GIS in Hydrology and Water Management

Leibniz Universität Hannover

General

- Sessions
  - Lectures: 10.04; 24.04; 15.05; ; 12.06; 26.06
  - Practice: 17.04; 08.05; 22.05; 05.06; 19.06; 03.07
- Grade
  - One home assignment (50%)
  - Final written examination (50%) – open book
  - Pass both parts; HA valid only on the 1st term exam
  - Basic GIS knowledge is required
  - Contact Claus Burwitz to get login/access in GIS-Lab
- Personnel
  - sagi.dalyot@ikg.uni-hannover.de (room 603, tel. 2472)
  - anna-walter@gmx.de

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General

- Motivation:
  - Age and era when natural resources are increasingly scarce and the effects of human activities are pervasive.
  - GIS have been increasingly used to support hydrological models and water resources management, planning, design, analysis, and decision making.
  - GIS tools are used to characterize the environment, predict impacts, and develop plans to minimize impacts - while enhancing sustainability.

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General

- Tools:
  - Demonstrating how the appropriate use of GIS in hydrological and water management studies can help to achieve the required/desired results efficiently.
  - The module will present applications and analysis related to an array of water-related applications of GIS and spatial information in hydrology and water management.
  - The main part of this module will be dedicated to specific hydrologic and water management applications in GIS working environment, referring to exercises and examples from hydrology and water management.

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General

- Tools:
  - The module will aim at familiarizing and understanding related contents: advance technologic skill developing for (2D and 3D) analysis, modeling and visualization of geospatial data as a decision-making, planning and environmental tool.
  - Emphasis will be given to understanding/working with topographic models (DTMs) and spatial interpolation concepts.
  - Various subjects and topics will be implemented in ArcGIS 10 as “hand-on”s, exercises and assignments, providing with opportunities for development of practical skills in GIS geo-processing data.

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Textbooks on GIS

Literature

- Geographic Information Systems in Water Resources Engineering, Lynn E. Johnson, CRC Press (2008)
- Hydrological Applications of GIS, A. M. Gurnell and D. R. Montgomery (Editors), Wiley (2000)
- Arc Hydro: GIS for Water Resources, David R Maidment (Editor), ESRI Press (2002)

ESRI ArcGIS

- Using ArcGIS 3D Analyst, *GIS by ESRI, Redlands, 2009.*
- Using ArcGIS Spatial Analyst, *GIS by ESRI, Redlands, 2009.*
- ArcHydro Tools - Tutorial, GIS by ESRI, *2009.*

Web resource

http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html

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Topics Outline

- General Introduction
  - GIS technology / affinity to hydrology
  - Modeling (with) spatial information
  - Overview of properties of spatial information in hydrology and water management
  - Current practice of GIS-Support for hydrological models
- Hydrological Models and GIS
  - GIS and spatial characteristics in support for hydrological models
  - Concepts of space and time
  - Linking GIS and hydrological models

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Topics Outline (continued)

- Digital Elevation Models / Application in Hydrology:
  - Introduction to DEM
  - Data quality aspects
  - Spatial analysis (3D/Spatial Analyst)
  - Application of DEM in hydrological modeling and applications
  - 3D Visualization (ArcScene)
- Interpolation of Hydrological Variables
  - Interpolation methods – concepts and guiding principles
  - Selecting the appropriate interpolation method for a hydrological problem

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Topics Outline (continued)

- GIS in support for Groundwater Modeling
  - Modeling regional groundwater flow
  - Modeling surface runoff
  - Parameters and boundary conditions
  - Groundwater models and decision support systems
  - Numerical models and GIS
- GIS in Water-related Information and Decision Support Systems
  - Functions and structure of GIS based information
  - Decision support systems for hydrological and water management purposes
  - Selected examples

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GIS in Hydrology and Water Management

Introduction to GIS

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Why GIS?!...

- There is a growing importance since early 1980s to ‚relate' data with its spatial phenomena
- This importance involves scientific, technical and socio-economic disciplines – as well as public sectors
- To date – more than 80% of all economic decisions have spatial components
- Large number of different products for a large bandwidth of applications
- „Geographic Information System" answers all that; it enables a vast array of geospatially-derived analysis capabilities, with flexible data-storage and visualization (2D and 3D and 4D)
- Strong affinity to hydrological and water management problems

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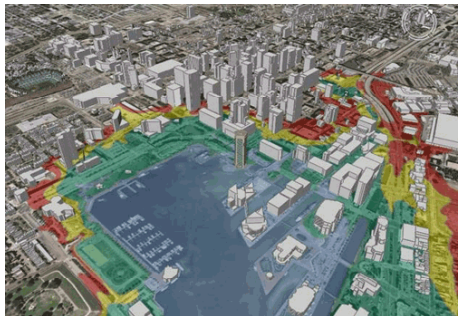
Why GIS?!...



Hydrological and water management problems: decision making, scenarios, scale-flexibility of analysis, integrated data-models (topography, city-models, raster,…), 2D/3D/4D, …

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Why GIS?!...

- Commercially available systems from early 1980 (ESRI ArcInfo, 1981); Today: ArcGIS Desktop 10
- GIS used more and more for
  - acquisition,
  - storage,
  - analysis,
  - Presentation/visualization

  of spatial data.
- (Geo)Spatial data has/presents elements existing in reality with respect to
  - Position within a coordinate system (=geo), and position/presence in general
  - Spatial relationship (topology), such as neighborhood, proximity,..
  - Properties (attributes) related to the specific element's position, for example: groundwater table, land use, etc.

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Why GIS?!...

- A GIS should be seen not only as a software package, but rather as a comprehensive system, consisting of hardware, software, data and users.

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GIS Components

- GIS consists of 5 major components:
  - **Hardware**/computer system that
    - Store,
    - Process, and
    - Present

    the digital spatial data (including: printers, screens, etc.);
  - **Software** that performs GIS operations/analysis;
  - Digital (or digitized) geographical/geospatial **data**;
  - **Procedures**/methods aiming at completing the desired tasks;
  - Expert knowledge to apply GIS appropriately (**professionals**).

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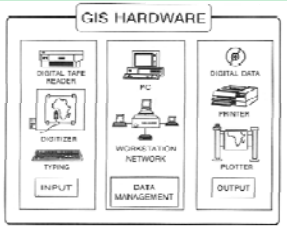
GIS Components - Hardware



Input devices	Computer CPU	Output devices
Digitizer Scanner Digital camera Data on EDP media Remote sensing	Mainframe Unix workstation PC	Monitor Inkjet printer Laser printer Offset printing (Plotter)

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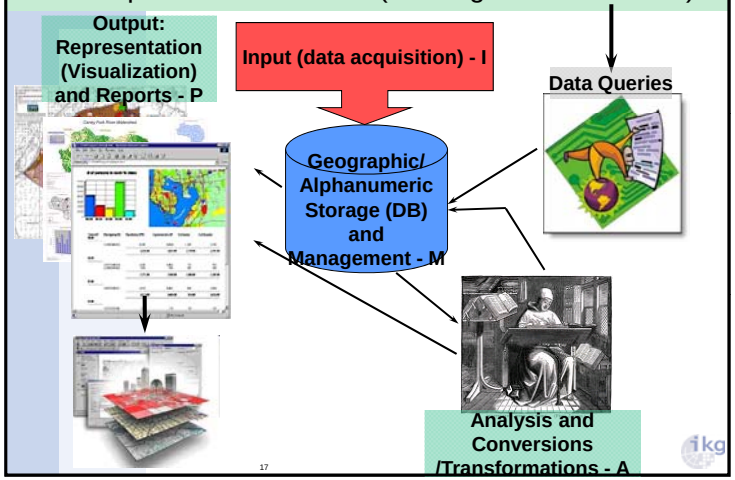
GIS Components – Software (working scheme - IMAP)



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GIS Components – Software (working scheme - IMAP)

- **I**nput Data Capture:
  - Data sources: images, raster maps, geodetic measurements, vector data, digital topographic landscape models, statistics, …
- Data **M**anagement:
  - Data modelling and data structures (databases)
  - Goal: rich data structures that support later analysis processes
- Data **A**nalysis:
  - Thematic queries (SQL – Structured Query Language for Database Management Systems)
  - Geometric analysis (intersection, buffering, overlaying, …)
- Data **P**resentation:
  - 2D-Visualization, maps, diagrams
  - 3D-Visualization (stereoscopic, screens)
  - 4D-Visualization
  - Simulation and VR

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GIS Components – Software – IMAP/Hydrology

- For example:
  - Defining watershed and its hydrologic and hydraulic characteristics to apply for rainfall-runoff modeling and processing
  - Mapping landuse and population demographics in support of water and wastewater demand estimation procedures
  - Interpolating groundwater contaminant concentrations via given sampled data at observation wells aquifers
  - Monitoring occurrences and intensities of severe thunderstorms and providing tools for warning
  - Coordinating simulation and optimization models for scheduling interactions between basin water supplies, reservoirs, diversions, demands, …
  - …

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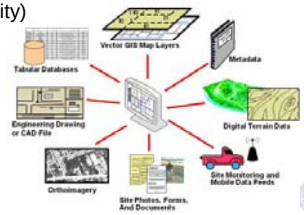
GIS Components – Software

- Data acquisition
  - Digitizer, import of raster data sets (scanner, RS (satellites, aerial), video digitizer), surveying, import of external data sets, attributes, CAD, …
  - Preferably, more than one source (integration of sources)
  - Error correction (data quality), topology editing, geo-referencing/rectification (Coordinate system)
  - Increasing availability of digital data
  - Data exchange (interoperability)



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GIS Components – Software

- Data management – organizing, formatting, structuring and storage
  - Efficient access/availability (unified interface for all software components) of data
  - Reliable architecture, optimization and completeness of stored data
  - GIS – normally data and information is organized in layers (data feature-sets)

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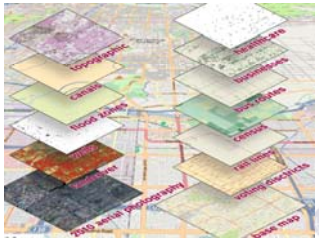
GIS Components – Software

- Data analysis – turning the geographical database to an information system
  - Where? GIS reports the coordinates (position) and/or the relation to other objects of a specific phenomena and its geometry
  - How many? GIS reports the number of occurrences of a specific feature set
  - What? When? GIS reports the attributes (semantics) of a specific feature object



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GIS Components – Software

- Spatial data analysis – examples:
  - *Where is object A?* coordinates of a monitoring site;
  - *Where is object A in relation to object B?* Relation of a potential polluter (A) to the protection area (B): within/outside/proximity/…
  - *How many objects of type A are within a distance D from object B?* How many monitoring wells (A) are available within an estimated extent (D = buffer) of a well's cone of depression? (also: adjacency, crossings, overlay, logical combination, …)
  - *What is the value of function z at a certain position?* For location x, calculate the groundwater table value via function z (interpolation)
  - *How large is object B?* Area, perimeter and length are calculated and managed; used to evaluate areal statistics for time-area diagrams

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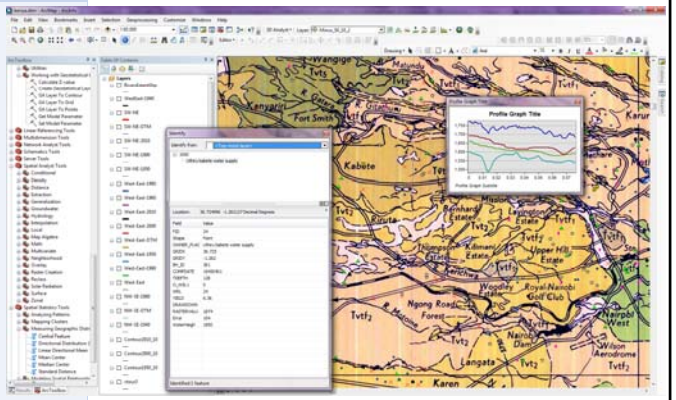
GIS – Geometry + Thematic Data



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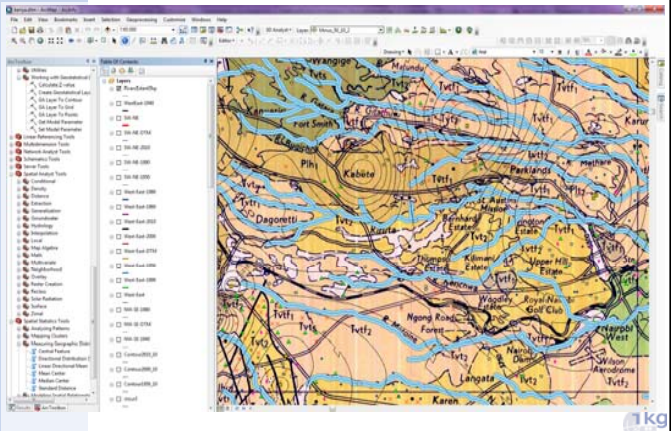
GIS - Spatial Analysis



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GIS in Hydrology and Water Management

Spatial Information in Hydrology and Water Management

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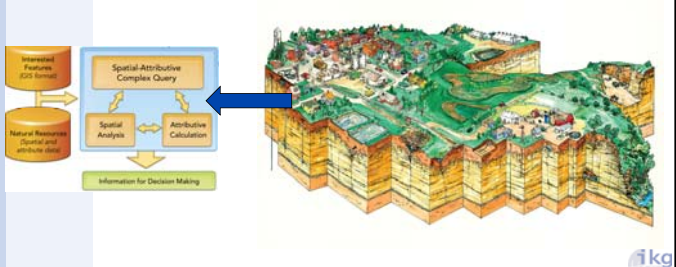
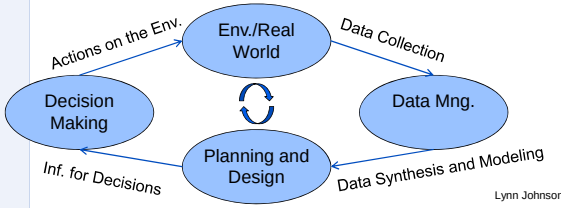
Introduction

- The motivation is to establish a relationship between problems in water resources analysis and management and the capabilities of GIS
- Achieved by comparing of terms and schematic figures
- Aiming at characterizing hydrological information



Introduction

- Water resources infrastructure is a long process involving information gathering and interpretations, plan development, decision making and financing, construction and operation.
- Setting objectives; data collection, management and synthesis; planning and design (modeling); gathering of information for decision making; taking action.
- **Cycle: real world -> model -> real world**



Lynn Johnson

Introduction

- Numerous developments and analysis capabilities in GIS technology originate from environmental and natural sciences
- The use of GIS in hydrology and water management is ‚natural'
- Hydrologic models are characterized, based and derived on information that have spatial extent (mainly area-driven), for which hydrologic processes are to be described
- Spatial hydrologic information is basis for water management planning, both for use and protection of water resources and the environment

Introduction

- Spectrum of domains for the application of GIS to water resources engineering:
  - Surfacewater hydrology
  - Groundwater hydrology
  - Water supply for municipalities and irrigation
  - Wastewater and stormwater
  - Floodplains
  - Water quality
  - Monitoring and warning
  - River basins
- Common to all:
  - Control of spatial and temporal distributions of water
  - Water use systems design
  - Natural environmental systems for sustainable functions

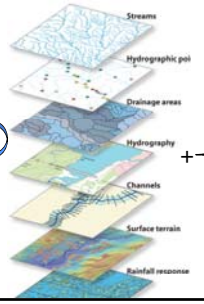
Motivation

- Concordance between tasks in hydrology and water management and functionality of GIS technology:

Hydrology and water management	**GIS**
The scientific study of the properties, distribution, and effects of water **on the earth's surface, in the soil and underlying rocks**, and in the atmosphere	GIS is a system of hardware and software used for storage, retrieval, mapping, and analysis of **geographic data**, … which references a **particular place on the earth**

Motivation

Hydrology and water management	**GIS**
Hydrologic cycle	GIS ‘reality’



+ Inter-Processes Action procedures

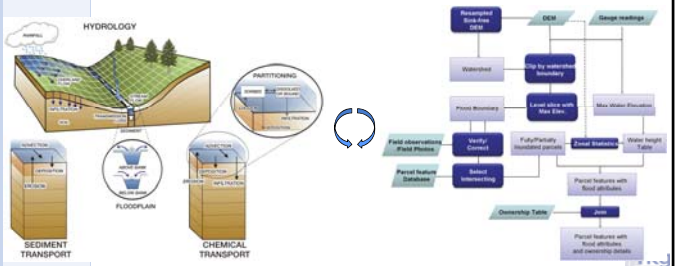
Motivation

- Relevant GIS Data Sets/layers

Data Category	Example Map Layers
Base-map data	Topography
	Major positional references
Area data	Landuse areas
	Demographic areas
Environmental data	Soils map
	Streams and water bodies
	Floodplain map
	Land cover
Network infrastructure facilities data	Water system
	Sewer system
Land records data	Parcel boundaries
	Land-parcel boundaries
Transportation…	…
…	

Motivation

Hydrology and water management	GIS
Hydrologic modeling	GIS modeling

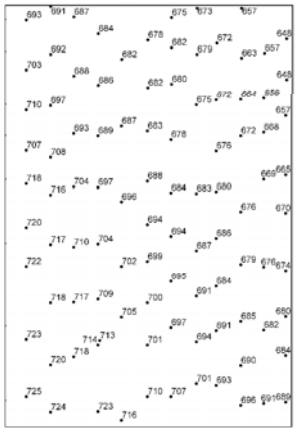


Data and Information

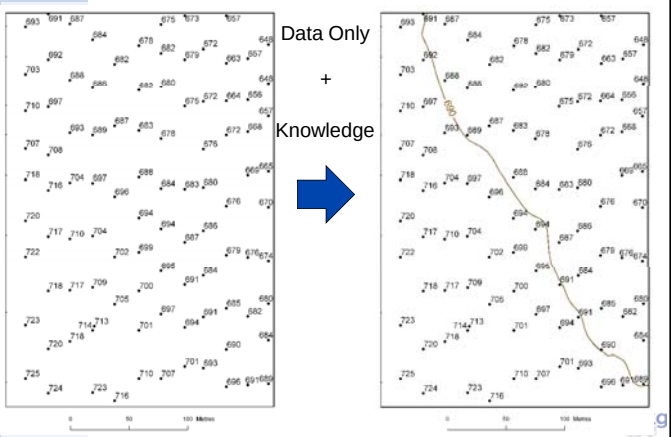
- Differentiate between „Data“ and „Information“ is mandatory:
  - **Data**
    - Facts, statistics used for reference of/or analysis
    - Numbers, characters, symbols, images etc., which can be processed by a computer
    - Must be interpreted - human or machine - to derive informative meaning
    - "Data is a representation of information“
    - ‘Datum' (Latin) = "that which is given"
  - **Information**
    - Knowledge derived from study, experience (senses), or instruction
    - Communication of intelligence
    - Any kind of knowledge that is exchangeable amongst people, about things, facts, concepts, etc., in some context
    - "Information is interpreted data"

Data and Information

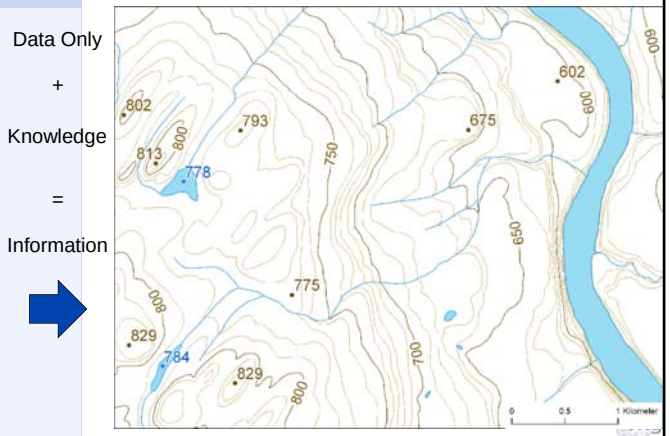
Data Only



Data and Information



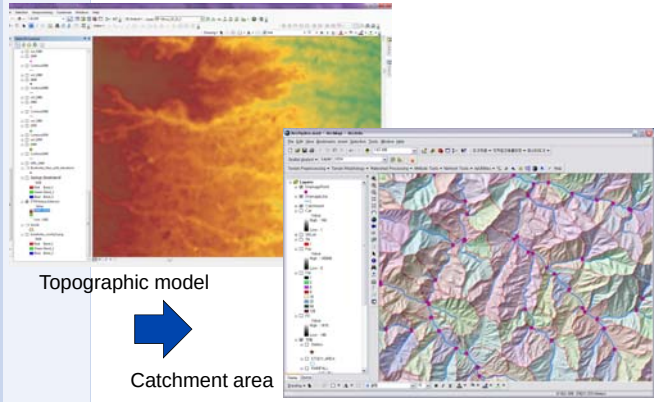
Data and Information



Data and Information

- Data + Knowledge = Information
  - Data: an array of geo-referenced heights describing the topography
  - Knowledge: creating heights iso-lines, which derive water-flow (creating knowledge)
  - Information: catchment area(s)
- The model concept determines data requirements
  - The unit hydrograph contains information about the watershed delineation, which depends on shape, size, height, geology, slope, etc.
  - Having a spatial reference
  - Models with distributed parameters use a spatially distributed characterization of catchment properties

Data and Information



Data and Information

- Information in maps:
  - Identify location via feature's symbols
  - Identify relationship between features (connected, adjacent, contained, intersect, …)
  - Display multiple/simultaneous attributes of an area
  - Discrimination of distributions, relationships, trends, …
  - Classification of feature attributes and graphic representations (thematic maps)
  - Visually interpret feature attributes as text, values, …
  - Detect changes over time
  - Integrate data from diverse sources to common geographic frame -> comparison

Data and Information

Properties of spatial information in hydrology and water resources

Information	Hydrol. time series	River network	Land cover	Terrain	Hydro-geology
Geometry	points	Lines (in 2D or 2.5D) (underwater – 3D?)	Polygons (in 2D or 2.5D)	2.5D/3D surface	bodies, volumes
Acquisition	point related, time dependent	ground survey, RS, derived from DEM	ground survey, RS, point and line samples/ classification	ground survey, photo-grammetry, RS, Radar	boreholes, geophysics, geology,…
Presentation	hydrographs, maps of monitoring networks, 4D simulation and animation	maps, longitudinal profiles, cross sections, …	maps, areal statistics, …	2.5D/3D, contours, raster maps, hillshading, cross sections, hypsometric curve	raster maps, contours, profiles, pseudo-3D, fence diagrams

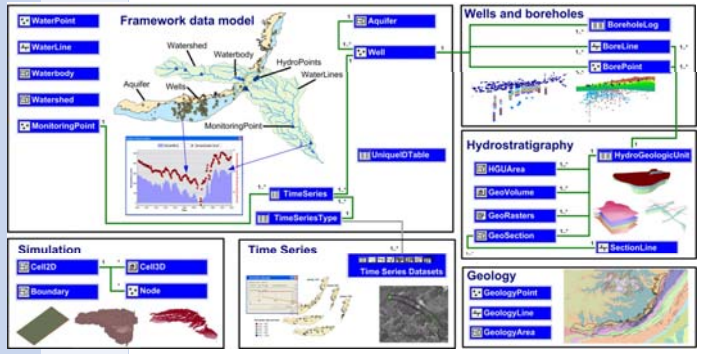
Data and Information

Properties of spatial information in hydrology and water resources

Information	Hydrol. time series	River network	Land cover	Terrain	Hydro-geology
Model application	Runoff, groundwater, flood statistics	Hydraulics, flood routing, ecology, limnology	Soil erosion, evapotranspiration, GW recharge	Synthetic drainage network, soil erosion, …	Groundwater, soils, river basin models, …
Attributes	Quantity, quality, thresholds, …	Discharge, quality, ecol. state, use, …	Nominal, ordinal, cardinal scales, …	Terrain elevation (elips/MSL)	Soil type, geological strata, conductivity, porosity, …
Topology	Neighbour-hood, spatio-temporal interpolation	Horton–Strahler number/order, administrative order, catchment, …	Neighbour-hood, thematic overlays, …	Aspect, slope, flow accumulation, …	Geological sequence, …

Based on Josef Fürst

GIS modeling / Water Resource Management



ArcHydro data model

GIS modeling / Water Resource Management

- GIS supports inter-disciplinary methods and processes related to hydrology-related processes
- Water resources management
  - Human impacts on surface and subsurface water
  - Conflicts between natural water supply and anthropogenic demands
  - Uses and functions
    - water supply, flood protection, water quality, sewage treatment, flow regulation, drainage, erosion, sedimentation, …
  - Protection and enhancement
    - Natural water bodies, water resources, eco-systems, water quality, …