

# REAL-TIME CARTOGRAPHY IN OPERATIONAL HYDROLOGY

*C. Lienert<sup>1\*</sup>, R. Weingartner<sup>2</sup>, L. Hurni<sup>1</sup>*

<sup>1</sup> *Institute of Cartography, ETH Zurich, Switzerland - {lienert, hurni}@karto.baug.ethz.ch*

<sup>2</sup> *Geographical Institute, University of Berne, Switzerland - wein@giub.unibe.ch*

The present paper describes a project in which real-time cartographic concepts are combined with the needs in operational hydrology. First, the current state of research in these and related domains are presented. Methodological considerations are made in term of the data and the data models as well as regarding to their access, visualization and technical environment. Finally, remarks are made as to the expected results of the project and the use for operational hydrology.

## **1. Introduction**

### *1.1. Aims, questions and problems*

Cartographers follow certain rules which apply to map production work steps such as acquisition, storage, processing, visualization and archiving of data in order to deliver spatial information. Up to the present, these work steps were mostly accomplished off-line, with human supervision. For a web-based real-time cartographic application, however, the entire map production process must be achieved in real-time, on-line and with as little human control as possible.

In the project which is described in this paper, real-time cartography is oriented toward operational hydrology. The automated cartographic process will be implemented in a web-based prototype application such that it can support decision makers in their task to monitor developments and actual situations of looming flood events. While much effort in flood risk management is made in the field of forecasting, the real-time monitoring component is likewise important in order to classify, document and assess ongoing flood events in relation to historical data. For this purpose, up-to-date and diversified, yet condensed and easy to grasp data visualizations are needed with which decision makers can constantly reevaluate actual hydrological situations.

## **2. Current Research**

### *2.1. Cartographic visualization*

Even though definitions for cartographic visualization slightly differ in the literature (see e.g., BUZIEK 2000; DYKES *et al.* 2005; KRAAK 2007), the common denominator is that cartographic visualization nowadays uses appropriate communication means and media, emphasizing the importance of interaction, dynamic use of maps and graphical presentations linked with animations. Closely associated with cartographic visualization in relation with ever-increasing data sets and amounts is the field of data-mining. In short, data-mining is concerned with techniques such as processing and analyzing very large data sets and filtering out important parts of it (BÉDARD *et al.* 2001). They may then be used for visualization.

### *2.2. Hydrological maps and diagrams*

In our project, maps are classified into those that represent either atmospheric or surface water. Height is the measured quantity to capture precipitation, resulting in a volumetric representation when combined with the area on which it falls. The key activity in precipitation mapping – and mapping of all phenomena deriving from it such as soil moisture – is interpolation. Different univariate and multi-variate interpolation techniques are applied to determine the spatial distribution of precipitation (see e.g., SEVRUK 1985). Today, however, radar imagery is used to determine the spatial extent of precipitation and intensities over a certain field. Ground station are more and more used to calibrate and to raise the accuracy of radar data (ZHIJIA *et al.* 2004; CHUMCHEAN *et al.* 2006; HABERLANDT 2007). All these data are used for the creation of hydro-meteorological maps. A good source for such depiction (e.g., area-related discharge using choropleth maps, flow maps of discharge quantities, extreme regional precipitation of varying duration and return period, etc.) are national atlas systems (e.g. HADES 1992-2004; ADS 2004).

Signs, graphic structure, meaning, context as well as multi-functionality and data density are all aspects to be considered in diagrammatic representations. In geo-spatial terms, choosing between maps or diagrams in the data visualization process is crucial because spatial relations are lost. Although only representative for a specific point, diagrams and numeric summaries are the most significant tool in exploratory data analysis (DENT 1996). Beside these

considerations, it must be distinguished between visualizations of actual data (e.g., the most recent hydrograph) and those that are made of actual data in combinations with existing data series, based on statistic inference (e.g. intensity-duration diagram). For the former, multi-dimensional query functions must be developed in order to show the existing situation at various measurement points and eventually suggest change and evolution over time. The latter require robust routines and rules that act on existing data models so that statistics can quickly be re-calculated.

### *2.3. Web cartography, web-GIS and decision support systems (DSS)*

The growth of map distribution through the internet has been especially dramatic since 1997 (PETERSON 2003). To tap the full potential of web cartography, technical receivables (interactivity, dynamic and multimedia) as well as information demand (accessibility, timeliness, authenticity) must result in two main effects: a more comprehensive information communication and enhanced cartographic exploration and analysis. While web maps can be classified into static, interactive and animated, designing them is associated with technical restrictions and specific semiotic requirements. Effective web map design is constituted by a balanced composition of the map's form and function (CARTWRIGHT 2003). The form of the initial web map should be simple but user should then be enabled to interactively make visualizations more complex (e.g., by increasing the level of detail) or less complex (e.g., by removing visualization elements through aggregation).

DSS, particularly in real-time flood forecasting, are widely discussed in scientific literature (MATTHIES *et al.* 2007). Originally developed to support business management, DSS are regarded as computer-based information systems furnished with interactivity, flexibility and adaptability. They support the recognition and solution of a complex, poorly structured strategic management problem for improved decision making. Such systems often include one model or several coupled models, databases and assessment tools and integration of a GUI. A GIS provides the data management functionalities. After SALEWICZ and NAKAYAMA (2004), the basic concept of a DSS applies well to purely technical environments, yet it falls short of considering the role of the human factor. Today, DSS research focuses on model management (allow uncertainty, see e.g., MOLINA *et al.* 2005), group support (clarification of user's needs, see e.g., TODINI 2004), design (choose from more than "yes" or "no", see

e.g., ALOYSIUS *et al.* 2006) and implementation (client-server architectures, see e.g., AL-SABHAN *et al.* 2003).

#### *2.4. Real-Time Cartography*

Programmes of a typical real-time system control the overall operations of the system, enable the program to synchronize with time itself, specify times at which actions are to be performed and completed and handle situations when timing requirements can not be met. Translated into cartography (see MOELLERING (1980) for a early discussion about theoretical strategies), temporal aspects bring about the difficulty of the representation of time (LAURINI *et al.* 2001; VALPREDA 2004). Due to the fact that time can not be tackled as a continuous entity, techniques such as time-stamping, time slicing or chaining are employed. Data storage and accessing voluminous time series data are identified to be a potential problem and updating in a GIS remains a challenge to this day, particularly in terms of maintaining the system's flexibility. Summarized, the critical steps for which the date of storing and updating information is very critical are:

- Input (data must be immediately taken into consideration),
- Storage (storing the maximum information in the main memory, flushing elderly data into data warehouses),
- Output (graphic semiology for real-time environments),
- Inter- and extrapolation (for representing spatial data between the time steps of their acquisition),
- Integrity (automatic check and maintenance of spatial and temporal integrity in case of system or sensor failure),
- Interoperability (reading and writing the same file formats and using the same protocols).

### **3. Methodology and Technologies**

#### *3.1. Data and test area*

Real-time data processed in the project are river discharge, precipitation (ground gages and radar imagery) and temperature. Temporal resolution is not lower than one hour and available no later than one hour after its measurement. The test area to which the planned prototype is geared is the Thur basin in northeastern Switzerland, roughly between Zurich and Lake

Constance (see Figure 1). Its area amounts to 1750 km<sup>2</sup> and its highest point is Mount Saentis with 2501 m a.s.l. At the estuary into the Rhine the altitude is 336 m a.s.l. A special feature of the basin is that it is the largest tributary to the Rhine in Switzerland without a lake which could have a retentive effect on the discharge. Severe precipitation events therefore are quickly perceivable.

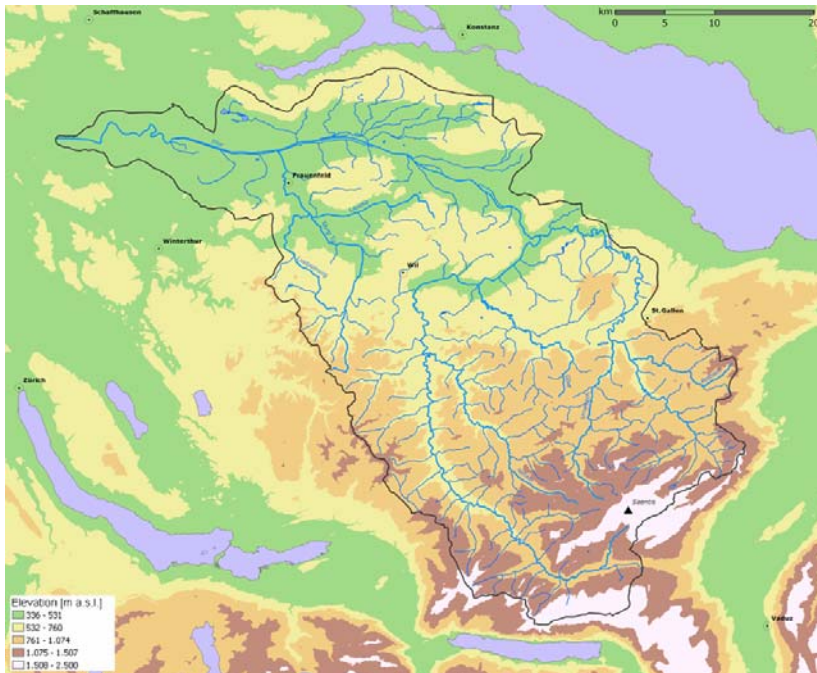


Figure 1: Overview map of the Thur basin (own representation).

### 3.2. Structure of the prototype

The methodology to develop a cartographic prototype for operational hydrology is based on, and guided by, three main questions which eventually result in a threefold prototype structure. The three questions are: what visualizations or functionalities are needed in order that operational hydrologists...

1. ...are enabled to quickly grasp and explore the overall picture of the hydrological situation in real-time.
2. ...may retrace short-term developments of the hydrological system status.
3. ...could learn from former events by comparing real-time data with, and statistically relating real-time data to, historical data.

Figure 2 shows the conceptual framework to address these questions. The first of these layers requires hydrological maps on the one hand and summarized, calculated information on the other. Thus, apart from spatial distributions of relevant phenomena, click-on features must be provided at certain locations that show measured or modelled values (such as tabular or graphical data at gage locations or the areal precipitation for sub-basins). Functions and rules are needed that recalculate all relevant statistics and render associated visualizations. Since the real-time's data range of dispersion is not a priori known, special attention must be paid to statistics of historical data and flexible algebraic-to-graphic transformation when producing, for example, graphs or choropleth maps.

The second layer allows a user to retrace the hydrological developments on the event-scale (past few days) from a chosen moment up to the present. Methodically, animations and multi-views in widgets are intended to visualize developments and different development stages (ANDRIENKO *et al.* 2005). Fast forward, backward, repeat, fix images and slow motion are options to provide interactivity on this layer. In order to contrast different frames, features will be developed such as dragging a desired representation from the main display area and dropping it over a target area next to it. This, way maps or graphs can be contrasted side by side.

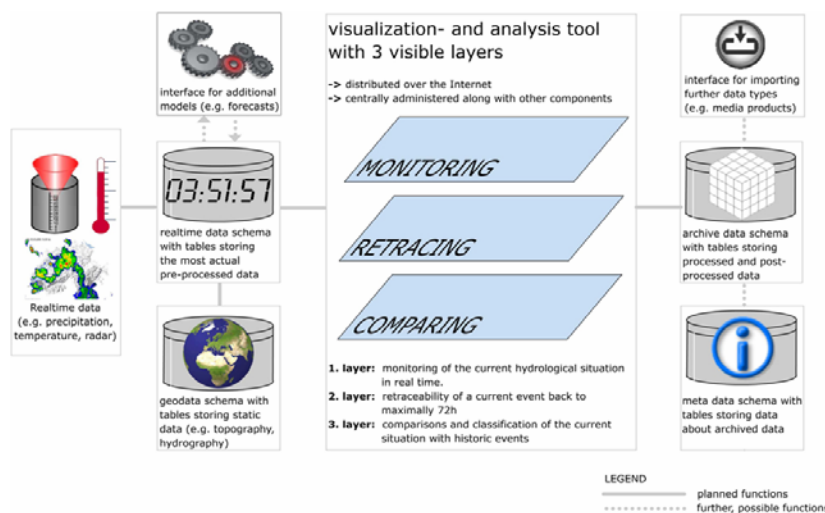


Figure 2: Conceptual framework of the project (own representation).

The third prototype layer eventually offers functionalities to compare real-time data with historical data (past few years). If actual, measured data resemble historical data, routines retrieve historical, measured data from an archive and pass them to visualization routines. Visualizations may come in form of the actual datum being plotted eye-catching in an extract of a historical hydrograph or even in a frequency-probability diagram of the whole observation period. Related information such as text or media products may also be accessible and displayed in a separate window. Realizing this prototype layer certainly not only requires complex operations such as fast retrieval and rendering of archived data but also demands keeping the archive up-to-date so that it becomes invaluable for operational hydrologists.

### *3.3. System architecture*

The planned prototype will have a client-server architecture where data and databases are tightly coupled to data models and processing steps on the server. At this stage of the research, one main database is set up which stores four different types of data: measured real-time data, measured archive data, static base-data and metadata. This way, one database connection process (i.e., one client connection) can access all available data. This, of course, requires meaningful indexing of these data and attaching unique identifiers to each of the records in order to fully take advantage of the relational concept of the database management system: joining and merging data that is related to specific identifiers. However, these different types of data just mentioned need to be kept separately within one single database in order to be more manageable. This is done by applying so called schemas (see the descriptions of the database symbols in Figure 2).

The way how real-time data and archive data correspond with each other is an important aspect that must further be examined. These two data components may, under some circumstances, be merged and managed together (BÉDARD *et al.* 2001). Alternatively, real-time data may also be periodically migrated to the archive which requires a set of auto-scheduled tasks and rules. One of these rules must always be alert for possible errors and handle them appropriately while another implements the temporal dimension of the data as an abstract data type “queue”. Such a data type works according to the “first-in-first-out”-principle: Those real-time data that are no longer actively manipulated are removed in the rear while new data are included in the front.

The combination of real-time data and static data, such as the actual distribution of temperature in dependence of altitude, will be calculated and visualized using server-side GIS-tools (NETELER and MITASOVA 2004). Metadata depend on the archive data in that the former internally query the latter for certain attributes (e.g. the length or the update of the archive, etc.).

As shown in Figure 2, there are two possible components of the prototype which will be considered in terms of providing an appropriate interface. The first component should allow for interposing between the real-time data and the visualizations some additional models (e.g., a forecast model). As to the basic cartographic workflow of the prototype, this should be doable since the same data types (but other values) are used for the visualizations. The second possible component is an import interface that enables a (super-)user to enrich the archive with additional information such as press clippings or eye witness accounts. In order to realize this idea, one of the necessary provisions is to create an additional schema to the existing database model.

### *3.4. Experimental procedure and technologies*

Owing to the intention to work with non-commercial software, we will use open-source products and reuse programming code where it is possible. A variety of open-source products and libraries for distinct aspects of web-cartography already exists and will be integrated into our project. The intended configuration, running on a LINUX Redhat server, is shown in Figure 3 and is incidentally similar to the system architecture of the Austrian Atlas Information System AIS (KRIZ *et al.* 2007). Imaginable are online analytical processing (OLAP) tools that employ a multidimensional data model to serve as a basis for the planned data archive. For storing this archive as well as for storing metadata, static geo-data and real-time data, we plan to use the object-relational database PostgreSQL. In-built scripting languages allow for creating rules and triggers to pre-process real-time data. PostgreSQL is run together with its spatial backend extension PostGIS which provides GIS functionalities and which fully complies with specifications issued by the Open Geospatial Consortium (OGC). GIS and statistical analysis at the server-side are carried out by GRASS and R-Project respectively. There is a variety of graphing options to choose from, such as PHPlot or JpGraph. At this stage of research, it is most likely that the cartographic visualization task will

be handled by the UMN-Mapserver. Its output will then attain over the internet to a viewer (or rather a GUI). Designed in consultation with operational hydrologists, the GUI is currently being developed in JAVA and distributed via JAVA WebStart. However, other techniques such as PHP/MapScript will also be tested.

Acting as the core of the prototype, a system interpreter (i.e., an array of modular programmes) handles user interactions, controls the overall procedure of the system and executes various processes at certain times directly on the data or between them. Here, too, the technology that is finally used will be the outcome of evaluating and testing PHP and JAVA techniques.

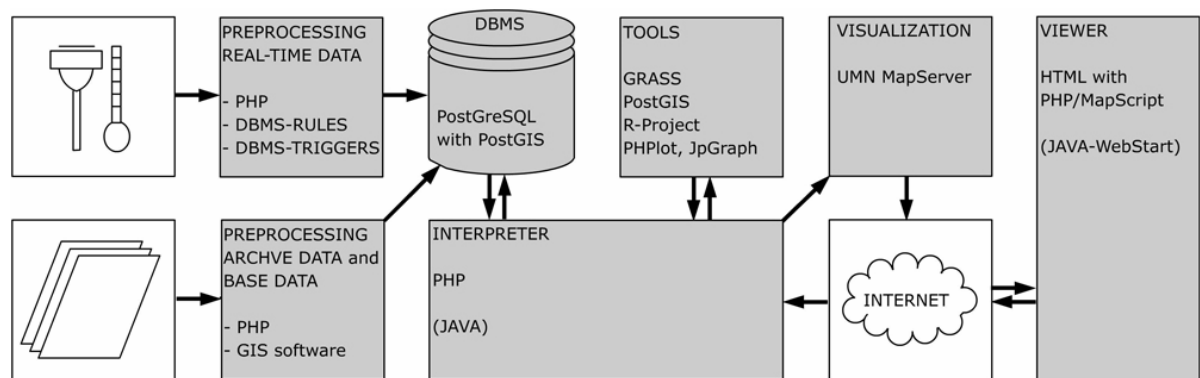


Figure 3: System architecture and intended software to be used (own representation).

#### 4. Discussion and Expected Results

On the one hand, we intend to gain deeper insight into parts of the automated, digital cartographic modelling process and its implications for web-based, interactive cartography. On the other hand, we expect to advance in the field of temporal cartography and temporal GIS, which is to this day a challenge and leaves much to be researched for. With our prototype, we would like to make available an application that significantly reduces offline work by automating large parts of the cartographic design process. We also would like to make available a centralized tool that increasingly considers the temporal aspects of thematic data in order that temporal dynamics can clearly be visualized and examined.

The practical link to operational hydrology and potential users has already been addressed and is obvious. Users of our monitoring system are decision-makers in crisis management groups who base and reevaluate their decisions according to their experience and the most actual

hydrological information of the basin they can get. In flood risk management, information is useful only if it is passed on time and if its meaning can be quickly grasped to make further decisions. Major floods, as they occurred in 1987, 1999 and 2005 in Switzerland had exhibited different previous histories (BWW 1991; BWG 2000; FREI 2005), yet they had had one thing in common: great damage. This is all the more alarming as we have to prepare for similar or even more severe events in the future (BEZZOLA and HEGG 2007). Monitoring ultimately helps to reduce damage as it improves the immediate preparedness and the early detection in order to anticipate and counter a looming event. Thus, enhancing the monitoring process is not only in every operational hydrologist's but in the whole national economy's interest.

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