MULTIPLE USES OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN CUMULATIVE EFFECTS ASSESSMENT (CEA)[a]

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ABSTRACT

Due to spatial and temporal considerations in CEA, GIS can be a useful tool within such studies. The uses can range from addressing temporal land use changes, to describing declines or recoveries of habitat types in the study area. GIS information can also be used in predictive modeling of historical, current, and future cumulative effects. Further, such GIS information can be used in planning local mitigation and regional management programs. Brief information from over 20 case studies illustrating these uses are described herein. Further, it should be noted that CEA usage is a natural outgrowth of GIS usage in the EIA process. These case studies provide illustrations of the use of GIS as a tool for presentation of both historical and current baseline information and the identification and analysis of direct and indirect effects from the proposed project, as well as cumulative effects from both the proposed project and multiple other actions in the study area. It can also be noted that larger geographic scale CEA studies which require regional analyses are typically more conducive to the use of GIS. Based on the legal system in the USA, it was also found that the use of GIS is currently been seen in favorable light when the topic appears in litigation. Finally, as GIS tools and skills become more practical and widespread, the use of this technology in CEA practice will be expected to increase.

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a Presented at Assessing and Managing Cumulative Environmental Effects, Special Topic Meeting, International Association for Impact Assessment, November 6-9, 2008, Calgary,Alberta, Canada.

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INTRODUCTION

Geographic information systems (GIS) refer to systems used for storing, retrieving, analyzing, and displaying spatial data (Joao, 1998). Since their initial usage in the 1960s, GISs have evolved as a means of assembling and analyzing diverse data pertaining to specific geographical areas, with spatial locations of the data serving as the organizational basis for the information systems. The structure of GISs is built around locational identifiers and the methods used to encode data for storage and manipulation. This paper deals primarily with computer-based or digital GISs. A digital GIS may be defined as a GIS wherein a major part of the device which does the processing is a computer. Numerous systems have been developed primarily for land-use planning and natural resources management at the urban, regional, state, and national levels of government. These types of systems can be used in environmental impact assessments (EIAs) at project and regional scales. Further, they can be an important tool in cumulative effects assessments (CEAs) at both scales.

FUNDAMENTAL INFORMATION ON GIS

Any GIS application and/or operation contains five essential elements: data acquisition; preprocessing; data management; manipulation and analysis; and product generation (Star and Estes, 1990; Antenucci, et al., 1991; and Canter, et al., 1994). Data acquisition refers to the process of identifying and gathering the data required for the application. Environmental data to be gathered are typically available in different forms that include maps and tabular and digital formats. After data gathering, the procedures used to covert a dataset into a suitable format for input into the GIS is called pre-processing. Data format conversion, such as digitization of maps and printed records and recording this information into a computer database, is the key step in preprocessing. Preprocessing also includes map projection, data reduction and generalization, error detection, and interpolation. Usually, data sets are manipulated before and after entering into the computer in such a way that they are referenced to a common geodetic coordinate (e.g. Universal Transverse Mercator (UTM)), orientation and scale.

Another element which is central to GIS is data management. The GIS software for database management provides users with the means to define the contents of a database, insert new data, delete old data, identify database contents and modify the contents of the database (Star and Estes, 1990). The datasets can be manipulated as required by the analysis. Some of the operations used in data manipulation are similar to those used in pre-processing. Many types of analyses are possible within a GIS; among these are mathematical combinations of layers, Boolean operations and, with external programs using the GIS as a database, complex simulations.

Another advantage of a GIS is the ability to perform sensitivity, or “what-if”, analyses. For example, in Boolean operations, if an investigator wanted to look at the effects of changing a criterion such as depth to ground water, it is a relatively simple matter to ask the GIS database to indicate locations where depth to ground water is between 0 and 10 meters, or between 10 and 20 meters, and so forth. Finally, the structure of a GIS contains software for displaying maps, graphs, and tubular information on a variety of output media; this enables the user to maximize the effect of results presentation. By storing all layers in a common format based on a spatial distribution, maps of input values, intermediate results, and final products may be generated at the same scale and orientation for clarity of analysis.

There are two types of GISs, depending on the method of data storage. These are referred to as raster-based or vector-based systems. In raster-based systems, the area of interest is divided into grid cells, or pixels (short for "picture elements"), and each cell or pixel has a single value for each layer in the database. Thus, a given cell (spatial location) could have a value of 6 in the land cover layer, meaning grassland, a value of 3 in the soil type layer, representing silty clay loam, and a value of 4 in the land surface slope layer, representing a 10 to 12% slope. Raster-based GISs are suited to input of remotely sensed digital data because those data are typically raster-based when recorded in an airplane or satellite. A commonly used example of this type of GIS would be Imagine, Inc.'s ERDAS software. Vector-based systems have the entities stored as points, lines, or polygons. Thus, an area of open land would be described by the vectors constituting its boundaries; a stream would be described by its linear course. This type of database is better suited to analog input, such as topographic sheets. One example of a vector-based GIS is ESRI, Inc.'s ARC/INFO software. Map layers are typically called "coverages", with each coverage showing selected attributes.

In describing the use of GIS in the EIA process, the World Bank (1995) noted three necessary components of a system – hardware (computer) and software (commercial programs for data layering and displays, and for integrating selected data into predictive models); the input data which could be derived from satellite remote sensing, aerial photography or digitized surveys, land use studies, etc.; and human resources as represented by trained and knowledgeable persons relative to the hardware, software, data, and modeling. These three components would also be requisites in using GIS as a tool in CEA.

GIS APPLICATIONS IN THE EIA PROCESS

Within recent years the application of GIS technology to the EIA process has steadily increased. Relative to typical EIA phases, GIS can have application, either directly or as a supporting tool, to all of them. To illustrate, Table 1 lists specific ways in which GIS could be used in various phases (after Joao and Fonseca, 1996). In addition, GIS can be used as a tool in follow-on impact monitoring, project management, and adaptive management. More specifically, Eedy (1995) described the EIA process usefulness or GISs relative to: (1) data management; (2) data overlay and analysis relative to site impact prediction, wider area impact prediction, corridor analysis, cumulative effects analysis, and impact audits; (3) trend analyses; (4) integration into impact models such as chemical or radio-nuclear dispersion and pathway models, climatic change models, and decision analysis using the Multi-Attribute Tradeoff System; (5) habitat analysis using the Habitat Evaluation Procedures; (6) aesthetic resources and impact analysis; and (7) public consultation.

Table 1: Examples of the Possible Usage of GIS in Various Stages of the EIA Process (after Joao and Fonseca, 1996)

Phase	Possible Usage of GISs
Screening and scoping	Useful in data gathering, spatial modeling, calculation of impact magnitude, and impact assessment.
Description of the project	Relationship of project to geographical context
Description of baseline conditions	Documentation and display of biophysical inventories (for example, vegetation, habitat, land use, etc.), hydrology, soils, archaeological and historical resources, land ownership, topography, roads, utilities, and others.
Impact identification	Use of overlay analysis to display pollutant distributions with resource maps or to integrate the results of air quality modeling and habitat suitability analysis.
Prediction of impact magnitude	Use for quantitative assessment of the percentage of resource base affected by a pollutant. Also, can create impact magnitude maps derived from the integration of the results of risk and air quality modeling with other data layers such as soil susceptibility to acidification.
Assessment of impact significance	Useful for spatially displaying the impact significance and how that variation changes with different alternatives, including the "do nothing" option.
Impact mitigation and control	Can be used to identify areas where mitigation measures should be applied. GISs can also be used to show the geographical location and the extent of mitigation activities over time.
Public consultation and participation	GISs can be used for preparing presentation material, to explain the project to the public, and also to allow a quick response to questions and suggested changes.
Monitoring and auditing	Can use GISs for designing monitoring programs, for processing and storage of monitoring data, for the comparison of actual outcomes with predicted outcomes, and for data presentation showing the variation of the location of pollutants with time.

Examples of study situations which are conducive to the use of GISs in EIA include:

- the necessary data can be used beyond the EIA process;
- complex environments (systems) need to be addressed and can be used to show system relationships;
- presentation of baseline environmental information
- impact identification and evaluation
- when PCs are available for usage [GIS are now available in user-friendly formats on PCs];
- when project-related and environmental information is not static;
- when a possible legal action may occur;
- when there is a need for consensus building resulting from the discussion and analysis of scenarios;
- when an audit trail is needed to reconstruct a decision;
- when there is a need for "creating data" for different scenarios and the use of professional judgment in their analysis; and
- when there is a need to link spatial attributes of the receiving environment to changes in spatial attributes of emitting environment.

Development and implementation of a GIS for use in the EIA process typically involves identification and conceptualization, planning and design, procurement and development, installation and operation, and review and audit (World Bank, 1995). This development and implementation process needs to be carefully planned if the benefits of a GIS as a data management tool are to be fully realized.

EXAMPLES OF GIS USAGE IN EIA

Some specific illustrations of how GISs can be used within the EIA process include:

- for pre-project and post-project "model" applications;
- as a communication tool (for the EIA study team, project proponent, stakeholder groups, the general public, and decision makers)
- to demonstrate siting opportunities or constraints (inclusive or

exclusive); such siting could involve sanitary landfills, gas pipelines, road alignments, etc.

- for scenario building and testing (to answer "what if" questions relative to project size and features, and for accident analysis);
- to display environmental system relationships (for example, the acidity of rain and watershed consequences, or ground water/surface water relationships);
- for modeling of species distribution/diversity and related influencing factors such as habitat characteristics;
- to analyze the contribution of diffuse sources or pollution (nonpoint sources) to receiving streams and lakes;
- to develop watershed management strategies based on problem assessment and prioritization;
- to explore human health risks (relative risks) in terms of where people live;
- to analyze disease vectors and prioritize controls;
- to display visual impacts on viewsheds;
- to explore risk management options;
- as an aid in defining spatial and temporal boundaries for the impact study (this is particularly important in CEA); and
- to display time snapshots of discrete or continuous events (the historical and future timelines).

GIS APPLICATIONS IN CEA

CEA typically requires the analysis of large complex data sets involving multiple actions, environmental resources and their selected indicators, and impact-causing factors associated with the spatial and temporal distribution of the actions. A potentially useful tool in CEA is GIS, because such systems have the ability to store, manipulate, analyze and display large sets of complex, geographically referenced data and are therefore well suited to spatial applications of this nature and complexity (Warner and Diab, 2002).

Layers of data are frequently used for presentation of historical to current environmental information. Such layers can be combined or eliminated for specific analyses or displays. Further, areas of environmental constraint, as reflected by selected indicators, can be easily identified. Combining various layers can be accomplished via the assignment of different importance or vulnerability weights. These assignments can be made via the use of a consistent weighting scheme described by Saaty (1977). Further, relative to environmental planning, buffers can be designated around intrusions, such as power lines or access roads, or around sensitive areas, such as nesting habitats (Warner and Diab, 2002).

Because the GIS tool is dynamic in that new environmental information can be added over time and space, and importance weights and protected areas can be modified, it is particularly useful in evaluating planning options (e.g., site or route locations). Further, GIS can be used to display the consequences of multiple actions, thus it is particularly useful in continuing CEA in designated areas or regions. However, it should be noted that the time required to prepare the database, the initial costs of the hardware and software, and the data collection and conversion (to digital format) costs can be deterrents to the application of this tool in every CEA study.

Potential Benefits of Linking GIS with CEA

In a discussion of primary and special methods for analyzing cumulative effects, the USA Council on Environmental Quality identified traditional overlay mapping and current GIS as one of seven primary tools (Council on Environmental Quality, 1997). Specifically, GIS can be used to effectively incorporate locational information into CEA, with the initial emphasis being related to the establishing both spatial and temporal boundaries for the study. Further, selected indicators of landscape and other environmental features (such features can be referred to as Valuable Ecosystem Components – VECs) can be used to identify both vulnerable resources and areas where the effects will be the greatest. Overlays generated by the GIS can be based on either, or both, the accumulation of effects in certain areas, and the relative suitability of various land units for development. Accordingly, the strengths of GIS within CEA include: (1) information assemblage and use relative to spatial patterns and proximity of effects, resource fragmentation, and established protection areas for species and cultural resources; (2) facilitation of effective visual presentations within EAs and EISs; and (3) demonstration of resource vulnerability which can, in turn, be used to optimize development options. Limitations of the GIS method can include: (1) the absence of specific attention to indirect effects; and potential difficulties in addressing the magnitude of cumulative effects from multiple past, present, and future actions. GIS is commonly used in land use planning, thus it can easily be extended to CEA. In this sense, decision-makers can be more effectively informed when considering cumulative effects and both development and environmental restoration plans and projects.

Linkages of CEA Steps with GIS

Blaser, et al. (2004) have identified how GIS can be used to assist the accomplishment of each of the steps in the CEQ's 11-step process for CEA (Council on Environmental Quality, 1997). Table 2 summarizes how GIS could be used in CEA studies related to growth associated with transportation infrastructure (Blaser, et al., 2004). As can be seen, the GIS tool can be used in some manner for each of the 11 steps.

GIS, CEA, and the Federal Courts

The topic of GIS use in CEA has not been widely tested in the federal courts, even though there is ample evidence that GIS has become very common for environmental resource analyses. For example, Li, et al. (2007) reviewed seven leading North American Forestry Journals and found that the usage of GIS analysis has grown by more than an order of magnitude from 3 (1976-1980 time frame) to 122 (2001-2005). Somewhat surprisingly, there are very few court challenges questioning the use of GIS for CEA (Figure 1).

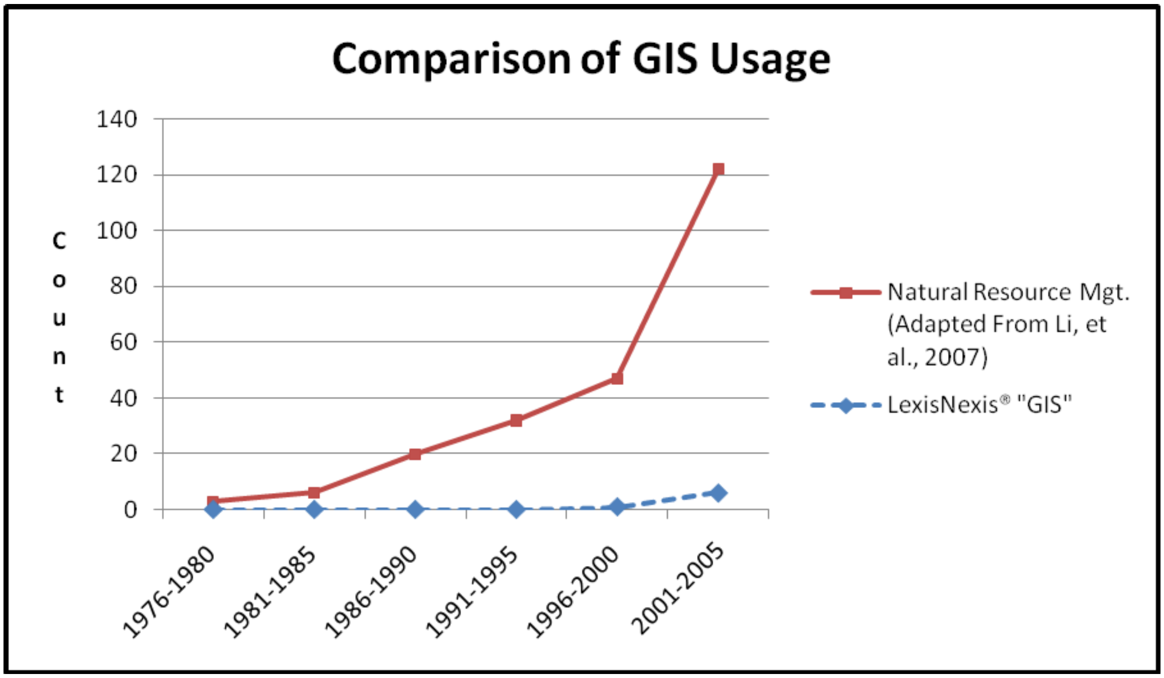
A LexisNexis® search of the U.S. federal court system (district courts, appellate courts, and the Supreme Court) reveals that the first litigation involving NEPA where the court's decision even mentions GIS is a 1998 case where the Navy and Marine Corps was sued by a group over the lack of preparing an EIS rather than an EA for proposed military housing (Surfrider Foundation vs. John Dalton, U.S. Secretary of the Navy, et al., 1998). In that case, a GIS had been used to catalog 60 years of aerial photographs, 70 years of water resource data and 25 years of natural and cultural resource data. The court was satisfied that the military had met NEPA's alternatives analysis requirement, based in part on the GIS data that were utilized.

Further LexisNexis® searching showed that of the 3380 results for "National Environmental Policy Act", 496 (14.6%) referenced cumulative effects, and only 9 (<2%) of those cases also referenced GIS (Table 3). These data indicate a continually increasing amount of litigation concerning NEPA work, and the increasing proportion of those cases that address CEA. The tool of GIS however, seems to have largely remained outside the courts deliberations in these cases.

It currently appears that in the eyes of the federal court system, using GIS for cumulative effects analysis is an acceptable tool. In Kettle Range Conservation Group vs. USFS, 2001, GIS was used to estimate impacts of a wide range of alternatives. The court ruled that GIS analysis helped satisfy NEPA's requirement to examine all reasonable alternatives to meet the stated purpose and need of a bark beetle infestation recovery plan. Further, the court found that a GIS based erosion/ sedimentation model provided a sufficient "hard look", one of the primary tests that the federal courts impose on NEPA cases. In Oregon Natural Resources Council Fund vs. BLM, 2004 (and its subsequent reversal and remanding in 2006), the court found that the Bureau of Land

Table 2: GIS Activities Associated with CEA Steps (after Blaser, et al., 2004)

CEA Steps	GIS Activities
1. Identify the significant cumulative effects issues associated with the proposed action and define the assessment goals.	Identify which VECs and their indicators have available data which can be used in a GIS, including metadata.
2. Establish the geographic scope for the analysis.	Collect data for selected VECs and their indicators, recognizing that the impact zones may be different for different resources (e.g., water, air, land uses, habitat types, human population density, etc.) Enter such data into a GIS database.
3. Establish the time frame for the analysis.	GIS data which are available for the past and present provide the means to track historical changes, and make forecasts of possible future conditions.
4. Identify other actions affecting the resources, ecosystems, and human communities of concern.	Create GIS overlays to depict the area of proposed action and identify impact zones, including effects from past, present, and reasonably foreseeable future non-project actions. Create maps aggregating all relevant activities.
5. Characterize the resources, ecosystems, and human communities identified in scoping in terms of their response to change and capacity to withstand stresses.	Use historical and remote sensing data sources to assess past resource responses to stresses. For example, resource responses could include changes in land use, habitat types, and human population density.
6. Define a baseline condition for the resources, ecosystems, and human communities.	Create a list of resources (VECs and their indicators) within the study area. Collect or create individual data layers for each VEC or indicator to be analyzed for a particular point in time.
7. Characterize the stresses affecting these resources, ecosystems, and human communities and their relation to regulatory thresholds.	Create overlays such as Habitat Suitability Indices (HSIs) or analyze historical trends to predict future impacts.
8. Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities.	Create overlays such as Habitat Suitability Indices (HSIs) to analyze historical trends and predict future impacts.
9. Determine the magnitude and significance of cumulative effects.	Perform selected map overlays and combinations thereof to determine aggregated impact levels. Compute spatial statistics of effects and compare with thresholds of significance.
10. Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects.	Perform local and regional analyses for all actions, including no-action, through use of overlays, various GIS functions, and computer simulation as appropriate.
11. Monitor the cumulative effects of the selected alternative and adapt management.	Perform periodic time-series analyses for comparison to baseline status. Such analyses will be in the post-EIS period. Adapt operational features of the adopted action so as to minimize adverse cumulative effects on specific VECs and their indicators.



<u>Figure 1</u>: Indication of GIS's prevalence and growth in natural resource literature, and the limited number of federal court cases that discuss the use of GIS in cumulative effects analysis for NEPA analysis

Table 3: Federal Court Cases Concerning NEPA, CEA and GIS

Dates	NEPA	Cumulative Effects (% of NEPA)	GIS (% of cumulative effects)
< 1975	313	16 (5.1%)	0
1976 – 1980	428	32 (7.5%)	0
1981 – 1985	435	32 (7.4%)	0
1986 – 1990	310	43 (15.5%)	0
1991 – 1995	317	48 (15.1%)	0
1996 – 2000	342	54 (15.8%)	1 (1.9%)
2001 – 2005	556	127 (22.8%)	6 (4.7%)
2006 – 2008	679	144 (21.2%)	2 (1.4%)

Management’s use of GIS was an appropriate way to examine the effects of timber harvesting alternatives on spotted owls. Although a few small errors in the GIS data base were uncovered, the court determined that BLM adequately took a “hard look” by using, in part, GIS. In Cascadia Wildlands Project vs. Scott Conroy, Rogue River-Siskiyou National Forest Supervisor, 2006, the court decided that GIS analysis, coupled with aerial photography, modeling and monitoring reports, adequately replaced ground-based, site specific soil surveys and fulfilled the “hard look” requirement in preparation of a management plan impact assessment. In Oregon Natural Desert Association vs. BLM, 2006, a GIS based wilderness inventory was prepared by the plaintiff in 2005 and provided to the agency during public review. The court determined that this constituted “new information” over the previous inventory prepared by the agency in 1992 and that it should have at least been considered by agency in its decision making process, stating "[t]o ignore all the documentation provided by ONDA's inventory efforts flies in the face of civil discourse.".

CASE STUDIES DEMONSTRATING USAGE OF GIS IN CEA

While the use of GIS is not a frequent topic in litigation, its use is clearly visible in environmental analyses, and its use is becoming very common for analysis trying to examine the cumulative effects of multiple projects. This section includes referrals to over 15 case studies wherein GIS was used in CEA.

Wetlands, Water Quality, and Modeling

GIS can be a valuable tool for assessing current study area wetlands conditions resulting past and other present actions. Such assessments can be based upon the development of empirical relationships between resource loss and environmental degradation. Johnston, et al (1988) described such a study in the Minneapolis-St. Paul metropolitan area. The study involved the use of aerial photo interpretation, multivariate statistical analysis, and GIS techniques to relate past and current wetland abundance with time-related stream water quality. Further, the study demonstrated the importance of wetland position in the watershed relative to the influence of local water quality.

Johnston also described several means by which GIS could be a useful tool for analyzing cumulative effects to wetlands in a watershed. Specifically, the following five examples were noted (Johnston, 1994, p. 54):

- GISs can depict cumulative impacts that affect wetlands both directly (e.g., the location of logged areas within wetlands) and indirectly (e.g., upstream sources of water pollution).

- Information on cumulative impacts can sometimes 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, information about the rate and location of wetland losses can be generated.

- A GIS can be used to analyze cumulative effects over time. For example, a GIS can be used to quantify wetland alteration by comparing wetland maps representing two different points in time and measuring rates of wetland change.

- A GIS can also be used to evaluate how wetlands function as landscape components, something that is difficult to assess in any other manner. A variety of quantitative measures are easily calculated with a GIS in combination with a suitable wetland map; examples include: loss of wetland area, decrease in number of wetlands, decrease in density of wetlands, decrease in connectivity, loss of wetland types, loss of wetland function, etc.

- GISs linked to watershed models also aid in analyzing the landscape-level role of wetlands because they can simulate the direction and magnitude of fluxes between pollutant sources (e.g., nonpoint-source runoff from farm fields) and sinks (e.g., wetlands).

Soil Erosion Contributions to Cumulative Water Quality Effects

Agricultural area runoff waters containing eroded soil, fertilizers and pesticides can be a major contributor to cumulative nonpoint source pollution loading in local and downstream surface waters. Remotely sensed data, GIS, and hydraulic modeling can be utilized to predict such loadings. The loadings will be a function of numerous variables, including land slope, soil and crop type, rainfall intensity, and chemical application rates. Accordingly, the water quality impacts of new agricultural projects, and modifications to existing ones, can be predicted by such a GIS-modeling approach. Further, the effectiveness of combinations of best management practices (BMPs) in reducing nonpoint source loadings can also be determined. To illustrate, a Water Erosion Prediction Project (WEPP) used a GIS-modeling approach to evaluate cotton and soybean crop-lands along the St. Francis River in northeast Arkansas (Stauber, Baker, and Daniels, undated). BMPs commonly used in Arkansas row crop agriculture were evaluated in each of 40 fields as eight statistical treatments. WEPP runoff simulations from cotton BMPs ranged from 100,488 to 132,391 m^3/yr. Simulations for soybean BMPs ranged higher, being from 181,535 to 278,042 m^3/yr. Runoff was significantly reduced in cotton and soybean systems using continuous cover con-tillage and continuous cover no-tillage with filter strips, respectively. WEPP soil loss simulations from continuous cover con-tillage cotton were reduced by 91.7 to 92.1% as compared to conventional tillage. Simulations of soil loss from continuous cover no-till soybeans were reduced by 61.5 to 62.7% as compared to conventional tillage. Accordingly, GIS technologies and available remote sensed databases provided detailed measurements for appropriate characterization of the St. Francis watershed study areas. The linking of remote sensed data and hydraulic models offers a rapid assessment for environmental planning of sensitive areas to meet compliance of nonpoint source sediment control. Further, although not addressed in this example, GIS-modeling of other nonpoint source loadings in a defined study area could be used to determine the cumulative loading from all sources in a CEA-focused study.

Pollution Potential for a Drinking Water Reservoir

Atrazine is a major agricultural herbicide which can move, via nonpoint runoff, from areas of application to nearby streams, rivers, and reservoirs. Atkinson, et al., 2001, addressed this situation in a practical study which documented the occurrence of atrazine in a large drinking water reservoir in the Dallas-Fort Worth area serving more than 3 million people. The study was based on the use of remotely sensed satellite imagery and GIS modeling, to analyze the spatial distribution of land use, soil erodibility, and surface slope information in the watershed study area. This information was aggregated via an atrazine pollution potential (APP) model based on assigned importance weights and ratings for the three data layers (Atkinson, et al., 2001,). The model results compared well with spatially-positioned atrazine measurements in the reservoir's watershed. Accordingly, sub-watersheds with higher APP scores were identified for the application of suites of best management practices. In this example, GIS was used for both mapping the key variables in the model and for modeling the three variables in relation to in situ water quality measurements.

Estuarine Modeling

Finally, university-based research has been conducted on the combined usage of environmental modeling with GIS. For example, Wijayanto (2002) examined the use of water quality modeling in an estuarine zone involving the Barker Inlet and Port River in South Australia. GIS was used to support the presentation of the modeling results. Scoping was used to delineate historical current, and future activities which have or could result in estuarine changes, establish spatial and temporal boundaries for the study, and select four water quality indicators for modeling (ammonia-nitrogen, total-nitrogen, chlorophyll a and phosphate). Hydrodynamic and water quality modeling was accomplished via the usage of two accepted computer-based models. The spatial and temporal characteristics of the modeling were used to establish that cumulative effects were occurring within the study area (due to both space crowding and time crowding). These results were then combined with qualitative information through scaling and weighting to determine the significance of the total cumulative effects. Synergistic effects were also demonstrated when estuarine dredging was conducted. Finally, it was noted that the combined modeling-GIS approach was data intensive, thus its usage would be limited to spatially unconstrained areas with robust available monitoring data.

Wildlife Species and Habitat

From the viewpoint of data layers within a GIS, such layers can be used to correlate measures of disturbance to various actions, and then relate those disturbances to impacts on VECs. Relatively large areas can be readily examined and quantitative results produced. To illustrate, GIS applications could include the determination of (Hegmann, et al., 1999, p. 33): area of land cleared (causing removal of vegetation and disturbance to soils); distances between (or overlap of) effects from other actions on natural features; length and density of road access; area of land in which wildlife are subject to sensory alienation; area of wildlife habitat lost or of reduced capability; degree of habitat fragmentation; and changes in any of the above between various planning scenarios.

A common application of GIS in CEA involves the assessment of loss and fragmentation of wildlife habitat. This approach was used in CEAs in four case studies described in the Canadian CEA Practitioners Guide (Hegmann, et al., 1999, p. 34), the Trans-Canada Highway Phase IIIA, Eagle Terrace, Cold Lake Oil Sands and Cheviot Mine projects. In each of these cases, a system of ecological land classification or vegetation community mapping was used within the regional study area. These types were then translated into habitat suitability, for terrestrial species, which was mapped to indicate areas of low, moderate and high suitability. When superimposed on a map of disturbances (e.g., the proposed action, roads, powerlines, other industrial activity), the area of habitat lost was determined. More specifically, this approach was used to address cumulative effects on elk habitat and grizzly bear for the Cheviot coal mine project. A specific GIS-based model for the grizzly bear is described in Stenhouse, et al., undated. A similar approach was used for elk, wolf, and Swainson's thrush in the Eagle Terrace project (Hegmann, et al., 1999, App.B). Accordingly, this GIS-based approach (along with air and water quality models) can provide defensible tools for assessing large-scale changes on a specific VEC and associated indicators.

Military Installations

Over the last decade military services in the United States have embraced the use of GIS within land use planning, facilities and utilities management, training area planning and management, and emergency planning and response. Further, GIS has become a foundational tool used for environmental, natural resources, and cultural resources management. Examples of these foundational uses include (Keys, et al., 2002):

- For environmental and natural resources management – inventory valuable resources (VECs), provide maps and data in support of NEPA compliance documentation, create and analyze site suitability constraint data layers, depict sources of pollution and ecological restoration sites, display noise levels for the installation, support analyses related to endangered species locations, natural resources and forestry management actions, pest management, and provide basic support related to environmental compliance reporting requirements.

- For cultural resources management – inventory archaeological sites and historic structures, enhance the coordination of cultural resource investigations with the State Historic Preservation Office (SHPO), link digital reports, photography, and scanned drawings/documents to archaeological sites and historic structures for virtually instantaneous background research, create site predictive models for archaeological surveys, and display viewsheds for historic districts or significant structures.

Each of the above foundational uses could also be included in a CEA study at the installation level. Such uses could be displayed as layers in a GIS, and then combined, as appropriate, to address the cumulative effects of multiple past, present, and future actions on specified VECs and their indicators. Further, GIS can aid the selection of spatial and temporal boundaries for a CEA study, as well as displaying known and anticipated information both spatially and temporally.

Power Line (Transmission Line) Routing

Warner and Diab (2002) have described a post-EIA study wherein one of the objectives was to compare the optimum power line route as identified by usage of a GIS method with that recommended within the original EIA. The EIA case study involved the routing of an overhead power line in an area where a large variety of biophysical and socially sensitive characteristics exist; their existence presented an enormous challenge in the identification of a suitable power line route. GIS was used to aid the identification of potential power line routes and the selection of an optimum route. The case study itself involved the routing of a 132 kV overhead power line in the Kranskop area of the province of KwaZulu-Natal on the east coast of South Africa. Several advantages gained from the use of a GIS included the clear usage of a documentable process, the identification of specific resources and issues not addressed in an original EIA, and the flexibility of conducting a sensitivity analysis based on adjusting weights for combining data layers. In general, the optimum route identified via the GIS represented a refinement of the route identified in the original EIA. A key disadvantage of the GIS usage was related to the time and costs associated with data conversions and incorporation into required formats.

Finally, it should be noted that route location decisions are also associated with roads and highways, and various types of pipelines (gas, oil, water, etc.). Accordingly, the methodology utilized by Warner and Diab (2002) could be adjusted for other route location studies, including those involving CEA. Further, the GIS tool can be an aid to CEA in areas which are environmentally and socially complex.

GIS-Based Scoping of a Highway

Haklay, et al. (1998) described several benefits of using a GIS during scoping for a planned highway in the vicinity of Tel Aviv, Israel. These benefits were based on a case study which compared the scoped issues both with and without the use of a GIS. The general finding was that a GIS-based analysis can improve the number and specificity of the issues identified for study, including issues related to CEA. For example, the GIS-based outcome identified an issue involving possible contamination of a local reservoir; the traditional scoping process did not identify this concern. Further, the GIS approach identified public buildings (school, hospitals, etc.) and one settlement that was not specified via the traditional approach. Accordingly, it was concluded that GIS-based scoping may help in reducing the probability of ignoring an important environmental issue or overlooking potential effects at the local level.

Interstate Highway Segment

Blaser, et al. (2004) demonstrated how GIS could be used to identify overlaps between the spatial locations of high-value wildlife habitat and high growth potential areas resulting from expanded or new highway developments. The study area was the I-25 corridor from Denver to Ft. Collins, Colorado (about 33 miles in the east-west direction and 60 miles in the north-south direction). Detailed information was included on how to develop GIS layers for five threatened or sensitive species of birds and animals (black-tailed prairie dog, Preble's meadow jumping mouse, ferruginous hawk, bald eagle, and American white pelican). Habitat suitability index (HSI) models for each species were used to identify the pertinent data layers.

To address the potential land use change in the study area, an Index of Development Attractiveness (IDA) model was used to predict which spatial locations within the area are likely to experience future growth. A GIS-based CEA tool was demonstrated by "overlaying" high growth potential areas with HSI data to identify where high-value wildlife habitat is potentially at risk (Blaser, et al., 2004). In effect, this example encompasses Steps 2, 4, 5, and 8 of the CEQ's 11-step CEA process. This tool could also be used to consider the cumulative effects associated with several ranges of population growth and associated land requirements. The resultant CEA information could then be used to consider alternative road alignments and potential designation of selected areas for land use conservation measures.

Area-wide Transportation Planning

An area-wide CEA (ACEA) was recently conducted for the Denver Regional Council of Governments (Denver, Colorado) to the year 2020 (Muller, et al., 2007). The ACEA, which was developed for the Colorado Department of Transportation (CDOT), identified cumulative environmental impacts resulting from the incremental impacts of multiple transportation and other projects (including induced developments from new transportation projects), and related urbanization in the study region. Three realms of cumulative effects were examined – land use, biological resources and habitat, and water quality. The utilized technology involved GIS data management and modeling tools. Retrospective analyses from pre-1970 to the present were utilized to project trends to 2020.

A policy-focused model was used to address potential cumulative effects on land use. The model involved a five-step method of data collection followed by GIS mapping and analysis. The five steps were (Muller, et al., 2007):

- Step 1. Build an inventory of past and present land use patterns and developable lands. This inventory relies on high-resolution spatial data.

- Step 2. Review and synthesize historical and current local plans and regulations. This includes the review of documents on local land use rules, local land use plans and local investment plans.

- Step 3. Review and synthesize regional plans and regulations, including transportation and land use plans, land use change models, and inter-jurisdictional agreements. After the reviews, focus was given to TAZ (Transportation Analysis Zones)-based demographic projections because they provide a consistent dataset across the region. Further, the TAZ projections had already undergone considerable review by local jurisdictions.

- Step 4. Evaluate other land market information. This step involves two additional information sources: (1) spatial models of land markets, and (2) expert judgment. A logit regression was used to analyze past residential growth choices and project these into the future. This regression predicted land use change as a function of variables such as distance to local road, presence of a special district, neighborhood housing density, and distance to the nearest secondary school.

- Step 5. Finally, numbers of developed acres at primary density ranges were tabulated at project, local and regional scales. These tabulations were classified into past and present categories. In the case of Western Jefferson County (for which data are available), the results were classified as development prior to 1970 and development between 1970 and 2000 (the present year in this analysis). (Jefferson County is a major county in the study area.)

This policy-focused land use model has been reviewed through a CDOT workshop and through discussions with project consultants and others. These stakeholders generally support the approach described above.

Two listed species were then selected for assessment under the biological resources and habitat realm. Their selection was based on a workshop involving pertinent experts from several state and Federal agencies. The Preble's meadow jumping mouse (Federally listed) and the black-tailed prairie dog (State listed as a species of concern) were chosen because they have been considered significant to other regional projects and it was the general consensus of the workshop that they are important resources within the study region. Only the analysis for the prairie dog will be described herein. The analysis was based upon the Habitat Suitability Index (HSI) model for the species. Specifically, the model is based upon three environmental variables (vegetation type, slope of terrain, and maximum elevation). The vegetation types were extracted from the CVCP (Colorado Vegetation Classification Project) classified Landsat Thematic Mapper data. The vegetation type given the greatest weight in the model was the grass dominated class. Slope as an indicator of terrain steepness was determined using a USGS (U.S. Geological Survey) digital elevation model (DEM) that originally had a spatial resolution of ten meters but was aggregated to a resolution of 25 meters so that it matched the CVCP data ArcGIS's spatial analysis tools, including a tool that calculates slope from DEM data. Slopes greater than 8% were considered to be too steep for prairie dog colonies. The maximum elevation of occurrence was also determined using the DEM data and established as 2700 meters. The vegetation types were scaled in terms of their likelihood to support prairie dog populations. The final step involved forecasting locational information on potential prairie dog habitat and overlaying the results of a 2030 projected growth model for the study area. Based upon these overlays, it was determined that approximately 1200 acres of grassland will be lost.

Water quality impacts of urbanization, including transportation projects and induced development, were identified as a key factor in the ACEA. Impervious surfaces can be used as an indicator of such nonpoint pollution. GIS-based water quality models which link land use (and impervious surfaces) to non-point water quality of runoff are well established as assessment and planning tools for identifying general trends in water quality for specific watersheds (e.g., EPA BASINS: Better Assessment Science Integrating Point and Nonpoint Sources -- http://www.epa.gov/OST/BASINS/). Further, strong correlations exist between the amount of urban runoff and its impacts on stream conditions and water quality with the percent of the drainage area having impervious surfaces. In addition to the correlations, imperviousness can be readily measured at a variety of scales.

The GIS procedures used in the ACEA for computing impervious areas involved the following steps: (1) collate the GIS data on land uses; highways, local roads, arterials and collectors; and sub-basin boundaries, (2) overlay-intersect the sub-basin boundaries onto the land use and highway coverages, (3) convert the intersected areas to a raster (i.e., cell) format, (4) tabulate the areas of various land uses and highways corresponding to each sub-basin, and (5) transfer the GIS area tabulations to Excel to summarize and create graphs. For purposes of the significance determinations for impervious areas, and based on research by others, it was decided that such sub-basin watershed relationships would be used in evaluating land uses and their associated imperviousness over the study period.

Based upon the application of the above approaches, several conclusions can be drawn with regard to the ACEA; they include (Muller, et al., 2007):

- Data to support the ACEA are generally available from public sources based on a modest effort to download data and collate to common formats. However, for the Denver region, it was determined that there are gaps in data collection and problems of access to published data-sets. Historical data are not available for all resources, and workshop participants made a variety of recommendations for further data collection.

- Metrics can be based on GIS data and models, and organized to pro-vide a comprehensive means for accounting of resources across a region. The resolution of the data in the Denver region is detailed enough such that specific characteristics of individual transportation projects can be tabulated and portrayed, and these project-scale characteristics can be accounted for across the entire study region for a collection of planned projects and associated land use changes.

- Stakeholder involvement is necessary to obtain a common understanding of the data and models, establish validation of the models, acknowledge priorities and preferences of participants who would use the models, and integrate model usage into administrative processes for decisions.

Cultural Resources Predictive Modeling

Clark and Lowell (2002) described a predictive modeling approach to address cultural and historical sites in the oil sands region of northeastern Alberta. The study included both existing and approved mining development projects. The overall study area was about 2.4 million acres (970,000 ha). The GIS-based model was constructed to both "predict" the general locations of cultural and historical sites in the area (based on known sites and professional knowledge), and to indicate locations within the area where developments have or could occur. Nine layers of environmental and anthropogenic information were utilized; they included land slope, aspect (e.g., southern exposure), elevation, flood zone, proximity to flowing water, proximity to standing water, historic forts, vegetation, and soils. Importance weights were assigned to each layered factor, and ratings were given to the conditions of the factors at various locations. The resultant aggregation of the weights and ratings were used to identify zones of high, moderate, and low potential for cumulative cultural and historical resources impacts within the study area. Such potentials could be used in planning a variety of siting and mitigation activities for specific mining development projects.

CEA-SPECIAL TOPIC MEETING

The International Association for Impact Assessment (IAIA) conducted a Special Topic Meeting on Cumulative Effects Assessment and Management in November, 2008. Eight specific presentations were focused on the use of GIS in assessment and/or management. Following is brief topical information on each presentation (paper):

- Atkinson, et al. (2008) – based on a literature review, over 20 types of uses of GIS in CEA were described.

- Ronzio and Sanders (2008) – described a GIS-based tool containing project-related information from the Canadian Environmental Assessment Registry. The information could be used to identify recent past, current, and short-term future projects that could contribute to local and regional cumulative effects for a proposed project being subjected to a CEA.

- Magro, et al. (2008) – addressed the contributions of multiple actions to cumulative effects via the generation of cumulative impact matrices for specific stressor-environmental vulnerability interactions.

- Menezes, et al. (2008) – a CEA-GIS tool was described for the selection of alternative corridors for expansions of gas pipeline networks. The focus was on the identification of alterntives which offer minimum cumulative environmental impacts and conflicting social and economic issues.

- Magro, et al. (2008) – this GIS-based scoping tool can be used for assessing cumulative effects from waste plants and dredging activities. Cumulative impact indices can be developed based on the project size, stressors, and local environmental vulnerability. Such indices can then be used to plan site-specific mitigation and compensation measures.

- Atkinson, et al. (2008) – GIS-based modeling at the watershed level was used to examine the cumulative effects of urbanizing watersheds on aquatic habitat quality. The study area was associated with the Trinity River in the Dallas-Fort Worth area in Texas. Evidence was provided that aquatic habitat characteristics can be predicted based on easily accessible watershed characteristics.

- Magro, et al. (2008) – a dynamic computational GIS tool was combined with the Habitat Equivalency Analysis method to estimate cumulative effects on ecological resources. Such effects (damages) from various actions are characterized by indicators and can be used to plan compensatory mitigation measures for the affected ecological services.

- Moroz (2008) – Northern Saskatchewan is being subjected to increased uranium exploration and potential mining projects. Surrogate impact indicator information, along with environmental monitoring data, is being integrated using GIS. This spatial integration is being used to identify areas needing regional approaches for cumulative effects management.

OBSERVATIONS AND LESSONS LEARNED

The above examples and case studies provide numerous illustrations of the use of GISs in both EIA and CEA processes. However, some specific problems (or constraints) related to the practical use of GIS in EIA and CEA include: (1) data errors resulting from entering data at different scales; (2) perception that GIS are exclusively held in the domain of specialists; (3) perception of a nonuser friendly technology (this is being overcome by desktop GISs); (4) cost of GIS (cost of data); (5) compatibility of different data systems; (6) reservations about trusting the output; (7) overhead requirements for GIS operation; (8) misuse of GIS results; (9) use of data sets for entry into a GIS which are already based on judgment (and uncertainties); and (10) lack of quality assurance/quality control (QA/QC) on data (bases) sets used in GIS (Joao, 1994 and 1998).

Further, in May, 1997, a workshop was held in South Africa to discuss the use of GISs in strategic environmental assessments (SEAs), including their CEA components. Table 4 identifies three topics which could be addressed to enhance

Table 4: Opportunities for Enhancing the Use of GISs in EIAs/SEAs/CEAs (Bosch, 1997)

Problem	Solution	Discussion
Spatial analysis—too much emphasis is placed on a GIS as a map making tool	Link GIS to algorithms and models for spatial analysis	Although GIS can be used to produce maps, their main purpose is that of information management and geographical analysis. Analysis is needed to convert base data to usable information that can be incorporated in a project, and thus add value to both the data and the project. The analysis does not need to be done within the GIS itself. The role of the GIS is often to manage information which can be delivered to and received from external models.
Management systems—tools do not exist to help decision making	GIS can be used to create Environmental Management Systems which integrate data from various sources and can be used to answer "what if" questions	A GIS needs to be configured in order to be used without the need for the user to become an expert, and who can then be free to use the GIS to ask "what if?" questions, and as a tool for decision making. This can be done by preparing "GIS projects" in advance with the important data layers, which then merely need to be turned on and off as the user requires.
Adding complexity—GIS analyses can be too simplistic and can produce misleading results	Ensure that the GIS is of high quality, and add datasets to model new scenarios	The end product that is required needs to direct the analytical process, rather than the analysis being driven by the limitations of the technology. Certainly, GIS does not have the components to undertake all possible analyses, but where appropriate, can be used to allow many scenarios to be run in a short time. The complexity of the analysis is limited by the resolution of the data when only large-scale maps are available.

the use of GIS in SEAs, project-focused EIA, and CEA (Bosch, 1997).

Finally, some concluding lessons learned from this review of multiple uses of GIS in CEA are that:

- GIS has been used in both EIA and CEA, with the uses involving the presentation of both historical and current baseline information and the identification and analysis of direct and indirect impacts from the proposed project as well as cumulative effects from multiple other actions in the study area.

- Larger-scale CEA studies which require regional analyses would typically be more conducive to the use of GIS.

- The use of GIS is currently being seen in favorable light when the topic appears in litigation.

- As GIS tools and skills become more practical and widespread, the use of this technology in CEA will be expected to increase.

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