Applications of Remote Sensing and GIS to the Assessment of Riparian Zones for Environmental Restoration in Agricultural Watersheds

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Abstract Geographical design of riparian buffers with long-term vegetation cover for environmental restoration in agricultural watersheds needs to assess how much farmland is located in the buffers of a concerned watershed. Traditionally, this assessment was done by field surveying and manual mapping, which was a time-consuming and costly process for a large region. In this paper, remote sensing (RS) and geographical information system (GIS) as cost-effective techniques were used to develop a catchments-based approach for identifying critical sites of agricultural riparian buffer restoration. The method was explained through a case study of watershed with 11 catchments and results showed that only four of the catchments were eligible in terms of higher priority for riparian buffer restoration. This research has methodological contributions to the spatial assessment of farming intensities in catchments-based riparian buffers across a watershed and to the geographical designs of variable buffering scenarios within catchments. The former makes the catchments-based management strategy possible, and the latter provides alternative restoration scenarios to meet different management purposes, both of which have direct implementations to the environmental restoration of riparian buffers in the real world. This study, thus, highlights the great potential of RS and GIS applications to the planning and management of riparian buffer restoration in agricultural watersheds.

Keywords farmland restoration; water quality; GIS; remote sensing

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Introduction

Growing awareness of the importance of riparian zones to eco-environmental functions has promoted riparian buffer restoration in agricultural watersheds.¹ This restoration is essentially an engineering project involving project planning, design, implementation, and management. Such a task requires scientific understanding and technical answers for many questions. For example, how much farmland is located in the riparian zones of a concerned watershed? Which zone should be targeted first in the watershed if the available restoration budget is limited for a fiscal year? What kind of restoration buffering shape and size should be designed for the riparian zone? How are these conceptual designs technically implemented in the planning maps? These questions have been partially addressed
in previous studies using remote sensing (RS) and geographical information system (GIS).

RS technologies have been increasingly used to the delineation and assessment of agricultural riparian buffers in environmental studies in recent years. For example, Landsat TM and digital line graph data were used to identify critical agricultural riparian strips for environmental restoration. RS images were applied to monitor coastal habitat conditions in terms of changes in land cover, riparian buffers, and wetlands. The uncertainties of image classification were assessed for accurately characterizing land cover of riparian buffers. New issues of applying RS images to mapping vegetation cover of riparian zones, locating restoration activities, and assessing previous management actions were recently examined. Soil moisture maps were derived from satellite images to detect seasonal changes of riparian zones in agricultural watersheds.

Similarly, GIS technologies have been used in few studies on agricultural riparian buffer restoration. For example, GIS was used to develop a new approach on generating variable buffers in riparian buffer restoration planning. GIS was also used to derive soil wetness from digital elevation model (DEM) for assessing the suitability of different sites in agricultural watersheds for either preservation or restoration of vegetative or farming riparian buffers. In a recent review on riparian buffer studies, the role of GIS in the parameterization and visualization of hydrological modeling on agricultural buffer restoration was highlighted.

On the basis of previous studies, this research further applies RS and GIS technologies to develop a methodological framework for the assessment of riparian buffers in agricultural watershed. The developed framework could be used to evaluate spatial dynamics of farming intensities in riparian buffers by catchments and by buffer sizes, thus providing critical information for land restoration planning. Specific objectives achieved through a case study are: (1) to derive a land cover map from satellite images for an agricultural watershed; (2) to generate riparian buffering scenarios using DEM data; (3) to estimate farmland areas in the buffers by catchments; and (4) to rank the priority of catchments for their riparian buffer restoration and management.

1 Data and methods

1.1 Study site

The Grand River watershed in Ontario, Canada, was selected as the study site (www.grandriver.ca). It drained an area of 6768 km² and run over 300 km long from Dundalk in the north to Dunnville on Lake Erie. The watershed covered the urbanized regional municipality of Waterloo and rural areas of intensive livestock farming, tobacco growing, and rural nonfarm communities.

The watershed was broadly divided into three sections: the upper, the middle, and the lower. The upper portion was mainly composed of wetlands and rural areas. The midportion was the most urbanized area in the watershed. Woodlands and wetlands had been severely fragmented and experienced the invasion of exotic plant and animal species. Land use in the lower section was dominated by agriculture, a major contributor to the landscape fragmentation and surface water quality degradation.

The watershed was selected as the study site for several reasons. First, it was experiencing water quality problems due to nonpoint source pollutions from intensive farming practices, road construction, and mining extraction. Thus, there was a high conservation need for water quality protection. Second, more than 140 species had been officially designated at risk in the area, indicating a high wildlife conservation concern in the site. Third, some conservation programs including Greencover Canada and Rural Water Quality Program had been ongoing in a few subbasins of the watershed, providing an applied background for this research.

1.2 Image classification and land cover map

The Landsat TM image used in this study was acquired on June 20, 2004. It was orthorectified, radiometrically, and atmospherically corrected by the data provider. The image was georeferenced to the UTM NAD1983 Zone 17N. It was then customized to the study area using the Grand River watershed boundary to reduce the image processing time. All the image processing described below was conducted by
A supervised classification was performed for the TM image. There were 14 information classes selected for the classification, which included builtups, row crops, small grains, forage, pasture/sparse forest, deciduous forest, conifer forest, mixed forest, mature plantation, water, marsh, extraction/bedrock/roads, golf courses, and bare agricultural fields. They were chosen on the ability to be separated within the image from other land uses as well as their hydrological properties that would be of interest in watershed management. Seven hundred GPS-based ground-truth points were collected for surveying land classes and 500 of them were used as image classification training sites. Another land cover map in 1999 with the same land use classes was available to assist the thematic information interpretation of each cluster. About 50 pixels per class were gathered for each training site. The training sites selected were distributed as evenly as possible throughout the image to account for regional variability within the same information class. Maximum likelihood classifier (MLC) was used as the classification algorithm to classify the pixels. The MLC assumed that the selected training data were normally distributed. Each pixel was classified according to its probability of membership to each information class. The limitation of this classification method was that pixels lying outside the probability of the information classes were set as “null class.” The classification results yielded an overall accuracy of 81.75% with the Kappa value of 0.7761. For the convenience in later analyses, the 14 class land use data were aggregated to 3 classes of agriculture, open water, and other land use/cover types, which were relevant to this study.

### 1.3 Water body and buffer generation

Landsat TM sensors could only detect such surface water bodies as wider rivers, reservoirs, ponds, and lakes, whose sizes were larger than one-pixel area (30 m×30 m). An additional DEM data layer with 10 m resolution was thus used to generate surface water networks of the watershed in ArcGIS 9.3. The hydrograph included linear stream/river systems and polygon water bodies (reservoirs, ponds, and lakes). For simplicity, no buffer was generated for the polygon water bodies. The buffers to be considered for restoration were generated only along the linear streams/rivers using a proximity analysis. Based on previous studies, buffer widths from 3 to 15 m were recommended for stabilizing eroding banks, from 3 to 60 m for filtering chemicals and from 20 to 200 m for establishing wildlife dispersal corridors and habitats. Thus, eight buffering widths of 25, 50, 75, 100, 125, 150, 175, and 200 m from both stream sides were designed as potential restoration scenarios to improve water quality and wildlife habitats. These buffers were converted into raster grids with 5 m resolution for farmland inventory within the buffer zones.

### 1.4 Farmland inventory

To refine the statistical unit for estimating the farmland area, the land cover data with 30 m resolution was resampled to a raster grid with a cell size of 5 m using the nearest neighbor assignment rule. This resampling process would not increase the accuracy of the land cover data but is necessary for counting the cropland area in the 25 m buffers. The resampled land cover map was then overlaid with the eight raster buffer grids to get new buffer grids with updated land use information. According to local watershed management plans, the Grand River watershed was divided into 11 subbasins using the DEM data. In each subbasin, there were eight buffers as candidates for environmental restoration. The subbasin data layer was overlaid with each buffer grid to summarize agricultural land areas in different buffers by subbasin.

### 2 Results

The classified land cover and DEM-derived water bodies for the watershed are shown in Figs.1 and 2, respectively. The DEM-derived vector water systems are in agreement with the visible surface water in the raster land cover map. The inventory of cropland in different buffering zones by subbasin is presented in Fig. 3. There is an approximately linear relationship between the cropland area in a buffer and its width. The Nith River (Id-6) has the largest cropland area in buffers among the 11 subbasins, whereas the Middle Grand (Id-5) has the smallest cropland area in buffers.
The spatial dynamics of cropland in different buffers by subbasin across the watershed are shown in Fig.4. The Nith River (Id-6) with the largest cropland area in buffers is also the largest one among all subbasins; however, the Middle Grand (Id-5) with the smallest cropland area in buffers is not the smallest subbasin. To make spatial comparison valid in selecting a potential site for environmental restoration, a relative cropland area as the percentage of cropland in a buffer over its total area is estimated and presented in Fig.5. Only do three basins that include the Middle Grand (Id-5), Speed River (Id-7), and Upper Grand (Id-8) have relatively small cropland ratios of the total land in buffers. Buffers of the remaining subbasins have more than 50% cropland, indicating high needs for restoration action in those subbasins. In addition, since most headwater streams are located in the Conestogo River (Id-1), the Nith River (Id-6), Upper Middle Grand (Id-9), and Whitemans Creek (Id-10), farming activities there would impact downstream water quality largely, thus making them into the first priority for land restoration.
3 Discussion

The results reported above show the current crop-land status of riparian buffers in the watershed. Such information is essential for the restoration planning and management of riparian buffers to achieve water quality improvement and refine wildlife habitats. The linear relationship between the cropland area in a buffer and its width is reasonable because if the riparian buffer within 25 m from the stream had been cleaned up for farming, then the land beyond the 30 m buffer from the stream was most likely be farmed. This inference could be verified from the classified Landsat TM image (Fig.1).

The Nith River (Id-6) has the largest cropland in buffers among all subbasins because it has the largest basin area with intensive farming activities (Figs.1 and 4). The Middle Grand (Id-5) has the smallest cropland area because it is largely occupied by urban buildings. The Speed River (Id-7) and Upper Grand (Id-8) have relative small cropland ratios of the total land in buffers because most of the riparian land in the Upper Grand basin remain naturally untouched, whereas land in riparian buffers of the other subbasin have been cleaned for urban development. This observation suggests that the three subbasins (Ids-5, 7, and 8) should not be prioritized for riparian buffer restoration.

This research contributes two innovative points on the spatial assessment of farming intensities in riparian buffers by buffer size across subbasins. One is the focus on the dynamics of cropland in buffers by subbasin across the watershed and the other is the designs of buffering scenarios with varying buffer widths. These contributions differ from previous studies. For example, similar studies were conducted in two previous studies. However, the critical sites indentified here were distributed across the entire study watersheds, thus making the subbasin management strategy impossible. Another closely related study focused on accuracy assessment of image classification and proposed biominimum mapping units to characterize land cover in riparian buffer zones and nonriparian buffer areas of the watershed. Goetz (2006) classified riparian buffers into 10 classes based on the density of tree cover in riparian buffers with a 30 m width, in which buffer areas with less than 50% of tree cover were considered as critical sites for environmental restoration. Makkeasorn et al. (2009) used both vegetation indices and soil moisture maps to accurately delineate riparian buffers from other land areas. However, none of those studies reported the ideas proposed here, which involved spatial assessment of riparian buffers by buffer size across subbasins.

4 Conclusion

This study contributes a simple method for assessing the spatial dynamics of farming intensities in riparian buffers by buffer size across subbasins, which are of interest to environmental planners and practitioners. This study also adds further evidences for the potential applications of RS and GIS technologies to the planning and management of riparian buffer restoration in agricultural watersheds. The RS images provide fundamental data sources for land cover and land use mapping. GIS could be used to estimate, analyze, and visualize the spatial distribution of cropland in designed restoration buffers. Such information is essential for environmental restoration planning and management. For example, the maps and charts in Figs.3-5 show where the restoration should be prioritized if the public fund is limited. The results suggest that the Conestogo River (Id-1), the Nith River (Id-6), Upper Middle Grand (Id-9), and Whitemans Creek (Id-10) in the watershed should be placed with a higher priority for buffer restoration.

Several issues might be considered for further studies. First, the accuracy of the classified image was not well assessed here. Further studies are needed using more ground references from field work, GPS surveying, and
other data sources. Second, the estimated cropland in the buffers may be incorporated with economic data, such as production net returns to predict restoration budgets for restoration planning. Third, the buffer widths also depend on the soil types, soil wetness, topographic slopes, and proposed vegetation types of local sites. These data should be collected to further examine the restoration buffer scenarios.

References

[1] Boyd R, Uri N (2001) A note on the use of conservation practices in U.S. agriculture [J]. Environmental Monitoring and Assessment, 72(2): 141-178
[2] Narumalani S, Zhou Y C, Jensen J R (1997) Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones [J]. Aquatic Botany, 58(3-4): 393-409
[3] Klemas V V (2001) Remote sensing of landscape-level coastal environmental indicators [J]. Environmental Management, 27(1): 47-57
[4] Lunetta R S, Edirwicke J, Liames J, et al. (2003) A quantitative assessment of a combined spectral and GIS rule-based land-cover classification in the Neuse River Basin of North Carolina [J]. Photogrammetric Engineering & Remote Sensing, 69(3): 299-310
[5] Goetz S J (2006) Remote sensing of riparian buffers: past progress and future prospects [J]. Journal of the American Water Resources Association, 42(1): 133-143
[6] Makkeasorn A, Chang N B, Li J H (2009) Seasonal change detection of riparian zones with remote sensing images and genetic programming in a semi-arid watershed [J]. Journal of Environmental Management, 90(2): 1069-1080
[7] Xiang W N (1996) GIS-based riparian buffer analysis: injecting geographic information into landscape planning [J]. Landscape and Urban Planning, 34(1): 1-10
[8] Russell G D, Hawkins C P, O’Neill M P (1997) The role of GIS in selecting sites for riparian restoration based on hydrology and land use [J]. Restoration Ecology, 5(4S): 56-68
[9] Shearer K S, Xiang W N (2007) The characteristics of riparian buffer studies [J]. Journal of Environmental Informatics, 9(11): 41-55
[10] Osborne L L, Kovacic D A (1993) Riparian vegetated buffer strips in water-quality restoration and stream management [J]. Freshwater Biology, 29(2): 243-258
[11] Lin Y F, Lin C Y, Chou W C, et al. (2004) Modeling of riparian vegetated buffer strip width and placement [J]. Ecological Engineering, 23(4-5): 327-339
[12] Wissmar R C, Beer W N, Timm R K (2004) Spatially explicit estimates of erosion-risk indices and variable riparian buffer widths in watersheds [J]. Aquatic Sciences, 66(4): 446-455

Notes to Contributors

Contributions are welcomed on one of the following subjects or in related areas:

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★ Geodynamic
★ Physical geo-surveying
★ GPS
★ Geo-surveying
★ Engineering surveying
★ RS
★ Photogrammetry
★ Mapping apparatus
★ Cartology
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