USING A GEOGRAPHIC INFORMATION SYSTEM TO ANALYZE THE EFFECTS OF SEA LEVEL RISE[1]

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ABSTRACT. *Mean sea level rise on the eastern seaboard has been documented over the last fifty years and may continue at an accelerated rate in the future if certain predictions concerning the greenhouse effect prove correct. A geographic information system (ERDAS) was used in conjunction with satellite imagery to determine the affect on land use of various sea level rise scenarios in a small portion of eastern Long Island. A general method for conducting such investigations was developed and the site specific problems of such an analysis were isolated. It was determined that a sea level rise of one to five feet would have a significant impact, although coastal flooding would not be as severe as anticipated.*

The mean sea level as measured at Sandy Hook, New Jersey, has been rising for the last fifty years at an approximate rate of 0.014 feet per year and is anticipated to continue to rise at the same rate for the indefinite future (Lyles et al. 1988, 72). This increase in sea level is attributed to general geophysical factors acting on the eastern seaboard that are causing the coastal region to sink and are not related to any increase in the volume of sea water in the Atlantic Ocean. Despite the lack of contemporary evidence for sea level rise induced by global warming, concern over this possibility is growing, encouraged by the debate over the inevitability or avoidability of the greenhouse effect and the consequences to be expected from it.

The goal of this project was to perform an initial analysis of the effect of sea level rise on the portion of the Long Island coast in the vicinity of Mecox Bay using a geographic information system (GIS) and a SPOT image. A general methodology for performing such analyses was to be developed, feasibility of economic valuations were to be determined, and technical problems were to be noted so that future efforts in this area can be more refined. In addition, the project would yield insight into the general usefulness of the method and the limitations imposed by specific site conditions. As a final result of the analysis, an outline of economic, social, and topographical effects of sea level rise on the area would be determined.

It was concluded that a GIS is an effective tool for studying the affect of sea level rise on selected areas, and that it is feasible to arrive at an assessment of projected effects. The technical problems associated with the task, in particular the registration of the SPOT image to the relevant map coordinates, were more difficult than anticipated, and the limits of the system's resolution, the accuracy of the land use classification, and terrain digitizing, all required that adjustments to the process of analysis be made. Many of these were site-specific and can yield only general insights into the analysis process. Finally, the affect of sea level rise on the study area would be marked, although not as severe as anticipated. The reason for this is that the local topography is not as low lying as had been believed.

Sea Level Rise

Sea level rise due to coastal subsidence has been observed at many locations worldwide, including several, such as the area near the Los Angeles Harbor, where human extraction of groundwater or oil is the cause. At this time, any effects of the projected

global warming are masked by the relative rise in sea level that is of geophysical origin (National Academy of Science 1987, 9-12).

If the more dire predictions of warming come to pass, and if the projected sea level rise that is associated with that phenomenon does occur, many urban areas, agricultural regions, and recreational areas would be flooded. The economic and social dislocations resulting from this would be extreme, although the gradualness of their realization might mitigate their effect. In order to plan appropriate responses to sea level rise, whatever its origin, data on the local affects in rise scenarios must be gathered. Planners will need information on road networks, sewer outfalls, croplands, and residential areas, among other data sets, that would be flooded or isolated by rising waters, so that rational decisions on whether to abandon or protect the properties may be made. In addition, such projections can be a useful tool for planning future development to avoid the impact of projected sea level rises.

Calculation of the affect of sea level rise can easily be performed using the "sunken valley" approach. A given increment of rise is postulated and topographical contour maps are consulted to determine the location of the new coastline. Naturally, those areas with steeply sloped coastal regions will suffer the least flooding, while low-lying, flat areas, such as southern Florida or Bangladesh, will suffer a large inland dislocation of the coastline. The affect of such a water level rise is indicated by the scum lines, in place of contour map lines, left on the banks of a reservoir with a falling water level.

The sunken valley approach, however, does not account for the migration of the coastline that is caused by erosion. This is an especially important phenomenon in this project's study area where the local coastal dynamic of the barrier island and sheltered beach is dominated by beach creation and erosion. Ignoring coastline migration due to erosion here would underestimate the loss of land to the rising sea.

Determining the degree of erosion for a given unit of sea level rise is a difficult undertaking not amenable to the formulation of clear-cut general rules, since coastal dynamics vary widely for each type of coastal morphology and for specific coasts. Various researchers have developed formulae that express the equilibrium profile of beach regimes and predict coastal recession associated with sea level rise. For this project, because no detailed data on the parameters involved were available and because the study is on a regional scale, use of such relationships was deemed unnecessary and would perhaps produce a false impression of precision.

Instead, a historical approach was used based on data and methodologies described in Responding to Changes in Sea Level (National Academy of Science 1987, 51-52). The average yearly recession rate for Maine-New York barrier islands of 0.3 meters was taken as a base erosion rate, since our study area is sheltered by a barrier island (May et al. cited in National Academy of Science 1987). Cumulative erosion figure over the last fifty years was projected backwards (50 x 0.3m = 15m), and this was divided by the concurrent rise in sea level at Sandy Hook of 0.7 feet. This yielded a working ratio of approximately 22 meters of beach recession for every foot of sea level rise.

This technique has been successfully applied to low-lying, easily erodible terrain from Texas to Maryland (Leatherman 1984, cited in National Academy of Science 1987, 51). The approach with the GIS was to employ the sunken valley method for a first estimate of the coastline change to be modified by the addition of a buffer representing the additional recession due to erosion. The degree of accuracy afforded is adequate, since the GIS used in this project has a cell resolution of 30 meters per side, rending further precision impossible. Naturally, the size of the added buffer was subject to significant rounding off, which was performed in the upward direction to produce worst case effects.

Method of Investigation

The first step in the investigation was to choose a suitable study area. Long Island was chosen because of its topical interest, its relevant topography (i.e., barrier islands sheltering relatively low lying terrain) and easy availability of satellite images. The immediate study area was limited to a small portion of the island, so that all capture of elevational data would be limited to one USGS quadrangle map. The Mecox Bay area (Figure 1) was chosen because its topography closely matched these criteria and it exhibits a variety of land uses in close proximity.

The relevant portion of a SPOT image of the eastern half of Long Island was extracted by examination and entered into its own file. The resulting image was then geo-registered to the UTM coordinate system of the USGS quadrangle by selecting ground control points on the map, locating them in the image, and assigning the image points the associated UTM coordinates. The ERDAS GIS software rubbersheeted the image to conform to the map geometry. Although locating the control points in the image was difficult, and in some sense highly subjective, the resulting error was small, less than one image cell, because the overall rectified area was relatively small.

There were no readily available digitized terrain data for the study area, so manual entry of digitized data was required. This introduced two sources of error for the overlay of terrain data onto the satellite image that was to follow: entry of the elevational data is itself a source of error, particularly when it is performed by novices; and the setup of the USGS map on the digitizer pad entails some error that may result in misalignment in subsequent overlays. Data entry errors were particularly noticeable along the coast where exact alignment of the overlays was desired. In addition, the interpolation of captured data to produce an elevational grid produced some oddities, such as above sea level projections located many meters off the beach in the open sea, which were safely ignored since they were of no relevance to the goals of this study.

The original SPOT image was converted to a GIS file through the unsupervised classification module. Land use was classified into the following categories: urban/residential, cropland, wetlands, water bodies, and undeveloped. The accuracy of this classification process directly affected, of course, the validity of the final statistics gathered from the study, and it presented some severe difficulties, since the urban/residential areas studied are very low density and not easily distinguished from all other categories. The barrier island also presented difficulties because its spectral signature resembled that of uncultivated cropland with which it was initially classed. Moreover, the USGS quadrangle used for digitizing has not been updated for thirty years and provided little assistance in checking the results of the unsupervised classification.

Prior to digitizing elevations, the existing shoreline elevation had to be determined. The USGS map indicates that the mapped shoreline represents the mean high water line and that the range between high and low water is 2.6 feet. Mean sea level was taken to be the zero datum about which the level oscillates from -1.3 to +1.3 feet, and the coastline was digitized as a high water elevation of 1.0 foot, rather than 1.3, since no decimal entries are allowed by the software. In the end, the analysis was determining the impact of a given increment of increase of the high water elevation on the location of the new shoreline, under the assumption that the range of high and low water levels would remain the same.

The overlay procedure followed was to extract a slice from the elevational data, from one foot above sea level to two feet above for a one foot rise in level, for instance, and add an appropriate buffer to represent recession due to erosion. The result is a polygon that includes the new area to be lost to a one foot sea level rise, and it was recoded with

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value zero while the surrounding area was recoded as fifteen, an arbitrary high value. This file was overlaid onto the land use file with a maximum dominance output so that the submerged areas, with land use values between one and ten, showed up, while the unflooded areas were masked. This method allows for easy extraction of statistics with the LISTIT function and provides visual information on what land features, natural and man-made, would be lost to flooding.

Additional adjustments and recoding on the basis of in-depth knowledge of local coastal dynamics would result in more accurate overlays for this area. For example, the barrier islands, fragile environments subject to severe erosion by surges, were not lost to a one- or two-foot sea rise, but the facts are that they most likely would be eroded by such a development. This level of detail was not included in this study. In general, the analysis assumes that the dynamics of the system would remain constant in the face of drastically altered morphology, a greatly simplifying assumption. A primary source of error in the analysis was the imperfect registration of images due to difficulties already discussed. The shorelines of the elevational data file and the land use file were not in absolute alignment, but were shifted in an east-west direction relative to each other. The
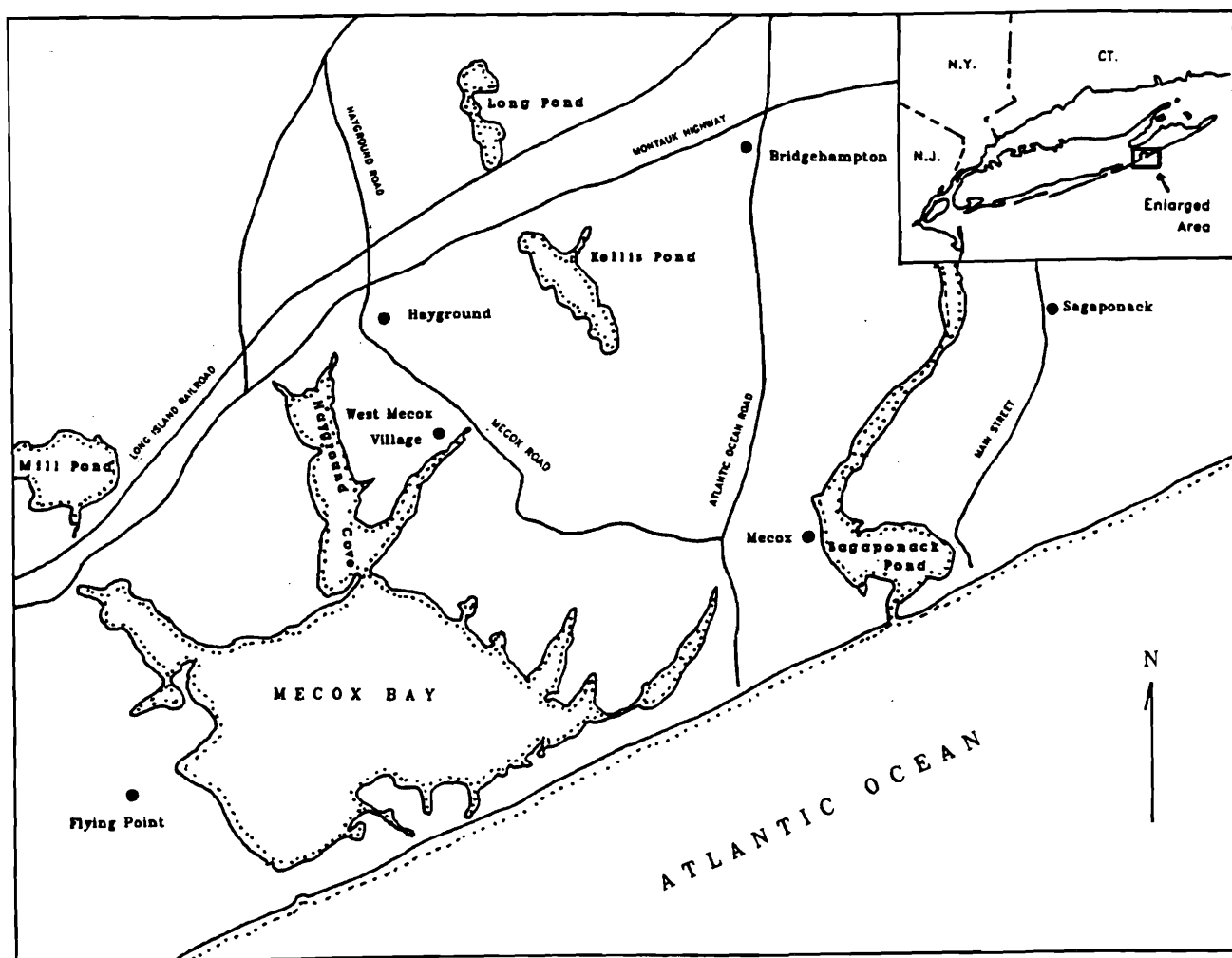

Figure 1

result of this was that land on the western side of certain fingers of water that extend inland was not submerged in our flooding scenarios, particularly where the shore had a relatively sharp slope, such as along Hayground Cove. The affect of this error is mitigated for the area-wide analysis because flooding of land to the east was increased, resulting in some rough cancelling of the error in the aggregate analysis.

One anticipated source of site-specific error did not occur, that is, the pseudo-inundation of inland low-lying areas that would, in fact, not be affected by shoreline changes. The study area comprises the outwash area of a glacial moraine and has a continuous slope without significant inland depressions. If this error had occurred, it would have had to be removed through examination and recoding.

The creation of new wetland areas as part of the modification of the coast under a new sea level regime was not accounted for in this analysis. Isolating areas likely to be transformed into wetlands would involve the description of criteria for such sites at another level of analysis.

Findings

The purpose of this exercise was to develop a method that would enable one to study effects on land use due to a rise in sea level. Using this tool could enable federal, state, and local planners to predict the extent of damage attributable to shoreline flooding. The creation of different scenarios would be helpful for formulating coastal management policies by assessing the potential damage and evaluating appropriate means of mitigation and their costs, long before the event takes place.

The study area includes a 9 kilometer stretch of shoreline extending from the village of Flying Point eastward to Sagaponack. The study area consists of 10,754.91 hectares, of which 2612.52 hectares are water. Table 1 lists the area of each land use category and its percentage of the overall study area. The shoreline area was not included in the analysis, since any area lost would be recreated elsewhere. Areas that are currently inland water bodies were also deemed irrelevant to this analysis.

The source from which land use data were classified and extracted was a recent SPOT image of eastern Long Island. Cropland clearly makes up the largest proportion of the study area, and urban/residential land is widely distributed; the largest cluster lying to the north is Bridgehampton.

As a means of assessing the potential land use categories damaged due to a rise in sea level, six different scenarios were developed. The first five represent an increase of one foot intervals, beginning at one foot; the sixth represents a ten-foot rise. Within each scenario, the ERDAS system generated a list of the number of pixels for each land use affected by the rise in sea level. The number of hectares was calculated by multiplying the number of pixels by their size, 0.09 hectares. Graph 1 depicts the affect of sea level rise in each scenario, while Table 2 breaks down the flooded land parcels by land use type.

The results were not as dramatic as anticipated. The topographical relief was much greater than what the analysts had attributed to this type of coastal area. Photographs of each scenario result were produced. Comparing these images, it was clear that even the worst case scenario is not a dramatic inundation, particularly since the study area contains a great deal of water already.

The logarithm of the area of flooded land for each land use category was plotted on a semi-log grid against the sea level rise increment (Graph 2) and a straight-line fit of the points was attempted. The slope intercept equation of the resulting line was trans-

formed into an exponential equation and plotted on a regular grid, resulting in Graph 3. Clearly, the rate at which cropland is flooded grows significantly as the level of rise increases, while the other land use categories follow a more nearly linear progression. This is presumably because the cropland in the study area was concentrated away from the shoreline. A second attempt to derive an equation from the semi-log plot took account of the apparent break point near a five-foot level rise. Two lines were fitted, one for a one- to five-foot rise and one for a five- to ten-foot rise, and the results were plotted in a similar fashion in Graph 4. It shows that after a five foot rise, even the inundation of cropland follows a nearly linear progression. It also accurately reflects the fact that wetlands begin with a higher flooding rate than undeveloped land, a plausible result for a coastal area with a sheltered bay.

The graphs developed from the analysis constitute a predictive tool applicable to coastal systems similar to the project area. Long Island coastal communities, from Montauk Point at the easternmost tip of the island to the Queens-Nassau County boundary, are situated in areas that are similarly protected by barrier islands, and the upland geomorphology of Long Island is dominated by its axial moraine. Thus, the utility of these graphs for predicting the effects of sea level rise on the Atlantic coast of the island is limited only by the relative mix of land uses as compared to this study area.

In the study area, under the one-foot rise scenario, a total of 6.58 hectares of urban/residential property would be affected. Telephone interviews with local realtors indicated that residential properties along the shoreline are valued as high as $1,000,000 per acre. Converting that into a per hectare value results in total land value losses of $16,252,000. Real estate values decrease as one moves inland; prices per acre drop dramatically to a range between $50,000 to $350,000. Therefore, under the worst case flood scenario, a total of 42.66 hectares of urban/residential properties would be destroyed at a cost of at least $20,708,000. Assessing specific values of undeveloped land uses was

TABLE 1
LAND USE TYPES IN STUDY AREA

Land Use	Land Area Size (ha.)	Percentage of Study Area
Undeveloped	909.18	8.42
Cropland	6683.04	62.28
Wetlands	200.61	1.86
Urban/Residential	310.86	2.88
Shoreline	38.7	0.36
Water Bodies	2612.52	24.20

Graph 1
Flooding of Land Use Types

Hectares Flooded

Sea Level Rise (ft.)

- ■ urban/residential
- ▨ wetland
- □ undeveloped
- ▦ cropland
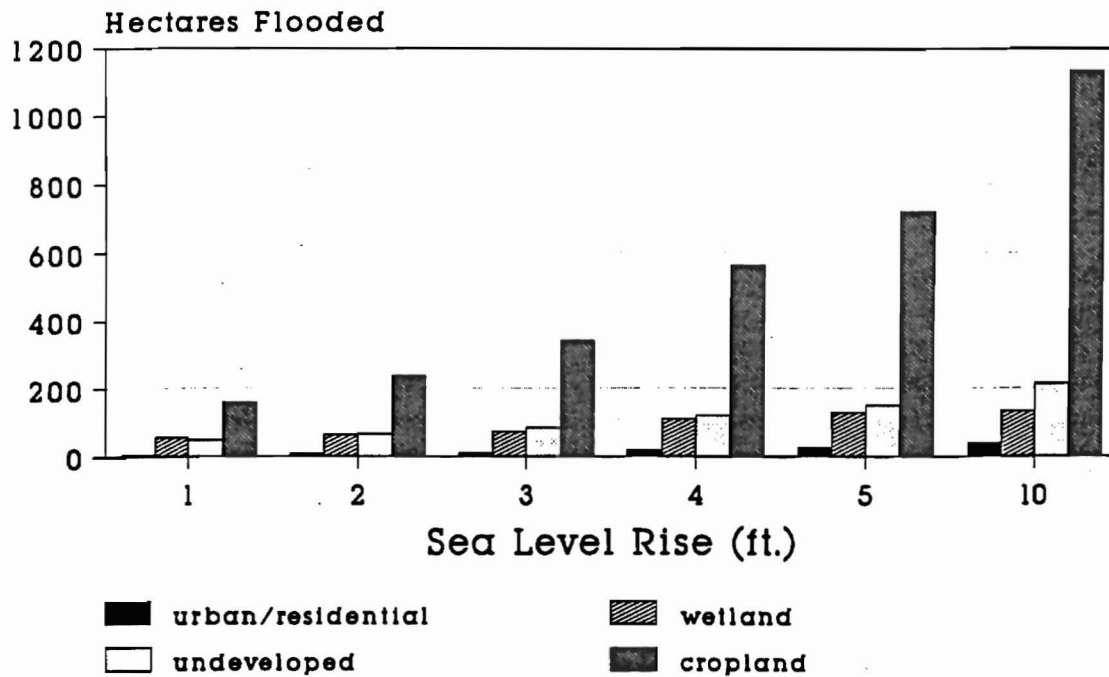
not appropriate in this study, since it is not known what zoning applies to the land parcels. If more detailed information were available, a cost valuation could be determined. Discussions with realtors indicated that most of the property in our study area is now zoned for residential and local commercial uses.

Land Use Management Techniques

Using a GIS to analyze the effects of sea level rise could be very beneficial for coastal management purposes. There are numerous planning issues that can be attributed to any significant rise in sea levels, such as:

1. stabilization and protection of coastal shore
2. saltwater intrusion into fresh water supplies
3. protection of limited shoreline recreation facilities
4. economic impact on local residential and business communities
5. destruction of wetlands

Each of these issues represents a significant potential environmental and economic impact on the local and regional area. Using this GIS model could assist coastal planners in identifying the numerous alternatives available, based on the extent of the

flooding, and provide raw data to evaluate the alternatives thought to be the most appropriate.

Coastal management policy is very complex since private and public interests must be weighed against each other. Controversies often arise due to the differences in possible approaches. Generally there are two main approaches to coastal management: using engineering techniques, which include beach nourishment, dune improvement, stabilization of vegetation, sea wall construction, and use of hydraulic fill; and using land use management techniques, which rely on regulatory solutions such as coastal zoning, specific building codes, flood plain management, delineation of flood hazard areas, and public acquisition of beach front property. The controversy arises in trying to choose between the technical solutions to control the flooding, or allowing it to take its course. Having the proper tools to predict the potential damage and to apply different solutions to the model before the damage occurs can greatly assist those who are developing the coastal management policies.

The affect of flooding on wetlands would be of particular interest on Long Island, since the local aquifers, which currently suffer from salt front intrusion problems, are the region's sole potable source. A rising sea level would increase the head on the salt water intrusion and could exacerbate this problem by pushing the salt front further inland toward wells. This represents a planning problem where a GIS system could be a significant aid to local officials with its ability to develop groundwater potential coverages and to identify sites where recharge might be a cost-effective operation.
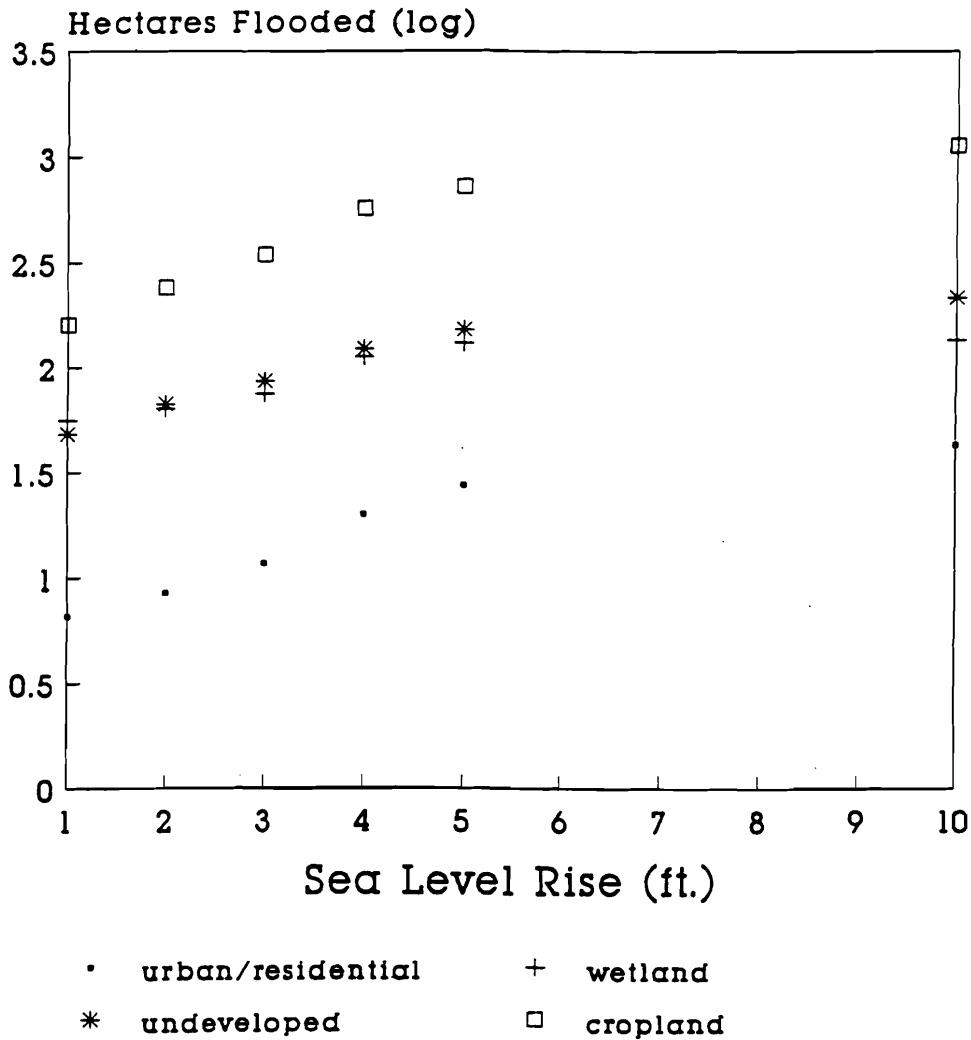
This GIS exercise presents one way in which imagery data can assist planners, engineers, and policy makers in making more intelligent decisions. The model could be elaborated to include the affect of building sea walls around the more densely populated areas and to analyze the resulting flooding effects, although sea walls themselves are controversial because of their long term affects on beach erosion. The results of this particular exercise were not as important as the creation of a framework for the development of more detailed models. Integration of more detailed data is crucial, but the exercise tells us what kind of information can be derived from such a model.

TABLE 2

AREAS FLOODED BY SEA LEVEL RISE (ha.)

	1 ft. rise	2 ft. rise	3 ft. rise	4 ft. rise	5 ft. rise	10 ft. rise
Urban/ Res.	6.57	8.46	11.61	19.80	27.36	42.66
Wetlands	55.89	63.54	74.16	111.24	129.87	134.91
Undevel.	48.06	66.24	85.14	121.05	150.57	213.21
Cropland	160.02	238.77	342.27	563.94	721.62	1132.92

Graph 2
Flood Results

Hectares Flooded (log)

Sea Level Rise (ft.)

- urban/residential   + wetland
* undeveloped   □ cropland

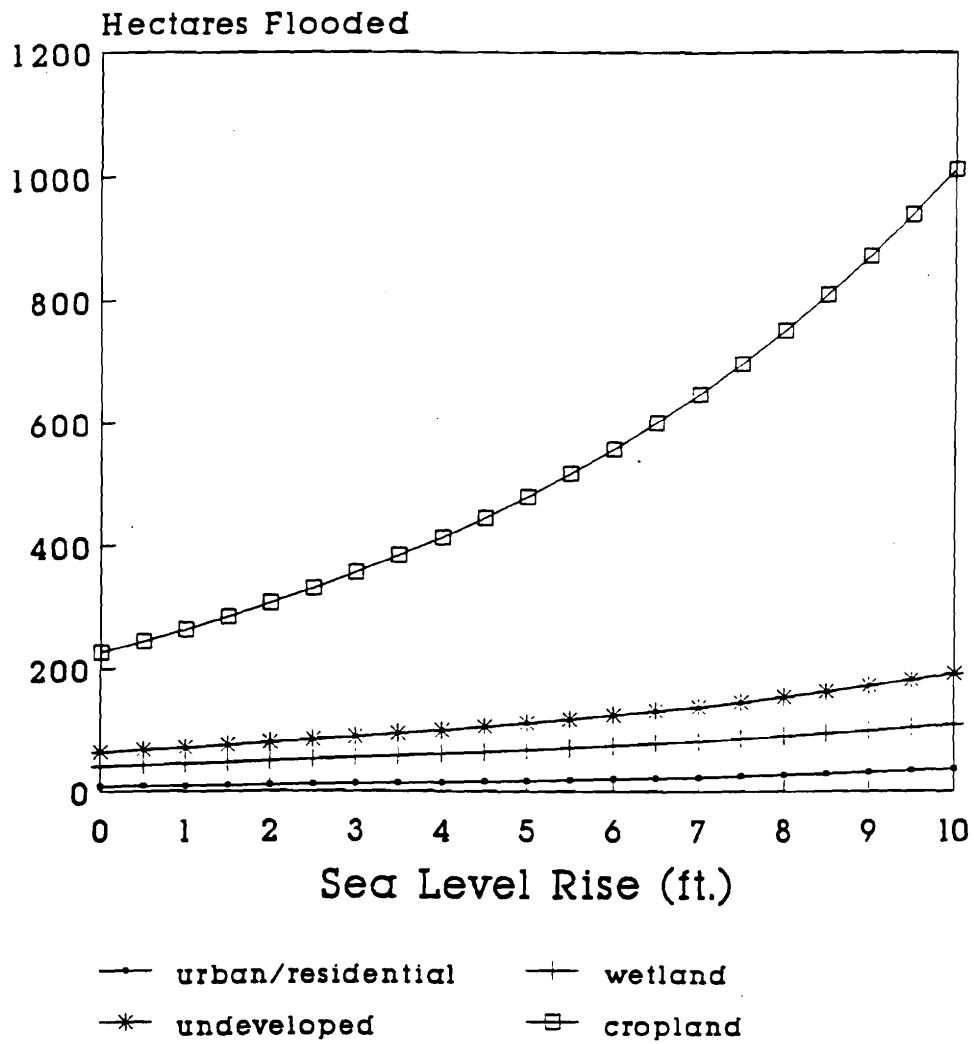
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Graph 3
Flooding Rates I

Hectares Flooded

Sea Level Rise (ft.)

- urban/residential
- wetland
- undeveloped
- cropland

Graph 4
Flooding Rates II

Hectares Flooded

Sea Level Rise (feet)

- urban/residential
- undeveloped
- wetland
- cropland