EXPLORING THE RELATIONSHIP BETWEEN HYDROLOGIC
PARAMETERS AND NUTRIENT LOADS USING DIGITAL ELEVATION
MODEL AND GIS – A CASE STUDY FROM SUGARCREEK
HEADWATERS, OHIO, U.S.A.

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Abstract. Ohio is typical among the Midwestern and Eastern United States with high levels of water
pollutants, the main sources being from agriculture. In this study, we used a digital elevation model
in conjunction with hydrological indices to determine the role of landscape complexity affecting the
spatial and temporal variation in pollutant levels, in one of the most impaired headwater streams in
Ohio. More than eighty five percent of the study area is dominated by agriculture. Spatial distribution
of slope (S), altitude and wetness index along with other watershed parameters such as flow direc-
tion, flow accumulation, stream networks, flow stream orders and erosion index were used within a
Geographic Information Systems framework to quantify variation in nitrate and phosphate loads to
headwater streams. Stream monitoring data for nutrient loads were used to correlate the observed
spatial and temporal patterns with hydrological parameters using multiple linear regressions. Results
from the wetness index calculated from a digital elevation model suggested a range of 0.10–16.39,
with more than 35% having values less than 4.0. A Revised Universal Soil Loss Equation (RUSLE)
predicted soil loss in the range of 0.01–4.0 t/ha/yr. Nitrate nitrogen levels in the study area paralleled
precipitation patterns over time, with higher nitrate levels corresponding to high precipitation. At-
mospheric deposition through precipitation could explain approximately 35% of total nitrate levels
observed in streams. Among the different topographic variables and hydrological indices, results from
the step-wise multiple regression suggested the following best predictors, (1) elevation range and up-
stream flow length for nitrate, (2) flow direction and upstream flow length for ammonia-nitrogen and
slope, and (3) elevation range for phosphate levels. Differences in the landscape models observed for
nitrate, phosphate and ammonia-nitrogen in the surface waters were attributed partly to differences
in the chemical activity and source strengths of the different forms of these nutrients through agricul-
tural management practices. The results identify geomorphologic and landscape characteristics that
influence pollutant levels in the study area.

Keywords: digital elevation model, GIS, hydrological parameters, non-point source pollution

1. Introduction

Non-Point Source (NPS) pollutants have a significant impact on the quality of
water resources (Narumalani et al., 1997). The NPS pollutants includes nitrate ni-
trogen (NO3−-N), ammonia-nitrogen (NH4+-N), phosphate (PO4−-P), heavy metals
and other chemicals from fertilizers, pesticides, herbicides, animal wastes, overland
flow wastewater treatment systems, urban storm water and other sources (Muscutt et al., 1993; Narumalani et al., 1997). Studies by the U.S. Environmental Protection Agency (1983) estimated that NPS pollution contributes over 65% of the total pollution load to the U.S. inland surface waters. During the early 1970’s there was widespread recognition of water quality problems related to NPS throughout the U.S. Numerous studies have investigated the relationships between catchment characteristics and nutrient levels in receiving waters (Omernick, 1977; Rast and Lee, 1978; PLUARG, 1978; USEPA, 1983). Also, several large regional studies were conducted, including the Connecticut Lakes study (Frink and Norwell, 1984), the Wisconsin lakes study (Clesceri et al., 1986), the Chesapeake Bay study (Donigian et al., 1990), the Long Island sound study (Frink, 1991) and the Hubbard Brook study (Likens and Bormann, 1995; Bernhardt et al., 2002). One of the major studies that is attempted to quantify the nutrient flows and fluxes from agriculture, point source discharges and atmospheric deposition is the Mississippi-Atchafalaya River Basin study (Goolsby et al., 1999). This study identified several watersheds in Ohio as the principal sources of nitrogen pollution in the mid-west region, using mass balance calculations and geographic information systems.

Even though much insight has been obtained from these watershed and regional scale studies, additional information can be gained by precise evaluation and analysis of landforms at smaller spatial scales, especially in relation to management and conservation practices implemented at the field scale. One of the important questions that remain challenging in addressing non-point source pollutants is the role of landscape complexity governing temporal and spatial aspects of pollutants. At a landscape scale, complexity is imparted by the spatial distribution of geomorphologic features (such as variation in bedrock, landforms, soils, elevation and degree of dissection, etc), biotic features (vegetation and water systems) along with human land use (Wood, 1999). Lateral flow in the complex landscape (re-distributing water, organic matter, and minerals) can lead to complex interrelated patterns of soil moisture, vegetation and biogeochemistry in terrestrial landscapes (Wood, 1999). Furthermore, lateral flow into open water aquatic systems causes considerable loss of nutrients. Topography affects these lateral hydrologic flows and plays an important role in the formation of streams and riparian wetland areas. Several of the hydrological, geomorphologic and biological processes active in the landscape are sensitive to topographic position (Moore et al., 1991; Bruin and Stein, 1998). In particular, topography affects the transport of chemicals and sediment from the land surface through the stream-channel system (Moore et al., 1991). The spatial distribution of terrain attributes can therefore be used as an indirect measure of the spatial variability of these processes. Several metrics to quantify the effects of the topography on hydrological processes have been developed. For example, Moore et al. (1991) classify these topographic attributes as primary and secondary characteristics, where primary characteristics are calculated directly from the elevation data and secondary characteristics are derived