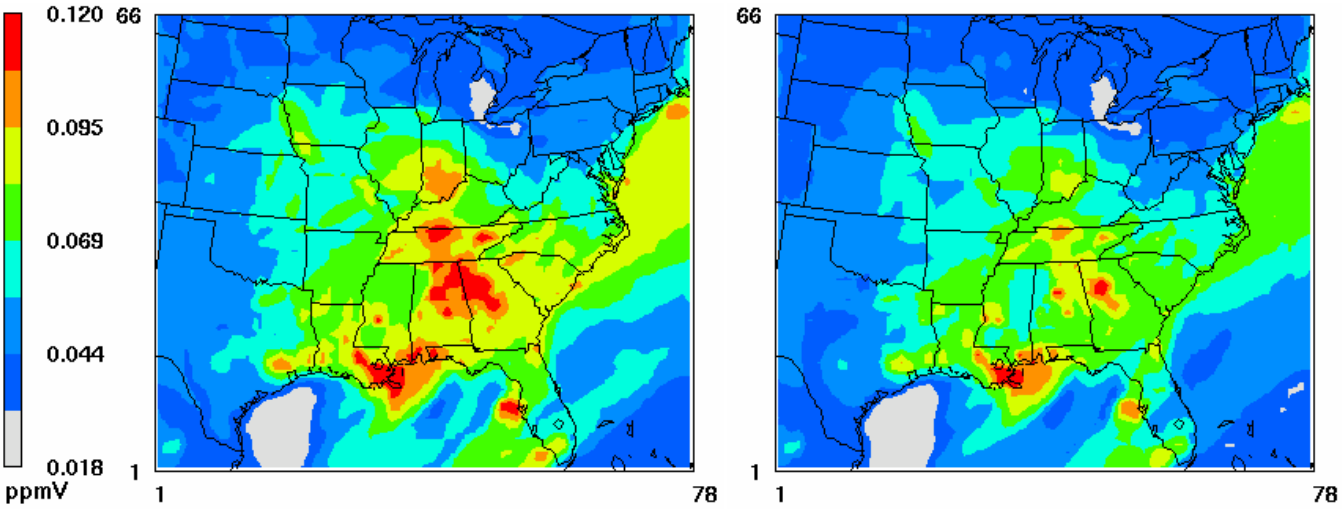
PERCH

Partnership for Environmental Research and Community Health

Air Quality Study
Final Report



An Assessment of Particulate Matter, Ozone, and Air Toxics in Escambia and Santa Rosa Counties

Phase I - Assessing the Relative Risks Associated with Criteria and Air Toxic Pollutants in the Pensacola Area

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About the PAQS

The Partnership for Environmental Research and Community Health (PERCH) is a comprehensive, multi-partner, and multi-disciplinary study to determine if a connection exists between elevated levels of illness in Northwest Florida and the levels of toxic pollutants in the area. The study was commissioned by the U. S. Congress in 2002 and is led by investigators at the University of West Florida. As part of this overall effort, a team of researchers at the Georgia Institute of Technology was challenged to develop an appropriate study to investigate if a connection exists between air pollution / air toxics and adverse human health outcomes in the Pensacola area, specifically Escambia and Santa Rosa counties. Over the course of five years (2002-2007), the PERCH Air Quality Study (PAQS) was conducted in three phases.

Based on a preliminary review of ambient monitoring data, available information regarding emissions, other studies, and discussions with various stakeholders, there are three classes of air pollutants that are of particular concern in the Pensacola area: ground-level ozone, fine particulate matter, and air toxics. Unfortunately, there is no scientific or community consensus regarding which of the three classes of pollutants poses the greatest health risk to the Pensacola community, nor is there a standard methodology by which to make inter-comparisons. In Phase I of this study, existing information was used to assess and prioritize local, urban, and regional threats to human health associated with air toxics and criteria pollutants (ozone and particulate matter) in the Pensacola area. In Phase II, a pilot field study was conducted to investigate the relationship between regional-scale measures of air quality provided by the existing regulatory-based air quality monitoring network, and neighborhood-scale measures of air quality that may be more representative of human exposures in the Pensacola area. In Phase III, a multi-pronged modeling and analysis approach was used to identify the primary contributors to PM, ozone, and air toxics pollution and quantify their relative contributions to local ambient concentrations (and hence potential exposures). The intent of this final phase was to provide local decision makers with the relevant technical information one would need to begin developing a comprehensive air quality management strategy. This report documents the results of phase I of this study. The total project report series includes:

- PERCH Air Quality Study – Executive Summary
- Phase I - Assessing the Relative Risks Associated with Criteria and Air Toxic Pollutants in the Pensacola Area
- Phase II - Summer 2003 Pilot PERCH Air Quality Field Study
- Phase III – Comprehensive Air Quality and Air Toxics Modeling and Analyses
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Phase I Summary

Assessing the Relative Risks Associated with Criteria and Air Toxic Pollutants in the Pensacola Area

Given limited resources with which to conduct a study of air quality and its potential impact on human health in the Pensacola area, it is rational to attempt to identify the type of pollution that may be presenting the greatest health risk in order to focus resources on that problem. Such a comparative analysis is made difficult, however, by the variety of acute and long-term health outcomes related to the different pollutants. While it is recognized that these various health outcomes are incommensurable, it is important to find ways in which they may be compared in order to prioritize and use efficiently the available research resources, and so that the community may likewise focus its efforts on reducing potential risks.

In this initial phase, a rudimentary study was conducted to assess the per capita costs related to the health impacts from ozone, particulate matter, and air toxics at concentrations observed contemporarily in Pensacola. A second, independent assessment focused on the health benefits that would be obtained if pollutant concentrations in the Pensacola area were decreased such that they were no longer considered a risk for any individual. It is important to note that the methodologies are considerably different for the two studies, and thus the costs cannot be directly compared with the benefits. However, within each assessment, it is reasonable to compare the ***relative*** estimates of costs and ***relative*** estimates of benefits. It is in this sense that both analyses suggested that, of the three pollutants of concern, elevated concentrations of particulate matter may pose the greatest health risk.

Costs of Health Impacts from PM, Ozone, and Air Toxics in Pensacola. (Note: due to different methods used to estimate, these costs should not be directly compared to the benefits below.)

	$/year/person (Medium)
PM	$1838.21
Ozone	$952.69
Air Toxics (Total)	$1.02

Benefits of reduced risks from PM, Ozone, and Air Toxics in Pensacola. (Note: due to different methods used to estimate, these benefits should not be directly compared to the costs above.)

	$/year/person (Medium)
PM	$34.00
Ozone	$0.70
Air Toxics (Total)	$3.50

In other Phase I activities, existing and on-going air quality studies pertinent to the Pensacola region were reviewed. This included the Gulf Coast Ozone Study, the West Florida Ozone Study, and the Fall line Air Quality Study.

Key Findings: For this initial assessment of particulate matter, ozone, and air toxics in Escambia and Santa Rosa Counties, rudimentary analyses suggest that **particulate matter likely presents the greatest risk to human health generally related to air quality in the Pensacola region**. It should be recognized however, that there could be highly localized areas for which other pollutants could pose a greater risk.

Implications: Of the three classes of pollutants, ozone is the most well understood pollutant, though it may not pose the greatest health risk. Less is known about particle pollution and air toxics. In terms of allocating PAQS resources, the investigation's ensuing primary focus (i.e. in Phases II and III) will be on PM, secondary on air toxics, and tertiary on ozone.

1. Challenges

In 1996, the United States Environmental Protection Agency began relocating residents living near the Escambia Treating Company Superfund site in Pensacola, Florida (US EPA, 1997). Despite the effort, concerns about lingering adverse health effects persisted within the relocated and nearby communities (CATE, 2004). In early 2001, the Pensacola News Journal began publishing a series of broader articles (Streater et al. 2001a) on pollution in the Pensacola region and its potential effect on human health, ecological integrity, and economic growth. Further, impending changes to federal air quality standards suggested that the region could be subject to increased regulatory oversight. Recognizing the specific concerns of the populations near the Superfund site, the heightening concerns of the general public over more widespread pollutants, and the potential impact of federal and state environmental regulation on regional economic growth, the 107th U. S. Congress directed funds to the University of West Florida for a study to determine if a connection exists between elevated levels of illness in Northwest Florida and the levels of toxic pollutants in the area. The resultant study: Partnership for Environmental Research and Community Health (PERCH, 2004) consists of seven tasks:

1. Construction of an Environmental bibliography for Northwest Florida
2. Assessing the Impact of Environmental Hazard Exposure on the Health Status of Geographically Defined Populations in Escambia and Santa Rosa Counties
3. Air Quality Studies
4. Assessment of Environmental Impacts of Toxic Pollutants in Bayou Texar
5. Assessing Fisheries as Vectors for Toxic Materials from the Environment to Humans
6. Environmental Follow-up: Assessments for Children with Elevated Blood Lead Levels
7. Clinical Toxicology and Public Health Evaluation of Communities Near Superfund Sites in the Palafox Redevelopment Area, Escambia County

Dr. K. Ranga Rao, Distinguished University Research Professor, Professor of Biology, and Director of the Center for Environmental Diagnostics and Bioremediation (CEDB) at the University of West Florida (UWF) is the PERCH Principal Investigator. He oversees the work of the many teams investigating each of the tasks above. Dr. John Lanza, Director, Florida Department of Health, Escambia County Health Department – a principal partner of PERCH – collaborates with Dr. Rao on several of the tasks. Task 3, Air Quality Studies, was subcontracted to the Georgia Institute of Technology in recognition of its expertise and experience in conducting such studies.

Streater (2001b) reasonably summarized three air quality problems facing the Pensacola area (Escambia and Santa Rosa counties). He noted that "[the American Lung Association] ranked Escambia as having the worst ground-level ozone problem in Florida, ….[that] the Pensacola area has the highest recorded concentrations of fine particle pollution in Florida, …[and that] Escambia County ranks among the nation's leaders in toxic air pollution." Unfortunately, there is no scientific or community

consensus regarding which of the three classes of pollutants – ozone, particulate matter, or air toxics – poses the greatest health risk to the Pensacola community.

On 30 January 2002, Professor Wade Jeffrey (CEDB-UWF) first contacted Dr. Michael Chang of the School of Earth & Atmospheric Sciences (EAS) at the Georgia Institute of Technology (Georgia Tech) in regards to the need for an air quality investigation in the Pensacola area. In this and subsequent communications, including a visit to Georgia Tech by Professors Rao and Jeffrey on 20 February 2002, it was suggested that the chief air quality concerns of residents and decision-makers in the Pensacola area were in regards to ground-level ozone and particulate matter (PM) pollution. The high priority of concern for these pollutants was confirmed anecdotally by attendees of a briefing to the PERCH Community Advisory Committee by Dr. Chang on 18 June 2002 (See Appendix A), at an air quality briefing on 20 November 2002 by Professor Ted Russell of the School of Civil & Environmental Engineering at Georgia Tech to a group of Georgia Tech alumni living in the Pensacola area (see Appendix B), and at an air quality briefing on 21 November 2002 by Dr. Chang to the Pensacola Area Chamber of Commerce (See Appendix C).

Understandably, local NW Florida's concern in early 2002 over ozone and particulate matter was likely driven by data collected in the preceding three years (1999-2001) at monitors in Escambia and Santa Rosa counties operated by the Florida Department of Environmental Protection (FL DEP). The data at the time suggested that the region could fail to meet National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter once the new standards for those pollutants were implemented in April and December, 2004[1, 2, 3]. See Table 1 to Table 7. Lower pollutant concentrations since 2001 have tempered this concern somewhat. Uncertainties over the cause of the recent decrease in pollutant concentrations however, means the concern has not fully abated (e.g. some have surmised that the decreases in Pensacola and elsewhere were largely due to favorable meteorological conditions that are unlikely to be sustained, see US EPA, 2004).

For the three year period 1999-2001, ambient ozone design values at the Naval Air Station (Table 1) and Warrington Elementary School (Table 3) monitoring sites, both in Escambia County, exceeded the 8-hour ozone NAAQS. Additionally, the 1999-2001 design value for the Navarre Beach Middle School monitoring site in Santa Rosa County (Table 4) was 84 ppbv, just below the 85 ppbv threshold of the 8-hour ozone NAAQS. For $PM_{2.5}$, no site in NW Florida has observed pollutant concentrations exceeding the $PM_{2.5}$ NAAQS, however concentrations have been sufficiently close to the annual

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[1] As authorized by Congress and the Clean Air Act, the US EPA has established air quality standards for six pollutants (called criteria pollutants): ozone, particulate matter, carbon monoxide, sulfur dioxide, nitrogen dioxide, and lead. More information about how the standards are set, who sets them, and what they are is available from the US EPA. See "Six Common Air Pollutants:" http://www.epa.gov/air/urbanair/6poll.html.

[2] The 8-hour ozone NAAQS is exceeded when the "design value" (i.e. the 3-year average of the annual 4th highest 8-hour average ozone concentrations) is greater than or equal to 85 parts per billion by volume (ppbv).

[3] The US EPA has promulgated an annual and a daily (24-hour) NAAQS for PM2.5. The annual standard is exceeded when the 3-year average of the annual average concentration is greater than 15.0 $\mu g/m^3$. The daily standard is exceeded when the 3-year average of the yearly 98th percentile daily values is greater than 65 $\mu g/m^3$.

average $PM_{2.5}$ NAAQS of 15.0 μg/m^3 at the Ellyson Industrial Park site in Escambia County to warrant concern (Table 5 and Table 6).

Table 1. Observed four highest 8-hour average ozone concentrations and running design values at the Naval Air Station monitor, Escambia County (AIRS ID# 12-033-0018-44201-01).

Rank	1998	1999	2000	2001	2002	2003	2004	NAAQS
1.	113	98	101	90	78	99	86	
2.	113	90	100	86	77	92	85	
3.	102	87	99	84	76	85	85	
4.	102	86	96	82	75	82	83	
3 year avg. of annual 4th highs			94	88	84	79	80	85

Table 2. Observed four highest 8-hour average ozone concentrations and running design values at the Ellyson Industrial Park monitor, Escambia County (AIRS ID# 12-033-0004-44201-01).

Rank	1998	1999	2000	2001	2002	2003	2004	NAAQS
1.	106	90	108	82	85	93	83	
2.	95	85	91	79	75	88	82	
3.	91	82	85	75	73	82	81	
4.	88	81	84	75	71	82	78	
3 year avg. of annual 4th highs			84	80	76	76	77	85

Table 3. Observed four highest 8-hour average ozone concentrations and running design values at the Warrington Elementary School monitor, Escambia County (AIRS ID# 12-033-0024-44201-01).

Rank	1998	1999	2000	2001	2002	2003	2004	NAAQS
1.	116	92	101	83	79	98	88	
2.	110	88	99	82	75	86	84	
3.	106	84	96	80	75	84	83	
4.	104	83	94	78	74	82	82	
3 year avg. of annual 4th highs			93	85	82	78	79	85

Table 4. Observed four highest 8-hour average ozone concentrations and running design values at the Navarre Beach Middle School monitor, Santa Rosa County (AIRS ID# 12-113-0014-44201-01).

Rank	1998	1999	2000	2001	2002	2003	2004	NAAQS
1.			100	88	80	104	84	
2.			98	88	77	89	84	
3.			98	82	77	85	83	
4.			96	81	75	84	83	
3 year avg. of annual 4th highs					84	80	80	85

Table 5. Observed annual average and annual peak 24-hour average $PM_{2.5}$ concentrations at the Ellyson Industrial Park Federal Reference Method monitor Escambia County (AIRS ID# 12-033-0004-88101-01).

Year	Annual Avg. (mg/m3)	3 Year Avg. of Annual Avg.	Peak 24-hour Avg. (mg/m3)
1999	14.8	NA	37.4
2000	13.8	NA	49.3
2001	11.4	13.3	26.5
2002	10.9	12.0	28.6
2003	11.2	11.1	31.9
2004 (1st Qtr. Only)	11.0	NA	21.7
NAAQS		15.0	65.0

Table 6. Observed annual average and annual peak 24-hour average $_{PM2.5}$ concentrations at the Ellyson Industrial Park Continuous TEOM Method monitor, Escambia County (AIRS ID# 12-033-0004-88101-03).

Year	Annual Avg. (mg/m3)	3 Year Avg. of Annual Avg.	Peak 24-hour Avg. (mg/m3)
1999	14.2	NA	38.1
2000	14.9	NA	45.8
2001	12.3	13.8	36.1
2002	11.5	12.9	30.8
2003	11.8	11.8	32.7
2004 (1st Qtr. Only)	11.6	NA	24.9
NAAQS		15.0	65.0

Table 7. Observed annual average and annual peak 24-hour average $PM_{2.5}$ concentrations at the Navarre Beach Middle School monitor, Santa Rosa County (AIRS ID# 12-113-0014-88101-01).

Year	Annual Avg. (mg/m3)	3 Year Avg. of Annual Avg.	Peak 24-hour Avg. (mg/m3)
2002	9.3	NA	25.8
2003	9.9	NA	29.8
2004 (1st Qtr. Only)	9.0	NA	21.4
NAAQS		15.0	65.0

In presenting some conceptual ideas for an air quality study for the Pensacola area at a meeting in Atlanta on 14 March 2002, representatives from the US Environmental Protection Agency, Region IV suggested that the study include an air toxics[4] component. Compelling reasons for addressing air toxics and health in the Pensacola area that were cited at the time include:

[4] Air toxics are a class of pollutants known or suspected to cause cancer or other serious health effects in humans (e.g. reproductive effects or birth defects). While there are no federal or state air quality standards for these hazardous air pollutants, the United States Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (DEP) regulate the industrial emission of 188 pollutants identified as toxics in the Clean Air Act.

1. Of the 67 counties in Florida, the 1999 Toxic Release Inventory (US EPA, 2001) shows Escambia County leading all others in total air toxics emissions. See **Table 8**.
2. US EPA's 1996 National Air Toxics Assessment (NATA, US EPA, 2002a) estimated the cancer risk from air toxics to be 42 in one million in Escambia County, and 37 in one million in Santa Rosa County, with both counties exceeding EPA's threshold of one in one million risk. See **Table 9** and **Table 10** .
3. In 2002, the US EPA Region IV developed a Relative Risk Screening Analysis (US EPA, 2002b) method for comparing the 736 counties in Region IV. The analysis ranked Escambia county 42nd and Santa Rosa County 290th in terms of the risks posed to those communities by toxic air pollutants.

Given these indicators of risk, it is uncertain why stakeholders in Pensacola did not vocalize more their concerns about health risks specifically associated with air toxics to investigators at meetings in which the proposed air quality studies were presented (Appendices A, B, and C). While this was not investigated, we suggest three reasons. First, the community may not be aware of or understand the implications of the air toxics rankings and measures (for which, public education regarding air toxics would be beneficial, but is beyond the scope of this work). Second, although the screening analysis ranks these counties relatively high, the estimated risks are generally comparable to the estimated risks for communities that leaders in the Pensacola area consider to be its peers. **Table 11** shows the ranking of Escambia and Santa Rosa counties relative to their peer communities in Region 4 as identified by the Pensacola Chamber of Commerce (Prim, 2003). Lastly, there are no corresponding NAAQS for air toxics for which failure to attain would require enacting specific regulatory mandates, and for which a "bright-line" test exists that would serve as an indicator of the presence of adverse health effects.

Table 8. 1999 Toxic Release Inventory (TRI), top ten county-level total air toxic emissions in Florida (US EPA, 2001).

Rank	County	Total Air Emissions (lbs/yr)
1.	Escambia	18,708,263
2.	Hillsborough	15,903,486
3.	Citrus	8,025,284
4.	Duval	7,525,546
5.	Polk	7,362,849
6.	Bay	6,579,631
7.	Putnam	6,216,633
8.	Nassau	2,486,199
9.	Palm Beach	2,413,461
10.	St. Lucie	2,302,906

Table 9. 1996 National Air Toxics Assessment Mean Estimated Cancer Risks for Escambia County (US EPA, 2002a).

Source	**Risk Score[5] (X 10^{-6})**	**Contribution (%)**
Major	1.1	2.5
Area and other	5.9	13.8
Onroad mobile	10.6	25.1
Nonroad mobile	4.8	11.4
Estimated background	20.0	47.2
Total	42.4	100.0

Table 10. 1996 National Air Toxics Assessment mean estimated cancer risks for Santa Rosa County (US EPA, 2002a).

Source	**Risk Score (X 10^{-6})**	**Contribution (%)**
Major	1.2	3.3
Area and other	6.7	18.0
Onroad mobile	4.1	10.9
Nonroad mobile	5.3	14.2
Estimated background	19.9	53.6
Total	37.1	100.0

[5] Probability of developing cancer due to inhalation over lifetime (70 years)

Table 11. Risks in Escambia and Santa Rosa Counties (US EPA, 2002b) relative to their Peer Counties (Prim, 2003).

County	EPA Risk Screening Rank[6]	NATA Cancer Risk Estimate[7] ($X\ 10^{-6}$)	NATA Non-Cancer Risk Estimate[8]
Mecklenburg, NC	12	58.6	6.4
Gaston, NC	22	51.4	5.5
Durham, NC	40	52.9	4.7
Escambia	**42**	**42.4**	**3.8**
Wake, NC	45	47.6	4.6
Chatham, GA	51	42.8	3.9
Lee, FL	67	35.4	3.8
Cabarrus, NC	75	45.9	4.7
Berkeley, SC	76	37.2	3.6
York, SC	88	44.9	4.5
Charleston, SC	90	42.4	3.3
Dorchester, SC	98	34.3	3.3
Rowan, NC	114	39.4	3.4
Orange, NC	137	43.7	4.2
Madison, AL	140	40.1	3.5
Lincoln, NC	151	41.3	3.6
Union, NC	232	35.3	3.1
Chatham, NC	252	35.8	3.1
Santa Rosa, FL	**290**	**37.1**	**3.6**
Limestone, AL	299	33.5	2.3
Johnston, NC	314	29.3	2.2
Effingham, GA	371	27.5	2.3
Bryan, GA	381	27.0	2.1
Franklin, NC	492	31.3	2.3

Given the preceding technical evidence, along with input from stakeholders in Pensacola and government agencies, the PERCH Air Quality Study Team was challenged to develop an appropriate study to investigate if a connection exists between air pollution / air toxics and adverse human health outcomes in the Pensacola area, specifically Escambia and Santa Rosa Counties.

Ideally, this study would be able to determine if there is a connection between airborne pollutants and observed morbidity or mortality in Pensacola. At the marginal to moderate concentration of current pollutant loads however, and combined with the

[6] Relative to 736 counties in US EPA Region IV. Higher rankings have higher risks.

[7] Risk of developing cancer as a result of exposure (via inhalation) to 32 air toxics compounds over a lifetime of 70 years.

[8] Hazard quotient, which is a ratio of pollutant concentrations to the inhalation reference concentrations at which no adverse health effect is expected.

relatively small population of the community, lack of detailed health tracking data, and sparseness of ambient air quality and air toxics monitoring, the effects of air pollution on human health in NW Florida are likely to be difficult, if not impossible to observe using traditional epidemiological approaches. Given the available resources, sparseness (in time, space, and chemical compound) of the existing regional air quality monitoring network, and expense of studies involving human subjects, a cohort study is similarly not possible. Based on studies from other communities however (for example from Atlanta: Tolbert et al. 2000a and 2000b; Metzger et al. 2004), it may be possible to infer risks in Pensacola based on relative pollutant concentrations, emissions estimates, patterns of dispersion, and demographic distributions. In Phase I of this study, we use existing information sources to assess and prioritize local, urban, and regional threats to human health associated with air toxics and criteria pollutants in the Pensacola area. Details regarding the goals and approaches of Phase I are described in our Phase I proposal submitted to UWF on or about 19 April 2002, and included here as Appendix D.

References

Chang, M.E., "PERCH Air Quality Study," presentation to the Pensacola Area Chamber of Commerce, Pensacola, FL, 11/21/2002.

Citizens Against Toxic Exposure (CATE), http://www.cate.ws/index.html, © 2002, accessed on 12/2/2004.

Metzger KB, Tolbert PE, Klein M, Peel JL, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H.; 'Ambient air pollution and cardiovascular emergency department visits;' Epidemiology 2004; 15(1):46-56.

Partnership for Environmental Research and Community Health (PERCH), http://www.uwf.edu/cedb/research/RPartnership.cfm, accessed on 12/2/2004.

Prim, N., Vice President, Community and Governmental Affairs; Pensacola Area Chamber of Commerce; Personal Communication; 3/26/2003.

Russell, A. "Air Quality, Health, and Economic Development in and around Pensacola," presentation to the Emerald Coast Georgia Tech Club, Pensacola, FL, 11/20/2002.

Streater, S., A. Caputo, G. Graybiel, and J. LaCoste, "Hidden Hazards," (Series), Pensacola News Journal, 18 February, 25 February, and 4 March 2001.

Streater, S. "Clearing the air," Pensacola News Journal, p. 1A, 26 August 2001b.

Tolbert, PE, Klein M, Metzger KB, Peel J, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H, "Interim Results of the Study of Particles and Health in Atlanta (SOPHIA)," J Exposure Analysis and Environmental Epidemiology, 10, 446-460, 2000a.

Tolbert, P.E., Mulholland, J.A., MacIntosh, D., Xu, F., Daniels, D., Devine, O., Carlin, B., Klien, M., Dorley, J., Butler, A.J., Nordenberg, D., Frumkin, H., Ryan, P.B., & White, M. "Air pollution and pediatric emergency room visits for asthma in Atlanta;" American Journal of Epidemiology, 151, 798-810; 2000b.

US EPA, "EPA Superfund Record of Decision: ESCAMBIA WOOD – PENSACOLA," EPA ID: FLD008168346, 2/12/1997 (available online 12/2/2004 at http://www.epa.gov/superfund/sites/rods/fulltext/r0497018.pdf).

US EPA, Office of Environmental Information, "Toxic Release Inventory;" data update as of 1 August 2001.

US EPA, "1996 National Air Toxics Assessment;" 31 May 2002a (available on-line 12/8/2004 at http://www.epa.gov/ttn/atw/nata/index.html).

US EPA; Region 4; "Air Toxics Relative Risk Screening Analysis;" 27 September 2002b.

US EPA, Office of Inspector General; "Evaluation Report: EPA and States Not Making Sufficient Progress in Reducing Ozone Precursor Emissions In Some Major Metropolitan Areas;" Report No. 2004-P-00033; September 29, 2004.

2. Assessing the Relative Risks Associated with Criteria and Air Toxic Pollutants in the Pensacola Area

The US EPA classifies air pollutants into two broad categories, Criteria air pollutants, and Air Toxics. Criteria pollutants consist of those compounds for which National Ambient Air Quality Standards (NAAQS) have been promulgated by the US EPA. These are 1) ozone, 2) particulate matter, 3) sulfur dioxide, 4) carbon monoxide, 5) nitrogen dioxide, and 6) lead. The NAAQS specify thresholds for concentrations of these six pollutants in the air above which adverse human health outcomes may be experienced by individuals, groups, or throughout the population. Air toxics are a class of pollutants known or suspected to cause cancer or other serious health effects in humans (e.g. reproductive effects or birth defects). While there are no federal or state air quality standards for these hazardous air pollutants, the US EPA regulates the industrial emission of 188 pollutants identified as toxics in the Clean Air Act.

Given limited resources with which to conduct a study of air quality and its potential impact on human health in the Pensacola area, it is rational to attempt to identify the type of pollution that may be presenting the greatest health risk in order to focus resources on that problem. Such a comparative analysis is made difficult however, by the variety of acute and long-term health outcomes related to the different pollutants. For example, exposure to ozone has been found to be related to the development of asthma in children (McConnell et al. 2002), the exacerbation of asthma in children and adults (Tolbert et al. 2000), birth defects (Ritz et al. 2002), and premature mortality (Bell et al. 2004). Exposure to $PM_{2.5}$ has been linked to increased incidence of myocardial infarction or heart attack (Peters et al. 2001), lung cancer, and cardiopulmonary mortality (Pope et al. 2002). Air Toxics present still other health risks. While we recognize that these various health outcomes are incommensurable, we are nevertheless challenged to find ways in which they may be compared in order to prioritize and use efficiently our available research resources. Here, we report on a rudimentary study to assess the per capita costs related to the health impacts from ozone, particulate matter, and air toxics at concentrations observed contemporarily in Pensacola. A second independent method assessed the health benefits that would be obtained if pollutant concentrations in the Pensacola area were decreased such that they were no longer considered a risk for any individual. Both of these risk assessments are presented here now.

2.1 Health Costs of PM, ozone, and air toxics in the Pensacola area

Annualized per capita health costs related to exposure to particulate matter, ground-level ozone, and air toxics are crudely estimated for the Pensacola area. These impacts are estimated from modeled (in the case of air toxics) and observed (ozone and PM) pollutant concentrations in Escambia County, and assumed rates of impact as reported by US EPA and other sources. While there are no assurances that the following calculations provide any reasonable estimates of the absolute costs related to exposure to any of these pollutants, this analysis may provide some insight into the relative costs associated with the different pollutants. In this latter sense, it may help in answering the

challenge stated above regarding how to allocate this study's remaining resources for air quality research.

2.1.1. Air Toxics

Air Toxics are not routinely measured in the Pensacola area. The last (and perhaps, the only) time any air toxics were sampled in the area was in 1990 at Ellyson Industrial Park as part of a study of Nonmethane Organic Compounds (NMOC). Data from that study is included here as Appendix F. The data are of such limited scope (time, space, and chemical diversity) and of sufficient vintage however, that they are of marginal value for the purposes needed here. Without any other source of ambient data available, we instead rely on air pollutant concentrations estimated by US EPA using estimated toxics emissions and a dispersion model.

The computer simulation model used by US EPA to estimate toxic air pollutant concentrations is called the Assessment System for Population Exposure Nationwide, or ASPEN. This model is based on the EPA's Industrial Source Complex Long Term model (ISCLT), which simulates the behavior of the pollutants after they are emitted into the atmosphere. ASPEN uses estimates of toxic air pollutant emissions and meteorological data from National Weather Service Stations to estimate air toxics concentrations nationwide. The ASPEN model takes into account important determinants of pollutant concentrations such as:

- Rate of release
- Location of release
- The height from which the pollutants are released
- Wind speeds and directions from the meteorological stations nearest to the release
- Breakdown of the pollutants in the atmosphere after being released (i.e., reactive decay)
- Settling of pollutants out of the atmosphere (i.e., deposition)
- Transformation of one pollutant into another (i.e., secondary formation)

The model was used to estimate toxic air pollutant concentrations in 1996 for every census tract in the United States as part of the National Air Toxics Assessment. NATA is the "Environmental Protection Agency (EPA)'s ongoing comprehensive evaluation of air toxics in the U.S. …Activities include expansion of air toxics monitoring, improving and periodically updating emission inventories, improving national- and local-scale modeling, continued research on health effects and exposures to both ambient and indoor air, and improvement of assessment tools (http://www.epa.gov/ttn/atw/nata/index.html)." The 1996 NATA provided estimates for 32 air toxics. NATA Risks in Pensacola however, were largely attributed to just three pollutants: benzene, 1,3 butadiene, and chloroform. Table 12 shows the annual emissions by source category, and modeled average annual concentrations for each of these three air toxics in Escambia County.

Table 12. NATA Data Used in Cost Analysis

Air Toxic	Major Emissions (tons/yr)	Area and Other Emissions (tons/yr)	Onroad Mobile Emissions (tons/yr)	Non-road mobile Emissions (tons/yr)	Total Emission (tons/yr)	Average Annual Ambient Concentration ($\mu g/m^3$)
Benzene	7	27	189	71	294	1.190
1,3-Butadiene	0	6	24	9	39	0.005
Chloroform	0.003	0.597	0.000	0.000	0.599	0.007

Additionally, the following assumptions are made:

- A person is assumed to breath 20 m^3 of air every day
- Chronic daily intake (CDI) is calculated by dividing the Average daily dose (μg/day) by the body weight (kg)
- Potency factors from inhalation, are given in (μg/kg-day)
- Incremental lifetime cancer risk is calculated by multiplying the potency factor into CDI
- The pre-mature mortality has been estimated to have a value of $6,000,000 per statistical life
- Statistical life has been assumed to be 70 years for an average person
- Total health costs are calculated by multiplying the incremental cancer risk by pre-mature mortality

Results are shown in Table 13. Additionally in Table 13, concentrations for these pollutants observed in 1990 are also shown. While there are some differences, this comparison suggests that the modeled concentrations are reasonable.

Table 13. Air Toxics Cost Analysis for Pensacola

	Observed 1990 Annual Concentration ($\mu g/m^3$)	Annual Exposure Estimated ($\mu g/m^3$)	CDI (μg/day-kg)	Potency factor (day-kg/μg)	Incremental lifetime risk	Pre-mature mortality ($/statistical life)	$/statistical life	$/year/person
Benzene	0.42	1.19	.34	.029	9.9E-06	6,000,000	59.4	0.8940
Chloroform	< detection limit of 0.005	0.068	.023	.081	1.86E-06	6,000,000	11.2	0.0121
1,3 Butadiene	< detection limit of 0.002	0.00504	.0014		1.41E-06	6,000,000	8.46	0.1210

2.1.2 Particulate Matter and Ozone

Unlike the air toxics, particulate matter and ozone concentrations are routinely measured at several sites in the Pensacola area in general and in Escambia County in particular. In 2000, the annual average $PM_{2.5}$ concentration measured at Ellyson Industrial Park (using the continuous method rather than the Federal Reference Method) was 14.9 $\mu g/m^3$. At the same location, the average annual ozone concentration for 2000 was 60.7 ppb. Coefficients relating changes in ozone concentrations and PM concentrations to health benefits were developed from an updated version of the Tracking

and Analysis Framework (Bloyd et al., 1996). TAF incorporates concentration-health response functions. In Table 14 the low, medium, and high estimate of benefit values in 2000 dollars is given. Health costs are estimated to be the product of these coefficients and average concentrations for Escambia County. See Table 15 and Table 16.

Table 14. Cost Coefficients for Ozone and PM.

	Ozone ($/day/ppb/person)	**PM ($/day/μg/m3/person)**
Low	.018	.047
Medium	.043	.338
High	.170	.864

Table 15. Ozone Cost Analysis for Pensacola

Escambia seasonal average (ppb)	**Benefit coefficient ($/day/ppb/person)**	**$/year/person**
60.7	.043(medium)	952.69
60.7	.17(high)	3766.43

Table 16. PM Cost Analysis for Pensacola

Escambia seasonal average (ug/m3)	**Benefit coefficient ($/day/ug/m3/person)**	**$/year/person**
14.9	.338(medium)	1838.21
14.9	.864(high)	4698.87

2.1.3 Cost Assessment and Prioritization of Research Activities

There exists considerable uncertainty associated with this rudimentary estimation of health impact costs, however the final results (Table 17) suggest that health impacts associated with PM are the greatest, air toxics are the least, and ozone falls somewhere in between. At the least, this simple analysis implies that in order to best address the potential health effects related to air quality in the Pensacola area, it may be prudent to focus future research efforts on particulate matter and, its emissions from sources; its formation, dispersion, and transformation in the atmosphere; and its effects on exposure and human health. A more sophisticated analysis is provided in the next section.

Table 17. Cost of Health Impacts from PM, Ozone, and Air Toxics in Pensacola

	$/year/person (Medium)
PM	1838.21
Ozone	952.69
Air Toxics (Total)	1.02

2.2 Health Benefits Related to Reducing Concentrations of PM, Ozone, and Air Toxics in the Pensacola Area[9]

Comparative risk analysis has significantly influenced national level research priorities at the US EPA (Kent & Allen, 1994; Patton & Huggett, 2003), and continues to do so, as is evident in the Strategic Plan of the Office of Research and Development (ORD) released in 2001 (EPA, 2001a). EPA's first foray into comparative risk, *Unfinished Business* (EPA, 1987), was based on technical risk assessments and expert judgment. Later efforts by states and municipalities to prioritize their environmental problems have involved not only technical experts but also the general public and other stakeholders in the form of a public advisory group (Feldman, Hanahan, & Perhac, 1999). Such efforts have been analyzed extensively (Gutenson, 1997; Jones & Klein, 1999; Konisky, 2001; Morgenstern, Shih, & Sessions, 2000; Perhac, 1998; Swaney, 1996). In this section, we utilize the characteristics of risk comparisons routinely made in other air pollution policies, and apply them to assess air pollutants in the Pensacola area.

2.2.1 Risk Assessment of Air Pollution

Typically risk assessments include four primarily analytic steps: hazard assessment, dose-response assessment, exposure assessment, and risk characterization (NRC, 1983; Russell & Gruber, 1987), although there has been new emphasis in the last decade on analytic-deliberative approaches (NRC, 1996). Full-scale risk assessment of air pollution includes identification of pollutants of concern and their sources, estimation of pollutant emissions, ambient concentrations, estimation of exposures, identification of human and ecological health endpoints of concern, estimation of dose-response, and potential quantification of risk and value.

- ***Identification of pollutants of concern***: Regulated air pollutants can be classified into two broad classes: the six criteria pollutants specified under National Ambient Air Quality Standards (NAAQS) and the 188 air toxics listed in the 1990 Clean Air Act (CAA) Amendments. The first step in assessing the risk of air pollutants is to identify potential sources – point, area, and mobile – of emissions within the region, and the pollutants emitted from those sources with potential adverse ecological or human health impacts. In conventional risk assessment, this is part of "hazard identification." Of the criteria pollutants, ozone and PM2.5 have violated standards in Pensacola on multiple occasions, as discussed below.
- ***Estimation of pollutant emissions***: Once the pollutants of concern for risk assessment are identified, the next step is to measure or estimate emission rates. Emissions can be estimated from the National Pollution Inventory (NPI), inventories of state department of environment, and emission factors.
- ***Estimation of ambient concentrations***: The dispersion of pollutants from the source of their release is a function of many factors, including gas characteristics at the point of release and the meteorology and topography of the region. Both U.S. EPA and State Departments of Environmental Protection have established air monitoring networks, such as Photochemical Assessment Monitoring Stations

[9] In slightly different form and content, this section was presented as a paper at the Association for Public Policy and Management meetings of October 28-30, 2004 in Atlanta, GA.

(PAMS) and State and Local Area Monitoring Stations (SLAMS) to measure ambient concentrations for criteria pollutants and some air toxics. Alternatively, ambient concentrations can be estimated using air dispersion models such as Industrial Source Complex (ISC) Model, CALPUFF, and CALINE3. This modeling is especially useful for air toxics that are not regularly measured by ambient air monitoring programs. In Pensacola, criteria air pollutants are monitored at three locations. Measurement of toxics is much more sporadic.

- ***Estimation of exposure concentrations*:** The actual concentration of air pollutants to which people and ecological systems are exposed depends on exposure pathways (e.g., inhalation or oral or dermal, for people, deposition or runoff for ecological systems) and the activity or function at the time of exposure. Typically, human exposure models such as the hazardous pollutant exposure model (HAPEM) (EPA, 2004b) are used for estimating exposure concentrations for groups of individuals.
- ***Identification of human and ecological health endpoints*:** Evidence produced by epidemiological and toxicological studies is used to identify the health endpoints relevant for each pollutant or pollutant mix. For example, air toxics can cause cancer, neurological, reproductive and developmental effects,[10] and criteria pollutants such as ozone can lead to respiratory and cardiac problems, and affect plant growth (e.g., Krupa and Manning, 1988). Risk assessment endpoint selection was carried out by program offices at EPA into the early 90's, and ecological risk assessment was based on ecological relevance, susceptibility, and relevance to management goals (USEPA, 1998). A weak point of many risk assessments is the failure to include ecological endpoints, or anything approaching the full range of known or suspected health endpoints.
- ***Dose-response assessment***: Dose-response assessment is the process of establishing a quantitative relationship between exposure concentrations and adverse health outcomes. In case of criteria pollutants, concentration-response (C-R) functions are developed to estimate the change in incidence of a given health end point (for example, a respiratory symptom), for a unit change in pollutant exposure concentration. For toxics, unit risk factors (URFs) are developed to represent the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to a pollutant at a concentration of 1 $\mu g/m^3$ in air.
- ***Quantification of risk and economic valuation*:** Once the exposure concentrations and baseline incidences are known, one can characterize the risk quantitatively, for example, PM 2.5 risk can be characterized in terms of the number of additional emergency room visits expected based on the exposure concentration of PM 2.5, the baseline incidence of emergency room visits, and the C-R function for the relationship between PM 2.5 and emergency room visits. Somewhat analogously, expected reduction in biomass from ozone exposure could be estimated for crops. Additional cancer cases from toxic air pollutants

[10] For further information see www.epa.gov/ttn/atw/hapindex.html, U.S. EPA Technology Transfer Network Air Toxics Website, (correct as of October 15, 2004), which is based on EPA's Health and Environmental Effects Profile for Formaldehyde (EPA, 1993) and EPA's Integrated Risk Information System (IRIS)

can be estimated using unit risk factors (URFs) for various toxics and the corresponding exposure concentrations. This step includes quantifying the uncertainty in risk estimates. Beyond estimating the additional incidence of each ecological or human health endpoint for different pollutants, depending on the management goals, the assessment can be summarized by assessing the benefits of reducing the pollutant exposures by a specified concentration in a given region, using either an abstract measure of health improvement, such as quality adjusted life years (QALYs) or monetizing benefits, as in willingness to pay (WTP) approaches (J. Hammitt, 2000). The latter is of course necessary for cost-benefit calculations.

In the following we compare the risks of PM2.5, ozone and air toxics in Pensacola, according to the risk assessment pieces described above.

2.2.2 Comparing the risks of air pollutants in Pensacola, FL

At the most basic level, hazard identification for air pollutants involves categorizing and labeling pollutants. While ozone is a molecule, both air toxics and particulate matter (PM2.5 here) are readily recognized as composite categories, with minor overlap. For example mercury is categorized as an air toxic, but it may also be manifest in the composition of PM. Another example is the case of diesel particulate matter, which was included as a toxic in the 1996 National Air Toxics Assessment. Here, we specifically exclude mercury from any analysis as the carcinogenicity data for mercury in the IRIS database is inadequate. Diesel particulate matter is addressed only in the PM analysis – i.e. we do not include diesel PM as an air toxic. Air toxics (or Hazardous Air Pollutants – HAPs) are classified as such based on the hazard they pose to human health, whereas particulate matter is defined by its physical size and state. To further complicate matters, there are not only overlaps between these categories, but also dependencies between them; for example benzene, a HAP, is also a volatile organic compound (VOC) and precursor to ozone.

The scope and focus of any comparison is determined by the identification of the target hazards; this and the related choice of health endpoints to assess are key for comparisons that rely on expert or lay judgment of risk. Unfamiliar terms may be meaningless to or misinterpreted by non-expert audiences, who are likely to have a general, less specific understanding of air pollution (Bostrom and Fischhoff, 2001). A recent survey elicited perceptions of "the quality of air" in Pensacola,[11] but risk comparisons between more specific air pollutants based on either expert or lay perceptions would require investigating if and how these distinguish pollutants, which is beyond the scope of this paper. The categorizations used in this case study stemmed from early discussions with PERCH partners and sponsors.

[11] UWF/Listener Group Panel Survey 0001, November 2003, Unpublished, Escambia County residents perceived their air as worse than residents in neighboring Santa Rosa County. Survey results available at http://uwf.edu/panel/IssuesCoveredBySurvey0001.cfm#Env (accessed October 23, 2004).

Comparison between Ozone and PM

Mass emissions are often measured and compared, as exemplified by the Toxic Release Inventory and reports of trends based on it. For example, EPA reported in June, 2004 that industries "that have reported to TRI since its inception have reduced on- and off-site disposal or other releases of TRI chemicals by 49% or 1.59 billion pounds."[12] However, comparison of mass emissions can be uninformative with respect to risk. Toxicity-weighted emissions have been suggested as an alternative and are widely used for comparisons (Horvath et al., 1995). Relative risks can also be derived from ambient concentration data. Where there are ambient air quality standards, whether the pollutant concentration violates or meets these is a simple comparison that relies on the ambient concentration standard as a basis for judging risk. The following tables (Table 18 and Table 19) show the air quality data for Escambia and Santa Rosa counties for recent periods and how they compare with National Ambient Air Quality Standards (NAAQS). Comparison of annual average concentrations of PM and ozone show that it is likely that both counties would meet both the ozone and the PM NAAQS. Thus this comparison is uninformative regarding the relative risks of PM and ozone in Pensacola.

Table 18. Eight-hour ozone design values (ppbv) in the Pensacola, FL area (FL DEP 2003).

		3 yr avg of annual 4th highest daily 8-hour average ozone (ppbv)	
County	**Site / Standard**	**1999-2001**	**2000-2002**
Escambia	Ellyson Industrial Park (AIRS ID # A033-0004)	80	78
	Warrington Elementary (AIRS ID # A033-0024)	85	82
	Naval Air Station (AIRS ID # A033-0018)	88	84
Santa Rosa	Navarre Beach Middle School (AIRS ID # L113-0014)	NA	84
	NAAQS	85	

Table 19. PM2.5 annual averages ($\mu g/m^3$) and 98th percentile daily observations ($\mu g/m^3$), 2000-2002 (FL DEP 2003)

		Annual average			**98th percentile**		
County	**Site / Standard**	**2000**	**2001**	**2002**	**2000**	**2001**	**2002**
Escambia	Ellyson Industrial Park (3-day filter)	11.4	11.4	11.0	13.8	22.0	22.4
	Ellyson Industrial Park (continuous)	15.0	12.3	11.5	NA	25.0	22.0
Santa Rosa	Gulf Breeze (3-day filter)	NA	NA	9.3	NA	NA	18.9
	NAAQS	15.0			65		

The above tables represent average concentrations aggregated over a year, and do not describe daily variability in concentrations, which would allow assessment of acute versus chronic risks. To identify variability and facilitate comparisons between ozone

[12] U.S. EPA "TRI and factors to consider when using TRI data," http://www.epa.gov/tri/tridata/tri02/index.htm (accessed October 23, 2004).

and PM we use the daily Air Quality index, which was introduced in 1999 as the successor to the 1976 Pollutant Standards index.

Based on short-term and long-term NAAQS, EPA calculates AQI values for each criteria pollutant such that a value of 100 corresponds to the ambient concentrations of that pollutant that represents health protection, based on the national air quality standard, which is health-based. A description of possible health impacts and the population at risk has been developed for each range of AQI. As an example, the AQI ranges and cautionary statements for particulate matter are shown in Table 20. Thus AQI is an ordinal measure of risk from air pollution based on ambient concentrations.

Table 20. Air Quality Index (AQI) Description for PM

Index Values	**PM2.5 concentration ($\mu g/m^3$)**	**Descriptor**	**Cautionary Statement**
0 – 50	0-15.4	Good	None
51 - 100	15.5-40.4	Moderate	None
101 - 150	40.5-65.4	Unhealthy for Sensitive Groups	People with respiratory or heart disease, the elderly, and children should limit prolonged exertion.
151 - 200	65.5-150.4	Unhealthy	People with respiratory or heart disease, the elderly, and children should avoid prolonged exertion; everyone else should limit prolonged exertion.
201 - 300	150.5-250.4	Very Unhealthy	People with respiratory or heart disease, the elderly, and children should avoid any outdoor activity; everyone else should avoid prolonged exertion.
301 - 400	250.5-350.4	Hazardous	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly, and children should remain indoors.
401 - 500	350.5-500.4	Hazardous	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly, and children should remain indoors.

To compare the relative risks of ozone and PM2.5 based on the AQI, we categorized the number of days the AQI would fall into various categories for ozone and PM2.5 during the last three years in the Pensacola region. We calculated the AQI for the three most recent years for which the data were available for Escambia county (Ellyson Industrial Park monitoring station). Table 21 shows the results of these analyses.

Table 21. Comparison of AQI between Ozone and PM2.5 for Ellyson Industrial Park (the values indicate percentage number of days falling within the AQI range).

AQI Range	**AQI Description**	**1999[1]**		**2000[2]**		**2001[3]**	
		8-hr Ozone	**PM2.5**	**8-hr Ozone**	**PM2.5**	**8-hr Ozone**	**PM2.5**
0-50	Good	89.1	59.8	85.3	62.4	94.2	77.4
51-100	Moderate	10.3	40.2	13.8	36.8	5.8	22.6
101-150	Unhealthy for Sensitive Groups	0.6	0	0.6	0.8	0	0
151-200	Unhealthy	0	0	0.3	0	0	0
201-300	Very Unhealthy	0	0	0	0	0	0
301-400	Hazardous	0	0	0	0	0	0
401-500	Hazardous	0	0	0	0	0	0

[1]Ozone results are based on data for 359 days and PM2.5 results are based on 112 days representing all 12 months
[2]Ozone results are based on data for 355 days and PM2.5 results are based on 117 days representing all 12 months
[3]Ozone results are based on data for 364 days and PM2.5 results are based on 115 days representing all 12 months

In all three years, PM 2.5 fell into a riskier range, the "moderate" category, more often than ozone. While this analysis doesn't support definitive conclusions about which pollutant – ozone or PM2.5 – is worse, PM2.5 appears riskier than ozone in Escambia County by this yardstick.

Assessment of Air Toxics

Air toxics can be compared in terms of mass emissions, toxicity-weighted emissions, or health end-points based on available data from the National Air Toxics Assessment (NATA) conducted by EPA in 1996, and EPA's Risk Screening Environmental Indicators (RSEI) modeling effort. NATA assessed cancer and non-cancer risks from 33 air pollutants at a census tract level for the entire United States. Toxicity weights, however, are only available for 23 of these from RSEI. Data on emissions and excess cancer risks from each of these pollutants were obtained for Escambia County in which Pensacola is located.

The first comparison below is of mass emissions of the 23 air toxics in Escambia. Figure 1 shows that of these, benzene, followed by formaldehyde and acetaldehyde, have the highest annual emissions in Escambia. A more meaningful comparison is of toxicity-weighted emissions of these 23 pollutants. The weighting here relies on the cancer-toxicity values[13] that EPA uses in their Risk Screening Environmental Indicators (RSEI) model. EPA derives these toxicity-weights from a variety of sources such as the Integrated Risk Information System and Office of Pesticide Program's Toxicity Tracking Reports. [14] As Figure 2 shows, 1,3-butadiene, chromium compounds, and formaldehyde are the top three pollutants in terms of toxicity-weighed emissions. As one might expect, this ranking differs from that for mass emissions in Figure 1.

[13] EPA lists cancer toxicity weights for several toxics in its Technical Appendix A to the methodology document of Risk Screening Environmental Indicators (RSEI) software.
[14] See http://www.epa.gov/opptintr/rsei/faqs.html for more details

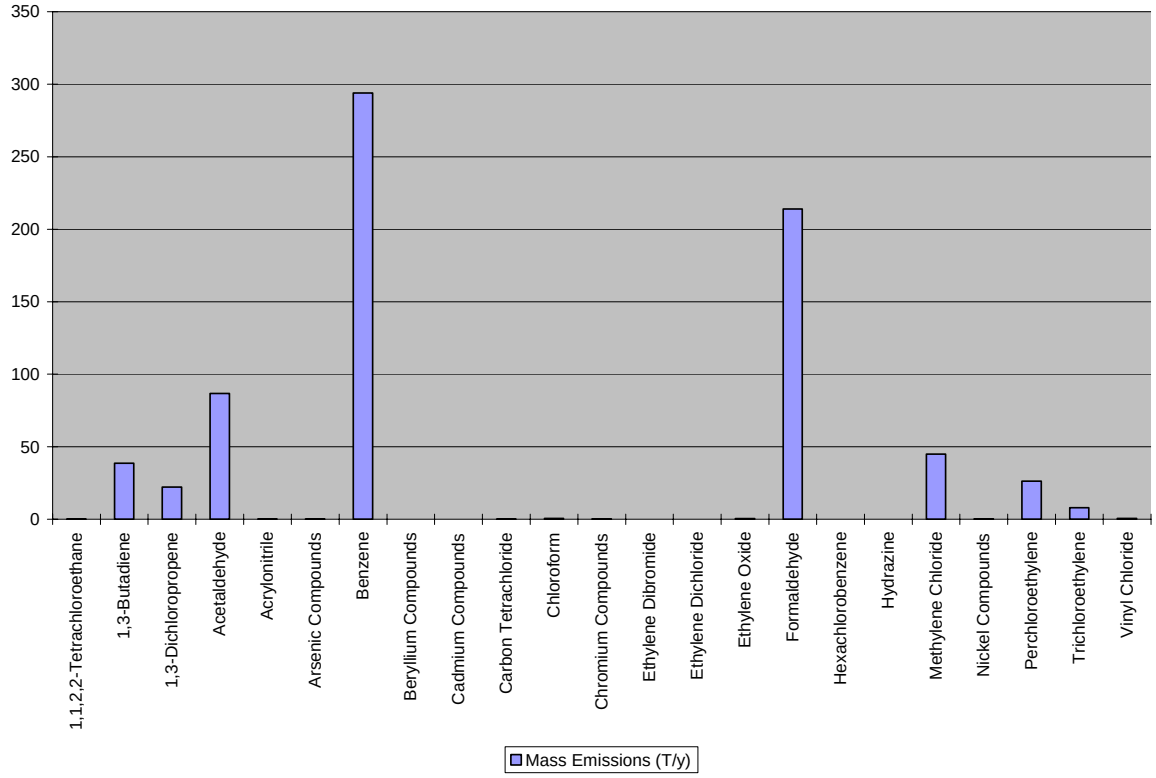

Figure 1. Mass Emissions of Air Toxics in Escambia

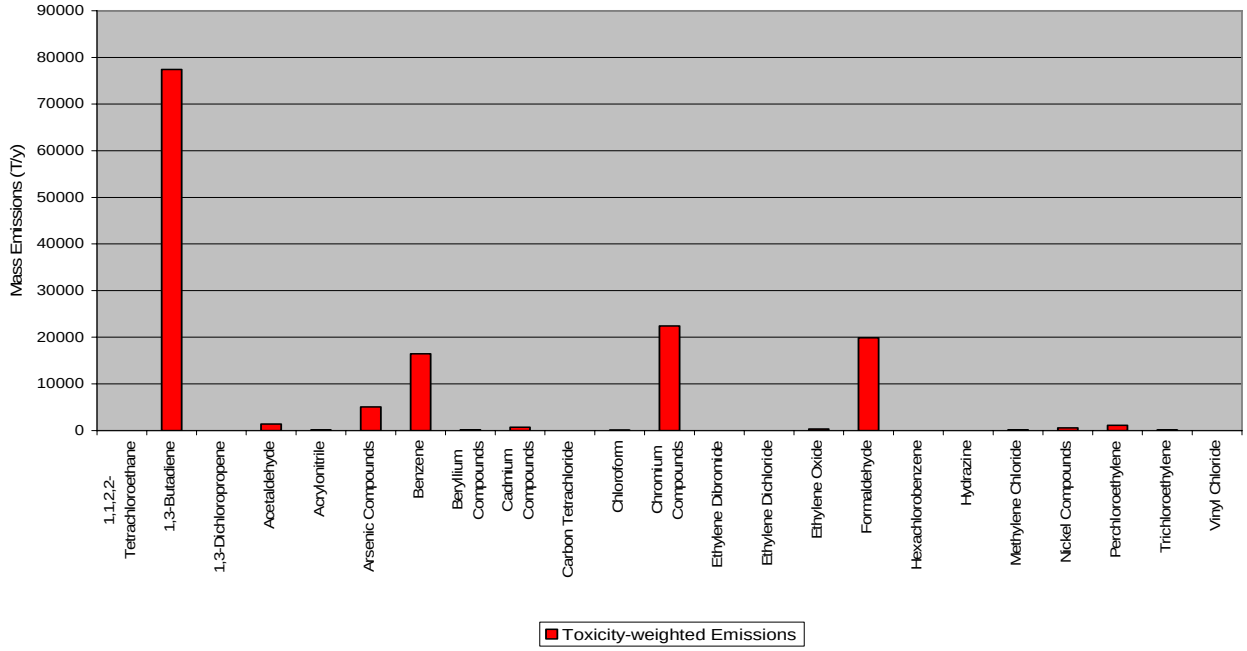

Figure 2. Toxicity-weighted Emissions of Air Toxics in Escambia

Toxics are of concern primarily due to the excess cancer risks they pose, although they also cause other health effects, as mentioned above. Figure 3 shows the excess

lifetime cancer risks of air toxics in Escambia County, based on inhalation unit risk estimates and exposures from NATA. Formaldehyde, carbon tetrachloride, and benzene top this list. This order differs from that based on toxicity-weighted emissions although the toxicity-weights are linearly related to inhalation unit risks (EPA, 2004d). The key difference between these two analyses is that lifetime cancer risk takes into account modeled exposures, whereas toxicity-weighted emissions are just that, without accounting for exposure. The toxicity-weights indicate the relative toxic potential of various air toxics. These weights do not, however, take into account the differences in dispersion across these pollutants after they are emitted into air. The dispersion depends on the physico-chemical properties of these toxics as well as the meteorological conditions and therefore emissions with similar toxic potential could end up with different exposure concentrations at the receptors.

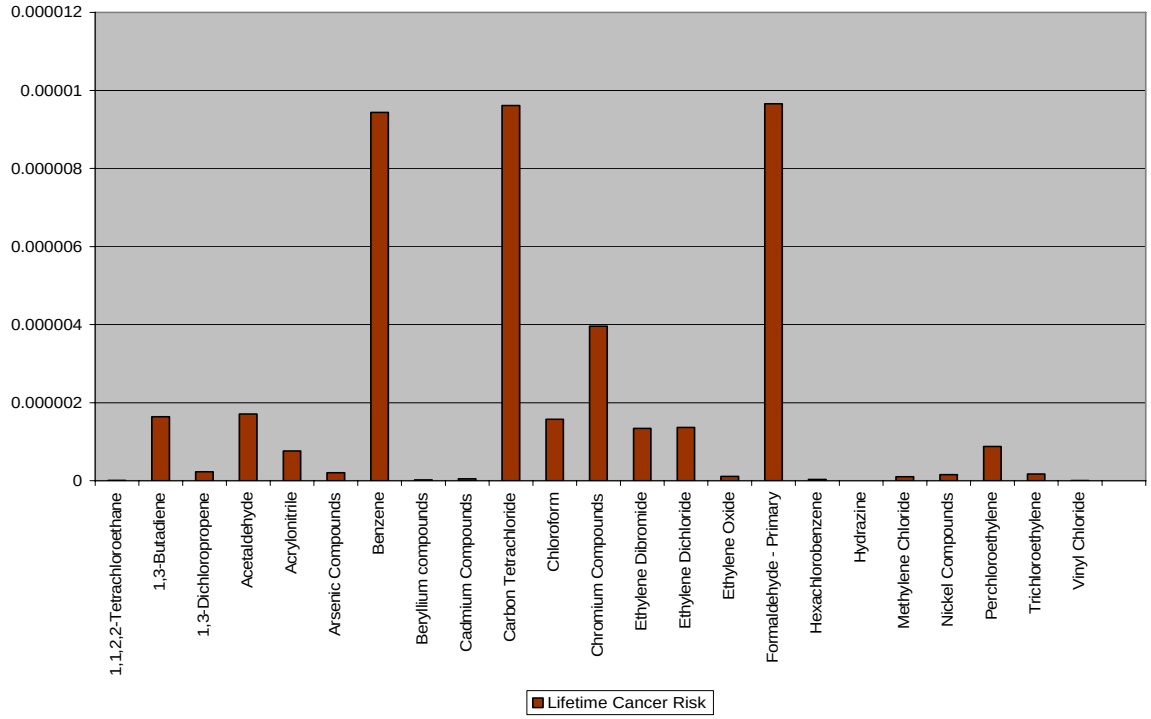

Figure 3. Comparison of Cancer Risk from Air Toxics in Escambia

The other possible explanation for the difference in the two rankings is the consistency of data used in the two assessments. For example, as explained earlier, the toxicity-weights applied to emissions are typically derived from the inhalation unit risks of the chemicals. In our analysis, we found that these values are not derived consistently across pollutants. In our case, the toxicity-weight derived for 1,3-butadiene from inhalation unit risk used in NATA assessment was 285 while EPA uses 2000 in its RSEI modeling – an order of magnitude difference! While our conclusion that the rankings based on toxicity-weights and lifetime cancer risks still hold, these inconsistencies in data could also affect the rankings depending on the choice of comparison method.

Total excess lifetime cancer risk from air toxics in Escambia was calculated in NATA as the sum of cancer risks from each of 33 pollutants assessed. Total cancer risk in Escambia County in 1996 on this basis was 42 in a million.

Comparison across PM2.5, Ozone, and Air Toxics

Unlike criteria pollutants, air toxics are not subjected to ambient standards. Comparing specific health endpoints is not straight-forward, because the health endpoints for PM2.5, ozone and air toxics differ, ranging from asthma and cardiovascular problems to cancer and neurological deficits. For these reasons and others, economists have proposed summary measures, such as Quality Adjusted Life Years (QALYs), which is a health index, and Willingness to Pay (WTP), which is a monetized measure of value. QALY is a health index extensively used in health economics literature to assess the effectiveness of medical interventions. Each health state in an individual's health profile is assigned a weight (called health related quality of life (HRQL) that varies between 0 and 1) to get an aggregate measure of health outcomes as the weighted sum of life years under each health state (J. K. Hammitt, 2002). Such summary measures are widely used to make such value judgments explicit and useful for comparisons and priority-setting, though they each have their problems (Krupnik, 2004).

To compare across PM2.5, ozone and toxics, we assessed the relative benefits of achieving specific comparable risk reduction goals for the three pollutants – to a safe or good level. The analysis relies on the following risk reduction goals for the three pollutants:

- **PM2.5**: Maintaining the daily average PM2.5 in the "good" range as defined by the AQI. This is defined as maintaining the daily average PM2.5 below 15.4 $\mu g/m^3$ for all the days in any given year.
- **Ozone**: Maintaining the daily average 8-hr ozone in the "good" range as defined by the AQI. This is defined as maintaining the daily average 8-hr ozone below 64 ppb for all the days in any given year.
- **Air Toxics**: Reducing the lifetime cancer risk in Escambia from 1996 levels of 42 in a million to the EPA guideline of 1 in a million risk (EPA, 2004e).

In this analysis coefficients relating changes in ozone concentrations and PM concentrations to health benefits were adopted from Shih, Bergin, Krupnick, & Russell, (2003), as developed from an updated version of the Tracking and Analysis Framework (Bloyd, 1996). TAF derives these coefficients from concentration-health response functions and willingness to pay values from hedonic pricing and contingent valuation studies for mortality reductions and a number of other morbidity endpoints (Bloyd, 1996). Table 22 shows low, medium, and high estimates of benefit values in 2000 dollars.

Table 22. Benefit Coefficients for Ozone and PM2.5

	Ozone ($/day/ppb/person)	**PM2.5 ($/day/µg/m3/person)**
Low	0.0018	0.047
Medium	0.0043	0.338
High	0.0170	0.864

Benefits of maintaining "good" air quality for PM2.5 and ozone in Escambia are calculated as an annual benefit for each of the three years 1999, 2000, and 2001. Daily average concentrations for 365 days are used to estimate the benefit of maintaining the air quality below the cutoff concentration for "good" air quality. If the concentration on a given day is already below the cutoff (15.4 $\mu g/m^3$), the benefit is zero. The aggregated benefits over 365 days represent the annual benefit of maintaining "good" air quality.

For air toxics, the risk reduction goal was to reduce from the 1996 lifetime cancer risk of 42 in 1 million to 1 in a million. A value of statistical life (VSL) of $6 million produces an annual benefit of $3.50 per person for reducing the cancer risk. Estimates of VSL, which is an estimate of society's willingness to pay for mortality risk reduction, range from $1 million to over $20 million (Mrozek and Taylor, 2002; EPA, 2004c; Viscusi and Aldy, 2003), which correspond to annual benefits of $0.60 to over $12. Six million is close to the $6.2 million commonly used by EPA based on its 2000 guidelines (USEPA 2000). Table 23 shows the benefits (in $ per person per year) of the risk reductions for all the three pollutants based on a VSL of $6 million.

Table 23. Benefit comparison of PM2.5, Ozone and Air Toxics

Pollutant	**1999**			**2000**			**2001**			**Average***		
	L	M	H	L	M	H	L	M	H	L	M	H
$PM_{2.5}$	36	87	670	37	90	688	14	33	83	14	34	257
Ozone	1.7	4.1	16.3	2.7	6.6	26	0.7	1.8	7.0	0.3	0.7	2.8
Air Toxics	3.5**											

All values are in $ per person per year
Notes: Ozone and PM2.5 data are for Ellyson Industrial Park Monitoring Station in Escambia County
* Average indicates daily average of three years (1999-2001)
**Data for air toxics is from the National Air Toxics Assessment (NATA), 1996

In Table 23, despite huge differences in benefits across different years, the general ranking seems to hold across years. Maintaining "good" PM2.5 is likely to produce greater benefits than achieving comparable risk reduction goals for ozone or air toxics. These comparisons also give an approximation of the relative size of benefits to be attained. Using this approach, it appears that investing in PM2.5 is likely to result in greater benefits to Escambia than investing in risk reduction for ozone and air toxics.

2.2.3 Dimensions of air pollution risk comparisons

Figure 4 places the comparisons above into a general analytical framework. The overall objective of these comparisons was to prioritize future investments in risk reduction for air pollutants. As is evident, comparisons can be made at every step in the risk assessment process, as well as at varying levels of quantification.

Assessing whether or not Pensacola air quality was in attainment with NAAQS - regulatory compliance – is near the origin (upper left corner of the matrix). Given that the standards are specified in terms of ambient concentrations, we compared the monitored ambient concentrations in Pensacola with the standards. The use of the air quality index to understand the relative risks of PM2.5 and ozone in Pensacola is based on the NAAQS,

but represents more explicitly the association of potential health risks with different ambient concentrations of criteria pollutants.

Figure 4. Comparison Matrix for Pensacola Case Study

Measurement Endpoint	**Categorical**	**Ordinal**	**Quantitative**
Emissions	PM2.5, ozone, and air toxics were identified as the pollutants of concern for Pensacola based on perceptions of various stakeholders		Twenty-three air toxics were compared based on mass emissions as well as toxicity-weighted emissions. The two methods produced different rankings for risk. Benzene topped in terms of mass emissions and 1,3-Butadiene topped in terms of toxicity-weighted emissions
Ambient Concentrations		PM2.5 and ozone both were found to be within NAAQS. AQI based on ozone and PM2.5 shows higher percentage of days in "moderate" air quality zone for PM2.5 than ozone	
Ecological and human health Endpoints			Twenty-three air toxics were compared based on their lifetime cancer risk. Formaldehyde poses greatest cancer risk followed by carbon tetrachloride and benzene.
Summary endpoints			Compared economic benefits of achieving human health risk reduction goals for PM2.5, ozone, and air toxics. The benefits from PM2.5 risk reduction appears to be highest among the three pollutants.

Comparisons based on National Air Toxics Assessment (NATA) data were made at three levels: mass emissions, toxicity-weighted emissions, and cancer risks. All three comparisons produced different priority lists for air toxics. For many regulatory goals, a mass emission comparison might be easier and more appropriate, leaving the risk reductions implicit rather than explicit. According to our analysis, formaldehyde is the air toxic that poses the greatest cancer risk in Escambia county. Obviously if the goal of comparison had instead been to compare emissions of formaldehyde, over sources or time, comparison of mass emissions would suffice.

To prioritize among PM2.5, ozone, and air toxics requires a common metric. For the Pensacola case, this comparison was made in terms of the relative economic benefits of achieving comparable risk reduction goals for each of the three pollutants. The benefit analysis of the risk reduction for the three pollutants involved benefit transfer method in which benefit coefficients generated elsewhere were used to assess benefits for Pensacola.

The uncertainties involved in benefit transfer are now well-documented (Brouwer, 2000). Generating site-specific concentration-response functions for various health endpoints and willingness to pay (WTP) values for health improvements would have reduced uncertainty considerably, but generating such site-specific details are extremely expensive. Thus, in addition to the goals of analysis, costs of analyses drives the analytical method of choice for risk comparisons. Cost of analysis also constrains the comprehensiveness of analysis and thus affects the level of uncertainty in the results. This case study of Pensacola air quality assessment relied on existing publicly available data and information, which constrained the analysis in several ways. This constraint is clearly reflected in the air toxics assessment, as the latest publicly available data on air toxics are from 1996.

In conclusion, two policy implications emerge from the analyses. First, it appears that $PM_{2.5}$ air pollutants pose a greater risk to Pensacola than do ozone or air toxics, at least judging from inhalation risks. Second, rankings may differ depending on the assessment endpoint compared. The prioritization based on toxicity-weighted emissions differed from that based on excess lifetime cancer risks from toxics; this difference is probably attributable to differences in how the pollutants disperse in air after they are emitted as well as on the consistency of application of various risk factors.

References

Bell, M. L. ; A. McDermott; S. L. Zeger; J. M. Samet; F. Dominici; "Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000;" JAMA. 2004;292:2372-2378.

Bloyd, C. et al. (1996). Tracking and analysis Framework (TAF) Model Documentation and Users guide. Argonne National Laboratory

Bostrom, A., & Fischhoff, B. (2001). Communicating health risks of global climate change. In G. Böhm, J. Nerb, T. McDaniels & H. Spada (Eds.), Environmental risks: Perception, evaluation and management (pp. 31-56). Amsterdam: JAI

Brouwer, R. (2000). Environmental value transfer: State of the art and future prospects. Ecological Economics, 32(1), 137-152.

EPA. (1996). Regulatory Impact Analysis for Proposed Particulate Matter National Ambient Air Quality Standard. Office of Air Quality Planning and Standards, Research Triangle Park, NC.

EPA. (1998). Guidelines for ecological risk assessment. Risk Assessment Forum, U.S. Environmental Protection Agency (EPA/630/R-95/002F), Washington D.C: US EPA .

EPA. (2001a). Office of Research and Development Strategic Plan (No. EPA/600/R-01/003). Washington, DC: US EPA.

EPA. (2002). Proposed Methodology for Particulate Matter Risk Analyses for Selected Urban Areas. Washington, DC: Office of Air Quality Planning and Standards, USEPA.

EPA. (2003a). Air Quality Index: A Guide to Air Quality and Your Health (No. EPA-454/K-03-002). Washington, DC: Office of Air and Radiation, US EPA.

EPA. (2004b). Human Exposure Modeling - Hazardous Air Pollutant Exposure Model. Retrieved 11 September 2004, from http://www.epa.gov/ttn/fera/human_hapem.html

EPA. (2004c). Value of Statistical Life Analysis and Environmental Policy: A White Paper by Chris Dockins, Kelly Maguire, Nathalie Simon, Melonie Sullivan, National Center for Environmental Economics, U.S. Environmental Protection Agency, Washington, D.C: US EPA Accessed October 20, 2004 at http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0483-01.pdf/$File/EE-0483-01.pdf

EPA. (2004d). EPA's Risk-Screening Environmental Indicators (RSEI) Chronic Human Health Methodology RSEI Version 2.1, Office of Pollution Prevention and Toxics, United States Environmental Protection Agency, Washington, DC 20460; January 2004. http://www.epa.gov/opptintr/rsei/docs/method2004.pdf

EPA. (2004e). Frequently Asked Questions, Technology Transfer Network: National Air Toxics Assessment. Accessed from http://www.epa.gov/ttn/atw/nata/natsafaq.html#B3 on 23 October, 2004

Feldman, D. L., Hanahan, R. A., & Perhac, R. (1999). Environmental Priority-Setting through Comparative Risk Assessment. Environmental Management, 23(4), 483-493.

Gutenson, D. (1997). Comparative risk: What makes a successful project? Duke Environmental Law & Policy Forum, 8(1), 69-80.

Hammitt, J. (2000). Valuing mortality risk: Theory and practice. Environmental Science & Technology, 34, 1396-1400.

Hammitt, J. K. (2002). QALYs Versus WTP. Risk Analysis, 22(5), 985-1001.

Jhih-Shyang Shih, M. Bergin, A. J. Krupnick, A. G. Russell, " Source-Receptor Matrices and Cost-Benefit Analysis with Meteoroligal Variability for Ambient Ozone and Fine Particulates"

Jones, K., & Klein, H. (1999). Lessons from 12 years of comparative risk projects. Annual Review of Public Health, 20, 159-172.

Kent, C. W., & Allen, F. W. (1994). An overview of risk-based priority setting at EPA. In A. M. Finkel & D. Golding (Eds.), Worst Things First? The Debate over Risk-based National Environmental Priorities (pp. 348). Washington, DC: Resources for the Future.

Konisky, D. M. (2001). Over a decade of comparative risk analysis: A review of the human health rankings. Risk: Health, Safety, and Environment, 12, 41-58.

McConnell, R. , K. Berhane, F. Gilliland, S. J. London, T. Islam, W. J. Gauderman, E. Avol, H. G. Margolis, and J. M. Peters, "Asthma in exercising children exposed to ozone: a cohort study," The Lancet, 359: 386-391, 2002.

Morgenstern, R. D., Shih, J.-S., & Sessions, S. L. (2000). Comparative risk assessment: an international comparison of methodologies and results. Journal of Hazardous Materials, 78, 19-39.

NRC. (1983). Risk assessment in the Federal government: Managing the process. Washington, DC: National Academy Press.

Patton, D. E., & Huggett, R. J. (2003). The risk assessment paradigm as a blueprint for environmental research. Human and Ecological Risk Assessment, 9, 1337-1348.

Perhac, R. M. (1998). Comparative risk assessment: Where does the public fit in? Science, Technology, & Human Values, 23(2), 221-241.

Peters A., D. W. Dockery, J. E. Muller, and M. A. Mittleman, "Increased Particulate Air Pollution and the Triggering of Myocardial Infarction," Circulation,103:2810-2815, 2001.

Pope, C. A., R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito, and G. D. Thurston, "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution," JAMA, 287:1132-1141, 2002.

Ritz, B., F. Yu, S. Fruin, G. Chapa, G. M. Shaw, and J. A. Harris, "Ambient Air Pollution and Risk of Birth Defects in Southern California," Am J Epidemiol, 155: 17-25, 2002

Russell, M., & Gruber, M. (1987). Risk assessment in environmental policy-making. Science, 236, 286-290.

Shih, J.-S., Bergin, S. M., Krupnick, A. J., & Russell, A. G. (2003). Controlling Ozone and Fine Particulates: Cost Benefit Analysis with Meteorological Variability (Discussion Paper No. 03-55). Washington, DC: Resources for the Future.

Swaney, J. A. (1996). Comparative risk analysis: Limitations and opportunities. Journal of Economic Issues, XXX(2), 463-473.

Tolbert, PE, JA Mulholland, DL MacIntosh, F Xu, D Daniels, OJ Devine, BP Carlin, M Klein, J Dorley, AJ Butler, DF Nordenberg, H Frumkin, PB Ryan and MC White, "Air quality and pediatric emergency room visits for asthma in Atlanta, Georgia, USA," American Journal of Epidemiology, Vol 151, Issue 8 798-810.

United States Environmental Protection Agency, 1999, " The Benefits and Costs of the Clean Air Act 1990 to 2010", Report to congress EPA draft for Tier 2 vehicle Emissions

Viscusi, W. Kip and Joseph E. Aldy. 2003. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Journal of Risk and Uncertainty 27(1): 5-76.

3. Other Studies

3.1 Review of the Gulf Coast Ozone Study

In this subsection we review and comment on the work done during the Gulf Coast Ozone Study (GCOS) and also during the West Florida Ozone Study (WFOS) as described in documents issued by the consulting firm of Systems Application International (SAI):

(1) "Gulf Coast Ozone Study (GCOS) Modeling Analysis: Phase II Methods and Results" of July 2001;
(2) "West Florida Ozone Study (WFOS) Data Analysis and Modeling Study" of January 2004, and
(3) "Conceptual Description of 8-Hour Ozone in the Pensacola Area and Along the Florida Panhandle" of January 2004.

The WFOS represents an extension of the databases and modeling tools developed for the GCOS. In the WFOS the emphasis was concentrated in Pensacola and other areas located along the Florida panhandle. The GCOS focuses, in addition to the Pensacola area, on other eastern Gulf Coast areas that include Mobile, Pascagoula, Biloxi, Port Bienville, New Orleans and Baton Rouge. Since the WFOS represents an update and an extension relative to the GCOS, in this evaluation we will emphasize the two WFOS documents identified above. Our analysis is divided in two parts: observation-based methods and modeling analysis.

3.1.1 Observation-based Methods

In this subsection we describe and evaluate the data analysis done by SAI using observations, emission estimates, and model results as described in the report "Conceptual Description of 8-Hour Ozone in the Pensacola Area and Along the Florida Panhandle". The full WFOS modeling analysis will be reviewed under subsection **3.1.2 Modeling Analysis**.

<u>1. Ozone data</u> – The period analyzed covered seven years (1996-2002) during the months of April to October. Ozone data from 24 AIRS monitoring stations were used. In addition, for the period 1999-2002, the four AIRS stations within the Pensacola area were increased by the two stations from the SEARCH program. The ozone data analysis included a regional (several areas in and around West Florida) and a local (specific to the Pensacola area) analysis. In addition to Pensacola, the regional analysis included Tallahassee, Panama City, Holmes County, Mobile, New Orleans, and the Mississippi Gulf Coast. Graphical comparisons and correlation analysis were made to compare the different regions. The local analysis included a comparison between coastal and inland sites.

Comment: The ozone data analysis was adequate for the purpose of the study.

2. Meteorological data – A review of weather maps for the period 1996-2003 was conducted to individualize regional-scale conditions that are conducive to high ozone concentrations. For coastal areas, the sea breeze circulation (also referred to as the "gulf breeze") plays an important role with regard to ozone values. Consequently, special consideration was given to the effects of the gulf breeze in the Pensacola area. A wind-rose analysis was conducted to correlate wind patterns with exceedance and non-exceedance ozone days. The wind-rose data was analyzed together with the gulf-breeze circulation and with data from upper-level winds. In addition, a Classification and Regression Tree (CART) analysis was conducted to study the relative importance of air quality and meteorological data on ozone concentrations in Pensacola. The air quality data included previous-day ozone for Pensacola, Mobile and Mississippi coastal counties. The meteorological data included surface meteorological parameters from Pensacola and upper air variables from Tallahassee.

Comment: The meteorological data analysis was thoroughly done.

3. Emissions data – The anthropogenic and biogenic emissions of ozone precursors (NO_x, VOC, and CO) in the Gulf Coast area for a typical weekday were analyzed. Anthropogenic emissions included precursors from motor vehicles, non-road (that includes railroad, marine vessels, aircraft and other engine-driven devices), area, low-level point and elevated point sources. The ozone precursor emissions were compared by state and by coastal counties. However, no information about the source of the emission inventory was given. Detailed emission inventory information is reviewed under the section "Modeling Analysis."

Comment: The emission data analysis was adequate for the purpose of the study.

4. Design value analysis – An analysis of the 8-hour ozone NAAQS design values for Pensacola was conducted for the period 1996-2003. The analysis examined the effects of meteorology on design values for Pensacola. The surface meteorological variables used were: maximum and minimum ambient temperature, surface pressure and relative humidity at noon, rainfall, vector wind speed and wind direction for three time intervals, and wind persistence. Wind persistence was used as an indicator of a gulf breeze. It was defined as the ratio of vector to scalar surface wind speed and a value less than 0.5 was taken as an indicator of a gulf breeze. The upper-air meteorological variables used were the morning, afternoon, and previous-day afternoon wind speeds and directions from Slidell, LA and Tallahassee, FL. The meteorological variables described above were compared with three yearly ozone-related values, namely, number of exceedances per year, fourth highest annual 8-hour ozone value, and design value. Using the CART technique, an algorithm was designed to compute design values that are less sensitive to yearly meteorological variation. The meteorologically adjusted values were compared with the observation-based design values for stability. Ozone values obtained from the design value analysis were used in the WFOS modeling analysis as the basis of the modeled attainment test.

Comment: The design value analysis was well done and the meteorologically adjusted design values represent an important improvement over the observation-based design values.

5. Process-Based analysis – This analysis was based on five multi-day modeling simulations using the UAM-V modeling system. During the executing of a given simulation, information is saved that can be used to assess the individual contributions of the different physical and chemical processes to the species concentrations. This is performed for each species, and for each grid cell within the modeling domain. The processes involved in this analysis are: chemistry, dry deposition, vertical advection, horizontal advection and diffusion, vertical diffusion, and the addition of material from the plume submodule. Two areas which are in proximity to each other were analyzed: Pensacola and Bay Co. The Pensacola area was divided into three parts representing offshore, coastal, and inland regimes. Two vertical arrangements of grid cells were considered, which consisted of (a) the surface layer, and (b) the total vertical column. Ozone concentrations were averaged together using different space and time scales and plots were used to display the contributions to ozone concentration due to the different physical mechanisms. Exceedance and non-exceedance days were contrasted as a function of processes.

Comment: The process-based analysis is a useful tool that provides further insight into the physical and chemical mechanisms that contribute to ozone concentrations. It should be noted however, that since the process-based analysis is based on model simulations, the findings from this analysis are only as good as the model's results.

6. Trajectory analysis - Backward trajectories were calculated using the UAM-V wind fields for several days within the five multi-day simulation periods. Two model layers were selected, (a) the surface layer, to represent transport close to the ground, and (b) layer 6 (at 1375 meters above sea level) to represent upper-level transport. Even though the pollutant transport trajectories in the model are three-dimensional, the trajectories used in this analysis are two-dimensional since they are confined to a specific model-layer. The trajectories were calculated for 24 hours, backward from the locations of the NAS Pensacola and Ellyson ozone monitoring sites, and from the time of the maximum one-hour ozone concentration at either site.

Comment: The trajectory analysis is a useful tool to identify the wind directions that are associated with ozone exceedances. However, since three-dimensional backward trajectories (e.g., like the ones provide by the NOAA READY site) were not included as part of the analysis, it is not possible to evaluate the quality of the UAM-V-based 2D trajectories.

7. WFOS modeling analysis – The results of this analysis were based on the five WFOS simulation periods. In addition to current-year simulations, two future years (2007 and 2009), and several future-year sensitivity simulations and control scenarios were done. The modeling database preparation and model performance evaluation are described in detail in the report summarizing the full WFOS modeling analysis. Since the WFOS

modeling analysis represents a relatively small subset of the full modeling report, it will not be repeated here. For more details, see subsection **3.1.2 Modeling Analysis**.

3.1.2 Modeling Analysis

This section describes and evaluates the modeling study done by SAI as described in the report "West Florida Ozone Study (WFOS) Data Analysis and Modeling Study".

1. Modeling System – The numerical model used is the Urban Airshed Model (UAM-V) Version 1.5. It is a variable-nested-grid photochemical model for regional- and urban-scale simulations. It includes several pre-processors: (a) EPS2.5, an emission system for preparation of emission inventories, (b) BEIS-2, a biogenic emission system for estimating biogenic emissions using land-use and crop data, (c) MM5, a mesosocale meteorological model for preparation of meteorological data, and (d) MOBILE6, a mobile emission system for estimating motor-vehicle emissions. Several tools were available for post-processing of output data including data reduction, visualization and to investigate strategies for ozone reduction.

Comment: This model is well suited for the WFOS study.

2. Simulation Periods – Five simulation periods were used. They included four episodes selected for the GCOS study and one new episode selected specifically for Pensacola. The simulation periods were selected in agreement with EPA guidance. A Classification and Regression Tree (CART) analysis was used to classify days according to meteorological and ozone conditions. Afterwards an optimization algorithm was used to select periods which represent the key meteorological condition identified by CART, together with the ozone design values for the area of interest.

Comment: The 42 days selected (five episodes) were a good mix of meteorological and ozone conditions that included exceedance and non-exceedance days, weekday and weekend days, and from four different months and four different years.

3. Emission Inventory Preparation – The emission inventory preparation consisted of a series of computer programs that transformed emission related information into an emission inventory for photochemical modeling. Emission data is usually organized at the county-level with annual or seasonal values. Some of the data was episode-specific, in particular hourly emission rates from power plants. Many emission data sources used for the WFOS inventories were updates and/or extensions of the data used for the GCOS inventories. The emission categories of point, area, non-road, biogenic, and on-road mobile were processed separately. The emission data from all categories were spatially and temporally allocated. All VOCs from all categories were chemically speciated into the Carbon Bond Mechanism. Spatial allocation was completed using different techniques. Point source emissions were directly assigned using geographic coordinates. Area and non-road mobile emissions were allocated using a combination of surrogates (e.g. population) and link locations. On-road mobile emissions were allocated using gridded roadways and population. Biogenic emissions were allocated using land-use

geographical data. Temporal allocation was done using default profiles provided with EPS2.5. The meteorological module MM5 provided estimates of temperature and solar radiation to compute day-specific emissions for biogenic and mobile sources (i.e. for the fraction of mobile emissions that are dependent on ambient environmental conditions, e.g. evaporative fuels).

Comment: The WFOS report provided detailed information about the emission inventory preparation. While more episode-specific emission data would be desirable, overall the emission inventory preparation was adequate for its use in photochemical modeling.

4. Meteorological Modeling and Input Preparation – The preparation of meteorological fields needed as input to the UAM-V were done using the meteorological model MM5. The meteorological data (observations) that are input to MM5 were obtained from the National Weather Service and NCAR. Output data from MM5 included hourly, gridded fields of temperature, wind, water vapor, atmospheric pressure, cloud cover, vertical exchange coefficients, and rainfall rate. The MM5 results were analyzed to asses the model's ability to represent the most important meteorological parameters that are more relevant for air quality modeling (i.e., surface temperatures and wind speeds and directions aloft and at the surface). Whenever possible, the MM5 results were compared with observed data.

Comment: The MM5 model is a well known meteorological model that has been used in several air quality modeling projects. It is well suited for the WFOS study.

5. Air Quality, Land Use, and Chemistry Input Preparation – Numerical models require initial and boundary conditions. UAM-V needs pollutant concentrations at the beginning of the simulation and ozone values in the lateral and top boundaries of the domain. In addition, land use data and ozone column values are required to compute biogenic emissions, deposition rates, albedo values, and photolysis rates. Initial conditions were computed using observed pollutant concentrations from the EPA Aerometric Information Retrieval System (AIRS). Observed data were interpolated to estimate initial conditions at the lowest level of the modeling domain. Surface layer values were extended to the second layer. For the third layer and above, EPA default values were used for all pollutants. The lateral and top boundary concentrations for all pollutants were assumed to be equal to the values used for initial conditions. Ozone values at the lateral boundaries and top were updated using average concentrations of layers contiguous to each boundary. Land use data were obtained from the U.S. Geological Service. Land use data are used to compute biogenic emissions, deposition rates, and albedo values. Total ozone column data were obtained from NASA satellites. Ozone column data together with albedo and haze values were used to compute photolysis rates. Chemical reaction rates were calculated using ambient temperatures.

Comment: The databases and techniques used for air quality, land use, and chemistry input preparation were adequate for its use in the UAM-V modeling system.

6. Model Performance Evaluation – Several techniques were used to evaluate the UAM-V performance. Statistical measures were used following EPA guidance. Diagnostic and sensitivity analysis are used to identify deficiencies in the inputs and to investigate the sensitivity of the model to changes in the inputs. Comparisons with observations were made and corrections were applied. Once a model simulation was considered acceptable, that simulation was called the "base case" simulation. As mentioned before, of the five simulation periods, four were previously selected for the GCOS study. For the WFOS study all five simulation periods were run by UAM-V and the performance of the base case simulations were analyzed. The diagnostic and sensitivity analyses were applied to initial and boundary conditions, to the emission inventory, and to the meteorological data. Process analysis was also used. The evaluation of the process analysis was done elsewhere and it will not be repeated here.

Comment: The model performance evaluation of the base case simulations showed that, in general, the UAM-V was able to reasonably reproduce the physical and chemical conditions leading to high ozone days. It should be noted however, that chemical comparisons (predictions versus observations) were made only for ozone concentrations. The WFOS report does not include any comparison with other chemical compounds (e.g. the important ozone precursors: VOCs and NOx). While US EPA modeling guidance does not require model validation beyond the usual measures of ozone performance, many studies have shown that it is possible for models of this type to generate ozone concentrations from aberrant precursor fields. Such an error, while not likely, could lead to different conclusions regarding causes and effects, and subsequent control strategies. These additional comparisons would improve confidence in all subsequent model results.

7. Future-Year Emission Inventory Preparation – To generate future-year emission inventories it is necessary to forecast the evolution of activity factors and the use of pollution controls. The future-year growth for area and non-road sources were based on the Bureau of Economic Analysis (BEA) projections of Gross State Products (GSP) and on BEA projections of employment. Energy adjustment factors were derived from the U.S. Department of Energy (DOE) publication "Annual Energy Outlook 1999". Future pollution controls were applied following EPA information. For on-road mobile sources information for future vehicle miles traveled (VMT), inspection and maintenance (I/M) programs, and Reid vapor pressure (RVP) were provided by some states. For other states VMT projections were provided by the Federal Highway Administration. While some states provided future year-growth and controls, most of the point source estimates were based on the BEA GSP and employment projections. Point source controls were obtained from the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. As with area sources, energy adjustment factors were derived from the DOE publication.

Comment: The databases and techniques used to obtain future-year emission inventories were adequate for utilization in near-future-year modeling simulations.

8. Future-Year Modeling – Several UAM-V runs were conducted for 2000 and for two future years (2007 and 2009). These runs included future-year baseline, assessment of source contributions, emission-sensitivity, and control-strategy simulations. The future-

year baseline simulations compared 8-hour-ozone-exceedance-population-exposure for 2007 relative to 2000. The assessment of source contribution simulations used the Ozone and Precursor Tagging Methodology (OPTM). This technique allows the assessment of contributions to ozone concentrations from selected emission source categories and/or from selected emission source regions. The emission-sensitivity simulations examined the relative effectiveness of different combinations of NO_x and VOC emission reductions. The control-strategy simulations compared the effect of local and regional control measures relative to base-case scenarios.

Comment: The future-year modeling exercise was well planned and thoroughly done. It provides useful information upon which air quality regulatory decisions could be based.

9. Ozone Attainment Demonstration Procedures – An attainment test was done for the Pensacola and the Bay County region. This test is a component of the 8-hour ozone attainment demonstration procedures and it is intended to demonstrate future attainment of the 8-hour ozone standard. Even though the WFOS simulation periods have different base years, the UAM-V was run for the five WFOS simulation periods using 2000 emissions. For the WFOS domain, the radius of influence, used to calculate the relative reduction factor and the estimated design values, was changed relative to the suggested EPA value.

Comment: In the context of the WFOS study and considering the characteristics of the Pensacola region, the selection of 2000 emissions for all five WFOS simulation periods and the selection of a radius of influence smaller that the one suggested by EPA appear reasonable.

3.1.3 Summary

Overall, the West Florida Ozone Study represents a thorough analysis of the physical and chemical conditions that are conducive to high ozone concentrations in Pensacola and in the Florida panhandle. It should be noted that the bulk of the conclusions were based on the result of a system of numerical models, the UAM-V modeling system. In this regard, the reported performance of the chemical component of the modeling system was based solely on one chemical species, ozone. Other than for ozone, the WFOS report did not include any comparison between other simulated and observed pollutants. It is possible for an emission-based modeling system (like the UAM-V) to reproduce reasonable ozone concentrations using an incorrect set of emissions. Even though a comparison between observed and simulated pollutants does not represent a definite test, it is an important gauge of the uncertainties of the calculations.

3.2 The Fall line Air Quality Study

A four-dimensional air quality model of ozone and particulate matter was run for a baseyear of 2000 and a future year of 2007 as part of another study funded by the state of Georgia – the Fall line Air Quality Study (FAQS). As of December 2004, the primary scope of work for the FAQS has been completed and a draft final report has been prepared. The report is available online at http://cure.eas.gatech.edu/faqs/finalreport.

While the main focus of the FAQS and of the report is concerned with ozone air quality in Augusta, Macon, and Columbus, Georgia, the model domain includes much of the eastern U. S. including the Pensacola area. Here we briefly report on a re-analysis of the model runs from a Pensacola perspective. These results were originally provided in a presentation at the PERCH investigators meeting in Pensacola on 3 November 2003.

Model inputs were prepared according to US EPA guidance and utilized in the Community Multiscale Air Quality (CMAQ) model. The episode studied was a high ozone event that occurred between 10-20 August 2000. The model reasonably replicated the historical event in Pensacola (Figure 6 through Figure 9), and predictions of future years suggest that national and regional controls that are already scheduled to be in place by 2007 (net of growth), may result in a 5% to 10% net decrease in peak ozone concentrations in the Pensacola area, but may have little effect on particulate matter concentrations (Figure 5 through Figure 9). The effect on air toxics was not assessed.

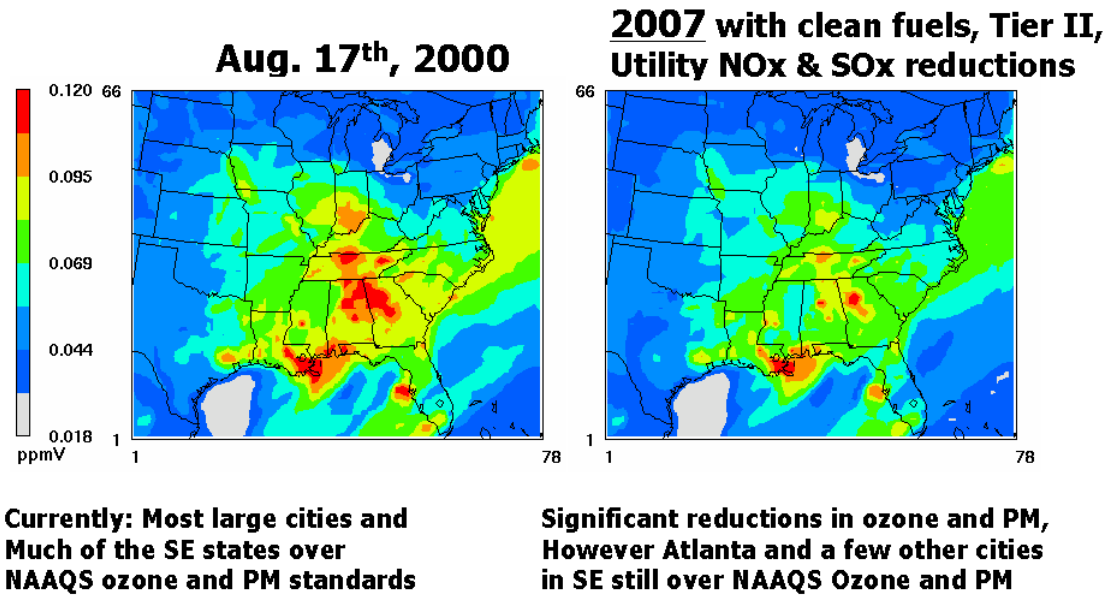

Figure 5. Impact of existing control strategies – i.e. controls that are already planned and will be implemented by 2007 – on a historically poor air quality episode 10-20 August 2000. The figures show changes in the concentrations of 8-hour average ozone.

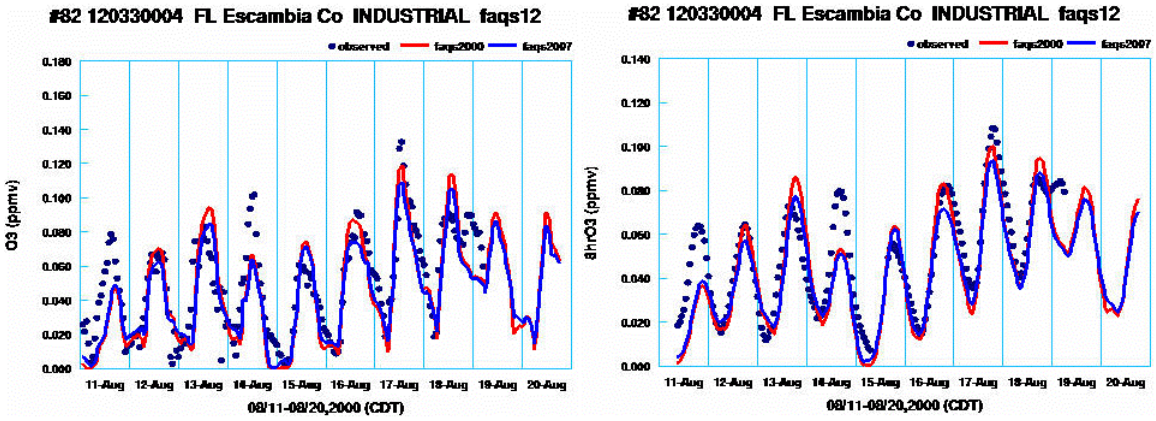

Figure 6. Observed 2000 (dots), simulated 2000 (red), and effect of existing control strategy 2007 (blue) on one hour average (left) and eight hour average (right) ozone concentrations at Ellyson Industrial Park, Escambia County.

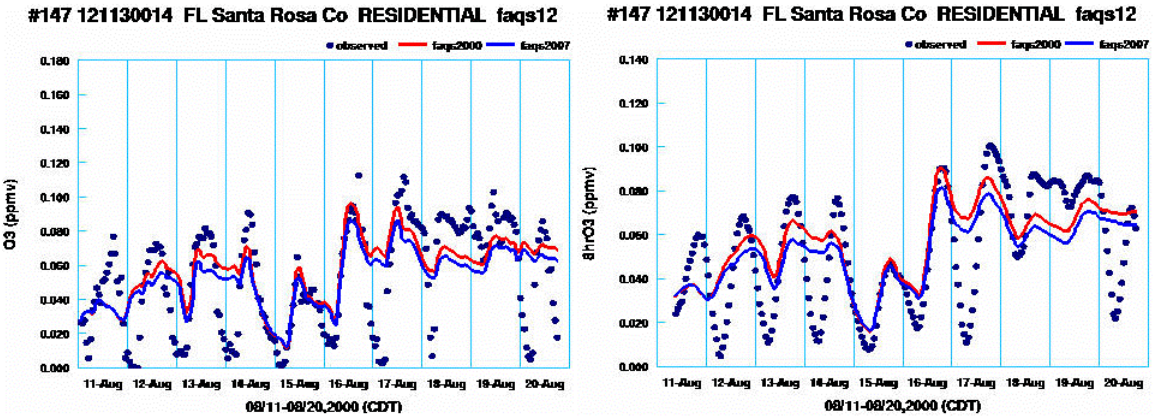

Figure 7. Observed 2000 (dots), simulated 2000 (red), and effect of existing control strategy 2007 (blue) on one hour average (left) and eight hour average (right) ozone concentrations at Navarre Beach Middle School, Santa Rosa County.

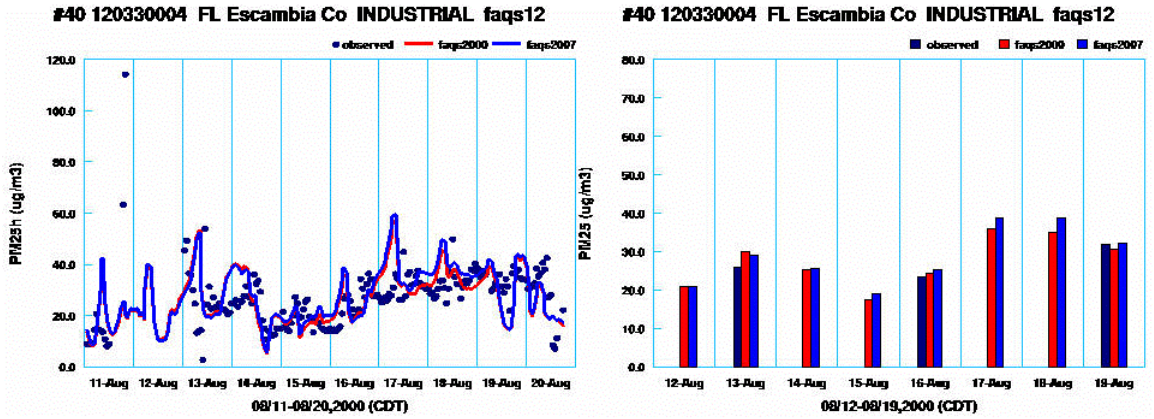

Figure 8. Observed 2000 (dots and dark blue bars), simulated 2000 (red), and effect of existing control strategy 2007 (blue) on one hour average (left) and 24 hour average (right) $PM_{2.5}$ concentrations at Ellyson Industrial Park, Escambia County.

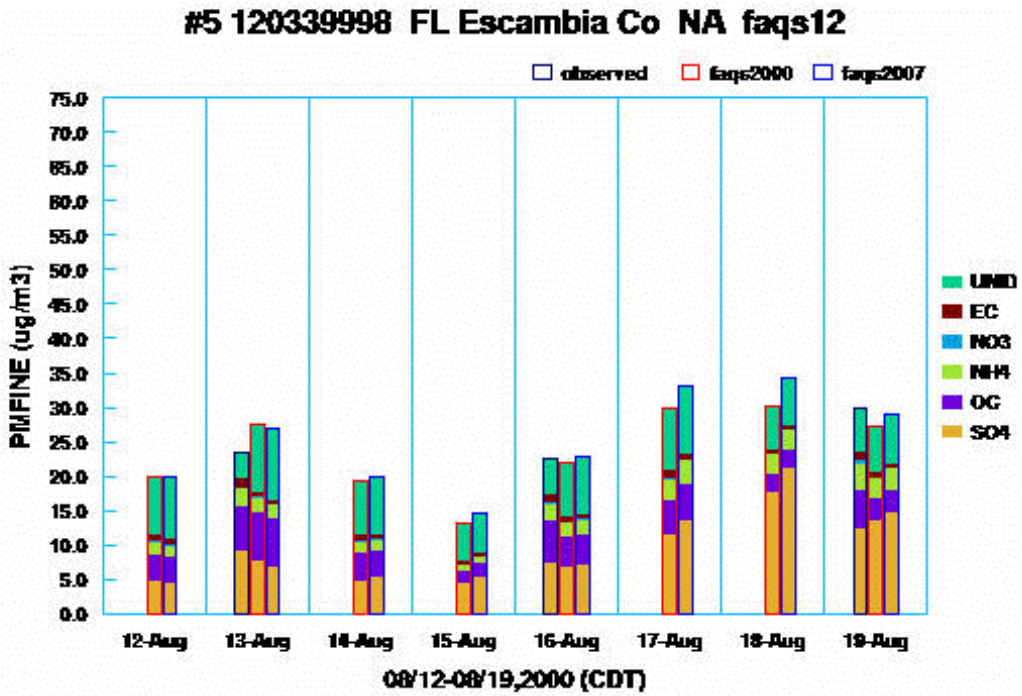

Figure 9. Observed (left bar, when available), 2000 simulated (middle bar), and 2007 predicted (right bar) speciated $PM_{2.5}$ concentrations in Escambia County.