

Linking CGE with Geographic Information System

Chen, Tze-Wei¹, Chang-Erh Chou² and Kuo-Chuang Chang³

Comment [TW1]:

Abstract

Computable general equilibrium is a power tool for policy analysis. However, its sectoral nature makes it not particularly user-friendly when the question at hand involves the spatial dimension but in the study of resource and environmental economics, policy decision-making often cannot be completed without spatial reference. Geographic information system, other the other hand is a new tool developed specifically to manage the spatial factor. As more GIS applications are developed to accommodate and enhance the traditional analytical and descriptive capacity of many disciplines, the study of Economics has seen little sign of this integration. This study is an attempt to explore the possible linkages between economic analysis and GIS. Through a water resource management planning process, several types of linkages at different stages of economic analysis are established. It is found that GIS cannot only improve the quality of data that CGE requires; it can also create value-added applications to the results of economic analysis⁴.

INTRODUCTION

Computable general equilibrium (CGE) models develop very fast in recent years and have made great impact on policies. Its wide applications range from international trade analysis to carbon tax impact assessment. The strength of a CGE model lies in its ability to analyze policy impacts of different scales and levels. This is of particular importance because while making economic policy decisions, welfare consideration of a particular industrial sector or household group is sometimes equally, if not more, important as the whole economy. CGE model, the most commonly applied multi-sectoral model for policy analysis, can provide detailed information on the policy impact of a certain variable, be it employment or output for instance, on the economy. In addition, CGE is capable of delivering equally detailed information on certain sectors of the economy, food and beverage, for instance. A CGE model normally includes three economic agents: industry, household and government. Under neoclassic

¹ Assistant Professor, National Taiwan Normal University

² Director, Research Division IV, Taiwan Institution of Economic Research

³ Section Chief, Water Resources Bureau

⁴ An earlier version of this paper was presented at the Geoinformatic 2000 conference, June 2000 and the authors thank Professor Mark Horridge for technical assistance in programming.

assumptions, industry maximizes its profits subject to technology constraint; household maximizes its utility subject to budget constraint. Government in a CGE model is treated as the producer of public goods and services who minimizes its cost subject to technology and budget constraints. These agents act accordingly and their behaviors will decide the amount of goods and services produced as well as consumption level. Through the mechanism of price adjustment, the market will eventually reach equilibrium. Given the sectoral nature of CGE, it is sometimes difficult for researchers to draw conclusion on the policy impacts on the regional scale that is not the default of the particular model. To aggregate or disaggregate within a CGE model requires a major restructuring that may require a large amount of additional information. If information of a sub-economy level is required, the original national model will have to be disaggregated by regions for every sector. One possible difficulty here may be the availability of data at the regional level. As this may be not as much a problem in developed nations, it is common obstacle in studying developing countries.

However, in the analysis of resource economics, spatial relations are usually of great interest. Policy makers often require information more than of the sectoral dimension. For instance, a CGE analysis that yields the results of a policy shock by percentage change of water demand of an economy may not be able to meet the needs for policy analysis. Decision makers are also interested in knowing where the impact is most likely to occur, what region(s) of the economy will generate a surplus or shortage of water and if yes, where the contingent reserves are available. None of these questions can be answered by CGE without a rather sophisticated process. Given the circumstance, if there is a tool that can fully utilize the strength of CGE and create value-added to the results, then perhaps the capacity of economic analysis can be advanced to a new stage.

Geographical Information System (GIS) is a set of tools that collects, stores, and manages spatial information. To many people, GIS is simply layers of electronic maps. In fact, its functions extend far beyond that. Display is merely a basic feature. The strength of GIS lies in analyzing spatial data and generating useful information that was not possible before. For instance, police in many cities around the world are utilizing GIS to explore the spatial characteristics of certain crimes. Applications of GIS are becoming an integrated part of many disciplines. Social science in general, except business applications, utilizes last the potential of GIS. Although business applications of GIS have developed so far to the extent that custom-made and packaged software are both already common practices, academic researchers have remained largely unfamiliar with GIS. Economics, being one of the oldest fields of social science, has yet seen the full potential of GIS. There may be different explanations to the lack of collaboration

but an obvious reason is that many economic issues, for instance exchange rate and utility function, are not spatial in nature. Nevertheless, there are areas of economics where spatial relationship is important. This is especially true in the subject of resource economics and GIS has been relatively active in this area. For example, forestry, marine resources and land economics are subjects that researchers use GIS more regularly (Hickey and Jankowski, 1997; Stone, 1998; Walpole and Sinden, 1997; Wu, 2000). Current applications, however, are mostly “one-way” devices whose functions are usually restricted to either displaying the results or, less frequently, visualizing constraints (Bateman, 1996, Geohegan, et al., 1997, Vandever, 1998). Due to the quick development of GIS technology, many analytical functions are now a standard part of many software packages. Analytical it may be, but in most of the cases, GIS functions as an independent process and usually do not provide any feedback to associated economic analysis, if there is any. What is of interest is the possibility of enhancing the decision support function through collaboration of GIS and economic analysis. To explore a new area of GIS application in economic analysis, this study uses a case of water resource management in Taiwan to explore a new mechanism to facilitate an interactive relationship between GIS and CGE. The purpose is to integrate GIS and economic modeling to develop a better decision support system.

That is to say, on one hand, there is a powerful policy analytical tool, CGE, that lacks a very important dimension of the question in concern. On the other, there is a set of analytical tool, GIS, which is developed to explore the spatial characteristics of the world. Given the situation, it is therefore quite sensible to ask the question of if there is any benefits that can be generated by integrating CGE with GIS. This paper will try to explore this question.

Following the introduction, a description of the system framework is presented. A case study is used as an illustration in the third section. The last section are the concluding remarks.

THE SYSTEM

This integrated system is one part of a larger study aiming to model the water resource management of Taiwan (Hong et al, 1999, 2000). As displayed in figure 1, there are three major components of the system: a database, an economic analysis module, and an ArcView – Arc/Info based GIS module.

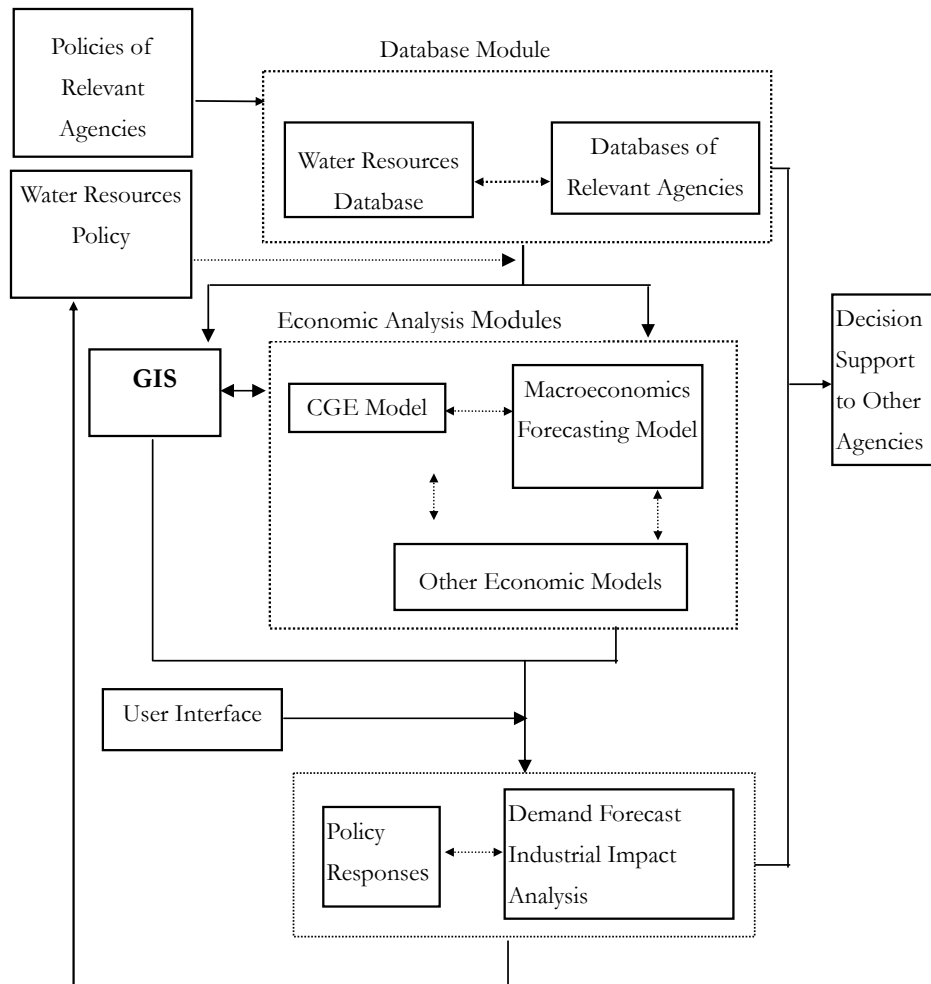


Figure 1. System Framework

The database module is divided into two major parts. The first one is the water resource database that includes major variables used in water resources policy analysis, mostly maintained by the Water Resource Bureau, such as precipitation, river, watershed, dam, land use, soil types, and other socioeconomic information. Most of the digitized maps are stored here. The second part consists of information provided by other agencies. This part of data includes relevant information such as economic indicators, demographics, zoning, industrial parks, location of individual factory, and others. For example, input-output tables compiled by the Directorate-General of Budget, Accounting and Statistics for the CGE module is a major part of it at this stage. Time series data may be added later when econometric models are to be built. In a multiple-use database such as this one, management of information system (MIS) plays a vital role. It is to be decided within the capacity of MIS the flow of information among modules and the actual workflow of the analysis. In this system, it is to be noted that the database by design is to be shared by several modules. It is planned in the way that ArcView and Arc/Info can easily access most data sets. It is also the major source of information for data fusion that comes in the post-economic analysis stage. Since the database module is designed to accommodate a large amount of data and will be used to provide input to other modules, the format of storage becomes an important issue. After assessing the data format required by individual models, the database module is designed to adapt the principle of model-based classification and communication between modules and data exchange is facilitated through temporary conversion of formats.

The economic analysis module includes, at the present stage, a computable general equilibrium (CGE) model. A macroeconomic forecasting model is to be developed in the next phase to complement the CGE model. Other economic models for particular policy questions will also be developed as needed. The major function of the economic analysis module is to simulate and analyze the effects of different water resource management policies such as the use of water rights fee and the impact of Taiwan's WTO accession on the use of water and shocks of various water prices. CGE model is used by this study for its ability to analyze simultaneously the impact of certain policy to the entire economy as well as individual sectors that are of concerns. The economic analysis module is to transfer simulation results to the GIS module for two purposes: visualization and geo-reference. Geo-reference is the process during which spatial information is integrated with sectoral impacts from CGE analysis. Through geo-reference, sectoral impacts can be disaggregated and/or aggregated and registered into individual locations. Details of the conversion process will be discussed in the following sections. Visualization enables decision-makers to visualize the results of

their policies and consequently improve the quality of their decision. As mentioned earlier, location is a major factor in water resources policy, visualization assists not only in obtaining a holistic view of the issues; it also improve the quality of communication among stakeholders. An additional benefit of integrating GIS and CGE is that through the process of data fusion, GIS will capture additional information that is not included in economic models and thus enables analysts to refine the economic analysis module. For instance, GIS is able to deliver water supply information and screens out inferior solutions to improve the quality of CGE scenarios. For instance, GIS can provide information on the total water supply of a certain region and thus prevent researchers from constructing scenarios that are physically impossible.

So, the economic analysis module is to handle the demand side of water resource, and the GIS module is to focus on the supply side. The GIS module consists of one ArcView-based application so far. Its database includes three major types of layers, including ArcView shapefiles and Arc/Info coverages, the basic natural environment, water resources management infrastructure, and economic development information. The basic function of the GIS module, as mentioned earlier, is to visualize the source of water supply. Combined with the demand information produced by the economic analysis modules, it will be able to effectively describe the market situation of water resources as results of different government policies. Water supply is registered by mapping sources, excluding groundwater. The GIS module currently contains information of rivers, reservoirs, and other water bodies. Their capacity is recorded through attribute tables and readily available when needed. In estimating water demand, the total demand is disaggregated into several uses according to the regulations of the Water Conservancy Law. The usages are domestic, agricultural, industrial. It is to be noted that the Water Conservancy Law stipulates that there is a priority of use as stated above in case of insufficient water supply. This is an important constraint to be taken into account when the system calculates the desirable distribution of water. The system has a database of industrial use of water. An ArcView theme is created to identify 3000+ individual factories that makes up 80% of the top 80% water-consuming manufacturing industries. For each factory, a specific type of estimation of water demand is applied to each industry using a mechanism developed by Yu (1999) and Hong et al, (2000). In Yu (1999), water demand of each industry is estimated with weightings of four variables: number of employees, factory lot size, annual total expenditure, and floor area. All four variables are built into the attribute table. A separate column ("field" in ArcView) is then created to accommodate the weighting scheme using an external database through the "Avenue" environment provided by ArcView. Water demand by Hong et al, (2000), on the other hand, is a statistically estimated schedule

from a survey. In both mechanisms, GIS is linked to a database that can be updated as necessary without going through the trouble of rewriting individual cells.

As the system consists of several modules, and some of the modules, such as Arc/info, need to operate under a network environment, a shell is therefore needed to accommodate all modules. It was considered to break the entire system into several smaller ones. However, when taking into consideration the benefit of modules sharing data and results under one environment, it is found that mobility and robustness can be maintained at the same time. Modulization preserves the independence of individual models but the shell links all modules together. Under this architecture, data, analysis and display are three parallel pillars. Maintenance of data and programs can be conducted with each module without interfering operations of others. While through the shell, analysis and display always retrieve updated data and algorithms. This shell also serves as the gateway between system and users. Because the entire system will be installed at the Water Resources Bureau upon completion and no single user will be using all modules, it is important to provide users an easy way to select. The shell is basically an interface with clickable buttons that lead users to the module they need.

For the GIS module, an experimental user interface was developed for testing purpose. The interface is to be built as the major communication between the system and the decision-makers. Aimed to provide the function of an information supporting system, it is emphasized throughout all stages of development that the system should provide maximum accessibility to users. After initial consultation with users, it is decided that the GIS interface will be based on ArcView for the reason that Water Resources Bureau is familiar with it and therefore it requires minimum training. The GIS interface provides most basic functions, including display, edit, query, and data maintenance. Figure 2 is an example of the interface. It is clear that the interface is very similar to the original ArcView layout with localization and a few extra functions. This improves greatly accessibility of users at the Water Resources Bureau.

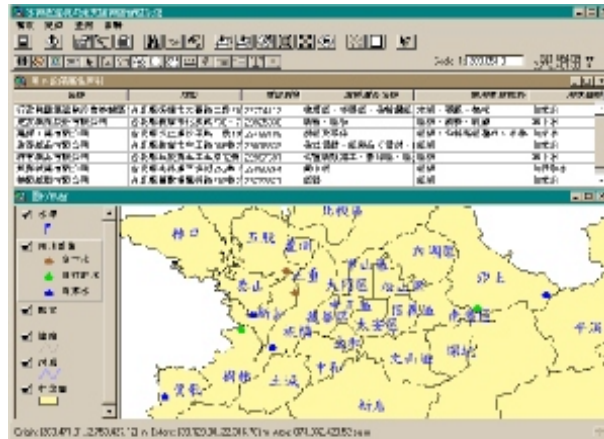


Figure 2. A GIS Application Example

A step further is the linkage between GIS and CGE model. There are two ways of linkage that can be built. A “one way” linkage, which is more traditional, pastes results of the CGE model to the GIS module for geo-referencing and visualization. A more advanced “two-way” linkage allows the GIS to manipulate the results and through data fusion create feedback to the economic model. This study has developed an interface for the “one way” linkage and is exploring the technical issues of the “two way” linkage. The “one way” linkage will be developed to introduce decision makers a set of given natural resources constraints and allow them to change policy parameters and therefore simulate different policy scenarios. GIS in this aspect is mainly for display purpose. Only a limited value-added and almost no automatic feedback will be in full function for now. Data exchange will be achieved through internal commands between models, or better known as “soft-link”. To upgrade to the “two way” linkage, the area of the CGE model that can be improved by GIS must be identified. Currently, preliminary study shows that GIS can help in making assumptions more realistic and therefore improve the practicality of the economic models.

A CASE Study

This study adopts a gradual approach in establishing the system. Two tracks of model

building are being pursued. So far, framework of the system and basic data preparation are completed and a preliminary linkage between CGE and GIS is established (Hong et al, 1999, 2000).

CGE is a powerful tool in analyzing resource policy impact. Although CGE can incorporate spatial factor but the process involves constructing regional data sets. This can sometimes be very time-consuming. Also, in many cases, this is not feasible because no regional sectoral data is available. What the combination of CGE and GIS can do is to provide a new dimension to the traditional economic analysis. This study links GIS and CGE by disaggregating sectoral information from CGE to the individual firm level and thus provide re-aggregated information at any regional level desired.

Take the levy of water rights fee for example, through CGE analysis, it was found that policies have various degrees of impacts on the cost of water from different sources, surface water and groundwater in this case (see table 1). So far all the information generated by the CGE model is sectoral. When the necessity of analyzing regional or sub-regional impacts arises, GIS is put to use.

Table 1. CGE Simulated Policy Impacts on Selected Sectors (%)

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
Sector	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Rice	2.72	-8.62	2.67	-8.67	3.02	-8.35	2.90	-8.46	2.96	-8.41
Forestry	2.61	-0.41	1.72	-1.27	1.33	-1.65	1.24	-1.74	1.29	-1.69
Food and Beverage	5.45	-5.23	5.41	-5.27	5.75	-4.96	5.65	-5.06	5.70	-5.01
Paper Products	11.10	-5.32	11.02	-5.38	11.22	-5.21	11.05	-5.36	11.14	-5.29
Chemical Products	4.05	-6.49	3.98	-6.55	4.13	-6.42	3.94	-6.59	4.03	-6.50
Metal Products	1.74	-13.61	1.71	-13.64	1.77	-13.58	1.58	-13.75	1.67	-13.66
Machinery	-0.49	-6.31	0.06	-5.80	-0.41	-6.24	-0.70	-6.51	-0.56	-6.38
Electronics	0.07	-5.18	0.02	-5.22	0.08	-5.17	-0.06	-5.30	0.01	-5.23
Transportation	2.87	-7.62	3.03	-7.47	3.17	-7.35	2.96	-7.54	3.07	-7.44
Construction	6.53	-4.12	6.80	-3.88	7.23	-3.50	6.71	-3.96	6.97	-3.73

*SW: Surface Water

*GW: Ground water

Source: Hong, David S. et al, 1999, 2000

It is clear from the table that one of the most significant impacts occurs in the surface water use by the paper products sector. Given the spatial characteristics of water resources, decision-makers will have to know the location of the industry for follow-up policies. However, a CGE model does not provide this information. By utilizing GIS, this study establishes a complementary relationship between GIS and CGE to form policy support.

Up to this stage, the basic policy support function begins to work. It is then almost-standard GIS procedure of various queries. Policy makers can now easily obtain information at all regional level on water demand. The changes can also be visualized for reference (figure 3).

Figure 3. Visualization of Policy Scenarios

A step further is the complete market information on supply and demand. Because information on water supply is already recorded, GIS can simply put all information together and through simple operations, such as a macro, calculates the difference between supply and demand of water both before and after policy changes.

The application of GIS goes on. It can provide very useful information for policy recommendations. For instance, if the results show that there is a 1,000 tones shortage of water in a certain area per day, relevant agencies will have to decide where to find additional supply. Suppose there are three options available, through assigning a weighting mechanism to attributes of concern, GIS can produce clear analysis on the relative feasibility of each option. This is where the value-added of economic analysis occurs.

The feedback from GIS module to economic analysis module can be found here. As GIS produces information of the market, further economic analysis can be performed. Using the same example, suppose the results of GIS analysis shows that the cheapest way for the government to fill up the gap is to transfer water from a nearby irrigation association, then follow-up economic analysis can be done to assess the impact of such a transfer. Even another round of CGE can be conducted using new sets of variables. This may very well develop into a very complete system of policy evaluation.

CONCLUDING REMARKS

This study argues that GIS can be integrated with CGE in three ways: data preparation, value-added to results and result enhancement through data fusion. In the stage of data preparation, there are several aspects in which GIS can help. First, physical constrains such as a river too small to carry enough amount of water to support a wildlife refugee, which are usually of vital importance but not presented in economic analysis, can be identified. This enables researchers to have a better understanding of the study and shortens the gap between theory and reality. Second, GIS can reduce the dependence on hypotheses by providing researchers with detail information of the study area. For instance, it is common for researchers in an economic analysis model to assume equal rainfall for a large area due to lack of data. With GIS, information can be linked between precipitation monitoring stations and other layers to eliminate the above hypothesis and improve the quality of the analysis. Third, GIS can pre-screen inferior

solutions by simple steps and provide information of better scenarios for the economic model.

The value-added function of GIS to an economic analysis is realized in the visualization of the results and collaboration with other models through graphic interfaces. Visualization provides an easier access to information for decision-makers and enhances the value of economic analysis. Graphic interfaces facilitate an avenue to link economic analysis with other science. Also, the spatial characteristics of GIS also add values to economic analysis. As explained earlier, through simple operations, GIS is able to add to the sectoral analysis provided by the CGE model spatial attributes and create extremely useful information to decision makers.

Data fusion is another new addition to the traditional wisdom of economic analysis. The function of data fusion is to explore the possible correlation among a large amount of data and variables. Researchers in other disciplines have found important new discoveries from seemingly unrelated variables. In this study, the results obtained from data fusion are expected to provide new information on the demand and supply of water and be used as feedback to the economic analysis. Interdisciplinary research is the trend of the future. A joint effort of economic analysis and GIS is a good test to see how the oldest field of social science can adapt to the new world of technology.

Another side of data fusion is the compatibility of data. As mentioned earlier, the system takes data from various sources, including databases maintained by the Water Resources Bureau and other agencies. It is therefore no surprise that different formats of data are found. This is another evidence of the importance of metadata. It is only through metadata is it possible to sort out all information and find a direction for the system.

To provide better policy support, this study is exploring the possibility of a virtual reality 3D flythrough mode. This function is thought to have several benefits. First of all, three dimensional visualization itself is a good way to improve decision makers' understanding of the problem. Also, this function can save time and manpower. For example, in the recent case of a major earthquake in Taiwan, the 3D flythrough mode can be used in meetings held in various agencies and save the time and efforts of repetitive field trips. Decision makers can therefore work on the same platform and improve coordination.

Although a fairly new idea in the discipline of economics, this study sees a great

potential in the collaboration between GIS and economics. It is very possible that the integration will bring about positive changes to both as more studies are done in the future. Many economic analysis lacks the spatial dimension when dealing with spatially related issues such as natural resources. That in turn limits the development of economics. GIS, on the other hand, is a tool in essence, without collaboration with other disciplines, it will not be able to reach its full potential. As this study has shown, there are actually many areas and levels where GIS and economics and cooperate to form a mutually beneficial alliance. What is perhaps most important for now is the communication between economists and those who possess GIS knowledge, to improve the understanding of both sides on each other. This is probably true for all inter-disciplinary studies.

REFERENCE

Bateman, Ian J. 1996, Measurement Issues in the Travel Cost Method: A Geographical Information System Approach, *Journal of Agricultural Economics*, 47(2): 191-205.

Geohegan, J.; Wainger, L.A.; Bockstael, N.E. 1997, Spatial landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS, *Ecological Economics*, 23(3), 251-264.

Hickey, R. and Jankowski, P. 1997, GIS and Environmental Decisionmaking to Aid Smelter Reclamation Planning, *Environment and Planning A*: 29(1), 5-19.

Hill, Michael J., Aspinall, Richard L. (eds.), 2000, *Spatial Information for Land Use Management*, Gordon and Breach Science Publishers.

Hong, David S., Huang, C.H., Li, P.T., Hsu, S.H., Chou, C.E., and Chen, T.W., 1999, *Water Resources Economic Modelling and its Policy Supporting System, Phase I Research Project Report*, Taiwan Institute of Economic Research, commissioned by Water Resources Bureau (In Chinese)

Hong, David S., Huang, C.H., Li, P.T., Hsu, S.H., Chou, C.E., and Chen, T.W., 2000, *Water Resources Economic Modelling and its Policy Supporting System, Phase II Research Project Report*, Taiwan Institute of Economic Research, commissioned by Water Resources Bureau (In Chinese)

Hsu, Shiang-Kueen and Hong, David S., 2000, *Water Resource Economic Modelling and Decision Supporting System*, Proceedings of the 2000 Water Resources Management Seminar, January, 2000, Taipei: 561-572. (In Chinese)

MacFarlane, Robert. 1998, Implementing Agri-environment Policy: A Landscape Ecology Perspective, *Journal of Environmental Planning and Management*, 41(5): 575-596.

Mark, David M. (eds.), 1999, *Geographic Information Science: Critical Issues in an Emerging Cross-Disciplinary research Domain*, A National Science Foundation Workshop Report.

Masser, Ian (eds.), 1998, *Governments and Geographic Information*, London: Bristol: Taylor & Francis.

Pickles, John (eds.), 1995, *Ground Truth, the Social Implication of Geographic Information System*, New York: The Guilford Press.

Richards, Paul L., Brenner, Andrew J., Barlage, Mike, and Sousounis, Peter, 1999, The Impact of Land Use and Climate Change on Water Quality and Quantity for Two Watersheds in Southeastern Michigan, in Li, B., et al., (eds.), *Geoinformatics and Socioinformatics*, the Proceedings of Geoinformatics '99 Conference, 1-8.

Stone, Steve, 1998, Using a Geographical Information System for Applied Policy Analysis: The Case of Logging in the Eastern Amazon, *Ecological Economics*, 27(1): 43-61.

Vandeeveer, Lonnie. 1998, Geographical Information System Procedures for Conducting Rural Land Market Research, *Review of Agricultural Economics*, 20(2): 448-461.

Walpole, S.C.; Sinden, J.A. 1997, BCA and GIS: Integration of Economic and Environmental Indicators to Aid Land Management Decisions, *Ecological Economics*, 1997, 23(1): 45-57.

Wu, Junjie, 2000, Slippage Effects of the Conservation Reserve Program, *American Journal of Agricultural Economics*, 82(4): 979-992.

Yu, Gwo-Shing. 1999, *A Study on the Rational Limit of Multi-purpose Water Use*, Water Resources Bureau Research Report (in Chinese)