IIHR-NCHC COLLABORATIVE RESEARCH PROJECT – INTEGRATED COMPUTER MODELS FOR RIVER FLOW AND APPLICATION TO TAN SUI RIVER FINAL REPORT

by

Virendra C. Patel and Mark A. Wilson

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IIHR—Hydroscience & Engineering
College of Engineering
The University of Iowa
Iowa City, Iowa 52242-1585 USA

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SUMMARY

The completed multi-year international collaboration between IIHR – Hydroscience & Engineering (IIHR) at The University of Iowa and a team of researchers from the National Center for High-performance Computing (NCHC), National Taiwan University (NTU) and National Chiao-Tung University (NCTU) in Taiwan was originally proposed to be completed in three years. A number of international events restricted travel opportunities and resulted in an extension of the collaboration to a fourth year. The project has now been successfully completed. The project met its objectives of facilitating a high level of collaboration among the various groups and has led to a stronger and more encompassing set of collaborative initiatives.

IIHR has been at the forefront of development and application of numerical models for hydraulic engineering problems. Current research in computational hydraulics at IIHR is concerned with numerical modeling of unsteady three-dimensional flow in rivers and associated hydraulic structures. NCHC supports high-performance computing in Taiwan by maintaining up-to-date hardware, software, and network communications. NCHC has assembled a team of researchers from within and outside the organization to address hydrologic problems of Taiwan by adapting numerical models of various levels of sophistication to develop state-of-the-art predictive methods for the flood-prone Tan Sui River, which flows through the metropolitan city of Taipei.

Under the completed collaborative research project, IIHR delivered a three-dimensional unsteady numerical code, known as RIVER3D, to predict the flow in selected segments (typically a few kilometers) of full-scale rivers, with natural and man-made features. Researchers at NCHC, NTU and NCTU integrated the IIHR code with their in-house rainfall, watershed, and one- and two-dimensional channel codes to develop a demonstration of a fully integrated flood-forecasting system. The fully integrated flood-forecasting system includes rainfall observation and prediction models, a runoff-prediction model, a reservoir operation model during flood period, a flood routing model, a display and decision support system, and an inundation simulation model, that

are developed in the on going project "The flood forecasting system model for the Tan Sui River Basin" in Taiwan. The participants focused their initial efforts on demonstrating the use of the RIVER3D code for use on the Tan Sui River. This project also accelerated IIHR research in river flow modeling by access to NCHC facilities and expertise in parallel computing, visualization and graphical user interface design.

OBJECTIVES

The principal project objectives were:

- Develop an integrated flood forecasting system and demonstrate it by application to the Tan Sui River in Taiwan.

- The new unsteady three-dimensional river flow model, RIVER3D, being developed at IIHR will be installed on NCHC computers.

- The RIVER3D code will be periodically updated by IIHR as new capabilities are added to it.

- NCHC researchers will enhance the performance of this code by adapting it to run on the evolving parallel computer architecture, notably, Origin 2000 arrays and NT clusters. NCHC has the manpower and computers to carry out this task in a timely and efficient manner.

- NCHC will also develop a graphical user interface (GUI) to facilitate integration of RIVER3D with other codes and models, and advanced visualization software using virtual reality Immersadesk and cave technologies. These facilities and expertise are not readily available to IIHR. However, IIHR will have access to these facilities at NCHC by the existing high-speed vBNS/Internet2 connection between the two organizations.

ACTIVITIES

Project activities were coordinated through a series of face to face meetings held at various locations and events within the United States and Taiwan. These meetings established work plans, facilitated joint development opportunities, and provided demonstrations of the developed products as they evolved. Additionally, a significant collaboration was done using Internet-based and grid-based technologies available at each participant's site.

A web site was established to present documents, computer codes, and results of the project. This site was the main distribution point for the RIVER3D code being used by both NCHC and IIHR. A list-serve mailing list was established to improve communication between participants.

Specific meetings were:

4th International Conference on Hydroinformatics, July 23-27,Cedar Rapids, IA

US and Taiwanese collaborators have met a number of times to review progress and define the scope of future work. The goal of the project is to develop an integrated computer model combining the IIHR river channel flow code, river3d, with an NCHC developed user interface producing interactive 3D visualizations of a river flow model. Initial project preparations were conducted over the internet with a project kick-off meeting at the 4th International Hydroinformatics Conference, 26 July 2000, in Cedar Rapids, Iowa. Agreements were reached on collaboration software to be used and specific functional connections between individuals at NCHC and IIHR

Papers presented at the 1st International Hydroinformatics Conference:

Water-Intake Pump Bays: Three-Dimensional Modeling, Validation, and Application by Songheng Li, Yong G. Lai, V.C. Patel, Jose Matos Silva

Rocky Reach Dam: A Comprehensive Look at the Calibration of a Numerical Model Applied to Fish Passage by Larry J. Weber, Yong G. Lai, Jeffrey C. Blank, Fernando De Andrade

U2RANS: A Comprehensive Hydraulic Flow Simulation code - Its Development and Applications by Yong G. Lai, Larry Weber, V.C. Patel

A Parallel Implementation of a Multi-Block Three Dimensional Incompressible Flow Solver on a DSM Machine by Weicheng Huang, Yong G. Lai

Supercomputing 2000, November 4-10, Dallas, TX

The next milestone occurred at the Supercomputing 2000 meeting in Dallas, Texas, 4-10 November, 2000. The user interface being developed by NCHC was demonstrated on a 3D virtual reality ImmersaDesk showing the initial Tan Sui River grid and bathymetry. Preliminary flow conditions were also visualized in the 3D virtual environment. Mark Wilson (IIHR) assisted Fang Pang (NCHC) at the NCHC SC2000 booth in order to become familiar with the hardware and software environment used by NCHC. Initial work to parallelize the RIVER3D code has been undertaken by NCHC. Preliminary results indicate a 32X speedup achieved on 64 processors (SGI Origin 2000) done in conjunction with the National Computational Science Alliance (NCSA). Further work on refining data structures and implementing finer grain parallelization is now underway

Supercomputing 2001, November 10–16, Denver, CO

The next meeting occurred at the Supercomputing 2001 conference in Denver, Colorado, 10-16 November, 2001. Mark Wilson (IIHR) worked with a number of NCHC personnel, coordinated by Fang Pang (NCHC) at the NCHC SC2001 booth. This week long collaboration focused on the user interface to the RIVER3D code and how to implement it. New developments in the 3D visualization and system integration were reviewed.

V.C. Patel visit to Taiwan, February 21-25, 2002

IIHR director V.C. Patel traveled to Taiwan and visited NCHC and NTU. They have made considerable progress in developing the GUI for RIVER3D but now are in need of guidance from IIHR to generalize the input/output sections for real, practical applications. They have also made considerable progress in developing a hardware and middleware layer for PC clusters. This work will be of great help to IIHR in defining its future computing environments.

Yong Lai visit to Taiwan, October 21-25, 2002

Yong Lai visited NCHC on 21-24 October 2002 and held seminars and discussions with engineers at NCHC, professors at National Chiao Tung University on a number of remaining development issues.

<u>Web-based GUI for RIVER3D</u>: NCHC originally developed the GUI using C++ for RIVER3D and it was shown when V. C. Patel visited them earlier in 2002. Since that time, all new development has been initiated using JAVA as the prime language. The JAVA based WEB GUI will be more flexible and platform independent. The new GUI has been implemented to support both RIVER3D and CFX, a commercial CFD software package

<u>Parallelization of RIVER3D</u>: There are a number of details remaining to be handled before the parallelization portion of the project is completed. Discussions with L. C. Lee and S. C. Cheng were held to move forward on these issues.

A seminar at NCHC on the RIVER3D and its applications was given to NCHC engineers and students and faculty members from National Chiao Tung University. A tour of the lab of Prof. Jinn-Chuang Yang, in Civil Engineering followed. A discussion with Dr. Yang-Yao Niu, professor of Mechanical Engineering at Chung Hua University covered use of RIVER3D in bio-fluid flow. There was a one-day visit to the Civil Engineering Department and Hydrotech Research Institute (HRI) at the National Taiwan University. A second seminar on the computational hydraulics and numerical applications was presented to more than 50 students along with a number of professors.

Supercomputing 2002, November 16-22, Baltimore, MD

The next meeting occurred at the Supercomputing 2002 conference in Baltimore, Maryland, 16-22 November, 2002. Mark Wilson (IIHR) worked with a number of NCHC personnel, coordinated by Fang Pang and Whey-Fone Tsai (NCHC) at the NCHC SC2002 booth. Developments over the last year were reviewed and plans made for the coming year's collaboration. Impressive new 3D visualizations of the Tan Sui River were demonstrated. It was decided to move parallelization efforts on RIVER3D from the original code base to the new one just released by IIHR. Most of the work done on the original RIVER3D will be directly transferable.

Supercomputing 2003, November 15-21, Phoenix, AZ

The next meeting was at the Supercomputing 2003 meeting in Phoenix, Arizona, November 15-21, 2003. Mark Wilson (IIHR) worked with a number of NCHC personnel, again coordinated by Fang Pang and Whey-Fone Tsai (NCHC) at the NCHC SC2003 booth. Recent developments in parallelizing the new RIVER3D code were discussed and plans were made to use this new code base for future project activity.

V.C. Patel visit to Taiwan, September 25-28, 2003

V.C. Patel visited NCHC and met with principal participants to review the progress and plan for completing the project without further delay. He also discussed the prospects of a follow on study involving several new staff members at IIHR.

1st Iowa Workshop on Large Rivers, Lucille A. Carver Mississippi River Environmental Research Station, Muscatine, Iowa, October 8-10, 2003

Prior to the meeting at LACMRERS the NCHC team met with the IIHR team, including V.C. Patel, Larry Weber, Ching Long Lin, George Constantinescu, Mark Wilson, and Songheng Li to discuss project plans and a possible follow-on project activities. A tour of IIHR was given and team members made presentations of progress in their area.

This project also co-sponsored the 1st Iowa Workshop on Large Rivers at IIHR's Lucille A. Carver Mississippi River Environmental Research Station, in Muscatine, Iowa, during October 8-10, 2003. A list of presentations made by the invited international participants is included in Appendix I.

George Constantinescu, Marian Muste, and Thanos Papanicolaou visit to Taiwan, March 18-24, 2004

George Constantinescu, Marian Muste, and Thanos Papanicolaou of IIHR visited Taiwan on 18-24 March, 2004, to wrap up the project, make plans for the final report, and discuss future plans. Extensive discussions with the NCHC team (Whey-Fone Tsai, Wei-Cheng Huang, Alexander F. Wu, Cherng-Yeu Shen, Wen-Yi Chang, Ren-Jieh Shih, Ho-Cheng Lien, Yi-Haur Shiau) focused on use of the computational GRID for simulation and visualization of hydrologic events such as flood mitigation. Details of recently developed middleware to enhance data handling (data GRID) and for human communication (ACCESS GRID) were discussed.

A near final implementation of a system for 3D stereo visualization was presented. IIHR may consider acquiring such a system in the future. The visualization software was completely developed in house at NCHC but built on open standards such as CAVELIB. The hardware costs about $50,000.

ACCOMPLISHMENTS

The joint project demonstrated how a successful international collaboration may be undertaken to provide significant benefits to all participants. IIHR provided the RIVER3D computational fluid dynamics technology and associated modeling and simulation expertise in applying this technology toward real problems along the Tan Sui River. The Taiwan team members provided demonstrations and expertise in developing a graphical user interface for the RIVER3D code and the ability to visualize in 2D and 3D the complex and extensive results of river simulations. The Taiwan team also provided several parallel versions of the RIVER3D code usable on selected platforms.

A major accomplishment was the development of an international agenda for further work. The 10 meetings, many of them working meetings, fostered a degree of understanding and intimacy between participants that would not have been otherwise available.

In terms of the specific objectives outlined for this collaboration, the project was a success.

- The Taiwan teams have developed significant portions of an integrated flood forecasting system that uses real-time observations of atmospheric and hydrologic processes to drive simulations and decision support systems related to flooding along the Tan Sui River in Taiwan.

- The unsteady three-dimensional river flow model, RIVER3D, developed at IIHR was installed on several different platforms at NCHC. The code base and technology of RIVER3D was explained and documentation was delivered concerning its use and maintenance.

- The RIVER3D code was updated over the course of the project. One major upgrade of functionality was delivered by IIHR.

- NCHC researchers enhanced the performance of RIVER3D by adapting it to run on the evolving parallel computer architecture, Origin 2000 arrays, NT clusters, and Linux clusters

- NCHC developed a graphical user interface (GUI) for RIVER3D. This permitted RIVER3D to to be integrated within the developing simulation and decision support system components. Advanced 2D and 3D visualization software was developed and used to view RIVER3D simulation results and to integrate the modeling effort within the decision support system.

FUTURE DIRECTIONS

The success of the current project in establishing working teams to address issues of mutual interest has encouraged the teams from IIHR, NCHC, and NTU to develop a set of goals for a follow-on project. The final meeting in Taiwan laid the groundwork for this next proposal and should be of great value to the hydrologic community. A draft of the proposal is attached as Appendix I.

Appendix I

Invited Presentations
At the
1st Iowa Workshop on Large Rivers
Lucille A. Carver Mississippi River Environmental Research Station, Muscatine, Iowa
October 8-10, 2003

The Adaptive Hydraulics Model (ADH): Shallow Water Examples Dr. Richard Stockstill of the U.S. Army Corps of Engineers, ERDC, USA

Software Development and Applications
Mr. Hans Enggrob, DHI Water and Environment, Denmark

Sediment Transport Modeling of Large Rivers
Dr. Sam Wang, National Center for Computational Hydroscience and Engineering, USA

Modeling Priorities to Achieve a Healthy River Ecosystem
Dr Ken Lubinski, U S Geological Survey, USA

Validation of Three-Dimensional Computational Models
Dr. Nigel Wright, University of Nottingham, United Kingdom

Lagrangian Simulation of River and Floodplain Flows
Mr. Bishnu Devkota, University of Western Australia, Australia

Ecohydraulic Modeling of Large Rivers
Dr. Klaus Jorde, University of Idaho, USA

Ecological Issues for Modeling Migratory Fish Responses in Dammed Large Rivers of the La Plata River Basin, South America
Dr. Claudio Baigun, Technological Institute of Chascomus (CONICET), Argentina

Numerical Model Developments in S. America
Dr. Angel Mendez, National Institute of Water and Environment, Argentina

Numerical Modeling of Fish Passage Facilities Along the Columbia and Snake Rivers
Dr. Larry Weber, IIHR, USA

Untitled Comments
Dr. John Nestler, U.S. Army Corps of Engineers, ERDC, USA

Reference River
Dr. Piotr Parasiewicz, Cornell University, USA

An Integrated Watershed Sedimentation Model
Dr. Thanos Papanicolaou, IIHR, USA

Laboratory, Field, and Numerical Investigations of the Shinano River in Japan
Shoji Fukuoka, Hiroshima University, Japan

The Development of Next Generation System Model and Decision-Supported Technologies for the Tan-Shui River Flood Forecasting
Dr. Whey-Fone Tsai, NCHC, Taiwan

Appendix II

IIHR-NCHC Collaborative Research--CyberInfrastructure for Adaptive Integrated Management of Aquatic Environments

Proposal Draft
NSF's East Asia Pacific Program
V.C. Patel, M. Muste, T. Papanicolaou, G. Constantinescu, L. Weber, M. Wilson

Background

IIHR-Hydroscience and Engineering, a unit of The University of Iowa's College of Engineering is one of the nation's premier and oldest fluids research and engineering laboratories (Mutel, 1998). The National Center for High-performance Computing (NCHC), founded in 1991, is Taiwan's first national institute dedicated to high-performance computing and network applications research. The present proposal aims at continuing a previous collaboration under NSF auspices: IIHR-NCHC Collaborative Research Project – Integrated Computer Models for River Flow and Application to Tan Sui River conducted between April 2000 and March 2004. Specifically, the project integrates and extends the initial modeling activities applied to river flows with additional tools and functions specific to the emerging cyberinfrastructure concept.

NCHC has recently initiated a comprehensive development effort aimed at setting a state-of-the-art integrated adaptive management framework for general use, including hydrological processes. The framework is based on grid technologies (denoting distributed computing infrastructure) that bring together remote resources (observational equipment, computers, data, and people) to one's local environment. IIHR-Hydroscience & Engineering have also initiated a similar effort with main focus on the hydrological processes and allied disciplines. The overall goal of the new collaboration is to design, develop, and test a multidimensional infrastructure that allows real-time adaptive integrated management of aquatic environments. The proposed work synergistically combines NCHC's on-going efforts for development of Flood Forecasting and Monitoring Network and EcoGrid, applications within the multi-institute Pacific Rim Applications and Grid Middleware Assembly (PRAGMA) with IIHR tools and functions developed for hydrocyberinfrastructure-based adaptive management. Based on the outcome of this effort, it is expected that a broader impact of the proposed research will be the development of a blueprint/framework that can be complementary to efforts undertaken by the NSF through the NEON and HYDROVIEW programs.

Components and Characteristics of Cyberinfrastructure-based Management

Cyberinfrastructure is a newly emerging concept in computer-based management-supporting information systems that provides users with relevant, reliable, and valid information which can easily be interpreted and applied (http://www.eng.nsf.gov/general/cyber/index.htm). Hydro-Cybernet defines a cyberinfrastructure customized for adaptive integrated management of aquatic environments. The overall architecture of the Hydro-Cybernet combines various spatial-temporal information sources, simulators, with management decisions (see Figure 1). The HydroCyberNet main characteristics are:

- combines monitoring, modeling, and decision-making activities in a seamless system
- addresses all water cycle components including vertical (precipitation, evapotranspiration, surface water, groundwater) and horizontal (runoff-stream) fluxes and interactions
- addresses the feedback process between hydrologic, geomorphological and ecological processes at different spatial and temporal scales
- employs data-driven modeling to simulate the above processes
- integrates hydrological/geomorphological/ecological processes with social, and economical aspects
- provides feed-back to decision-support and environment-control systems
- integrates strong academic and public education considerations

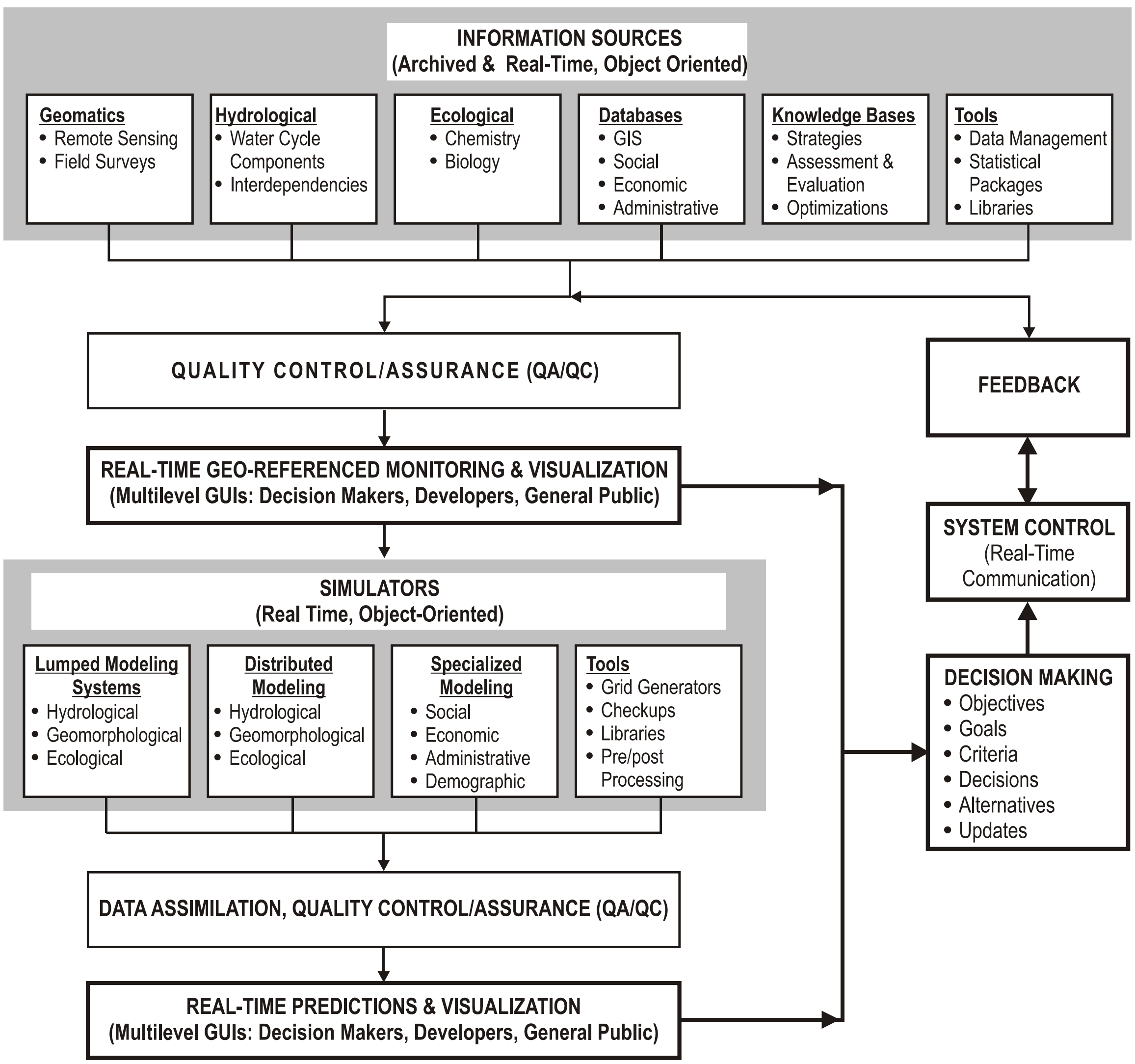

Figure 1. Layout of the Hydro-Cybernet. The cyber-infrastructure: a generic eco-problem solver, web-based (platform independent), multilevel and multitask environment

Information sources can be either static or dynamic. The static information can take various forms such as a description of a topology, the location of a sensor. The dynamic information can be on-line measurements such as hydraulic parameters, geomorphological indicators, ecological indicators or numerical model results. Numerical models include traditional numerical models that solve particular aspects of a hydrological/geomorphological/ecological problem and "meta-models" that combine information from various sources, integrate interdependent tasks, and provide an overall control of the decision-making process. The traditional numerical models should have the abilities to describe physical, chemical, and biological processes in the aquatic environment as well as their interactions and interdependencies over a large range of time and space scales and conditions. The meta-models are key components of the Hydro-Cybernet where the information is processed to create new knowledge. Within these models reasoning processes are orderly performed without human intervention to include in the modeling tasks natural-scientific, and economic-social knowledge. The human interfaces display the results of information processing in a form suitable for promoting the perception of the new knowledge.

A set of tools and functions are needed to assemble the Hydro-Cybernet. Among them are those for organizing the information (object-oriented, semantic and other classes of data bases), interfacing data bases, libraries, transferring and communicating data, handling knowledge in linguistic description, and visualizing the results in a suitable form. Hydro-Cybernet can be used at two levels. The first level concerns decisionmakers, politicians, water resource managers and project engineers. They ask questions about the status of the eco-system, the necessity, feasibility and impact of measures, possible alternatives strategies, etc. The second level aims at analysts, software developers, software maintainers and also, to a certain extent, to project engineers.

Along with the above-mentioned problem-solving components, the Hydro-Cybernet includes a quality-control component. The system acquires data from instruments of various accuracy, performs many computations and data conversions that are potentially introducing errors; hence quality control is crucial before the delivery of the end product to the client. There are two types of quality control: quality control (QC) during the development of a tool and data acquisition, and the quality assurance (QA) for an application. As to the first aspect, quality standards should be defined and checks should be built in that make sure that the systems are developed in such a way that the quality is ensured. For the second aspect a substantial effort should be put into the validating the simulation models. The validation process should produce arguments and evidence that justify the use of the model in a particular situation, and at providing well-founded information about the expected accuracy of models' prediction.

The NCHC's Disaster Mitigation Grid (DMG) parallels Hydro-Cybernet's components and characteristics. DMG is one of several grids currently under development within Knowledge Innovation National Grid (KING) initiative (see Figure 2.a). The modeling and monitoring activities are conducted on the Taiwan Advanced Research and

Education Network (TWAREN) also currently under development (See Figure 2.b). The general architecture of the NCHC Grids software is provided in Figure 3.

a)

b)

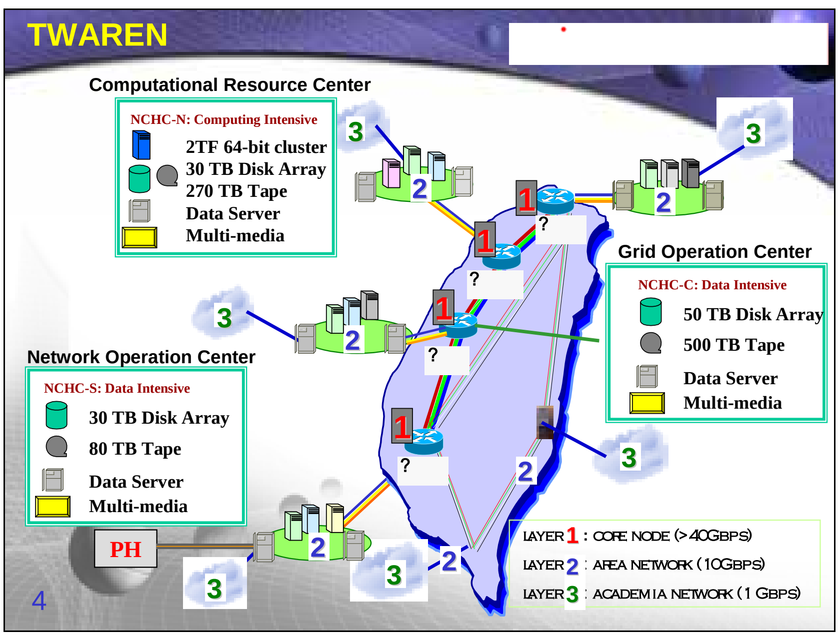

Figure 2. NCHC cyberinfrastructure: a) applications (KING); network (TWAREN); (NCHC, 2004)

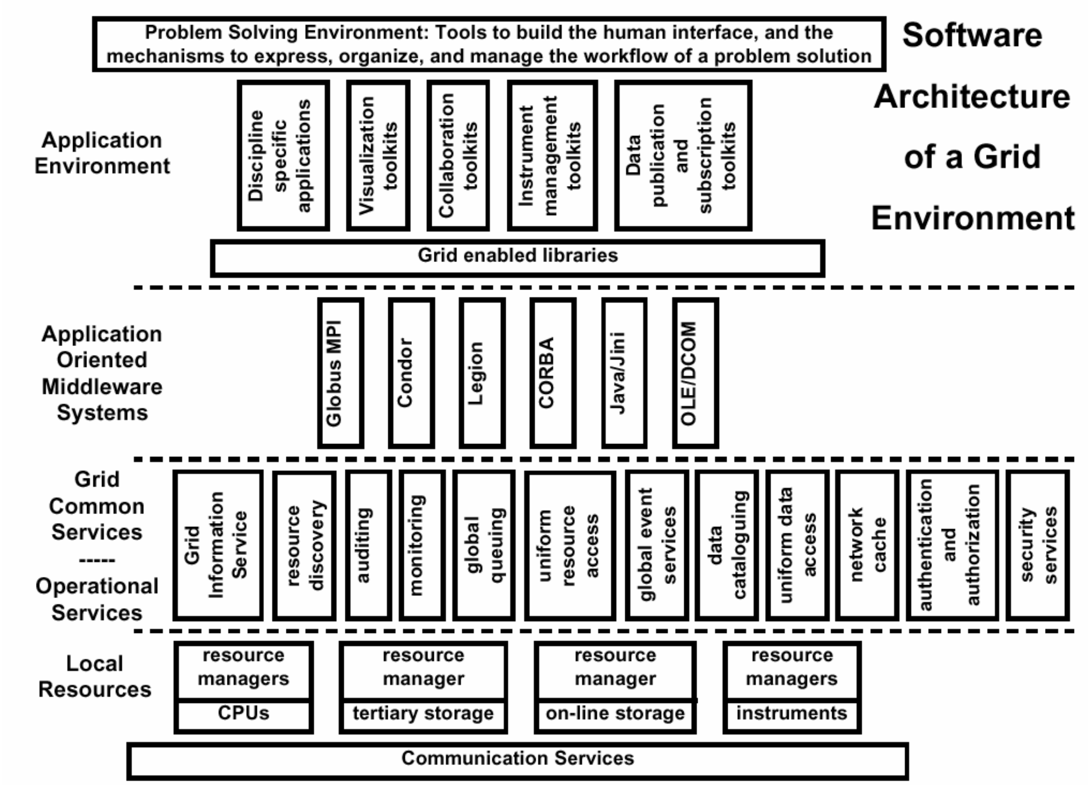

Figure 3. General layout of the software associated with a Grid (NCHC, 2004)

The development of the cyberinfrastructure management frameworks poses a number of challenges that require considerable multidisciplinary research efforts using the most advanced Information Technology (IT), engineering, communication tools and functions. Main challenges are listed below:

Hydro-specific

- large-scale monitoring and simulation conducted at natural landscape unit-level (watershed) for all water cycle processes including their interactions
- remote control and management of monitoring systems
- integration of monitoring and modeling tools with variable spatial and temporal scales to characterize fluxes, residence time, and paths of water, solid and biological material
- development and validation of accurate computational hydraulics tools to model 1D, 2D and 3D processes and development of interfaces in between these models and between these models and hydrological models at the watershed level
- formulation of casual relationships between hydrological processes
- integration of hydrological processes with allied disciplines (e.g., biological, chemical, geomorphological, economic, social)
- quality control/quality assurance analysis

Computer-specific

- integrating geographically-distributed monitoring facilities with simulators and real-time dissemination of measurements and predictions
- data storage, conversion, handling, fusion, mining
- interfacing databases of various natures and conversion to geo-referenced system
- providing adequate computing power, time, and memory
- multilevel (managerial, scientific, education), multitask (qualitative, quantitative) visualization and post-processing routines
- CFD process fluency: latency tolerance, load balancing, job migration, co-scheduling, meta-scheduling
- security, intellectual property, and privacy issues

The similarity of the objectives, components, functions, and challenges of IIHR's Hydro-CyberNet and NCHC's Disaster Mitigation Grid offers a variety of collaborative research opportunities. Research efforts coordinated through the proposed work will bring together the complementary expertise and infrastructure of the two institutes and avoid duplicative work. The specifics of the project implementation details are specified next.

Project plan details

The basis of the present collaborative research was outlined during the March 22, 2204 meeting at NCHC headquarter in Hsinchu, Taiwan. The project foundation will be TWAREN, the high-speed broadband networking infrastructure for research and education currently under development in Taiwan. The Disaster Mitigation Grid (DMG) will be the implementation framework for the proposed collaborative research. Extensive sensor net, middleware software, communication and visualization tools are already in place to support DMG.

CyberInfrastructure tools and functions developed by IIHR to be shared/implemented in DMG:

1. Extension of the NCHC's real-time surveillance system capabilities from qualitative observation to quantitative measurements using Large-Scale Particle-Image Velocimetry (LSPIV). LSPIV is a remote non-contact measurement method for determining free-surface velocity on large scales such as rivers. A summary of previous experiments conducted with LSPIV is provided in Appendix A. This task will also include the results of the IIHR's on-going research of linking the free-surface velocity with the velocity in the water column (USGS-NIWR, 2001).
2. Implementation of uncertainty analysis standards for assessment of data quality, a crucial aspect of the decision-making process. The PIs have extensively used the American Association of Aeronautics and Astronautics Standard (AIAA, 1995) for assessment of uncertainty in various engineering and hydraulic applications. An implementation guide was developed in IIHR for this purpose (Stern et al., 1999).
3. Sharing experience for implementation of remote-control components in the DMG sensor net. IIHR has recently finalized proof-of-concept tests whereby real facilities are controlled over the internet allowing conduct of measurements in real time (Muste et al., 2004).

4. Development of databases for data storage, efficient handling, and “intelligent” data retrieval. A prototype database aimed at facilitating selection of erosion and sediment control measures (ESCM) has recently prepared by the PIs for the Iowa Department of Transportation (Muste and Ettema, 2002). The mini-expert system allows users with limited background in the ESCM area to efficiently store, handle, and retrieve information and, more importantly, to identify the best approach for controlling sediment erosion and runoff at specific construction sites (http://webdev.iihr.uiowa.edu/escm/index.htm). The knowledge database of the expert system is based on a compilation of the most recent manuals on erosion and sediment control. A similar database was prepared for the International Association of Hydraulic Research and Engineering to guide users in selection of hydraulic instrumentation (http://www.iihr.uiowa.edu:88/instruments/index.jsp).
5. Development and validation of advanced Computational Fluid Dynamics codes for simulation of three-dimensional complex flows using advanced turbulence models. NCHC already supports various 1D, 2D and 3D codes which are use to model surface water processes of different complexity. IIHR’s main CFD modeling efforts were focused over the last couple of years on the development of the next generation of codes that use eddy resolving techniques (Large Eddy Simulation – LES and Detached Eddy Simulation - DES) and highly (time and space) accurate numerical methods to simulate flow of interest in hydraulics, river engineering, water resources and environmental fluid dynamics. Recent examples of use of this code for applications related to hydraulics are the LES simulation of the flow in pump intakes of realistic geometry and simulation of the flow around bridge piers. One of the main challenges in the development and validation of such codes is that they require access to high performance computers. IIHR will develop a DES model into its existing massively parallel LES solver on unstructured hybrid meshes (Mahesh, Constantinescu and Moin, 2004, Mahesh et al., 2002) that will allow the application of this state of the art LES solver for complex geometries to simulation of flows of interest in river engineering and hydraulics (flow around hydraulic structures, flow in compound channels and rivers of complex bathymetry, pollutant dispersion studies, gravity driven flows, etc). In particular we are interested in applications that are relevant to flooding concerns in the heavily populated Taipei area. IIHR stands to gain experience in application of this code to a challenging practical problem.
6. Development of a parallel MPI version of a finite differences 3D multiblock code in generalized curvilinear coordinates developed at IIHR (Constantinescu and Patel, 1998) that presently has the capability to solve for sediment (suspended and bed-load) transport with a loose bed and a deformable free surface. The turbulence models available in the code range from near-wall RANS (k- , k- , SST, Spalart-Almaras, k- -v2-f) turbulence models to hybrid RANS-LES approaches (Detached Eddy Simulation) that can accurately calculate the dynamically most important coherent structures in these flows at realistic Reynolds numbers. Our modeling group is one of the leaders in applying DES for complex turbulent flows (Constantinescu and Squires, 2004). Example of applications that IIHR and NCHC are interested is the study of the flow and sediment transport in a 2-3 miles reach of Tan Sui River, flow over bridge piers and bridge abutments and other river-engineering related applications. The present state of the art for these applications

consists of using 2-equation RANS models with wall functions and grids with less than 1 million mesh points. We hope that we can efficiently parallelize this code using MPI and insure code portability to various computer platforms via interaction with the CFD group in NCHC who has lots of experience in this area. This will allow to use grids with 3-10 million points that are required by accurate DES for complex geometries. We also are interested in developing interfaces with 2D depth averaged codes or 1D codes supported by NCHC. We hope to achieve this objective by close collaboration with the NCHC's CFD group. NCHC and NCSA will provide access to the necessary computer resources. IIHR will have access to NCHC facilities by the existing high-speed VBNS connection.

7. Development of visualization tools for particle laden flows. Our parallel LES flow solver described in section 5 has the capability to perform two-phase flow simulations involving Lagrangian Particle tracking of up to 6 million independent particles on grids containing up to 20 million grid points (Mahesh et al., 2002). Application of interest range for particle laden flows to fish passage and protection of the life of endangered fish species in river habitats. These kinds of simulations create a huge database that has to be analyzed so as to investigate the flow physics. NCHC virtual reality visualization laboratory is one of the most advanced in the world. There is a mutual interest between IIHR and NCHC to start using these visualization tools for particle laden flow applications.
8. Development of an integrated watershed tool to predict the fate of flow, sediments, and biological loads (microbes and nutrients). The tool will account for the effects of anthropegenic and natural processes occurring at different spatial and temporal scales and will evaluate the impact of these processes on stream health via aquatic indicators. To do so, upland and instream processes will be interconnected via different methodologies (Papanicolaou et al. 2003). Two types of integrated watershed models will be developed, namely, the river continuum concept and the flood pulse concept. The latter one will be applicable to the geomorphologic settings in Taiwan.

The multitude of activities and the breadth and depth of the proposed collaboration require a dynamic interaction compared to the previous collaborative research. Sharing/transfer/development/implementation of the above technical tasks will be accomplished through direct exchange of graduate students and researchers in addition to regular communication and direct team meetings. It is proposed that at least two graduates students from IIHR, and NCHC-based researchers with expertise in the above listed areas to spend one year at NCHC and IIHR, respectively, to ensure appropriate accomplishment and integration of the proposed tasks.

Impact and Deliverables

NCHC partners will be invited to participate with contributions to the special issue of the ASCE-EWRI's Journal of Hydraulic Engineering and to the ASCE-EWRI's 2005 Watershed Conference Special Technical Session dedicated to cyberinfrastructure and organized by co-PIs Papanicolaou and Muste of IIHR. Both initiatives are led by IIHR with support from ASCE and NSF/hydrological sciences program.

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