Final Report

Project Title: An Integrated Cross-Border GIS for the San Diego-Tijuana Interface

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Goal:

This is the third year of a three-year program involving the development of a comprehensive geographic information system (GIS) for the San Diego - Tijuana interface and its use in addressing a set of border environmental concerns.

Rationale:

The San Diego/Tijuana metropolitan area, now exceeding three million inhabitants, is the largest urban concentration on the United States-Mexico border. The social, economic and environmental interactions between the populations on either side of the border have increases in volume and intensity in recent years. Unfortunately, in many ways the international border remains a significant barrier which impairs the understanding of many basic problems and impedes the resolution of numerous applied policy issues. In anecdotal terms, this probably is most graphically reflected by the fact that many maps published on either side of the border leave the other side blank. Virtually everyone who has conducted research on the border region has confronted problems of data accessibility and compatibility. This problem is not restricted to socioeconomic measures, but also is true of most physical parameters as well. Thus, there is a major need for a comprehensive cross-border GIS data base which can be used as a foundation for systematic research.

Approach:

The purpose of this project is to create a GIS database for the San Diego - Tijuana area and examine its utilization in a set of environmental concerns. The three-year goals of the research are:

1) to inventory GIS databases and GIS users in the California-Baja California section of the United States-Mexico border.

2) to develop a large scale geospatial database for the San Diego-Tijuana region.

3) to model the spatial patterns of vehicular pollution in Tijuana, Mexico using remote sensing and GIS.

4) to model the spatial patterns of industrial pollution in Tijuana, Mexico using a GIS.

5) to document population growth and urban land use in Tijuana.

6) to extend natural vegetation mapping and database development south of the United States-Mexico border.

7) to train researchers from the United States and Mexico in border GIS research.

Status:

The status of each task is detailed in the following paragraphs:

1) Inventory of GIS databases and GIS users in the California-Baja California section of the United States-Mexico border.

2) Development of a large scale geospatial database for the San Diego-Tijuana region. Prior to beginning this project, San Diego State University, in conjunction with the University of Utah, conducted two user needs workshops involving GIS developers and users from SCERP universities, from government agencies, and from the private sector on both sides of the border period.With this background, SDSU researchers embarked on the development digital environmental data for the San Diego County section of the border. All phases of the database development have been closely coordinated with other SCERP border environmental GIS and data projects and with other GIS projects along the border, including the Transboundary Resource Inventory Project (TRIP). Two examples of geospatial database development are as follows:

> **a**. San Diego County Hypsography - To create the hypsography layer a high quality digital elevation model (DEM) is being created from large scale topographic maps. The DEM, which is 80 percent complete, will allow for the generation of a wide variety of products such as slope steepness, slope aspect, contours, shaded relief, and sub-basins. The digital data are being derived from more than 80 scanned USGS 1:24,000-scale mylar contour separates. Arc/Info software are used to convert the scanned contours to GRID format and then to vectorized contour lines. The contours are edited to correct scanning problems.

Afterwards, elevation values and other information such as depression contours, and supplementary contours were added. This process yields a high quality digitized contour map that meets USGS quality standards.

b. San Diego County Soils - Soils polygons were digitized from the U.S. Soils Conservation Survey 1:24,000-scale maps. The classification employed on these maps is the Seventh Approximation, a hierarchical system in which soils are classed according to soil properties such as texture, chemical composition land depth. Six levels - order, sub-order, great group, sub-group, family, and series - comprise the classification system.

The issues involved in harmonizing geospatial across the U.S. - Mexico border are both numerous and complex. Two examples of data incompatibility and solutions follow:

a. Scale and Generalization - Perhaps most common are the difficulties of generating a uniform database from maps and other sources that, in some instances, differ widely in scale and generalization. In the case of hypsometry, for example, the San Diego County DEM we are building is based on 1:24,000-scale maps with contour intervals of 20 and 40 feet whereas the Mexican DEM constructed by COLEF is derived from 1:50,000 scale maps with contour intervals of 10 and 20 meters. To harmonize these two databases it is necessary to generalize the contour lines to reduce the number of points to be used for interpolation. This is necessary because of the large number of points in the contour maps and GIS software limitations. After line generalization, the elevation values are converted from feet to meters so that x, y, and z coordinates are in the same type of unit. Fifteen - meter DEMs are generated for each quadrangle and then in a way that provides smooth transitions between quadrangles.

b. Data Classification - Many types of environmental data are classed differently from one side of the border to the other. Harmonizing data of this type requires that one select from a number of alternatives. For example, one could employ (1) the classification employed on U.S. maps, (2) the classification employed on Mexican maps, (3) some combination of the first two alternatives, and (4) a "neutral" classification scheme that permits crosswalking from one country's classification to the other. We are harmonizing U.S. and Mexican soils maps in two different ways. The first product is a highly generalized representation created by using the great group catagories from the soils maps on the U.S. side, which is approximately similar to the primary catagories of the Food and Agricultural classification used on the Mexican maps. The second, still under preparation, is a logit model that equates soil types on the U.S. side with certain physical parameters, e.g. climate, vegetation, topography, geomorphology, and geology. This model will be applied to the Mexican portion, resulting in a soils database corresponding to a scale of 1:50,000.

3) Model the spatial patterns of vehicular pollution in Tijuana, Mexico using GIS and satellite imagery. Particulate matter less than 10 microns in diameter, known as PM10, pose serious health problems in the Tijuana - San Diego region. In this study we attempt to identify and analyze spatial patterns of street related PM10 air emissions in the City of Tijuana making use of GIS, satellite imagery, and relatively simple, inexpensive

approach. The research focuses on the examination of both mobile and fugitive emission levels for the following street types which have been identified using a combination of aerial photographs, image processing, and field methods:

a) Highways, arterials, and connector streets. The assumption with this classification system is that particulate emission levels will increase as the traffic load increases from connectors to arterials to highways. IT is also assumed that the number of heavy emitting vehicles, e.g. trucks will likewise increase from connectors to highways.

b) Paved and unpaved streets. Fugitive emissions will be greater from unpaved roads than from paved roads. Unpaved roads, which constitute more than two-thirds of Tijuana's streets, is thought to be a major source of air pollution.

c) Commercial land use, mixed commercial/residential land use, and residential land use. The assumption here is that greater quantities of particulate emissions from vehicles will be exhibited on streets that abutt commercial areas than mixed commercial/residential areas and greater for mixed commercial/residential areas than residential areas.

Combining these three street classification systems allows us to examine the spatial pattern of street-related emissions in the Tijuana region.

An equation will be employed to generate emission estimations by street segment for the area. This equation contains three catagories of variables: traffic, vehicle, and environmental. Traffic variables include average traffic composition, vehicle speed, and traffic load. Vehicle variables are the average number of wheels and vehicle weight. Environmental variables are soil characteristics and average annual precipitation. Sampling techniques in the field will be employed to obtain parameters for the traffic variables for each street type, street condition, and abutting land use. The parameters for vehicle and environmental variables are obtained from existing databases. The products of this research will be digital data and a map of Tijuana's street network showing estimated emissions by street segment and an analysis of the spatial distribution of these emissions.

4) Modeling Spatial Patterns of Industrial Pollution in Tijuana, Mexico. Increased economic development along the U.S. - Mexico border makes the study of air quality a necessary component of environmental analysis and policy formation for both the U.S. and Mexico. Despite their importance, data are not extensively gathered on air quality or pollutants being emitted from maquiladoras and other industries. In this research, estimates of industrial air pollutant emissions for the City of Tijuana and sub-areas of the City are generated . The air quality of Tijuana is of concern in the U.S. because the sister cities of San Diego and Tijuana share a common air basin (Brown 1989). San Diego is extensively monitored whereas Tijuana is not.

The principal goal of this study is to identify areas with high pollutant emissions and to make inferences about environmental and human health.

There are shortcomings associated with air pollution modeling even when adequate data are available (Benarie 1987). The simplest models contain two basic types of variables - information on emissions and meteorological conditions (Boubel et al 1994). Air quality modeling in areas where reliable data regarding emissions or meteorological conditions, such as wind speed and direction are inadequate, is even more problematic. However, attempts have been made to examine hazardous waste generation in Mexican border cities using models that do not require extensive emission and meteorological data (Bowen et al 1995; Sanchez 1990). Using INVENT, a World Bank model, (Bowen et al 1995) estimated hazardous waste in selected Mexican cities along the U.S. - Mexican border. INVENT makes use of a standard classification of industrial sectors and the number of employees to generate estimates of hazardous wastes. The study by Bowen et al demonstrated the use of this type of model for making rapid assessments in an area where direct measurements of industrial emissions do not exist. However, INVENT does not provide estimates that allow for inferences about air quality to be made (World Bank 1995-6).

The data source for this study is the Directorio Industrial Canacintia "93 , which was compiled by Camara Nacional de la Industria de Transformacion Oelagacion Tijuana. It includes the names of industrial firms and their addresses, Mexican census divisions (AGEB=area geo-estadistica basica), items produced, and employment figures.

The Industrial Pollution Projection System (IPPS) model developed by the World Bank is employed in this study for generating estimates of air pollutant emissions from industry. It was designed particularly for the developing world where industrial pollution data are not available, but industrial survey is collected. The IPPS model is based on the premise that industrial pollution is heavily affected by the scale of activity, represented by the number of employees, the process technologies used, and the sectoral composition of industrial employment. The model provides estimates for sulfur dioxide (SO_2) nitrogen dixoxide (NO_2), carbon monoxide (CO), volatile organic compounds (VOC) , and particulates less than 10mm in diameter (PM10); these estimates are given in pounds for each International Standard Industrial Classification (ISIC) code.

The model was implemented by creating a database from the Tijuana industrial facilities survey and assigning each facility and ISIC code based on the type of product manufactured. The ISIC codes and employment information were then employed in the IPPS model to generate the air pollutant emissions for Tijuana. The disaggregated emissions data were achieved by locating each facility, by AGEB and colonia, and then implementing the IPPS model for each industrial park or area.

The IPPS model generated industrial emissions for Tijuana for the EPA criteria air pollutants. It is estimated that the nearly 70,000 industrial employees produced the following pollutant levels in tons for the 1993 calendar year:

SO_2	NO_2	CO	VOC	PM10
11,951	6,286	4,045	5,182	5,248

The percentage composition of Tijuana's industrial air pollutant emissions is as follows:

SO_2	NO_2	CO	VOC	PM10
36.5	19.2	12.4	15.8	16.0

Although not shown here, a breakdown of air pollutant emissions was also computed for 20 industrial areas of Tijuana that comprise 83 percent of Tijuana's industrial labor force.

The results of this estimation of industrial air pollutants are useful first steps in making serious and educated plans to fully monitor air quality in Tijuana. The lack of meteorological data makes inferences regarding the environmental impacts on surrounding residential areas very difficult. However, there are specific geographic areas where the majority of industrial air pollutants are emitted. This information is useful for monitoring and modeling the influences of pollution on human health. It is important to note that unlike in the U.S., industrial areas are often contiguous to residential zones. It can be expected that people living near industrial are more susceptible to respiratory problems consistant with exposure to sulfur dioxide and fine particulate matter. Air pollution, however, does not recognize political boundaries nor does it respect social class boundaries and, as a result, the industrial air pollutants emitted in Tijuana are a concern for all occupants of the San Diego - Tijuana region.

5) Document population growth and urban land use in Tijuana.

a) Context of research problem
b) Research approach
c) Data
d) Methods
e) Housing quality classes
f) Problems encountered
g) Conclusions

6) Extend natural vegetation mapping and database development south of the international border. We have adopted a strategy for mapping vegetation and land cover types in Baja California that is similar to that employed by the City of San Diego in its Multiple Species Conservation Planning (MSCP) effort to map vegetation in southwestern San Diego County. In some cases the MSCP decision mapping rules were

modified to correct deficiencies or to better accomodate interregional differences. Color photographs at a scale of 1:12,500 were used for vegetation interpretation. Minimum mapping units (MMUs) were chosen to be consistent with MSCP mapping and to aid interpreters in delineating features on the photos.

Field and laboratory mapping has occurred during the past year focusing on the Tijuana River Watershed. We hope to continue mapping east and west of the watershed in the next two years. While most of our mapping was accomplished by photo interpretation in the laboratory, a modest amount of field mapping and a substantial amount of ground truthing occurred throughout the mapping effort. Individual stands of vegetation and land cover types were identified and delineated as polygons on clear acetate overlays placed upon aerial photos.

The automation process for creating a vegetation database involved using an "on-screen digitizing" or "heads-up digitizing" approach and was based on SPOT image data. This was achieved using ERDAS IMAGINE software to generate a vector GIS layer in ARC/INFO format. SPOT panachromatic and multispectral data were obtained in geo-referenced and terrain corrected form. These images were merged to exploit the high spatial resolution of panachromatic data and the better spectral resolution of the multispectral data. The merged SPOT imagery formed the background onto which vegetation polygons from the aerial photo transparencies were transferred. Color contrast, edge, and texture enhancement routines in the IMAGINE software facilitated boundary delineation. Polygons were digitized in the graphic overlay phase of the color monitor by using a convential mouse for locational control. An AML program was developed and used to efficiently add the vegetation category codes and any attributes for each polygon.

The final step in the automation process was to harmonize the Mexican portion of the database with MSCP vegetation data north of, and contiguous to the international border to create the transborder vegetation database.

7) Train researchers from the United States and Mexico in border GIS research . GIS training is accomplished in several ways. First, we meet with our counterparts from COLEF, UABC and other Mexican institutions on a regular basis to discuss technical issues of data sharing, data integration, and GIS standards. Second, we submitted a proposal for funding to the Department of Commerce to improve the telecommunications and GIS infrastructure between the United States and Mexico in conjunction with this SCERP project. Unfortunately, the project was not funded, but we continue to look for ways to improve the process of transborder data integration. Third, we have provided small group GIS training when requested by local organizations, the most recent being to personnel from UABC, Tijuana and the Tijuana Planning Department. Our experience is that this type of on-demand training in response to specific needs is an effective approach to GIS technology transfer. Fourth, a one-day workshop focusing on applications of GIS along the border is scheduled for Saturday, September 14, 1996. This hands-on workshop to be attended by approximately 20-30 persons from the United States and Mexico is sponsored by San Diego State University, El Colegio de la Frontera Norte, the University of Utah, Arizona State University, New Mexico State University, and the University of

Texas, El Paso.

Results:

Describe what the outcomes are and how these will help, or have helped, resolve specific border environmental problems. How will the "clients" for the results of your work benefit from your project? What are the next steps for use or implementation of your findings?

1) As indicated above, we published a directory of US-Mexico border environmental datasets with assistance of IRSC staff, and we distributed two hundred copies of this publication to a wide range of border environmental researchers (IRSC, 1995). As intended, this directory provides a listing of these datasets, revelant metadata and information for contacting staff in the agencies that hold these data. As such, it is a good first step for identifying where certain datasets may be held, facilitating contact of these agencies, and describing the general terms of data exchange and access may be. Researchers at the University of California at Santa Barbara, the Arizona Toxics Project, and local agencies in the San Diego/Tijuana region have made use of this instrument for these purposes. Future research in the San Diego/Tijuana region will also gain from the use of this directory. Staff within the Department of Geography at San Diego State University are proceeding with several research initiatives concerning air and water quality, and these researchers will be using the contacts and metadata held in this publication to advance this work. Investigations into wastewater management in the Tijuana River basin, population and air pollution modelling in the Tijuana airshed, and water quality monitoring of surface water in the Tijuana River are all ongoing efforts that will benefit from this directory. The metadata held here allow researchers to more efficiently survey a broad range of data holdings, contact relevant staff, and begin the dialogue needed to arrange access to and exchange of these spatial datasets.

2) The geospatial database being produced for the San Diego - Tijuana region is needed to help solve a wide range of border environmental problems such as air and water pollution. For example , the digital terrain data being generated is one of the basic data layers required for airshed and hydrologic modeling. Soils , vegetation and climate data are key variables in modeling the generation and dispersal of dust particles in the atmosphere. In the coming year we intend to add information about our database to our Home Page. Eventually, all data will be made available to those working on border environmental research.

3) This study seeks to estimate spatial patterns of street - related air pollution generation in Tijuana using a relatively simple model. The results will be made available to researchers and public agencies who are concerned with air pollution and its impacts on public health. The model employed may be transferable to

other cities along the border that do not have adequate emission inventories. Future improvements to the model can be made through linkage with air dispersion models and calibration modeling based on data from the new air quality monitoring stations in Tijuana.

4) Future work in air quality analysis for Tijuana should be driven by the need to ascertain health effects on the people of Tijuana. Much potential exists for further research on air quality modeling and monitoring. The results of this study are more useful if combined with meteorological data to produce models of air pollutant emissions, movement and concentration. The IPPS model allows forecasts of future industrial air pollutant emissions based on changes in the number of employees in different types of industries. Future placement of air quality monitoring stations should take into consideration the industrial areas emitting the greatest amounts of air pollutants. Failure to acknowledge the impact of industrial emissions on air quality would underestimate the levels of air pollution within the City of Tijuana. Further research is needed, but the efficacy of the IPPS model has been demonstrated as a first step in providing estimations that can aide in policy development and further research and monitoring.

5) Already, other border researchers are using the results of this research to examine land use and structural change and impacts on air and water quality. Researchers at SDSU are examining the interactions between population growth, labor force participation, and the level of industrial activity and its impact on air quality. The land use data from this have been helpful in this work. Other researchers are examining how urban structure and population change are driving water consumption and the generation of wastewater, and the manner in which this is having a negative impact on surface water quality in the basin. The structural trends uncovered in this work are the basis for projecting this change in the future. These projections will then be used to form recommendations for appropriate technologies to meet future wastewater treatment and disposal needs. Last, the lessons we have learned in this research will be very useful in future work funded by SCERP to develop an environmental GIS to study similar issues in the Mexicali and Imperial Valleys. Both regions have experienced rapid population growth in the past, with attendant impacts on environmental quality. The techniques and methods used and fine tuned in this work in Tijuana can be employed more efficiently by researchers doing similar work along the border.

6) Transborder vegetation mapping is a recognition that vegetation and other natural phenomena transcend international boundaries. The California - Baja California region is home to a large number of sensitive plants and animals. To do effective multiple species habitat preserve planning, plants and animals must be mapped on both sides of the border and transborder preserves created. Our vegetation mapping inventory is the first major large scale transborder effort along this section of the border. It is hoped that other similar databases will be developed in adjoining areas, eventually resulting in a large scale vegetation map for the entire California - Baja California border. With this type of baseline data

we will be able to measure and assess the natural resource impacts of future urbanization.

7) Building local capability in geographic information systems technology is an essential requirement for conducting environmental research and management in the US-Mexico border region. Thus, it is desirable to continue, even expand, the level of GIS training for border researchers. Through ongoing and future collaborative research efforts, we will strengthen this capacity within individual agencies and also build on needed linkages across the border. By doing so, we will advance these research efforts and increase opportunities for cross-border and inter-agency cooperation and data exchange.

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