Geographic Information Systems for Cumulative Impact Assessment

Carol A. Johnston, Naomi E. Detenbeck, John P. Bonde, and *Gerald J. Niemi*
Center for Water and the Environment, Natural Resources Research Institute, University of Minnesota, Duluth, MN 55811

ABSTRACT: Geographic Information Systems (GIS) are a valuable tool for assessing cumulative environmental impact, the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions. GIS can be used to quantify rates of regional resource loss by comparing data layers representing different years. GIS can also be used to develop empirical relationships between resource loss and environmental degradation. A cumulative impact evaluation method involving aerial photointerpretation, multivariate statistical analysis, and GIS techniques was developed and used to relate past and present wetland abundance with stream water quality in the Minneapolis-St. Paul metropolitan area. The results demonstrate the importance of wetland position in the watershed to water quality, a relationship which would have been difficult to detect without the benefit of GIS assisted analysis.

INTRODUCTION

IMPACTS which may be individually insignificant can accumulate over time and space to cause significant environmental degradation. Hamann (1984), for example, reported the destruction of 4,000 ha of Florida wetlands over an 18-month period, all by projects legally permitted by state and federal regulatory agencies charged with protecting the wetland resource. Although the individual impacts were not significant enough to warrant permit denial, taken together they resulted in a substantial loss. The piece-meal degradation of natural resources through many individually insignificant activities is a common outcome of conventional environmental impact assessment. A cumulative approach to environmental impact analysis can help prevent such consequences.

Cumulative impact, the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions, has been an area of increasing national and international environmental concern (CEARC, 1986; Hirsch, 1988). The concept of cumulative impact was introduced a decade ago by the U.S. Council on Environmental Quality in their 1978 recommendations for implementing the National Environmental Policy Act (NEPA: 40 C.F.R. Sect. 1508.7). Although NEPA gave federal agencies the legal tool to consider environmental degradation in a context beyond an individual impact, the scientific tools and knowledge needed to implement cumulative impact (CI) assessments have been lacking until recently (Gosselink and Lee, 1987). The development of CI assessment tools has been ranked as the most pressing technical need for CI assessment by several federal agencies (Williamson *et al.*, 1986).

Geographic Information Systems (GIS) provide a practical means of conducting CI assessments because of their ability to compile, process, and evaluate data collected over a long time period for a large geographic area. Although GISs have been used for other types of environmental impact analysis (Campbell *et al.*, 1987; Foresman, 1987), there are few studies which have used GIS for cumulative impact evaluations. Walker *et al.* (1986) describe the use of a GIS to evaluate the cumulative impacts of gravel placement and road construction in the Alaskan tundra, but the types of indirect impacts found (i.e., flooding and melting of thermokarst) occur only in permafrost areas, and are directly observable on aerial photography.

Most cumulative impacts are neither as obvious as those studied by Walker *et al.* (1986), nor as easily attributable to a particular disturbance. Therefore, we have developed a CI assessment methodology which relates the mosaic of disturbed and undisturbed land in headwater watersheds to its cumulative effect on downstream water quality. The methodology combines current and historical water quality data, aerial photointerpretation, multivariate statistical analysis, and GIS techniques to evaluate the CI of wetland loss. Our method is an improvement over that of Walker *et al.* (1986) in that it empirically relates offsite effects (i.e., water quality) to the extent and location of the remaining resource (i.e., wetlands). The objectives of the study were (1) to evaluate GIS as a means of describing the past and present wetland mosaic for entire watersheds using parameters relevant to their cumulative water quality function; (2) to empirically relate GIS-derived data to measurements of stream water quality for those watersheds during a period of wetland loss; and (3) to draw conclusions about the importance of wetland abundance, type, and location in the watershed to downstream water quality measured at the watershed outlet. Objectives 2 and 3 are discussed in detail elsewhere (Johnston *et al.*, 1988a), and will only be summarized here. This paper focuses on the methods used to obtain, enter, manipulate, and analyze wetland and watershed characteristics using a GIS.

BACKGROUND

Cumulative impact assessment differs from conventional impact assessment by considering antecedent as well as current impacts, and by considering the entire resource within a region as a whole, rather than as individual parts. The region may range in size from 500 to 20,000 km² (Gosselink and Lee, 1987). Studies by the U.S. Army Corps of Engineers (1972), for example, have shown that wetlands in the 800 km² Charles River basin play a critical role in protecting downstream Boston from flooding. Therefore, additional wetland losses in the Charles River watershed would constitute a significant cumulative impact because of their collective functional importance to flood peak reduction. This is a regional function, not attributable to any individual wetland within the watershed. The resource is remote from the functional benefits it provides: most of the wetlands are tens of miles upstream from Boston, but their effect on flood peak reduction is transmitted downstream through the drainage network.

Cumulative impact assessment also considers the location of the resource in the landscape. The spatial distribution of wetlands relative to the drainage network is important because sediment and phosphorus accumulation is greatest in wetland areas within 20 m of streams (Johnston *et al.*, 1984). Likewise, nitrogen concentrations were significantly reduced in groundwater flowing through a 16-m stream riparian zone (Schnabel, 1986) and in surface runoff flowing from agricultural fields through 19 m of riparian forest (Peterjohn and Correll, 1984).

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 54, No. 11, November 1988, pp. 1609–1615.

0099-1112/88/5411–1609$02.25/0

A GIS is a powerful tool for cumulative impact evaluation because it can help analyze temporal change, provide a regional perspective, and evaluate the importance of landscape position. A GIS can be used to evaluate resource loss rates by comparing data layers representing different years (Plate 1a). This not only provides information about the magnitude of wetland loss, but also the location of losses. This type of data can be generated as a by-product of updating GIS data layers. For example, by using a GIS to record the location of permits issued for wetland drainage or filling under county shoreland zoning ordinances, the Wisconsin Department of Natural Resources is generating information about the rate and location of wetland losses in the state (Johnston *et al.*, 1988b). This kind of GIS record keeping can provide an institutional "memory" useful in monitoring the cumulative effect of permit issuance.

While quantification of resource losses is an important step in cumulative impact assessment, the loss of a resource is not in itself sufficient justification for permit denial. In order to be considered a significant impact under NEPA, a resource loss must "significantly affect the quality of the human environment." Therefore, resource managers must be able to reliably predict the ecological consequences of a resource loss in order to establish its significance. Our method uses GIS analysis of the resource mosaic to provide them with this capability.

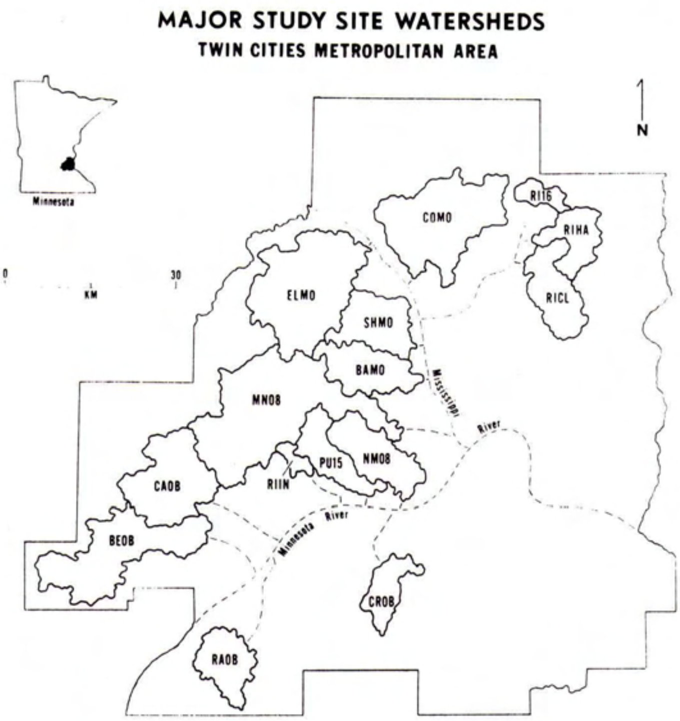

FIG. 1. Watershed study sites in the Minneapolis-St. Paul metropolitan area. Watershed codes are listed in Table 1.

TABLE 1. WATERSHED CODES AND AREAS.

WATERSHED	WATERSHED CODE	AREA (HA)
Bassett Creek	BAMO	10666
Bevens Creek	BEOB	21652
Carver Creek	CAOB	17370
Clearwater Creek	RICL	10222
Coon Creek	COMO	24456
Credit River	CROB	6221
Elm Creek	ELMO	27629
Hardwood Creek	RIHA	7296
Minnehaha Creek	MNO8	37496
Nine Mile Creek	NMO8	11683
Purgatory Creek	PU15	8538
Raven Stream	RAOB	8477
Rice Creek	RI16	2639
Riley Creek	RIIN	1559
Shingle Creek	SHMO	11391

LAND USE DATA COLLECTION

Fifteen watersheds covering 2,073 km^2 in the seven county Minneapolis-St. Paul metropolitan area were selected as study sites (Figure 1, Table 1). Wetlands in these watersheds have been subjected to a variety of developmental pressures from agriculture and rapid urban expansion. Because the primary objective was to relate wetland abundance and location to changes in water quality over time, watersheds were chosen for which historical aerial photography could be used to document ground conditions existing at the time of water quality data collection. A total of 37 watershed-years of data were available, each watershed-year representing a year for which *both* stream monitoring data and aerial photography were available for a given watershed.

Water quality data collected between 1957 and 1987 were obtained primarily from the STORET computerized database (U.S. Environmental Protection Agency, Office of Water and Hazardous Materials). Water quality data from individual sampling dates were weighted by sampling interval to produce time-weighted averages for nutrients, suspended solids, lead, fecal coliforms, and other water quality parameters using the following equation:

$$P_t = \frac{\sum_{i=1} (P_i \times t_i)}{\sum_{i=1} t_i}$$

where P_t = time-weighted average,
t_i = time interval between samples, and
P_i = individual measurement of a given parameter

Logarithmic and square-root transformations were used to improve the normality of data distribution and stabilize the variance.

Aerial photography was used to map wetland and non-wetland land use/land cover for each year for which water quality data were available (Table 2). Because our methodology is oriented toward land-use managers, our air photointerpretation and data entry methods were designed to provide the greatest amount of information per person-hour of effort, at a level of resolution suitable at the watershed scale. Mapping was done by U.S. Public Land Survey quarter-quarter sections, about 40 acres (400 by 400 m) each. The quarter-quarter section boundaries correspond well with land-use boundaries (e.g., roads, fields, fence lines, woodlot boundaries), so they are easily located on aerial photos. Although a clear mylar overlay gridded into 40-acre (400- by 400-m) cells was prepared for each photo scale, it was used primarily as a guide for locating the actual quarter-quarter boundaries on the photos. In this way, the ground location of each area mapped was exactly the same from year to year, despite air photo scale differences.

The land-use designation for each cell was determined by its major covertype: agriculture, forest, urban/residential, lake, or wetland. If the major covertype was wetland, it was further classified into one of nine wetland categories based on U.S. Fish and Wildlife Service criteria (Cowardin *et al.*, 1979). Although wetlands smaller than about 20 acres (8 ha) were not recorded, our methods did not appear to be underestimating total wetland

TABLE 2. AERIAL PHOTOGRAPHY USED TO MAP WETLANDS AND LAND USE.

YEAR	SCALE OF ENLARGEMENT	TYPE	SOURCE
1957	1:20,000*	B&W Panchromatic	ASCS
1966	1:12,000	B&W Panchromatic	Minneapolis-St. Paul Metropolitan Council
1968	1:24,000	B&W Panchromatic	Minnesota State Planning Agency
1970	1:9,600	B&W Panchromatic	Minneapolis-St. Paul Metropolitan Council
1975	1:24,000	B&W Panchromatic	Minneapolis-St. Paul Metropolitan Council
1980	1:24,000	B&W enlargements of CIR photos	National Wetlands Inventory (enlargements of National High Altitude Program photography)
1980	1:9,600	B&W Panchromatic	Minneapolis-St. Paul Metropolitan Council
1984	1:9,600	B&W Panchromatic	Minneapolis-St. Paul Metropolitan Council
1987	1:9,600	B&W Panchromatic	Minneapolis-St. Paul Metropolitan Council

* contact prints used.

area when compared with wetland area data reported by Oberts (1981) for some of the same watersheds. As land-cover determinations were made from the air photos, they were called out and recorded by a second person on 1:24,000-scale USGS topographic maps gridded into corresponding 400- by 400-m cells.

GIS ANALYSIS

Two raster format IBM PC/AT-based GIS were used to enter, manipulate, and measure the landscape data. An ERDAS GIS was used to digitize land cover, steam order (Morisawa, 1968), and watershed boundaries from the topographic quadrangles. Stream lengths were measured as vectors directly from the X, Y coordinates in the digitized stream order file, but were rasterized into 50- by 50-m pixels for merging with other databases. Land-cover data were originally digitized as 40-acre (400- by 400-m) parcels, but were also rasterized into 50- by 50-m pixels. Although this conversion did not increase the resolution of the actual data, it allowed the stream and land-use data to be overlaid, and was a more suitable pixel size for evaluating land use adjacent to wetlands and streams. EPPL7, a PC-based GIS developed by the Land Information Center of the Minnesota State Planning Agency, was used to read existing soils and topographic data files (100- by 100 m-pixels) from the Minnesota State Planning Agency, and to convert them to 50- by 50-m pixels. ERDAS was used to cut the individual watersheds from these regional data files. Data files were exchanged between ERDAS and EPPL7 using a program written by Anderson and Scheer (1987).

Our purpose in using GIS was to derive numerical descriptors for each watershed which could be empirically related to water quality. Therefore, data, rather than a map, were the primary output from the GIS analysis. The GIS was used to make area measurements for each variable and watershed-year (Plate 1b). These were compiled and summarized using a spreadsheet program (LOTUS 1-2-3). Watershed areas were expressed as hectares, but all other variables were expressed as percent of watershed area to facilitate inter-watershed comparison (Table 3).

The ability of the GIS to create a buffer zone around linear and polygonal features was used to quantify land uses adjacent to streams (Plate 1c) and land uses adjacent to wetlands (Plate 1d). Stream fringe area as a whole was expressed as a percentage of the watershed area, while different classes of stream fringe (e.g., stream order, land use) were expressed as a percentage of total stream fringe area (Table 3). Osborne and Wiley (1988) have used this technique to empirically relate stream water quality to streamside land use in an agricultural watershed.

Another parameter potentially important to wetland functions is wetland location within the stream drainage network. Relative wetland position, computed by subtracting the stream order of the wetland from the stream order of the watershed outlet, was used as a simple measure of wetland location in the watershed (Plate 1e).

Physical landscape characteristics, such as soil erodibility, soil permeability, soil phosphorus content, soil pH, watershed slope, and watershed elevation difference, were determined as the average value of all pixels within each watershed. Other topographic variables measured included maximum slope and maximum elevation difference. A sequential comparison index (Cairns *et al.*, 1968) was used to quantify the diversity of land use adjacent to the stream by dividing the number of runs (i.e., a string of adjacent pixels with identical classification) by the number of pixels bisected by the stream. Channel slope, watershed elongation ratio, and watershed compactness ratio (U.S.G.S., 1978) were measured and computed manually.

STATISTICAL ANALYSIS

Principal components analysis (Norusis, 1988) was used to reduce the 31 landscape variables, many of which were highly correlated with each other, to eight principal components (Table 4). These eight components explained 86.5 percent of the variance among the original variables. Principal component 1 (PC1) was related to wetland extent (i.e., wetland percentage of watershed area). Principal component 2 (PC2) was related to wetland position in the landscape, so that watersheds having wetlands concentrated close to the outlet had high PC2 values. Principal component 8 was related to the extent of marshy wetlands (e.g., cattail marshes) in the watershed. The other principal components were primarily related to upland watershed characteristics (Table 4).

The advantage of using principal components rather than the original landscape variables is that there are fewer variables and those variables are uncorrelated with each other. For example, because wetlands have negligible slope, those watersheds with abundant wetlands tended to have low average slope. The com-

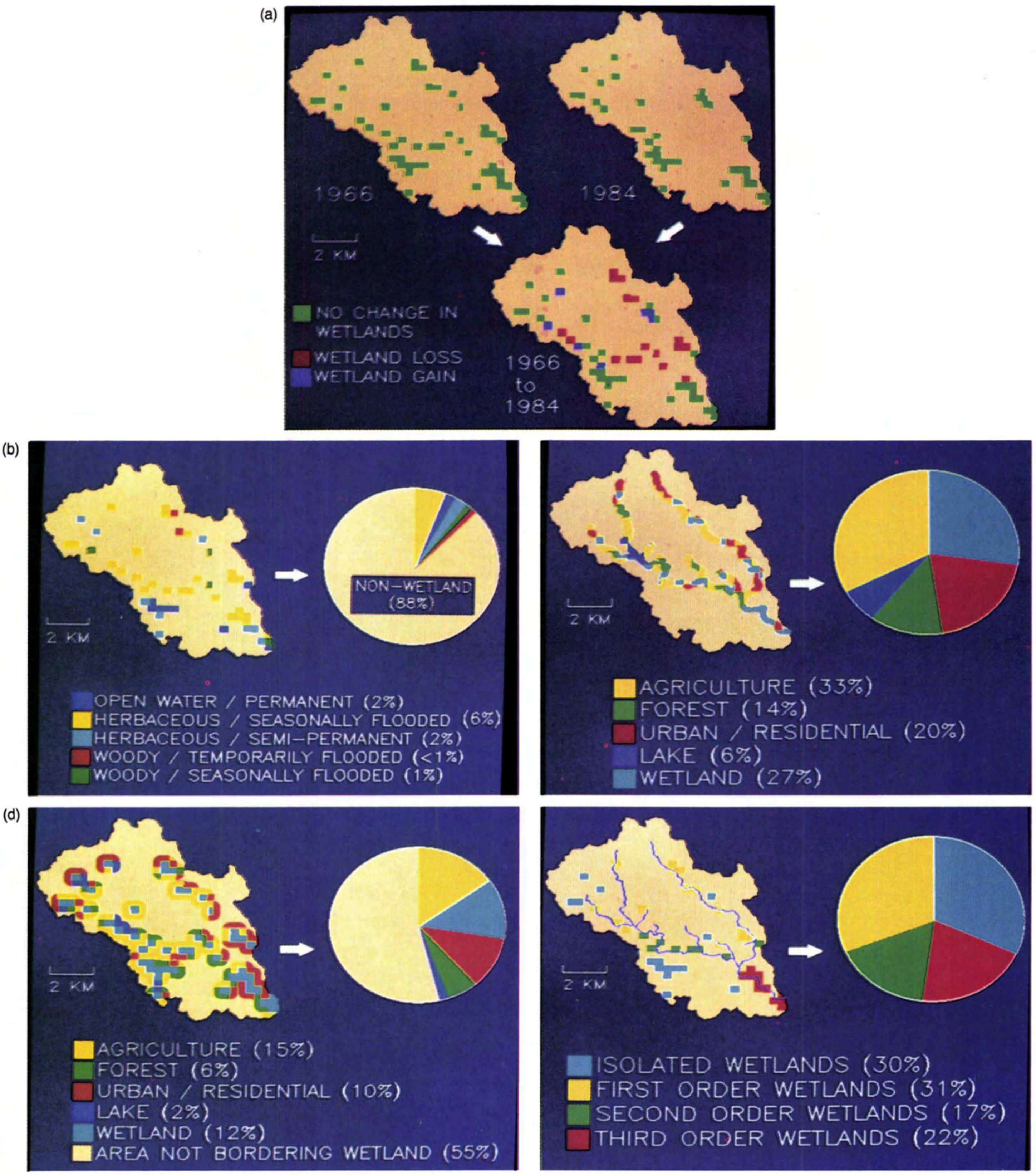

PLATE 1. (a) Use of a GIS trend analysis to determine wetland losses and gains in the Nine Mile Creek watershed. Information derived from aerial photographs taken in 1966 and 1984. Each pixel represents 400 by 400 m. (b) Wetlands in the Nine Mile Creek watershed as of 1966, by water regime (Cowardin *et al.*, 1979). Data are expressed as percentage of watershed area. (c) Stream fringe area in the Nine Mile Creek watershed as of 1966, by land-use/land-cover type. Stream fringe search radius = 175 m. Data are expressed as percentage of total stream fringe area. (d) Wetland fringe area in the Nine Mile Creek watershed as of 1966, by land-use/land-cover type. Wetland fringe search radius = 400 m. Data are expressed as percentage of watershed area. (e) Wetlands in the Nine Mile Creek watershed as of 1966, by relative wetland position (= stream order of the wetland minus stream order of the watershed outlet).

TABLE 3. VARIABLES USED TO QUANTIFY WETLAND AND OTHER LANDSCAPE CHARACTERISTICS. WETLAND AND LAKE FRINGE INCLUDES ALL LAND WITHIN A 400 M BAND LANDWARD OF THE WETLAND OR LAKE PERIMETER. STREAM FRINGE INCLUDES ALL LAND WITHIN A 175 M BAND ON EACH SIDE OF THE STREAM. %W = DATA EXPRESSED AS PERCENTAGE OF TOTAL WATERSHED AREA. %S = DATA EXPRESSED AS PERCENTAGE OF STREAM FRINGE AREA.

	CODE	UNITS
WETLAND VARIABLES		
Total wetland	WTLD	%W
Herbaceous wetland	HERB	%W
Herbaceous wetland, seasonally flooded	HERBSF	%W
Herbaceous wetland, semipermanently flooded	HERBSP	%W
Woody wetland, seasonally flooded	WDYSF	%W
Wetland/lake fringe	WLKEFR	%W
Wetland/upland fringe, agricultural	WAGRFR	%W
Wetland/upland fringe, urban	WURBFR	%W
Wetland position by stream order[a]	RELWTPOS	# stream orders
OTHER LANDSCAPE VARIABLES		
Total watershed area	AREA	ha
Lake fringe area	LAKE	%W
Stream fringe, agricultural	STAGRPFR	%S
Stream fringe, forested	STFORPFR	%S
Stream fringe, urban	STURBPFR	%S
Stream fringe, wetland	STWTLDFR	%S
Stream fringe, 1st order streams	STR1FR	%S
Stream fringe, 2nd order streams	STR2FR	%S
Stream fringe, 3rd order streams	STR3FR	%S
Stream fringe	STRFRG	%W
Sequential comparison index	SCI	runs/# seq'l pixels[b]
Average soil K-factor (erodibility)	KFCTR	—
Average soil surface permeability	SRFPRM	cm min^{-1}
Average available soil phosphorus	SOILP	Index (1-3)[c]
Average soil pH	SLPH	-log[H$^+$]
Average watershed slope	AVSLP	degrees
Maximum watershed slope	MAXSLP	degrees
Average watershed elevation difference	AVDIF	m
Maximum watershed elevation difference	MAXDIF	m
Channel slope	CHNLSL	m/km
Elongation ratio[d]	ELNG	dimensionless
Compactness ratio[e]	CMPCT	dimensionless

[a] average difference between stream order number of wetlands and stream order of sampling point
[b] run = number of adjacent pixels with identical classification
[c] qualitative ranking of available phosphorus in rooting zone based on interpretation of soil landscape units and geomorphic region: 1 = low, 2 = low to medium, 3 = medium
[d] ratio of diameter of a circle of equal area to the basin length
[e] ratio of perimeter of basin to circumference of a circle of equal area

TABLE 4. FIRST EIGHT PRINCIPAL COMPONENTS, AND THE ORIGINAL VARIABLES WITH WHICH THEY WERE SIGNIFICANTLY CORRELATED (P < .05).

Principal component rank	General interpretation of principal component	Correlated watershed variables
PC1	Wetlands extent	WTLD (+) STWTLDFR (+) HERB (+) HERBSF (+) WDYSF (+) AVSLP (−) STRFRG (+) MAXSLP (−) MAXDIF (−) CHNLSL (−) HERBSP (+) WFRG (+)
PC2	Wetland proximity	RELWTPOS (−) AREA (−) AVDIF (−) SCI (+) SOILP (+) STR3FR (−)
PC3	Agr/Urb land use	STURBPFR (−) WAGRFR (+) STAGRPFR (+) WURBFR (−) LAKE (+) WLKEFR (+) CMPCT (+)
PC4	3rd order-high diversity-soil pH	SLPH (−) STR3FR (+) SCI (+) WFRG (+) CMPCT (+)
PC5	Forested stream fringe	STFORPFR (−) STR2FR (+) STR1FR (−)
PC6	Elongated headwater watersheds	ELNG (+) STR1FR (+) STR2FR (−) CMPCT (−)
PC7	Forest/soils: erodibility permeability	KFCTR (−) STFORPFR (+) SRFPRM (+) CMPCT (−)
PC8	Herbaceous marshes	HERBSP (+) LKFRG (+)

mon effect of both variables is explained by PC1 because the variables are highly correlated. Because principal components are uncorrelated, they are independent of each other in regression analyses.

The eight principal components were used in stepwise multiple regression analysis to identify characteristics best related to the water quality data (Figure 2). The results showed that watersheds with a low proportion of wetlands in close proximity to the sampling site (i.e., low PC2 values) were significantly related ($p < .05$) to increased annual concentrations of inorganic suspended solids, nitrate, fecal coliforms, and specific conductance (a measure of the total concentration of ionic substances dissolved in water). Decreased wetland extent (PC1) was related only to higher annual concentrations of lead, chloride, and specific conductance. These results are consistent with site-specific studies which have shown wetlands to be sites of sediment deposition (Johnston *et al.*, 1984), denitrification (Nixon and Lee, 1985), fecal coliform reduction (Godfrey *et al.*, 1985), and heavy metal retention (Giblin, 1985), but illustrate that most of those effects are undetectable downstream unless the wetlands are concentrated near the sampling point. Thus, the cumulative effect of wetlands on regional water quality depends on the location of wetlands in the watershed. The results are discussed more fully in Johnston *et al.* (1988a).

CONCLUSIONS

These findings have important implications for assessing cumulative impact potential. Because proximal wetlands appear to be most beneficial to water quality maintenance, disturbances to those wetlands may result in greater cumulative impact to downstream water quality. Therefore, evaluation of wetland permit applications should consider wetland location as a factor

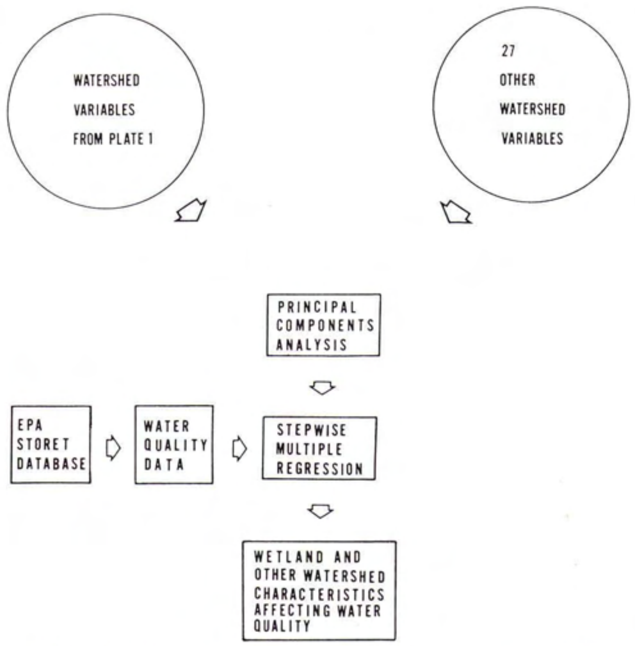

FIG. 2. Schematic diagram of GIS and statistical analysis process used.

contributing to potential cumulative impact. The use of GIS in combination with digitized stream and wetland maps (e.g., the National Wetlands Inventory maps currently being digitized by the U.S. Fish and Wildlife Service) provides an excellent means of incorporating this information into a cumulative impact assessment.

The use of a relatively coarse level of spatial resolution (400 by 400 m) allowed us to rapidly but quantitatively describe the 37 watershed-years. A total of 4826 km^2 were mapped at an average rate of 24.1 km^2/hr. This level of resolution was found appropriate for the scale and objectives of this project. The development of statistically significant empirical relationships at the watershed scale requires a large number of observations, each watershed-year representing a single observation for each landscape variable. Therefore, more watersheds, rather than more map detail, might have improved the results.

The GIS methodology used was shown to be a successful means of developing empirical relationships between a composite resource (wetlands) and water quality. Principal components analysis allowed us to uniquely describe complex watersheds using only eight variables. Although numerous landscape measurements were used to derive the principal components due to the exploratory nature of the research, only a few measurements would be needed once those empirical relationships were established. Resource managers may choose the simplest measurement from a list of variables that covary without having to measure all the variables considered here. For example, relative wetland position, the stream order of the wetland minus the stream order of the watershed outlet, may be a simple substitute for PC2 used here. Thus, even if resource managers lack the equipment or expertise to develop such empirical relationships, their assessments can still benefit from GIS-derived information about which data are necessary and which are superfluous.

This method worked well for evaluating the impact of wetland loss in the Minneapolis-St. Paul metropolitan area, and has applicability to a wide range of resources and impacts. We believe that GIS is an essential tool for cumulative impact evaluation, as well as any ecological assessment at the landscape scale.

ACKNOWLEDGMENTS

Michael Broschart, Bill Ballew, and John Ring assisted with air photointerpretation. The Minneapolis-St. Paul Metropolitan Council loaned the aerial photos used for wetland and land-use mapping. Gary Oberts of the Metropolitan Council was particularly helpful in study site selection. Kathy Swanda of the Minnesota Pollution Control Agency provided assistance with STORET access and use. Two consulting firms, Barr Engineering and Hickok and Associates, provided water quality data for several of the watersheds.

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency agreement EPA CR-814083-010 to the University of Minnesota, it has not been subjected to the Agency's review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

REFERENCES

Anderson, K. L., and B. W. Scheer, 1987. *A Program to Exchange ERDAS and EPPL7 Data Files*. Water Resources Research Ctr. Tech. Rep. 16. University of Minnesota, St. Paul, Minn.

Cairns, J. Jr., D. W. Albaugh, F. Busey, and M. D. Chaney, 1968. The sequential comparison index — a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. *J. Water Pollution Control Fed*. 40:1607–1613.

Campbell, W. G., G. D. Bishop, M. R. Church, J. J. Lee, D. A. Lammers, and L. H. Liegel, 1987. The Environmental Protection Agency's Direct/Delayed Response Project: The role of a geographic information system. *GIS '87. Second Annual International Conference on Geographic Information Systems, Proceedings (Vol. II)*. American Society for Photogrammetry and Remote Sensing, Falls Church, Virginia. pp. 456–467.

Canadian Environmental Assessment Research Council (CEARC) and United States National Research Council (NRC), 1986. *Cumulative Environmental Effects: A Binational Perspective*. Minister of Supply and Services Canada.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe, 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. Biological Services Program, U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Foresman, T. W., 1987. Present and future role of GIS technology for hazardous waste facility management. *GIS '87. Second Annual International Conference on Geographic Information Systems, Proceedings (Vol. II)*. American Society for Photogrammetry and Remote Sensing, Falls Church, Virginia. pp. 468–475.

Forman, R. T. T. and M. Godron, 1986. *Landscape Ecology*. John Wiley & Sons, New York.

Giblin, A. E., 1985. Comparisons of processing of elements by ecosystems. II. Metals. *Ecological Considerations in Wetlands Treatment of Municipal Wastewater*. (P. J. Godfrey, E. R. Kaynor, S. Pelczarski, and J. Benforado (eds.)) Van Nostrand Reinhold, NY. New York. pp. 158–179.

Godfrey, P. J., E. R. Kaynor, S. Pelczarski, and J. Benforado, 1985. *Ecological Considerations in Wetlands Treatment of Municipal Wastewater*. Van Nostrand Reinhold, New York.

Gosselink, J. G., and L. C. Lee, 1987. *Cumulative Impact Assessment in Bottomland Hardwood Forests*. Center for Wetland Resources Rep. LSU-CEI-86-09. Louisiana State University, Baton Rouge.

Hamann, R., 1984. Legal issues in water resource management. *Water Resources Atlas of Florida* (E. A. Fernald and D. J. Patton (eds.)), Institute of Science and Public Affairs, Tallahassee, Florida.

Hirsch, A., 1988. The regulatory context for cumulative impact research. *Environ. Management* (in press).

Johnston, C. A., G. D. Bubenzer, G. B. Lee, F. W. Madison, and J. R. McHenry, 1984. Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland. *J. Environ. Qual*. 13:283–290.

Johnston, C. A., N. Detenbeck, and G. J. Niemi, 1988a. The cumulative effect of wetlands on stream water quality and quantity: A landscape approach (manuscript).

Johnston, C. A., B. Marlett, and M. Riggle, 1988b. Application of a computer-automated wetlands inventory to regulatory and management problems. *J. Soc. Wetland Scientists* (in press).

Morisawa, M., 1968. *Streams: Their Dynamics and Morphology*. McGraw-Hill, New York.

Nixon, S. W., and V. Lee, 1985. *Wetlands and Water Quality*. U.S. Army Technical Report Y-85. Washington, DC.

Norusis, M. J., 1988. *SPSS/PC+ for the IBM PC/XT/AT*. SPSS Inc., Chicago, Illinois.

Novitzki, R. P., 1985. The effects of lakes and wetlands on floodplains and base flows in selected northern and eastern states. *Wetlands of the Chesapeake, Proceedings* (H. A. Groman, T. R. Henderson, E. J. Meyers, D. M. Burke, and J. A. Kusler (eds.)). Environmental Law Institute, Washington, D.C. ISBN 0-911937-19-6.

Oberts, G. L., 1981. Impact of wetlands on watershed water quality. *Selected Proceedings of the Midwest Conference on Wetland Values and Management* (B. Richardson (ed.)). Minnesota Water Planning Board, St. Paul. pp. 213–226.

Osborne, L. L., and M. J. Wiley, 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. *J. Environ. Mgmt*. 26:9–27.

Peterjohn, W. T., and D. L. Correll, 1984. Nutrient dynamics in an agricultural watershed: observations of the role of a riparian forest. *Ecology* 65:1466–1475.

Schnabel, R. R., 1986. Nitrate concentrations in a small stream as affected by chemical and hydrologic interactions in the riparian zone. *Watershed Research Perspectives* (D. L. Correll (ed.)). Smithsonian Institution Press. Washington, D.C. pp. 263–282.

U.S. Army Corp of Engineers, 1972. *Charles River Watershed, Massachusetts*. New England Division, Waltham, Massachusetts.

U.S. Geological Survey, 1978. *National Handbook of Recommended Methods for Water-Data Acquisition*. U.S.G.S. Office of Water Data Coordination, Reston, Virginia.

Walker, D. A., P. J. Webber, M. D. Walker, N. D. Lederer, R. H. Meehan, and E. A. Nordstrand, 1986. Use of geobotanical maps and automated mapping techniques to examine cumulative impacts in the Prudhoe Bay oilfield, Alaska. *Environmental Conservation* 13:149–160.

Williamson, S. C., C. L. Armour, and R. L. Johnson, 1986. Preparing a FWS cumulative impacts program: *January 1985 workshop proceedings*. U.S. Fish and Wildlife Service Biological Report 85(11.2).

Photogrammetric Society Winter Lecture Program United Kingdom 1988–1989

15 November 1988 – Annual General Meeting

to be followed by Remote sensing and Satellite Navigation: Complementary Tools of Space Technology

Various types of sensor will be used for earth observation in the era of polar platforms. At the same time, satellite navigation will become a widely used technique which should support remote sensing by its capability to determine orbit, position, velocity and attitude. Navigational systems can also benefit considerably from remote sensing systems and their capabilities. Basic concepts, technical solutions and practical applications will be reviewed and discussed.

13 December 1988 – Analytical Plotter Forum

A panel of representatives of Corporate Members will discuss user experience and answer questions from the audience.

17 January 1989 – Digital Restitution: Current Status and Future Developments

The current state of development and digital restitution systems is reviewed with examples and results from digital plotters and automatic correlation. The prospects for the future are discussed.

21 February 1989 – X-Ray Photogrammetry of Artificial Joints

The surgical revision of artificial hip and knee joints which have loosened after many years of use is demanding and absorbs almost as many resources as all the original replacements. Methods of X-ray photogrammetric measurement are reviewed and a technique will be described which is intended to identify potential loosening and lead to improved joint designs and surgical techniques.

23 February 1989 – CD ROM and Videodisc Technologies: Their Application in Mapping and Remote Sensing.

An afternoon meeting arranged jointly with the Remote Sensing Society and the British Cartographic Society.

9 and 21 March 1989 – Mapping for Development Corporations

A review of the background to and requirements for contract mapping on typical urban development sites. A joint meeting with the British Cartographic Society.

5 April 1989 – Geomorphology and Photogrammetry

A one-day symposium arranged jointly with the British Geomorphology Research Group.

For further information please contact

The Photogrammetric Society
Department of Photogrammetry and Surveying
University College London
Gower Street
London WC1E6BT
United Kingdom