An Ecological Economic Model for Integrated Scenario Analysis in the Hudson River Watershed

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Abstract

Many communities across the nation and world have succumbed to what Alfred Kahn (1966) referred to as “the tyranny of small decisions”. Land use decisions made one property, one home, and one business at a time in the name of economic growth have accumulated without regard to social and environmental values. For communities deriving their livelihoods directly from environmental, cultural or other local amenities, the accumulation of small decisions over time threatens the very foundation of economic activity. The purpose of this study is to develop a model making the links between economy, ecology, and land use explicit and transparent. We examine some of the analytical tools available to construct scenarios that link economic change to land-use patterns and correlated environmental quality. An on-going research project in the Wappingers Creek and Fishkill Watersheds of Dutchess County, New York, illustrates how regional economic models, geographical information systems, and environmental monitoring can be linked in a manner amenable to scenario analysis, regional planning, and watershed management. The research framework of this project combines local expertise, diverse stakeholder inputs, and local planning capacity toward shared goals of community and environmental quality. We argue that the framework developed in this study has wide applicability in the United States and Europe.

I. THE TYRANNY OF SMALL DECISIONS

The “tyranny of small decisions” describes the long-run, often unanticipated, consequences of a system of decision making based on marginal, near-term evaluation. Incremental decisions made by weighing marginal benefits against marginal costs by an individual isolated in a point in time are the hallmark of traditional economics. The “tyranny” results when the accumulation of these singular decisions creates a scale of change, or a conversion from one system dynamic to another, which would be disagreeable to the original individual decision-makers. In fact, if given the opportunity to vote on a future that required a redirection of near-term decisions, a community of these same individuals may have decided on a different path. Under a tyranny, maximizing the well-being of both society and the individual becomes an exercise in identifying and pursuing a collective will, quite different than assuming that community held goals will result from individual pursuits of well-being.

At the watershed scale, the tyranny of small decisions has emerged in the form of urban sprawl – a dispersed, automobile dependent, land-intensive pattern of development. One house, one subdivision, one strip mall at a time, the once hard edge between city and country throughout the United States has incrementally dissolved. By structuring the land-use decision problem as a series of individual choices, the tyranny has resulted in losses of watershed functions such as water supply, purification, and habitat provision – so-called natural capital depreciation. Associated social capital depreciation includes decline in school quality, loss of social networks, and degradation of community services.

These are all outcomes that a democracy may not have chosen if given the chance, yet individuals can't appreciate in their own land-use decisions.

To emerge from the tyranny, the challenge is not to predict, but to anticipate the future. Prediction of integrated social, economic and ecological systems implies a simplification of multiple scales and time dimensions into one set of assumptions, and a defense against alternative hypotheses on different futures. Quantitative assessment and model building is often limited to one system, with relations to others treated as exogeneous corollaries. In contrast, anticipation implies a process of envisioning scenarios of the future and embracing the complexity that is inherent between and within the spheres of social, economic, and ecological change. As a process-oriented approach to decision-making, anticipation focuses on the drivers of change, the connections between spheres of expertise, and a reliance on local knowledge and goal-setting. Through scenario analysis, decision makers can vary the assumptions within degrees of current knowledge, foresee the accumulation of small decisions, and decide upon group strategies that decrease the likelihood of undesirable consequences.

The following case study describes a project in Dutchess County, New York, that has developed in this spirit. Section II introduces Dutchess County, and its own version of the "tyranny of small decisions." Section III describes an integrated approach to model development in Dutchess County, including description of economic, land-use, and ecological sub-models that provide both the detail within and connectivity between their spheres of analysis. Section IV concludes with a scenario analysis of expansion of the county's semi-conductor industry.

II. WATERSHED COMMUNITIES AND THE DUTCHESS COUNTY DEVELOPMENT GRADIENT

Watershed communities include the physical, ecological, and human components of a topographically delineated water catchment. Our study area is part of the larger Hudson River watershed of eastern New York State, which draws water from over 34,000 square kilometers of land (mostly in New York, but also reaching into Massachusetts, Connecticut, New Jersey, and Vermont) on its journey from the southern slopes of the High Peaks of the Adirondack Mountains to the Atlantic Ocean (Stanne et. al, 1996). Dutchess County (2,077 km^2) is located in the lower Hudson watershed, midway between the state capital of Albany and New York City. Figure 1 highlights both Dutchess and its two principal Hudson tributary watersheds, the Wappingers (546.5 km^2) and Fishkill (521 km^2) Creeks, which together drain over half of the county landscape. The full county includes approximately 970 km of named streams that serve as a source of public water, irrigation, recreational use, and waste disposal. The focus of this study is on the county's economy, its land-use patterns, and the general health of the Wappingers and Fishkill systems.

The Dutchess economy through the mid-twentieth century was principally agrarian, specifically mixed row-crop, dairy, and fruit agriculture. While today's county economy is characterized by 203 distinct sectors, with a total employment of over 132,000, much of the recent economic history has followed the rapid growth and then cyclical behavior of the International Business Machine Corporation (IBM). In 2000, IBM was the second largest employer (>11,000) in the county, preceded only by local government (13,800), and followed by state government (7,600) (DCDPD, 2000). Other major economic themes cutting across the county – identified at an early stakeholder meeting of this project – include the influence of seasonal home ownership and commuting patterns (particularly in relation to New York City wealth and employment), the transformation of traditional agricultural to more agro-tourism activities, and the impact of an aging population and growth in retirement homes and services.

County land-use intensity follows a development gradient from the rural northeast to urban southwest. The Wappingers Creek watershed mirrors this gradient, beginning in mostly forested headwaters, continuing through a predominantly agricultural landscape, flowing through mixed suburban use, and discharging into the Hudson in the urban areas of Wappingers Falls and Poughkeepsie. The Fishkill Creek is generally more heavily populated, follows a similar northeast-southwest development gradient, and enters the Hudson through the city of Beacon. The geology of both watersheds is primarily a mix of limestones, dolostones, and shales, and annual precipitation is approximately 1040 mm (Philips and Hanchar 1996).

These rural to suburban to urban development gradients provide a unique opportunity to model the impact of economic change on land-use intensity and watershed health. In particular, a pattern of urban sprawl that stretches up each watershed provides a cross-sectional analysis of an increasing impervious surface gradient on aquatic health assessment. Land use is changing most rapidly in the south-central portion of the county, a consequence of high-tech industry growth and a general push of suburban expansion radiating out from the New York City greater metropolitan area. Residential development, in particular, is rapidly converting forest and field to roads and housing.

According to county planners, about 75% of the houses in Dutchess are located in the southern half, but new building is spreading north and east. Since 1980, the average annual number of building permits for single-family dwellings was 877 (Real Estate Center, 2000). However, this average is significantly skewed by the 1983-1989 and 1998-2000 building booms, with each year surpassing 1,000 permits, compared with an off-peak annual average closer to 500 permits. The slowdown in the early 1990s can be attributed to IBM's downsizing. These layoffs "glutted the housing market, depressing prices and making houses more affordable to people looking to move out of New York City" (Lynch, 2001). Non-residential building permits averaged 744 between 1980 and 1995 without much annual variation.

With new households comes new income that cascades across the county economy creating further business and household growth, and consequent land-use change. Average per capita income in Dutchess County is the seventh highest of sixty-two New York counties. Dutchess households have had a median buying power of \$47,380, much higher than the New York State (\$38,873) and U.S. (\$35,056) medians (DCDPD, 1997). Dutchess County's effective buying income (EBI) ranks 15th in the United States, with over 46 percent of county households with an EBI of over \$50,000. This household income creates multipliers that are cause for concern for some of the more rural municipalities. A planning report from the small town of Red Hook (2002) in the northwest county states, "These factors will continue to bring commercial development pressures on any significant highway corridors, as businesses seek to exploit the growing pool of disposable income in Red Hook and Rhinebeck." Growth is viewed as both an opportunity for business and a challenge for municipalities that struggle to preserve their rural landscape and level of community and ecosystem services.

Fundamental among these services are watershed functions. Ecological risks associated with current and changing land use include the loss of water quality, hydrological function, physical habitat structure (e.g., alterations of riparian zone), and biodiversity. In order to anticipate and perhaps avoid irreversible loss in these functions, the challenge is to link ecological change to land-use change and its economic drivers. The next section outlines an approach to integrated modeling, combining synoptic ecological surveys with economic and land-use models in a framework capable to stakeholder informed scenario analysis.

III. ECONOMIC ANALYSIS, LAND USE, AND ECOSYSTEM INTEGRITY: AN INTEGRATED ASSESSMENT

The analytic building blocks for the integrated watershed model include a social accounting matrix (SAM) describing economic activity in Dutchess County, a geographical information system (GIS) of land use, socio-economic, and biophysical attributes, and an assessment of aquatic ecosystem health based on indices of biotic integrity (IBI). Figure 2 illustrates these sequential model components, with system drivers and feedback loops denoted in solid and dashed arrows, respectively.

Starting with the left side of the diagram, regional economic activity is characterized as dollar flows between industry (in the center), households (top right), government (top left), capital markets (bottom right), and the outside economy (bottom left). The middle panel illustrates the multiple layers of biophysical and social context within which land-use decisions are made. The right panel highlights the watershed as the scale of ecosystem impact from economic and land-use change. Total economic activity has a direct effect on watershed health through waste output and material input, and an indirect effect through land use change. Land use change and ecosystem health can similarly impact economic activity through feedback loops. For example, soil erosion impacts agricultural industries, water quality impacts water-based tourism, and environmental amenities influence real estate values. Drivers or feedbacks can be either marginal or episodic, accounting for system surprises.

The three analytical components of the model are described in more detail below.

A. SOCIO-ECONOMIC SUB-MODEL: GEO-REFERENCED SOCIAL ACCOUNTING MATRIX (G-RSAM)

A widely used tool in national and regional economic analysis is the input-output model (IO) developed in the 1930s by Nobel laureate Wassily Leontief. As a system of accounting that specifies interdependencies between industries, IO has been used to understand how changes in final demand (household consumption, government expenditure, business investment, and exports) are distributed across an economy. To meet new demand requires industrial production, which in turn requires industrial and value-added inputs, which in turn requires more production, and so on and so forth. Each addition in the production chain sums to an output multiplier which accounts for the original demand and all intermediate production generated to meet this demand. Value-added inputs include income contributions from labor as wages, capital as profits, land as rents, and government as net taxes, and can be related to output to capture various income (wage, profit, rent, and tax) and employment multipliers.

The IO system is represented as an extension of the economic sphere in Figure 3. The three boxes symbolize the main systems of accounts – final demand, industry production, and value-added inputs – in a traditional IO system. These accounts are specified as matrices, with rows read across as outputs and columns read down as inputs. For instance, reading down the column of the semi-conductor industry for the Dutchess County model, the top ten sector inputs include other firms within the same aggregated industry, wholesale trade, maintenance and repair, computer and data processing, electric services, legal services, real estate, electronic computers, personal supply services, and banking. The sum of all these regional inputs, value-added, and any imports required from outside the region equals total inputs to the industry. Similarly, the sum of the semi-conductor industry's outputs generated for other industries to use in intermediate production and final products to demand equals its total output. To balance the accounts within a particular time period, inputs must equal outputs.

By itself, the economic sphere misses key dependencies between the economic and social systems. Traditional IO has focused on the structure of production, the matrix in the upper left corner of Figure 3, with industry disaggregated into over 500 sectors, each with its own input-output relations specified. However, the structure and detail of final users has typically been highly aggregated, most often specified only as its four major components of household, government, business, and foreign consumption. This restricted treatment of households in particular – the major driving force in economies as both consumers and suppliers of labor and capital – limits the ability of the IO model to specify income distribution, investigate the effect of welfare and tax policies, and model the impacts of changing patterns of household spending. The need for a more detailed treatment of households led researchers, beginning with the work of Nobel laureate Richard Stone in the 1960s, to expand the IO system into a social accounting matrix (SAM) (Stone 1970, Pyatt and Round 1985).

In the SAM, components of final demand and value-added are called institutions. The interdependencies between and among industry and institutions are illustrated by the three boxes linked to the social sphere of Figure 3. For instance, households specified as an institution (not just a factor input of labor) can reveal their non-labor inputs to industry in the left box, distribution of labor income in the center box, and interdependencies with other institutions in the right box (the distribution of rents, profits, and net taxes to households). Households – as consumers in final demand and labor supply in value-added – can be disaggregated into columns and rows according to criteria (and data) relevant to the policy question at hand. For instance, households have been disaggregated by income category, wage group, and skill or occupation class.

The creation of a SAM for this study is based on a regional database called IMPLAN (IMpact analysis for PLANning). IMPLAN tables are available for any collection of states, counties, or zip codes in the U.S. based on federal and state databases, which can then modified using best available local data. The main modification for the Dutchess County SAM was the disaggregation of IMPLAN's single labor income row into eleven occupation categories (Nowosielski 2002). Using Bureau of Labor Statistics data from the 2000 census, and following a procedure outlined by Rose, Stevens, and Davis (1988), each occupation row shows the input relation to each industry column, and each occupation column shows the distribution of labor income to nine household institutions categorized by income ranges.

Finally, to complete the image of a nested system of accounts within Figure 3, economic activity and its distribution is linked to the ecosystem. To explore these linkages, the basic IO/SAM framework has been expanded to incorporate environmental and natural resource accounts (Victor 1972, United Nations 1993, Lange 1999). In Figure 3, inputs from the environment to industry and institutions are tallied in the bottom two boxes, and outputs from industry and institutions to the environment are tallied in the far right boxes. Environmental inputs include energy, minerals, water, land, and numerous ecosystem services. Outputs discarded into the environment include the gamut of solid, liquid, and gaseous wastes. For the current study, the main consideration is the use of land as an input to the socio-economic systems. Of particular interest is how scenarios of industrial sector change and growth lead to changes in household institutions that ultimately drive new residential land development.

In order to link economic change and social distribution to spatial patterns of land-use, the Dutchess County SAM was referenced to a geographical information system (Nowosielski 2002). For example, the geo-referenced SAM can place household institutions (disaggregated by both occupation class and income range) within the spatial context of race, education, age, commuting patterns, wealth, income, and numerous other census-defined household characteristics. Spatial patterns and concentrations of industry sectors can be viewed with business point data and linked to information on business size, year of establishment, and income range. The spatial dimensions of the entire economy (both institutions and industry) can be further referenced to tax parcel data with information on acreage, taxable use, zoning, infrastructure, and various ownership characteristics. These ownership units can then be linked to biophysical characteristics such as soil, slopes, wetlands, and location within watersheds.

B. LAND USE SUB-MODEL: PROBABILISTIC GEOGRAPHICAL INFORMATION SYSTEM

Moving from the first sub-model to the second outlined in Figure 2, scenarios generated by the geo-referenced social accounting matrix (GR-SAM) then inform a model of land-use change. The GR-SAM is a static tool that is helpful to identify the source of new land demands, but not necessarily how these demands could play out on the landscape. Most economic models do not include spatial variation of activity; however, location is critical to estimating environmental loading (Bockstael 1996).

Of particular interest to Dutchess County is growth in residential land use. Land currently characterized on the tax rolls as vacant-residential, agriculture, and private forest provides an inventory of total vacant land potentially available for conversion to residential use. By this characterization, in the Wappingers Creek watershed in 2001 there were 19,024 parcels in residential use and 4,507 vacant. The conversion from vacant to residential was modeled with a binomial logit regression procedure to estimate the probability of land conversion of individual tax parcels throughout the Wappingers Creek watershed (Polimeni, 2002). These probabilities were assumed to be depend on both tax parcel characteristics and neighborhood characteristics (defined by census blocks). Tax parcel independent variables included land assessment value per acre and distance to the nearest central business district. Neighborhood independent variables included household income and population growth and the density of residential land use classes in each census neighborhood.

Polimeni (2002) provides a detailed discussion of model calibration, results, and diagnostics (including tests for spatial autocorrelation). The final model provides the basis for simulating residential development patterns given changes in independent variables. For instance, if incomes or population continue to grow according to inter-census year rates (1990-2000), a Monte Carlo procedure can demonstrate where conversion to residential use would likely occur. Figure 4 plots the outcome of a single status quo Monte Carlo run, assuming a continuation of the 1990s decadal growth rates of 53% in per capita income and 8% in population. The average of 100 runs provides a point estimate of 1,132 parcels converted to residential use. Development favors the upper (rural) watershed with 677 new residential parcels averaging 18.39 acres. The lower (urban) and middle (suburban) watershed includes 228 and 215 new residential parcels, with an average size of 3.3 and 8.61 acres, respectively.

The model only simulates conversion of use class, not the percentage or acreage of parcels that become physical homes. In order to estimate the maximum number of new homes on new residential parcels, tax parcels were screened according to both biophysical and zoning layers. Biophysical GIS layers included slope, hydric soils, wetlands, riparian river corridors, and agricultural land. Acreage can be removed from development according to rules imposed by these layers. Zoning maps further limit the number of principle buildings allowed per acre. To account for development infrastructure requirements, particularly new roads, various percentages of buildable land can also be assumed. Following a biophysical screening of wetlands, hydric soils, and >10% slopes, a town specific zoning overlay, and assuming 80% buildable land, the status quo scenario (highlighted by Figure 4) can accommodate a maximum of 10,370 new homes.

Given economic scenarios from the GR-SAM sub-model, the binomial logit model can simulate residential land conversion for the Wappingers Creek watershed. These scenario derived land-use profiles are then used to hypothesize changing land-use intensity within each of the 16 sub-catchments of the Wappingers Creek watershed. This provides the empirical link to the ecosystem health assessment.

C. ECOSYSTEM HEALTH SUB-MODEL: SPATIALLY CORRELATED INDICES OF BIOTIC INTEGRITY

The third component of the Figure 2 project overview is an estimate of ecosystem health impact based on land development scenarios. The concept of ecosystem health, while not new, is enjoying a resurgence as a useful means of assessing the impacts of human activities, and for protecting and restoring ecosystems (e.g., Rapport 1992, Shraeder-Frechette 1994, Rapport et al. 1995), while considering societal goals (Rapport et al. 1998). Ecosystem health may be defined as the maintenance of biotic integrity, resistance and/or resilience to change in the face of anthropogenic disturbance, and the absence of factors that degrade population, community, and ecosystem structure and function. Ecologists have spent the past twenty-five or more years exploring various indicators that best reflect ecosystem responses to anthropogenic stress, and have found them to vary with the particulars of the ecosystem of interest. Nevertheless, some indicator methods have emerged as robust, when adjusted to local or regional biogeographic and geomorphological constraints.

Among these is the “index of biotic integrity” or IBI method (Karr 1981, 1991). Karr worked out a set of criteria for assessing the health of mid-western streams with which argued that fish were a good end-point for observing ecological effects. As the “downstream receiving end” of numerous complex ecological processes, fish can serve as integrating indicators of the quality of the system. A stream IBI combines a number of different metrics that reflect fish biodiversity, community structure, and health of populations. For example, a water body that has high species richness (number of species present), a high proportion of which are endemic, including a mix of species occupying different trophic positions, and showing very few indications of disease or starvation, would be scored with a high IBI. Conversely, an ecosystem with only a few pollution-tolerant species, low biomass, or containing only stocked or exotic species, would be scored with a low IBI.

Key to developing and using an IBI is knowledge of what kinds of fish would be expected in an undisturbed system under local conditions. Regional benchmarking has been done in a number of systems, including streams in southern Ontario (Steedman 1988), New England, western Oregon, and the central Appalachians (Miller et al. 1988), and more recently in estuaries (Deegan et al. 1997; Weisberg et al. 1997) and the California Sierras (Moyle and Randall 1998). Against these control groups, IBIs in disturbed systems have been well correlated to land-use (Steedman 1988, Karr 1991, Allan et al. 1997, Moyle and Randall 1998) and under some circumstances to nutrient loading (Miltner and Rankin 1998). Furthermore, IBIs developed with stream macroinvertebrates have also proven to be sensitive indicators of ecosystem disturbance (Fore et al. 1996; Karr 1999). Indeed, stream and river macroinvertebrate monitoring has been used in the Hudson River and its tributaries since the 1970s, and has proven to be a good indicator of river recovery following the cleanup of streams and rivers in New York State (Bode et al. 1993).

This study uses the metrics developed for a recently published New England fish IBI (Daniels et al. 2002), and a benthic macroinvertebrate IBI developed by the New York State Department of Environmental Conservation. In addition, several other parameters are being examined, including whole-ecosystem metabolism (Odum 1956, Bott 1996), non-point source enrichment of ^{15}N as indicated by the $\delta^{15}N$ isotopic ratio of a standardized ecosystem components, water quality parameters (including their variability, as this varies with degree of urbanization [Limburg and Schmidt 1990]), and a number of ancillary measures of human interventions or alterations of streams. These system-level metrics and water quality parameters are known to vary with land use (e.g., Parsons and Lovett 1992, Wahl et al. 1997, Wall et al. 1998; Bunn et al. 1999).

A series of synoptic surveys were conducted in 2001 and 2002 at a total of 33 stream sites in the two watersheds. The surveys included physical habitat assessments, using a modification of EPA standard protocols (Fitzpatrick et al. 1998), fish surveys, macroinvertebrate surveys, and water chemistry surveys. Surveys also included collection of materials for stable isotope analysis, focusing on the simplified food chain of seston, macrophytes, and a cosmopolitan fish species (blacknose dace, *Rhinichthys* *atratulus*). A short-term study of diurnal oxygen variation was also carried out simultaneously in six sub-catchments with different land use.

Although much of the data analysis is still in progress, patterns are beginning to emerge. As expected from visual impressions, variation is high and patterns of some parameters would likely not be visible without geographic presentation of the entire dataset. For example, Figure 5 shows an index of anthropogenic nitrogen (the percent of total N in the inorganic forms of nitrate and ammonia) over the watersheds. The Fishkill, the more developed watershed, has significantly higher inorganic N to total N ratio than does the Wappingers Creek. The next step is to correlate such metrics with land-use intensity within each watershed. In the analysis to date, only one fish community in the study area was severely depressed, and the rest, by the IBI index, vary widely. The reasons for this are complex, but include factors such as the presence of shading by riparian cover, benthic habitat type, and physical structures that might serve as attractive habitat.

One indicator of health that is comparable to past studies has been species richness. The New York State Conservation Department undertook a comprehensive biological survey of watersheds across the state in the 1920s and 1930s, with the lower Hudson and its watershed being assessed last (NYS Conservation Dept. 1936). Schmidt and Kiviat (1986) also surveyed the Fishkill system in the 1980s, and made comparisons of their findings with unpublished New York State Conservation Department data from the 1950s, 60s, and 70s where possible. Tables 1 and 2 compare these surveys with work completed in 2001 on the Fishkill mainstem and Sprout Creek, one of the largest tributaries in the Fishkill system. This characterization of fish community structure and change offers two main observations. First, the mix of species in any given time frame differs, reflecting natural ecological processes (e.g., competition, predation) as well as anthropogenic drivers (e.g., water quality alteration, species introductions). Second, there has been a general decline in species richness at all sites, with the greatest percent decline (36%) in the Sprout Creek.

Further analysis and synthesis is in progess. The ecological datasets will be used to develop statistical relationships between ecological variables and land use, indicators of urbanization (e.g., catchment imperviousness, see Klein 1979, Wang et al. 2001), and associated economic activities. These relationships can be displayed as graphs, and as suggested by Karr (1999, p. 228) become "ecological dose-response curves" that "show a measured biological response to the cumulative ecological exposure, or dose, of all events and human activities within a watershed." These statistical relationships will then form the basis of ecological indicators of economic and land-use scenarios. Early analysis has hinted at the complexity of the relationship between anthropogenic drivers and metrics of ecosystem health. Indicators will not likely point in the same direction, and that information may be key to understanding how the upstream inputs are responding to human activities on the landscape.

IV. SCENARIO ANALYSIS

In order to follow the progression within and between the three sub-models described above, this section concludes the chapter with a scenario analysis based on growth in the Dutchess County semi-conductor industry. During the first project workshop – with state and county planners, representatives of local and regional non-governmental organizations, and project technical advisors – growth in the semi-conductor industry was identified as one of the scenarios most worth studying. In particular, IBM has recently built a semiconductor plant in East Fishkill that will employ approximately 1,000 people when operational in 2003. An existing building at IBM's Fishkill site will be adapted and remodeled to house the chip plant, an activity that is expected to create 1,400 temporary construction jobs (DCEDC 2001). IBM is estimated to invest $2.5 billion in the plant (Shantz-Feld 2001). The county is promoting the project by offering IBM tax exemptions valued at $475 million, as well as grants and loans worth $28.75 million (Lyne, 2000).

The first step in the analysis is to identify the semi-conductor industry within the Geo-Referenced Social Accounting Matrix (GR-SAM) and estimate its input-output and spatial linkages with other components of the regional economy. The semi-conductor industry of Dutchess County was identified as a key sector based on both its relative size and connectivity to regional industry and households (Nowosielski 2002). In relative terms, it has the highest location coefficient in the county economy (a relative measure of importance of the industry locally as compared to the national average; see Watkins 1980), followed closely by the related industries of computer peripheral equipment and electronic computers. By further combining location quotients with data on input-output linkages, keystone sectors are identified as those with both high location quotients and strong linkages to other high location quotient industries (Kilkenny & Nalbarte, 1999). This method further highlights the semi-conductor industry's relative importance to the Dutchess County economy. A final step in the keystone sector description delineates those sectors with strong forward linkages (i.e., selling proportionately larger amounts of inputs to other sectors within the region), as well as those with strong backward linkages (i.e., purchasing larger amounts of inputs from other sectors in the region's economy) (see Sonis, Hewings, and Guo 2000). The semi-conductor industry demonstrates both above average forward and backward linkage to other regional industries.

Within this context, the next step is to understand how an increase in employment of the semi-conductor industry translates into countywide income and employment change, distribution of income amongst households and wage classifications, and the generation of new households. An increase of 1,000 new employees in the semi-conductor industry multiplies into nearly 2,300 economy-wide jobs. The industry has the 11th highest earnings per employee ($79,604) in the county, contributing to a relatively large countywide income increase of over $238 million. About 70% of the impact is direct (due to semi-conductor wages, profits, etc.), with 17% indirect (due to inputs from other sectors) and 13% induced (due to new household income expenditures). The top five industries affected are semiconductors (by a large margin), maintenance and repair other facilities, eating & drinking (due primarily to induced household expenditures), wholesale trade, and personnel supply services.

Growth in employment by wage and household income category is next translated into new households. The cases of both local full employment and unemployment within the occupation classes were considered. The percentage of new commuters from outside the county economy was also considered when estimating new within-county household generation. Depending on the degree of local production assumed to fill new input demands from the semi-conductor industry, new households are estimated to be between

1,777 to 2,051. The full employment scenario was assumed more likely as unemployment in the county is generally low, and IBM currently employs many high skill workers at their other facilities. However, commuting may play a factor. The IBM facility in Poughkeepsie employs several people who live in neighboring Ulster County.

In order to locate new households, a binomial logit model can be employed to estimate the most likely tax parcels to convert to residential. The degree of new home construction will depend on the amount of real estate on the market, the distance workers are willing to drive to a new IBM plant, as well as other locational variables considered in the logit model. Using the GIS system, the high probability vacant parcels can be identified within various radii from direct, indirect, and induced business locations in the GR-SAM. Various biophysical and zoning constraints can also define sub-scenarios that would shape development patterns.

To complete the scenario, new residential land use identified in the GIS is translated into land use indices by use class and impervious surfaces in each sub-catchment impacted. The correlation with human disturbance and ecosystem health is then drawn according to estimated statistical relationships. An ecological risk assessment can then be viewed in the full light of its primary determinants, spatial relationships, and its potential for amelioration by economic and land-use policy.

V. CONCLUSION

The complexities involved in economic and watershed systems are enormous. Both are complex evolutionary systems characterized by non-linearities, historical contingencies, and pure uncertainty. The task of analyzing either of these systems alone would be daunting. Economic analysis is particularly hamstrung by a long history of reliance on static equilibrium models that have proved to be of limited value in modeling evolutionary change. The goal of this study, an integrated risk assessment of economy-ecosystem interactions, is even more ambitious than modeling each system separately. However, progress has been made toward that goal. The social accounting approach proved to be flexible enough to capture the major economic drivers of Dutchess county, and was amenable to the scenario approach crucial to this study. Collecting and analyzing land use data was straight-forward and proved to be a reliable way to link economic and ecosystem changes. The index of biological integrity, while still under development, has shown promise in capturing the relationship between land use patterns and the biological health of the streams studied. Most importantly, this study provides a framework upon which to build a transparent model that can illuminate interconnections between economy, society and ecosystems. To emerge from under the tyranny of small decisions will require such tools that envision long-run change, help to shape shared community goals, and encourage dialogue between local and credentialed expertise.

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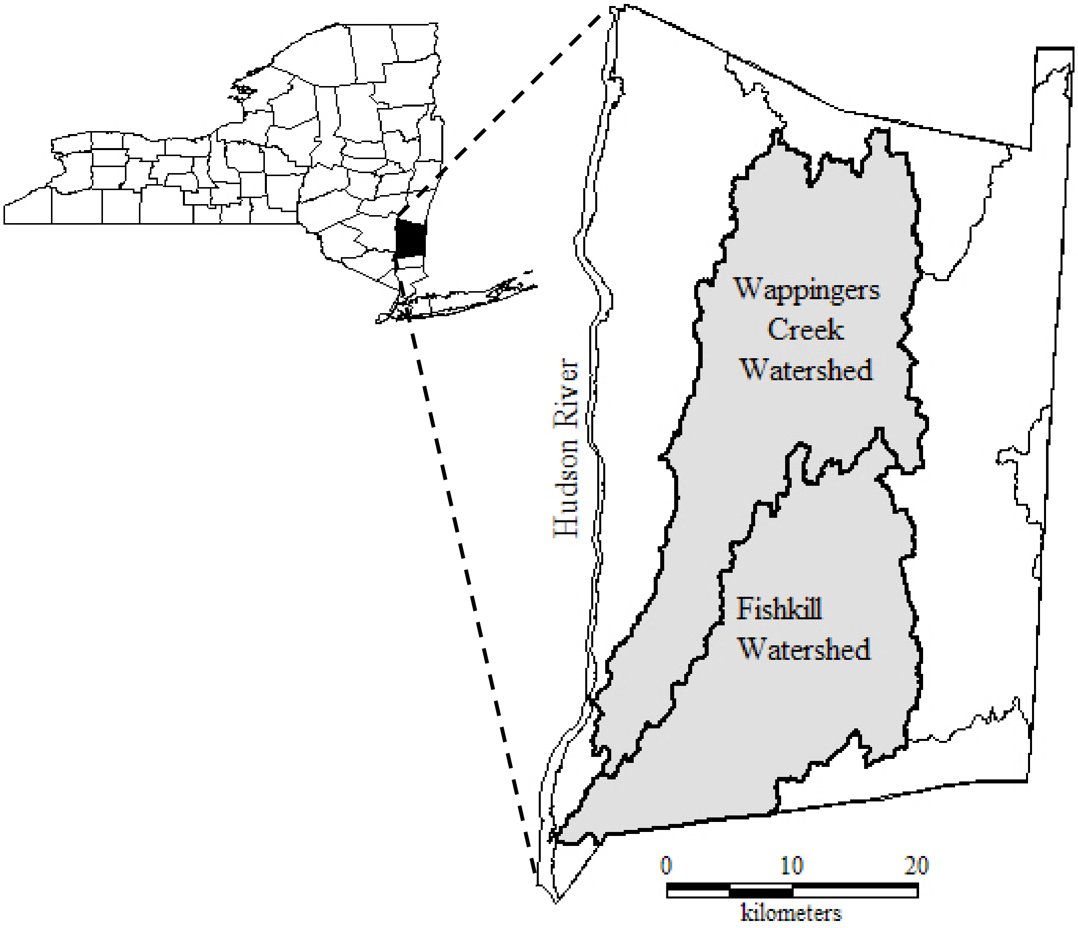

Figure 1. Dutchess County, New York, and its Main Hudson Tributary Watersheds

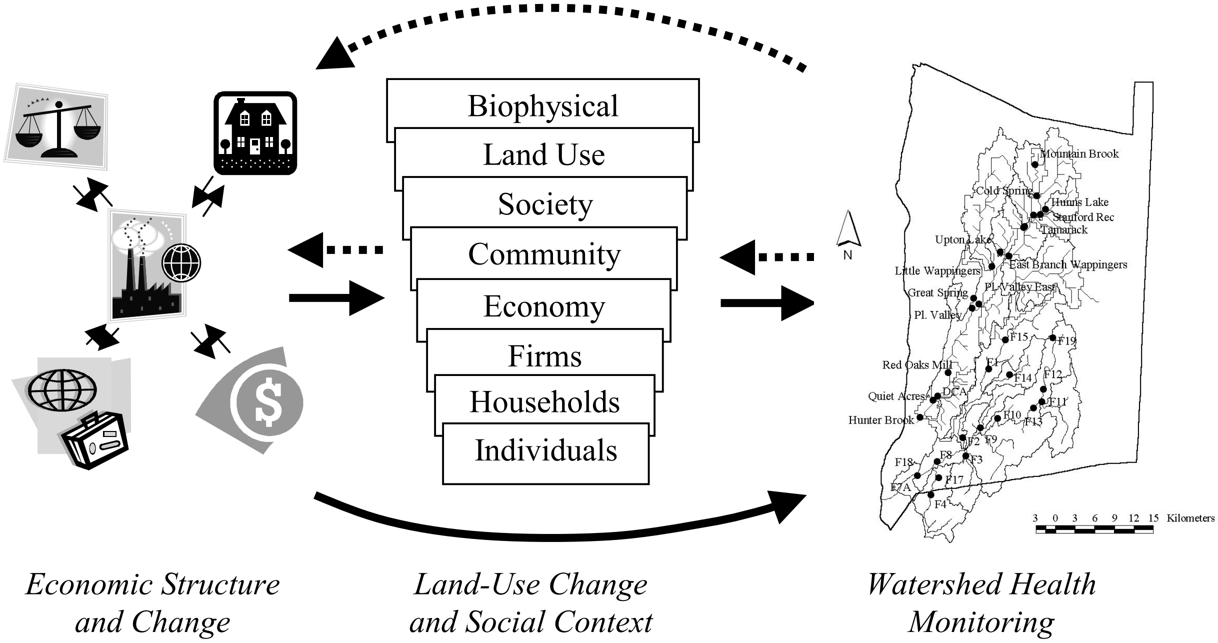

Figure 2. Conceptual Model Components and Linkages

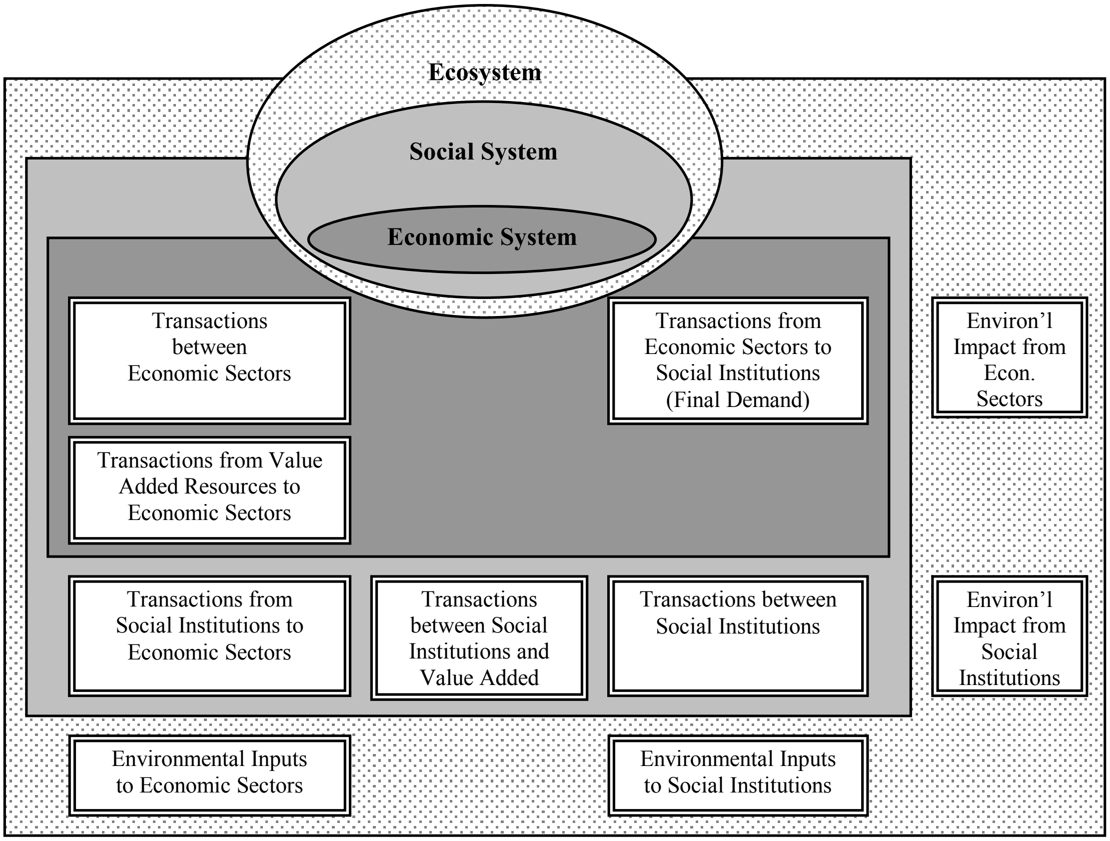

Figure 3. Industry Sector, Social Institution, and Natural Resource System of Accounts.

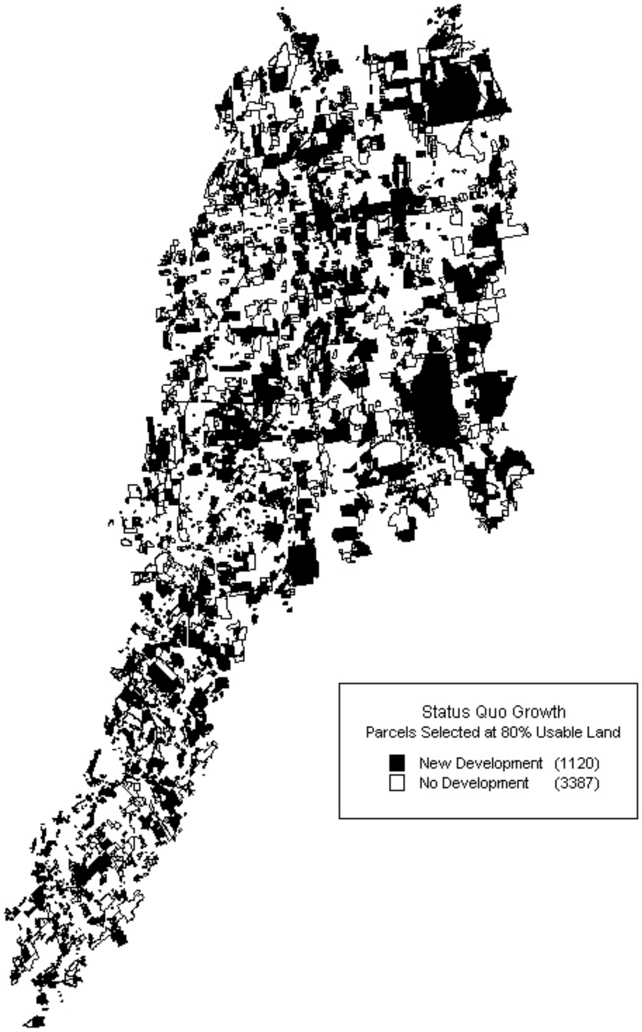

Figure 4. New Residential Land Use in the Wappingers Creek Watershed under Inter-Census Year Trend in Population and Household Income Growth (Polimeni 2002, Fig. 12).

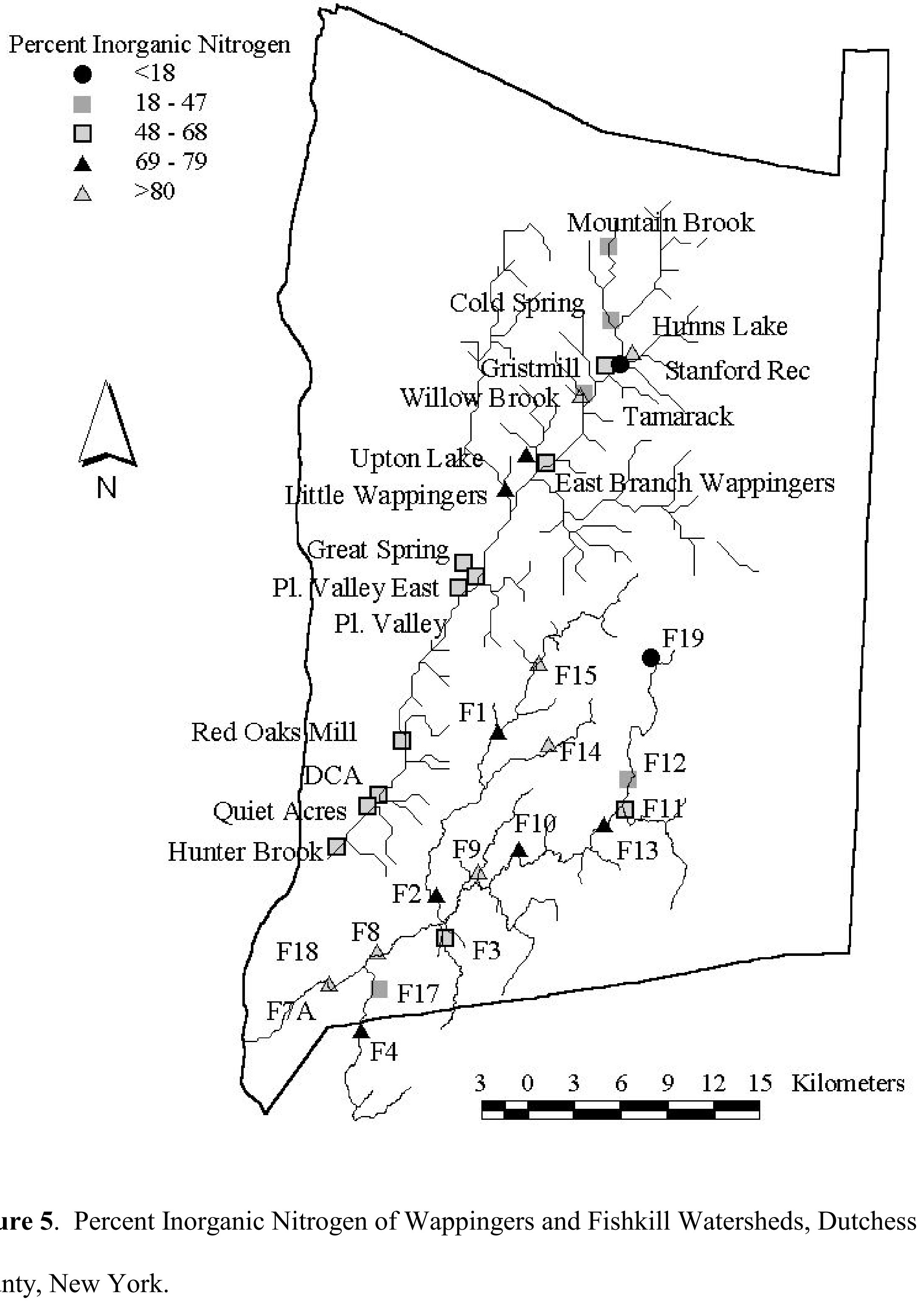

Figure 5. Percent Inorganic Nitrogen of Wappingers and Fishkill Watersheds, Dutchess County, New York.

Table 1. Changes in fish species present in the Fishkill mainstem over time. Current study (2001) compared with NYS Conservation Department (1936) and Schmidt and Kiviat (1986).

Species	**Common name**	**1930s**	**1950s**	**1980s**	**2001**
Anguilla rostrata	American eel			x	x
Esox americanus americanus	redfin pickerel	x	x	x	
Ameirus natalis	yellow bullhead				x
Ictalurus nebulosus	brown bullhead	x	x		x
Catostomus commersoni	white sucker	x	x	x	x
Carassius auratus	goldfish	x			
C. auratus X C. carpio	goldfish-carp hybrid	x			
Cyprinus carpio	carp	x		x	
Erimyzon oblongus	creek chubsucker	x			
Exoglossum maxillingua	cutlips minnow	x	x	x	x
Luxilus cornutus	common shiner	x	x	x	x
Luxilus spilopterus	spotfin shiner			x	x
Notemigonus crysoleucas	golden shiner	x			x
Rhinichthys atratulus	blacknose dace	x	x	x	x
Rhinichthys cataractae	longnose dace	x		x	x
Semotilus atromaculatus	creek chub	x	x	x	x
Semotilus corporalis	fallfish	x		x	
Oncorhynchus mykiss	rainbow trout				
Salmo trutta	brown trout	x	x	x	x
Salvelinus fontinalis	brook trout			x	
Fundulus diaphanus	banded killifish			x	
Ambloplites rupestris	rock bass	x	x	x	x
Lepomis auritus	redbreast sunfish	x		x	x
Lepomis gibbosus	pumpkinseed	x	x	x	
Lepomis macrochirus	bluegill	x		x	x
L. gibbosus X L. auritus	pumpkinseed X redbreast	x			x
Micropterus dolomieui	smallmouth bass	x	x	x	
Micropterus salmoides	largemouth bass	x	x	x	x
Pomoxis nigromaculatus	black crappie	x			
Etheostoma olmstedi	tesselated darter	x	x	x	x
Percina peltata	shield darter	x			
Perca flavescens	yellow perch	x		x	x
Total number of species		**26**	**13**	**22**	**19**

Table 2. Changes in fish species present in Sprout Creek over time. Current study (2001) compared with NYS Conservation Department (1936) and Schmidt and Kiviat (1986).

Species	**Common name**	**1930s**	**1960s**	**1980s**	**2001**
Anguilla rostrata	American eel			x	x
Esox americanus americanus	redfin pickerel	x	x	x	x
Ictalurus nebulosus	brown bullhead	x			
Catostomus commersoni	white sucker	x	x	x	x
Erimyzon oblongus	creek chubsucker	x			
Exoglossum maxillingua	cutlips minnow	x	x	x	x
Luxilus cornutus	common shiner	x	x	x	x
Notemigonus crysoleucas	golden shiner	x			x
Rhinichthys atratulus	blacknose dace	x	x	x	x
Rhinichthys cataractae	longnose dace	x	x	x	x
Semotilus atromaculatus	creek chub	x	x	x	
Semotilus corporalis	fallfish	x	x		x
Oncorhynchus mykiss	rainbow trout				x
Salmo trutta	brown trout	x	x	x	x
Salvelinus fontinalis	brook trout	x			
Micropterus dolomieui	smallmouth bass	x			
Micropterus salmoides	largemouth bass	x	x		
Ambloplites rupestris	rock bass	x	x	x	
Lepomis auritus	redbreast sunfish	x	x	x	x
Lepomis macrochirus	bluegill	x	x	x	
Lepomis gibbosus	pumpkinseed	x	x	x	
Etheostoma olmstedi	tesselated darter	x	x	x	x
Perca flavescens	yellow perch	x			
Cottus cognatus	slimy sculpin	x	x		x
Total number of species		**22**	**16**	**14**	**14**