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Vision and Progress - Data Models for Multi-dimensional Representation of the River Processes

Hydrolink

Vision and Progress:
Data Models for Multi-dimensio

The vast amount of available observational data on rivers along with the recent advancement in instrumentation, GIS, and informatics call for the development of a standardized framework for accessing river data, maps, imagery and models, and share the information with the community through search and discovery tools.

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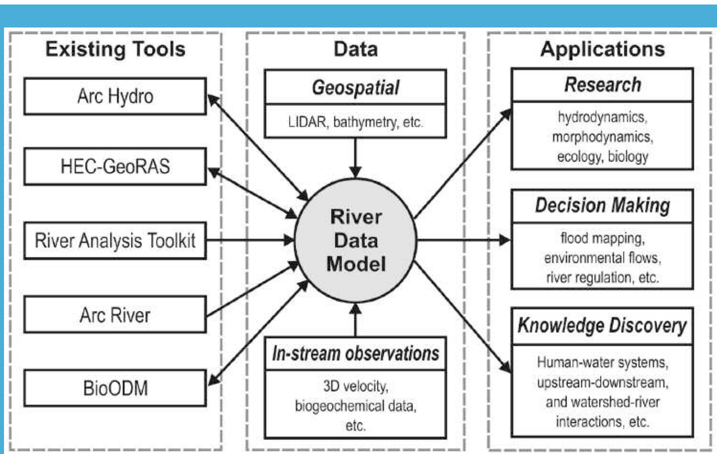
Currently, there are an increasing number of substantial ecological sustainability concerns regarding the world's rivers. Most of these concerns are related to streamflow depletion related to water supply, irrigation, power production, and industrial needs, and extensive use of the in-stream flow conditions for navigation, recreation, waste assimilation, and aquatic habitat. Although many studies have examined human-water dynamics, the complexity of rivers as coupled systems is not well understood largely because of the gaps in our knowledge of river and river network processes, the isolated and disciplinary approach used in the typical analyses, and the lack of efficient tools and data for multidisciplinary studies.

The traditional pillars of the natural systems scientific studies are observation, theory, and analysis. Modern information and communication technology capabilities now allow us to address a new class of problems around the organization of data and information leading to knowledge extraction (Baker and Barton, 2003). The digital revolution is changing radically the way we conduct our science, as well as affecting all facets of society, and it can be argued that informatics has become the fourth pillar of any scientific study. The informatics concept is, however, not new, and it has predecessors in water sciences. The rapid process of electronic encapsulation of information and knowledge in hydroscience since 1990 led to development of the Hydroinformatics field (Abbott, 1991).

So far, the major focus of hydroinformatics has been in the area of numerical simulation, with little emphasis in the area of data representation, organization, and analysis at watershed scale level to further enhance the use of the data. Data can originate from sensors placed on satellites, airborne, located at close range or deployed in the rivers. Integration of the data from all these sources is a difficult task as the data is heterogeneous with respect to type, format, storage media, accuracy, and spatio-temporal resolution. The integration necessarily requires the use of data models that represent properties and relationships among classes of geospatial and temporal hydrologic and hydraulic data regardless of their provenance. An excellent example of a data model for hydrology is the ArcHydro data model (Maidment, 2002). Data models are necessarily associated with convenient software toolkits for resource discovery, interactive visualization and analysis, and collaboration among distributed teams of investigators.

The vast amount of available observational data about rivers along with the continuously increasing capabilities offered by the Geographic Information Systems (GIS) and the advanced river instrumentation calls for integration and thematic synthesis. For this purpose the geospatial datasets need to be linked with the morpho- and hydrodynamics observational data in GIS web-portals that supply data, maps, imagery and models, and share the information with the community through search and discovery tools (Dangermond and Maidment, 2010). The essential idea of the river data models is that a river is a lot more than just a GIS line feature. Rivers are multi-dimensional objects characterized by geographic (drainage area, river network, soil

Figure 1. Synergy of the River Data Model with existing components for acceleration of the practical implementation



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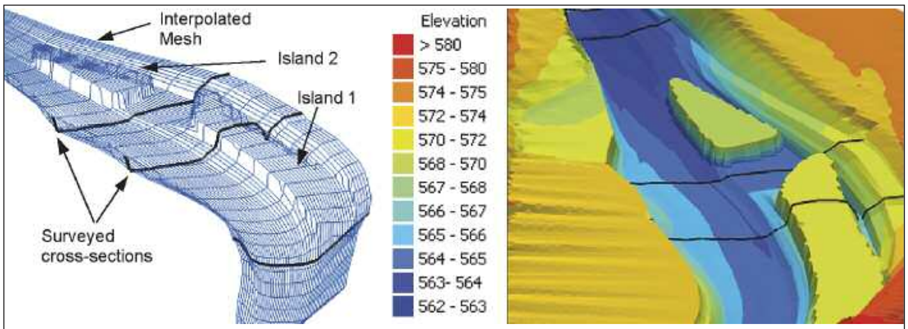

a) Interpolated mesh from surveyed cross-sections b) Integrated terrain with mesh and DEM

Figure 2. Bathymetry generation for Kootenai River (Idaho): (a) interpolation of surveyed cross-sections; and (b) integration with LIDAR digital elevation model (Merwade et al., 2008).

and morphologic data, land use and coverage, socio-economic), hydrodynamic (flows, levels, inundation maps, and three-dimensional in-stream data), and water quality (sediment, pollutants, biologic, and ecohabitat data) characteristics.

Our vision for the River Data Model (RDM) is to support storage, discovery and manipulation of river-related data for scientific and engineering applications including hydrodynamics, morphodynamics, ecology and biology (Fig. 1). Similar to other data models, RDM will be supported by a toolkit for river applications.

There are ongoing developments in the area of river data modeling that can be readily used to accomplish the vision for RDM. These developments include the river channel model within Arc Hydro (Maidment, 2002), the preprocessing toolkit (HECGeoRAS) for hydraulic modeling of the river (USACE, 2009), river bathymetry analysis toolkit (Merwade et al., 2008), Arc River model for ingesting river measurements (Kim et al., 2007), and the recent development of BioODM (Maidment, personal Communication) for biological river data using the Consortium for Advancement of Hydrologic Sciences Inc. (CUAHSI) Hydrologic Information System's (HIS) Observation Data Model (ODM). Essentially all these developments provide unique core functionalities for RDM including handling of geospatial data, observational data, geospatial and temporal analysis, and numerical modeling. For example, ArcHydro and HECGeoRAS have a data model for storing river morphology in the form of cross-sections and profile-lines. River analysis toolkit has functions for spatial interpolation of river bathymetry using orthogonal coordinate system, linear interpolation and integration of river-cross-sections with Light Image Detection and Ranging (LIDAR), and tools for creating approximate river morphology using limited river bathymetry data obtained from acoustic instruments (Fig. 2). The Arc River data model has tools for handling 3D river observations acquired with Acoustic Doppler Current Profilers (Fig. 3). Within RDM, the 3D river characterization will be connected with the

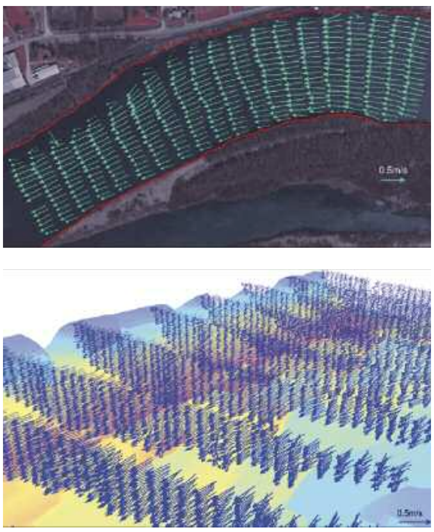

Figure 3. River morphology and mean hydrodynamic characteristics obtained from ADCP measurements on a Mississippi River reach; (a) 2D reach scale representation of spatially double-averaged velocity field; (b) spatially averaged ADCP transect measurements within the reach (Muste et al., 2010).

available mapping for river networks to enable the connection of the rivers with their watersheds. While the developments described above provide a proof of promising progress towards the vision of RDM, several challenges and/or opportunities exist. These include: (i) formulation and development of a data and modeling framework for supporting 2D and 3D modeling of rivers; (ii) integration of real-time point observations (e.g., streamflow and stage) and satellite data (e.g., flood inundation) within RDM; (iii) data mining capabilities for extracting river features from remote sensing data including LIDAR and satellite images; (iv) ability to link river data with other national datasets such as soils and geology for scientific discovery; and (v) meeting the needs of regulatory agencies flood inundation studies and in-stream flow studies. The importance of elevation data in producing accurate flood inundation maps has resulted in availability of more detailed data in the form of LIDAR. Similarly, the need for determining reliable environmental flow conditions requires collection of detailed bathymetry datasets using in-situ acoustic methods for 2D modeling of river channels. All these developments call for a standardized framework for handling and processing river data including supporting tools for river modeling.

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