INFLUENCE OF LAND USE/LAND COVER CHANGE ON SAINT LOUIS BAY WATERSHED MODELING

Author 1,† Zhiyong Duan‡ Author 2,† Jairo N. Diaz Author 3,† James L. Martin Author 4,† William H. McAnally

† Department of Civil and Environmental Engineering, Mississippi State University
‡ Corresponding author: Department of Civil and Environmental Engineering, Mississippi State University

ABSTRACT

Saint Louis Bay Watershed is a coastal watershed located in southern Mississippi, which composes two basins: Jordan River Basin and Wolf River Basin. Two land use/land cover (LULC) datasets: the Geographic Information Retrieval and Analysis System (GIRAS) and the National Land Cover Data (NLCD) are applied on these two basins to simulate the hydrologic and water quality parameters by using the Hydrological Simulation Program - FORTRAN (HSPF) and the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). The difference of GIRAS dataset and NLCD dataset for the Saint Louis Bay represents the LULC change from 1977 to 1992. The area percentages of Forest Land and Urban or Built-up Land decrease for both these two basins. However, the area percentages of Wetlands and Barren Land increase. The Rate of Soil Erosion has a great increase in the area changing from other LULC classifications to Barren Land. As a result of the loss of vegetation and the aggravation of soil erosion, the Total Outflows of Sediments has a great increase, which deteriorates the water quality. However, other hydrologic and water quality parameters including Streamflow, Water Temperature, and Dissolved Oxygen, in contrast, result in insignificant changes.

ADDITIONAL INDEX WORDS: Saint Louis Bay Watershed, land use/land cover change, GIRAS, NLCD, water quality.

INTRODUCTION

Land use/land cover (LULC) represents the function or activity the land is used for. It has significant effects on the watershed environment. Some previous studies have explored the relationships between the LULC change and its impacts to the watershed environment including water, chemicals and organisms. For example, Wang et al. (1997) studied on the influences of LULC on habitat quality and biotic integrity in Wisconsin Streams. Osborne and Wiley (1988) explored some empirical relationships between LULC and stream water quality. Herlihy et al. (1998) developed a relationship between the stream chemistry and the watershed LULC. Richards and Host (1994) examined the influences of LULC on stream habitats with a GIS approach.

Better Assessment Science Integrating Point and Non-point Sources (BASINS) (USEPA 2001) is developed by the Environmental Protection Agency (EPA) which is a comprehensive environmental analysis software package integrating watershed dataset, geographic information system (GIS), hydrological and water quality simulation programs. Hydrological Simulation Program - FORTRAN (HSPF) is a component program of BASINS which can be used to simulate watershed hydrology and water quality (Bicknell et al. 2001). HSPF can be used for the simulation of rainfall-runoff and watershed non-point water pollutant loads. It can also be used to simulate the fate and transport processes in streams. These functions are performed in HSPF with three main modules, PERLND, IMPLND, and RCHRES. HSPF divides the simulated watershed into reaches and two types of land segments, pervious lands and impervious lands. The hydrology and water quality processes in pervious land segment are simulated by the PERLND module. The hydrology and water quality processes in impervious land segment are simulated by the IMPLND module. The processes in an open channel reach are simulated by the RCHRES module.

BASINS/HSPF has been widely applied to watershed modeling, Best Management Practices (BMP), and environmental management. Laroche et al. (1996) modeled and analyzed the transport of atrazine in an agricultural watershed. Srinivasan (1998) utilized HSPF to do a hydrological modeling for two glaciated watersheds in Pennsylvania. Zarriello and Ries
invested the effects of water withdrawals on streamflow in the Ipswich River Basin, Massachusetts. Fontaine and Jacomino (1997) performed the sensitivity analysis of simulations of contaminated sediment transport. Donigian et al. (1997) utilized HSPF to design the multipurpose detention facilities for flood protection and Nonpoint Source Pollution Control. Moore et al. (1992) performed Modeling of Best Management Practices on North Reelfoot Creek, Tennessee. Tsihrintzis et al. (1996) applied HSPF to invest the prevention alternatives for nonpoint source pollution at a wellfield in Florida. Ng and Marsalek (1989) applied HSPF to the Waterford River Basin near St. John’s, Newfoundland, Canada to simulate the influence of urbanization on streamflow. McCuen and Thomas (1990) indicated that stormflow and baseflow of watershed can be greatly influenced by urbanization. Choi and Deal (2007) used HSPF to invest the response of streamflow to the possible future urbanization in the Kishwaukee River basin in the Midwestern U.S.A.

The Geographic Information Retrieval and Analysis System (GIRAS) is a LULC dataset developed by U.S. Geological Survey (USGS) between 1977 and 1977 (USEPA 1994). The National Land Cover Data (NLCD) is a LULC dataset developed by USGS in 1992 (USGS 2000). In this study, these two LULC datasets are applied to the Saint Louis Bay Watershed respectively to obtain the LULC change of this watershed from 1977 to 1992. The hydrological and water quality parameters are simulated with BASINS/HSPF by using these two LULC datasets respectively. The purpose of this study is to determine the effects of LULC change on the water quality in the Saint Louis Bay Watershed by assimilating the LULC datasets into the hydrological decision system of BASINS/HSPF as the inputs for the watershed modeling.

**STUDY SITE**

The Saint Louis Bay Watershed is a coastal watershed located in southern Mississippi. It is the west part of the Mississippi Coastal Watershed with the USGS Hydrologic Unit Code (HUC) of 03170009. The Saint Louis Bay Watershed includes two coastal basins, the Jordan River Basin and the Wolf River Basin. As Fig.1 shows, these two coastal basins are adjacent to each other in the Saint Louis Bay Watershed, Mississippi. The Jordan River flows through Pearl River County, Harrison County and Hancock County in Mississippi and drains into the Saint Louis Bay. The Wolf River flows through Pearl River County, Harrison County and Hancock County in Mississippi and drains into the Saint Louis Bay. The Wolf River Basin has a drainage area of 931 km2, an average basin slope of 1.22%, and average annual precipitation of 158 cm and a land elevation range from 0 m to 127 m.

**STUDY APPROACHES**

The GIRAS dataset represents the land use/land cover of Saint Louis Bay Watershed in 1977. The NLCD dataset represents the land use/land cover of Saint Louis Bay Watershed in 1992. The difference of these two LULC datasets represents the change of land use/land cover in Saint Louis Bay Watershed. The GIRAS dataset and the NLCD dataset are assimilated into BASINS for hydrologic and water quality modeling respectively. The comparison of the simulated hydrologic flow and water quality parameters by using these two LULC datasets represents the effects of the land use/land cover change on the hydrologic flow and water quality of the watershed.

The Mississippi Coastal Watershed (containing the Saint Louis Bay Watershed) map is downloaded with the data downloading tools of BASINS and displayed in the geographic information system (GIS) platform of ArcView. The related terrain datasets, LULC datasets, streamflow monitoring stations, water quality monitoring stations, etc. are downloaded in BASINS with the data downloading tools. In the watershed modeling, terrain data, LULC data, weather data, streamflow data, water quality data, etc. are necessary inputs for BASINS. They come from multiple databases of sources. The terrain data are from DEM database of USGS. The LULC data are from GIRAS database and NLCD database of USGS. The weather data are from NCDC database of NOAA. The streamflow data are from the Surface Water database of USGS. The water
quality data are from STORET database of EPA and USGS. These geospatial datasets are also displayed with the GIS interface of ArcView.

The terrain dataset of National Elevation Dataset (NED) is a raster dataset which was assembled by the United States Geological Survey (USGS). It has 30 meter resolution, namely 1:24000-scale digital elevation. NED has a better resolution than DEM as it is developed by merging the highest resolution and the best quality elevation data into a seamless raster dataset across the United States (USGS 2005). The NED is applied to the delineation of the Jordan River Basin and the Wolf River Basin. The threshold used in delineation is based on the considering of basin size and subbasin amount. With the delineation results, BASINS calculates the relevant physiographic parameters such as mean elevation, area, slope, etc. Both of these two basins are delineated into multiple subbasins connected by the Jordan River and its contributors, and the Wolf River and its contributors. Outlets are added at the locations where BASINS generates automatically and where the selected streamflow and water quality stations are located. After the BASINS delineates the Saint Louis Bay Watershed based on the NED terrain dataset, the BASINS launches the channel network of the Jordan River Basin and the Wolf River Basin as Figs.2-3 show. The Jordan River Basin is composed of 11 sub-basins, while the Wolf River Basin is composed of 5 sub-basins. The sub-basins are considered homogeneous in LULC and are connected with the stream channels in these two basins.

These channel networks are used by the HSPF model for the simulations of hydrologic and water quality parameters including Streamflow, Water Temperature, Dissolved Oxygen, and Total Outflows of Sediments. Weather data such as rainfall, cloud cover, wind, air temperature, etc. are imported into WDM files as time series. WDMUtil, the meteorological data management component of BASINS, is used to edit, aggregate/disaggregate the meteorological data, and fill missing data. User defined weather data from other sources can also be imported into WDM files by WDMUtil. The streamflow is simulated by HSPF with the imported basin model and LULC datasets from BASINS after the delineation of basins and calculation of parameters are completed in BASINS. The measured data from the streamflow monitoring stations are used to calibrate the simulation of the streamflow. Subsequently, the water quality parameters are simulated with the HSPF model. GenScn is a component of BASINS which provides an interactive framework to generate and analyze the watershed modeling results and scenarios. GenScn is a graphical user interface (GUI) to create simulation scenarios, analyze modeling results and compare scenarios.

The important data resources used in this study are given as Fig.4 shows. Daily rainfall data are from the MS Saucier Experimental Forest Station (MS007840) dated from 01/01/1948 to 12/31/2004 (NOAA 2005). Hourly precipitation data recorded in Poplaville Experiment Station are used to disaggregate those of MS Saucier Experimental Forest Station (MS007840) (NOAA 2005). The meteorological parameters of hourly Potential Evapotranspiration, Air Temperature, Dew Point, Wind Speed, Solar Radiation, Evaporation, and Cloud Cover data are from the MS Saucier Experimental Forest Station (MS007840) (McAnally et al. 2006). Hydrologic flow in the Jordan River Basin is calibrated at USGS 02481570 Station. Water quality monitoring data in the Jordan River Basin are from USGS 02481660 Station. Hydrologic flow in the Wolf River Basin is calibrated at USGS 02481510 Station. Water quality monitoring data in the Wolf River Basin are from USGS 02481510 Station (McAnally et al. 2006).
RESULTS AND DISCUSSIONS

The model hydrology parameters are calibrated with the observations at USGS 02481570 Station and USGS 02481510 Station. Fig.5 shows the calibration process.

As showed in Figs.6-7, the statistical results for the calibration of daily hydrologic flows indicated the coefficient of determination (R2) is 0.653 for the Jordan River Basin and 0.685 for the Wolf River Basin by using HSPF model incorporating GIRAS dataset. As showed in Figs.8-9, the coefficient of determination (R2) is 0.635 for the Jordan River Basin and 0.686 for the Wolf River Basin by using HSPF model incorporating NLCD dataset. The values of coefficient of determination obtained in this study are in the same order of magnitude as those reported in the literature. For example, Engelmann et al. (2002) obtained a R2 of 0.74 for a three-year simulation period. Chew et al. (1991) obtained a R2 of 0.64 for a 50-month simulation period.
Fig. 9. Scatter plot of observed and simulated streamflow for the validation period at USGS 02481510 Station (08/01/1971-09/30/2003) in Wolf River Basin with NLCD LULC dataset.

The LULC classifications are grouped into six categories: Forest Land, Urban or Built-up Land, Agricultural Land, Barren Land, Water, and Wetlands. The difference between the LULC distributions in GIRAS and that in NLCD represents the LULC changes during 1977 to 1992. The LULC distributions in the Jordan River Basin and the Wolf River Basin are displayed in Table 1 and Table 2 respectively. For both these two basins, the area percentages of Forest Land and Urban or Built-up Land decrease. However, the area percentages of Wetlands and Barren Land increase.

There are many factors influencing soil erosion. They are soil physical characteristics (such as soil texture), climatic factors (including rainfall frequency, intensity, and amount), slope steepness, length, roughness, vegetation, etc. Among these factors, vegetation is the most significant factor influencing soil erosion. The vegetative LULC of the watershed can provide a good shield for soil from erosion. Furthermore, the vegetative LULC can help the soil to resist the washing of runoff by binding it together (Mays 2005). A good vegetative LULC will slow down the runoff to mitigate its washing to soil. When the vegetative LULC changes as a result of deforesting, construction, and other human activities, the soil erosion of this area will also have appropriate change.

The GIRAS and NLCD LULC datasets are successfully assimilated into BASINS/HSPF model respectively. These two LULC datasets represent the land use/land cover of the Saint Louis Bay Watershed in 1977 and 1992 respectively. As Tables 1-2 show, the LULC is typically classified into Forest Land, Agricultural Land, Urban or Built-up Land, Wetland, Water, and Barren Land. According to the definition of Barren Land in the HSPF model, this type of LULC classification includes Dry Salt Flats, Beaches, Sandy Areas Other than Beaches, Bare Exposed Rock, Strip Mines, Quarries, and Gravel Pits, Transitional Areas and Mixed Barren Land (Bicknell 2001). Apparently the vegetation is completely lost in Barren Land. Without the protection of vegetation, Barren Land is seriously threatened by erosion. Rate of Soil Erosion is a parameter which describes how much soil is eroded in a unit area during a period. Table 3 shows the recommended values for the Rate of Soil Erosion of different LULC classification from Grace (2004). The annual soil erosion is calculated with the values of Rate of Soil Erosion in Table 3 and the areas of different LULC classifications. Barren Land has a much higher value of Rate of Soil Erosion than all the other classifications. Thus, the change of Barren Land area percentage has significant effects on the soil erosion extent. The Rate of Soil Erosion becomes much greater in an area when it changes from other LULC classifications to Barren Land as a result of the loss of vegetation. The annual soil erosion by land use/land cover in the Jordan River Basin is as Table 4 shows. The annual soil erosion by land use/land cover in the Wolf River Basin is as Table 5 shows. With the changes of land use/land cover from 1977 to 1992, the soil erosion has a great increase in both Jordan River Basin and Wolf River Basin.
The HSPF model simulates the hydrologic and water quality parameters in these two basins. Table 6 shows the HSPF simulation results by using GIRAS and NLCD LULC datasets in the Jordan River Basin respectively. The simulation results of Streamflow, Water Temperature, and Dissolved Oxygen with these two LULC datasets are very close to each other. But the Total Outflows of Sediments increase as Barren Land has a great increase in area percentage.

Sediments are the soil particles which are transported by water flow to the receiving water body and are eventually deposited on the bed of the receiving water body as a layer of solid particles (Mays 2005). In this way, sediments are the direct results of soil erosion. The type and amount of LULC is the most significant factor influencing soil erosion. For example, the soil layer under a forest is protected by an organic layer and a little layer from erosion. When rainfall events occur to the forest area, the rainfall goes through the porous structure inside of the soil layer under the forest with highly permeable characteristics. Thus, the rainfall except the severe one will not cause overland flow which leads soil erosion. However, when the LULC is changed to Barren Land, the soil layer will lose the protection and become vulnerable to erosion. The Rate of Soil Erosion will have a great increase accordingly. The ground drainage pattern will change as a result of the LULC change. Overland flow will become the major pattern during the rainfall events. Soil particles are carried and transported by surface runoff to overland flows. A great amount of sediments will be brought to the receiving water body and the corresponding water quality parameters such as Total Outflows of Sediments will have a tremendous increase in scale, which indicates the deterioration of the water quality in the receiving water body. Thus, the increase of Total Outflows of Sediments in Table 6 is the result of the increase of Rate of Soil Erosion lead by the area increase of the Barren Land.

Since Table 7 shows, similar situation occurs in the simulations of the Wolf River Basin with GIRAS and NLCD LULC datasets respectively. For the Streamflow, Water Temperature, and Dissolved Oxygen, the simulation results with these two LULC datasets are similar to each other. But for the Total Outflows of Sediments, the simulation results increase as Barren Land has a great increase in area percentage.

Table 5. Annual Soil Erosion of different LULC classifications in Wolf River Basin

<table>
<thead>
<tr>
<th>LULC Classifications</th>
<th>Forest Land</th>
<th>Agricultural Land</th>
<th>Barren Land</th>
<th>Total Sediment Loss (ton/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Soil Erosion in 1997 (ton/year)</td>
<td>1544</td>
<td>55</td>
<td>23</td>
<td>1791</td>
</tr>
<tr>
<td>Annual Soil Erosion in 1997 (ton/year)</td>
<td>1790</td>
<td>30</td>
<td>13</td>
<td>2131</td>
</tr>
</tbody>
</table>

Table 6. Evaluation of HSPF simulations using GIRAS and NLCD LULC datasets respectively in Jordan River Basin

<table>
<thead>
<tr>
<th>Flow Parameter</th>
<th>GIRAS land use</th>
<th>NLCD land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow and Water Quality Parameters</td>
<td>Mean (m³/s)</td>
<td>Standard Deviation (m³/s)</td>
</tr>
<tr>
<td>Streamflow</td>
<td>8.73</td>
<td>8.47</td>
</tr>
<tr>
<td>Water Temperature (WT)</td>
<td>Mean (°C)</td>
<td>Standard Deviation(°C)</td>
</tr>
<tr>
<td>Temperature (WT)</td>
<td>17.08</td>
<td>13.01</td>
</tr>
<tr>
<td>Dissolved Oxygen (DO)</td>
<td>Mean (mg/l)</td>
<td>Standard Deviation (mg/l)</td>
</tr>
<tr>
<td>Dissolved Oxygen (DO)</td>
<td>9.20</td>
<td>9.24</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The two land use/land cover datasets, GIRAS and NLCD, are successfully assimilated into BASINS/HSPF model respectively for the hydrologic and water quality modeling of Saint Louis Bay Watershed. The GIRAS and NLCD datasets represent the land use/land cover of the Saint Louis Bay Watershed in 1977 and 1992 respectively. About 97% area of the Jordan River Basin is covered by Forest Land, Agricultural Land and Wetlands, more than 92% area of the Wolf River Basin is covered by Forest Land, Agricultural Land and Wetlands. With the NED terrain dataset, the Jordan River Basin is delineated into 11 sub-basins, while the Wolf River Basin is delineated into 5 sub-basins. During the HSPF model calibration, the coefficient of determination (R²) ranges from 0.63 to 0.69, which magnitude is in the same order as those in the existing reports.

The comparison of GIRAS and NLCD LULC datasets shows that the area percentage of Barren Land increases from 0.16 to 2.09 in the Jordan River Basin, and increases from 0.36 to 6.90 in the Wolf River Basin from 1977 to 1992. The vegetation on the ground of Barren Land is almost completely destroyed. The soil layer loses protection from vegetation and the Rate of Soil Erosion becomes much larger in the area changing from other LULC classifications with vegetation to Barren Land. As a result of the aggravation of soil erosion, the Total Outflows of Sediments has significant increase in the receiving water body and deteriorates the water quality. In the Jordan River Basin, the annual Total Outflows of Sediments increases from 3719 ton/year to 7828 ton/year. In the Wolf River Basin, the annual Total Outflows of Sediments increases from 3609 ton/year to 17900 ton/year. But Streamflow, Water Temperature and Dissolved Oxygen have insignificant changes.
ACKNOWLEDGEMENTS

The writers would like to acknowledge the constructive comments for the early version of the manuscript from Dr. Wenrui Huang at the Florida State University. Financial support is provided by the NASA-Stennis Space Center grant No. NCC13-99001.

REFERENCES


