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The Use of Spatial Analysis at The World Bank

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Contents

1. Introduction 1
   - 1.1 What are Spatial Data? 1
   - 1.2 What is Spatial Analysis 2
   - 1.3 The Value of Spatial Analysis 2

2. Spatial Analysis at the Bank 5
   - 2.1 China: Land Use Planning in the Loess Plateau 5
   - 2.2 Nepal: Effects of Alternate Access Road Location on Forest Degradation 6
   - 2.3 Mali: Onsite Costs of Soil Erosion 9
   - 2.4 Mexico: Predicting the Location of Air Pollution-Induced Illness in Coatzacoalcos and Minatitlan 11
   - 2.5 Indonesia: Opportunity Cost of Protecting Biodiversity Rich Areas in Kalimantan 11
   - 2.6 Sierra Leone: Soil Erosion Hot Spots 13
   - 2.7 Burkina Faso: Targeting Public Works Programs 15
   - 2.8 Chad: Effects of Woodlot Property Rights on Woodfuel Prices and Fuel Biomass Availability 17

3. Decision Support Systems with Spatial Components 21
   - 3.1 The Regional Air Pollution Information and Simulation Model for Asia (RAINS-ASIA) 21
   - 3.2 Decision Support System for Industrial Pollution Control (DSS/IPC) 22
   - 3.3 Multi-Objective Environmentally Sustainable Development Using Systems Analysis (MEDUSA) 24

4. Enhancing the Contribution of Spatial Analysis to Bank and Client Operations 27
   - 4.1 New Approaches to Data Collection and Management 27
   - 4.2 Development of Analytical Techniques 27
   - 4.3 Support for Spatial Analysis in the Bank 28

5. Conclusion 29

References 31

Appendix 33

Figures

Figure 1: Critical Area For Strict Soil Conservation in Sijia Gou Basin 7
Figure 2: Priority Sites for Orchard Development in Sijia Gou Basin 7
Figure 3: Forest Areas of Potentially High Ecological Value Within 5 Km. of the Arun Dam Service Road 8
Figure 4: Foregone Farm Income From Erosion in the Current Year for a Given Location 9
Figure 5: Value of Yield Loss Due to Soil Erosion 10
Figure 6: Coatzacoalcos and Minatitlan Areas Under the "Plume" of SO_2 and NOX Emissions from Point Sources 12
Figure 7: Preliminary Results for the Supply Curve for Biodiversity in West Kalimantan 13
Figure 8: West Kalimantan: Preliminary Estimates of the Opportunity Cost of Biodiversity Conservation 14
Figure 9: Predicted Soil Loss Using 1986 Vegetation Cover 16
Figure 10: Biomass Around N'Djamena in 2016 With and Without the Project 18
Figure 11: Distribution of Sulfur From Sulfur Dioxide Emissions 23

Tables

Table 1: Examples of Spatial Analysis 5
Table 2: Land Use Summary in 2 Km. and 5 Km. Buffer Zones on Route Alignment 9

1 Introduction

Spatial analysis is necessary because location matters. Most economic activities are location-specific. Location provides special advantages - natural resource endowments or other desirable geophysical characteristics, proximity to markets or other favorable socioeconomic attributes. Location also influences the severity of the external effects of an activity, neighbors usually receiving offsite effects first.

Spatial analysis *is the use of models that quantify the interactions of behavioral, biological and physical relationships using* ***spatial data.***[1] The decline in price and growth in capacity of computing hardware and software for spatial analysis now makes possible analytical techniques that were impossible only a few years ago. Many of these techniques now have the potential to make important contributions to World Bank operations, sector analysis and policy research. The purpose of this paper is to highlight examples of spatial analysis carried out at the Bank and to describe how some recent advances in these techniques are being utilized in several on-going projects

After a brief introduction to spatial data and spatial analysis, we provide short descriptions of eight examples of spatial analysis carried out at the Bank. Next, we discuss three larger modeling efforts designed to produce decision support systems that include a spatial component - RAINS Asia, DSS/IPC, and MEDUSA. In the final section, we discuss ways to improve the contribution of spatial analysis to Bank operations focusing on trends in data collection, data management and analytical techniques.

1.1 What are Spatial Data?

The key feature of spatial data is that every data element includes location coordinates on the surface of the earth. These coordinates may be in a variety of reference systems (e.g., latitude-longitude, UTM, state plane; see the glossary for definition of these and other spatial analysis terms). Each data point represents a feature that exists at the location. Data may be represented as points (location of a well), lines (road), or polygons (municipal boundaries). Examples of data that can be spatially referenced include land use (crop, forest, urban), elevation, rainfall, prices, population, pollution sources, social variables, and Bank projects.

A growing number of spatially-referenced data sets are readily available through the internet or by way of information initiatives involving government, educational institutions, non-

[1] This definition of spatial analysis is intentionally broad. ESRI (a leading GIS software development company) uses a somewhat narrower definition.

"[Spatial analysis is] the process of modeling, examining, and interpreting model results. Spatial analysis is useful for evaluating suitability and capability, for estimating and predicting, and for interpreting and understanding. There are four traditional types of spatial analysis: topological overlay and contiguity analysis, surface analysis, linear analysis, and raster analysis." http://www.esri.com/base/users/glossary/glossary.html.

governmental organizations and the private sector. This has not only dramatically reduced the costs associated with spatial analysis but is also resulting in rapid improvements in data quality - making it possible to use the approach in an ever-expanding range of applications.

1.2 What is Spatial Analysis?

Spatial analysis generates quantitative estimates of the spatial consequences of behavioral and physical relationships. The results of spatial analysis are often depicted qualitatively (in maps). Both quantitative and qualitative representations can be used to reveal relationships that are not readily apparent. The best-known set of tools for spatial analysis falls under the rubric of geographic information system (GIS). These tools permit manipulation of spatial data, taking advantage of spatial relationships. The standard tools of spatial analysis, as implemented in a GIS, are topological overlay and contiguity analysis, surface analysis, linear analysis, and raster analysis. An example of classic GIS-based analysis is to use overlays of several data sets to find specific locations that have key attributes. An example would be to identify all potential factory sites within 3 kilometers of a port, more than 300 meters from a riverbank, bounded by a major road, or which have compacted soil.

More recently, it has become possible to combine technical and/or behavioral relationships with traditional spatial analysis tools and statistical software to simulate the effects of policy changes or project activities. Two examples illustrate this approach. A process model of industrial pollution is combined with spatial data on population distribution around a factory and cost of treating pollution-based health effects to estimate the benefits of installing pollution control. A model of profit-maximizing agricultural producers is combined with spatial data on geophysical and socioeconomic characteristics of individual plots (e.g., soil quality, distance to nearest marketing center) to assess the extent of deforestation if a policy reform raises the price of maize. Other examples are mentioned below.

1.3 The Value of Spatial Analysis

Spatial data and spatial analysis have much to offer the Bank and its clients throughout the project cycle. In particular, several features of this approach combine to produce benefits. These are illustrated in the examples given in Chapters 2 and 3:

- Simulation of the effects of an activity facilitates low-cost evaluation of project impacts in varying conditions. These can range from investigation of the classic "What...if" scenario through to the use of complex models. Which forested areas are likely to be cleared following the construction of a road? When agricultural subsidies are removed what locations will see the largest effects on rice production and rural income? Which location for a water treatment plant brings the greatest reductions in pollutant concentrations?

- Spatial disaggregation: Spatial analysis allows the investigation of policy and project options in a spatially disaggregated framework utilizing both quantitative and qualitative approaches. This can enhance traditional approaches to cost/benefit analysis, the targeting of investment, and the investigation of tradeoffs and possible mitigation measures

- The value of visualization of data and relationships is often underestimated. The use of spatial data and analysis can provide a readily understood graphic representation of project activities and their relationship to other features – impossible in a tabular form. Examples include the simple display of project activity in relation to other features in the landscape, the mapped display of single or multivariate data (e.g. population density, or estimated pollution

loads) through to 3-dimensional models of watershed run-off impacts.

- Monitoring – combines the benefits of quantitative and qualitative analysis to examine change over time due to project impacts and or policy changes. Increasingly, this approach utilizes environmental indicators or other indexes based on readily available data to provide the basis for decision-making.

- Decision support systems – increasingly, these capabilities of spatial analysis are being combined with the power of information systems to produce systems which can support day-to-day policy-making.

Spatial data and analysis are the ideal tools for investigation of many Bank activities and the effects of policy changes. Further, the results can facilitate stakeholder understanding and participation. Finally, when combined with information systems, these techniques can provide the basis for cost-effective monitoring and decision support.

2 Spatial Analysis at the Bank

The following examples demonstrate how spatial data and analysis have been (or could be) used in various Bank operations. These are summarized in Table 1.

2.1 China: Land Use Planning in the Loess Plateau

The Loess Plateau region of central China covers over 620 million hectares. When dry and undisturbed, loess soils can sustain large stresses and nearly vertical walls more than 20 meters high are common. However, when there is an increase in soil moisture content, rapid breakdown of the soil structure occurs and extremely high rates of erosion are common. An integral part of the Chinese approach to land management in this region is the development of local land use plans using small watersheds as the basis for investment planning. The preparation of these plans seemed like a natural application of spatial analysis technology. As a part of project preparation work, the Bank developed a prototype of a multi-purpose GIS that could be used as a tool for land resource assessment, evaluation of investment alternatives, and as a basis for monitoring project implementation. It was originally developed for the Sijia Gou Basin and the following examples are from there. However, the approach is now widely used throughout the Plateau.

Chinese planners had been using manual techniques to identify physical land suitability for different land uses, but these practices are time consuming and error prone. With the existing data digitized, it was possible to rapidly produce

Table 1: Examples of Spatial Analysis

Example	Bank operations in which it was (or might be) used
China: Land use planning in the Loess Plateau	project preparation
Nepal: Effects of alternate access road location on forest degradation	project preparation, environmental assessment, project evaluation
Mali: Onsite costs of soil erosion	country assistance strategy, project preparation
Mexico: Predicting the location of air pollution-induced illness in Coatzacoalcos and Minatitlan	project preparation and monitoring, environmental assessment
Indonesia: Opportunity cost of protecting biodiversity rich areas in Kalimantan	project preparation, environmental assessment
Sierra Leone: Soil erosion hot spots	country assistance strategy
Burkina Faso: Targeting public works programs	country assistance strategy, project preparation
Chad: Effects of woodlot property rights on woodfuel prices and fuel biomass availability	project preparation, environmental assessment

a variety of tables and maps of characteristics important to land use planning. Given the nature of loess soil, it is critical that areas with high erosion risk are identified and erosion control plans implemented. With the spatially referenced data it was possible to estimate the number of hectares with high risk or erosion and a three-dimensional map showing their locations (see Figures 1 and 2).

One method of erosion control is to plant tree crops. Fruit-bearing trees have the added advantage of producing a valuable crop. Chinese specialists defined favorable areas for apple and pear orchard development as being south-facing and having slopes between 8 and 25 degrees. The GIS software was used to estimate the number of hectares with those characteristics and to produce a map with their locations.

This use of spatial analysis did not rely on formal modeling. Instead it was used as an interactive tool for visualizing and evaluating alternate land use scenarios. The planners were able to suggest potential land uses and the software was used to generate data and maps that were then used to refine the plans or develop new alternatives.

Potential Use/Role in Bank Operations:

- land resource assessment
- evaluation of land use investment alternatives
- monitoring project implementation.

For more information on the spatial analysis for the Loess plateau project see: "Using GeographicInformation Systems to support Watershed Management: Case Studies from Nepal and China," Glenn Morgan and Petter Nyborg, Asia Technical Department, The World Bank, ITLAB Technical Paper: GIS Series Number 1, 1993.

2.2 NEPAL: EFFECTS OF ALTERNATE ACCESS ROAD LOCATION ON FOREST DEGRADATION

It is frequently necessary to build service roads for infrastructure development projects. These roads often provide improved access to hitherto remote regions and encourage more intensive land use. If the road passes through an area where soil erosion is a potential problem, biodiversity is high, or habitat is important, the new land uses could have serious negative environmental consequences. Spatial analysis can be used to examine alternate road alignments to minimize these negative effects.

The service road for the proposed Arun Dam in eastern Nepal could potentially pass through important forest areas. Using standard GIS techniques, "impact corridors" were generated by identifying land use areas with buffers around the road of 1 to 10 km. Both a quantitative (areas affected, see Table 2), and qualitative (mapped) assessment of the kinds of land use that would be included in the buffer areas was done (see Figure 3). In the project review, the GIS database was used interactively to assess the impact of different road alignments on sensitive forest areas. For example, an alternate road alignment to the east (not presented here) that was at a higher elevation was also evaluated. In addition to facilitating the optimal placement of roads, the maps and the statistical reports allow project management teams to develop site-specific mitigation and management plans and facilitate long-term monitoring.

An interesting extension would be to model the behavioral effects explicitly. Geophysical factors such as soil type, temperature and rainfall, and socioeconomic factors such as the location-specific prices of inputs and outputs and land tenure determine land use at a particular location. The development of a road lowers transport costs, changing relative costs. It is possible to estimate econometrically the effects of both geophysical and socioeconomic characteristics on existing land use. The estimated parameters could then be used to predict more precisely land use changes as a result of building a new road and suggest alternate approaches to mitigation of negative effects.

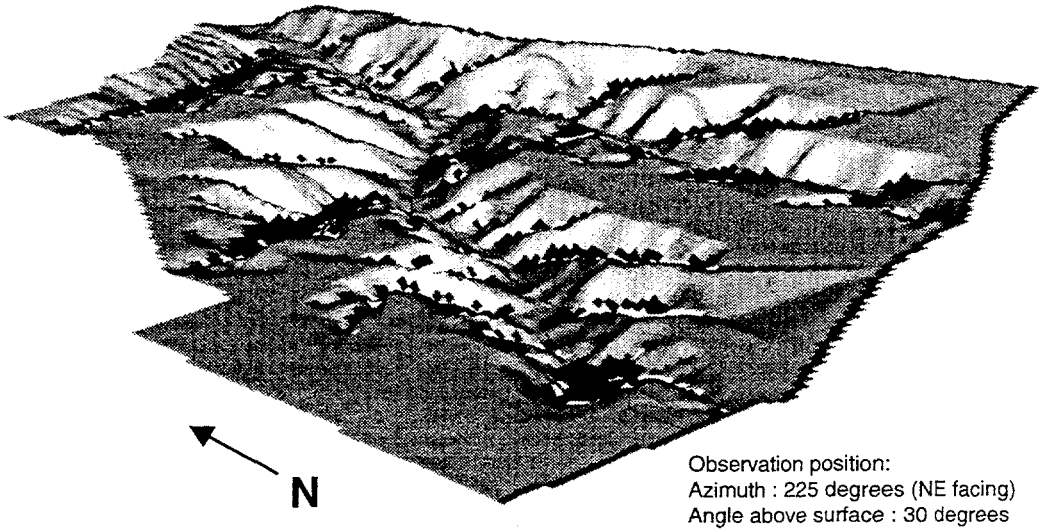
Potential Use/Role in Bank Operations:

- identify locations potentially affected by project development-

Figures 1 & 2

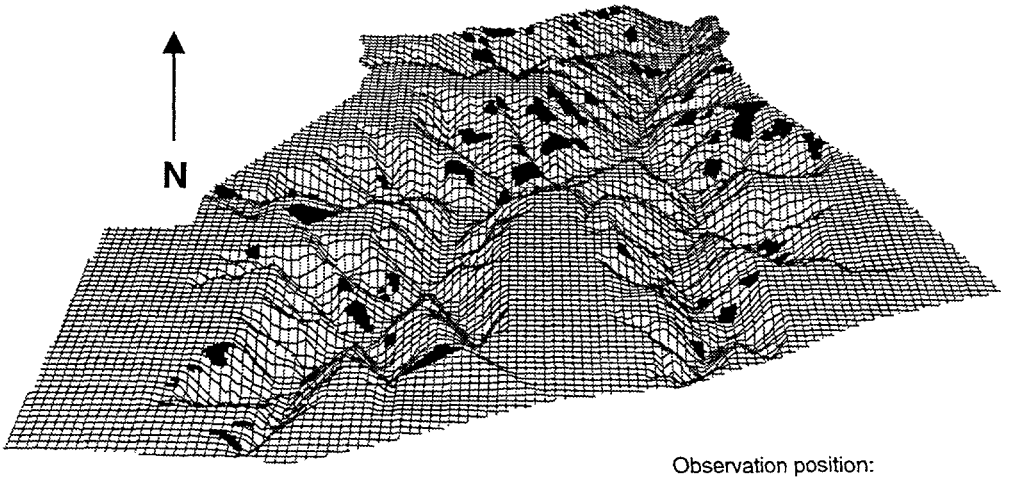
China
Land Use Planning in the Loess Plateau

Figure 1 - Northeast perspective view of Sijia Gou Watershed



Observation position:
Azimuth : 225 degrees (NE facing)
Angle above surface : 30 degrees
Vertical exaggeration : 1.5

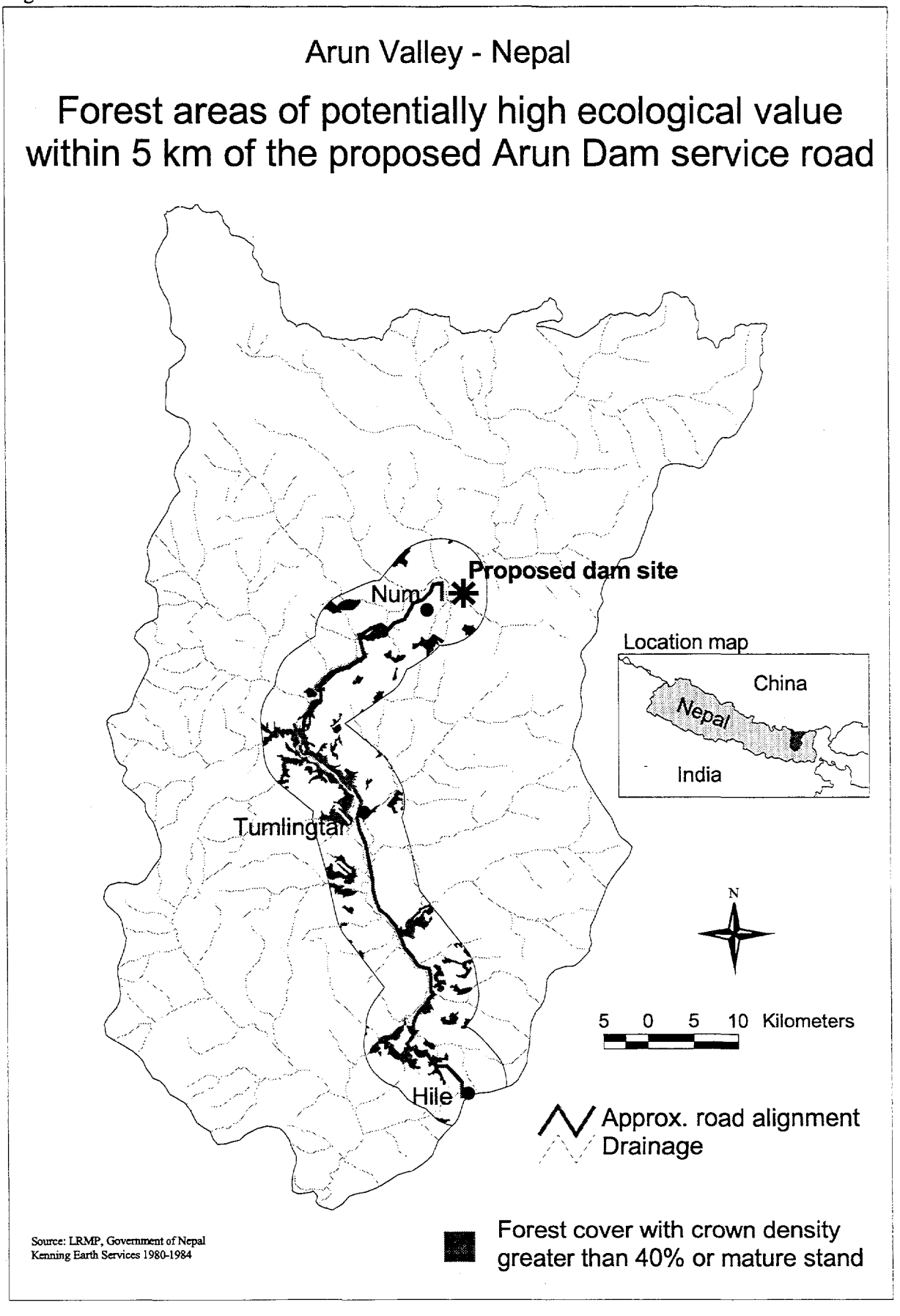
Figure 2 - Priority sites for orchard development in Sijia Gou Basin



Southfacing slopes between 8 and 25 degrees (8 Hectares)

Observation position:
Azimuth : 180 degrees (Northfacing)
Angle above surface : 30 degrees
Vertical exaggeration : 1.5

Figure 3



The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of the World Bank Group, an judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

Table 2: Land use summary in 2 km and 5 km buffer zones on route alignment

	2 km buffer		5 km buffer	
	Total area (hectares)	% of total	Total area (hectares)	% of total
Forest	16,954.9	52.5	40,251.5	49.7
Agriculture/Grazing	12,477.7	38.7	37,330.3	46.1
Misc. non-arable land cover	2,854.6	8.8	3,389.9	4.2
Total	32,287.2	100.0	80,971.7	100.0

- model nature and extent of project effects
- simulate effects of alternate location of infrastructure
- project preparation, environmental assessment, project evaluation

For more information on the spatial analysis for the Arun project see: "Using Geographic Information Systems to support Watershed Management: Case Studies from Nepal and China," Glenn Morgan and Petter Nyborg, Asia Technical Department, The World Bank, ITLAB Technical Paper: GIS Series Number 1, 1993.

2.3 MALI: ONSITE COSTS OF SOIL EROSION

Soil erosion has both off-site and on-site effects. The off-site effects include clogging of irrigation channels and river channels. An important on-site effect is reduced crop yield. On-site effects of soil erosion can make investments in soil conserving technologies pay off for farmers. A country- or region-wide estimate of the yield losses associated with soil erosion can guide infrastructure planners to specific locations where investments in soil conservation technologies have positive rates of return.

An early use of spatial analysis at the World Bank that combined behavioral models with GIS techniques was a study that estimated the on-site costs of soil erosion in Mali. The study looked at a north-south swath containing one-third of the county's most productive agricultural areas and identified areas where soil erosion might be causing yield declines. Mean rates of soil erosion caused by rainfall were estimated using the Universal Soil Loss Equation (USLE, described below). Yield losses were estimated using the following relationship:

$$Y = C^{-\beta x}$$

where

Y = yield in tons per hectare
C = yield on uneroded (newly cleared) land
β = estimated coefficient varying with crop and slope
x = cumulative soil loss in tons per hectare

The study used values of β that implied annual yield losses ranging from 2 to 10 percent.

Combining this information with region-specific crop budgets, the income foregone by not implementing soil erosion techniques can be estimated (Figures 4 and 5). This loss can then be compared with the costs of various technologies to reduce soil erosion. Areas around Bamako where soil erosion control is potentially profitable are shaded in Figure 5. Most of these areas were located south of Bamako.

Figure 4: Foregone farm income from erosion in the current year for a given location.

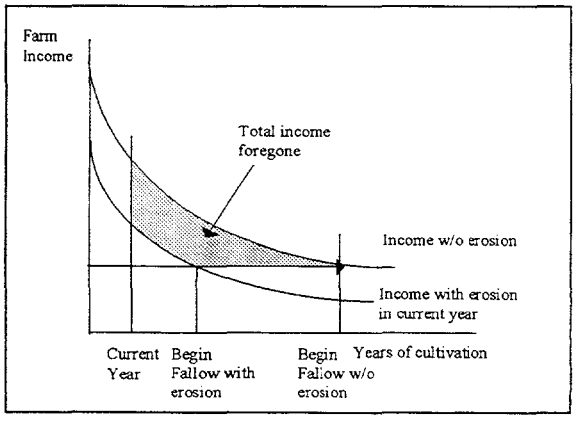
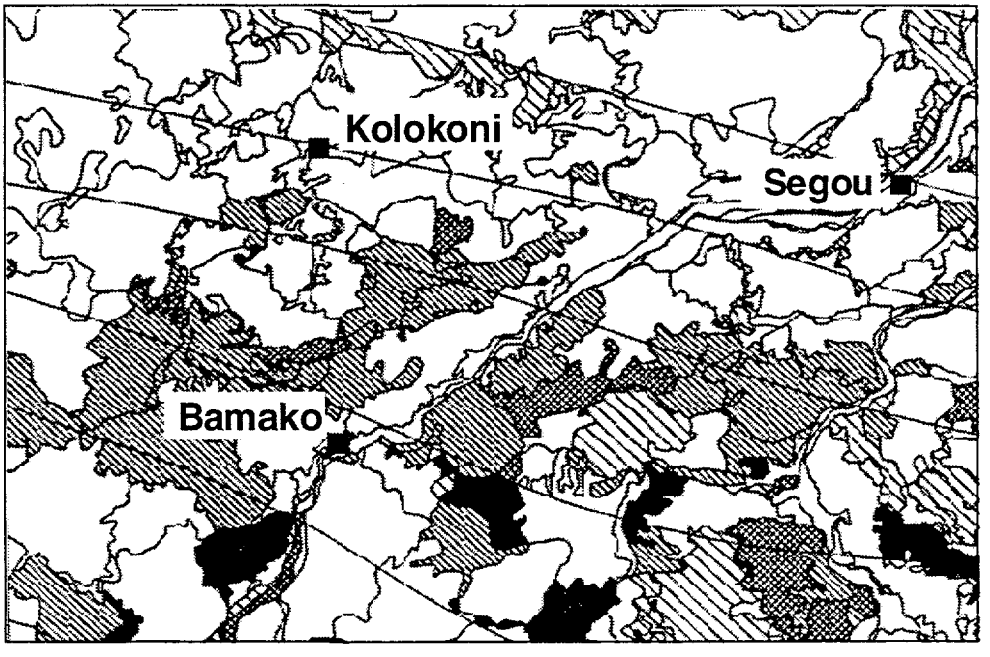
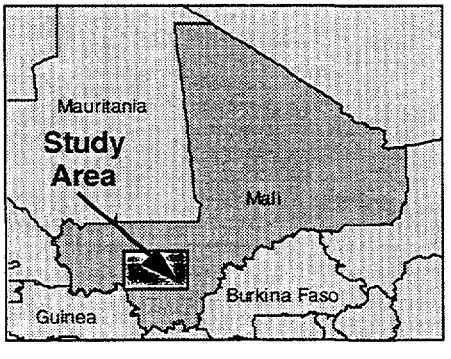


Figure 5

Mali
Bamako Area
VALUE OF YIELD LOSS DUE TO SOIL EROSION

(based on 1985 prices, assuming a 10 year horizon and a 10% discount rate)





Value of yield loss due to soil erosion

- High
- ↓
- Low
- City
- Isohyet (rainfall)

Note: For all hatched areas the value of yield loss due to soil erosion is greater than 40,000 CFA/ha

Potential Use/Role in Bank Operations:

- identify areas where soil conserving techniques are profitable
- evaluate the benefits of different soil erosion control technologies
- country assistance strategy, project preparation

For more information see "The On-Site Costs of Soil Erosion in Mail," Joshua Bishop and Jennifer Allen, World Bank Environment Department, Environment Working Paper No. 21, November 1989.

2.4 MEXICO: PREDICTING THE LOCATION OF AIR POLLUTION-INDUCED ILLNESS IN COATZACOALCOS AND MINATITLAN

Industrial air and water pollution are responsible for health-related economic costs around the world. Reducing industrial pollution can improve health and reduce both direct health costs such as medical expenses for treating pollution-induced illnesses and indirect health costs such as lost workdays. However, retrofitting firms with pollution control equipment can be very expensive. Spatial analysis makes it possible to estimate the location-specific costs and benefits of pollution amelioration.

As part of the development of the Decision Support System for Industrial Pollution Control (DSS/IPC; described in more detail in Section 3.2), the locations of neighborhoods at high risk of air pollution from industrial pollution in the Coatzacoalcos and Minatitlan, Mexico areas were identified. This was done using spatial data sets of the location of housing, industrial, mixed use and swamp areas and locations of firms emitting various kinds of industrial pollution. Using a pollution dispersion model it was possible to identify locations where plumes from different factories overlapped. There are many sources of NOX but the dispersion is limited. Hence, high and medium-high NOX concentrations were confined largely to industrial areas and mainly affected industrial workers. Only a small part of the residential area falls under the NOX plume (Figure 6). SO_2 comes primarily from a single source and has a wide dispersion plume, covering most industrial and residential areas. Because of the combined patterns of dispersion there is a small part of the residential area that falls under the pollution plumes of both NOX and SO_2.

Although this study did not do so, it would be possible to estimate the health-related economic costs associated with pollution both to industrial workers who receive frequent exposure to both NOX and SO_2 and the residents of the area in both NOX and SO_2 plumes. This could be compared with the cost of retrofitting NOX and SO_2 control equipment.

Potential Use/Role in Bank Operations:

- locate areas where inhabitants are exposed to pollutants from different sources
- predict health costs of exposure to pollution and compare to retrofitting pollution control devices
- project preparation and monitoring, environmental assessment

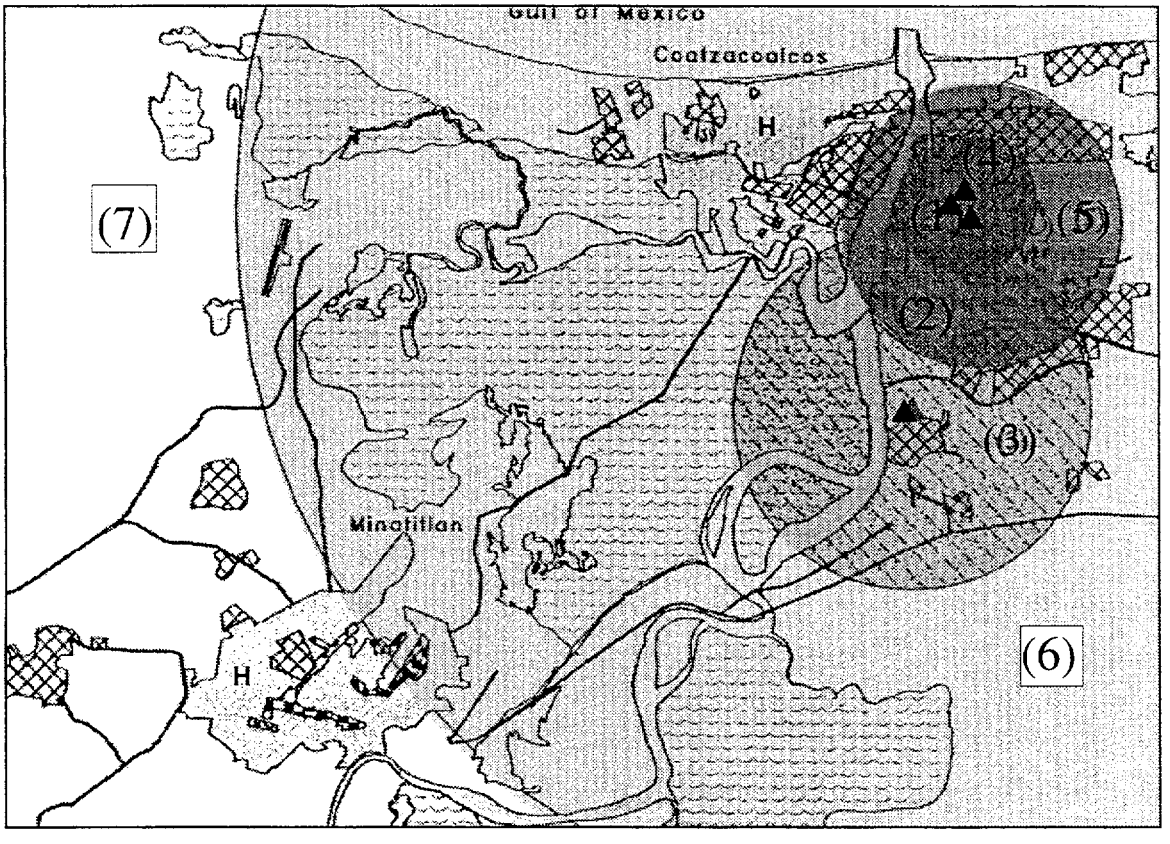
For more information see Decision Support System for Industrial Pollution Control, Volume 1: Methodology and Results, Iona Sebastian and Henk de Koning, May 1996, World Bank and WHO-Pan American Health Organization.

2.5 INDONESIA: OPPORTUNITY COST OF PROTECTING BIODIVERSITY RICH AREAS IN KALIMANTAN

Areas rich in plant and animal species can also generate large private profits in other uses. For instance, they might contain high-value tree species, fertile soil for annual crop production, or be located near roads and urban areas where conversion to industrial use or housing is profitable. Using spatial analysis it is possible to construct a spatial "supply curve" of biodiversity that measures the opportunity cost of setting aside areas rich in biodiversity. The basic procedure has two steps. First, evaluate each

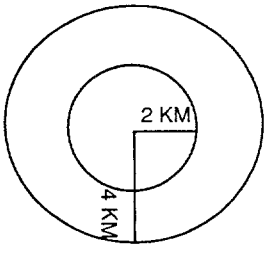
Figure 6

MEXICO
Coatzacoalcos & Minatitlan
Areas Under the "Plume" of SO2 & NOX Emissions From Point Sources



- Housing
- Industrial Areas
- Mixed Use
- Swamp areas
- Point source

(1) High SO2 & NOX
(2) High SO2, medium high NOX
(3) High SO2, medium NOX
(4) High NOX, low SO2
(5) Medium high NOX, low SO2
(6) Low NOX & SO2
(7) Outside affected area



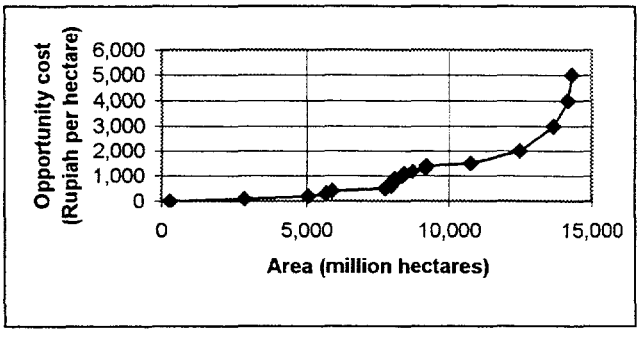
Distance from point source

location for both its biodiversity and economic value. Second, construct a new variable - average cost per biodiversity adjusted hectare. By sorting locations from lowest to highest average biodiversity cost, a supply curve is traced out. Locations plotted close to the y-axis have low opportunity cost of preserving biodiversity while areas to the right have higher opportunity cost. A map of areas with low opportunity cost also shows whether they are contiguous and hence easy to protect, or scattered widely.

West Kalimantan, Indonesia is widely recognized as having a very high degree of biodiversity, but other economic uses of the land also exist. Smallholder cultivation of tree crops and rice cultivation are important agricultural activities. A biodiversity index was constructed with data drawn primarily from interpretation of satellite imagery. Forty-five different land use types were identified. From these land use types it is possible to estimate the extent of species-richness and diversity and construct a biodiversity richness variable. These values were weighted by a conservation priority index to avoid bias against small but rarer areas. The opportunity cost of leaving the land uncultivated was determined by identifying the alternate land use with the highest private profitability.

Preliminary results for the biodiversity supply curve (Figure 7) show that for West Kalimantan, a large fraction of the land could be set aside with little or no opportunity cost.

Figure 7: Preliminary results for the supply curve for biodiversity in West Kalimantan



With an estimate of the biodiversity supply curve, it is possible to perform policy experiments. For example, how does the supply curve shift if stumpage rates or trade policies for annual crops are changed. In addition, the location of sensitive areas under pressure can be identified (Figure 8).

Potential Use/Role in Bank Operations:

- identify locations where the cost of conserving biodiversity is low
- modify infrastructure location to reduce impact on areas rich in biodiversity
- develop simulations of the consequences of policy changes and projects for conversion of areas rich in biodiversity
- project preparation, environmental assessment

For further information see, "The Economic Supply of Biodiversity in West Kalimantan: Preliminary Results," William B. Magrath, Charles M. Peters, Nalin Kishor and Puneet Kishor, in Environmental and Economic Issues in Forestry: Selected Case Studies in Asia, Susan Shen and Arnoldo Contreras-Hermosillo, editors.

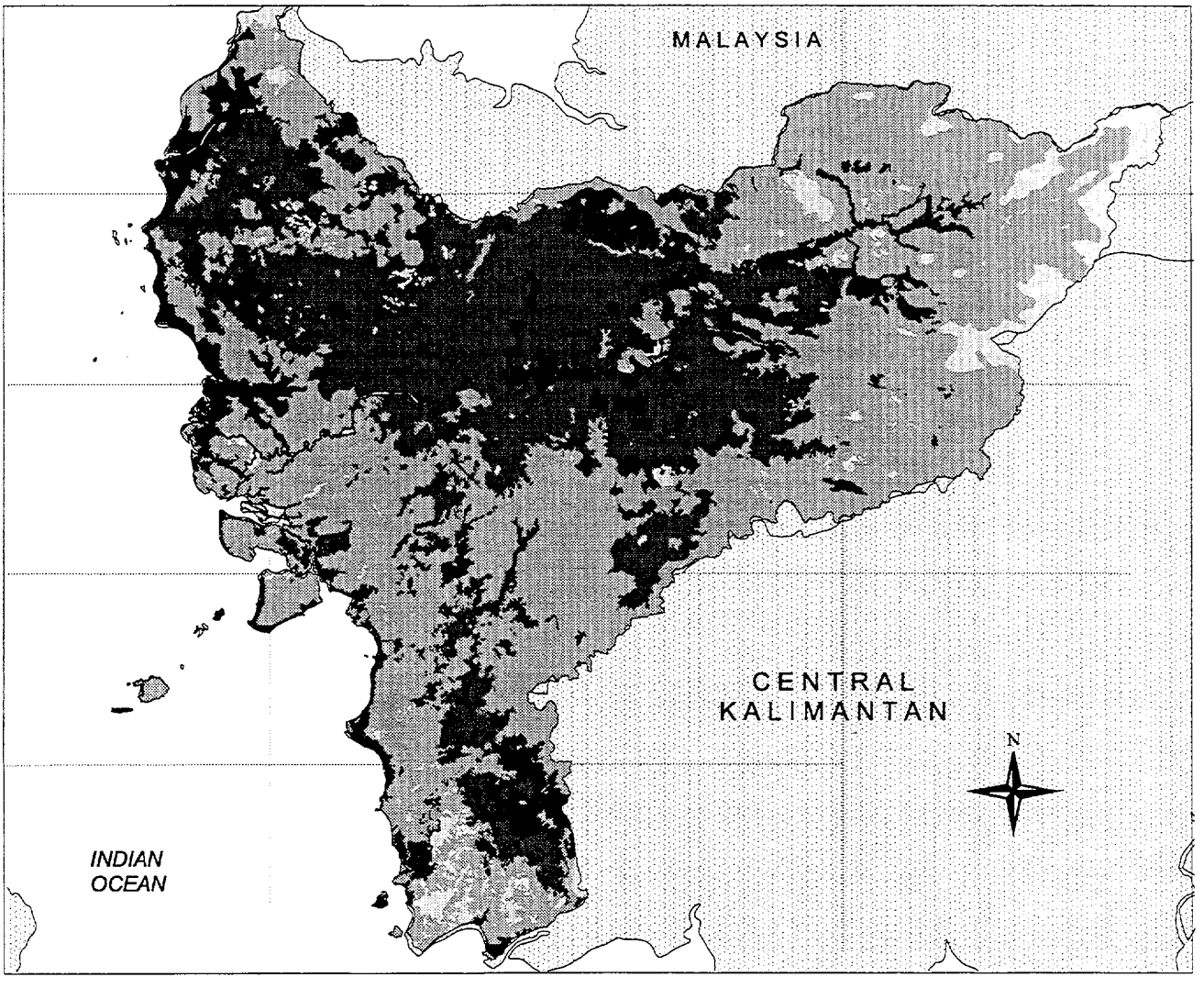
2.6 SIERRA LEONE: SOIL EROSION HOT SPOTS

As a country plans infrastructure development such as roads, irrigation works, or dams, it needs to know about possible unintended negative consequences of these developments. An example is soil erosion cause by road development that opens new areas to cultivation that are susceptible to erosion. Irrigation works and dams can have shortened lives if eroded soil fills canals or lakes.

The Universal Soil Loss Equation (USLE) can be used to assess the potential for soil loss from sheet and rill erosion under a variety of geophysical and land use conditions.

Figure 8

INDONESIA
WEST KALIMANTAN
Preliminary Estimates of the Opportunity Cost of Biodiversity Conservation



80 0 80 160 Kilometers

Opportunity Cost (Rupiah/Ha.)
- 0
- 1 - 1000
- 1001 - 2000
- 2001 - 4000
- Greater than 4001
- Outside study area

Areas having lower opportunity costs are predominantly forested with relatively high levels of biodiversity; they also possess limited capacity to support economically viable alternative land uses

The equation is:

A = RKLSCP where:

A - computed soil loss per unit area
R - rainfall factor
K - soil erodibility factor
L - a slope length factor
S - a slope degree factor
C - a crop practice factor
P - a conservation practice factor.

The USLE was originally developed in the U.S. for field-specific conditions. However, with certain assumptions it can be used over larger areas. For the Sierra Leone National Environmental Action Plan, the USLE was modified to estimate predicted soil loss under different cropping practices. Spatial data used include soil type, rainfall, slope and crop practices. These data are available for most parts of the world.

The analysis generated a map of the soil loss per unit area highlighting areas of low and high soil erosion potential under existing cropping practices in 1985 (Figure 9). The highest risk of soil erosion is in the coastal delta areas and in parts of the northwest region where soil type and slope combine to increase the threat of soil erosion. A second map not shown here identifies areas of high erosion risk if the most appropriate agricultural practices were adopted

Sensitivity analysis also can be performed. For example, if an investment project in a particular area will bring about a change in cropping practices, say conversion of forest to annual crops, the effect on soil loss in that area can be estimated.

Potential Use/Role in Bank Operations:

- identifying soil erosion hot spots
- simulating the impact of policy changes or projects on soil erosion
- identifying areas for soil conservation project development
- country assistance strategy, national environmental action plan, project development

For more information, see "Assessment of Soil Erosion in Sierra Leone," Petter A. Nyborg, Consultant, The World Bank, November 1995.

2.7 Burkina Faso: Targeting Public Works Programs

When designing projects to provide social infrastructure, it helps to know where the very poor live. Infrastructure in these communities can be subsidized while facilities in better off communities can be developed on a cost-recovery basis. Traditional survey methods to identify the poorest communities are expensive and spatial analysis can provide a low-cost alternative.

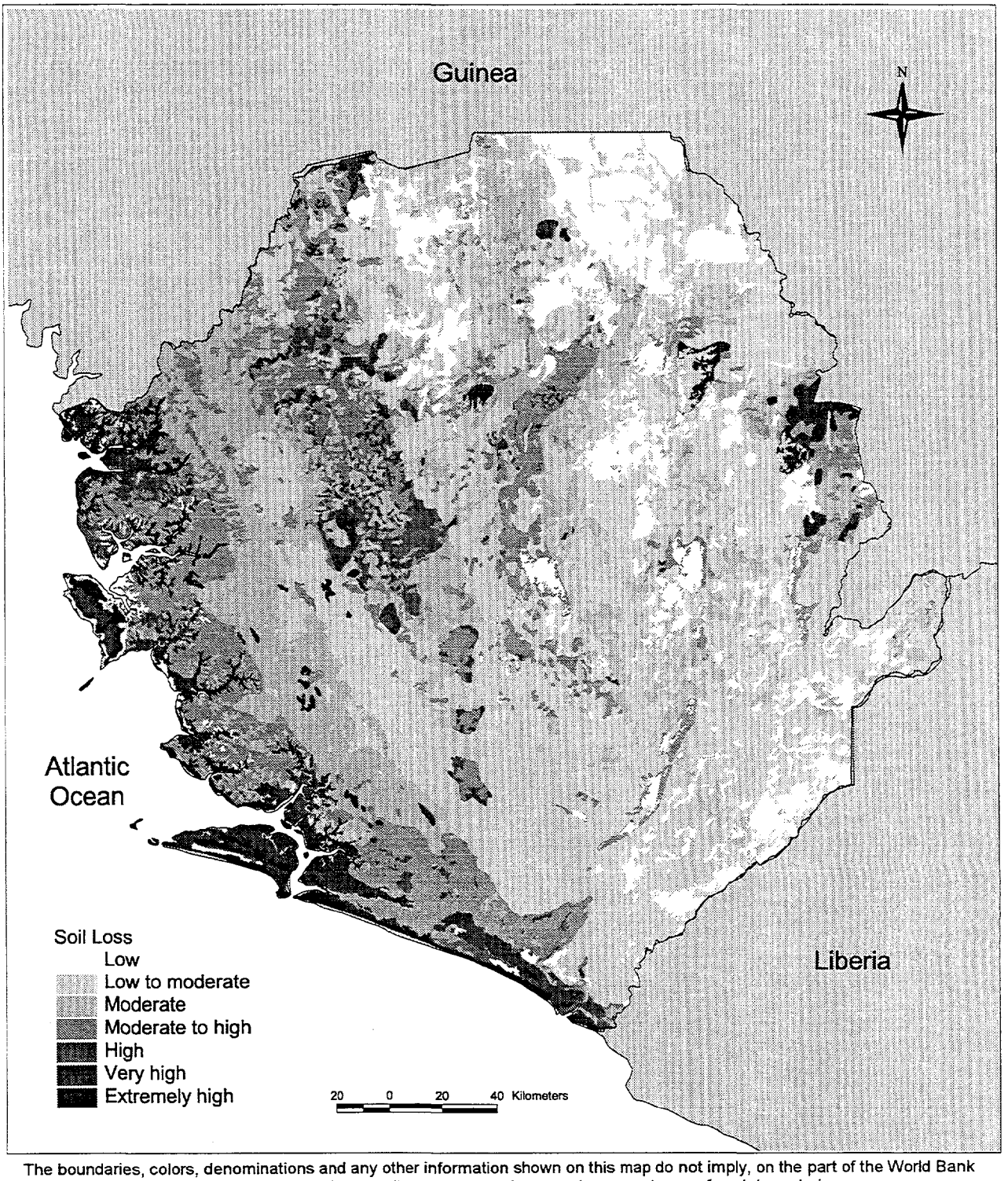
The principal goal of a research project underway in the ISP Division of the Africa region is to develop criteria for narrow geographical targeting of public projects and programs of individual villages or of clusters of two or three neighboring villages. These criteria will allow a comprehensive analysis of the cost-effectiveness of individual projects and the selection of the most desirable policy interventions. By identifying the poorest villages the planner can achieve the maximum benefits for the poor. The criteria will also identify the better-off villages in which user-fees can be introduced.

The focus on the community as the target of poverty-reduction activities introduces another dimension both to the analysis of geographical targeting and the implementation of these projects and programs. Whereas geographical targeting often focuses on agroclimatic conditions, community level targeting takes into account community-specific environmental factors (such as the proximity to a source of water for drinking and/or irrigation), location factors (including the proximity to the main market center and the quality of the access road), and demographic, economic and institutional factors.

The analysis will combine spatial, agro-climatic, and census data available for all communities

Figure 9

Sierra Leone
Predicted Soil Loss using 1986 Vegetation Cover



The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of the World Bank Group, an judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

with data from the Household Income and Expenditure Survey, the Agricultural Survey and the Demographic and Health Survey which are only available for a sample of communities. The use of limited dependent variable econometric techniques makes it possible to estimate the probability that in a given community the majority of the households are relatively poor. It also makes it possible to assess quantitatively the contribution of individual spatial and demographic characteristics to that probability.

The second part of the study will use the characteristics of communities to develop operational rules for determining the location of public facilities in health, education, water supply, road construction, etc. that are cost effective and reach as many of the poor as possible given resource constraints. These rules will also be used to identify better-off communities and suggest guidelines for establishing user-fees there.

This research has already started in Burkina Faso and will start soon in Cote d'Ivoire.

Potential Use/Role in Bank Operations:

- use small, intensive village surveys to develop parameters to predict whether villages outside the sample are poor

- simulate effects of alternate program or project formulation on effectiveness in reaching the poor

- country assistance strategy, project preparation

For more information contact David Bigman, ISP Division, Africa Region, World Bank.

2.8. CHAD: EFFECTS OF WOODLOT PROPERTY RIGHTS ON WOODFUEL PRICES AND FUEL BIOMASS AVAILABILITY

In many developing countries, wood and charcoal are important energy sources for cooking and heating. Fuelwood supplies often come from open-access resources; that is, wood lots are effectively open to anyone to collect wood without payment. When this situation occurs there is no incentive to manage the wood resource for higher productivity. A central feature of the Chad Household Energy Project is to grant villages near the city of N'Djamena exclusive rights to manage and harvest woodlots in their vicinity. The hope is that villagers will increase yields above regeneration rates. The paper develops a model where owners are assumed to manage (spatially referenced) woodlots to maximize intertemporal profits. The model is used to develop a woodfuel supply curve with and without the assignment of property rights.

Spatial analysis makes it possible to derive the following data sets for every 1 km square around N'Djamena:

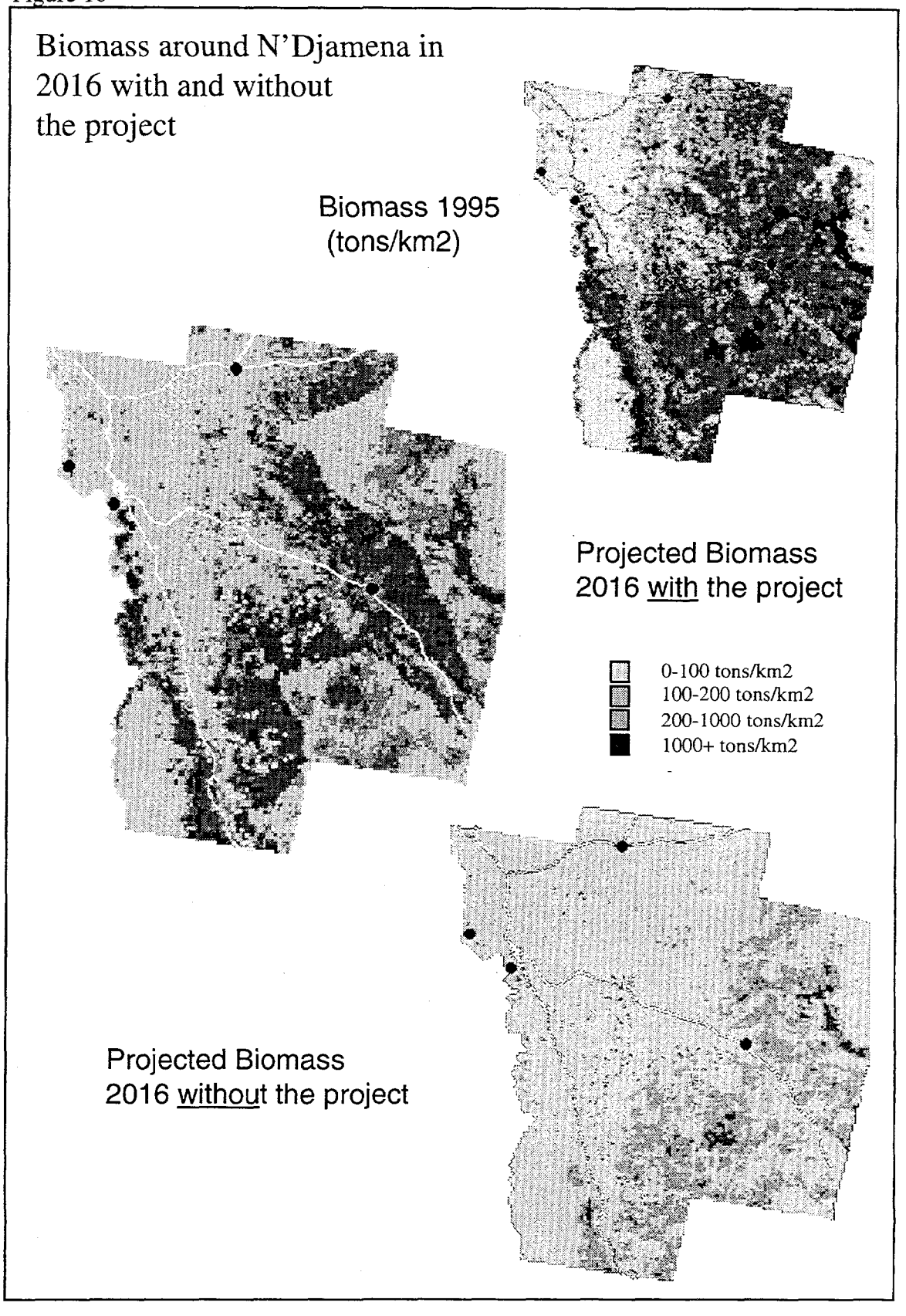
- transport cost per ton to N'Djamena for wood and charcoal
- spatially-explicit prices of wood and charcoal, with and without the project
- future land use and biomass, with and without the project
- potential yield under sustainable and unsustainable exploitation
- spatial distribution of income changes brought about by the project.

The output of the analysis is a spatial data set that predicts rights (and other project activities) on land use and biomass (Figure 10). By mapping the predicted biomass levels it is possible to identify areas where there are likely to be environmental pressures (soil erosion and other nontimber woodland benefits), with and without the project. The spatial analysis can also show how income is distributed spatially as a consequence of the project.

With the results of the analysis, several interesting policy experiments are possible. For example, it is possible to compare the effects of imposing a property tax or a wood tax at the gates of N'Djamena on land use and wood prices.

It is also possible to estimate a rate of return on project expenditures. Based on the spatial

Figure 10



analysis, the present discounted value of fuel supply cost savings as a result of the project is about $5.9 million. The present discounted value of project costs is about $3.9 million.

Potential Use/Role in Bank Operations:

- quantify overall costs and benefits of assigning property rights
- simulate effects of different pricing regimes for fuels
- simulate effects of alternate tax and subsidy policies for fuels
- project preparation, environmental assessment

For further information, see "An Economic Analysis of Woodfuel Management in the Sahel: The Case of Chad," Kenneth M. Chomitz and Charles Griffiths, Development Research Group, Policy Working Paper 1788, World Bank, June 1997.

3 Decision Support Systems with Spatial Components

In addition to specific uses of spatial analysis in various units around the Bank, we describe three larger modeling efforts incorporating spatial analysis in various stages of development - Regional Air Pollution Information System (RAINS-ASIA), Multi-objective environmentally-sustainable development Using Systems Analysis (MEDUSA), and the Decision Support System for Industrial Pollution (DSS/IPC). These activities provide a generalized approach with applicability beyond a single project or program. Substantial effort is devoted to developing underlying data sets (e.g., engineering coefficients relating processes to pollution outputs) and software to perform complex calculations and display the results.

3.1. The Regional Air Pollution Information and Simulation Model for Asia (RAINS-ASIA)

Growing concern about acid rain prompted a series of expert meetings in Asia during the late 1980s. A consensus emerged that an assessment tool was needed to understand acid rain in Asia and to help develop strategies to mitigate or avert the problem. A project to develop an integrated assessment model called RAINS-ASIA (The Regional Air Pollution Information and Simulation Model for Asia) emerged from this consensus.

RAINS-ASIA is a computerized scientific tool to help policy makers assess and project future trends in emissions, transport, and deposition of air pollutants, and their potential environmental impacts. The model was developed as an international cooperative venture, involving scientists from Asia, Europe and North America. It is designed to run on standard IBM-compatible computers and be user-friendly. Individual modules can guide users through the sequence of steps necessary for creating and evaluating emission control plans. The RAINS-ASIA model consists of three modules, each addressing a different part of the acidification process. The Regional Energy and Scenario Generator (RESGEN) module estimates energy pathways based on socioeconomic and technological assumptions. The Energy and Emission (ENEM) module uses the energy scenarios to calculate sulfur emissions and costs of control strategies. The Deposition and Critical Loads (DEP) module calculates the levels and patterns of sulfur deposition resulting from a given scenario, and then assesses the resulting environmental impacts.

In its current version, the model is designed to analyze emissions and impacts of sulfur dioxide at a regional level (the spatial resolution is 1 degree). It assesses only the indirect impacts of sulfur deposition on soil. The model does not include the effect of sulfur dioxide on terrestrial ecosystems through direct exposure, or the effect on human health, aquatic ecosystems, and materials damage.

A number of scenarios have already been analyzed using the RAINS-ASIA model. These

are based on forecasts of future socioeconomic conditions and energy demand, and predicted levels of energy use, emissions, and environmental pollution. The starting point of these analyses is the "base case" or the status quo scenario which forecasts future conditions assuming that no changes are made in present rates of economic and population growth or in present economic, energy and environmental policies. In the base case, total energy demand increases at an average rate of 4 percent per year over the period 1990–2020, and the relative importance of coal in primary energy production remains relatively stable at, or near, 1990 levels of 41 percent of total fuel use. Because of the high rate of economic growth forecast for the region, sulfur emissions are projected to increase from 33.6 million tons in 1990 to over 110 million tons by 2020, an increase of 230 percent, if no actions are taken to restrict emissions (Figure 11).

This huge increase in energy consumption and sulfur dioxide emissions brings about similar increases in sulfur deposition. Many industrialized areas of Indonesia, Malaysia, the Philippines, and Thailand experience sulfur deposition levels of 5–10 grams per square meter per year, while local "hot spots" in some industrialized areas of China receive over 18 grams of sulfur per square meter every year. In comparison, the maximum levels reached in the most heavily polluted parts of Central and Eastern Europe -- the black triangle -- were approximately 15 grams per square meter per year. These levels resulted in the premature death of many tree species in an area covering southwest Poland, northwest Czech Republic and southeast Germany. The model projects that large sections of southern and eastern China, northern and eastern India, the Korean peninsula, and northern and central Thailand would receive levels of acid deposition beyond the carrying capacity of the ecosystem.

While the base case scenario may be used as the worst-case scenario, since it assumes that no new measures are undertaken to control emissions, one can also investigate the best-case scenario, of the "Best Available Technology" (BAT) strategy. In this scenario, sulfur dioxide emissions are halved in 30 years, from 33.6 million tons in 1990 to 16.3 million tons by 2020. As a result, nearly all areas of Asia attain sustainable levels of sulfur deposition that avoid ecosystem damage, although problems still exist in areas of China where there is heavy industrial activity. The cost of implementing the BAT strategy is estimated at US$90 billion per year, or about 0.6 percent of the region's gross domestic product (GDP).

The RAINS-ASIA model can be used for a variety of purposes. Examples include:

- energy and environmental planning,
- identifying critical ecosystems and their sulfur carrying capacities,
- following emissions from an area or point source to estimate deposition,
- identifying the contributing sources to deposition in an ecosystem,
- exploring different mitigation strategies and estimating associated costs,
- selecting pre-defined energy pathways; modifying pathways to explore impacts of alternative energy development strategies, and
- defining control strategies for individual fuel types, economic sectors, emission control technologies, and sub-regions or countries.

For more information on RAINS- ASIA, contact Jitendra Shah, (ASTEN) (20)-458-1598.

3.2. Decision Support System for Industrial Pollution Control (DSS/IPC)

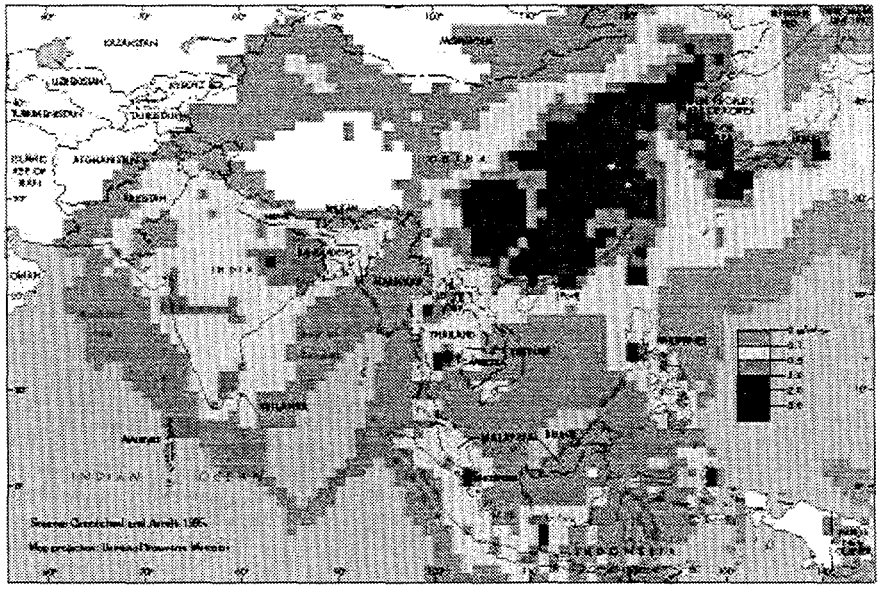
The Decision Support System for Industrial Pollution Control (DSS/IPC) was developed to serve a variety of operational and policy research needs of the environmental and industrial development community in the World Bank, in developing countries and elsewhere.

The system is built from four groups of software modules: (1) an inventory of the pollution loads geographically distributed by media of discharge;

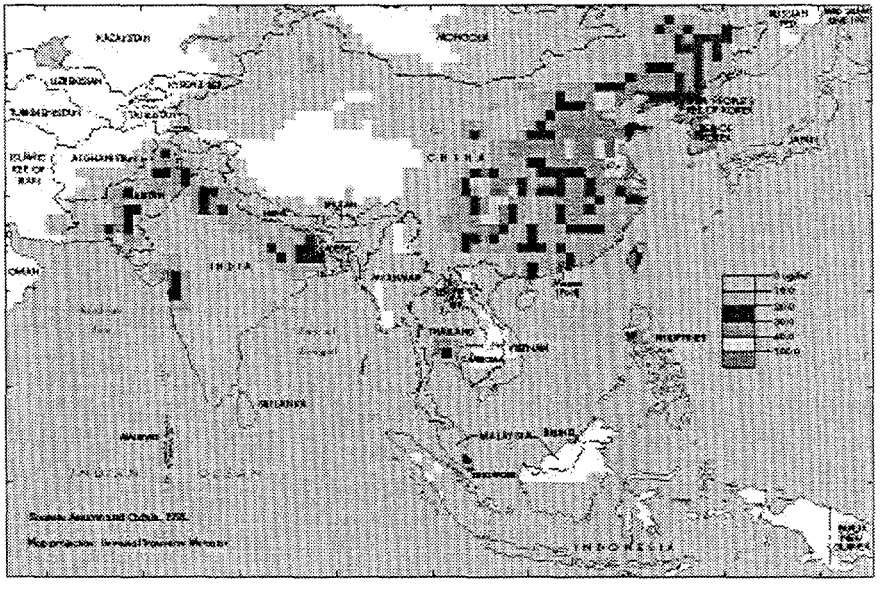
Figure 11

Distribution of sulfur depositions from sulfur dioxide emissions in Asia

Sulfur deposition in Asia, 1990 ($g/m^2/yr$)



Ambient levels of sulfur dioxide concentration in 2020 under the reference scenario



(2) evaluation of the resulting ambient pollution concentrations; (3) the identification of priority pollutants, their main industrial contributors, and the available control measures and technologies; and (4) the costs of alternative control measures and technologies, by type of pollutant and by industrial sectors and processes generating the pollution. The DSS/IPC software package includes the following databases:

- emission factors by media of discharge of the most often encountered processes used in energy production, industry, agriculture and public services, as well as of mobile sources in transportation,
- a comprehensive review of the most important air and water pollutants for which the estimated concentrations of no concern have been evaluated, and
- a list of the most commonly encountered pollution control measures and technologies available in each industrial sector, their potential emission reduction effect, and the standardized costs associated with adopting the control measures.

Whereas the RAINS Asia model is designed mainly for regional modeling, the DSS/IPC can model effects in the region of a single factory or a heavily industrialized area.

Questions the DSS/IPC was designed to answer include:

Which regions are most susceptible to environmental pollution damage, or where are the most probable concentrations of pollution, given some preliminary comparative analysis of pollution loads; in other words, where are the pollution "hot-spots"?

In any one area, what are the most hazardous pollutants for the habitat?

What is the most cost effective, economically feasible option to control the most hazardous pollutants?

What are the best control strategies given the current state of the art in pollution control technologies, the degree of market concentration in the sectors generating the most hazardous pollutants, the cost structure of the industry, the availability of budgetary resources to implement pollution control measures, the level of risk faced by the most exposed and their risk preferences?

See Section 5.4 for an example of how DSS/IPP can be used.

Questions or inquiries should be directed to Kseniya Lvovsky at KLvovsky@WORLDBANK.ORG.

3.3. Multi-objective environmentally-sustainable development Using Systems Analysis (MEDUSA)

The goal of the South Asia Development triangle initiative is to identify benefits to India, Bangladesh, Nepal and Bhutan of cooperation in utilizing the region's natural and manmade resources. A central challenge is to coordinate information (and later projects and programs) in various sectors within and among the countries and external lending institutions.

The Decision Support Systems unit of ASTEN has proposed the development of MEDUSA, an information system and a set of models, to examine specific resource issues. The information system will consist of a network of socioeconomic, resource and development information on the triangle, including user-friendly, interactive spreadsheets, maps, web pages, and an inventory of useful web sites. The first model, MEDUSA-1, will analyze the water resources of the region. It is an interactive multiple-objective optimization model that focuses on potentials and tradeoffs in water use, agricultural output, hydropower, in-stream water quality, ground water recharge, and policy, legal and other constraints under a variety of scenarios. The objective is to make the best use of available data to illustrate tradeoffs, identify areas of cooperation, estimate the value of additional information, and examine physical and

social options for the supply-side and demand-side for water resources planning and management in a river basin framework.

The MEDUSA 2 model will look at transport infrastructure for various commodities including coal, oil, hydropower and agricultural and industrial goods. The model uses an innovative methodology to support intersectoral infrastructure and policy design and evaluation. It focuses on multi-commodity production, consumption, trade, and transport issues.

Questions that MEDUSA 2 could answer are:

- What are the benefits of better connecting Nepal to the northern India power grid?
- What are the capacity constraints that hurt most in various forms of transport?
- What are the shadow prices of energy-related commodities under scenarios with different objectives, constraints, and assumptions?

Both models are currently at a nascent stage - further development would include the participation of technical experts in the countries, updating data, and an initial prioritization of development constraints.

For further information, contact Nagaraja Rao Harshadeep, (ASTEN), (202)-473-9173.

4 Enhancing the Contribution of Spatial Analysis to Bank and Client Operations

Spatial analysis has demonstrated its value to Bank operations in selected cases but clearly has the potential to make a far greater contribution. There are a number of developments likely to accelerate the use of spatial data and analysis in Bank activities in the next few years. These can be traced to dramatic improvements in data availability and quality due largely to the advent of the Internet. This is providing the stimulus for the production and ready exchange of spatially referenced data and increasing interest in the development and application of spatial analysis techniques.

4.1 New Approaches to Data Collection and Management

By its nature, spatial data lends itself well to qualitative representation in maps. However, maps are often difficult to incorporate in a meaningfully way into traditional reports and are often a static and inefficient way of conveying quantitative information - depending largely on the cartographic skills of those producing them (see Tufte, 1983 and 1990). In addition to maps, the Bank is experimenting with innovative and dynamic ways of combining qualitative and quantitative representations of data. Recent advances in information technology allow the integration of spatial data with simple interactive spatial analysis tools on CD-ROMS. These can be produced and disseminated at low cost - allowing the user to investigate and manipulate the data and produce output tailored to a particular demand.

The recent expansion of the Internet and the World Wide Web offers the most exciting potential for the mainstreaming of spatial data and spatial analysis. Despite difficulties associated with the large data volume of many GIS data sets, it is now possible to make them available anywhere in the world via an Internet connection. As this technology is implemented, it will no longer be necessary to centralize data or rely on lengthy and time-consuming delivery schedules. Data compatibility issues will also become less of a problem.

These innovations, and the renewed interest in data exchange accompanying them, have encouraged previously independent and disbursed groups of organizations to work together to facilitate data harmonization and dissemination. These groups (e.g., Consortium for International Earth Science Information Network (CIESIN) or the Biodiversity Conservation Information System (BCIS)) are improving data availability and quality and are beginning to provide data of immediate utility for spatial analysis for practically any area in the world.

4.2 Development of Analytical Techniques

The history of spatial analysis has resulted in the development of two different sets of techniques to analyze spatial data - vector and raster analysis. Geographers were instrumental in developing GIS software that manipulated data for irregularly shaped areas such as counties, cities, and bodies of water. Traditionally GIS software

focused on the manipulation of "vector" data; that is, a point, line or polygon represents a location. An attribute (e.g., population, and water quality) has a constant value for that area.

Remote sensing experts with digital data from aerial photographs and satellite images developed techniques for analyzing raster data. A raster data element is a pixel, which represents an attribute value for a small, regularly shaped area (rectangle or square). Typically the data value is an index that represents the intensity of light of a given frequency received at a sensor on the satellite or airplane.[1] Modern GIS software now incorporates both vector and raster analysis techniques.

The analytical techniques and computer algorithms for classical GIS and remote sensing analysis are well developed. However, the development of empirical behavioral models with spatial attributes is relatively recent. Incorporation of statistical techniques into commercial GIS software is just beginning. There are especially challenging econometric issues that arise with the use of spatial data (see Anselin, 1988). Economic models of land use that take advantage of spatial characteristics and can be tested econometrically have recently been developed (see Chomitz and Gray, 1995, Nelson and Hellerstein, 1997), but additional research is needed to test the validity of these approaches in a variety of settings.

It should be possible to develop a set of "current best practices" for spatial analysis with wide use in Bank operations. These would include many of the approaches used in the examples described above. Other, less-well developed spatial analysis techniques could be tried on an experimental basis. An important issue is how to promote these best practices. For the foreseeable future it seems likely that the level of expertise needed to manipulate the software and hardware implies some centralization, either for the whole Bank or in the regions.

4.3 Support for Spatial Analysis in the Bank

The Bank has a fully operational unit capable of undertaking the tasks associated with spatial analysis, from data compilation and automation through development and application of techniques to the production of output (web pages, maps, CD-ROMS). The ENGIS unit supports the activities of the GIS Working Group, a Bank-wide group of professionals dedicated to the development and application of spatial analysis and related technologies in Bank projects (see Prevost and Gilruth, 1997). Many of the examples listed in this publication have arisen due to collaborative exercises between ENGIS and staff in other units.

[1] A commonly used and widely available source of satellite images is the Landsat Multispectral Sensor MSS). This camera was first carried aboard a Landsat satellite in 1973 and images from successive versions are available for most of the world since that time. Each sensor in the camera captures the light reflected from an area about 80 meters by 80 meters. Four frequencies are recorded - green, red and two near infrared. These frequencies were chosen because they were absorbed or reflected in different ways by chlorophyll, soil, and water. Combinations of these frequencies make it possible to identify areas of annual and perennial vegetation, urban development, and other land uses. MSS images are raster data; each pixel represents the intensity of light in a given frequency as reflected from an 80-meter square area.

5 Conclusion

Spatial analysis has already made important contributions to Bank operations as the examples above illustrate. The continued decline in cost of software and hardware opens up new opportunities to use these emerging techniques to improve Bank support for its clients. In addition, the availability of high quality, spatially referenced digital data sets is improving rapidly, driven by the development of the Internet and the World Wide Web. The Bank can play a key role in hastening the contribution of spatial analysis to its clients by supporting developments in the activities outlined above.

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Appendix

This glossary is derived from a GIS glossary made available on the World Wide Web by the British Columbia Ministry of Environment, Lands, and Parks. The address is http://www.env.gov.bc.ca/gis/glosstxt.html. Some terms have deleted or modified; others have been added.

Appendix 1: A GIS Glossary

Accuracy	1) The closeness of an estimated (measured or computed) value to a standard or accepted value of a particular quantity, i.e., relates to the quality of the result. 2) With regards to numbers in a mathematical table or those produced by a computer Accuracy may mean (a) the number of significant digits in the numbers, (b) the order of magnitude of the least significant digit. (See also Precision)
Algorithm	A set of rules for solving a problem. An algorithm must be specified before the rules can be written in a computer language.
Analog	A continuously varying electronic signal (contrast with Digital). Also refers to traditional paper mapping products and aerial photographs.
Arc	A line connecting a set of points that make up one side of a polygon.
Area	A fundamental unit of geographical information. See polygon.
Attribute	Non-graphic information associated with a point, line, or area element in a GIS.
Bit map	A pattern of bits (i.e. ON/OFF) on the grid stored in memory and used to generate an image on a raster scan display.
CAD(D)	Computer-Aided Drafting (Design)
Cadastral	Related to records of land-related tenure, whether surface or sub-surface and whether linear, parcel-based or defined as a single point.
Cell	The basic element of spatial information in the raster (grid) description of spatial entities.
Chain	A sequence of coordinates defining a complex line or boundary. See Arc.
Choropleth map	A map consisting of areas of equal value separated by abrupt boundaries.
Contour	A line connecting points of equal elevation.

Coordinate system	A system of linear or angular quantities which designate the position that a point occupies in a given reference frame or system. Also used as a general term to designate the particular kind of reference frame or system. There are several coordinate systems that can be roughly grouped into the following types: Cartesian (or plane) coordinate system, geographical (or spherical) coordinate system and rectangular coordinate systems. All of these systems establish a grid of lines and upon a two- or three-dimensional surface. See also, state plane and universal trans mercator.
Database	A collection of interrelated information usually stored on some form of mass-storage system such as magnetic tape or disk. A GIS database includes data about the position and the attributes of geographical features that have been coded as points, lines, areas, pixels or grid cells.
Digital elevation model (DEM)	A quantitative model of landform in digital form. Also digital terrain model (DTM).
Digital	The ability to represent data in discrete, quantized units or digits.
Digitizer	A device for entering the spatial coordinates of mapped features from a map or document to the computer.
Edge matching	The process of ensuring that detail along the edge of two adjacent map sheets matches correctly.
Element	A fundamental geographical unit of information, such as a point, line, area, or pixel. May also be known as an entity.
Feature Code	A set of characters (alpha, alpha/numeric or numeric) within the GIS, which uniquely identifies a feature class or homogeneous group of features. The following examples are from the TRIM 120 000 Mapping Specifications 33750000 - Wooded Area 25100190 - Paved Road 25000120 - Loose Surface Road (Gravel)
Filter	In raster graphics, particularly image processing, a mathematically defined operation for removing long-range (high-pass) or short range (low-pass) variation. Used for removing unwanted components from a signal or spatial pattern.
Geodesy	The scientific study of the size and shape of the earth and determination of positions on it.
Geodetic framework/ network	A spatial framework of points whose position has been precisely determined on the surface of the earth.
Geographic Information System (GIS)	A system of capturing, storing, checking, integrating, analyzing and displaying data about the earth that is spatially referenced. It is normally taken to include a spatially referenced database and appropriate applications software.
Geo-referencing	The process of delimiting a given object, either physical (e.g. a lake) or conceptual (e.g. an administrative region), in terms of its spatial relationship to the land. The geographic reference thus established consists of points, lines, areas or volumes defined in terms of some coordinate system (usually latitude and longitude, or UTM northings and eastings, and elevation).
Geocoding	The activity of defining the position of geographical objects relative to a standard reference grid.

Geographics or geographic projection	Representation of the earth's surface as a projection onto rectangular lines of latitude and longitude.
Global Positioning System	A system of earth satellites, each providing precise time and position information that enables a GPS receiver to compute the distance to each satellite. The distance measurements of at least three satellites are required to fix the receivers position in latitude and longitude. Measurements from a fourth satellite are required to provide vertical (altitude) positioning.
Grey scales	Levels of brightness (or darkness) for displaying information on monochrome display devices.
Grid	1. A network of uniformly spaced points or lines on the CRT for locating positions. 2. A set of regularly spaced sample points. 3. In cartography, an exact set of reference lines over the earth's surface. 4. In utility mapping, the distribution network of the utility resources, e.g. electricity or telephone lines.
Image analysis	The processing and interpretation of graphic images held in digital form.
Isopleth map (Isoline)	A map displaying the distribution of an attribute in terms of lines connecting points of equal value; See contour, contrast with Choropleth map.
LANDSAT	The generic name for a series of earth resource scanning satellites launched by the United States of America.
Latitude	Angular distance expressed in degrees and minutes along a meridian north or south of the equator.
Legend	The part of the drawn map explaining the meaning of the symbols used to code the depicted geographical elements.
Longitude	The angular distance east or west from a standard meridian to another meridian on the earth's surface, expressed in degrees and minutes.
Line	One of the basic geographical elements, defined by at least two pairs of xy coordinates.
Look-up table	An array of data values that can be quickly accessed by a computer program to convert data from one form to another, e.g. from attribute values to colors.
Map projection	The basic system of coordinates used to describe the spatial distribution of elements in a GIS
Meta-Data	Meta-data is data about data. It typically includes information such as currency, accuracy, extent, custodianship, and collection methodology. Meta-data is typically stored in data models, dictionaries, schemas and other representations.
Multi-spectral scanner system (MSS)	A device often carried in airplanes or satellites for recording received radiation in several wavebands at the same time.
Network	1. Two or more interconnected computer systems for implementation of specific functions. 2. A set of interconnected lines (arcs, chains, strings) defining the boundaries of polygons.
Node	The point at which areas (lines, chains, strings) in a polygon network are joined. Nodes carry information about the topology of the polygons.

Overlay	The process of stacking digital representations of various spatial data on top of each other so that each position in the areas covered can be analyzed in terms of these data.
Pixel	Contraction of picture element. The smallest unit of information in a grid cell map or scanner image.
Polygon	A multi-sided figure representing an area on a map.
Precision	A measure of the tendency of a set of random numbers to cluster about a number determined by the set. The usual measure is either the standard deviation with respect to the average i.e., relates to the quality of the method by which the measurements were made and is distinguished from accuracy which relates to the quality of the result.
Projection	The representation on a plane surface of any part of the surface of the earth.
Raster-to-vector	The process of converting an image made up of cells into one described by lines and polygons.
Raster	A regular grid of cells covering an area.
Reference Ellipsoid	An ellipsoid associated with a geodetic reference system or geodetic datum, whose surface is equipotential and approximates the geoid in size and position. Reference ellipsoids are most commonly ellipsoids of revolution and are sometimes called reference spheroids.
Resolution	The smallest spacing between two display elements; the smallest size of feature that can be mapped or sampled.
Rubber sheeting	The transformation of spatial data to stretch or compress them to fit with other data
Scale	The relation between the size of an object on a map and its size in the real world.
SPOT	A series of earth resource satellites with high-resolution sensors. France launched the first in January 1986.
State Plane Coordinate System	The State Plane coordinate system (SPCS) is a rectangular system of x/y coordinates defined by the U.S. Geological Survey and unique to each state. Locations within a state are given in terms of their positions relative to some defined origin with that state. Coordinates are measured in feet. An example coordinate is 380,930N 1,996,821E Wisconsin South.
Tesselation	The process of splitting an area into tiles.
Thematic map	A map displaying selected kinds of information relating to specific themes, such as soil, land-use, population density, suitability for arable crops, and so on. Thematic information may be represented as labeled polygons. lines or points, chloropleth maps, isolines, etc.
Tile	A part of the database in a GIS representing a discrete part of the earth's surface. By splitting a study area into tiles, considerable savings in access times and improvements in system performance can be achieved.
Topographic map	A map showing natural and man-made features as well as relief, often in the form of contours.
Topography	The configuration of a planetary surface including its relief and the position of its natural and man made features.

Topology	The way in which geographical elements are related to each other. The topology of the data must be defined before GIS analysis can be performed.
Toponymy	The study of the place names of a region. A toponym is a place name.
Transform	The process of changing the scale, projection, or orientation of a mapped image.
Universal Transverse Mercator (UTM) Coordinate System	The Universal Transverse Mercator (UTM) coordinate system is a Transverse Mercator projection of the ellipsoid to which specific parameters have been applied. The UTM projection grid was adopted by the US Army in 1947 and NATO in the 1950's for designating rectangular coordinates on large-scale military maps of the world. The UTM projection maps the Earth between latitudes 84°N. and 80°S. in 60 zones, each 6° wide in longitude. The bounding meridians of each zone are divisible by 6° and each zone has a unique central meridian and zone number. Zones are numbered consecutively from 1 to 60 beginning with the zone bounded by meridians 180°W. and 174°W. and continuing eastwards. Each UTM zone has a true origin at the intersection of the central meridian and the equator and a false origin established so that grid coordinates within a zone are positive. In the northern hemisphere, the origin of grid coordinates (the false origin) is on the equator and 500,000 m west of the true origin. In the southern hemisphere, the origin of grid coordinates is 500,000 meters west and 10,000,000 south of the true origin. Units of measurement are meters.
Vector graphics structure	A means of coding line and area information in the form of units of data expressing magnitude, direction, and connectivity.

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