The Use of Spatial Data in Creating a Riparian Buffer Suitability Model: Whitewater River Watershed, Minnesota

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Abstract

An analysis of the Whitewater River Watershed in Southeastern Minnesota was performed to determine suitable locations for riparian habitat buffers. A model was created to determine subwatersheds most suitable for potential riparian habitat buffer sites. Three factors were used in determining the subwatershed ranking system for the potential buffer sites. The three factors used in creating the model were proximity of row crops to streams and rivers, subwatershed slope, and proximity of feedlots to rivers and streams of the Whitewater River Watershed. Much of the analysis for this project was done to determine a subwatershed ranking system that ranks the need for riparian buffers on a subwatershed level. Landuse/Landcover data was obtained from GAP Analysis data obtained from the United States Geological Survey (USGS). Gap Analysis data were obtained from Landsat images classified at 30-meter resolution. The subwatersheds that ranked highest in the need for riparian habitat buffers were primarily located in the heavily used agricultural areas located near the headwaters of the watershed. Intensive agriculture practices were the major factor in the riparian buffer model determining that the highest potential for riparian buffers is near the headwaters of the watershed.

Introduction

Riparian stream buffers are small areas or strips of land in permanent vegetation, designed to intercept pollutants and manage other environmental concerns along stream ecosystems (NRCS, 2001). Riparian stream buffers, also to be referred to as buffers, serve a wide variety of purposes. Riparian stream buffers serve to reduce excess amounts of sediments, nutrients, organic material, pesticides and other pollutants carried by surface runoff. Riparian stream buffers also moderate stream water temperature and decrease impacts to riparian areas including stream channels and adjacent lands caused by high and low water flows (Twin Platte Natural Resource District, 2000). Properly installed buffers have the capacity to remove 50 percent of nutrients and pesticides, 60 percent of certain pathogens, and 75 percent of sediment. Buffers also have a beneficial impact on wildlife. They provide food, nesting cover, and shelter for many wildlife species. Riparian buffers also serve as important connecting corridors that allow for wildlife to move safely from one habitat to another (NRCS, 2001).

The whitewater watershed (Figure 1) is located in Southeastern Minnesota in what is classified as the driftless area. The

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driftless area was barely touched by the last glacial movement, which caused the unique and diversified landscape of the Whitewater River Watershed. The watersheds diverse array of landscape types are dominated by the hilly bluff lands of the Mississippi River basin and the relatively flat areas of the upland landscape.

Figure 1. The whitewater watershed is located in Southeastern Minnesota and contains parts of Wabasha, Winona, and Olmsted counties.

The Whitewater River consists of three branches that converge into the main branch of the Whitewater River. The three branches of the Whitewater River are simply called the North, Middle, and South Branches. The main branch of the Whitewater River drains into the Weaver Bottoms of the Mississippi River. The watershed is located in what is a predominantly rural landscape in an area that is not heavily populated by people. The towns of the Whitewater River Watershed include St. Charles, Utica, Plainfield, Elba, Dover, Eyota, and Altura (Figure 2).

Figure 2. The Whitewater River Watershed drains into the Weaver Bottoms of the Mississippi River and is located in a predominantly rural area.

The watershed is best known for the cold-water streams that are home to abundant populations of naturally reproducing Brown Trout (*Salmo trutta*) and Brook Trout (*Salvelinus fontinalis*). Much of the conservation practices that take place within the watershed are in attempt to protect the cold-water streams and trout populations of the Whitewater River Watershed. Without doubt, it is important to spend time and money protecting and enhancing the rivers and streams in the watershed that contain healthy trout populations. However, this project will try to prove that it may be more beneficial in the long run to concentrate on the headwaters of the watershed instead of concentrating money and other resources on specific restoration sites within the classic trout waters. The reason it is important to concentrate on the headwaters of the watershed is because this is the area where much of the intensive row cropping is taking place. Traditional row crops such as corn and soybeans increase the probability that runoff will enter the streams. Traditional row crops leave much of the soil uncovered for much of the year and allow for the water to form runoff channels during heavy rain events that carries pesticides, sediments, and other pollutants into the streams.

Agriculture runoff is responsible for 64% of the total non-point source pollution for all non-federal rivers and streams in the United States (Doopelt, et. al., 1993). Protecting water quality in the headwaters of the watershed will help solve many of the problems facing the watershed at its source. Instead of concentrating on projects that improve stream habitat in the areas containing classic trout waters, attention should be directed to the headwaters where the problem starts so that stream habitat restoration in the classic trout waters doesn't need to be done in the first place.

The protection of headwaters through riparian stream buffering will improve water quality throughout the entire watershed. The small streams of the headwaters are most vulnerable to human disturbance because they respond dramatically and rapidly to disturbances in riparian areas and are also most sensitive to changes in riparian vegetation in the surrounding watershed. Even though there aren't any fish in the much of these headwaters, these small streams provide high levels of water quality and quantity, sediment control, nutrients and woody debris for downstream reaches of the watershed. Thus, headwater streams serve as critical ecological anchors for riverine systems and important refuges for biodiversity (Doopelt, et al., 1993).

Subwatershed Priority Rankings

The subwatersheds of the Whitewater River Watershed have been given a priority ranking for restoration efforts by the Natural Resource Conservation Service (NRCS) in Lewiston, Minnesota. There were many different subjective and objective factors that went into giving the subwatershed priority rankings. Each subwatershed of the Whitewater River Watershed was placed into one of four categories based on its restoration potential. The four categories developed by the NRCS according to restoration potential are; high, moderately high, moderate, and low restoration potential (Figure 3).

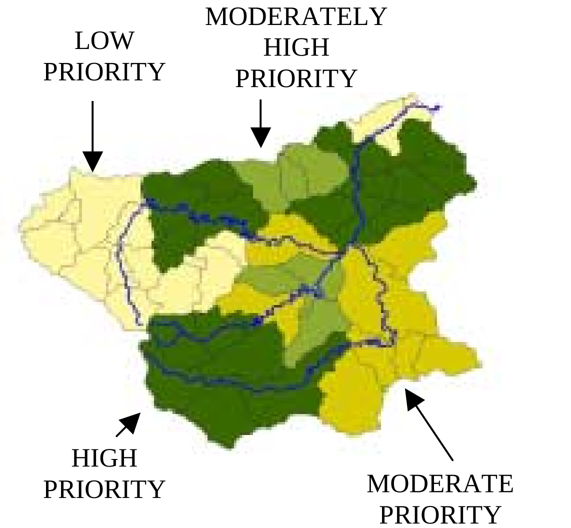

Figure 3. NRCS subwatershed ranking system based on its guidelines for restoration potential.

Primarily, the subwatershed ranking system employed by the NRCS consisted of designating subwatersheds rankings by matching the subwatersheds trout population with the information obtained from an Agriculture Nonpoint Source Pollution Model (AGNPS). AGNPS was developed by the U.S. Department of Agriculture and is used to simulate sediment and nutrients loads from agricultural watersheds for a single storm event or for continuous simulation (National Research Council, 1999). However, there are a few problems with the use of AGNPS as a source of deciding the total potential for agricultural runoff. The AGNPS model does not simulate pesticide runoff (Young, 1989). Also, the AGNPS model doesn't account for point sources such as feedlots. Another factor that was used in determining this subwatershed ranking system was to examine the groundwater influx in each of the subwatersheds.

New Subwatershed Ranking System

It is the author's belief that the subwatershed potential restoration ranking system currently being used doesn't pay close enough attention to the agricultural lands close to the headwaters of the watershed. A new subwatershed ranking system was developed using Geographic Information Systems (GIS) to determine where excess nutrients and sediment are entering the rivers and streams of the Whitewater River Watershed.

Methods

The GIS software used for this project was ESRI's ArcView 3.2a™. The Spatial Analyst™ extension was needed to view all the GAP data and to work with the USGS Digital Elevation Models (DEMs). The Grid Analyst extension was used to clip all of the GAP Analysis and DEM data. The Grid Analyst extension is available as a free download from ESRI.com. Dr. Arun K. Saraf of the University of Roorkee, INDIA, developed the Grid Analyst extension. The X-Tools extension was used to determine area for many different shapefiles used throughout the project. The X-Tools extension was downloaded from the Minnesota Data Deli.

GAP Analysis Data

One of the most important factors in this study was to obtain accurate and detailed landuse/landcover data. The most accurate and detailed landuse/landcover data available for the study area was GAP Analysis (GAP) data obtained from the USGS in Onalaska, Wisconsin.

The purpose of GAP is to identify "gaps" in the network of conservation lands with respect to land cover or habitat types as well as individual species, and to build partnerships around the development and application of this information (Jennings, 1995). The hope for GAP is to provide focus and direction for proactive land management activities at the local, watershed, and basin-wide landscape levels (Fitzpatrick, 1999).

GAP data is extracted from Thematic Mapper (TM) satellite images at a ground resolution of 30 m. The TM images use three band-to-color assignments in a false color composite. The colors of the bands are:
TM Band 4 (Near-infrared) – Red
TM Band 5 (Mid-infrared) – Green
TM Band 3 (Visible Red) – Blue

The original GAP data that I received from the USGS was classified into 184 different classes assigned by perceived dominant landuse/landcover characteristics in the 30 m cell. The 184 classes assigned by the USGS was more detailed than what was needed for the project so the data was reclassified into six new classes. The GAP data was re-classified into these six classes:
1. Row Crops
2. Forest
3. Grassland
4. Urban
5. Transportation
6. Open Water.

Determining Amounts of Row Crops Adjacent to Riparian Areas

The only area of the watershed that was of interest to the project as far as creating riparian habitat buffers were those areas within 50-meters of a river or stream. A buffer distance of 50 meters was set because it was theorized that 50 meters is probably the largest distance that farmers could get incentive money to create riparian habitat buffers.

Buffering the streams coverage in ArcView to 50 m created the areas that would be used for the potential riparian habitat buffers. The streams coverage was obtained from the Whitewater Watershed Data CD available from the NRCS in Lewiston, MN. The streams coverage was composed of many interconnected arcs, which created the problem of having the buffers overlap each other when the streams were buffered. To solve this problem, the buffered stream coverage was dissolved so that there was not any overlapping buffer areas. This was important because it allowed for accurate measurements of buffer area to be calculated within the 50-meter buffer distance.

The next step in the project was to clip the GAP data to the 50-meter stream buffers. Since the GAP data is in GRID format, the Grid Analyst extension was used to clip the GAP data. The clipped grid was then converted to a shapefile so that the X-Tools extension could be used to determine total buffer area.

The next thing that had to be done to the potential riparian stream buffers was to dissolve the potential stream buffer coverage based on class name so that it was possible to query polygons based on total area. After the individual cells were dissolved, it was possible to query the buffers to search for areas greater than a specified amount. For this project, areas of row crops within the potential buffer sites over 15 acres were queried. The area of 15 acres was an subjective selection based on areas within the potential buffer sites that would be targeted for improvements first. Hopefully, by determining areas with greater than 15 acres of continuous row crops within the potential buffer sites the project would be able to determine the areas where most of the sediments and pollutants are entering the rivers and streams of the Whitewater River Watershed (Figure 4).

Figure 4. The potential stream buffers were queried to determine areas where there was continuous areas of row crops over 15 acres within the riparian stream buffers.

The total area for each of the six classifications (row crops, forest, grassland, transportation, open water, and urban) was totaled for each subwatershed. The total area of row crops within the potential buffer areas was then divided by the total area of all the six classes to determine the percentage of potential buffer sites that are row crops within each subwatershed.

Creating a New Subwatershed Ranking System

Determining a Ranking System for Row Crops

After the percentage of row crops within the potential buffer areas was calculated, a new subwatershed restoration priority ranking was created. The subwatersheds were given one of four classifications: high, moderately high, moderate, or low potential restoration.

The method used for assigning each subwatershed a ranking was pretty straightforward. If the subwatershed had greater than 65% of its potential buffer areas in row crops then it was given a restoration ranking of high. If the subwatershed had

45% - 65% of its potential buffer sites in row crops it was given a restoration potential of moderately high. If the subwatershed had 25% - 45% of its potential buffer sites in row crops it was given a restoration potential of moderate. Finally, if a subwatershed had less than 25% of its potential buffer sites in row crops it was given a low restoration potential.

Determining a Ranking System for Proximity of Feedlots to Streams

The Whitewater Watershed Data Disc from the NRCS had data for the locations of feedlots within the watershed. The data for feedlots within the Whitewater River Watershed contained exact locations of feedlots obtained with the use of a Global Positioning System (GPS). The feedlot points were buffered to 230 meters to simulate the area that would be immediately susceptible to waste runoff. The buffered feedlots were then clipped to the 50 m potential buffers sites to simulate areas around streams that would be immediately susceptible to waste runoff. Ranking each subwatershed based on feedlot proximity to riparian areas was done by totaling the area of buffered feedlots that fall within the potential buffer sites for each subwatershed.

Determining a Ranking System for Subwatershed Slope

Determining slope for the entire watershed was important to determine the direction that non-point source pollutants are flowing when they run off the land and into the rivers and streams of the Whitewater River Watershed. Slope was determined by first obtaining the Digital Elevation Models (DEMs) from the Minnesota Data Deli. Since the DEMs have a ground resolution of only 30-meters, it is not realistic to think that slope inside the potential buffer sites are accurate enough to determine exact locations where nutrients and sediments are entering the rivers and streams of the watershed. However, when the DEMs are used to determine slope over a large distance they can be extremely useful. Slope for the watershed was determined by using the Spatial Analyst extension in ArcView to convert the grid of elevation values to a slope grid that shows slope for the entire watershed.

It was also important to determine slope with reference to each subwatershed for the role that slope plays on a smaller scale. The Creation of 300-meter buffers around all rivers and streams within the Whitewater River Watershed were created to help determine the role slope plays on a smaller scale. The 300-meter stream buffers were then clipped to the entire elevation model for the watershed so that only slope values within the 300-meter buffer would be used in the slope analysis.

In order to determine the affect that slope plays at a subwatershed level, the 300-meter stream buffers that contained slope values were clipped to each subwatershed. Next, the statistics button in the legend editor of ArcView was used to determine the mean slope value within 300 meters of all rivers and streams for each subwatershed. The mean slope value for each subwatershed was ranked and classified as having high, moderately high, moderate, or low restoration potential.

Determining Overall Restoration Potential for each Subwatershed

There were three factors that went into determining restoration potential for each subwatershed. The three factors that were used are as follows: (1) the percentage of row crops within the 50 meter stream buffer, (2) the mean slope value within 300 meters of all streams and rivers within the subwatershed, and (3) by the total area of buffered feedlots that are within the 50 meter stream buffers.

Each of the three factors was categorized into one of four criteria. The four ranking criteria given to each subwatershed for all three factors were low, moderate, moderately high, and high. The four ranking criteria of low, moderate, moderately high, and high correlate to the values of 1, 2, 3, and 4. For example, if subwatershed 11 is given a ranking criteria of high for amount of row crops within its 50-meter stream buffer it would be given a value of 4 for that factor.

Each factor was weighted according to its significance by the author in promoting non-point source pollution into the rivers and streams of the Whitewater River Watershed. All of the weighted factors used in determining restoration potential were assigned based on their perceived impact on increasing non-point source pollution. Proximity of row crops to the rivers and streams was seen as having the greatest potential for producing non-point source pollution. The proximity of row crops to the rivers and streams was given a weighted factor of .65. The mean slope value of the each subwatershed within 300 meters of each river and stream was determined to have the second greatest potential for producing non-point source pollution. The mean slope value of each subwatershed within 300-meters of each river and stream was given a weighted value of .25. The last factor in determining non-point source pollution is proximity of feedlots to riparian areas. The total acreage of feedlots within the 50-meter stream buffers was given a weighted value of .10.

RESTORATION POTENTIAL = (x * 0.65) + (y * 0.25) + (z * 0.10)

Results

The new subwatershed ranking system analyzed the percent of row crops within the potential buffer zone, mean slope value for each subwatershed within 300 meters of riparian areas, and total area of feedlots within the 50-meter buffer zone.

Row Crop Results

Each of the subwatersheds was ranked according to amount of row crops within a 50-foot buffer around all riparian areas (Figure 5).

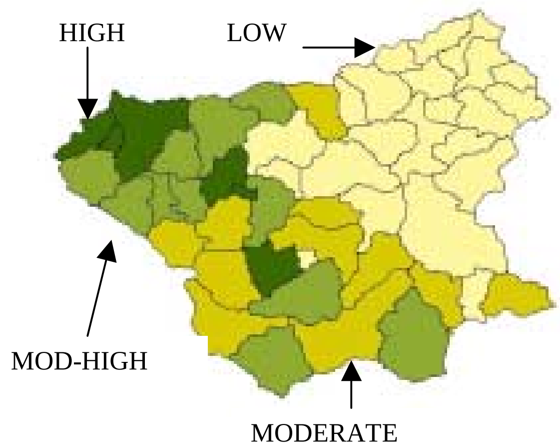

Figure 5. All subwatersheds were ranked based on percentage of row crops within a 50-meter buffer.

Subwatershed Slope Results

All of the subwatersheds were ranked based on the mean slope value of each subwatershed for areas within 300 meters of riparian areas (Figure 6).

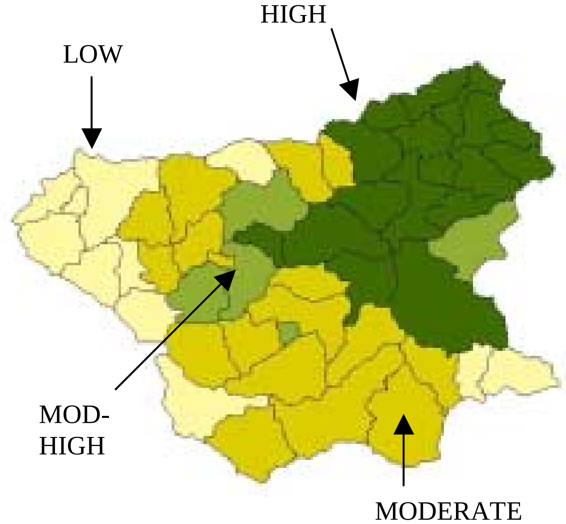

Figure 6. All subwatersheds were ranked from low to high based on the subwatersheds slope.

Feedlot Results

Every major feedlot in the watershed was analyzed to determine its potential for waste runoff into the rivers and streams of the watershed. Each subwatershed was ranked based on the acreage of the buffered feedlot that falls within the 50-meter stream buffer (figure 7).

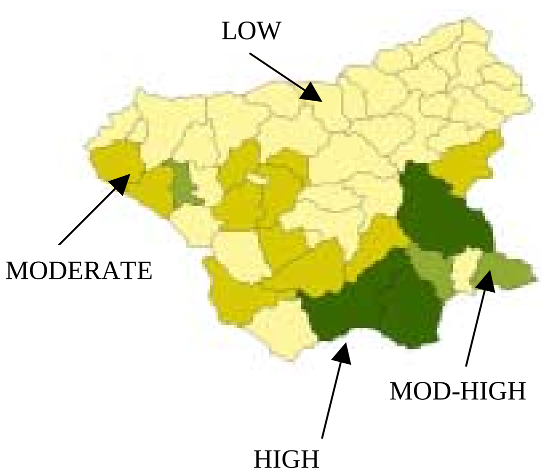

Figure 7. All subwatersheds were ranked based on acreage of buffered feedlots with 50-meter buffer.

New Overall Subwatershed Rankings

The new subwatershed ranking system created by analyzing percentage of row crops, mean slope value, and acreage of feedlots created a priority ranking system (figure 8) which differed very much from the one currently being used (figure 9) by the Whitewater Watershed Project and the NRCS.

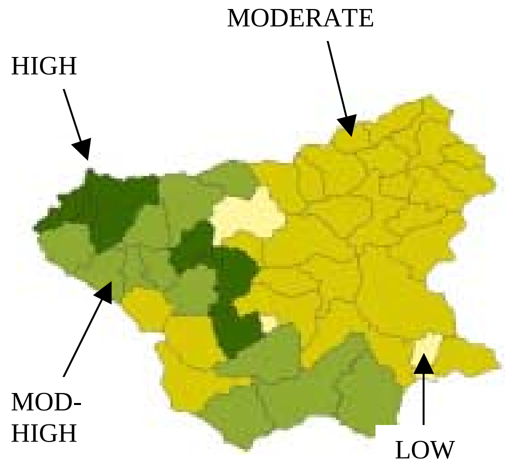

Figure 8. The new subwatershed buffer implementation ranking system was ranked based on row crops, slope, and feedlot proximity based on their relationship to streams.

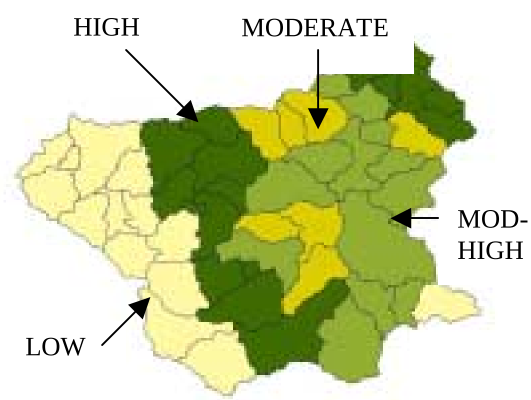

Figure 9. Overall restoration potential rankings currently being used for the Whitewater River Watershed.

Discussion

The Whitewater River Watershed is an ecological refuge for many different plants and animals. Part of the watershed encompasses the bluff lands of the

Mississippi River while other parts of the watershed are located in an area that was predominantly prairie during pre-settlement times. Change detection analysis was done comparing the 1890 landuse/landcover data with the 1995 GAP Analysis data and it was determined that 50% of what was originally prairie within 50-meters of a stream is now in agricultural row crops. The change of landscape from one of prairie and grasslands to one that is dominated by agriculture has had a severe impact on the water quality throughout the watershed. Almost one third of the soil that runs off of agricultural land enters streams (Dopplet, et.al., 1993).

Ecologically healthy watersheds require the maintenance and protection of the lateral, longitudinal, and vertical connectedness of the mosaic of habitat patches and ecosystem components within the watershed over time (Dopplet, et.al., 1993). Because of the changes that have taken place within the watershed over the last 100 years, steps need to be taken to protect the ecosystems of the Whitewater River Watershed. The small streams of the headwaters of riverine systems are the most vulnerable to human disturbance because they respond dramatically and rapidly to disturbance to their riparian areas. Even where inaccessible to fish, these small streams provide high levels of water quality and quantity, sediment control, nutrients and wood debris for downstream reaches of the watershed. Intermittent and ephemeral headwater streams are, therefore, often largely responsible for maintaining the quality of downstream riverine processes and habitat for considerable distances (Dopplet, et.al., 1993)

Many of the conservation practices that have taken place in the Whitewater River Watershed have taken place with emphasis on trout populations. Often these conservation practices include localized restoration projects that are very expensive. The purpose of this project was to provide evidence that enough non-point source pollution is occurring in the headwaters of the watershed that the watershed could be better served by protecting the headwaters with the use of riparian habitat buffers. Prevention of water quality problems is more effective and cost-efficient than control or repair measures, which oftentimes fail (Dopplet, et.al., 1993).

Ideally, the way to combat the amount of runoff entering the water systems of the watershed would be to implement a new standard for the way the land is used. However, implementing a new farming standard will take years to get accomplished. In the short term, the use of riparian buffers can be used to quickly and effectively reduce the amounts of excess nutrients and sediments entering the waterways while also providing valuable habitat for the wildlife of the watershed.

A subwatershed restoration potential ranking currently exists for the Whitewater River Watershed that used Agricultural Non-Point Source (AGNPS) model to determine the ranking basis of sediment and nutrient delivery from the fields. The AGNPS rankings were then weighted according to the highest quality stream segments. Because the cold-water spring flow that supports the trout starts where sharply incised valleys begin, this ranking system failed to target the intensively farmed areas of the upper watershed. It is because of this that this project set out to create a new subwatershed restoration potential model that concentrated on the areas where intense agriculture is taking place.

National Conservation Buffer Initiative

In April 1997, the United States Department of Agriculture (USDA) initiated the National Conservation Buffer Initiative.

The USDA pledged to help private landowners install 2 millions miles of conservation buffers by the year 2002. The USDA's goal for the buffer initiative is to get agricultural producers to improve soil, air, and water quality while enhancing wildlife habitat, restoring biodiversity, and creating scenic landscapes (NRCS, 2001).

The buffer initiative is led by the National Resource Conservation service (NRCS) who encourages farmers and ranchers to understand the economic and environmental benefits of buffers. There are a variety of programs offered by the NRCS, which help farmers install and maintain buffer areas on private lands. Some of the programs used to help private landowners install buffers include continuous Conservation Reserve Program (CRP), Environmental Quality Incentives Program (EQIP), Wildlife Habitat Incentives Program (WHIP), Wetlands Reserve Program (WRP), Stewardship Incentives Program (SIP), and Emergency Watershed Protection Program (EWP) (NRCS, 2001). The USDA realizes that the key to improving watershed water quality is no longer about building expensive barnyards for a few farmers but rather in making it economically beneficial for a large number of landowners to attack non-point source pollution (Kinney, 1999).

The use of GIS in Watershed Planning

GIS gives resource managers the ability to make sound decisions regarding the ecosystem "health" of the watershed. The use of Geographic information systems allows resource managers to look at many different factors affecting the watershed such as landuse, elevation, and infrastructure. Much of the data that managers need to display and analyze watersheds is available from the Internet at no charge. This makes watershed models accessible for any project where the resource manager has access to a geographic information system.

The intent of this project was to make it a model that can be used by other watersheds. GAP data is now available for all the states surrounding the Mississippi River. This gives every watershed partnership in the area an extremely accurate landuse dataset. The only piece of data that was used that can't be located from the Internet was the feedlot data. The feedlot data could be excluded from future models on different watersheds or each individual watershed could obtain the data themselves.

Conclusion

This paper outlines a method of assessing the potential for riparian stream buffer placement on a subwatershed level in the Whitewater River Watershed. The three factors this model used in determining restoration potential for stream buffers were the proximity of row crops, slope, and feedlots to riparian areas. All three of the factors can be assigned different weights according to their perceived significance in causing non-point source pollution.

This study found that it is most important to install riparian stream buffers in areas adjacent to the headwaters of the watershed. A large majority of the agricultural lands are located in this area and thus this is where much of the excess nutrients and sediments are entering the aquatic ecosystems of the Whitewater River Watershed. Oftentimes resource managers neglect the headwaters because they don't support large vertebrate populations compared to the rivers and streams further downstream. However, this model helps illustrate why it is important to protect the headwaters of the watershed.

This study should be able to assist resource managers from other watersheds to do their own potential riparian buffer study.

This model was designed with the idea that it can be used on any watershed. More or less factors can be used with this study according to the resource managers desired specifications. Most of the time all of the data needed to conduct a complete potential riparian buffer study is available from public agencies or the Internet at no charge.

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