FINAL REPORT
Modeling and Measuring the Process and Consequences of Land Use Change in the Hudson River Watershed

HUDSON RIVER FOUNDATION

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SUMMARY

The accomplished goal of this project was to incorporate measures of economic activity, land use change, and environmental quality together in an integrated model capable of evaluating scenarios for policy analysis in Hudson tributary watersheds. We documented how economic activity links to ecological alterations in tributary systems through sectoral economic growth and resulting conversion of forested and agricultural land to residential land use. The Wappinger Creek and Fishkill watersheds of Dutchess County served as the case studies to this approach. Development scenarios and policy variables were developed in concert with a citizens group representing various interests in the County in a participatory modeling framework. This project produced a wealth of information that continues to be useful within the Hudson Valley, and has also broken new ground within the field of ecosystem health.

MILESTONES

Project milestones can be divided into four categories: study site selection, development of sub-model components, integrated model development and scenario analysis, and participatory watershed workshops.

Study Site Selection

The Wappinger Creek and Fishkill watersheds of Dutchess County were chosen in consultation with regional Department of Environmental Conservation staff, the Hudson Greenway, HRF board members and staff, the Dutchess County Planning department, the Dutchess County Environmental Management Council, the U.S. Geological Survey, and other representatives from the Hudson Valley research, planning, and NGO communities. Dutchess County tributary watersheds were ultimately selected due to the willingness of the watershed communities to participate in our project, prior planning experience and historical watershed data, current inter-municipality cooperation with the Dutchess County Greenway plans, and the existence of necessary economic and ecological gradients within watersheds entirely contained in a single county.

Model Sub-Components

To link economic change to land-use conversion to Hudson tributary watershed health, the following model sub-components were developed:

(1) *Economic Model and Metrics*. A geo-referenced economic model of the industry structure and makeup of Dutchess County was developed and served as the centerpiece to a simulation model of economic change in the county. The simulation model was designed with a web-page style user interface, capable of guiding a user through a series of windows that describe:

(a) the economic base (as income generation, employment, and household income distribution) and inter-industry relationships within Dutchess County;
(b) spatial distribution of economic data layers in a coupled GIS system;
(c) a number of pre-defined economic scenarios (developed at the first project workshop);
(d) user-defined economic scenarios;
(e) sensitivity analysis to key model assumptions; and
(f) report generation in Microsoft Excel.

The pre-defined scenarios specifically simulate the potential economic impact of change in the semi-conductor industry, expansion of agro-tourism activities, and commuting behavior (both in and out of the county) and second-home development. The design and use of this model served as the basis for the Ph.D. dissertation of Audra Nowosielski at RPI. The model was initially demonstrated at a meeting of the Intermunicipal Watershed Council of Dutchess County in January 2002, and was further refined with input from the Dutchess County Environmental Management Council.

(2) *Land-Use Change Model and Metrics*. A second Ph.D. dissertation, by John Polimeni of RPI, developed an econometric-based model that estimates tax parcel specific probabilities of residential development. Development scenarios can be run and displayed on tax parcel maps to explore the impact of changes in income, population, distance to central business districts of vacant lots, residential density of neighborhoods, zoning, agricultural land restrictions, and

riparian zone designations, as well as the impact on the total buildable land stock when accounting for wetland, slope, soil, and other development restrictions. In the fully integrated model, this component is backwards-linked to the economic drivers and forwards-linked to ecosystem health estimates through changes in impervious surface and other land development indices.

(3) *Ecosystem Health Model and Metrics*. Following an extensive review of techniques for watershed health characterization, field studies were conducted over two summers at 33 sites covering all of the major tributaries and a longitudinal transect of each creek's mainstem. Sites were chosen in collaboration with Dave Burns of the Dutchess County Environmental Management Council and Bob Schmidt of Simons Rock College, and additional technical assistance was offered by the Institute of Ecosystem Studies, Tom Lynch of Marist College, Karen Murray of the USGS NAWQA program, and Bob Daniels of the NY State Museum. Four major surveys were conducted:

(a) a physical habitat assessment, following a modification of the USGS NAWQA protocols (in consultation with Hudson NAWQA staffer Karen Riva-Murray);
(b) a fish survey, using protocols for completing the regional Index of Biotic Integrity as modified by Daniels et al. (submitted to TAFS);
(c) a benthic macroinvertebrate survey; and
(d) water chemistry (surveyed twice each in high and low flows, respectively), including chlorophyll, TSS, TDS, and major nutrients (we will also assay for heavy metals, but are not set up to do organics).

In addition, we conducted two assays to capture whole-ecosystem behavior: in one, we sampled simplified food webs at each site (consisting of seston, periphyton, and a "standard fish," black-nose dace) and analyzed them for carbon and nitrogen stable isotopes. The idea is that sewage-affected systems will show an increase in the nitrogen heavy isotope, and food webs stressed by other factors may have shortened trophic transfer lengths, measured by the difference between producer and consumer. We also conducted a partial synoptic survey of six sites for ecosystem production. The bulk of the analyses formed the basis of Karen Stainbrook's master's thesis at SUNY ESF.

Integrated Model Development and Scenario Analysis

A fully coupled model of the Dutchess County Watershed Economy was completed, linking economic projections, to land-use change and impervious surface metrics, to ecosystem health parameters. An initial model was programmed with PowerSim and included a web-page style model-interface for ease of use and capable of user-defined scenario analysis. A newer version of the model has been developed by Bongghi Hong, a post-doctoral student at SUNY-ESF supervised by Karin Limburg, and is described in a manuscript currently under review at *Ecosystems*. Model development, scenario analysis, and sub-components are fully described in a book being published by Elsevier early in 2007, as well as a number of peer-reviewed papers listed under outcomes below.

Participatory Watershed Workshops

(1) *Technical advisory workshop*. A major component of our research was to have local stakeholder groups inform the project design, as well as participate in scenario analysis for watershed planning. A year one workshop was created with the design goal in mind. The

workshop was held at Marist College, in cooperation with Ann Davis of the Economics Department. Workshop goals included: (a) to better understand the evolution of an urban to rural gradient, (b) to discuss methods to integrate sub-models and diverse metrics, (c) to develop scenarios to test and evaluate with an integrated model, (d) to begin to envision policy options and tools for decision-makers, and (e) to build a broad base of interest and expertise. The semi-conductor scenario was used to illustrate the SAM and GIS sub-models. Other economic scenarios that arose from discussions included changes in the agriculture sector (from traditional production to an agro-tourism base), the role of second-home development in rural Dutchess County, suburban sprawl and Greenway policies, and changing county income expenditure patterns resulting from out-of-county commuting.

(2) *Participatory planning workshop*. Once the integrated model was complete, a second workshop was held at Marist College to explore the land-use planning and policy implications of model projects. The workshop was co-organized by the Wappinger Creek Watershed Intermunicipal Council and the Dutchess County Environmental Management Council. Members of planning and zoning boards from Wappinger Creek and Fishkill watershed communities participated. Preparatory and follow-up work to the workshop was included as part of a multi-criteria decision analysis of watershed management which formed the basis for a Ph.D. dissertation by Caroline Hermans at the University of Vermont.

OUTCOMES

Workshops

"The Wappinger Creek Watershed Economy: Trends, Challenges, and Solutions," co-organized and hosted by the Wappinger Creek Watershed Intermunicipal Council, Marist College, May 15, 2004.

"Dutchess County Watershed Economy Model Demonstration and Scenario Analysis," hosted by the Intermunicipal Watershed Council of Dutchess County, Jan. 2002.

"Modeling and Measuring the Process and Consequences of Land Use Change: an Advisory Workshop for Hudson River Tributaries of Dutchess County," Marist College, Mar. 23, 2001.

Student Theses

Hermans, C., "Methods in Collaborative Decision-Making: Managing Group Deliberative Processes in Watershed Communities," Ph.D. Dissertation, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT, Feb. 2006.

Stainbrook, K.M., "Using Ecological Indicators to Detect Environmental Change in Urbanizing Watersheds: Case Study in Dutchess County, NY," M.S. Thesis, SUNY College of Environmental Science & Forestry, Syracuse, NY, 2004.

Polimeni, J., "A Dynamic Spatial Simulation of Residential Development in the Hudson River Valley, New York State," Ph.D. Dissertation, Department of Economics, Rensselaer Polytechnic Institute, Troy, NY, Aug. 2002.

Nowosielski, A., "Geo-Referenced Social Accounting with Application to Integrated Watershed Planning in the Hudson River Valley," Ph.D. Dissertation, Department of Economics, Rensselaer Polytechnic Institute, Troy, NY, Aug. 2002.

Publications

Hong, B., Limburg, K.E., Erickson, J.D., Gowdy, J.M., Nowosielski, A., Polimeni, J. and K. Stainbrook, "An Interdisciplinary Modeling Framework Assessing How Human Activities Effect Socio-Economic, Landscape, and Ecosystem Health in an Urbanizing Area," *Ecosystems*, under review.

Stainbrook, K.M., Limburg, K.E., Daniels, R.A. and R.E. Schmidt, "Long-term changes in ecosystem health of two Hudson Valley watersheds, New York, USA, 1936-2001," *Hydrobiologia*, in press.

Limburg, K.E. and K.M. Stainbrook, "Assessing Ecosystem Health in Dutchess County, New York," in J.D. Erickson and J. Gowdy (Eds.), *Frontiers in Environmental Valuation and Policy*, Edward Elgar, Cheltenham, UK, in press.

Polimeni, J.M., and R. Iorgulescu Polimeni, "Urban Spawl – Scenario Analysis for Public Policy Makers," *Journal of Business and Economics Research*, in press.

Erickson, J.D., Messner, F. and I. Ring (Eds.), *Ecological Economics of Sustainable Watershed Management*, 16 chs., Series on Advances in the Economics of Environmental Resources, Elsevier Science, forthcoming.

Erickson, J.D., Messner, F. and I. Ring, "Ecological Economics at the Watershed Scale: Comparing and Contrasting the United States and German Experiences and Approaches," Ch. 1 in Erickson et al. (Eds.), *Ecological Economics of Sustainable Watershed Management*, Elsevier Science, forthcoming.

Hong, B., Limburg, K.E., Hall, M. and J.D. Erickson, "Scenario Analysis of Economy-Ecology Interactions in the Hudson River Basin," Ch. 5 in Erickson et al. (Eds.), *Ecological Economics of Sustainable Watershed Management*, Elsevier Science, forthcoming.

Nowosielski, A. and J.D. Erickson, "Regional Economic Modeling and Spatial Key Sector Analysis," Ch. 8 in Erickson et al. (Eds.), *Ecological Economics of Sustainable Watershed Management*, Elsevier Science, forthcoming.

Polimeni, J. and J.D. Erickson, "Residential Location Theory, Modeling, and Scenario Analysis of Urban Growth and Planning," Ch. 9 in Erickson et al. (Eds.), *Ecological Economics of Sustainable Watershed Management*, Elsevier Science, forthcoming.

Hermans, C. and J.D. Erickson, "Multicriteria Decision Analysis: Overview and Implications for Environmental Decision-Making," Ch. 10 in Erickson et al. (Eds.), *Ecological Economics of Sustainable Watershed Management*, Elsevier Science, forthcoming.

Polimeni, J.M., "Simulating Agricultural Conversion to Residential Use in the Hudson River Valley: Scenario Analysis and Case Studies. *Agriculture and Human Values* 22: 377-393, 2005.

Limburg, K.E., Stainbrook, K.M., Erickson, J.D. and J.M. Gowdy, "Urbanization Consequences: Case Studies in the Hudson Valley," in L.R. Brown and M. Meader (Ed.), *The Effects of Urbanization on Aquatic Ecosystems*, American Fisheries Society, 2005.

Erickson, J.D., Limburg, K.E., Gowdy, J., Stainbrook, K., Nowosielski, A., Hermans, C. and J. Polimeni, "Anticipating Change in the Hudson River Watershed: an Ecological Economic Model for Integrated Scenario Analysis," Ch. 13, pp. 341-370, in R. Bruins and M. Heberling (Eds.), *Economics and Ecological Risk Assessment: Applications to Watershed Management*, CRC Press, Boca Raton, FL, 2004.

Erickson, J.D. and K.E. Limburg, "Balanced Growth Vital: Uncoordinated Development Harms Watersheds," *Poughkeepsie Journal*, March 7, 2004.

Presentations

Limburg, K.E., "Measuring Ecosystem Health in Dutchess County, NY," *Hudson River Environmental Society Conference on Indicators of Sustainability*, May 2006.

Limburg, K.E., "Connecting the Dots: Modeling and Measuring the Process and Consequences of Land Use Change," Institute of Ecosystem Studies, Dec. 2005.

Limburg, K.E., "Connecting the Dots: Modeling and Measuring the Process and Consequences of Land Use Change," Alfred University, Nov. 2005.

Hong, B., "Connecting the Dots: How Economic Activities on the Landscape Affect Stream Ecosystem Health," Ecological Society of America Annual Meeting, Montreal, Canada, Aug. 2005.

Erickson, J.D., "Participatory Decision-Making at Bioregional Scales: Thoughts on Decision Structure, Group Process, and Bottom-Up Politics," Leeds University, Leeds, UK, Apr. 21, 2005.

Limburg, K.E., "Modeling and Measuring the Process and Consequences of Land Use Change," Columbia University, New York, NY, Dec. 2004.

Limburg, K.E., "Modeling and Measuring the Process and Consequences of Land Use Change," Royal Academy of Sciences, Stockholm, Sweden, Sep.2004.

Limburg, K.E., "Modeling and Measuring the Process and Consequences of Land Use Change," Griffith University, Brisbane Australia, July 2004.

Limburg, K.E., "Urbanization Causes and Consequences: Case Studies in the Hudson River Watershed," *Annual Meeting of the American Fisheries Society*, Quebec City, Aug. 2003.

Erickson, J.D., "We Paved Paradise and Put Up a Parking Lot: Economic, Social, and Ecological Implications of Incremental Choice," *Research Experience for Undergraduates Program*, National Science Foundation, Clarkson University, Potsdam, NY, July 1, 2003.

Hermans, C., "An Application of Outranking MCDM in Land-Use Planning," *Second Biennial Conference of the U.S. Society for Ecological Economics*, Saratoga Springs, NY, May 22-24, 2003.

Polimeni, J., "Application of a Dynamic Spatial Simulation of Residential Development to Evaluate Land Value Taxation in the Hudson River Valley," *Second Biennial Conference of the U.S. Society for Ecological Economics*, Saratoga Springs, NY, May 22-24, 2003.

Stainbrook, K.M., "Assessing Ecosystem Health in Dutchess County, NY: Multiple Metrics to Evaluate Watershed Condition," *Second Biennial Conference of the U.S. Society for Ecological Economics*, Saratoga Springs, NY, May 22-24, 2003.

Limburg, K. (Poster), "Modeling and Measuring Economic Drivers and Ecosystem Health: Case Studies in the Hudson River Watershed," *Sixteenth Biennial Conference of the Estuarine Research Federation*, St. Pete Beach, FL, Nov. 4-8, 2002.

Erickson, J.D., "Participatory Scenario Analysis in a Spatial Social Accounting Framework: Applications in Watershed Planning," *Environmental Research Group Seminar Series*, University of New Hampshire, Durham, NH, Oct. 3, 2002.

Limburg, K.E., "Modeling and Measuring Economic Drivers and Ecosystem Health: Case Studies in the Hudson River Watershed," *Healthy Ecosystems, Healthy People*: I*naugural Meeting of the International Society for Ecosystem Health*, Washington, DC, June 7-10, 2002.

Polimeni, J., "Simulating Residential Development for Better Development Decisions in the Hudson River Valley, New York State," *Healthy Ecosystems, Healthy People*: *Inaugural Meeting of the International Society for Ecosystem Health*, Washington, DC, June 7-10, 2002.

Gowdy, J., "Participatory Scenario Analysis in the Hudson River Watershed, New York, USA," *Seventh Biennial Conference of the International Society for Ecological Economics*, Sousse, Tunisia, Mar. 6-9, 2002.

Polimeni, J., "Simulating Residential Development from Economic Trends in the Hudson River Valley, New York State, USA," *Seventh Biennial Conference of the International Society for Ecological Economics*, Sousse, Tunisia, Mar. 6-9, 2002.

Limburg, K.E., "Modeling and Measuring the Process and Consequences of Land Use Change: Hudson River Tributaries of Dutchess County, NY," SUNY College of Environmental Science and Forestry, Jan. 2002.

Limburg, K.E., "Modeling and Measuring the Process and Consequences of Land Use Change: Hudson River Tributaries of Dutchess County, NY," Dutchess County Environmental Management Council, May 2002.

Nowosielski, A. (Poster), "Social Accounting Matrices and Landscape Change in Dutchess County, New York," *Seventeenth Annual New York State GIS Conference*, Albany, NY, Oct. 29-30, 2001.

Polimeni, J. (Poster), "A Spatial Approach for Linking Economic Trends to Land Use Change in the Hudson River Valley," *Seventeenth Annual New York State GIS Conference*, Albany, NY, Oct. 29-30, 2001.

Erickson, J.D. (Plenary Speaker), "Connecting Land Use, Economics, and Water Quality," *Annual Meeting of the New York Planning Federation*, Saratoga City Center, Saratoga Springs, NY, Oct. 9, 2001.

Nowosielski, A., "Social Accounting Matrices and Landscape Change in the Hudson River Valley," *Biennial Meeting of the United States Society for Ecological Economics*, Duluth, MN, July 11-13, 2001.

Polimeni, J., "Linking Economic Trends to Land Use Change in the Hudson River Valley,"*Biennial Meeting of the United States Society for Ecological Economics*, Duluth, MN, July 11-13, 2001.

Polimeni, J. "Linking Economic Trends to Land Use in the Hudson River Valley," Symposium on Environmental Sustainability, Clarkson University, Potsdam, NY, June 16-19, 2001.

Stainbrook, K.M. (Poster), "Bridging economic activity, land use, and ecosystem health for two watersheds in Dutchess County, New York," Symposium on Environmental Sustainability, Clarkson University, Potsdam, NY, June 16-19, 2001.

Erickson, J.D., "From Economy to Ecology: Modeling and Measuring the Socio-Ecological Dynamics of Land-Use Change," UFZ Centre for Environmental Research, Leipzig, Germany, Apr. 25, 2001.

Extensions and Collaborations

"Regional Sustainability: Bridging Resource Conservation and Economic Development" – A research exchange funded by the National Science Foundation and its German counterpart between Rensselaer Polytechnic Institute (Troy, NY) and UFZ Centre for Environmental Research (Leipzig, Germany) for 2001 through 2003.

"Land Use as a Driver of Ecological Change in the Wappinger and Fishkill Creeks, Hudson River Valley, New York" – A 2002 planning grant funded by the Hudson Valley Regional Council and directed by the Dutchess County Water Quality Strategy Committee.

"Hudson River Waterfront Development Project: Economic Impact Study" – A 2001 research grant funded by the Center for Economic Growth of the Rockefeller Institute and the New York State Department of State that extended input-output modeling work funded by HRF to the Albany and Rensselaer County Hudson waterfront communities.

"MapInfo GIS Project" – Data and GIS training investment by MapInfo, Inc. at Rensselaer Polytechnic Institute between 1998 and 2002, valued at $1,300,000, that directly benefited the HRF project.

"Symposium on Sustainability" – A research symposium funded by the National Science Foundation, highlighting HRF-funded work, and co-organized and hosted by the Clarkson University Center for Environmental Management, Potsdam, NY, June 16-19, 2001.

"An Integrated Monitoring/Modeling Framework for Assessing Human-Nature Interactions in Urbanizing Watersheds: Onondaga and Wappinger Creeks" – this is a newly funded project, sponsored by the Syracuse Center of Excellence in Energy and Environmental Systems. In this project, we will further refine the modeling approaches developed in the HRF project, and in particular will bring in state-of-the-art assessments of impervious surface and link these to a watershed loading model.