Panel Three: Remote Sensing of Land Use/Land Cover in the Watershed

Panel Three focused on land use and land cover in the Bay watershed in a departure from discussions of *in-situ* and aircraft/satellite remote sensing. Steve Prince of the University of Maryland, College Park noted that our emphasis on *in-situ* and remote sensing measurements of water quality in receiving waters of the Bay leads naturally to a focus on the land, where many of the problems originate. He stressed the need for comprehensive, consistent maps that cover the Bay watershed. Historic mapping has played an essential role in monitoring and analysis, providing a spatial context for land management and planning on local and regional scales. Many of the maps currently in use are, in fact, derived from remote sensing. A fundamental change from the "old days" of remote sensing manifests as an appreciation of data and information derived from new technology, including recognition that variables we retrieve are far more quantitative than mere pictures. These comments echoed a theme introduced earlier that the jump in quality of data and information is traceable to extensive calibration and validation that are integral elements of contemporary remote sensing.

Habitat protection and restoration are specific issues that benefit from improved characterizations of stream corridors, riparian buffers, and wetlands. The commercial satellite instrument, IKONOS, from Space Imaging, Inc., is an example of new technology that provides imagery of increased spatial resolution (1 to 4 m) useful to delineate forested riparian buffers, in Montgomery County, Maryland (Figure 22). A combination of radar and optical approaches has also been applied to resolve ambiguities of boundaries in mapping wetlands. Prince showed an example of Synthetic Aperture Radar (SAR) and Landsat Thematic Mapper (TM) imagery that have been used for this purpose (Figure 23).

Quantifying impervious surfaces in urban and suburban areas of the watershed using remote sensing data has been a major emphasis of RESAC. Prince showed an example of GIS data layers gridded at a spatial scale of 3 m^2 and combined into blocks of 30 m^2 (Figure 24). Each of the 100 units comprising the blocks was categorized as impervious or not, generating a "binary" product. These products were then binned to give the percentage of impervious cover on a spatial scale of 30 m^2. This approach gives detailed information to classify thematic data and is amenable to machine-learning techniques, providing a map of impervious surfaces in the Baltimore and Washington, D.C. area, rivaling the content and quality of photographic sources (Figure 25). Prince also presented examples of remote sensing data and information used to characterize the land surface, including DEMs that are essential to quantify topography underlying stream maps and to estimate runoff. Airborne LIDAR is currently used for topographic mapping, as discussed in a subsequent presentation by Morris that addresses sea-level rise and marsh elevation.

Remote sensing has increasing value for evaluating the effects of climate change in coastal wetlands. The C2K Agreement mandates "no net loss" of existing wetlands, a goal that contradicts one of reducing sediment loads to the Bay, since survival of wetlands in the face of sea-level rise depends on a sufficient sediment supply. To evaluate effects of climate change on Bay wetlands, it is necessary to separate long-term trends from short-term variability, as depicted for sea level near Charleston, South Carolina and Boston, Massachusetts (Figure 26). These elevation data from surveys over 80 years show that sea-level rise does not occur as a simple linear trend indicated by the regression slope of 0.3 cm y^{-1}, but is punctuated by increases and decreases that can be on the order of tens of centimeters. Resolving the long-term, low-frequency signal from short-term variability is a significant challenge.

Sea-level rise is expected to impact marshes in several ways, including changes in: (1) the absolute and relative elevations of coastal wetlands; (2) total wetland area; (3) the location of wetlands as migration of existing wetlands and colonization of terrestrial habitats occur; (4) wetland community boundaries; (5) total and area-specific productivity; (6) landscape scale patterns within wetlands. Many of these changes can be detected remotely. Marsh surface elevations will also increase, as shown in the example for North Inlet (Figure 27). A key question that new technology could help address is, "Will increases of this magnitude keep pace with sea-level rise?" Based on this dataset, the slope is >0.5 cm yr^{-1} for a period of four years, indicating that at least over a relatively short period of time, marshes kept up with the long-term trend of sea level. On the other hand, short-term trends exemplified by the Charleston and Boston sea-level data exceeded increases of marsh elevation. The record for annual primary production from South Carolina marshes spanning almost two decades shows interannual variability superimposed on the long-term trend (Figure 28). The upward trend of primary production could be due to the fact these marshes are not keeping up with sea-level rise. These marshes are perched at a very high elevation within the intertidal zone, and occur at super-optimal elevations with respect to plant productivity. As sea level rises relative to the elevation of the marshes, productivity improves until the marsh surface reaches an optimal elevation, and then a continued rise of sea level crosses a threshold and productivity declines.

Landsat imagery of North Inlet shows the effectiveness of the Enhanced Thematic Mapper (ETM) for capturing differences in plant communities (Figure 29). Forest, *Spartina* marsh (green), and brackish marsh (red) are readily distinguishable in this example. The spatial resolution with the ETM is 30 m, and this instrument is well suited to quantify the total area of different coastal wetland habitats. Plant pigment signatures provide information on environmental conditions in wetlands. The rationale for making such measurements is that an underlying environmental condition, such as a change in nutrient status or nutrient loading, evokes changes in the distributions of pigments in leaves that can be resolved by examining hyperspectral data. Figure 30 shows a typical reflectance spectrum for a leaf of *Spartina alterniflora*. There is a region in the visible part of the spectrum where reflected light depends primarily on the assortment of pigments, especially chlorophylls, but also on the secondary pigments. There is also a region in the near infrared (NIR) where cell structure and anatomy are most important, and a region in the short IR where water absorption is very important. Pigment spectra for *S. alterniflora* in unfertilized vs. P-fertilized plants are significantly different in the NIR (Figure 30). These reflectance differences should be detectable using remote sensing, as should environmentally relevant variations in the other spectral regions.

Various kinds of multispectral remote sensing data are available to assess the status and trends of wetlands in the Bay, particularly the boundaries and patterns of these environments. LIDAR can be used to track changes of elevation and perhaps to measure canopy heights and biomass. Hyperspectral data may provide information on the level of stress in plant communities. Thermal imaging and fluorescence are also promising technologies that may give insights to stress in plants.

Remote sensing imagery enables visualization and interpretation of land cover and land use. Tom Fisher of HPL-UMCES drew a clear distinction between the two concepts. Land cover is "what you see in an image" when you look at a land surface, e.g., wetlands, grasslands, or forest. Land use is how that land cover is being used. For example, a classification of forest cover could have a number of distinct uses, including forest itself (i.e., state or federal forest), undisturbed primary forest, multi-use parkland, a Christmas tree farm, abandoned farmland. All these uses interact very differently with the environment, and are important in determining how a particular cover mediates N and P export and CO_2 sequestration. A commercial forest may export more N and P to streams than would parkland or undisturbed forest because of fertilization and disturbance. An undisturbed primary forest may not remove as much atmospheric CO_2 as a young, rapidly growing forest since net primary production approaches zero in older forests when primary production and respiration are balanced. Many models used to estimate export from a terrestrial basin into an aquatic system require data on land use rather than land cover.

Analysis of land cover change is essential to gain a historical perspective. Land cover data can be reconstructed using satellite imagery originating with the first Landsat satellite with the Multispectral Scanner (MSS) launched in 1972. Images are available for the period 1972 to 1978. The Thematic Mapper (TM) is a more recent Landsat instrument, available from 1982 to the present and the Enhanced Thematic Mapper Plus (ETM+) has recently become available on Landsat 7.

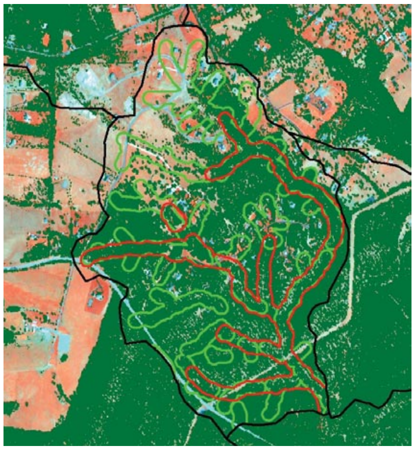
These instruments have different spatial resolutions — 80 m for MSS, 30 m for TM, and 15 m for ETM+. In the 1930s, aerial photographs taken at decadal intervals mapped the continental U.S., and these photographs provide high-resolution imagery on the order of 2 m (depending on the time period, flight altitude, etc.). These aerial photographs are available from USDA for the period 1937 to the present. Other historical maps produced for various purposes are available at irregular intervals and are often very useful to reconstruct land cover.

There are a number of important considerations for reconstructing land cover from different data sources, particularly spatial and spectral resolution of the underlying data. Spatial resolution differs among instruments and approaches and the extent of coverage has changed in the past several decades. The availability of multiple sources of imagery is key, as sensors of differing capabilities have overlapping temporal coverage and a range of spatial and spectral resolutions. Higher resolution aerial photographs or maps can be used to improve upon lower spatial resolution Landsat TM imagery. For example, an aerial, color infrared photograph taken in 1988 improved upon the Landsat TM to obtain land use and land cover data for Easton, Maryland (Figure 31). TM imagery indicated "agriculture" in the center of the town of Easton (yellow within the red area) that was actually parkland with the spectral signature of grass. Photographic data were used to make this correction.

A major effort of Fisher's research group has been to combine historical and contemporary data from a variety of sources to analyze land cover changes in the Choptank River basin since colonial settlement. Historical maps from 1850 and 1900 have been used to estimate 19th century land cover in the basin, and aerial photographs from 1937, along with a series of Landsat MSS and TM images for 1972 to 1996 have been used to characterize agriculture, forest, and urban areas. This analysis shows that the Choptank River basin has been predominantly agricultural for >100 years (Figure 32). The area has remained relatively stable in agriculture, although there has been a slight decline since ~1900 due to steady urbanization over that time period.

Information on hydrology can also be derived from remote sensing imagery and used to estimate the effects of land-use changes on nutrient input. Land cover has a large impact on hydrology and is an important input to most water quality models. For this application, the differences between land cover and land use may be insignificant since forest hydrology is stable compared to urban hydrology. Forested areas have good infiltration, a large base-flow component, small storm flow, whereas forests absorb water, retain it, release it slowly, and have low erosion rates. Urban areas, in contrast, have poor infiltration, a small base-flow component, and large storm flows. This produces flash flows with high erosion rates. Land cover and land use also have profound impacts on hydrology and stream chemistry. Forests affect stream chemistry because they retain nutrients, and the export of N or P from forested areas is low, both in loss rates and concentrations. Streams in urban and agricultural areas have much higher nutrient concentrations, and greater export as higher concentrations are coupled with flash runoff.

Two examples of products derived from land use and land cover clearly illustrate the utility of such data. In the first example, groundwater nitrate concentrations, expressed as a function of land use, showed a strong influence of forests in retaining nitrate (NO_3) compared to fertilized agricultural fields and septic systems that export large amounts of NO_3^-. In the second example, N export from the river basin to the Choptank River was estimated from historical changes of land cover and a common hydrologic model, the Generalized Watershed Loading Functions (GWLF), to show a tenfold increase since ~1900 due to the application of fertilizer through agricultural fields.



IKONOS Statistics for Forested Riparian Buffers

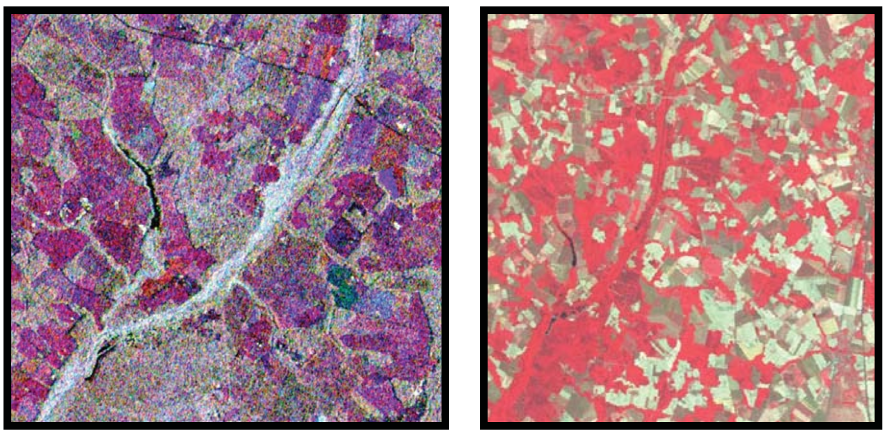
Riverwood Area, Mont. Co
30m Buffer

Current Hydro Layer
85% forested

5' Topo DEM Hydro Layer
65% forested

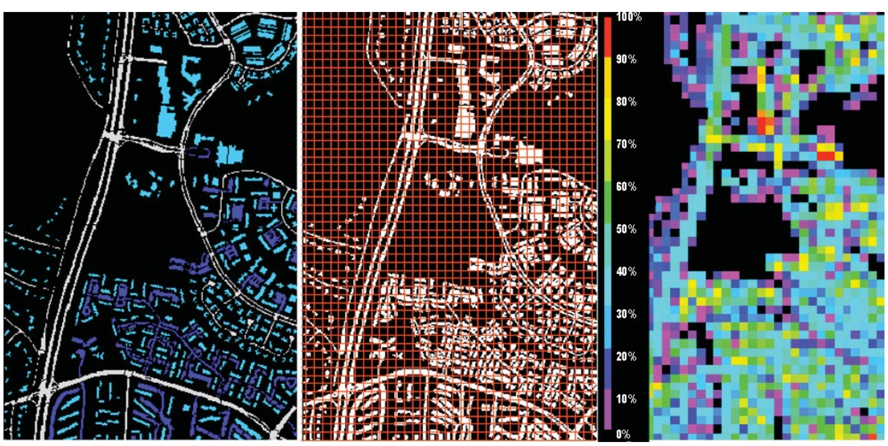
Figure 22. Riparian buffers based on imagery from the commercial satellite IKONOS (Space Imaging, Inc.) for Montgomery County, Maryland.

Wetlands as Viewed with Synthetic Aperture Radar and Optical Data



Multitemporal SAR **Landsat TM (June)**

Figure 23. Synthetic Aperture Radar (SAR) and Landsat Thematic Mapper (TM) views of wetlands.



Vector Extraction → 3m to 30m Grid → %Impervious Cover

GIS Processing Steps– Training Data

Figure 24. GIS processing steps for deriving percent impervious cover.

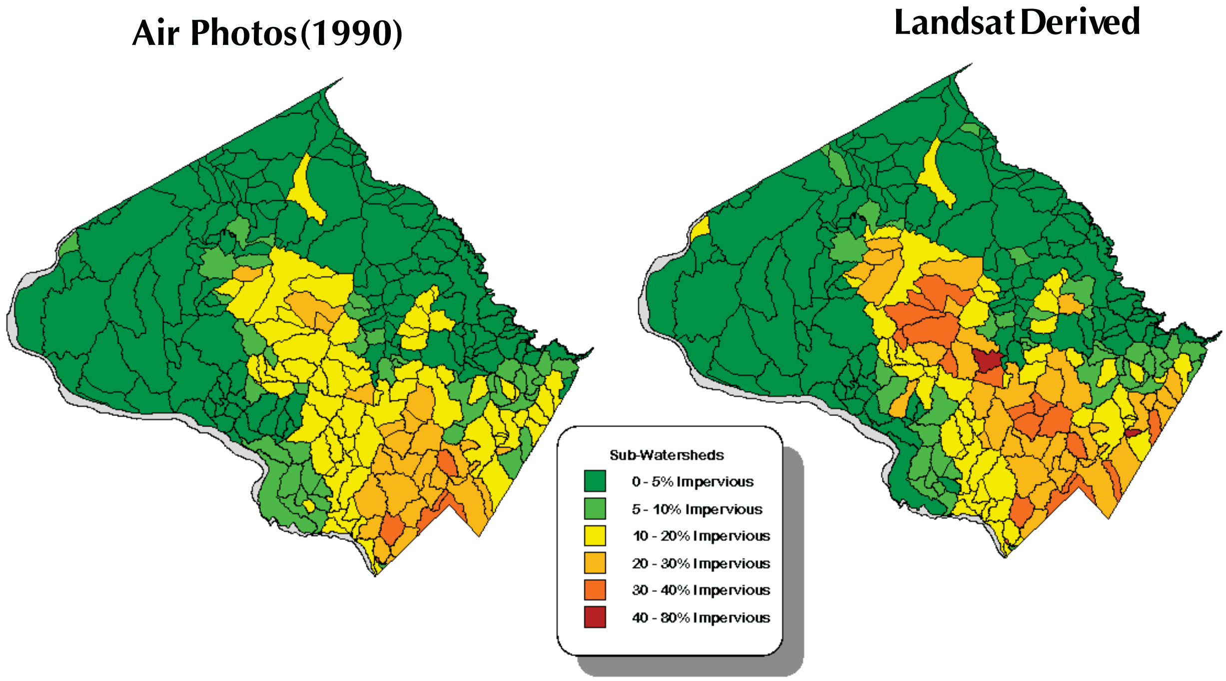


Figure 25. Small area impervious cover identified using aerial photography and Landsat data.

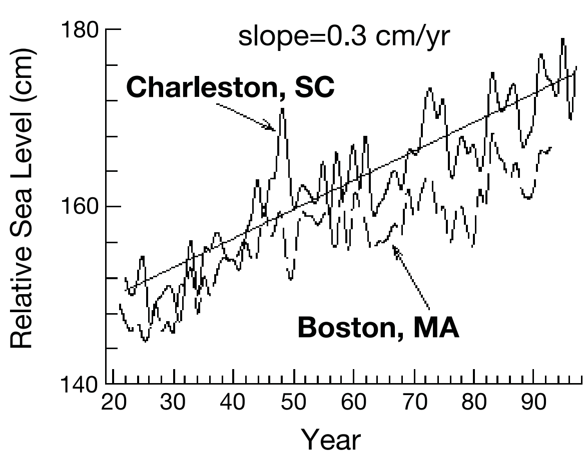


Figure 26. Sea-level and marsh-elevation rise at Charleston, South Carolina and Boston, Massachusetts.

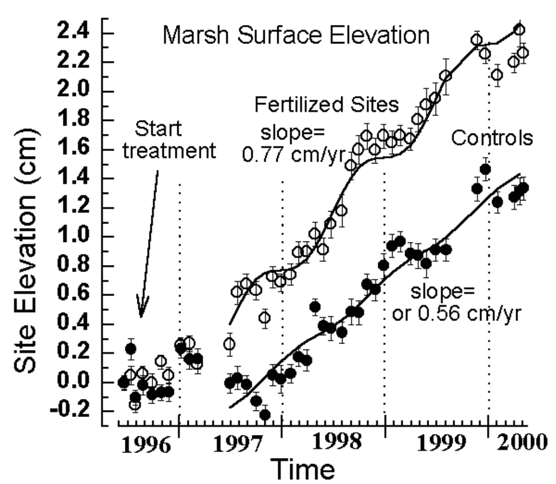


Figure 27. Rise of marsh surface elevation in control and fertilized sites in North Inlet, South Carolina.

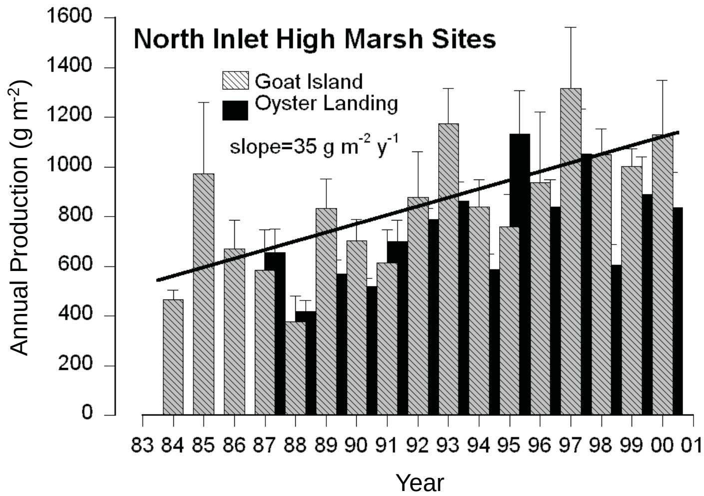


Figure 28. Annual primary production (g m^{-2}) at two sites in North Inlet, South Carolina – 1984-2001.

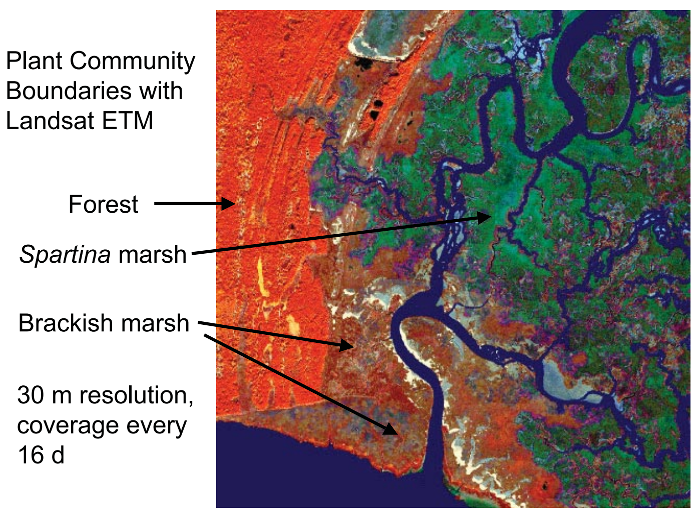


Figure 29. Landsat Enhanced Thematic Mapper (ETM) coverage of North Inlet showing plant community boundaries.

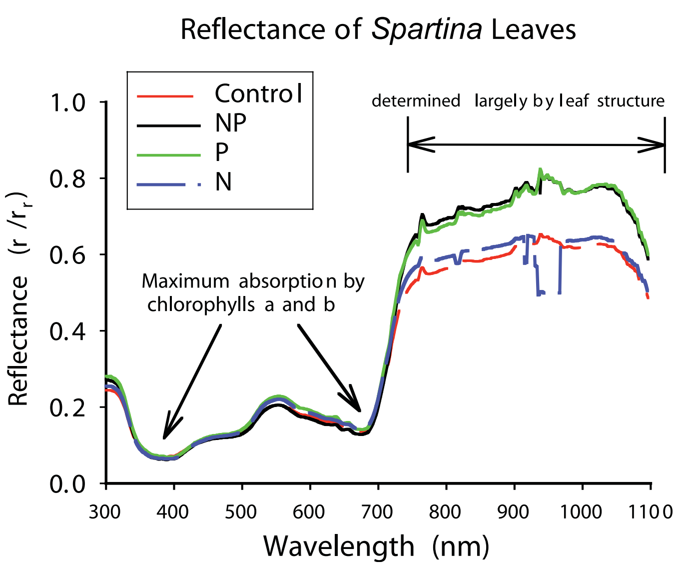


Figure 30. Spectral differences in control and fertilized Spartina alterniflora *leaves associated with structural changes in the leaves.*

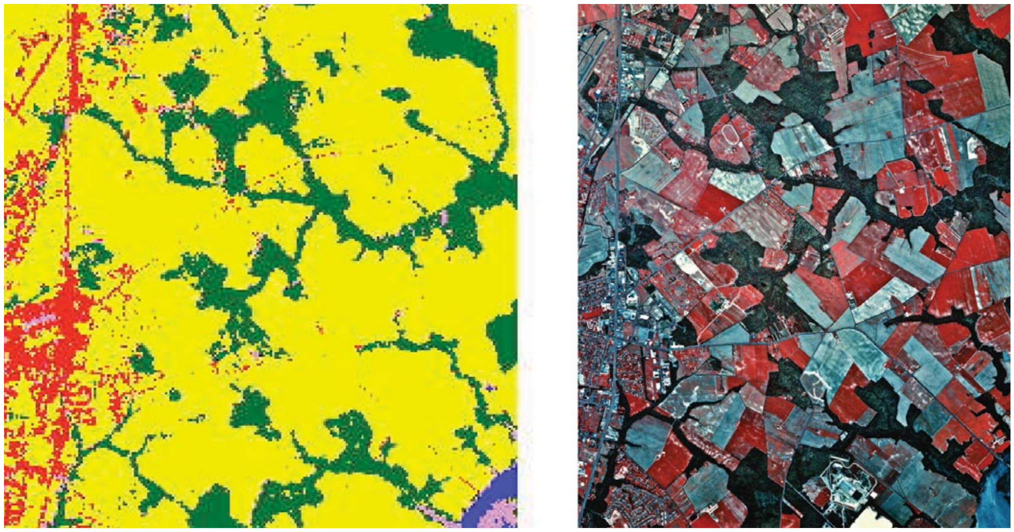


Figure 31. Landsat TM image of the Easton, Maryland area and an aerial, color infrared photograph of the same area.

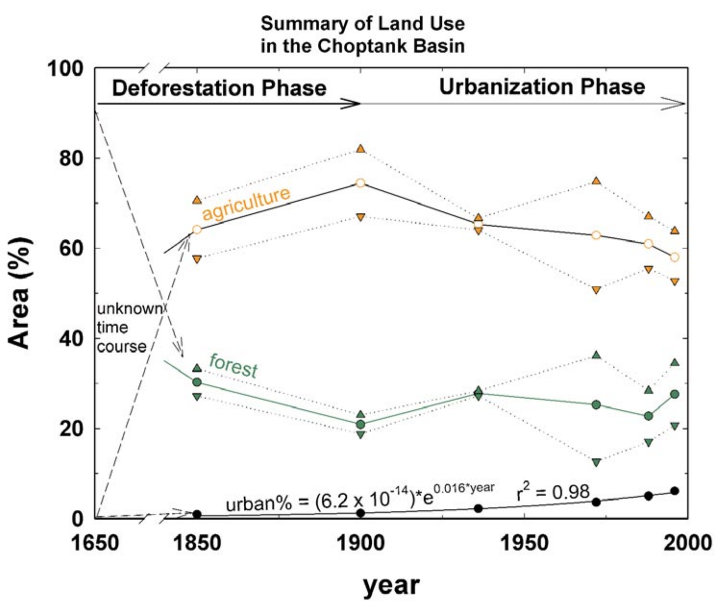


Figure 32. Reconstruction of historical land cover based on several data sources including old maps, photographs, and remotely-sensed imagery. Dotted lines are estimates of confidence intervals.