

**DYNAMIC MODELLING STUDIES OF WATER RESOURCES  
SYSTEM FOR REGIONAL DEVELOPMENT APPLICATIONS :  
THE CASE OF PUNJAB REGION OF INDIA**

By  
**GAYATRI AGNIHOTRI**

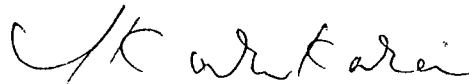
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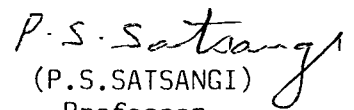
CERTIFICATE

Certified that the thesis entitled, "DYNAMIC MODELLING STUDIES OF WATER RESOURCES SYSTEM FOR REGIONAL DEVELOPMENT APPLICATIONS: THE CASE OF PUNJAB REGION OF INDIA", which is being submitted by Ms. GAYATRI AGNIHOTRI for the award of the degree of Doctor of Philosophy in the Centre for Systems and Management Studies of Indian Institute of Technology, Delhi, is a record of the student's own work carried out by her under our supervision and guidance.

The matter embodied in this thesis has not been submitted for the award of any other degree.



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## ABSTRACT

In India water resources studies have been carried out independently basinwise mainly for purposes of qualitative analysis, assessment of utilisable potential of water resources and further feasibility of development, and for deciding upon flood control measures. The development of water resources depends on and affects economic development in a region. It is thus necessary to review the nature and dimension of economic development together with water resources development.

We recognize that the water resources system affects the way in which the socio-economic activity system grows and changes, while the changes in socio-economic system in turn call forth changes in the water resources system. This two way interdependence is fundamental to the systems viewpoint in this research, where water resources system has been regarded as a subsystem (sector) of the comprehensive activity system.

No integrated comprehensive socio-technical systems study of regional water resources development seems to have been attempted thus far particularly in view of the inadequate information data-base for the purpose. For implementation of a national/regional water-energy-economic system model we require among other data, estimates of utilisable potential of water resources, population growth, economic activity levels and related intensities of water use rates in various sectors and regions of the country.

There has long been a need for developing a general theoretical framework for socio-technical systems research which imbeds dynamical, structural, and spatial aspects in system models, and emphasizes descriptive behavioural modelling with predictive powers. The regional economy is identified here as a collection of interconnected components and the approach taken is that of a

system theory construct. Each economic component is modelled in terms of two fundamental complementary variables, a through variable  $Y$  - the flow of "commodities" valued in constant monetary terms, and an across variable  $X$  - the unit cost/price index.

Certain basic concepts and postulates of the linear graph theoretic physical systems construct, when suitably generalized, do encompass a variety of socio-economic systems. In the present research an effort is made for their appropriate further generalization and extension to dynamic modelling of water resources system at both mini and macro levels of application. For instance, on one hand, the Graph-Theoretic Field Modelling has been suitably adapted and applied with special emphasis on multi-terminal representations to a micro level bench mark problem with known solution for relevant comparison with other well established methods such as the Finite Element Method. On the other hand, the physical system theory has been applied at the macro-level to a large and complex regional water-energy-economic system for dynamic model and analysis of regional development in the context of the Punjab region of India.

The most common form of dynamic models encountered in the modern system and control theory is the state-space form. Because of its mathematical and computational tractability, it forms the basis for analysis, simulation, synthesis, control and optimization concepts and procedures. The extensive literature available in these areas, developed by mathematicians and engineers can be applied directly to socio-economic systems when they are modelled in this form.

The socio-economic system is considered here as a multi-dimensional system having temporal, sectoral and regional dimensions. Although monetary value is a prevalent measure of economic value, it is an inadequate metric

for evaluating social-cost benefits. Therefore, it needs a coordinated analysis of the trade-off between the mass-energy and the economic (mass-monetary cost) characteristics of the human life support system particularly at the regional level as attempted in the context of Punjab in this thesis.

The aggregated water-energy-economic system is viewed as consisting of several interdependent subsystems (sectors). Each sector is treated as a material energy transformation process and its "free-body" model is developed considering it in isolation. A system model which represents in an aggregate sense, both component terminal characteristics (free-body models) and their interconnections or systemic structure, is formulated by combining component terminal equations with interconnection constraint equations in a regularized manner amenable to computer automation.

The regional water-energy-economic system model so developed has been demonstrated to be viable for real world application through validation of the results generated by the identified model in the context of the water-energy-economic system of Punjab. Scenario constructions based on the dynamic macro-model provide an opportunity for using simulation results for analysis and policy studies of future choices.

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