A PROCESS FOR CHARACTERIZING URBAN LAND-USE INTENSITY IN DRAINAGE BASINS

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Three investigations are underway, as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program, to study the relation between varying levels of urban land-use intensity in drainage basins and in-stream water quality, measured by physical, chemical, and biological factors. These studies are being conducted in the vicinities of Boston (Mass.), Salt Lake City (Utah), and Birmingham (Ala.), areas where rapid urbanization is occurring. For each study, water quality will be monitored in approximately 30 basins that represent a gradient of urban intensity. During the planning phase of each study, basin characteristics were developed for all potential study basins and the information in the individual characteristics was combined to develop a single index of urban intensity. Basin characterization efforts associated with the Boston study are described here for illustrative purposes.

CHARACTERIZING THE NATURAL LANDSCAPE

Information about biological communities has been used increasingly in the assessment of water quality (Yoder, 1995). In-stream water quality, including the distribution of fish, invertebrates, and algae, is controlled by natural and anthropogenic factors (Angermeier and Winston, 1998; Cuffney et al., 1997). When studying the water-quality effects caused by basin anthropogenic characteristics, investigators must limit the amount of variability in natural landscape characteristics, since natural variability may obscure the effects of varying intensity in basin anthropogenic characteristics. Basin characteristics must, therefore, include both natural and anthropogenic factors.

U.S. Environmental Protection Agency (U.S. EPA) level-III ecoregions (Omernik, 1995) were used as the top-level of a hierarchical environmental framework for characterizing natural factors. This national-scale framework delimits broad areas that are relatively homogeneous in terms of both biotic and abiotic characteristics. Ecoregions have been widely used to investigate water-quality patterns (Hughes et al., 1994). At the next, more detailed, level of the hierarchy, U.S. Forest Service ecological region boundaries were used to define subregions within U.S. EPA regions. The Forest Service regions were compiled by using larger scale data than the level-III boundaries and indicate distinct patterns associated primarily with large-scale vegetation, geology, and soil data (Keys et al., 1995).

Other natural basin characteristics controlled for include basin area, soil drainage, and bedrock lithochemistry. Basins of 20 to 50 square miles were delineated and considered as candidates for the study. Basin area delineation relied on 30-meter digital elevation model data and basin delineation

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procedures contained in geographic information system (GIS) software. Soil drainage characteristics were developed by using the basin boundaries and soil hydrologic group information from the State Soil Geographic Data Base (STATSGO) (U.S. Department of Agriculture, 1994). Using these data, the potential set of study basins--all basins in an ecoregion in the size range of 20-50 square miles--has been further subset to only include basins with similar soil-drainage characteristics. In the Boston-area study, a map of bedrock lithochemical zones was used to further characterize the population of basins (Robinson, 1997).

CHARACTERIZING THE ANTHROPOGENIC LANDSCAPE

Information about the human-influenced landscape was derived from land cover, infrastructure, and census data. Mapped data for these anthropogenic characteristics were developed for the entire study area and summarized for each of the candidate study basins.

The primary source of land cover information was data developed as part of the Multi-Resolution Land Characteristics (MRLC) consortium, a federal interagency project to develop mapped land-cover data for the contiguous United States that are based on Landsat Thematic Mapper satellite images. In addition to providing a direct measure of the intensity and location of urban land uses, the MRLC land-cover data were used to derive estimates of another important characteristic of urban land-use intensity--impervious surface area. At the planning stage of these studies, the amount of impervious surface area in each basin was derived using land-cover information. Typical ranges of impervious surface percentages associated with land-cover classes used in the MRLC classification were compiled from existing literature. Simple distributions (e.g., uniform, triangular) were developed by using these literature values, and used in a spreadsheet-based simulation to estimate the total impervious surface proportion of each potential study basin. During later stages of the project, efforts will be made to directly characterize the amounts of impervious surface area in all basins that are included in the study.

Other physical features associated with anthropogenic activities were used in the planning stage of the studies; they included: road density, the number of point-source dischargers, the number of dams, and the number of Toxic Release Inventory sites. Only the features digitally mapped across the entire study area were included in the basin characterization.

Counts (1990 data) and estimates (1997) for population, labor, income, and housing characteristics, based on census block group areas, also were used to characterize the urban landscape. Some of these measures, such as population density, average age of the housing stock, and housing density, can easily be interpreted as a measure of urban intensity. Values for each of these variables were attributed to the candidate basins by using GIS. Other census measures, which can be labeled as "quality-of-life" indicators (Ryzner, 1998), have a less apparent direct link with physical processes affecting water quality. Nevertheless, the spatial distribution of family, labor, and income characteristics are intimately tied to the definition of an area as "urban." These socio-economic characteristics were considered, in an exploratory vein, as contributing to the intensity or degree of urban development in the study basins.

DEVELOPING AN INDEX OF URBAN LAND-USE INTENSITY

The urban landscape can be depicted by a variety of physical (e.g., impervious surface, housing density) and socio-economic (e.g., percent of families living in poverty) characteristics. An investigation of the effects of varying intensities of this urban landscape on physical, chemical, and biological measures of water quality will need to include measures of urban intensity that integrate information about these multiple characteristics or lines of evidence. This requires an interdisciplinary perspective.

A multiple metric approach was used to characterize the relative urban intensity of each basin (Karr and Chu, 1997). This approach allows the integration, for each study basin, of information contained in a number of familiar urban characteristics, such as urban land area, amount of impervious surface, road density, and population density. This is an exploratory effort, and the effort to characterize urban intensity will be iterative during the design phase of the studies.

In the Boston area study, digital maps of the natural and anthropogenic characteristics were combined and data were summarized for each watershed. A basin attribute table with 88 variables was developed for each of the 208 potential study basins within the level-III ecoregion. Principal component analysis (PCA) was used to analyze the variance structure of the 88 variables across the 208 candidate basins. The PCA indicated that 1997 population (the most recent population data available) was the most important variable in explaining the variation among the basins. Nineteen variables that had a correlation with 1997 population of greater than 0.50 were used in the calculation of a multimetric index of urban intensity. The index value at a site was calculated by first dividing the value of each variable by its maximum value across all sites. The ratios for each variable were summed and divided by the maximum sum to produce an index with a maximum value of 1. Sites were then classified by dividing the index scores into quintiles; sites with an index value between 0 and 0.2 had the lowest urban intensity and sites with a score between 0.8 and 1.0 had the highest urban intensity (Figure 1).

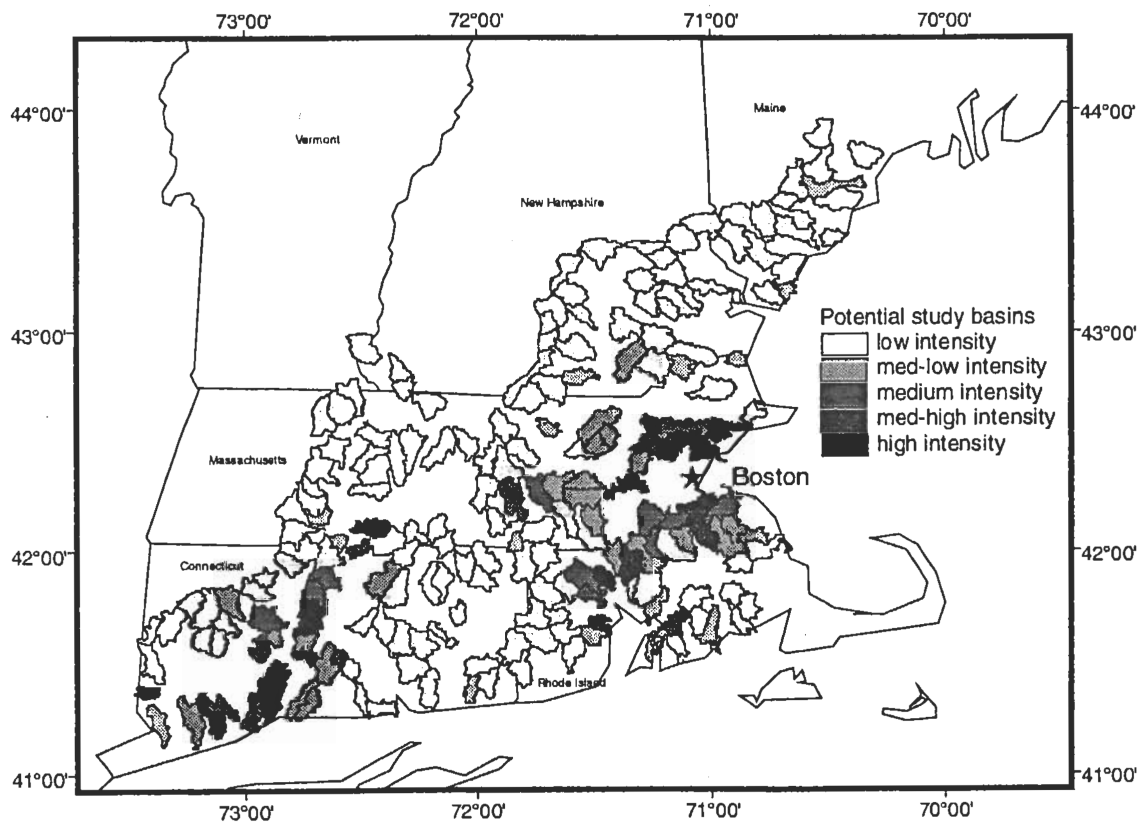

Figure 1: Relative urban intensity of potential study basins in the Boston (Ma) area

A reconnaissance of candidate basins in each quintile of the index will be conducted during Fall 1999. Thirty study basins will be selected following this reconnaissance. Site-selection factors will include the ability to limit the sites to as few of the ecological subregions as possible to minimize natural variability, complete all sampling activities at each site, and establish approximately the same number of sites in each quintile.

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