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Modelling animal waste pathogen transport from agricultural land to streams

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Abstract. The transport of animal waste pathogens from crop land to streams can potentially elevate pathogen levels in stream water. Applying animal manure into crop land as fertilizers is a common practice in developing as well as in developed countries. Manure application into the crop land, however, can cause potential human health. To control pathogen levels in ambient water bodies such as streams, improving our understanding of pathogen transport at farm scale as well as at watershed scale is required. To understand the impacts of crop land receiving animal waste as fertilizers on stream's pathogen levels, here we investigate pathogen indicator transport at watershed scale. We exploited watershed scale hydrological model to estimate the transport of pathogens from the crop land to streams. Pathogen indicator levels (i.e., *E. coli* levels) in the stream water were predicted. With certain assumptions, model results are reasonable. This study can be used as guidelines for developing the models for calculating the impacts of crop land's animal manure on stream water.

1. Introduction

Bacterial pollution in stream water is a major concern [1]. For example, more than 50% of the assessed streams and rivers in the U.S. are impaired, and elevated pathogen/pathogen indicator levels are the leading cause of impairment [1]. The major sources of bacteria pollution in streams are agricultural activities. Agricultural non-point source pollution, particularly, animal waste in cropping land has a potential to elevate pathogen levels in stream water [2]. Excessive amount of manure produced in confined feeding operations (CAFOs) can potentially contaminate surface and ground water. As an example, more than 238,000 CAFOs in the U.S. produces more than 317 million gallons manure annually, managing such a huge quantity of manure can be a daunting task. Events such as rainfall after manure application in cropping land produces runoff, which can transport a large number of pathogens from farms to streams. In addition, events such as accidental spill from CAFOs can transport a large number of pathogens from CAFOs locations to streams [3, 4, 5, 6].

Mitigating the hazardous impacts of animal manure on environment is a serious issue. In addition to agricultural activities, the landscape characteristics of the watershed, soil, geology, land cover, and hydrology also play crucial roles in influencing stream water quality [7]. Predicting stream water quality requires understanding the various level of complexities and uncertainties involved in the watershed. One approach can be exploiting the hydrological models and Geographical Information



System (GIS) based dataset to understand the impacts of watershed characteristics (i.e., land cover, CAFOs, grazing, and feedlots) on the stream water quality. The GIS based data can provide the locational information about CAFOs, manure production, manure application rate, open feed lots, cropping land, and the land receiving animal manure; hydrological model can be used to understand the transport of pathogens from the watersheds via runoff to streams. The goal of this study is to utilize modelling approaches to understand the potential impacts of the watershed's animal waste on stream water quality.

There are many water quality models, which can be utilized for predicting stream water quality such as Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), ArcView Generalized Watershed Loading Function (AVGWLF), Soil Water Assessment Tool (SWAT), and Watershed Analysis Risk Management Framework (WARMF). The models use watershed characteristics such as soil, land cover, elevation, and hydrology for predicting water quality. The BASINS was developed by the U. S. EPA to develop the Total Maximum Daily Load (TMDL) program, where the TMDL (mass per unit time) is the sum of the individual waste load allocations for non-point sources and natural background, load allocations for point sources, and a margin of safety. The AVGWLF was developed by Pennsylvania State University's Environmental Resources Research Institute for watershed assessment and TMDL development. The SWAT model, which was developed by Texas A & M University, Black Land Research center, is a river basin scale model, which quantifies the influence of land management practices on large watershed and assesses the point and non-point pollution loading. These watershed scale models have been used extensively for estimating stream water quality such as the nutrient concentrations in stream water. Recently multiple studies have exploited the SWAT model for predicting stream water bacteria levels [8, 9, 10]. Considerable progresses are reported in improving stream water bacteria predictions utilizing the SWAT model. The objective of this paper is to describe briefly input data, model, processes, simulation approaches required for implementing the SWAT model and predicting stream bacteria levels. The details of the study are available elsewhere [10].

2. Study area descriptions

The work was conducted in the Squaw Creek Watershed, Iowa, USA. The study area and DEM are shown in Figure 1(top). Squaw Creek passes through four counties (Story, Webster, Hamilton, and Boone Counties), and it is a tributary of the South Skunk River. The total drainage area of the Squaw Creek watershed (Hydrological Unit Code (HUC 10)) is 592.39 sq km. The basin length and perimeter of HUC 10 watershed is 43.53 km and 134.02 km, respectively. The average slope of the watershed is 2.01% with the basin relief of 111.51 m. While main channel length is 60.46 km, total streams length within watershed are 346.72 km. The 2002 HUC 10 watershed land use estimates 0.09, 0.17 and 0.05% of watershed as water, wetland and wetland forest, respectively. Deciduous forest, ungrazed grass, grazed grass, CRP grassland, and alfalfa are 2.71, 10.87, 2.52, 1.7, and 1.84%, respectively. Corn and soybeans, and other row crops are 41.16, 32.95, and 0.43%, respectively. Common/industrial, residential, and barren land are 1.67, 1.27, and 0.06%, respectively. Land cover map is shown in Figure 1(bottom). The study area has average annual rainfall of 804 mm (arithmetic mean of 2007, 2008, 2009, and 2010 years). The watershed data were obtained from Natural Resources Geographic Information System (NRGIS) library. The library is maintained by GIS section of the Iowa Department of Natural Resources (IDNR). Data of stream flow were obtained from the U.S. Geological Survey gaging station 05470500 (Lat 42°01'23", long 93°37'49") on Squaw Creek in Ames. The air temperature and precipitation data of Ames (Lat 42° 01'48", long 93° 04'48") were obtained from Iowa Environmental Mesonet (IEM), Agronomy Department, Iowa State University, USA. To quantify the manure applied in the watershed, we used manure application map 2006, which was prepared by the Iowa Department of Natural Resources (DNR) that describes the area which potentially receives the manure. The map uses the CAFO locations, manure production, and manure application rates to calculate the land area receiving animal manure as fertilizers.

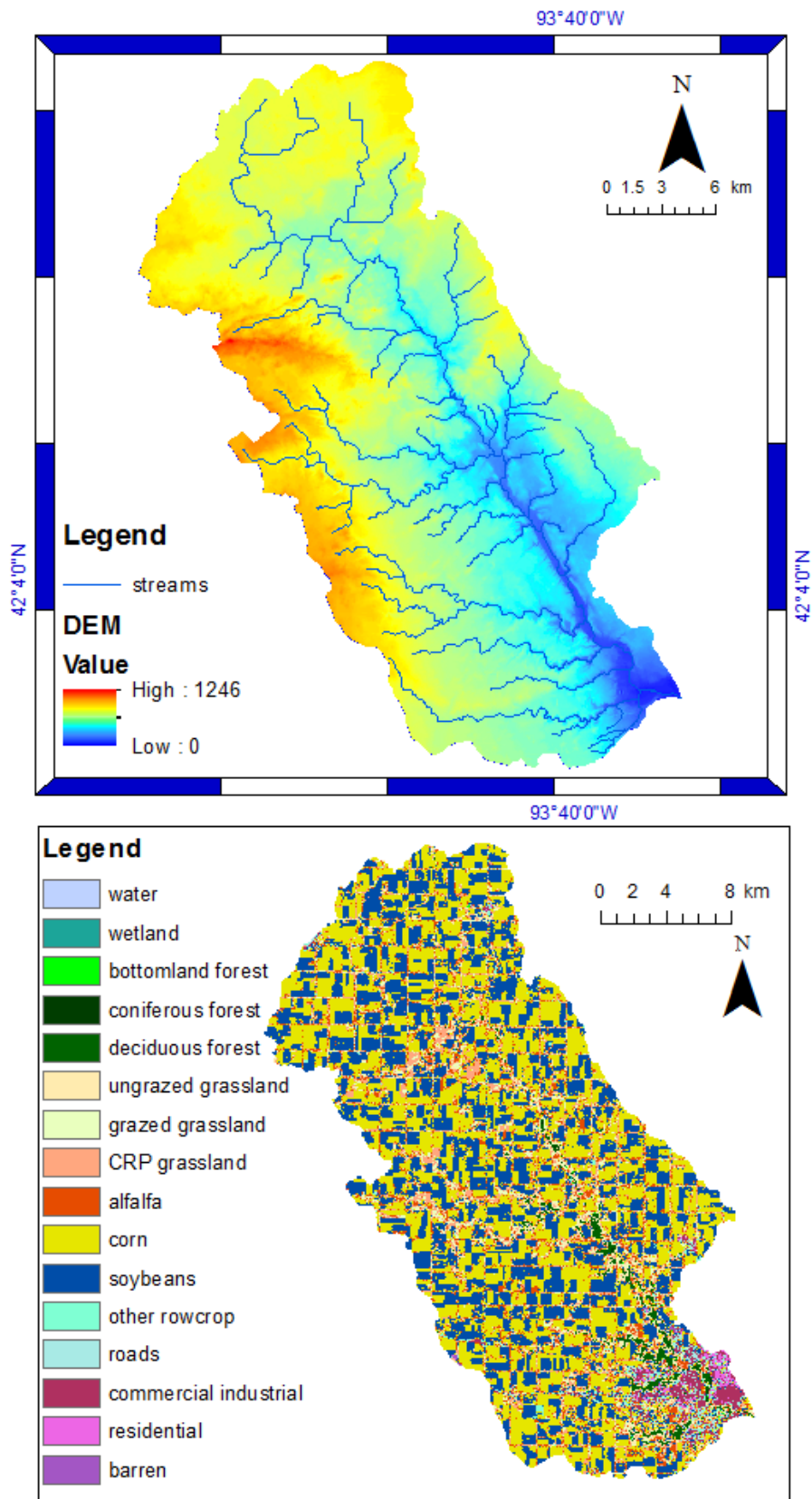


Figure 1. Study area maps: DEM and streams (top) and land cover (bottom)

3. Methods

The SWAT model, which was used in this study, requires input parameters such as land cover area, soil type, rainfall, temperature, slopes, and streams of the watershed. Using the watershed characteristics and hydrology, the model predicts stream flow. The SWAT (a river basin/watershed scale hydrological model), developed and supported by United State Department of Agriculture (USDA) Agricultural Research Service, is available freely at <http://swat.tamu.edu/>. The model has been extensively used in predicting daily/monthly stream flow and water quality (i.e., nutrients, pesticides, sediment) around the world [11]. Numerous studies have exploited the SWAT model for understanding the impacts of land use management practices on water quantity as well as water quality [11, 12, 13].

The SWAT model divides a watershed into multiple sub-basins. These sub-basins are called hydrological response units (HRU). The HRU includes the homogenous land use and management, soil types, and slopes. The implementation of the SWAT model for predicting stream flow and nutrients is described extensively [12, 13, 14]. Implementation and application of SWAT model for predicting the bacteria concentrations is described elsewhere [8, 9, 15]. The input parameters such as manure application rate, crop land receiving manure, crop rotation, land cover, erosion rate, and particle attached and non- particle attached bacteria are used in the SWAT to estimate bacteria loading into the streams. The SWAT model estimates overland bacteria transport from the crop land to streams. While predicting overland bacteria transport, the model involves simulating bacteria in surface runoff, bacteria attached to sediment in surface runoff, and bacteria lag in surface runoff. The details of the overland bacteria transports processes and related parameters are described elsewhere [8, 9, 10, 14, 15]. In this study we used the modified SWAT model, which is reported elsewhere in details [10] (<http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=3862&context=etd>).

4. Results and Discussion

Figure 2 shows measured and predicted stream flow. Results show that the predictions of daily stream flow by the model are well matched with the daily stream flow observations at gaging station. Stream

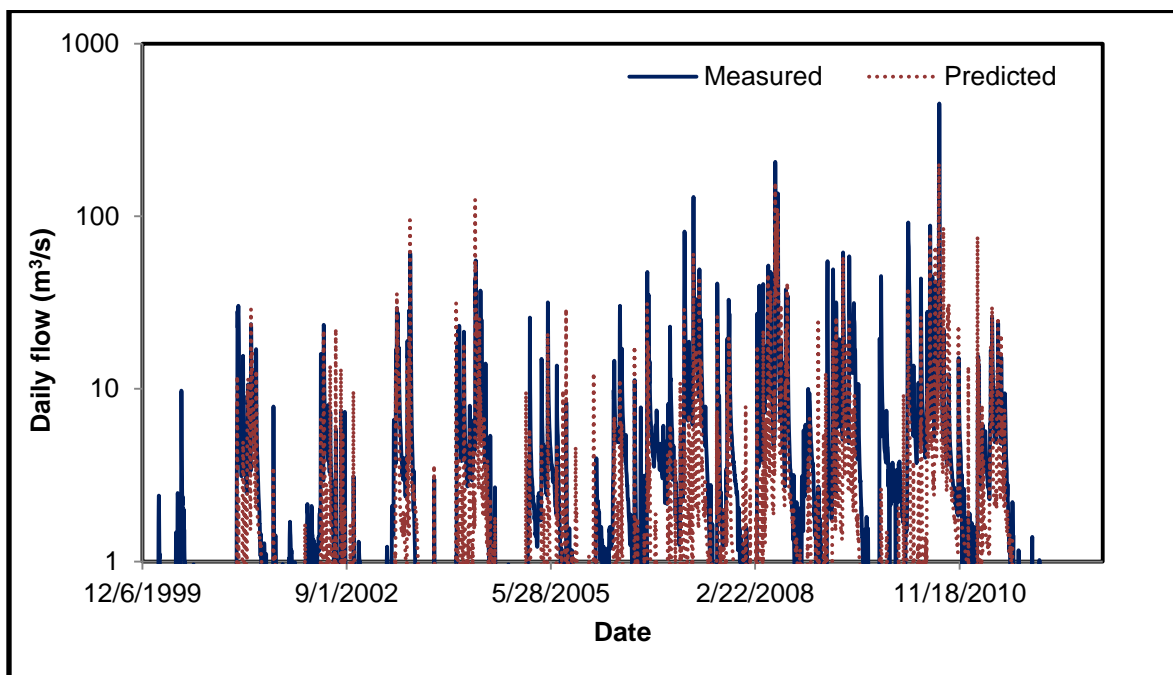


Figure 2. Observed and predicted daily stream flow

flow was simulated from 2000 to 2011, and observed stream flow data (shown in Figure 2) were obtained from USGS gaging stations. The coefficient of determination (r^2) and Nash-Sutcliffe's efficiency coefficient (NSE) values were estimated to verify the model predictions. The r^2 and NSE values between predicted and measured daily stream flow were $r^2 = 0.42$ and $NSE = 0.39$. The correlation coefficient (r) between predicted and measured daily flow was 0.65. While r^2 and NSE values for daily flows were lower, for average monthly daily flow these values were considerably higher [10]. The model was also used to predict bacteria concentrations (*E. coli* levels) in streams, which is shown in Figure 3. As shown in the figure, increase and decrease in bacteria concentrations followed the stream flow. These results are similar to findings by previous studies, which have shown that bacteria concentrations in the stream increases with elevated stream flow [10, 8, 9]. To verify the model predictions, we compared predicted *E. coli* levels with the measured *E. coli* levels in stream water. Comparison between measured and predicted data indicated that approximately 82% of the predictions were within one order of magnitude of the observed values [10]. These results are satisfactory considering the uncertainties and complexities involved in predicting stream bacteria levels at the watershed scale. While this study summarizes a tool and method describing general guidelines, published studies, application methods, and study and data sources to implement the SWAT model for predicting stream bacteria levels, we recommend readers studying SWAT model manual and relevant papers. Further studies understanding how the manure application rates in the watershed, variation in rainfall, and temperature can potentially impact in-stream bacteria concentrations are required for identifying the efficient manure management practices, which can support in mitigating bacteria concentrations in the streams.

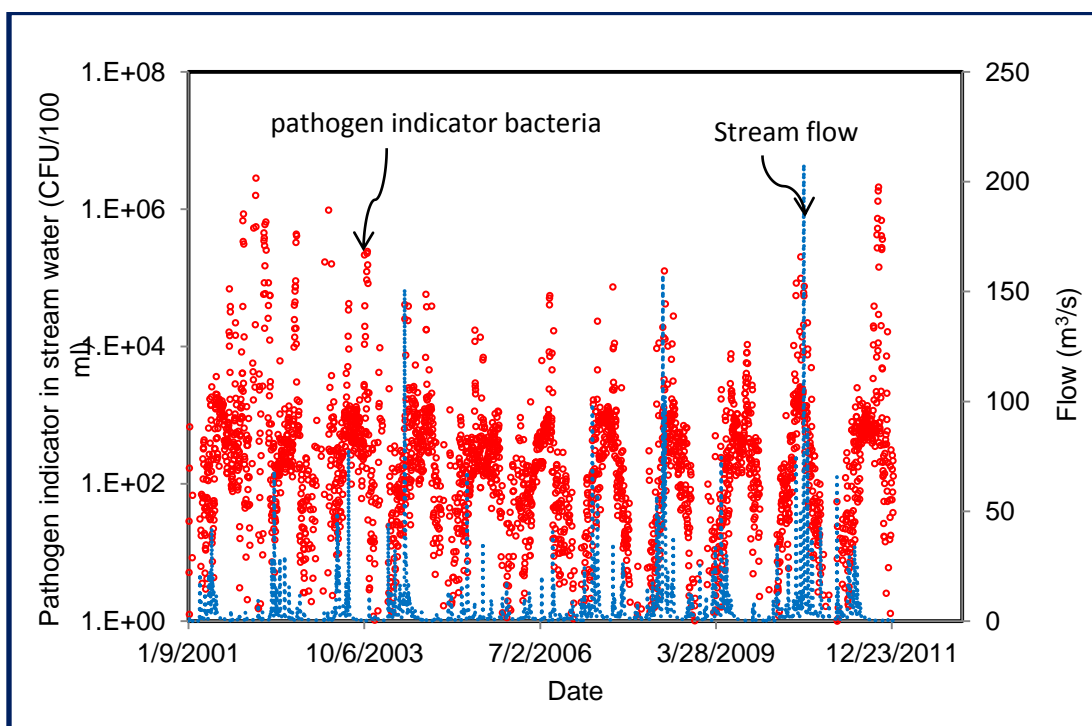


Figure 3. Predicted pathogen indicator bacteria and stream flow.

5. Conclusions

Here we have described briefly the hydrological modelling approach to simulate animal manure bacteria transport from cropping land receiving manure as fertilizers to stream water. The SWAT

model, input data, methods, published studies on model application, and simulation processes are summarized; however, to implement the model additional studies will be required, which are recommended in this paper. We suggest readers to review SWAT manual and input and output documentation, which is available freely, prior to exploiting the model. While here we have presented the results of stream flow and bacteria predictions of a single watershed, readers are encouraged to review multiple studies which are already published, describing the SWAT model applications at watershed scale, for predicting bacteria levels as well as nutrient concentrations in streams.

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