US/China Digital Government Collaboration[1]:
Comparing Water Resources Decision Support Situations, Techniques, and Tools
Project Description

## Problem Statement

Water resource management decision making continues to be a significant problem world-wide and is increasing in importance as nations such as China and the US continue to develop, placing significant demands on water resources to sustain and improve a way of life. Adding to that challenge is the geographic reality that water is not distributed evenly. Thus, from region to region large deficits for available clean water are foreseen. A core problem within regions involves efficient, effective and equitable distribution of water under conditions of increasing shortages due to growth. More and more stakeholder groups are voicing their concerns (who might not have in the past) about what availability and access, as they want to participate in the decision process in more meaningful ways. A regional, basin-level investigation that incorporates diverse stakeholder groups (decision makers, technical specialists, and environmental groups) is now recognized as an important part of effective and equitable management of water resources. However, water can be transported between basins, and thus we need to incorporate hydrologic, economic, environmental, and institutional considerations that at times involve multiple basins. All of the considerations taken together create a rather complex decision problem, not the least of which involves providing diverse stakeholder groups with access to information. Information techniques and tools designed to address complex human-computer-human decision problems are still under-developed, as the science of participatory design itself is under-developed. As such, their application in society is next to nonexistent. This problem of providing participatory access to information has been recognized in the US for quite some time, but in the past several years, public (stakeholder) participation has also been an emerging issue in China – particularly for environmentally related topics like water resources. In addition, two approaches to decision support – multi-objective and multi-attribute have not been compared in regards to their support of participatory decision support for water resources. Multi-objective techniques emphasize optimization among competing objectives when choosing options. Multi-attribute techniques emphasize interactive trade-off analyses when choosing options. Integrated and improved designs for advancing participatory cyberinfrastructure tools are important issues contributing to the advancement of digital governance.

The *intellectual merit* of this project stems from advancing knowledge within geospatial information science and engineering by integrating constructs from complex adaptive systems theory and enhanced adaptive structuration theory as the conceptual underpinnings of the participatory, geospatial decision information support tools developed as part of their respective (NSFC and NSF) research activity over the past several years. These tools have been applied to the water resource management situations in China and the US at a regional scale. Further merit stems from a conceptual comparison and contrast of multi-objective and multi-attribute techniques embedded within participatory modeling environments for water decision support.

[1] This research is funded by National Science Foundation, Division of Experimental and Integrative Activities, Information Technology Research (ITR) Program, Project Number EIA 0325916, funds managed within the Digital Government Program, now Information, Integration and Informatics of the CISE Directorate. All ideas are the responsibility of the researchers.

The *broader impacts of this study* include enhancement of graduate student training and application benefits to society.  The materials developed in this research are to be discussed in participatory GIS graduate seminar in order to enhance graduate student training.  This material will provide students with a cross-cultural perspective of information technology design and deployment. The theoretical framework is intended to support grad student research about case studies, providing a cross-cultural perspective. The major benefit to society is that the participatory information techniques and tools designed as a result of this research are intended to benefit regional governments in both China and the US. Human-computer interaction theories that span cultural and societal contexts can improve our ability to frame complex decision situations, and thus contribute to creation of more reflexive information technology solutions.

From that problem statement, encouraged by the intellectual merit to knowledge creation and broader impacts to society, the following research question is posed to focus the effort. *In what way can the conceptual underpinnings of the participatory, geospatial decision information support techniques and tools developed as part of recent NSFC and NSF research activity within China and the US at a regional scale be integrated to provide enhanced solutions for water resource management decision support technology designs in both China and the US?*

To address that question, Dr. Jianshi Zhao, Department of Hydraulic Engineering, Tsinghua University, and Dr. Timothy Nyerges, Department of Geography, University of Washington will separately and then jointly explore decision situations and technology designs to synthesize a broader perspective incorporating both optimization system models and multi-attribute decision models. They are specialists in decision support technology, and will compare theories and synthesize approaches for development of geospatial information techniques and tools that support participatory water resource management decision making at a regional scale. The project timeframe will span one year September 1, 2007 – August 31, 2008.

Drs. Zhao and Nyerges will explore the synergy between two theoretical frameworks - Complex Adaptive Systems Theory and Enhanced Adaptive Structuration Theory - as a basis of the approaches to systems modeling and decision modeling, respectively. They will carry that comparison through to information technology being designed and implemented as a result of those approaches, particularly in relation to the participatory nature of the modeling that is being performed in the linkage between humans and water systems.

Zhao has used Complex Adaptive Systems (CAS) Theory (Holland 1995) to characterize complex decision management for water resources in China at the basin level. Zhao, Wang, and Weng (2003, 2004),  have been developing the Integrated Hydrologic-Economic-Environment-Institutional model to assess water management and policy issues in a river basin setting. Although conventional geographic information systems technology is available to offer modeling and analysis of river basins, decision support systems technology based on GIS technology are needed to enhance the interactivity of access to information.  Such decision support systems embed traditional water resources simulation and optimization models. The approaches range from loose coupling (the transfer of data between GIS and numerical models) to tight coupling (GIS and the models share the same database). The tightest of couplings consists of an integrated system, in which modeling and data are embedded in a single manipulation framework. At the basin level, hydrologic, environmental, and economic relationships can be integrated into a comprehensive modeling framework and, as a result, policy instruments, can then offer a more rational economic use of water resources. Improved basin-level modeling of water policy options will be an important direction for water management research in the immediate future. Efficient and comprehensive analytical tools are needed to make the water allocation decisions necessary to achieve sustainable water use strategies for many river basins. A major direction for modeling will lie in GIS-based decision support systems that integrate economic, environmental, institutional, and hydrologic components.

The theory and modeling methods of the CAS were developed for Hai River basin in China, but are being examined for the Yellow River basin, to set up holistic models for water resource systems. A key part of CAS Theory is the Constrained Generating Procedures (CGP). CGP is a basic modeling method of CAS Theory. “Procedures” means that the model is dynamic. “Generating” means that the process is produced by the interaction of all kinds of agents and “Constrained” means that the system has certain rules to constraint itself. Based on the theory of self-organization and synergetics, CAS theory considers that the units of the system are self-aimed, initiative and active agents, adding considerable progress for conceptualizing complex systems. Surrounding the core concept of “adaptive agent”, the CAS theory advocates some system evolution related concepts that include: aggregation, nonlinearity, flow, diversity, tagging, internal model, and building blocks, etc. These conceptions can be used to annotate water resources system, which has the basic characteristics of CAS. Thus, the theory and modeling approach are suitable for water resources system analysis.  Complex adaptive systems theory has a basis in systems engineering. The information technology is therefore oriented to systems modeling.

A river basin system is made up of three system components: (1) source components such as rivers, canals, reservoirs, and aquifers; (2) demand components off-stream (irrigation fields, industrial plants, and cities) and in-stream (hydropower, recreation, environment); and (3) intermediate components such as treatment plants and water reuse and recycling facilities. However, the state of the basin (for example reservoir and aquifer storage, and water quality) and the physical processes within the basin (for example stream flow, evapotranspiration (ET), infiltration and percolation) are also characterized by human actions, including impoundment, diversion, irrigation, drainage, and discharges from urban areas. Therefore, water resources modeling of a river basin system should include not only natural and physical processes, but artificial “hardware” (physical projects) and “software” (management policies) as well. An ideal, complete management model also needs some sub-model of human behavior in response to policy initiatives, in which the characteristic of the system components (such as resident, irrigation area, enterprise, and government) can be described necessarily.

Over the past ten years Nyerges has been formulating and refining a theoretical framework for complex decision situations in society call Enhanced Adaptive Structuration Theory (Nyerges and Jankowski 1997).  EAST was developed to characterize complex decision situations in which geospatial information technology is a main component to support decision processes. Thus, the main thrust of the theory was intended to focus on human-computer-human interaction with complex information settings, as many realistic decision settings with multiple stakeholder perspectives are common of such complexity.  A second version of EAST (EAST2 – Jankowski and Nyerges 2001) extended the applicability to long decision situations, whereby several macro and micro steps of a decision process must be considered to provide effective decision support. Dr. Nyerges has shown considerable success using Enhanced Adaptive Structuration Theory (EAST2) to articulate the decision situations – in a variety of settings including transportation (Nyerges et al. 1998, Jankowski and Nyerges 2001), hazardous waste cleanup (Drew and Nyerges 2004), and water resources (Jankowski and Nyerges 2001, Nyerges et al. 2006) decision making. In all cases, the decision situations were actual field situations, not contrived circumstances. The basis of the research comes from literature mostly in the geospatial information sciences and decision sciences. The information technology is therefore oriented to decision modeling.

In Nyerges' current NSF-funded research, a participatory GIS web portal supports analytic-deliberative, participatory interaction in transportation improvement decision making that involves diverse stakeholder groups (Nyerges, Ramsey and Wilson 2006). Although it has been designed to support transportation improvement decision making, past research about water resource systems makes it evident that the portal design is likely applicable to water resource improvement decision making as well – due to the "projects within systems" aspect of the resource problem. Previous research about water resources in the US indicates that there exists a connection among planning, improvement programming, and project implementation decision situations in a similar manner to a connection among decision situations for transportation (Nyerges and Jankowski in review). Information techniques and tools are needed to link one decision context to another in order to promote sustainable development approaches to decision making. Lack of a linkage between decision models and transportation/water systems models hinders our ability to undertake sustainable development. This appears to be the case in decision situations in both the US and China.

A synthesized framework, bringing together CAS and EAST2, has the potential to foster a comprehensive and deep shared understanding about the participatory nature of the modeling for water resources, involving human-institutional and natural systems. That understanding will move forward step by step using the following research plan composed of six tasks.

## Research Plan

Drs. Zhao and Nyerges together have articulated six tasks that will address that research question posed in problem statement. Each of the tasks has a stated objective to focus the research effort.

Task 1. Water Resource Management System in China and US
*Task 1 Objective*: Document the advantages and disadvantages for characterizing water resource decision situations by integrating complex adaptive systems theory and enhance adaptive structuration theory.

1.1. Description of Institutional Context
In China, the water management allocation decision context is predominantly at a high level in the national government. Little decision activity is managed at a level below the region; whereas in the US, water management occurs at many levels depending on the supplies of water, but is increasingly being managed at the regional level. To establish a base line for comparison we will work at a regional (basin) level.

In this 1st task, Drs. Zhao and Nyerges will document separately the institutional aspects of the regional water resource management decision situations in their respective countries in terms of their respective theoretic approaches. Dr. Zhao will focus on the Yellow River water management challenge in north western China. Dr. Nyerges will focus on the Spokane Valley Rathdrum Prairie Aquifer water management challenge in eastern WA / western Idaho. They will then exchange information details about the results.

1.2 Develop Synthesis
From these characterizations, Drs. Zhao and Nyerges will together develop a synthesis of the theoretical approaches. We will start with complex adaptive systems theory as a base, and then add constructs from enhanced adaptive structuration theory. We will then describe the Yellow River and Rathdrum Prairie Aquifer cases in the synthesized framework. The main idea behind this task is to become familiar with each others approach, and at the same time synthesizing an overall approach to water resource management decision situation characterization. A graduate student research assistant will help with the synthesis process, taking the material from both Zhao and Nyerges and suggesting connections.

We will pay particular attention to the information needs of stakeholders to set the stage for the synthesis. This information need in water management can be distinguished in terms of a) water allocations using an optimization approach (China) versus using a preferential priority setting (US), b) the nature of the demand – who deserves water given the environmental conditions, and c) the water laws that guide water allocation, without considering environmental conditions.

Dr. Nyerges will make a one week visit to Beijing (Sept 2007) to discuss the results of synthesis with Dr. Zhao. As part of that week, Dr. Zhao and Dr. Nyerges will take a field trip to the Yellow River region to see and discuss the Yellow River decision situation with stakeholders.

Task 2. Water Resource Decision Making Mechanism in China and US
*Task 2 Objective:* Document the basic decision mechanism at play in the China and US water management decision cases.

In task 2, Drs. Zhao and Nyerges will use the integrated complex adaptive systems approach to fully describe the decision making mechanisms of their respective decision situations. The mechanism focuses on who, how, meeting arrangement, and outcome among several aspects. The enhanced adaptive structuration theory identifies 25 such aspects to provide insight into details of complex situations. We will document how information flows among humans and computer systems, addressing what information and how information is used in decision settings, and particularly the participatory part of these processes. A graduate student research assistant will review compile the information about mechanisms, providing this information to Dr. Nyerges for consideration in the materials to be provided to Dr. Zhao.

Dr. Zhao will travel to Seattle to visit Dr. Nyerges to discuss the results of their decision mechanism investigations. Drs. Nyerges and Zhao and the U of Washington research assistant undertake a field trip to Eastern Washington to discuss the Rathdrum Prairie Aquifer decision situation with stakeholders in The WA Department of Ecology and the Idaho Department of

Water Resources (IDWR). Dr. Nyerges has been invited to visit with the Dr. David Tuthill, Director of IDWR, to begin a second collaboration involving advanced water resource decision support techniques and tools. Dr. Tuthill was the agency collaborator during the development of NSF-funded WaterGroup project (Nyerges, Jankowski, Tuthill, and Ramsey 2006).

Task 3. Identify Technology in Water Resource Decision Making
*Task 3 Objective:* Identify the decision support technology available to be used in the water management decision cases.

In task 3, Drs. Zhao and Nyerges will document the information techniques and tools developed to date as part of their respective research activities. They will share insights about concept, technique and tool for each of the information techniques and tools developed.

Dr. Zhao and his colleagues (Zhao, Wang, and Weng 2003, 2004) have created the Integrated Hydrologic-Economic-Environment-Institutional model to assess water management and policy issues in a river basin setting. The model consists of several integrated submodels that feed information to a multi-objective optimization model. The architecture of the Yellow River systems model is depicted in Figure 1. The Yellow River systems model is actually an integrated set of models. Submodels for economic, water supply, water quality, agricultural agenda, evapotranspiration, enterprise and urban issues all contribute information to a multi-objective optimization model. Dr. Zhao will document the principal character of the design, extracting information from current publications, and assemble the information in Task 4.

Dr. Nyerges and his colleagues (Jankowski and Nyerges 2001b; Nyerges, Jankowski, Tuthill, Ramsey 2006; Nyerges, Ramsey, Wilson 2006) have created three group decision support platforms with NSF funding. The earliest was oriented to nearshore site selection for salmon ecosystem redevelopment in the Duwamish Waterway in Seattle WA (Jankowski, Nyerges, et al. 1997, Jankowski and Nyerges 2001b.). The second development was for regional water resource conjunctive water (groundwater and surface water) planning in the Boise River Basin of southwestern Idaho (Nyerges, Jankowski, Robischon et al. 2006). The third is a web-based portal designed for transportation improvement decision making, but can transfer to water resource improvement decision making, since both application domains involve systems of project improvements (Nyerges, Ramsey, and Wilson, 2006). The focus of their efforts over the past several years has been multi-attribute decision modeling. The architecture of the participatory GIS portal architecture is depicted in Figure 2. A multi-attribute decision model with sensitivity analysis is part of the choice modeler component in Figure 2. A choice modeler allows one to interactively specify the aspects of the decision problem to be considered and then perform "what-if" alternative considerations to choose among infrastructure projects. A research assistant will support Dr. Nyerges within documenting the principal character of the designs, extracting information from current publications, and assembling the information in Task 4.

Task 4. Prepare Case Studies for Comparison
*Task 4 Objective:* Prepare decision cases for exchange and comparison.

Drs. Zhao and Nyerges will develop a template for a case study description. Following this template preparation we will then separately document each of the cases using the template to prepare the case studies for preparation. A research assistant will help Dr. Nyerges collate the material. This activity will give researchers an opportunity to reflect upon the design considerations in the systems as driven by the information needs of the decision situations.

Task 5. Compare and Contrast China and US Cases

*Task 5 Objective:* Compare the decision cases and the technology that supports the cases, synthesizing an overall approach to water decision management.

Task 5.1 Compare and Contrast the Decision Situations

In task 5, Drs. Zhao and Nyerges will compare the modeling techniques and tools developed to date across the two researchers' activities in light of the case studies. We will highlight how systems modeling and decision modeling are used in water resources decision making in the respective cases. The research assistant will be instrumental in the process.

Task 5.2 Compare and Contrast Technology Designs

Drs. Zhao and Nyerges will create a design for an overall approach using systems modeling and decision modeling. The design will be contextualized to the respective decision cases. Advantages and disadvantages of using different technology approaches to address the decision situations will be highlighted. The research assistant will help Dr. Nyerges make the connections between the systems.

It is in this task that Drs. Zhao and Nyerges will form new design ideas by comparing technologies. A major direction for modeling with Dr. Zhao will lie in GIS-based decision support systems that integrate economic, environmental, institutional, and hydrologic components, and host these components in a web–based environment to improve access to information, and thus foster participatory contributions. It is for this reason that the research of Dr. Nyerges rather interesting. The future direction for Dr. Nyerges' work is in holistic systems modeling, supported by simulation modeling. It is for this reason the research of Dr. Zhao is of considerable interest to Dr. Nyerges.

Dr. Nyerges will visit with Dr. Zhao in Beijing in late February 2008 to discuss the case study and technology approaches.

Task 6. Develop Report

*Task Objective 6:* What is the best way to communicate the results of the research project?

Dr. Zhao will visit with Dr. Nyerges in Seattle WA in the March-June timeframe to discuss and compile the final report. We will jointly develop a research report documenting the approach of each researcher and the synthesized approach as a result of this research effort. A version of the report will be presented at the Digital Government Society Conference commonly occurring in May. The report(s) will be refined for submission to a journal such as *Water Resources Management and/or Water Resources Journal.*

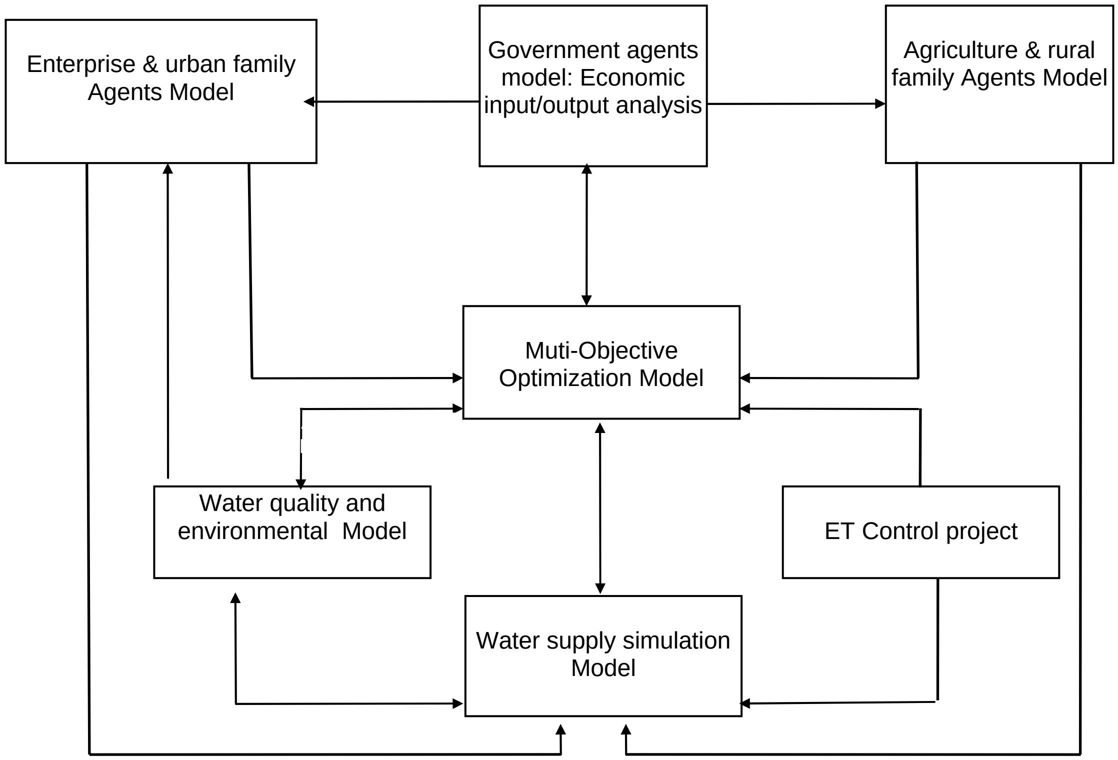


Figure 1. Hai River / Yellow River System Model Structure

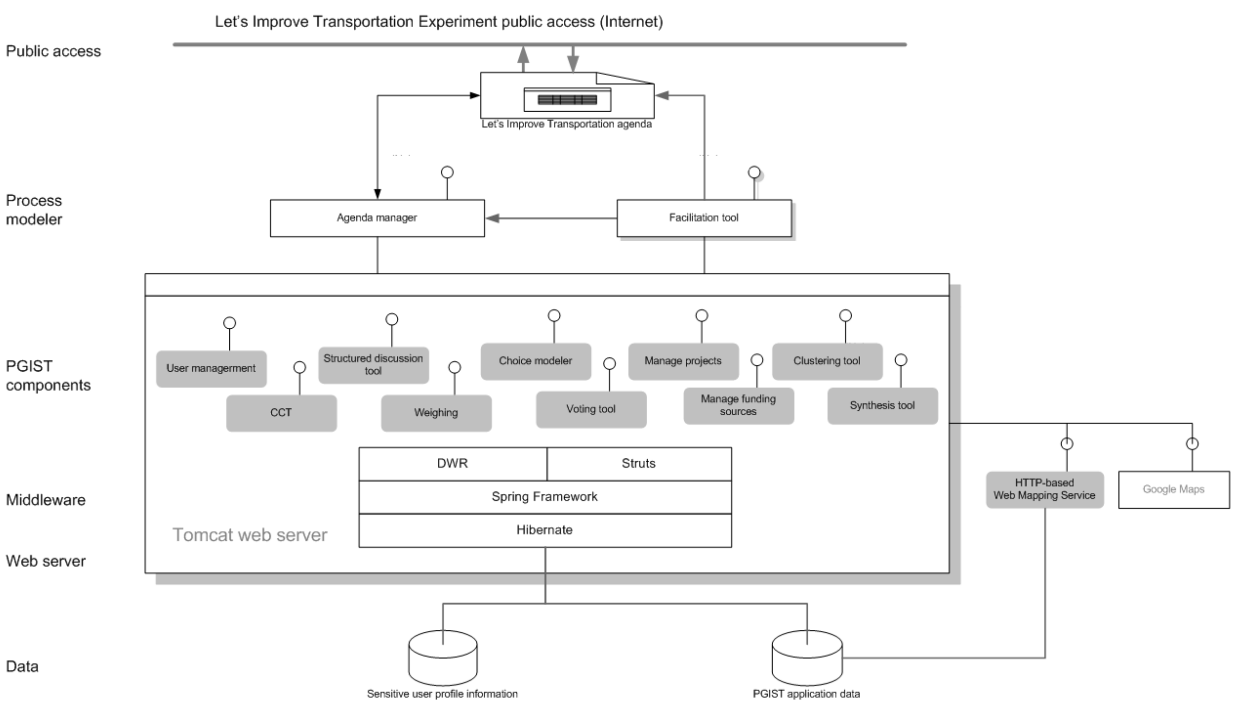


Figure 2. Participatory GIS for Transportation Portal System Architecture

**Task Schedule**

The project will cover a period of twelve months.  Each of the six tasks outlined earlier are depicted in Figure 3 together with the time at which that task will be addressed.

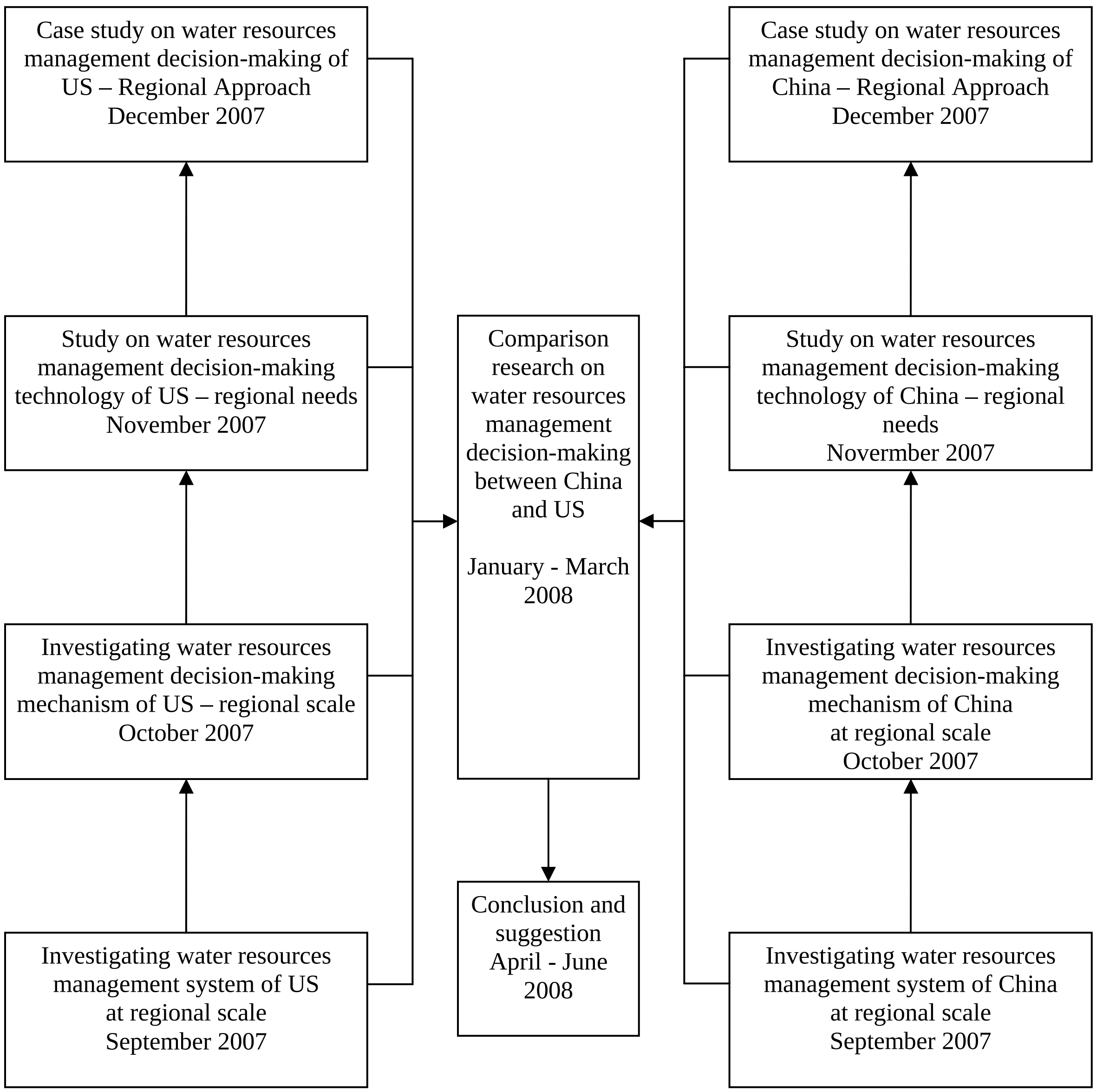


Figure 3. China-US water resource decision support project – task schedule.

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