MANAGEMENT AND DEVELOPMENT OF WATER SYSTEMS

Columbia University, Spring 2002

SEAS (EAEE, CEEM) and SIPA (U6252)
with the collaboration of the IRI-CP

Instructor Team (an asterisk indicates a coordinator)

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Format Two sessions per week (3 units). Mix of formal lectures, group presentations, and invited talks.

Grading Presentations (20%), Written Reports (30%), Participation (10%), Quizzes (25%), Homework (15%).

Prerequisites the student will need prior background in at least one of the following areas, or instructor's consent: hydrology, quantitative geography, urban or rural planning, economics, applied statistics, and operations research.

Background Water is an essential resource, important for ecology, human consumption, mineral processing and distribution, agriculture, and energy. The regional demand and supply of water vary in response to an array of factors including climate, price, market structure, poverty, social values, and prevalent industry and technology. In addition to the provision of water of adequate quality, integrated river basin management needs to consider environmental objectives and regulations, flood hazard mitigation, land use planning, and growth, as well as social considerations such as poverty, human rights and environmental justice. Hence, water issues have a high profile in international relations, and even in conflict resolution. Consequently, a variety of technical (both physical and economic) and policy mechanisms have evolved for managing and developing water resources to attain multiple, competing objectives. Technically, water systems possess a complex physical and institutional infrastructure. Understanding how this infrastructure functions, and can be designed, financed and operated, is central to integrated water management and development. Major changes in the social infrastructure are projected as privatization of water resource infrastructure and hazard mitigation services is considered. Uncertainties associated with inter-annual and longer climate variations/change as well as changing social values pose risks for managing and developing water systems from source to delivery and disposal of wastewater. This is an integrative course that seeks to develop a balanced perspective for the systematic analysis of water distribution and treatment systems given the above context. Case studies are used to introduce selected problems and the formal approaches in context, and students are expected to work in inter-disciplinary teams as role players to develop information sources, and propose solutions through quantitative analyses. The topics for the case studies will vary from year to year depending on instructor interests and current concerns.

Rationale for the Course SEAS and SIPA are jointly developing a comprehensive, interdisciplinary program on natural resource, environmental, energy and hazards management, that takes an integrated systems approach to the development of solutions for resource management and hazard mitigation. This course will complement courses on hydrology, water, energy and environmental systems management, environmental economics, and environmental policy. It will provide a context for the real world application of water resource engineering principles. Given adequate participation of representative students, the case studies will be conducted by teams of students that are representative of a resource-management team that might work for the World Bank, for national development agencies, for state and local resource and environmental managers, or for larger consulting firms. SIPA and SEAS students will thus get relevant experience on working in an interdisciplinary practical context. Students from GSAS and Barnard with interests in water resources will also find this course useful since it bridges aspects of environmental science and policy.

Role In SIPA Curricula This course will be taught as a SIPA/EPS (Environmental Policy Studies) course, cross-listed as both an MPA and an MIA class. Course studies will include both domestic and international examples, and the curriculum suits both the management aspects of the MPA and the international policy and development and finance aspects of the MIA. It should be appropriate also for EPD, as the development of water resources is a foundation for much economic and political development. This course makes use of much of the material covered in the MIA and MPA core curricula. Use within real management decisions of economic, statistical, and financial analysis will be prominent, as will the role of the political and institutional issues around water. Case studies will provide students with practical experience, in the context of real institutions, conducting systems and scenario analyses of use of a natural resource, and of financing projects with social and ecological constraints in mind. This application of core skills will be useful in many of the arenas in which SIPA students concentrate. The direct interaction with Engineering students and the presentation of Engineering approaches will foster an appreciation of these technical disciplines and promote the ability to communicate with technical specialists.

Role in SEAS Curricula The course will be cross-listed in the departments of Earth & Environmental Engineering and Civil Engineering & Engineering Mechanics. For the undergraduate engineering student, the course will meet ABET accreditation criteria for Environmental Engineering and Civil Engineering through the development of: (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to analyze and interpret data; (c) an ability to analyze and design a system, (d) an ability to function on multi-disciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global and societal context; (j) a knowledge of contemporary issues; and (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. This course will also convey an understanding of the roles and responsibilities of both public institutions and private organizations in environmental management; and foster a capability to apply systems modeling techniques for water supply and Resource management. The course is also suitable for graduate students in Engineering who are interested in understanding the institutional context of practice in the water field and seek to develop skills to solve problems at the system level. For both graduate and undergraduate students the course can provide an orientation to the field that helps research and career path selection.

Role for the IRI-CP As a research institute, the IRI-CP seeks to develop societal applications of research in the understanding of climate variability and change, and specifically for the use of seasonal to inter-annual climate forecasts. The management of water resources and river basins is a key application since it has a bearing on irrigated agriculture, energy production, vector borne diseases (health) and flood hazards, and hence on poverty and human vulnerability. The IRI-CP seeks to develop an international training and education component for climate research and its applications. The IRI-CP academic component is being developed in partnership with other units at Columbia University. It promises to deliver a number of qualified and funded MS and PhD students as well as trainees in these areas. The proposed course is one of the first such classes at Columbia. The IRI-CP will formally participate by providing instructors and materials for International case studies. Opportunities for further research and studies at the IRI-CP may be available to selected students from the class.

Course Objectives

- Introduce the student to the interplay between the physical and social infrastructure embodied by water systems, and regional development and environmental issues.

- Foster an understanding of the key attributes of water sources, and the variability of water quantity and quality in space and time; the structural and non-structural options used to develop water supplies and their impact on the environment.

- Review aspects of economics and sociology as they pertain to the development and management of water supply and demand. This includes project analysis, market and non-market methods of regulation and public and private sector operation, principles of investing and asset management, and policy evaluation and formulation.

- Integrate these ideas in a systems analytic context to analyze and develop solutions to basin scale water management and planning problems in much the same way as practicing professionals would need to develop analyses for a client. This includes a focus on data collection and analysis on physical, cultural, institutional and economic factors, stakeholder values, environmental justice and equity issues, and the use of simulation, optimization and statistical decision theoretic techniques.

- Engender the ability to identify and use information sources, understand the regulatory process, and approach technical problems and literature in the water resource area.

Approach The course will have a mix of formal instruction and an open ended, case study format. Lectures and invited talks will be used to introduce analytical techniques and to provide background on institutional and regulatory structure. The class will participate in designing and evaluating alternate solutions in the context of selected case studies. One case study will emphasize near term management of a water system, including the projection of supply from different sources and demands for different user classes, given climate and economic forecasts. A focus will be on identifying stakeholders and their objectives, and designing a gaming strategy under which management alternatives can be evaluated and presented as part of a collaborative decision framework. This will necessitate modeling and data analysis for the estimation of the near term outcomes of each management plan (resource allocation and demand management) and the associated risk. Team members working on the case study will be asked to play the roles of different interests and develop supporting analyses and negotiation documents. A second case study will extend these ideas to a planning and development context and also revisit the management problem in the context of specific changes in regulatory or fiscal policy that will change the hierarchy of preferred short-term management solutions. The case studies may focus on locations and issues in the United States, or on issues of direct interest in international settings. Depending on the situation and location, a different mix of physical and socio-economic options will be investigated. Climate will likely be a recurring theme in all case studies.

Specific areas that will be developed as part of the case studies include:

- useful sources of relevant data
- identification of key regulatory and management agencies and stakeholders operating in a river basin
- network representations in the modeling of physical and social interconnections
- articulation of management goals and performance criteria relevant to different actors
- identification of structural and non-structural management and planning options, with all key details
- assembly of individual options or management alternatives into several alternative plans (including the identification of costs, phases, contingencies, and management and oversight agency responsibilities)
- use of statistical, physical and economic models to evaluate and rank the alternatives
- formal and informal methods of water-related decision analysis that take into account both subjective and objective factors including the quantification of risks
- presentation of information for decisions, including for adaptive management (ongoing data collection, data analysis and model protocols, and criteria for getting additional information or modifying an operation)

Texts -- ***none are required for purchase, but the following will provide background materials***

Chow, V.T., D.R. Maidment and L.W. Mays, *Applied Hydrology*, McGraw-Hill, Inc., New York, 1988

Goodman, A.S., *Principles of Water Resource Planning*, Prentice-Hall, 1984.

Grigg, N.S., *Water Resources Management: Principles, Regulations and Cases*, McGraw-Hill, 1996

Hanley, N., J.F. Shogren and B. White. *Environmental Economics in Theory and Practice*. Oxford Univ. Press, NY.

Hartwick, John M. and Nancy D. Olewiler. *The Economics of Natural Resource Use*. Addison-Wesley, 2nd edition.

Heathcotte, I. W., *Integrated Watershed Management: Principles and Practice*, John Wiley and Sons, 1998.

Jensen, F.V., *Bayesian Networks and Decision Graphs*, Springer-Verlag, 2001.

Kolstad, Charles D. *Environmental Economics*. Oxford University Press, Oxford and New York, 2000, 400p.

Loucks, D. P., Stedinger, J.R., and Haith, D.A., *Water Resource Systems Planning and Analysis*, 1981

Maas, A. et al., *Design of Water Resource Systems*, Harvard, Cambridge, 1962

Major, D.C., and R.L. Lenton, *Applied Water Resources Systems Planning*,Prentice Hall, Englewood Cliffs, 1979

Mays, L.W. and Y.K. Tung, *Hydrosystems Engineering and Management*, McGraw-Hill, 1992

NRC, *Watershed Management for Potable Water Supply: Assessing the New York City Strategy*, 2000.

NRC, *Assessing the TMDL Approach to Water Quality Management*, National Academy Press, 2001.

Revelle, C., *Optimizing Reservoir Resources*, John Wiley and Sons, 1999.

Tietenberg, Tom. *Environmental and Natural Resource Economics*. Harper Collins, 1996, 4th edition, 614p.

Willis, R.L., and W. W-G. Yeh, *Groundwater Systems Planning and Management*, Prentice Hall, Englewood Cliffs.

Topical Areas

I. PHYSICAL SYSTEM CHARACTERIZATION

The Physical Setting

Introduce the elements of water resource/river basin analysis through a discussion of the sources of supply (surface and groundwater sources, desalination) & sectors of demand (industry, agriculture, domestic, ecology), and their variability and conjunctive development and use potential. The river basin setting and its interaction with human activity and the water system. Components of a water storage, supply, treatment and distribution network. Waste water generation and treatment. Networks as a graphical and conceptual tool to understand physical interconnections and fluxes of water and other materials.

Modeling Water Systems

Concepts of mass balance, and their application at different scales (e.g., reservoir vs river basin, hillslope erosion to river sediment load; diurnal vs annual). Concepts of firm and secondary yield. Reservoir sizing using a modified sequent peak algorithm. Aquifer yield. Understanding and modeling variation of fluxes in time – trends and time series models; applications to risk analysis (demand >supply in a drought; pollutant concentrations in a lake). Spatial variations and structure – using river/sewer networks and mass balance ideas to design a system simulator.

The Nature and Role of Climate

Concepts of atmospheric and oceanic circulation and their determination of the space and time structure of planetary water and energy cycles. Climatic Teleconnections and organization of space-time fields. ENSO, NAO, PDO. Diagnostic analyses of relationships of water inflows or sediment loads to rain to prior ocean conditions. Graphical Markov Models or Bayesian Networks to represent cause-effect relationships.

II. SOCIAL SYSTEM CHARACTERIZATION

The Social/Institutional Setting

Introduction to the management and operation of water systems. The role of water in regional development and poverty reduction. Defining integrated water management and establishing its need. Identifying water uses, impairments, stakeholders, goals and the need for public involvement. Establishing the hierarchy between policy, planning and development and management of the system. Regulatory and management structures for water systems and regional planning. Water rights and markets. Role of public and private sector. Assets and development perspectives. Financing Mechanisms. Cultural Perspectives. Planning and development vs. Operation and Management. Identifying constraints, objectives, state variables and management options as part of a conceptual model of the decision process. Networks as a tool to visualize social hierarchies and interconnections to the physical system.

Project Economics

Economic analysis of water resource development projects including valuation, cost allocation, and assessment of primary and secondary benefits. Public and Private Sector models for financing and cost recovery. Review of time value of money, and investment analysis.

Market Economics Review

Water rights and markets and their implementation. Advantages and disadvantages of market and non-market mechanisms. Issues in water rationing, sectoral water allocation and pricing, and drought planning. Review of Price Theory.

III. CASE STUDIES

Multiple case studies may proceed simultaneously following a general design and framework prescribed by the instructors. The relatively large team of instructors will make it possible to work closely with student teams in a supervisory capacity. These studies will emphasize an end-to-end process for the use of information and the development of all relevant analysis from project initiation to design and recommendation of an approach using appropriate techniques (simulation, optimization, gaming, economic analysis…). Necessary models and data will be made available to the extent possible. Students will be required to use these models with appropriate data and/or interpret and use results from existing simulations (e.g., from climate models). The emphasis will be on problem formulation and approach towards solution, and the communication of salient results from diagnostic and scenario analyses. Case studies in the first year may include:

- development of strategies for water supply and rural development in Ceara, Brazil
- investigation of alternatives for managing Combined Sewer Outflows (non-point source pollution) in the Croton River watershed of New York City, part of EPA's Total Maximum Daily Load (TMDL) process
- privatization of a municipal water supply system
- the vulnerability and re-engineering of an antiquated urban water supply system to reduce system losses, and to increase water conservation
- a flood warning and artificial recharge system to flush arsenic from groundwater system for Bangladesh

The subsequent description of case studies illustrates the generic structure to be followed. The details will clearly differ. Each week, visitors who introduce specific elements of the case study, and in later weeks by student presentations will augment technical presentations. Student teams prior to week 6 will select the case study topics.

CASE STUDY Stage I– Assessing the Physical and Social Setting and Identifying Data Sources

Develop watershed inventory (existing and potential sources and demands) and data bases. Identify key stakeholders and outline a process for interaction. Review applicable policies, regulations, agreements and other institutional arrangements. Identify physical constraints and develop framework for system description and simulation

CASE STUDY Stage II– Operation and Management

Presentation of the existing water system and identification of management options for near term operation and their relation to longer term targets and policies. Developing and using climate, water supply and demand and sectoral economic forecasts. Elicit and define goals and performance metrics and a list of options (specifically reservoir and groundwater operation policies, rationing and pricing decisions and sectoral allocation strategies, short term investments in other sectors to mitigate drought impacts). Identify conflicts and international issues that pose constraints. Evaluate options through system operation & management, simulation & optimization. Relate management options to regulatory and stakeholder goals. Negotiation process and identification of best option. Implementation of selected option in an "adaptive" management framework

CASE STUDY Stage III - Development and Planning

Develop the long run analysis context in terms of projected sources of supply, demand attributes, regional development and population growth scenarios, and social values. Rural vs. Urban factors, and potential changes due to changing climate, urbanization and sector shifts. Discuss implications of technological, economic and social uncertainty. Revisit definition of system and stakeholders and long-term goals and performance metrics. Interpret efficiency, resilience, flexibility and space-time and sectoral trade-offs in this context. Develop a list of options and their combination as part of an analysis of future scenarios. For each structural and non-structural project alternatives, and use the tools of financial analysis (cash flow profiles, discounting analysis, investment & financing decisions, and sensitivity analysis), social and environmental impact assessment, and decision analysis (expected value, subjective probabilities; valuing information and flexibility) to assess project feasibility for each alternative. Comparative analysis of plans and development of contingent implementation schedules for the superior subset through scenario analysis in consultation with stakeholder groups. Document deliberations and treatment of risk and uncertainty and implications for near term management. Identify needs for ongoing data collection and provide manual of practice for the use of this data for plan updating and near term system management.

Project Presentations Final presentations of a finished product by each team.