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POLICY IMPLICATIONS OF GIS TECHNOLOGY FOR THE 1994 CLEAN WATER ACT AMENDMENTS

Abstract: Five recommendations are made regarding how GIS technology should be addressed in the 1994 Clean Water Act amendments. These include providing funds for geospatial data collection; acknowledging GIS as a tool for water resources management; requiring geospatial data collected with federal funds to adhere to national standards; promoting coordinated, quality-controlled monitoring and reporting methods to improve data interpretation; and including GIS development and training as valid research goals.

INTRODUCTION

Geographic information systems (GIS) have emerged over the last decade as powerful tools for the evaluation of environmental resources. HR 3948, the U.S. House of Representatives bill to amend and reauthorize the Clean Water Act (CWA), is currently being developed by the House Committee on Public Works and Transportation. Based on the authors' work together during the spring of 1994, this paper makes recommendations regarding the role of GIS in this legislation to facilitate the implementation of the Clean Water Act's objectives by federal, state and local agencies.

BACKGROUND

The U. S. Congress has a long history of developing legislation to protect the water resources of our nation, which began with passing the River and Harbor Act of 1899. For the past quarter-century, the Federal Water Pollution Control Act (more commonly referred to as the Clean Water Act) and funding authorized by it has caused substantial progress to be made in the control and reduction of point sources of water pollution. This success is attributable, in part, to the fact that point sources of pollution were identifiable and measurable, water treatment technology existed or feasibly could be developed, and responsibility for compliance was clearly delineated. Now, our next great challenge as a nation is to reduce nonpoint sources of pollution from agricultural water use and urban stormwater run-off. These problems are more complex, but may be addressed in part by the incorporation of GIS technology in Congress strategy for sensible utilization and preservation of national water resources.

The Federal Water Pollution Control Act Amendments of 1972 were a departure from previous water pollution legislation. Prior legislation had been based on the concept of maintaining minimum receiving water quality, that is, not degrading a water body below a minimum standard. In contrast, the objective of the 1972 Act was to "restore and maintain the chemical, biological, and physical integrity of the Nation's waters." The goals of the act were to eliminate discharge of all pollutants by 1985, and as an interim step, to restore the nation's waters to be suitable for swimming and fishing. To achieve these goals, Congress authorized about $56 billion in grants for the construction of wastewater treatment plants between 1972 and 1990 in Section 207. Congress continues to provide approximately $2 billion to states for revolving loan funds. In addition, the 1972 amendments gave the Environmental Protection Agency (EPA) the responsibility for issuing discharge permits, without which any discharge into the nation's waterways is prohibited, under the Section 402 National Pollutant Discharge Elimination System (NPDES) program. Although the Act's emphasis was on controlling *point* sources of pollution, area-wide management plans (Sec. 208) were intended to address *nonpoint* sources of pollution such as urban and agricultural run-off. Section 319, added in the 1987 amendments, required states to inventory waters which were not meeting water quality standards due to nonpoint source pollution, and develop plans to bring these waters into compliance. A total of $400 million for 1988-91 was authorized for appropriation for grants to states for implementation of these nonpoint source plans (Kovalic 1987).

Since the Act's inception, and through its major amendments in 1977, 1981, and 1987, the right and responsibility of the states to control water pollution has been maintained. Each state is to designate an intended beneficial use for each of its water bodies. For example, Lake Alpha might be designated as a drinking water supply, Estuary Beta for supporting fish and wildlife, River Gamma for swimming, etc. Every two years, states are required by Section 305 (b) to report to EPA the degree to which these designated uses have been attained using five categories: fully supporting designed use, threatened, partially supporting designated use, not supporting designated use, and not attainable. Due to the enormity of this task and competing management priorities, only a portion of the nation's waters are actually reported upon. In 1992, only 18% of the nation's river miles were assessed and reported upon (EPA 1994). The state-issued reports are compiled by the EPA into the National Water Quality Inventory which serves as a basis for assessment as to whether, as a nation, we are meeting our water quality objectives (Adler 1993).

THE 1994 CLEAN WATER ACT AMENDMENTS

Since the inception of the Clean Water Act, much progress has been made regarding the control of point sources of pollution. Now, of the nearly 222,000 river miles assessed as impaired in 1992, 72% are impaired by agricultural nonpoint pollution, and 11% are impaired by urban stormwater discharge. In contrast, only 7% of impaired river miles are attributable to industrial point sources (EPA 1994). Clearly, nonpoint source pollution is a large contributor to river impairment. HR 3948 would strengthen the Clean Water Act's approach to controlling nonpoint source pollution in several ways.

First, the amendments strengthen the existing nonpoint program (Sec. 319) by authorizing appropriations of $200 million starting in 1994, and increasing appropriations at a rate of $50 million per year to $500 million in 2000. This money will be used by states to develop and implement enforceable nonpoint pollution control programs.

Secondly, states are given incentives to adopt a *watershed planning approach* to pollution control with the addition of the proposed Section 322. The incentives include flexible use of funds authorized by other parts of the Act to implement the watershed plan; 10-year rather than 5-year NPDES permit cycles; the synchronization of permit cycles so all the permits in a watershed terminate at one time; and extension of the public review cycle of state water quality standards from a minimum of once every 3 years to once every 5 years. In addition, states can propose plans to control pollution at the most cost effective source using transfer credits. For example, instead of requiring a point source discharger to eliminate 100% of a particular pollutant's discharge, the state (or watershed authority) may allow the discharger to eliminate 80% of its discharge from that source, provided the discharger reduces discharge of the pollutant from another source by an amount equivalent to the remaining 20%. Thus, trade-offs can be made between controlling point and nonpoint sources depending on the most cost effective solution to meet the overall goals of pollution control in the watershed as a whole. This concept of trade-offs, or transfer credits, will contribute to a coordinated, holistic approach to restoring and protecting the ecological integrity of watersheds.

THE STATUS OF GIS AND DIGITAL DATA FOR WATER RESOURCES MANAGEMENT

A significant challenge inherent in HR 3948's emphases on watershed planning and on nonpoint source pollution control is the complexity of pollution control. There is a wide variety of variables affecting the ecological integrity of any watershed or region, causing the vulnerability of the nation's waters and soils to vary widely from region to region of the country (Kellogg 1992). Legislation which mandates blanket limits on urban stormwater runoff pollution or agrichemical application levels is not appropriate; such an approach is not sensitive to the differing needs of different geographic areas. Instead, HR 3948 recognizes that pollutants of concern and management strategies may be more effectively judged and controlled on a more local, watershed by watershed basis. This approach, though more complex than blanket mandates, now may be technically feasible because of advances in GIS technology and the growing experience and expertise of an emerging community of GIS users. GIS and environmental modeling techniques can be applied to watersheds (Figure 1) to help policy makers, issuers of permits, and the public

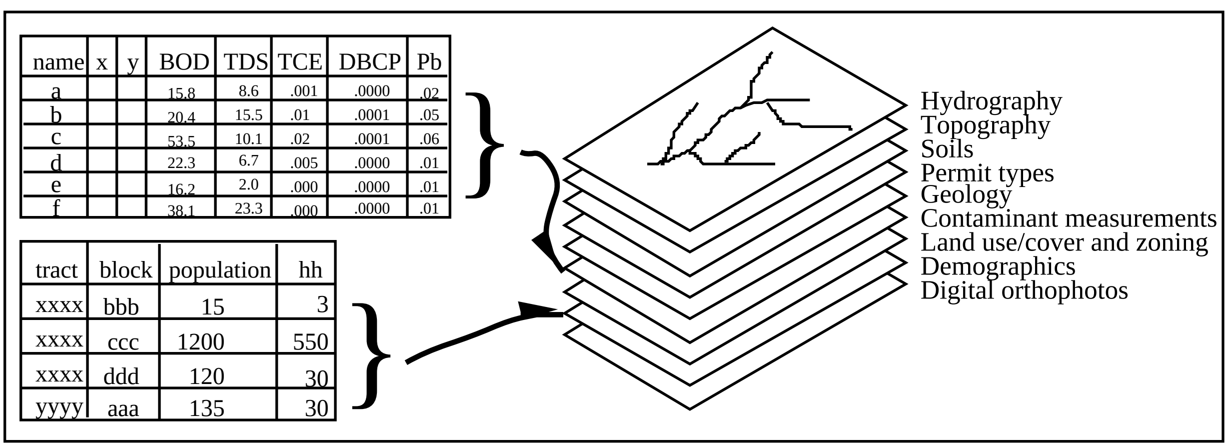

Figure 1. Watershed planning requires understanding the complex interaction of many features of the social, economic, natural, and built environments, which may vary substantially between geographic locations.

gain a better understanding of local and regional conditions and issues relevant to water quality management.

The important potential of GIS as a policy making tool for controlling water resources is widely recognized (Goodchild 1993; NRC 1993). An abundance of papers that demonstrate the value of GIS as a scientific problem solving tool appear in two recent conference proceedings (AWCA 1993; Adams 1993), and the text Environmental Modeling with GIS (Goodchild 1993). Maidment (1993) discusses GIS and watershed modeling particularly. As yet, there are few instances in which the scientific value of GIS technology has been explicitly acknowledged or incorporated in public policy (Fedra 1993). However, several examples will demonstrate the increasingly crucial role of GIS technology in federal, state, and local agencies for managing and evaluating geospatial water quality information.

The U. S. Geological Survey's (USGS's) biannual National Water Summary has reported on water resources on a state by state basis since 1983 to supplement EPA's biannual reporting requirement mandated by Section 305 (b) (USGS 1993). Information for this report is drawn from a GIS composed of the USGS's National Water Information System and EPA's STORET data base of monitored water pollution data. The data is presented on a state by state basis with clear maps indicating land use, population, physiographic divisions, hydrography, drainage basin delineations, monitoring station locations, and some water quality indicators. The National Stream Quality Accounting Network (NASQAN) and the National Water Quality Assessment program (NAWQA) are additional USGS programs which rely on GIS for data storage, analysis, and presentation (USGS 1993; Zelt 1991; Knopman 1993).

The Soil Conservation Service's (SCS) assessment and monitoring efforts with respect to the National Resource Inventory (NRI) are primarily directed to groundwater contamination, but have produced arguably one of the most valuable data sets in existence for water quality management. NRI includes data pertaining to nearly 200 variables including soil type, groundwater depth, land cover, slope, precipitation, etc. for about 200,000 sample points in the U. S. These data have been used primarily to evaluate the vulnerability of groundwater to contamination by agricultural run-off (Kellogg 1992). Unfortunately, because of confidentiality agreements, the SCS has been unable to release the geographic coordinates of the NRI data points, making the data unusable for applications outside of the SCS. This is particularly disturbing since the NRI data would be ideal for providing ground truth for EPA's cooperative land cover classification effort of a complete nation-wide 1992 satellite imagery coverage. This classified coverage could replace the badly outdated Land Use Land Cover (LULC) map from the early 1970s, potentially providing highly valuable, yet cost effective information to a broad range of GIS applications.

The SCS's 1:250,000 STATSGO soils data set also covers the entire nation and will prove to be valuable for many watershed management applications. Using orthophoto coverages, GIS efforts at local levels by the SCS are educating farmers to alter their practices so that damaging effects of agrichemicals are minimized.

In cooperation with the USGS, EPA has developed the River Reach III data coverage, which spatially represents most U. S. bodies of water. Its classification scheme uniquely identifies every stretch (or "reach") of water in the U. S., and is being continually refined. Also in cooperation with the USGS, stream flow data is being linked to the river reaches for which they are available. Using GIS techniques, EPA utilizes the Reach III data as a base map on which to display levels of various reported water quality parameters. Data reported to EPA in digital format reside in STORET, EPA's water quality data base. Unfortunately, quality control and statistical reliability problems with data reported to EPA currently prevent their more extensive use for water resources assessment and management.

Monitoring of water quality is a crucial part of water resources management. However, advancing GIS capabilities highlight the current lack of coordination and duplication of effort among monitoring agencies, and make obvious the need for better definition of monitoring needs and standards (ASIWPCA 1991). Monitored data are important, though expensive, spatial themes. Dependent upon the needs of particular locations, monitoring may include factors such as fish contamination levels, water constituents such as dissolved oxygen, polluting chemicals and metals such as DDT and lead, pathogen-indicating bacteria, biodiversity indicators, and changes in hydrologic structure such as damming and diversion practices (EPA 1994).

Increasingly, states, counties, and cities are using GIS to manage point and nonpoint pollution in watersheds and coastal zones. The New Jersey Department of Environmental Protection and Energy is using GIS to "prevent and evaluate the impact of point and nonpoint sources of pollution in both freshwater and coastal watersheds," (Garie 1994). The state of Oregon employs the powerful visualization and public communication capabilities of GIS by displaying water bodies in the state coded by their degree of attainment of designated uses (Adler 1993). The Counties of Los Angeles and Santa Clara, California, and the cities of Kansas City, Missouri, and Lynchburg, Virginia are examples of local government agencies using GIS in the context of NPDES permit compliance and stormwater management. (Lehman 1994; Teresi 1994; Barber 1994; Juhl 1994).

The established and emerging uses of GIS for pollution control, water quality monitoring, and watershed management highlight the utility of the technology for water resources management. The above examples have shown that federal agencies such as the USGS, SCS, and EPA, as well as agencies that report to the EPA throughout the country, are using digital data such as hydrology, land use, land cover, geology, soil types, topography, cadastre, population density, effluent constituents, and monitored water quality (including physical, chemical, and biological indicators). They are storing, analyzing, and visualizing this data using GIS and computer modeling technology for water resources management.

However, these efforts on their own are not enough to achieve the vision of significant, sustainable improvements in national water quality. At the federal level, we need to acknowledge the role that GIS will play in state and local agencies as a tool for watershed analysis, policy development, and communication. In this paper, we make five recommendations toward this end.

METHODOLOGY FOR DEVELOPMENT OF RECOMMENDATIONS

The methodology for developing recommendations consisted of performing telephone and in-person interviews with experts in GIS, computer modeling, and water quality monitoring from federal, state and non governmental agencies including EPA, USGS, SCS, National States Geographic Information Council (NSGIC), and others. Snowball sampling (using members of a specialized population to find others in the same population) was used to identify experts to interview. Approximately 25 interviews were performed. Interview questions differed from person to person depending upon their agency and area of expertise. The objectives of the questions were threefold:

1) to determine the level of use of GIS and computer modeling in water resources management at the federal, state, and local levels,

2) to survey the availability of data sets suitable for watershed management, and

3) to determine how HR 3948 could harness the potential of GIS technology to improve the nation's water quality by facilitating improved understanding and management.

Supporting documentation from the experts was provided in many cases. In addition, discussions with committee staff, literature review, and repeated readings and analysis of the original Act and HR 3948 provided essential background.

RECOMMENDATIONS

1. Use of nonpoint funds by state and local agencies for geospatial data collection.

Due to the inherent complexity of managing nonpoint sources of pollution, many state and local agencies do and will utilize GIS technology to integrate spatial data such as soil types, land use/cover, population density, etc. as a central part of their management efforts. Collection and development of geospatial data is, in many cases, a sensible part of performing watershed water quality management and nonpoint source pollution management. It is important to recognize that different watersheds can have vastly different data needs (Figure 2), so decisions regarding data requirements belong at the state and local levels. However, because the CWA currently does not explicitly allow the use of grant and other funds for geospatial data collection and development, EPA has, in the past, refused approval of States' plans to use funds in this manner (NSGIC 1994b).

	Watershed A	**Watershed B**
Size:	1000 sq. mi.	25 sq. mi.
Predominant Land Use:	agriculture and silviculture	urban and industrial
Example of most pressing spatial data needs:	digitization of existing maps: soils, geology, and land use.	digital orthophotos
Scale:	1:24,000 or 1:100,000	1:480

Figure 2. Every watershed has different characteristics, leading to different spatial data needs. Decisions regarding what data is needed at what scale can best be made at the watershed (local) level of analysis. To achieve national water quality goals, the federal government should explicitly allow nonpoint source pollution control funds to be used for geospatial data collection.

Under the nonpoint program, **the Act should allow the use of Section 319 (h) grant money for collecting and developing geospatial data.** If states and local agencies also adopt watershed management plans under the proposed Section 322, flexibility in the use of the Section 319 funds would enable the funds to be used for data collection pertaining to point sources and permit tracking as well. Legislative language should be drafted to include spatial data collection as a valid use of Section 319 (h) funds.

2. Acknowledgement of GIS as a water quality management tool

At the time of this writing, geographic information systems are not yet addressed in HR 3948 or the CWA. However, the watershed management approach to water quality control espoused by Section 322 implicitly assumes the use of GIS because this technology is the only known way to effectively integrate the broad range of interrelated geospatial variables affecting water quality in a watershed. One of the reasons that nonpoint source problems have not been successfully addressed in the past is the complexity of factors which contribute to a water quality problem. GIS and computer modeling help people understand the relationship of these complex influences.

The following water quality management activities depend on GIS to spatially integrate diverse geographic themes (NSGIC 1994a):

" * watershed management approaches
* coordinated permit and enforcement efforts
* nonpoint source control strategies
* combined sewer overflow problems
* toxic pollutant impacts
* groundwater/surface water interactions and interactions with sewer infrastructure
* definition of wellhead protection zones, aquifer recharge areas"

Because of its facility to manage and spatially integrate data required for watershed planning, **the potential of GIS use should be one of the points considered in watershed management program development.** Section 322 watershed programs should include a consideration or discussion of the potential of GIS and computer modeling as tools to assist in a coordinated management strategy to effectively control point and nonpoint source pollution (Figure 3).

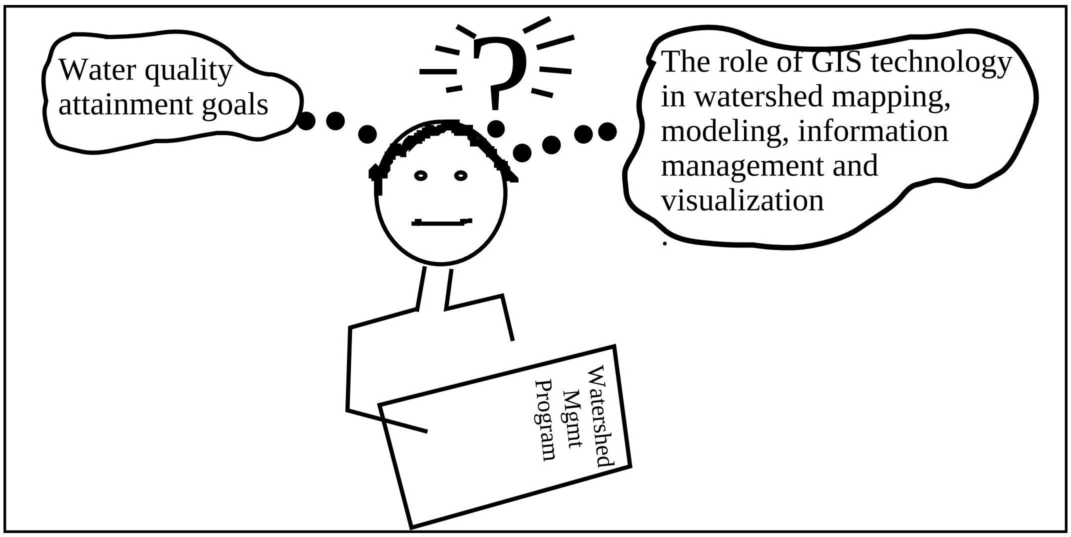

Figure 3. The potential role of GIS should be considered and discussed as part of watershed management program development.

This explicit acknowledgement of GIS in the CWA would affirm its value as a management tool, and ideally would prompt state and local agencies to budget for current and future use of GIS as a tool in their planning and permitting processes. *Actual use of GIS would* ***not be required*** by this provision. However, promising examples of successful GIS applications strongly suggest that GIS provides a cost effective, fruitful approach to managing point and nonpoint pollution. The added dimension of administering transfer credit permits makes GIS use even more sensible. Thus, legislation which requires states to consider and discuss GIS use as one of the minimum requirements for watershed management program approval should be drafted for inclusion in proposed Section 322 (b).

3. Encompass data collection in the national spatial data infrastructure

Without coordination, agencies collecting geospatial data might duplicate their efforts and miss opportunities for collaboration, with resulting waste of funds. This problem was recently addressed in President Clinton's Executive Order 12906 of April 11, 1994 (Clinton 1994). If federal funds are indeed used for spatial data collection as suggested by recommendation 1 above, the following should be implemented to avoid the duplication of data collection efforts:

(1) any **data collection activities that directly or indirectly use federal funds must be consistent with mapping standards** developed by the Federal Geographic Data Committee created by Office of Management and Budget (OMB) Circular A-16 (NRC 1993);

(2) the **collecting agency must register the data** by providing the Federal Geographic Data Committee's national clearinghouse (Clinton 1994) with the "metadata" of the collected data (including content description, geographic extent, ancestry and source, quality, data base schema, and accuracy). Thus, such data will contribute to the development of the National Spatial Data Infrastructure (NSDI), and its existence can be made known to others;

(3) to ensure that the collected digital spatial data maintains its value over time, and is collected in accordance with sound practice, EPA should develop **data management standards** for state and local agencies to follow in designing their own data management plans. The standards should address development of a data dictionary, a procedure for updating the data, and consideration of how the data will be used for trend analysis over time. This requirement is analogous to *designing* a building before it is *constructed*; thus certainly saving money and effort.

To address items (1) and (2) legislative language should be drafted to require federally funded spatial data collection to be consistent with Executive Order 12906. In addition, legislative language should be drafted that requires EPA to develop guidance for states to use in developing data management plans. This language would be linked to the authorization of funds in Section 319 (Figure 4).

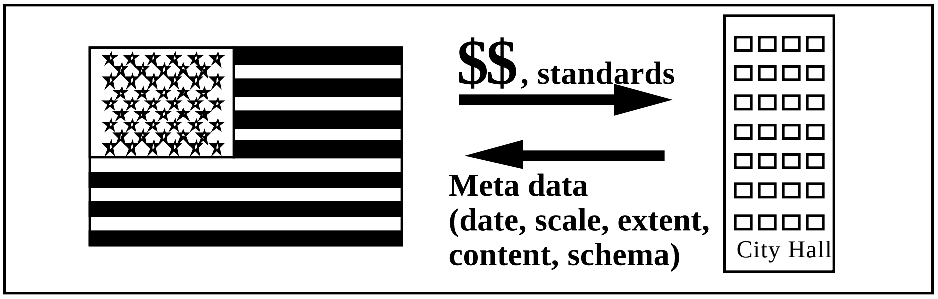

Figure 4. If federal money is used for data collection, it should be with the expectation that proper data collection standards and data management practices are followed to ensure the integrity and reusability of the data.

4. Improve ability to aggregate reported water quality and effluent data to regional and national levels, and increase quality control

Because the effluent and water quality data reported by dischargers to local agencies, by local agencies to states, and by states to EPA, are poorly standardized, they cannot be aggregated or compared (using a GIS) to give a picture of effluent and water quality trends at the regional or national level (Knopman 1993). Thus, as a nation, we have great difficulty assessing our progress toward eliminating pollution and making waters swimmable and fishable. To address these problems, there are quality control procedures, such as checking for reasonable ranges of values, which can be inexpensively automated. To check for expected continuity patterns of monitored data in stream reaches, data can be plotted in a GIS and outliers visually identified (Hewitt 1994). Such quality control checks would increase the validity of the reporting efforts, and allow subsequent users of reported data to aggregate and use such data with more confidence.

HR 3948 should require EPA to **require reporting agencies to use *standardized methods* to test constituent levels in effluent and water. Constituent levels should be reported in a *standardized format.* EPA should implement *quality control* procedures** to assure the quality of the data submitted to it by local and state agencies. These efforts would enable the creation of policy-relevant knowledge from raw data. These concepts are illustrated in Figure 5.

The bill that has been introduced to the Senate to reauthorize the Clean Water Act, S 2093, would add a paragraph to Section 305 to address the development of quality control standards by the Intergovernmental Task Force on Monitoring (ITFM). Similar legislative language should be drafted for inclusion in HR 3948 to require the use of standardized methods and reporting, and the implementation of simple quality control procedures to screen data reported to EPA under the NPDES program.

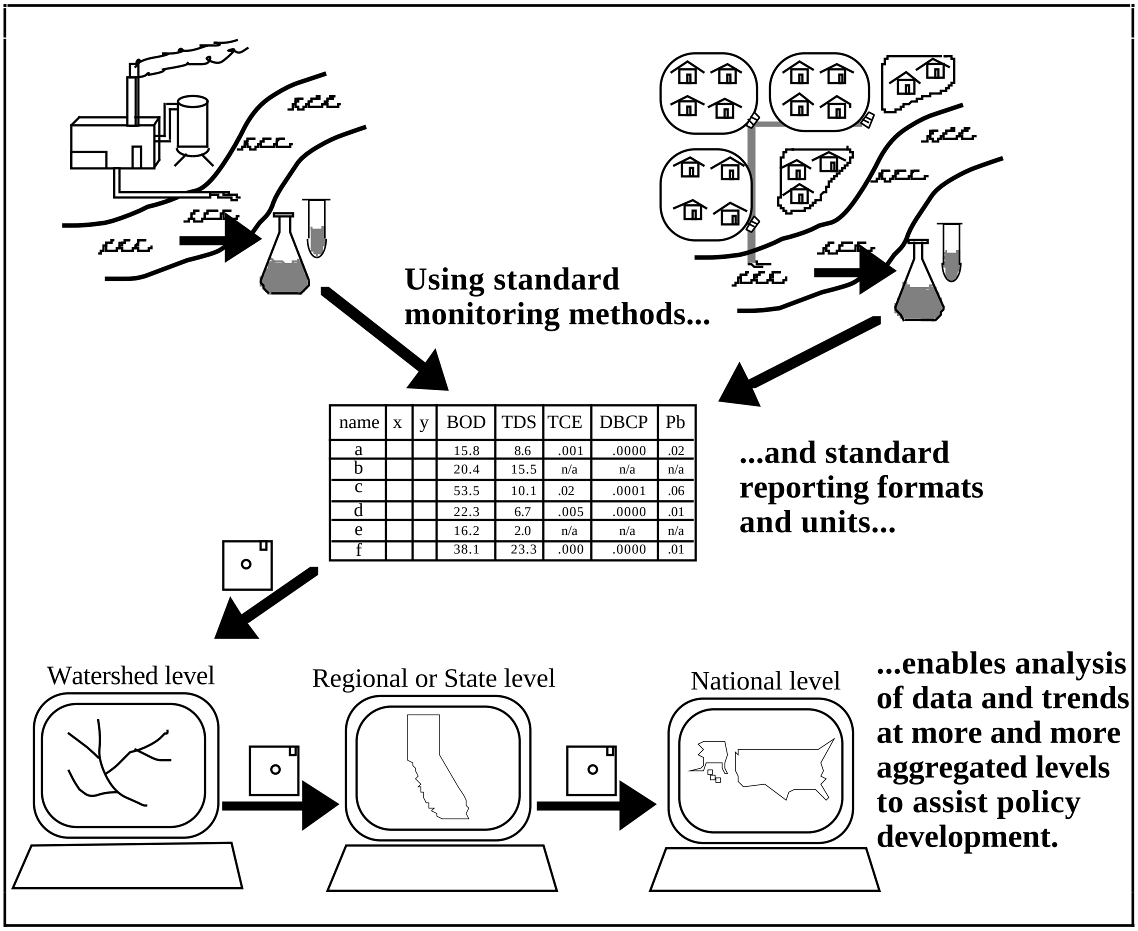

Figure 5. Standard methods should be used to gather water quality data. The measured data should be recorded and transmitted (via floppy disk or network) in standard electronic formats so they can be aggregated at the watershed, state, and national levels. Examples of data that, when aggregated, benefit policy makers include: 1) measured contaminant levels (e.g. metals, pesticides, conventional contaminants, etc.), 2) alternative water quality indicators such as biodiversity and ecosystem productivity, and 3) water quality attainment levels (meets designated use, threatened, partially meets, does not meet, etc.)

A related problem is that the constituents in effluent typically reported by dischargers are generally not related to the constituents in water typically reported by water quality monitoring efforts. Thus, efforts are thwarted which seek to use computer modeling techniques to establish cause and effect relationships between effluent sources and resultant water quality. Measured water quality constituents need to match reported effluent constituents and/or their chemical derivatives (as appropriate) to calibrate computer watershed models on an ongoing, periodic basis. The effluent constituents required to be reported by permit holders should correspond to water quality indicators. Water quality monitoring must mesh with the NPDES Permit Compliance System. However, important as these issues are, they are operational matters for EPA and the ITFM to address, and thus it is not appropriate to legislate solutions in this regard. Indeed, some steps have already been taken to address these problems by the ITFM (EPA 1994).

5. Research and development of computer models, GIS, user interfaces, and training programs to manage water quality

Watershed planning is an important goal of HR 3948. Due to the complexity of factors which influence water quality in a watershed, the use of computer models and GIS technology will necessarily play a central role in watershed planning by state and local agencies. However, current computer modeling efforts generally do not combine the behavior of point and nonpoint source water pollution in the same model, although certain models approach this concept (Srinivasan 1993). Little work has been done in the area of managing water pollution transfer credits in a watershed. In recognition of the role GIS technology may have in States' and local agencies' ability and effectiveness in performing watershed management, research should be pursued that seeks to concurrently simulate the behavior of point and nonpoint source water pollution in a watershed (Figure 1a). EPA, states, local agencies, and universities should research and develop computer models with links to geographic information systems that perform such simulations, and incorporate methods to calibrate such models with measured water quality to improve their predictive capability and usefulness for watershed management. Another need is to link policy alternatives to such models to understand their economic consequences (Bouzaher 1994).

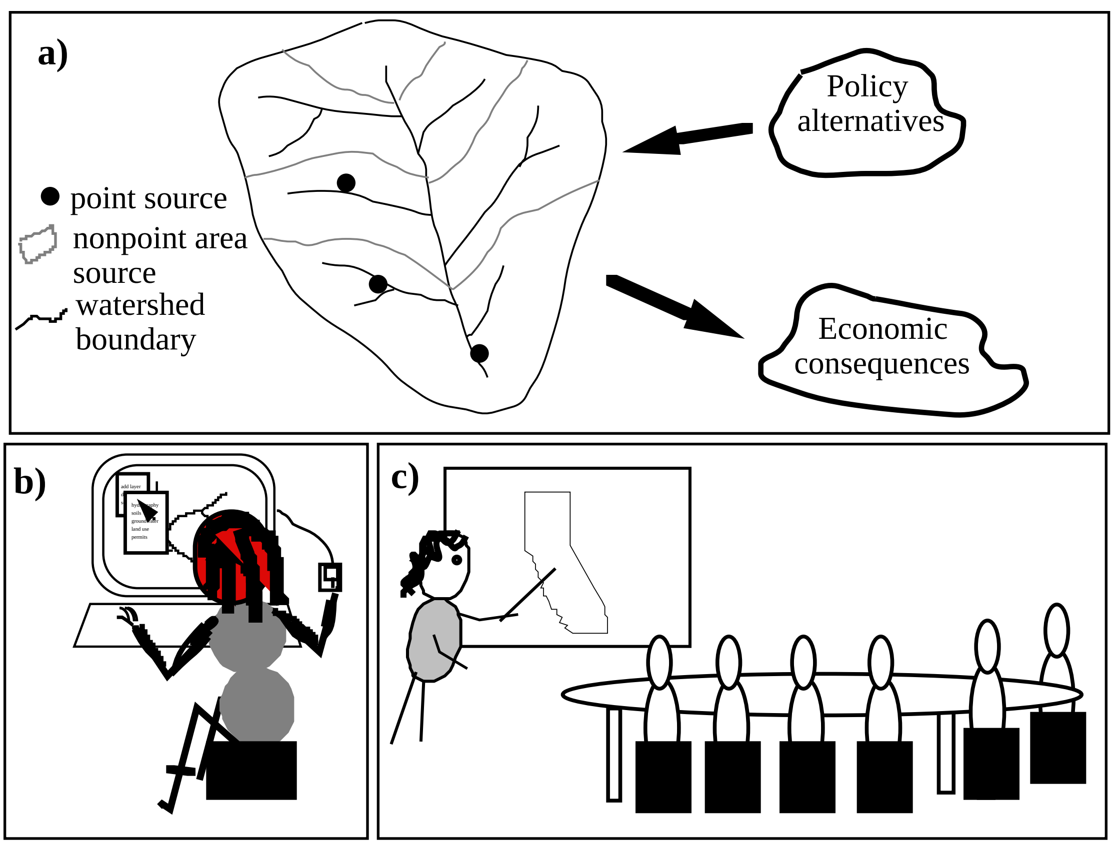

Figure 6. Suggested research to improve the use of computer technology in the context of the Clean Water Act includes a) watershed-wide analysis of point and nonpoint sources and the management of transfer credits, b) user interface development for viewing, analysis, and data management tasks, and c) the role of GIS for visualization, communication, and policy development. Training programs are needed in all three areas to increase the pool of knowledgeable GIS users.

User interfaces to perform simple map display, overlay, and analysis in a geographic information system context are at a youthful stage of development. It would be extremely expensive and wasteful for each local and state agency to develop user interfaces individually. EPA, states, local agencies, universities, and vendors should research and develop standard computer user interfaces for simple display, analysis, and permitting tasks in a geographic information system computer environment (Figure 6b).

Finally, the effectiveness of GIS as a tool for visualization (Srinivasan 1991) and communication deserves attention (Figure 6c).

In alignment with the development of these GIS techniques, models, and user interfaces, is the essential issue of their dissemination. Computer technology for watershed management is a very young field, with very few experts and very few trained users. Thus, training programs to increase the number of knowledgeable users is paramount. Seminars and other types of outreach can be used to disseminate the developed techniques to state and local agencies. An example of an innovative partnership that uses local, state, and federal and non governmental agency funds to finance research and training efforts is the Texas Water Resources Partnership in Temple, Texas (Jones 1994).

Section 104 of the CWA provides for research into a variety of issues relevant to the Act's implementation. Some generic language which expands the scope of acceptable research topics to include computer-oriented research may be appropriate. However, it is not appropriate to use the law to dictate the type of research to be performed.

Instead, the legislative report should be used to communicate this intent to EPA. The legislative report is based on congressional debate and is developed in conjunction with the amendments to HR 3948 as the bill evolves through the legislative process. This report will be used to convey the intentions of the Act as amended by HR 3948, including the intentions of the legislators regarding specific research objectives. Report language should specify that research is needed to further develop watershed modeling and GIS user interfaces, and that training programs are needed to disseminate the results of this recommended research.

CONCLUSION

Our investigation yielded evidence of the significant potential of GIS to improve and preserve the quality of the nation's water resources. Based on the investigation, five recommendations were made for incorporating GIS into the Clean Water Act's strategy for assessment and monitoring of water resources. These recommendations include providing funds for geospatial data collection; acknowledging GIS as a tool for water resources management; requiring geospatial data collected with federal funds to adhere to national standards; promoting coordinated, quality-controlled monitoring and reporting methods to improve data interpretation; and including GIS development and training as valid research goals. It is important to note that we do not envision a role for GIS in enforcement; the science (and art) of GIS use is too young and inexact (Walker 1994).

At the time this paper is being written, no one can predict the outcome of the efforts of Congress and President Clinton to pass a reauthorization of the Clean Water Act. In addition, it is too early to tell what the reaction of lawmakers will be to the specific recommendations made in this paper. For what reasons will they be adopted or rejected? What lessons will we learn that might help future efforts to incorporate GIS in policy development? Continuing to follow the fate of these recommendations may alert GIS proponents to the attitudes of lawmakers regarding this powerful, beneficial, and growing area of technology, and may highlight issues on which more education of policymakers is required.

REFERENCES

Adams, D. B., Harlin, J. M., and Lanfear, K. J., editors, Geographic Information Systems and Water Resources, Conference Proceedings, March 14-17, 1993, American Water Resources Association, Bethesda, Maryland.

Adler, R. W., J. C. Landman, and D. M. Cameron, The Clean Water Act 20 Years Later, 1993, Island Press, Washington, D. C.

Barber, J., *"Stormwater analysis using GIS,"* abstract, 1994 URISA conference, Milwaukee, WI.

Bouzaher, A., P. T. Dyke, M. Burkart, R. Kellogg, *"A proposal for the development of a system of models for evaluating regional environmental and economic effects of alternative farming systems in the midwest,"* 1994, Iowa State University and others, unpublished proposal submitted to CSRS.

Bouzaher, A., J. F. Shogren, *"An integrated systems approach to regionalization with application to atrazine and water quality,"* pages 306-309 of Agricultural Research To Protect Water Quality: Proceedings of the Conference.

Braun, K. D., *"Changing the Clean Water Act: Congress Kicks off the Debate,"* March 1994, Environmental and Energy Study Institute, Washington, D. C.

Clinton, President W. J., *"Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure, Executive Order 12906 of April 11, 1994,"* Federal Register Vol. 59, No. 71, April 13, 1994.

Eddy, John A., *"Environmental research: What we must do,"* Chapter 1 of Goodchild, et al, Environmental Modeling with GIS, 1993, Oxford University Press, New York.

Environmental Protection Agency (EPA), The Quality of Our Nation's Water: 1992, March 1994, Office of Water, Washington D.C., EPA841-S-94-002.

Fedra, K., *"GIS and environmental modeling,"* Chapter 5 of Environmental Modeling with GIS, 1993, Oxford University Press, New York.

Garie, H., and Cummen, P., *"Watershed management in New Jersey: the role of GIS,"* abstract, 1994 URISA conference, Milwaukee, WI.

Goodchild, Michael F., B. O. Parks, L. T. Steyaert, Environmental Modeling with GIS, 1993, Oxford University Press, New York.

Goodchild, Michael F., *"The state of GIS for environmental problem solving,"* Chapter 2 of Environmental Modeling with GIS, 1993, Oxford University Press, New York.

Hewitt, M., telephone communication, March 17, 1994.

Jones, Allen, *"Texas Water Resources Partnership,"* 1994, Blacklands Research Center, Temple, TX.

Juhl, G. M., *"GIS helps Lynchburg Meet Combined Sewer Overflow Mandate,"* Jan. 1994, Public Works.

King, J. L., and Kraemer, K. L., *"Models, facts, and the policy process: the political ecology of estimated truth,"* Chapter 34 of Environmental Modeling with GIS, 1993, Oxford University Press, New York.

Kovalic, Joan M., The Clean Water Act of 1987, 1987, Water Pollution Control Federation (WPCF), Alexandria, VA.

Kellogg, Robert L., Maizel, M. S., Goss, D. W., Agricultural Chemical Use and Ground Water Quality: Where Are the Potential Problem Areas?, USDA and National Center for Resource Innovations, Dec. 1992.

Knopman, D. S., and R. A. Smith, *"Twenty years of the Clean Water Act: has U. S. water quality improved?"* Environment, Vol. 35, No. 1, Jan.-Feb. 1993.

Lehman, D., *"Building a GIS,"* abstract, 1994 URISA conference, Milwaukee, WI.

Maidment, David R., *"GIS and hydrological modeling,"* Chapter 14 of Environmental Modeling with GIS, 1993, Oxford University Press, New York.

National Research Council, Toward a Coordinated Spatial Data Infrastructure for the Nation, 1993, National Academy Press, Washington, D. C.

National States Geographic Information Council (NSGICa), comment document on submittted to the Water Resources Subcommittee, April 1994.

National States Geographic Information Council (NSGICb), telephone communication with H. Garie, April 25, 1994.

Peck, D. L., *"Keynote speech: Geographic information systems and water resources,"* Geographic Information Systems and Water Resources, Conference Proceedings, March 14-17, 1993, American Water Resources Association, Bethesda, Maryland.

Rejeski, David, *"GIS and risk: A three-culture problem,"* Chapter 30 of Environmental Modeling with GIS, 1993, Oxford University Press, New York.

Rogers, B., Slesinger, S., and Kopocis, K. *two documents internal to the Water Resources and Environment Subcommittee, Public Works and Transportation Committee of the United States House of Representatives summarizing the HR 3948 amendments to the CWA,* April 1994.

Savage, R. and L. Eichmiller, Association of State and Interstate Water Pollution Control Administrators, *"Monitoring,"* testimony before the U. S. House of Representatives Committee on Public Works and Transportation Subcommittee for Water Resources, May 8, 1991.

Soil and Water Conservation Society, Agricultural Research To Protect Water Quality: Proceedings of the Conference, Feb. 21-24 1993, Minneapolis, MN.

Srinivasan, R., and B. A. Engel, *"GIS: a tool for visualization and analyzation,"* 1991 Winter Meeting, American Society of Agricultural Engineers, Chicago, IL.

Srinivasan, R., J. Arnold, R. S. Muttiah, C. Walker, P. T. Dyke, *"Hydrologic Unit Model for the United States (HUMUS),"* Advances in Hydo-Science and -Engineering, Volume 1, editor Sam S. Y. Yang, ISBN 0-937099-02-3.

Sutton, J. D., *"Measuring effectiveness of management systems to reduce agricultural nonpoint source of pollution,"* pages 282-283 of Agricultural Research To Protect Water Quality: Proceedings of the Conference.

Teresi, J., City of Palo Alto, personal communication, May 9, 1994.

Tchobanoglous, G., Schroeder, E. D., Water Quality, 1985, Addison Wesley, Reading, Massachusetts.

Tosta, N., personal communication, March 24, 1994.

United States Congress, *"Federal Water Pollution Control Act, (33 U. S. C. 1251 et. seq.)"*, reprinted in Compilation of Selected Water Resources and Environmental Laws, U. S. Government Printing Office, Washington, 1993.

United States House of Representatives, *"Amendment in the Nature of a substitute to H. R. 3948,"* April 21, 1994.

United States Senate, *"S. 2093 [Report No. 103-257] To amend and reauthorize the Federal Water Pollution Control Act, and for other purposes,"* May 10, 1994.

United States Geological Survey, National Water Summary, 1983, 1984, 1985, 1986, 1987, 1988-89, 1990-91, U. S. Government Printing Office, Washington, D. C.

Walker, C., personal communication, April 21, 1994.

Zelt, R. B., *"GIS technology used to manage and analyze hydrologic information,"* GIS World, Aug. 1991.

ACKNOWLEDGEMENTS

We express our sincere gratitude to the GIS and computer modeling experts throughout the country who took the time and energy to contribute their knowledge and experience to this effort. The staff of the Water Resources and Environment Subcommittee kindly nurtured and coached the first author in their offices during the late winter and spring of 1994. Karen Rose has been especially helpful. Chairman Norman Mineta of the House Public Works and Transportation Committee initially approved the undertaking of this effort, for which we are grateful. Prof. James Leckie and Paul M. Teicholz of Stanford University, and Dave Matson and Chip Eitzel at the City of Palo Alto also encouraged and motivated this effort.