Risk assessment of surface water quality using BASINS

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06-25-2004

ABSTRACT

Hydrologic models are necessary to understand the risk faced by the environmental system. Available Arc View spatial data was used to integrate geographic datasets and their spatial relationships through Better Assessment Science Integrating Point and NonPoint Sources (BASINS). This interface provided a platform for the integration of land use management from point and non-point discharges. BASINS is an environmental simulation analysis tool, and its components are HSPF, a watershed scale model for estimating in stream concentration from land use practices; and SWAT, a soil and water assessment tool. Arcview provides the interface for integrating environmental information and displaying relationships.

Three case studies were selected from a broad literature review for their use of HSPF and SWAT. The result of this research and review support the suitability of this approach to reveal vulnerable surface waters at risk to the impact of pollutant loadings from nonpoint sources.

Introduction

Water has been an increasingly expensive commodity because of the costs involved in the treatment and the increase in demand. Water as a resource continues to be a major source of societal concern. Surface waters have been the recipients of contaminants from nonpoint sources and point sources.

Water pollution problems from nonpoint sources are not as easy to detect as point source pollution through the traditional treatment strategies, because they do not generate from specific, distinct and identifiable locations, as in the case of industrial discharges. Rather, they emanate from surface areas such as cultivated fields. The high variability of rainfall events, complexity of landscapes, nature of geologic strata and lack of an exclusive source often make it hard to ascertain a specific cause and effect relationship.

These releases of chemicals can cause various types of impacts rendering the water undrinkable, or even toxic to humans or aquatic life, or contributing towards the eutrophication of water bodies (Giupponi and Rosato, 1999). Also, runoff from different agricultural lands may be enriched with nutrients and sediments. Similarly, runoff from highly urbanized areas may be enriched with heavy metals and waste from vehicle leaks and emissions In addition, through evapotranspiration, interception, infiltration, percolation and absorption, different types and coverage of vegetative surfaces can change the land surface characteristics, water balance, hydrologic cycle, and the surface water temperature (Leblanc et al., 1997).

Effective watershed management requires a comprehensive perceptive of hydrologic and biogeochemical processes within the watershed. These relationships are frequently examined through mathematical models and geospatial tools analysis and are used to make management decision; these relationships among land use practices, agricultural activities and water quality are both spatially and temporary multifaceted.

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) developed by the United State Environmental Protection Agency (USEPA) Geographical Information system (GIS) provides a framework for integrating spatial data e.g.; land use, vegetation, climate, elevation, and spatial data e.g.; land use, vegetation, climate, and elevation. The data are calculated using a set of modeling tools such as Soil and Water Assessment Tool (SWAT), which is produced for flow, sediments, and nutrients in the watershed to assess management scenarios and their effects in pollution control, and the Hydrologic Simulation Program-FORTRAN (HSPF) which is a watershed scale model for estimating in stream concentration from land use practices, it simulates the hydrology of a watershed and water quality (Bicknell et al., 1996). SWAT is a hydrologic quality model developed jointly by the United States Department of Agriculture (USDA), Agricultural Research Service and Texas A&M Agricultural Experiment Station. Land management impacts on water quantity have been predicated by SWAT (Srinivasan and Arnold 1994), sediment yield and nutrient loss (Luzio et al. 2002), and pesticide fate and transport in a wide range of watershed scales. The model estimates significant hydrologic components including evaportranspiration, surface runoff, return flow, and ground water recharge at the delineated sub-watershed. Hydrologic Simulation Program-FORTRAN (HSPF) has been used to simulate: (1) a wide variety of hydrologic conditions (Srinivasan et al., 1998), (2) transport of various non-point source pollutants, including contaminated sediment (Fontaine and Jacomino, 1997) and pesticides (Laroche et al., 1996), and (3) Land use management and flood control scenarios

Overview of the reviewed materials

Case Study 1

The United States Environmental Protection Agency (USEPA) reported that the major cause for impairment of water bodies in the United States is nutrient enrichment (USEPA, 1994). In a study conducted on the Upper North Bosque River (UNBR) within Erath County in central

Texas by Mauro Di Luzio et al. SWAT was calibrated on the 932km^2 Bosque River Watershed that flows into lake Waco in Waco, Texas, where confined animal feeding operations produced non point pollution as a source of concern (Texas Commission on Environmental Quality (TCEQ) 1999). The SWAT model was calibrated for a 60month period. Parameter Table 1 shows the list of USGS cataloging unit 12060204 and it's information in 303(d) list.

State	Identification	Waterbody	Parameter of Concern	Potential Sources of pollution
TX	TX-1226-1998	North Bosque River	Pathogens, Nitrogen, Phosphorus, Pathogens, Organic Enrichment/Low	Non point source
TX	TX-1255-1998	Upper North Bosque River	Chloride, Nitrogen, Phosphorus Sulfate, Dissolved Oxygen, Total Dissolved Solids	Non point source

USGS Cataloging Unit 12060204 information in the 303 (d) List: After (Mauro Di Luzio, Raghavan Srinivasan, and Jeffrey G. Arnold, 2002. Integration of Watershed Tools and SWAT Model into Basins. Journal of the American Water Resources Association. Vol. 38, (4), 1127-1141).

Landuses in this entire watershed involve urban, and agricultural activities, which include dairy farming, cropland, pasture, and range. The Texas Institute for Applied Environmental Research (TIAER) has monitored stream runoff, nutrients, and sediments for some areas in the watershed since the early 1990s(McFarland and Hauck, 1999). Within the UNBR watershed there are 16 storm water-monitoring sites equipped with automated samplers.

Mauro Di Luzio et al. in this paper used BASINS embedded GIS databases; the databases used are:

- 1: 250,000-scale United states Geological Survey (USGS) raster digital elevation model (DEM) which is a watershed delineator for cataloging unit 12060204,
- National Hydrography Dataset (NHD), this feature identifies the stream segments that compromise the US surface water drainage system.

- USGS land use and the State Soil Geographic Database (STATSGO) soil map.

Objective

The UNBR program main objective was to find ways to manage dairy waste in order to reduce runoff pollution. The SWAT as a tool was used to study the effect of different best management practices (BMPs) in assessing and reducing pollution,

To validate the model, the input parameters are set in the calibration process without any change and the results are compared to the observational data. The watershed was delineated and the observed data was compared to the simulated data using the SWAT model, the results of the simulation period of 60months are listed in Table 2

Variable	Observed	Simulated	Nash and Sutcliffe (1970) E (monthly time step)
Water Discharge (m^3/s)	4.43	4.29	0.82
Sediment Yield (t)	4489.90	3625.91	0.78
Organic Nitrogen (kg)	20793.36	15165.59	0.60
Nitrate (kg)	8469.26	6091.20	0.60
Organic Phosphorus (kg)	3699.21	2955.56	0.70
Orthophosphate (kg)	2524.45	1981.84	0.58

Table 2. Sampling Station result: Averaged Observed and Simulated Loading in UNBR Watershed Using Swat Within BASINS-Analysis period is for 60months(January 1993- July 1998): After (Mauro Di Luzio, Raghavan Srinivasan, and Jeffrey G. Arnold, 2002. Integration of Watershed Tools and SWAT Model into Basins. Journal of the American Water Resources Association. Vol. 38, (4), 1127-1141).

Result and Discussion

SWAT simulation for the period of 60months, showed their goodness and fit and reproduced the same result as that of Santhi et al. (2001). This result showed the efficient dairy waste management system. The BASINS system was particularly useful in the description of the major channel, the sub watershed outlets, location of the point sources, linkage with the soil database, definition of the land use classes and input of all the data at the subwatershed level. The results of the SWAT simulation in the BASINS system showed the reliability and efficiency of UNBR watershed analysis.

Case Study 2

Tong et al. (2002) used BASINS to model the quantity and quality of the runoff from different types of land use in the East Fork Little Miami River, Ohio, which covers more than 5840 sq km.

Objective

The author set out to investigate the hydrologic effects of land use on the quantity and quality of Surface Water at a regional scale in the State of Ohio by looking at all the possible spatial relationships of land use and the different impacts of the relative land use types in the study area.

The watershed for the analyses was delineated in BASINS. The simulation was performed on the hydrology and water quality parameters. A basic hydrologic model for the East Fork Little River Basin was built by first running the HSPF module in (NPSM) Non point Source Model. Data was collected for an eight yr period.

The simulated flow results when compared with the observed daily discharge records during the simulation period from existing USGS monitoring data revealed that the simulated flow was close to the actual monitored flow rate with an error rate of about 8.12%, if error rate is less than 10%, then the model is regarded to be good and acceptable if rate ranges between 10-20%. The simulated flow results for five smaller sub-watersheds were compared with the observed flow records. The results of the flow values were close to the monitored values and within acceptable limits. The result for reach 05090202002 on January 1, 1993 was 10.93cu m/s; it was just about equal to the sum of the flow in the upper reaches, Reach 05090202003 (8.22cu m/s) and reach 05090202010 (2.37cum/s).

Total nitrogen, total phosphorus and *Feacal coliform* had a strong correlation with land use types. The analysis of variance on the ranked values of nitrogen and phosphorus showed that both variables exhibited significant differences with p=0.0001 between the land used classes, mean of nitrogen was 407 and phosphorus was 426, the mean values were higher in the agricultural watersheds than the urban ones, which had a nitrogen mean of 372 and phosphorus 388. Forested area had much lower nitrogen and phosphorus ranking, mean of nitrogen 239 and mean of phosphorus 252.

Result

The agricultural land use produced the highest level of contaminants and barren land use the least amount of contaminants. The simulated result of the phosphorus was similar to that of nitrogen for all land types except that phosphorus output was 10 times smaller than the nitrogen. From the results, runoff from agricultural land and impervious urban land use had more phosphorus output as compared to other land use types like forest and barren land types, the maps also revealed a high correlation between agricultural land use and phosphorus level. *Feacal coliform* level was highest in agricultural land use types and least in the barren land use types.

Case Study 3

Pollution was found in the storm water drains and a link to it impacts on the creek was set be established. Rahman M., et al. performed a study using HSPF on the 416km^2 South Creek catchment located in Australia. Two thirds of the land is mostly agricultural (360 km^2), while the urban area is about 56 km^2 in size

The Hawkesbury-Nepean river system is an important water resource of the Sydney region. It receives effluent from 40 sewage treatment facilities and it is a major provider of Sydney drinking water. South Creek is a rapidly developing urban town. Urban area produces more runoff than an undeveloped area (USEPA 1983); therefore water quality depreciation from diffuse and point source poses a problem to a rapidly growing region.

Model Description

The model was calibrated by using ten nodes, each of the nodes were followed by a stream reach, each reach produced the future urbanization effect on the up stream catchment, the models were carried out in a hierarchical process. Hydrology was calibrated first, chloride, sediment, and nutrient. Values for theses concentrations were estimated and adjusted for better calibration. The benthic, nitrate process within the reaches were not simulated. All other values were simulated for the existing relationship with stream quality data at different locations

In this paper the model output was used to explore the impacts on water quality of a range of possible water control strategies and land use changes. A frequency –duration analysis was performed for output time series to determine the amount of time the specified levels were exceeded by output values. In this study a long-term climate record from1976-1993 consisting of rainfall, evapotranspiration, wind, radiation, and temperature were input to the model in association with land use types.

Results

The median predicted non point contribution of the Total Phosphorus (TP) from urbanization would increase by 20% by 2010; in this study they found out that non point sources exceeded the ANZECC maximum contaminant level (ANZECC 1992). With the existing (Sewage Treatment Plant) STP treatment condition, the TP concentration always exceeded the maximum concentration. The proposed urbanization is predicted to increase total nitrogen (TN) by 20% due to the non point sources. TN contribution from the non point sources did not meet (ANZECC) maximum contaminant level by 20%. With the STP, the TN level was well above the maximum contaminant level, and the TN concentration met the maximum contaminant level 70% of the time.

HSPF was very successful with the use of frequency duration analyses, to identify the contribution of diffuse and point sources in an urbanizing catchment. However the model results showed that the even the highest level of nutrient removal at the STP would not reduce nutrient levels in South Creek adequately to meet the ANZECC nutrient maximum contaminant level.

Performance of the three case studies

In Case 1 Mauro Di Luzio et al. talked about the SWAT model in BASINS as a successful hydrologic model tool. It concluded that the model could estimate the reduction of nutrients in the watershed if efficient watershed management tools are used. The results of the SWAT simulation in the BASINS system showed the reliability and efficiency of UNBR watershed analysis. In Case 2 BASINS proved to be a comprehensive water quality analysis tool in the research carried out by Tong et al; it also proved to have the capability to predict possible hydrological effects of changes in land use. All the simulated values were close to the actual observed values. The research findings by Tong et al. can greatly contribute to the possible hydrologic implications of land use. In Case 3 Rahman et al. performed a study using HSPF on the 416km^2 South Creek catchment located in Australia; HPSF model was successful in identifying the contribution of non point source in the urbanizing catchment, and it also revealed that South Creek could not reduce it's nutrient level sufficiently to meet the ANZECC nutrient maximum contaminant level.

Conclusion

In most instances simulated values were closer to the observed values during the calibration period, calibration should also be based on several years of simulation in order to appraise parameters under a wide range of climatic and soil conditions. In each case calibrated models were developed in identifying land use characteristics responsible for adversely impacting in stream water quality. The Arcview interface was effective at reducing the spatial data into formatted input files for the models. SWAT, and HSPF calibration and validation procedures presented in all this case studies will be useful to researchers and planners in studying water quality problems and taking decisions.

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