI and overall SCI scores calculated from summer and winter data collection efforts.

The data shows a significant relationship exists between the intensity of human land use and biological integrity of the stream systems. It is also apparent in the data that dissolved oxygen plays an important role in the biological health of the lotic systems in west-central Florida. All measures of dissolved oxygen were significantly correlated with the SCI scores over all stations (see Table 13). The mean dissolved oxygen value showed a positive correlation (Spearman r = 0.41, p = 0.003) with SCI indicating the biological health of a stream is positively affected by the amount of oxygen available to the community (Figure 9). As the diel range in oxygen values increased the overall SCI score as well as the number of taxa listed as sensitive decreased (Spearman r = -0.43 and -0.46, p = 0.001 and p < 0.01, respectively) while the percentage of very tolerant taxa increased (Spearman $r = 0.46$, $p < 0.001$). The mean oxygen deficit was also negatively correlated the SCI score (Spearman $r = -0.40$, $p = 0.04$) over all stations, while the percent of exceedances was negatively correlated with SCI over all stations and in the non-channelized streams (Spearman $r = -0.40$ and -0.39, $p = 0.004$ and $p = 0.03$, respectively).

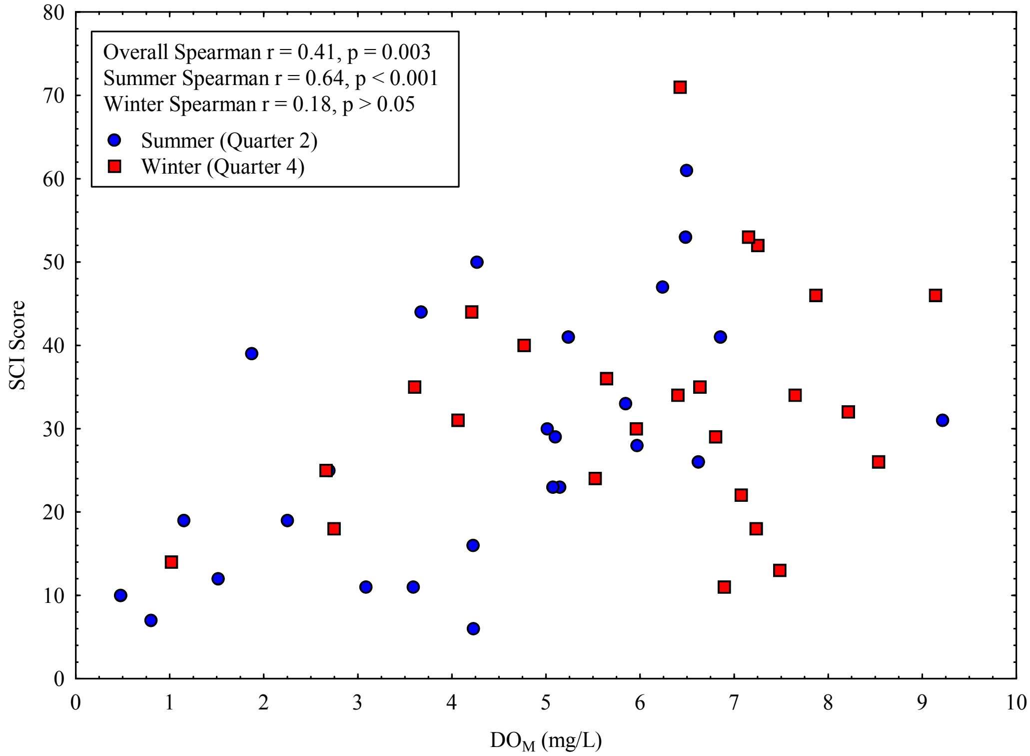


Figure 9. Mean dissolved oxygen (DO_M) and SCI scores calculated from summer and winter data collection efforts.

While the mean oxygen deficit calculated over a four day deployment is an adequate measure of oxygen when compared to the intensity of human land uses, it may not be the most ecologically significant measure of oxygen deficit (Dr. Douglas Durbin, pers. comm.). Macroinvertebrates sensitive to oxygen levels are likely to evacuate sections of a stream during times of minimum oxygen concentrations, and are less likely to be affected by oxygen deficit when concentrations are higher (Dr. Douglas Durbin, pers. comm.). Therefore, the oxygen deficit calculated during times of minimum oxygen concentrations (i.e. nighttime oxygen levels) is a more accurate measure of oxygen that is likely to result in affects to macroinvertebrate assemblages. Figure 10 presents the oxygen deficit calculated at the minimum oxygen concentration over each day of deployment, for each station, during the summer and winter SCI data collection periods. The figure shows a strong negative correlation between SCI and oxygen deficit when concentrations are at a minimum. This relationship was stronger during the summer (Spearman $r = -0.55$, $p < 0.001$) than the winter (Spearman $r = -0.38$, $p < 0.001$) While the mean oxygen deficit calculated over the 4-day deployment period showed a negative correlation with SCI score, it is actually the oxygen deficit at the minimum oxygen concentration that is driving the lower SCI scores. These data coincide with previous studies that show adequate availability of oxygen significantly impacts the biological health of a stream community (Hynes 1960, Giller and Malmqvist 1998, Dodds 2002, Connolly et al. 2004, Walton et al. 2007, and Jacobsen 2008).

The biological integrity of channelized streams in this study showed no relationship with the LDI or any measure of dissolved oxygen. The lack of relationship in these systems likely means there are other factors at work affecting biological integrity in channelized streams. Channelization is known to have negative affects on the habitat availability, relative abundance, and richness of macroinvertebrates compared to non-channelized systems (Rohasliney and Jackson 2008, Smiley and Dibble 2008). Channelization is expected to occur more frequently in areas of more intense human land use, which is the case in this study where the majority of channelized streams have higher LDI scores than non-channelized systems. While channelization seems to have a negative effect on the biological integrity of the streams (this relationship is observed when viewing all stations together), increasing the intensity of land use in systems that have already been channelized does not seem to be significant. This shows the channelization itself is the human activity causing the negative effect on stream ecology.

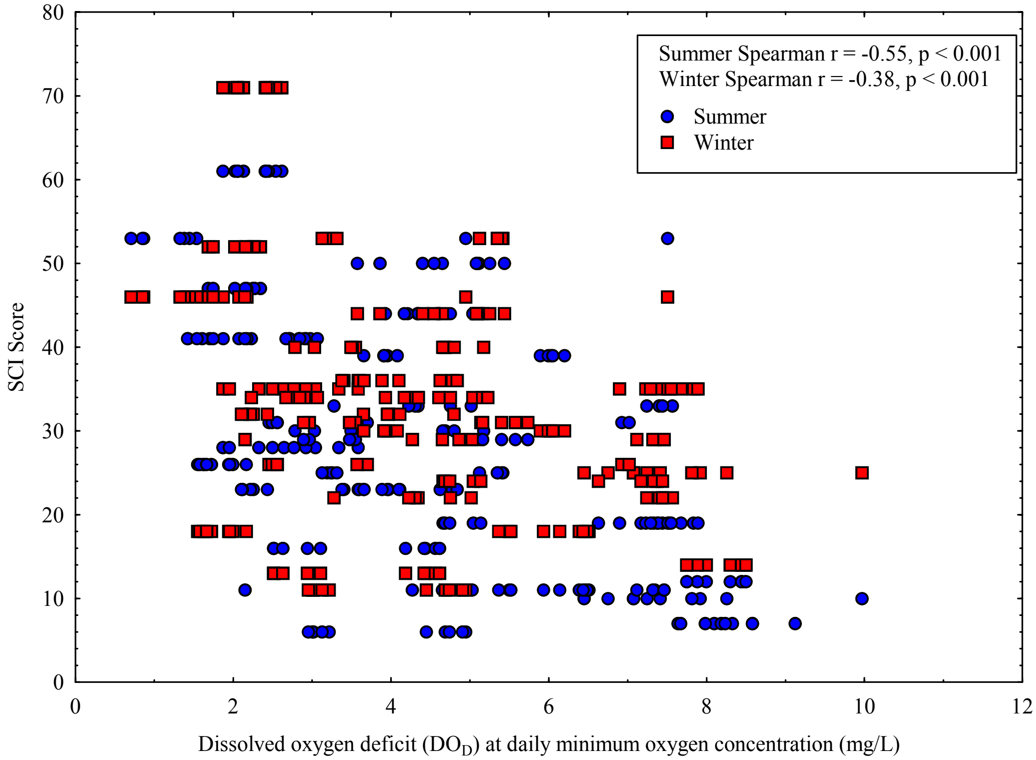


Figure 10. Dissolved oxygen deficit (DO_D) calculated at the minimum oxygen concentration for each day of the 4-day deployment, during summer and winter data collection efforts.

This study shows the intensity of human land use has a negative effect on the biological integrity of streams and is consistent with previous studies showing the same relationship (Fore 2004 and 2007). In addition, measures of dissolved oxygen were significantly correlated with the SCI indicating the availability and stability of oxygen levels also play an important role in the health of the streams in this study. As previously indicated in this chapter, the intensity of human land use has significant effects on measures of dissolved oxygen that are also shown to affect the biological integrity of the streams. While many factors associated with human activity in a watershed can affect streams, these data show it is important to directly address dissolved oxygen as altered oxygen regimes in streams can directly affect the overall health of the system.

POLICY IMPLICATIONS

This research effort provides valuable insight for assessing the impairment status of lotic systems for dissolved oxygen in Florida. The Clean Water Act requires for the establishment of protective regulatory criteria known as Total Maximum Daily Loads (TMDLs). A TMDL is defined as the maximum amount of a pollutant the waterbody can assimilate and still meet its designated state water quality standards (FDEP 2008). Water bodies known to exceed water quality standards (as determined through Florida's Impaired Waters Rule, Chapter 62-303, F.A.C.) are required to have a TMDL established by the State of Florida, or, if the state does not establish a TMDL in a timely manner, the US Environmental Protection Agency (EPA) will develop a TMDL instead.

In Florida, oxygen depletion and elevated nutrient concentrations are the most common parameters of concern in the majority of "impaired" waterbodies (FDEP 2008). Currently, the FDEP (2008) lists 248 streams and rivers as verified impaired for dissolved oxygen, with the majority of those also impaired for nutrients (nitrogen and/or phosphorus) and are slated for TMDL development. Half of the stations in this study are listed as impaired for dissolved oxygen; the other half either not impaired or have not yet been assessed. According to the FDEP (2009) TMDL website, 16 dissolved oxygen TMDLs have been finalized throughout the state. Typically, the determination of a TMDL for dissolved oxygen is completed through an assessment of the relationship between oxygen and nutrient concentrations. In each case, the implemented TMDL requires a reduction in overall nutrient loading to a level presumed to be at or below the assimilative capacity of the subject stream; which is designed to remove the cause of oxygen stress, thereby increasing oxygen concentrations to meet the state water quality standard. This methodology coincides with research previously cited in this text indicating the link between increasing nutrient concentrations and decreasing oxygen concentrations. While this relationship is undeniable, the data presented from this research effort shows additional antecedent relationships may significantly obscure the effectiveness of the TMDL.

Oxygen concentrations in this study showed a positive correlation with total phosphorus and no correlation with total nitrogen. This seemed to be the result of an increase in primary production driving up the overall concentration of oxygen. With lower nutrient levels, primary production is reduced and thus lower dissolved oxygen concentrations are observed. In the scenario presented by the data in this project a reduction in the nutrient inputs to the subject streams would essentially decrease the oxygen concentrations giving the appearance of a failed TMDL. However, as presented here, stations with lower LDI scores typically showed low nutrient inputs, lower oxygen concentrations, yet showed generally higher levels of biological integrity. This shows the macroinvertebrate assemblages in streams with lower human impact have the ability to adapt to naturally lower oxygen conditions. It is possible for a reduction in nutrient loading to reduce overall oxygen concentrations to a more natural state without adversely affecting the biological integrity of the stream. A TMDL for dissolved oxygen does not currently account for the biological integrity of the stream and solely relies on nutrient load reduction to assume oxygen levels will rebound above the standard for TMDL compliance. There fore, the current method of assessing dissolved oxygen TMDLs can not account for the relationships observed in this study and, in some cases, may not be adequate to effectively alleviate an impaired determination.

Additionally, a dissolved oxygen TMDL does not account for physical characteristics of streams, such as channelization, that can also have significant effects. In this study, the streams with the highest LDI scores tend to be channelized with variable oxygen concentrations and few discernable correlations, as opposed to the non-channelized streams which were strongly correlated with oxygen and nutrients. This variability and lack of correlation with nutrient concentrations indicate a TMDL set for a channelized stream may not alleviate oxygen impairment. For these systems, it will be important to address the physical as well as chemical components of the stream to successfully address impairment. The physical effects of channelization were not included in this study and additional research will help to fully understand the TMDL implications of these systems.

Diel variation (difference between daily high and low oxygen concentration) was the measure of dissolved oxygen in this study with the most significant correlations with other variables, such as LDI, nutrients, and stream biological integrity. Diel variation was shown to be greatly affected by intensity of human land use overall and in both the channelized and non-channelized streams. This measure of oxygen is presumed to be the driving force behind the correlations between oxygen concentration, nutrients, and primary production observed, as well. This research indicates dissolved oxygen range may be a more effective and appropriate indicator of the oxygen regime in a stream than straight measurements of oxygen concentration.

Current methods of data collection for assessing dissolved oxygen regimes for TMDL purposes are based on *in situ* measurements of oxygen concentration, collected seasonally and evaluated against Florida's fresh water quality standard. A complete description of the methodology used, including sample sizes, locations, and assessments of impaired status is given in Florida's Impaired Waters Rule (Chapter 62-303, F.A.C.). However, this method is highly variable and subject to unintended human influence as well as other factors, such as those described in this study. TMDL data collection efforts for dissolved oxygen are conducted during the daytime hours with no requirement to standardize or stagger the time of day the measurements are collected. An exceedance is measured as any oxygen concentration reported below the 5.0 mg/L standard regardless of time of day. Once a predetermined threshold of exceedances is reached over the course of a year of monitoring, the waterbody is deemed impaired. However, oxygen measurements vary greatly throughout the day depending on factors such as canopy cover, sunlight, algal community and chlorophyll-*a* concentrations, among others, and time of day the measurements are collected can play a significant role in determining the impairment status of the water body.

Figure 11 shows the percentage of all dissolved oxygen values collected at all stations during this research effort that were above the 5.0 mg/L standard for each hour of the day. As the figure indicates, only about half of the oxygen measurements collected during the evening, nighttime, and morning hours were above the 5.0 mg/L threshold. This number climbs to approximately 60 percent for the afternoon hours (~1 to 5 pm), indicating an increased likelihood a sample collected during the afternoon in these systems will be above the standard. In contrast, a sample collected at 8 am has slightly less than 50 percent chance to be above the standard. Since samples collected for TMDL purposes are typically collected during normal working hours (8am to 5pm), stations sampled during the morning may have an increased likelihood to be measured below the standard, and therefore increased chance of acquiring an impaired status. Also, since scheduling for this type of sampling can be logistically challenging, it is likely that stations may inadvertently be sampled at the same time of day on many sampling trips.

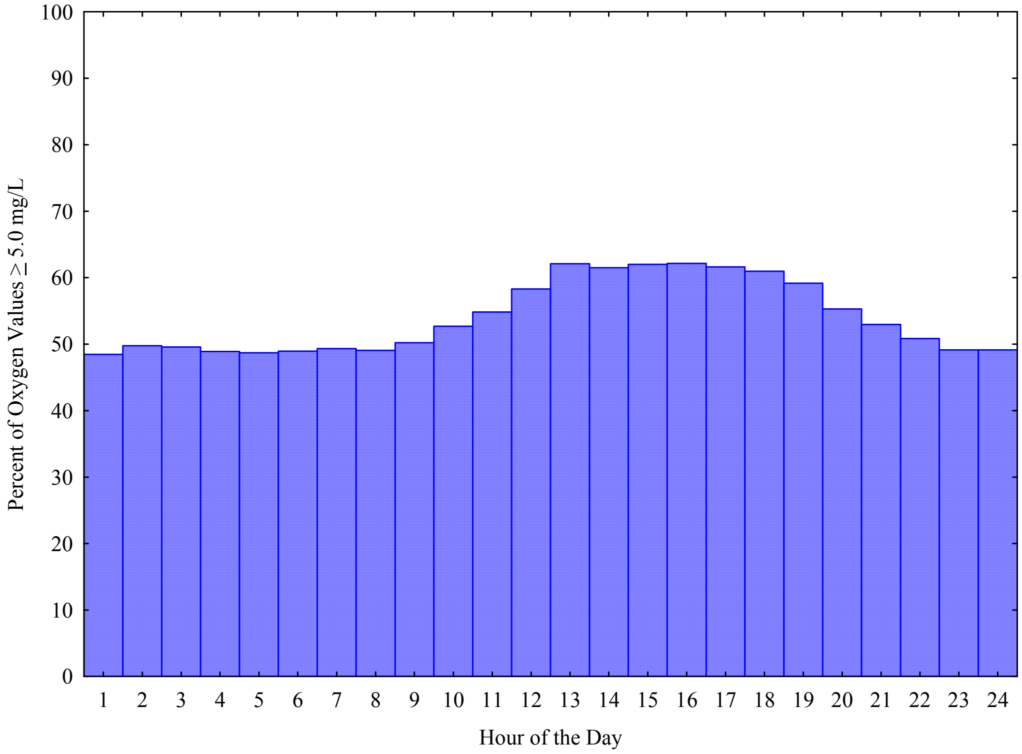


Figure 11. Percent of dissolved oxygen values collected from all stations, over all quarters observed above the 5.0 mg/L state water quality standard by hour of the day.

As this research indicates, the reference stations, with the lowest rate of human influence, typically had low mean oxygen concentrations (< 5.0 mg/L) throughout the year. This is evident when displaying the percentage of dissolved oxygen values above the standard at all six of the reference stations in this study by hour of the day (Figure 12). The same temporal pattern is observed with mid afternoon sample collections exhibiting the greatest percentage of values above the standard. However, it is interesting to note the percentage of oxygen values observed above the standard at the reference stations was only between ~30 and 40 percent throughout the day. This indicates there is increased opportunity to measure oxygen below the standard at the reference stations compared to stations with a higher intensity of human influence, regardless of time of day. In fact, two of the reference stations in this study are currently verified as impaired for dissolved oxygen by FDEP. These data show streams in watersheds with increased intensity of human land use, compared to the reference stations, have a greater chance to be measured above the standard. As a result of the inherent variability in oxygen measurements and timing of sample collections, this research shows direct measurements of oxygen concentration may not be adequate to accurately determine the impairment status of streams.

Diel variation was the measure of oxygen in this study showing the most significant correlations with intensity of land use, nutrients, chlorophyll-*a*, and measures of biological integrity. Measuring diel variation, as a measure of the daily shift in oxygen values eliminates the potential effect of time of day on determining the impaired status of a waterbody. In addition, diel variation is the only measure of oxygen in this study that can potentially account for the physical effects of channelization or the effect of primary production and nutrient loading on oxygen values. Future research should focus on diel variation to fully explore the complex nature of the relationships presented here. The daily range of oxygen values may be a more appropriate measure of oxygen to determine the impaired status of flowing systems.

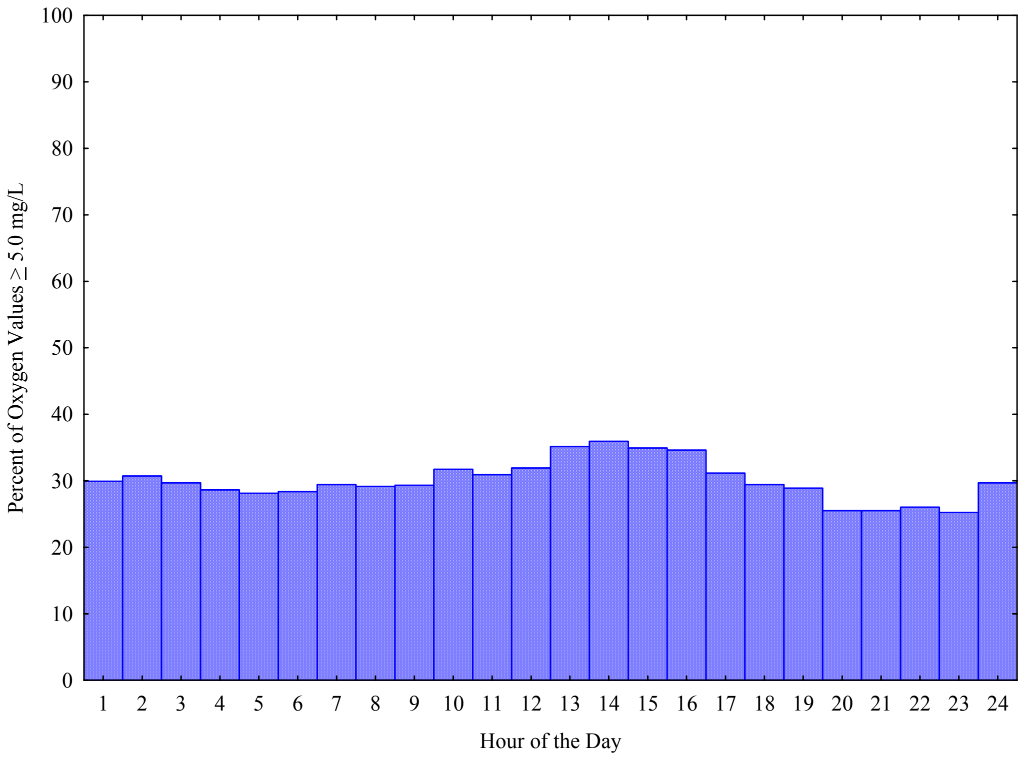


Figure 12. Percent of dissolved oxygen values collected from the reference stations, over all quarters observed above the 5.0 mg/L state water quality standard by hour of the day.

CONCLUSIONS

Landscapes dominated by intense human activity are known to have significant effects on natural communities (Brown and Vivas 2005). Degradation of aquatic communities is known to occur as a result of urban and agricultural point and non-point sources (Tsegaye et al. 2006, Carpenter et al. 1998, USEPA 1996 & 2001). In Florida, substantial monetary funds are spent each year assessing Florida’s aquatic systems to determine anthropogenic sources of impairment and design strategies to mitigate those impacts. Oxygen depletion is the most common impairment in Florida streams, with over 2,000 miles of assessed rivers and streams listed as impaired for low dissolved oxygen (FDEP 2008). This study set out to evaluate dissolved oxygen in streams in west-central Florida and provide greater understanding of how the intensity of human land use in the surrounding watershed affects dissolved oxygen regimes. In addition, an index of human land use and oxygen was evaluated against a measure of the biological integrity of the streams to identify the response of natural communities to altered oxygen regimes as a result of increasing human land use.

Twenty-six lotic systems throughout west-central Florida (Tampa Bay basin) were used in this project and sampled quarterly for one year (2005-2006). Data collection included dissolved oxygen, temperature, nutrients, chlorophyll-*a*, and benthic macroinvertebrate assemblages (Stream Condition Index). The intensity of human land use was evaluated using the Landscape Development Intensity Index (LDI) (Brown and

Vivas 2005). Mean dissolved oxygen concentration, range, deficit, and percentage of values below Florida's fresh water dissolved oxygen standard (5.0 mg/L) were chosen to characterize the oxygen regime of each stream. Data were analyzed for relationships using Spearman rank order correlations.

Through this effort significant relationships were identified that present valuable insight into the effect of human land uses on dissolved oxygen regimes and biological communities in Florida streams. Diel variation in oxygen measurements was significantly correlated to the LDI score indicating as land uses become more intense with human activity, the range between high and low oxygen measurements increases. This is not surprising as other studies have linked increased diel variation in streams to anthropogenic sources (Walsh et al. 2005). This relationship seems to be linked to nutrient and chlorophyll-*a* concentrations in the streams. The most significant relationships were seen with total phosphorus, which is understandable since phosphorus is typically the limiting nutrient in freshwater systems (Hecky and Kilham 1988 and Mallin et al. 2004). As the intensity of human land use increases, the concentration of phosphorus shows a corresponding increase, as does the concentration of chlorophyll-*a* in the waterbody. This relationship has the effect of increasing the diel variation in oxygen measurements. The data show this alone has the effect of lowering the biological integrity of stream systems in west-central Florida (see Table 13).

The most significant conclusions regarding the effect intensity of human land use has on dissolved oxygen regimes are apparent when the morphology of the stream channel is taken into account. As previously described, the LDI is a measure of the non-renewable energy consumed by human activities and is therefore not capable of addressing the morphology of a stream channel. However, stream morphology is known to affect many factors of water quality including dissolved oxygen (Brilly et al. 2006, Meyer et al. 2005, Paul and Meyer 2001, and Walsh et al. 2005). The stations in this study were separated into channelized and non-channelized, then analyzed separately with considerable results. Channelized streams can reasonably be expected to be found more frequently in landscapes of more intense human activity, as was the case in this study with the majority of channelized systems having higher LDI scores while most of the non-channelized streams were associated with lower LDI scores (see Figure 7).

The effect of human land use on dissolved oxygen seemed to come from different sources in the non-channelized and channelized systems. In the non-channelized streams all measures of dissolved oxygen were significantly correlated with LDI scores indicating the highest oxygen concentrations, lowest oxygen deficit, and fewest exceedances of the standard were found in streams with the most intense human land use. In addition, the greatest diel variation was also found with higher LDI scores. This relationship gives the overall impression of improving oxygen regimes in areas of increasing intensity of human land use as opposed to reference (natural) aquatic communities. However, the same relationship was not observed in the channelized streams, which tend to have the highest LDI scores.

In the non-channelized systems, phosphorus is the key nutrient driving the relationship between dissolved oxygen and human land use. Phosphorus concentrations increased relative to the intensity of land use and, interestingly, measures of dissolved oxygen also showed improvement as phosphorus concentrations increased. This relationship seems to contradict the generally accepted notion that increased nutrient levels are associated with oxygen depletion (MacPerson et al. 2007, Mallin et al. 2006, NRC 2000, Wang et al. 2003, and Wilcock 1986). This positive correlation was observed during all four quarters of data collection indicating the relationship was not linked to seasonal variables. Analyzing chlorophyll-*a* concentrations shows an increase in primary producers in relation to increasing phosphorus concentrations. The increase in primary production is linked to an increase in diel variation of oxygen measurements and subsequent increase in overall dissolved oxygen concentrations. Platt (1981) has presented studies indicating that dark respiration by primary producers consumes less oxygen (5 – 50 percent) than is produced by photosynthesis. This results in a net increase in oxygen when diel variation increases. The complex relationships explained here indicate how intense human land use can result in increased dissolved oxygen concentrations and fewer exceedances of Florida's oxygen criteria, as shown in this study. This was only evident in streams with natural sinuosity, and was not observed in stream systems that have been channelized.

As previously described, the channelized streams in this study were mostly concentrated on the higher end of the LDI scale. The majority of quarterly mean dissolved oxygen concentrations were below the 5.0 mg/L criteria set for freshwaters. These systems, while typically exhibiting low overall dissolved oxygen regimes relative to the standard, did not show the same relationship with nutrients and chlorophyll as the non-channelized systems. It is likely these relationships still exist, however they are obscured by other physical factors affecting dissolved oxygen. Channelized streams tend to include straight, incised banks, greater depth, low velocity, and may include other structures such as impoundments that can have significant effects on dissolved oxygen.

These, and other physical characteristics of channelization were not included in this study so their impact on the dissolved oxygen regimes of the systems could not be examined. However, the results seem to indicate that channelization has a greater effect on dissolved oxygen regimes than the variables included in this study. Additional research in this area could help to identify which variables have the greatest effect as well as understand the relationships between the variables.

Human land use affects dissolved oxygen regimes in streams to varying degrees dependent upon the physical characteristics of the stream itself. In west-central Florida the reference streams used in this research exhibited some of the lowest overall oxygen regimes with the greatest number of exceedances of Florida's fresh water standard. These streams tend to exhibit natural sinuosity with the least amount of human influence. As human influence increases in the watershed surrounding non-channelized streams, increased nutrient (phosphorus) inputs seem to increase the overall oxygen regime through increased primary production. As human influence continues to increase and land uses surrounding the streams become more dominated by high intensity agriculture, residential, commercial, and industrial uses, lotic systems are more likely to be channelized. This physical alteration of the stream system takes over as the dominant force affecting dissolved oxygen resulting in lower overall regimes.

Altered dissolved oxygen regimes and intense human land use can have significant effects on the biological integrity of a stream. Fore (2004) showed how increasing LDI can result in lowered biological integrity using the Stream Condition Index (SCI). The same relationship was observed in this research. In addition, the SCI showed a strong correlation with dissolved oxygen. Benthic macroinvertebrate community structure increased with increasing mean oxygen concentrations and decreased with increasing diel variation. Although the reference stations typically exhibited lower oxygen concentrations (see Figure 7), they also showed more stable diel variation (see Figure 4). Increasing intensity of human land use results in increased diel variation of oxygen measurements and corresponds to a decrease in SCI score. Increased diel variation was linked with a loss of sensitive taxa, and an increase in the percent of tolerant taxa as well as an increase in the dominant taxon (reduced diversity). This was only observed when viewing all stations together and was not evident when separating the stations into channelized and non-channelized systems. In this research, the diel shift in oxygen measurements showed the greatest effect on the biological integrity of the streams. Seasonal variation was observed in the relationships between oxygen, land use, and SCI scores as well. Biological integrity showed strong correlation with measures of oxygen during the summer, but was not correlated with the LDI scores. In contrast, the winter SCI scores showed a negative correlation with LDI, and did not correlate with measures of dissolved oxygen. This interesting dichotomy indicates that altered oxygen regimes as a result of intense human activity in a watershed may not be the most effective indicator of stream biological integrity. However, the data indicates oxygen does play a significant role, and these effects should be accounted for when assessing the overall health of the lotic system.

The results of this research effort may have significant impacts for Florida's TMDL program and for methodologies used to assess the impairment status of stream and river systems throughout the state. Current TMDL evaluations do not account for the relationships observed in this study and instead rely solely on nutrient reduction to alleviate oxygen stress. The data presented here indicate a simple reduction in nutrient inputs may have no affect or may actually decrease overall oxygen concentrations giving the appearance of a failed TMDL for dissolved oxygen. In addition, current TMDL data collection methodologies are based on *in situ* measurements of oxygen concentration and are subject to unintended bias from the effects of photoperiod as previously described. As a result of the inherent variability in oxygen measurements and timing of sample collections, this research shows *in situ* oxygen concentration measurements may not be adequate to accurately determine the impairment status of streams and rivers. Diel variation more accurately reflects the relationship between oxygen and the intensity of human land use and antecedent variables including nutrients and primary production. Therefore, diel variation may be a more accurate predictor of oxygen impairment and TMDL efforts should focus on this measure of oxygen to determine impairment status.

Additional research will be necessary to fully explore and understand the relationships presented in this study. The relationship between oxygen, intensity of human land use, and nutrients (phosphorus) observed in this research seems to contradict previous studies; therefore, additional research should be conducted to determine if the same relationship is observed in flowing systems on a state-wide scale or in other types of waterbodies. In addition, it will be important to incorporate the effect of stream morphology on the oxygen regime of a flowing system to be able to fully characterize the impact of human land uses. Based on the results observed in this study, future research should focus on diel variation as a more appropriate indicator of oxygen regimes in lotic systems. It will also be important to include biological integrity in any assessment of impairment to determine when a system has been altered as a result of human activity.

Dissolved oxygen is widely considered a general indicator of aquatic health. Research presented here from lotic systems in west-central Florida indicates the intensity of human land use has a significant effect on dissolved oxygen regimes. Chemical as well as physical alterations in watersheds as a result of increased human activity have differing effects on dissolved oxygen, some which may actually lead to increased overall oxygen regimes. These complex relationships must be fully explored and integrated into regulatory frameworks to accurately delineate between impairment as a result of human influence and natural variability for which an impaired determination is not necessary. The relationships presented here may also be useful, in conjunction with further research and analysis, when attempting to revise the dissolved oxygen state water quality standard to allow for greater protection of Florida’s most valuable resource.

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APPENDIX A: Landscape Development Intensity Index Raw Data

Appendix A

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
HIL-1	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	119134.21
HIL-1	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	9912.87
HIL-1	Residential, High Density	1000	1300	1300	8.66	34268.28
HIL-1	Commercial and Services	1000	1400	1400	8.00	306841.24
HIL-1	Institutional	1000	1700	1700	8.07	1905.64
HIL-1	Pastures and Fields	2000	2100	2100	3.51	252280.40
HIL-1	Feeding Operations	2000	2300	2300	5.15	46963.03
HIL-1	Other Open Lands	2000	2600	2600	2.06	455459.88
HIL-1	Shrub and Brushland	3000	3200	3200	2.06	12.34
HIL-1	Mixed Rangeland	3000	3300	3300	2.06	12483.40
HIL-1	Hardwood - Conifer Mixed	4000	4300	4340	1.00	119690.80
HIL-1	Lakes	5000	5200	5200	1.00	141399.70
HIL-1	Reservoirs	5000	5300	5300	4.09	57867.97
HIL-1	Wetland Hardwood Forests	6000	6100	6100	1.00	7905.01
HIL-1	Freshwater Marshes	6000	6400	6410	1.00	45386.54
HIL-1	Emergent Aquatic Vegetation	6000	6400	6440	1.00	38740.59
HIL-1	Transportation	8000	8100	8100	7.81	45207.50
HIL-2	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	175260.46
HIL-2	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	79842.27
HIL-2	Residential, High Density	1000	1300	1300	8.66	1390843.78
HIL-2	Commercial and Services	1000	1400	1400	8.00	9826.64
HIL-2	Industrial	1000	1500	1500	8.32	3917.11
HIL-2	Institutional	1000	1700	1700	8.07	5743.99
HIL-2	Recreational	1000	1800	1800	4.09	282488.55
HIL-2	Other Open Land	1000	1900	1940	1.85	18739.88
HIL-2	Pastures and Fields	2000	2100	2100	3.51	52430.53
HIL-2	Specialty Farms	2000	2500	2500	4.06	3962.25
HIL-2	Other Open Lands	2000	2600	2600	2.06	111283.46
HIL-2	Hardwood - Conifer Mixed	4000	4300	4340	1.00	73407.39
HIL-2	Streams and Waterways	5000	5100	5100	1.00	28726.40
HIL-2	Lakes	5000	5200	5200	1.00	143360.67
HIL-2	Lakes	5000	5200	5200	1.00	1892.69

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
HIL-2	Reservoirs	5000	5300	5300	4.09	153070.47
HIL-2	Wetland Hardwood Forests	6000	6100	6100	1.00	63992.046
HIL-2	Bottomland Hardwood Forest	6000	6100	6150	1.00	667547.82
HIL-2	Cypress	6000	6200	6210	1.00	138286.75
HIL-2	Freshwater Marshes	6000	6400	6410	1.00	34269.853
HIL-2	Wet Prairies	6000	6400	6430	1.00	14978.685
HIL-2	Emergent Aquatic Vegetation	6000	6400	6440	1.00	16987.59
HIL-2	Transportation	8000	8100	8100	7.81	20216.169
HIL-2	Utilities	8000	8300	8300	8.32	56912.633
HIL-3	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	78930.407
HIL-3	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	890656.66
HIL-3	Residential, High Density	1000	1300	1300	8.66	732371.61
HIL-3	Commercial and Services	1000	1400	1400	8.00	72601.006
HIL-3	Institutional	1000	1700	1700	8.07	15014.416
HIL-3	Recreational	1000	1800	1800	4.09	13160.573
HIL-3	Tree Crops	2000	2200	2200	4.06	21946.072
HIL-3	Nurseries and Vineyards	2000	2400	2400	4.06	27378.881
HIL-3	Other Open Lands	2000	2600	2600	2.06	28396.57
HIL-3	Hardwood - Conifer Mixed	4000	4300	4340	1.00	23881.708
HIL-3	Lakes	5000	5200	5200	1.00	1259338.1
HIL-3	Reservoirs	5000	5300	5300	4.09	92499.327
HIL-3	Wetland Hardwood Forests	6000	6100	6100	1.00	126337.74
HIL-3	Cypress	6000	6200	6210	1.00	23355.02
HIL-3	Freshwater Marshes	6000	6400	6410	1.00	25260.713
HIL-3	Wet Prairies	6000	6400	6430	1.00	8378.1596
HIL-3	Emergent Aquatic Vegetation	6000	6400	6440	1.00	156937.75
HIL-3	Transportation	8000	8100	8100	7.81	33736.33
HIL-3	Utilities	8000	8300	8300	8.32	23196.836
HIL-4	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	11822.737
HIL-4	Residential, High Density	1000	1300	1300	8.66	1613098.1
HIL-4	Commercial and Services	1000	1400	1400	8.00	408590.61
HIL-4	Industrial	1000	1500	1500	8.32	254016.34
HIL-4	Institutional	1000	1700	1700	8.07	178451.84
HIL-4	Recreational	1000	1800	1800	4.09	318860.12
HIL-4	Other Open Lands	2000	2600	2600	2.06	212258.23
HIL-4	Hardwood - Conifer Mixed	4000	4300	4340	1.00	16735.22
HIL-4	Streams and Waterways	5000	5100	5100	1.00	56692.101
HIL-4	Lakes	5000	5200	5200	1.00	3955.8125

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
HIL-4	Reservoirs	5000	5300	5300	4.09	70194.454
HIL-4	Wetland Hardwood Forests	6000	6100	6100	1.00	111413.08
HIL-4	Mixed Wetland Hardwoods - Mixed Shrubs	6000	6100	6172	1.00	13594.419
HIL-4	Freshwater Marshes	6000	6400	6410	1.00	13056.659
HIL-4	Wet Prairies	6000	6400	6430	1.00	4311.2752
HIL-4	Emergent Aquatic Vegetation	6000	6400	6440	1.00	6696.6415
HIL-4	Disturbed Lands	7000	7400	7400	4.09	322.21467
HIL-4	Transportation	8000	8100	8100	7.81	141969.9
HIL-4	Utilities	8000	8300	8300	8.32	13532.158
HIL-5	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	394098.55
HIL-5	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	316616.89
HIL-5	Residential, High Density	1000	1300	1300	8.66	518076.75
HIL-5	Commercial and Services	1000	1400	1400	8.00	28859.891
HIL-5	Industrial	1000	1500	1500	8.32	25336.661
HIL-5	Extractive	1000	1600	1600	8.32	996969.39
HIL-5	Recreational	1000	1800	1800	4.09	327157.92
HIL-5	Other Open Land	1000	1900	1940	1.85	92877.063
HIL-5	Pastures and Fields	2000	2100	2100	3.51	2195553.5
HIL-5	Tree Crops	2000	2200	2200	4.06	11681.442
HIL-5	Specialty Farms	2000	2500	2500	4.06	196848.24
HIL-5	Other Open Lands	2000	2600	2600	2.06	208834.97
HIL-5	Shrub and Brushland	3000	3200	3200	2.06	895488.83
HIL-5	Upland Coniferous Forests	4000	4100	4100	1.00	36183.116
HIL-5	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	443756.87
HIL-5	Hardwood - Conifer Mixed	4000	4300	4340	1.00	1090666.5
HIL-5	Tree Plantations	4000	4400	4400	1.58	242459.21
HIL-5	Streams and Waterways	5000	5100	5100	1.00	31393.902
HIL-5	Lakes	5000	5200	5200	1.00	1548.3869
HIL-5	Reservoirs	5000	5300	5300	4.09	92748.65
HIL-5	Wetland Hardwood Forests	6000	6100	6100	1.00	125288.56
HIL-5	Bottomland Hardwood Forest	6000	6100	6150	1.00	5971996.8
HIL-5	Wetland Coniferous Forests	6000	6200	6200	1.00	343464.99
HIL-5	Cypress	6000	6200	6210	1.00	690591.84
HIL-5	Freshwater Marshes	6000	6400	6410	1.00	517490.07
HIL-5	Wet Prairies	6000	6400	6430	1.00	47648.132
HIL-5	Emergent Aquatic Vegetation	6000	6400	6440	1.00	27356.268
HIL-5	Transportation	8000	8100	8100	7.81	89907.839
HIL-6	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	207101.41

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
HIL-6	Commercial and Services	1000	1400	1400	8.00	7108.4487
HIL-6	Recreational	1000	1800	1800	4.09	319.95671
HIL-6	Pastures and Fields	2000	2100	2100	3.51	135231.46
HIL-6	Hardwood - Conifer Mixed	4000	4300	4340	1.00	48884.646
HIL-6	Reservoirs	5000	5300	5300	4.09	5773.0507
HIL-6	Wetland Hardwood Forests	6000	6100	6100	1.00	4820.7962
HIL-6	Bottomland Hardwood Forest	6000	6100	6150	1.00	87996.433
HIL-6	Cypress	6000	6200	6210	1.00	14537.081
HIL-6	Freshwater Marshes	6000	6400	6410	1.00	18653.427
HIL-6	Wet Prairies	6000	6400	6430	1.00	3802.0102
HIL-6	Emergent Aquatic Vegetation	6000	6400	6440	1.00	704.04688
HIL-7	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	94573.227
HIL-7	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	133495.37
HIL-7	Residential, High Density	1000	1300	1300	8.66	671131.69
HIL-7	Commercial and Services	1000	1400	1400	8.00	247569.83
HIL-7	Institutional	1000	1700	1700	8.07	4098.5562
HIL-7	Recreational	1000	1800	1800	4.09	13496.567
HIL-7	Other Open Land	1000	1900	1940	1.85	11759.91
HIL-7	Pastures and Fields	2000	2100	2100	3.51	407192.06
HIL-7	Specialty Farms	2000	2500	2500	4.06	227206.38
HIL-7	Other Open Lands	2000	2600	2600	2.06	465123.46
HIL-7	Shrub and Brushland	3000	3200	3200	2.06	479097.92
HIL-7	Upland Coniferous Forests	4000	4100	4100	1.00	23526.337
HIL-7	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	179134.67
HIL-7	Hardwood - Conifer Mixed	4000	4300	4340	1.00	126167.26
HIL-7	Streams and Waterways	5000	5100	5100	1.00	14013.474
HIL-7	Reservoirs	5000	5300	5300	4.09	110637.28
HIL-7	Wetland Coniferous Forests	6000	6200	6200	1.00	12162.855
HIL-7	Freshwater Marshes	6000	6400	6410	1.00	34670.047
HIL-7	Wet Prairies	6000	6400	6430	1.00	56953.816
HIL-7	Disturbed Lands	7000	7400	7400	4.09	18304.171
HIL-7	Transportation	8000	8100	8100	7.81	159869.79
HIL-7	Utilities	8000	8300	8300	8.32	218514.66
HIL-8	Shrub and Brushland	3000	3200	3200	2.06	34055.778
HIL-8	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	16510.836
HIL-8	Hardwood - Conifer Mixed	4000	4300	4340	1.00	34851.584
HIL-8	Wet Prairies	6000	6400	6430	1.00	10741.891
HIL-9	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	81838.278
HIL-9	Extractive	1000	1600	1600	8.32	579870.8

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
HIL-9	Other Open Land	1000	1900	1940	1.85	26114.404
HIL-9	Pastures and Fields	2000	2100	2100	3.51	877142.53
HIL-9	Row Crops	2000	2100	2140	4.63	313127.74
HIL-9	Nurseries and Vineyards	2000	2400	2400	4.06	5860.5774
HIL-9	Tropical Fish Farms	2000	2500	2550	5.15	36136.794
HIL-9	Shrub and Brushland	3000	3200	3200	2.06	123160.77
HIL-9	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	180621.33
HIL-9	Hardwood - Conifer Mixed	4000	4300	4340	1.00	225452.7
HIL-9	Reservoirs	5000	5300	5300	4.09	110597.32
HIL-9	Bottomland Hardwood Forest	6000	6100	6150	1.00	1838776.7
HIL-9	Freshwater Marshes	6000	6400	6410	1.00	83145.647
HIL-9	Wet Prairies	6000	6400	6430	1.00	2657.2139
HIL-9	Emergent Aquatic Vegetation	6000	6400	6440	1.00	4977.9042
HIL-10	Extractive	1000	1600	1600	8.32	31205.763
HIL-10	Pastures and Fields	2000	2100	2100	3.51	19.076471
HIL-10	Row Crops	2000	2100	2140	4.63	300317.51
HIL-10	Tropical Fish Farms	2000	2500	2550	5.15	36136.877
HIL-10	Shrub and Brushland	3000	3200	3200	2.06	3169.5782
HIL-10	Hardwood - Conifer Mixed	4000	4300	4340	1.00	93494.231
HIL-10	Reservoirs	5000	5300	5300	4.09	1645.9179
HIL-10	Bottomland Hardwood Forest	6000	6100	6150	1.00	405017.15
HIL-10	Freshwater Marshes	6000	6400	6410	1.00	4984.1752
HIL-10	Emergent Aquatic Vegetation	6000	6400	6440	1.00	1623.0436
HIL-11	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	1575.1535
HIL-11	Other Open Land	1000	1900	1940	1.85	14527.211
HIL-11	Pastures and Fields	2000	2100	2100	3.51	3714970.5
HIL-11	Row Crops	2000	2100	2140	4.63	766952.6
HIL-11	Tree Crops	2000	2200	2200	4.06	970982.66
HIL-11	Tropical Fish Farms	2000	2500	2550	5.15	4167.1185
HIL-11	Herbaceous	3000	3100	3100	2.06	32671.283
HIL-11	Shrub and Brushland	3000	3200	3200	2.06	1590687.5
HIL-11	Mixed Rangeland	3000	3300	3300	2.06	65657.966
HIL-11	Upland Coniferous Forests	4000	4100	4100	1.00	13195.292
HIL-11	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	890633.11
HIL-11	Upland Hardwood Forests	4000	4200	4200	1.00	7233.4841
HIL-11	Hardwood - Conifer Mixed	4000	4300	4340	1.00	931002.68
HIL-11	Reservoirs	5000	5300	5300	4.09	28271.351
HIL-11	Bottomland Hardwood Forest	6000	6100	6150	1.00	6410783.4
HIL-11	Wetland Coniferous Forests	6000	6200	6200	1.00	18784.265
HIL-11	Cypress	6000	6200	6210	1.00	88718.112
HIL-11	Freshwater Marshes	6000	6400	6410	1.00	226309.52
HIL-11	Wet Prairies	6000	6400	6430	1.00	169213.24

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
HIL-11	Emergent Aquatic Vegetation	6000	6400	6440	1.00	8528.3823
HIL-11	Transportation	8000	8100	8100	7.81	8849.5754
MAN-1	Pastures and Fields	2000	2100	2100	3.51	6596.1826
MAN-1	Tree Crops	2000	2200	2200	4.06	13100.616
MAN-1	Shrub and Brushland	3000	3200	3200	2.06	449079.58
MAN-1	Lakes	5000	5200	5200	1.00	1298.9011
MAN-1	Reservoirs	5000	5300	5300	4.09	853.8375
MAN-1	Bottomland Hardwood Forest	6000	6100	6150	1.00	13279.696
MAN-1	Freshwater Marshes	6000	6400	6410	1.00	555069.66
MAN-1	Wet Prairies	6000	6400	6430	1.00	223147.92
MAN-2	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	2057.04
MAN-2	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	33269.686
MAN-2	Residential, High Density	1000	1300	1300	8.66	409293.85
MAN-2	Commercial and Services	1000	1400	1400	8.00	314301.32
MAN-2	Recreational	1000	1800	1800	4.09	89725.468
MAN-2	Other Open Lands	2000	2600	2600	2.06	3776.6216
MAN-2	Streams and Waterways	5000	5100	5100	1.00	5125.6063
MAN-2	Reservoirs	5000	5300	5300	4.09	3854.0894
MAN-2	Bottomland Hardwood Forest	6000	6100	6150	1.00	17069.604
MAN-2	Transportation	8000	8100	8100	7.81	16443.235
MAN-3	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	208024.74
MAN-3	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	8927.0862
MAN-3	Residential, High Density	1000	1300	1300	8.66	22875.597
MAN-3	Extractive	1000	1600	1600	8.32	275699.12
MAN-3	Recreational	1000	1800	1800	4.09	124420.01
MAN-3	Other Open Land	1000	1900	1940	1.85	12742.744
MAN-3	Pastures and Fields	2000	2100	2100	3.51	793419
MAN-3	Row Crops	2000	2100	2140	4.63	446156.48
MAN-3	Feeding Operations	2000	2300	2300	5.15	176251.43
MAN-3	Other Open Lands	2000	2600	2600	2.06	99171.916
MAN-3	Shrub and Brushland	3000	3200	3200	2.06	199978.84
MAN-3	Upland Coniferous Forests	4000	4100	4100	1.00	10444.616
MAN-3	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	286928.95
MAN-3	Hardwood - Conifer Mixed	4000	4300	4340	1.00	244461.95
MAN-3	Reservoirs	5000	5300	5300	4.09	37164.572
MAN-3	Bottomland Hardwood Forest	6000	6100	6150	1.00	320116.97
MAN-3	Cypress	6000	6200	6210	1.00	10049.837

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
MAN-3	Freshwater Marshes	6000	6400	6410	1.00	334871.06
MAN-3	Wet Prairies	6000	6400	6430	1.00	50020.913
MAN-3	Emergent Aquatic Vegetation	6000	6400	6440	1.00	773.96845
MAN-3	Transportation	8000	8100	8100	7.81	69365.49
MAN-3	Utilities	8000	8300	8300	8.32	24347.971
PAS-1	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	18873.929
PAS-1	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	72040.837
PAS-1	Residential, High Density	1000	1300	1300	8.66	263783.53
PAS-1	Commercial and Services	1000	1400	1400	8.00	15364.252
PAS-1	Recreational	1000	1800	1800	4.09	153240.89
PAS-1	Other Open Land	1000	1900	1940	1.85	33114.96
PAS-1	Pastures and Fields	2000	2100	2100	3.51	404273.09
PAS-1	Other Open Lands	2000	2600	2600	2.06	75620.87
PAS-1	Shrub and Brushland	3000	3200	3200	2.06	11525.723
PAS-1	Upland Coniferous Forests	4000	4100	4100	1.00	693.17876
PAS-1	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	664618.68
PAS-1	Reservoirs	5000	5300	5300	4.09	19702.82
PAS-1	Bottomland Hardwood Forest	6000	6100	6150	1.00	2166514.8
PAS-1	Wetland Coniferous Forests	6000	6200	6200	1.00	6177.9626
PAS-1	Cypress	6000	6200	6210	1.00	26375.67
PAS-1	Freshwater Marshes	6000	6400	6410	1.00	36659.585
PAS-1	Wet Prairies	6000	6400	6430	1.00	13512.952
PAS-2	Pastures and Fields	2000	2100	2100	3.51	16502.045
PAS-2	Hardwood - Conifer Mixed	4000	4300	4340	1.00	6055.2146
PAS-2	Streams and Waterways	5000	5100	5100	1.00	7755.5175
PAS-2	Bottomland Hardwood Forest	6000	6100	6150	1.00	17001.945
PAS-3	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	66763.983
PAS-3	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	39658.338
PAS-3	Commercial and Services	1000	1400	1400	8.00	55628.623
PAS-3	Recreational	1000	1800	1800	4.09	1746.6295
PAS-3	Other Open Land	1000	1900	1940	1.85	26039.509
PAS-3	Pastures and Fields	2000	2100	2100	3.51	459622.14
PAS-3	Shrub and Brushland	3000	3200	3200	2.06	75257.372
PAS-3	Upland Coniferous Forests	4000	4100	4100	1.00	19630.382
PAS-3	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	253054.24
PAS-3	Pine - Mesic Oak	4000	4100	4140	1.00	69365.055
PAS-3	Hardwood - Conifer Mixed	4000	4300	4340	1.00	296771.37
PAS-3	Tree Plantations	4000	4400	4400	1.58	235.36299

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
PAS-3	Streams and Waterways	5000	5100	5100	1.00	30256.273
PAS-3	Lakes	5000	5200	5200	1.00	237751.58
PAS-3	Wetland Hardwood Forests	6000	6100	6100	1.00	93775.468
PAS-3	Bottomland Hardwood Forest	6000	6100	6150	1.00	797738.67
PAS-3	Wetland Coniferous Forests	6000	6200	6200	1.00	4843.1828
PAS-3	Cypress	6000	6200	6210	1.00	314267.48
PAS-3	Freshwater Marshes	6000	6400	6410	1.00	472672.44
PAS-3	Wet Prairies	6000	6400	6430	1.00	1336588.1
PAS-3	Emergent Aquatic Vegetation	6000	6400	6440	1.00	756448.75
PAS-4	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	18253.189
PAS-4	Residential, High Density	1000	1300	1300	8.66	41817.535
PAS-4	Recreational	1000	1800	1800	4.09	23269.552
PAS-4	Other Open Lands	2000	2600	2600	2.06	4791.2946
PAS-4	Upland Coniferous Forests	4000	4100	4100	1.00	8298.8856
PAS-4	Hardwood - Conifer Mixed	4000	4300	4340	1.00	141706.15
PAS-4	Tree Plantations	4000	4400	4400	1.58	29701.799
PAS-4	Reservoirs	5000	5300	5300	4.09	2974.5896
PAS-4	Bottomland Hardwood Forest	6000	6100	6150	1.00	344309.86
PAS-4	Freshwater Marshes	6000	6400	6410	1.00	2312.3331
PAS-4	Wet Prairies	6000	6400	6430	1.00	2039.7336
PAS-5	Residential, High Density	1000	1300	1300	8.66	259787.58
PAS-5	Recreational	1000	1800	1800	4.09	153240.89
PAS-5	Other Open Land	1000	1900	1940	1.85	32971.232
PAS-5	Pastures and Fields	2000	2100	2100	3.51	184555.31
PAS-5	Other Open Lands	2000	2600	2600	2.06	38377.723
PAS-5	Shrub and Brushland	3000	3200	3200	2.06	100112.79
PAS-5	Upland Coniferous Forests	4000	4100	4100	1.00	693.17876
PAS-5	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	845758.19
PAS-5	Reservoirs	5000	5300	5300	4.09	13436.965
PAS-5	Bottomland Hardwood Forest	6000	6100	6150	1.00	2445514.3
PAS-5	Wetland Coniferous Forests	6000	6200	6200	1.00	6177.9626
PAS-5	Cypress	6000	6200	6210	1.00	314204.26
PAS-5	Freshwater Marshes	6000	6400	6410	1.00	34803.354
PAS-5	Wet Prairies	6000	6400	6430	1.00	5187.3811
PIN-1	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	2984.2955
PIN-1	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	111640.54
PIN-1	Residential, High Density	1000	1300	1300	8.66	622904.18
PIN-1	Commercial and Services	1000	1400	1400	8.00	317304.3
PIN-1	Industrial	1000	1500	1500	8.32	58228.677

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
PIN-1	Institutional	1000	1700	1700	8.07	20181.514
PIN-1	Recreational	1000	1800	1800	4.09	485.15483
PIN-1	Upland Coniferous Forests	4000	4100	4100	1.00	43970.217
PIN-1	Hardwood - Conifer Mixed	4000	4300	4340	1.00	32863.48
PIN-1	Lakes	5000	5200	5200	1.00	17155.079
PIN-1	Reservoirs	5000	5300	5300	4.09	18289.497
PIN-1	Bottomland Hardwood Forest	6000	6100	6150	1.00	25597.411
PIN-1	Freshwater Marshes	6000	6400	6410	1.00	11434.21
PIN-1	Transportation	8000	8100	8100	7.81	49695.954
PIN-1	Utilities	8000	8300	8300	8.32	45744.383
PIN-2	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	29983.96
PIN-2	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	29851.893
PIN-2	Residential, High Density	1000	1300	1300	8.66	341793.57
PIN-2	Commercial and Services	1000	1400	1400	8.00	138418.48
PIN-2	Industrial	1000	1500	1500	8.32	34009.784
PIN-2	Other Open Lands	2000	2600	2600	2.06	67809.102
PIN-2	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	59517.248
PIN-2	Hardwood - Conifer Mixed	4000	4300	4340	1.00	19015.797
PIN-2	Reservoirs	5000	5300	5300	4.09	26631.561
PIN-2	Wetland Hardwood Forests	6000	6100	6100	1.00	3445.4238
PIN-2	Bottomland Hardwood Forest	6000	6100	6150	1.00	20387.758
PIN-2	Freshwater Marshes	6000	6400	6410	1.00	1245.8583
PIN-2	Transportation	8000	8100	8100	7.81	55752.133
PIN-2	Utilities	8000	8300	8300	8.32	20974.459
PIN-3	Residential, High Density	1000	1300	1300	8.66	109469.69
PIN-3	Commercial and Services	1000	1400	1400	8.00	11925.313
PIN-3	Reservoirs	5000	5300	5300	4.09	5102.2832
POL-1	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	51932.521
POL-1	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	579818.65
POL-1	Residential, High Density	1000	1300	1300	8.66	541346.1
POL-1	Commercial and Services	1000	1400	1400	8.00	66836.434
POL-1	Industrial	1000	1500	1500	8.32	151275.17
POL-1	Extractive	1000	1600	1600	8.32	317481.02
POL-1	Institutional	1000	1700	1700	8.07	40547.45
POL-1	Recreational	1000	1800	1800	4.09	341007.89
POL-1	Pastures and Fields	2000	2100	2100	3.51	519752.01
POL-1	Other Open Lands	2000	2600	2600	2.06	313034.73
POL-1	Shrub and Brushland	3000	3200	3200	2.06	2448.6147

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
POL-1	Mixed Rangeland	3000	3300	3300	2.06	619.22005
POL-1	Hardwood - Conifer Mixed	4000	4300	4340	1.00	308837.32
POL-1	Streams and Waterways	5000	5100	5100	1.00	17039.833
POL-1	Lakes	5000	5200	5200	1.00	326422.64
POL-1	Reservoirs	5000	5300	5300	4.09	76788.566
POL-1	Wetland Hardwood Forests	6000	6100	6100	1.00	265339.35
POL-1	Bottomland Hardwood Forest	6000	6100	6150	1.00	202512.87
POL-1	Freshwater Marshes	6000	6400	6410	1.00	49374.517
POL-1	Wet Prairies	6000	6400	6430	1.00	2907.9548
POL-1	Emergent Aquatic Vegetation	6000	6400	6440	1.00	31683.677
POL-1	Transportation	8000	8100	8100	7.81	237384.47
POL-1	Utilities	8000	8300	8300	8.32	65371.213
POL-2	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	138749.49
POL-2	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	1102147.4
POL-2	Residential, High Density	1000	1300	1300	8.66	314461.66
POL-2	Commercial and Services	1000	1400	1400	8.00	134003.82
POL-2	Extractive	1000	1600	1600	8.32	981998.43
POL-2	Institutional	1000	1700	1700	8.07	139851.48
POL-2	Recreational	1000	1800	1800	4.09	432495.44
POL-2	Pastures and Fields	2000	2100	2100	3.51	201706.78
POL-2	Lakes	5000	5200	5200	1.00	1638227
POL-2	Reservoirs	5000	5300	5300	4.09	763754.78
POL-2	Bottomland Hardwood Forest	6000	6100	6150	1.00	6831.5392
POL-2	Freshwater Marshes	6000	6400	6410	1.00	7746.6639
POL-2	Emergent Aquatic Vegetation	6000	6400	6440	1.00	26130.051
POL-2	Utilities	8000	8300	8300	8.32	82616.927
POL-3	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	6142.5118
POL-3	Other Open Land	1000	1900	1940	1.85	6965.5704
POL-3	Tree Crops	2000	2200	2200	4.06	271147.03
POL-3	Shrub and Brushland	3000	3200	3200	2.06	111807.27
POL-3	Upland Coniferous Forests	4000	4100	4100	1.00	2439.47
POL-3	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	639745.37
POL-3	Hardwood - Conifer Mixed	4000	4300	4340	1.00	135699.69
POL-3	Lakes	5000	5200	5200	1.00	1581619.6
POL-3	Bay Swamps	6000	6100	6110	1.00	1873.253
POL-3	Bottomland Hardwood Forest	6000	6100	6150	1.00	3134160.9
POL-3	Freshwater Marshes	6000	6400	6410	1.00	15775.901
POL-3	Wet Prairies	6000	6400	6430	1.00	17348.341

Appendix A (Continued)

Site	Land Use	FLUCC Code Level I	FLUCC Code Level II	FLUUCS Code	Land Use Coeff.	Total Area (m^2)
POL-3	Emergent Aquatic Vegetation	6000	6400	6440	1.00	2946.8974
POL-4	Residential, Low Density <Less than two dwelling units per acre>	1000	1100	1100	6.79	169487.3
POL-4	Residential, Medium Density <Two - five dwelling units per acre>	1000	1200	1200	7.59	890858.33
POL-4	Residential, High Density	1000	1300	1300	8.66	23395.488
POL-4	Commercial and Services	1000	1400	1400	8.00	8895.8554
POL-4	Industrial	1000	1500	1500	8.32	44833.447
POL-4	Institutional	1000	1700	1700	8.07	6068.2736
POL-4	Recreational	1000	1800	1800	4.09	58636.902
POL-4	Other Open Land	1000	1900	1940	1.85	50836.399
POL-4	Pastures and Fields	2000	2100	2100	3.51	834192.24
POL-4	Unimproved Pastures	2000	2100	2120	2.06	1139.5766
POL-4	Tree Crops	2000	2200	2200	4.06	662997.28
POL-4	Citrus Groves	2000	2200	2210	4.06	41961.949
POL-4	Dairies	2000	2500	2520	5.15	82226.457
POL-4	Other Open Lands	2000	2600	2600	2.06	10649.299
POL-4	Shrub and Brushland	3000	3200	3200	2.06	481196.5
POL-4	Other Shrubs and Brush	3000	3200	3290	2.06	3493.7209
POL-4	Pine Flatwoods or Mesic Flatwoods	4000	4100	4110	1.00	623766.24
POL-4	Hardwood - Conifer Mixed	4000	4300	4340	1.00	17468.857
POL-4	Hardwood - Conifer Mixed	4000	4300	4340	1.00	309811.33
POL-4	Lakes	5000	5200	5200	1.00	19884528
POL-4	Reservoirs	5000	5300	5300	4.09	39310.909
POL-4	Bay Swamps	6000	6100	6110	1.00	68730.221
POL-4	Bottomland Hardwood Forest	6000	6100	6150	1.00	3872203.5
POL-4	Mixed Wetland Hardwoods - Mixed Shrubs	6000	6100	6172	1.00	1309.1105
POL-4	Freshwater Marshes	6000	6400	6410	1.00	1390218
POL-4	Wet Prairies	6000	6400	6430	1.00	166761.57
POL-4	Emergent Aquatic Vegetation	6000	6400	6440	1.00	145910.79
POL-4	Utilities	8000	8300	8300	8.32	8352.4423