EXAMINING SPATIO-TEMPORAL RELATIONSHIPS OF LANDUSE CHANGE, POPULATION GROWTH AND WATER QUALITY IN TAMPA BAY

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ABSTRACT

Clean water is vital for living organisms. However, industrial, agricultural and urban development in recent years has impacted the water quality of the Tampa Bay area located within the South West Florida Water Management District of Florida. This study examines the spatio-temporal relationships of surface and ground water quality to population growth and landuse change as well as physical factors such as soils and Digital Elevation Models (DEM). The GIS data layers used in this study are: landuse (1988, 1995 and 1999), population (1980s, 1990s and 2000s), soils, water quality data (surface and ground water 1980 - 2000) and DEMs. Preliminary results show a significant relationship between population and groundwater quality for some contaminants and years.

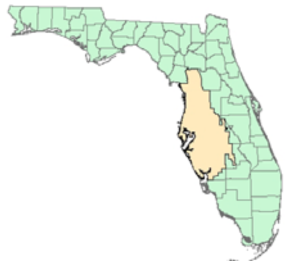
INRTODUCTION

There are many pressures on Florida's water resources. Both surface and groundwaters are affected by industrialization, intensification of agriculture and explosive changes in population over the past twenty years. Worsening of groundwater quality as a result of land-use practices is a major concern not only for public health but also for its potential to affect surface water quality and aquatic ecosystems (Robinson, 2003). The objective of this study is to analyze the relationship between landuse, population growth, and ground and surface water quality in one of Florida's (and the US's) fastest growing areas. Using findings from this study we hope to predict probable future impacts of human growth on water quality for other similar areas.

1.1 DISCRIPTION OF STUDY AREA

This research looks at the surface and groundwater quality of the South west Florida Water Management District (SWFWMD) region (Fig 1). The study looked at all counties of SWFWMD for ground and surface water quality analysis additionally; the near shore waters of the immediate Tampa Bay were examined Pinellas, Hillsborough, and Manatee for marine surface water analysis.

FIGURE 1. STUDY AREA

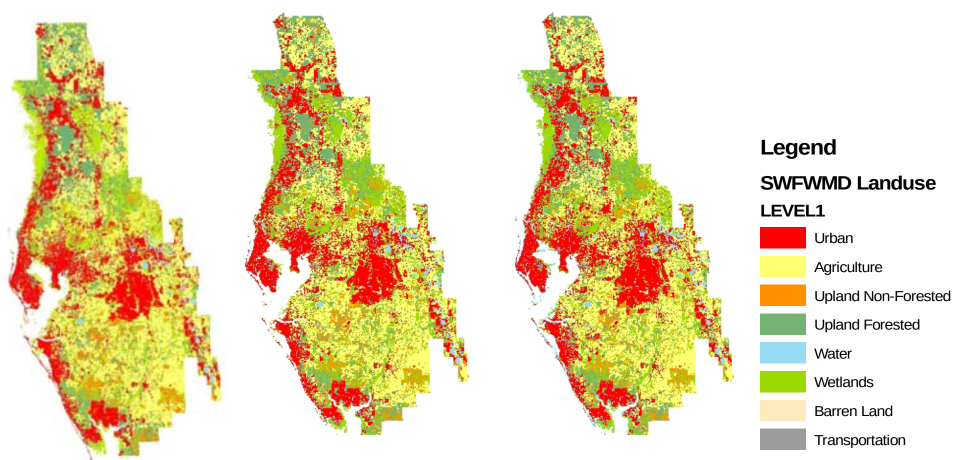


The SWFWMD District area is a large region encompassing most of west-central Florida and includes the counties of Pinellas, Polk, Pasco, Hillsborough, Manatee, Marion, Citrus, Hernando, Levy, Sumter, Lake, Sarasota, Charlotte, De Soto, Hardee, and Highlands counties. Landuse varies greatly across the district from mainly urban in the western counties of Pinellas, Hillsborough and Manatee to mixed use (urban/agricultural/rural) in the northern and eastern portions (Polk, Lake, Marion) of the district.

The eight Level 1 landuse (Fig 2) classes (in descending order) in the entire SWFWMD area for 1999 are: Agricultural (27%), Urban (20%), Wetlands (16%), Water (15%), Upland Forested (15%), Upland Non-Forested (5%), Transportation (1%) and Barren Land (0.18%).

FIGURE 2. LANDUSE 1988 1995 AND 1999

A. 1988 B. 1995 C. 2000

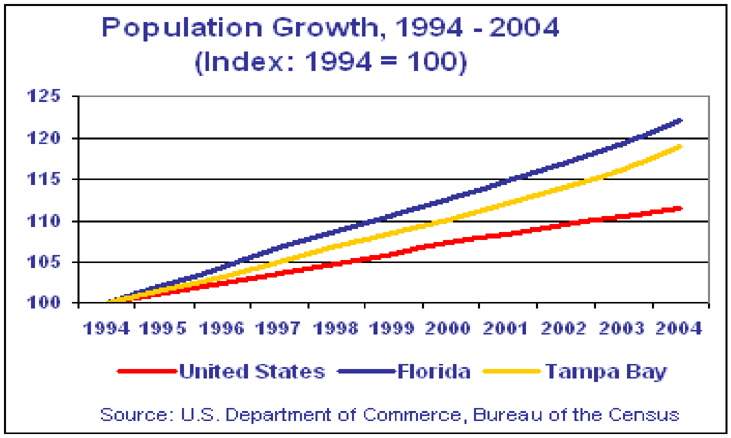


1.2 POPULATION

The Tampa Bay region Metropolitan Statistical Area (MSA) is home to more than 3 million residents (as of 2004) and has seen a population increase in the last 30 years (1970-2000) of approximately 121 percent (US Census Bureau). For the past ten years (1994-2004) the Tampa Bay regions population as a whole has grown faster than that of the national average, between 1994 and 2004 the population increased by about 625,000 residents or about 19 percent, which is almost double the national average of 11 percent (Fig 3). In

2004 alone the population increased by 91,500 residents or 2.4 percent. The population is expected to continue to grow at an annual rate of 6 percent (or about 129,000 residents) per year.

FIGURE 3 POPULATION GROWTH FOR FLORIDA AND TAMPA BAY (1994-2004)



1.3 LANDUSE AND POPULATION

The Tampa Bay area is ranked number 8 in the nation (6th in per person per acreage growth) and the number one area in the state of Florida on a list of the nation's worst cities for urban sprawl (Farago, 2002). Between 1970 and 1990, 359 square miles of land was built over to accommodate population growth. The total land area of the Tampa Bay MSA went from 291 sq mi. in 1970 to 650 sq mi. in 1990 (US Census Bureau). Also as the population increased so has the percentage of land usage, in 1970 the average per person land-usage was 8 percent, in 1990 that number was 13 percent which has placed pressure on surrounding wetlands and aquifer recharge areas. It is estimated that 860 acres of land are lost to development in the Tampa Bay region daily. Although landuse changes as a result of population growth is inevitable the way the growth/urban sprawl are taking place has an impact on water quality. A thorough understanding of the population growth and environmental dynamics is necessary for managing the urban sprawl with minimal environmental impact.

2. GROUNDWATER

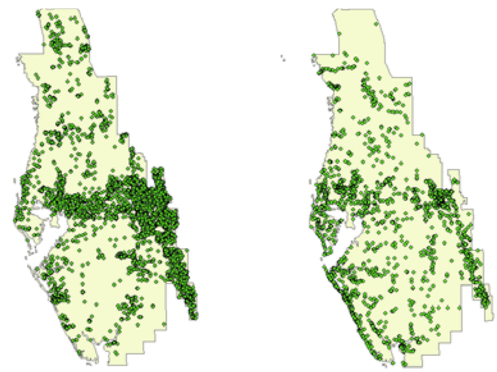
Millions of Floridians rely on groundwater for their drinking water needs; groundwater provides vital water supplies for agriculture and industry and is an integral part of the hydrologic cycle interacting with streams lakes and wetlands and supporting their ecosystems (Crowe et al. 2002).

Not all substances in groundwater that are harmful to human health are man-made. Naturally occurring elements and compounds such as arsenic and fluoride are often present in groundwater concentrations above the Environmental Protection Agencies (EPA) Maximum Contaminant Level (MCL). Various natural processes and human water-use practices can cause release of these substances into the groundwater system and often lead to heightened concentrations. This study will focus on human induced contaminates. Groundwater data for this study was taken from the Florida Department of Environmental Protection's Water Supply Restoration Program (WSRP) and EPA Storage and Retrieval (Storet) programs. This study used well water quality data for nitrate (NO_3), bromacil, and benzene. WSRP program voluntarily tests various private wells for these contaminates across the state of Florida. Approximately 36,111 wells were sampled by WSRP in the study area starting in 1994. Data from the EPA Storet Program, a repository for biological and physical water quality data dates back to 1980's. For this study, we have used Storet for 1980 and 1990 and WSRP for 2000 well water quality data. About 429 wells for the Storet database are located in the study

area. Only areas that had the highest concentration of a
contaminant were viewed for in-depth analysis. Figure 4 shows the location of wells sampled in their respective programs.

FIGURE 4 WATER QUALITY DATA

A. WSRP B. STORET



3. SURFACE WATER

Surface water is defined as all water naturally open to the atmosphere such as rivers, lakes, resevoirs, ponds, streams, seas, oceans, estuaries as well as springs, wells, or other collectors directly influenced by surface waters (USGS, 2005). This study looks at the surface waters of the Tampa Bay estuarine system.

Surface water quality data for this study were obtained from the EPA Storet Program for the decades of the 1980s, 1990s and years 2000-2004. For surface water, this study looked at two common contaminates known to be a cause of human health problems, total nitrogen (NO_2 & NO_3) and fecal coliform. Only areas that had the highest concentration of a contaminant were viewed for in-depth analysis.

4. METHODOLOGIES

This study used Geographic Information Systems (GIS) to overlay and analyze the data. The groundwater analysis began with well data (which was in point format) which was then transformed into a geostatistical surface using various kriging methods. Using visual comparison, the best method was chosen for by looking at surfaces where “hotspots” matched well with point input data, for further analysis. The resulting surfaces were then exported to vector format (for easier data processing) and intersected with census blocks for the studied decades (1980-2000). The following methods were used for each contaminant: (1980): nitrate – universal, bromacil – ordinary, benzene – ordinary; (1990): nitrate – universal, bromacil – ordinary, benzene – ordinary; (2000): nitrate – indicator, bromacil – indicator, benzene – indicator. The areas of the highest concentration of contaminants were queried for and subsequently made into a new layer. All other study parameters (which included: landuse (1 meter resolution), soils (1 meter resolution), Florida Aquifer Vulnerability Assessment (FAVA), and DEM (30 meter resolution; in feet)) were then clipped to the high concentration area.

The second part of the study dealt with population, the methodology is basically the same except the query was performed was for highly populated blocks (≥ 2,000, total population per block). Once queried, the study parameters were clipped to the selected tracts.

For surface water analysis, the methodology was the same as the groundwater analysis but the kriging map after being exported from vector format was clipped to the National Hydrologic Boundary Dataset. After the clip and the selection of the highest concentration area, a 1,000 foot buffer was placed around the selected surface water features and study parameters are clipped to the buffer. For the Tampa Bay analysis, the analysis was similar to the surface water methodology but high concentration areas were not queried and a buffer of 1 mile was placed around the Bay.

After the data was gathered a linear regression analysis was conducted between the population and contaminant concentration data to see if there is a significant relationship between the two. The analysis was undertaken using SPSS.

5. RESULTS

5.1 GROUNDWATER RESULTS

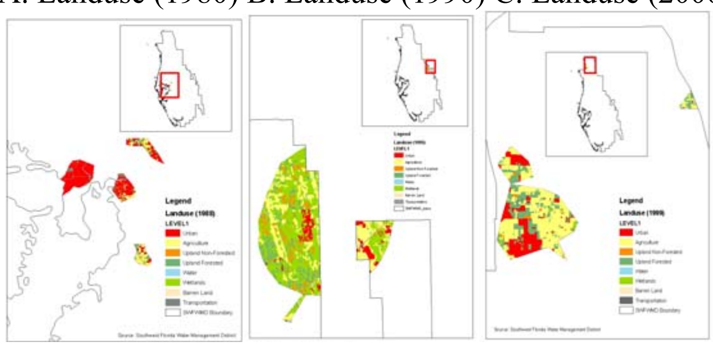
Results for groundwater contaminated areas show two dominant landuses urban and agriculture. With every high concentration areas for every contaminant (with exception of 1990 nitrate and 1980 benzene) containing these landuses.

For all three decades studied, population seems to be a slight factor with total population of contaminated areas around 5,000 - 50,000 (with a few outliers: 1980 Nitrate). The soil occurring most often type in all three contaminated areas was a Candler-Astatula-Tavares type soil (Spodic, Quartzipsamments, Hyperthermic, Uncoated, sandy soil) occurring. Elevation analysis revealed that most of the contamination was occurring between the elevations of -0.41 and 91 feet.

Nitrate (NO_3) Results

FIGURE 5

A. Landuse (1980) B. Landuse (1990) C. Landuse (2000)



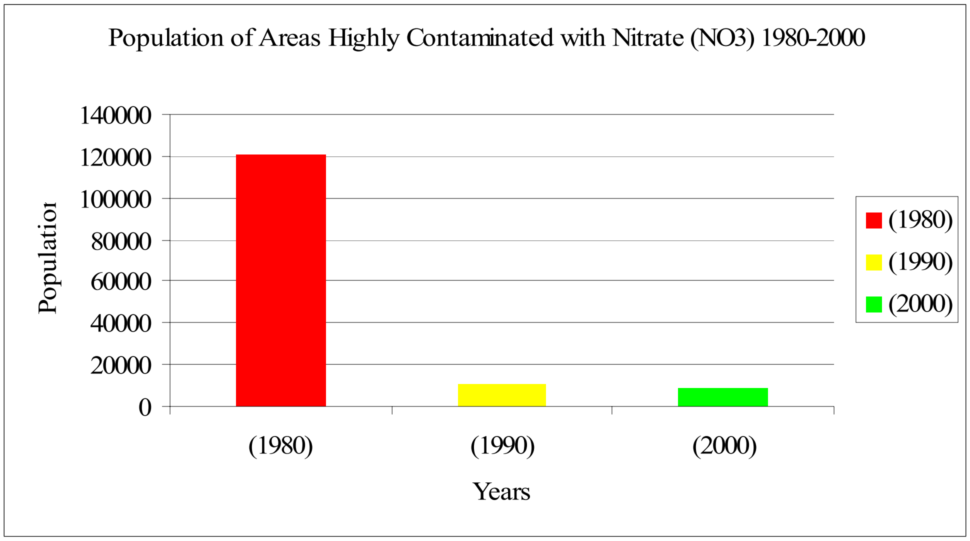
For nitrate results showed that the dominant landuse was mixed (Fig 6) with 1980 having urban, 1990 wetlands and 2000 agriculture as the dominant landuse in contaminated areas. As a result the population of contaminated areas declined from 1980 through 2000 (Fig. 7) from 120,589 in 1980 to 8,315 in 2000.

The soil type occurring most often in the contaminated areas was Candler-Smyrna-Tavares. Elevation analysis showed that the contamination was occurring at a broad range of elevations (between -0.41 and 67 Feet).

TABLE 1: NITRATE CONTAMINATED AREAS RESULTS

Year	Contaminant	Dominant Landuse	Dominant Soil	Total Population	Number of Sample Sites	Highest Conc.	Elevation (DEM)
1980	Nitrate	Urban	URBAN LAND-SMYRNA-MYAKKA	120,589	204	2.34 mg/L	-0.41 – 40 Feet
1990	Nitrate	Wetlands	CANDLER-ASTATULA-TAVARES	10,537	224	1.50 mg/L	33 – 67 Feet
2000	Nitrate	Agriculture	CANDLER-ASTATULA-TAVARES	8,315	36,111	110 mg/L	6 – 62 Feet

Figure 6. Population of Areas Contaminated with NO_3 (1980-2000)



Bromacil Results

Bromacil results illustrated that the dominant landuse was agriculture (Fig. 9) for 2 out 3 study periods. As with nitrate the population of areas highly contaminated with bromacil declined from 1980 through 2000 (Fig 10), with a high 48,132 in 1980 to a low of 5,187 in 2000. Candler-Astatula-Taveres was still the soil occurring most often. Elevation analysis showed that the contamination for bromacil for all three decades occurred on elevations between 18 and 91 feet.

FIGURE 7

A. Landuse (1980) B. Landuse (1990) C. Landuse (2000)

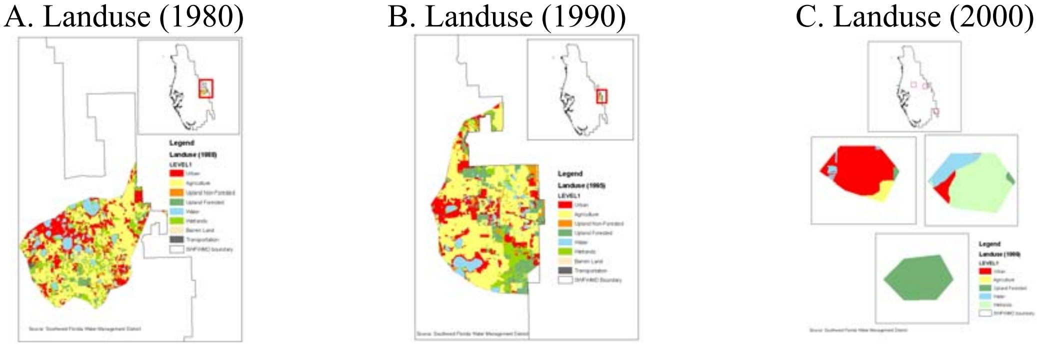
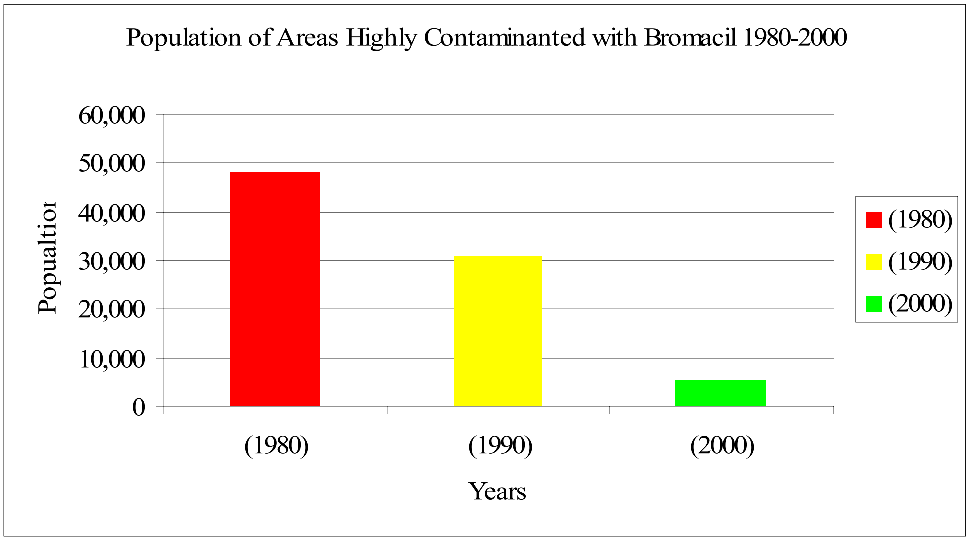


TABLE 2: BROMACIL CONTAMINATION ANALYSIS RESULTS

Year	Contaminant	Dominant Landuse	Dominant Soil	Total Population	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Bromacil	Agriculture	CANDLER-ASTATULA-TAVARES	48,132	36,111	2.67 ug/L	18 – 91 Feet
1990	Bromacil	Agriculture	CANDLER-ASTATULA-TAVARES	30,681	224	2.83 ug/L	19 – 91 Feet
2000	Bromacil	Urban	ARENTS-MATLACHA-HYDRAQUENT	5,187	204	84 ug/L	25 – 36 Feet

Figure 8. Population of Areas Highly Contaminated with Bromacil (1980-2000)



Benzene Results

For benzene (Fig. 4) the landuse (Fig. 12) was variable with 1980 having dominant upland forested, 1990 agriculture and 2000 urban. As with other contaminants the population of contaminated areas declined between 1980 and 2000 (Fig. 13) with a high of 42,965 in 1980 and 6,049 in 2000. Soils were mixed with 2 out of 3 decades having a Candler-type soil occurring most often. Elevation analysis showed that most contamination was occurring at elevations between 0.53 and 49 Feet.

FIGURE 9:

A. Landuse (1980) B. Landuse (1990) B. Landuse (2000)

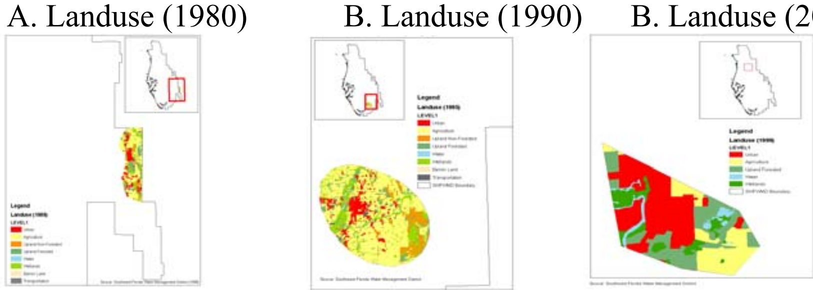
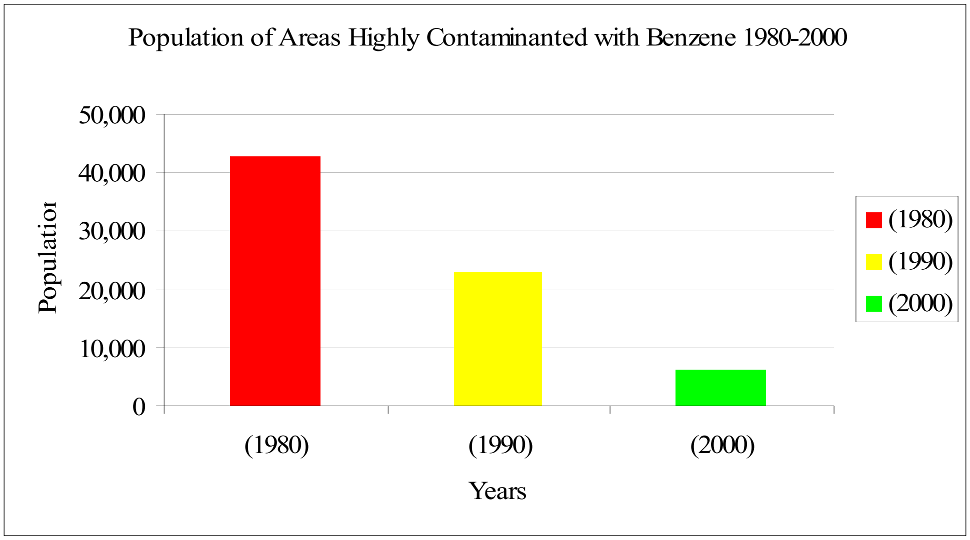


TABLE 3: BENZENE CONTAMINATION ANALYSIS

Year	Contaminant	Dominant Landuse	Dominant Soil	Total Population	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Benzene	Upland Forested	CANDLER-ASTATULA-TAVARES	42,965	36,111	92 ug/L	2 – 49 Feet
1990	Benzene	Agriculture	SMYRNA-IMMOKALEE-BASINGER	22,851	224	707 ug/L	0.53 – 23 Feet
2000	Benzene	Urban	CANDLER-ARREDONDO-ASTATULA	6,049	204	8700 ug/L	12 – 33 Feet

Figure 10. Population of Areas Highly Contaminated with Benzene 1980-2000.

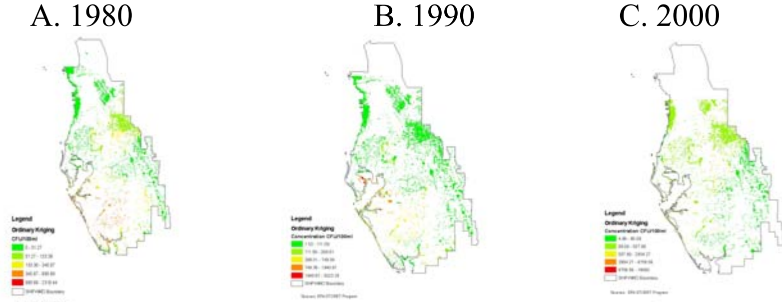


5.2 SURFACE WATER RESULTS

Surface water contamination (Fig 15) shows that the dominant landuses are wetlands and urban for the highly contaminated areas. The soil types occurring most often was Pomona-Eaugllie-Malabar and Candler-Astatula-Tavares soils. Again population didn't seem to be a factor with highest concentration areas having relatively low population and non-urban landuses. Also population fluctuated greatly among the years. Elevation analysis showed contamination occurring at lower elevations from -3.3 Feet to 64 Feet.

FIGURE 11. KRIGING OF SURFACE WATERS FOR FECAL COLIFORM

A. 1980 B. 1990 C. 2000



Fecal Coliform Results

For fecal coliform the dominant landuse (Fig 16) was wetlands, for 2 out the 3 years. Population was very different from groundwater analysis revealing a peak in 1990 of 68,227 and the years 1980 and 2000 having a population around 13-14,000 (Fig. 17) Soils were mixed with 1980 having a Pomona-type soil, 1990, urban land-Smyrna-type soil, and 2000 Arents-type soils. Elevation analysis showed that most contamination is occurring between -0.33 and 62 Feet.

FIGURE 12.

A. STATSGO Soils 1980 B. STATSGO Soils 1999 C. STATSGO Soils 2000

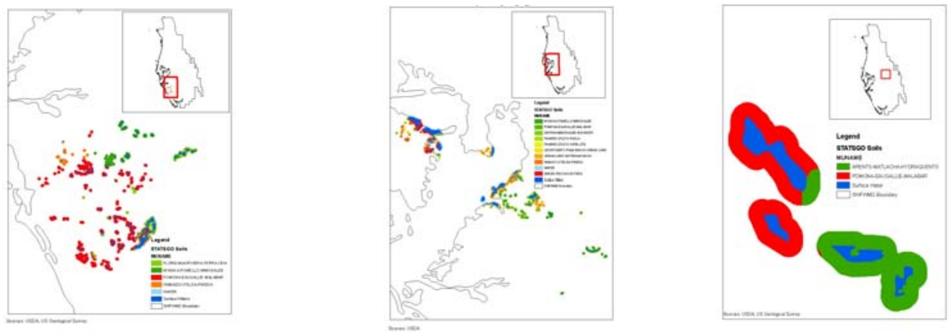
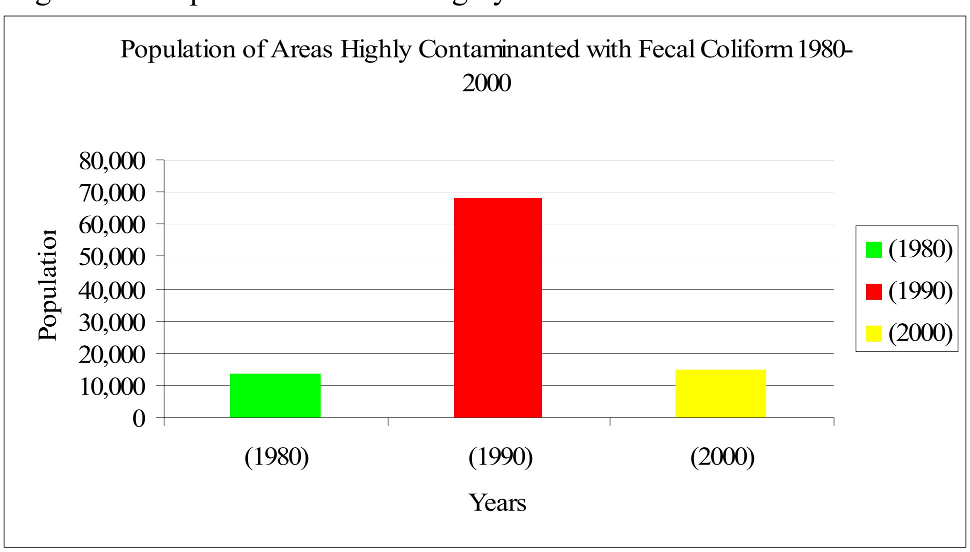


Table 4: Fecal Coliform (Surface) Results

Year	Contaminant	Dominant Landuse	Dominant Soil	Total Population	Number of Sample Sites	Highest Concentratio
1980	Fecal Coliform	Wetlands	POMONA-EAUGALLIE-MALABAR	13,784	204	2318 CFU*/100ml
1990	Fecal Coliform	Wetlands	URBAN LAND-SMYRNA-MYAKKA	68,227	224	5,023 CFU*/100ml
2000	Fecal Coliform	Urban	ARENTS-MATLACHA-HYDRAQUENTS	14,646	36,111	16,000 CFU*/100ml

*-Colony Forming Units

Figure 13. Population of Areas Highly Contaminated with Fecal Coliform



Total Nitrate (NO_2 & NO_3)

For total nitrogen (Fig 19), wetlands was the dominant landuse 2 out of the 3 years. Population as with earlier surface water analysis peaked in 1990 with 182,282 resulting with a low in 1980 of 5,905 and median in 2000 of 65,767 (Fig 20). The soil type occurring most often was Candler-Astatula-Tavares. Elevation analysis shows contamination occurring between -0.45 and 64 Feet.

FIGURE 14

A. Landuse (1980) B. Landuse (1990) C. Landuse (2000)

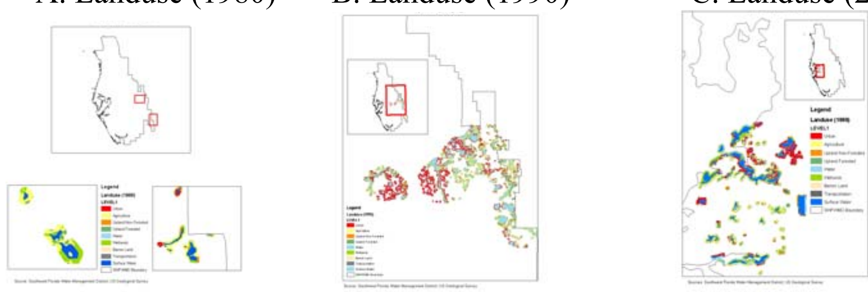
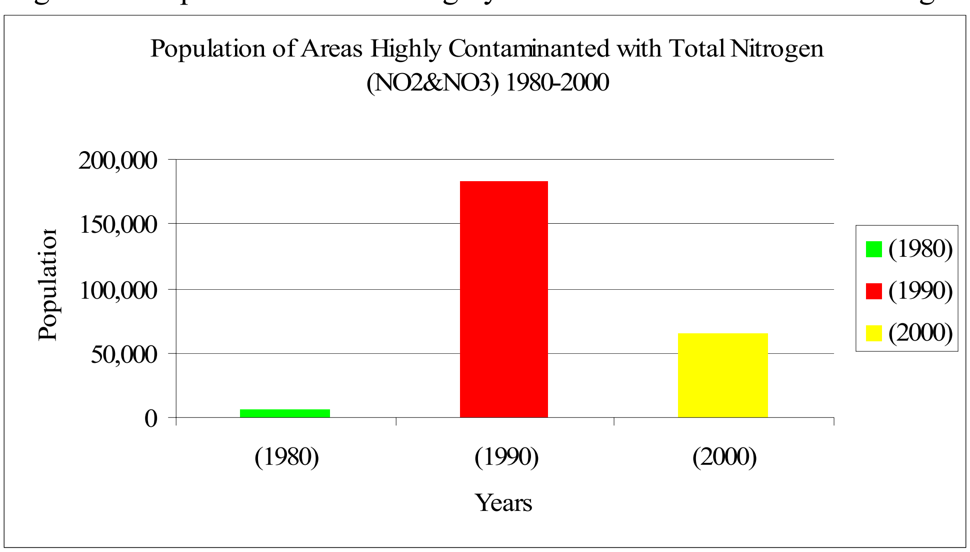


Table 5: Total Nitrogen (Surface) Results

Year	Contaminant	Dominant Landuse	Dominant Soils	Total Population	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Total Nitrogen	Wetlands	CANDLER-ASTATULA-TAVARES	5,905	445	11.82 mg/L	11 – 38 Feet
1990	Total Nitrogen	Urban	CANDLER-ASTATULA-TAVARES	182,282	447	11.59 mg/L	8 – 64 Feet
2000	Total Nitrogen	Wetlands	POMONA-MALABAR	65,767	1,600	390 mg/L	-0.45 – 21 Feet

Figure 15. Population of Areas Highly Contaminated with Total Nitrogen



Acreage (Fig. 21) was similar to population with a peak in 1990 of 175,032 acres resulting in a bell-shaped curve when graphed, with a low in 1980 of 3,379 acres and a median in 2000 of 27,341 acres.

5.3 POPULATION ANALYSIS RESULTS

GROUNDWATER

Population analysis showed the dominant landuse to be urban with 2 out of the 3 years having this landuse. The dominant soil was Pomona-Eugallie-Malabar Soil-type (Ultic Haplaquods, Sandy, Siliceous, Hyperthermic soil) 2 out of 3 years. Total population showed an increase for every year.

FIGURE 17. KRIGING OF BENZENE FOR HIGHLY POPULATED AREAS

A. 1980 B. 1990 C. 2000

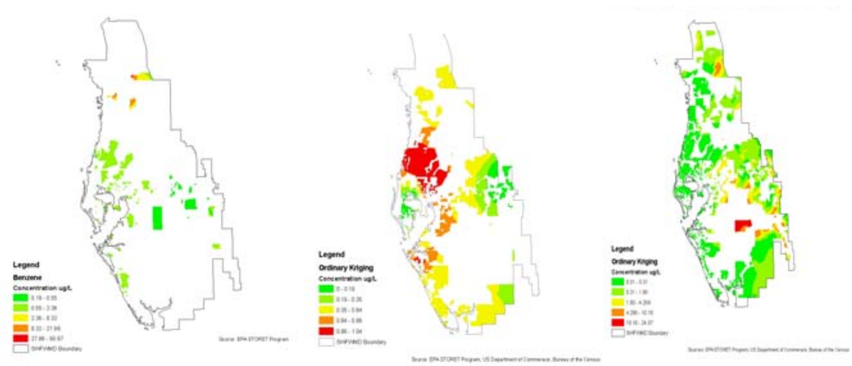


FIGURE 18. KRIGING OF BROMACIL FOR HIGHLY POPULATED AREAS

A. 1980 B. 1990 C. 2000

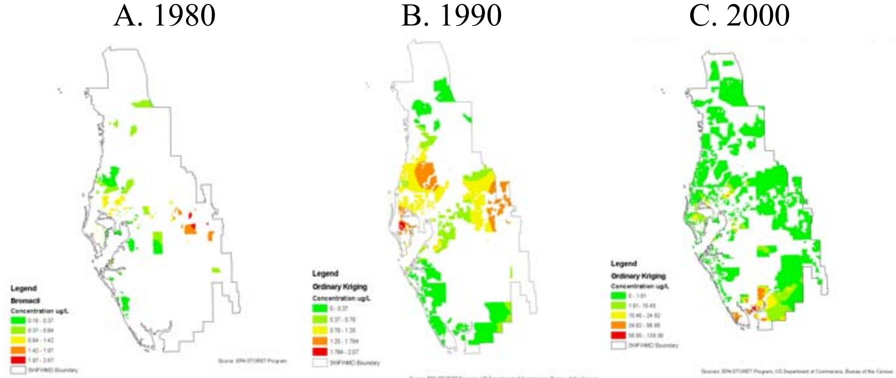


FIGURE 19. KRIGING OF NITRATE FOR HIGHLY POPULATED AREAS

A. 1980 B. 1990 C. 2000

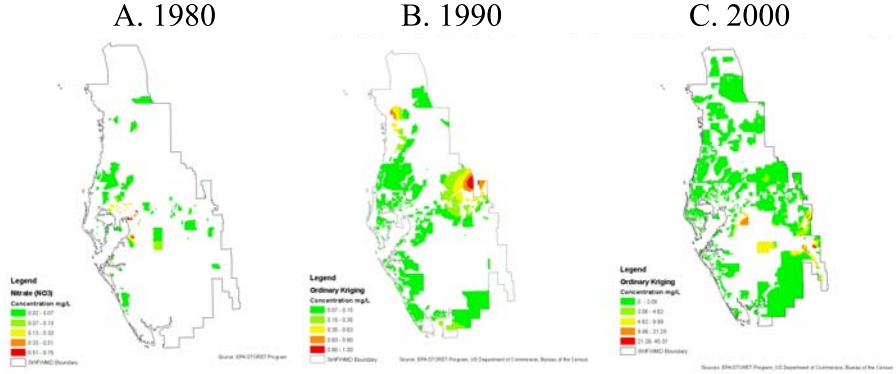


TABLE 6: BENZENE FOR POPULATED AREAS

Year	Contaminant	Dominant Landuse	Total Population	Dominant Soil	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Benzene	Urban	510,765	SMYRNA-IMMOKALEE-BASINGER	204	50.67 ug/L	-0.45 – 80.18 Feet
1990	Benzene	Urban	1,538,353	POMONA-EAUGALLIE-MALABAR	224	1.04 ug/L	-0.56 – 83 Feet
2000	Benzene	Agriculture	2,194,035	POMONA-EAUGALLIE-MALABAR	36,111	24.07 ug/L	-0.61 – 89 Feet

TABLE 7: BROMACIL FOR POPULATED AREAS

Year	Contaminant	Dominant Landuse	Total Population	Dominant Soil	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Bromacil	Urban	510,765	SMYRNA-IMMOKALEE-BASINGER	204	2.67 ug/L	-0.45 – 80.18 Feet
1990	Bromacil	Urban	1,538,353	POMONA-EAUGALLIE-MALABAR	224	2.07 ug/L	-0.56 – 83 Feet
2000	Bromacil	Agriculture	2,194,035	POMONA-EAUGALLIE-MALABAR	36,111	84 ug/L	-0.61 – 89 Feet

TABLE 8: NITRATE FOR POPULATED AREAS

Year	Contaminant	Dominant Landuse	Total Population	Dominant Soil	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Nitrate	Urban	510,765	SMYRNA-IMMOKALEE-BASINGER	204	0.75 mg/L	-0.45 – 80.18 Feet
1990	Nitrate	Urban	1,538,353	POMONA-EAUGALLIE-MALABAR	224	1 mg/L	-0.56 – 83 Feet
2000	Nitrate	Agriculture	2,194,035	POMONA-EAUGALLIE-MALABAR	36,111	45 mg/L	-0.61 – 89 Feet

SURFACE WATER

FIGURE 20. KRIGING OF FECAL COLIFORM FOR HIGHLY POPULATED AREAS

A. 1980 B. 1990 C. 2000

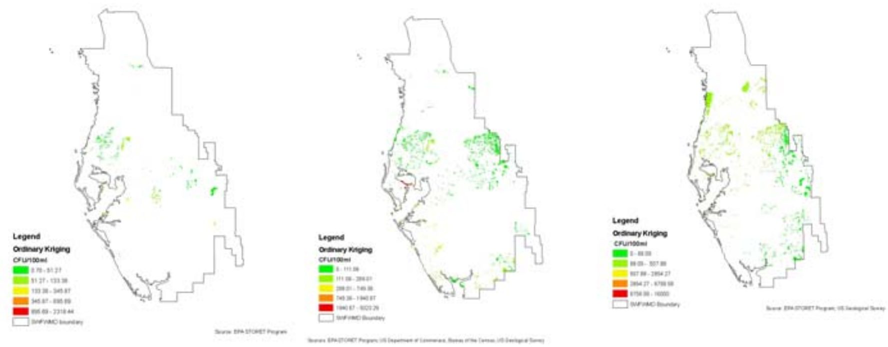


FIGURE 21. KRIGING OF TOTAL NITROGEN FOR HIGLY POPULATED AREAS

A. 1980 B. 1990 C. 2000

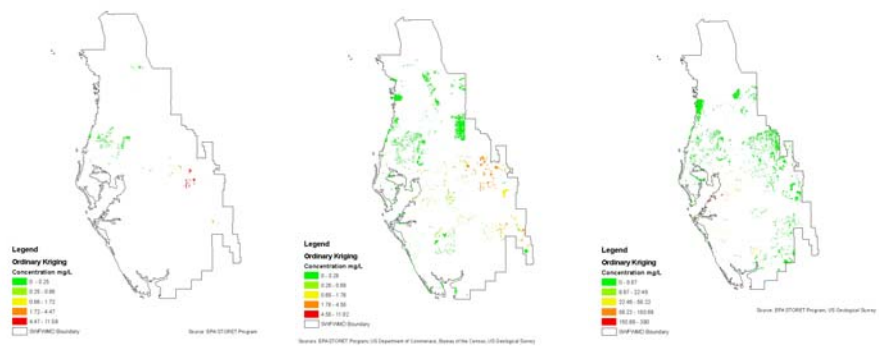


TABLE 9: FECAL COLIFORM FOR POPULATED AREAS

Year	Contaminant	Dominant Landuse	Total Population	Dominant Soil	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Fecal Coliform	Urban	510,765	SMYRNA-IMMOKALEE-BASINGER	445	2,318 CFU/100ml	-0.45 – 80.18 Feet
1990	Fecal Coliform	Urban	1,538,353	POMONA-EAUGALLIE-MALABAR	447	5,023 CFU/100ml	-0.56 – 83 Feet
2000	Fecal Coliform	Agriculture	2,194,035	POMONA-EAUGALLIE-MALABAR	1,600	16,000 CFU/100ml	-0.61 – 89 Feet

TABLE 15: TOTAL NITROGEN FOR POPULATED AREAS

Year	Contaminant	Dominant Landuse	Total Population	Dominant Soil	Number of Sample Sites	Highest Concentration	Elevation (DEM)
1980	Total Nitrogen	Urban	510,765	SMYRNA-IMMOKALEE-BASINGER	445	11.59 mg/L	-0.45 – 80.18 Feet
1990	Total Nitrogen	Urban	1,538,353	POMONA-EAUGALLIE-MALABAR	447	30 mg/L	-0.56 – 83 Feet
2000	Total Nitrogen	Agriculture	2,194,035	POMONA-EAUGALLIE-MALABAR	1,600	390 mg/L	-0.61 – 89 Feet

5.4 TAMPA BAY RESULTS

Results of Analysis of Tampa Bay showed that for both years studied (1990 & 1999) urban landuse was dominant. For soils urban land-Smyrna Myakka soils was the soil-type occurring most. Population grew at rate of about 10% from 462,008 to over 481,252.

Fecal Coliform Results

FIGURE 22:
A. Ordinary Kriging (1990) B. Ordinary Kriging (1999)

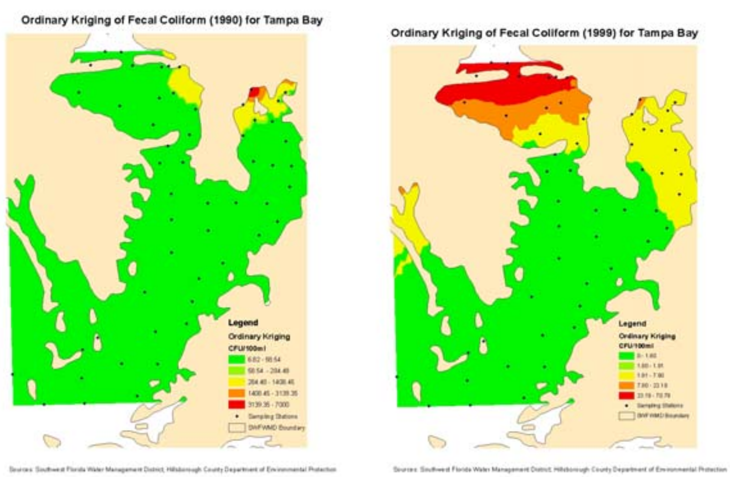


Table 10: Fecal Coliform (Tampa Bay) Results

Year	Contaminant	Dominant Landuse	Dominant Soils	Total Population	Number of Sample Sites	Highest Concentration
1990	Fecal Coliform	Urban	URBAN LAND-SMYRNA-MYAKKA	462,008	54	7,000 CFU/100ml
1999	Fecal Coliform	Urban	URBAN LAND-SMYRNA-MYAKKA	481,252	54	218 CFU/100ml

For Fecal Coliform (Fig. 28) in Tampa Bay the dominant landuse was urban both study years. Population for both years stayed around the 460-480,000 range, growing about 10% between 1990 and 2000. Both years had the same soil type-Urban-Smyrna-Myakka (Aeric Hyplaquods, Sandy, Siliceous, Hyperthermic class soil) occurring most often.

Total Nitrate (NO_2 & NO_3) Results

FIGURE 23:

A. Ordinary Kriging (1990) B. Ordinary Kriging (1999)

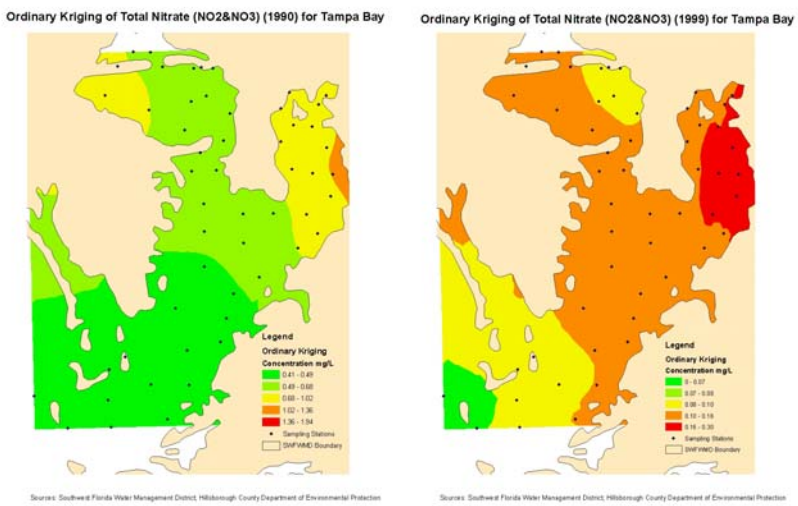


Table 11: Total Nitrogen (Tampa Bay) Results

Year	Contaminant	Dominant Landuse	Dominant Soils	Total Population	Number of Sample Sites	Highest Concentration
1990	Total Nitrogen	Urban	URBAN LAND-SMYRNA-MYAKKA	462,008	54	1.94 mg/L
2000	Total Nitrogen	Urban	URBAN LAND-SMYRNA-MYAKKA	481,252	54	0.67 mg/L

Total Nitrogen (Fig 29) had exactly the same results as Fecal Coliform with a dominant landuse of urban, population around 460-480,000 and soil-type of urban land-Smyrna-Myakka.

STATISTICAL ANALYSIS

Results of statistical analysis using bi-variate linear regression showed mixed results when looking for significant relationships between population and contamination. For Benzene when population for each of the 3 study years was compared with the highest concentration of each of the 3 study years, the resulting r-square was .761, this shows a significant relationship between the two variables (closer an r-square is to 1, the more significant the relationship). For bromacil the r-square was .838 showing a very significant relationship. For nitrate the r-square was .263 showing very little significance between population and contamination.

For Surface water the results showed that there was very little significance between population and contamination with fecal coliform having an r-square of .10 and total nitrogen an r-square of .033.

CONCLUSIONS

Careful planning (identification and management of optimum soils, slopes and landuse patterns) that enhances protection of streams, rivers, and ground water we can achieve a balanced population growth with minimal environmental impact. Development that takes place without such considerations, however, can lead to significant degradation of streams and ground water, which will eventually negatively impact the economic development and growth.

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