USING GIS TO MODEL THE EFFECTS OF POTENTIAL WETLAND MITIGATION SITES ON WATER QUALITY IN GEORGIA

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Abstract. We are currently developing a map of prioritized potential wetland mitigation sites to increase the effectiveness of wetland mitigation in Georgia. The purpose of this project is to create a single mapped resource that all players working on wetland restoration and mitigation can use to coordinate their activities, thus potentially providing greater positive cumulative effects on the health of watersheds. We are mapping assessed wetland functions and values determined via consultations with various federal, state and local stakeholders through a wetlands steering committee organized by the Georgia Environmental Protection Division. The result of this project is a landscape level planning tool identifying areas within high priority watersheds where potential wetland mitigation sites may be located. In this report we concentrate on one of the 18 layers we have developed to address how creation of potential wetland mitigation sites may positively affect water quality and quantity and potentially flood attenuation. Initial trends indicate that the creation of wetlands at identified high priority sites may have a positive effect on water quality through reduction of non-point source runoff.

INTRODUCTION

The protection and restoration of wetlands and riparian areas are an important aspect in protecting the quality of our water and for flood control. Wetland restoration and mitigation can be costly and time consuming for all parties involved and are often opportunity driven. With the limited resources available it is necessary to develop proactive approaches (Randhir et al. 2001) for focusing mitigation to areas most likely to satisfy management objectives in a cost efficient manner (Wang 2001). Wetland mitigation can be used as a tool to meet watershed planning objectives for protecting water quality. Identifying and ranking priority areas allows managers to more effectively choose mitigation sites and achieve such objectives (McAllister et al. 2000). To do this we need to model the link between landscape variables and the spatial dynamics of a watershed to water quality.

Numerous research projects have proven the link between human altered landscaped and the levels of water quality variables (Berka et al. 2001; Herlihy et al. 1998; Mattikalli & Richards 1996; Wang 2001). Identification of these areas is paramount to mitigating their effects. Often this is more than strictly identifying a land cover based on its percent of a watershed. Spatial location and configuration are important (Gergel 2005; Gergel et al. 2002; Houlahan & Findlay 2004; Johnston et al. 1990; McAllister et al. 2000) in determining the effect of a land cover on water quality. The spatial location and configuration are also important when considering watershed planning objectives. Mitigation of headwater wetlands may be more effective for flood attenuation (McAllister et al. 2000), while riparian wetlands and forests may be more beneficial for water quality and reducing impacts to stream biota (Johnston et al. 1990; Wang 2001).

Under the direction of the Georgia Environmental Protection Division and other stakeholders we are developing a GIS based model to identify where wetland mitigation will have the greatest impact on assessed wetland functions and values. The wetland functions and values assessed were; water quality and quantity, flood control, flow regulation, wildlife habitat, biodiversity conservation, ecological services, recreation, education, connectivity, ease of restoration and scenic value. The product of the model will be a GIS based map identifying prioritized potential wetland mitigation sites that is usable at multiple spatial scales, statewide to local watersheds. To accomplish this we have developed 18 layers to address all wetland functions and values, one of which is the water quality and quantity index designed specifically to address water quality and quantity, flood control and flow regulation.

METHODOLOGY

The water quality and quantity index (WQQI) is the product of two separate indices, a Potential Runoff Index (PRI) and a Distance to Impairment Index (DII). Both indices were created using Arc Marco Language (AML) in ArcINFO (Environmental Systems Research Institute, Redlands, California) with the final data processing done in ArcGIS 9.1.

Potential Runoff Index

The Potential Runoff Index was designed to calculate the potential proportion of non-point source runoff originating from a landscape matrix after a one inch rain event. To accomplish this we incorporated into the PRI; land cover classification, hydrologic soil groups (HSG), hydrologic conditions and antecedent runoff conditions. We used the Georgia Land Use Trends database (GLUT) developed by the Natural Resources Spatial Analysis Laboratory at the University of Georgia for our land cover classification. GLUT was developed through remote sensing of LandSat MSS (1974, 1985, 90 meter spatial resolution) and LandSat TM data (1992-2005) at a 30 meter spatial resolution (NARSAL 2006). For development of our index we used only the 1998 GLUT database. All 13 identified land cover classes were used in development of this model: beaches/sand , open water, low and high intensity urban, clearcut, barren ground, deciduous forests, evergreen forests, mixed forests, agriculture, forested wetlands, brackish marshes and emergent marshes (NARSAL 2006). All GLUT forests were lumped into one cover type, woods, to obtain a SCS curve number.

PRI was calculated using the SCS runoff curve number (NRCS 1986) method. To identify the HSG of each land cover we related each pixel in the 1998 GLUT database to its corresponding STATSGO hydrologic soils group (NRCS 2006). We then assigned the appropriate curve number (CN) by relating land cover/HSG to the values in Table 2.2 in TR-55 (NRCS 1986). Gergel (2005) noted that during large storms a significant proportion of annual nutrient input occurs for many watersheds. Based on this, we chose to base runoff on a one inch storm event. Runoff was calculated using the SCS runoff equation (eq. 1) (NRCS 1986).

$$Q_i = \frac{\left(P - 0.2\left(\frac{1000}{CN_i} - 10\right)\right)^2}{P + 0.8\left(\frac{1000}{CN_i} - 10\right)} \quad \text{(eq. 1)}$$

Where:
Q_i = Runoff (in)
P = Rainfall (in); in our case P = 1
CN_i = Curve number of pixel *i*

After calculating the runoff from each pixel we needed to know the potential amount of runoff from each watershed. This was accomplished through running un-weighted and weighted flow accumulation models. An un-weighted flow accumulation model (FA) calculates the accumulated flow of all upstream pixels assuming that there is no initial abstraction. Weighted flow accumulation (WFA) takes into account initial abstraction by incorporating Q_i as the weighted value. The potential runoff index is then calculated using eq. 2.

$$PRI = \frac{FA - WFA}{FA} \quad \text{(eq. 2)}$$

PRI is in essence the proportion of rainfall that may enter open water. PRI is an inverse index between 0-1, with 0 have exhibiting greatest potential amount of non-point source runoff.

Distance to Impairment Index

The distance to impairment index was developed to rank individual pixels based on their flow distance to 305 (b)/ 303 (d) listed streams (GAEPD 2002). DII is used to incorporate the spatial relationship of a land cover to an impaired water and thus its potential influence on water quality (Johnston et al. 1990; McAllister et al. 2000). To calculate DII we used an AML to run a series of ArcINFO flow length and cost allocation models. The distance to Impairment Index is an unbounded inverse index from 0 - ∞, with 0 implying that a pixel drains directly into an impaired water. Location is important as it has been noted that riparian wetlands are the most important wetlands for protecting water quality and minimizing flow directly in to open water (Cedfeldt et al. 2000; Johnston et al. 1990). We did not limit the distance that beyond which a land cover would have no effect on water quality. Houlahan and Findlay (2004) detected sediment and water nutrients in wetlands originating up to 4000 meters away.

Water Quality and Quantity Index

The water quality and quantity index (WQQI) is a ranked set of areas that may contribute the greatest amount of potential runoff to an impaired stream. The ranking is distance, saying that areas contributing the highest potential amount of runoff are located close to impaired waters; thus, having a greater negative effect on water quality than areas further away and should be considered as priorities for mitigation sites. WQQI is calculated using eq. 3.

$$WQQI = PRI_{rcls} * DII_{rcls} \quad \text{(eq. 3)}$$

Where:
PRI_{rcls} = Reclassified Potential Runoff Index
DII_{rcls} = Reclassified Distance to Impairment Index

WQQI is scaled from 1 - 81. Not all land covers are considered feasible as mitigation sites, these areas were given a value of 1 regardless on there initial ranking. These include low intensity urban, high intensity urban, barren ground, and existing wetlands. Existing wetlands are included because we are look at areas where creation of wetlands through mitigation may have a significant effect. The water quality and quantity index was reclassified using Jenks Optimization on a scale of one to nine.

Study area

The WQQI was developed at a statewide spatial scale and tested for trends on local watersheds. We looked at 50 watersheds across Georgia for trends describing the relationship between the proportion of high ranked WQQI values (7, 8 and 9) and watersheds listed as partially or not supporting their designated use (GAEPD 2004). We also looked at the relationship between low (1, 2, and 3) and medium (4, 5 and 6) ranked WQQI values and watersheds either supporting or not supporting their designated use.

The 50 streams, from which testable watersheds were developed, were selected based on the following criteria. Supporting streams had to have been surveyed and listed in the Georgia 2004 305 (b)/303 (d) list as supporting their designated use (GAEPD 2004). Not supporting or partially supporting streams were listed for dissolved oxygen, fecal coliform bacteria, Ph, biota impacted and/or fish consumption guidelines. Sources were non-point source and/or urban runoff (GAEPD 2004). The total study area encompassed 7092 km^2, of which 2987 km^2 were supporting its designated use (28 watersheds) and 4104 km^2 not supporting its designated use (22 watersheds).

DISCUSSION

The WQQI model was developed to highlight locations for wetland mitigation that would lessen the impact of non-point source pollution on Georgia's streams and rivers. The number of potential contributors to non-point source pollution (NPS) makes this problem difficult to control (Randhir et al. 2001). It has been proven that the proportion of human altered land covers in a watershed is a good indicator of the variance in water quality measures (Berka et al. 2001; Herlihy et al. 1998; Jones et al. 2001; Mattikalli & Richards 1996; Wang 2001). Others have highlighted the importance of the spatial location and configuration of land covers in determining their contribution to non-point source pollution (2005; Johnston et al. 1990). Gergel et al. (2002) and Jones et al. (2001) stated that several attempts have been made to relate regional spatial location of landscapes to water quality and as of yet, none have been successful. Based on initial observations the relationship trends of the WQQI show that as the proportion of high value WQQI increases the likelihood of impairment increases. To test these observations further statistical tests will be conducted. The multiple components of the water quality and quantity index incorporated both land covers and their spatial location and configuration to identify where mitigation sites may reduce the effects of non-point source pollution the water quality.

Table 1. Proportion of Grouped Land Covers Present in Supporting and Not-Supporting Watersheds. * Significant at p<0.05

	Supporting	**Not Supporting**
Urban	0.041	0.112 *
Clearcut	0.082	0.075
Forests	0.534	0.566
Agriculture	0.270	0.196
Wetlands	0.061	0.040

Gergel et al. (2002) noted that as the complexity in a landscape increases the spatial variables become increasingly important. With 13 land cover classifications in the WQQI and four of them considered as human altered and potential contributors to non-point source pollution, spatial location and configuration may be the driving factor behind the trends seen in our model. In our study area urban land cover is the only land cover where the mean significantly differed (p<0.05, Table 1.) between the supporting and not-supporting study areas. Others have noted this relationship between urban areas and the decrease in water quality (Boyer et al. 2002; Meador & Goldstein 2003; Wang 2001). The relatively small proportion of urban classification in some of our not supporting study areas (27% had <= 1% urban, 36% <= 2% urban and 57% <= 5%) though, point to the importance of including the spatial location and configuration into the model. The similar proportion of forests to agriculture in supporting and not-supporting watersheds is also an interesting relationship. It is important to note that in general the proportion of forests and wetlands in a watershed has a positive effect on water quality (Johnston et al. 1990) while the proportion of agriculture is assumed to negatively affect it (Berka et al. 2001; Mattikalli & Richards 1996; Wang 2001). Based on the similarities of our proportions, the spatial location of these two land covers may be influencing our model, and further investigations should be conducted to test this relationship.

McAllister et al. (2000) and Johnston et al. (1990) discussed the affect of the spatial location of wetlands. McAllister et al. (2000) stated that wetlands higher in the watershed have a greater affect on flood attenuation while Johnston et al. (1990) stated that distant wetlands will have less affect on downstream water quality. In building a model it is a question of what is your objective, the WQQI objective was to address not only water quality and quantity but also flood control and flow regulation. The WQQI serves us well in that depending on the management objective of a watershed both riparian areas and distant headwater areas are highlighted as potential mitigation areas.

The objective of this project was the development of a landscape level planning tool identifying potential areas within high priority watersheds where potential wetland mitigation sites may be located. Wetland mitigation is often driven by opportunity and economic viability (McAllister et al. 2000), especially in the case of mitigation banking. And through prioritization programs we can be more resource economical (McAllister et al. 2000; Randhir et al. 2001; Wang 2001) by focusing our efforts to where wetland mitigation will have the greatest positive effect on the health of a watershed. By incorporating the water quality and quantity index into the priority potential wetland mitigation sites model and providing this information to all agencies, more informed decisions can be made regarding watershed planning. Thereby increasing the likelihood of achieving the desired effects of state and local watershed protection initiatives.

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