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Simulation of Atrazine Discharge in the Auglaize Watershed Using Satellite-Generated Images

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Satellite-generated land scenes were used for simulating the discharge rate of atrazine in the Auglaize river watershed. The land images obtained by the satellites, Landsat 1 and Landsat 7, were digitized to be used as an input data for SWAT (Soil and Water Assessment Tool, version 2000) simulation. The digitalized regional data enabled SWAT to produce more reliable results, and the simulation results represented the actual data well. A few discrepancies between the simulation and actual data are thought to be reduced when the more rigorous regional and seasonal data are used. In this paper, the digitalization procedure of satellite scenes is introduced in detail.

The simulation has been performed as a part of a project that develops an integrated modeling system for watershed dynamics simulation. The watershed dynamics includes the movement of surface and ground water, contaminants, and biological and abiotic activities in soil and water. The modeling system will be used for analyzing and predicting the impact of land management practices in association with the fate of contaminants and the responses of the ecosystem. Our preliminary simulation results showed that the discharge rate of atrazine in various forms, such as dissolved, adsorbed, and vaporized, could be predicted within a reasonable error range. The atrazine amounts in these forms are critical in estimating and predicting the effects of atrazine on ecology and human health. In this paper, we focus on the discharge rate of atrazine into the Auglaize River which is a part of Maumee Watershed sub-basins.

Atrazine is one the most widely used herbicides in the Auglaize Watershed, Western Lake Erie and the Maumee Basin, OH, USA (NRDC 2003). With the implementation of no-till agriculture and conservation tillage practices in the United States, the use of herbicides to control weeds has increased dramatically and atrazine is commonly used with corn to control broadleaf weeds. Once applied, it breaks down in water and through bacterial activity. It is estimated that atrazine lasts approximately 60 days in topsoil, but it may persist longer in deeper soil layers Residues of this herbicide have been detected in surface and ground water supplies raising concerns about its safety. Recently, atrazine was listed as a potential disrupter of amphibian endocrine regulation at levels as low as 0.1 ppb (Hayes et al. 2002). Atrazine levels as high as several thousand ppb in water near

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agricultural areas are not uncommon, and may threaten the ecosystems and human health (Myers et al. 2000). Low concentrations of atrazine cause a variety of adverse effects in fish, hormone system disruption of amphibians, and genetic damage in a variety of plant species as well as a reduction in populations of aquatic plants and insects (EPA 2001a).

MATERIALS AND METHODS

The Auglaize River is one of the major rivers draining into the Maumee River. The Upper Auglaize River basin, shown in Figure 1, was selected as the study area that encompasses a major portion of the Auglaize River. The Upper Auglaize River basin area encompasses an area of over 770 square kilometers and includes nine different land use classes. About 65 % of the watershed area is occupied by cropland. A large amount of atrazine, sediments and nutrients are transferred from the cropland area into the Auglaize River, which eventually drains into the Maumee River. A United States Geologic Survey (USGS) monitoring station at Ft. Jennings lies near the Auglaize River Watershed outlet.

Two Landsat 1 scenes and two Landsat 7 scenes were obtained from the data archive at the University of Toledo Geography Department and from the USGS Earth Resources Observation Systems (EROS) Data Center. These scenes were used to cover the Upper Auglaize Watershed and the time period of the early 1970s and the late 1990s for model simulation.

Landsat 7 scenes are received in a format that is compatible with ERDAS IMAGINE™ (v. 8.7) and geo-rectified to the area covered. Landsat 1 scenes, however, come in a raw form and require an import of each band of the scene into ERDAS and subsequent stacking of the bands into a single image. This image can then be geo-rectified by corresponding it to a Landsat 7 scene of the same area. All scenes are then subset to a focus watershed area based on the Natural Resource Conservation Service (NRCS) watershed boundaries and an appropriate buffer.

A multi-temporal classification approach was chosen to help better delineate wet areas in the Upper Auglaize watershed. By incorporating a spring image and a summer image into the classification, accuracy of the definition of wet areas increased because of the difference in foliage and soil moisture in the two images.

A form of supervised classification known as the decision tree classification scheme was chosen for the summer images. The decision tree is a "classification procedure that recursively partitions a data set into smaller subdivisions on the basis of a set of tests defined at each branch (or node) in the tree" (Friedl and Brodley 1997). The main decision will be between urban and non-urban areas. If an urban area exists, it will be removed from the image and classified separately. After all urban areas are removed, the remaining image will be classified, and then all results will be combined into a single result. Urban areas were defined and hand-digitized with the polygon area of interest (AOI) tool in ERDAS

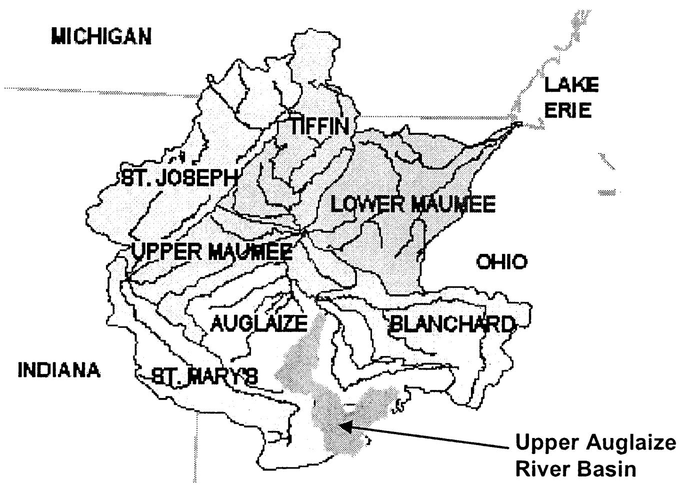


Figure 1. Location of the Upper Auglaize River basin within the Maumee River basin.

Imagine. Once digitized, the urban areas can be individually subset from the image. A total of seven urban areas were chosen and removed. Each then underwent an individual supervised classification with four classes: water, low density residential, commercial, and forest. A decision tree scheme for classification can result in a higher accuracy than other methods (Friedl and Brodley, 1997). The seven classified urban images were then combined with the mosaic function in ERDAS.

The image that remained after all urban areas were removed, the non-urban image, also had a supervised classification applied. Five classes were used including: forest, water, vegetated agricultural fields, non-vegetated agricultural fields and low density residential. The image was now ready to receive the urban areas, once again with the mosaic function in ERDAS, resulting in a single classified image.

The spring images were used for the classification of wet areas because the lack of foliage on trees created less interference for the spectral response of the underlying forest floor. Band 4, the infrared band, was used for the classification because it is the most sensitive to moisture (Jensen, 2000). Ohio Wetland Inventory Data from the Ohio Department of Natural Resources, in shapefile format, was used to overlay band 4 in ERDAS to help determine the location of wet areas to identify training sites for the classification. Once executed, a result containing two classes, wet and non-wet areas, was created.

It was then possible to isolate only the forests that were classified in the summer images by recoding all other classes to 0. The result was an image with two classes, forest and non-forest. This image could then be formed by intersectmosaics of the wet areas and non-wet areas images for an output of 3 classes. If an area was wet and fell within a forest the final class was forested wetland, wet areas in non-forested areas were non-forested wetland, forest and non-wet areas were still considered forest. The wetland classification image was now ready to be overlap-mosaicked with the original summer classification for a final classification including eight classes: water, forest, vegetated agricultural fields, non-vegetated agricultural fields, low density residential, commercial, forested wetlands, and non-forested wetlands.

The Landsat scenes were processed to generate individual USGS 30 m DEMs. Each DEM were put together to result in the Digital Elevation Model (DEM) shown in Figure 2. Figure 2 describes Maumee Watershed sub-basins. The DEM was analyzed to delineate the stream network. This area was set to 250 ha in order to obtain a detailed stream network as well as a large number of sub-basins (Figure 3).

Before incorporation with SWAT, the land use and soil classifications were added into the DEM (Figure 4(a)). Land use data themes for 1990s were obtained from the USGS Geographic Information Retrieval Analysis System (GIRAS) landuse/landcover databases. Finally, Hydrologic Response Units (HRU) were then obtained by specifying the threshold value of the land use and soil cover within each sub-basin (Figure 4(b)).

After determining the HRU distribution, the final form was used with SWAT input data such as weather, chemical, and initial loading data. The weather and chemical data were generated using the SWAT weather generator and a built-in U.S. weather database that came with SWAT package. The simulation was carried out for the period from January 1994 to December 1997.

RESULTS AND DISCUSSION

Daily rates of soluble and sorbed atrazine were obtained for the period of January 1994 through December 1997. The soluble atrazine rates were used for the discharge rate of atrazine to the Auglaize River. The daily discharge rates were averaged by month, and the average monthly discharge rates were compared with the actual data for 1997 in Figure 5. The actual data were measured at USGS station #4186500 in 1997, near Fort Jennings, Ohio (USGS 1998).

The simulation results matched with the measured data fairly well within an order of magnitude range. Most of all, the simulation result represented the pattern of monthly discharge rate of atrazine. The 2-3 orders of magnitude differences in January, February, March, April, and July are thought to be due to inaccurate weather data. In this simulation, the national average weather data were used instead of the local data. A further study is underway using the local weather data. However, it is thought that it will take considerable time to compile local data.

In addition to the weather data, it should be noted that a few input data such as initial loading of atrazine on the foliage and the initial amount of atrazine in soil,

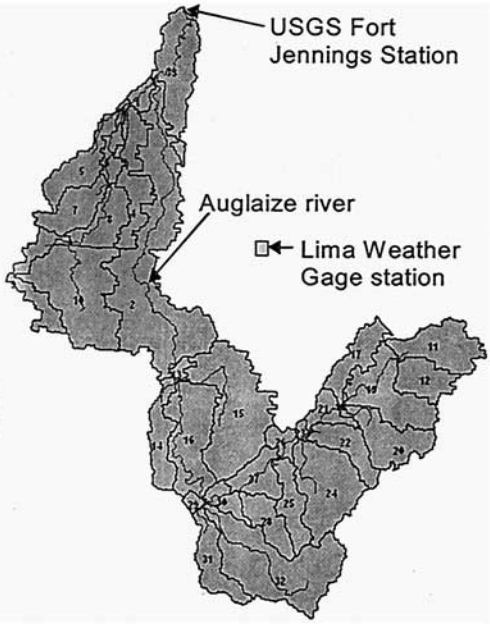
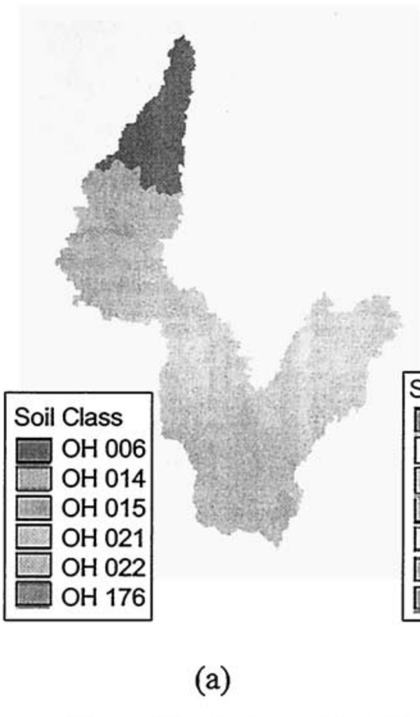


Figure 2. Digital Elevation Model (DEM) For the Upper Auglaize River basin.

Figure 3. Delineated sub-basin and Stream network from the DEM.



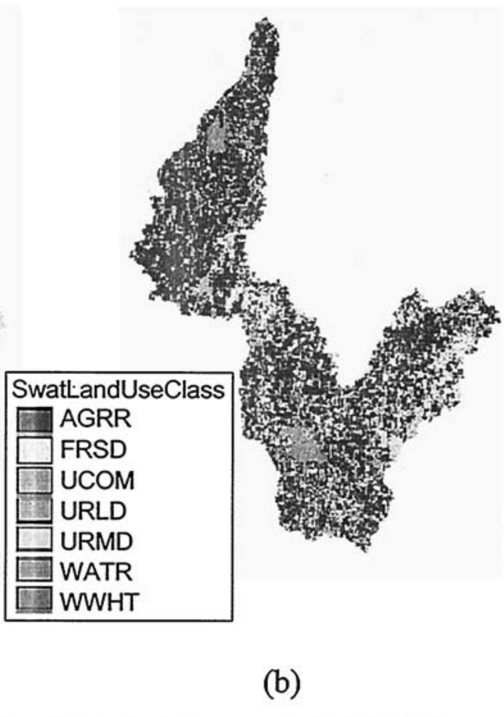


Figure 4. The land use/soil data (a) and Hydrologic Response Units (HRU) (b).

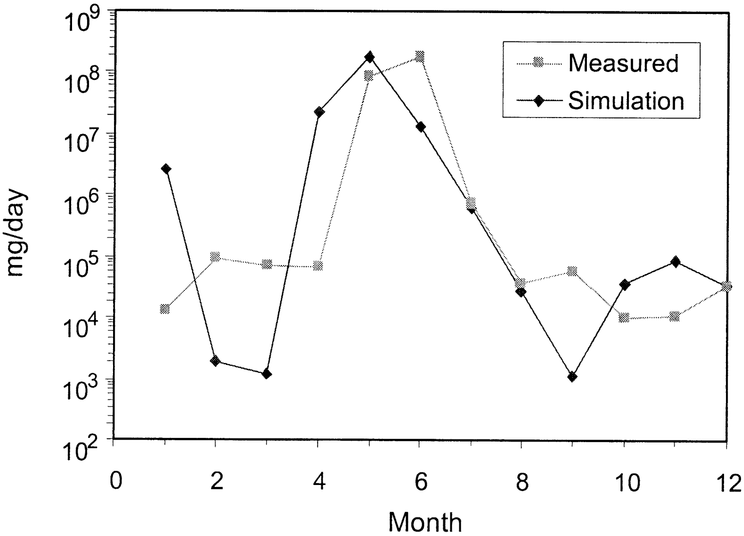


Figure 5. Monthly average discharge rate of dissolved atrazine at Ft. Jennings Station in 1997.

were roughly estimated due to a lack of reliable actual data. Since the pesticide application rates are unknown and variable between agricultural fields, it is difficult to predict the transport of atrazine through the watershed. The simulation may be more realistic when these data are available. In this study, the average atrazine application rate was obtained through back-calculations by initially assuming an atrazine application and then estimating the concentration that would enter the Auglaize River until it matches with the actual concentration in the River using EPA's PLOAD (U.S. EPA 2001b). The atrazine application rate was found to be 0.92 lbs/acre/year.

An annual mean concentration of atrazine, 2.4 µg/L, with a maximum concentration of 8.9 µg/L was reported (Myers et al. 2000), which exceeded the U.S. EPA aquatic-life guideline for atrazine of 1.8 µg/L. In this study, the use of satellite information in a SWAT simulation provided a reliable prediction of atrazine concentration in the Auglaize River, which indicates a potential use of satellite data for predicting, regulating and controlling atrazine in the watershed.

Consequently, the SWAT simulation using the Landsat image information and DEM clearly demonstrated that the pesticide transfer in the watershed could be properly simulated.

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REFERENCES

Friedl MA, Brodley CE (1997) Decision tree classification of land cover from remotely sensed data. Remote Sens Environ 61:399-409

Hayes TB, Collins A, Lee M, Mendoza M, Noriega N, Stuart AA, Vonk A (2002) Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses. Proc Nat Acad Sci 99 (8): 5476-5480

Jensen JR (2000) Remote Sensing of the Environment. Prentice-Hall Inc, New York

Myers D, Thomas M, Frey T, Rheaume S, Button D (2000) Water quality in Lake Erie and Lake Saint Clair drainages. U.S. Geological Survey Circular 1203:1-43

National Resources Defense Council (2003) Toxic herbicide atrazine contaminating water supplies, while EPA cuts special deal with manufacturer (http://www.nrdc.org/health/pesticides/natrazine.asp#)

U.S. Environmental Protection Agency (2001a) Atrazine: Toxicology Chapter of the Registration Eligibility Decision. (http://www.epa.gov/oppsrrd1/reregistration/atrazine/tox_chapter.pdf)

U.S. Environmental Protection Agency (2001b) PLOAD version 3.0 User Manual:1-48

U.S. Environmental Protection Agency (2002) User Guide for AMS/EPA Regulatory Model – AERMOD. Office of Air Quality Planning and Standards Emissions, Monitoring and Analysis Division: 1-228

USGS (1998) Water Resources Data - Ohio, Water Year 97, Vol. 2 (http://oh.water.usgs.gov/AR/sw97/04186500.html)