EnviroInfo 2004 (Geneva)
Sh@ring – EnviroInfo 2004

GIS and Cumulative Risk Analysis to Address Environmental Contamination

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1. GIS and Cumulative Risk Analysis

Evaluating spatial features is a key aspect of addressing environmental issues, extending from natural resources to contaminated sites, and geographic information system (GIS) tools have proven essential to these analyses. Use of GIS is prevalent in natural resource management (Bettinger/Wing 2004), where accurate geographic information is an integral part of decision making. This information is also important for decisions at contaminated sites, and GIS approaches have been widely applied to display extensive information from multiple databases to support risk assessments and cleanup plans. Such plots help highlight key hazards, priority areas, and related cumulative risk issues. Cumulative risk analyses address multiple hazards not only across space and time but also across disciplines, so in evaluating the impacts of current conditions and various management options, not just human health and ecological resources are assessed but also sociocultural and economic resources.

These two areas, managing natural resources and contaminated sites, are being more closely integrated as the importance of minimizing harm to site ecosystems and allocating funds wisely gains visibility (Whicker et al. 2004). Until recently, contamination has typically been addressed by aggressive engineering measures that caused ecological harm and were very expensive, with questionable benefit to the overall protection of local communities and cleanup workers. The GIS offers a powerful tool for integrating analyses of both natural and contaminated resources to promote sustainable more environmental decisions that achieve net protection.

To review, a GIS provides for storage, organization, manipulation, interpretation and display of points, lines, polygons and raster data as attribute themes and maps. Attribute files stored in a GIS are linked to specific geographic locations to maintain

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a spatially registered database for accurate overlays and efficient queries. In addition to spatial registration, attention is focused on database architecture (hierarchical, network and relational) and quality (accuracy and consistency) to ensure reliable information for decision makers (Chrisman 2002).

Cumulative risk assessment approaches have gained momentum as interest in environmental mixtures and combined effects has increased. Information on multiple chemicals in air, water, and soil from various sources is broadly available, and synergistic effects are a common concern. Beyond ambient urban exposures, many industrial sites contaminated by operations and disposal practices pose a cumulative risk concern to local communities. Thousands of sites are being assessed to determine appropriate long-term management options that will protect human health the environment, including resources such as ecosystems and groundwater. Cumulative risk methods provide a framework for evaluating multiple chemicals in multiple media (soil, water, and air) to which people and biota could be exposed via various routes over time, to assess whether combined effects might differ from those predicted using a single-chemical approach. The U.S. Environmental Protection Agency (EPA) has developed guidance for assessing mixtures and recently drafted a framework for cumulative risk assessment that acknowledges interconnections among contaminated media and exposures (EPA 2000, 2003). Examples that illustrate GIS approaches for natural resources and cumulative risk analysis follow.

2. Resource Application: Use of Local Groundwater

In a recent project in southern Oklahoma, GIS technology was used to evaluate the potential of a local spring within a karst aquifer system to provide irrigation water for a local ranching operation. Tully Spring sits on a 16-hectare ranch in intensely folded and faulted limestone terrain, and it flows year-round. Critical to the study of its capacity to serve as an irrigation well was accurately mapping the faults and fractures in the area, monitoring yearly precipitation patterns, measuring the fluctuating water table, and tracing groundwater flow. Also crucial was assessing possible impacts from exploiting the local aquifer system. This included projecting aquifer capacity, estimating the impact on surrounding wells, developing an irrigation delivery system, and projecting long-term impacts on the aquifer system.

Collected data were entered into a GIS as separate spatially registered attribute files that included rainfall distribution, topography, geology, faults/fractures, land use, water table changes, well pump test results, dye tracer analysis, and groundwater flow patterns. Geocoded layers were then integrated to produce co-registered maps to analyze the resource and risks. Results from a two-year study indicated that this is a well-developed free-flow aquifer system that responds rapidly to intense rainfall filling and subsequent well withdrawals. The geologically interconnected nature of this aquifer also implies that any future use for irrigation needs to be investigated for potential risks to other ranchers who use the aquifer.

GIS-simulated pump test models suggested that high utilization of Tully Spring could potentially produce detrimental water table drawdown on local wells. Substantial rapid withdrawal to irrigate 16 hectares was predicted to expose more than 60 hectares to reduced supplies of much needed water during the hot, dry summers. To reduce the vulnerability of surrounding ranches, a plan was developed to construct a nearby reservoir to store the natural flow of Tully Spring. Such a pond could be used as needed without impacting the water table, thereby reducing potential risks to wells on neighboring ranches. A 2-hectare reservoir was filled by gravity flow and has operated successfully since 2002 as an on-demand irrigation supply system for the 16 hectares with no measurable impacts to surrounding wells.

3. Contamination Application: Cumulative Site Risk

Industrial sites can be contaminated by up to 100 chemicals or more, and GIS tools are valuable in defining locations and combinations of multiple hazards that need to be assessed. At large sites, such as facilities formerly used by the U.S. government for scientific research and industrial activities, the characterization needed to frame cleanup decisions can be very costly. Data collected for various purposes over many decades (including general environmental monitoring) are being tapped to focus further sampling on media, locations, and hazards that need to be better understood to determine appropriate response measures. For example, at the Hanford site in Washington State, millions of records of contaminant data have been captured in multiple GIS layers, to illustrate concentrations in different media and at different depths that represent specific geological formations and aquifers with distinct background concentrations, in order to determine where chemicals are elevated to concentrations that could be of concern. These displays identify collocated contaminants that should be jointly evaluated, and GIS plots are also used to identify areas with susceptible subpopulations (such as day care centers or nursing homes) higher disease incidence so the risk assessment can consider exposures of concern.

To illustrate an evaluation of joint toxicity, if a GIS plot showed multiple contaminants in a well being used for drinking water, then interaction toxicity data for those chemicals could be reviewed to assess potential synergistic effects (i.e., higher than additive, the default assumption). For example, if levels of arsenic, cadmium, chromium, and lead in a well were high, the toxicity assessment might indicate that arsenic and cadmium could enhance the toxic effect of lead on the neurological system, while chromium could enhance the toxic effect of arsenic on the skin (based on data in ATSDR 2001). Beyond this health example, GIS tools are also valuable for assessing concentration trends to guide analyses of natural resource protection, to determine whether systems are recovering from past insults via natural attenuation so more aggressive measures are not warranted. Thus, GIS tools can help indicate when natural attenuation processes are achieving overall protection.

4. Summary

Environmental relationships are complex, and conditions and actions that affect human and environmental resources in one location can significantly impact those in other locations. GIS tools allow extensive data to be integrated across multiple disciplines, which coupled with cumulative assessment approaches can produce risk information that reflects real-world interconnections, to guide decisions that promote sustainable environmental management.

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