Assessing Watershed Nonpoint Source Pollution Using a Geographical Information System (GIS)

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The non-point source (NPS) pollutants are contaminants of surface and subsurface soil and water resources (e.g., sediment, fertilizers, pesticides, salts, and trace elements) that are diffuse in nature and cannot be traced to a point location. Often times, NPS pollutants are usually naturally occurring such as salts and trace elements in soils or are the consequence of direct application by humans (e.g., pesticides and fertilizers), but regardless of their source they are generally the direct consequence of human activities (e.g., agriculture, urban runoff, hydromodification, and resource extraction). The USEPA (1990) identified agricultural nonpoint runoff of sediment and agricultural chemicals to cause impairment of 55% of surveyed river length and 58% of surveyed lake area that still have water-quality problems. Throughout the world 30 to 50% of the earth’s land is believed affected by NPS pollutants including erosion, fertilizers, pesticides, organic manures, and sewage sludge (Pimental, 1991). Assessing the environmental impact of NPS pollutants at watershed scale is a key component to achieving sustainability of agriculture, as well as preserving the environment.

Modeling the impact of non-point source pollution in catchments is a complex problem, and one that has troubled natural resource managers for many years. The development of spatially distributed hydrologic models has led to improved model forecasting at the cost of requiring more detailed spatial information. In addition, the analysis is much more sensitive to errors in the data. Incorporation of catchment models into a Geographical Information System (GIS) has improved matters by streamlining data input and providing better interpretation of model outputs (Pullar and Springer, 2000).

Historically, GIS has been coupled with three general categories of NPS pollution models: regression models (Corwin et al., 1989), index models (Rundquist et al., 1991), and transient-state solute transport models (Corwin et al., 1993a, b). More recently numerous hydrologic/water quality models of runoff and soil erosion have been used with a GIS to determine surface sources of nonpoint pollutants from watersheds (Pelletier, 1985; Warwick and Haness, 1994), agricultural areas (Hopkins and Clausen, 1985; Tim and Jolly, 1994), and urban areas (Smith and Brilly, 1992; Smith, 1993).

The first applications of GIS for assessing the impact of NPS pollutants in the vadose zone occurred in the late 1980s. Corwin et al. (1988), Corwin and Rhoades (1988), and Corwin et al. (1989) applied the use of GIS to delineate areas of accumulation of salinity in the vadose zone by coupling a GIS of the Wellton-Mohawk Irrigation District to a phenomenological model of salinity development.

The St. Johns River Water Management District (SJR-WMD) used a Geographic Information System (GIS) screening model to estimate annual nonpoint source
pollution loads to surface waters and determine nonpoint source pollution problem areas within the SJRWMD (Adamus and Bergman, 1995).

Petach et al. (1991) and Corwin et al. (1993a, b) used transient state solute transport models coupled to a GIS to assess the leaching potential of some common nonpoint source agricultural chemicals under nonequilibrium conditions.

Burrough (1996) identified three components or aspects to GIS-based environmental modeling: data, GIS, and model. He stated that first and foremost, the solute transport model must be developed; secondly, the data for the model must be obtained; finally, the solute transport model must be coupled to a GIS containing the spatial input data. Each component will be briefly reviewed to provide general background information.

Basnyat et al. (2000) examined a methodology to determine nitrate pollution ‘contributing zones’ within a given basin based on basin characteristics. In their study, land use/land cover types were classified and basins and ‘contributing zones’ were delineated using geographic information system (GIS) and remote sensing (RS) analysis tools.

Tim et al. (1992) applied an integrated approach coupling water quality computer simulation modeling with a GIS to delineate critical NPS pollution at the watershed level. Two simplified pollutant export models were integrated with the Virginia Geographic Information System (VirGIS) to estimate soil erosion, sediment yield, and phosphorus (P) loading from the Nomini Creek watershed located in Westmoreland County, Virginia.

The State of Texas has initiated the development of a Total Maximum Daily Load program in the Bosque River Watershed, where point and nonpoint sources of pollution are a concern. Soil Water Assessment Tool (SWAT) was validated for flow, sediment, and nutrients in the watershed to evaluate alternative management scenarios and estimate their effects in controlling pollution (Santhi et al, 2002).

Oki and Yasuoka (2008) analyzed the relation between the land cover types estimated from monthly maximum Normalized Difference Vegetation Index (NDVI) imagery calculated from NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery and the annual total nitrogen load discharged from river basins, produced two advanced maps of the potential annual total nitrogen load (PTNL) index and the potential annual total nitrogen load for each river basin area (PTNL/area) index by considering the relationship between the land cover types and the annual total nitrogen load discharged from river basins in Japan.

Although GIS has been frequently applied in assessing watershed nonpoint source pollution, there are still some aspects that this application needed to be improved. Reliable and cost-effective approaches for measuring kept pace with developments in solute transport modeling or GIS applications to NPS pollutants. Concomitantly, models, though intrinsic to the scientific method, should not supplant observation, but rather complement observation. The application of environmental models should augment and not replace actual observation regardless of the user.

Therefore, three areas of more intensified study are needed to enhance the capability of modeling NPS pollutants in the watershed level: more cost-effective and
efficient methods/ instruments of measuring transport parameter data at an increased resolution, a knowledge of the uncertainties associated with the visualized results generated from transport models coupled to a GIS, and continued research into those mechanisms involved in solute transport in the watershed that are not clearly understood (e.g., preferential flow).

References:
Corwin, D et al. 1993b. Predicting area1 distributions of salt-loading to the groundwater. Paper 932566. ASAE, St. Joseph, MI.


**ANNOTATED BIB (6 papers selected)**


The St. Johns River Water Management District (SJR-WMD) is using a Geographic Information System (GIS) screening model to estimate annual nonpoint source pollution loads to surface waters and determine nonpoint source pollution problem areas within the SJRWMD. The model is a significant improvement over current practice because it is contained entirely within the district’s GIS software, resulting in greater flexibility and efficiency, and useful visualization capabilities. Model inputs consist of five spatial data layers, runoff coefficients, mean runoff concentrations, and stormwater treatment efficiencies. The best part of this paper is that it is a site-specific study, the model was created to serve a major planning effort at the SJRWMD, and results are being actively used to address nonpoint source pollution problems.


This study examines a methodology to determine nitrate pollution ‘contributing zones’ within a given basin based on basin characteristics. In this process, land use/land cover types were classified and basins and ‘contributing zones’ were delineated using geographic information system (GIS) and remote sensing (RS) analysis tools. The best section in this paper was the ‘land use/land cover-nutrient-linkage-model’. In the model, the residential/urban/built-up areas have been identified as strong contributors of nitrate.


In this study, Oki and Yasuoka first analyzed the relation between the land cover types estimated from monthly maximum Normalized Difference Vegetation Index (NDVI) imagery calculated from NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery and the annual total nitrogen load discharged from river basins. They found that the runoff load factor from urban areas is higher than those of forested areas. Finally, they produced two advanced maps of the potential annual total nitrogen load (PTNL) index and the potential annual total nitrogen load for each river basin area (PTNL/area) index by considering the relationship between the land cover types and the annual total nitrogen load discharged from river basins in Japan. The most useful section in this paper is that they found that the PTNL map will be
useful for the risk assessment of total nitrogen load impact on lakes and the sea through rivers from each basin. The PTNL/area index, which considers the effects of river basin areas, will allow evaluation of the state of river basins.


An integrated approach coupling water quality computer simulation modeling with a geographic information system (GIS) was used to delineate critical areas of nonpoint source (NPS) pollution at the watershed level. Two simplified pollutant export models were integrated with the Virginia Geographic Information System (VirGIS) to estimate soil erosion, sediment yield, and phosphorus (P) loading from the Nomini Creek watershed located in Westmoreland County, Virginia. On the basis of selected criteria for soil erosion rate, sediment yield, and P loading, model outputs were used to identify watershed areas which exhibit three categories (low, medium, high) of non-point source pollution potentials. In general, the study demonstrated the usefulness of integrating GIS with simulation modeling for nonpoint source pollution control and planning. Such techniques can facilitate making priorities and targeting nonpoint source pollution control programs.


The State of Texas has initiated the development of a Total Maximum Daily Load program in the Bosque River Watershed, where point and nonpoint sources of pollution are a concern. Soil Water Assessment Tool (SWAT) was validated for flow, sediment, and nutrients in the watershed to evaluate alternative management scenarios and estimate their effects in controlling pollution. This paper discusses the calibration and validation at two locations, Hico and Valley Mills, along the North Bosque River. The best section of this study is that it showed that SWAT was able to predict flow, sediment, and nutrients successfully and can be used to study the effects of alternative management scenarios.


Because of their ubiquitous nature and potential chronic health effects, nonpoint source (NPS) pollutants have become a focal point of attention by the general public, particularly regarding pollution of surface and subsurface drinking water sources. The NPS pollutants pose a technical problem because of the areal extent of their
contamination that increases the complexity and sheer volume of data far beyond that of point-source pollutants. The spatial nature of the NPS pollution problem necessitates the use of a geographic information system (GIS) to manipulate, retrieve, and display the large volumes of spatial data. The most useful section of this paper is that it provides a brief introduction and review of the modeling of NPS pollutants with GIS and a brief discussion of some of the papers presented at the ASA-CSSA-SSSA 1995 Bouyoucos Conference entitled Applications of GIS to the Modeling of Nonpoint Source Pollutants in the Vadose Zone.