Northwest Florida
Water Management District

Effects of Septic Systems in the Lake Jackson Watershed

Developed by the Northwest Florida Water Management District under the auspices of the Surface Water Improvement and Management Program and in cooperation with the Florida Department of Environmental Protection, Leon County, and the Leon County Public Health Unit of the Florida Department of Health

Northwest Florida Water Management District
Water Resources Special Report 00-2

November 2000

Effects of Septic Systems in the Lake Jackson Watershed

Lake Jackson SWIM Project Q-9: Evaluation of Septic Tank and Sewer Issues

Paul Thorpe and Peter Krottje

Developed by the Northwest Florida Water Management District under the auspices of the Surface Water Improvement and Management Program and in cooperation with the Florida Department of Environmental Protection, Leon County, and the Leon County Public Health Unit of the Florida Department of Health

---

Northwest Florida Water Management District
Water Resources Special Report 00-2

November 2000

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

For additional information, write or call:

Northwest Florida Water Management District
81 Water Management Drive
Havana, Florida 32333
(850) 539-5999; Suncom 771-2080
FAX #: (850) 539-4380 (Main Bldg.)

Acknowledgements:

Contributors and Editors:	Nick Wooten, Tyler Macmillan, Graham Lewis, Duncan Cairns, Ron Bartel, Maria Culbertson, Christine Stafford, and Craig Diamond
Study Design:	Nick Wooten, Duncan Cairns, Chris Howell, Tyler Macmillan, Pamela Latham, Ron Bartel, Graham Lewis, Tom Pratt, Paul Thorpe, and Craig Diamond
Geographic Information Systems:	Jim Dukes and Paul O'Rourke
Statistical Analysis:	Peter Krottje
Graphics:	Bill Humphries and Tracy Hunt
Water Quality Sampling:	Stan Tucker, Mark Ihlefeld, Robert Breon, Nick Wooten, and Paul Thorpe
Drainfield Survey:	Florida Department of Health, Leon County Public Health Unit
Parcel and topography data:	Leon County GIS

Table of Contents

List of Figures

List of Tables

Introduction

Located just northwest of the city of Tallahassee, Lake Jackson has historically provided valuable fish and wildlife habitat and a recreational and aesthetic amenity for Leon County. It has earned a reputation as an exceptional recreational fishing lake, and it has been designated an Outstanding Florida Water (OFW). Unfortunately, the effects of pollution have been apparent since at least the early 1970s, when water quality problems in the southern portion of the lake were first documented (Harriss and Turner 1974). Recent studies (LaRock and Landing 1991; Livingston 1995a, 1995b) have concluded that the lake suffers from a persistent discharge of polluted urban stormwater runoff, resulting in eutrophication throughout much of the lake. Evidence has also been found to suggest that residential onsite sewage treatment and disposal systems (septic tanks and drainfields) in the lake's western drainage sub-basins are exporting bacteria and nutrients into streams that discharge to the lake (LaRock and Landing 1991). The effects of pollution from any source are exacerbated by the closed nature of the Lake Jackson watershed, which traps pollutants within the sediments and biomass. Unless abated, continuing pollution of the lake will further degrade its quality as habitat and as a recreational and aesthetic resource.

The Lake Jackson Management Plan (Macmillan and Diamond 1994; Macmillan 1997) was developed under the Northwest Florida Water Management District's Surface Water Improvement and Management (SWIM) Program as a cooperative, intergovernmental effort to protect and, as necessary, restore the quality of the lake. Among the plan's goals is to restore water quality to meet or exceed Florida Class III and OFW standards. Within the plan's Water Quality Program is the Evaluation of Septic Tank and Sewer Issues (Project Q-9), the results of which are presented here.

The purpose of this study was to identify the effects of septic systems on surface water quality in the Lake Jackson watershed. In order to accomplish this, it was necessary to identify if conditions were conducive to the export of pollutants from septic systems to surface waters, if substantial numbers of drainfields in the study area were failing, and if surface waters entering the lake from unsewered neighborhoods were of poor quality. The study was accomplished in four components:

1. a geographic analysis to identify and compare the distribution of septic systems and land uses within different sub-basins of the study area and across different soil and slope characteristics;
2. a mail survey to identify the prevalence of resident practices in the study area with the potential to affect surface water quality;
3. a drainfield site survey to identify the frequency of drainfield failure in the study area; and
4. water quality monitoring to compare water quality between sub-basins, between saturated and unsaturated conditions, and between upper and lower stations on the drainage streams.

Background

LaRock and Landing (1991) analyzed Lake Jackson water quality from September 1990 to September 1991. On one occasion, samples were taken prior to and immediately after a storm. The effects of rain were to increase concentrations of indicator bacteria by a factor of nearly 100 and to increase the number of species present in the indicator population. Among their conclusions were the following (LaRock and Landing 1991):

> Based on bacteriological findings after rain events, we feel septic tank effluents containing nutrients and indicator bacteria are being released to Lake Jackson, particularly along the western and southern shorelines.
>
> The development along the western and southern shorelines appears to be adding nutrients in the form of septic tank effluent (based on our finding of bacteria of fecal origin). It would be appropriate to investigate the possibility of installing sewer lines and restricting all future development until the necessary infrastructure is in place.

In 1993, very high values of fecal and total coliform bacteria were measured by the Florida Department of Environmental Protection in a small pond behind the Lake Jackson Trading Post at the corner of Crowder Road and U.S. Highway 27. This pond had been impacted by construction sedimentation and sewage overflows from an adjacent lift station. It discharges into a stream which enters Lake Jackson via Lake Jackson Mounds State Archaeological Site.

Except for a few small subdivisions and the corridor adjacent to U.S. Highway 27 (N. Monroe St.), the western portion of the lake's watershed is served entirely by septic systems. Several large subdivisions in this area are dominated by lots smaller than one-third of an acre. Additionally, the general soils map of the county shows that much of the land on the west side of the lake is underlain by soils with moderate or severe limitations for drainfields, primarily due to high seasonal water tables and slow percolation rates. Direct observation has also found that a number of discharges from residential washing machines, sinks, and tubs have been re-routed from septic systems. These untreated graywater discharges enter swales that drain into Lake Jackson.

Thus, it was reasonable to suspect that septic systems west of Lake Jackson were contributing pollutants to surface water. A cause-and-effect relationship between onsite sewage treatment and disposal systems (OSTDS) and water quality problems, however, had not been established. It was unknown whether drainfields were failing in large enough numbers to cause a significant risk to water quality or public health, and it had not been established whether the density and numbers of septic systems were high enough in and of themselves to result in substantial export of pollutants. Additionally, little water quality data existed for streams entering the lake from the watershed.

Performance of Onsite Sewage Treatment and Disposal Systems

Conventional OSTDS treat domestic wastewater through a two-stage process whereby household wastewater flows first into a septic tank for initial treatment and then into a drainfield infiltration system. Solids are retained within the septic tank and reduced by bacterial digestion. Liquid effluent is distributed via the drainfield into the soil where most treatment occurs (HRS 1993). The average household system receives about 45 gallons per capita per day of bathroom, kitchen, and laundry wastewater (Ayres Associates 1993). Effluents entering drainfields normally contain varying amounts of nitrogen, phosphorus, suspended solids, chlorides, and sodium (Bicki and Brown 1990). Other constituents that may be present include microbial pathogens, detergents, heavy metals, and toxic organic compounds.

The mobility of pollutants discharged via a drainfield depends on such factors as the thickness of the unsaturated zone beneath the drainfield; plant cover; temperature; and the composition, conductivity, pH, moisture, and oxygen content of the soil. Properly sited and functioning OSTDS can remove biochemical oxygen demand (BOD), fecal indicator bacteria, suspended solids, and surfactants within two to five feet of the drainfield infiltrative surface (Ayres Associates 1993). Phosphorus and metals are also removed by retention in the soil underneath the drainfield. The treatment of nitrogen is typically less complete, however. Organic nitrogen is converted into ammonium (NH_4) in the septic tank, and most of this is converted into nitrate (NO_3) in aerobic soil. Some nitrate may be used by plants, and some may undergo denitrification given alternating anaerobic zones and a carbon source. Most, however, escapes into the ground water where little further treatment occurs other than dilution (Ayres Associates 1993).

Given proper OSTDS function, most if not all pathogenic indicator bacteria die off or are retained within a few feet of the infiltrative surface (Ayres Associates 1993). Inadequate system design, siting, or maintenance, however, can result in the introduction of bacteria into ground water, where survival can be greatly extended. Survival tends to be greatest during the rainy season, with soil moisture being the dominant regulating factor (Canter and Knox 1984). Viruses may travel further and have longer residence times than bacteria (EPA 1987; Carlile et al. 1981), but their presence in septic tank effluent is intermittent (Ayres Associates 1993).

Septic tanks can last quite a long time, perhaps 50 years or more for properly designed and maintained concrete, fiberglass, or plastic tanks (Martin and McPherson 1990). The practical lifespan of drainfields may be more limited and is dependent upon soil conditions, maintenance, and construction practices. Drainfields can clog, both due to construction practices and through regular use. Clogging can slow infiltration rates and contribute to eventual hydraulic failure. Causes include soil compaction during construction, deposition of solids, microbial biomass and metabolic byproducts, and soil swelling from prolonged saturation (Ayres Associates 1993). Clogging is controlled through proper placement and construction and can be alleviated by periodic drainfield resting.

Related to the useful life of a drainfield is the phosphorus retention capacity of soil. The ultimate capacity of a site for phosphorus retention depends on such factors as soil mineralogy, particle size, redox potential, pH, and volume. More finely textured soils provide extensive surface area for sorption, and iron, aluminum, and calcium in the soil allow precipitation reactions to occur. With continued loading, phosphorus may be expected to move deeper in the soil profile. Penetration rates beneath drainfields of 10 and 52 cm per year for sand and silt/loam soils, respectively, were reported by Ayres Associates (1993). Most sites have sufficient soil characteristics to provide very long-term phosphorus treatment capacity (Wagner 1992), although the adequacy of treatment in areas where septic systems are heavily concentrated or are located in close proximity to surface waters may be more suspect.

Exactly what comprises OSTDS failure somewhat depends on how these systems are evaluated and the interpretation used as to the overall functionality of septic systems. The Florida Department of Health and Rehabilitative Services (1993) described four classes of OSTDS failure (after Brown 1990):

- Class I Failure. The system hydraulically fails to transport sewage from the building to the system, creating an indoor backup. Such failures are readily identified and corrected and so are normally of limited concern for surface and ground water quality.
- Class II Failure. Wastewater is inadequately conveyed and treated in the drainfield, causing ponding and other problems at the surface. This type of failure may not be readily detected without direct inspection and can impact public and environmental health.
- Class III Failure. Wastewater effluent receives inadequate treatment in the drainfield infiltration system prior to being discharged into ground and/or surface waters. Because this type of failure is difficult to identify and may be systemic across a contributing basin, health and environmental impacts can result.
- Class IV Failure. Inadequate treatment persists on a sustained basis, causing long-term impairment of water quality, biological quality, and public uses of ground and/or surface waters. Such impacts typically occur on a gradual basis and are intractable and expensive to address when finally detected.

Of primary importance to OSTDS treatment performance is the vertical distance between the drainfield and the water table. A sufficient unsaturated (or vadose) zone beneath the infiltrative surface ensures adequate aeration and travel time and thus provides for pollutant biodegradation, nutrient transformation and retention, and bacterial and viral die-off. Effluent that does not travel through a sufficient unsaturated zone is likely to reach the water table with its initial pollutant content substantially unchanged (Bicki and Brown 1990). A minimum separation of 24 inches between the bottom of the drainfield and the wet season water table is typically cited, although greater distances (such as 36 or 48 inches) may be advisable depending on soil permeability (Bicki and Brown 1990; HRS 1993). Where high rainfall causes soil saturation, treatment will likely be incomplete, and lateral flow and/or effluent discharge at the surface may result. Excessively drained soils may also result in inadequate travel time and soil contact before effluent reaches the water table.

High densities and numbers of septic systems in a contributing basin may affect water quality even where individual site conditions are considered adequate for OSTDS use. Where densities are sufficiently low, the relative contribution of OSTDS effluent to overall ground water recharge is likewise low. This helps to ensure dilution of pollutants that do make it to the ground water. High OSTDS densities, however, can result in a substantial portion of local ground water recharge being derived from drainfields (Bicki and Brown 1991). The adverse effects of excessive densities are compounded when exacerbating conditions, such as excessive soil saturation, exist. Bicki and Brown (1991) reviewed minimum densities recommended in the literature. The results varied based upon local conditions, with recommended minimum lot sizes ranging between 0.5 and 2 acres.

Septic tanks and drainfields are subject to state and local regulation. Leon County standards and regulations implemented by the Florida Department of Health are briefly described in Appendix A.

Interaction with Surface Waters

Ground waters affected by OSTDS effluent may interact with surface waters by percolation through bottom sediments when a hydraulic head differential exists between the surface waters and the water table on the adjacent land mass (Lapointe and Matzie 1996). This can occur via tributary streams or directly within the receiving waterbody. Effluent may also enter stormwater runoff when the water table is at or near the ground surface or when failing drainfields otherwise discharge at the surface.

Maintenance of an adequate horizontal distance between septic systems and surface waters is important to provide space and time for pollutant treatment and uptake, nutrient transformation, and dilution before effluent constituents enter surface waters. The distances from drainfields required for nutrients to reach background levels vary depending on local soil conditions and densities and numbers of septic systems. Literature-suggested distances range from about 25 feet (Carlile et al. 1981) to hundreds of feet (Andersen et al. 1996).

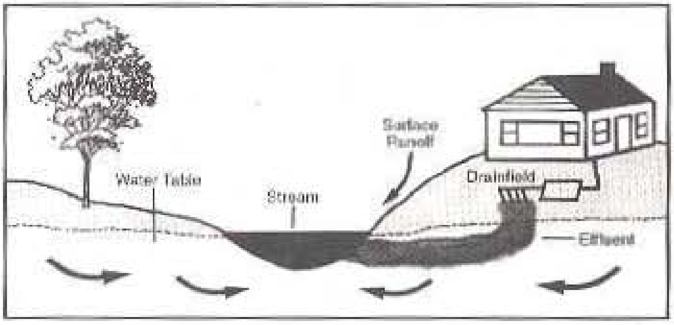


Figure 1. Pathways to Surface Water

Many assessments of OSTDS effectiveness have been conducted in Florida and elsewhere. Four with implications for surface water quality are briefly discussed here. The results and conclusions of these studies vary considerably, demonstrating the difficulty in establishing generalized patterns or standard protection criteria. Lapointe et al. (1990) compared ground and surface water quality over one year between a residential area served by OSTDS and an undeveloped control area in the Florida Keys. Dissolved inorganic nitrogen (nitrite+nitrate and ammonium) levels were elevated over 400 times in OSTDS-affected ground waters over those observed at the control site. Phosphorus enrichment was also observed but was less pronounced. Most ground water nitrogen was in the ammonium form, indicating anoxic, reducing conditions. In surface waters, nitrogen levels adjacent to the OSTDS area were highest in the wet summer season, the reverse of ground water observations. The explanation offered was that ground water-surface water exchange increased during the wet season due in part to the hydraulic head differential. It was also suggested that nutrients may be stored in the ground water during dryer periods and discharged into surface waters during periods of increased precipitation and hydraulic pressure.

Ayres Associates (1993) measured OSTDS effluent, wastewater flow, and ground and surface water quality over two years in the Turkey Creek basin of the Indian River Lagoon. In general, ground water concentrations of nitrite, nitrate, total Kjeldahl nitrogen, total phosphorus, and conductivity were observed to be significantly higher in the vicinity of OSTDS than in upgradient wells. Contaminant concentrations located 20-40 feet downgradient from the OSTDS were found to be at or below background levels, however, and no surface water effects were observed. Bacterial levels were elevated in surface waters, but this was attributed to waterfowl and stormwater runoff.

Wicks and Erickson (1982) evaluated septic system impacts on two lakes (Joanna and Unity) in Lake County, Florida, by monitoring shallow wells located upgradient and downgradient from areas served by septic systems and control areas. Nearshore lake surface water samples were also collected. Conductivity and concentrations of chloride and nutrients were generally elevated downgradient of residential areas served by septic tanks, and similar effects were observed in lake waters adjacent to higher density residential areas. The poorest lake bacteriological water quality tended to be found adjacent to residential areas, although the source of the bacteria was not evaluated. The report concluded that adverse ground water and localized surface water effects were associated with high densities (≥4 units per acre) of residential septic systems, but not with lower (≤2 units per acre) densities.

Following nine months of weekly surface water quality sampling in coastal Wakulla County waters, Williams et al. (1982) concluded that septic tank leachate was the most important source of elevated fecal coliform in the county's coastal waters. The authors noted that characteristics of the area, such as the shallow ground water table and the common close proximity of residences to surface water, reduced the effectiveness and appropriateness of OSTDS for domestic wastewater treatment.

Study Area

Lake Jackson covers approximately 4,000 acres in the Tallahassee Hills physiographic region of west-central Leon County, Florida. The lake has an average elevation of 86.5 feet National Geodetic Vertical Datum (NGVD), and its closed watershed covers 43.2 square miles. It is characterized by open water and lush emergent, floating, and submerged aquatic vegetation and associated fauna. The generally flat bottom of the lake is broken by two major depressions, Lime and Porter sinks. Lake levels fluctuate naturally, swelling during periods of sustained precipitation and declining during droughts when precipitation and runoff fail to replace losses to ground water and evapotranspiration. Lake level extremes on record (since 1950) include a maximum elevation of 96.53 feet NGVD in 1966 and a minimum elevation of 75.68 feet during the drought of 1957 (Hughes 1969; Wagner 1984). The most recent major decline in lake level occurred during 1999-2000, exposing virtually the entire lake bottom.

The study area includes five sub-basins along the western shore of Lake Jackson: Okeeheepkee, Lake Jackson Mounds, Bellwood, Harbinwood, and Sunset (Figure 2). Except for some properties adjacent to U.S. 27, land use in the study area is primarily single-family residential. The Bellwood sub-basin and a small subdivision at the top of the Lake Jackson Mounds sub-basin are served by sanitary sewer, while all other residential units in the study area use septic systems.

The Okeeheepkee sub-basin is the southern most portion of the study area. It is located north of Interstate-10 and drains into Megginnis Arm. Land use is primarily low density residential and wooded, along with some commercial development within the upper portion of the sub-basin along Highway 27. At the time of the study, a small herd of cattle grazed north of Fuller Drive, downstream of the sampling station.

Lake Jackson Mounds is adjacent to and north of the Okeeheepkee sub-basin. It includes the stream catchment that bisects Lake Jackson Mounds State Archaeological Site and the ravine system that extends west toward Highway 27. Land use varies and includes medium and low density residential, wooded, recreational, and—at the western boundary of the basin—medium-to-high intensity commercial.

Bellwood is the upper drainage area of the Harbinwood sub-basin. It includes the Park Hill subdivision and is the only portion of the study area not served by septic systems. Bellwood is characterized by high density residential land use with curb and gutter and subsurface stormwater drainage. Harbinwood is downstream of Bellwood, and it includes the Harbinwood and Harbinwood North subdivisions, including most of Faulk, Longview, and Harriet drives. Land use in Harbinwood is primarily medium-density residential. Some chickens were being raised near Ruth Drive during the study period. The primary drainage stream includes substantial storage and impoundment in its lower reach.

The Sunset sub-basin drains south into the northwestern portion of the lake. The associated stream drains low-density residential land use, wooded areas, and wetlands and enters the lake near the Sunset public landing. A dog kennel and horse pasture are located in the upper portion of the basin. Some wooded and wetland areas along the stream are used for unauthorized garbage disposal.

Methods

The evaluation included geographic analysis, a property-owners survey, a drainfield site survey, and surface water quality monitoring. Methods were as follows.

Geographic Analysis

To delineate and characterize the study area, a geographic database was created using several existing geographic information system (GIS) coverages and limiting them to the study area:

1. a basin delineation developed for a Lake Jackson basin stormwater study (Bartel et al. 1992);
2. a soil data coverage based on the Leon County Soil Survey (USDA SCS 1981);
3. topography based on two-foot contour maps provided by Leon County and U.S. Geological Survey 1:24,000 quad sheets; and
4. a lot-line coverage provided by the Leon County Property Appraisers Office, indicating property boundaries and identification numbers.

Soil and slope coverages were overlaid to create a means of evaluating soil limitations and slope together. Soil data were partitioned into three drainfield suitability classes: severe, moderate, and slight, as classified by the Natural Resource Conservation Service (NRCS) and designated within the soil survey. The NRCS ratings are based on soil properties, site features, and observed soil performance (USDA SCS 1981). The topographic coverage was partitioned into two classes: slopes from 0 to 2 percent and slopes of greater than 2 percent grade. These coverages were then merged to create six "site classes" to describe suitability for septic systems (Figure 3).

Site Class 1: 0-2% slope and slight limitations for septic tanks and drainfields.

Site Class 2: > 2% slope and slight limitations for septic tanks and drainfields.

Site Class 3: 0-2% slope and moderate limitations for septic tanks and drainfields.

Site Class 4: > 2% slope and moderate limitations for septic tanks and drainfields.

Site Class 5: 0-2% slope and severe limitations for septic tanks and drainfields.

Site Class 6: > 2% slope and severe limitations for septic tanks and drainfields.

The lot-line coverage was merged with both basin and site class coverages to provide for parcel-level analyses by basin and site class. Where parcels were initially partitioned into two or more sub-basins and/or site classes, the entire parcels were reassigned to those single site class or sub-basin polygons that comprised the majority of the parcels.

Resident Survey

A survey of residents based on surveys previously used by the Florida Department of Health and Rehabilitative Services (now Department of Health) and private consultants was mailed to study area property owners in March 1994. Survey questions covered respondent demographics, water and fertilizer use, and OSTDS history. The survey instrument is included as Appendix B.

The Leon County Property Appraiser's Office provided a printout of and mailing labels for residential lots within the study area. Unimproved properties were deleted, and remaining parcels were assigned sequential code numbers. A pre-stamped return mailing label annotated with the assigned number was enclosed, and the survey was mailed out. Where property-owner addresses were outside the study area or where they owned multiple improved parcels, additional instructions for completing the survey or forwarding it to appropriate renters were enclosed.

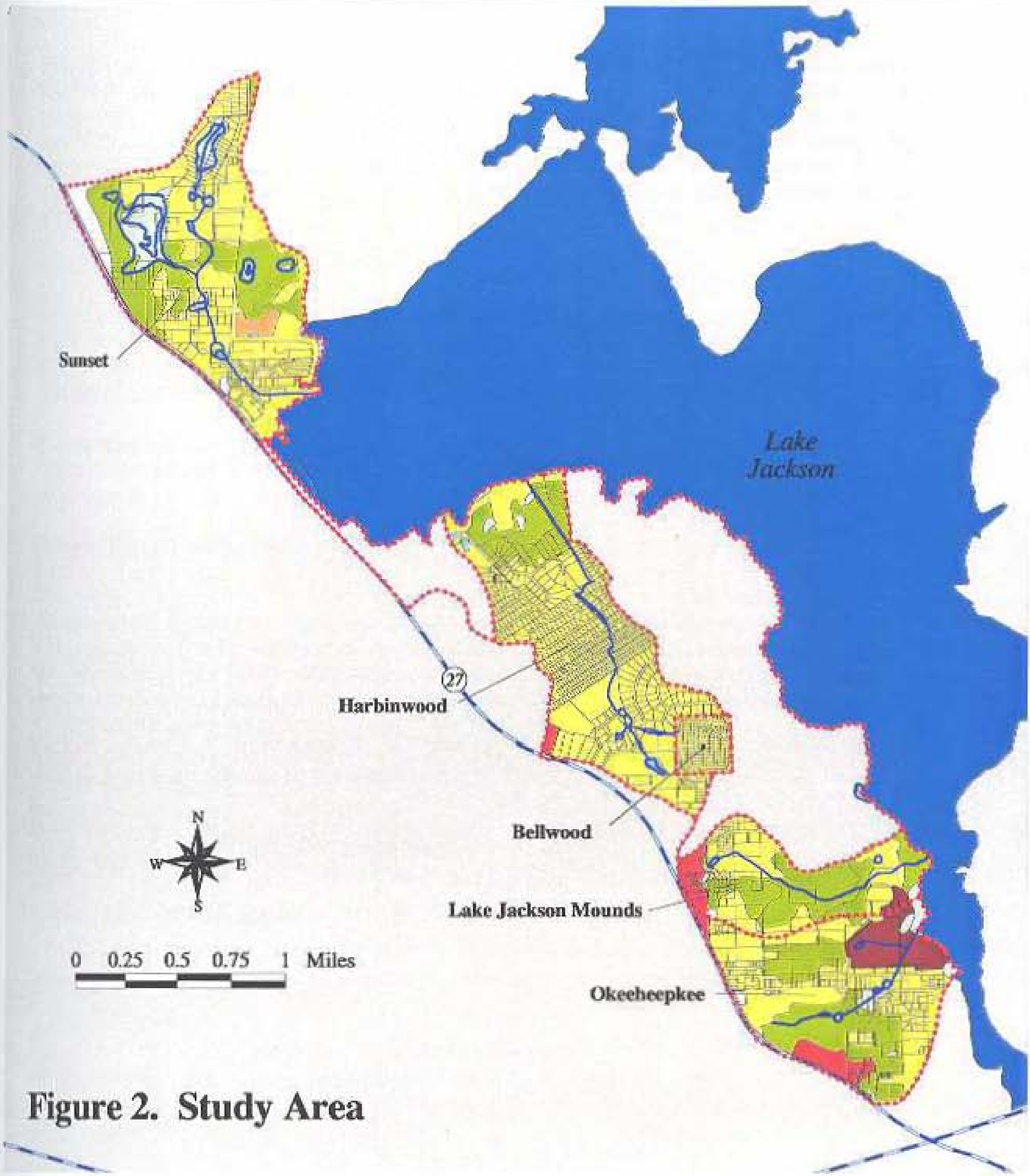


Figure 2. Study Area

Legend

Sub-Basin Boundaries

Existing Land Use Catagories

Residential
Commercial & Services
Industrial
Institutional
Recreational
Agriculture
Upland Forests
Water
Wetlands
Barren Land
Trans, Com, & Utilities
Open Land

03-09-001

Survey responses were entered into a text file with entries left blank when no response was given and the maximum value entered when a range was provided. A "5" would be entered, for example, if a respondent indicated that "4-5" loads of laundry were washed per week. Survey code numbers with associated property appraiser parcel identification numbers were included in a second file, which was then merged with the survey response file. Responses were thus linked to specific parcel identification numbers. Selected response data were exported to the GIS, providing survey responses as lot-line polygon attributes.

Drainfield Survey

To provide a field evaluation of the distribution of drainfield failures, the NWFWMD contracted with the Leon County Public Health Unit to survey drainfield conditions in the study area. The survey consisted of soil borings taken via manual auger at apparent drainfield edges and evaluations of soil color and texture and depth to water table. Field staff also noted locations of disconnected graywater discharges.

Twenty-four lots were randomly selected from lists of parcel identification numbers created for each site class. Residents were asked for permission to access the properties for the survey, and at least 20 lots were selected for sampling from each list. The survey was accomplished in June and July 1994.

Surface Water Quality Monitoring

The water quality sampling effort was designed to screen for differences in water quality between upstream and downstream stations, saturated and unsaturated conditions, and sub-basins. To do this, sampling stations were established upstream and downstream of the primary concentration of improved lots within each sub-basin. It was suspected that saturation would reduce drainfield effectiveness and increase stream connectivity between upper and lower stations, thus resulting in increased pollutant concentrations under saturated conditions and at downstream stations.

Sampling station locations, by sub-basin, were as follows.

1. Okeeheepkee
    a) upper: east side of the south end of Laris Road
    b) lower: north side of Fuller Road between Doris and Ty Cobb Roads
2. Lake Jackson Mounds
    a) upper: immediately downhill into the ravine below Bellwood Circle
    b) lower: creek in Lake Jackson Mounds State Archaeological Site
3. Bellwood
    a) upper: drainage ditch on the north side of Nepal Drive
    b) lower: stormwater outfall on the west side of Sonnet Drive
4. Harbinwood
    a) upper: drainage ditch on the south side of Harriet Drive
    b) lower: drainage stream adjacent to the corner of Oakmont Street and Jacksonview Drive

Sampling stations are illustrated on Figure 4. Stations were also initially established in the Sunset sub-basin; however, these were dropped from the study after the first three sampling events due to a reduction in the project scope.

Six sampling events, three during dry and three during saturated soil conditions, were conducted. Water quality parameters analyzed for are listed in Table 1.

Table 1 . Water Quality Parameters

Chemical parameters	Biological parameters	Field parameters
Orthophosphate (mg/l)	Fecal coliform (MPN/100 ml)	Dissolved oxygen (mg/l)
Total Phosphorus (mg/l)	Total coliform (MPN/100 ml)	PH
Nitrite+Nitrate Nitrogen (mg/l)	Fecal streptococci (MPN/100 ml)	Conductivity (μmho/cm)
Ammonium Nitrogen (mg/l)	*Escherichia coli* (MPN/100 ml)	Flow (cfs)
Total Kjeldahl nitrogen (mg/l)		

Sampling was conducted from March 1995 to March 1996. Dry condition samples were collected during March and April 1995. Saturated condition samples were collected following significant rain events during October 1995 and January, February, and March 1996. The saturated condition samples were not storm samples, but were targeted for the period after precipitation and surface runoff were complete—thus attempting to avoid surface runoff and rainwater dilution that might mask the effects of septic effluent. Rainfall during the study is depicted in Appendix D.

Statistical analysis was conducted with the microcomputer application JMP Version 3 (SAS Institute). Independent variables examined were sub-basin, wet versus dry sampling conditions, and upstream versus downstream sampling locations within sub-basins. Dependent variables were fecal coliform bacteria, total coliforms, fecal streptococci, *E. coli*, orthophosphorus, total phosphorus, nitrate-nitrite nitrogen, ammonium nitrogen, and total Kjeldahl nitrogen (TKN).

Preliminary analysis using the Shapiro-Wilk W test indicated significant deviation from normality for most of the dependent variables. All variables could be rendered more nearly normal through simple logarithmic transformation and generation of geometric means, and this would allow the use of parametric statistics. The use of geometric means, however, is undesirable for a number of reasons, not least of which being that arithmetic means are more intuitive (Parkhurst 1998). The statistical analysis of water quality data in this study therefore used nonparametric methods that do not require transformation. The Wilcoxon rank sum test was used to determine differences among sub-basins and was employed separately for each sub-basin to determine the influence of wet versus dry conditions and upstream versus downstream sampling sites on water quality within each sub-basin. An additional three-way analysis of variance (ANOVA), performed using log-transformed data, is provided in Appendix C.

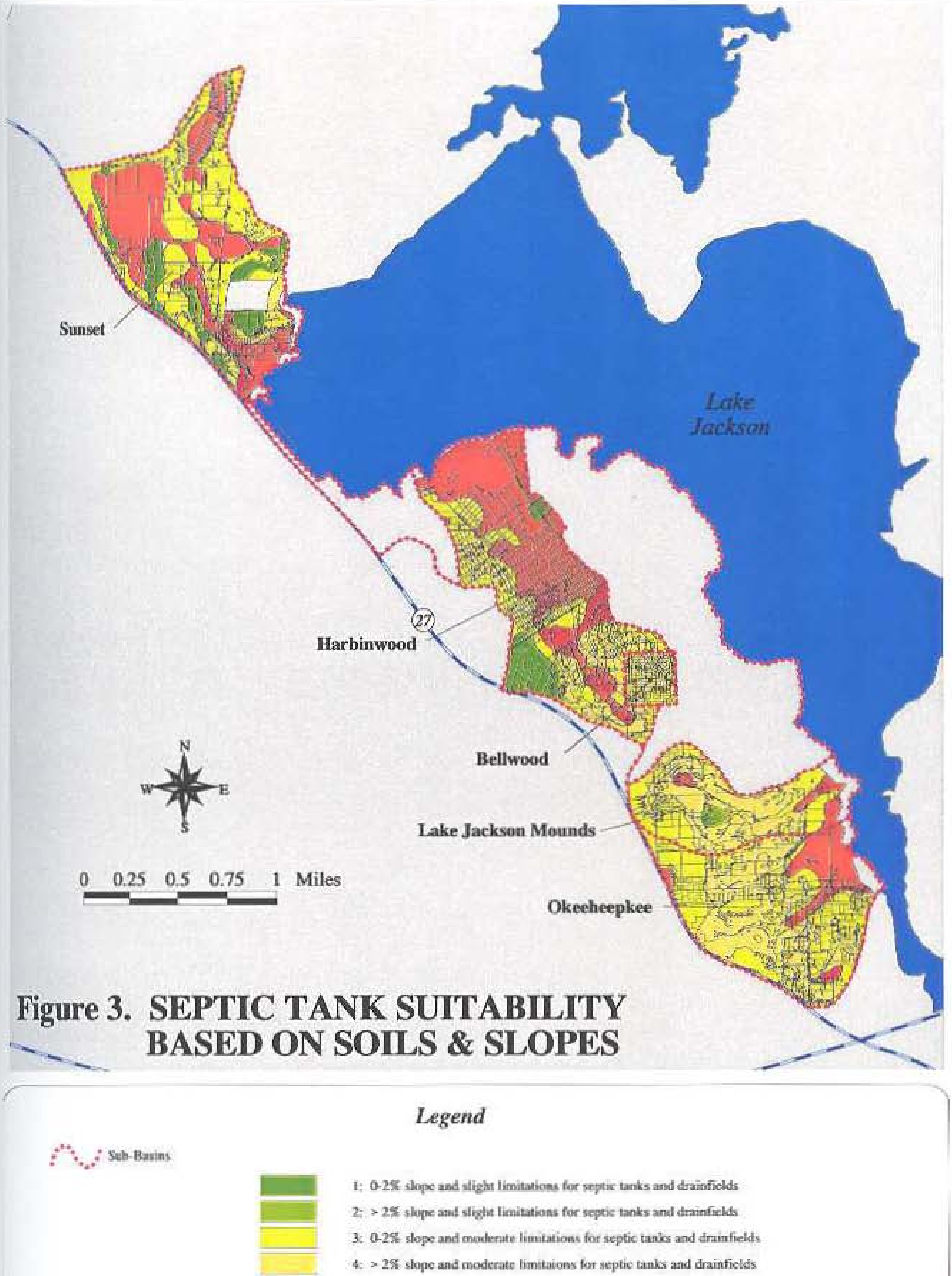


Figure 3. SEPTIC TANK SUITABILITY BASED ON SOILS & SLOPES

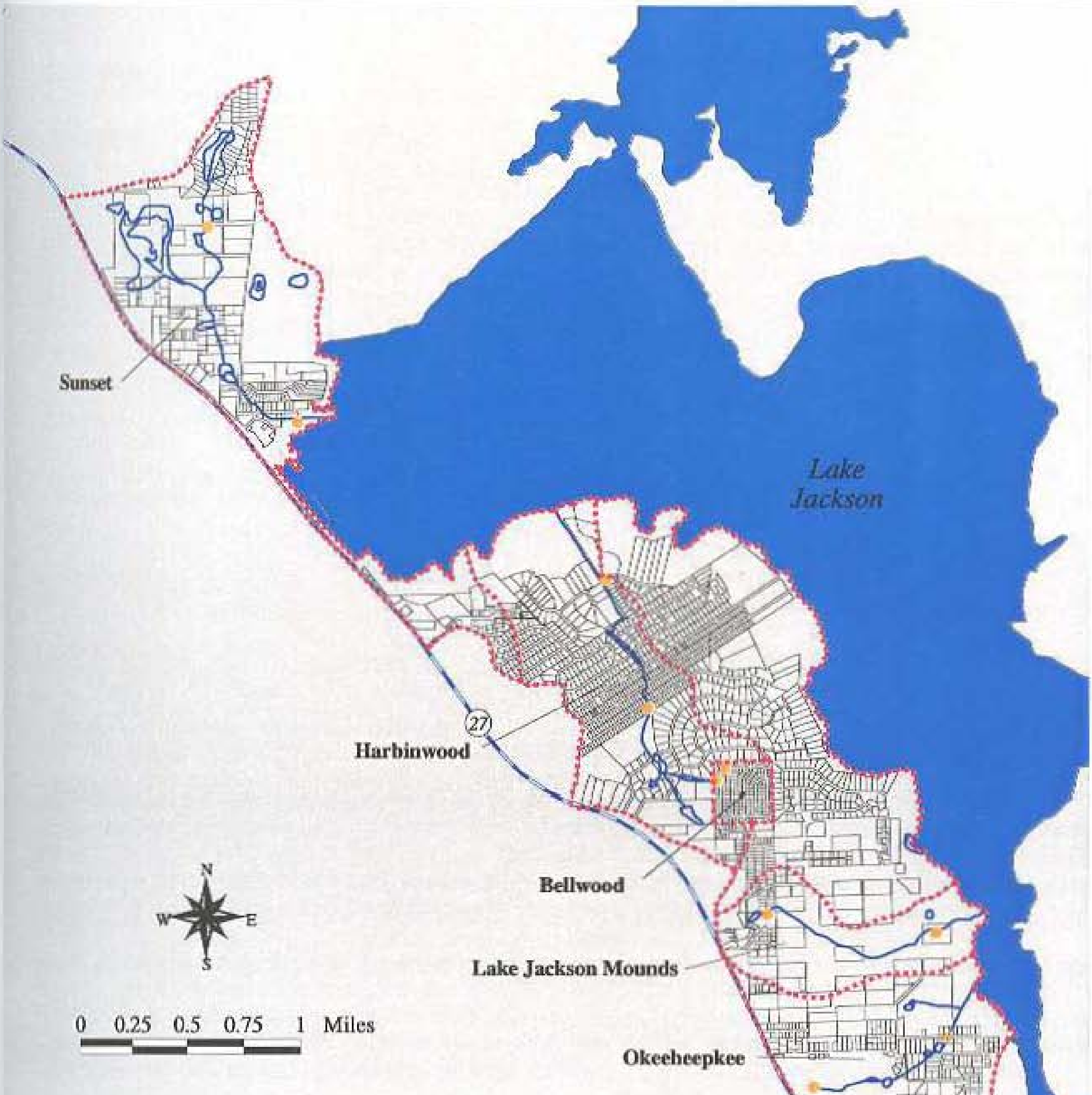


Figure 4. SURFACE WATER SAMPLING STATIONS

Legend

Sub-Basin Boundaries

Sampling Stations

Major Streams

03-09-003

esults

ographic Analysis

ble 2 displays the areas, numbers of residential lots, and unit densities within each sub-basin as a hole and within the contributing areas of the sampling stations. Harbinwood covers the largest area and s the greatest number of lots. It also has the highest unit density of the unsewered sub-basins, while e sewered Bellwood sub-basin has the highest overall density. Within the approximate contributing eas of the water quality sampling stations, slightly higher unit densities prevailed in unsewered sub-sins. The most dense of these is Harbinwood, with 1.22 units per acre in the contributing area.

Table 2. Characteristics of Study Sub-basins

Sub-basin	Total Area (acres)	Residential Lots	Units per Acre (Overall)	Contributing Area* (acres)	Residential Lots	Units per Acre (contrib. area)
Okeeheepkee	414.8	221	0.53	374.9	195	0.52
LJ Mounds	235.9	75	0.32	204.5	74	0.36
Bellwood	41.0	169	4.12	41.0	169	4.12
Harbinwood	550.8	512	0.93	408.1	497	1.22
Sunset	612.9	219	0.36	581.1	219	0.38
Total	1,855.4	1,196	0.66	1,609.6	1,154	0.72

*Basin area upstream of the lower sampling station.

An analysis of the number and density of septic system-served parcels within 100 feet of the streams in he study sub-basins was also performed. The Harbinwood sub-basin had 84 parcels in the 100-foot stream corridor at a density of 1.49 units per acre. The Lake Jackson Mounds stream corridor had 24 parcels at a density of 0.82 per acre, the Okeeheepkee corridor had 55 parcels at 1.75 per acre, and the Sunset sub-basin corridor had 85 parcels at a density of 0.62 units per acre.

Table 3 provides an analysis of the study sub-basins based on the site classes described earlier. The majority of the lots are concentrated in site classes 3 (0-2% slope and moderate soil limitations), 4 (>2% slope and moderate soils), and 5 (0-2% slope and severe soil limitations). The distribution of lots per site class appears most problematic in the Harbinwood and Sunset sub-basins, within which the largest number were in site class 5. Lots were concentrated in site classes 3 and 4 in the other sub-basins.

Table 3. Area and Lots Per Site Class by Sub-basin

Site Class	Okeeheepkee		LJ Mounds		Bellwood		Harbinwood		Sunset		Total	
	Acres	Lots	Acres	Lots	Acres	Lots	Acres	Lots	Acres	Lots	Acres	Lots
1	0	0	0	0	0	0	38.8	24	34.3	30	73.1	54
2	0	0	0	0	0	0	0	0	14.2	8	14.2	8
3	177.4	117	40.7	41	23.7	72	119.6	168	117.4	69	394.9	467
4	173.8	74	194.5	33	17.3	97	88.0	80	19.7	17	541.4	301
5	53.3	25	0.7	1	0	0	266.3	212	201.1	78	514.9	316
6	10.3	5	0	0	0	0	38.1	28	8.9	17	50.5	50
Total	414.8	221	235.9	75	41.0	169	550.8	512	*395.6	219	1,589.0	1,196

*217.3 acres in Sunset designated as a borrow pit were outside the site class delineation.

Resident Survey

Of 1,016 surveys distributed, 402 were completed and returned, yielding a 39.6% response rate. Table 4 summarizes the means, medians, modes and sums of the survey. Sums associated with variables followed by question marks (?) indicate positive responses.

Table 4. Summary of Resident Survey Responses (N=402)

Variable	Mean	Median	Mode	Total
Residents Per Household	2.48	2	2	989
Pets	0.98	1	0	394
Water Use (month)	5,224.69	4,820	5,000	2,100,325
Gallons per Capita per Day	74.80	65	66.67	---
Laundry Wash Freq. (loads/week)	4.87	4	4	1,958
Irrigation Freq. (days/month)	1.86	1	0	748
Car Wash Freq. (per month)	1.37	1	1	551
Lot Size (acres)	1.32	0.49	0.49	---
Annual Fertilizer Applications	1.05	1	1	422
Lbs. Fertilizer Per Application	40.01	15	0	---
Age of Home (years)	20.74	20	20	---
Number of Septic Tanks	1.18	1	1	474
Septic Tank Ever Pumped?	---	---	---	244
# of Times (of those pumped)	2.22	2	1	---
Last Year Pumped	1990	1991	1993	---
Drainfield Ever Replaced?	---	---	---	138
# of Times (of those replaced)	1.27	1	1	174
Last Year Replaced	1987	1989	1991	---
Washing Machine?	---	---	---	388
Machine Connected?	---	---	---	229

Sixty-one percent of the respondents reported knowing that their septic systems had been pumped at least once in the history of the property. Twenty-six percent reported that their systems had never been pumped, and the remainder did not know or did not respond to the question. Thirty-four percent of the respondents reported that their drainfields had been replaced in the past. Forty-eight percent reported their drainfields had never been replaced, and the remainder did not know or did not respond to the question.

Based on the responses provided and the survey response rate, a number of estimates may be extrapolated for the study area by generally applying the mean survey responses to the total number of residential lots identified.

- There were approximately 2,499 residents and 996 outdoor pets in the study area at the time of the survey.
- Total water demand was approximately 5.3 million gallons per month, including water use for approximately 1,392 car washes, 1,890 lawn and garden waterings, and 19,792 laundry loads per month.
- There were approximately 1,067 applications of fertilizer per year, averaging 40 lbs. per application. The total annual load was approximately 42,682 lbs.
- There were approximately 980 washing machines in the study area, of which an estimated 402 (41 percent) may not be connected to the wastewater treatment system.
- There were approximately 1,199 septic tanks in the study area.
- Of those homes where OSTDS repairs or maintenance were reported, systems were pumped an average of twice and drainfields were replaced once during the known history of the property.

Table 5 displays reported drainfield replacements and pumping by sub-basin and site class. Site classes 3 and 5 showed the highest percentages of respondents reporting drainfield replacements. Site classes 1, 3, and 6 had the highest percentages of respondents reporting having pumped their septic tanks. The highest combined percentages were in site classes 1, 3, and 6. The distribution of reported maintenance actions by sub-basin was consistent with the general distribution of lots by sub-basin (Table 3).

Table 5. Reported Drainfield Maintenance Actions: Number and Percentage of Survey Respondents Reporting by Sub-basin and Site Class

		Site Class													
		1		2		3		4		5		6		Total	
	Sub-basins	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	Total	%
Tanks Pumped	Okeeheepkee	0	0	0	0	8	8	8	7	0	0	0	0	16	5
	Harbinwood	2	40	0	0	34	34	11	10	37	33	6	33	90	26
	LJ Mounds	0	0	0	0	4	4	3	3	0	0	0	0	7	2
	Sunset	1	20	0	0	1	1	1	1	5	4	2	11	10	3
	Subtotal	*3*	*60*	*0*	*0*	*47*	*47*	*23*	*21*	*42*	*38*	*8*	*44*	*123*	36
Drainfields Replaced	Okeeheepkee	0	0	0	0	3	3	7	7	0	0	0	0	10	3
	Harbinwood	1	20	0	0	17	17	9	8	21	19	1	6	49	14
	LJ Mounds	0	0	0	0	4	4	1	1	0	0	0	0	5	1
	Sunset	0	0	0	0	0	0	0	0	4	4	2	11	6	2
	Subtotal	*1*	*20*	*0*	*0*	*24*	*24*	*17*	*16*	*25*	*22*	*3*	*17*	*70*	*20*
	Total	**4**	**80**	**0**	**0**	**71**	**71**	**40**	**37**	**67**	**60**	**11**	**61**	**193**	**56**
No. of respondents		5		0		100		107		112		18		342	

Drainfield Survey

Drainfield surveys were attempted at 99 sites. Of these, 12 sites were not surveyed due to refusal by the occupants to allow access. Of the 87 drainfields that were evaluated, five drainfield failures and 17 graywater disconnects (20% of the sites surveyed) were identified. Although the drainfield survey was intended to identify the frequency and distribution of septic systems that could be polluting the lake, it is likely that only Class I and II failures, as described earlier, were identified. Table 6 presents the results of the drainfield survey by sub-basin.

It is interesting to contrast the observed 20% disconnect rate with the 41% rate of unconnected washing machines reported in the mail survey. Field observation indicates that disconnects are not distributed evenly throughout the study area, and it is possible that the limited site survey did not fully represent the prevalence or distribution of the practice.

Table 6. Results of Drainfield Survey by Sub-basin

	Okeeheepkee	LJ Mounds	Harbinwood	Sunset	Out*	Overall
Surveys	8	2	57	6	14	87
Failures	2	0	1	1	1	5
Disconnects	2	0	12	3	0	17
Failure Rate (%)	25	0	2	17	7	6
Discon. Rate (%)	25	0	21	50	0	20

*Attempted surveys in the vicinity of but outside the project sub-basin boundaries.

Table 7 displays an analysis of observed drainfield failures and graywater disconnects by site class and sub-basin. Both failures and disconnects seemed concentrated in site class 3 (0-2% slope and moderate soil limitations), which is consistent with the general distribution of lots in the study area (Table 3). A relatively large number of disconnects, considering the overall distribution of lots, were observed in site class 1, which is classified as having slight slopes and slight soil limitations. A relatively high number of disconnects were also observed in site class 6 (steep slopes and severe soils), as was one failure. It is notable that no observed failures and only three disconnects were observed in site class 5 within Harbinwood, although the preponderance of Harbinwood lots are within this site class.

Table 7. Observed Drainfield Problems by Site Class and Sub-basin

		Site Classes						
	Sub-basins	1	2	3	4	5	6	Total
Number of Failures	Okeeheepkee	0	0	0	1	0	1	2
	Harbinwood	0	0	1	0	0	0	1
	LJ Mounds	0	0	0	0	0	0	0
	Sunset	1	0	0	0	0	0	1
	Out	0	0	1	0	0	0	1
	Subtotal	*1*	*0*	*2*	*1*	*0*	*1*	*5*
Number of Disconnects	Okeeheepkee	0	0	0	0	0	2	2
	Harbinwood	2	0	5	2	3	0	12
	LJ Mounds	0	0	0	0	0	0	0
	Sunset	2	0	0	0	0	1	3
	Out	0	0	0	0	0	0	0
	Subtotal	*4*	*0*	*5*	*2*	*3*	*3*	*17*
TOTAL		**5**	**0**	**7**	**3**	**3**	**4**	**22**

Surface Water Quality Monitoring

Mean water quality concentrations are compared between sub-basins in Table 8. Overall mean fecal coliform counts were lowest in the sewered Bellwood sub-basin (164 organisms/100 ml) and highest in Harbinwood (4,781/100 ml). Harbinwood fecal coliform counts were significantly higher than those in Bellwood and Okeeheepkee (Wilcoxon rank sum test; p=0.05) but did not significantly differ from those in Lake Jackson Mounds. Total coliform results were similar but with higher values, with concentrations ranging from 2,763/100 ml for Bellwood to 15,189/100 ml for Harbinwood. For *E. coli*, sub-basin rankings were the same as those observed for fecal and total coliforms, with values ranging from 131/100 ml in Bellwood to 4,360/100 ml in Harbinwood. Harbinwood also showed the highest fecal strep values, with a mean of 12,183/100 ml, while the Okeeheepkee sub-basin had the lowest mean value at 1,356/100 ml.

Table 8. Overall Mean Water Quality Concentrations by Sub-basin
(Bacteria values as organisms per 100 ml. Other values as mg/L.)

Parameter	Okeeheepkee	LJ Mounds	Bellwood	Harbinwood
Fecal Col.	405[1]bc	1,608[2]ab	164c	4,781[2]a
Total Col.	8,608[2]a	12,637[2]a	2,763[2]b	15,189[2]a
E. coli	349ab	1,115ab	131b	4,360a
Fecal Strep	1,356b	3,080ab	2,248b	12,183a
NO_2+NO_3	0.43a	0.48a	0.57a	0.13b
NH_4	0.06a	0.06a	0.15a	0.07a
TKN	0.35ab	0.25b	0.26b	0.52a
Ortho-P	0.03ab	0.04ab	0.03b	0.07a
TP	0.11b	0.09b	0.07b	0.23a
DO	7.7a	9.9a	8.0a	9.2a

Note: Values within a row followed by the same letter are not significantly different (Wilcoxon rank sum test, p=0.05).
[1]Exceeds monthly Class III fecal coliform standard (200/100 ml) or monthly total coliform standard (1,000/100 ml).
[2]Exceeds one-day Class III fecal coliform standard (800/100 ml) or one time total coliform standard (2,400/100 ml).

When compared to Florida Class III surface water quality standards (Chapter 62-302, Florida Administrative Code), the mean fecal coliform concentrations in the Lake Jackson Mounds and Harbinwood sub-basins exceeded the one-day standard of 800 organisms per 100 ml (Table 8). The Okeeheepkee sub-basin mean exceeded the monthly fecal coliform standard of 200/100 ml. All sub-basin mean total coliform concentrations exceeded the Class III total coliform standard of 2,400/100 ml (any time).

Fecal coliform to fecal streptococcus (FC:FS) ratios averaged 0.51 and ranged from 0.11 at the Okeeheepkee upstream station under wet conditions to 3.17 at the same station under dry conditions. These ratios have historically been used to distinguish bacteria from human sources from those originating from animals. Ratios higher than 4 were considered indicative of human sources, while ratios below 0.7 were considered indicative of animal sources, with intermediate ratios indicating a mixed source. However, FC:FS ratios are subject to a great deal of variability due to differing survival rates between the two groups under various environmental conditions and other complicating factors. For such reasons, the 18th edition of Standard Methods for the Examination of Water and Wastewater (APHA 1992) discourages use of FC:FS ratios for determining sources of bacteria.

Sub-basin relationships for nitrate/nitrite levels were the reverse of those seen for bacteriological parameters, with Harbinwood showing significantly lower mean concentrations (0.13 mg/L N) than the other sub-basins (0.438-0.57 mg/L N). Values observed in Harbinwood were moderate, while those observed in the other sub-basins were high to very high based on DEP's statewide stream database (Friedeman and Hand 1989). Ammonium concentrations were relatively low in all sub-basins (0.06-0.15 mg/L). Total P and ortho-P concentrations were moderate to high in Harbinwood (0.23 mg/L TP, 0.07 mg/L ortho-P) and moderate in the Bellwood, Lake Jackson Mounds, and Okeeheepkee sub-basins (0.07-0.11 mg/L TP, 0.03-0.04 mg/L ortho-P).

Mean concentration values found under different saturation conditions for each sub-basin are presented in Table 9. Significant differences between saturated and unsaturated conditions were evident for bacteriological parameters in the Lake Jackson Mounds and Okeeheepkee sub-basins. In both cases, fecal coliforms, *E. coli*, and total coliforms were much higher under wet conditions.

Table 9. Mean Concentrations by Saturation Condition
(Bacteria values as organisms per 100 ml. Other values as mg/L.)

		Water Quality Parameter									
	Sub-basins	Fecal C.	Total C.	E. coli	Fecal S.	NO_{2+3}	NH_4	TKN	Ortho-P	TP	DO
Unsaturated	Okeeheepkee	114	3,925[2]	91	1,034	0.50	0.06	0.31	0.04	0.11	7.45
Unsaturated	Harbinwood	7,678[2]	15,286[2]	7,239	13,532	0.15	0.07	0.39	0.07	0.19	8.05
Unsaturated	LJ Mounds	420[1]	3,536[2]	303	1,431	0.55	0.07	0.23	0.04	0.07	9.65
Unsaturated	Bellwood	163	1,921[1]	109	3,344	0.57	0.15	0.27	0.03	0.08	7.7
	Mean	*2,094*	*6,167*	*1,935*	*4,835*	*0.44*	*0.09*	*0.30*	*0.04*	*0.11*	*8.2*
Saturated	Okeeheepkee	696*[1]	13,292*[2]	608*	1678	0.36	0.06	0.40	0.03	0.11	7.9
Saturated	Harbinwood	1,884[2]	15,092[2]	1,482	10,834	0.12	0.07	0.65	0.07	0.27	10.35
Saturated	LJ Mounds	2,797*[2]	21,738*[2]	1,926*	4,729	0.41	0.05	0.27	0.04	0.11*	10.2
Saturated	Bellwood	165	3,605[2]	153	1152	0.58	0.15	0.25	0.04*	0.07	8.25
	Mean	*1,385*	*13,432*	*1,042*	*4,598*	*0.36*	*0.08*	*0.39*	*0.05*	*0.14*	*9.2*

*Saturated condition values significantly higher than unsaturated condition values (Wilcoxon rank sum test, p=0.05).
[1] Exceeds monthly Class III fecal coliform standard (200/100 ml) or monthly total coliform standard (1,000/100 ml).
[2] Exceeds one-day Class III fecal coliform standard (800/100 ml) or one time total coliform standard (2,400/100 ml).

In unsaturated conditions, mean fecal coliform concentrations in Harbinwood exceeded the one-day Class III fecal coliform standard, while the Lake Jackson Mounds sub-basin exceeded the monthly average fecal coliform standard. Under saturated conditions, Harbinwood and Lake Jackson Mounds exceeded the one-day fecal coliform standard, and Okeeheepkee exceeded the monthly standard. Mean total coliform values in all sub-basins except Bellwood exceeded the one time standard, and Bellwood exceeded the monthly total coliform standard. Under saturated conditions, mean total coliform values from all sub-basins exceeded the one time standard.

Table 10 compares mean values from upstream and downstream stations within each sub-basin. Few significant differences and no consistent patterns were apparent. Widespread exceedances of Class III bacterial standards were again apparent at both upstream and downstream stations with the exception of Bellwood and lower Okeeheepkee in the case of fecal coliform.

Table 10. Mean Concentrations by Station Location

(Bacteria values as organisms per 100 ml. Other values as mg/L.)

		Water Quality Parameter								
	Sub-basins	Fecal C.	Total C.	E. coli	Fecal S.	NO_{2+3}	NH_4	Ortho-P	TP	DO
Upstream Station	Okeeheepkee	658[1]	10,853^,[2]	586	2,022	0.72^	0.02	0.01	0.11	6.6
	Harbinwood	2,227[2]	8,245[2]	1,909	7,800	0.14	0.07	0.06	0.22	10.2
	LJ Mounds	2,141[2]	11,702[2]	1,396	1,636	0.38	0.10^	0.03	0.08	9.7
	Bellwood	182	2,506[2]	146	3324	0.71	0.02	0.03	0.09^	7.1
	Mean	*1,302*	*8,327*	*1,009*	*3,696*	*0.49*	*0.05*	*0.03*	*0.13*	*8.4*
Downstream Station	Okeeheepkee	151	6,363[2]	112	690	0.14	0.10	0.05	0.11	8.7
	Harbinwood	7,334[2]	22,133[2]	6,812	16,566	0.12	0.07	0.08	0.24	8.2
	LJ Mounds	1,076[2]	13,571[2]	833	4,524	0.57*	0.02	0.05*	0.10	10.2
	Bellwood	147	3,020[2]	115	1,171	0.42*	0.27*	0.03	0.05	8.8
	Mean	*2,177*	*11,272*	*1,968*	*5,738*	*0.31*	*0.12*	*0.05*	*0.13*	*8.98*

*Downstream values significantly higher than upstream values (Wilcoxon rank sum test, p=0.05).
^Upstream values significantly higher than downstream values (Wilcoxon rank sum test, p=0.05).
[1]Exceeds monthly Class III fecal coliform standard (200/100 ml) or monthly total coliform standard (1,000/100 ml).
[2]Exceeds one-day Class III fecal coliform standard (800/100 ml) or one time total coliform standard (2,400/100 ml).

Discussion

Conditions within the study area appear conducive to the export of pollutants from residential septic systems to surface waters in the Lake Jackson watershed. Large numbers of septic systems are present, and these are concentrated at high densities in some areas. A number of drainfields are also located in close proximity to streams flowing to the lake. Additionally, substantial numbers of septic systems are located in soils that are classified as generally inappropriate for drainfields. The Harbinwood sub-basin appears particularly suspect, given the density and number of units within the sub-basin, the concentration of many in inappropriate soils, and the density of units in the 100-foot stream corridor. Maintenance of septic systems may also be generally inadequate. For example, a substantial proportion of mail survey respondents indicated no knowledge of their systems ever having been pumped, even though most of these residences and septic systems have probably been around for decades.

There are alternative sources of pollutants to septic systems that could account for some of the enrichment observed, including the full range of nonpoint source pollutants commonly generated by suburban communities. As expected, for example, the mail survey indicated substantial use of fertilizer and considerable numbers of pets throughout the study area. Impacts from these sources and runoff from streets and structures are subject to the same geographic factors (e.g., density, lack of stream buffers) that increase impacts from septic systems. Stream channelization, lack of infiltration capacity, and stream bank erosion also contribute to surface water pollution. Wildlife may be significant in places, particularly within Okeeheepkee and Lake Jackson Mounds.

The suspicion that comparing upstream and downstream stations would reveal increased concentrations downstream was not confirmed in the water quality monitoring, while the effects of saturation on pollutant concentrations were mixed. Bacterial concentrations were significantly higher under saturated than unsaturated conditions in the Okeeheepkee and Lake Jackson Mounds sub-basins, but not in the others. No such effect was found for nutrients.

e water quality results did, however, reveal very high bacteria values in nearly all sub-basins, ticularly in Harbinwood, Okeeheepkee, and Lake Jackson Mounds. This was true under all conditions Harbinwood and particularly under wet conditions in Okeeheepkee and Lake Jackson Mounds. This ation, and the fact that the sewered Bellwood sub-basin generated the least bacteria under all ditions, lends credence to the suspicion that septic systems are polluting the lake.

rate/nitrite enrichment patterns were the reverse of those seen for bacteria, and ammonium ncentrations tended to be relatively low. Phosphorus enrichment patterns seemed more consistent h those found for bacteria, although OSTDS are generally thought to be better at removing phosphorus n nitrogen. In considering nutrient concentrations, however, it is important to note that it is unknown at the concentrations in the respective sub-basins would be in the absence of anthropogenic impacts m septic systems or other sources. That ammonium values were relatively low suggests that vadose nes in the study area may be generally adequate for nitrification. Nitrate from the septic systems could entering surface waters, but it is not known if the nitrate values in the drainage streams are different n they would be under sewered conditions. Interestingly, Bellwood, the only sewered study sub-basin, d the highest nitrite/nitrate values. These were significantly higher than those found in Harbinwood, ich had the highest unit density of the septic sub-basins and the worst bacteriological quality. It is spected that the much higher unit density found in Bellwood results in greater nitrite/nitrate loading from npoint sources of pollution common to urban stormwater runoff.

87 drainfields physically surveyed, five failures and 17 disconnects were identified. The survey was likely, however, to detect systemic but less than obvious (Class III and/or IV) treatment deficiencies. e distribution of the failures and disconnects discovered was generally consistent with the overall tribution of lots in the study area. There were, however, a relatively large number of disconnects served in conditions of slight slopes and soil limitations, as well as in the reciprocal conditions of steep pes and severe soils. The percentage of disconnects among sites surveyed seemed particularly high the Sunset, Okeeheepkee, and Harbinwood sub-basins. It may be that wastewater treatment pacities of the typical septic systems and drainfields in the area tend to be inadequate.

onclusions and Recommendations

e observations obtained through this assessment do not provide a conclusive determination about the portance of septic system effluent as a source of nonpoint source pollution in the Lake Jackson atershed. Some of these observations are, however, consistent with concerns that pollutants are being ported to surface waters. Fecal and total coliform bacteria values were often found to be quite high, d they frequently exceeded state water quality standards. Bacteria values were found to be relatively v in the only sewered sub-basin. The nutrient enrichment patterns observed, however, were not nsistent with the bacterial enrichment patterns.

e results of this analysis are also consistent with those of a number of recent studies that describe npoint source pollution as posing a continuing threat to the health of Lake Jackson. Protection of the e requires effective treatment of both surface runoff and baseflow discharge in areas affected by velopment. This can be provided through stormwater treatment systems, improved maintenance of isting systems, implementation of a variety of urban best management practices, riparian buffer zones, d public education.

e high bacteria values warrant further attention and monitoring. If such conditions persist, the potential k to public health should be evaluated and treatment measures should be considered. The popularity disconnecting graywater from septic systems also suggests that the general adequacy of wastewater pacity for homes in the area should be evaluated. The feasibility of adding sewer service to the stern Lake Jackson sub-basin should be evaluated pursuant to Policy 1.2.3 of the Tallahassee-Leon unty 2010 Comprehensive Plan Utilities Element. This policy provides for the city and Talquin Electric operative to enter into an agreement to extend sanitary sewer service to septic tank problem areas in e Lake Jackson watershed. Treatment of stormwater runoff and baseflow discharges through treatment systems, best management practices, and public pollution prevention may also reduce concentrations of bacteria and other microbial pathogens.

An effort to educate homeowners about proper septic system maintenance should be considered. A number of studies (e.g., Martin and McPherson 1990), as well as the survey results obtained through this project, suggest that the frequency between septic system pumpings is typically too long and that many residents never pump systems until they fail. In addition to information on direct septic system maintenance, educational material could stress household water conservation. Such conservation could reduce wastewater flow and pollutant loadings, extend drainfield life, and reduce the frequency of failure (Martin and McPherson 1990).

It is suggested that the Harbinwood sub-basin be a priority for further evaluation and corrective measures. This basin had the highest bacteria values under all conditions, and it has the largest number and greatest concentration of septic systems, both basin-wide and within the 100-foot stream corridor. Nitrite-nitrate levels in this basin were moderate, but phosphorus levels were high. Given the overall density of septic systems, the number and density of units in the 100-foot stream corridor, and the length of time these systems have been in operation, it is conceivable that drainfields in Harbinwood are exporting bacteria and possibly nutrients to the lake. The Lake Jackson Mounds and Okeeheepkee sub-basins should be considered for evaluation and treatment, as well.

Further analysis could be pursued to better determine the importance of septic systems as a source of bacteria in the watershed. Dye-trace analysis and monitoring of shallow ground water wells have been pursued in other locations (e.g., Wicks and Erickson 1982). These activities, however, would be expensive and difficult over a large area. Some other potential alternatives are described below.

- Additional sampling. Samples could be collected elsewhere in the Lake Jackson watershed to compare bacteria and nutrient values. Streams draining relatively undeveloped sub-basins include one flowing just south of the Phipps-Overstreet park, north of Lake Ridge Road, and another that drains into the lake north of Miller Landing Road. In-lake sampling may also be conducted to help identify receiving waterbody effects and to facilitate public health advisories concerning body-contact water recreation.
- Testing for *Clostridium perfringens* in sediment cores. *Clostridium perfringens* is described by Valente et al. (1992) as a human enteric bacterium that produces endospores that are resistant to treatment and that survive long periods in terrestrial and aquatic environments. Although *C. perfringens* may originate from other sources, including boat wastes and stormwater runoff, higher concentrations tend to be spatially associated with sustained human wastewater sources (Valente et al. 1992). Combining *C. perfringens* analysis with a general map of benthic enrichment may permit a distinction to be made between enrichment from human wastewater versus non-sewage enrichment or physical disturbance.
- Other microbiological techniques. Probable sources (human or other) of *E. coli* can be estimated through multiple antibiotic resistance (MAR) and genetic analysis. Additionally, signature lipid biomarker (SLB) analysis for quantitatively detecting biological components of urban runoff based on the analysis of lipids is described by White et al. (n.d.). Microbes can be analyzed for coprostanol, a steroid that is formed in human digestive systems, but not in those of birds, fish, or domestic or wild mammals.

References

American Public Health Association. 1992. ***Standard Methods for the Examination of Water and Wastewater.*** Eighteenth Edition. Washington: American Public Health Association.

Andersen, Mariben E., Donald D. Moores, Thomas R. Cuba, and Hans W. Zarbock. 1996. ***An Estimate of Nutrient Loads from Properties with Septic Tanks to Allen's Creek.*** Clearwater: Pinellas County Department of Environmental Management.

Ayres Associates. 1993. ***Onsite Sewage Disposal System Research in Florida.*** Tampa: Department of Health and Rehabilitative Services. HRS Contract LP-596.

Bartel, Ronald L, Tyler L. Macmillan, and Felton B. Ard. 1992. ***Lake Jackson Regional Stormwater Retrofit Plan.*** Water Resources Special Report 92-1. Havana: Northwest Florida Water Management District.

Bicki, Thomas J., and Randall B. Brown. 1990. "On-Site Sewage Disposal: The Importance of the Wet Season Water Table." ***Journal of Environmental Health*** 52, 5 (March/April 1990): 277-279.

Bicki, Thomas J., and Randall B. Brown. 1991. "On-Site Sewage Disposal: The Influence of System Density on Water Quality." ***Journal of Environmental Health*** 53, 5 (March/April 1991): 39-42.

Brown, Randall, B. 1990. "Soils and Onsite Wastewater Disposal." ***Notes in Soil Science*** 41: 1-11.

Carlile, B.L., C.G. Cogger, Mark D. Sobsey, John Scandura, and Steve J. Steinbeck. 1981. ***Movement and Fate of Septic Tank Effluent in Soils of the North Carolina Coastal Plain.*** Raleigh: North Carolina State University.

Florida Department of Health and Rehabilitative Services. 1993. ***Suwannee River Floodplain Onsite Sewage Disposal System Inventory Annual Report.***

Friedman, Mark, and Joe Hand. 1989. ***Typical Water Quality Values for Florida's Lakes, Streams, and Estuaries.*** Tallahassee: Florida Department of Environmental Regulation.

Hughes, G.H. 1969. ***Hydrologic Significance of 1966 Flood Levels at Lake Jackson near Tallahassee, Florida.*** U.S. Geological Survey Hydrologic Investigations Atlas HA-363.

Lapointe, Brian E., Julie D. O'Connell, and George S. Garrett. 1990. "Nutrient Couplings Between On-Site Sewage Disposal Systems, Groundwaters, and Nearshore Surface Waters of the Florida Keys." ***Biogeochemistry*** 10: 289-307.

LaRock, Paul A. 1991. ***Microbial Indicator Assays: A Comparison of Coliforms Enterococci, E. Coli, and Vibrio Sp. in Marine and Freshwater Environments.*** DER Contract WM322. Tallahassee: Florida Department of Environmental Regulation.

LaRock, Paul A., and William M. Landing. 1991. ***Diagnostic Study on Lake Jackson, Florida: Sources, Sinks, and Solutions. Volume I: Summary and Analysis.*** DER Contract WM345. Tallahassee: Florida Department of Environmental Regulation.

Livingston, Robert J. 1995a. ***The Ecology of the Lakes of Leon County, Florida: Lake Jackson.*** Tallahassee: Center for Aquatic Research and Resource Management, Florida State University.

Livingston, Robert J. 1995b. "Summary of Results, Lake Jackson: 1993-1995." 1 December 1995. Tallahassee: Center for Aquatic Research and Resource Management, Florida State University.

Macmillan, Tyler L. 1997. ***Lake Jackson Management Plan: 1997 Revision (Addendum to the 1994 Lake Jackson Management Plan)***. Havana: Northwest Florida Water Management District. NWFWMD Program Development Series 97-4.

Macmillan, Tyler L., and Craig Diamond. 1994. ***The Lake Jackson Management Plan: A Comprehensive Plan for the Restoration and Preservation of Lake Jackson***. Havana: Northwest Florida Water Management District. NWFWMD Program Development Series 94-2.

Martin, Randy G., and John K. McPherson. 1990. ***Placement and Maintenance of Individual Septic Systems (On-Site Disposal Systems)***. Southwest Florida Water Management District.

Parkhurst, David F. 1998. "Arithmetic Versus Geometric Means for Environmental Concentration Data." ***Environmental Science and Technology*** (February 1, 1998): 92A-98A.

U.S. Department of Agriculture, Soil Conservation Service. 1981. ***Soil Survey of Leon County, Florida***.

U.S. Environmental Protection Agency. 1987. ***Septic Tank Siting to Minimize the Contamination of Ground Water by Microorganisms***. Washington: EPA 440/6-87.

Valente, R.M., D.C. Rhoads, J.D. Germano, and V.J. Cabell. 1992. "Mapping of Benthic Enrichment Patterns in Narragansett Bay, Rhode Island." ***Estuaries*** 15, 1: 1-17

Wagner, Jeffrey R. 1984. ***Hydrogeologic Assessment of the October 1982 Draining of Lake Jackson, Leon County, Florida***. Water Resources Special Report 84-1. Havana: Northwest Florida Water Management District.

Wagner, Rich. 1992. Memorandum concerning literature review on septic tank loadings accomplished for the Sarasota Bay National Estuary Program.

Water and Air Research, Inc. 1981. ***Water Quality Impacts of Septic Tanks at Three Study Lakes in Central Florida***. Central Florida Regional Planning Council.

White, A.B., D.B. Ringelberg, and D.C. White. n.d. "Bioremediation Potential and Bioprocessing Control by Microbial Community Analysis." Unpublished.

Wicks, Kenneth R., and Robert A. Erickson. 1982. ***Septic Tank Water Quality Impact Study***. Lake County Department of Pollution Control.

Williams, Leslie A.., Peter W. Mason, and Joseph M. Faircloth. 1982. ***An Assessment of Selected Areas in Coastal Wakulla County, Based Upon Total and Fecal Coliform Bacteria***. Tallahassee: Florida Department of Environmental Regulation.

Regulation of Septic Systems

Florida Statutes (F.S.), states that the Florida Department of Health (DOH) shall issue ıction, installation, modification, abandonment, and repair of onsite sewage treatment ɜms (OSTDS) where publicly- or investor-owned sewerage systems are unavailable. rules for placement of such systems in Rule 64E-6 of the Florida Administrative Code rule, no septic system may be installed, repaired, altered, modified, abandoned, or n as permitted by the Department. All systems are required to be located, installed, that they "function in a sanitary manner, do not create sanitary nuisances or health ɔt endanger the safety of any domestic water supply, ground water or surface water." e and effluent from these systems may not be discharged onto the surface or directly or es, drainage structures, ground waters, surface waters, or aquifers.

requires that septic systems not be located laterally within 75 feet of the boundaries of ies. Systems are to be a minimum of 15 feet from the design high water line of swales ention areas designed to contain standing or flowing water for less than 72 hours after vater table elevation at the wettest season is required to be at least 24 inches below the the drainfield. The rule contains further requirements for lot size, system size, setbacks uctures, setbacks from tidal surface waters, limitations for floodprone areas, and use of ms. General surface water setback requirements are modified in sections nd 2, F.S.

Leon County Comprehensive Plan 2010 states that "no new on-site sewage disposal installed in the Lake Jackson Special Development Zone on lots having less than one ɔt for single family properties which were platted with less than one (1) net acre prior to s plan except where sanitary sewer is available." Existing septic tanks may be replaced ɔr larger units as required by local regulations. No permits will be issued for new septic ear floodplain in the Lake Jackson Special Development Zone "except for replacement ingle family lots which were platted prior to the adoption of this plan except where available."

nent, Leon County has set standards for septic tanks within Zone A of the Lake Jackson nent Zone. Zone A is defined as the wetland and floodplain ecotone, from elevation 89 water's edge, whichever provides the greater area of protection, to 100 feet NGVD. enacted by the Leon County Code, Chapter 10, Article 7, are as follows:

lot size is one acre net usable land, exclusive of all paved areas, public rights- nd prepared road beds within easements and exclusive of streams, lakes, ditches, marshes, or other such bodies of water as determined by the state nt of Environmental Protection or the director of Growth and Environmental ent.

wage disposal systems shall be sized according to the predominant naturally soil type beneath the proposed system or a maximum sewage loading rate of per square foot per day, whichever yields a greater size drainfield.

of any onsite sewage disposal system shall be located within 75 feet upland of 89 feet NGVD, within 75 feet of any waterbody or watercourse or the al limit of a wetland as determined by the state Department of Environmental or the director of Growth and Environmental Management, or within any 100- plain area.

g, previously platted, lot or lot of record existing on January 15, 1990, when single-family residential use, shall be exempt from the standards of this (b)(1)b but shall comply with all other applicable laws, ordinances and s relating to septic tanks. Existing septic tanks may be replaced by the same size or larger units as required by other applicable laws, ordinances, and regulations relating to septic tanks, except where sanitary sewer is available.

It should be noted that item number 4 applies to the majority of the project area.

Appendix B. Resident Survey

LEON COUNTY AND THE NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

LAKE JACKSON NON-POINT WATER QUALITY SURVEY

Please respond as completely as possible to each question below. The more accurate the information you provide, the better our assessment and understanding of Lake Jackson will be.

All information shall remain anonymous and shall be used only for the evaluation of non-point pollution of Lake Jackson. This information is being collected as part of ongoing research and planning for the protection of the lake under Florida's Surface Water Improvement and Management (SWIM) Program.

Water Use

1) How many individuals reside in your home? ________ People
2) On average, about how many gallons of water does your home use a month? _______ Gallons
   (You can get this information from your monthly water bill.)
3) On average, about how often do you water your lawn? _______ Times per Month
4) On average, about how often do you wash your car(s) at home? _______ Times per Month
5) Do you have a private well for irrigation, car washing, etc.? _______ (Y or N)

Property Information

6) What is your approximate lot size? (Please check box)
   less than 1/4 Acre [ ] 1/4 to 1/2 Acre [ ] 1/2 to 1 Acre [ ] More than 1 Acre [ ]
7) Do you maintain your own yard? _______ (Y or N)
   If YES, please go on to question 8.
   If NO, which lawn/yard service do you use?
   ______________________________ Please go on to Question 11.
8) Approximately how many times a year do you apply fertilizer to your lawn, shrubs, or trees?
   _________ Times A Year
9) On average, about how many pounds of fertilizer do you apply each time?
   _________ Pounds per Application
10) What fertilizer mix do you apply the most of (for example, 6:6:6)? _________ N : P : K Ratio
   [If you do not know the mix, what product do you apply the most of (for example,
   Scott's Turf Builder)? ______________________________]
11) How many outdoor pets (dogs and cats) do you have? ______ Dogs ______ Cats

OVER ------>

On-Site Treatment and Disposal System Information

12) How old is your home? _______ Years [ ] Don't Know

13) Is there more than one septic tank or wastewater treatment system serving your property?
______ (Y or N) [ ] Don't Know

14) To the best of your knowledge, has your septic tank(s) ever been pumped out or cleaned?
______ (Y or N) [ ] Don't Know

If NO, or you don't know, please go on to question 15.

If YES, how many times has it been pumped out or cleaned? ______ Times

When was the last time this was done? _______ (Year) [ ] Don't Know

15) To the best of your knowledge, has your drainfield(s) ever been replaced?
_______ (Y or N) [ ] Don't Know

If NO, or you don't know, please go on to question 16.

If YES, how many times has it been replaced? _______ Times

When was the last time this was done? ________ (Year) [ ] Don't Know

16) Do you use a washing machine at home? ______ (Y or N)

If NO, or you don't know, please go on to question 17.

If YES, is the machine's outlet connected to your septic tank?
_______ (Y or N) [ ] Don't Know

What brand of detergent or soap do you usually use? ____________________________

On average, about how many loads a week do you launder? _________ Loads per Week

17) Are you aware of any other devices (kitchen disposal, showers, etc.) in your home that are not connected to your septic tank?
______ (Y or N) [ ] Don't Know

If NO, or you don't know, then you are done. Thanks.

If YES, please list the devices: ____

– THANK YOU FOR YOUR RESPONSES –

Appendix C. Study Period Rainfall

Sampling Events

Figures C-1 through C-7 illustrate rainfall throughout the study period. The amounts indicated represent an average of two rainfall monitoring stations: one at the Crowder Road landing and the other at the Lake Jackson stormwater facility. Sampling events are indicated by rectangular blocks along the x-axis.

Sampling events were conducted on the following dates.

Dry Condition Samples

March 27,1995 (Okeeheepkee)
March 28, 1995 (LJ Mounds, Bellwood)
March 29, 1995 (Harbinwood, Sunset)

April 17, 1995 (Okeeheepkee, Bellwood)
April 18, 1995 (LJ Mounds, Sunset)
April 19, 1995 (Harbinwood)

April 24, 1995 (Harbinwood, Sunset)
April 25, 1995 (Okeeheepkee, LJ Mounds)
April 26, 1995 (Bellwood)

Saturated Condition Samples

October 12, 1995 (Okeeheepkee, LJ Mounds)
January 2, 1996 (Bellwood, Harbinwood)

February 21, 1996 (Okeeheepkee, LJ Mounds)
February 22, 1996 (Bellwood, Harbinwood)

March 19, 1996 (Okeeheepkee, LJ Mounds)
March 20, 1996 (Bellwood, Harbinwood)

Figure C-1. January 1995-March 1996 Rainfall

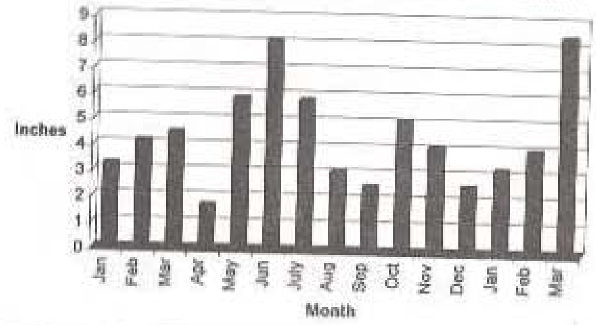


Figure C-2. March 1995

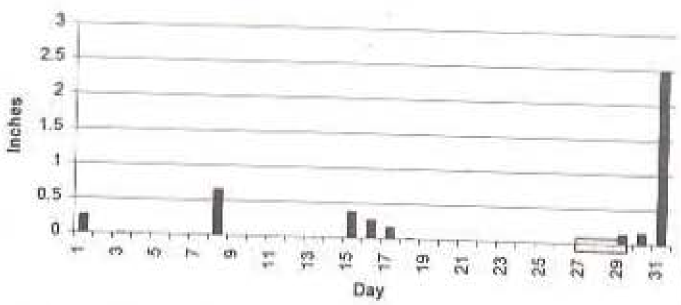


Figure C-3. April 1995

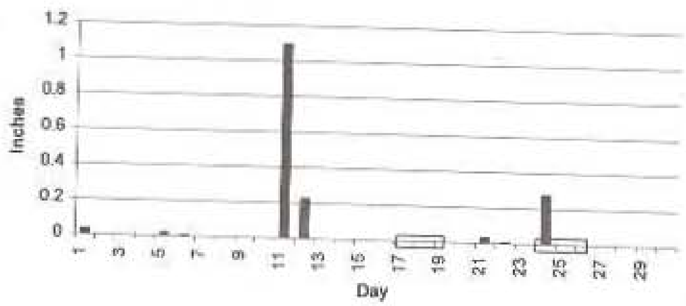


Figure C-4. October 1995

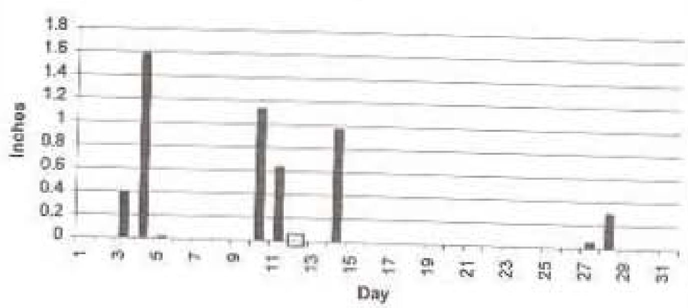


Figure C-5. January 1996

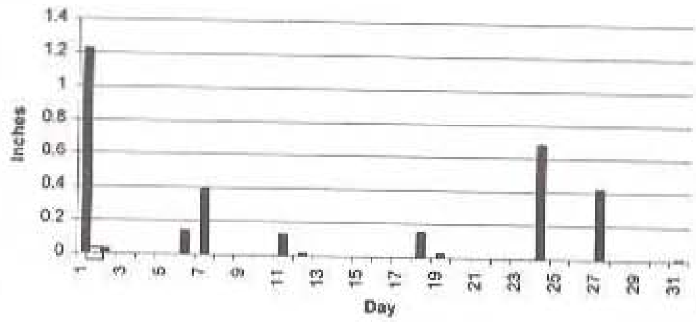


Figure C-6. February 1996

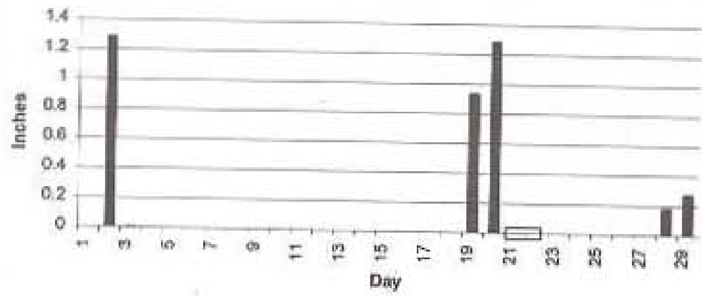
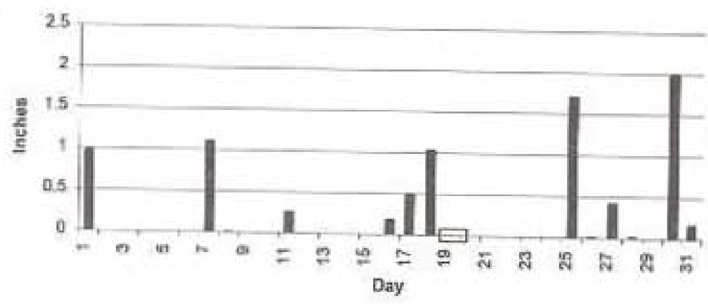


Figure C-7. March 1996



Appendix D. Analysis of Variance

Analysis of variance (ANOVA) was conducted to evaluate differences in bacteriological and chemical water quality parameters among sampled sub-basins and to determine if these parameters varied between wet and dry conditions or between upstream and downstream sampling locations within sub-basins. Parameters examined were fecal coliform bacteria, total coliforms, fecal streptococci, *E. coli*, ortho-phosphorus, total phosphorus, nitrate-nitrite nitrogen, ammonium nitrogen, and total Kjeldahl nitrogen (TKN). For reasons described in the methods section, both bacteriological and chemical variables were logarithmically transformed prior to analysis. ANOVA tables resulting from these analyses are presented below.

Sampling location within basin (upstream vs. downstream) had no consistent effect on any bacteriological or chemical water quality parameter. Differences between wet and dry condition sampling were observed for all bacteriological variables except fecal streptococci. Fecal coliforms, total coliforms, and *E. coli* numbers were significantly higher under wet than dry conditions. TKN concentrations were modestly higher under wet conditions, while no wet-dry differences were observed for the other chemical parameters. The differences detected between wet and dry conditions were generally much smaller in magnitude than differences observed among basins.

Response: logecol

Summary of Fit

RSquare	0.676238
RSquare Adj	0.524474
Root Mean Square Error	0.52272
Mean of Response	2.499417
Observations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
basin	3	3	11.796034	14.3905	<.0001
loc	1	1	0.774700	2.8353	0.1019
wet	1	1	2.248136	8.2278	0.0072
basin*loc	3	3	0.855800	1.0440	0.3864
basin*wet	3	3	1.724217	2.1035	0.1193
loc*wet	1	1	0.060350	0.2209	0.6416
basin*loc*wet	3	3	0.803310	0.9800	0.4144

Whole-Model Test

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	18.262548	1.21750	4.4559
Error	32	8.743554	0.27324	Prob>F
C Total	47	27.006102		0.0002

Response: logfecol

Summary of Fit

RSquare	0.670334
RSquare Adj	0.515802
Root Mean Square Error	0.521106
Mean of Response	2.607021
Observations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F

basin	3	3	11.191394	13.7376	<.0001
loc	1	1	0.696249	2.5640	0.1192
wet	1	1	1.924403	7.0867	0.0120
basin*loc	3	3	0.722619	0.8870	0.4583
basin*wet	3	3	1.724781	2.1172	0.1175
loc*wet	1	1	0.121706	0.4482	0.5080
basin*loc*wet	3	3	1.288109	1.5812	0.2131

Whole-Model Test
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	17.669261	1.17795	4.3379
Error	32	8.689648	0.27155	Prob>F
C Total	47	26.358909		0.0002

Response: logstrep

Summary of Fit

RSquare	0.486437
RSquare Adj	0.245705
Root Mean Square Error	0.69491
Mean of Response	3.138521
Observations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
basin	3	3	7.4408921	5.1363	0.0052
loc	1	1	0.0550130	0.1139	0.7379
wet	1	1	0.6756880	1.3992	0.2456
basin*loc	3	3	2.7310061	1.8851	0.1520
basin*wet	3	3	0.4613421	0.3185	0.8119
loc*wet	1	1	1.6609800	3.4396	0.0729
basin*loc*wet	3	3	1.6117061	1.1125	0.3585

Whole-Model Test
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	14.636627	0.975775	2.0207
Error	32	15.452807	0.482900	Prob>F
C Total	47	30.089434		0.0466

Response: logtot

Summary of Fit

RSquare	0.593125
RSquare Adj	0.402402
Root Mean Square Error	0.503103
Mean of Response	3.646583
Observations (or Sum Wgts)	48

: Test

:e	Nparm	DF	Sum of Squares	F Ratio	Prob>F
	3	3	4.0559908	5.3415	0.0043
	1	1	0.2017613	0.7971	0.3786
	1	1	3.9928403	15.7750	0.0004
*loc	3	3	0.9242092	1.2171	0.3194
*wet	3	3	0.1782725	0.2348	0.8715
et	1	1	0.9667363	3.8194	0.0594
*loc*wet	3	3	1.4874225	1.9588	0.1400

e-Model Test

sis of Variance

e	DF	Sum of Squares	Mean Square	F Ratio
	15	11.807233	0.787149	3.1099
	32	8.099603	0.253113	Prob>F
al	47	19.906836		0.0034

onse: logop

nary of Fit

are	0.861141
are Adj	0.796051
Mean Square Error	0.121132
of Response	1.553893
vations (or Sum Wgts)	48

Test

e	Nparm	DF	Sum of Squares	F Ratio	Prob>F
	3	3	1.2352951	28.0627	<.0001
	1	1	0.5035221	34.3162	<.0001
	1	1	0.0607627	4.1411	0.0502
loc	3	3	0.7948030	18.0559	<.0001
wet	3	3	0.1104217	2.5085	0.0765
t	1	1	0.0004419	0.0301	0.8633
loc*wet	3	3	0.2066133	4.6937	0.0079

-Model Test

sis of Variance

e	DF	Sum of Squares	Mean Square	F Ratio
	15	2.9118599	0.194124	13.2300
	32	0.4695369	0.014673	Prob>F
l	47	3.3813968		<.0001

nse: lognh4

ary of Fit

re	0.773316
re Adj	0.667057
Mean Square Error	0.244874
of Response	1.718078
vations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
basin	3	3	0.7639795	4.2469	0.0124
loc	1	1	0.9459855	15.7761	0.0004
wet	1	1	0.0177917	0.2967	0.5897
basin*loc	3	3	4.4117525	24.5248	<.0001
basin*wet	3	3	0.1410944	0.7843	0.5115
loc*wet	1	1	0.0126063	0.2102	0.6497
basin*loc*wet	3	3	0.2526895	1.4047	0.2594

Whole-Model Test

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	6.5458994	0.436393	7.2777
Error	32	1.9188208	0.059963	Prob>F
C Total	47	8.4647202		<.0001

Response: logno3

Summary of Fit

RSquare	0.826538
RSquare Adj	0.745228
Root Mean Square Error	0.177603
Mean of Response	2.478881
Observations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
basin	3	3	2.7946931	29.5333	<.0001
loc	1	1	0.5044878	15.9937	0.0004
wet	1	1	0.0789203	2.5020	0.1235
basin*loc	3	3	1.2422909	13.1281	<.0001
basin*wet	3	3	0.0740722	0.7828	0.5124
loc*wet	1	1	0.0733386	2.3250	0.1371
basin*loc*wet	3	3	0.0417950	0.4417	0.7248

Whole-Model Test

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.8095981	0.320640	10.1652
Error	32	1.0093701	0.031543	Prob>F
C Total	47	5.8189682		<.0001

Response: logtkn

Summary of Fit

RSquare	0.68106
RSquare Adj	0.531557
Root Mean Square Error	0.154636
Mean of Response	2.4792
Observations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
basin	3	3	0.82558896	11.5085	<.0001
loc	1	1	0.03979216	1.6641	0.2063
wet	1	1	0.11036756	4.6155	0.0394
basin*loc	3	3	0.44008660	6.1347	0.0020
basin*wet	3	3	0.05357955	0.7469	0.5322
loc*wet	1	1	0.01151762	0.4817	0.4927
basin*loc*wet	3	3	0.15305595	2.1336	0.1154

Whole-Model Test

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	1.6339884	0.108933	4.5555
Error	32	0.7651958	0.023912	Prob>F
C Total	47	2.3991842		0.0002

Response: logtp

Summary of Fit

RSquare	0.669358
RSquare Adj	0.514369
Root Mean Square Error	0.195398
Mean of Response	1.990658
Observations (or Sum Wgts)	48

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
basin	3	3	1.5799191	13.7935	<.0001
loc	1	1	0.0003862	0.0101	0.9205
wet	1	1	0.1526730	3.9987	0.0541
basin*loc	3	3	0.2848938	2.4873	0.0782
basin*wet	3	3	0.0876114	0.7649	0.5221
loc*wet	1	1	0.0829622	2.1729	0.1502
basin*loc*wet	3	3	0.2849188	2.4875	0.0782

Whole-Model Test

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	2.4733645	0.164891	4.3188
Error	32	1.2217666	0.038180	Prob>F
C Total	47	3.6951310		0.0003

endix E. Water Quality Data

Laris Rd S482

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S482*	27-Mar-95	138.000	185.330	1933.330	6016.670	0.011	0.010	0.800	0.257	0.350	14.333	7.000	5.860	50.000	19.300
2-S482	17-Apr-95	80.000	144.000	1100.000	8000.000	0.015	0.010	0.880	0.250	0.038	NS	6.700	5.660	41.000	18.900
3-S482	25-Apr-95	200.000	200.000	1800.000	6500.000	0.012	0.014	0.900	0.370	0.041	NS	7.000	6.020	47.000	17.700
4-S482	12-Oct-95	600.000	620.000	100.000	9800.000	0.018	0.059	0.180	0.530	0.082	NS	5.000	6.190	75.000	24.000
5-S482		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6-S482	21-Feb-96	2000.000	2200.000	7000.000	28000.000	0.013	0.025	1.100	0.620	0.110	NS	6.800	6.010	48.000	14.400
7-S482	19-Mar-96	500.000	600.000	200.000	6800.000	0.014	0.016	0.440	0.400	0.058	NS	7.300	5.910	40.000	14.900
MEAN		586.333	658.222	2022.222	10852.778	0.014	0.022	0.717	0.405	0.113	14.333	6.633	5.942	50.167	18.200
STD Dev		722.873	784.850	2557.400	8509.213	0.002	0.019	0.340	0.148	0.119		0.826	0.179	12.797	3.491
Maximum		2000.000	2200.000	7000.000	28000.000	0.018	0.059	1.100	0.620	0.350	14.333	7.300	6.190	75.000	24.000
Minimum		80.000	144.000	100.000	6016.670	0.011	0.010	0.180	0.250	0.038	14.333	5.000	5.660	40.000	14.400

Fuller Rd S483

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S483*	27-Mar-95	18.67	30.00	580.00	640.00	0.047	0.016	0.067	0.205	0.066	16.333	8.100	6.900	68.000	19.300
2-S483	17-Apr-95	64	76	320	1800	0.057	0.094	0.140	0.320	0.062	NS	7.600	7.300	79.000	21.200
3-S483	25-Apr-95	42	47	470	590	0.070	0.210	0.200	0.460	0.120	NS	8.400	7.460	99.000	16.900
4-S483	12-Oct-95	135	255	1150	4550	0.043	0.155	0.100	0.355	0.092	NS	7.600	6.810	187.000	25.000
5-S483		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS				
6-S483	21-Feb-96	210	250	820	25000	0.040	0.051	0.240	0.200	0.100	NS	10.800	6.670	58.000	12.900
7-S483	19-Mar-96	200	250	800	5600	0.049	0.046	0.090	0.280	0.190	NS	9.700	7.150	63.000	14.900
MEAN		111.612	151.333	690.000	6363.333	0.051	0.095	0.140	0.300	0.105	16.333	8.700	7.048	92.333	18.367
STD Dev		82.208	110.905	295.973	9360.642	0.011	0.074	0.068	0.100	0.047		1.287	0.305	48.611	4.403
Maximum		210.000	255.000	1150.000	25000.000	0.070	0.210	0.240	0.460	0.190	16.333	10.800	7.460	187.000	25.000
Minimum		18.670	30.000	320.000	590.000	0.040	0.016	0.067	0.200	0.062	16.333	7.600	6.670	58.000	12.900

* The given value is the mean of triplicate sample values

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S486*	28-Mar-95	284.67	354.67	2533.33	4280	0.032	0.027	0.683	0.353	0.131	13.667	6.000	5.710	67.000	18.000
2-S486	17-Apr-95	42	64	310	1400	0.028	0.017	0.800	0.170	0.110	NS	7.100	6.130	68.000	21.400
3-S486	26-Apr-95	96.5	270	15000	3225	0.028	0.023	0.800	0.130	0.051	NS	7.500	5.330	58.000	16.800
4-S486		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5-S486	2-Jan-96	52	80	500	330	0.035	0.015	0.760	0.190	0.062	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1-S486*	28-Mar-95	284.67	354.67	2533.33	4280	0.032	0.027	0.683	0.353	0.131	13.667	6.000	5.710	67.000	18.000
2-S486	17-Apr-95	42	64	310	1400	0.028	0.017	0.600	0.170	0.110	NS	7.100	6.130	66.000	21.400
3-S486	26-Apr-95	56.5	270	15000	3225	0.028	0.023	0.800	0.130	0.051	NS	7.500	6.330	68.000	16.800
4-S486		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5-S486	2-Jan-96	82	80	500	330	0.035	0.015	0.760	0.190	0.062	NS	7.600	5.880	72.000	17.200
6-S486	22-Feb-96	90	100	1000	3600	0.048	0.030	0.440	0.160	0.099	NS	6.900	5.870	68.000	15.800
7-S486	20-Mar-96	280	220	600	2000	0.031	0.024	0.800	0.130	0.080	NS	8.000	6.850	59.000	13.200
MEAN		145.862	181.445	3323.888	2505.833	0.034	0.023	0.714	0.189	0.089	13.667	7.117	5.962	67.000	17.067
STD Dev		107.409	118.366	5776.408	1520.047	0.008	0.006	0.142	0.084	0.030		0.747	0.509	4.290	2.694
Maximum		284.670	354.670	15000.000	4280.000	0.048	0.030	0.800	0.353	0.131	13.667	8.000	6.850	72.000	21.400
Minimum		42.000	64.000	310.000	330.000	0.028	0.015	0.440	0.130	0.051	13.667	6.000	5.330	59.000	13.200

Sonnet Dr. S487 All Storms

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S487*	28-Mar-95	1.00	1.00	1.00	13.00	0.009	0.078	0.158	0.112	0.048	12.333	7.600	7.450	249.000	21.000
2-S487	17-Apr-95	26	58	117	605	0.024	0.370	0.500	0.420	0.049	NS	8.700	6.840	89.000	21.000
3-S487	26-Apr-95	200	230	2100	2000	0.029	0.380	0.440	0.440	0.040	NS	9.100	6.360	85.000	18.900
4-S487		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5-S487	2-Jan-96	315	385	3200	5000	0.041	0.240	0.570	0.330	0.061	NS	8.700	6.630	95.000	17.200
6-S487	22-Feb-96	60	96	1500	8000	0.025	0.270	0.430	0.340	0.039	NS	9.500	6.500	90.000	16.000
7-S487	20-Mar-96	88	110	110	2500	0.032	0.290	0.440	0.350	0.047	NS	9.100	6.540	81.000	9.100
MEAN		114.667	146.667	1171.333	3019.667	0.027	0.271	0.423	0.332	0.047	12.333	8.783	6.720	114.833	17.200
STD Dev		120.006	139.097	1318.610	2996.861	0.011	0.110	0.140	0.117	0.008		0.652	0.391	65.898	4.446
Maximum		315.000	385.000	3200.000	8000.000	0.041	0.380	0.570	0.440	0.061	12.333	9.500	7.450	249.000	21.000
Minimum		1.000	1.000	1.000	13.000	0.009	0.078	0.158	0.112	0.039	12.333	7.600	6.360	81.000	9.100

Bellwood Rd. S484

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S484*	28-Mar-95	144.750	143.250	197.500	2312.500	0.0130	0.078	0.415	0.295	0.047	15.000	9.000	7.080	61.000	19.900
2-S484	18-Apr-95	160.000	180.000	300.000	1400.000	0.0200	0.130	0.390	0.300	0.055	NS	9.000	6.410	112.000	19.900
3-S484	25-Apr-95	270.000	400.000	920.000	2500.000	0.0180	0.160	0.510	0.380	0.050	NS	9.600	6.450	98.000	16.300
4-S484	12-Oct-95	2800.000	4800.000	4600.000	20000.000	0.047	0.095	0.260	0.350	0.110	NS	8.300	7.600	119.000	24.000
5-S484		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS				
6-S484	21-Feb-96	4500	6600	3500	36000	0.024	0.068	0.560	0.260	0.081	NS	10.800	6.980	81.000	14.000
7-S484	19-Mar-96	500	720	300	8000	0.033	0.043	0.170	0.330	0.110	NS	11.300	7.710	75.000	15.900
MEAN		1395.792	2140.542	1636.250	11702.083	0.026	0.096	0.384	0.319	0.075	15.000	9.650	7.036	91.000	18.333
STD Dev		1831.395	2822.758	1918.933	13798.008	0.012	0.043	0.148	0.043	0.029		1.161	0.550	22.494	3.629
Maximum		4500.000	6600.000	4600.000	36000.000	0.047	0.160	0.560	0.380	0.110	15.000	11.300	7.710	119.000	24.000
Minimum		144.750	143.250	197.500	1400.000	0.013	0.043	0.170	0.260	0.047	15.000	8.300	6.410	61.000	14.000

Indian Mound S485

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S485*	28-Mar-95	633.33	916.67	2566.67	4400.00	0.041	0.022	0.617	0.150	0.103	15.000	9.800	7.340	50.000	18.200
2-S485	18-Apr-95	250	430	2100	5000	0.049	0.019	0.660	0.100	0.096	NS	9.700	7.100	64.000	18.900
3-S485	25-Apr-95	360	450	2500	5600	0.047	0.016	0.700	0.120	0.084	NS	10.800	6.940	55.000	15.200
4-S485	12-Oct-95	1500	1800	2000	17000	0.071	0.016	0.520	0.220	0.110	NS	8.200	7.380	83.000	24.000
5-S485		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS				
6-S485	21-Feb-96	1825	2325	15500	41250	0.037	0.032	0.535	0.185	0.093	NS	11.000	6.790	69.000	14.500
7-S485	19-Mar-96	430	532.5	2475	8175	0.043	0.040	0.395	0.240	0.125	NS	11.800	7.600	59.000	14.500
MEAN		833.055	1075.695	4523.612	13570.833	0.048	0.024	0.571	0.169	0.102	15.000	10.217	7.192	63.333	17.550
STD Dev		662.548	801.766	5382.287	14339.512	0.012	0.010	0.111	0.056	0.014		1.262	0.302	11.708	3.687
Maximum		1825.000	2325.000	15500.000	41250.000	0.071	0.040	0.700	0.240	0.125	15.000	11.800	7.600	83.000	24.000
Minimum		250.000	430.000	2000.000	4400.000	0.037	0.016	0.395	0.100	0.084	15.000	8.200	6.790	50.000	14.500

Upper Sunset S490

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S490*	29-Mar-95	20.67	34.67	100.67	873.33	0.044	0.267	0.020	1.667	0.140	13.333	2.000	5.690	47.000	18.500
2-S490	18-Apr-95	340	390	15000	1100	0.058	0.260	0.020	1.500	0.210	NS	1.600	5.910	48.000	20.000

Upper Sunset S490

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S490*	29-Mar-95	20.67	34.67	100.67	873.33	0.044	0.267	0.020	1.667	0.140	13.333	2.000	5.690	47.000	16.500
2-S490	18-Apr-95	340	390	15000	1100	0.058	0.260	0.020	1.500	0.210	NS	1.600	5.910	48.000	20.000
3-S490	24-Apr-95	200	400	6200	2700	0.083	0.440	0.020	2.100	0.250	NS	1.700	6.640	52.000	19.700
4-S490		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5-S490		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6-S490		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
7-S490		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MEAN		186.890	274.890	7100.223	1557.777	0.062	0.322	0.020	1.756	0.200	13.333	1.767	6.080	49.000	18.733
STD Dev		160.068	208.097	7490.348	995.666	0.020	0.102	0.000	0.310	0.056		0.208	0.497	2.646	1.940
Maximum		340.000	400.000	15000.000	2700.000	0.083	0.440	0.020	2.100	0.250	13.333	2.000	6.640	52.000	20.000
Minimum		20.670	34.670	100.670	873.330	0.044	0.260	0.020	1.500	0.140	13.333	1.600	5.690	47.000	16.500

Lower Sunset S491

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S491*	29-Mar-95	1393.33	1866.67	2966.67	4733.33	0.024	0.041	0.140	0.713	0.078	17.333	8.800	6.640	53.000	18.500
2-S491	18-Apr-95	235	250	670	3850	0.024	0.053	0.240	0.600	0.058	NS	8.300	6.550	54.000	20.900
3-S491	24-Apr-95	2350	1850	7150	7750	0.029	0.072	0.480	0.620	0.086	NS	7.700	7.170	77.000	18.700
4-S491		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5-S491		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6-S491		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
7-S491		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MEAN		1326.110	1322.223	3595.557	5444.443	0.026	0.055	0.287	0.644	0.077	17.333	8.267	6.787	61.333	19.367
STD Dev		1059.101	928.610	3285.456	2044.939	0.003	0.016	0.175	0.060	0.009		0.551	0.335	13.577	1.332
Maximum		2350.000	1856.670	7150.000	7750.000	0.029	0.072	0.480	0.713	0.086	17.333	8.800	7.170	77.000	20.900
Minimum		235.000	250.000	670.000	3850.000	0.024	0.041	0.140	0.600	0.058	17.333	7.700	6.550	53.000	18.500
												8.267	6.787	61.333	19.367
												na	na	na	na

Harriet Rd. S488

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S488*	29-Mar-95	1157.500	1750.000	1300.000	2550.000	0.056	0.066	0.120	0.380	0.138	14.000	10.500	6.880	122.000	17.800
2-S488	19-Apr-95	2675.000	3150.000	11800.000	4820.000	0.074	0.052	0.195	0.370	0.150	NS	8.800	7.120	98.000	20.000
3-S488	24-Apr-95	4500.000	4600.000	20000.000	10000.000	0.110	0.097	0.160	0.580	0.530	NS	8.900	7.560	120.000	19.600
4-S488		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS				
5-S488	2-Jan-96	2000.000	2600.000	5700.000	6100.000	0.033	0.022	0.100	1.300	0.210	NS	10.500	7.430	79.000	15.100
6-S488	22-Feb-96	570.000	610.000	3500.000	20000.000	0.052	0.072	0.130	0.290	0.140	NS	10.800	7.190	81.000	14.500
7-S488	20-Mar-96	550.000	650.000	4500.000	6000.000	0.059	0.083	0.140	0.520	0.170	NS	11.600	7.410	60.000	12.100
MEAN		1906.750	2226.667	7800.000	8245.000	0.064	0.065	0.141	0.573	0.223	14.000	10.183	7.265	93.333	16.517
STD Dev		1517.424	1546.049	6940.893	6246.035	0.026	0.026	0.033	0.371	0.153		1.109	0.249	24.590	3.126
Maximum		4500.000	4600.000	20000.000	20000.000	0.110	0.097	0.195	1.300	0.530	14.000	11.600	7.560	122.000	20.000
Minimum		550.000	610.000	1300.000	2550.000	0.033	0.022	0.100	0.290	0.138	14.000	8.800	6.880	60.000	12.100

Oakmont St. S489

All Storms

	Date	E. Coli	Fecal Coli	Fecal Strep	Total Colif.	Ortho-Ph.	Ammon.-N	NO2+NO3	TKN	TP	Boron	DO	pH	Cond.	Temp
1-S489*	29-Mar-95	160.00	213.33	613.33	346.67	0.047	0.072	0.082	0.303	0.091	14.667	6.600	7.250	121.000	17.900
2-S489	19-Apr-95	340	350	480	2000	0.067	0.063	0.150	0.350	0.097	NS	6.900	6.950	112.000	20.900
3-S489	24-Apr-95	34600	36000	47000	72000	0.074	0.072	0.150	0.370	0.140	NS	6.700	7.710	102.000	20.000
4-S489		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS				
5-S489	2-Jan-96	4000	5500	32700	33000	0.083	0.044	0.080	0.580	0.230	NS	10.100	7.970	80.000	14.000
6-S489	22-Feb-96	1140	1200	11500	19500	0.120	0.080	0.110	0.510	0.390	NS	9.700	7.160	76.000	15.600
7-S489	20-Mar-96	630	740	7100	5950	0.072	0.110	0.140	0.700	0.480	NS	9.300	7.490	75.000	13.500
MEAN		6811.667	7333.888	16565.555	22132.778	0.077	0.074	0.119	0.469	0.238	14.667	8.217	7.422	94.333	16.983
STD Dev		13686.525	14182.314	19052.826	27399.319	0.024	0.022	0.033	0.154	0.163		1.647	0.377	19.987	3.106
Maximum		34600.000	36000.000	47000.000	72000.000	0.120	0.110	0.150	0.700	0.480	14.667	10.100	7.970	121.000	20.900
Minimum		160.000	213.330	480.000	346.670	0.047	0.044	0.080	0.303	0.091	14.667	6.600	6.950	75.000	13.500