Pollution is defined as the introduction of substances by man that negatively affects living resources or hinders commercial or recreational activity. There are three general types of pollution: point source, nonpoint source and eutrophication. Point source pollution (PS) can be linked specifically to one institution or groups of institutions (such as wastewater discharged from an industrial plant). Nonpoint source pollution (NPS) cannot be linked to a specific institution and is also known as polluted runoff. NPS may come from these areas: forestry, agriculture, urban areas, marinas, shoreline modification, and wetlands/vegetated shorelines. NPS is considered to be the greatest threat to coastal areas (NOAA 2007). One of the largest nonpoint source pollutants is the excessive input of nutrients. This type of pollution is called eutrophication and can cause excessive algal growth, depletion of oxygen, and alter food webs and species composition (Howarth et al. 2000). Eutrophication has become the largest pollution problem faced by coastal areas, with 60% of coastal rivers and bays in the US being affected by it (Howarth et al. 2000).

Estuaries are where land meets the sea, and have become extremely important to humans. Commercially important species, like lobsters, flounder and crabs, are found in these waters. These areas are also important for recreational activities, making them popular with humans throughout the year. For these reasons, and many others, human populations have congregated around estuaries. The dense population creates conservation issues as managers are charged with pollution abatement and maintaining the qualities of the estuary that humans like (such as recreational areas and commercial fishing grounds). One of the largest pollution sources for urban estuaries is nutrient-rich wastewater discharge, which causes eutrophication. In addition, high agricultural use of the land near the estuary causes much NPS run-off, also adding to the increasing eutrophication (Howarth et al. 2000). Researchers, managers and policy makers realized the need for an integrated technology, which would fuse existing pollution data with new data in a program that could be widely used and manipulated (Tortell 1992).

For the better part of the last century, there have been many advances in marine observational techniques, such as remote sensing (RS) and geographic information systems (GIS). Through advances in RS, such as better resolution and quality of sensors, scientists have been able to remotely monitor various properties of coastal waters – phytoplankton pigments, salinity, temperature, wind, ocean color, surface organic slicks and surfactants (Muller-Karger 1992). GIS has changed the face of cartography. It began as a land-planning tool and has evolved into a dynamic system, with the most recent advancements being made in the coastal and marine environments. Various types of GIS data (e.g. discharge data from the EPA, wetlands inventory data from the USFWS, USGS NLCD, DEM, and NHD) have been used to quantify pollution, wetland types as well as land use/cover, elevation and hydrologic variables (Host et al. 2005 and Ricketts 1992). Traditionally, however, estuarine processes were quantified using mathematical models. While these models were valuable and could easily predict unknown values, they were incomplete. The coupling of mathematical models, available RS/GIS datasets, and site-specific (newly created) datasets have produced very detailed bio-physical and socio-economic regional maps and monitoring programs that have become increasingly important to managers and policy makers. The “user-friendly” software and high-speed internet access has enabled all this data to be shared around the globe.
RS, GIS and pollution modeling/mapping in estuaries has become an important integration of techniques for researchers to create maps and models for the instruction of management policies. Many of these integrated models are specifically designed to track land use/cover changes that could lead to different forms of NPS flowing downstream (Di Luzio et al. 2004, Focardi et al. 2006, He 2003, and Yang & Lui 2005). These modeling systems start with mathematical models, such as Soil and Water Assessment Tool (SWAT) or Agricultural Nonpoint Source (AGNPS) which are complex hydrological programs that predict the impact of land management decisions on watersheds (Di Luzio et al. 2004 and He 2003). These types of mathematical models are the most commonly used when creating an integrated RS/GIS/pollution monitoring model. Since these integrated models are created on an ArcView/GIS personal computer platform, these programs are perfect for individuals with limited GIS knowledge.

By monitoring pollution through these integrated models, maps have been created to show sources (such as agricultural lands upstream and industrial discharge of heavy metals), (Focardi et al. 2006 and Gowri et al. 2008) and where pollutants leave the estuary. These maps have enabled managers to direct efforts to specific areas and provide specific relief, particularly if the type of pollution can be identified. Defining the type of pollution has been a source of problem for most researchers. Most have included other techniques to accomplish this, such as stable isotopes. Stable isotopes have long been known as an accurate way of tracking nutrients, such as nitrogen and carbon, from their source. The combination of stable isotope research and GIS/RS pollution maps create a powerful tool to analyze pollution sources and types (NPS versus PS) (Constanzo et al. 2001). Using the stable isotopic signatures and GIS/RS mapping programs, nutrient pollutants can be grouped by signature, mapped and effective management policies can be put into effect. Nutrient pollution can also be tracked with remote sensing (Tripathi & Patil 2004). Nutrients significantly alter the optical properties of water, and while the signal is not as strong as chlorophyll a, nutrients can still be quantified using shortwave infrared (SWIR) sensors with accuracy. Increasing the sensitivity of these sensors can add one more tool to pollution maps, by accurately representing nutrients in urban estuaries.

The integration of pollution mapping models, RS and GIS, has become an invaluable tool in the last couple of decades. These models have a comprehensive, interdisciplinary approach while maintaining “user friendly” commands. This provides specific conclusions to management issues, taking out much of the guesswork in conservation and management practices (Sarapathy et al. 2007). In addition, the maps are easy to understand for all viewers. This makes presenting data and arguing for specific policies more effective. As more data becomes available for analysis, RS/GIS/pollution mapping models will continue to be invaluable for managers. Increased efforts should be put towards tracking excess nutrients and other pollutants by increasing sensitivity of remote sensing sensors. However, it is important to continue monitoring and mapping pollution using other techniques, such as stable isotopes, to give a two-prong approach. This approach gives both techniques a comparison point, increasing the robustness of the model.

GIS and RS are the perfect partners for estuarine pollution maps. Most estuaries have long-term datasets ranging from salinity measurements to light, phytoplankton concentrations and PS pollution discharge data. Consistently updating the integrated
models would give managers a real-time response to new pollution data or land use/cover changes. Instead of making pollution abatement policies after the pollutant has been discovered, the real-time responses allow managers to forecast where pollutants will travel and the extent of damage. This “offensive” rather than “defensive” position will keep estuary quality and health for years to come.

**Literature Cited**


Annotated Bibliography


This research combined stable isotopic analysis with GIS to detect and map sewage impacts. The researchers studied the stable isotopic composition of macroalgae in the Moreton Bay, Australia. They first analyzed signatures from macroalgae occurring naturally in each region of the bay, and then constructed a grid (using differential GPS) and distributed a red alga in deployment chambers throughout the grid. These deployment chambers held the alga in place while allowing it to assimilate nitrogen flowing through the chamber. The results were then analyzed and mapped with GIS software to show plumes of sewage outflow. These results were used to initiate improvements to the sewage treatment facilities in the region.


The researchers introduced AVSWAT (Arc View Soil and Water Assessment Tool). This was a model that linked SWAT with GIS combining the assessment of point and nonpoint source pollution loading at a watershed scale. Users supplied DEM, NHD, STATSGO data. Nonpoint source pollution was assessed within SWAT which itemized categories of nonpoint source pollution to account for land use changes. Point source pollution was assessed by merging discharge records with AVSWAT for the watershed of interest. The researchers concluded that the user-friendly program was excellent for users with limited GIS skills, flexible to allow for analysis with any watershed, and, by coupling with Arc View, allowed for the use of other GIS functions.


This article describes how remote sensing was used to assess land use/cover changes over time while chemically quantifying pollution in fish standing stock. Lake Victoria has seen a decline in fisheries, while an increase in urbanization, bringing increased pollution of many kinds (siltation, degradation of wetlands, nutrient loading, heavy metals, insecticides, etc). Remote sensing data was gathered from satellite
based measurements in the visible, near IR, Thermal IR spectrums as well as Landsat Thematic Mapper. Historical data was available for comparison. According to the satellite data, wetlands decreased, agricultural use has increased, and the agricultural area is at a higher elevation than the lake, allowing sediments (including pesticides and heavy metals) and nutrients to be brought to the lake via a river system. The researchers concluded that more analysis needed to be done on the fish for pesticides and heavy metals quantification. However, the authors were able to confirm the need for more pollution control and management of the lake for future use.


This research used GIS to study the transport of pollutants to the Bay of Bengal through the Adyar and Cooum rivers. Both rivers are undergoing heavy urbanization, leading to the discharge from commercial, residential, industrial and recreational activities. Monthly samples were collected in 1994 and analyzed for suspended solids, nutrients and heavy metals. GIS techniques were employed to overlay the results on a base map of the city to study the impacts of pollution on the coastal environment. The authors would like to see continued monitoring of the rivers/coastal areas as well as methods to improve the water quality.


This article provides a description and case study of a simulation model for watershed assessment. It integrates GIS and agricultural nonpoint source pollution model to create the ArcView nonpoint source pollution model (AVNPSM). Digital databases of soil, land use/cover, climate, topography, hydrography and management practices were used to simulate land use change, runoff, sedimentation and nutrient differences that may occur in the future. While inputting all the necessary information into all the cells would be time consuming, the combination of available digital datasets enables cells and parameters to be automatically filled by the GIS software. This program appears to be user-friendly, robust and improves the efficiency of nonpoint source pollution monitoring.


This article provided an overview of remote sensing capabilities in the late 1980s. For the current paper, it provided a background of information on various measurable properties: ocean color, phytoplankton standing stock, temperature, wind, salinity, etc. These are vital statistics for marine pollution (includes estuaries). The author described various satellite and aircraft mounted sensors in use and on the horizon. The article concluded with future directions remote sensing could take in monitoring marine pollution.

The author provides an overview of how GIS is used to manage coastal areas. He also discusses the future, citing needs for GIS and RS to developed in developing countries, the need for fiber optics to replace copper wire so that more information can be passed along remotely. Discussions are presented on how that the hardware and software being developed for GIS applications might require too much expertise for general use. However, these developments are necessary for proper coastal management. The author discusses the need for an infrastructure, data sharing and ownership rules. Even with its faults, the author believes GIS will be an invaluable tool and that a dynamic GIS is fundamental for coastal management.


This article is a prime example of how GPS, GIS, and RS are combined to map an entire community. These maps were created to quantify mangrove loss and monitor land use/cover changes over 12 years. GIS was used to map soil types and hydrological information, while RI was used to map land use/cover changes and vegetative cover (including mangroves). Finally, GPS was used to randomly select sampling sites to ground-truth the satellite and computer data. The results show that mangroves were killed by anthropogenic influences. The researchers believe that the combination of these three types of mapping can be used as a comprehensive set of data used for decision making.


The research presented here quantitatively defines the spectral band needed to analyze nutrients such as ammonia-nitrogen, phosphate-phosphorus, total suspended solids (TSS) and total dissolved solids (TDS). The authors used data collected from Landsat 5, IRS IC sensors. Water samples were also collected to quantify polluted and non-polluted sites. The analysis was conducted on the assumption that all data (including digital numbers) from non-polluted sites would remain fairly constant. This meant that any change in water quality would change reflectance. It was shown that pollutants, like ammonia-nitrogen, phosphate-phosphorus and TDS can significantly alter the optical properties of water. Ammonia-nitrogen and TDS influence the shortwave infrared (SWIR) bands and phosphate-phosphorus influences the red band. While these results also confirmed that these nutrients do not have as strong an influence as chlorophyll a or TSS, they can still be traced using remote sensing.

The authors were involved in an interdisciplinary effort to develop environmental indicators for an estuarine ecosystem assessment in the Gulf of Mexico region. This project started with developing a method to use RS and GIS to monitor land use/cover in the Pensacola estuarine drainage area (PEDA), Florida. Once this method was developed, they applied it to PEDA and analyzed the results. Landsat TM and ETM+ were used as the primary data, followed by USGS DOQs, digital topographical maps, ESRI 2002 roads and political boundaries, National Wetland Inventory (NWI), HUCs, Florida DEP land-use maps and USGS land use/cover maps (both complied with Anderson classifications). The researchers found this to be an accurate, detailed method to distinguish land use/cover changes.