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SOCIO-ECONOMIC SIMULATION FOR WATER RESOURCE SYSTEM PLANNING

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"Decide not rashly. The Decision made
Can never be recalled. The gods implore not,
Plead not, solicit not; they only offer
Choice and occasion, which once being passed
Return no more. Dost thou accept the gift?"

Henry Wadsworth Longfellow

INTRODUCTION

Application of simulation techniques to water resource policy planning and decision-making is of comparatively recent origin. The pioneering work in this direction was started by the Harvard Water Program in the late 1950's, and the now famous Harvard "Blue Book", Design of Water-Resource Systems,[1] was an output of that program. The program attempted to integrate economic, engineering and governmental planning in designing multi-purpose, multi-unit water resource systems. The group made the first computer simulation of a simplified river basin and also developed mathematical models for programming river systems. Since then, considerable progress has been made in the application of simulation techniques to water resource policy planning and decision-making. The purpose of this paper is to examine briefly the current status of socio-economic simulation in water resource planning.

SIMULATION OF SOCIO-ECONOMIC SUBSYSTEM

Even though the concept of systems analysis has been used in water resource planning and development for more than 50 years, the term itself has been applied to the field only recently. The two broad classes of subsystems in water resource planning, are physical-technologic and socio-economic. A subsystem may be defined as a "set of functionally related elements which can feasibly be analyzed as an entity, and which

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[1] Maass, A., Hufschmidt, M.M., Dorfman, R., Thomas, H.A., Marglin, S.A., & Fair, G.M., "Design of Water-Resource Systems, " Harvard University Press, Cambridge, 620 pp., 1962.

can be tied effectively to a larger system by means of well-defined links."[2] The ultimate aim is to link the various subsystems to form one grand system, at least conceptually, in which case it may be possible to trace the effect of a perturbation in any one subsystem on the over-all grand system. But before such a grand system can be formulated, we would have to have detailed knowledge of the workings of each subsystem (thus, the relevant functional relationships) and the nature of linkages between the various subsystems. We also should have enough data on system parameters and variables, larger computer capacity, and better methods of evaluation of policy impacts in disparate regions of the country as well as on distinct socio-economic groups. Regional Science Research Institute of Philadelphia, for example, is now attempting to create such a major simulation model by linking the Delaware River simulation model and the Delaware River estuary model with the input-output model for the Philadelphia Metropolitan region.

During the last decade or so, the progress in the simulation of physical-technological and economic aspects of water resources planning has been considerable, but sociological models have not been all that prominent. There is no doubt that sociologists are keenly interested in models: for example, Rex states that the "important question for the sociologist is not whether he should interpret observed human behaviour in terms of models, but what sort of model he should apply."[3] There are some fundamental and important questions which the sociologists can help us to solve in terms of conceptual models, i.e., "Why are some societies different from others in the way they utilize their resources and distribute themselves in space, and, further, given a particular account of activities in relation to certain resources, what leads to change?"[4] Thus, one may legitimately ask why the sociologists have not been exactly involved in the water resource planning field - especially when it is considered that there are many fascinating issues and questions that have to be answered. It is difficult to answer. One reason may be that sociology is comparatively a recent science, and water resources planners have only recently begun to realize that sociologists can make significant contributions to the planning process. It could be due to the planners' strong attachment as well as dependence to quantification. Also, sociology is a theoretical subject, and there seems to exist a relative neglect of applied research in the area of water resources by sociologists. For example, Resources for the Future (RFF), during the early parts of its life, did contact some leading sociologists about the possible contributions they could make to water resource research. RFF, however, found out that the type of research

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[2] Hufschmidt, M.M., "Water Resources Systems Analysis", Publication No. 138, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, 1966.

[3] Rex, J., "Key Problems in Sociological Theory", Routledge & Kegan Paul, London, 1961, p.60.

[4] Pahl, R.E., "Sociological Models in Geography", in "Models in Geography", Eds. Chorley, R.J., & Haggett, P., Methuen & Co. Ltd., London, 1967, p. 222.

sociologists were interested in did not blend with the type of natural resource problems RFF was investigating at that time. Consequently, RFF concentrated mainly on economic research, and very little work was done on the sociological aspects of these problems. Whatever may be the reason for this comparative absence of sociological inputs to water resource planning and research, one should not underestimate the potential sizeable contribution the sociologists can make to this field.

ECONOMIC SIMULATION

An economic model may be defined as "an organized set of relationships that describe the functioning of an economic entity ..... under a set of simplifying assumptions."[5] By selecting the significant variables in a given economy, and analyzing the interaction between them, it is possible at present to develop economic models which are "of great value in interpreting, if not predicting, economic behaviour in the real world."[6] Model-building of this kind depends upon the special scope of the investigation, which, in turn, is most influenced by the policy purposes the model-builder has in mind. The state of the art in building, testing and integrating economic models to overall design of water resource system has considerably improved since the pioneering work of the Harvard Water Group in the late 1950's - so much so that there is no excuse at present in not using these models in complex water resource policy planning and decision-making.

Economic models can be broadly divided into three categories: supra-national (continents or even the whole world), national, and sub-national or regional. Most economists generally tend to agree that "in analyzing economic growth and structure ..... national states are the natural units of comparison."[7] In United States, for example, a major portion of quantitative economic research has been at the national macro-economic scale. This is not surprising as "state units generally exhibit not only a high level of internal economic homogeneity but also a low degree of openness, in that they are surrounded by considerable barriers to the free flow of commodities - labour, capital, goods, ideas - vital to the process of economic growth."[8] Also, until recently, most U.S. Government data, like gross national product, total consumption, total investment, etc., which constitute the major source for national economic research, had not been disaggregated below the national level. Furthermore, national policy formulations in many fields, such as, unemployment, inflation, economic

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[5] Department of Economic and Social Affairs, United Nations, "Use of Models in Programming," Industrialization and Productivity, 1961, Vol.4, pp. 7-17.

[6] McNee, R.B., "The Changing Relationships of Economics and Economic Geography," Economic Geography, Vol. 35, No. 3, 1959, p. 191.

[7] Goldsmith, R.W., "The Comparative Study of Economic Growth and Structure," Pt. 1, 1959, National Bureau of Economic Research, New York, p. 23.

[8] Keeble, D.E., "Models of Economic Development," in "Models in Geography," Eds. Chorley, R.J., & Haggett, P., Methuen & Co. Ltd., London, 1967, p. 247.

stability, etc., need macroeconomic model building and macroeconomic forecasting for evaluation of policy impacts.

Probably the largest econometric model built so far is the Brookings-SSRC model with over 400 original equations. The model, sponsored by the Brookings Institution and the Social Science Research Council, is designed to "explain the variations in GNP and its major components, as well as major price movements, employment, and wage rates."[9] More than 20 experts on various sectors of the economy have participated in the construction of the model.

The alternative to the large scale macroeconomic simulation of national economic system is the microunit approach. The microanalytical models would generally give policy planners and decision-makers better knowledge about the responses of dependent variables of an economic system to different policy measures. Thus, the decision-makers will have a better prediction about the actual behaviour of the economy, which, in turn, will help in better policy formulation. In contrast, the macro approaches tend to give mean behavioural pattern. An example of the microanalytical model is the Orcutt model, which assumes that "predictions about aggregates should be obtained by aggregating the behaviour of elemental units rather than by attempting to aggregate behavioural relationships of these elemental units."[10] The major problem with microanalytical model building is the unavailability of data in disaggregated form.

Since the publication of the Harvard "Blue Book,"[1] regional income redistribution has been accepted as a legitimate output of water resource planning, and hence, national-scale regional income inequality models are of considerable interest to water resource planners. Probably the most important one of this type is the conceptual model of Myrdal [11,12] suggested in the late 1950's. He contends that in a free economy, changes in spatial variation in levels of development within a country do not "call forth countervailing changes but, instead, supporting changes, which move the system in the same direction as the first change but much further."[13] Myrdal concludes, applying this "cumulative causation" concept, that "the play of the forces in the market normally tends to increase, rather than decrease, the inequalities between regions."[14] However, it has to be remembered that the Myrdal model was implicitly framed for countries having a low level of economic development, and a basic assumption was government non-intervention in the development process. But, he does point out that in advanced economies, governments are more concerned with regional disparities, and as such government policies are aimed at stimulating growth

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[9] Duesenberry, J.S., & Klein, L.R., "The Brookings Quarterly Econometric Model of the United States", North-Holland Publishing Co. Ltd., Amsterdam, 1965, p.3.

[10] Orcutt, G.H., Greenberger, M., Korbel, J., & Rirelin, A., "Microanalysis of Socioeconomic Systems: A Simulation Study," Harper & Brothers, New York, 1961.

[11] Myrdal, G., "Development and Underdevelopment," Cairo, 1956.

[12] Myrdal, G., "Economic Theory and Under-Developed Regions," Gerald Duckworth, London, 1957.

[13] Ibid., p. 13.

[14] Ibid., p. 26.

in economically backward regions. This effect can, however, be considered as another aspect of cumulative causation in development.

Some of the other types of regional income inequality models have been suggested by Hirschman,[15] Hicks,[16] and Ullman[17].

Table 1 shows the details of some of the major national and regional models

REGIONAL MODELS

Regional economic growth models provide a better structural understanding of the complex processes of economic and behavioural interactions of a system, as well as regional forecasts or projections, and these, in turn, provide guidelines for better policy planning and decision-making. The various regional models that would be briefly discussed herein are problem-oriented models.

In the water resource field, three such models are Lehigh, Ohio and Susquehanna basin models. The Lehigh model emphasizes the hydrological aspects of the river basin and assumes the regional economy as given.[1, 18] Even though the model can be extended to deal with any type of water demand, in its original version it studies only four types of demand functions - water supply, hydro power, flood control and irrigation. Milliman has criticized the model because of its emphasis on engineering and water management and not upon regional growth and development:

> "Regional economic analysis and large-scale river basin planning should take into account the effects of the economy upon the water and also the possible feedbacks from the water sector back upon the economy. In this view, it would be incorrect to plunge into river basin planning by designing optimal management systems for the water variables without first having a general regional economic model of the basin which includes a water sector. From this standpoint, models of the Lehigh basin type should follow not precede the more general approach."[19]

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[15] Hirschman, A.D., "The Strategy for Economic Development", Yale University Press, New Haven, 1958.

[16] Hicks, J.R., "Essays in World Economics", University Press, Oxford, 1959.

[17] Ullman, E.L., "Regional Development and the Geography of Concentration", Papers, Regional Science Association, Vol. 4, 1958, pp. 179-198.

[18] Hufschmidt, M.M. & Fiering, M.B., "Simulation Techniques for Design of Water-Resource Systems", Harvard University Press, Cambridge, 1966.

[19] Milliman, J.W., "Large-Scale Models for Forecasting Regional Economic Activity: A Survey, "School of Business, Indiana University, Bloomington, 1968, p. 41.

TABLE 1 - SOME NATIONAL AND REGIONAL SOCIO-ECONOMIC MODELS

Model	Major Process Considered	Principal Investigator(s) and Institution(s)	Date Initiated
NATIONAL MODELS			
Brookings-SSRC	U.S. National Economy	J. Duesenberry - Harvard U. G. Fromm - Brookings I. L. Klein - Pennsylvania U. K. Kuh - M.I.T.	1961
Econometric Model of the U.S. Economy	U.S. Economy	D. Suits - Michigan U.	1953
Microanalytical Model of Socio-economic System	Microanalysis of Economy	G. Orcutt - Wisconsin U.	1960
Regional Income Inequality Model	Spatial Variation in Economic Prosperity	G. Myrdal - Sweden	1956
Transportation Evaluation Model	Alternative Transportation Investment	J. Meyer - Harvard U. D. Kresge - Harvard U. B.V. Martin - Harvard U. C. Warden - Harvard U.	1962
REGIONAL MODELS			
Lehigh Model	Streamflow	M.M. Hufschmidt - N. Carolina U. M.B. Fiering - Harvard U.	1961
Ohio Basin	Regional Development	P. Stern - Arthur D. Little Inc.	1962
Susquehanna Basin	Demographic & Economic Sectors	H.R. Hamilton - Battelle Memorial Institute	1962
Dynamic Economic Evaluation of Programs (DEEP)	U.S. Regional Economy after Nuclear Exchange	M.K. Wood - National Planning Association	1964
Multiregional Interindustry Model	Interregional Study of U.S. Industry	W. Leontief - Harvard U.	1962

The Ohio model [20] forecasts the level of industrial activity within a vast area of 163,000 square miles in order to estimate total water requirements for the 50-year period of 1960 to 2010. It does not contain a water sector and assumes that sufficient water of desired quality and quantity would always be available to sustain the projected economic development.

The Susquehanna model[21] is a sophisticated one which attempts to tie demographic and economic sectors together. It is a simulation model of the "industrial dynamics" type,[22] which projects demands for water quantities and qualities - along with economic projections - on a 50-year time base. Thus, it successfully combines water and economic sectors.

There are other problem-oriented models which should be of considerable interest to water resource planners from a technical point of view. The Pittsburg Urban Simulation model simulates the entire metropolitan area - including industrial growth and movement, residential and commercial movements, labour flows and land uses. The Activities Allocation Model, which started as the Penn Jersey Transportation study, uses seven sub-models - residential location model, residential space consumption model, manufacturing location model, manufacturing space consumption model, nonmanufacturing location model, nonmanufacturing space consumption model, and street area model - to examine the relationships between economic growth and availability of new transportation services. The Leontief Multi-Regional model analyzes the impact of a cut in armament production on the industrial composition and the regional distribution of employment. The Dynamic Evaluation of Economic Programs (DEEP) Model evaluates, on a regional basis, the economic consequences of different levels of war damages on the U.S.

WEAKNESSES OF SOCIO-ECONOMIC MODELS

The weaknesses of socio-economic models are many, but some of the major ones are enumerated below.

1. Limitation in computer capacity for use of linear and quasi-linear programming models.

2. Strong dependence on quantification that is frequently inadequate.

3. Lack of well-defined goals and precise criteria.

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[20] Arthur D. Little, Inc., "Projective Economic Study of the Ohio River Basin", U.S. Government Printing Office, Washington, D.C., 1964.

[21] Hamilton, H.R., Goldstone, S.E., Milliman, J.W., Pugh, A.L., Roberts, E.B., & Zellner, A., "Systems Simulation for Regional Analysis: An Application to River Basin Planning", M.I.T. Press, Cambridge, 1968.

[22] Forrester, J.W., "Industrial Dynamics", M.I.T. Press, Cambridge, 1961.

4. Unclear definition of relevant functional relationships.

5. Lack of adequate data on system parameters and variables.

6. Incapacity to deal with conflicting non-commensurate values.

7. Inability to deal with large and complex systems other than through sub-optimizations.

8. Inability to incorporate the problems of political feasibility.

9. Inability to account for individual motivations, irrationality and human idiosyncrasy.

CONCLUSION

Efficient allocation of limited national resources amongst a variety of competing government programs can only be achieved by the measurement of their relative cost-effectiveness, and this can be done by the evaluation of social, political and economic effects on human beings. Until and unless national and sub-national socio-economic models are available (and hence the macro and micro data on which the models are to be based), it would be difficult for policy planners and decision-makers to make systematic evaluation of alternative public policy programs on disparate regions as well as distinct socio-economic groups.

The state of the art in socio-economic modelling has advanced sufficiently to be useful in water resource policy planning and decision-making. Admittedly, some of the current models in this field are fairly crude, and depend - to a great extent - on the judgement of the analyst, but still the issue is very definitely on the side of having a model, even a crude one, against having no model at all. Modelling also gives the analyst a better insight into the various interactions within the complex processes, and will point out, in no uncertain manner, the significant gaps in our knowledge of, and the methods for dealing with the socio-economic phenomena associated with water resource system design. Furthermore, "if an econometric model is nothing else, it is a highly sophisticated method of observing the past operation of the economy and systematizing the information obtained."[23]

Finally, up to now, the ecologic system in general has not been included in the general conceptual framework of a multi-regional social system. If water resource policy planning and decision-making has to be more effective, a comprehensive system would have to be developed which will incorporate the existing and potential interdependence of a multi-region socio-ecologic system that would allow more satisfactory sets of policy alternatives to be posed and evaluated. These discussions, because of space limitations, must remain the subject of another paper.

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[23] Suits, D., "Forecasting & Analysis with an Econometric Model", American Economic Review, Vol. 52, March 1962, p. 131.