GEOGRAPHIC INFORMATION SYSTEMS APPLIED TO THE ANALYSIS OF RIPARIAN BUFFER ZONES AND LAKES

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Contents

Summary

Geographic information system (GIS) and remote sensing technologies have contributed much to the field of aquatic environmental engineering by their capacity to analyze and represent management effects or future trends of spatially distributed riparian forests or aquatic ecosystems.

The technologies are used to decide the effective buffer width of a riparian buffer zone that can filter out nutrients, or to target nonpoint critical area analysis, including soil erosion problems. Further research is needed to validate the analytical method itself by comparing water quality before and after the management. The buffer vegetation type may have an important role, so the effect of different vegetation must be considered, especially in relation to the denitrification process. Proper management of riparian ecosystems by periodic harvest of trees or other new management techniques should be made to maintain long-term performance.

Application of GIS to the analysis of aquatic ecosystems has provided researchers and managers with much information on the assessment of management practices, the future spatial growth and distribution of aquatic macrophytes. In future, more ecological factors should be used for managing aquatic vegetation, so as to understand the ecological landscape as an ecological system that includes phytoplankton, zooplankton, and fishes. Proliferation of aquatic vegetation that affects human activities should be managed appropriately, but the benefits of aquatic macrophytes that preserve aquatic

diversity should also be evaluated. To make full use of GIS technologies, fundamental analysis of lake ecosystems including aquatic vegetation is needed. Moreover, aquatic vegetation is now classified into emergent, submergent, and free-floating categories, and a more detailed classification should be discussed to consider the characteristics of each category, such as nutrient uptake kinetics, growth dynamics, decomposition, or accommodation to the surrounding environment for managing lake ecosystems as a whole.

1. Introduction

In the past few decades, as human activities have been affecting the natural equilibrium of the environment, plant and animal species have been diminishing every day. Political decision-makers or managers must decide how to preserve the diversity and the quality of the natural environment. However, applying ecological knowledge to regional or global problems is very difficult because a tremendous amount of information about the flora, fauna, geology, soil type, nutrients, temperature, from a variety of sources is needed. Maps can be a convenient tool for integrating important and complex information about the environment. Transformation of the information on to a sheet of paper is indispensable but sometimes time-consuming for analyzing ecological events or predicting the future composition of vegetation or water quality. However, new computer technologies make it possible to store, retrieve, manipulate, analyze, and display large amounts of spatial information according to user-defined specifications. New database systems, statistical computing, and traditional maps are combined in the GIS. GIS technologies have been developed to solve several problems in lake or river management related to ecological aspects, such as nutrient loading in the open water and excessive growth of aquatic vegetation. Excessive nutrient loading leads to marked ecological effects on the water of lakes and streams receiving nutrients and the proliferation of aquatic vegetation sometimes affects human activities, so the vegetation should be managed appropriately.

The GIS is used for rivers to determine the optimum width of a riparian buffer zone that can remove nutrients of nonpoint source pollutants, such as agricultural fields, because it is a function of geological data, such as slope or soil. Unlike the management of point sources, where treatment systems can be applied to nearly all discharges, the problem with nonpoint sources is that they require more flexible site- and source-specific solutions. Critical source areas, defined as areas where the potential contribution of pollutants to the water receiving the pollutants is markedly higher than in other areas, are also represented by GIS for the best management of watersheds.

In the management of aquatic macrophyte distributions, GIS and remote sensing technologies provide resource managers with efficient methods to monitor plant distributions over large geographic areas. Spatial analysis using GIS permits managers to determine changes in macrophyte distributions over time and to identify critical environmental parameters influencing their growth.

Here, the research on nonpoint source analysis and aquatic vegetation analysis is reviewed; GIS and remote sensing technologies have contributed greatly to solving the above problems.

2. Analysis of Riparian Buffer Zones

2.1 Hydrologic Effects of Buffer Zones

The effects of riparian buffer zones on nonpoint source pollution depends largely on the hydrological response. As all stream flow passes through the riparian ecosystem, the riparian zone is the source of nutrients from the watershed. The effectiveness of buffer zones is influenced by the processes of the pollutant pathways. These processes are roughly surface- and subsurface-dominated processes.

Subsurface flow is likely to be a major mechanism in the transport of soluble pollutants in many catchments, particularly in winter when the water table approaches the soil surface. Artificial subsurface drainage greatly reduces the drainage time of water from fields once the water reaches the drain line. Subsurface flow is frequently the major pathway of nitrogen transport in watershed runoff and high concentrations commonly occur in artificial subsurface drains.

Surface runoff occurs when the rainfall intensity exceeds the capacity of soil, or when the surface soil is saturated, for example as a result of a high groundwater table, and its pathways converge as a result of topographic effects. Surface runoff is a major transport mechanism for soluble pollutants in runoff events.

Riparian ecosystems also control the baseflow in areas where baseflow depends primarily on downslope movement of water stored in the soil profile. Alluvial soils in riparian zones often store much water from rainfall and from water moving down slopes. Vegetation and soil processes in the riparian ecosystem affect this alluvial groundwater before the groundwater flows out of the watershed into the stream channel. These soil and vegetation processes serve as the basis for nonpoint source pollution control by riparian ecosystems.

2.2 Relation between Nonpoint Source Pollution and Buffer Zones

Freshwater wetlands can filter out nutrients and improve water quality. Riparian zones in upland agricultural watersheds that are heavily fertilized can also help control agricultural nonpoint source pollution. Riparian zones recognized as useful have three processes, physical, vegetative, and soil, that affect nutrient loads in the surface water.

Physical factors include sedimentation in the riparian zone, stream bank stabilization, and water temperature reduction by canopy shading of the stream channel. Suspended sediments from soil erosion of agricultural land worsen the quality of stream habitats, because they are abrasive to macroinvertebrates and attached algae, decrease light penetration in the stream, and fill the interstices where they live. Sediment deposition is a natural process that takes place during periodic flooding in riparian zones. Accelerated upland erosion can increase sediment deposition in streamside areas because of downslope movement of dislodged soil material. Such deposition has changed the soils, drainage, and vegetation. Accelerated deposition and erosion adversely affects riparian areas, but the deposition prevents much of the eroded material from immediately reaching the stream channel.

Riparian vegetation is essential both to stabilize stream banks and to regulate water temperatures. Stream bank stabilization is important because much of a stream's sediment load is the result of bank erosion. Levels of suspended sediments increase quickly without vegetation. Streamside vegetation can regulate running water temperature and increase the stream's oxygen-carrying capacity. Vegetation removal may increase the temperature and adversely affect the stream biota. The most important role of vegetation is the uptake and long-term storage of nutrients in woody material. Riparian vegetation can also remove nutrients from the subsurface flow, which is important because soluble nutrients, such as nitrates, move easily in subsurface flow without woody shrubs or trees.

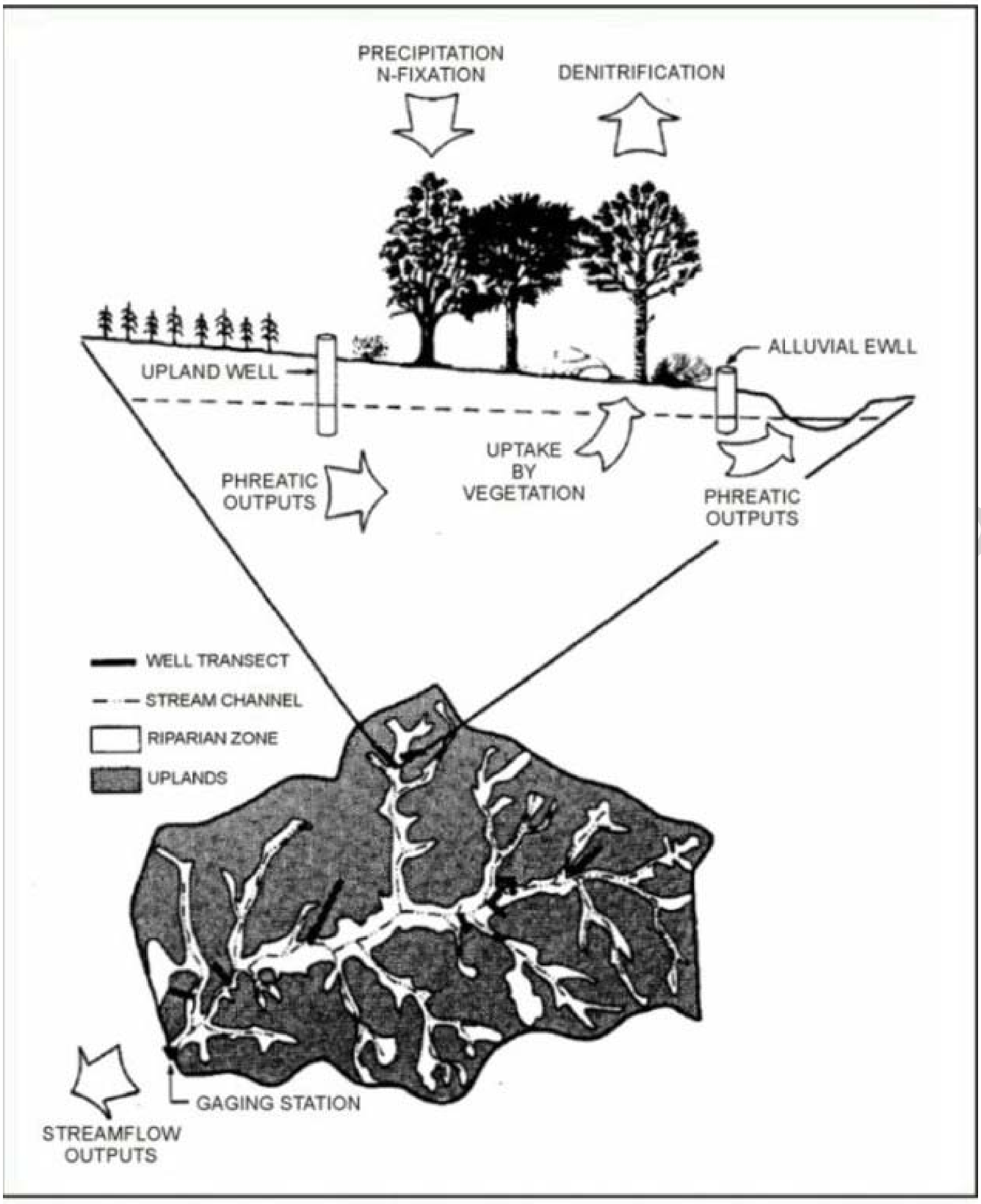

Figure 1. Schematic illustration of the measurement of nutrient inputs, outputs, and storage (Lowrance et al., 1984)

Soil processes are the accumulation of nutrients deposited along with sediments or clay, and gaseous loss by microbial denitrification. Laboratory experiments show high rates of nitrogen loss from flooded soil, especially soils that undergo periodic flooding and drying, as in floodplain wetlands. High rates of denitrification also occur in fields, such as in the muck from drainage ditches and in swamps. Because riparian soils on agricultural watersheds often contain high levels of carbon and nitrates, denitrification rates can be high under certain conditions.

Previous studies have provided conflicting conclusions about the long-term effectiveness of riparian vegetation. Riparian vegetation may reduce nutrients in stream flow by shading and stream bank stabilization. The effectiveness of riparian vegetation can be demonstrated by the fact that 36–60% of all annual nutrient input is retained in the riparian zone. However, mature forests with streams are not useful as nutrient filters, as they may reach a steady state with no net annual uptake.

Studies based on nutrient cycles and nutrient flux across ecosystem boundaries have helped provide an understanding of the nutrient filtering effect of the riparian zone. The nutrient filtering capacity was investigated using nutrient budgets of the riparian zone of an entire agricultural watershed. Figure 1 shows a schema of the measurement of inputs, outputs, and storage of nutrients in the riparian ecosystem. The maintenance and proper management of riparian ecosystems by periodic harvest of trees, or by other new management techniques, is necessary, to maintain nutrient uptake and avoid degradation of water quality due to increased nutrient loss from agricultural watersheds.

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Bibliography

Delong M. D. and Brusen M. A. (1991). Classification and spatial mapping of riparian habitat with applications toward management of streams impacted by nonpoint source pollution. *Environmental Management* **15**(4), 565–571. [This presents a riparian habitat classification by using GIS and the potential use for management applications.]

Jensen J. R. Narumalani S. Weatherbee O. and Morris Jr., K. K (1992). Predictive modelling of cattail and waterlily distribution in a South Carolina Reservoir using GIS. *Photogrammetric Engineering and Remote Sensing* **58**(11), 1561–1568. [This presents predictive modeling of the dominant freshwater macrophytes in L Lake in South Carolina.]

Lowrance R. Todd R. Fail J. Jr., Hendrickson O. Jr., Leonard R. and Asmussen L. (1984). Riparian forests as nutrient filters in agricultural watersheds. *BioScience* **34**(6), 374–377. [This work provides data about nutrient budgets for the riparian zone.]

Muscatt A. D. Harris G. L. Baily S. W. and Davies D. B. (1993). Buffer zones to improve water quality: a review of their potential use in UK agriculture. *Agriculture, Ecosystems and Environment* **45**, 59–77. [This work assesses the effectiveness of buffer zones for retention of nitrogen and phosphorus.]

Narumalani S. Jensen J. R. Althausen J. D. Burkhalter S. and Mackey H. E. Jr. (1997). Aquatic macrophyte modelling using GIS and logistic multiple regression. *Photogrammetric Engineering and Remote Sensing* **63**(1), 41–49. [This presents modeling techniques for predicting areas of aquatic macrophyte growth and distribution.]

Phillips J. D. (1989). Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology* **110**, 221– 237. [This provides the detention time model of buffer effectiveness and simulated buffer width.]

Remillard M. M. and Welch R. A. (1993). GIS technologies for aquatic macrophyte studies: Modeling applications. *Landscape Ecology* **8**(3), 163–175. [This represents a cartographic model of aquatic macrophyte distributions to identify lake areas that are susceptible to excessive macrophyte growth.]

Sivertun A. Reinelt L. E. and Castensson R. (1988). A GIS method to aid non-point source critical area analysis. *International Journal of Geographical Information Systems* **2**(4), 365–378. [This study shows the potential of using GIS in selecting critical source areas for sediment-related water quality problems and land resource protection.]

Verry E. S. and Timmons D. R. (1982). Waterborne nutrient flow through an upland-peatland watershed in Minnesota. *Ecology* **63**, 1456–1467. [This assesses the effectiveness of a riparian buffer zone by calculating gross watershed nutrient budget.]

Xiang W. (1993). A GIS method for riparian water quality buffer generation. *International Journal of Geographical Information Systems* **7**(1), 57–70. [This presents a variable riparian buffer width model by integrating a scientifically tested model into a GIS framework.]

Biographical Sketch

Dr. Norio Tanaka received an ME degree in 1988 and Ph.D. in 1991 in river engineering at the University of Tokyo. He has worked as a construction consultant from 1991 to 2000 in the field of river engineering and information technology. He is now an assistant professor at the Department of Civil and Environmental Engineering, Saitama University. His research interests are growth dynamic analysis of macrophytes, such as transition, competition, and enlargement of vegetation, using bioenergetic models and nutrient cycling in an aquatic environment.