The Earth Institute
AT COLUMBIA UNIVERSITY

URBAN DESIGN LAB
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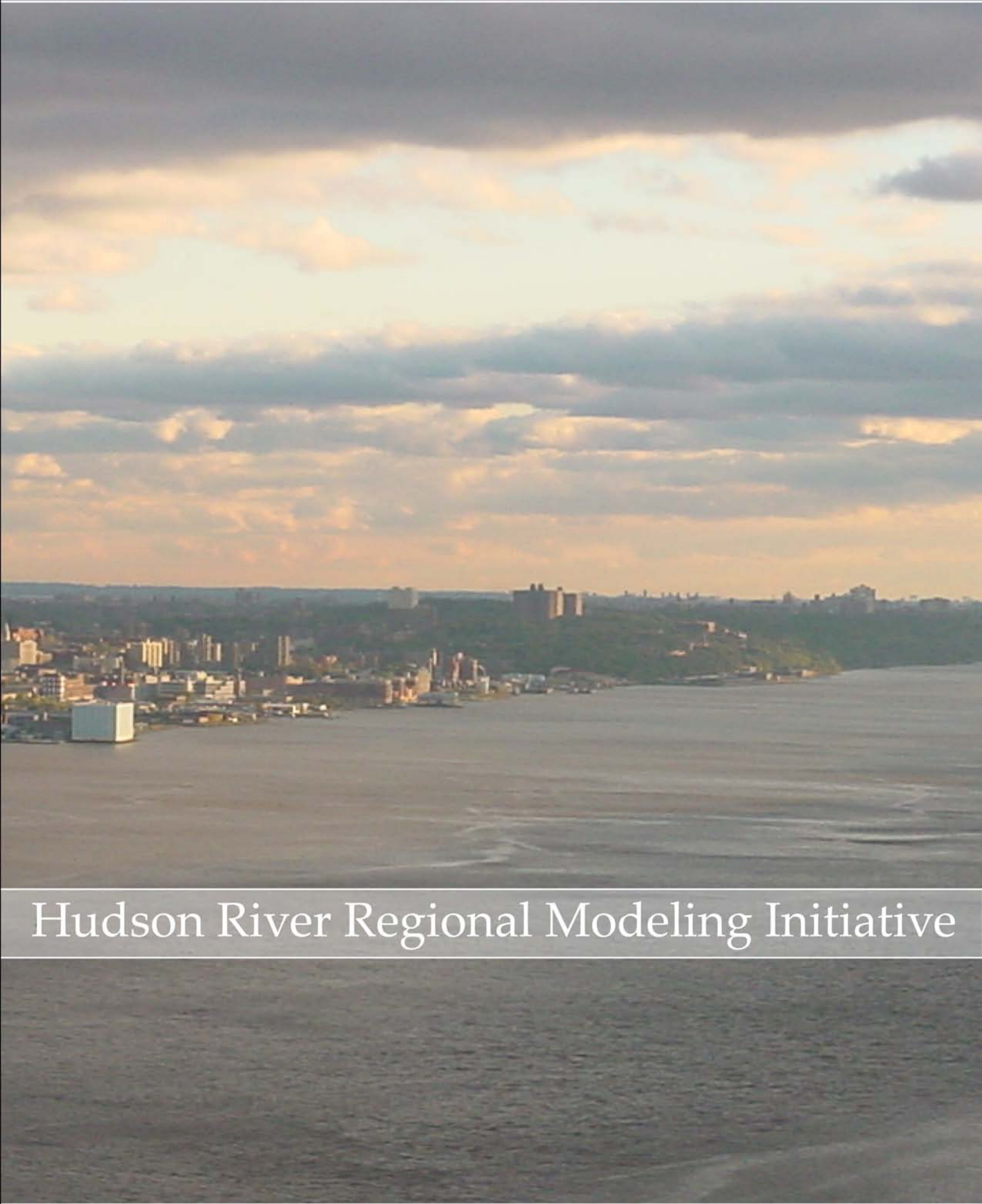

Hudson River Regional Modeling Initiative

ACKNOWLEDGEMENTS

Urban Design Lab
The Earth Institute at Columbia University

Funded by The Earth Institute Cross Cutting Initiatives

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FOREWORD

With this initiative the Urban Design Lab brings to the table the discussion on the urgent planning needs that the pace of the new development is creating within the Hudson River basin; in particular for identification of comprehensive, appropriate, cost-effective and realistic land use and urban water resource planning policies which sustain ecosystems, while supporting growing human populations at higher densities.

The time has arrived to consider the options for comprehensive densification modeling that can be deployed as a tool for decision-making around development projections. Involved is interdisciplinary collaboration between urban design, architecture, engineering, urban planning; and public policy, climatology, information technologies, economics and public health.

With the support of the Earth Institute Cross-Cutting Initiative (CCI), created to encourage greater synergies between disciplines and across units, the Urban Design Lab has prepared this report as a beginning point for a large effort that is needed for a sustainable urban future within the Hudson Basin.

Richard Plunz, Director, Urban Design Lab

THE HUDSON REGIONAL MODELING INITIATIVE

The Hudson Regional Modeling Initiative (HRMI) is proposed by the UDL as a test bed for integrating urban planning and policy with design, technology, and sustainable development. HRMI is proposed as a potential "decision-support" model for the long-term future design and planning of the Hudson Valley Region. It may also serve as an urban-knowledge platform to evaluate the challenges of climate change, population growth, and environmental health facing the wider New York City area and global cities around the world.

Critical to the success of the HRMI will be the development of a digital urban model to enable city planners, policy makers, designers, and other stakeholders to better utilize scientific knowledge. The model will be a multi-scaled GIS database interlaced with real-time data about the region's ecosystem. It would provide accurate, scientific data to support long-term decisions. This cross-cutting predictive tool will represent a new generation of urban modeling and data gathering.

The UDL is in a unique position to bridge the information gaps between scientists and community groups and policy makers. There already exists a wealth of data on land-use patterns and existing ecological conditions in the region. This data, however, is fragmented and can be difficult to interpret for non-scientists seeking to understand the actual implications of the documented patterns on proposed projects or policies. Our partnerships within the various stakeholder communities will allow local groups and governing bodies access to the vital hard data necessary for informed decision-making while concurrently creating a broader platform for ecologists, biologists, economists, planners, and other relevant professionals to disseminate and apply their findings.

The scope of the project has expanded from that outlined in the original CCI proposal to accommodate a regional metropolitan perspective. Recognizing the need to address the issues of urbanization and development within a regional context, rather than focusing narrowly on a specific metropolitan area, the UDL is focusing the model on the Hudson River Estuary. This change has also been motivated by the discovery of existing resources and work already undertaken on the Hudson River region within the Earth Institute, that has allowed the UDL's work to be truly interdisciplinary. Focusing on the region allows our work to complement the work and interests of our partners at the Lenfest Center on Sustainable Energy, CIESIN, and Lamont-Doherty Earth Observatory.

Shifting the area of focus to the Hudson River Estuary recognizes its position as a critical environmental indicator for the wider metropolitan region. Its diverse land-use and ecosystem distribution and the rapidly changing nature of its urban character and demography position is at the forefront of the struggle to define sustainable development and land-use policies in rapidly urbanizing areas. Our work in the area has the potential to establish a paradigm for addressing socioeconomic and environmental pressures through comprehensive regional planning initiatives.

The scope of the project has expanded beyond the goal of developing a merely projective modeling tool. While the projection of future development scenarios is critical in any modeling platform, our intent is to take the next step of making detailed qualitative assessments of the economic and environmental impacts of development and policy projections. This will take place through the application of in-depth regional geographic data, which we are gathering in collaboration with our partners, to cutting-edge modeling and impact assessment software. Through this process we hope to evaluate the region's overall "carrying capacity" with respect to anthropogenic development and recommend specific policy directions.

ACCOMPLISHMENTS TO-DATE

Promoting Interdisciplinary Collaboration

The UDL has engaged in discussions with a number of different entities within the Earth Institute. The intent of the project is to foster collaboration within the Institute and to build on and contribute to existing projects and interests. The Futures Initiative provides numerous opportunities for synergy as we take advantage of existing resources and apply them in new, innovative ways. The advantage of the UDL's model is its ability to bridge various scientific and social disciplines dynamically to provide a comprehensive picture of a complex region.

The UDL is engaged in discussions with the Lenfest Center on Sustainable Energy to incorporate analyses of how continuing development will affect regional energy use and distribution, incorporating carbon footprint analyses into the model, and evaluating carbon management policy scenarios.

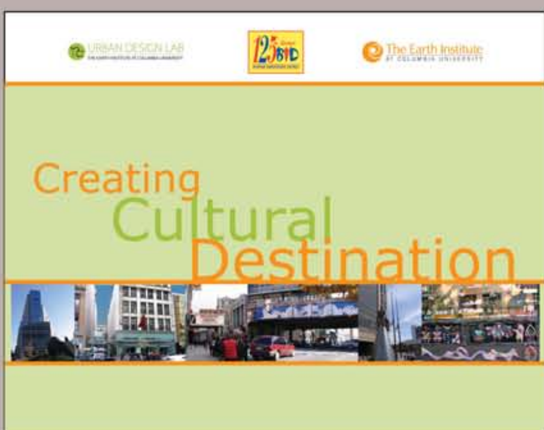
The UDL is exploring a collaboration with CIESIN to assist with assembling and correlating regional geographic data on land use, habitat designations, demography, and development patterns. This work will draw on the resources of the National Biological Information Infrastructure (NBII) database. We are also working with CIESIN on the application of cutting-edge development forecasting and impact modeling software.

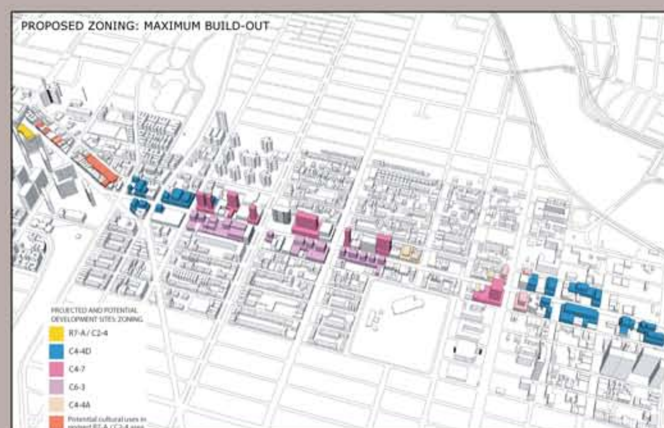
The UDL is consulting with Robin Bell at LDEO, who has developed a trove of detailed geographic information on the Hudson River itself. Other than providing critical data for the evaluation of development impacts, the partnership has the potential to help correlate the existing riverbed mapping data to development patterns on land and contribute to the continued funding and expansion of LDEO's mapping efforts in the region.

The UDL is consulting with Stuart Gaffin and Cynthia Rosenzweig of Goddard Institute for Space Studies on assessing the capabilities of various computer modeling techniques, specifically related to modeling the regional effects of global climate change. Their work with the New York Climate and Health Project (NYCHP) Land Use Change Assessment Group on modeling the impacts of climate change on public health within the New York City area is a particularly important precedent for our work.

Establishing Community Partnerships

The UDL has established a strong partnership with the 125th Street Business Improvement District in Harlem and has completed a comprehensive waste study for the area as well as an in-depth report on potential of zoning changes along 125th Street to strengthen the neighborhood's economic position though the promotion of cultural uses. Both of these projects involved predictive modeling of future scenarios and incorporated environmental and socioeconomic concerns. As such, they have been instrumental in helped us define an effective approach to "spatial-izing" complex urban dynamics. The Futures Initiatives project is continuing with these efforts and expanding them to encompass the regional context.





Excerpts from the 125th Street Cultural Zoning Study

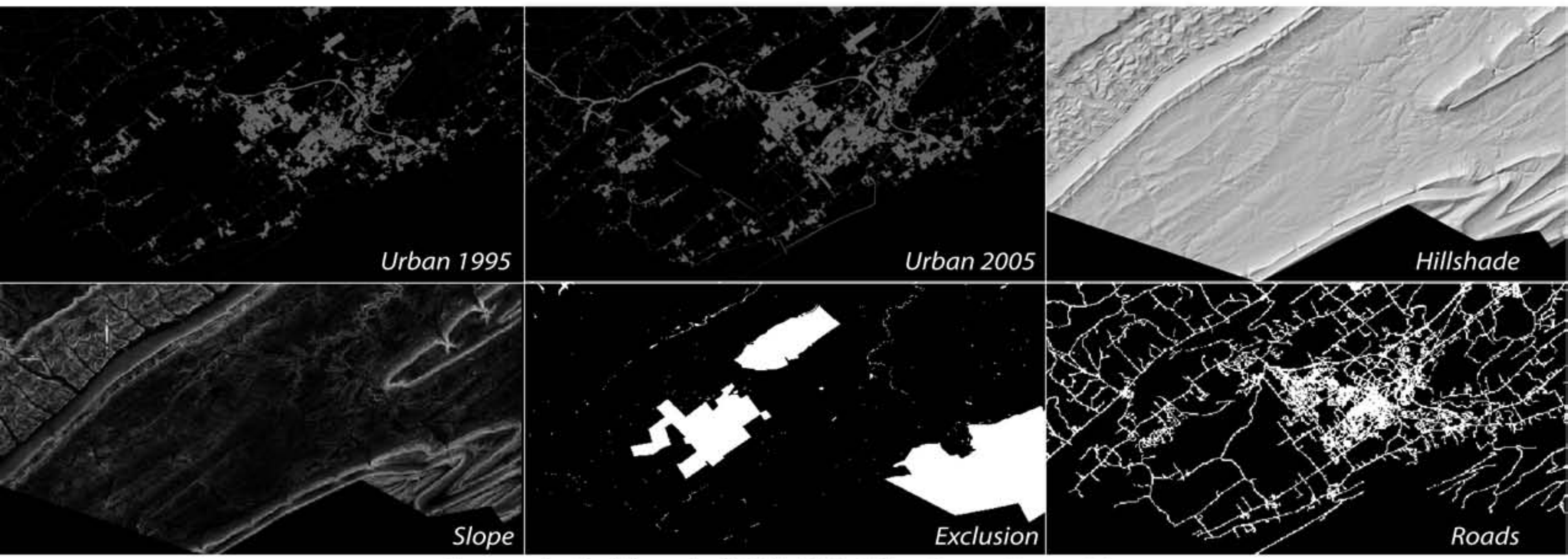
The UDL is also collaborating with Scenic Hudson to identify specific areas, sites, and projects within the Hudson River Estuary which will be critical in shaping the overall trajectory of the region with regards to development and conservation. Our relationship with Scenic Hudson is assisting us in clearly defining the socioeconomic and environmental pressures that need to be addressed comprehensively at a regional level, and it is in a unique position to be able to help us define the issue of regional carrying capacity.

Through our collaboration with Scenic Hudson we are in the process of establishing contact with a wide array of other community organizations who represent the pool of potential clients for the model once it is developed. Scenic Hudson is planning a conference to be attended by a number of these organizations in which we will present our work to-date and demonstrate the capabilities of regional impact modeling.

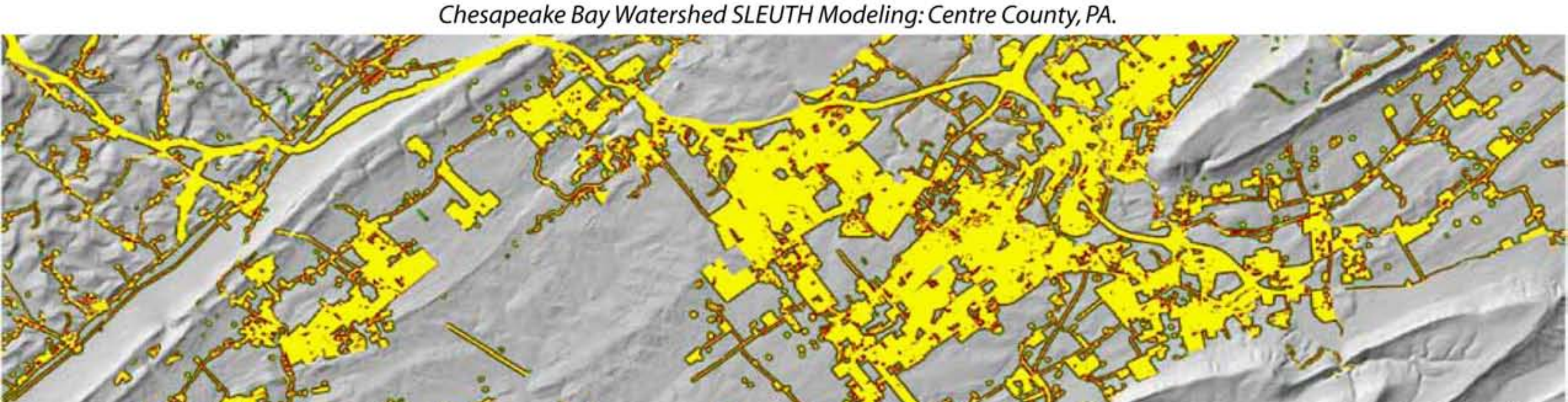
Applying Cutting-Edge Information Technologies

The project offers an opportunity to significantly enhance the capabilities of existing tools, leading to their potential application for a wide range of problems and geographic regions. The UDL has researched and experimented with a number of existing development forecasting and impact modeling software applications. Of the applications we have examined, the SLEUTH and CommunityViz© programs seem to hold the most promise. They represent industry standards in the development forecasting and impact modeling fields, respectively.

The SLEUTH application analyzes existing patterns of urban development and projects them into the future through a complex series of determinations. These include designating how development is concentrated around transportation corridors, how existing land-use affects development patterns, factoring in landscape characteristics that impact development, such as slope and hillshade, and excluding protected areas (hence the acronym SLEUTH, which stands for Slope, Land-use, Exclusion, Urbanization, Transportation, and Hillshade).

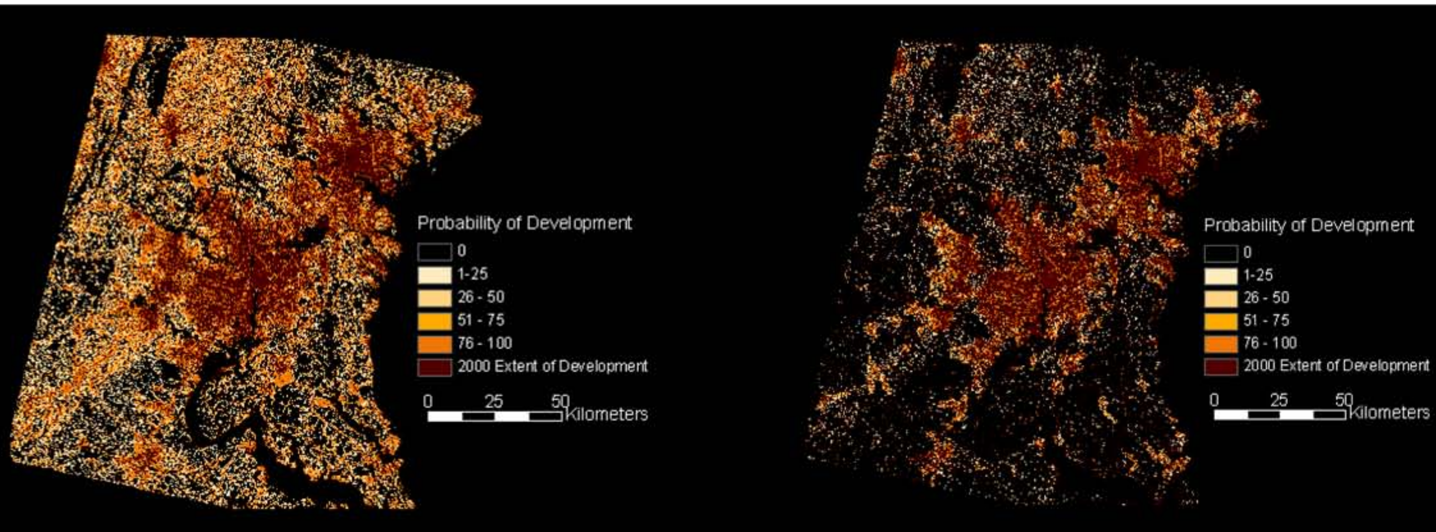


Chesapeake Bay Watershed SLEUTH Modeling: Centre County, PA.



The model has been applied in a number of urban and watershed areas including New York City, where it was used by the New York Climate and Health Project (NYCHP) Land Use Change Assessment Group to forecast changes in air quality and impacts on public health, and in the Chesapeake Bay Watershed to forecast changes in land cover that might impact runoff into the Bay.

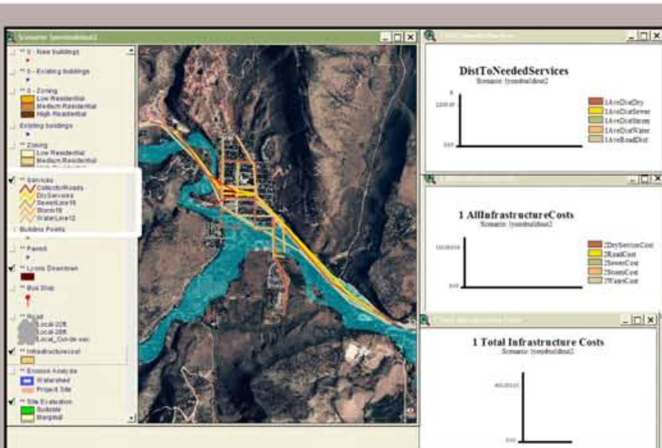
New York City development projections from the New York Climate and Health Project (NYCHP) Land Use Change Assessment Group

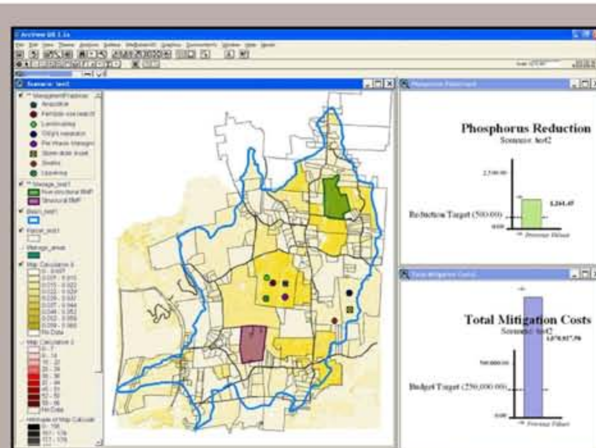


Chesapeake Bay development projections from Woods Hole Oceanographic Institute

Although the application has a strong capacity to accurately forecast development patterns based on large-scale trends, the accuracy of the model diminishes with the scale of the area under consideration, and it is not applicable at the scale of a small municipality. We have identified other critical limitations with this type of predictive modeling, such as its inability to distinguish degrees of density of development or urban land use designations. The importance of differentiating between various densities in assessing impacts is mentioned in a number of sources, including in Kleppel, et al., *Responses of Emergent Marsh Wetlands in Upstate New York to Variations in Urban Typology* (2004), in which they write that, "The observed relationships between land use attributes and environmental quality [are] consistently associated with typology…that is, the way that people and infrastructure are distributed on the landscape seems to influence the kinds and magnitudes of the impacts that occur." Because the results of the analysis tend to be self-fulfilling (projections set up with greater protections within the exclusion zones necessarily result in less development, and vice-versa), the analysis is of limited usefulness in evaluating complex environmental impacts and making concrete recommendations to alleviate them. SLEUTH has been used primarily by scientists and demographers who wish to make detailed projections based on an understanding of current conditions, but the model stops short of evaluating the implications of the research for policy decisions. Despite these limitations, it is clearly a very useful tool for large-scale regional modeling that we have the opportunity to expand upon.

The CommunityViz application is a modeling tool developed by the Orton Family Foundation in Vermont that includes both predictive forecasting and impact modeling capabilities. It analyzes proposed development schemes according to any number of metric that are determined by the user, and is capable of performing comparative analyses. It allows users to alter the assumptions and algorithms that drive the analysis as well as develop formulas of their own. As such, it is an extremely flexible tool that has essentially unlimited potential as far as the range of concerns it is able to evaluate, though the quality and reliability of the evaluations are entirely dependent on the accuracy of the information on local trends and conditions that are provided by the user. Issues such as the total energy consumption, public transportation use, and sensitive habitat encroachment associated with a particular development are best evaluated using manual input based on knowledge of local conditions rather than generic national trends.





Examples of CommunityViz applications: Infrastructure planning, watershed management

The tool has been used to assist with planning decisions in a number of municipalities including New Hartford, Connecticut and Tacoma, Washington. It has also been used to contribute to resource management planning and coastal development, most notably by the National Oceanic and Atmospheric Association for a coastal site in Georgia.

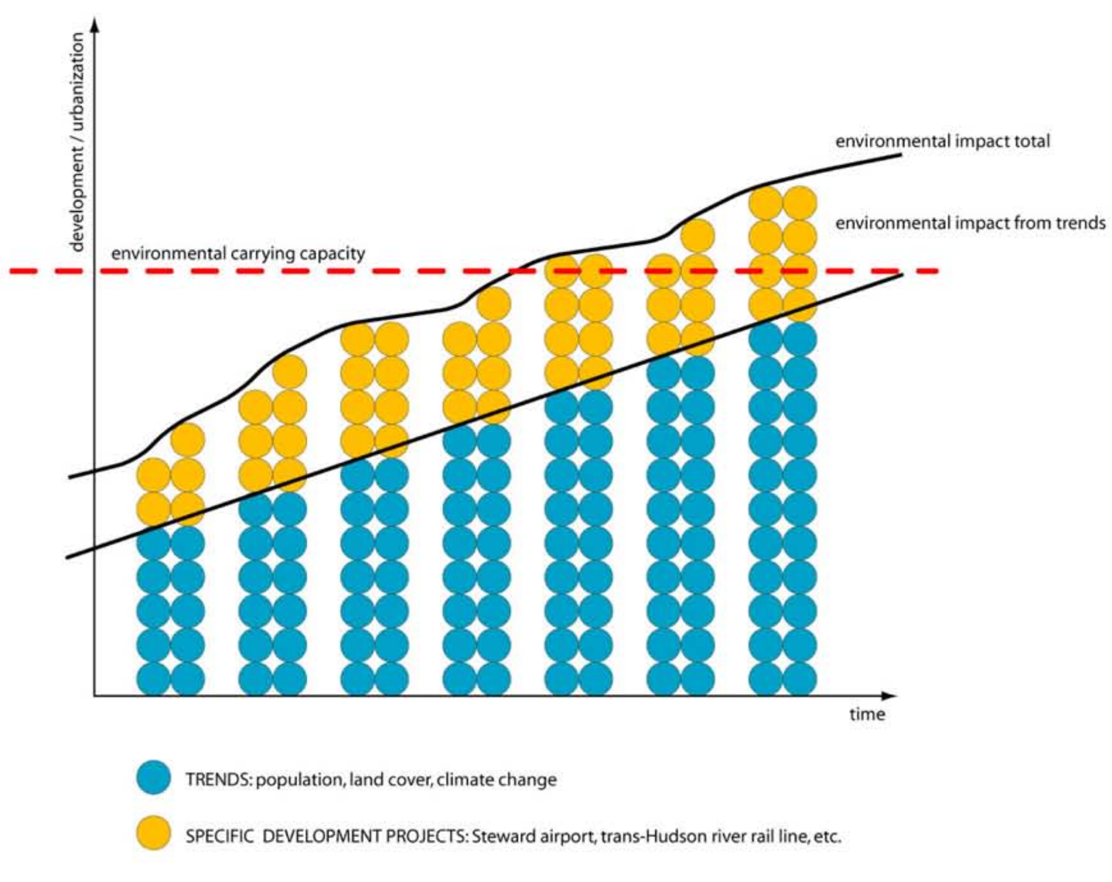
Alternatives for coastal development in Georgia, from a National Oceanic and Atmospheric Association study

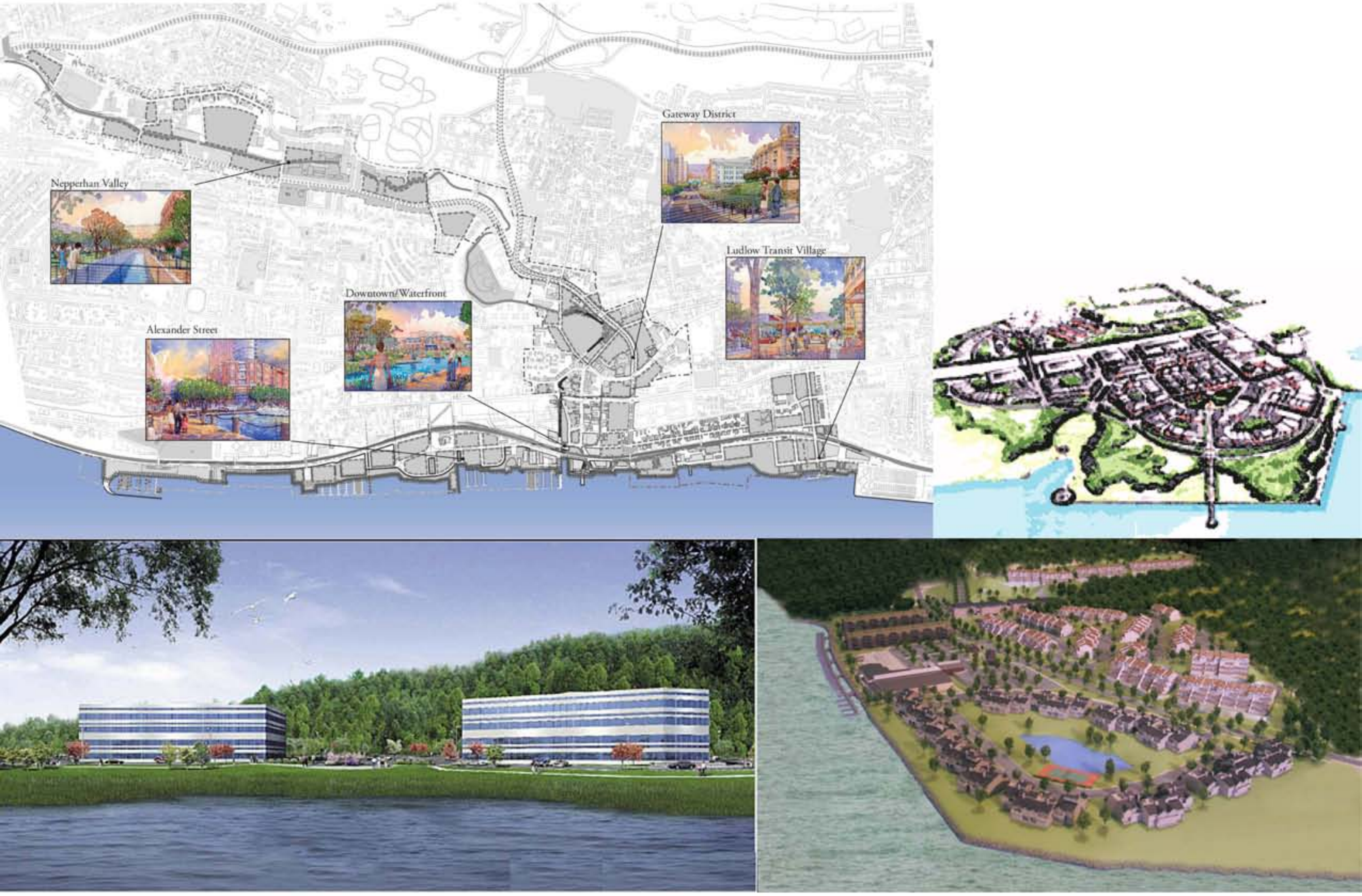
The limitations of the software include the fact that it operates best on a local, municipal scale and its capacity to evaluate urban development on a regional scale has not been adequately tested. Again, the opportunity exists to expand the capacity of existing cutting-edge software applications. We have the opportunity to act as liaison between members of the scientific community who have access to the hard data necessary to make accurate projections and the municipalities and community groups who are engaged in difficult decisions involving sustainability, economic development, and quality of life issues. This synergy of state-of-the-art technology and detailed data gathering and analysis capacity contributed by our partners could result in a rigorous and authoritative tool for determining the impacts of various regional development scenarios. The Hudson River Estuary model will be able to assess the comparative impacts and benefits of several alternative development and policy scenarios in order to contribute to truly informed decision-making.

The UDL has been amassing GIS and other data sets for the region from publicly available sources, including the USGS Seamless Data Distribution System. Additionally, through our proposed collaboration with CIESIN, the UDL has access to geospatial data from the Westchester Department of Information Technology. As we progress, we will contact other county and local agencies to coordinate geographic data gathering techniques.

Understanding Regional Development Issues

The 125th Street zoning study completed by the UDL is an example of the type of analysis that we hope to expand to a regional scale. In the study, we examined the demographic, cultural, and economic implications of proposed policy changes, projected their impacts, and made recommendations on how zoning policy could be changed to offset these impacts and sustain the cultural character of Harlem. We will continue similar work with the Hudson River Estuary model, and will supplement it with extensive scientific research into the environmental surrounding future development in the region. These include the conversion of agricultural land to residential use, increased rates of impervious surface cover, development incursion into riparian buffer zones, point-source and non-point source pollution, transportation infrastructure, etc. (For a preliminary spreadsheet of potential impacts related to urbanization in the Hudson Valley region, see the Appendix, pages 20-21.) The model will superimpose general endogenous trends, such as land-use changes, and general exogenous trends, such as global climate change, on a foundation of existing conditions. This analysis may then be combined with an understanding of the impacts of specific developments to create a comprehensive picture of regional change.





Clockwise from top left: Waterfront development proposals for Yonkers, Sleepy Hollow, Kingston, and Peekskill

Our research has resulted in the identification of several potential "case-study" developments, which will help us establish stronger community and governmental partnerships and develop and calibrate our modeling and analysis tools. These opportunities include developments such as the downtown and waterfront redevelopment proposal in Yonkers, the former General Motors plant in Sleepy Hollow, the Annsville Creek office development proposal in Peekskill, the Landing and Sailor's Cove in Kingston, and proposals for the expansion of Stewart International Airport.

GOALS FOR THE FUTURE

The UDL recognizes that the creation of a truly comprehensive development forecasting and impact modeling tool is an extremely time consuming and complex exercise that must be approached incrementally. Rather than starting immediately with the development of the regional model, we believe that smaller-scale applications will allow us to achieve demonstrable results in the short term while contributing to the long-term goal. Our approach involves subdividing the project timeline into coherent, incremental phases with concrete deliverables along the way. The first of these phases is the case study model, the result of which will be a demonstration of the tool's capacity and a useful analysis in its own right. (See page 19 for project timeline.)

PHASE 1: CASE STUDIES
(approximately 9 – 12 months)

Preliminary Research and Outreach
(completed)

Identify Case-Study Scenarios

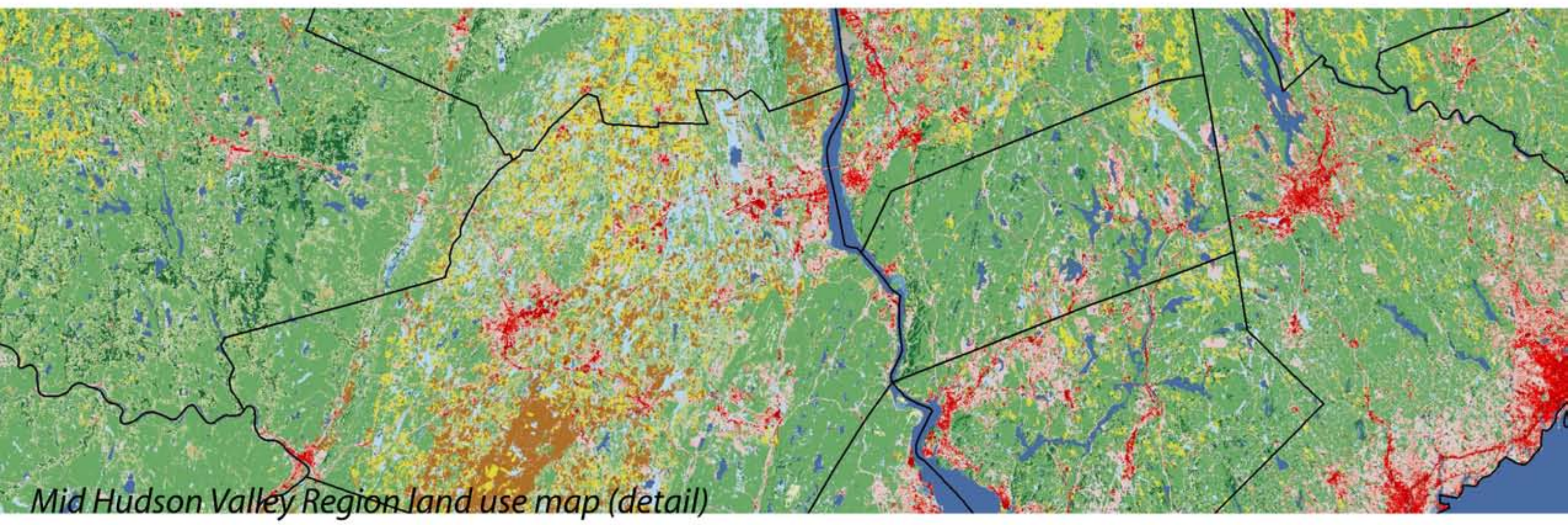
Case-study analyses of actual developments and trends will allow for the creation of efficient data-gathering and coordination techniques, will provide a more manageable scale for the cultivation of our modeling approaches, and will help us calibrate the model to reflect measurable "real-life" impacts against which we may test our assumptions. Most importantly, they will provide us with an opportunity to demonstrate the power of the tool to address the issues which are of most concern to our collaborators and to provide them with rigorous, verifiable assessments of specific impacts of particular developments.

We are currently appraising the advantages and disadvantages of several different approaches to selecting case-study scenarios. Options include evaluating proposed residential, commercial, or industrial projects, evaluating existing policy recommendations, or analyzing specific environmental or socioeconomic issues at the scale of the region. Considerations will include availability of existing data, the concerns and priorities of community partners, and the ability to establish "buy-in" from the necessary stakeholders. Our internal Earth Institute collaborations, such as the relationship we are establishing with the Lenfest Center for Sustainable Energy, can be instrumental in determining the scope of the initial analysis, which will likely study of the effects of development on regional energy use.

For these initial applications we are concentrating on the Mid-Hudson region, where development pressures seem to be most acute. This area is facing imminent large development projects that will have direct, measurable impacts on the surrounding communities and the estuarine environment. Ultimately, the selection of our initial case-study sites or scenarios will depend upon input from our community partners and the contacts we forge with existing institutions who are already involved in collecting relevant data.

Gather and Correlate Data

The UDL will continue with its efforts to gather and compile GIS and other regional data and establish standards throughout the data sets to make them compatible for the purposes of the model. At present, geospatial data sets for the region are highly fragmented, with each county and municipality operating under their own standards and guidelines and with varying degrees of public access. Designations of land use can be inconsistent across data sets and dependent on differing interpretations of the classification system. As an example, golf courses are included as "open space" in some county surveys while other counties may classify them as developed or agricultural land. Similar coordination issues exist within all detailed geospatial data at the local level and the project will require the input of data specialists from many of the counties that are included in the Estuary region. The Hudson River estuary basin comprises 21 counties in 4 states, and correlating the data between multiple sources will be a major undertaking. Data will also have to be optimized to work with the software platform of the model and to ensure that it is relevant to the issues we wish to analyze.



Mid Hudson Valley Region land use map (detail)

Data gathering and correlation will take place with the assistance of our partners at CIESIN, among others, who have extensive experience with these types of issues and are engaged in a similar exercise in the region and in Long Island Sound. We also hope to collaborate with other entities who are also working on gathering and standardizing regional data sets, such as NBII and the Beacon Institute. We are exploring the possibility of coordinating with GIS experts at the Westchester Department of Information Technology to have access to their extensive database. Despite the issues outlined above, the above, the amount of accessible, reliable geospatial data is increasing and we are finding that national coordinated databases such as the USGS Seamless Data Distribution System will be extremely helpful. Access to regional data will also require the support and trust of regional stakeholders, which is one of the many reasons that establishing close relationships with community groups will be critical to the success of the project.

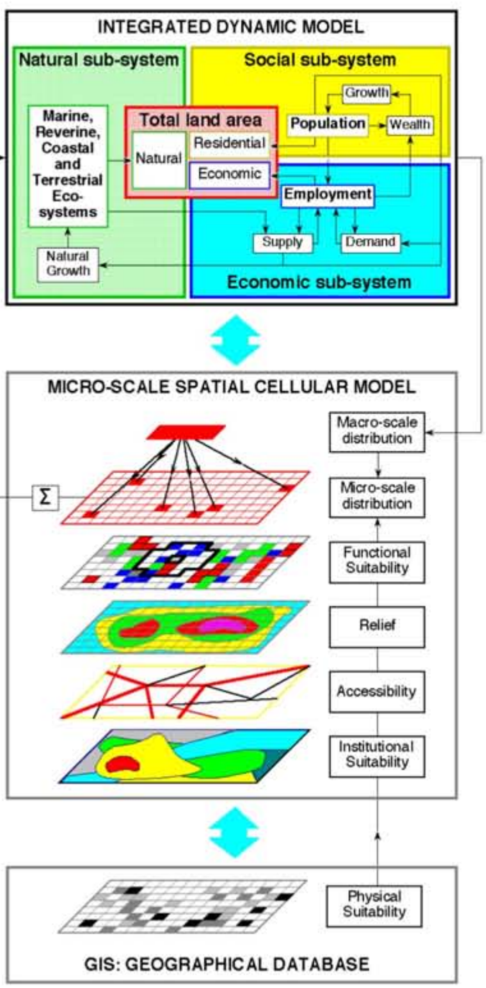
Expand Community Partnerships

Even as the UDL collaborates with entities within the Earth Institute, we recognize that the success of the project will require significant support from the community groups on the ground who have immediate interests in the issues we will be evaluating. Our partnership with Scenic Hudson is helping us connect with community groups that could benefit directly from the development of the regional model. The upcoming meeting will help us solidify these relationships. In the meantime, we have compiled our own list of potential stakeholders and are continuing with our outreach efforts (Appendix 3). We also plan to increase our contacts with local governmental agencies as well as state regulatory and environmental agencies such as the NYS DEC Hudson River Estuary Plan who would be obvious beneficiaries of the tool.

Establishing "buy-in" from community groups will be particularly important in the initial case-study phase as we focus on a specific development which may be associated with some degree of controversy at the local level. In order to maintain our credibility and the validity of the results of the modeling exercise (and to have access to critical data from all parties involved with the project) it will be necessary to avoid any image of prejudice or partisanship without compromising our ability to make concrete recommendations. If we can effectively establish incentives for the participation of stakeholders on both sides of the development vs. conservation debate, the model could serve as a powerful mediation tool. This potential obstacle can be overcome through the assistance of our community partners in the region, through continuing outreach efforts, and through careful analysis of the political sensitivities of the projects we will be evaluating.

Develop the Model

Even as we develop the case-study model, we will work towards the creation of the larger-scale, regional model. Solutions and approaches developed for the case study can then be concurrently applied to our work on the regional model. This approach will ensure that the model has seamless scale capacity; that is, that it will ultimately be able to operate at multiple scales simultaneously. We have gained valuable experience from the 125th Street zoning study on modeling socioeconomic impacts on a local scale, and will apply many of the same methods to the regional assessment. The challenge will be to develop the capacity to define and quantify the feedback loops that govern the relationships between socioeconomic and environmental trends such that we can create accurate algorithms to describe those relationships. This effort will require a high level of understanding of these complex processes and a good deal of trial-and-error as we calibrate the model to correspond to observed development trends in the area. Once the model is calibrated to reflect historical patterns of change, we will run the projection scenarios identified in our case-study analysis.



The UDL believes that the goals of the modeling tool should extend beyond merely making projections and assessing impacts to providing insight into the implications of our findings. The concept of "carrying capacity" may prove to be useful in articulating these concerns. Raising the issue of a regional carrying capacity for anthropogenic burdens will allow us to define actual thresholds and engage more meaningfully in the discussion of sustainability in rapidly urbanizing areas. The idea of a carrying capacity is abstract and potentially contentious, so defining our approach to the issue will require significant input from our collaborators working in other disciplines.

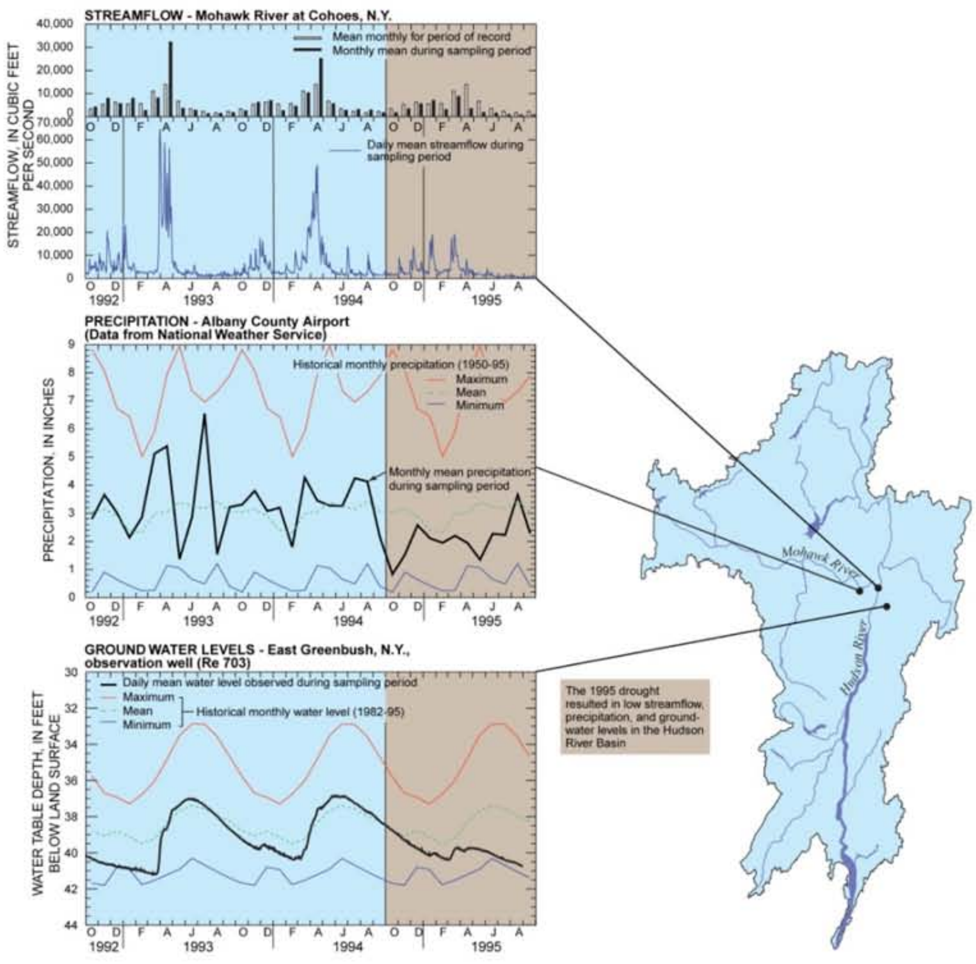
Left: Integrating several modeling approaches, such as dynamic, econometric, and cellular automaton models (of which SLEUTH is an example) will allow for more accurate and responsive impact assessments.

Publish Findings

The outcome of the case-study phase will consist of a detailed report on the findings of the modeling analysis directed at community groups, members of the scientific community, and policy makers.

Complete Additional Case Studies

As we develop the model, there will likely be other pressing issues related to specific regional developments that could benefit from the application of the modeling tool. We will identify issues of concern to interested community groups and stakeholders as we hope to incorporate several case-study projects into the development of the comprehensive regional model.



Right: Examples of the some of the existing real-time environmental monitoring systems that could be integrated into an expanded comprehensive regional model.

PHASE 2: COMPREHENSIVE REGIONAL MODEL
(approximately 1 -2 years)

- Define trajectory of model expansion

- Gather and correlate data
  a) Gather & organize geospatial data (GIS, Landsat, etc.)
  b) Correlate data to create continuous area maps
  c) Gather impact assessment data from relevant experts

- Develop Model
  a) Create comprehensive model of existing conditions and impacts
  b) Calibrate model to historical patterns of change
  c) Identify projection scenario parameters
  d) Run projection scenarios

- Produce and publish report of findings

PHASE 3: MODEL EXPANSION
(indefinite)

- Expand geographic parameters
- Expand ecological assessment capabilities
- Link to real-time environmental "sensor-ing" technology
- Apply to other geographic areas nationally and internationally

HUDSON RIVER ESTUARY REGIONAL MODELING INITIATIVE
(HYPOTHETICAL) PROJECT TIMELINE

Phase 1: Case Study

Preliminary Research and Outreach
- Research modeling precedents and Hudson River Estuary development issues
- Establish contacts and partnerships within Earth Institute

Identify Case-Study Scenarios
- Define scope of study relating to regional development and energy consumption with Lenfest Center on Sustainable Energy

Gather and Correlate Data
- Gather & organize geospatial data (GIS, Landsat, etc.)
- Correlate data to create continuous area map

Develop Model
- Apply and expand upon one or more existing applications
- Calibrate model to historical patterns of change
- Identify projection scenario parameters
- Run projection scenarios

Produce and Publish Report of Findings

Complete Additional Case-Studies
- Identify areas and issues of concern to community groups (Scenic Hudson Stakeholder meeting)

Phase 2: Comprehensive Regional Model

Define trajectory of model expansion

Gather and Correlate Data
- Gather & organize geospatial data (GIS, Landsat, etc.)
- Correlate data to create continuous area maps
- Gather impact assessment data from relevant experts

Create comprehensive model
- Calibrate model to historical patterns of change
- Identify projection scenario parameters
- Run projection scenarios

Produce and publish report of findings

Phase 3: Model Expansion

Expand geographic parameters

Expand ecological assessment capabilities

Link to real-time environmental "sensor-ing" technology

Apply to other geographic areas nationally and internationally

A preliminary overview of land-use types, variables, and potential impacts associated with each variable. Each x represents a quantifiable relationship between the variable and impact (this relationship can be either positive or negative). Each will be replaced with a figure or range of figures upon consultation with the appropriate experts. This will allow us to assess the impacts of land-use changes dynamically, and address questions such as:

- *What are the impacts on water quality of developing a unit of x type of farmland to a unit of y type of residential development?*
- *What are the relative impacts of developing a specific unit of forest versus developing a specific unit of farmland?*
- *How would those impacts change if, say, the runoff coefficient for the unit of residential development was decreased by the inclusion of permeable surfaces?*

The model will allow us to manually input all the variables and examine the impacts of a range of factors, and it will allow us to assess the impact of development not just in terms of the development itself but also in terms of what it being replaced.

LAND USE TYPE VARIABLES	
URBAN RESIDENTIAL	density (high/med/low)
	runoff coefficient
	distance from mass transit
	riparian buffer zone
URBAN INDUSTRIAL	density (high/med/low)
	industry type
	runoff coefficient
	riparian buffer zone
	associated pollutants
URBAN COMMERCIAL	density (high/med/low)
	runoff coefficient
	riparian buffer zone
	distance from mass transit
AGRICULTURE PASTURE	type
	riparian buffer zone
	associated pollutants
	runoff coefficient
AGRICULTURE CROP	crop type
	riparian buffer zone
	associated pollutants
	runoff coefficient
TRANSPORTATION ROAD	size
	frequency of use
	riparian buffer zone
	runoff coefficient
TRANSPORTATION RAIL	frequency of use
	riparian buffer zone
TRANSPORTATION AIRPORT	size
	riparian buffer zone
	associated pollutants
	runoff coefficient
	distance from mass transit
FOREST	type (deciduous/coniferous/mixed)
	runoff coefficient
	size/contiguity
	riparian buffer zone
MEADOW (non-forested upland)	runoff coefficient
	size / contiguity
	riparian buffer zone
WETLAND	type (estuary/non-tidal)
LAKE / POND	size
LONG-TERM CHANGE temperature sea-level precipitation	

IMMEDIATE IMPACTS (presumed)							LONG-TERM IMPACTS (presumed)	
waterborne (specify)	airborne (specify)	surface (erosion)	water	energy	traffic	habitat contiguity	biodiversity	global warming
x	x	x	x	x	x	x	x	x
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	x			x	x			x
x		x						
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IMAGE CREDITS

Front and back cover: View of Spuyten Duyvil from State Line lookout, retrieved from Hamilton Action Galleries' *Hudson River School: Then and Now* gallery: http://hamiltonauctiongalleries.com/HudsonRiver.htm

03: View of the Hudson River looking towards the Catskills from the Vanderbilt Mansion, Hyde Park, retrieved from Hamilton Action Galleries' *Hudson River School: Then and Now* gallery:
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05: Urban Design Lab

06: All images from: Zhu, Y. and Day, R. 2005. *Using SLEUTH Model for Forecasting Urban Growth*. Chesapeake Pennsylvania State University. Retrieved from http://gisconference.cas.psu.edu/2005/proceedings/2_mon_0330.pdf

07 top: New York Climate and Health Project (NYCHP) Land Use Change Assessment Group SLEUTH model:
http://csam.montclair.edu/luca/index.html
bottom: Woods Hole Research Center, *WHRC researchers use a "SLEUTH" to Predict Urban Land Use*:
http://whrc.org/pressroom/press_releases/PR-2004-03-25-SLEUTH.htm

08: ComunityViz online Resource Galley application examples:
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09: National Oceanic and Atmospheric Administration Coastal Services Center, *Alternatives for Coastal Development: One Site, Three Scenarios:* http://www.csc.noaa.gov/alternatives/

10: Urban Design Lab

11: clockwise from upper left: City of Yonkers conceptual development plan: http://www.sfcyonkers.com/plan/Yonkers-Sect%202%20-%20Development.pdf, Lighthouse Landing development proposal in Sleepy Hollow: http://www.gm.com/corporate/responsibility/environment/plants/brownfield_redev/roseland_062101.jsp, Sailors Cove on the Hudson, Kingston: http://www.sailorscoveonthehudson.com/3d.asp, and Annsville Creek development proposal, Peekskill: http://www.nytimes.com/2007/08/01/realestate/commercial/01hudson.html?ei=5088&emc=rss&en=22f5e503a807572a&ex=1343620800&partner=rssnyt

12: Hudson River looking north from the Bear Mountain Bridge, photograph by Rolf Müller, from
http://commons.wikimedia.org/wiki/Image:Hudson_river_from_bear_mountain_bridge.jpg

14: Urban Design Lab

16: From Engelem, G., White, R., and Ulgee, I. 1997. "Integrating Constrained Cellular Automata Models, GIS and Decision Support Tools for Urban Planning and Policy Making," in *Decision Support Systems in Urban Planning.* London: E&FN Spon.: http://citeseer.ist.psu.edu/cache/papers/cs/7539/http:zSzzSzwww.riks.nlzSzRiksGeozSz paperszSzVaals.pdf/integrating-constrained-cellular-automata.pdf

17: From United States Geological Survey. 1998. *Water Quality in the Hudson River Basin: New York and Adjacent States, 1992 -1995,* p. 5: http://pubs.usgs.gov/circ/circ1165/pdf/Circular1165.pdf