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Decision-Support Tool for Residential Pesticides in the South Carolina Coastal Zone

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Decision-Support Tool for Residential Pesticides in the South Carolina Coastal Zone

by

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DEDICATION

This work is dedicated to everyone who took time from their lives and helped me from June 2011 through 2013. In particular: ASPH & ENHS (everyone); the University of South Carolina's TSHC (everyone); USCPD; Palmetto Health (Richland and Baptist) – Susan Hughes; USC ODS; USC Orthopedics – Dr. Christopher Mazoue and his team; Sports Plus Physical Therapy (everyone) – Lindsey Morgan; Rhea, Mark, and Ian McCoy, my brother – Jamie, my Mom – Carol; Maria Parker; Misty Seawright; Dr. Megan Howard; Mary Hicks; Deb Zippel; Calvin Gallman; Jan Ziegler; Dwayne Porter; Bruce Coull; Tom Chandler; Cheryl Addy; Christy Smith; Phil; Geoff Scott; Chris Marsh; Tara Sabo-Attwood; Gaye Betcher; Dave Volz; James Hibbert; Brad Wyche; Heather Nix; Laura Bain; Hart Scott; Dan Ramage; Jeff Jefferson; Alison Pierce; Renee Dickman; Kristen and Philip Miller; Erin Fichot; Gene and Pat Feigley; Matt and Dana Augustine; my neighbors – Erich, Ted, and Bo *and* Jamil, Ahmad, Brit, Chad and Katie, and Kurt; Jamelle Ellis; Ford Tupper; Jane Richter; Bahiyyih Young, Karen Pettus; Salty's Board Shop – Paul and Jess; Maggie Johnson; Will Johanessen; Virginia Shervette; Stephanie Do; Francine Davis; Leslie Greene and family; Sierra Jones and Wesley Johnson; Krystle and Joe (and Russell) Yazzo; Michelle Flowers; Shonda Jones; The Roost; and my cousins Julie Wickliffe and James Wickliffe. Each one of you played a vital role in my life to make this dissertation possible. In addition, this dissertation is dedicated to the memory of my father, W. Harry Wickliffe, who always encouraged and supported me in my goals and aspirations in life.

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University of Georgia Center for Invasive Species and Ecosystem Health, the University of Maryland Center for Environmental Science, Cypress Gardens – Dr. Dwight Williams, the National Pesticide Information Center (NPIC), the Environmental Protection Agency (EPA), and South Carolina Department of Health and Environmental Control (DHEC). I would also like to thank my classmates – John McKenzie, Jamelle Ellis, Max Henzler, Sean McGee, Gustavo Dominguez, Miguel Uyaguari, Ben Bay, Gargi Dayama, Eva Preisner, and Sumith Jayasinghe – who all pushed me to learn more and always do my best just to keep up with them. You all contributed to this dissertation in some respect.

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ABSTRACT

The Environmental Protection Agency (EPA) is charged with ensuring pesticides do not pose unreasonable adverse risks to the public and to the environment. This is a daunting task with over one billion pounds of pesticides used across the nation each year. The U.S. EPA estimates approximately 75% of all pesticide usage in the U.S. are agricultural while 25% is for home, garden, industrial, commercial, and government applications. One area of application of concern to public health and the environment regarding misuse of pesticides is in residential settings. In these instances, individuals may not have any knowledge of identifying whether they have a pest problem (i.e., pests have reached intolerable levels), the proper steps to take in determining the best solution to solve the pest problem, and measures needed to protect themselves and the surrounding area from pesticide exposure if chemical application occurs. As the nation's population continues to grow, it is imperative to learn which pesticides – as well as uses – should be accounted for in residential scenarios. Using a three county study area in coastal South Carolina, we developed a pesticide knowledgebase, a hazard-based relative cumulative ranking system for one hundred of the most commonly used pesticides, and geospatial models allowing for more informed choices regarding pesticide use and application. Implemented as an easy-to-use dynamic system of tools for residential pesticides – sccoastalpesticides.org acts an educational platform – allowing users to quickly make decisions regarding pesticides, and allowing us to educate more of the target by using a website, acting as a cost effective strategy to maximize efficiency in reaching multiple stakeholder groups.

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LIST OF ABBREVIATIONS

AI	Active Ingredient
EEC	Estimated Environmental Concentration
ERMQ	Effects Range Median Quotient
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FQPA	Food Quality Protection Act
HTML	Hypertext Markup Language
IPM	Integrated Pest Management
K_{oc}	Soil/Water Mobility Coefficient
K_{ow}	Octanol/water Partitioning Coefficient
LCI	LowCountry Institute
LD ₅₀ /LC ₅₀	Lethal Dose/Concentration that kills 50% of the test population
LOC	Level of Concern
mg/kg	milligrams per kilograms (usually of body weight)
mg/kg/day	milligrams per kilogram per day
MOA	Mode of Action
NOAEL/NOAEC	No Observable Adverse Effects Level/Concentration
ppm	parts per million
ppb	parts per billion
T _{1/2}	Half-life
US EPA	United States Environmental Protection Agency

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The US Environmental Protection Agency (EPA) is charged with ensuring pesticides do not pose unreasonable adverse risks to the public and to the environment (EPA 2005). This is a challenging task as over a billion pounds of pesticides are used across the nation in agricultural, industrial, commercial, and urban settings each year (Gilliom et al. 2006). Further, conveying important information regarding possible adverse impacts of applying pesticides to all the individuals is a task that the EPA can regulate, but potentially cannot always enforce in the many diverse instances of pesticide application. One of the application areas of current concern regarding misuse of pesticides is in residential settings. In these instances, individuals may not have appropriate knowledge of identifying whether they have a pest problem (i.e., pests have reached intolerable levels), the proper steps to take in determining the best solution to solve the pest problem, and measures needed to protect themselves and the surrounding area from pesticide exposure if chemical application occurs. Label instructions on pesticide containers are a requirement of the EPA for the use of pesticide formulations on the market, but often labels are not read or difficult to read (e.g., text is too small), and many individuals assume they know proper application and handling procedures for pesticides because they have used them in the past. Additionally, in many residential settings recreational areas use pesticides as well – and the public is unaware of potential exposures in these

areas. For example, diverse arrays of pesticides are used on golf courses – a factor many golfers probably do not consider when participating in a leisure activity. Therefore, given the large gap in knowledge in proper pesticide use and potential adverse effects occurring in residential scenarios, the overarching goal of the research and educational strategies outlined in this dissertation is to develop and implement an easily understandable system for residential pesticide applicators so they may make more informed pesticide decisions in these settings.

As a preface to Chapters 2, 3, and 4, Chapter 1 is divided into sections to provide background knowledge and previously completed research to establish a basis for the reader. The main topics discussed in Chapter 1 are pesticides, urbanization in the coastal zone of South Carolina, ecological risk assessment, integrated pest management, and previously developed pesticide risk indicator systems. Chapters 2 and 3 of this dissertation focus on developing a relative cumulative ranking system for commonly-used residential pesticides within a specific geographic region of the US, and developing a spatial model to enhance knowledge of variables that should be accounted for before pesticide application occurs. Chapter 2 will go through the developed relative cumulative ranking of residential pesticides in detail – taking complex pesticide toxicity and environmental fate data and creating an easily understandable system for the public. Chapter 3 explains the spatial and temporal components represented within the educational map built using geographic information systems (GIS) for smarter pesticide application decisions for residents. Chapter 4 of this dissertation describes the platform (sccoastalpesticides.org) whereby the two important components outlined in chapters 2

and 3 were combined to create an interactive educational strategy for residential pesticide applicators within the chosen study area.

1.2 PESTICIDES AND URBANIZATION

1.2.1 Pesticides

Approximately one billion pounds of conventional pesticides (i.e., herbicides, insecticides, fungicides, and a mixed group of fumigants, nematicides, and other pesticides) are used each year in the US to contain or control pests (Gilliom et al. 2006). As of 1997, approximately 900 pesticides were registered in the US for use in more than 20,000 different products on the market (Aspelin and Grube 2006, Gilliom et al. 2006). Additionally, about 4 million pounds of non-conventional pesticides (e.g., chlorine disinfectants, wood preservatives, and other specialty products) are used each year in the U.S. (Gilliom et al. 2006). New active ingredient pesticides – typically 10-20 per year as indicated by registration from 1967 to 1997 – are introduced as new pest-related problems arise, organisms gain resistance, and older products are determined to be more harmful than initially reported and are phased out (Aspelin and Grube 2006). The US EPA estimates that approximately 75% of all pesticide usage in the United States is agricultural and the remaining 25% is for home, garden, industrial, commercial, and government applications (Hartwell 2011). Much emphasis has been placed on pesticides and use in agricultural areas, as this usage category does account for the majority of application. However, as the nation's population continues to grow, it is imperative to learn which pesticides – as well as uses – should be accounted for in residential scenarios. By their very nature, most pesticides create some chance of adverse effects on non-target species as they are designed to kill or otherwise control living organisms when exposure occurs (EPA 2011). Sparse (infrequent, with coarse geographic coverage) data exist for

agricultural uses of pesticides in the U.S. and data are even more limited for nonagricultural uses (Gilliom et al. 2006). Given the estimated quantity of pesticides used per year in the US and that 25% are used for non-agricultural scenarios, knowledge gaps related to this sector should be addressed.

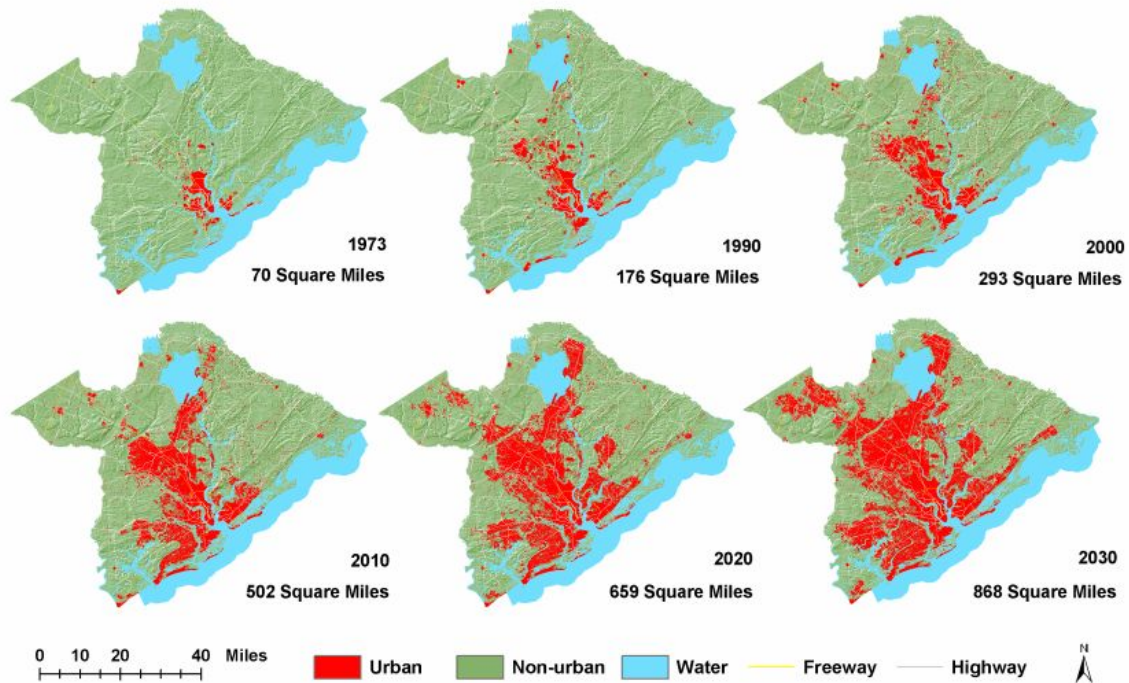


Figure 1.1: The GIS figures illustrate predicted urban expansion over a portion of the South Carolina coastal zone with the current population growth to urban expansion ratio of 6:1 into the year 2030. The model was built using a binomial logistic framework, along with a rule-based suitability module and focus group involvement, and is designed to predict land transition probabilities and simulate urban growth under different scenarios. Image from Allen and Lu (2003).

Pesticides – regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Food, Drug, and Cosmetic Act (FD&C Act) and the Food Quality Protection Act (FQPA) – undergo a tiered exposure and toxicity testing regime to ensure safety (if label instructions are followed) before products enter the market (EPA 2011a). Therefore, all pesticides currently on the market are considered safe by the EPA if used

properly. However, wide variance in exposure and toxicity occurs – among the same classes of pesticides – and among organisms (Hartwell 2011) and with factors such as age, species, or life stage. Pesticides are currently registered through the EPA by a human health and ecological risk assessment framework of individual active ingredient (AI) pesticides (i.e., the compound that causes the pesticidal effect within a brand name formulation). While this is a valid approach, it is difficult to assess the potential toxicity differentials that occur in brand name formulations containing multiple active ingredient pesticides, synergists (e.g., PBO) and inert ingredients (e.g., surfactants). The variance in testing protocol and realistic exposure scenarios leaves uncertainty for toxicological effects for formulations available to the public and pesticide applicators.

Many legacy pesticides (e.g., organochlorine (OC), organophosphate (OP) insecticides) are broad-spectrum (i.e., non-target specific) and increase the probability of adverse effects to non-target species, particularly if product use deviates from label instructions. While some OPs are still in use, almost all OC uses are banned in the US due to concerns for both human and ecological health as most are highly persistent and bioaccumulative (Hartwell 2011, USEPA 2010a). No matter what class of pesticides is being applied, these chemical compounds often pose significant expense to those who use them on large spatial expanses and temporal scale applications (e.g., farmers, golf course managers, power companies) – creating interplay between the cost of the pesticide and the efficacy of the product (Hartwell 2011).

Current-use pesticides are considerably more labile (i.e., capable of changing state or becoming inactive) than older generations of pesticides and therefore degrade in the environment more readily, ultimately posing less ecological risk than those pesticides that

are persistent and bioaccumulate (Hartwell 2011). There are however, pesticides designed to be least persistent, but may have more toxic metabolites than the parent compound (e.g., fipronil and its metabolites). The lack of persistence means in order to be effective pest control agents, pesticide acute toxicity must be increased (especially to target organisms) or applied in greater quantity and/or frequency (Hartwell 2011). Toxicity varies widely though even among the same class of pesticides. For instance, pyrethroid toxicity varies among levels of taxonomic organization generally exhibiting low toxicity to mammals and birds ($LD_{50s} > 1000\text{mg/kg}$) and exhibiting a substantially higher toxicity to sediment dwelling aquatic crustaceans (LD_{50s} in the ng/L range) (Solomon et al. 2001). This differential in toxicity is by design – as pyrethroids are selective to insects while also minimizing off-target effects in mammals. This paradigm shift in pesticide toxicity and usage leads to a different set of concerns for potential adverse ecosystem impacts. Consideration of high runoff rates from urbanized areas is important, as higher peak concentrations of pesticides may occur – and concurrently may lead to higher acute exposures to toxic substances – particular problematic for sensitive aquatic and benthic organisms in surrounding waters.

Given the paradigm shift in pesticides, accompanied by higher residential pesticide usage as urban areas expand into previous undeveloped areas, it is important that resident pest applicators themselves understand pesticides and the various potential adverse impacts they may have on surrounding ecosystems. As a resource management and regulatory strategy – an integrated pest management (IPM) approach (i.e., exhausting non-chemical pest control efforts before pesticides are implemented) accompanied by

user education and informed decision-making can aid in effective management of pest problems and also decrease the potential adverse impact on the natural environment.

1.2.2 Classes of Pesticides

Herbicides

Herbicides – chemicals used to control or eradicate undesirable vegetation – are predominantly applied to row crops to improve yields by minimizing weedy species competing with the desired crop (Todd and Sutter 2012). In suburban and urban areas, herbicides are applied to lawns, parks, golf courses, right-of-ways, on roadsides, and around structures to prevent structural damage (Ware 1991, Todd and Sutter 2012). Herbicides are also applied to waterbodies to control aquatic nuisance plant and algae species that impede irrigation withdrawals or interfere with recreational and industrial uses of water (Folmar et al. 1979). Herbicides used in waterbodies are typically referred to as algaecides. Improper use of herbicides can lead to adverse biological effects and should be taken into consideration during application (Figure 1.2).

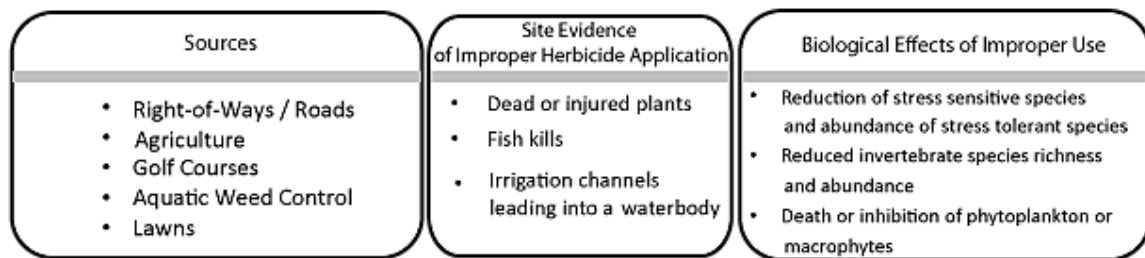


Figure 1.2: Potential sources and evidence of improper herbicide use and the resulting ecosystem effects. Figure adapted from Todd and Sutter (2012)

Herbicides are selective when application patterns are target-specific (i.e., not intended to harm non-target vegetation) and non-selective when used to destroy all

vegetation in an area (Ware 1991). Herbicides generally fall into three basic classifications: a) pre-plant – used in crop scenarios before planting for control of annual weeds, b) pre-emergent – used to establish control before growth of the weedy species can be seen above ground, c) post-emergent – used once weedy species are above ground and already established (Ware 1991). Pre-emergent (and pre-plant) and post-emergent herbicides are generally distinguished by various modes of action. The molecular site of action is challenging to predict due to unidentified structural associations (Duke 1990), but modes of action are generally well-established (Todd and Sutter 2012). The mode-of-action (MOA) is the overall manner – or mechanism – by which an herbicide affects the health and physiology of the plant or the plant's cellular tissue (Ross and Childs 1996). Herbicides with the same MOA should produce similar injuries when target species are exposed (Ross and Childs 1996). Herbicidal MOAs include several various routes of toxicity such as inhibition of cell division, photosynthesis, or amino acid production or by mimicking natural auxin hormones, which regulate plant growth, and cause deformities in new growth (Ross and Childs 1996). Specifically, pre-emergent herbicide MOAs include photosynthetic inhibitors (e.g., atrazine) and cell division inhibitors – including root inhibition (e.g., benefin), shoot inhibition (e.g., dimethenamid), and shoot and root inhibitors (e.g., dithiopyr) (Ross and Childs 1996). Post-emergent herbicides MOAs include amino acid inhibition (e.g., glyphosate), chlorophyll/carotenoid pigment inhibitors (e.g., fluridone), lipid biosynthesis inhibitors (e.g., fenoxaprop), and cell membrane destroyers (e.g., diquat).

Fungicides

Fungicides – traditionally used to control fungal plant pathogens – are also used to eliminate other blights and diseases on plants and trees caused by bacteria, viruses, mycoplasma-like organisms, algae, some insects, and parasitic seed plants (Ware 1991). There are numerous plant and tree blights and diseases including root rots, gall diseases, seedling diseases, vascular wilts, leaf blights, rust, smuts, mildews, storage rots, and viral diseases (Ware 1991). Root rots were one of the initial reasons for the development of fungicides and are generally caused by *Phytophthora*, *Rhizoctonia*, *Fusarium*, and *Verticillium* (Ware 1991). Fungal pathogens are difficult to control, can arise from a number of different sources (i.e., soil, air) and usually live in close quarters with its host. Given the proximity to the host, chemical treatment is difficult for some blights and diseases, as you must eliminate it without killing or injuring the plant host (Ware 1991). Many fungicides act by preventing spore germination and subsequent fungal penetration into host plant tissues. There are many synthetic fungicides, but inorganic compounds – such as copper compounds – are also still in use for the control of some blights and diseases. The copper ion is the toxic component killing pathogenic cells. Some fungicides come in fumigant form (i.e. injected as a gas into the soil) and must be applied with great care as to not cause adverse impacts to surrounding areas.

Insecticides

As the names imply, insecticides are used to treat insect pests (Ware 1991, EPA 2010), but also are sometimes generalized out to other invertebrates (e.g., slug, snails). For three major classes of insecticides the MOA of toxicity are non-target specific and effects can occur in many taxa – including humans. There are five major classes of

insecticides including: 1) organochlorines (e.g., DDT, endosulfan), 2) organophosphates (e.g., malathion, diazinon), 3) carbamates (e.g., carbaryl, aldicarb), 4) pyrethrins and synthetic pyrethroids (e.g., permethrin, deltamethrin), and 5) insect growth regulators (e.g., methoprene) (Ballantyne et al. 1999). Of these different insecticide classes, three classes have MOAs worth further discussion due to their ability to interfere with proper nervous system functioning in mammalian species – organochlorines, organophosphates, and carbamates. The mode of action for organochlorine compounds (OCs) is generally thought to act by the interference with cation exchange across the nerve cell membranes resulting in hyperactivity of the nerves, whereas with organophosphate (OPs) and carbamate insecticides the mode of action in insects and other non-target species is the inhibition of acetylcholinesterase (AChE) causing continuous firing of neurons leading to cell death and paralysis (Britt 2000). However, for carbamates, unlike OPs, oral and dermal mammalian toxicity is comparatively low (Ware 1991). Many OCs have been phased out of use in the United States due to their physical and chemical properties (EPA 2010); however given their persistence and continued use of OCs such as DDT in developing nations that the U.S. imports seafood from (e.g., Ecuador) it is likely that exposure and bioaccumulation is still occurring at low levels from these compounds.

Organochlorines (OCs)

Organochlorines are generally considered to be the most chronically hazardous insecticides – particularly for higher orders of taxa. Organochlorine insecticides (OCs) contain chlorine, hydrogen, and sometimes oxygen (Ware 1991). The chlorine atoms on the organic moieties of OCs make them very stable compounds, but also lead to slow degradation rates (Ballantyne et al. 1999, Britt 2000). OCs are considered legacy

contaminants due to their high lipid solubility, low vapor pressure, environmental persistence, and the ability to bioconcentrate, bioaccumulate and biomagnify up the food web (Ballantyne et al. 1999). OC pesticides, including DDT, were utilized widely in the U.S. from the early 1940s until the 1960s for insect control in forestry, agriculture, and building protection and were predominantly phased-out in the 1970s (Calle et al. 2002). However, due to their persistence and lipid solubility, it appears that low-level exposures are still occurring as OCs have accumulated in sediments and other mediums over long-periods of time (i.e., chronically). Chronically, many OCs are considered endocrine disrupting compounds because they are weakly estrogenic or antiestrogenic in toxicological assays (Calle et al. 2002). This can lead to reproductive and developmental issues.

Organophosphates (OPs)

OP insecticides have become widely used as replacement pesticides for the persistent organochlorine insecticides as they do not bioaccumulate (Britt 2000). OP toxicity varies widely at the organismal level (Hartwell 2011), but given the non-target specific mode of action of OPs - neurotoxicity via inhibition of acetylcholinesterase (AChE) – it is possible to see various induced adverse effects – depending of the exposure concentration and duration – in a multitude of organisms at various levels of biological organization. Overall use of OPs in the U.S. has decreased, potentially due to the changes of application in chlorpyrifos – accounting for 69% of all insecticides applied in 2004 (Hartwell 2011). Currently, the EPA estimates that approximately 60 million pounds of organophosphates are applied to U.S. agricultural crops annually and another

17 million pounds per year are used for non-agricultural uses – accounting for about half (by amount sold) of all insecticides used in the U.S. (EPA 2005a).

Acutely, OPs are generally considered the most toxic of all pesticides to vertebrate animals (Ware 1991). Inhibition of AChE – an enzyme that plays a critical role in acetylcholine neurotransmission as it breaks down acetylcholine preventing continuous neural firing – leading to cell death and paralysis (Britt 2000). OPs are readily absorbed via ingestion, dermal, and inhalation routes and can produce local toxic effects or systemic effects (Britt 2000). Systemic toxicity occurs when signals in somatic motor nerves in the skeletal muscle and in some central nervous system activities cease (Britt 2000).

Carbamates

Carbamate insecticides are made from carbamic acid and are considered broad-spectrum effecting both target and non-target species alike (Ware 1991). The first successful carbamate was carbaryl, developed in 1956 (Ware 1991). Like OPs, carbamates inhibit the vital enzyme AChE leading to CNS injury and eventually paralysis or death if acute exposures are high enough. Carbamates appear to be the least toxic of the insecticides to many species, but are substantially more toxic to invertebrates than fish species (Hartwell 2011). Concerning carbamate usage, it has temporally declined with the phase out of the granular application of carbofuran used on food crops (Hartwell 2011). Some carbamates work well for nematode control, such as aldicarb, but are highly toxic to vertebrate species (Ware 1991). Carbamates such as methiocarb are effective against fruit and foliage-eating insects (Ware 1991).

Insect Growth Regulators (IGRs)

Insect growth regulators (IGRs) work by either altering the production of chitin – the compound insects use to make their exoskeleton – or by altering an insect's development into adulthood. Some growth regulators force the insect to develop too rapidly, while others bring development to a halt. IGRs are biopesticides and work on certain hormonal pathways in insects making them less likely to have effects on other non-target species (NPIC 2013). Importantly, these compounds must be applied during certain life stages of the target organisms to be effective insecticides.

There are concerns with IGRs given the effects on hormonal pathways possibly leading to endocrine disruption to many invertebrate species. IGRs mimic juvenile hormone III (JH-III) – which if altered – could potentially lead to reproductive and developmental problems in non-target crustacean and insect species. Methyl farnesoate (MF) – the unepoxidated form of juvenile hormone III (JH-III) – appears to regulate some aspects of both development and reproduction in crustaceans and insects (Olmstead and LeBlanc 2002). MF regulates molting, larval development, osmoregulation, morphogenesis, behavior and general protein synthesis in many crustacean species (Purna and Nagaraju 2007). In other crustaceans and arthropods, juvenoids – of which JH-III is an example – regulate various aspects of development, growth, maturation, and reproduction (Wang et al. 2005). Changes in concentrations of naturally occurring juvenoids in non-target invertebrates by IGR hormone-mimics could potentially lead to population level problems in the environment by impacting the aquatic food web (i.e., bottom-up ecosystem impact) (Crosby and Tucker 1971). Furthermore, because of the various life stages in invertebrates in general, endocrine systems are considerably diverse

(Oehlmann and Schulte-Oehlmann 2003). In this respect, one may not observe the same effects (i.e., toxicity and linked adverse effects) in all crustaceans when juvenile hormones are altered by IGRs or other endocrine disrupting chemicals.

Pyrethrins and Pyrethroids

Pyrethrins are derived from chrysanthemum flowers and work by altering nerve function causing paralysis in target insect pests, eventually resulting in death (EPA 2013a). Pyrethroids are synthetic versions of pyrethrins and are similar in chemical structure and MOA. Pyrethroids were developed to increase the insecticides' stability in sunlight (EPA 2013a). Pyrethrins and pyrethroids are registered in over 3,500 formulations, and have become a dominant urban insecticide for landscape maintenance, structural pest control, and public health pest control (Holmes et al. 2008, EPA 2013a). Pyrethroid toxicity varies among levels of taxonomic organization – as by design synthetic pyrethroids target insect species and minimize toxicity to mammals. Pyrethroids generally exhibit substantially higher toxicity to sediment-dwelling aquatic crustaceans (LD_{50} s in the ng/L range) relative to mammals and birds (LD_{50} s > 1000mg/kg) (Solomon et al. 2001). Pyrethroids are of particular concern to sediment-dwelling organisms because the high K_{oc} value (approximately 350,000) leads to rapid and extensive binding to particulate matter, aquatic plants, as well as sediment (Solomon et al. 2001, Maund et al. 2002). The extensive binding to sediment leaves less bioavailable to pelagic organisms, but still may pose adverse effects to benthic organisms particularly with decreasing temperature (i.e., <15°C) (Maund et al. 2002). The use of this class of insecticides has increased during the past decade with the declining use of

organophosphate pesticides. Pyrethroids are often combined with synergists (e.g., PBO, MGK-264) increasing their toxicity (EPA 2013a).

Synergists - PBO

Piperonyl butoxide (PBO) was first registered in the 1950's and acts as a synergist (i.e., increases toxicity of an active ingredient pesticide) but is not considered toxic or insecticidal alone (EPA 2006). Approximately 100,000-200,000 pounds are sold every year for non-agricultural uses in the U.S (EPA 2006). PBO is a registered active ingredient in over 1500 products used to control many different types of flying and crawling insects and arthropods (EPA 2006). PBO acts as a synergist by inhibiting the activity of cytochrome P-450 dependent polysubstrate monooxygenases (PSMOs) preventing the degradation of toxicants (Todd and Sutter 2012). These enzymes have many functions, including breakdown of toxic chemicals and transformation of hormones. The available toxicity data from PBO plus other active ingredients like pyrethrins or pyrethroids show greater toxicity to invertebrates than if exposure was to occur to the pyrethrin/pyrethroid alone (EPA 2006).

1.1.3 Urbanization

Preceding the Civil War, South Carolina was an essential agricultural asset to the nation (Allen and Lu 2003). In the post-Civil War era, South Carolina's growth came to a halt for almost a century (Allen and Lu 2003) until urbanization and new suburban areas began to increase in the state in the 1950's and 60's (Frey and Speare 1988, Long 1988). In the 1970's immigration to the state resulted in substantial population growth due to augmentation of natural population increases (Brown and Wardwell 1980, Allen and Lu 2003). Acceleration of this changed population dynamic has occurred over the previous

two decades – particularly within the South Carolina coastal zone (Allen and Lu 2003). From 1960 to 1990, urban growth well exceeded population growth at a ratio of 6.2:1 – almost triple that of the national average (2.3:1) (Allen and Lu 2003). Encroachment and overlap of urbanized areas into natural coastal environments may potentially impact the surrounding estuarine ecosystem and economically important ocean-related commerce if proper management strategies are not integrated into urban development and city planning.

Intricately linked to urban expansion is the use of pesticides within, around, and under homes, on lawns and turf grass, in right-of-way easements, landscaped areas (ornamentals), and for vector control. As pest problems (e.g., severity of infestation, area of application, and type of application) are unique in many respects, educational efforts on overall toxicity, environmental fate and transport characteristics, and proper application of pesticide formulations needs to occur for the general population – particularly within the coastal zone given its continued population growth rate and development preferences. Suburban developments are potentially located on or downstream of agricultural areas as well and have close proximity to the estuarine and coastal ecosystems. If residents understand the potential hazard improper use of pesticides presents – then efforts can be made by all to maintain the functionality, economic viability, and aesthetic appeal of a balanced estuarine ecosystem.

1.3 THE IMPORTANCE OF INTEGRATED PEST MANAGEMENT (IPM)

Integrated Pest Management (IPM) is defined by the EPA as an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices (EPA 2011b). IPM is a process consisting of the balanced use of

physical, cultural, biological, and chemical procedures that are environmentally compatible, economically feasible, and socially acceptable to reduce pest populations to tolerable levels. There are many advantages to implementing IPM plans in both agricultural and non-agricultural settings (e.g., home, garden, schools, workplace) including: maintaining a balanced ecosystem, easy implementation and cost reduction, avoiding situations when chemical pest control can be ineffective, promoting a healthy environment and creating a good public image (Figure 1.3) (NPIC 2012). Many IPM measures are preventative in nature to inhibit or prevent pest problems. IPM approaches to pest management emphasize preventative techniques such as: cultural controls (i.e., changes that disturb the natural environment of the pest), biological control (i.e., beneficial organisms), physical barriers, use of pheromones (i.e., natural insect hormones and scents for communication), and planting pest-resistant varieties of ornamental areas and vegetable gardens (NPIC 2012). Monitoring is another important component to an IPM approach. Monitoring involves regular checks of areas for pests so early detection and documentation can occur. When monitoring occurs, proper identification of pest species is very important to finding a viable pest solution. Finally, assessment is the process of determining the potential for pest populations to reach an economic threshold (i.e., depletes the value of the crop below an established bottom-line) or an intolerable level or when a threshold of a public health concern is being approached. Then one may determine the action needed in order to address the pest problem.

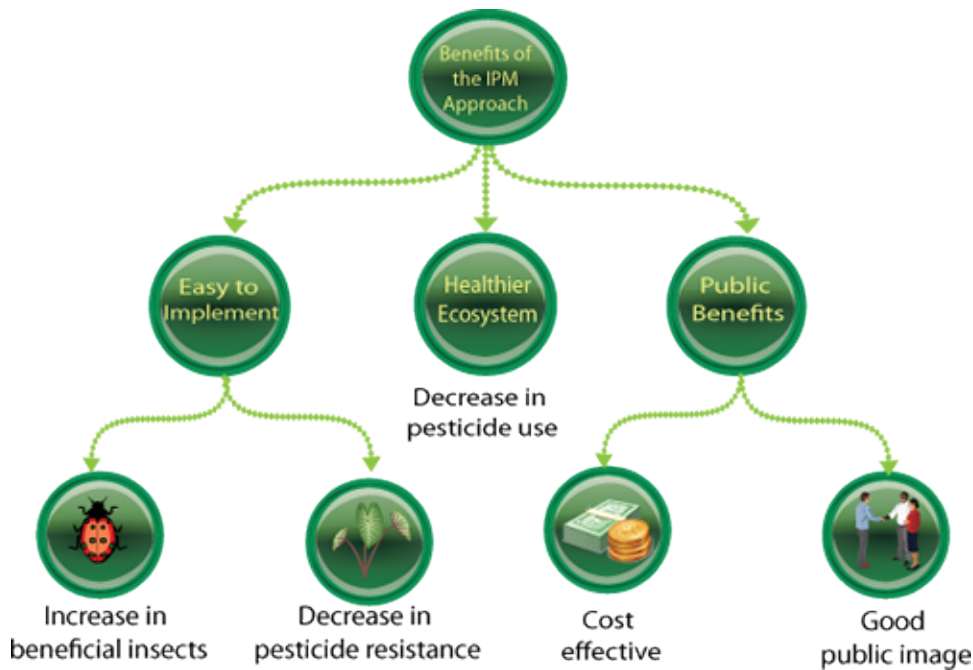


Figure 1.3: The benefits of taking an IPM approach to pest management

1.4 ECOLOGICAL RISK ASSESSMENT FOR PESTICIDES

1.4.1 The US EPA's Ecological Risk Assessment Framework

Ecological risk assessment is generally defined as the characterization of the potential adverse health effects of environmental exposures to hazards, and the process is divided into distinct steps: hazard identification, exposure assessment, and risk characterization (Figure 1.4) (NAS 1983). The EPA implements the National Research Council's (NRC) process for risk assessment:

Hazard Identification measures the toxicity of the pesticide

Exposure Assessment analyzes the effects of different types of exposure (ingestion, inhalation) to a pesticide

Risk Characterization combines the hazard, dose-response and exposure assessments to describe the overall risk from a pesticide.

The EPA takes a tiered approach to the Risk Assessment process conducted for pesticides (Figure 1.5) (EPA 2011). If a compound has several concerns of adverse effects at the Tier 1 level, then the risk assessment increases in complexity to reduce uncertainty. For Tier I and II ecotoxicological bioassays, Risk Quotients (RQ = EEC/LD₅₀, LC₅₀, EC₅₀) are generated for representative taxa from different trophic levels (e.g., non-vascular and vascular plants, aquatic and terrestrial invertebrates, warm and cold water fish species, avian species, and mammalian species). In most cases, a risk-based approach for cumulative environmental risk assessment has been an effective methodology. In many cases for these types of analyses, pesticide use data were estimated or available to risk managers so there were measures of exposure. RQs are compared to an established Level of Concern (LOC) that should not be exceeded or adverse effects may be observed in non-target organisms. The RQ threshold (LOC) varies depending on acute and chronic endpoints, and if a species is federally listed as threatened or endangered. Often, a pesticide RQ may exceed the LOC for the some toxicity endpoints being assessed, but not for other assessed endpoints. In these cases, label changes and mitigation measures are tools the EPA uses to address exceeded LOCs in an active ingredient pesticide on the market. It is important to note when looking at the LD₅₀/LC₅₀ for toxicity values, the lower the value the more toxic the compound is for the endpoint being assessed. Furthermore, for chronic toxicity, if the RQ value exceeds 1.0, then it exceeds the LOC set for chronic toxicity (Figure 1.6).

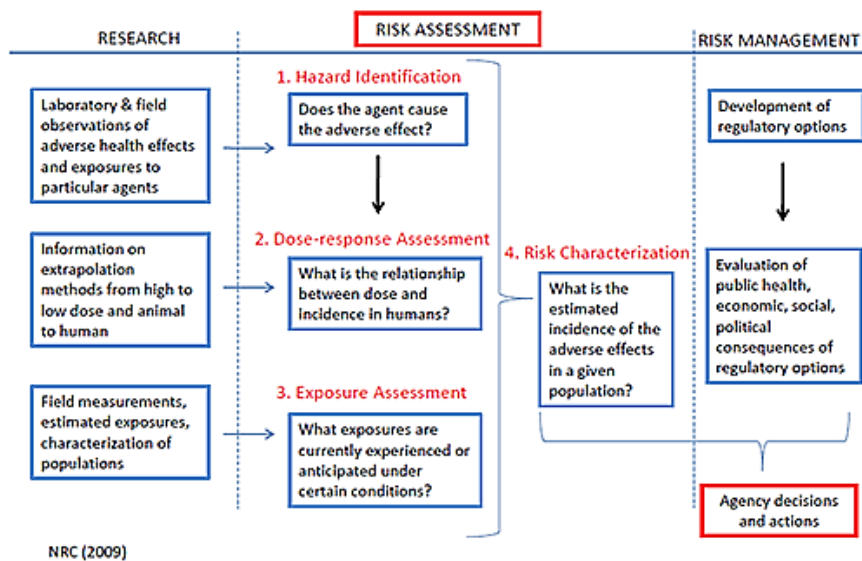


Figure 1.4: Diagram illustrating the interface between research, risk assessment, and risk management and the components of each that plays a role in determining how the EPA makes a final decision about a pesticide (Paustenbach 2002, NRC 2009).

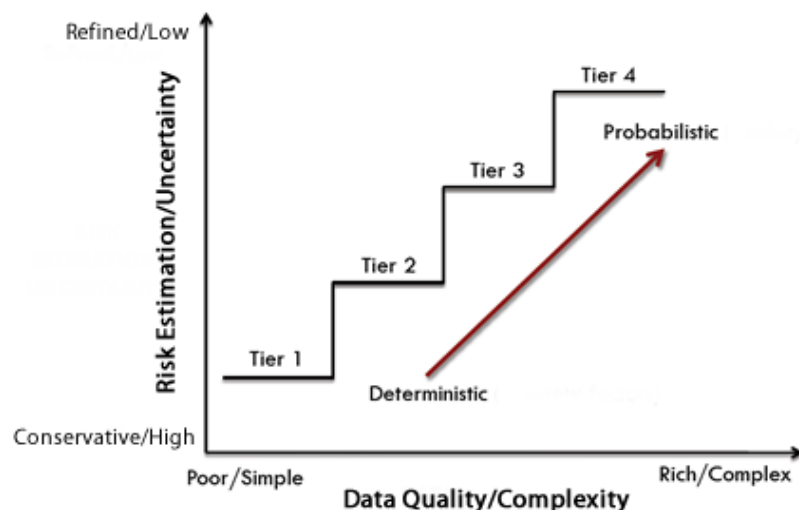
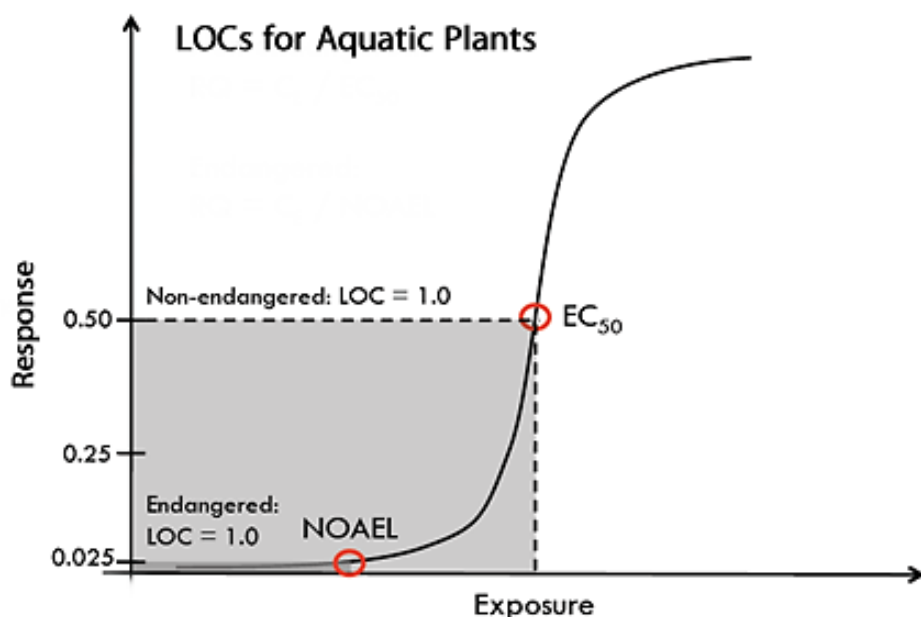


Figure 1.5: Illustration of the EPA's tiered risk assessment process for pesticide registration in the US Tier 1 is deterministic, uncertainty is high, and data are simplistic. If a compound requires further testing, it moves up the tiers increasing in data richness and complexity, decreasing uncertainty and in some cases (tier 4) analyzed in a probabilistic fashion. Image courtesy of David C. Volz (University of South Carolina).



Source: http://www.epa.gov/oppefed1/ecorisk_ders/toera_risk.htm#Deterministic

Figure 1.6: Example of how the Risk Quotient (RQ) value is compared to the Level of Concern (LOC) – in this case for aquatic plants. For endangered species the RQ's toxicity value is the NOAEL, making estimations of risk very conservative. For non-endangered species the LOC is set higher and the EC_{50} is used as the measure of toxicity. Image courtesy of David C. Volz (University of South Carolina).

To determine the estimated environmental concentration (EEC) used in the RQs for ecological risk assessment, the EPA uses the PRZM (Pesticide Root Zone Model) (Carsel et al. 1984) – EXAMS (Exposure Analysis Modeling System) (Burns et al. 1991) model to simulate environmental fate and transport of a compound. The PRZM model simulates chemical movement in soil within and immediately below the plant root zone and EXAMS is a surface water model that evaluates the fate, transport, and exposure concentration of pesticides. Together, the PRZM-EXAMS model simulates pesticide runoff scenario predominantly for agricultural applications. The model uses a 10-hectare field (crop area) with simulated runoff into a static 1-hectare pond that is 2 meters in depth. The output from the model provides daily pesticide EECs (usually in ppb) in the

standard farm pond over the thirty year period for which rainfall data are available. This became the Environmental Fate and Effects Division (EFED) of the EPA standard method for pesticide aquatic ecological exposure assessment as it was shown to also be a good predictor for concentrations in small but ecologically important upland streams (Effland et al., 1999). Importantly, the EFED's Tier 2 assessment model contains golf course adjustment factors to account for percent acreage of a golf course that is labeled for treatment with an individual pesticide - creating more accurate estimates for golf course scenarios (EPA 2013). This utility of this environmental fate and transport model is limited though, most likely not working well in tidally dominated streams in estuarine ecosystems.

Estuarine ecosystems are dynamic with lotic (i.e., moving rather than static) waters and a diverse array of substrates and organisms. Ideally, for residential pesticide application, applicators could view an interactive geospatial map – containing important landscape and climatic components needing consideration before pesticide application occurs. Moreover, efficacy of pesticide application among residents could be improved if they could search for the property where pesticide application is going to occur (i.e., address search) for more spatially-detailed information on important landscape features needing to be considered for proper application.

The EPA utilizes the Office of Chemical Safety and Pollution Prevention (OCSPP) Harmonized Guidelines for hazard assessments (EPA 2013). Also, surrogate species are used to represent larger groups of organisms. For instance the honeybee acts as the surrogate test species for all non-target terrestrial insects. Appendix A provides a

brief overview of some of the main toxicity assays required for pesticide registration by the EPA.

1.3.2 Uncertainty within Ecological Risk Assessment

At the ecosystem-level variation within habitats (and organisms) creates a range of values for exposure to pesticides (i.e., hazard) (Figure 1.8). Accounting for the uncertainty due to this variation for quantifying hazard and exposure for risk assessments is a necessity. If this uncertainty is unaccounted within the ecological risk estimates then it compounds with further estimates. Ecological hazard assessments performed in a laboratory setting, with surrogate species to represent various taxa, leave uncertainty in toxicity points being assessed due to species to species variation, chosen concentrations for exposure regimes, and various other factors. Realistically, ecosystem function, makeup, and biodiversity vary widely. Estimates must be assessed for many species based on one representative species. There is also great variation in ecosystems – from terrestrial habitats to aquatic and marine habitats – as well as spatiotemporal variations in ecological endpoints where extrapolation of values may create more uncertainty (Figure 1.7).

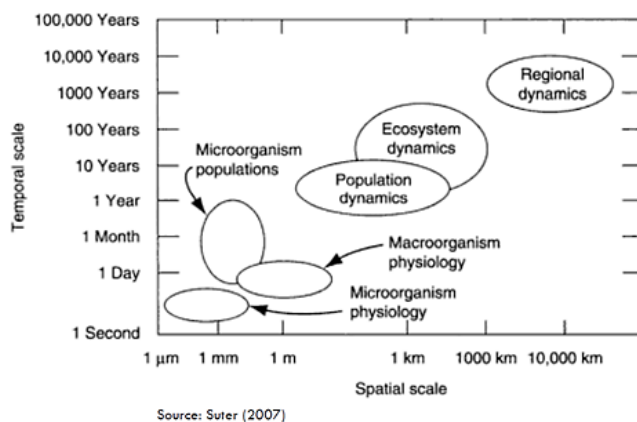


Figure 1.7: Spatiotemporal scales of ecological endpoints, emphasizing the complexity of forecasting long-term changes due to impairments. Image from Suter (2007).

Next, inherent uncertainties (unknown factors that are a property of observer and may be reduced by further research) in toxicological data occur, as it would be exceedingly costly and nearly impossible to test all possible non-target/target species that may be exposed to a pesticide. Variation in response from the surrogate species used for testing in the EPA's current regulatory framework for ecological toxicity tests. However, there are many pest species within the United States and there is likely species-to-species variability in susceptibility to pesticides that is unaccounted for in the data.

Also, lack of availability of pesticide use data, especially at larger spatial scales (i.e., county level) creates uncertainty in risk estimates. Pesticide sales data are available for pesticides for the entire United States, as reported by the registrants. One cannot truly calculate risk without accurate estimates of pesticide use (i.e., exposure). For South Carolina, the National Agricultural Statistics Service (NASS) has the best approximation of use that can be obtained, and it is not broken down into specific pesticides. These data are only for agricultural areas as well not fully encompass all areas where pesticides are applied, particularly in coastal areas. Use (i.e., application) data of products are proprietary with the exceptions being in California and New York. Given the lack of pesticide use data in the coastal study area (for both agricultural and non-agricultural applications), it is difficult to estimate risk of pesticides to the environment or to human health (Table 1.1 – NASS 2007). Farmers in South Carolina voluntarily submit use data to show proper use of pesticides (i.e., no improper use that potentially cause adverse effects to the surrounding ecosystem), but this still does not account for residential use of pesticides. The level of risk always varies as a function of exposure (Samuel et al. 2007). However, the review and evaluation of various residential pesticides can act as a baseline

for decision-making concerning the use of less toxic pesticides and implementation of IPM practices for homeowners, local legislators, landscapers, golf course managers, and developers alike.

With these challenges acknowledged, we proceeded to develop a relative cumulative ranking system with the best available data and using the most conservative (and therefore safest) estimates for all endpoints considered within the relative cumulative ranking assessment. Only the active ingredient (AI) is tested during toxicological testing, but is usually found in a formulation with more than one AI, possibly altering the toxicity of an AI. An AI's byproducts (pesticide changes state as it enters into the environment or is absorbed, distributed, metabolized, and excreted by organisms) may be more or less toxic than the original AI that is applied.

1.3.3 Increasing Complexity in Risk Modeling

In order to estimate risk, one must also consider hazard and an estimate of exposure. RQs give one measure of ecological risk, but are based on deterministic quotients and not necessarily accounting for effects distributions over space and time. While this method of risk assessment is an effective strategy and much easier to convey to the public, it is also filled with uncertainty. Taking a probabilistic approach generates distributions of exposure and effects decreasing uncertainty in the risk assessment. Using Monte Carlo analysis (Zolezzi et al. 2005) gives 10,000 simulations generating a distribution expressing the likelihood of quotients being exceeded. This gives more realistic estimates of exposure as it takes temporally and spatial variables into consideration. The utility of this more complex approach comes into play when decision-making and risk management is limited in a space (e.g., a point-source discharge on a river posing potentially risk to downstream populations). There are currently programs

Table 1.1: Farmland (# acres) treated with various pesticides for control of insect, weed, nematode, and disease pests in South Carolina (SC), and in the three target counties: Beaufort, Hampton, and Jasper Counties, SC.

	Pest treated	Acres of farmland treated	% of total farm acres treated	Total acres in farms*
By County				
Beaufort				49,401
	Insects	2,912	5.9%	
	Weeds	2,417	4.9%	
	Nematodes	1,354	2.7%	
	Diseases	742	1.5%	
	Total_{Beaufort}	7,425	15.0%	
Hampton				126,753
	Insects	21,876	17.3%	
	Weeds	28,257	22.3%	
	Nematodes	10,801	8.5%	
	Diseases	7,712	6.1%	
	Total_{Hampton}	66,646	52.6%	
Jasper				52,132
	Insects	3,618	6.9%	
	Weeds	3,793	7.3%	
	Nematodes	142	0.27%	
	Diseases	D	-----	
	Total_{Jasper}	7,553	14.5%	
SC		746,890		4,889,339
	Insects	746,890	15.3%	
	Weeds	1,087,492	22.2%	
	Nematodes	222,707	4.5%	
	Diseases	175,644	3.6%	

*All Farms included in the National Agricultural Statistics Service (NASS) includes dairy farms, ornamentals, as well as vegetable and fruit farms; D = Withheld to avoid disclosing data for individual farms

available used for taking the probabilistic risk approach including @Risk (Palisade – www.palisade.com/risk) or Crystal Ball (Oracle – www.oracle.com). It should be noted that the author is not endorsing the aforementioned probabilistic risk modeling systems, but rather is using them as viable examples. Picado et al. (2010) predicted risk of mercury to children inhabiting a gold mining region of Nicaragua using a probabilistic risk-based

approach. When the likelihood of an endpoint hazard quotient exceeded the benchmark level of 1.0 then, @Risk would run 10,000 iterations giving a distribution of values and the probability of posing unacceptable risk (Picado et al. 2010). Figure 1.8 depicts the spatial distributions of the risk of groundwater contamination for people living in the region. This example of using probabilistic risk approaches allowed the region with the highest risk to be identified first – an economically viable and effective public health strategy.

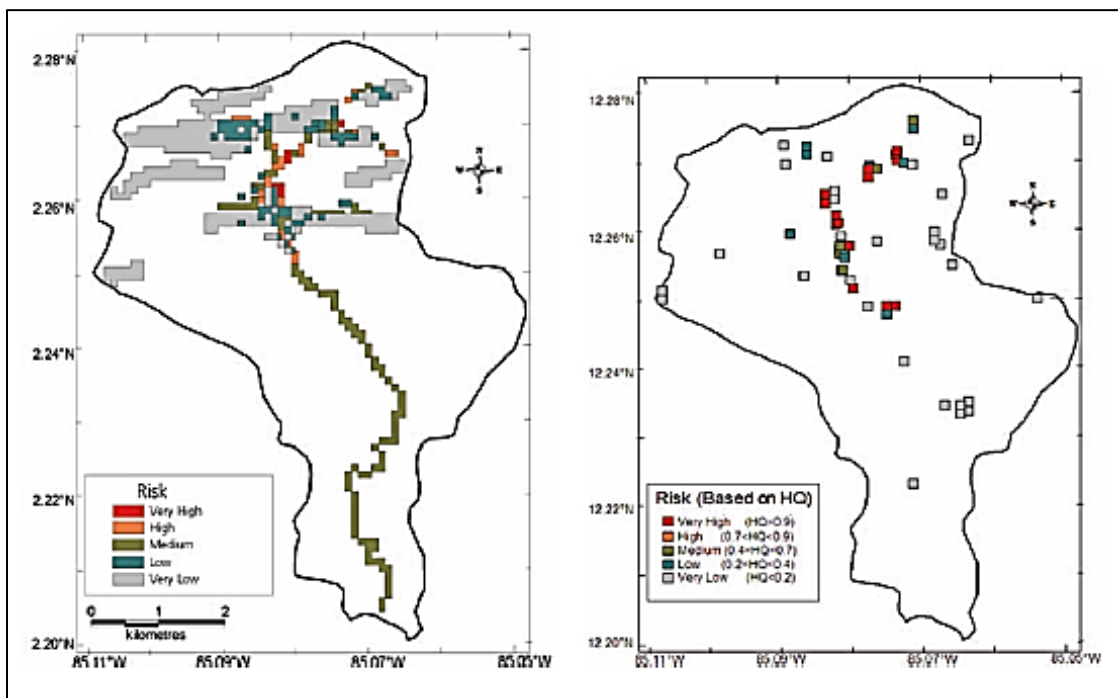


Figure 1.8: Example of the increasing spatial accuracy provided in risk assessment when a probabilistic approach (left) is taken looking at effects distribution rather than a single quotient (right). This leads to risk reduction strategies being applied to the areas with highest risk first, decreasing response time and saving money by reducing the area of mitigation. Image from Picado et al. (2010)

From a hazard (toxicity) perspective – the process of gathering all of the toxicological data required is long, expensive, and brings debate over ethical boundaries given the numbers of animals used in chemical/pesticide testing. Going back to a tiered

approach, current developments in high throughput assays – creating an initial hazard screening that is relatively fast and uses small animal (i.e., lower taxa) models – provide useful initial data, indicating if the chemical should move to testing in higher taxa. Utilizing this hazard assessment framework begins with a baseline assessment for each chemical tested – allowing for prioritization of compounds that potentially cause adverse effects as well as decreasing animal (e.g., rodents, dogs, and primates) usage for hazard testing. Ultimately, this can increase profits for manufacturers’ and allows for more focus to be placed on chemicals possibly causing adverse effects that need further hazard testing.

1.4 PREVIOUSLY DEVELOPED CUMULATIVE RANKING SYSTEMS FOR PESTICIDES

Estimating realistic models of risk of residential pesticides to the environment presents challenges as exposure data are not known to be available for the study area; all species are not directly tested for effects hazards, and comparability among pesticides concerning relative hazard to the environment is difficult. In an effort to estimate the adverse impacts that pesticides potentially have on the environment and human health, several attempts have been made to develop indicator systems (e.g., Rues et al. 2000, Brown et al. 2003, Hart et al. 2003, Lewis et al. 2003, Whelan et al. 2005, Benbrook et al. 2007, Samuel et al. 2007). There is increasing consensus that such indicators should be based on risk (rather than hazard) and should be consistent with methodology utilized in the current regulatory framework (Brown et al. 2003, Hart et al. 2003, Lewis et al. 2003, Whelan et al. 2005). Often, the indicator systems to-date focus on identifying cases when pesticides are over used thereby making mitigation measures more effective (Whelan et al. 2005), or focus on monitoring pesticide application over time to determine impacts to water quality. Many risk indicators and assessment tools developed to date are

predominantly intended for agricultural chemical applications alone, as these were the intended user groups. Ultimately, it must be decided by the system developer and based upon user group needs as to what should be considered in a multi-compartment pesticide risk indicator system. Measurement systems must find an acceptable balance between complexity and accuracy, and practicality and cost (Benbrook et al. 2007). Based on our need for an easily understood yet viable ranking system for public users – and based on feedback from the public within the study area – we focused on the relative hazard on the ranked pesticides, and also consider bioaccumulation ($\log K_{ow}$), persistence in the ecosystem (half-life), and potential runoff or sorption to soils (K_{oc}). EPA risk estimates for pesticides are estimated for the nation, whereas we are focusing on a very specific geographical region. Parameters such as estimated soil saturation, variability across the landscape (pervious cover not included), and the tidal fluxes within the study region introduce uncertainty into ecological risk assessments. Using raw data for each endpoint assessed will give the users information about the relative safety to the surrounding ecosystem.

In summary, with the discussed background information, the following chapters will clearly discuss each section of the project (chapters 2, 3, 4) and determine some conclusions and discussion on the major implications (chapter 5) of the dissertation research completed. Taken in total, it is the intent readers will have a better understanding of the pesticide educational outreach strategy presented in this work.

CHAPTER 2

DEVELOPMENT OF A RELATIVE CUMULATIVE RANKING SYSTEM FOR COMMONLY-USED RESIDENTIAL PESTICIDES IN THREE SOUTH CAROLINA COASTAL COUNTIES

2.1 ABSTRACT

Pesticide usage has supported numerous societal benefits such as a decrease in vector-borne diseases and an increase in food production. In US residential scenarios, pesticides increase overall comfort by decreasing pests in and around homes, and by providing a means of structural protection (e.g., underneath homes). Questions concerning possible adverse effects of pesticides to non-target species (e.g., humans and pets, and organisms in the surrounding ecosystems) have been raised, particularly regarding broad-spectrum pesticides.

The development and usage of pesticides has increased over the past two decades. Approximately 75% of all pesticide usage in the U.S. is in agricultural settings, while the remaining 25% is in home, garden, industrial, commercial, and government applications. All registered pesticides used in the US have been deemed safe by the EPA via a tiered exposure and toxicity testing regime. However, given the population growth and urban expansion of coastal communities, it is imperative that local educational efforts are made to reduce improper application and possible non-point source contamination to adjacent waterbodies by pesticides. One educational strategy is to design and implement pesticide indicator systems at a regional level. A relative cumulative ranking system was

developed for the top one hundred most common residential pesticides used in the SC coastal study area. This system is designed to aid in pesticide decision-making (i.e., by identifying those pesticides that are less toxic and not persistent or bioaccumulative in the environment) for six use categories. Specifically, pesticides for 1) residential applications (indoor and outdoor), 2) golf courses, 3) vector control, 4) right-of-ways, 5) nuisance aquatic species, and 6) tomato farms were cumulatively ranked for relative ecosystem safety. The ranking system is designed to aid residents and residential pesticide applicators make more informed decisions when pests have reached a threshold and chemical pesticides are necessary for control. The indicator system is focused on choosing the safest yet most effective pesticide for infestation scenarios residents may face.

The relative cumulative ranking system normalizes values for thirteen different endpoints for each pesticide – giving each endpoint equal importance in the final analysis. All endpoint data were derived from EPA documents to maintain consistency with the current regulatory framework. Endpoints were chosen in an effort to reflect what was deemed important to the public and to take a relatively complex group of values and develop an easily understandable ranking system that can be implemented by everyone. With proper implementation and use, this approach can help identify the safest pesticides and potentially reduce adverse impacts on the surrounding ecosystems.

2.2 INTRODUCTION

The worldwide transition into a global-driven economy has resulted in a substantial conversion of rural lands into urbanized areas, affecting the mix and availability of commodities and services to all populations (Alig et al. 2004). From 1990

to 2010, the global population grew by ca. 1.6 billion people (United Nations 2010). Within the U.S., the population has grown to an estimated 310 million people (United Nations 2010), over half of whom live in the coastal zone (Culliton 1998). The growing population has resulted in urban expansion into sensitive ecosystems and has threatened the economic viability of the coastal zone, as seen in Figure 2.1 (Alig et al. 2004). Correlations between an increase in urbanized land use and a decrease in water quality have been well documented (Vernberg et al. 1992; Young and Thackston 1999; DHEC et al. 2000). The increased levels of anthropogenic influences on the marine ecosystem due to urbanization have created a variety of changes, including a change in the overall trophic structure of the ecosystem (Gislason et al. 2000, Arcos 2001).

New suburban areas began to flourish in the 1950's, 1960's and 1970's in South Carolina (Frey and Speare 1988, Long 1988). Immigration to the state resulted in a new population dynamic, augmenting the natural population increase (Brown and Wardwell 1980, Allen and Lu 2003). From 1960 to 1990, urban growth and sprawl (i.e., urban growth that does not provide infill in already developed areas, but rather moves to undeveloped terrestrial areas expanding the urban geographical coverage) exceeded population growth at a ratio of 6.2:1 – almost triple that of the national average (2.3:1) (Allen and Lu 2003). More recently, the U.S. Census Bureau (2010) indicated that South Carolina's population has grown 15-25% between 2000 and 2010 (Figure 2.2). The census data for the study area of this project (Beaufort, Jasper, and Hampton Counties, South Carolina) demonstrates more than 25% population growth in Beaufort, between 16 to 25% growth in Jasper County, and population loss in Hampton County (Figure 2.2).

The rapidly growing population of South Carolina coastal communities is reflected in its booming tourism industry.

Tourism in South Carolina, which is largely reliant on coastal recreation, represented \$9.6 billion of commerce in 2003 (Dorfman 2005). Ecosystem health and the coastal economy are tightly linked, as the tourism industry relies on the aesthetic appeal of coastal lands and the harvested seafood (e.g., fish, shrimp, shellfish) from the Atlantic Ocean. The reliance upon for a healthy coastal ecosystem is a reality – thus making reductions in anthropogenic risks and impacts to the natural environment vital to the sustainability of ecosystem services in the area.

As population and land conversion increase along the Southeast coast of the U.S., water quality impairments become more frequent (Mallin et al. 2001). Determining the sources and cause of impairments is important to resource managers. For example, the source and cause of water quality impairment in tidal creek ecosystems is the human population density and the associated urbanization (Holland et al. 2004). Urbanization, particularly impervious land cover (e.g., roofs, parking lots, roads), alters the hydrological cycle creating measureable adverse impacts in water quality parameters. Such parameters are demonstrated in Figure 2.3 by a study of multiple ecosystem variables in relation to increased levels of impervious surface (Holland et al. 2004). If land cover reaches or exceeds 10-20% imperviousness, altered hydrography, increased sedimentation, and increased microbial and chemical contaminant loading occur – all leading to measureable water quality impairments (Figure 2.3) (Holland et al. 2004). Once the degree of impervious surface within a watershed reaches thirty percent, severe biological degradation occurs (Schueler 1994, Arnold and Gibbons 1996). Chemical

pesticides are just one type of compound that contributes to water quality impairments, but one that deserves attention in an effort to decrease future impairments.

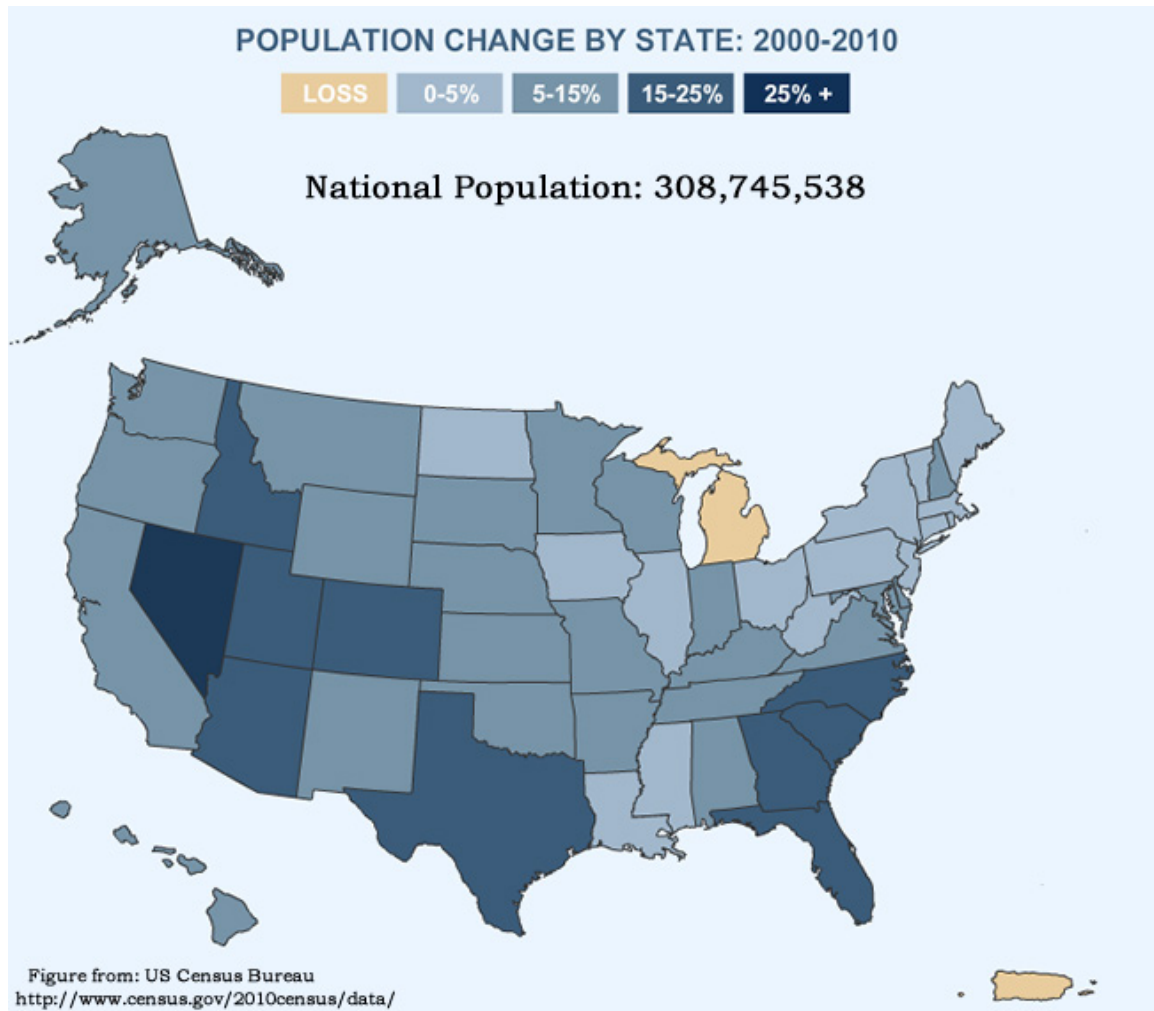


Figure 2.1: Percent population change per state in the U.S. between the years 2000 and 2010. South Carolina's population increased between 15-25% within the ten year period.

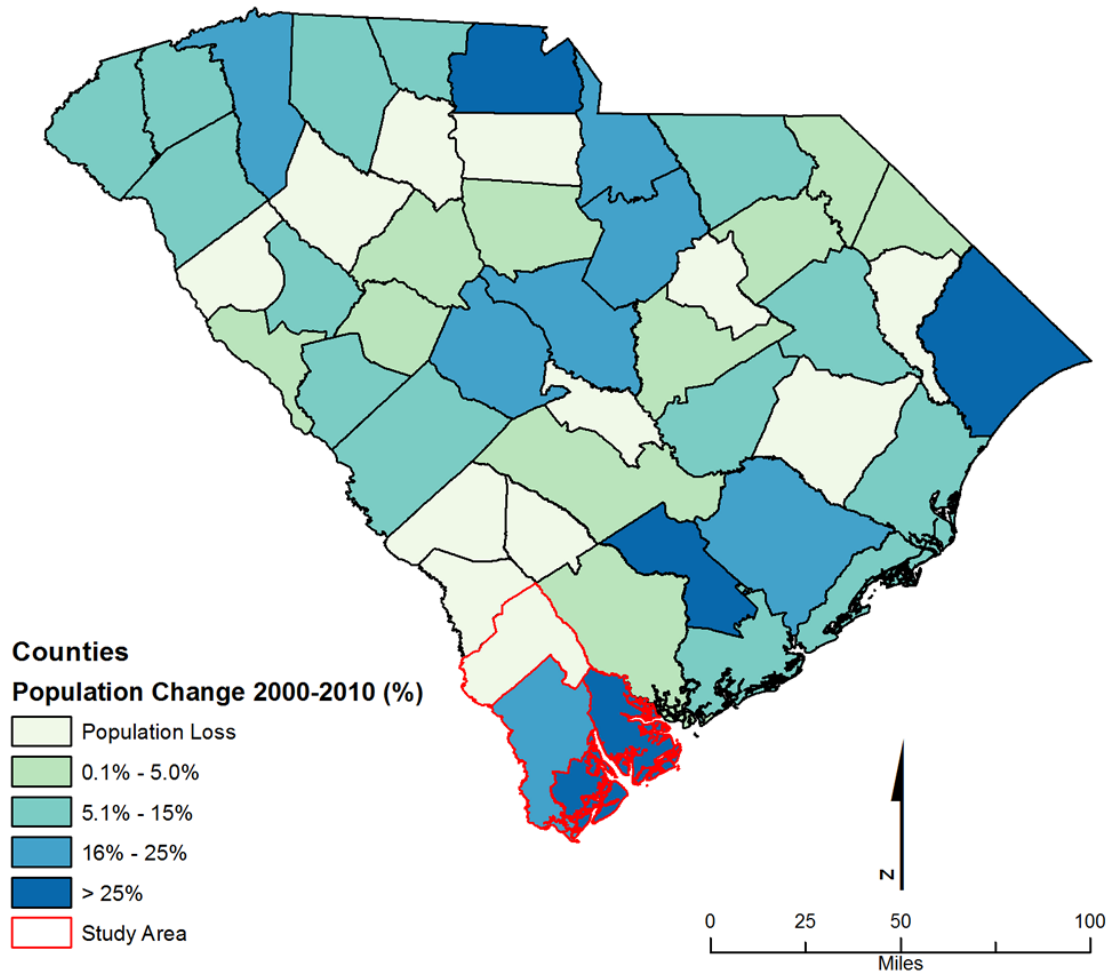


Figure 2.2: Population change between 2000 and 2010 for each South Carolina County. For the target counties, the 2010 census data (US Census Bureau) estimates >25% growth in Beaufort, between 16-25% in Jasper, and population loss in Hampton County.

One group of chemical contaminants potentially leading to water quality impairments are pesticides. Approximately one billion pounds of conventional pesticides (i.e., herbicides, insecticides, fungicides, and a mixed group of fumigants, nematicides,

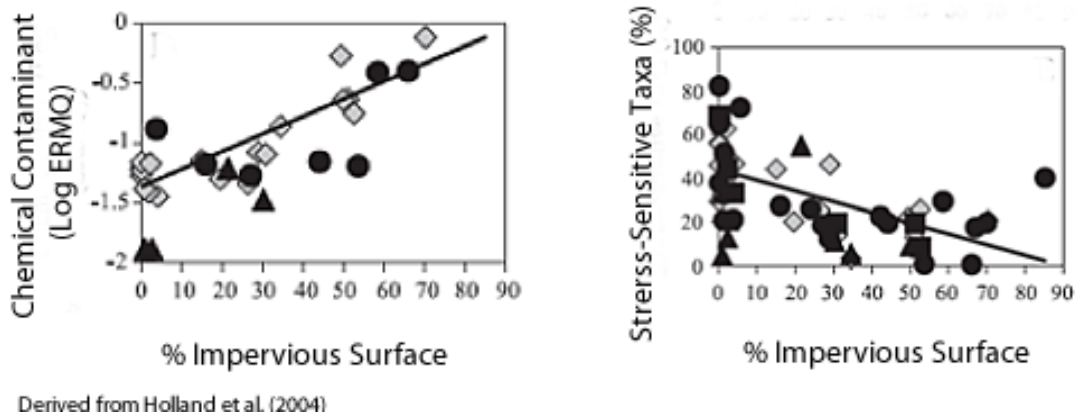


Figure 2.3: Holland et al.'s (2004) findings for chemical contaminant loading and presence of stress-sensitive taxa as the percent of impervious surface increases. The regression lines indicate an increasing trend in chemical contaminant loading and a decrease in stress-sensitive taxa (e.g., grass shrimp) as the percent of impervious surface increases. Once land is 30-40% imperviousness, it increases runoff by 300%.

and other pesticides) are used each year in the U.S. to contain or control various pests (Gilliom et al. 2006). As of 1997, approximately 900 pesticides were registered in the U.S. for use in more than 20,000 different products on the market (Aspelin and Grube 2006, Gilliom et al. 2006). Additionally, about 4 million pounds of non-conventional pesticides (e.g., chlorine disinfectants, wood preservatives, and other specialty products) are used each year in the US (Gilliom et al. 2006). New pesticides – typically 10-20 per year as indicated by registration from 1967 to 1997 – are introduced as new pests-related problems arise, organisms gain resistance, and older products are determined to be more harmful than initial laboratory testing indicated (Aspelin and Grube 2006).

Pesticides – regulated under FIFRA, FQPA, FD&C Act, and PIRA3 in the US – undergo a tiered testing regime to ensure safety (if label instructions are followed) before products enter the market (EPA 2011a). Therefore, all pesticides currently on the market

are considered safe by the EPA if used properly. However, the toxicity of pesticides varies widely (even among the same classes of pesticides) among organisms (Hartwell 2011) due to factors temperature, age, or life stage. Pesticides are currently registered through the EPA by risk assessment of individual active ingredient pesticides. While this is a valid approach, it is difficult to assess the potential additive toxicity that occurs in brand name formulations with multiple active ingredient pesticides, synergists (e.g., PBO) and inert ingredients. This leaves uncertainty for toxicological effects for formulations available to the public and pesticide applicators.

Although the full effect of pesticides is not fully known, pesticide usage has resulted in numerous benefits such as decreases in vector-borne disease and an increase in food production (Gilliom et al. 2006). However, by their very nature, most pesticides pose some risk negative impacts on non-target species, as they are designed to kill or otherwise adversely affect living organisms when exposure occurs (EPA 2011). Sparse (infrequent, with coarse geographic coverage) data exist for agricultural uses of pesticides in the US and data are even more limited for nonagricultural uses (Gilliom et al 2006).

The US EPA estimates that approximately 75% of all pesticide usage in the nation is agricultural, while 25% is for home, garden, industrial, commercial, and government applications (Hartwell 2011). Given the proportion of pesticides used in non-agricultural scenarios in the U.S. each year, it is important to account for use in residential areas. Pesticide use intricately ties to urban expansion and suburban sprawl. As a resource management and regulatory strategy, an integrated pest management (IPM) approach accompanied by user education and access to decision-making tools can aid in

maintaining the control of pest problems and also decrease the potential adverse impact on the natural environment within non-agricultural settings.

Pesticides used in residential areas include applications within homes, on lawns and turfgrass, in right-of-way easements, landscaped areas (ornamentals), and for vector control. As pest problems (e.g., severity of infestation, area of application, and type of application) are unique in many respects, educational efforts for commonly-used residential pesticides and proper application are imperative. If residents understand the potential hazard improper use of pesticides presents – then efforts can be made by all to maintain the functionality, economic viability, and aesthetic appeal of a balanced estuarine ecosystem.

Localized (i.e., county and regional scale) efforts can minimize water quality impairments in surrounding surface waters and groundwater within watersheds. With the support of grassroots efforts and local communities, specific pesticides used in a given area can be identified and a relative cumulative ranking system can be developed. Indicator systems have been previously developed to estimate the adverse impacts pesticides potentially have on the environment and human health (e.g., Rues et al. 2000, Brown et al. 2003, Hart et al. 2003, Lewis et al. 2003, Claeys et al. 2005, Whelan et al. 2005, Benbrook et al. 2007, Samuel et al. 2007). Often, the indicator systems focus on identifying cases when pesticides are over used, thereby making mitigation measures more effective (Whelan et al. 2005). Additionally, indicator systems focus on monitoring pesticide application over time to determine impacts to water quality.

Many risk indicators and assessment tools developed to date are predominantly intended for agricultural chemical applications alone. One indicator system, the POCER

(Claeys et al. 2005) is intended for non-agricultural purposes, but is based on European data and endpoints. Ultimately, it must be decided by the system developer and based upon user group needs as to what should be considered in a multi-compartment pesticide risk indicator system. Measurement systems must find an acceptable balance between complexity and accuracy, and practicality and cost (Benbrook et al. 2007).

In an effort to provide the residents of Beaufort, Jasper, and Hampton counties with a comprehensive evaluation of the hazard of commonly used pesticides, the major **goal** of this study was to cumulatively evaluate pesticides commonly utilized for 1) residential applications (indoor and outdoor), 2) golf courses, 3) vector control, 4) right of ways, 5) algae removal, and 6) tomato farms (Figure 2.4). The aforementioned categories were chosen based public and non-governmental organizations (NGOs) input in Beaufort County, SC and do not necessarily address specific areas that have been identified as problematic concerning pesticide use. The *first aim* of this study was to develop a list of the one hundred most commonly used residential pesticides. The *second aim* was to mine data from EPA databases on thirteen endpoints for each pesticide. The *third aim* was to relatively cumulatively rank the compounds based on what the public expressed as important when evaluating pesticides for overall safety. The cumulative evaluation process for pesticides is based on acute and chronic toxicity values (i.e., hazard data) and physical and chemical properties (i.e., environmental fate and transport characteristics) of pesticides. Values were derived from the US EPA documents as to not deviate from the values utilized in the regulatory framework and to maintain consistency in comparing the compounds. It should be emphasized here that this evaluation emphasizes hazard (i.e., acute and chronic toxicity values) and predicted movement of the pesticide based on

physical and chemical properties of that pesticide. The basic assumption emphasized here is that if applied according to label instructions, unacceptable levels of risk will not be exceeded. The developed ranking system will give users information on the relative hazard a pesticide may pose in the presence of proper and safe pesticide application rates and practices.

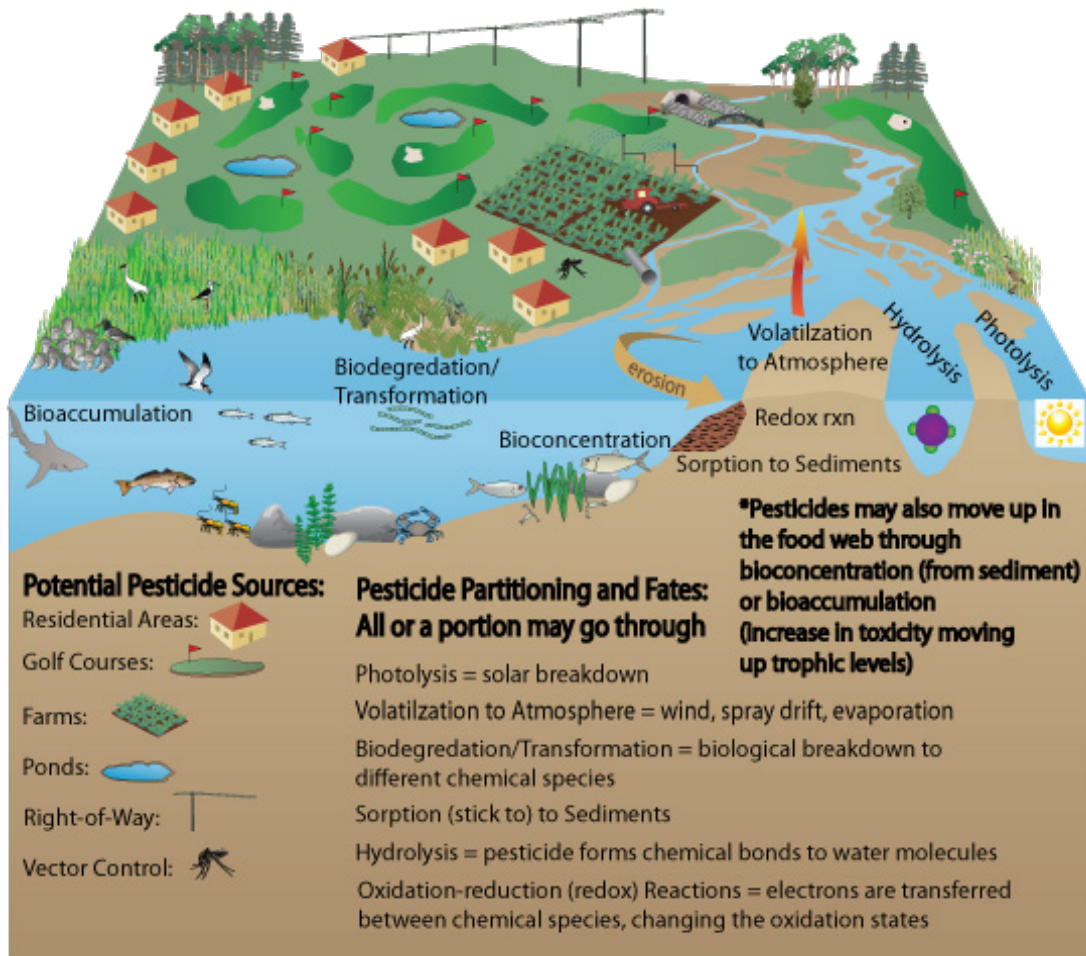


Figure 2.4: Conceptual Diagram of the potential sources of pesticides, and the environmental processes that potentially influence the final fate of pesticides in a South Carolina coastal suburban residential scenario.

2.3 METHODOLOGY

2.3.1 Study Area

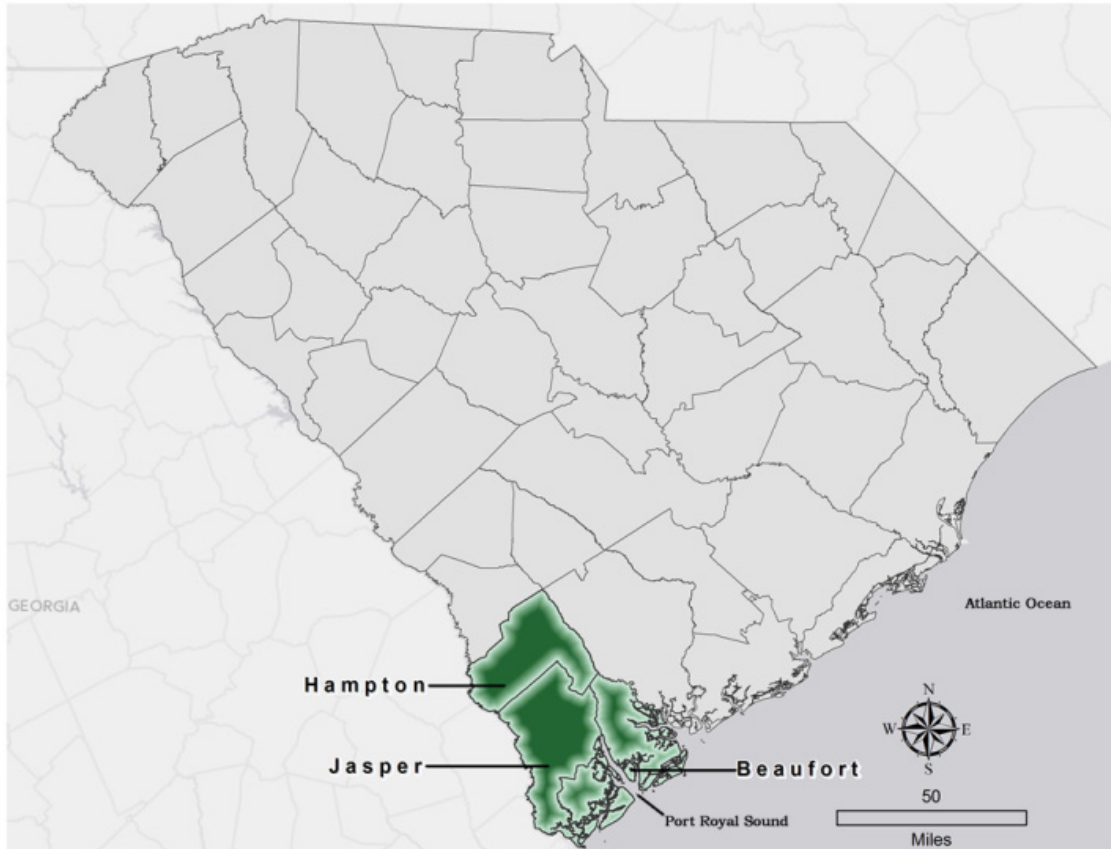


Figure 2.5: The three target counties chosen for the initial trial of the pesticide decision-support tool in South Carolina. Beaufort and Jasper Counties both share boundaries that line the Port Royal Sound and contain coastal borders. Hampton County is unique in that it does not share these same characteristics, but importantly urban and agricultural areas within the county may contribute to water quality impairment's as water moves downstream to the Atlantic Ocean.

The study area consists of the three most southern counties in South Carolina: Beaufort, Jasper, and Hampton Counties (Figure 2.5). As mentioned earlier, census data indicates that the population within Beaufort and Jasper Counties has increased by 25% between 2000 and 2010 (U.S. Census Bureau 2010) – giving rise to greater urbanization and residential pesticide usage. Hampton County decreased in population over the ten-

year period, but still remains important as water from urban and agricultural activities ultimately affects the quality of water in the water table and some surface water eventually flowing into the Port Royal Sound. The Port Royal Sound system is unique compared to other coastal areas in North America due to the large embayment dominated by expansive salt marshes and high salinity water. An embayment was created when rising sea levels submerged valleys along the coast and extended the marine habitat inland for 10 miles (LowCountry Institute 2012). The Sound also has exceptionally high tidal amplitude, low lying topography, and extensive salt marsh habitat. Beaufort County alone accounts for half of South Carolina's salt marsh habitats. The geographical features and location, along with population and land use changes within the target counties makes it an ideal study area for initial implementation of a residential relative cumulative ranking system for pesticides.

2.3.2 Developing a List of Commonly-Used Residential Pesticides in the Tri-county Area

Identification of the top one hundred pesticides was determined for the six identified use categories within the study area (Table 2.1). Clemson University's Office of Pesticide Regulation and the Cooperative Extension Office were integral in this process. Specifically, vector control agents used within the tri-county area, were identified through records kept on vector control efforts (predominantly for mosquito control). Next, Lowe's Home Improvement Store generously provided a comprehensive list of pesticide formulations that were most frequently purchased for in home pest control and lawn care. A list of pesticides registered for use on golf courses in South Carolina was obtained from the 2013 Clemson University Pest Control Guidelines for Professional Turfgrass Managers (http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/) (McCarty 2013). Within this comprehensive list of pesticides used

on turf grass, herbicides, insecticides, fungicides, and algaecide data were compiled as well as pests treated. For algaecides the South Carolina Department of Natural Resources Nuisance Aquatic Species Program (<http://www.dnr.sc.gov/invasiveweeds/homeowner.html>) was also used to comprise a comprehensive list of algaecides. For herbicides used in right-of-way areas, the local utilities company generously provided both information of pesticides used and best management practices implemented in treated areas. Finally, the Southeastern U.S. 2013 Vegetable Crop Handbook (<http://www.thegrower.com/south-east-vegetable-guide/pdf/>) was referenced for commonly used pesticides on tomato farms (Kemble 2013). Gathering these lists was time intensive and could not have been completed without collaborative efforts with multiple stakeholder contributions.

2.3.3 Data Mining

Values for each endpoint in toxicity and environmental fate tests being considered for each of the one hundred pesticides were mined from published documents from relevant governmental agencies. Data were gathered from US EPA Reregistration Eligibility Decisions (REDs), Interim REDs (IREDs), and the US National Library of Medicine's Toxicology Data Network (<http://toxnet.nlm.nih.gov/index.html>). Data were gathered from the OCSPP guideline assays conducted for registration or reregistration of an active ingredient pesticide under EPA guidelines (EPA 2013). Briefly, representative or (surrogate) species are chosen to represent a much larger community of organisms. For instance, the honeybee is used to represent all terrestrial insect species. Acute (short-term), sub-chronic (non-fatal endpoints), and chronic tests (long-term) are conducted

Table 2.1: One hundred active ingredient pesticides chosen for the relative-cumulative ranking of commonly-used pesticides in the Beaufort, Hampton, and Jasper counties, SC. Pesticide class is: A = algaecides, F = fungicide, H = herbicides, A = algaecides, and S = synergist. In total, 12 fungicides, 6 algaecides (strictly), 43 herbicides, 39 insecticides were included in the analysis. Several of the pesticides reviewed, fall into two or more pesticide classes (e.g., algaecide, herbicide) and should be noted here.

Active Ingredient	Pesticide Class	Active Ingredient	Pesticide Class	Active Ingredient	Pesticide Class
2,4-D	H, A	Napropamide	H	Imidacloprid	I
Copper compounds	A, F	Pendimethalin	H	Malathion	I
Glyphosate	A, H	Fluroxypyr	H	Etofenprox	I
Imazapyr	A, H	Siduron	H	Trichlorfon	I
Penoxsulam	A, H	Benefin	H	Dicofol	I
Carfentrazone	A, H	Fenoxaprop-ethyl	H	Cyfluthrin	I
Endothall	A, H	Indaziflam	H	Temephos	I
Flouridone	A, H	Metolachlor	H	Hydramethylnon	I
Triclopyr	A, H	Oryzalin	H	Indoxacarb	I
Simazine	A, H	Bromoxynil	H	Chlorpyrifos	I
Hydrothol	A, H	Pronamide	H	Methiocarb	I
Sodium-carbonate Peroxyhydrate	A,H	Diclofop-methyl	H	Endosulphan	I
Fosetyl-Al	F	Fluazifop-butyl	H	Abamectin	I
Mandipropamid	F	Paclobutrazol	H	Fipronil	I
Thiophanate-methyl	F	Dimetthenamid	H	Piperonyl butoxide (PBO)	I, S
Pyraclostrobin	F	Atrazine	H	Boric Acid	I, F, A
Mancozeb	F	Dithiopyr	H	Glufosinate	H
Myclobutanil	F	Oxadiazon	H	Clopyralid	H
Trifloxystrobin	F	Bensulide	H	Quinclorac	H
Difenoconazole	F	Bispyribac-sodium	H, A	Trinexapac-ethyl	H
Iprodione	F	Diquat	H, A	Clethodim	H
Vinclozolin	F	Metham-sodium	H, F, I	Ethofumesate	H
Asoxystrobin	F	DEET	I	Isoxaben	H
Chlorothalonil	F, I	Bacillus thuringiensis (BTI)	I	Halofenozide	I
Rimsulfuron	H	Naphthalene	I	Permethrin	I
Dicamba	H	Dinotefuran	I	Chlorantraniliprole	I
Asulam	H	Thiamethoxam	I	Clothianidin	I
Mesotrione	H	Methoprene	I	Spinosad	I
Metasulfuron-methyl	H	Pyriproxyfen	I	Carbaryl	I
Aminocyclopyrachlor	H	Acephate	I	Hexaflumuron	I
Foramsulfuron	H	Sumithrin	I		
Imazaquin	H	Bifenthrin	I		
Sethoxydim	H	Deltamethrin	I		
Sulfentrazone	H	Lambda-cyhalothrin	I		

for hazard assessment of pesticides. Within the relative cumulative ranking system acute and chronic endpoints were used, but not sub-chronic, as these endpoints vary based on the pesticidal mode of action and were not consistently found for all the pesticides covered in the analysis. Sub-chronic endpoints should be considered when human health risk assessment and characterization is being conducted, but may not always be relevant to decision-making within an ecological assessment. Additionally, only *in vivo* tests are used in the cumulative ranking scheme, as *in vitro* assays are aimed more towards human health risk assessment. The terrestrial plants tests (OCSPP GLN #'s: 850.4100, 850.4150, 850.4230, 850.4300) (EPA 2013) were also excluded from the analysis as these data were not consistently found for all compounds. Figure 2.6 illustrates the endpoints considered for each pesticide. Each assay considered has an assigned Office of Chemical Safety and Pollution Prevention (OCSPP) guideline number for it (EPA 2013). The following representative bioassays for hazard assessment were used in the cumulative ranking of the chosen 100 residential pesticides. Detailed descriptions of each assay's guidelines can be found in Appendix A.

- Acute Toxicity: Acute Oral Rat Toxicity – updated in 1996; GLN #: 870.1100 (EPA 2013)
- Chronic Toxicity: Chronic Feeding Study – updated in 1998; GLN #: 870.4100 (EPA 2013)
- Acute Toxicity: Avian Acute Oral Toxicity Test – updated 2012; GLN #: 850.2100 (EPA 2013)
- Chronic Toxicity: Avian Dietary Toxicity Test – updated 2012; GLN #: 850.2200 (EPA 2013)
- Acute Toxicity: Honey Bee Acute Contact Toxicity – updated 2012; GLN #: 850.3020 (EPA 2013)

- Acute Toxicity: Aquatic Invertebrate Acute Toxicity Test – updated 1996; GLN #: 850.1010 (EPA 2013)
- Chronic Toxicity: Daphnid Chronic Toxicity Test – updated 1996; GLN #: 850.1300 (EPA 2013)
- Acute Toxicity: Fish Acute Toxicity Test – updated 1996; GLN #: 850.1075 (EPA 2013)
- Chronic Toxicity: Fish Early Life-stage Toxicity Test – updated 1996; GLN #: 850.1400 (EPA 2013)
- Acute Toxicity: Algae Toxicity Test – updated 1996; GLN #: 850.5400 (EPA 2013)

There were also environmental fate and transport values considered that are also considered by the EPA during registration of a compound and include:

- ***n*-octanol-water partitioning coefficient (K_{ow})**

The *n*-octanol-water partitioning coefficient (K_{ow}) is used to predict the bioaccumulation potential in aquatic and terrestrial organisms and to estimate the amount of sorption to soil and sediment (Paustenbach 2002). The equation for the K_{ow} is:

$$K_{ow} = \frac{\text{concentration of chemical in octanol phase}}{\text{concentration of chemical in aqueous phase}}$$

- **Soil Organic Carbon-Water Partitioning Coefficient (K_{oc})**

The Soil Organic Carbon-Water Partitioning Coefficient (K_{oc}) is a ratio of the mass of a chemical that is adsorbed in the soil per unit mass of organic carbon in the soil per the equilibrium chemical concentration in solution (EPA 1996). The K_{oc} is an important predictor of water mobility from the point of application. The K_{oc} is calculated by:

$$K_{oc} = K_d / f_{oc}$$

where: K_d is based on total soil mass and dependent on soil type and % organic matter and increasing K_d values result in decreasing mobility and decreasing values result in increasing mobility.

$$K_d = \frac{\text{concentration of chemical in soil}}{\text{concentration of chemical in water}} = \frac{\text{grams adsorbed / grams organic carbon}}{\text{grams / mL solution}}$$

and f_{oc} = weight fraction of organic carbon

- **Half-life ($T_{1/2}$)**

The half-life of a compound is a measure of persistence and is generally calculated for soil (aerobic and anaerobic), groundwater, and surface water. It is the amount of time (usually in days) it takes a compound to breakdown, transformed, or degraded by 50%.

Compound (Active Ingredient Pesticide)	Aquatic and Non-target Terrestrial Organism Parameters							Mammalian		log Kow	half-life (days)	Koc (ml/g OC)
	Acute				Chronic			Acute	Chronic			
	Phyto toxicity EC50 (ppb)	Aquatic LC50 (ppm)		Avian LD50 (mg AI/kg)	Bee LD50 (μ g/bee)	NOAEL or NOAEC (ppm)		Oral LD50 (mg/kg)	NOAEL (mg/kg/day)			
		Invert	Fish		Avian	Invert	Fish					

Figure 2.6: For each of the 100 pesticides, 13 different endpoints (values) were mined in order to relatively cumulatively rank the active ingredient pesticides.

2.3.4 Cumulative Scoring

Thresholds for the toxicity values were set according to the EPA hazard ranking system and environmental fate and transport values (EPA 2013) (Table 2.2). It is important to note when looking at the LD₅₀/LC₅₀ for toxicity endpoints, that the lower the value the more toxic the compound. Furthermore, for toxicity data, values used for each endpoint are the most conservative values (e.g., lowest LD₅₀/LC₅₀). In the ranking process, the most conservative value from acute and chronic toxicity aquatic non target species (i.e., invertebrates or fish species) was used in the analysis for each pesticide. Relative cumulative rankings are based on thirteen different but equally weighted endpoints. Each endpoint being assessed was given numeric values (1= low, 5= moderate, 10= likely to impact surrounding ecosystems) based on the given thresholds for that endpoint set by the EPA test guidelines (Figure 2.7). Once numeric values were assigned to each endpoint for a pesticide, a summation was taken across all endpoints and averaged. Cumulative values were assigned for all 100 pesticides. It is important to note that occasionally data for all thirteen endpoints was not available (i.e., data gaps) or could not be located by the author for all one hundred pesticides; in these cases a null value of 5

was assigned to that endpoint for that pesticide. This only occurred 4% in the dataset and was therefore deemed an acceptable approach. To create an easily understandable outcome of the analysis for end users, the cumulative scores were used to divide the pesticides into subcategories (low, moderate, and likely hazard to the ecosystem) and were given a corresponding color as an indicator of each category of the three categories – termed bins (Figure 2.8).

2.3.5 Statistical Analysis for Categorical Grouping (3 bin approach)

A cumulative frequency distribution was generated to obtain a final cumulative ranking (i.e., potential relative ecosystem hazard) for all pesticides. The cumulative frequency distribution starts from the lowest and goes to the highest summed values - with the lowest values falling into the low hazard category (“low” bin) and the highest values in to the more “likely” bin. Once normality and variance were checked (Normality = Shapiro-Wilk test, Variance = Levene’s test; $P < \alpha$), cumulative scores were statistically separated into one of three bins using tertiles (33% and below, 33 -67%, and 67-100%) of the distribution. A one-way ANOVA procedure ($\alpha = 0.05$) was performed to determine if significant differences were present between the three bins. Using the post hoc Tukey's Studentized Range (HSD) test to indicate significant differences among all three categorical bins ($\alpha = 0.05$), each tertile (comprising a bin) was checked against the others to confirm that means among bins were significantly different.

2.4 RESULTS

Relative cumulative ranking values ranged from 2.182 (glyphosate) to 9.091 (fipronil). Descriptive statistics indicated that the overall mean ranking value was 5.453 for all pesticides. The active ingredient pesticides with the highest ranking for relative

Table 2.2: Cumulative values assigned for each category being considered for each pesticide. A numeric value (1, 5, or 10) was assigned to each categorical level, with the numeric value increasing with increasing toxicity or environmental fate characteristic. Corresponding color codes to the final cumulative ranking are applied based on summation and then average of the values from each category. This process normalizes the endpoints being considered for each pesticide in the analysis – equally weighing each endpoint. Thresholds were based on EPA thresholds set during ecological hazard or environmental fate assessment (EPA 2013).

I. Acute Aquatic Organism Toxicity Thresholds
(invertebrates and fish) (units = ppm)

10 = $LC_{50} \leq 1$ (very highly to highly toxic)

5 = $LC_{50} > 1$ to 10 (moderately toxic)

1 = $LC_{50} \geq 10$ (slightly to practically non-toxic)

III. Acute Avian Toxicity Thresholds (units = mg/kg)

10 = $LD_{50} \leq 50$ (very highly toxic to highly toxic)

5 = $LD_{50} > 50$ to 2000 (moderately to slightly toxic)

1 = $LD_{50} \geq 2000$ (practically non-toxic)

V. Acute Mammalian Toxicity Thresholds (based on rodent oral LD_{50}) (units = mg/kg)

10 = $LD_{50} \leq 50$ (very highly toxic to highly toxic)

5 = $LD_{50} > 50$ to 2000 (moderately to slightly toxic)

1 = $LD_{50} \geq 2000$ (practically non-toxic)

VII. Acute Honey Bee Toxicity Thresholds (oral or topical application) (units = $\mu\text{g}/\text{bee}$)

10 = $LD_{50} \leq 2$ (highly toxic)

5 = $LD_{50} > 2$ to 11 (moderately to slightly toxic)

1 = $LD_{50} \geq 11$ (practically non-toxic)

IX. Bioaccumulation Potential

10 = $\log K_{ow} \geq 4$ (high bioaccumulation potential)

5 = $\log K_{ow} > 2$ to 4 (moderate bioaccumulation potential)

1 = $\log K_{ow} \leq 2$ (low bioaccumulation potential)

XI. Soil/Water Mobility (Units = ml/g_{oc})

10 = $K_{oc} \leq 1000$ (highly to moderately mobile)

5 = $K_{oc} > 1000$ to 10000 (slightly mobile)

1 = $K_{oc} \geq 10000$ (hardly mobile to immobile)

II. Chronic Aquatic Organism Toxicity Thresholds (units = ppm)

10 = NOAEC ≤ 1 (very highly to highly toxic)

5 = NOAEC > 1 to 10 (moderately toxic)

1 = NOAEC ≥ 10 (slightly to practically non-toxic)

IV. Chronic Avian Toxicity Thresholds (units = mg/kg)

10 = NOAEL ≤ 500 (very highly toxic to highly toxic)

5 = NOAEL > 500 to 5000 (moderately to slightly toxic)

1 = NOAEL ≥ 5000 (practically non-toxic)

VI. Chronic Mammalian Toxicity Thresholds (units = ppm)

10 = NOAEL ≤ 500 (very highly toxic to highly toxic)

5 = NOAEL > 500 to 5000 (moderately to slightly toxic)

1 = NOAEL ≥ 5000 (practically non-toxic)

VIII. Plant Phytotoxicity Thresholds (units = ppb)

10 = $EC_{50} \leq 1100$ (complete control)

5 = $EC_{50} > 1100$ to 10000 (complete to selective control)

1 = $EC_{50} \geq 10000$ (practically non-toxic)

X. Estimated Half Life (from water or soils, whichever is longest)

10 = $t_{1/2} \geq 180$ days (persistent)

5 = $t_{1/2} > 45$ to 180 days (moderately persistent)

1 = $t_{1/2} \leq 45$ days (nonpersistent to slightly persistent)

Compound (Active Ingredient Pesticide)	Aquatic and Non-target Terrestrial Organism Parameters								Mammalian				
	Acute				Chronic				Acute	Chronic			
	Phyto toxicity EC50 (ppb)	Aquatic LC50 (ppm)		Avian LD50 (mg AI/kg)	Bee LD50 (µg/bee)	NOAEL or NOAEC (ppm)			Oral LD50 (mg/kg)	NOAEL (mg/kg/day)	log KOW	half-life (days)	Koc (ml/g OC)
		Invert	Fish			Avian	Invert	Fish					
fosetyl-Al	6790	188	141.4	8000	100	1500	17	100	5400	250	-2.1	5.7	20
fosetyl-Al	5	1		1	1	5	1		1	1	1	1	10



Cumulative Score = 2.545

Figure 2.7: The process of taking the raw value given for an assay (top row) and assigning it a numerical value (bottom row) based on the set thresholds for each endpoint included in the relative cumulative ranking of pesticides. The cumulative value is outlined in blue and is the average of the values. The most conservative of the aquatic assays – acute and chronic – were based on the most conservative (i.e. most toxic) raw values and then assigned a single value for the final ranking.

$$\text{AVG}_{\text{ranking}}(n_1 + n_2 \dots) (> 67\% \text{ in cumulative scoring}) = \text{likely} = \text{orange checkered box}$$

$$\text{AVG}_{\text{ranking}}(n_1 + n_2 \dots) (> 33\% < 67\%) = \text{moderate} = \text{green dotted box}$$

$$\text{AVG}_{\text{ranking}}(n_1 + n_2 \dots) (> 0\% < 33\%) = \text{low} = \text{diagonal striped box}$$

Figure 2.8: Cumulative Scoring of frequency distribution on parameters/pesticide. Thresholds = tertiles of distribution (i.e., lower 33% = highly safe to the ecosystem)

potential ecosystem impact consisted of four insecticides (5 – methiocarb, 4 – endosulfan, 2- abamectin, 1- fipronil) and one herbicide (3 – bensulide). These pesticides were assigned the numerical value of 10 for at least three of the endpoints being considered for each pesticide.

The distribution of values was statistically divided into significantly different tertile regions (e.g., safety bins). Significant differences were found between the mean value for each of the three bins ($F = 2, 205.5, P < 0.0001$) (Figure 2.9). The mean for the compounds between 0 – 33% (highly safe) of the relative cumulative ranking was 3.90. The means for the 33% - 67% (moderate) and 67% (likely) and above were 5.67 and

7.21, respectively. For the 100 active ingredient compounds covered, 35 fell into the low category, 39 were in the moderate category, and 26 were placed in the likely to be a relative potential ecosystem hazard bin (Figure 2.9). The three different representative colors were then assigned to each corresponding bin based significantly on differences of low, moderate, and likely relative potential ecosystem hazard (Figure 2.9). The thresholds set by the tertile binning system of the distribution of relative cumulative ranking analysis were set at ≤ 4.545 as low (dark green), $> 4.454 \leq 6.128$ as moderate (light green), and above 6.128 as likely (orange) (Figure 2.10). Pesticides (AI) and pesticide class, and the distribution of cumulative ranking values are found in Figure 2.11. The slope of the distribution indicates 3 distinct regions. The steepness of the slope is highest in the low and likely compartments and flattens out for the moderate compounds. This indicates there is a portion of pesticides that on average rank about the same when the thirteen endpoints cumulatively scored per pesticide.

For the thirteen endpoints considered for each of the one hundred pesticides, acute avian toxicity (68 pesticides – low), honeybee toxicity (68 pesticides – low), and acute mammalian toxicity (59 pesticides – low) were the endpoints with the most pesticides falling into the “low” bin (Figure 2.12). Both acute (46 – likely) and chronic (58 – likely) aquatic toxicity values, along with phytotoxicity (43 – likely) endpoints, contained the higher numbers of pesticides with “likely” classifications (Figure 2.12). Chronic mammalian toxicity also had 58 compounds in the “likely” bin. The endpoint with the most pesticides in the moderate category was for chronic avian toxicity.

For the environmental fate endpoints considered, 61 pesticides fell into the likely

to be hazardous to the ecosystem (i.e., scored a numerical ranking of 10 based on EPA EFED thresholds for soil/water mobility) categories based on K_{oc} . High runoff rates are a concern for these pesticides. Fifteen pesticides fell into the high soil binding category (i.e., scored a 1 on the numerical ranking based of set thresholds by the EPA), where erosion (i.e., potential soil loss) should be taken into consideration if water quality impairments occur in surrounding waters (Figure 2.12). For the log K_{ow} values determined, 33 pesticides fell into the “likely” bin, 30 in the “moderate” bin, and 37 in the “low” categorical bin. Most compounds had a low ranking for half-life with only 20 in the “likely” bin, 28 in the “moderate” bin, and 52 in the “low” bin.

Based on pesticide class, herbicides had the most AIs in the low group with insecticides having the most AIs in the likely category according to cumulative ranking (Figure 2.13). Notably, these two classes also had the most pesticides falling into the moderate category as well. Algaecides largely fell into the low category, while fungicides had the highest number of rankings falling into the moderate category.

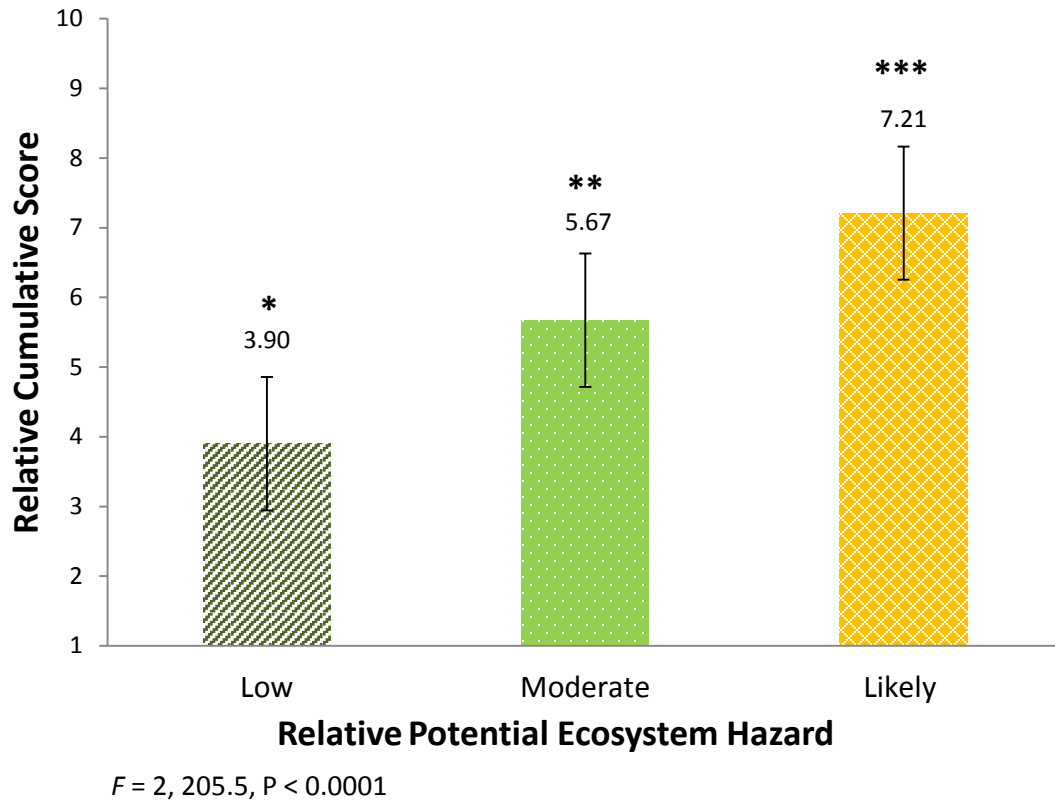


Figure 2.9: Means and significant differences ($\alpha = 0.05$) among the three different binning compartments (low, moderate, likely – relative potential ecosystem hazard). A one-way ANOVA procedure indicated significant difference among means (immediately above each bar) within each binning compartment ($F = 2, 205.5, P < 0.0001$). Using the post hoc Tukey's Studentized Range (HSD) Test ($\alpha = 0.05$) indicated significant difference among all three binning groups and are indicated by asterisks at the top of each bar.




$AVG_{\text{ranking}}(n_1 + n_2 \dots) (> 67\% \text{ in cumulative scoring}) = \text{likely} =$ 
 $AVG_{\text{ranking}}(n_1 + n_2 \dots) (> 33\% < 67\%) = \text{moderate} =$ 
 $AVG_{\text{ranking}}(n_1 + n_2 \dots) (> 0\% < 33\%) = \text{low} =$ 

Figure 2.10: All three groups (low, moderate, likely) were significantly different from each other at the $\alpha = 0.05$ significance level. Each bin was assigned a representative color.

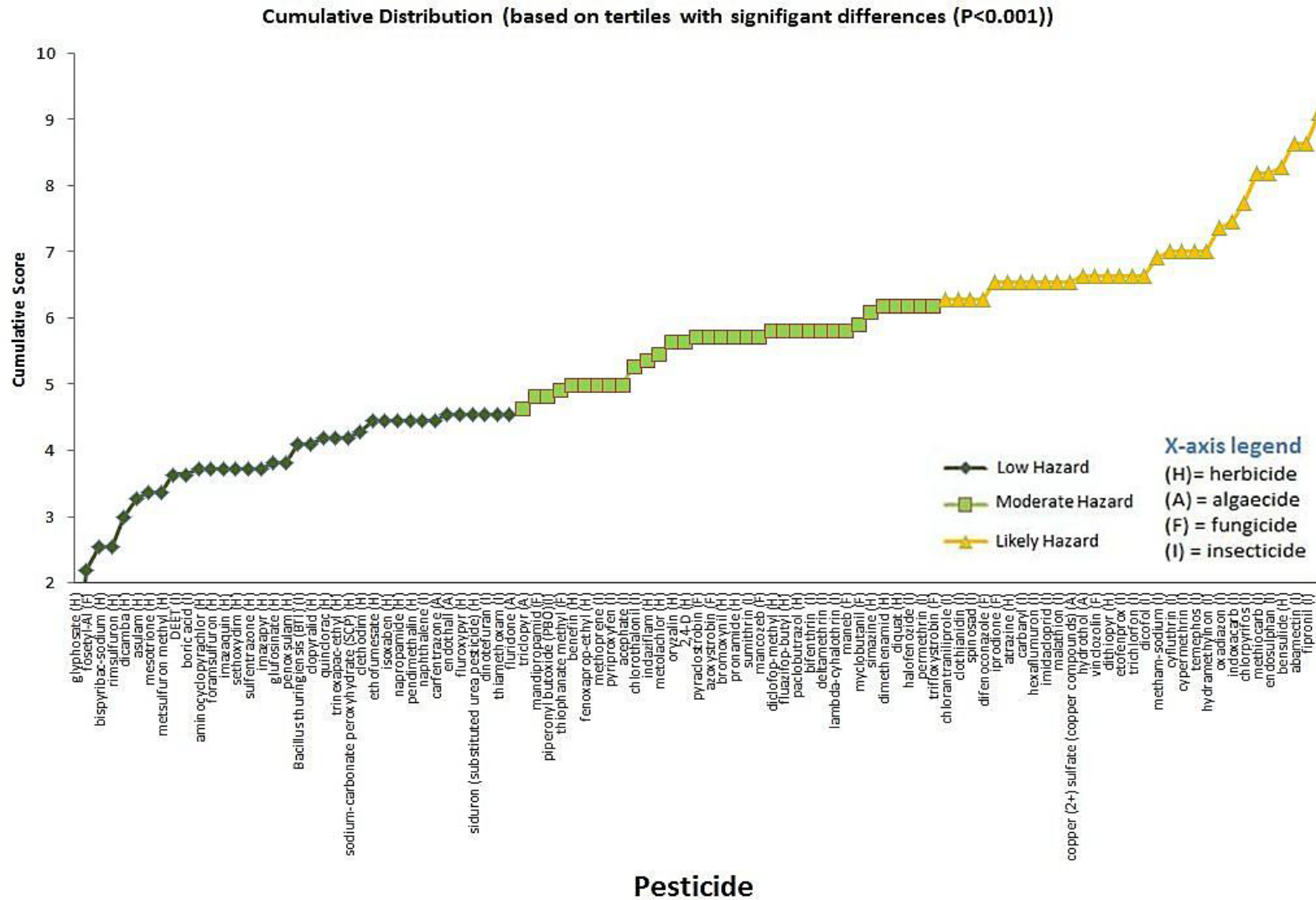


Figure 2.11 The 100 pesticides covered in the relative cumulative ranking system separated by color based on tertiles from the frequency distribution of values.

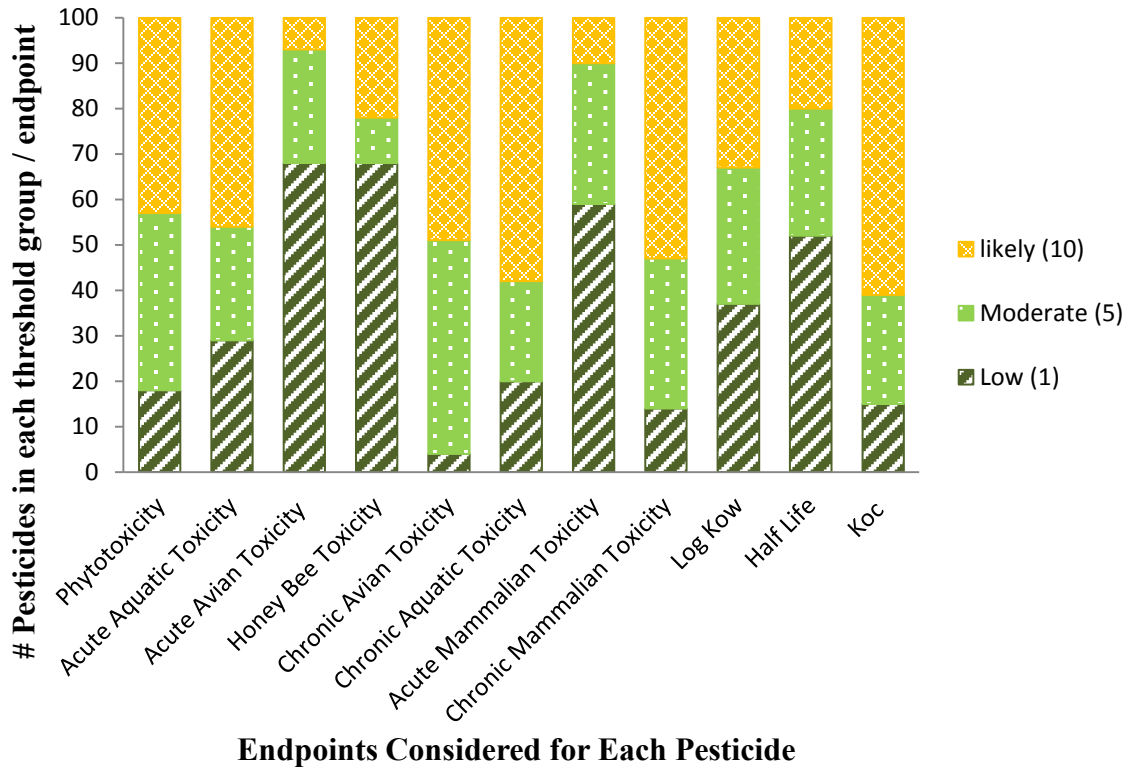


Figure 2.12: The number of pesticides – of the group of 100 – that fell into each categorical bin. The k_{oc} was ranked in a manner that the tendency to runoff soils (i.e., low K_{oc} value) obtained the highest numerical ranking value of 10; For the 100 pesticide reviewed, 61 fell into the likely to be hazardous to the ecosystem. 15 pesticides fell into the high soil binding category (i.e., scored a 1 on the numerical ranking based of set thresholds by the EPA), where erosion (i.e., potential soil loss) should be taken into consideration if water quality impairments occur in surrounding waters.

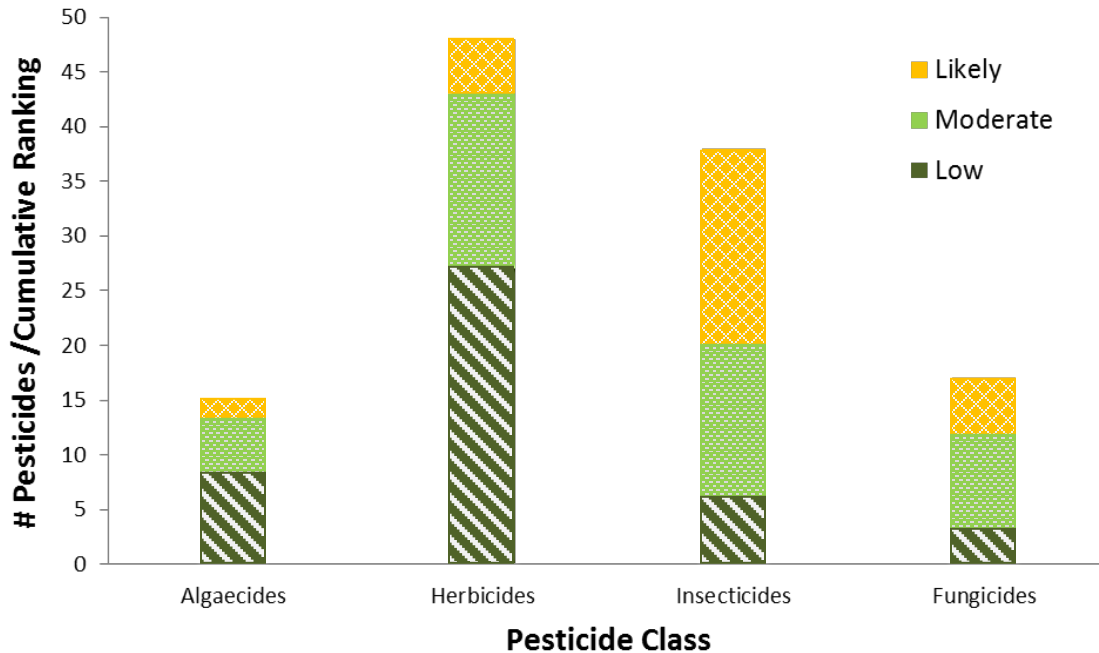


Figure 2.13: The number of pesticides – based on relative cumulative ranking score – that fell into each categorical bin.

According to use categories, golf courses potentially use 88 of the 100 pesticides considered. Residential use also had over 80 pesticides that could potentially be used in that scenario (Figure 2.14). Right-of-way pesticides and algaecides had the largest proportion of pesticides in the low categorical bin (based on cumulative score), while vector control agents had no compounds fall into the low bin. The largest proportion of pesticides considered for tomato farms fell into the likely bin. For golf courses alone, the majority of pesticides used for this category were herbicides (Figure 2.15), followed by insecticides – which also had the most compounds fall into the likely bin.

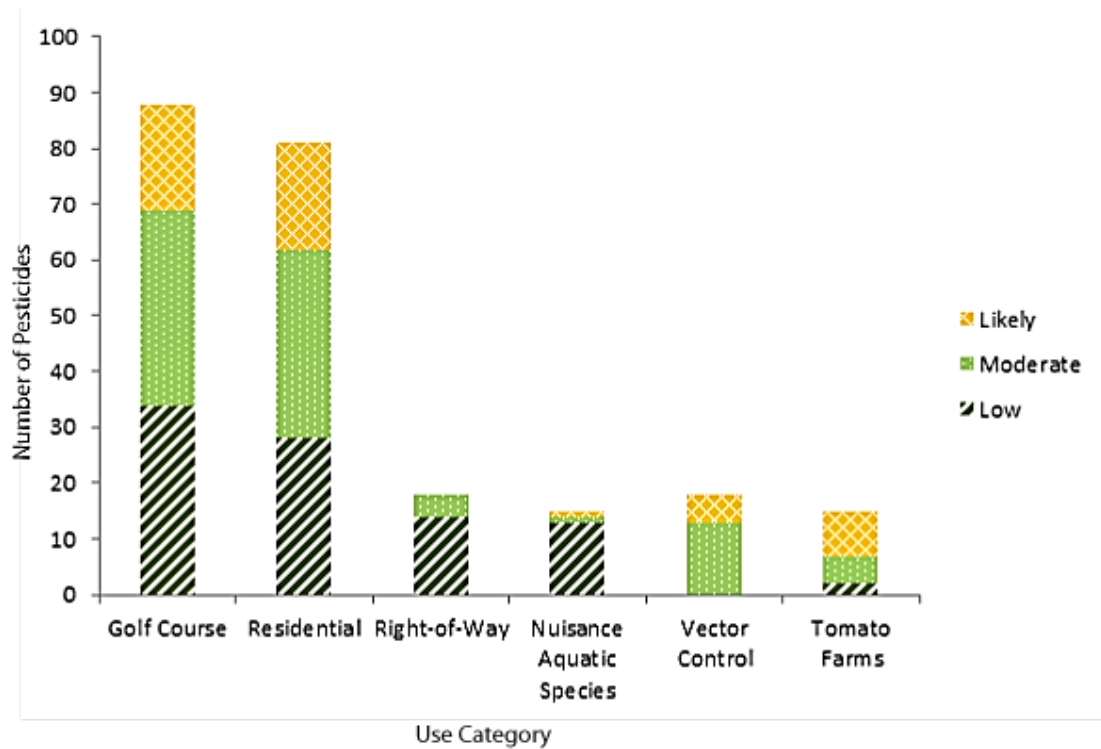


Figure 2.14: Number of pesticides for each use category considered and the bins for each category based on cumulative scores of the pesticides considered for each category.

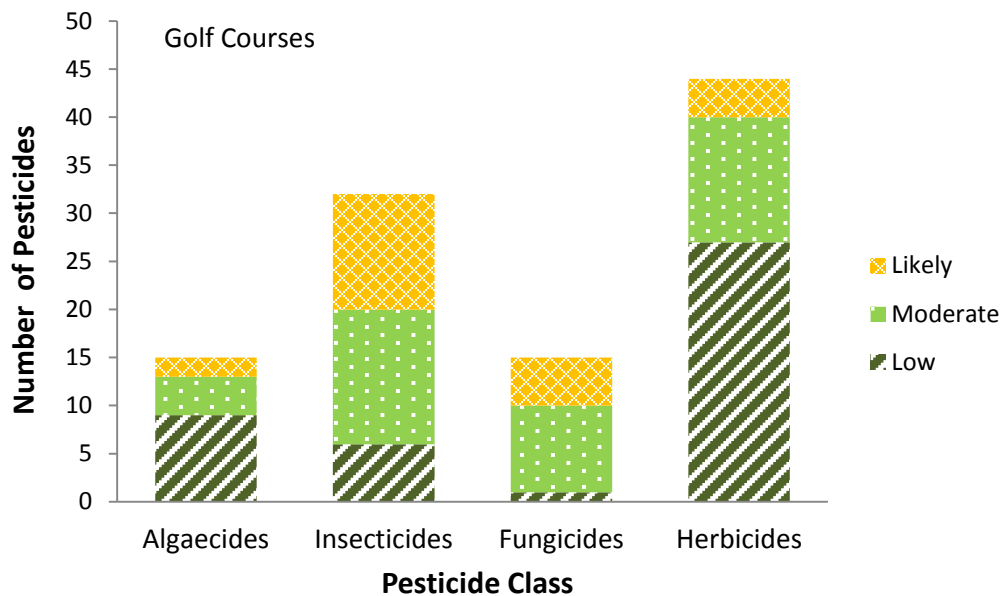


Figure 2.15: The number of pesticides used on golf courses (n = 88) by each pesticide class considered.

2.5 DISCUSSION

The mix of pesticides applied to the landscape is constantly changing, as different products are introduced and others fall out of favor or are restricted by regulation (Hartwell 2011). It is important, given the diversity (i.e., mode of action) and number of different active ingredients registered for residential use in the U.S., that individuals have the necessary information and tools on hand when trying to determine the pesticide that will best address the pest situation. Equally as important is that residents within a community understand the environmental implications of pesticide uses. In South Carolina, as seen through interactions with different demographic groups, it appears there are two pervasive schools of thought – some believe we must not use pesticides and there are those who believe that pesticides are the best action to address all pest problems. Realistically, pesticides are necessary in the US in order for homes, schools, and industrial facilities to be powered (e.g., right-of-way areas), to control vector-borne diseases, maintain infrastructure, maintain comfort in and out of homes, and – from an agricultural standpoint – to feed the growing population.

However, pesticides are not the only solution to pest problems. All other options (IPM options including cultural, biological, and physical controls) should be exhausted before chemical pesticides become a pest control option. Overtime, pests gain resistance to pesticides and therefore should only be used when economic thresholds (agricultural) or tolerance (residence) levels are exceeded. Often, at larger scales (spatial and temporal) a Risk-Cost Benefit Analysis (RCBA) is conducted to determine if pesticide use should be considered (Wilson and Crouch 2001). If the economic benefit of using pesticides, for instance on a golf course, outweighs the overall risk of using pesticides and will result in a net gain in profits, then implementing pesticide application is an option. Pesticides

themselves are a substantial cost to the applicator, so the net monetary gain – without theoretically exceeding levels of concern for risk – is often considered. Uncertainty arises in these cases though as pesticide application must be conducted at recommended label rates and in a manner that does not contaminate the surrounding ecosystems.

Variance across the landscape within the three coastal target counties for initial implementation of the relative cumulative ranking system is substantial. This ultimately decreases the validity of risk estimates across the study area. Therefore, the indicator system is based on hazard values and certain environmental fate characteristics. Another important consideration in developing the relative cumulative ranking system for the tri-county area was the variability among the pesticides themselves. Also, environmental fate and transport varies, based on the physical and chemical properties of pesticides, variance in partitioning, soil type, rainfall, and other landscape characteristics.

Moreover, risk estimates are deterministic in nature and are expressed in quotients that may not be easily understood by the public at large. When data mining occurred, values for all parameters to estimate risk were not readily available for each pesticide, while hazard data could more readily be identified through the EPA databases and publications. By using hazard data, we also address what the public emphasized as “important” to the ranking process – developing an ecological value system allowing them to identify different levels of toxicity for pesticides and the most important ecological attribute they want to protect. The relative cumulative ranking system accounted for other components perceived as important by the target audience, including bioaccumulation in the ecosystem ($\log K_{ow}$), persistence in the environment (half-life),

and the potential for pesticides to runoff from the point of application into surrounding waterbodies (K_{oc}).

The final relative cumulative ranking system, using the EPA thresholds for each endpoint considered per pesticide, generally aligns with EPA assessments of these compounds. Pesticides perceived as problematic (e.g., fipronil) were among the highest cumulative scores. The scale developed to place the one hundred chosen residential pesticides into three separate bins – utilizing the distribution of cumulative scores and tertiles – worked well as each was significantly different from the others. It also clearly identified that more insecticides are binned into the “likely” category. Fungicides largely fell into the “moderate” bin. Herbicides and algaecides generally fell into the “low” category most frequently. When looking at the distribution of cumulative scoring values for all pesticides, the moderate category contained the most pesticides. The moderate category also created some degree of ambiguity when endpoints considered were equally weighted, and therefore not necessarily identifying potential concerns for these compounds. In these cases, the user must consider the area of application and the specific concerns for each pesticide that is stated to control their identified pest problem. Additionally, for pesticides falling into the “likely” category, users should consider the specific concerns and weigh the potential hazards of individual compounds. This binning system provides an easily understandable ranking system to implement for public use, but the simplicity creates some room for interpretation by users. The outcome of the analysis for the compounds is strictly based upon user group needs and values in the multi-compartment pesticide risk indicator and analysis system. The intension was to find an acceptable balance between pesticide concern and complexity, accuracy, and practicality

and cost (Benbrook et al. 2007). The binning process simplifies multiple complex components of pesticides, and is based upon sound scientific-methods used by the EPA to develop values and thresholds, increasing the accuracy of the system.

2.5.1 Alternative Approaches

While the cumulative frequency distribution is one method of analysis, another option is to utilize cluster analysis techniques. By utilizing Eisen Lab's software (<http://rana.lbl.gov/EisenSoftware.htm>), specific concerns can be addressed for the pesticides covered in the decision-support tool. Clusters are established by comparing the compartment, or parameters, considered for each pesticide among the pesticides. This will determine clusters (or groups) of compounds with certain concerns. For example, one cluster could be high acute aquatic invertebrate toxicity. If aquatic invertebrate toxicity is the concern, then specific recommendations for use of pesticides within that cluster can be made, such as: do not apply near water (100 ft. buffer zone) as this pesticide is highly toxic to aquatic invertebrates. Since penaeid shrimp are a major commercial and recreational fishery in South Carolina, this would be an appropriate concern.

While a color coded binning system works well, another approach proven effective with the public is a "report card-like" approach for final assessment. For instance, the system implemented in the Chesapeake Bay Report Card (<http://www.eco-check.org/reportcard/chesapeake/2010/methods/>) works well to convey important water quality information to the public. Here, cumulative ranking occurs, but it is along a percentage gradient, and the end result is an overall grade (score) based on the selected

criteria. This is another way to present information to the public in an easily understandable way.

CHAPTER 3

DEVELOPMENT OF SPATIALLY EXPLICIT MAPS AS A GUIDE FOR RESPONSIBLE RESIDENTIAL PESTICIDE APPLICATION WITHIN THE SOUTH CAROLINA COASTAL ZONE

3.1 ABSTRACT

Geographic Information Systems (GIS) have been used extensively to identify areas with the potential for high contaminant loading into surrounding ecosystems. These geospatial approaches allow multiple landscape characteristics (e.g., erosion, soil type, land cover and land use data) to be applied to a decision-making process in order to create an output with visual and statistically viable answers. One area where spatial characteristics or the natural or built environment are important considerations is in residential pesticide application. Residential development adjacent to salt marsh habitats (e.g., tidal creek areas) can potentially increase accumulation of anthropogenic contaminants from upland sources (e.g., development, agricultural). Many South Carolina estuarine ecosystems (including tidal creek areas) are now intertwined with human-dominated landscapes receiving potential contaminants (e.g., pesticides).

In this study, spatially explicit maps were developed as a guide for identification of specific land-characteristics needing consideration for residential pesticide decision-making and application practices. The major goal of the study was to provide residents within the study area information on land characteristics as well as other important climatic variables (e.g., wind speed and direction, precipitation, temperature) to make

more informed decisions concerning the timing and specificity of pesticide applications. Specifically, geophysical factors (slope, soil type, climate, land use and land cover, percent imperviousness, FEMA flood-risk zones and RUSLE potential soil loss), *in situ* data (temperature, wind direction and speed) and forecasting data (i.e., potential for rainfall) were generated for the coastal study area. Through collaborative community efforts – having the common goal of reducing pesticide use and implementing proper application techniques – anthropogenic inputs into the surrounding estuarine ecosystems becomes less of a threat. The maps produced for residential pesticide applicators – if implemented in a precautionary approach – are one of the necessary tools in implementing proper pesticide application approaches and limiting adverse environmental impacts.

3.2 INTRODUCTION

Geographic Information Systems (GIS) have been used extensively to identify areas with the potential for high contaminant loading for a variety of pollutants (Poiani and Bedford 1995). Studies have assessed sediment and nutrient movement in surface waters (DeRoo et al. 1989, Walker et al. 1992, Levine et al. 1993), leaching and runoff of pesticides (Wagenet and Rao 1990, Petach et al. 1991), and numerous other ecologically-based questions. Depending upon the research question, GIS can be used to build a model to predict real world ecosystem impacts (i.e., large spatiotemporal scales), or can be used to point out sensitive or vulnerable habitats based on anthropogenic impacts (Figure 3.1). GIS can aid in taking multiple landscape characteristics needing consideration (e.g., erosion, soil type, land cover and land use data) in a decision-making process and create an output with visual and statistically viable answers. One area where spatial

characteristics are an important consideration is in residential pesticide application. However, perceived knowledge of proper application techniques may vary. In this study, we used GIS generated geospatial maps as a tool to addressing specific aspects of residential pesticide decision-making and application practices. The **major goal** of the study was to provide residents within the study area information on land characteristics as well as other important climatic variables (e.g., wind speed and direction, precipitation, temperature) to make more informed decisions concerning the timing and specificity of pesticide applications. The **first aim** was to identify GIS layers needed for users to make more informed decisions before pesticide application occurs. The **second aim** was to generate a series of maps for the study area for numerous variables – defining areas where pesticide application may lead to inputs into tidal creeks, potentially adversely affecting the overall health of the ecosystem.

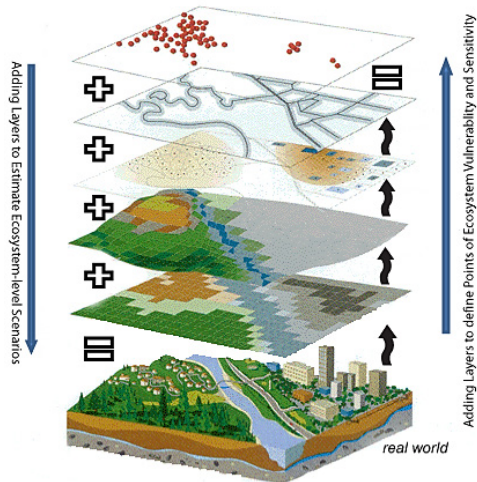


Figure 3.1: Illustration depicting spatial modeling within Geographic Information Systems (GIS) of natural resource, infrastructure development, water quality and quality based on various land characteristics. In many cases, to answer a question regarding complex questions where geography comes into play, variability across a landscape translates into multiple considerations – and therefore multiple layers on one map – must be considered and accounted for.

Robust growth of transient and permanent populations in coastal regions of the Southeastern United States is leading to increased pressure on tidal creeks and estuarine ecosystems vital to the region (Sanger et al. 1999, White et al. 2004). South Carolina's coastal population grew by 30% over the last 15 years and is conservatively estimated to grow another 35% over the next 25 years (SC Budget and Control Board 2005). To accommodate the population growth in the region, land use patterns have transitioned from rural agricultural lands to more suburban and urban areas (Holland et al. 2004). These land use changes have led to more frequently occurring expanses of impervious surface (e.g., roof tops, roads, parking lots, etc.) that are generally accompanied by higher rates of stormwater runoff into adjacent waterbodies. Additionally, watersheds dominated by urban development are associated with surface water contributions from municipal wastewater discharges and industrial point source discharges (Long et al. 1997, Dauer et al. 2005). Once the degree of impervious surface within a watershed reaches 30%, severe biological degradation occurs (Schueler 1994, Arnold and Gibbons 1996) and reductions in groundwater infiltration rates occur (Dennison et al. 2009) (Figure 3.2). Moreover, current trends in coastal development practices indicate that we are consuming land at a rate 3-6 times faster than the population is growing (DiDonato et al. 2009).

Tidal creeks provide nursery habitat and feeding grounds for commercially and recreationally important species of finfish and shellfish and also serve as breeding grounds for several species of wading birds (Scott et al. 1998, Holland et al. 2004). These coastal habitats contribute to the economic viability of the region (Bergquist et al. 2009). For example, commercial and recreational fishing generates over \$690 million annually and domestic tourism in South Carolina results in over \$9 billion to local economies

(Southwick Associates 2008). Loss of these vital habitats due to anthropogenic contributions would not only have an impact on the hydrologic and ecosystem dynamics but also substantially affect the economic viability of the region.

Development adjacent to salt marsh habitats can potentially increase accumulation of anthropogenic contaminants from upland sources (e.g., development, agricultural) (Sanger et al. 1999). Many South Carolina estuarine ecosystems (including tidal creek areas) are intertwined with human-dominated landscapes receiving sediment, nutrients, and other potential contaminants (e.g., pesticides) in excess of historical inputs (Neely and Baker 1989). Studies have shown adverse impacts on species occupying these areas as well as negative effects on ecosystem functioning (Moore et al. 1989, Ehrenfeld and Schneider 1991). Soil erosion into these stressed systems is associated with environmental impacts (Clark et al. 1985) and thus is considered to have the greatest impact among surface hydrologic processes (de Jong van Lier et al. 2005). Runoff is responsible for soil transport and deposition, ultimately playing a major role in erosive processes (de Jong van Lier et al. 2005). Further, rainfall-induced surface runoff acts as a main entry route for non-point-source pesticide pollution (Probst et al. 2005) – one of the main anthropogenic inputs of concern in human-dominated tidal creek ecosystems.

For residents and residential pesticide applicators, the use of multiple data layers with a visual output creates a framework for more informed decision-making during application. Given the rise in residential areas associated with population growth within the study area, the probability for residential pesticide use also increases. Information about land characteristics are important, but only if the pesticide applicator is properly applying the pesticide according to label standards (e.g., correctly calibrated equipment).

Specifically, by using spatial data the user can specify small geographical areas (e.g., 0.5 acres – home/lawn) where they intend to apply pesticides and use GIS models to view specific land characteristics with the chosen multiple layers in the spatial output. If residents can only view land characteristics over small spatial scales, then detail needed

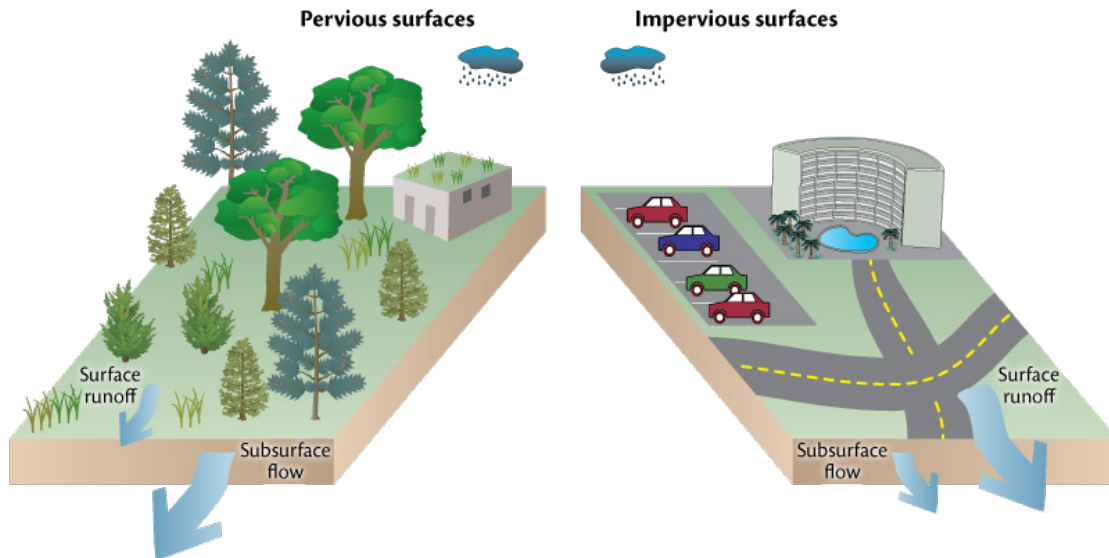


Figure 3.2 (modified from Dennison et al. 2009): Conceptual diagram illustrating the changed hydrography due to impervious surface such as asphalt, cement and roofing. The flow of water in pervious surfaces (left diagram) such as grasses and soils allow water to infiltrate the ground – reducing total surface water runoff and recharging groundwater. Flow across pervious surfaces increases the volume and velocity of surface water – introducing greater amounts of sediment, nutrients, and potential contaminants (e.g., pesticides, hydrocarbons) into surrounding rivers, bays, and sounds. Pervious surfaces also decrease groundwater recharge due to the high flow rate off the surface.

for proper residential application (unless abatement occurs) is lost. There are many factors influencing pesticide entry into tidal creek runoff (geophysical factors - slope, soil type, climate, land use and land cover, physical and chemical pesticide properties) (Probst et al. 2005). *In situ* data for parameters such as temperature, wind direction and

speed, and forecasting data (i.e., potential for rainfall) also should be taken into consideration before pesticide application occurs.

3.3 METHODOLOGY

3.3.1 Study Area

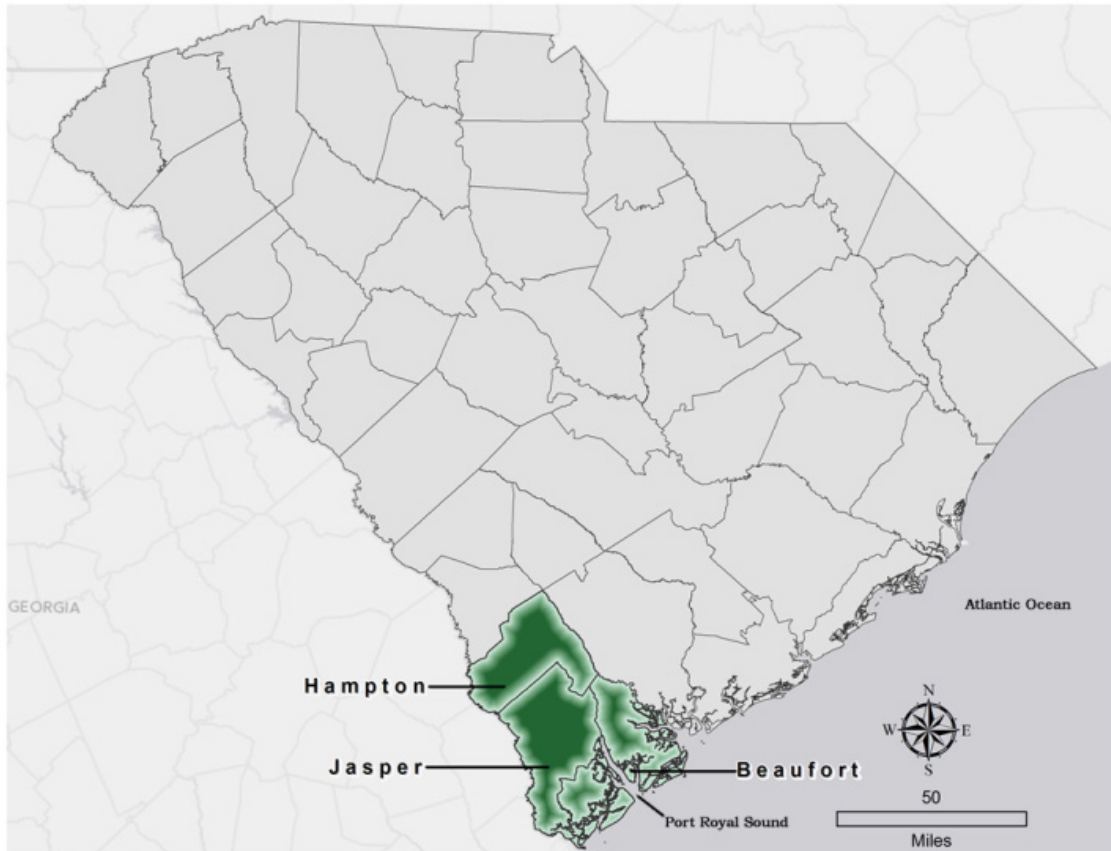


Figure 3.3: The three target counties chosen for the initial trial of the pesticide decision-support tool in South Carolina. Beaufort and Jasper Counties both share boundaries that line the Port Royal Sound and contain coastal borders. Hampton County is unique in that it does not share these same characteristics, but importantly urban and agricultural areas within the county may contribute to water quality impairment's as water moves downstream to the Atlantic Ocean.

The study area consists of the three most southern counties in South Carolina: Beaufort, Jasper, and Hampton Counties (Figure 3.3). The Port Royal Sound system is unique compared to other coastal areas in North America due to the large embayment

dominated by expansive salt marshes and high salinity water. An embayment was created when rising sea levels submerge valleys along the coast with the net result being marine habitat that extends inland for 10 miles (LowCountry Institute 2012). The Sound also has exceptionally high tidal amplitude, low lying topography, and extensive salt marsh habitat. Beaufort County alone accounts for half of South Carolina's salt marsh habitats. The geographical features and location, along with population and land use changes within the target counties makes it an ideal study area. Initial implementation of a spatial model will allow users to make more informed decisions – accounting for land and climatic considerations – when it comes to proper pesticide application.

3.2.2 Identification of Spatial Data for the Study Area

Base Layers

A GIS was used to construct the necessary maps for residential pesticide applicators and Bing aerial and Bing hybrid maps were automatically installed as possible base layers. The Bing aerial and Bing hybrid maps both offer high resolution, allowing users to visualize images at large spatial scales (i.e., homes or property). For this study, the Bing Aerial map was used for an initial base along with the U.S. Geological Survey (USGS)'s topographical maps (<http://topomaps.usgs.gov/>). The USGS topographical map uses 7.5-minute quadrangles giving more detail to the maps – predominantly over small spatial scales. Contour lines are a combination of two line segments that connect but do not intersect and represent changes in elevation. These changes in elevation indicated on the topographical map indicate areas where variance in slope values may need to be considered during the decision-making process for pesticide application.

Land Cover and Impervious Surface Layers

The National Land Cover Database 2006 (NLCD 2006) (Fry et al. 2011) classification scheme was used to develop the land use layer for the study area. The NLCD (2006) is a 16-class land cover classification scheme (Figure 3.4) that has a spatial resolution of 30 meters (Fry et al. 2011). NLCD2006 is predominantly based upon unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) (2006) satellite data (Fry et al. 2011). The NLCD quantifies land cover change between 2001 and 2006 and was generated by comparing spectral characteristics of Landsat imagery over the six year period.

To determine the level of imperviousness over the study area, the NLCD (2006) Percent Imperviousness ranking scheme was used. Percent imperviousness is determined by raster calculations and is originally set along a color gradient to represent increasing levels of impervious surface. In order to make this a useful map layer for residential pesticide applicators, measurements of imperviousness were manually reclassified into six distinct groups (Figure 3.5). The lowest category was no impervious surface (white), followed by 5 distinct categories of percent imperviousness – each group increasing in color intensity with increasing imperviousness.

Soil Data Layer

The U.S. Department of Agriculture's National Resources Conservation Service (USDA-NRCS) Soil Survey Geographic (SSURGO) Database was used to develop the soils layer for the spatial model. The SSURGO database contains soils data collected by the National Cooperative Soil Survey over the course of a century (NRCS 2013).



Figure 3.4: NLCD (2006) 16-class land cover classification scheme used in the land cover data layer.

Impervious Surface (NLCD 2006)

% Impervious Surface

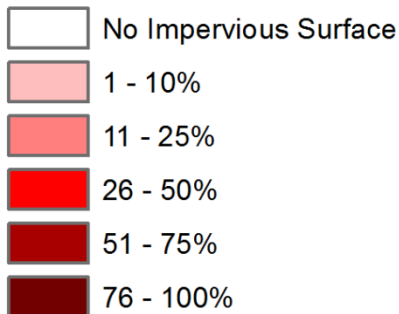


Figure 3.5: NLCD (2006) percent imperviousness based on land cover classification scheme. The raster dataset was manually regrouped into six categories for ease of understanding and explanation for residential pesticide users within the study area.

The SSURGO data was downloaded as a shape file in geographical coordinates and corresponding colors were assigned to various soil types among the three county study area. For each county – Beaufort, Jasper, and Hampton – the top three soil types (% land cover/county) by land area were calculated. Percentages of dominant soil types by

County were used for the purposes of generalizing estimates over smaller spatial scales, while soil type – as classified by the SSURGO database – were used for larger spatial scales.

FEMA Flood Zone-risk Zones Layer

For the study area, flooding hazards should be taken into consideration when thinking of pesticide application practices – particularly in low-lying, high-risk coastal areas. In 1968, U.S. Congress passed the National Flood Insurance Act establishing the National Flood Insurance Program (NFIP). Subsequently, this act was expanded by the Flood Disaster Protection Act of 1973. The Act required the identification of all floodplain areas within the U.S. and established flood-risk zones within those areas with the responsibility falling under the Federal Insurance Administration of the Federal Emergency Management Agency (FEMA). Therefore, the flood-risk zones data from FEMA(<https://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=1&content=floodZones&title=FEMA%2520Flood%2520Zone%2520Designations>) were used and applied as a spatial layer within the study area. It should be noted here that only the 100 to 500 year flood-risk zones are displayed on the map. Within the coastal zone, however there are mandatory areas (indicated by the FEMA V and VE, V1-30 designations) where persons owning property in high-risk coastal areas must purchase flood insurance. Specifically, the FEMA zones used for spatial modeling for residential pesticide applicators used were: A = 100-year flooding, AE = 100-year flooding where areas of complete inundation have been identified, VE = 100-year flooding with velocity hazards (i.e., wave action), X = areas determined to be outside of the 100 and 500-year floodplains, and X500 = inundation by 500-year flood events and

with 100-year flooding inundation up to one foot or with drainage areas less than one square mile.

Implementation of the Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) was used as an estimate of the amount of sediment that could potentially enter nearby waterways. Given that erosive processes potentially play an important role in pesticide inputs into the ecosystem, we used the RUSLE equation to identify areas of high soil loss. The Universal Soil Loss Equation was described and published in Agriculture Handbook No. 537 in 1965 and revised in 1978 (Wischmeier and Smith) and is widely accepted as a major conservation-planning tool. Application of the RUSLE equation still allows for the identification of areas where high soil loss and low soil occur within the region. Once we identified data needed to construct the model, all data were prepared for the RUSLE model by converting them into raster datasets of equal-cell size. Model properties were set to designate 30x30 meter raster cells, in the North American Datum 1983, UTM Zone 17. Layers were added together, resulting in a final map where each cell has a value representative of total potential soil loss within the study area (Figure 3.6). The following equation defines the parameters considered within the RUSLE estimate:

$$A = C * R * LS * K * P$$

where A= potential soil loss (tons/acre/yr), C= cover, R= rainfall erosivity, LS= slope length and steepness, K= soil erosivity, and P= support practice.

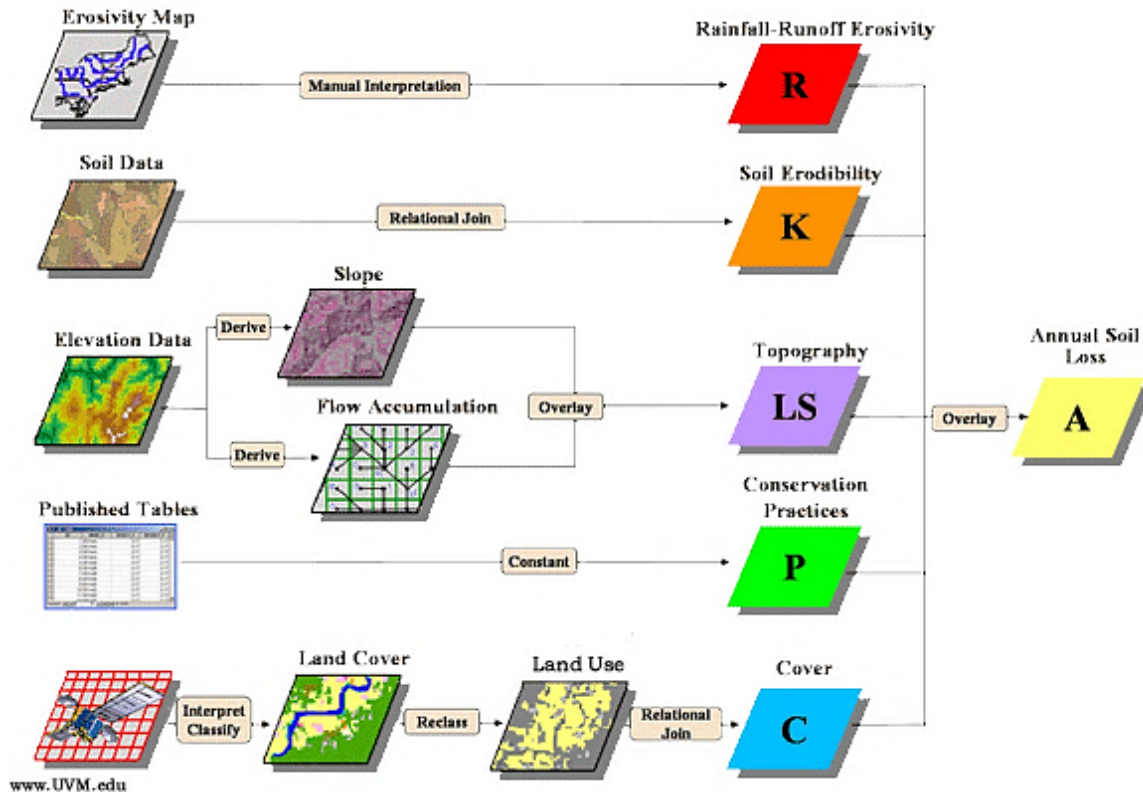


Figure 3.6: Conceptual model of the GIS-based implementation of the RUSLE equation. The final output is in tons/acre/yr and is an estimate of loss of soil (i.e., erosion). Illustration adapted from www.UVM.edu.

The cover variable (C) is intended to account for the influence of specific crops and crop rotations on erosion rates. In this model, we used the NLCD land cover classes from 2006. Values were estimated from a previous study completed at Cornell University (Ma and Limbo, 2001). High C-values correspond to land cover types that allow greater rates of sedimentation. Rainfall Erosivity (R) is an indication of the two most important characteristics of a rainstorm: the amount of rainfall and peak intensity. The R-value is the product of the total kinetic energy of a storm (E) multiplied by its maximum 30-minute intensity (I). Rainfall erosivity maps are available from the USDA Agriculture Handbook No. 703 (Renard *et al.* 1996). Slope Length and Steepness (LS) represents the effect of the physical landscape on erosion. This variable is more difficult to adapt to a

study area, therefore using smaller areas for analysis is important. An equation proposed by Moore and Burch (1986a and 1986b) and used in a process described by Engel (2003), was used to approximate the LS value over the study area:

$$LS = (\text{Flow Accumulation} * \text{Cell Size} / 22.13)^{0.4} * (\sin \text{slope} / 0.0896)^{1.3}$$

Soil Erosivity (K) is a measure of the susceptibility of bare surface to soil erosion. This data is readily available in the SSURGO database and was easily appended to soil polygon layers. The Support Practice (P) factor reflects the impact of support practices on the average erosion rate, traditionally referring to tilling practices and row-to-slope orientation. Given that our study area covers a larger expanse of land (i.e., three counties) we assume a worst-case scenario by letting $P = 1$, meaning there are no practices in place to reduce soil erosion. After calculation of each aforementioned variable, the raster layers were multiplied to calculate A, the potential soil loss in tons/acre/year from each 30x30 meter cell.

In situ Data

The National Oceanic and Atmospheric Administration (NOAA) has established a system of buoys, shore stations, and land stations that collect real time data on several environmental variables (wind speed, wind gust, wind direction, air temperature, air pressure, water temperature (if a buoy), and humidity. In a collaborative effort, NOAA generously has allowed access to the real time observations made at these buoys and stations within the study area. Residential pesticide applicators in the area can find the buoy/station closest to them, and gather information important for determining if timing to appropriate for application.

3.4 RESULTS

Base Maps

Once all maps were constructed in ArcGIS 10.1, each map layer generated for the study area was assessed for potential areas of concern for pesticide applicators. First, an aerial view of the study area shows the user land characteristics of the entire region (Figure 3.7). Greater detail of the Bing Aerial data can be seen when viewing it on a county by county basis. Next, USGS topographical mapping allows users to view contour lines and specific land features possibly important to pesticide application in a given area (Figure 3.8). Individual maps for each county – for both the aerial and topographical maps -- are located in Appendix A.

Land Cover, Soil Type, and Impervious Surface Mapping

According the NLCD (2006) land cover classification scheme, Hampton County appears to have mixed forests and shrub/scrub areas that dominate the county (Figure 3.9). Cultivated crops and pastureland appear to be the dominant land uses. On the fringe of the county, emerging herbaceous wetlands are also present. Further, the highest percentage of impervious cover – and therefore developed land – coincides with the two major highways running through the county (Figure 3.10).

For Jasper County, mixed forest, woody wetlands, and emergent herbaceous wetlands appear to dominate the county (Figure 3.9). Notable land use practices for the county are cultivated crops and pasture land – however to a lesser extent relative to Hampton County. Developed land and percent imperviousness again surround areas for major highways occur in the county (Figure 3.10).



Figure 3.7: Bing™ Aerial map of the three target counties comprising the study area. The yellow line indicates the county boundaries for Beaufort, Jasper, and Hampton Counties.

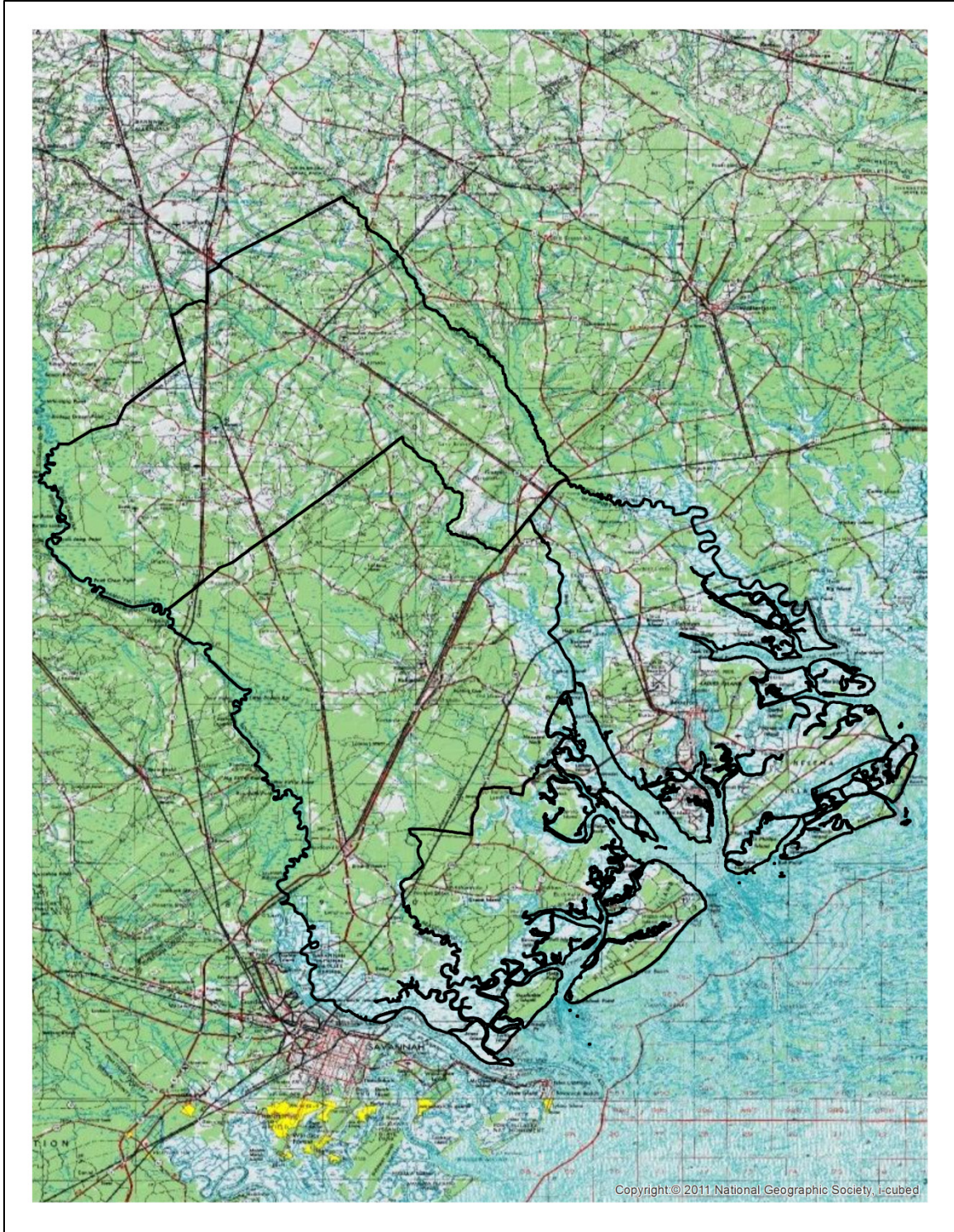


Figure 3.8: USGS topographical map of the three most southern counties in South Carolina (Beaufort, Jasper, and Hampton Counties). The black line indicates county boundaries for the study area.

Beaufort County – relative to the other two counties within the study area – contains the largest proportion of woody wetlands, emergent herbaceous wetland areas, and open water areas (Figure 3.9). Mixed forest also occurs within the county. Sparse amounts of cultivated land and pasture land occur within Beaufort. Proportionally, Beaufort County has the most developed land and highest percent imperviousness.

Based on land cover classification in all three counties, pesticide runoff from land around wetlands is a concern. Soil types vary widely across the tri-county area (Figure 3.11). For Beaufort and Jasper counties, an association of soil types comprises the most dominant soils, making up 33.3% and 39.2% of the soil, respectively. Beaufort’s second most dominant soil was fine sand (25.4%). For Hampton and Jasper counties, fine sandy loam was the second most dominant soil, comprising 18.5% and 20% of the soils, respectively. All three counties had fine sandy loam as the third most dominant soil type – with it comprising 19.4% in Jasper County, 14.5% in Beaufort County, and 10.3% in Hampton County. Individual maps of each county (minus soil type) are located in Appendix B.

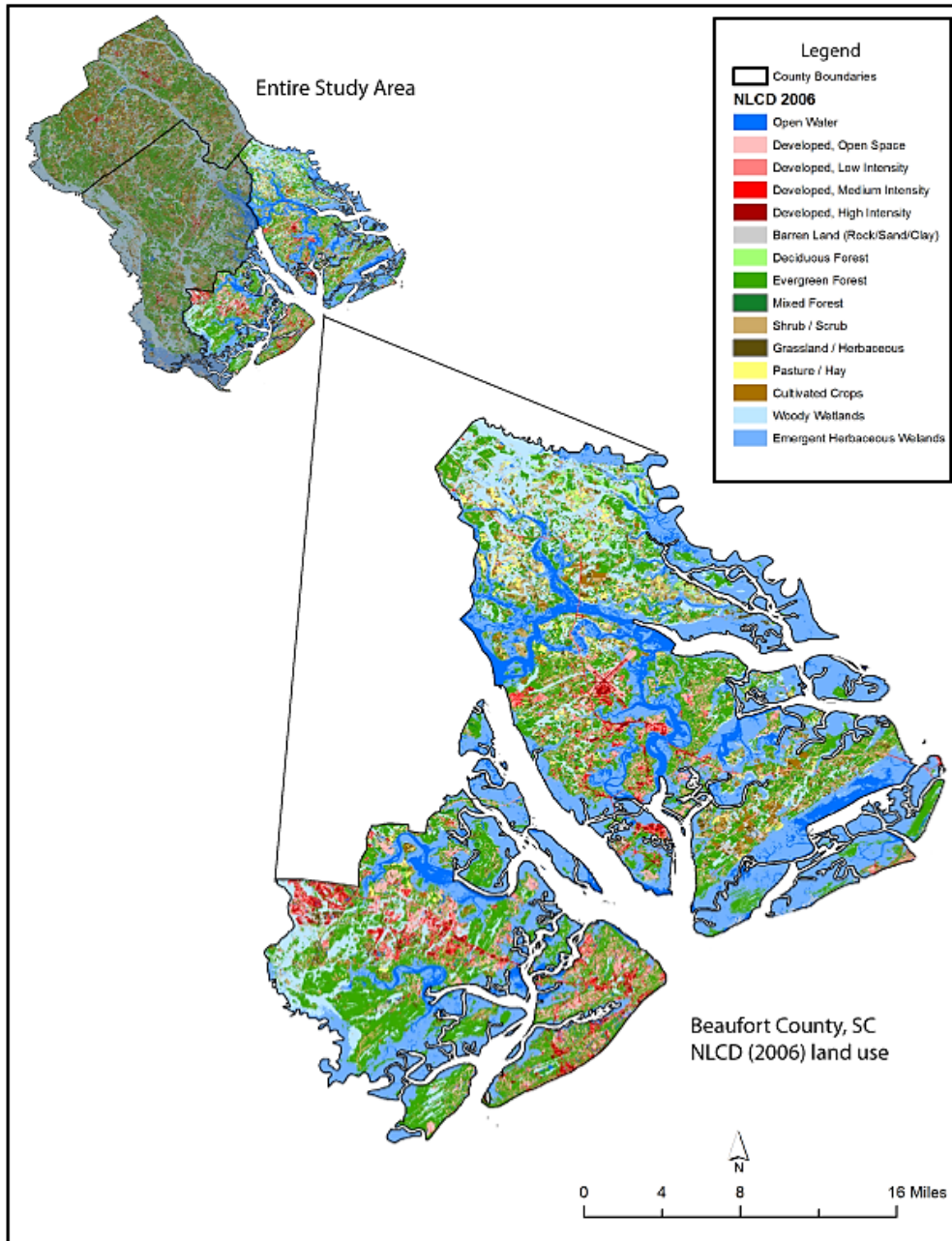


Figure 3.9: NLCD (2006) land use classification for the study area. The Beaufort County area is expanded from the entire study area as an example of the amount of detail in classification the user can see for the 16-level classification scheme.

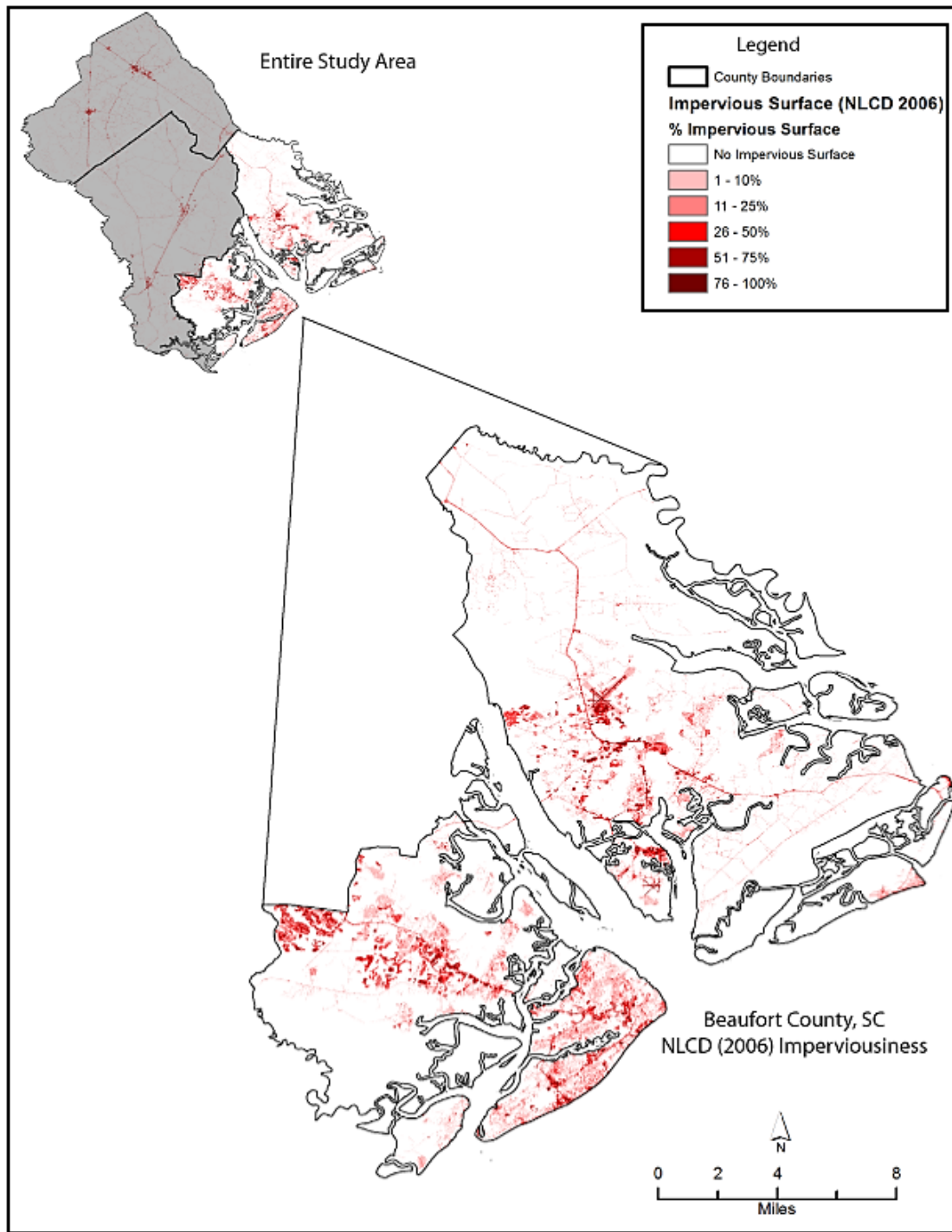


Figure 3.10: Percent imperviousness as defined by the NLCD (2006) classification. Areas with the highest percent impervious surface are bright red.

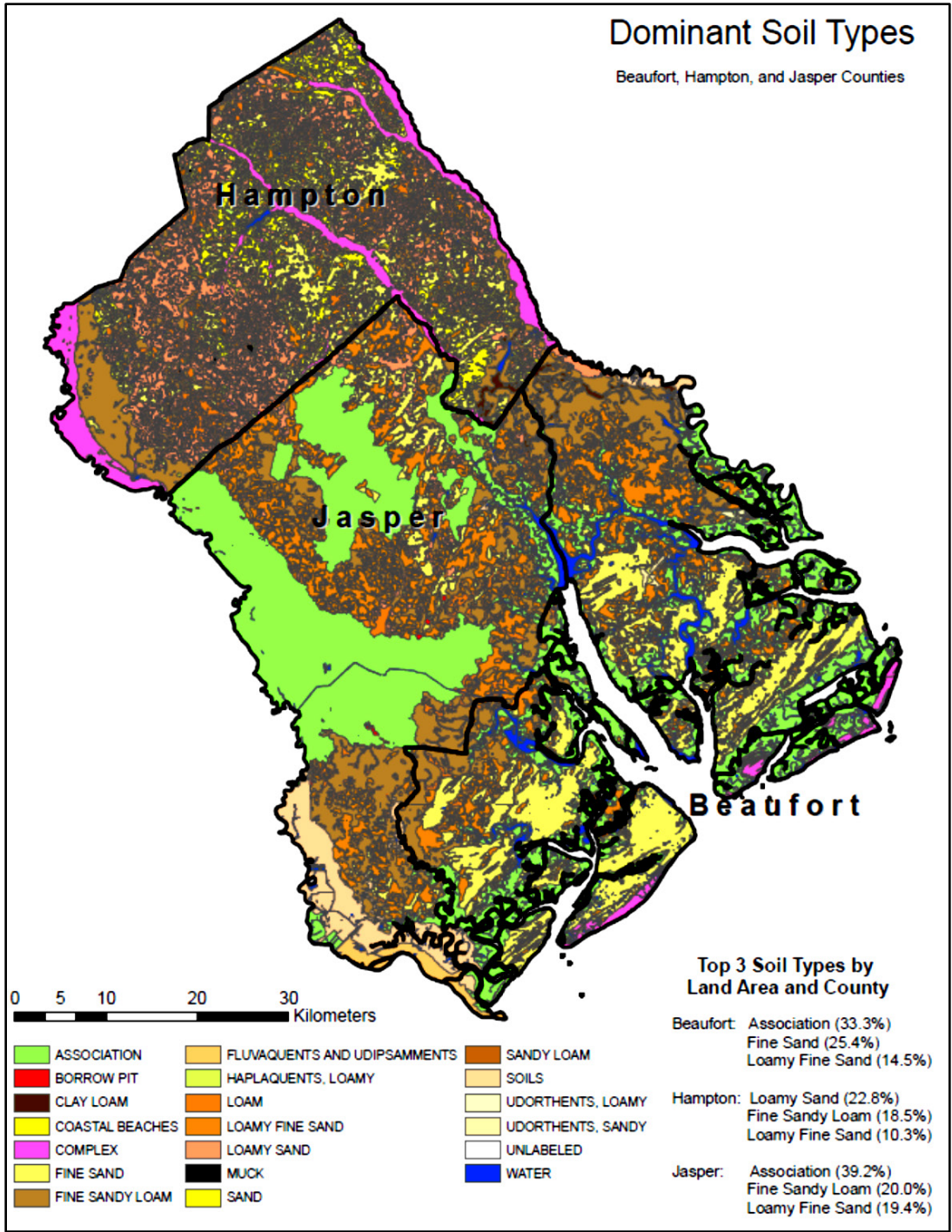


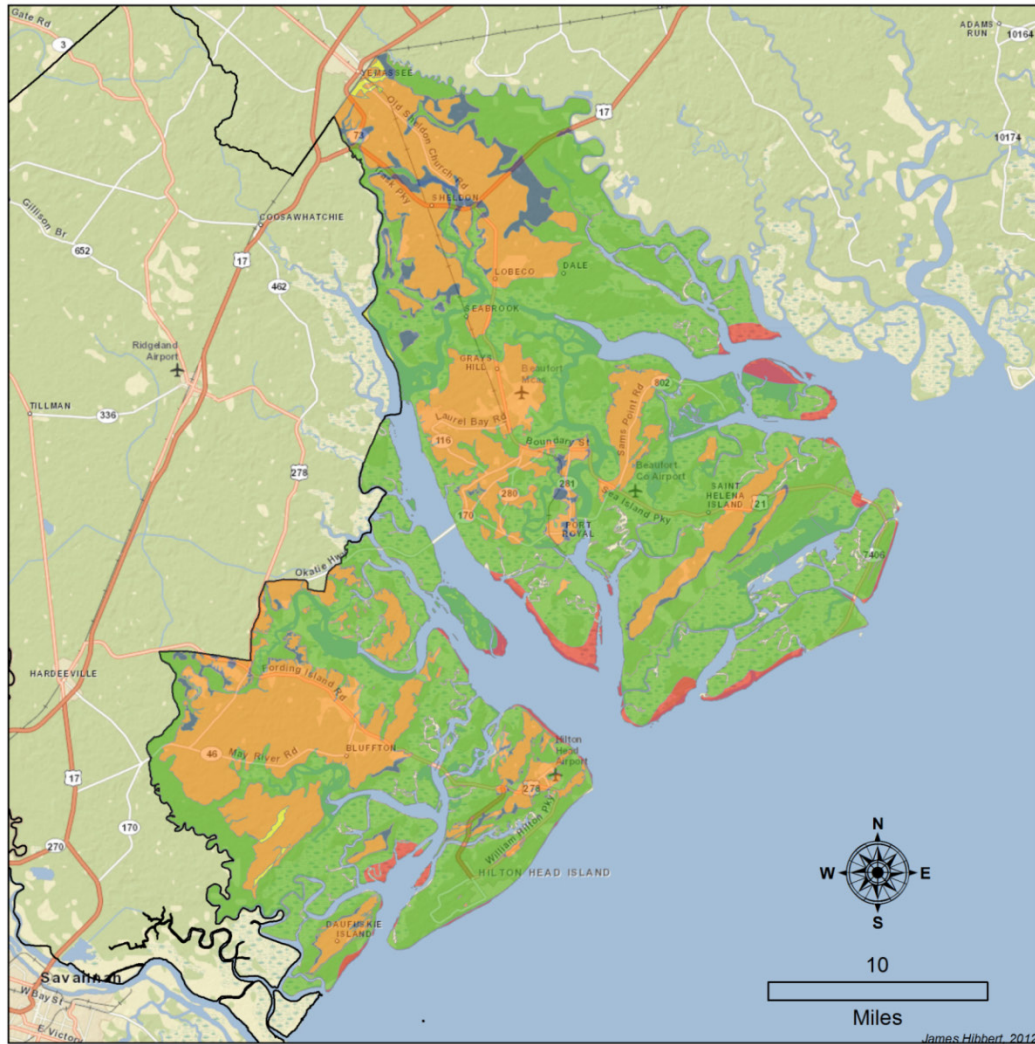
Figure 3.11: USDA-NRCS soil types in Beaufort, Jasper, and Hampton Counties. The percentage of the three most dominant soil types for each county can be seen in the lower right-hand corner of the map.

FEMA Flood-risk Zone Maps

The FEMA flood-risk zone classification indicated that several portions of Beaufort County (i.e., generally areas surrounded by open water) and a small portion of Jasper County (the southernmost tip) contain areas where 100-year flood would cause complete inundation with wave action (Figure 3.12). The majority of Beaufort County is within the 100-year floodplain where complete inundation will occur as well as a portion of Jasper County. There are also large expanses of land in that were determined to be outside the 100 and 500-year floodplain in Beaufort and Jasper counties. Hampton County – being that it is considered an inland county only has the 100-year floodplain zone, and therefore little information can be derived from this.

RUSLE Output

In all three target counties, the RUSLE equation differentiated areas of high soil loss and low soil loss (Figure 3.13). Areas of high soil loss due to erosion are an important consideration for pesticide applicators. The utility of the RUSLE equation is illustrated in Figure 3.14 where an aerial photo of a section of land containing an agricultural plot, a golf course, a cluster development, and development next to a highway. In this example, applying the RUSLE equation indicates that high levels of erosion occur around the golf course, agricultural areas, the development to the left of the golf course, and the industrial area directly south of the major road in the image. RUSLE outputs for the three individual counties can be found in Appendix B.



<p>Legend</p> <p>Beaufort Q3 Flood Zones</p> <p>Zone</p> <ul style="list-style-type: none"> A AE VE X X500 	<p>Zone Definitions</p> <p>A: An area inundated by 100-year flooding, for which no BFEs have been determined.</p> <p>AE: An area inundated by 100-year flooding, for which BFEs have been determined.</p> <p>VE: An area inundated by 100-year flooding with velocity hazard (wave action); BFEs have been determined.</p> <p>X: An area that is determined to be outside the 100- and 500-year floodplains.</p> <p>X500: An area inundated by 500-year flooding; an area inundated by 100-year flooding with average depths of less than 1 foot or with drainage areas less than 1 square mile; or an area protected by levees from 100-year flooding.</p>
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Figure 3.12: FEMA Q3 flood zones within one of the three target counties (Beaufort County, SC). Definitions of each zone are described to the right of the legend.

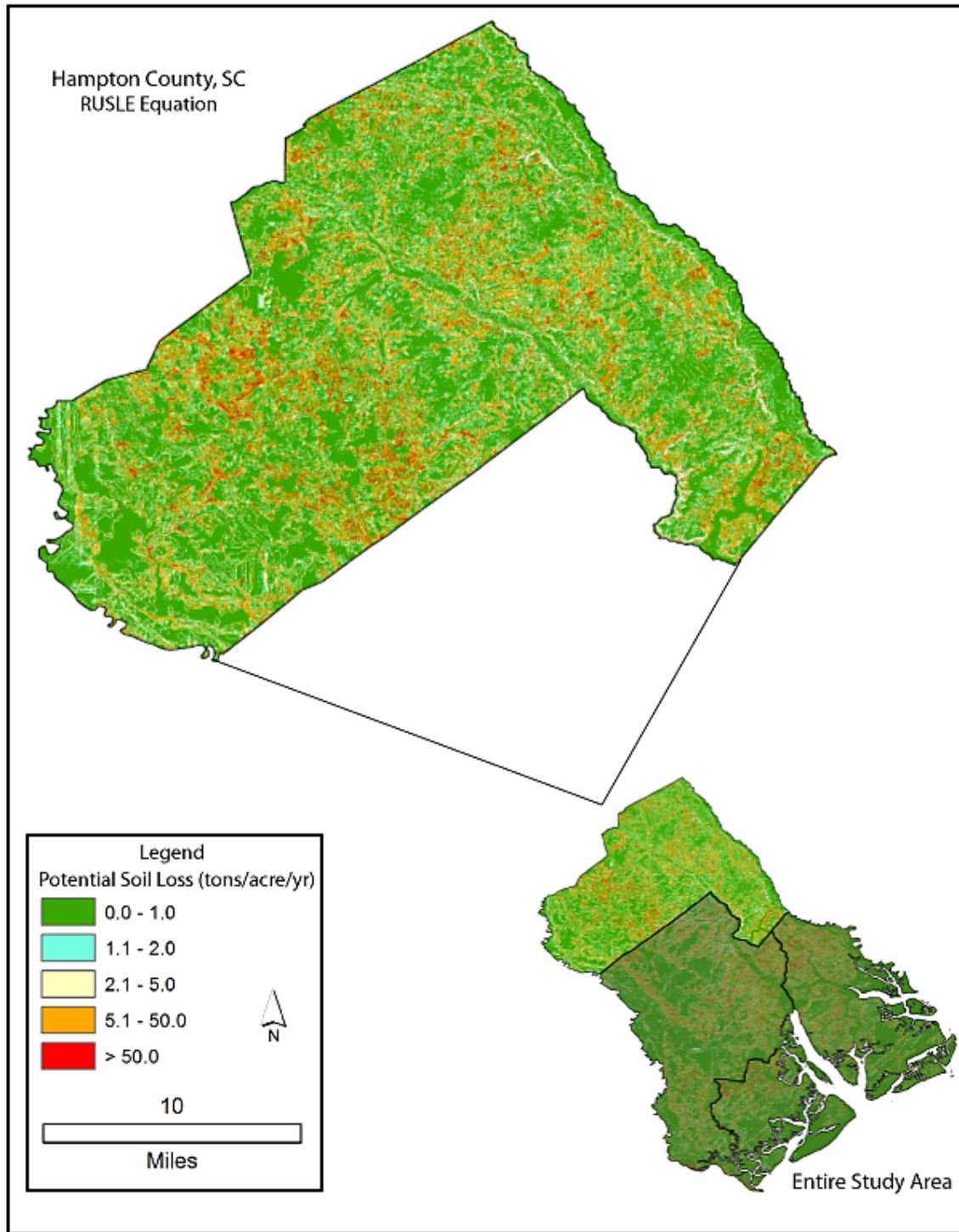


Figure 3.13: RUSLE output for the entire study area with Hampton County expanded to indicate the detail of RUSLE values for a given county.

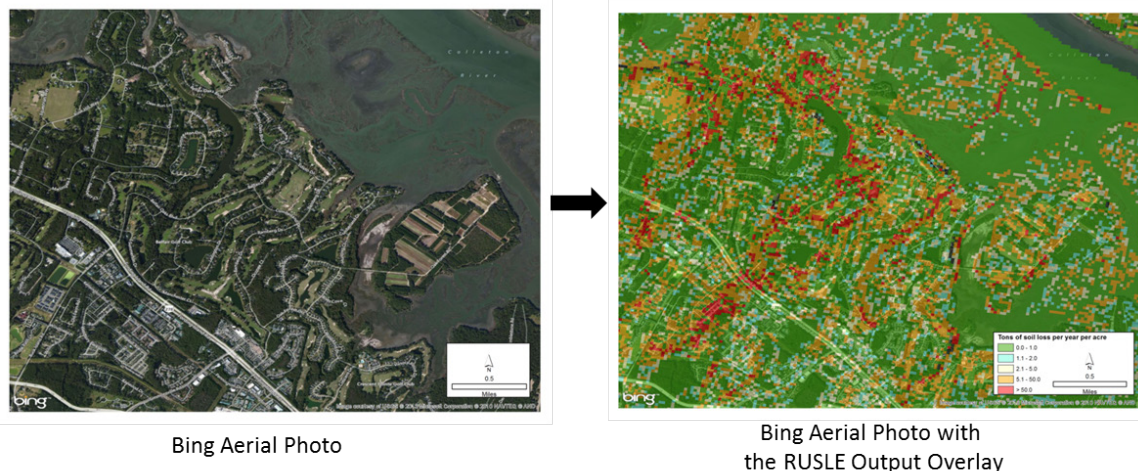


Figure 3.14: An example of how the RUSLE equation allows the user to view land use practices. Those areas with high RUSLE values potentially translates into soil loss in areas – particularly important when considering pesticide application is in areas where development is relatively high and adjacent to a waterbody.

NOAA In Situ Data

Given the strategic positioning of the NOAA buoys, platforms, and land stations, pesticide applicators can gather real time data to make decisions for pesticide application. When a data collection device is accessed, information is immediately available, giving the user necessary information on current weather conditions (Figure 3.15).

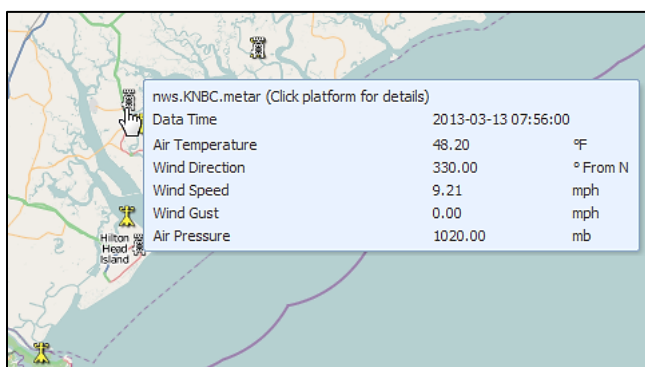


Figure 3.15: An example of the real time data output for a NOAA platform within the study area.

4.5 DISCUSSION

The implications of improper pesticide use within southeastern coastal tidal creeks and estuarine ecosystems could lead to adverse trophic effects, particularly if functional redundancy and assimilative capacity are lacking. The objective of proper pesticide application should be to take a precautionary approach in order to preserve the integrity of the surrounding environment. In the world of pest management, an integrated pest management plan should be implemented in all application scenarios – when all physical, biological, or cultural methods are exhausted before chemicals (i.e., pesticides) are applied. Using spatial analytical methods and maps provides the user with information necessary for proper decision-making for application when and if it needs to occur (i.e., the pests infestation has exceeded an economical or tolerance threshold). The maps generated within the tri-county area of South Carolina are geographically specific – allowing for site-specific identification of land characteristics. For initial implementation, the identified important spatial characteristics provide users with necessary information for improved residential pesticide application. Our final maps included aerial and topographical maps, soil type, potential soil loss, flood-risk zone, coastal and offshore *in situ* data on important meteorological conditions within the study area. These data layers were all deemed important in making real time – pesticide-specific application decisions.

Each set of maps (e.g., RUSLE for all three target counties) generated brings various information to users wanting to take a precautionary approach to pesticide application. The base layers (i.e., Bing aerial map and USGS topographic map) provide users with spatial references and information at the county-level. Bing Aerial map allows users to view their property from a different perspective as well as consider land uses

around their property of interest. These are however, base layers to build upon in GIS. When looking at land use and percent imperviousness, the area with the most impervious cover was in Beaufort County. Dominant developed features include the Beaufort Marine Corps Air Station, Paris Island, Port Royal, Sun City, and Bluffton areas, major highways, and Hilton Head Island. Precautionary approaches and proper pesticide application within these areas is of the utmost importance to minimize coastal impairments since current use pesticide risk assessment do not include the effects of impervious surface in predicting estimated environmental concentrations. This is particularly due to the faster velocities on paved (impervious) surfaces during rain events leading to higher runoff rates and therefore higher probability of acute increases in environmental concentrations of pesticides in surface water. In Hampton and Jasper Counties, agricultural land still appears to be an important land use – relative to Beaufort County. This possibly translates into upstream surface waters having more pesticide inputs from rural and suburban land, rather than runoff from impervious surfaces (Beaufort County). However, the lesser degree of imperviousness also allows for greater groundwater recharge and less runoff possibly lessening pesticide loading into surrounding surface waters.

The proximity of developed land to open water and wetland areas is an important parameter to consider when pesticide application is occurring. All three counties contain wetland areas, meaning all should consider preventative techniques on land adjacent to these ecologically important areas. Maps of FEMA flood-risk zones indicated Beaufort County had the most area within the 100-year floodplain where complete inundation and wave action during flooding is expected to occur. Ideally, in developed areas falling into

this FEMA flood-risk zone (VE), long-term plans are needed– including precautionary decisions about what, when, and where pesticide application occurs – as flooding can lead to areas of high ecosystem contamination.

There are pesticides that bind to soil – those having high K_{oc} values – and pesticides that likely do not bind to soil (low K_{oc} values) and have a tendency to runoff into adjacent waterbodies during rain events. The RULSE equation is most useful for those pesticides that have the tendency to bind to soil, but sediment can also enter a system through high runoff rates when intense rain events do occur. Using the RUSLE equation is one of the more useful areas for decisions concerning pesticide application, especially in areas where high nutrient loads are entering an estuarine system (e.g., agricultural use or residential lawns), or in areas of high development (i.e., high imperviousness) as numerous chemical contaminants – including a variety of pesticides – may enter the ecosystem.

Once information from all data layers are considered together within an area, specific precautions can be taken to prevent contamination within an ecosystem where areas of higher concern overlap among layers. There are several examples of reduced adverse effect when these parameters are considered before large scale (e.g. individual applicator) and/or small-scale (e.g., county level) application occurs. First, if wind speed is high (*in situ* data) then users may wait for spraying pesticides until the wind decreases in velocity – either on lawns or during abatement. Similarly, if temperature is not ideal for current application, the user may choose to wait until the temperature increases or decreases (depending upon the pesticide) for application. Next, application occurring in residential areas lining tidal creek and estuarine areas, users may establish vegetative

buffers – reducing potential ecosystem contamination. In areas where high erosion occurs, users can try to prevent the erosion or not apply pesticides with high soil binding properties in these areas. On land, where soil type is predominantly composed of fine sand, leaching may be a problem for some pesticides and should be considered. If application is occurring in an area classified as highly imperviousness, other IPM techniques can be implemented. For example, if weeds are problematic – instead of using chemical options – simply deal with the issue using a more laborious method – manually removing them or planting alternative vegetation. This approach will also identify highly erodible areas with potentially high soil loss and may conversely become higher risk in more vulnerable areas during pesticide decision-making and application.

At the county and tri-county level, when possible pesticide application is identified in high impervious surfaces (i.e., each raster cell = 30m x 30m) across a large expanse of land – educational strategies for residential applicators within neighborhoods and communities can be implemented. Further, if an area of high imperviousness occurs within the 100-year floodplain where inundation and wave action are expected – precautionary approaches may be developed – as intense coastal storms have the potential to quickly increase tidal amplitude and therefore flood suburban and urban areas. Events such as this have the potential to acutely raise environmental concentrations of pesticides, particularly within tidal creek areas, and cause large-scale events due to water quality impairments such as fish kills or mammal strandings.

Use of the spatial variables within the three counties in the South Carolina coastal zone in this study indicates that important considerations for pesticide application can be quickly visualized and identified. Implementation by residential pesticide users has the

potential to prevent future large/small-scale adverse events and reduce pesticide inputs into critical ecosystems within this portion of the southeastern coastal zone. Through collaborative community efforts – having the common goal of implementing pesticide use reduction and proper application techniques – less of a threat occurs from anthropogenic inputs into the surrounding estuarine ecosystems. As urban and suburban areas continue to grow (i.e., sprawl) – overlapping in some cases – with vital ecological systems critical to coastal health, the probably for water quality impairments due to overuse or improper use of residential pesticides increases within their developed areas. Large-scale efforts in implementing precautionary approach for coastal pesticide application using spatial methods decreases residential pesticide applicators from accidentally misusing pesticides and aids in forming a resource management plan – decreasing incidences of adverse pesticide-related events now and in the future.

Limitations

Errors inherent to geographic information systems and geographic analysis potentially propagate within models (Poiani and Bedford 1995). Sources of errors from geographic data can be numerous (Burrough 1986, Goodchild1993). The RUSLE equation is typically used for small areas of land, such as a field or pasture – as it is predominantly used for agricultural scenarios. In using the RUSLE equation, given the land mass the equation was applied to – it appears possible overestimations of potential soil loss may have occurred. However, because there are categories for the different amounts of loss, areas where soil loss is high and soil loss are low may still be identified.

The National Land Cover Database 2006 (NLCD 2006) (Fry et al. 2011) classification scheme was used to develop the land use layer and based upon

unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) (2006) satellite data (Fry et al. 2011). Epstein et al. (2002) found that deriving accurate information on urban extents can be difficult due to instances where rural areas were also present in the analysis. Within the study area of this project it is possible some misclassification occurred and that such things are constantly changing over time. Within the raster grid cell, estimations of land use/cover are calculated over a 30m x 30m area, most likely leading to some erroneous classification. Further, the data are from the years 2001 to 2006, with possible changes occurring after 2006 concerning land use since 2006.

Future Directions

Integrating the data layers for the study and implementing it in an interactive fashion – where users can zoom in and out of land areas and control the data layers they are viewing – is the most important next step to this study. Transparency of each layer can be added in order for the user to view and pan around multiple GIS layers at once. Additionally, an address search for precision in location would also be a useful element of web-based implementation of the map layers for the study area. Web-based implementation offers the user easy access to the information, and more importantly, gives the user the power in deciding what they want to view and deem important during pesticide decision-making and application.

Next, some areas will be more vulnerable than others based on geographical and temporal variations over the study area. It is important to account for *sensitivity* (the ease with which chemicals can move from the surface to the groundwater through underlying soils and geological formation) and *vulnerability* (determined by combining groundwater

sensitivity maps with the presence of crop type, land-use practices, pesticide use and applied water) when discussing pesticides as this will allow for even more accurate recommendations for pesticide application (Dixon 2005). This is particularly important in the coastal region of South Carolina, as soil type and land use patterns are not homogeneous across the geographical area.

Further, implementing hydrological modeling with physical and chemical properties of residential pesticides will help determine the environmental transport and fate of the most highly used residential pesticides. Flow patterns of the surrounding waters to determine if upstream agricultural activities or construction (i.e., increased turbidity) may be impacting the waters can be determined. Also, using a coupled mapping approach may also aid in addressing spatiotemporal variations in pesticide use as probabilistic risk models for pesticides work with spatial layers to identify land areas where people and the ecosystem have the highest health risk. Combining an approach where geographic information systems (GIS) are used to address landscape variability with a probabilistic risk estimates potentially generates the most realistic estimates for pesticide fate and transport. Additionally, limiting the geographical range to one community at a time (i.e., subdivision), allows people living within that community to identify if they live in a vulnerable area, and to ultimately make better decisions about pesticide use in and around their homes. Moreover, certain portions of golf courses – or other land use features in a community – may have greater runoff rates, slope, and distance from estuarine habitat, allowing for site specific recommendations for sections of the golf course or other recreational land uses. At this spatial scale, this approach can act as an example for other communities and can then be applied to any community

aiming to reduce the impairments caused by improper pesticides on human health and the health of the surrounding ecosystem.

CHAPTER 4

DEVELOPMENT OF AN INTERACTIVE EDUCATIONAL WEBSITE FOR COMMONLY-USED RESIDENTIAL PESTICIDES IN THREE SOUTH CAROLINA COASTAL COUNTIES

4.1 ABSTRACT

The objective of an online learning system is to outline an intuitive framework to implement an educational strategy easily understood by its intended users. Sccoastalpesticides.org offers a unique approach where researchers, educators, and outreach can quickly work with a large portion of the intended audience within the study area. Dissemination of pertinent, easily-understood pesticide information and strategies that are geographically relevant allows the community to maintain functionality, economic viability, and aesthetic appeal of the surrounding environments.

Encroachment and overlap of urbanized areas into natural coastal environments potentially impacts the surrounding ecosystem and economically important commodities if proper management strategies are not integrated into development planning. Intricately linked to urban expansion is the use of pesticides within homes, on lawns and turf grass, in right-of-way easements, landscaped areas (ornamentals), and for vector control. As pest problems (e.g., severity of infestation, area of application, and type of application) are unique in many respects, educational efforts on overall toxicity, environmental fate and transport characteristics, and proper application of pesticide formulations needs to occur for the general population – particularly within the coastal

zone given its continued population growth rate and development preferences. Design and development of sccoastalpesticides.org allows researchers to address water quality impairments in their area, and potential options for residents to prevent or control problems in the future. This allows residents living in the area to readily control and access residential pesticide questions they may have.

The website developed in this study is designed to enhance the user's knowledgebase of pesticides and pesticide regulation as well as provide access to two interactive tools – the Pesticide Decision-Support Tool (A system developed to aid in proper identification of pests and pest treatment options) and the Data Portal (interactive geospatially explicit maps of the study area). The knowledgebase is a pesticide educational tool as it includes addressing many different aspects of pesticides and pesticide regulation in the U.S. The emphasis here should be on Integrated Pest Management (IPM) practices and approaches to decrease overall pesticide use. This not only decreases the probability for surface water contamination from pesticide inputs, but also decreases the time for pest species to gain resistance to the pesticide treatment.

Combining knowledge on proper pesticide practices, an interactive pesticide decision-support tool, and an interactive geospatial map for property-specific application improves the pesticide decision-making at the individual level. The interactive map provides the user with information identifying land and water characteristics, soil type, potential soil loss, floodplain zone, coastal and offshore *in situ* data on important meteorological data, and forecasting data – all to aid the user in making real time – pesticide-specific application decisions.

4.2 INTRODUCTION

4.2.1 Population Growth and the Health of Estuarine Ecosystems

More than one-third of the nation's assessed surface waters are listed as impaired – with almost 40% too polluted for recreational activities (e.g., swimming, fishing) (EPA 2013). In bays and estuarine systems – as defined by the EPA – 32,659 square miles were assessed nationally out of a total of 87,791 square miles. Out of those assessed, 66% were found to be impaired (EPA 2013). As a result of those surface water impairments, 66.9% of aquatic life harvesting and 47.9% of shellfish harvesting were also impaired (EPA 2013). Two of the contributing sources of surface water impairments in bays and estuaries are pesticides and stormwater runoff (EPA 2013). Over half of the US population lives in the coastal zone (Culliton 1998) with urban expansion encroaching upon these sensitive and economically viable regions. Continued population growth (coupled with sprawling suburban and urban development) increases the potential for water quality impairments from stormwater runoff and residential pesticide use (Figure 4.1). In the southeastern coastal zone of the US, bays and estuarine ecosystems dominate – particularly around barrier islands. South Carolina's coastal population has grown by 30% over the last 15 years and is conservatively estimated to grow another 35% over the next 25 years leading to increased pressure on tidal creeks and estuarine ecosystems vital to the region (Sanger et al. 1999, White et al. 2004, SC Budget and Control Board 2005). Given that local coastal and state economies benefit from tourism and fishing industries—reducing anthropogenic inputs from both the individual to the regional level are vital to ecosystem health and continued economic success in the South Carolina coastal zone.

Pesticides used in coastal residential areas (i.e., areas including suburban and urban centers) include applications within homes, on lawns and turf grass, in right-of-way easements, landscaped areas (ornamentals), and for vector control. As pest problems vary (e.g., severity of infestation, area of application, type of application) with toxicity of the pesticide and number of annual applications, it is important for residents to be educated about pests and pesticides in suburban and urban areas. This is particularly true in the South Carolina coastal zone where residential communities continue to grow. Until implementation of proper precautionary techniques for pest management are instilled into the fabric of communities, potential ecological hazards remain from improper pesticide use. Dissemination of pertinent, easily-understood pesticide strategies allows the community to maintain the functionality, economic viability, and aesthetic appeal of the surrounding estuarine ecosystem.

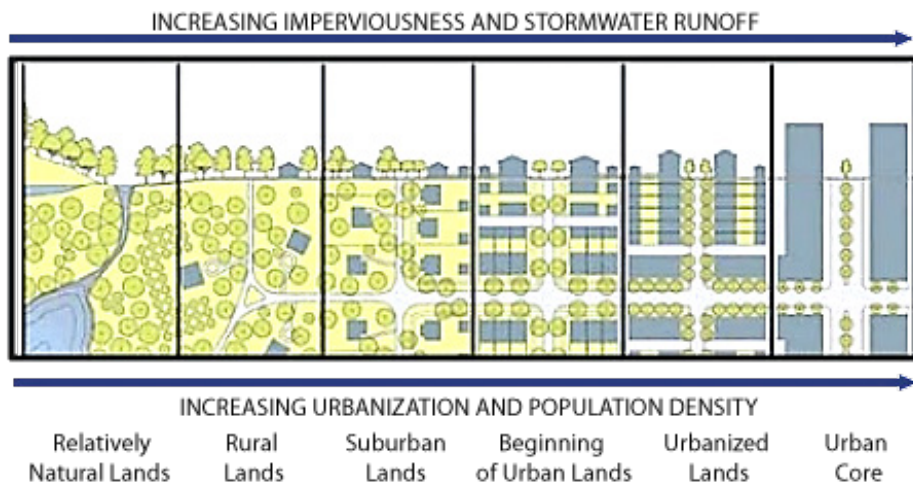


Figure 4.1: Generalized diagram of different zones of land use transitioning from relatively natural land with little human presence to a human-dominated urban core. As human population density increases, urbanization, impervious surface, and stormwater runoff also increase. Pesticide application in suburban and urban areas has a greater potential to runoff in stormwater, therefore causing acute increases in surrounding surface waters during rain events. Illustration adapted from <http://www.transect.org>.

4.2.2 Developing Interactive Tools for Pesticide Education

Information transfer has improved vastly over time – as today, we have powerful computing machines with hardware and software constantly improving performances in data processing, transfer, reception, and memory. The use of the Internet – acting as a network between computing machines via the World Wide Web – allows information transfer to occur quickly on a global platform. The ability to reach people with an educational strategy through a website framework improves the efficiency of information transfer reducing overall costs and increasing communications. Designers of online learning systems have access to a plethora of software tools and resources for dissemination of information (Anido 2001). Using the HTML programming language provides website designers a way to build and retrieve predefined informational pages, but lacks the object-oriented programming language Java programs allow (Deol and Tim 1998). Often, interactive tools – or Java powered pages – are embedded within a static system developed using HTML coding that fetches and displays information. Java powered pages allow for user queries to occur by clicking hyperlinks that send a request to a Web server. The web server locates the program, executes it, and the program information is then sent back to the web browser for the user.

In this study – designed to have both informational pages and embedded Java powered pages – the major goal was to design a user-friendly website to improve environmental decision-making as it relates to residential pesticides within a pre-defined study area. The first aim was to build a knowledgebase where users might better-educate themselves about the many complex facets of pesticides, integrated pest management

(IPM), and pesticide regulation in the U.S. The second aim was to develop a pesticide decision-support tool – using Java powered pages – to aid users in choosing commonly used residential pesticides that are less persistent, bioaccumulative, and harmful (i.e., toxicity) to population and environmental health. The pesticide decision-support tool is based on a relative cumulative ranking system of one hundred commonly-used pesticides and an evaluation of potential pests within the study area. The third aim of the project was to develop an interactive (i.e., Java powered pages) spatially explicit model using GIS to improve user understanding of land use, land management, and pesticide management options. The interactive geospatial tool (termed *data portal*) provides the user with information identifying land and water characteristics, soil type, potential soil loss, FEMA flood-risk zones, coastal and offshore *in situ* data on important meteorological data, and forecasting data – all to aid the user in making real time – pesticide-specific application decisions. Together these three aims address knowledge gaps in public understanding and proper implementation of residential pesticides.

4.3 METHODOLOGY

4.3.1 Study Area

The study area consists of the three most southern counties in South Carolina: Beaufort, Jasper, and Hampton Counties (Figure 4.2). Census data indicate that populations within Beaufort and Jasper Counties have increased by 25% between 2000 and 2010 (US Census Bureau 2010) – giving rise to greater urbanization and therefore most likely coinciding increased residential pesticide usage. The Port Royal Sound system is unique compared to other coastal areas in North America due to the large embayment dominated by expansive salt marshes. The Sound also has exceptionally high

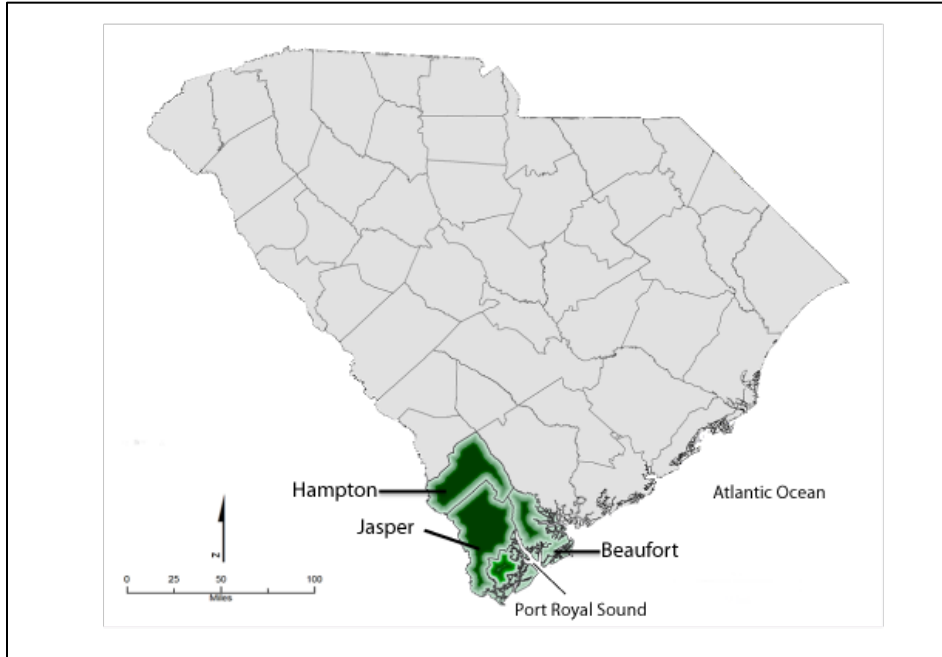


Figure 4.2: Geospatial map of the three target counties chosen for the initial trial of the pesticide decision-support tool in South Carolina. Beaufort and Jasper Counties both share boundaries that line the Port Royal Sound and contain coastal borders. Hampton County is unique in that it does not share these same characteristics, but importantly urban and agricultural areas within the county may contribute to water quality impairment’s as water moves downstream to the Atlantic Ocean.

tidal amplitude, low-lying topography, and extensive salt marsh habitat. Beaufort County alone accounts for half of South Carolina’s salt marsh habitats. The geographical features and location, along with population changes within the target counties makes it an ideal study area for initial website implementation for residential pesticides.

4.3.2 Website Design

The first step in implementing the three-pronged pesticide educational system was to establish a domain name (via doster.com) and a Web host server (via bluehost.com) for the website. The established website address (URL) was sccoastalpesticides.org. Design of the website was completed in Adobe Dreamweaver CS5.5 using HTML programming to author webpages and Cascading Style Sheets (CSS) rules for various stylized

components. Adobe Dreamweaver was used as it reads multiple coding languages – as we needed the design tool to recognize JavaScript for the pesticide-support tool and the spatially explicit model of the study area. Two additional plug-ins were purchased for design and mobile device implementation. The wire framework for the website was initially created and pages were then built within this framework (Figure 4.3). Design parameters were set with the target audience in mind – spanning from your everyday gardener to licensed pesticide applicators. Sccoastalpesticides.org framework includes elements that run through each page to increase user-friendliness in terms of website navigation.

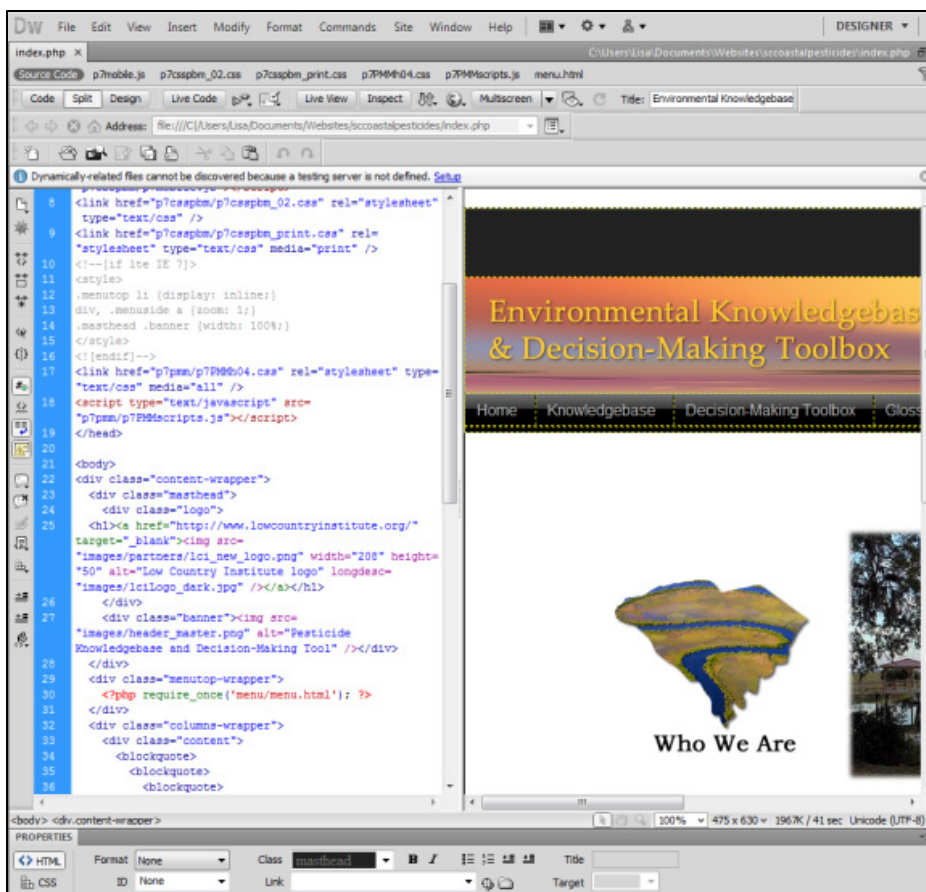


Figure 4.3: Screenshot of website design and HTML coding within Dreamweaver CS5.5. The display shows both the coding screen and the design output within a design view window.

4.3.3 The Knowledgebase

Sccoastalpesticides.org environmental knowledgebase was established as a top menu item with multiple sub-categories. It was framed to outline information on pesticides, integrated pest management (IPM) approaches and benefits, toxicology, risk assessment, and water quality arranged in an order where the information builds upon the previous material covered – making understanding pesticide decision-making easier for the user (Figure 4.4). Special attention was given to the IPM approach and benefits as this will aid the user in determining if they need the decision-support tool (i.e., chemical solutions to pest problems). The key elements to the IPM approach for managing pests problems begins by exhausting all non-chemical treatment options – physical, biological, cultural controls – before chemical (pesticide) options are implemented (EPA 2012, NPIC 2012). Each area covered in the environmental knowledgebase was based on published (or established) literature. In addition to the knowledgebase, it was decided that recent updates, facts sheets, links to useful third-party websites and a glossary of terms were necessary for a full understanding of pesticides and pesticide regulation. These items are included in different top menu items – besides the knowledgebase – or within a left sidebar running throughout the majority of the website.

4.3.4 Pesticide Decision-Making Using the Relative Cumulative Ranking System

Development of the Relative Cumulative Ranking System

In order to develop a relative cumulative ranking system for one hundred commonly-used residential pesticides within the tri-county area, multiple stakeholders made contributions to compile the list for residential applications (both indoor and outdoor), golf courses, vector control agents, right-of-ways, nuisance aquatic species, and

tomato farms. The system normalizes values for thirteen different endpoints, or parameters, for each pesticide – giving each endpoint equal importance in the final analysis. All endpoint data (toxicity and environmental fate and transport values) were derived from EPA documents

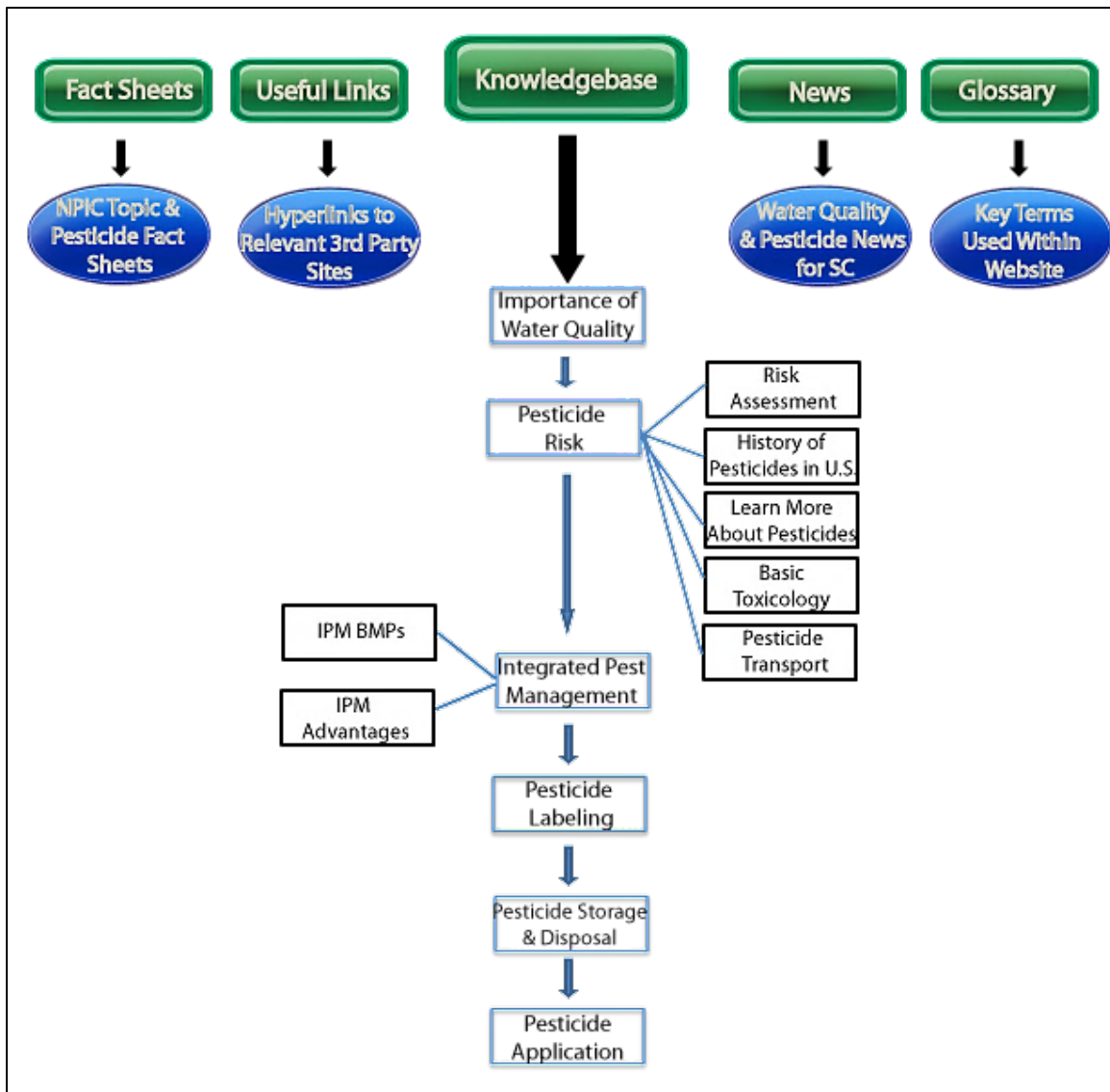


Figure 4.4: Flow diagram illustrating the different components of the Knowledgebase.

to maintain consistency with the current regulatory framework. Endpoints were chosen in an effort to reflect importance to the public and to take a relatively complex group of values and develop an easily-understandable ranking system that can be implemented by everyone. Ultimately, pesticides were divided into a three bin color-coded system (low, moderate, and likely potential ecosystem hazard) based on statistically valid tertiles of the cumulative scoring for each of the pesticides (Figure 4.5). The active ingredient pesticides, the class of pesticide, and the final ranking are summarized in Table 4.1.

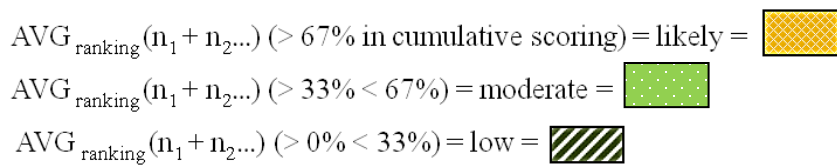


Figure 4.5: Cumulative Scoring of frequency distribution on parameters/pesticide. Thresholds = tertiles of distribution.

Implementing the Cumulative Ranking System in an Interactive Decision-support Tool

The interactive decision process (i.e., pesticide decision-support tool) begins with two main user options: 1) pesticide search by either active ingredient or brand name or, 2) identify the pest first, then identifying appropriate pesticides used for that pest (Figure 2.9). The user may already have a pesticide they want to learn more about or want to access an easy-to-read label about their purchased pesticide or pesticide formulation. If this is the case, the user chooses choice 1 – pesticide search. Within this search option, the user may search by active ingredient pesticide or by brand name (Figure 2.9). The search engine accesses the pesticide formulations within Clemson University’s database of registered pesticides for South Carolina as well as search for the active ingredient(s) within those formulations.

Table 4.1: One hundred active ingredient pesticides chosen for the relative-cumulative ranking of commonly-used pesticides in the Beaufort, Hampton, and Jasper counties, SC. Pesticide class is in parentheses after the active ingredient pesticide, where : A = algaecides, F = fungicide, H = herbicides, A = algaecides, and S = synergist. In total, 12 fungicides, 6 algaecides (strictly), 43 herbicides, 39 insecticides were included in the analysis. Several of the pesticides reviewed, fall into two or more pesticide classes (e.g., algaecide, herbicide) and should be noted here. Pesticide ranking based on relative cumulative scoring for potential ecosystem hazard is located in the cells to the right of the pesticide.

Active Ingredient Pesticide	Pesticide Ranking	Active Ingredient Pesticide	Pesticide Ranking	Active Ingredient Pesticide	Pesticide Ranking
2,4-D (H,A)	moderate	Napropamide (H)	low	Imidacloprid (I)	likely
Copper compounds (A,F)	likely	Pendimethalin (H)	low	Malathion (I)	likely
Glyphosate (A,H)	low	Fluroxypyr (H)	low	Etofenprox (I)	likely
Imazapyr (A,H)	low	Siduron (H)	low	Trichlorfon (I)	likely
Penoxsulam (A,H)	low	Benefin (H)	moderate	Dicofol (I)	likely
Carfentrazone (A,H)	low	Fenoxaprop-ethyl (H)	moderate	Cyfluthrin (I)	likely
Endothall (A,H)	low	Indaziflam (H)	moderate	Temephos (I)	likely
Flouridone (A,H)	moderate	Metolachlor (H)	moderate	Hydramethylnon (I)	likely
Triclopyr (A,H)	moderate	Oryzalin (H)	moderate	Indoxacarb (I)	likely
Simazine (A,H)	moderate	Bromoxynil (H)	moderate	Chlorpyrifos (I)	likely
Hydrothol (A,H)	likely	Pronamide (H)	moderate	Methiocarb (I)	likely
Sodium-carbonate Peroxyhydrate (SCP) (A,H)	low	Diclofop-methyl (H)	moderate	Endosulphan (I)	likely
Fosetyl-AI (F)	low	Fluazifop-butyl (H)	moderate	Abamectin (I)	likely
Mandipropamid (F)	moderate	Paclobutrazol (H)	moderate	Fipronil (I)	likely
Thiophanate-methyl (F)	moderate	Dimethenamid (H)	moderate	Piperonyl butoxide (PBO) (I,S)	moderate
Pyraclostrobin (F)	moderate	Atrazine(H)	likely	Boric Acid (I,F,A)	low
Mancozeb (F)	moderate	Dithiopyr(H)	likely	Glufosinate(H)	low
Myclobutanil (F)	moderate	Oxadiazon(H)	likely	Clopyralid (H)	low
Trifloxystrobin (F)	moderate	Bensulide(H)	likely	Quinclorac (H)	low
Difenoconazole (F)	likely	Bispyribac-sodium (H,A)	low	Trinexapac-ethyl (H)	low
Iprodione (F)	likely	Diquat (H,A)	moderate	Clethodim (H)	low
Vinclozolin (F)	likely	Metham-sodium (H,F,I)	likely	Ethofumesate (H)	low
Asoxystrobin (F)	moderate	DEET (I)	low	Isoxaben (H)	low
Chlorothalonil (F,I)	moderate	<i>Bacillus thuringiensis</i> (BTI) (I)	low	Halofenozide (I)	moderate
Rimsulfuron (H)	low	Naphthalene (I)	low	Permethrin (I)	moderate
Dicamba (H)	low	Dinotefuran (I)	low	Chlorantraniliprole (I)	moderate
Asulam (H)	low	Thiamethoxam (I)	low	Clothianidin (I)	moderate

Mesotrione (H)	low	Methoprene (I)	moderate	Spinosad (I)	moderate
Metasulfuron-methyl	low	Pyriproxyfen (I)	moderate	Carbaryl (I)	likely
Aminocyclopyrachlor	low	Acephate (I)	moderate	Hexaflumuron (I)	likely
Foramsulfuron (H)	low	Sumithrin (I)	moderate	Maneb (f)	moderate
Imazaquin (H)	low	Bifenthrin (I)	moderate		
Sethoxydim (H)	low	Deltamethrin (I)	moderate		
Sulfentrazone (H)	low	Lambda-cyhalothrin (I)	moderate		

Ease of use is an attribute that is generally preferred by users making interactive web-based decisions. Using pictures and an easily understandable flow within a website format allows for fast identification of a pest if the right questions are originally asked. One of the most important things to implement in the IPM system is the correct identification of the pest before control measures are taken. The users of the decision-making tool may choose to decide to identify the pest through a series of questions they can answer by clicking a picture accompanied by a written description of the pest – choice 2. A conceptual diagram illustrates how the background information generates decisions – or next page options – for the user (Figure 4.6).

This decision tree system allows the user to positively identify their pest before they view the pesticides targeted for that pest. The decision-making “identify my pest, then pesticide” option begins with the user clicking on one of four general categories (Figure 4.6, level 2) based on four main groups of pests for the six use categories: a) bugs (insecticides), b) nuisance aquatic species (algacides), c) blights and diseases (fungicides) and d) weeds and grasses (herbicides). The user starts with these four major groups of pests, and then by clicking the picture “button,” moves to a subcategory of more precise groupings (Figure 4.6, level 3) falling under the major category. By adding this layer to the process, it narrows down the pests – and associated pesticides – resulting in increased speed of identification. Once the user finds and clicks on an appropriate sub-

category (e.g., stinging and biting bugs), then a larger list of potential pests, and associated pictures are populated for the user (Figure 4.6, level 4). The final groups displayed are specific pests allowing users to view and click – making the final decision in the tree – and transferring them to the next page – the output (Figure 4.6, level 5).

The output displayed for the user differs slightly based on the original starting point in the decision-support tool. If the user chooses to conduct a pesticide search, then there are two possible outcomes based on either searching by active ingredient (option 1) or by brand name (option 2) (Figure 4.7). If the user searches by an active ingredient pesticide, the output also includes a clickable button that displays the brand names registered in South Carolina for use (Figure 4.7). This action operates in a similar but opposite manner when the user searches by brand name pesticide. Searching by brand name leads the user to an output page with the brand name – along with a clickable button to the label for that product – as well as the active ingredient and a clickable button leading to other brand names that contain it (Figure 4.7). Both of these search options populate a list of pests treated by that active ingredient or brand name pesticide. The output displayed when starting with the identification of the pest also differs slightly from option 1 and 2 (Figure 4.7, option 3). This output displays the pest identified by the user, the active ingredient pesticide(s) used to treat the pest as well as the option to view brand names, and other pests treated by that active ingredient pesticide.

Additionally, for all aforementioned decision-making systems, particular concerns are identified to the user as the relative cumulative ranking is based on the average of the endpoints included in the analysis. If a compound in the ranking system may rank as low relative potential ecosystem hazard, it may still have specific concerns users should note.

A system of concern buttons was developed for this purpose (Figure 4.8). If one of the endpoints considered for a pesticide was assigned a numerical value of 10 – based on the EPA thresholds set – then a concern button is displayed in the output.

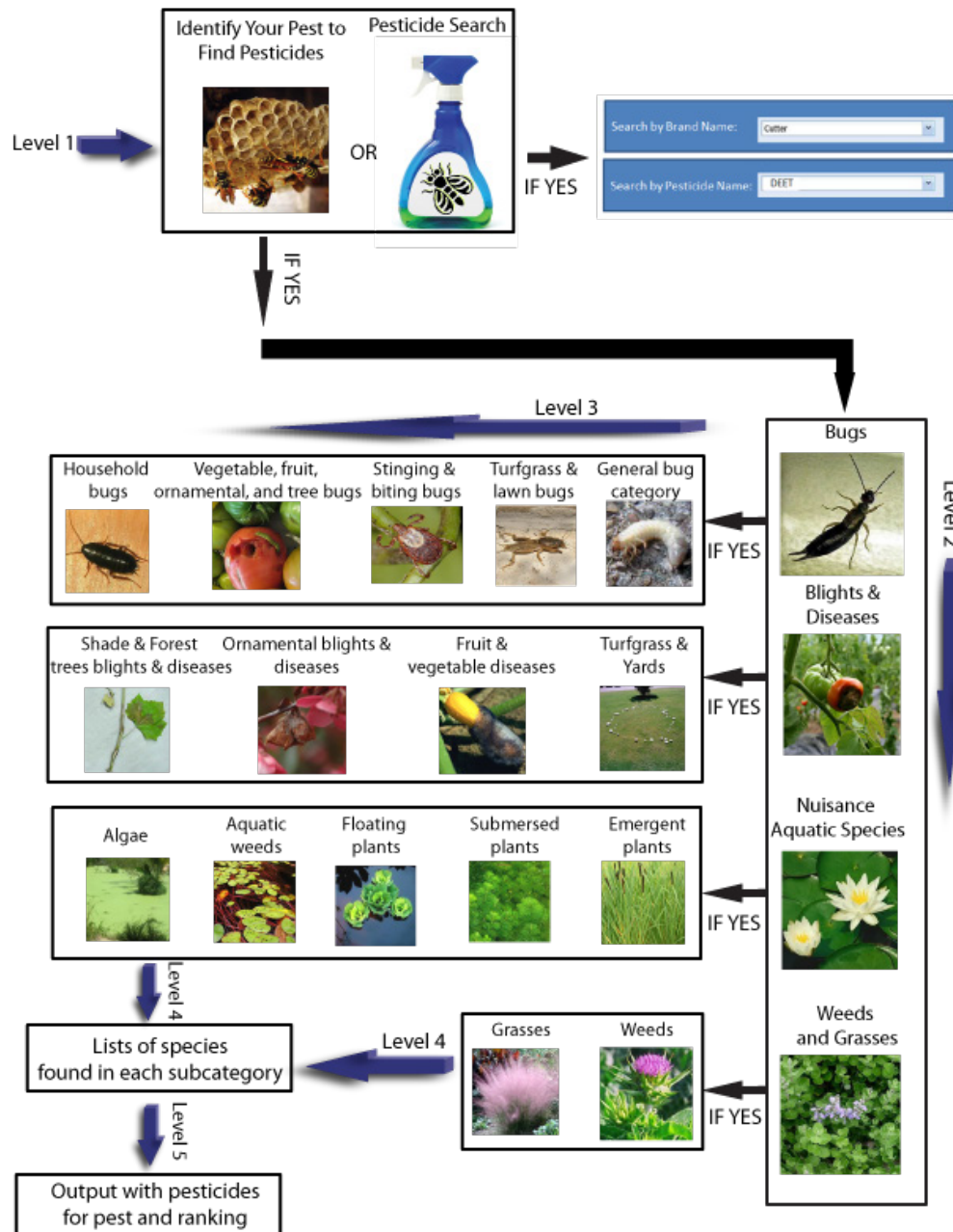




Figure 4.6: Decision-making flow chart for the interactive pesticide tool on sccoastalpesticides.org. The brand name and active ingredient within these examples were randomly chosen and the author is not promoting nor insulting the brand or pesticide.

Examples of Potential Output Options

Option 1

Pesticide	DEET <input type="button" value="Brand Names"/>
Pests Treated	Horsefly; stable fly; greenhead fly; ticks; chigger
Potential Ecosystem Hazard	Low
Class of Pesticide	Insecticide
Concern	

Option 2

Brand Name	Cutter <input type="button" value="Label"/>
Active Ingredient Pesticide	DEET <input type="button" value="Other brand names"/>
Pests Treated	Horsefly; stable fly; greenhead fly; ticks; chigger
Potential Ecosystem Hazard	Low
Class of Pesticide	Insecticide
Concern	

Option 3


Pest Type	Adult Mosquito
Pesticide	DEET <input type="button" value="Brand Names"/>
Potential Ecosystem Hazard	Low
Class of Pesticide	Insecticide
Other Pests Treated	Horsefly; stable fly; greenhead fly; ticks; chigger
Concern	

Figure 4.7: *Example* of the output from the automated decision-making coded within the script. By working through a series of pictures and questions (each based on a prior decision) the user arrives to the final option where the output is displayed for the cumulative ranking system, brand names, pesticide class, classes treated and the concern buttons for the compound. The brand name and active ingredient within these examples were randomly chosen and the author is not promoting nor insulting the brand or pesticide.



Figure 4.8: Concern buttons developed to indicate to the website user specific concerns about a pesticide. Even though a pesticide comes up as low potential ecosystem hazard within the ranking system, there still may be endpoints considered in the analysis where precautionary measures should be taken before application occurs. If a numerical ranking value on 10 for an endpoint for a pesticide, then a concern button will be displayed in the output for that endpoint for that particular pesticide – allowing users to pinpoint specific concerns for each pesticide.

Developing an Interactive Geospatial Model

The first aim in developing an inactive geospatial map for residential pesticide applicators within the study area was to generate a series of maps for the study area using GIS for numerous variables – defining areas where pesticide application may lead to inputs into tidal creeks potentially adversely affecting the overall health of the ecosystem.

Specifically, base maps were chosen (USGS topographical and OpenStreetMaps) and geophysical factors such as slope, soil type, land use and land cover, percent imperviousness, FEMA flood-risk zones, RUSLE potential soil loss, and *In situ* data for parameters on temperature, wind direction and speed, and forecasting data (i.e., potential for rainfall) were input in GIS for the coastal study area. Geospatial data were also provided from NOAA on biological measures including algal blooms, fish kills, and mammal strandings – all of which are indicative of acute water quality impairments. After the various geospatial data layers were developed in GIS, Java powered pages were used to reference and give the user the power to manipulate the spatial variables. A framework was developed for the geospatial data (termed the *data portal*) to be embedded within the HTML-coded website. Within the framework, the user has the option to view each geospatial map developed (Figure 4.9).

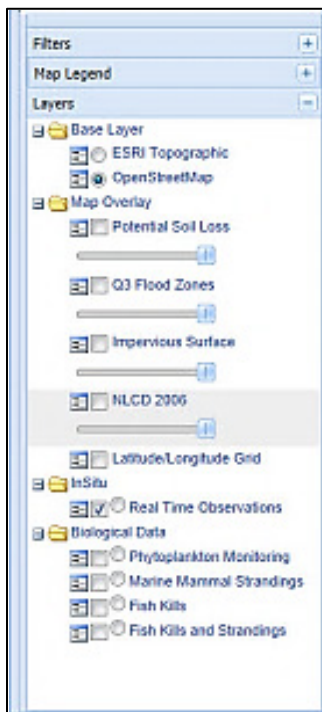


Figure 4.9: Framework for the interactive spatial explicit model of the study area. This control panel allows the user to manipulate what they are viewing.

4.4 RESULTS

In order to execute an interactive pesticide educational strategy, sccoastalpesticides.org was designed as the platform for dissemination of pertinent information as well as the hub for the pesticide decision-making toolbox (Figure 4.10). Combined – this grouping provides users with all the components needed to understand and make informed decisions about residential pesticides within the target counties. The website begins with a “splash” page to give a brief explanation of the collaborative effort sccoastalpesticides.org represents among multiple partners and presents the overarching goal of the website. Users may also click a link to view the complete list of contributors to the site including: University of South Carolina, The LowCountry Institute at Spring Island, NOAA, Southeast Coastal Ocean Observing Regional Association (SECOORA), the Governors’ South Atlantic Alliance, SC Sea Grant Consortium, Clemson University, University of Maryland Center for Environmental Science, the U.S. EPA, the National Pesticide Information Center (NPIC), University of Georgia Center for Invasive Species and Ecosystem Health, Cypress Gardens, and the South Carolina Department of Health and Environmental Control (DHEC).

Next, users continue to the homepage displaying all of the top menu items and the left sidebar that runs throughout the majority of the website – acting as a quick link to several important aspects of the website (Figure 4.10). This sidebar includes a quick link to the basics of pesticides page, fact sheets on other important topics and pesticides – generously provided by the National Pesticide Information Center (2012). The sidebar also acts as a quick link to the pesticide decision-support tool (i.e., “select your pesticide” button) and quick links to the interactive geospatial models. The geospatial models may

be accessed by clicking on “data portal,” or by clicking on the map of the target counties. Additionally, the homepage contains an embedded brief (i.e., less than 4 minutes) instructional video tutorial developed using Camtasia Studio (techsmith.com). The tutorial walks the user through various aspects of the website, decreasing navigation time among pages and increasing user-friendliness.

The top menu bar options begin (left to right) with a link that will always take the user back Home (i.e., the homepage). The Knowledgebase menu item consists of several drop-down subcategories – some of which have further tertiary categories (e.g., IPM, Pesticide risk) as outlined in the methodology (Figure 4.4, Figure 4.10). This knowledge is ordered such that the user learns about pesticides in a logical manner – where at the end of all sections being reviewed – provides a basic comprehension of pesticides. Terminology associated with many sections of the Knowledgebase and Decision-making Toolbox can be found under the Glossary menu tab – as the language of pesticides and toxicology contains terms that are specific to those fields – this seemed a necessary feature for users (Figure 4.10). The News tab and Useful Links top menu items contain hotlinks to external third-party sites helpful in keeping up with the most up-to-date information particularly in the state of South Carolina. A necessary aspect to all websites is the Contacts menu item – found farthest to the right on our list – containing email addresses for users to report about problems with the website (e.g., broken links) or ask further questions about pest management. This is specifically important if a user cannot properly identify their pest within the website and needs further guidance from experts in the field.

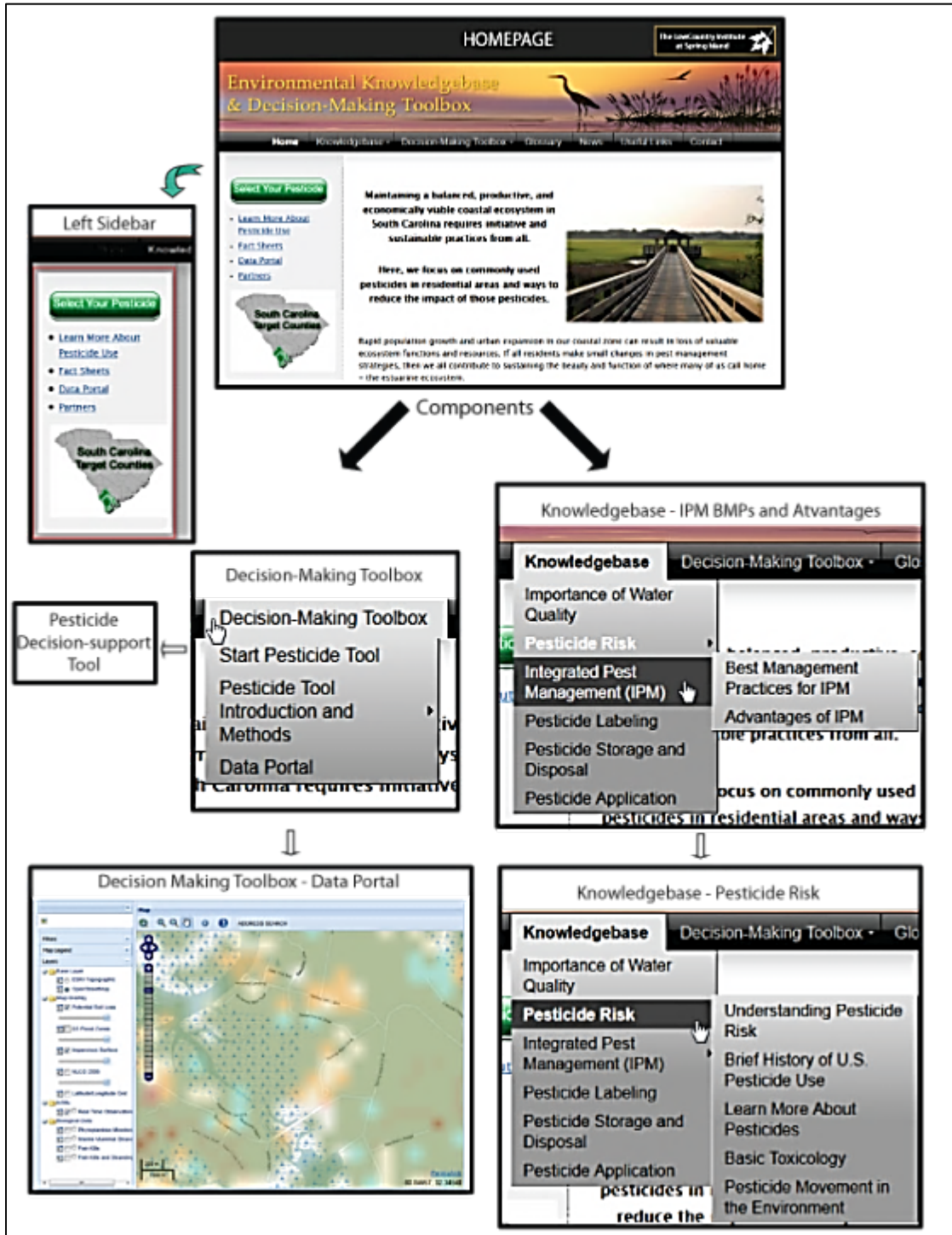


Figure 4.10: scoastalpesticides.org homepage and examples of the various components of the interactive website. The major components are the knowledgebase and the decision-making toolbox.

The interactive portions of sccoastalpesticides.org are found under the Decision-making Toolbox menu item (Figure 4.10). The Toolbox menu item contains links to the technical information about the decision-support tool (PDF document), an introduction with a guide to concern buttons, color codes, and a video tutorial of using the tool, and the actual decision-support tool itself, an overview of the cumulative ranking system used for the tool, and the inherent uncertainties and limitations of the decision-support tool (Figure 4.11).

Additionally, the data portal (i.e., interactive geospatial model) is housed within the Decision-making Toolbox of sccoastalpesticides.org (Figure 4.10). The data portal is embedded within one HTML-coded page of the website. The framework established to display the various geospatial characteristic options gives the user the power to control the flow and display options for the data portal. One aspect of the framework that makes it extremely user-friendly for residents making pesticide application decisions is the address search option. The user has the option to locate their property or view a specific area within a county. The user may then chose to alter the transparency of each layer, zoom in and out to various resolutions, and pan around the image once the desired resolution is reached.

Base layers for the data portal were imported (Figure 4.12), followed by each of the geospatial models developed using ArcGIS 10.1. The power of having them in an interactive web format gives users the ability to view multiple layers or features at once and manipulate geospatial layers rather than having static geospatial information. For example, zooming into the Port Royal Sound region and viewing the NLCD (2006) land classification and then looking at percent impervious surface at the same scale allows the

Decision-support Tool Pages for User Understanding

Decision-support Tool (Java Powered Pages)

The figure illustrates the user interface of a pesticide decision-support tool, divided into two main sections: informational pages for user understanding and the interactive tool interface.

Informational Pages (Left Side):

- Introduction to the Decision-support Tool:** This page provides an overview of the tool's purpose, which is to assist in pesticide selection based on environmental and pest-related factors. It includes a 'Did you know?' section and a 'Green Your Pesticide' sidebar.
- Value-ranking System Used for the Tool:** This page details the methodology used to rank pesticides, including the derivation of values and thresholds for relative cumulative ranking systems. It mentions the use of various pesticides and the involvement of the Environmental Protection Agency (EPA).
- Limitations to the Decision-support Tool:** This page discusses the tool's constraints, such as the reliance on specific data sources and the potential for user error in data entry.

Interactive Tool Interface (Right Side):

The tool interface is a Java-powered page that guides the user through the following steps:

- Option 1 User Choice:** The user is prompted to 'ID Your Pest, Then ID Pesticide Treatments' and 'Pesticide Search by Brand or Pesticide'. This step includes a magnifying glass icon for searching.
- Option 2 User Choice:** The user selects a pest category from a menu: Bugs, Blights & Diseases, Nuisance Aquatic Species, and Weeds & Grasses.
- Option 3 User Choice:** The user selects a specific pest type from a grid of images: Household bugs, Vegetable, fruit, ornamental, and tree bug, Stinging & biting bugs, Turkeys & lawn bugs, and General bug category.
- Option 4 User Choice:** The user selects a specific pest from a grid of images: Biting Flies, Hornets & Wasps, Adult Mosquitoes, and Fire Ants.

Output:

The final output screen provides the following information:

- Pest Type:** Adult Mosquitoes
- Pesticide:** DEET
- Potential Ecosystem Hazard:** Low
- Class of Pesticide:** Insecticide
- Other Pests Treated:** Horsefly; stable fly; greenhead fly; ticks; chigger
- Concern:** (Indicated by a warning icon)

Figure 4.11: Outline of items found under the pesticide decision-support tool menu item. The user may read the introduction on how to use the tool, view the developed ranking system, and limitations of the tool (left side). The user may also access a PDF document for technical explanation of the decision-making process. The Decision-support Tool is run through Java powered pages embedded into the website (right side). The user clicks on various options navigating to the specific pest problem or pesticide. The user-driven system allows for choices to be made by the resident and the output gives information useful in pesticide decision-making for specific pest problems.

user to view both land use and areas of high development where more precautionary approaches to pesticide application may be implemented (Figure 4.13). Similarly, viewing two different geospatial layers that overlay on top of the base map provides the user with useful information for pesticide application. For instance, zooming into specific regions and applying the RUSLE soil loss layer with the percent impervious layer allows the user to view the effect percent impervious surface potentially has on soil loss (Figure 4.14). One may also choose to view the FEMA high-risk flood zones along with percent impervious surface to determine if they live in an area where flooding may lead to potential high runoff of pesticides (Figure 4.14). RUSLE soil loss information can be viewed at different spatial scales to determine areas where soil loss is highest (Figure 4.15). Potential correlations between events, such as fish kills, can be viewed with potential soil loss – a factor that could lead to such an event; this may also be relevant for phytoplankton (algal) blooms as well. Then, data from the NOAA buoys and platforms can be combined with information gathered among various geospatial layers to make real-time decisions concerning pesticide application (Figure 4.16). NOAA biological data may also be viewed by the user to determine where historical major biological die offs occurred and determine areas that may need special consideration to prevent such future events from occurring (Figure 4.17).

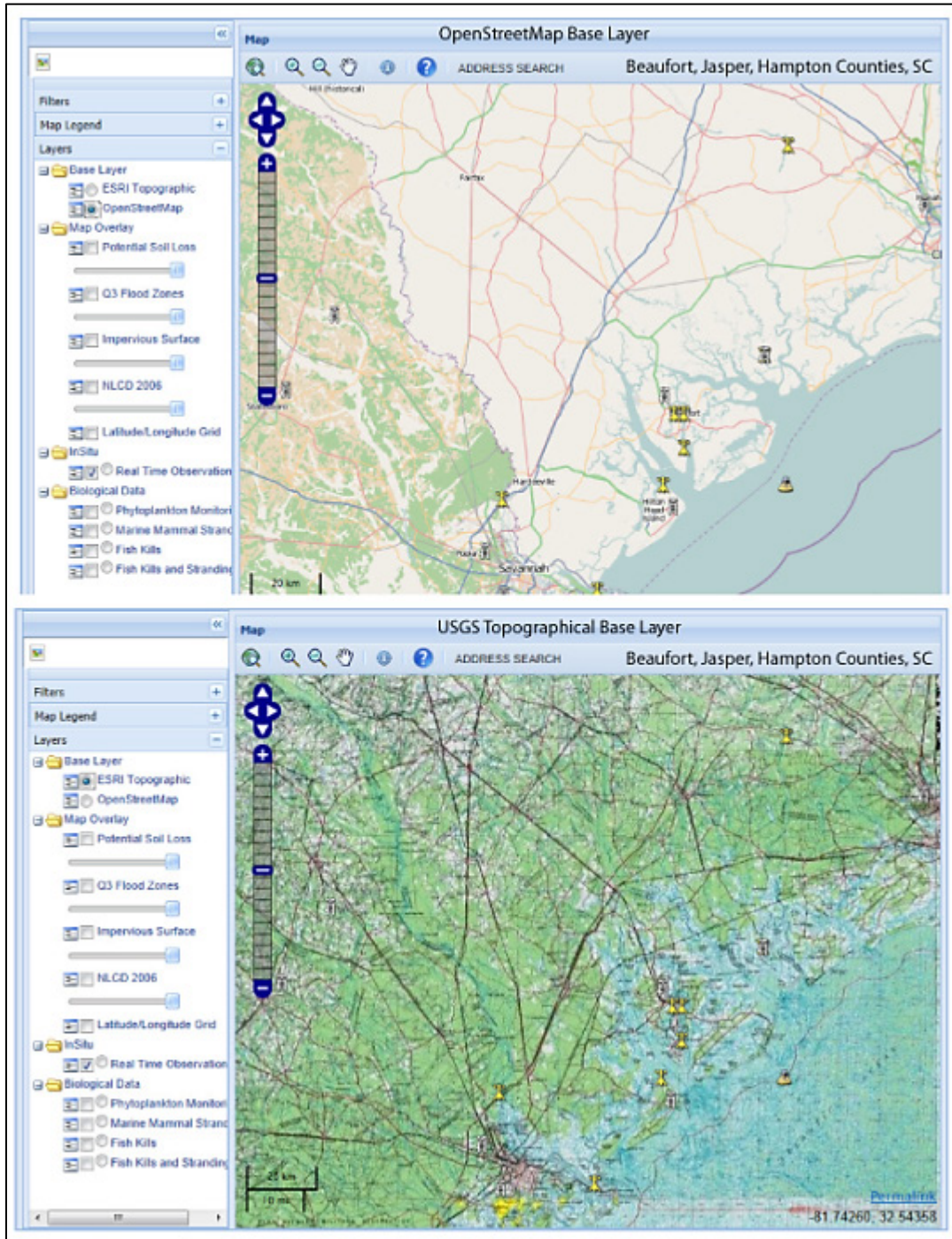


Figure 4.12: Base maps (OpenStreetMaps – top and USGS topographical – bottom) embedded within the online interactive framework.

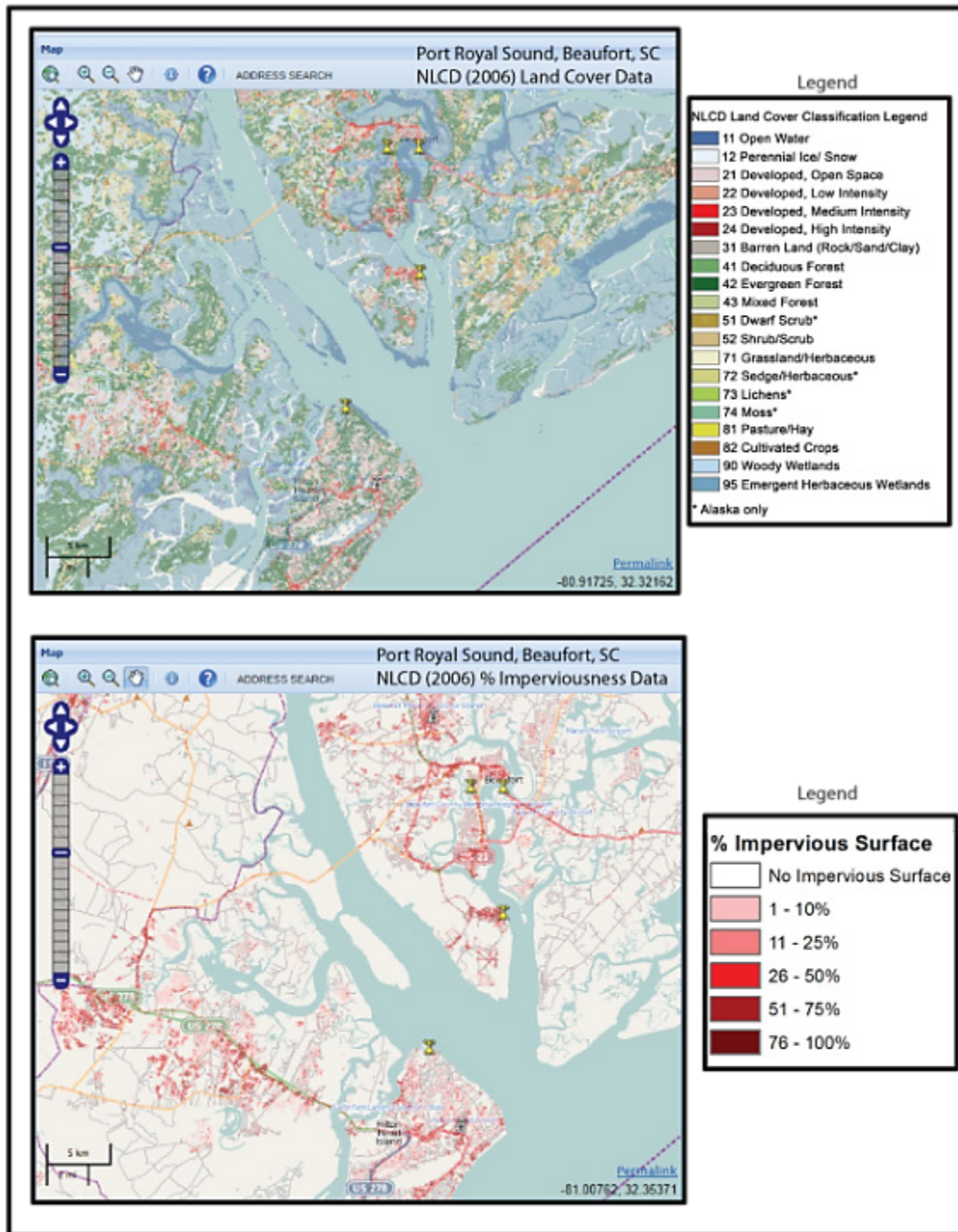


Figure 4.13: NLCD (2006) land classification (top) and percent impervious surface (bottom) as single layer displays at the same spatial resolution.

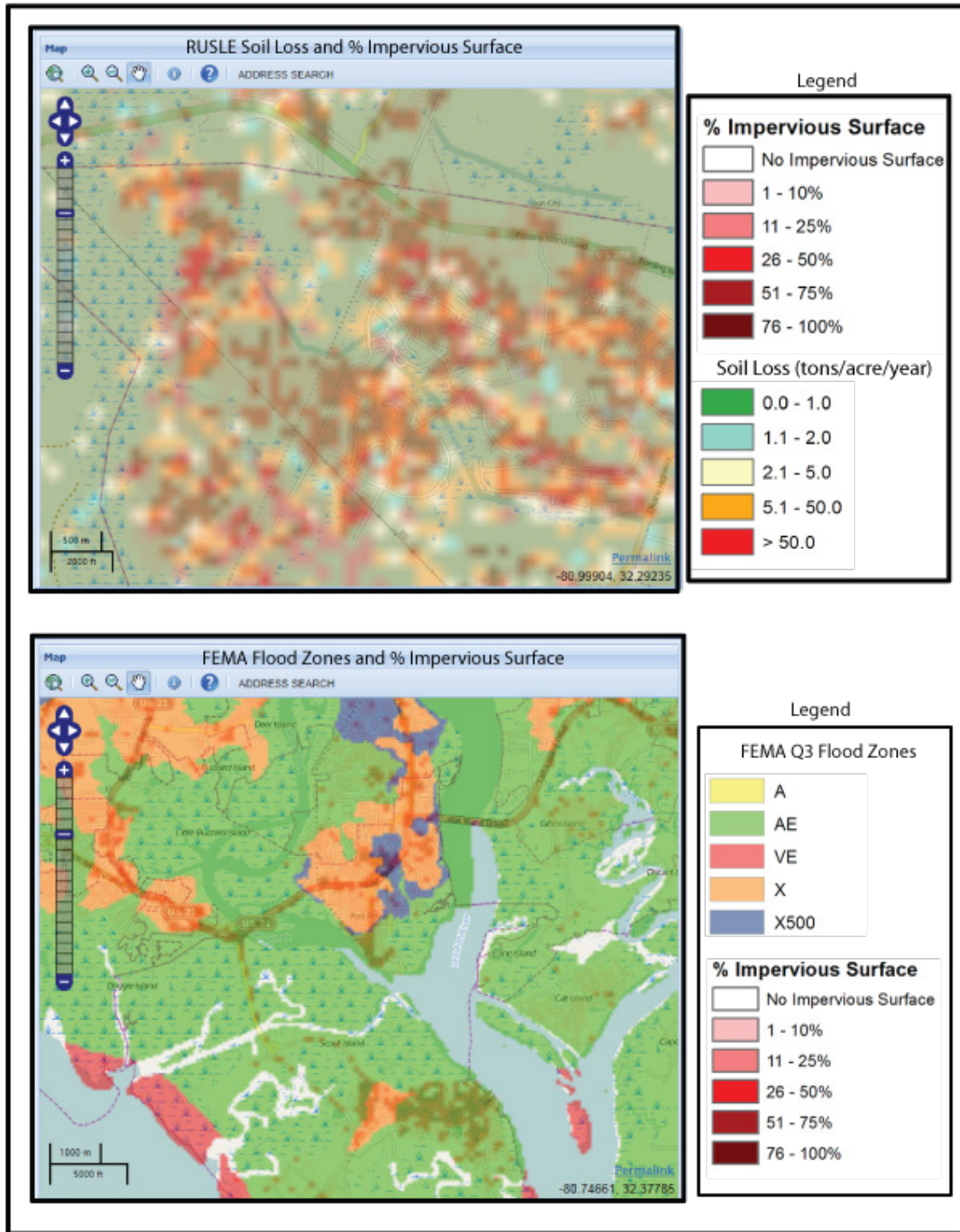


Figure 4.14: The RUSLE soil loss model and percent impervious surface within a specific high population density area (top). The FEMA flood-risk zone model is shown with percent impervious surface to determine if highly developed areas overlap with high risk floodplain zones.



Figure 4.15: The RUSLE soil loss model combined with various other data options at different spatial scales.

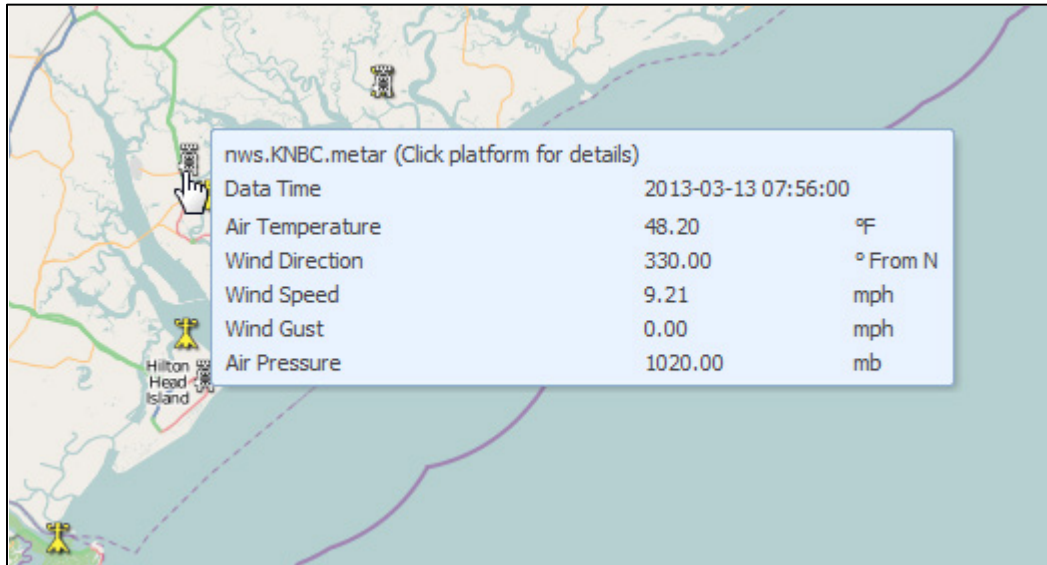


Figure 4.16: Example of a NOAA platform collecting in situ coastal data for a variety of climatic variables. Viewing this information gives pesticide applicators necessary information about when and if pesticides should be applied in a certain area.

4.5 DISCUSSION

Sccoastalpesticides.org offers a unique strategy where researchers can quickly work with a large portion of the intended audience within the study area. The Knowledgebase menu item creates a pesticide educational tool as it includes many different aspects of pesticides and pesticide regulation in the U.S. The emphasis here should be on IPM practices and approaches to decrease overall pesticide use. This not only decreases the probability for surface water contamination from pesticide inputs, but also decreases the time for pest species to gain resistance to the pesticide treatment. The automated decision-support tool increases accuracy and decreases working time for users in pesticide and pest identification through the various decision options offered. The output gives the user important information concerning the active ingredient pesticide(s), brand names registered in South Carolina, the relative cumulative ranking value, pests treated, and concern buttons to indicate specific issues for specific endpoints.

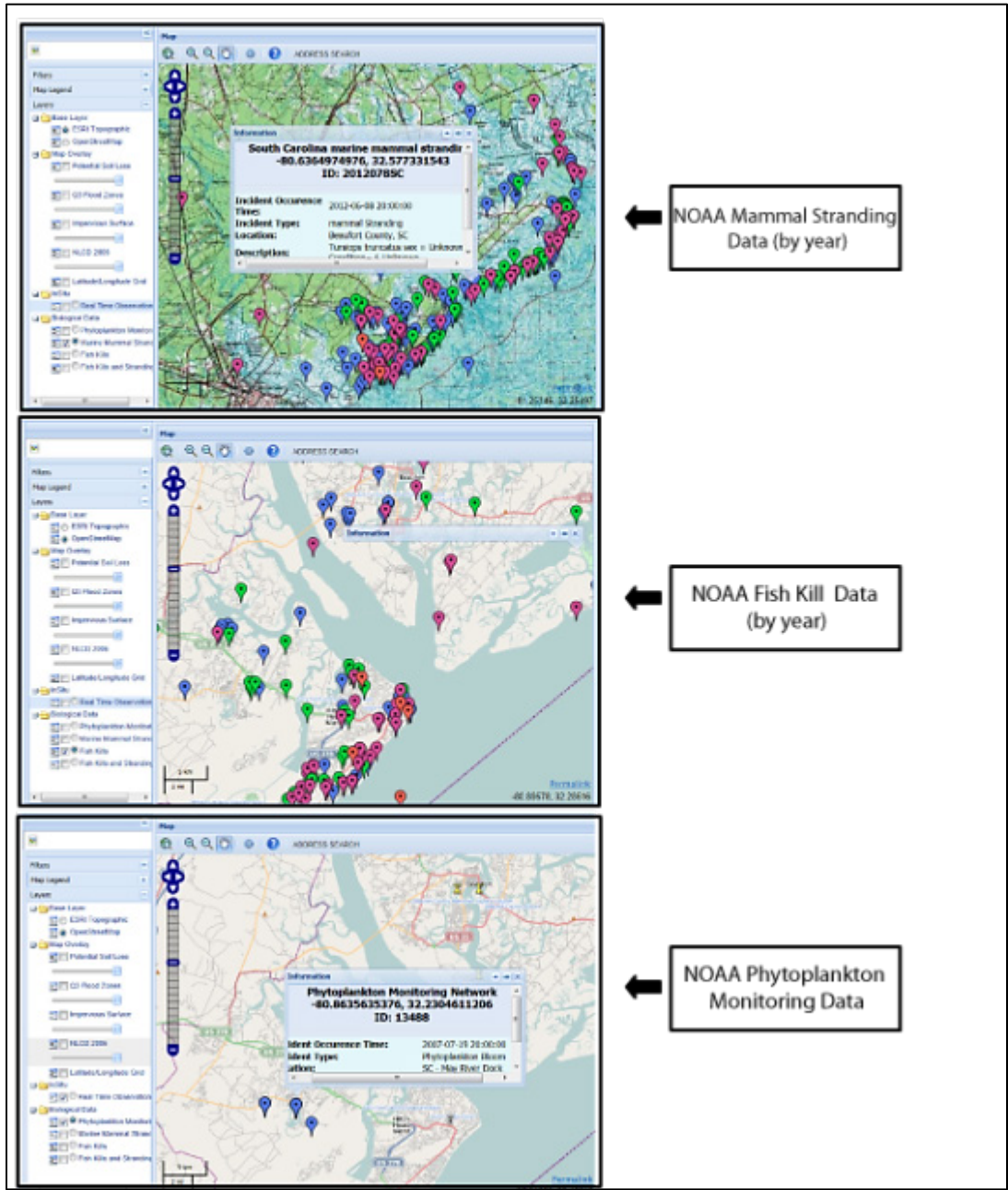


Figure 4.17: NOAA data of mammal strandings (top) and fish kills (middle) as indicated by the symbols on the interactive map. Different colors indicate events that occurred in different years. Clicking the symbol brings up a summary of the details of the event. NOAA phytoplankton data (bottom) are sparse in the study area, but still are indicated by clickable-symbols giving specific information about the event.

These concern buttons allow users to consider what they perceive as important considerations for a pesticide (e.g., toxicity to honey bees) and for the environment (e.g.,

high potential runoff from land). If pest identification is needed first, the dichotomous tree structure with a hierarchal breakdown of pests, allows users to easily identify pests first – an important part of implementing an IPM strategy. In total, the system includes over 430 different pest species found regionally structured in a hierarchical fashion for ease of identification. The website also reaches a large audience without visiting every community in the tri-county area. This increases the number of residents that can potentially be reached and have a greater impact factor within the region within a shorter time period. In all, the development of the ranking system and implementation within the website platform offers a unique, user-friendly strategy for pesticide decision-making in the tri-county area.

The interactive geospatial tool (i.e., the data portal) allows for users to view land use, land management, and in turn pesticide management improves given the spatial information readily available to residential pesticide applicators. Identifying areas where pesticide application may be problematic from an ecosystem health perspective is of the utmost importance to prevent future inputs. Further, with the address search option, residents may view specific characteristics of their land, making property-specific decisions about pesticide application. In total, sccoastalpesticides.org offers a wealth of relevant information on residential pesticides, and provides two user-friendly, interactive tools– all housed in one easy to access website available to everyone. Ultimately, with proper implementation, sccoastalpesticides.org will lead to better pesticide decision-making as a whole for the study area.

The next step to ensure proper implementation of the website is having website content peer reviewed. Next, development of focus groups with a diverse grouping of

people from the region to indicate the efficacy of the website and inefficiencies or problems that needs to be addressed. This will help refine the website. The next step is to advertise the website to the public in an effective manner. Necessary steps include visiting and demonstrating the website to HOAs, golf course managers, pesticide applicators, developers, and local legislators. This will allow wide scale understanding and implementation of the website. Importantly, if implemented properly, the website and toolbox could provide subdivisions with smarter choices in terms of reducing water quality impairments due to improper pesticide usage. Further, if the process was incentivized (e.g., tax breaks) developers could also implement the process to create “greener” communities. Successful implementation of the website will ultimately rely upon people – using the knowledgebase and toolbox to better inform their pesticide decisions.

CHAPTER 5

DISCUSSION

The US Environmental Protection Agency (EPA) is charged with ensuring that pesticides on the market do not pose unreasonable adverse risks to the public and to the environment. This is a challenging task with over one billion pounds of pesticides used across the nation each year. The US EPA estimates approximately 25% of all national pesticide usage is residential (e.g., home, garden, commercial) and to a lesser degree, industrial and government applications. As the nation's population continues to grow, residential pesticide application is an emerging public health concern regarding unintended adverse effects due to misuse. The implications of improper pesticide use within southeastern coastal tidal creeks and estuarine ecosystems could lead to reduced trophic functionality. The objective of proper pesticide decision-making and application should be to take a precautionary approach in order to preserve the integrity of the surrounding environment. Moreover, it is vital to educate residential pesticide applicators about proper pesticide use to reduce human and ecological exposures – as pesticides by design are intended to cause adverse effects to organisms.

In the collection of studies presented within this dissertation, knowledge gaps were addressed concerning pesticide application at the community level, and dissemination of important information regarding residential pesticide application (i.e., the public). To address these gaps, a study area was chosen along the South Carolina

coastal zone where population growth is accompanied by developments encroaching upon sensitive, vital tidal creek ecosystems. Specifically, the study focused on Beaufort, Hampton and Jasper Counties, incorporating land surrounding the Port Royal Sound – a unique and vital portion of the South Carolina coastal zone. A developed pesticide learning system with an intuitive framework easily understood by its intended users is critical to better inform residents about pesticides and proper pesticide use. Localized (i.e., county and regional scale) efforts allow for more geographically relevant data to be used, but also allow ideas to work themselves into the fabric of the community. This is critical if actual change is to be seen in prevention of future adverse events involving residential pesticides, particularly at the community and ecosystem levels.

Toxicological data for pesticides can be cumbersome, complex, and difficult to interpret if one is not in not in that field of study. Therefore, Chapter 2 explains the relative cumulative ranking system developed for one hundred of the most commonly-used residential pesticides for six use areas including 1) residential applications (indoor and outdoor), 2) golf courses, 3) vector control, 4) right-of-ways, 5) nuisance aquatic species, and 6) tomato farms. Using this system, active ingredient pesticides were grouped into three color-coded bins based on eleven EPA hazard and environmental fate and transport values. Data were gathered via EPA databases and documents for the thirteen endpoints considered for each pesticide, normalized, statically analyzed, and separated into tertiles for the three category binning system (color-coded). Although this system is not risk-based, it focuses on parameters that were deemed important to the community and decision-making at the community and individual levels. The end result of the relative cumulative ranking system gives users information that is easily

understood, easy to implement, and indicates to the user compounds likely to pose potential adverse hazards to the ecosystem they call home. The ranking system contains uncertainties, but any ranking system must balance complexity and cost during development.

Chapter 3 of this dissertation addresses land and climatic characteristics, needing consideration for better decision-making concerning pesticide application over distinct areas of land within the study area. The spatially explicit maps developed using GIS allow residents to view many aspects of their land and the environment needing consideration when making decisions concerning pesticide application. Geophysical factors (slope, soil type, climate, land use and land cover, percent imperviousness, FEMA flood-risk zones and RUSLE potential soil loss), *in situ* data (temperature, wind direction and speed) and forecasting data (i.e., potential for rainfall) were generated for the coastal study area. Through collaborative community efforts – having the common goal of considering land characteristics and climatic conditions – reduction in pesticide-caused water quality impairments may occur if residents consider these variables and implement proper pesticide application techniques.

Chapter 4 of this dissertation discusses the educational component of this research – combining both the ranking system for toxicological endpoints of pesticides and geospatial considerations for residential pesticide application, and disseminates the system to the public via a website platform (sccoastalpesticides.org). Design and development of the website was time intensive, but remains the best strategy to educate the public at large in a cost-effective, efficient manner. A knowledgebase, containing much information about multiple facets of pesticides was the first component of the

website. Without proper knowledge of pesticides and pesticide regulation, it is difficult to understand the importance of avoiding persistent, bioaccumulative pesticides and improper pesticide application. In the world of pest management, an integrated pest management (IPM) plan should be implemented in all application scenarios – when all physical, biological, or cultural methods are exhausted before chemicals (i.e., pesticides) are applied. The Knowledgebase and Useful Links sections of the website provide specific IPM recommendations for residents. If chemical options are needed for pest control, the relative cumulative ranking system incorporated within the pesticide-support tool allows users to decide of less hazardous pesticide options (when chemical control is needed) that will still address their pest problem. The two options for decision-making (i.e., identify your pest and find pesticides, or conduct a pesticide search) allows users to properly identify their pest and then consider various treatment options. The pesticide-support tool is combined with the data portal of spatially explicit maps of the area. The maps are within an interactive framework on sccoastalpesticides.org, allowing the user to control land and climatic factors they want to view and what geographical area they want to focus on. Further, users may view historical NOAA biological monitoring data to determine areas where water quality impairments possibly led to fish kills, mammal strandings, or algal blooms.

In summary, with these studies combined and implemented through the web-based platform, a unique strategy was developed for residential pesticide users within the study area, providing tools that work with an IPM plan to better residential pesticide decision-making. Ideally, this interactive web-based pesticide educational strategy will be

implemented as a part of an IPM plan and continue to propagate into other South Carolina counties.

REFERENCES

- Allen, J and K Lu. (2003). Modeling and prediction of future urban growth in the Charleston region of South Carolina: a GIS-based integrated approach. *Conservation Ecology*, 8(2): 2.
- Alig, RJ, Kline, JD, Lichtenstein, M. (2004). Urbanization on the US landscape: looking ahead in the 21st century. *Landscape and Urban Planning*, 69:219-234.
- Anido, L, Llama, M, Fernandez, MJ, Caeiro, M, Santos, J, and J Rodriguez. (2001). *A Component Model for Standardized Web-based Education*. ACM 1-58113-348-0/01/0005. Retrieved on March 19, 2013 from <<http://www10.org/cdrom/papers/106/>>
- Arcos JM. (2001). *Foraging ecology of seabirds at sea: significance of commercial fisheries in the NW Mediterranean*. PhD thesis, University of Barcelona 114pp.
- Arnold, CL, and CJ Gibbons. (1996). Impervious surface coverage. *Journal of the American Planning Association*, 62(2): 243-258.
- Aspelin, AL, and Grube, AH. (1999). Pesticides industry sales and usage – 1996 and 1997 market estimates: U.S. Environmental Protection Agency, Pesticide Industry Sales and Usage Report 733-R-99-001, 39 p.
- Ballantyne B, Marrs TC, Syversen T. (eds.). (1999). *General and Applied Toxicology*, 2nd Edition. John Wiley and Sons, Inc. New York, NY.
- Benbrook C, Benbrook KL, and P Mineau. 2007. *Pesticide Environmental Assessment System (PEAS): A tool for tracking and managing the impacts of IPM system design and pesticide use*. Benbrook Consulting Services, Enterprise, OR.
- Bergquist DC, Van Dolah RF, Riekerk GHM, Levisen MV, Crowe SE, Brock L, Greenfield DI et al. (2009). The condition of South Carolina's estuarine and coastal habitats during 2005-2006. South Carolina Estuarine and Coastal Assessment Program, Technical Report No. 103.
- Britt J. (2000). *Properties and Effects of Pesticides*. In: Principles of Toxicology: Environmental and Industrial Applications, 2nd Edition. Eds., Williams PL, James RC, and Roberts SM. John Wiley and Sons, Inc. New York, NY.

- Brown, CD, Hart, A, Lewis, KA and Dubus, IG. (2003). p-EMA (I): Simulating the environmental fate of pesticides for a farm-level risk assessment system. *Agronomie*, 23: 67-74.
- Burns, LA. 1991. *Exposure Analysis Modeling System: Users Guide for EXAMS II version 2.94*, Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, GA.
- Calle EE, Frumkin H, Henley SJ, Savitz DA, Thun MJ. (2002). Organochlorines and breast cancer risk. *CA Cancer Journal for Clinicians*, 52:301-309.
- Carsel, RF, Smith, CN, Mulkey, LA, Dean JD and P Jowise. (1984). *User's manual for pesticide root zone model (PRZM): Release 1*, Rep. EPA-600/3-84-109, 219 pp. Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, GA.
- Crosby, DG, and RK Tucker. (1971). Accumulation of DDT by *Daphnia magna*. *Environmental Science and Technology*, 5:714-716.
- Clark, EH, Haverkamp, JA, and W Chapman. (1985). *Eroding Soils: the Off-farm Impacts*. The Conservation Foundation, Washington DC 252 pp.
- Culliton, TJ. (1998). *Population: Distribution, Density and Growth*. Silver Spring, MD, National Oceanic and Atmospheric Administration (NOAA).
- Dauer DM, Ranasinghe JA, Weisberg SB. (2000). Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. *Estuaries*, 23 (1):80-96.
- Dennison, WC, Thomas, JE, Cain, CJ, Carruthers, TJB, Hall, MR, Jesian, RV, Wazniak, CE, and DE Wilson. (2009). *Shifting sands: Environmental and cultural change in Maryland's coastal bays*. IAN Press, University of Maryland Center for Environmental Science.
- Deol, D and US Tim. (1998). *Interactive Web-based Modeling of Pesticide Loss in a Watershed Using GIS*. Retrieved on March 19th, 2013 from <
<http://proceedings.esri.com/library/userconf/proc03/p0431.pdf>>
- Department of Health and Environmental Control (DHEC), South Carolina, South Carolina DNR and NOAA NOS. (2000). *A baseline assessment of environmental and biological conditions in Broad Creek and the Okatee River, Beaufort County, South Carolina*. RF Van Dolah, DE Chestnut and GI Scott. Columbia, SC: 281.
- DeRoo, APJ, Hazelhoff, L, and GBM Heuvelink. (1992). Estimating the effects of spatial variability of infiltration on the output of a distributed runoff and soil erosion model using Monte Carlo methods. *Hydrologic Processes*, 6: 127-143.

- De Jongvan Lier, Q, Sparovek, G, Flanagan DC, Bloem, EM, and E Schnug. (2005). Runoff mapping using WEPP erosion model and GIS tools. *Computers and Geosciences*, 31: 1270-1276.
- DiDonato GT, Stewart JR, Sanger DM, Robinson BJ, Thompson BC, Holland FA, Van Dolah RF. (2009). Effects of changing land use on the microbial water quality of tidal creeks. *Marine Pollution Bulletin*, 58: 97-106.
- Dorfman, M. (2005). *Testing the Waters 2005*. Natural Resources Defense Council, Washington, DC.
- Duke SO. (1990). Overview of herbicide mechanisms of action. *Environmental Health Perspectives*, 87: 263-271.
- Effland, WR, Thurman, NC, and I Kennedy. (1999). *Proposed Methods For Determining Watershed-Derived Percent Cropped Areas and Considerations for Applying Crop Area Adjustments To Surface Water Screening Models*; USEPA Office of Pesticide Programs; Presentation To FIFRA Science Advisory Panel, May 27, 1999.
- Ehrenfeld, JG and JP Schneider. (1991). *Chumaeryparis thyoides* wetlands and suburbanization: effects on hydrology, water quality and plant community composition. *Journal of Applied Ecology*, 28A: 67-490.
- Engel, B. (2003). Estimating soil erosion using RUSLE (Revised Universal Soil Loss Equation) using ArcView.
- Epstein, J, Payne, K, and E Kramer. (2002). Techniques for mapping suburban sprawl. *Photogrammetric Engineering and Remote Sensing*, 63 (9): 913-918.
- Frey, WH and A Speare. (1988). *Regional and metropolitan growth and decline in the United States*. Russell Sage Foundation, New York, New York, USA.
- Folmar LC, Sanders HO, and AM Julin. (1979). Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. *Archives of Environmental Contamination and Toxicology*, 8:269-278.
- Fry, J, Xian, G, Jin, S, Dewitz, J, Homer, C, Yang, L, Barnes, C, Herold, N, and J Wickham. (2011). Completion of the 2006 National Land Cover Database for the Conterminous United States, *PE&RS*, 77(9):858-864.
- Gilliom, RJ, Barbash, JE, Crawford, CG, Hamilton, PA, Martin, JD, Nakagaki, N, Nowell, LH, Scott, JC, Stackelberg, PE, Thelin, GP, Wolock, DM. (2006). *Pesticides in the Nation's streams and ground water, 1992-2001*. pp.172. United States Geological Survey, Circular 1291

- Gislason H, Sinclair, M, Sainsbury, K and R. O'Boyle. (2000). Symposium overview: incorporating ecosystem objectives within fisheries management. *ICES Journal of Marine Science*, 57: 468-475.
- Gunasekara, AS, Troiano, J, Goh, KS, and RS Tjeerdema. (2007). Chemistry and fate of Simazine. *Reviews of Environmental Contamination and Toxicology*, 189:1-23.
- Hart, A, Brown, CD, Lewis, KA and J Tzilivakis. (2003). P-EMA (II): evaluating ecological risks of pesticides for a farm-level risk assessment system. *Agronomie*, 23: 75-84.
- Hartwell, SI. (2011). Chesapeake bay watershed pesticide use declines but toxicity increases. *Environmental Toxicology and Chemistry*, 30: 1-9.
- Holland, AF, Sanger, D, Gawle C, Lerberg SB, Santiago, MS, Riekerk, GHM, Zimmerman LE, and GI Scott. (2004). Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. *Journal of Experimental Marine Biology and Ecology*, 298: 151-178.
- Holmes, RW, Anderson, BS, Phillips, BM, Hunt, JW, Crane, DB, Mekebri, A, and V Connor. (2008). Statewide investigation of the role of pyrethroid pesticides in sediment toxicity on California's Urban Waterways. *Environmental Science & Technology*, 42:7003-7009.
- Kemble JM (ed.). (2013). *Southeastern U.S. 2013 Vegetable Crop Handbook*. Retrieved on February 23, 2013 from <<http://www.thegrower.com/south-east-vegetable-guide/pdf/>>
- Koskinen, WC, and PA Banks. (2008). Soil movement and environmental fate of triazine herbicides. p. 355-385. In: H. M. LeBaron, O. C. Burnside, and J. McFarland (eds.) *The Triazine Herbicides*. Elsevier Science, Amsterdam, the Netherlands.
- Levine, DA, Hunsaker, CT, Timmins, SP, and JJ Beauchamp. (1993). *A geographic information system approach to modeling nutrient and sediment transport*. Publication No. 3993. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN.
- Lewis, KA, Brown, CD, Hart, A and J Tzilivakis. (2003). p-EMA (III): overview and application of a software system designed to assess the environmental risk of agricultural pesticides. *Agronomie*, 23: 85-96.
- Long ER, Scott GI, Kucklick J, Fulton M, Thompson B, Carr RS, Scott KJ, Thursby GB, Chandler GT, Anderson JW, and GM Sloane. (1997). Final Report. *Magnitude and extent of sediment toxicity in selected estuaries of South Carolina and Georgia*. NOAA Technical Memorandum NOS ORCA: Technical Summary Report 57. 178pp.

- Long, L. (1988). *Migration and residential mobility in the United States*. Russell Sage Foundation, New York, New York, USA.
- Mallin, MA, Ensign, SH, McIver, MR, Shank GC, and PK Fowler. (2001). Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. *Hydrobiologia*, 460: 185-193.
- Ma, J. and A Lembo. (2001). Combining the USLE and GIS/ArcView for Soil Erosion Estimation in Fall Creek Watershed in Ithaca, New York.
- Maund, SJ, Hamer, MJ, Lane, MCG, Farrelly, E, Rapley, JH, Goggin, UM, and WE Gentle. (2002). Partitioning, bioavailability, and toxicity of the pyrethroid insecticide cypermethrin in sediments. *Environmental Toxicity and Chemistry*, 21(1):9-15.
- McCarty, B. (2013). *2013 Clemson University Pest Control Guidelines for Professional Turfgrass Managers*. Retrieved on January 23rd, 2013 from < http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/>
- Moore, I and G Burch. (1986a). Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal*, 50:1294-1298.
- Moore, I and G Burch. (1986b). Modeling erosion and deposition: topographic effects. *Transactions of the American Society of Agricultural Engineers* 29(6):1624-1630,1640.
- Moore, DRJ., Keddy, PA, Gaudet, CL and IC Wisheu. (1989). Conservation of wetlands: do infertile wetlands deserve a higher priority? *Biological Conservation*, 47:203-217.
- National Agricultural Statistics Service (NASS). (2007). *Chemical Usage by State*. Retrieved on May 15th, 2011 from < <http://www.nass.usda.gov/>>
- National Pesticide Information Center (NPIC). (2013). *Insect Growth Regulators*. Retrieved on March 1, 2013 from < <http://npic.orst.edu/ingred/ptype/igr.html>>
- National Pesticide Information Center (NPIC). (2012). *Integrated Pest Management (IPM)*. Retrieved on March 1, 2013 from <<http://npic.orst.edu/pest/ipm.html>>
- National Research Council (NRC). (1983). *Risk Assessment in the Federal Government: Managing the Process*. National Academy of Sciences (NAS), Washington, DC.
- Natural Resources Conservation Service, United States Department of Agriculture (NRCS). (2013). Soil Survey Geographic (SSURGO) Database for Beaufort, Jasper, and Hampton Counties, South Carolina. Retrieved on March 13, 2013 from at <<http://soildatamart.nrcs.usda.gov>>

- Neely, R.K., and J.L. Baker. (1989). Nitrogen and phosphorous dynamics and the fate of agricultural runoff. p. 92-131. In A.G. van der Valk (ed.) *Northern Prairie Wetlands*. Iowa State Univ. Press, Ames, IA.
- Oehlmann J and U Schulte-Oehlmann. (2003). Endocrine disruption in invertebrates *In: Implication of Endocrine Active Substances for Human and Wildlife* (J. Miyamoto and J. Burger, editors). *Pure Appl. Chem.* 75:1617–2615.
- Paustenbach, D. (2002). *Human and Ecological Risk Assessment: Theory and Practice*. 2nd ed. John Wiley and Sons, Inc. New York, NY.
- Petach, MC, Wagenet, RJ and SD DeGloria. (1991). Regional water flow and pesticide leaching using simulations with spatially distributed data. *Geoderma*, 48:245-269.
- Poiani, KA and BL Bedford. (1995). GIS-based nonpoint source pollution modeling: considerations for wetlands. *Journal of Soil and Water Conservation*, 50(6):613-619.
- Purna, G and C Nagaraju. (2007). Is methyl farnesoate a crustacean hormone? *Aquaculture*, 272:39-54.
- Renard, KG, Foster, GR, Weesies, GA, McCool, DK, and DC Yoder. (1996). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation*. US Department of Agriculture, Agriculture Handbook No. 703.
- Renwick, AG. (1995). The use of additional safety or uncertainty factor for nature of toxicity in the estimation of acceptable daily intake and tolerable daily intake values. *Regulatory Toxicology and Pharmacology*, 22: 250-261.
- Reus, J, Leendertse, P, Bockstaller, C, Fomsgaard, I, Gutsche, V, Lewes, K, Nilsson, C, Pussemier, L, Trevisan, M, van der Werf, H, Alfarobba, F, Blümel, S, Isart, J, McGrath, D, and T Seppälä. (2002). Comparison and evaluation of eight pesticide environmental risk indicators developed in Europe and recommendations for future use. *Agriculture Ecosystems and Environment*, 90: 177-187.
- Ross, MA and DJ Childs. (1996). *Herbicide Mode-of-Action Summary*. Purdue University: Department of Botany: Plant Pathology, West Lafayette IN. Report No. WS-23-W.
- Samuel, O, Dion, S, and L St-Laurent. (2007). Québec Pesticide Risk Indicator – QPRI – Health and Environment. Accessed on February 11, 2011 from <<http://www.mddep.gouv.qc.ca> and <http://www.inspq.qc.ca>>
- Sanger DM, Holland AF, Scott GI. (1999). Tidal creek and salt marsh sediments in South Carolina coastal estuaries: II. Distribution of organic contaminants. *Environmental Contamination and Toxicology*, 37:458-471.

- Schueler, TR. (1994). The importance of imperviousness. *Watershed Protection Techniques*, 1: 100-111.
- Scott GI, Fulton MH, Bearden D, Sanders M, Dias A, Reed LA, Sivertsen S, et al. (1998). Chemical contaminant levels in estuarine sediment of the Ashepoo-Combahee-Edisto river (ACE) basin national estuarine research reserve and sanctuary site. National Oceanic and Atmospheric Administration (NOAA), Charleston, South Carolina.
- Solomon, KR, Giddings, JM, and SJ Maund. (2001). Probabilistic risk assessment of cotton pyrethroids: I. Distributional analyses of laboratory aquatic toxicity data. *Environmental Toxicity and Chemistry*, 20(3):652-659.
- Southwick Associates. (2008). Sportfishing in America: an economic and conservation powerhouse. Produced by the American Sportfishing Association with funding from the Multistate Conservation Grant Program.
- South Carolina Budget and Control Board. (2005). South Carolina Statistical Abstract 2005. Prepared by the Office of Research and Statistics 1919 Blanding St., Columbia, SC 29201. Available online at www.ors2.state.sc.us/abstract/index.asp
- Sutter, GW II. (2006). *Ecological Risk Assessment, 2nd Ed.* CRC Press, Boca Raton, FL.
- Swaen, GMH. (1988). The use of epidemiological data in risk assessment. *Regulatory Toxicology and Pharmacology*, 8: 422-430.
- Todd, B and GW Sutter II. (2012). *Herbicides*. US Environmental Protection Agency (EPA): CADDIS Volume 2: Sources, Stressors & Responses. Retrieved on March 4th, 2013 from <http://www.epa.gov/caddis/ssr_herb_int.html>
- US Environmental Protection Agency (EPA). (1996). *Exposure Factors Handbook, Vol. I: General Factors-SAB Review Draft*. EPA/600/P-95/002Ba. Office of Research and Development, Washington, DC.
- US Environmental Protection Agency (EPA). (1996). *Soil Screening Guidance: Technical Background Document*, EPA/540/R-95/128, Table 38.
- US Environmental Protection Agency (EPA). (2013). Watershed Assessment, Tracking, and Environmental Results. Retrieved on March 18, 2013 from <http://ofmpub.epa.gov/waters10/attains_nation_cy.control>
- US Environmental Protection Agency (EPA). (2002). *Consideration of the FQPA safety factor and other uncertainty factors in cumulative risk assessment of chemicals sharing a common mechanism of toxicity*. Retrieved on January 12th, 2011 from <<http://www.epa.gov/oppfead1/trac/science/APPS-10X-SF-for-CRA.pdf>>

- US Environmental Protection Agency (EPA). (2003). *Integrated Risk Information System (IRIS) Glossary*. Retrieved on January 12th, 2011 from <http://www.epa.gov/iris/gloss8_arch.htm>
- US Environmental Protection Agency (EPA). (2005a). Organophosphate Pesticides in Food - A Primer on Reassessment of Residue Limits. Retrieved on January 14th, 2011 from <<http://psych.umb.edu/faculty/adams/fall2005/US%20EPA%20-%20Organophosphate%20Pesticides.htm>>
- US Environmental Protection Agency (EPA). (2005b). Quantification of Exposure: Chemical and Physical Properties Affecting Multimedia Fate and Transport. *In: Risk*, 1: chapter 17. Retrieved on February 26, 2013 from <http://www.epa.gov/ttn/fera/data/risk/vol_1/chapter_17.pdf>
- US Environmental Protection Agency (EPA). (2006). Reregistration Eligibility Decision for Piperonyl Butoxide (PBO). EPA 738-R-06-005, retrieved on February 1, 2013 from <<http://www.epa.gov/oppsrd1/reregistration/status.htm>>
- US Environmental Protection Agency (EPA). (2010). *About Pesticides*. Retrieved on January 14th, 2011 from <http://www.epa.gov/pesticides/about/index.htm#what_pesticide>
- United States Environmental Protection Agency (EPA). (2011a). *Pesticides*. Retrieved on March 21, 2011 from <<http://www.epa.gov/pesticides/about/index.htm>>
- US Environmental Protection Agency (EPA). (2011b). *Integrated Pest Management (IPM) Principles*. Retrieved on May 28th, 2011 from <<http://www.epa.gov/pesticides/factsheets/ipm.htm>>
- United States Environmental Protection Agency (EPA). (2011c). *Pesticides*. Retrieved on March 21, 2011 from <<http://www.epa.gov/pesticides/about/index.htm>>
- US Environmental Protection Agency (EPA). (2012). *Pesticides and Food: What "Integrated Pest Management" Means*. Retrieved on February 28th, 2013 from <<http://www.epa.gov/pesticides/food/ipm.htm>>
- US Environmental Protection Agency (EPA). (2013a). *Pyrethroids and Pyrethrins*. Retrieved on March 4, 2013 from <<http://www.epa.gov/oppsrd1/reevaluation/pyrethroids-pyrethrins.html>>
- Environmental Protection Agency (EPA). (2013b). *Chemical Safety and Pollution Prevention Harmonized Test Guidelines*. Retrieved on February 26, 2013 from <<http://www.epa.gov/ocspp/pubs/frs/home/guidelin.htm>>
- United Nations (UN). (2013). *World Population Prospects: The 2010 Revision*, Retrieved on February 18th, 2013 from <<http://esa.un.org/unpd/wpp/index.htm>>

- Vernberg, FJ, Vernberg, WB, Blood E, Fortner, A, Fulton, M, Mckellar, H, Michener, M, Scott, G., Siewicki T, and K Elfigi. (1992). Impact of Urbanization on High-Salinity Estuaries in the Southeastern United-States. *Netherlands Journal of Sea Research*, 30: 239-248.
- Wang, Y, Olmstead, AW, Li H, and GA LeBlanc. (2005). The screening of chemicals for juvenoid-related endocrine activity using the water flea *Daphnia magna*. *Aquatic Toxicology*, 74:193-204.
- Ware GW. (1991). *Fundamentals of Pesticides: a self-instruction guide*, 3rd Edition. Thomson Publications, Fresno, CA.
- White DL, Porter DL, Lewitus AJ. (2004). Spatial and temporal analyses of water quality and phytoplankton biomass in an urbanized versus relatively pristine salt marsh estuary. *Journal of Experimental Marine Biology and Ecology*, 298: 255-273.
- Wischmeier, WH, and DD Smith. (1978). Predicting Rainfall Erosion Losses: *A Guide to Conservation Planning*. US Department of Agriculture, Agriculture Handbook No. 537.
- Wilson, R and EAC Crouch. (2001). *Risk-Benefit Analysis (2nd ed)*. Harvard University Press, Newton, MA. 370 pp.
- Young, KD and EL Thackston. (1999). Housing density and bacterial loading in urban streams. *Journal of Environmental Engineering*, 25(12): 1177-1180.

APPENDIX A – OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION
HARMONIZED GUIDELINES FOR HAZARD ASSESSMENTS

1. **Mammals** (terrestrial non-target vertebrate): For mammalian values used, the acute and chronic rat studies were used with the LD₅₀ (ppm) considered for acute toxicity and the NOAEL (mg/kg/day) from the chronic study being considered.

Surrogate species: Sprague Dawley rat (rat strain may vary between pesticides tested)

Acute Toxicity: Acute Oral Rat Toxicity – updated in 1996; GLN #: 870.1100 (EPA 2013)

- Acute oral dosing gauges adverse effects occurring due to an oral administration (capsule or gavage) of a single dose or multiple does within a 24 hour period; generally a single sex is used to reduce variability; dosing of the test population should begin between 8-12 weeks of age.

Chronic Toxicity: Chronic Feeding Study – updated in 1998; GLN #: 870.4100 (EPA 2013)

- Rodent testing should begin no later than 8 weeks old, should have at least 20 males and 20 females, and should last at least 12 months in duration.

2. **Avian Species** (terrestrial non-target vertebrate): the EPA requires data from an upland game bird (Bobwhite quail) that predominantly feeds on seed in short grass, and a waterfowl species (the Mallard duck) that feeds in static surface water and in terrestrial settings. The species with the lowest LD₅₀ (mg/kg) or NOAEL (mg/kg) values were chosen when inputting data for the cumulative ranking analysis.

Surrogate species: Mallard duck (*Anas platyrhynchos*) and Bobwhite quail (*Colinus virginianus*)

Acute Toxicity: Avian Acute Oral Toxicity Test – updated 2012; GLN #: 850.2100 (EPA 2013)

- Birds are administered the test compound via gavage or capsule as a single oral dose. Test populations consist of both sexes of birds and are at least 16 weeks old at the time of dosing. Five birds are used as controls.

Chronic Toxicity: Avian Dietary Toxicity Test – updated 2012; GLN #: 850.2200 (EPA 2013)

- Birds are fed a diet containing the test substance and exposed for five days; all birds should be in good health and each test should contain negative controls. The minimum number of birds per exposure level is ten.

3. **Honeybees** (*Apis mellifera*) (terrestrial non-target invertebrate species)

Acute Toxicity: Honey Bee Acute Contact Toxicity – updated 2012; GLN #: 850.3020 (EPA 2013)

- Honey bees have a single topical application of the test compound applied and are exposed for a period of 96 hours. The dose of the test compound is expressed in µg/bee. The test is conducted on young adult worker bees. Two control groups are required for the test: both a vehicle control group and a negative control group.

4. **Aquatic Invertebrates:** For our analysis the daphnid (freshwater crustacean) was chosen because values could be consistently identified for all compounds. Saltwater species (i.e., Oyster Acute Toxicity Test) are more applicable to the study area, but values could not be consistently identified for all pesticides.

Surrogate Species: Daphnia magna

Acute Toxicity: Aquatic Invertebrate Acute Toxicity Test – updated 1996; GLN #: 850.1010 (EPA 2013)

- A minimum of 20 daphnids should be exposed to each test concentration for the compound. Exposure in either static-renewal or flow-through systems and should be 48 hours. Concentrations of the test chemical in test solutions should be analyzed prior to use. An equal number of daphnids should be placed in two or more replicates. Parameters such as temperature, DO, and pH are kept constant throughout the exposure duration. Immobilization of the daphnids is considered as the endpoint. First instar daphnids (i.e., ≤ 24 hours old) should be used at the start of the exposure. A maximum of 10% mortality of the control group is allowed.

Chronic Toxicity: Daphnid Chronic Toxicity Test – updated 1996; GLN #: 850.1300 (EPA 2013)

- In static-renewal tests, ten or more replicates of one daphnid/concentration should be used. In flow-through tests, an equal number (20 individuals) per concentration should be placed in two or more replicate chambers. The test duration is 21 days; less than 20% of control organisms can expire during the test and endpoints assessed are immobilization, growth, and number of offspring.

5. Aquatic Vertebrates: Fish species

Surrogate species: bluegill sunfish (*Lepomis macrochirus*) (warm water surrogate), rainbow trout (*Oncorhynchus mykiss*) (cold water surrogate)

Acute Toxicity: Fish Acute Toxicity Test – updated 1996; GLN #: 850.1075 (EPA 2013)

- The goal of this assay is to determine concentration response-curves for fish mortality (LD₅₀) for each species tested at 24, 48, 72, and 96 hours. Juvenile fish <3.0 grams are used and the fish must be the same age.

Chronic Toxicity: Fish Early Life-stage Toxicity Test – updated 1996; GLN #: 850.1400 (EPA 2013)

- Early life-stage testing is intended to identify the lethal and sublethal effects of chemical exposure on the life stages and species tested. The NOAEC (ppm) is used as the final measurement for this assay.

6. Aquatic Non-target Plants

Acute Toxicity: Algae Toxicity Test – updated 1996; GLN #: 850.5400 (EPA 2013)

Surrogate species: unicellular green alga species (*Selenastrum capricornutum*)

- This assay is specifically designed to gather data on the acute toxicity of chemical compounds on non-vascular algae species. All algae are derived from the same source. The endpoint for this assay is phytotoxicity and is generally expressed in EC₅₀ values in the ppb range. Phytotoxicity (% inhibition compared to the controls) is determined by the number of algal cells per milliliter in each treatment and control group at the 24, 48, 72, and 96 hour time points during exposure. Exposure for the chemical compound under review is a total of 96 hours. Test conditions require a standard photoperiod, temperature ($\pm 2^{\circ}\text{C}$), and pH.

Coefficients are often used to aid in the determination of the environmental fate and transport of pesticides once application occurs. The following coefficients are often used in ecological risk assessment:

1. *n*-octanol-water partitioning coefficient (K_{ow})

The *n*-octanol-water partitioning coefficient (K_{ow}) is used to predict the bioaccumulation potential in aquatic and terrestrial organisms and to estimate the amount

of sorption to soil and sediment (Paustenbach 2002). The K_{ow} describes the tendency of nonionized organic chemicals to accumulate in lipid (fatty) tissue (Paustenbach 2002). *n*-Octonol is considered a good medium for simulating natural fatty substances (Paustenbach 2002). An advantage of using the K_{ow} or $\log K_{ow}$ is it acts as an indicator for assessing trophic level transfer of lipophilic compounds. It does not however, account for differences in metabolism among organisms, but is widely used as a reference system and many data are reported in the literature using K_{ow} values (Sato and Nakajima 1979, Tulp and Hutzinger 1978). The equation for the K_{ow} is:

$$K_{ow} = \frac{\text{concentration of chemical in octonol phase}}{\text{concentration of chemical in aqueous phase}}$$

2. Soil Organic Carbon-Water Partitioning Coefficient (K_{oc})

The Soil Organic Carbon-Water Partitioning Coefficient (K_{oc}) is a ratio of the mass of a chemical that is adsorbed in the soil per unit mass of organic carbon in the soil per the equilibrium chemical concentration in solution (EPA 1996). The K_{oc} acts as an important predictor of water mobility from the point of application. This ratio assesses whether a chemical will sorb to sediment or soil (depending on % organic matter) or will runoff into adjacent waterbodies. The higher the K_{oc} value the more likely a compound is to sorb to soils. Low K_{oc} values indicate that a compound is likely to runoff for the point of application. K_{oc} is calculated by:

$$K_{oc} = K_d / f_{oc}$$

Where: K_d is based on total soil mass and dependent on soil type and % organic matter and increasing K_d values result in decreasing mobility and decreasing values result in increasing mobility. f_{oc} = weight fraction of organic carbon.

$$K_d = \frac{\text{concentration of chemical in soil}}{\text{concentration of chemical in water}} = \frac{\text{grams adsorbed / grams organic carbon}}{\text{grams / mL solution}}$$

3. Half-life ($T_{1/2}$)

The half-life of a compound is a measure of persistence and is generally calculated for soil (aerobic and anaerobic), groundwater, and surface water. If field studies are available for a compound then, different soil types may be considered as well. Half-life is defined as the time required for one-half of the original mass of the chemical to be degraded, transformed, or destroyed in a given medium (EPA 2005). Half-life values are either measured directly (i.e., field studies) or estimated using computer models that predict the half-life based on chemical structure (EPA 2005). The half-life for chemical compounds are usually reported in days. Degradation, transformation, or destruction of a compound – once in the environment – occurs through transformation reactions (e.g., photolysis, hydrolysis, complexation and chelation, acid-base reactions, redox reactions, chemical precipitation, and aerobic/anaerobic biodegradation).

APPENDIX B – ADDITIONAL MAPS OF THE STUDY AREA



Figure B.1: Bing aerial photo of Beaufort County, South Carolina (outlined in yellow).

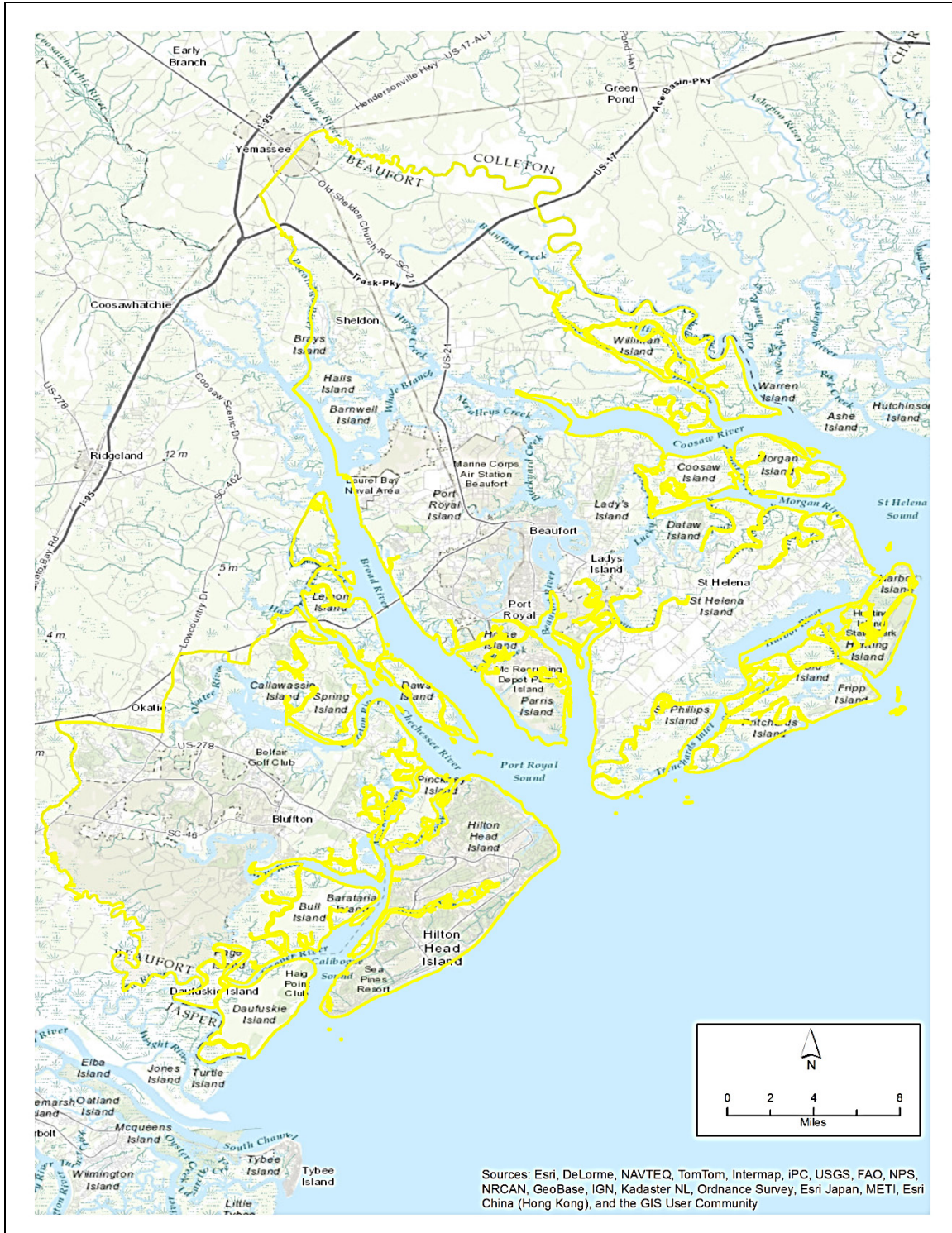


Figure B.2: USGS topographical map of Beaufort County, South Carolina (outlined in yellow)

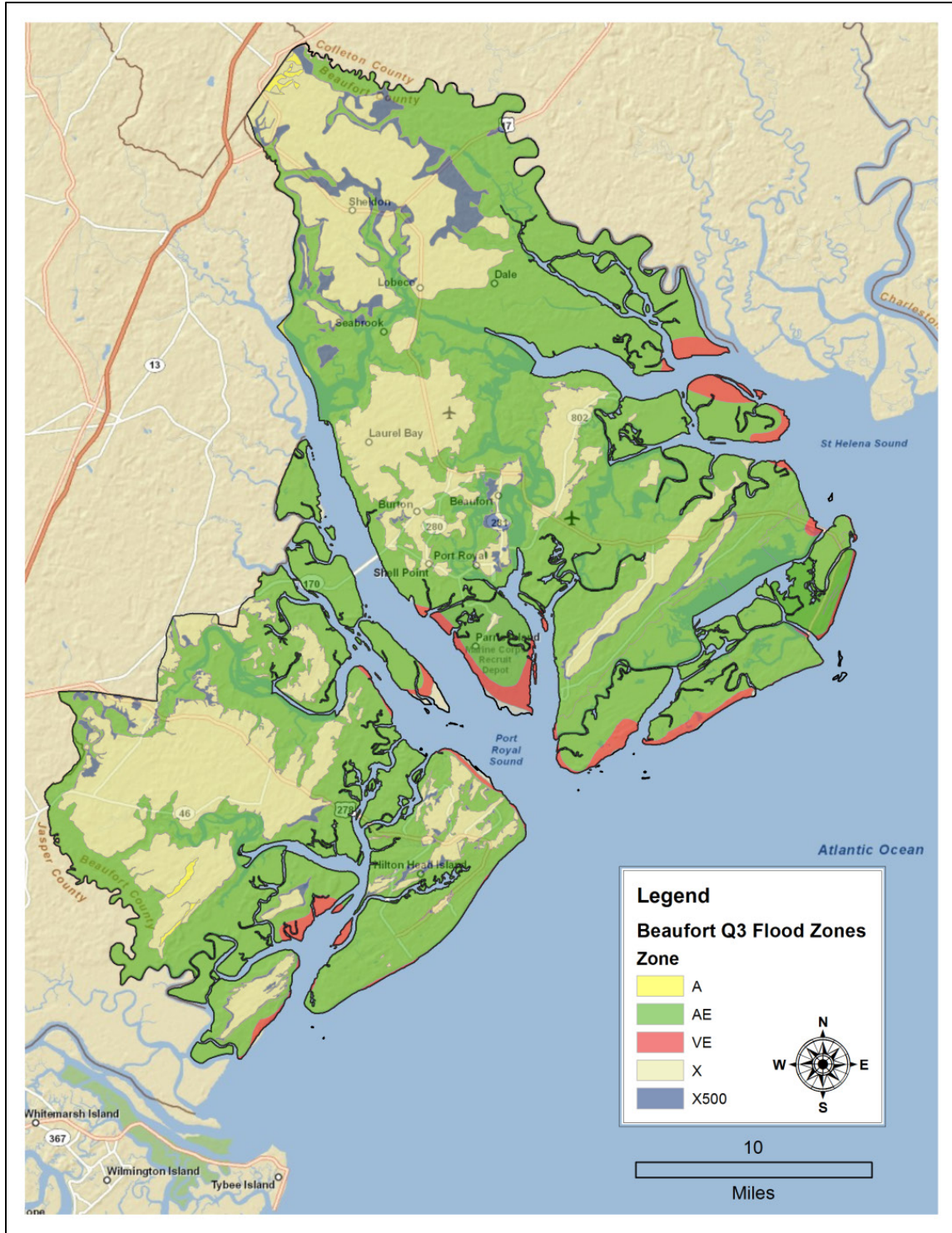


Figure B.3: FEMA flood-risk zones map of Beaufort County, South Carolina (outlined in yellow)

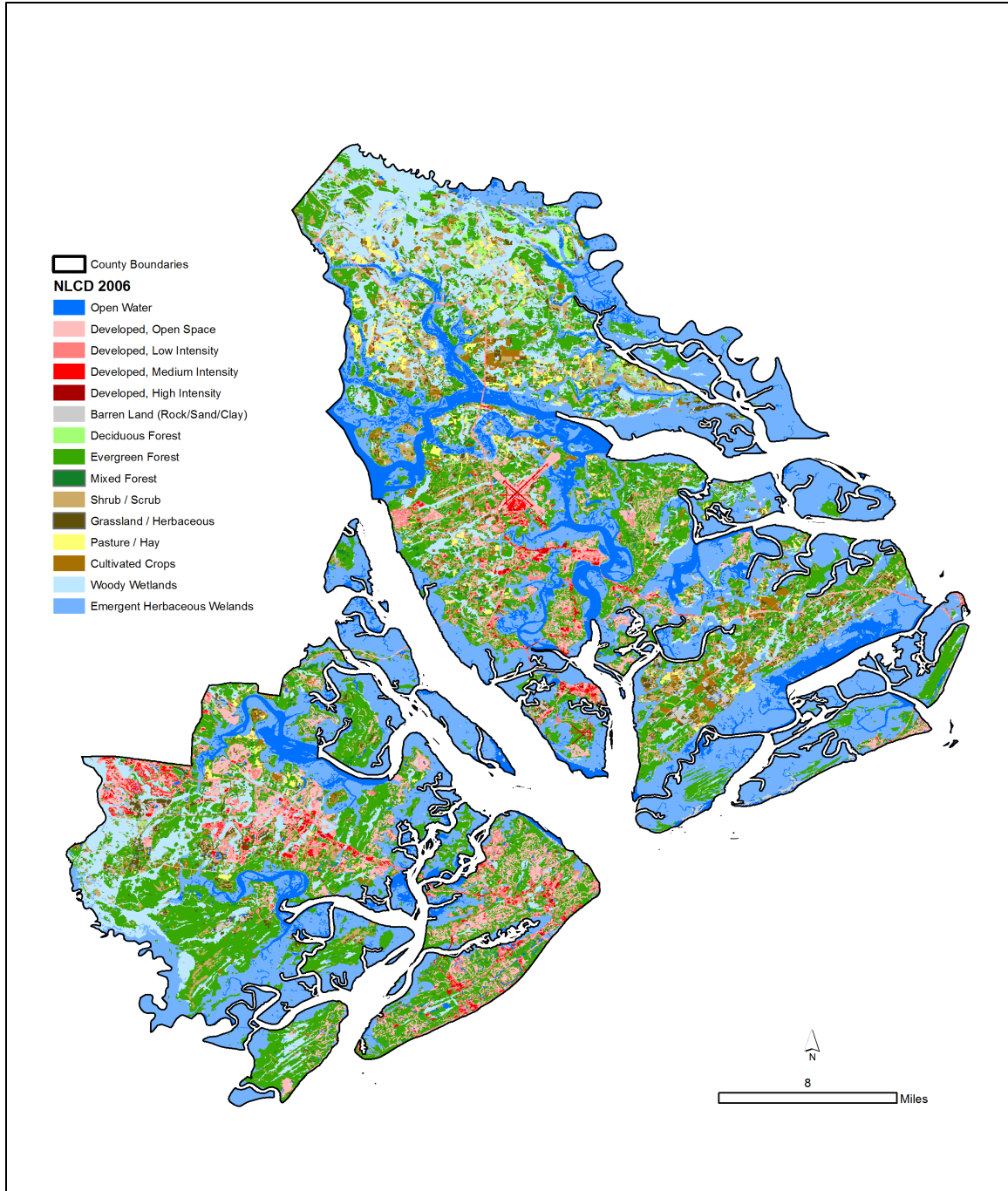


Figure B.4: NLCD (2006) land cover map of Beaufort County, South Carolina

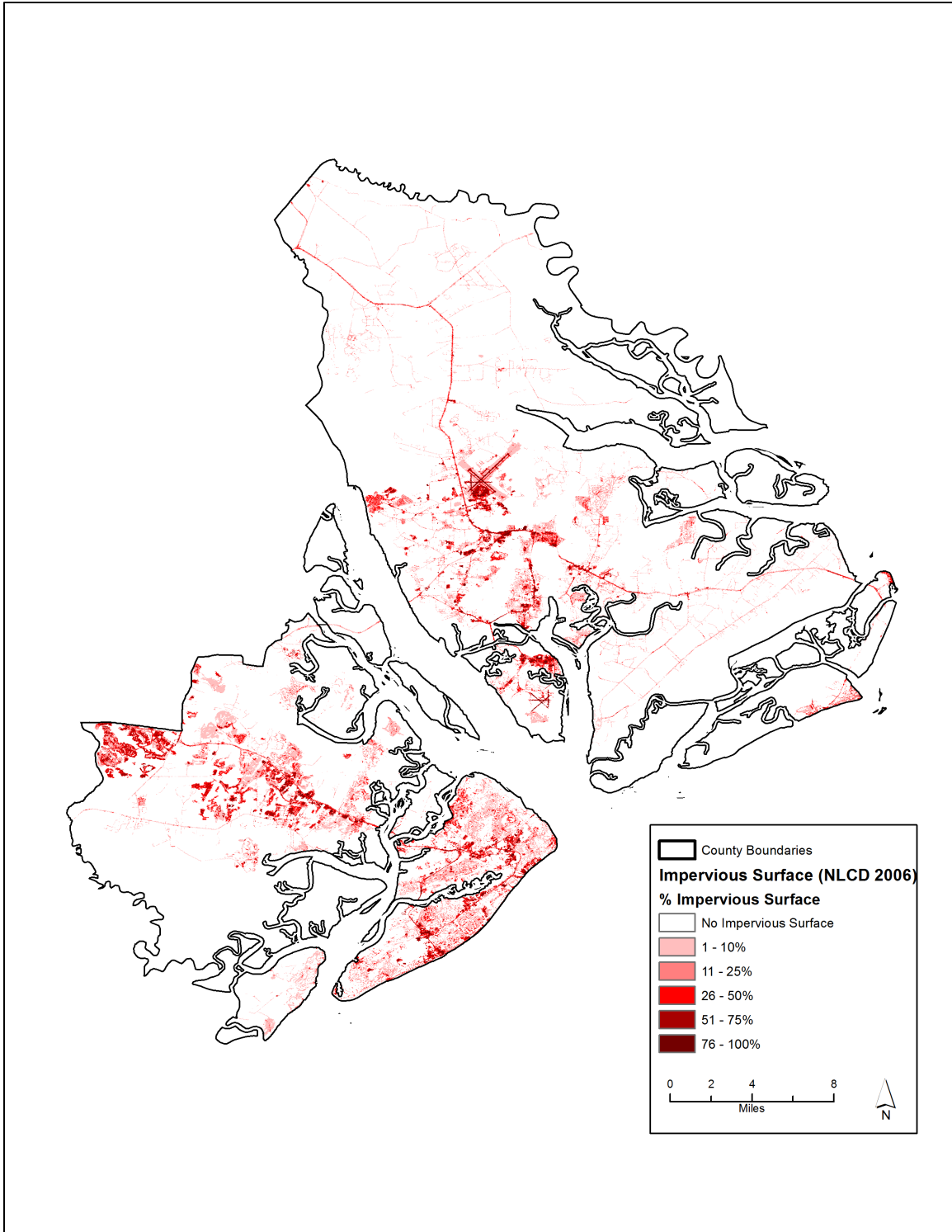


Figure B.5: NLCD (2006) percent imperviousness map of Beaufort County, South Carolina

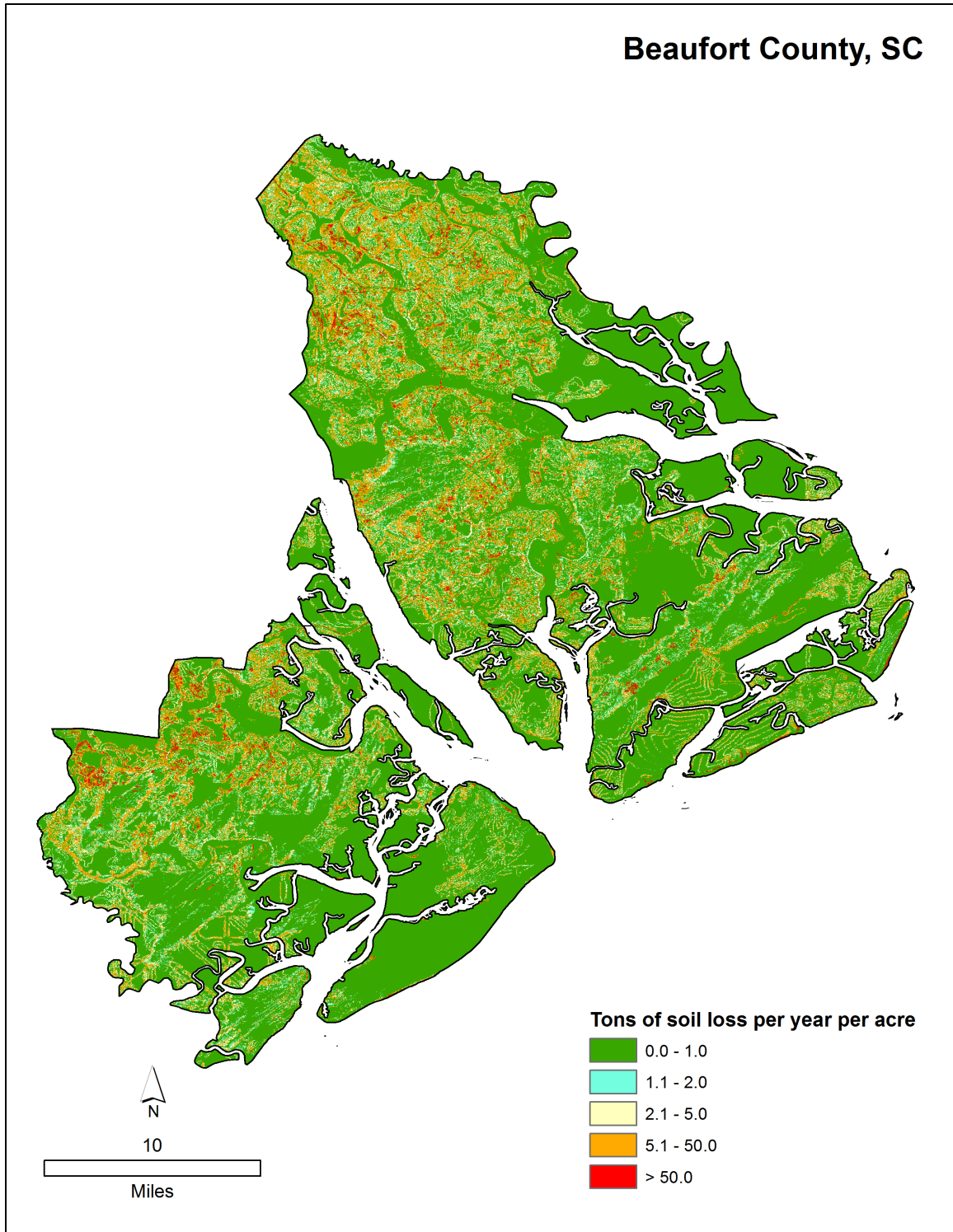


Figure B.6: RUSLE output map of Beaufort County, South Carolina

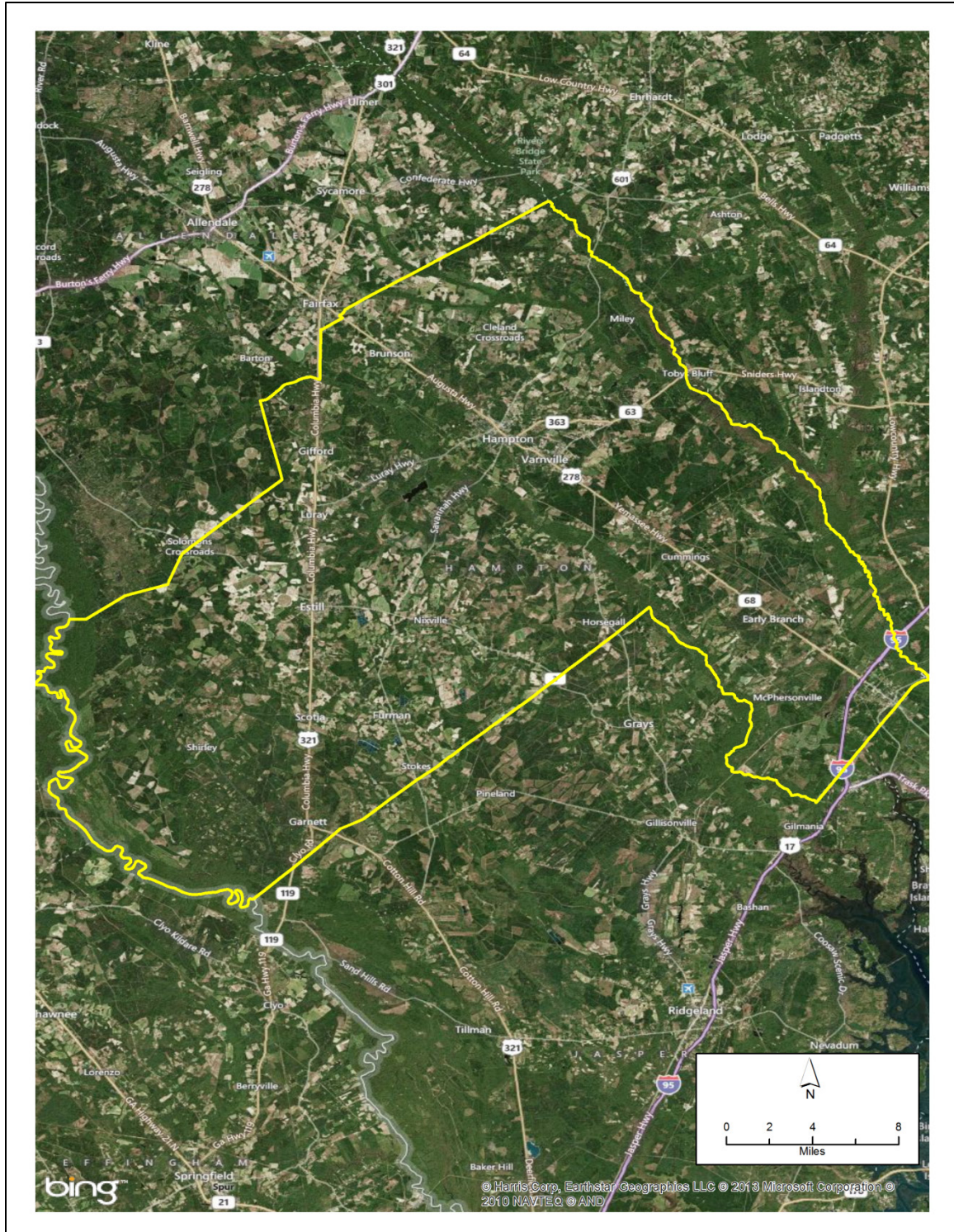


Figure B.7: Bing aerial photo of Hampton County, South Carolina (outlined in yellow).

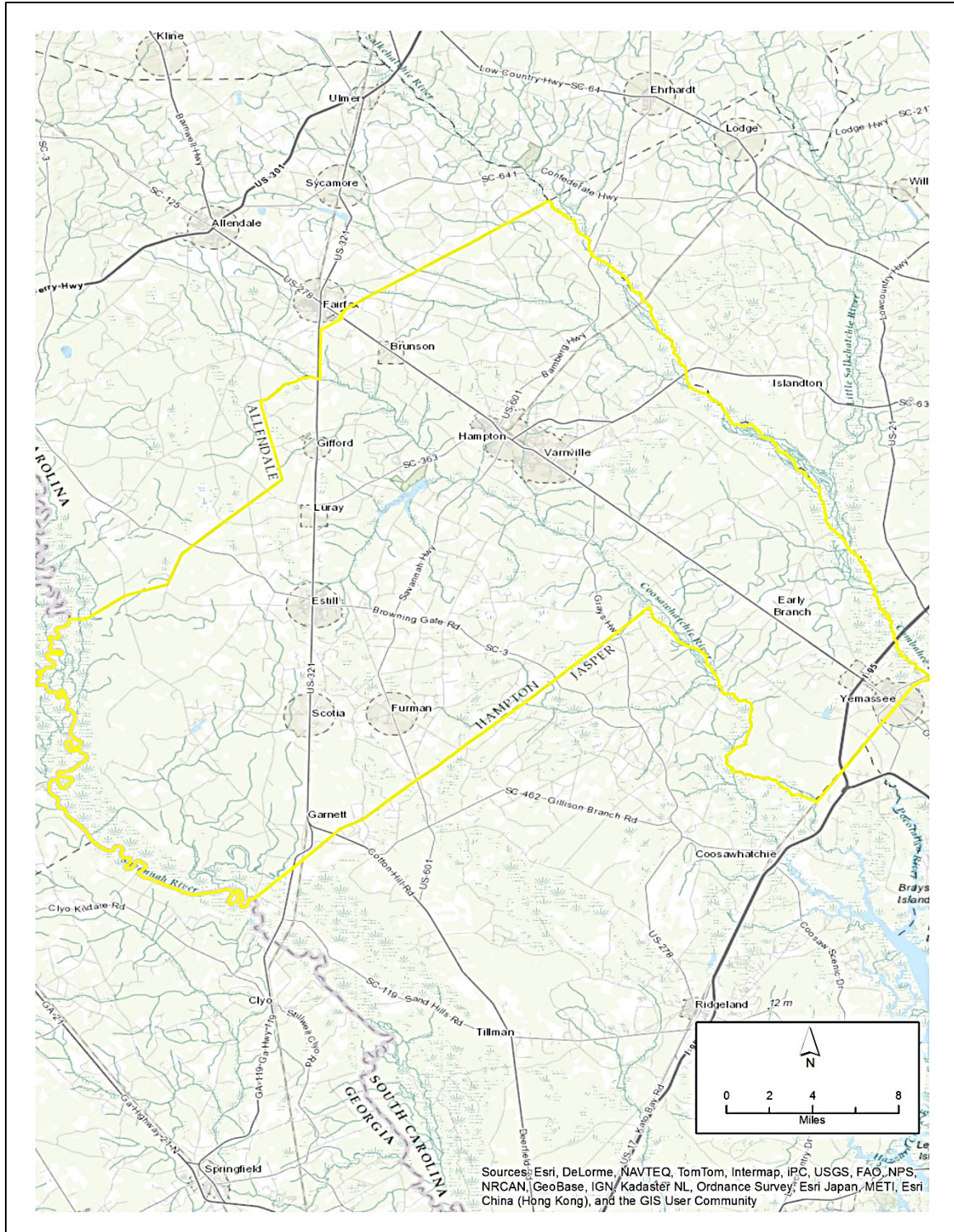


Figure B.8: USGS topographical map of Hampton County, South Carolina (outlined in yellow)

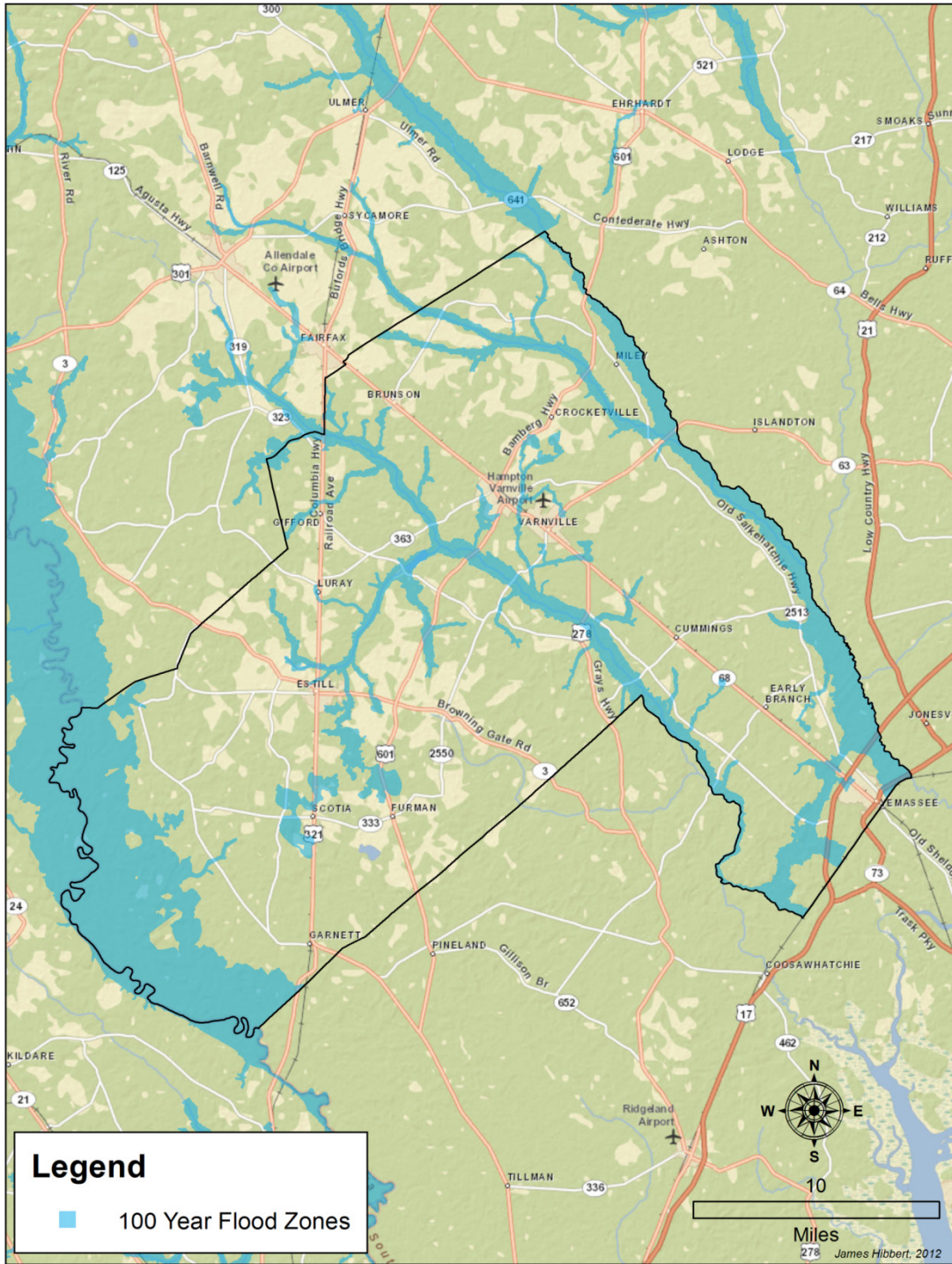


Figure B.9: FEMA flood-risk zones map for Hampton County, South Carolina (outlined in black)

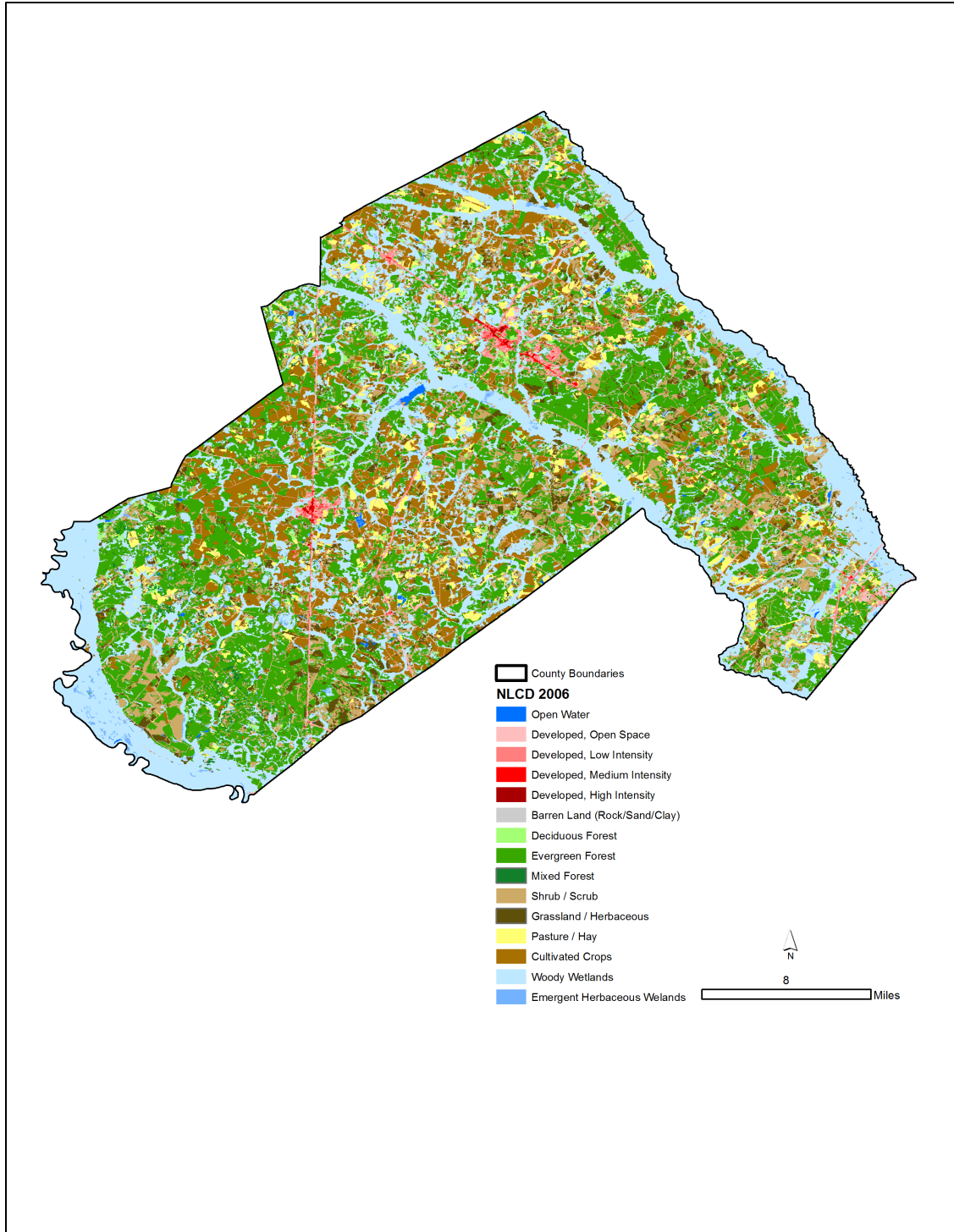


Figure B.10: NLCD (2006) land cover map of Hampton County, South Carolina

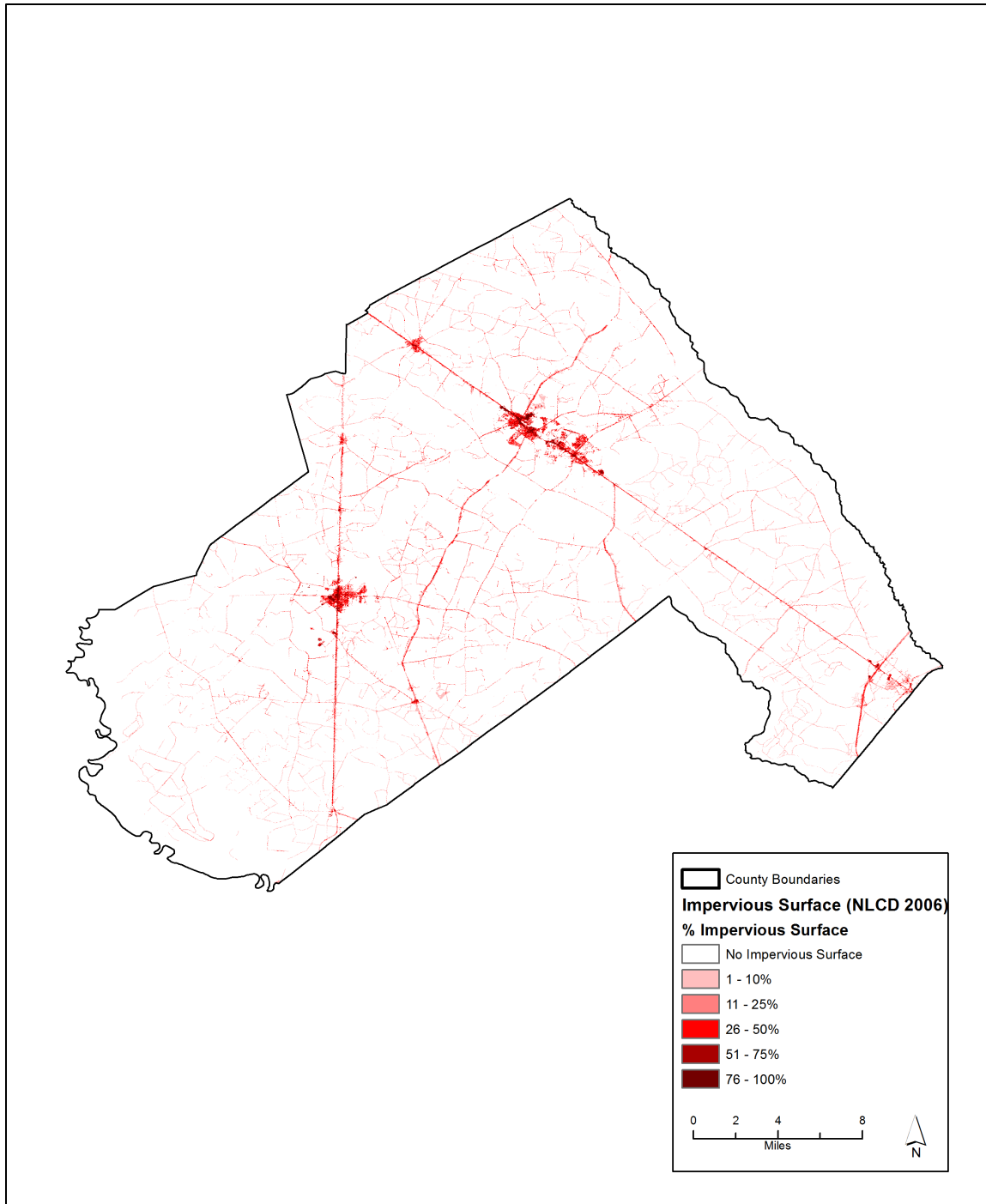


Figure B.11: NLCD (2006) percent imperviousness map of Hampton County, South Carolina

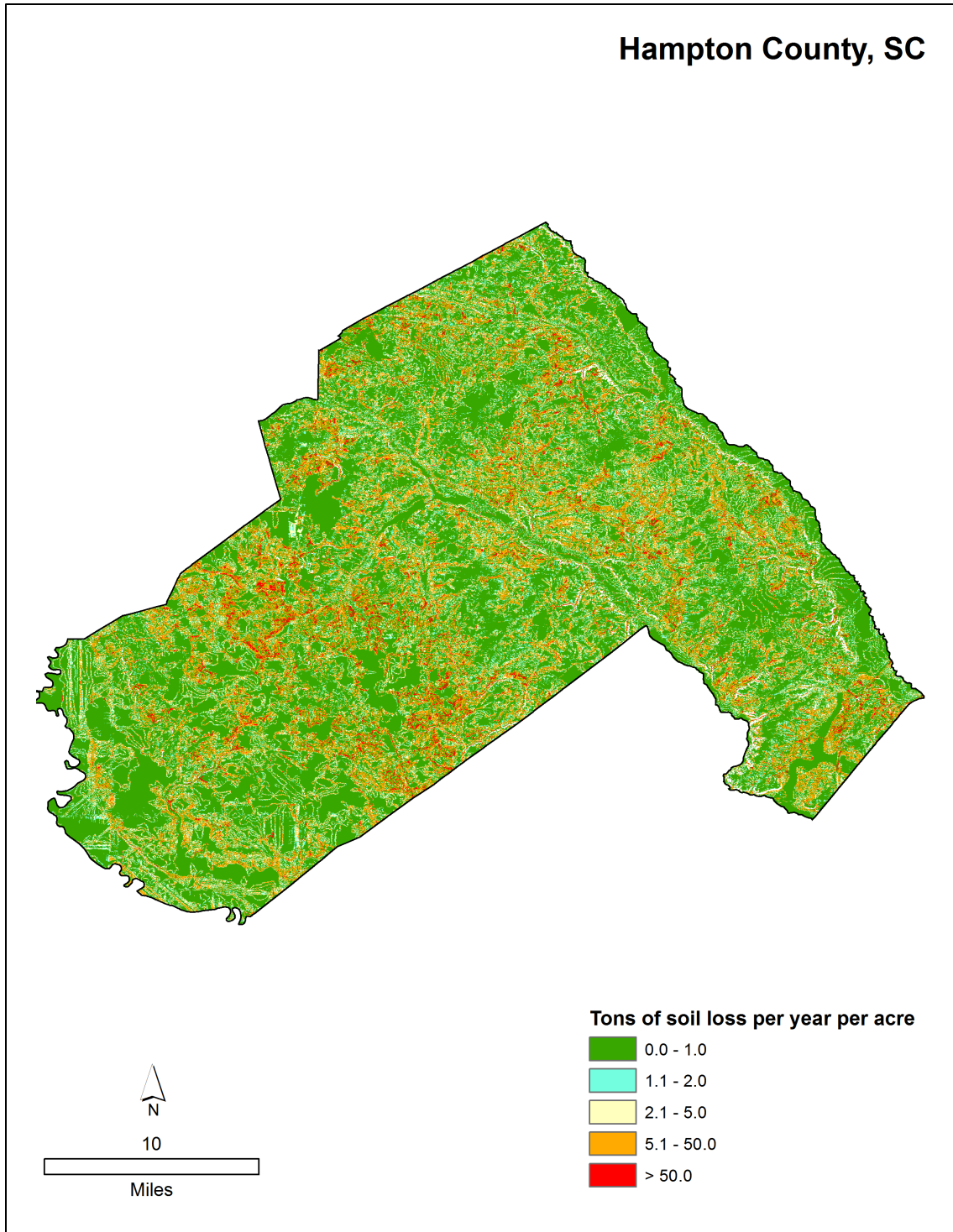


Figure B.12: RUSLE output map of Beaufort County, South Carolina

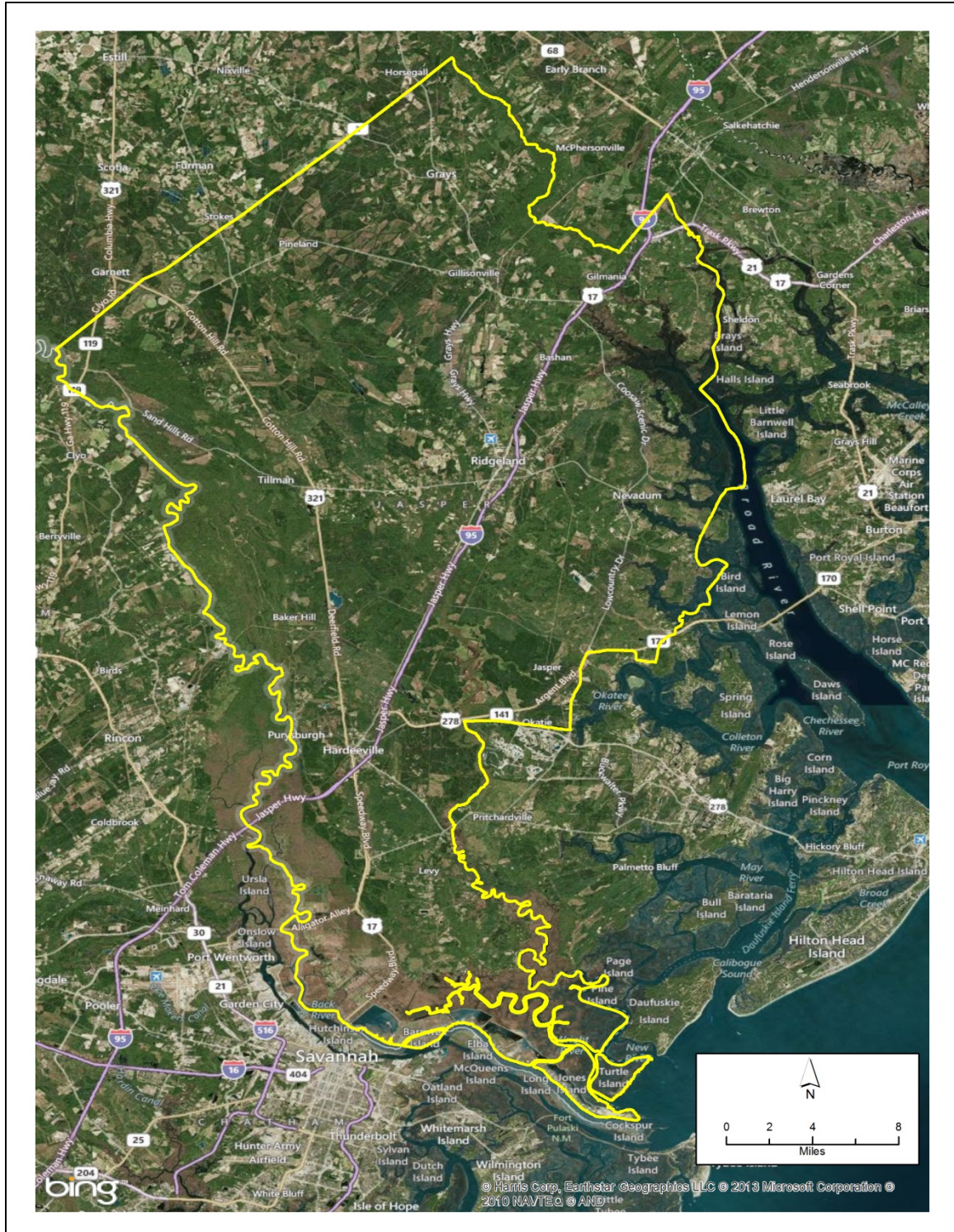


Figure B.13: Bing™ aerial photo of Jasper County, South Carolina (outlined in yellow).

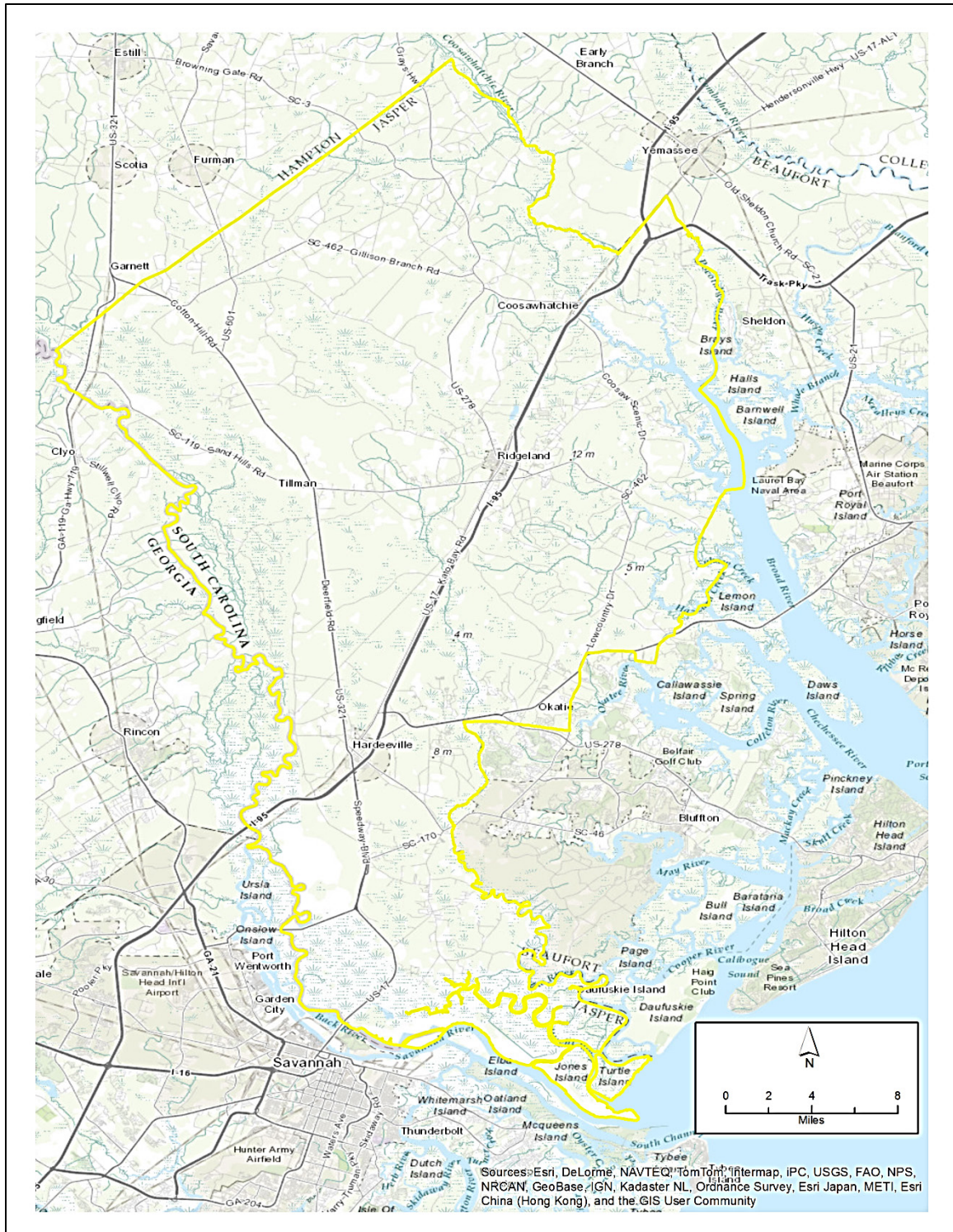


Figure B.14: USGS topographical map of Jasper County, South Carolina (outlined in yellow)

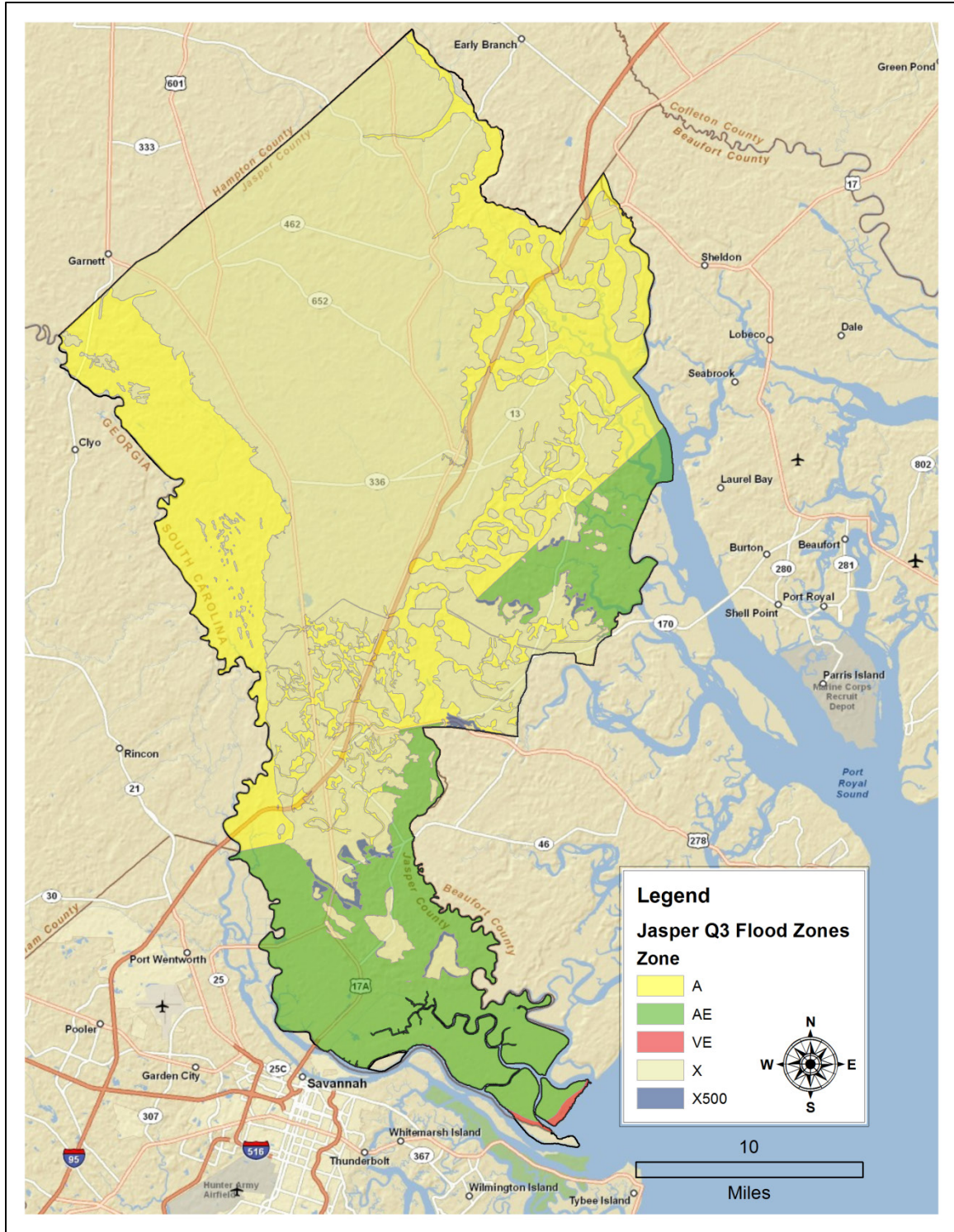


Figure B.15: FEMA flood-risk zones map of Jasper County, South Carolina

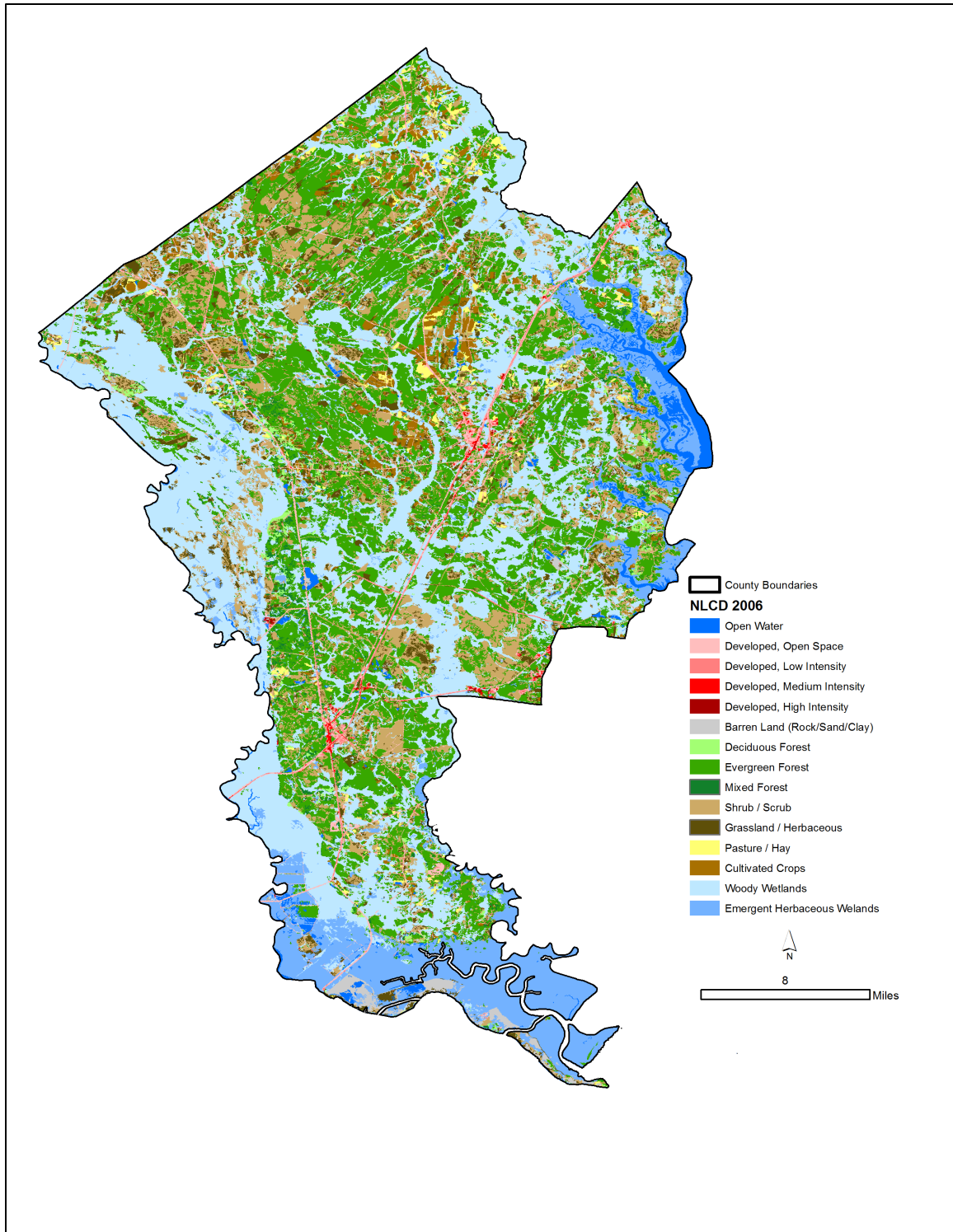


Figure B.16: NLCD (2006) land cover map of Jasper County, South Carolina

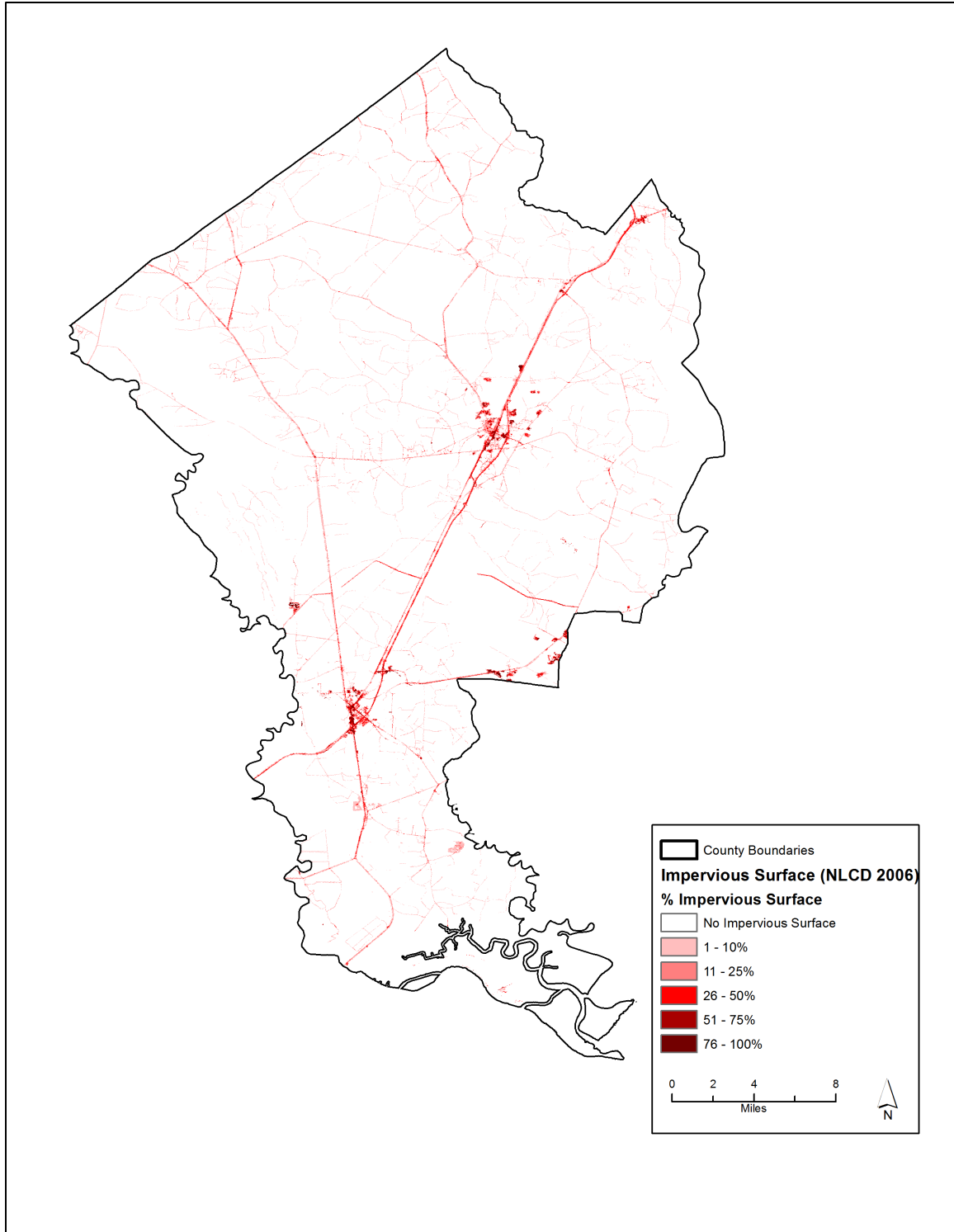


Figure B.17: NLCD (2006) percent imperviousness map of Jasper County, South Carolina

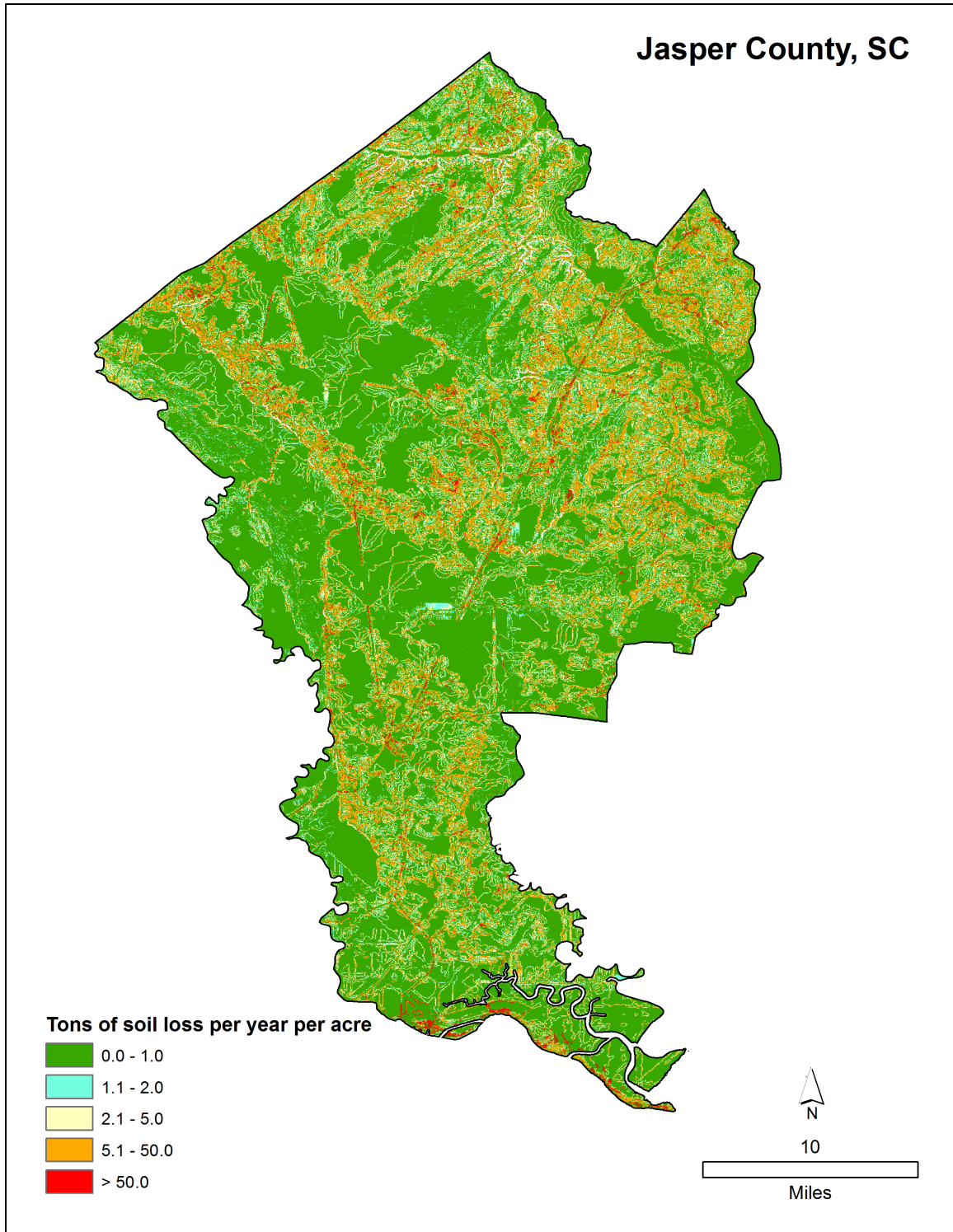


Figure B.18: RUSLE output map of Jasper County, South Carolina

APPENDIX C – RAW DATA FOR RELATIVE CUMULATIVE RANKING

Table C.1: Raw data considered for each of the one hundred compounds in the ranking system. Units for each parameter can be found in Chapter 2.

Compound	Acute					Chronic			Mammal				
	Phyto	Invert	Fish	Avian	Bee	Avian	Invert	Fish	Acute	Chronic	log Kow	half-life	Koc
									Oral LD ₅₀	NOAEL			
carfentrazone	5700	9.8	2	2250	200	167	----	16.4	5140	3	3.36	8.6	750
copper (2+)	85	0.057	13.2	384	23.5	100	0.045	0.065	300	11.7	0.44	1600	9500
2,4-D	290	2.2	64	5620	11.5	962	2	14.2	639	5	2.81	15	72.2
diquat	750	1.03	14.8	80.6	100	5	1	0.122	600	0.5	-4.6	32	2000
fluridone	20000	1	18	2000	362.58	68	48	50	10000	8	1.9	90	862
glyphosate	12500	780	86	2000	100	830	49.9	25.7	4320	31	-3.4	8.1	33
hydrothol	300	0.36	0.75	736	100	94	5	5.7	233.4	2	1.91	1	2
imazapyr	18	100	100	5000	100	400	109	43.1	5000	250	0.22	63	8.81
penoxulam	300	98	103	1900	100	501	7.1	10.2	5000	50	-0.35	38	30
triclopyr	5900	132.9	117	1698	100	100	80.7	104	630	25	4.9	46	25
endothall	4000	48	110	5000	100	94	5	5.7	38	2	1.91	30	2
sodium carbonate peroxy hydrate	1900	4.9	70.7	----	----	----	2	7.4	1034	81	1.36	0.5	----
metsulfuron methyl	1200	150	150	2250	25	2510	150	4.5	5000	25	2.2	30	50
atrazine	130	4.6	48	2000	96.69	0.1	2.2	389	1869	5.76	2.6	578	110
benfenin	250	2186	65	2000	101	----	----	0.37	10000	12.5	5.29	1	9840

bensulide	150	0.58	0.72	138	1.6	2.5	----	0.374	270	25	4.2	200	2943
				6									
metham-sodium	5900	0.55	0.094	211	----	200	0.025	0.026	55	50	1	0.2	228
dicamba	3700	28	34.6	200	90	160	174.6	28	274	45	2.2	28	13
				9		0			0		1		
dimethenamid	14	12	6.3	562	94	900	1.36	0.12	429	25	1.8	610	396
				0							9		
dithiopyr	20	5.6	0.47	225	81	316	----	0.056	410	0.6	4.7	418	3748
				0		0			0	22	5		
indaziflam	53	1	0.1	200	100	----	0.578	0.578	200	136	2	200	1000
				0					0				
isoxaben	1400	1.3	1.1	500	101.	300	0.69	0.4	100	500	2.6	120	3300
				0	7				00		4		
mesotrione	1300	900	120	200	100	120	----	----	500	63.	1.4	32	160
	0			0					0	5	9		
metolachlor	61	25	3	251	85	10	9.4	2.2	120	50	2.8	37	200
				0					0		9		
napropamide	3400	14.3	6.4	464	113.	100	1.1	1.9	500	12	3.3	17	200
				0	5	0			0				
oryzalin	42	1.4	2.88	500	11	100	0.19	1	100	13.	3.7	65	600
				0		0			00	82	3		
oxadiazon	41	2.18	0.88	104	100	500	0.03	0.001	500	12	4.8	180	3236
				0				5	0				
pendimethalin	1250	0.28	0.14	142	49.7	----	14.5	6.3	105	60	5.2	34	1340
	0			1					0				0
pronamide	760	5.6	72	870	100	----	0.056	----	562	8.4	3.2	82	548
				0					0	6			
simazine	450	3.5	90	500	96.7	100	2.5	0.31	500	1.8	2.1	60	160
				0					0		8		
quinclorac	500	29.8	31.6	190	181	500	110	16	219	160	0.2	176	36
				0					0		66		
siduron	220	13.7	8.1	225	120	280	0.006	2.6	500	150	0.4	120	330
				0		0			0		31		
clopyralid	700	232	103.5	464	100	150	66	17	430	15	-	71	25
				0					0		1.8		
											1		
fluroxypyr	2600	51	14.3	750	25	250	100	5	316	100	5.0	23	74
	0								2		4		
aminocyclopyrachlor	1220	19.9	120	204	112	100.	6	11	500	349	-	164	28
				5		9			0	.4	2.4		
											8		
sulfentrazone	8100	60.4	93.8	225	49.8	316	150	----	285	70	0.9	510	43
				0		0			5		9		
fenoxaprop-ethyl	5100	1.06	0.46	500	1700	180	0.22	0.051	235	32	4.5	6	1135
				0					7		8		4
fluzifop-butyl	510	10	0.53	352	200	----	0.25	0.077	245	2	4.5	7	6700
				8					1				
paclobutrazol	4150	33.2	23.6	500	100	312	0.37	0.19	133	2.5	3.2	365	400
	0			0					6				

trinexapac-ethyl	1600	142.5	68	200 0	100	200	2.4	0.8	505 0	31. 6	1.7	25	140
diclofop-methyl	200	0.16	0.15	440 0	100	200	0.009	0.015	563	20	4.5	10	2444 0
ethofumesate	600	13.5	17	500	50	----	1.2	25	113 0	127	2.7	28	213
rimsulfuron	2900 0	360	390	562 0	100	562 0	0.82	110	500 0	81. 8	- 1.4 7	19	19
foramsulfuron	2500	6.9	7.8	200 0	163	200 0	0.4	0.65	200 0	849	- 0.7 8	40	51
bispyribac-sodium	2119 4	99.2	102	225 0	25	100 0	110	9.2	411 1	10	1.2 5	11	1700 0
glufosinate	3600 0	15	13	200 0	100	400	10	----	162 0	2	0.1	40	430
clethodim	1140 0	20.2	18	200 0	100	100 0	5.5	18	136 0	100	4.2 1	214	8000
asulam	440	27	175	400 0	36.2 6	100 0	----	----	500 0	36	1.0 1	28	18
sethoxydim	302	78.1	170	251 0	10	----	----	----	267 6	14	1.6 5	11	190
bromoxynil	80	19.2	53	193	14.5	102	2.5	18	81	1.5	2.7	11. 5	1003 5
imazaquin	31	280	320	215 0	100	116 6	100	51.2	500 0	500	2.3	168	60
endosulphan	427. 8	0.166	0.008	28	4.5	30	0.002	0.001	30	0.6	4.7 9	60	1060 0
carbaryl	2797	0.0057	0.25	200 0	0.00 11	300	0.0015	0.21	301	75	2.2 9	14	207
methiocarb	----	0.019	1.9	107 1	0.37 5	100	0.0017	2.5	30	1.5	2.9 2	111	920
acephate	5000 0	1.3	2.82	718	1.2	5	10	4.7	739	0.5	0.1 3	32	2.73
chlorpyrifos	300	0.001	0.001 8	10	1.14	25	0.0000 4	0.000 57	223	0.0 3	4.9 6	60	6070
trichlorfon	----	0.0001 8	3.8	36.8	59.8 3	27	7.1	0.11	136	4.4	0.5 1	20	6
malathion	2320	0.0011 4	0.03	236 9	0.16	110	0.0000 6	0.044	390	7.1	2.3 6	14	1200
temephos	----	0.0000 11	4.3	27.4	1.55	0.04	0.0000 025	0.01	444	0.3	4.9 1	30	1825 0
fipronil	140	0.015	0.083	11.3	0.00 5	10	0.0098	0.006 6	97	0.0 19	4	122	825
piperonyl butoxide (PBO)	----	0.51	0.013 4	562 0	11	300	5.1	3.6	457 0	15. 5	4.9 5	0.3	399

boric acid	1200	52.2	4.6	251 0	362. 58	30	13.6	12.2	345 0	17. 5	0.1 75	1.2	62
bifenthrin	----	0.0016	0.000 35	128 0	0.01 5	100 00	0.0000 14	0.000 03	540 0	2.5	6	14	1480 94
cyfluthrin	----	0.0001 41	0.000 3	200 0	0.03 7	250	0.0001 5	0.004	500	2.5	5.6 2	63	1000 0
cypermethrin	----	0.0000 036	0.000 39	200 0	0.02 3	50	0.0005 9	0.000 14	247	6	6.6	60	8721 6
deltamethrin	2560	0.0001 8	0.000 36	225 0	0.00 15	100 00	0.0000 31	0.005	128	1	6.2	14	7900 0
lambda- cyhalothrin	1500 0	1.05E- 06	0.000 04	200 0	0.09 8	617	0.0000 05	0.000 01	56	1.8	6.8	30	8000 0
permethrin	----	0.0001	0.000 79	100 00	0.13	500	0.0000 39	0.000 3	228 0	25	6.5	125	6310 0
clothianidin	1100 00	0.051	105	200 0	0.00 37	525	0.12	93.6	500 0	9.8	0.7	495	60
dinotefuran	9760 0	0.79	99.3	200 0	0.02 3	215 0	95.3	----	200 0	20	- 0.5 49	81. 5	6
imidacloprid	----	10.44	211	152	0.08	61	1.14	----	450	5.7	0.5 7	190	210
thiamethoxam	8180 00	82.9	100	576	0.02 99	300	100	20	156 3	21	- 0.1 3	30	68.4
spinosad	6100	1	4	200 0	0.00 36	100	0.0012	0.5	200 0	4.8 9	4.0 1	17. 3	3502 4
abamectin	3900	0.0000 2	0.003 2	85	0.41	12	0.0000 3	0.000 52	10.6	0.1 2	4.4	60	5000
methoprene	----	0.089	4.62	200 0	7.8	30	0.002	0.048	100 00	250	5.5	14	2300 0
pyriproxyfen	64	0.4	0.27	200 0	100	600	0.0000 15	0.004 3	500 0	27. 31	5.3 7	7.5	4050 00
Bacillus thuringiensis (BTI)	----	0.8	370	307 7	15	----	0.5	100	200 00	840 0	3.4 1	4	5000
DEET	4300 0	75	75	137 5	100	----	----	----	217 0	100	2.0 2	1.3 8	300
etofenprox	150	0.0002 9	0.002 7	200 0	0.13	100 0	0.0005	0.000 7	200 0	3.7	6.8	7	8548
halofenozide	780	3.6	8.4	225 0	100	600	0.03	0.45	285 0	5.7	3.4 5	818	149
hydramethylnon	2.74	1.14	0.15	113 6	68	50	----	----	817	1.6 6	4.4 5	391	3300
indoxacarb	110	0.029	0.024	808	0.18	720	0.004	0.000 6	268	2	4.6 5	114	8100

chlorantraniliprol e	1460 0	0.0116	13.8	225 0	0.1	120	0.0044 7	0.11	500 0	805	2.8 6	410	153
naphthalene	3300 0	1.6	2	269 0	----	----	0.48	0.86	264 9	100	3.9	40	200
hexaflumuron	----	0.0001 11	0.5	200 0	0.1	500	0.0001 11	0.183 8	500 0	75	5.4 6	280	6092
sumithrin	----	0.0044	0.015 8	500 0	0.00 67	----	0.0004 7	0.001 1	500 0	50	6.0 1	173 .3	1410 00
dicofol	----	0.14	0.124	165 1	50	10	----	0.001	587	5	5.0 2	113	8073
vinclozolin	1020	3.65	3.5	251 0	100	50	2.7	0.007	250 0	2.5	3.1	100 0	100
azoxystrobin	106	0.26	0.47	250	200	----	44	147	500 0	18. 2	2.6 4	365	207
chlorothalonil	190	0.068	0.023	200 0	181	100 0	0.039	0.003	100 00	3	3.0 5	30	1800
myclobutanil	830	11	2.4	510	100	500 0	9.5	2.2	160 0	3.0 9	2.9 4	244	950
pyraclostrobin	----	15.7	6.2	500 0	73.1	106 2	0.004	0.002 4	500 0	9	4.1 8	248	9304
mancozeb	1100	0.58	0.46	150 0	179	125	0.0073	0.002 19	500 0	4.8 3	1.3 3	35	1000
trifloxystrobin	37	0.025	0.014	200 0	200	320	0.0028	0.004 3	500 0	9.8 1	4.5	3	2709
fosetyl-Al	6790	188	141.4	800 0	100	150 0	17	100	540 0	250	-2.1	5.7	20
difenoconazole	150	3.3	3.2	215 0	100	25	0.0005 6	3.2	145 3	0.9 6	4.3	56	3470
iprodione	2000	0.24	3.1	930	120. 86	300	0.18	0.26	446 8	4.7	3	90	700
thiophanate methyl	8500	5.4	8.3	100 00	100	103	0.003	0.002	500 0	8	1.4	4	330
maneb	13	0.12	0.042	500 0	12	20	0.11	6.1	500 0	5	0.6 2	1	240
mandipropamid	2500	7.1	4.4	562 0	200	100 0	0.87	0.5	500 0	15. 2	3.3	75. 3	405

Table C.2 Average scores, pesticide type, bin, and use categories for each of the one hundred compounds in the ranking system.

Active Ingredient Pesticide (not formulations)	Cumulative rank	Pesticide Class	Relative Potential Ecosystem Hazard	Pesticide Usage Category (golf course; residential - home, garden and lawn care; right-of-way; vector control; algaecide; tomato
glyphosate	2.182	algaecide; herbicide	low	algaecide; golf course; residential; right-of-way
fosetyl-Al	2.545	fungicide	low	algaecide; golf course
bispyribac-sodium	2.545	herbicide; algaecide	low	residential; golf course; tomato farm
rimsulfuron	3.000	herbicide	low	golf course; residential
dicamba	3.273	herbicide	low	algaecide; golf course; residential
asulam	3.364	herbicide	low	algaecide; golf course; residential
mesotrione	3.364	herbicide	low	golf course; residential
metsulfuron methyl	3.636	herbicide	low	golf course; residential
DEET	3.636	Insecticide	low	right-of-way; residential; golf course
boric acid	3.727	insecticide; fungicide; algaecide	low	residential; golf course
aminocyclopyrachlor	3.727	herbicide	low	algaecide; golf course; right-of-way
foramsulfuron	3.727	herbicide	low	golf-course; residential
imazaquin	3.727	herbicide	low	golf course; residential
sethoxydim	3.727	herbicide	low	golf course; residential
sulfentrazone	3.727	herbicide	low	golf course; residential; right-of-way
imazapyr	3.818	algaecide; herbicide	low	golf course; residential; algaecide
glufosinate	3.818	herbicide	low	golf course; residential

penoxsulam	4.091	algaecide; herbicide	low	algaecide; golf course; residential
Bacillus thuringiensis (BTI)	4.091	insecticide	low	golf course; residential; algaecide
clopyralid	4.182	herbicide	low	algaecide; golf course
quinclorac	4.182	herbicide	low	golf course
trinexapac-ethyl	4.182	herbicide	low	golf course; residential; right-of-way
sodium-carbonate peroxyhydrate (SCP)	4.273	algaecide; herbicide; fungicide	low	algaecide; golf course; residential; right-of-way
clethodim	4.455	herbicide	low	algaecide; golf course; right-of-way
ethofumesate	4.455	herbicide	low	right-of-way
isoxaben	4.455	herbicide	low	right-of-way; residential; golf course
napropamide	4.455	herbicide	low	residential; golf course
pendimethalin	4.455	herbicide	low	right-of-way; golf course; residential
naphthalene	4.455	insecticide	low	golf course; residential; right-of-way
carfentrazone	4.545	algaecide; herbicide	low	algaecide; golf course; tomato farm
endothall	4.545	algaecide; herbicide	low	algaecide; golf course; residential
fluroxypyr	4.545	herbicide	low	residential; golf course; right-of-way
siduron (substituted urea pesticide)	4.545	herbicide	low	residential; golf course; right-of-way
dinotefuran	4.545	insecticide	low	golf course; residential
thiamethoxam	4.545	insecticide	low	right-of-way; golf course; residential
fluridone	4.636	algaecide; herbicide	moderate	golf course; residential
triclopyr	4.818	algaecide; herbicide	moderate	golf course; residential
mandipropamid	4.818	fungicide	moderate	golf course
piperonyl butoxide (PBO)	4.909	insecticide/synergist	moderate	vector control; residential; golf course; tomato farm

thiophanate methyl	5.000	fungicide	moderate	golf course; algaecide; residential
benefin	5.000	herbicide	moderate	golf course; residential; right-of-way
fenoxaprop-ethyl	5.000	herbicide	moderate	residential; golf course; vector control
methoprene	5.000	insecticide	moderate	golf course; residential
pyriproxyfen	5.000	insecticide	moderate	residential; tomato farm; golf course; vector control
acephate	5.273	insecticide	moderate	residential; golf course
chlorothalonil	5.364	fungicide; insecticide	moderate	golf course; right-of-way
indaziflam	5.455	herbicide	moderate	residential; golf course
metolachlor	5.636	herbicide	moderate	golf course; residential; vector control
oryzalin	5.636	herbicide	moderate	residential; golf course; vector control
2,4-D	5.727	herbicide; algaecide	moderate	golf course; residential; tomato farm
pyraclostrobin	5.727	fungicide	moderate	golf course; residential
azoxystrobin	5.727	fungicide	moderate	golf course; residential; tomato farm
bromoxynil	5.727	herbicide	moderate	golf course
pronamide	5.727	herbicide	moderate	vector control
d-phenothrin (sumithrin)	5.727	insecticide	moderate	golf course; residential; vector control
mancozeb	5.818	fungicide	moderate	golf course; residential
diclofop-methyl	5.818	herbicide	moderate	golf course; residential
fluazifop-butyl	5.818	herbicide	moderate	golf course; residential
paclobutrazol	5.818	herbicide	moderate	residential; vector control; golf course
bifenthrin	5.818	insecticide	moderate	golf course; residential; vector control
deltamethrin	5.818	insecticide	moderate	residential; golf course

lambda-cyhalothrin	5.818	insecticide	moderate	residential; golf course; vector control
maneb	5.909	fungicide	moderate	golf course; residential
myclobutanil	6.091	fungicide	moderate	golf course; residential
simazine	6.182	algaecide; herbicide	moderate	residential
dimethenamid	6.182	herbicide	moderate	residential; right-of-way
diquat	6.182	herbicide; algaecide	moderate	vector control; residential; golf courses
halofenozide	6.182	insecticide	moderate	golf course; residential; vector control
permethrin	6.182	insecticide	moderate	golf course; residential
trifloxystrobin	6.273	fungicide	moderate	golf course; residential; right-of-way
chlorantraniliprole	6.273	insecticide	moderate	residential; golf course
clothianidin	6.273	insecticide	moderate	golf course; vector control; residential; tomato farm
spinosad	6.273	insecticide	moderate	residential; golf course
difenoconazole	6.545	fungicide	likely	residential; vector control; golf course
iprodione	6.545	fungicide	likely	residential; golf course; vector control
atrazine	6.545	herbicide	likely	residential
carbaryl	6.545	insecticide	likely	residential
hexaflumuron	6.545	insecticide	likely	tomato farm; golf course
imidacloprid	6.545	Insecticide	likely	golf course
malathion	6.545	insecticide	likely	golf course
copper (2+) sulfate (copper compounds)	6.636	algaecide; fungicide	likely	residential; tomato farm; golf course
hydrothol	6.636	algaecide; herbicide	likely	residential; golf course; vector control
vinclozolin	6.636	fungicide	likely	vector control; residential
dithiopyr	6.636	herbicide	likely	residential; golf course
etofenprox	6.636	Insecticide	likely	golf course; residential

trichlorfon	6.636	insecticide	likely	tomato farm
dicofol	6.909	insecticide	likely	residential; golf course; tomato farm
metham-sodium	7.000	herbicide; fungicide; insecticide	likely	golf course; residential
cyfluthrin	7.000	insecticide	likely	residential; golf course; tomato farm
cypermethrin	7.000	Insecticide	likely	golf course
temephos	7.000	insecticide	likely	golf course; residential
hydramethylnon	7.364	insecticide	likely	golf course
oxadiazon	7.455	herbicide	likely	residential; golf course
indoxacarb	7.727	insecticide	likely	tomato farm
chlorpyrifos	8.182	insecticide	likely	residential; vector control; golf course
methiocarb	8.182	insecticide	likely	golf course; residential
endosulphan	8.273	insecticide	likely	residential; algaecide; tomato farm
bensulide	8.636	herbicide	likely	residential; golf course
abamectin	8.636	insecticide	likely	residential
fipronil	9.091	insecticide	likely	tomato farm