Real-Time Data in Operational Hydrology - Ways of Visualizations in an Online Cartographic Application

Christophe Lienert[1,*], Rolf Weingartner[2], Lorenz Hurni[1]
[1] *Institute of Cartography, ETH Zurich,Wolfgang-Pauli-Strasse 15, CH-8093 Zurich, Switzerland*
[2] *Geographical Institute, University of Berne, Hallerstasse 12, CH-3012 Berne, Switzerland*

ABSTRACT: Early warning and monitoring activities in the field of operational hydrology – and any other natural hazard management field – are crucial in order to limit damages to life and assets caused by extreme natural events. Statistics show that hydro-meteorological events both on a global and a local scale are increasing in their number of occurrence as well as in their intensities. Decision makers such as operational hydrologists must be enabled to quickly and comprehensively overlook an on-going situation, to go more into its details and then take further actions in collaboration with crisis management groups based on the information they have. Thus, more than ever, real-time data from different measurement networks and sources have to be compiled, processed and presented in real-time to these decision makers.

The scientific, cartographic challenge is to deliver automated, real-time visualizations in consideration of sound cartographic rules and standards. In this paper, the conceptualization of a web-based cartographic real-time information system is presented. Based on this concept, a prototype has been tested that integrates acquisition, processing and visualizations of real-time hydro-meteorological data in different ways, depending on the chosen timeframe and level of detail. Besides monitoring visualizations, data are retraceable using visualizations that clearly stress the course of the event and the data's spatio-temporal character. Further visualizations and functionalities are provided that allow for putting real-time data in relation to a broader historical context. Data are instantaneously retrievable from a data archive, classified and visualized in order to learn from former events and experiences.

KEYWORDS: real-time cartography, web cartography, operational hydrology, early warning

* Corresponding author. E-mail address: lienert@karto.baug.ethz.ch (Chr. Lienert)

Introduction

Due to global climatic changes and accompanying rise of air temperatures, extreme precipitation and consequent natural hazards - such as floods – are increasing both regarding their recurrence interval and intensities. Newly conducted research shows that in reality, extreme events in precipitation-rich regions even tend to exceed the scenarios previously predicted by models (ALLAN and SODEN 2008). Breaking down from the global to the regional level confirms such findings. Recent studies associated with the post-event analysis of the memorable August 2005 event in Switzerland, for example, conclude that these floods did not parallel with any other observed event since the year 1972. Classified in a much longer time span, however, this event's intensities and discharge quantities are far from extraordinary and it must rather be termed rare than extraordinary (BEZZOLA and HEGG 2007). Societies will have to anticipate similar events and thus, it is imperative to improve methods and measures to manage flood events at an early stage and as they evolve in order to eventually control and reduce damage costs caused by floods. An overview of ever-increasing damage costs in Switzerland due to flooding and associated landslides is shown in Figure 1.

Enhancing monitoring capabilities for the operational hydrology sector, and others, improves the immediate preparedness to anticipate and counter looming floods. An efficient real-time monitoring infrastructure may enable users to observe on-going events and take further appropriate actions based on the information that is instantly available. Today, data are no longer just analyzed as to their spatial and temporal fluctuation but also as to their meaning and lifespan. Moreover, to become and remain a cost-effective and sustainable strategy component in operational hydrology, opportunities and challenges of hydro-meteorological early warning and monitoring systems must encompass several aspects: the exploitation of technological progress, maintenance of cooperation among public bodies, the supply of free, rapid, unrestricted data exchange as well as partnership with the media (LAURINI *et al.* 2001; ZILLMAN 2003).

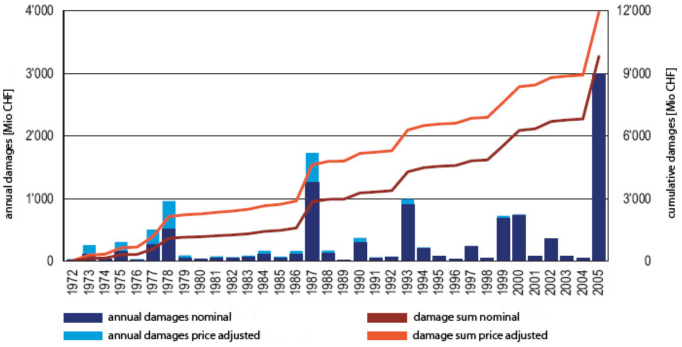


Fig. 1: Flooding and landslide damages in Switzerland since 1972 (BEZZOLA and HEGG 2007)

Much effort in operational hydrology is made by governmental agencies and research institutes in various flood hazard related domains, particularly in the field of forecasting. Improving the coupling of various forecast models, such as the output of meteorological models with hydrological and hydraulic models (see, e.g., USGS 2002; BARTHOLOMES and TODINI 2005; D-PHASE 2007; REGGIANI and WEERTS 2008). In flood risk management, applications are being tested or in use that let users analyze flood hazard and flood loss model, as well as emergency management (see, e.g., FORACI *et al.* 2005; FEMA-HAZUS 2008). But supplementary to analyzing forecast data, monitoring and constant checking of observed real-time data is likewise important. Classifying, assessing and documenting upcoming or on-going flood events against a database of archived data with the most actual data available can help to see the bigger picture. Given an appropriate technical and visual environment, operational hydrologists may instantly compare current data with historical data sets, linking them with other thematic data of the past and thus learn from former events and experiences. Needless to say that such comparison with historical data may also be carried out using forecast data, but for the time being, tests in this paper are limited to true real-time data.

Bringing real-time requirements of operational hydrology forward to the domain of cartography means to examine new cartographic concepts and to extend existing user-interfaces and visualization applications. Up to the present, cartographic map production work steps were mostly accomplished off-line, with considerable editorial work involved. Handling real-time data in real-time implies that acquisition, storage, processing, visualization and archiving of data is achieved on-line, preferably error-free and with the highest degree of automation possible. A robust system is needed, capable of displaying real-time data in different ways and on different level of details as to spatial and temporal resolution. Time-sensitive data have to be represented dynamically and the system must be able to classify data of which the accuracy, range and absolute values are not known in advance. In addition to these requirements, the maps have to be delivered to any computer, regardless of user's current location, implying that cartographic products have to be compiled centrally and distributed over the web and therefore comply with current web-standards.

This project obviously touches many research fields ranging from real-time applications in geosciences, web-based GIS and decision support system, web cartography, and web-services in general. An overview of current research in these fields is given in LIENERT *et al.* (2007).

Data base, data sources and data management

The prototype application handles observed real-time data and manually collected archive data. These data are stored in a database and managed by a database management system. Real-time data are automatically collected using routines that are released at certain intervals. Archived data have previously been processed and inserted into the data base by manually released routines. Tables 1 and 2 provide an overview of these two kinds of data. Not only do the parameters of real-time data and archive data correspond, but so does their temporal resolution. This is important in order that river discharge, meteorological parameters, radar images and groundwater data can be correctly linked and compared as will be discussed later on. To be qualified for our research purpose, data must reside on the local or a remote server, accessible through a network. Another initial criterion was to incorporate data having a delivery interval less than or equaling two hours. Later, data with lower temporal resolutions (such as groundwater and additional precipitation gauges), were also included.

Table 1: Overview of the automatic real-time data colletion.

Parameter	Spatial Extent	Delivery Intervals	Temporal Resolution
Hydrological Parameters: river discharge, lake levels	Switzerland (Federal network)	1 hour	10 minutes
Meteorological Parameters: precipitation, temperature, air pressure, air humidity	Switzerland (Federal network), focus area *Thur* basin (State networks)	1 hour	10, 30 and 60 minutes (irregular at some State gauges)
Remote sensing products: radar imagery	Switzerland	1hour	5 minutes
Add. Hydrological Parameter: groundwater	focus area *Thur* basin (State networks)	daily	5 minutes

On the one hand, data are provided by Swiss Federal Offices and cover the whole area of the country. On the other hand, data have been collected from certain Swiss State Offices whose State territories are partly covered by our study's focus area, the *Thur* basin in northeastern Switzerland (see Figure 1). The number of stations involved in the projects totals to over 300.

The length of the archive time series varies depending on the parameter and the data supplier. With a total of 23 years, as shown in Table 2, river discharges at most of the gauging stations constitute the longest time series while radar images are available only as from 1998. The programmed routines used for inserting data into the archive are re-usable to insert more data into the archive and keep it up-to-date. This is especially useful after data suppliers have officially approved the accuracy of their data and publish them to third parties such as this project.

Table 2: Overview of the archive data collection.

Parameter	Archive from – to	Spatial Extent	Temporal Resolution
Hydrological Parameters: river discharge, lake levels	01.01.1974 – 01.01.2007	All gauges in the Swiss part of Rhine basin (covering *Thur* basin)	10 minutes
Meteorological Parameters: precipitation, temperature, air pressure, air humidity	01.01.1981 – 31.12.2007	All gauges in *Thur* basin, plus some 20 more stations in Switzerland	10 minutes
Remote sensing products: radar imagery	01.01.1998 – 31.12.2005	all over Switzerland	1 hour
Add. Hydrological Parameter: groundwater	01.01.1996 – 01.05.2007	focus area *Thur* basin (State networks)	5 minutes

A set of static topographic data have been collected. These data comprise a multi-resolution relief, forest and settlement areas. Political data cover Canton and community boundaries. Static hydrological data in the application involves lakes, groundwater areas, the complete 1:200‘000 and 1:25‘000 river network and hydrological balance area geometries.

As mentioned above, the project's focus is on the *Thur* basin in north-eastern Switzerland. An overview of this basin is given in Figure 2. It has an area of 1700 km^2 and the altitude ranges from 336 m to 2501 m above sea level. From a hydrological point of view, it is attributed a pre-alpine basin with snow melt contributing considerably to the river discharge in spring time. Heavy thunderstorms in summer characterize the meteorological regime. Storms or a combination of snow melt and precipitation often lead to floods. In addition, the *Thur* basin is the largest contributing basin to the Rhine in Switzerland and does not contain a lake or a dam that could retain or attenuate flood waves.

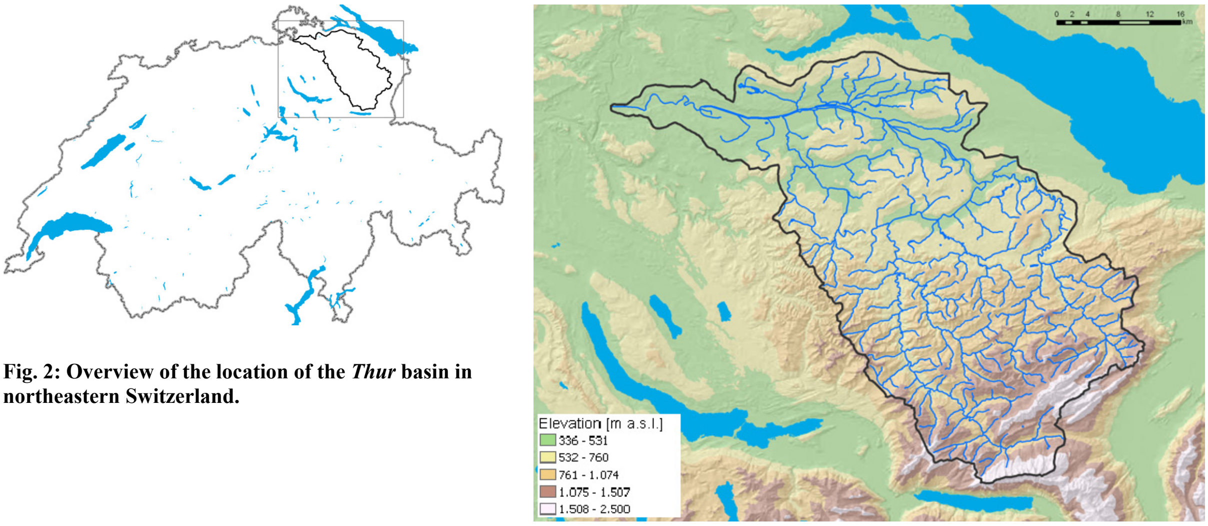


Fig. 2: Overview of the location of the *Thur* basin in northeastern Switzerland.

Needless to say that in the course of the project huge amounts of data have to be handled. For this purpose an object-relational database management system has been installed on a separate, physical project server. The database contains numerical data, vector data and links to raster data (but not raster data itself, they are stored on the file system). An overview of the technologies used in the project is given.

Conceptual Considerations and Methodology

The overall concept, the subsequent data modeling and the prototype implementation were guided by the following three user-oriented questions: What visualizations and functionalities are needed, in order that operational hydrologists may…

1) …quickly and comprehensively capture and monitor the overall situation in real-time?
2) …retrace short-term developments of the hydrological situation?
3) …learn from former events by comparing real-time data with historical data?

The *first question* leads to visualizations for monitoring and exploring the momentary situation. Workflows have been developed that combine measurement data with spatial data resulting in cartographic objects. These objects are visualized so that users can quickly grasp and explore the data and the overall picture of the hydrological situation in real-time. Yet, provisions on the user interface have to be provided to display higher level of detail data and dynamic legends. Map navigation tools are an integral part of the user interface. Depending on the data, visualizations are made for points, lines and areas and they don't differ from standard hydrological map depictions. They principally follow the graphical semiology developed by BERTIN (1967) with the graphical variables color, shape, pattern, size, brightness and direction. Graphs play an important role to show real-time data at certain points varying over time. The workflow and the functions are responsible that the application automatically orders and classifies these huge amounts of data. In a next step, functions apply meaningful algebraic-to-graphic transformations for sound cartographic displays on the computer screen.

The *second question* concerning the retraceability of a flood event gears towards underlining the temporal character of the data and therefore, animated map visualizations are applied here. Single, chronologically ordered map depictions are put one after another to become visualizations that allow for a quick capture of how a current event has evolved on the event-scale (i.e., back to the past few days) from a chosen moment up to the present. Such visualizations particularly help to document a flood event and to communicate between crisis management groups. Theoretically, the graphic semiology must be extended by the term 'change', and for that purpose, variables are introduced such as display date, duration, order or frequency of the change (DIBIASE *et al.* 1992; PEUQUET 2000). While technically, this part proves to be the most complex to implement, first testing with users show that it may be worth integrating such visualizations into the user interface.

The *third question* deals with the effects of learning from former events and comparing real-time data with historical data (i.e., back to the past few years). A user is able to input via the interface a certain time stamp that represents a point in time. The application retrieves the associated data of this time stamp from all tables of the database and applies the same workflows and functions as for real-time data. The result is a map showing the hydrological situation of that time with the same (and therefore easy to compare) symbolization that is applied for real-time data. To achieve such visualizations, any data record containing measurement data (real-time or archive) has been modeled in the database along with its related time of measurement. This way, the time inherent to such a measurement record has been represented by the technique of time stamping where time information is itself treated as a relational entity (VALPREDA 2004) and chosen to be the unique identifier for the record. Operational hydrologists may instantaneously relate real-time data to the historical context by contrasting the map containing the current situation with the one containing historical data. When further exploring the data in the user interface on a higher level of detail, developing of the historic flood is quickly conveyed (see later in Figure 8). At the time of writing, the comparison of current and historical data is accomplished by taking advantage of today's browsers with their tabbed view: one tab may show the current situation while the other displays the historical situation. Further development on the user interface is planned to allow for switching between these maps within the interface.

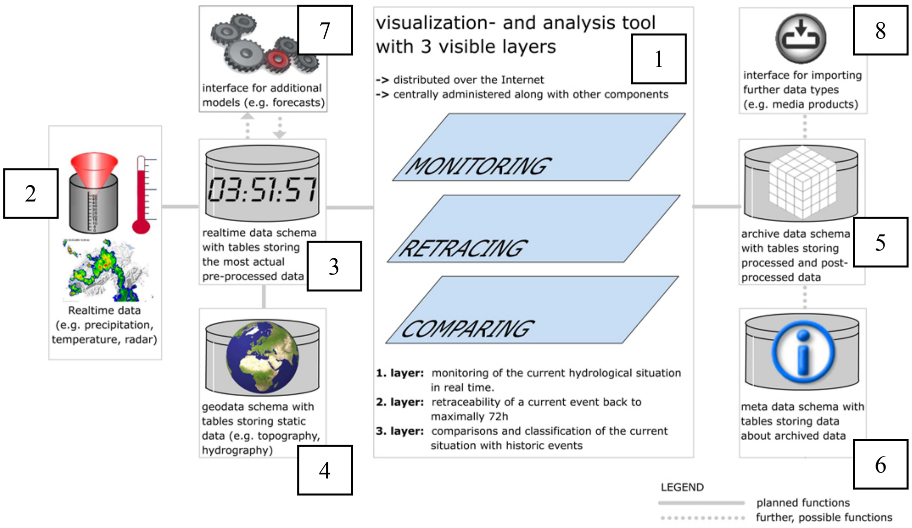


Fig. 3: Conceptual framework of the real-time cartographic prototype, see text for explanations.

In a conceptual workflow in Figure 3, the three questions outlined above have each been assigned to a visualization layer. The cartographic prototype has a modular character and is presently set up of eight main components of which most are fully functional by now: The visible part of the prototype (1) is represented by one single user interface, conceptually split into three visualization layers (monitored, retraced and compared data). Other components are the incoming real-time data (2) that are fetched on a regular basis and inserted into the real-time database schema (3) which stores these newly measured data in gauge-separated tables along with the uniquely identifiable "time of measurement" and the respective gauge numbers. The gauge numbers act as foreign keys linking to the database schema that stores static topographic data (4) such as river networks, gauging networks and other topographic vector data. They also link to the tables of the archive database schema (5) that store short-interval measurement data and to the metadata database that holds data about the data. Additional interfaces are (going to be) implemented. The first (7) lets a user tie other sorts of models (e.g., cartographic or hydrological). The second interface (8) will allow (super-)users to enrich the historical data by inserting additional attributive and measurement data to the archive schema of the database. Implementation of these two interfaces is in the development stage.

All programs and data are stored on a *Linux RedHat AS4* server. The heart of the system is a database that contains data schemas (see Figure 4). Such schemas are combinations of tables which store real-time measurement data, static topographic vector data, archive measurement data and metadata. The database is managed by a *PostGreSQL* system together with *PostGIS*, an object-relational extension to store geometries. *PostGIS* has inbuilt functions that allow for spatial querying of geometries limited to a desired bounding box. When requesting data over the user interface, a spatio-temporal query string is iteratively concatenated by several loops, and sent to the database. The result is code that can be read by browsers to show a map with its symbolizations. As mentioned above, joining of data records is accomplished using the defined unique identifiers and foreign keys. Because the 'time of measurement' timestamp is used as the unique key, the database management system only allows inserts into the database when this timestamp is different from the other, i.e., when new data has arrived. *UNIX*-based control jobs drive the data inserting scripts at an arbitrary small interval. When no new data set are available and the script fails to do the inserts, the resulting error message is trashed. This method assures that each new point in time associated with new measurement data is treated uniquely and stored in the database. Additional rules and function triggers on the database server make for a correct allocation of real-time data into the respective tables.

Archive data is first pre-processed off-line using *UNIX* tools and GIS software or any other suitable external software. *PostGIS*-based and other scripts are used to read measurement and vector data into the database. These scripts are re-used each year when data suppliers publish their approved time series.

The interpreter shown in the middle of Figure 4 is a set of modular programs, mostly based on *HTML* Preprocessor (*PHP*) which are usually run on the command line interface or by browsers. Such scripts can also be run by just calling them together with the respective executable and thus can be run automatically. Running on a regular basis these scripts take care of the data inserts, the data's consecutive processing by calling other tools, and the archiving at the correct location on the server. While vector data, measurement data and file path of raster data are stored in the database, raster and grid files are directly stored on file system.

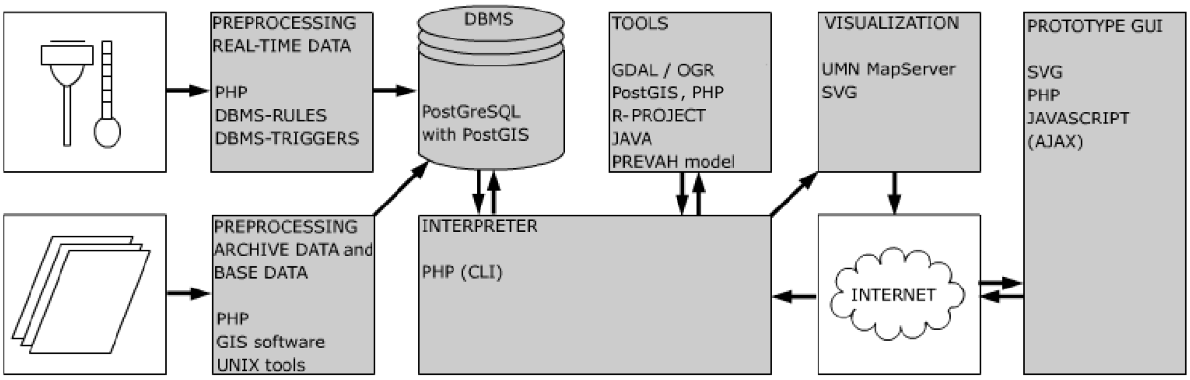


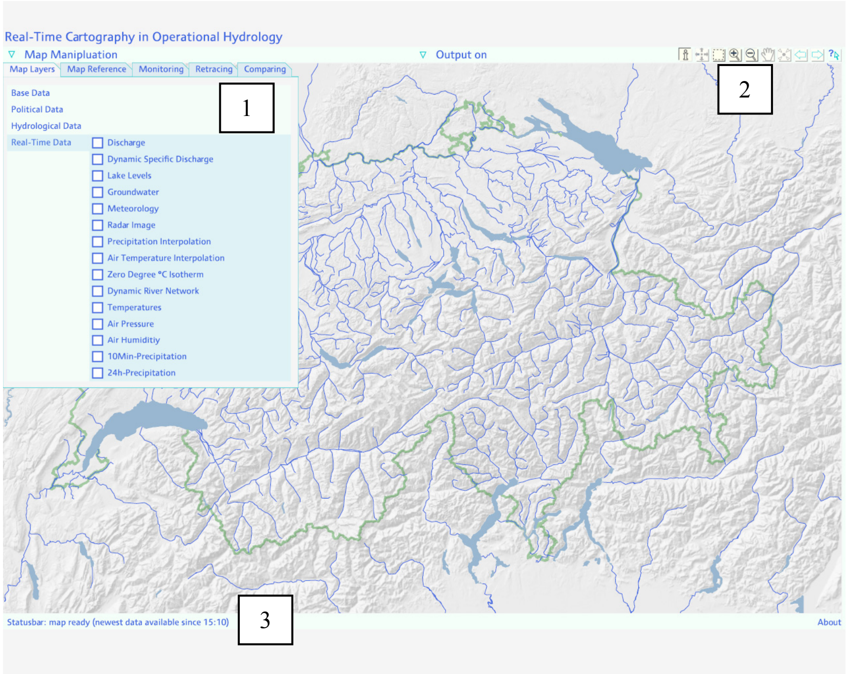
Fig. 4: System architecture and used technologies.

For the automatic processing of data, a range of tools are put in place: *GDAL* and *OGR* can convert various data formats. *PostGIS* functions are used to fit vector data into the correct spatial reference system or to convert spatial query results into scalable vector graphic (*SVG*), or to limit the spatial queries to the bounding box of the user interface. *PHP* is an excellent tool to automatically apply fundamental cartographic abstractions and rules to measurement data before they are output in *SVG* code and then displayed on screen as map symbols. Data selection, ordering, classification, and symbolization are accomplished in a first step followed by techniques of quantitative mapping, such as creating dot, flow and choropleth maps (DENT 1996). R-Project is an open-source statistical software. Linked with its database connectivity and spatial libraries, precipitation and temperature point data are interpolated to the area (HOTHORN *et al.* 2001). The output raster files are then integrated in the user interface. *JAVA* is used for handling radar data: first, in order to convert byte input streams into a web-readable raster format and second for reading out timestamp data from byte input streams. Also belonging to the group of tools and being an acronym for *'Precipitation Runoff Evapotranspiration Hydrotope'*, the hydrological model *PREVAH* (VERBUNT *et al.* 2006) may become an integral part of whole system architecture and the real-time cartographic application. However, more programming efforts and tests are necessary in order to have this separate hydro-model integrated on the project server and running in real-time mode. If applicable, the output of a hydrological model would allow for contrasting modeled with observed discharge and to visualize water volumes of subsurface storage of complete hydrological balance areas. It is assumed that once *PREVAH* runs in real-time mode with real-time data, the step to have it running in real-time mode with forecast data would not be far-off.

Visualizations, as shown in Figure 4, are prepared after the employment of data processing tools. In case of raster data, the *UMN MapServer's* web mapping service is called to display the appropriate raster data over the internet, depending on the map scale and bounding box of the viewer. Measurement and vector data are combined and eventually sent over the internet as *SVG* code. Not only are all maps encoded in *SVG*, so is the web-based prototype with its functionality tools. *SVG* is the web standard for two-dimensional graphics and meets well the needs of web-cartography projects (PETERSON 2008). The index *SVG* file that gathers all the information and data to be viewed by the user can is further supplemented by *PHP* code insertion, making the file more dynamic, for instance when new *SVG* elements are to be created or when variables have to be passed to the application. *JavaScript* is a well-known scripting language for web applications and is used to provide interactivity within user interface. *JavaScript* is used to handle intrinsic user events such as clicks or mouse-overs. Standing for a technology by which data are asynchronously transferred between the server and the browser, *AJAX* reloads only parts of the index site without having to reload it completely. This is especially advantageous when organizing thematic data in separate on and off clickable layers.

Results

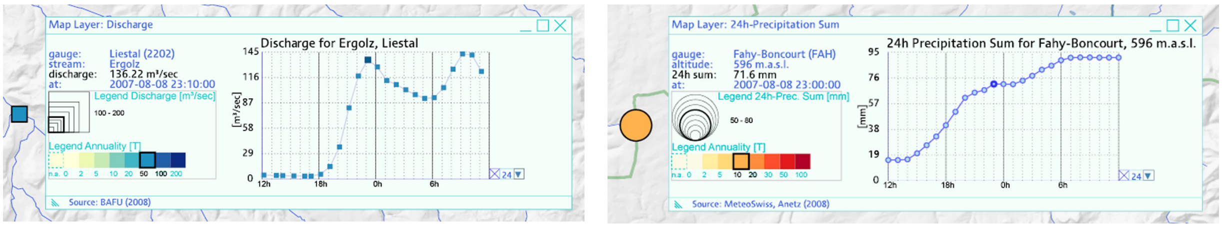
The start settings of the user interface, shown in Figure 5, display a simple form of a topographic map, with the country boundaries, lakes and river networks on top of a shaded relief. On the top left in Figure 5, denoted by (1), a click-on window can be opened, featuring different tabs such as one holding various groups of data layers. Other tabs allow users to see a reference map and adjust settings on the graphical interface. In addition to static base data, political data and static hydrological data, the group of real-time data is provided here. Various map navigation tools (2) allow for map zooming, panning, re-centering and tracking the history of viewed maps. The status bar on the bottom left of the interface (3) informs about the loading progress of the data and shows the time of the most recently available real-time data. At the time of writing, available real-time data comprises river discharge, groundwater, lake levels, air temperatures, air humidity, air pressure and radar images. Some data have been visualized differently but base on the same data. Air temperatures, for example, are shown as point and areal symbols (latter in terms of the zero degree Celsius line). Or river discharge is visualized by point symbols, flow and choropleth maps (as shown in the following figures).



Statusbar: map ready (newest data available since 15:10)

Fig. 5: Start setting of the real-time application with relief, boundaries, lakes and river network.

Before map examples are presented, a selection of real-time data symbolization and appertaining legends are discussed. Meaningful and easy-to-grasp cartographic objects are created both in real-time and out of real-time data and then set onto the topographical map of the graphical user interface. As all of the data measured by hydro-meteorological gauges are quantitative, cartographic rules for mapping these kind of data have been applied (see, e.g., SLOCUM 2005). For point data, varieties of different shapes, sizes and colors have been tested. In Figure 6a, left, river discharge at the gauging location is depicted by a square, while right, 24-hour precipitation sums are represented by circles. The classification that determines these shape's sizes is partly taken from atlas systems (ADS 2004). The legend for these sizes is shown on-the-fly as is the color legend. The color legend has been developed using Mr. C. Brewer's *ColorBrewer* software. Colors are used to denote the recurrence interval, i.e., the annuality, of the value under consideration (currently available for river discharge and 24-hours precipitation sums only). These intervals are an important as they allow for assessing the severity of the event. The darker the color the higher is the annuality and thus the more seldom is the value.



Map Layer: Discharge

gauge: Liestal (2202)
stream: Ergolz
discharge: 136.22 m³/sec
at: 2007-08-08 23:10:00

Source: BAFU (2008)

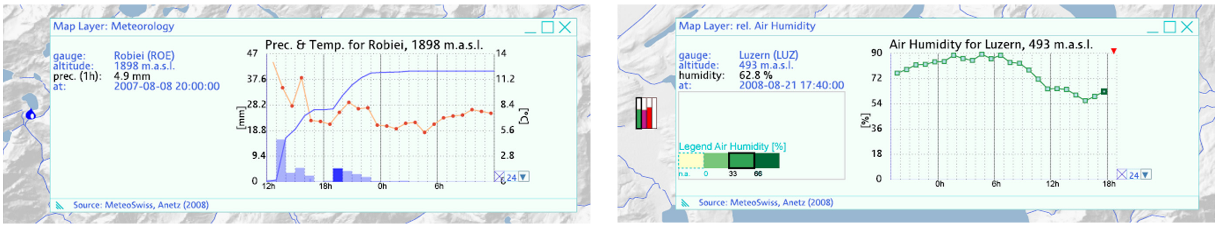
Map Layer: 24h-Precipitation Sum

gauge: Fahy-Boncourt (FAH)
altitude: 596 m.a.s.l.
24h sum: 71.6 mm
at: 2007-08-08 23:00:00

Source: MeteoSwiss, Anetz (2008)

Fig. 6a: proportional point data symbolization: river discharge (left) and 24-hour precipitation sums (right). When moving over the values in the graph, values are highlighted and legends automatically adjust.

Other symbolizations have been tested, such as the ones shown in Figure 6b. Here, precipitation is symbolized by a raindrop combining a whole set of meteorological parameters. The main advantage of this form of symbolization is that it saves space on the map since it stands for parameters that are measured at the same location. When clicking on such a symbol, graphs may contain a second parameter as shown left in Figure 6b, but displaying more than two parameters in a graph may quickly become confusing. Disadvantages, however, outweigh such pictorial point presentations: On a map, only the position of the gauging locations can be shown since variation in scales are not recommendable. Colors of these raindrops may be varied, in turn, but an alternative symbolizations is deemed more suitable for visualizing meteorological parameters: the framed-rectangles, introduced first by CLEVELAND and MCGILL (1984). Even in reality, precipitation, air pressure, air humidity and air temperature are measured in columnar devices. Thus, a rectangle is a suitable symbol for showing absolute values at one location and for comparing with values at other locations. As shown for air humidity on the right in Figure 6b, the values between 0% and 100% humidity are classified into three equal classes and underpinned by varying color saturation. Positioned close to each other, the framed-rectangles allow for a separate depiction of different meteorological parameters at the same location.



Map Layer: Meteorology

gauge: Robiei (ROE)
altitude: 1898 m.a.s.l.
prec. (1h): 4.9 mm
at: 2007-08-08 20:00:00

Source: MeteoSwiss, Anetz (2008)

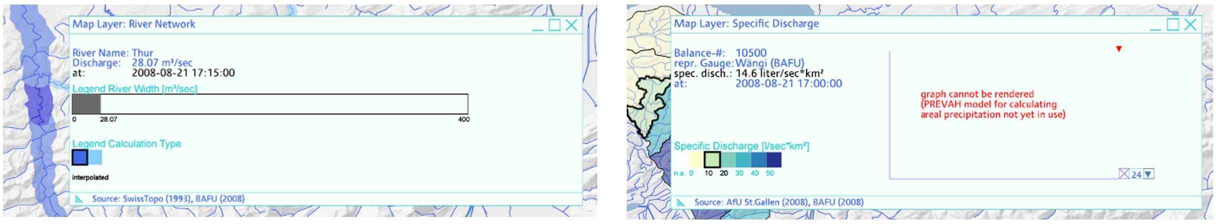
Map Layer: rel. Air Humidity

gauge: Luzern (LUZ)
altitude: 493 m.a.s.l.
humidity: 62.8 %
at: 2008-08-21 17:40:00

Source: MeteoSwiss, Anetz (2008)

Fig. 6b: additional point data symbolization: pictographic symbolization in form of a raindrop for meteorological data (left) and framed-rectangle symbols for any of these meteorological parameters (air humidity, air pressure, air temperature and 10-minute precipitation). On the right, the legend and graph for air humidity is highlighted.

For a more dynamic representation of river discharge, a line scaling algorithm has been developed that creates a flow map out of real-time data. Left in Figure 6c, a highlighted section of the river is shown. Its width is proportional to the measured discharge at gauging locations, and proportional to the interpolated discharge between gauges, respectively. A horizontal bar representing an arbitrary total of 400 m^3/sec contains the river width one-to-one while the modeled discharge quantity is displayed below. The algorithm works well for the *Thur* basin in case of normal flow conditions or on large scales. Yet, improvements are necessary when the flow map is viewed on small scale and when river discharge quantities are high, as visualizations look unpleasantly “bloated” (LIENERT *et al.* 2008). On the right in Figure 6c and in Figure 7, choropleth visualizations of river discharge are shown. To each hydrological balance area (previously defined by hydrologists), the discharge is assigned. This combination results in a map showing the specific discharge [liter / sec * km^2] and helps operational hydrologist to better identify complete areas that are substantially contributing to a flood.



River Name: Thur
Discharge: 28.07 m³/sec
at: 2008-08-21 17:15:00

Source: SwissTopo (1993), BAFU (2008)

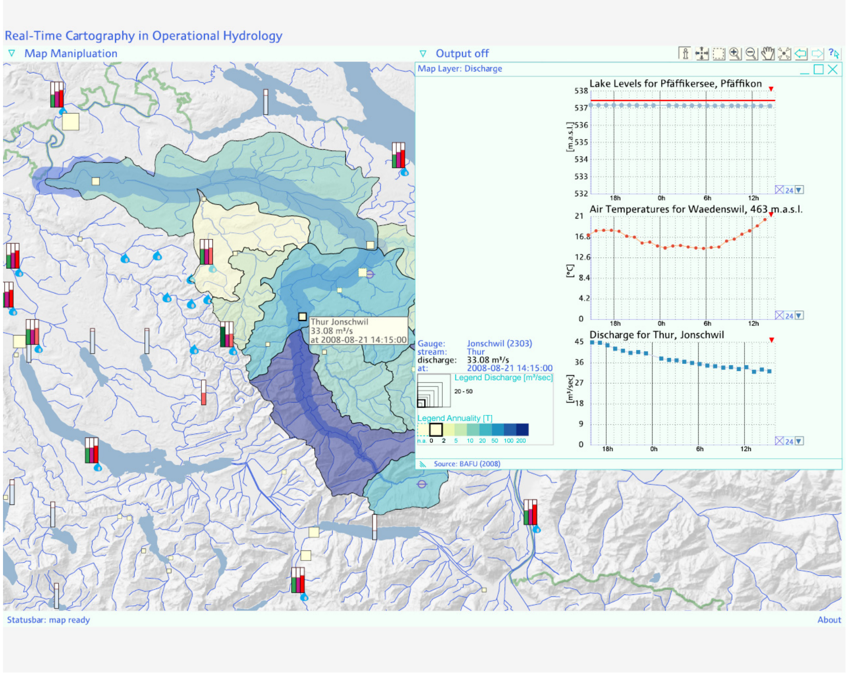
Balance-#: 10500
repr. Gauge: Wängi (BAFU)
spec. disch.: 14.6 liter/sec*km²
at: 2008-08-21 17:00:00

graph cannot be rendered
(PREVAH model for calculating
areal precipitation not yet in use)

Source: AfU St.Gallen (2008), BAFU (2008)

Fig. 6c: flow map symbolization (left) and choropleth symbolization (right) of river discharge.

Figure 7 shows an overview of available real-time data with the bounding box focused on the *Thur* basin in north-eastern Switzerland. This overview map presents the first and coarsest level of detail. If one intends to remain on this level, the use of tooltips aids to just look up the values behind the map object. When clicking on such a symbol, a higher level of detail of this map object is shown in that a time series graphs is being displayed on an output window. This output window is a placeholder for more detailed information and it is both resizable and movable, allowing for optimizing the main map space. Graphs can easily be added or removed from this window and as such, they act as yet another level of detail of the map objects. The data of these graphs are dynamically loaded out of the database and passed to several functions before they are rendered in these graphs. Functions automatically check for the accuracy of these data making use of pre-defined classifications and adequate thresholds. To anticipate the problem of missing data, linear interpolation functions are put in place. In case the most actual value is missing, no function is applied but the most recent available value is taken from the database. Another – much wanted – feature in Figure 7 is the possibility of compiling and visualizing different data parameters from different locations during the same time period. Such displays provide comparative and composites look at the relevant data.



Thur Jonschwil
33.08 m³/s
at 2008-08-21 14:15:00

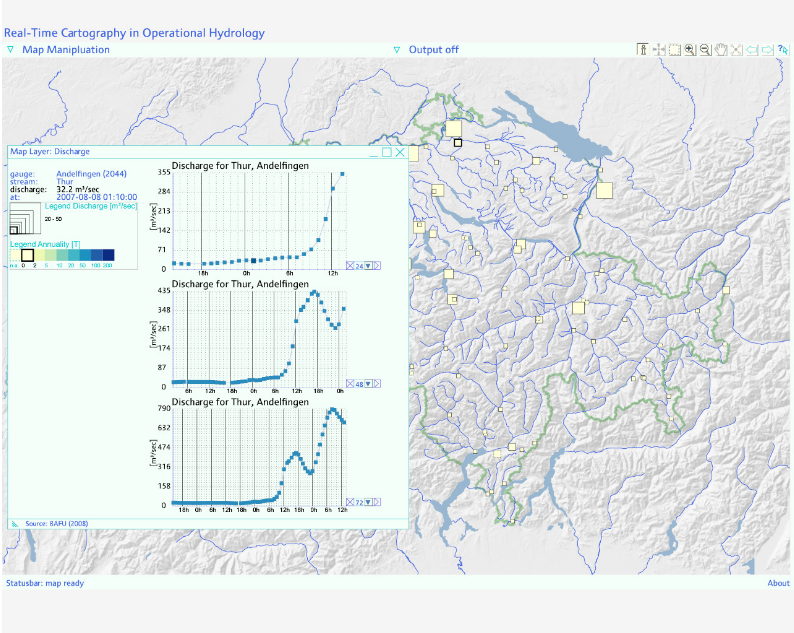
Gauge: Jonschwil (2303)
stream: Thur
discharge: 33.08 m³/s
at: 2008-08-21 14:15:00

Source: BAFU (2008)

Fig. 7: comparison of different parameters within identical time windows.

In contrast, Figure 8 shows graph visualizations of the same parameter at the same gauging location, but within varying time windows. This is an implemented example of the “comparing” concept discussed above (see Figure 3). The cartographic application has been passed the time stamp of a known flood event in the *Thur* basin (August 08 to 09, 2007). When clicking on a desired gauging station, the graph is rendered with the data centered around this time stamp (i.e., the data are used lying 12h before and after). The river in the graph on top suggests a continuous increase of discharge to much over 300 m^3/sec. When enlarging the time span to 48 hours, the graph in the middle confirms the increase to over 400 m^3/sec, with a successive decrease and an unimpressive new increase. The time period of 72 hours shows that this small increase is the start of the main flood peak which is yet to come: about 24 hours after the input timestamp, discharge reaches about 800 m^3/sec.

This flexibility of data exploration of past events should enable operational hydrologists to put real-time data in the historical context and to learn how similar events in the past have turned out. Together with the symbolization and legends provided, past data is instantly statistically classified in the statistical context. Improving early warning efficiency based on this knowledge and with these visualizations may be facilitated.



gauge: Andelfingen (2044)
stream: Thur
discharge: 32.2 m³/sec
at: 2007-08-08 01:10:00

Fig. 8: comparison of the same parameters (river discharge) within 3 different time windows (24 hours, 48 hours, 72 hours). The data of the graphs are centered around the value measured on August 08, 2007 at 01:10 a.m.

The overall map view of Switzerland depicting river discharge and 24-hours precipitation sums is shown in Figure 9 (for the legend, refer to Figure 6a). The left picture shows the situation on August 08, 2007 at 11 p.m., while on the right, the situation represents August 09, 2007 at 08 a.m. The shifting of the flood wave from central parts of Switzerland toward the outlet of the Rhine in Basle is well observable as are the increase of the 24 hours precipitation sums at many gauging stations.

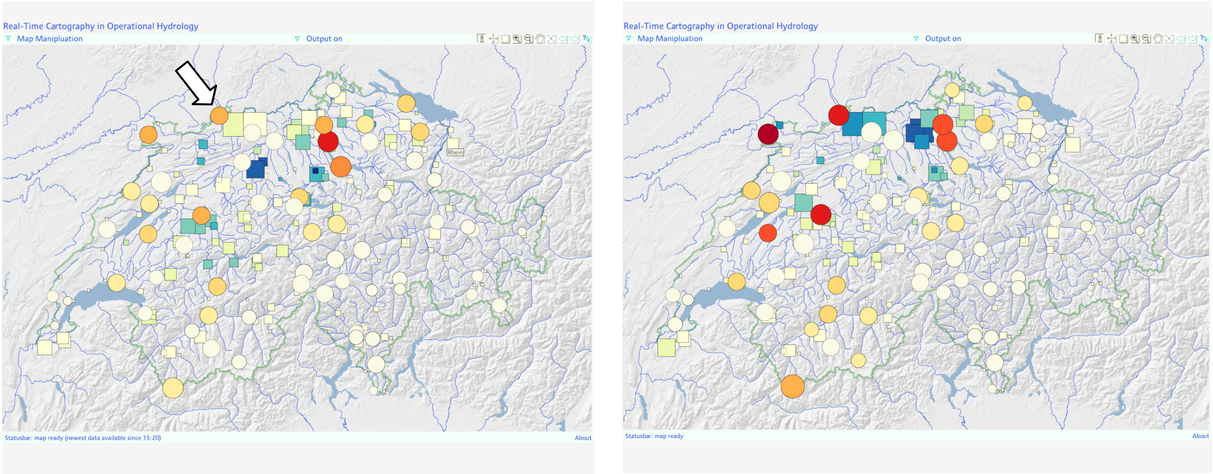


Fig. 9: two frames of flood event. The situation left is from 2007-08-08 23:00:00. Right, the situation dates from 2007-08-09 08:00:00. The arrow indicates the outlet of the Rhine river in Basle.

Placing more pictures in between these times to better accentuate the dynamics of this flood event is not possible here due to space constraints. In the cartographic online application, however, developments are made to view these pictures in an animated sequence, along with additional data parameters such as radar imagery or river flow map. The "retracing" concept, discussed in Figure 3 will be realized this way. Making use of the tremendous temporal dynamics of flood data may further aid operational hydrologist in exploring ongoing and past flood events. Animated views of flood events aim at helping understand the spatio-temporal patterns of flood events within the operational hydrologist peer-group on the one hand. On the other, animated views of severe floods, packaged in exportable software, can be a very useful tool to communicate between various stakeholders such as crisis management groups, politicians or the press.

Conclusion

In this paper, the conceptual, technical and visualization framework of a real-time cartographic application has been discussed. Hydro-meteorological visualizations produced by this prototype application using true real-time data have been presented. They are sent to the user group – preferably operational hydrologists – over the web and placed in a graphical interface allowing for three different ways of looking at the data: by monitoring and retracing them, and by comparing them with an existing data archive. On different levels of details, various parameters can be compiled interactively and explored on different spatial and temporal scales. Such composite map and graph products as well as the classification of real-time data in the historical context data are highly demanded by the user group. So is the "single-tool" approach followed in this project, allow for user-friendly and time-saving analysis and visualization.

Beside huge amounts of data, a considerable technical infrastructure coupled with robust data processing workflows are needed to achieve what was once done off-line and with significant editorial work: collecting, processing, visualizing and archiving the ever-increasing amount of measurement data. Results show that it is possible to present real-time data in a sound cartographic way. Data filtering, ordering, classifying, coloring, positioning as well as other cartographic activities can be accomplished automatically and in real-time. It is little surprising, however, that missing or faulty data constitute the main problem in such an application, whether data are used to render cartographic objects or to drive an entire hydrological model. Automatic and particularly error-free adjustment of inaccurate data still remains a difficult task. Simple check and interpolation functions may anticipate parts of the problem, but data suppliers and network operators may as well continuously work on these problems and enhance data quality.

It is therefore desirable and recommended that cartographers and scientist in the field of early warning and crisis management continue, deepen and advance their cooperation with network operators. Cooperation is necessary especially with those operators working in regions where no or few real-time data are available, but damages often occur. The installation of fix or mobile gauging stations or the extension of existing networks at key locations can certainly be very effective. Needless to say that the availability and accessibility of real-time data – and related products based on them such as the online cartographic application presented in this paper – are indispensable for efficient work in operational hydrology and similar professional groups.

Acknowledgements

This research is funded by the Swiss National Science Foundation (SNF), grant number 200021-113315.

Bibliography

ADS (2004). Atlas of Switzerland - 2D-maps and 3D-maps. Wabern: Federal Office of Topography swisstopo.

ALLAN, R. P., SODEN, B. J. (2008). Atmospheric Warming and the Amplification of Precipitation Extremes. *Science*: 1160787.

BARTHOLOMES, J., TODINI, E. (2005). Coupling meteorlogical and hydrological models for flood forecasting. *Hydrology and Earth System Sciences* 9(4): 333-346.

BERTIN, J. (1967). Sémiologie graphique les diagrammes - les réseaux - les cartes. Paris: Mouton.

BEZZOLA, G. R., HEGG, C. (Eds.). (2007). Ereignisanalyse Hochwasser 2005. Berne and Birmensdorf, Swiss Federal Office for the Environment Swiss Research Center for Forest, Snow and Landscape.

CLEVELAND, W. S., MCGILL, R. (1984). Graphical perception: Theory, experimentation, and application to the development of graphical methods. *Journal of the American Statistical Association* 79(387): 531-554.

D-PHASE. (2007). "Mesoscale Alpine Programme - Demonstration Project of the benefits in forecasting heavy precipitation and related flood events". Retrieved 30. Jan., 2008, from http://www.map.meteoswiss.ch/map-doc/dphase/dphase_info.htm.

DENT, B. D. (1996). Cartography thematic map design. Dubuque: Brown.

DIBIASE, D., MACEACHREN, A. M., B., K. J., REEVES, C. (1992). Animation and the Role of Map Design in Scientific Visualization. *Cartography and Geographic Information Science* 19(4): 201-214.

FEMA-HAZUS. (2008). "HAZUS - FEMA's Software Program for Estimating Potential Losses from Disasters". Retrieved 13. Aug., 2008, from http://www.fema.gov/plan/prevent/hazus/.

FORACI, R., BIDER, M., COX, J. P., LUGLI, F., NICOLINI, R., SIMONI, G., TIRELLI, L., MAZZEO, S., MARSIGLI, M. (2005). M3Flood: An Integrated System for Flood Forecasting and Emergency Management. IN: OOSTEROM, P. (Ed.) Geo-information for disaster management. Berlin, Springer: 1193-1210.

HOTHORN, T., JAMES, D. A., RIPLEY, B. D. (2001). R/S Interfaces to Databases. Proceedings of the 2nd International Workshop on Distributed Statistical Computing, Vienna.

LAURINI, R., SERVIGNE, S., TANZI, T. (2001). A primer on TeleGeoProcessing and TeleGeoMonitoring. *Computers, Environment and Urban Systems* 25(3): 249-265.

LIENERT, C., SCHNABEL, O., HUTZLER, E., HURNI, L. (2008). A real-time flow map of the Swiss 1:200'000 river network. Considerations on its preparation and its dynamic integration into a web-based prototype. Proceedings of the 6th ICA Workshop on Mountain Cartography, Lenk, Switzerland.

LIENERT, C., WEINGARTNER, R., HURNI, L. (2007). Real-Time Cartography in Operational Hydrology. Proceedings of the 23rd International Cartographic Conference, Moscow.

PETERSON, M. P. (Ed.) (2008). International Perspectives on Maps and the Internet. Lecture Notes in Geoinformation and Cartography. Berlin, Springer.

PEUQUET, D. J. (2000). Space-time representation: An overview. IN: HERES, L. (Ed.) Time in GIS issues in spatio-temporal modelling. Delft, NCG Nederlandse Commissie voor Geodesie: 3-12.

REGGIANI, P., WEERTS, A. H. (2008). A Bayesian approach to decision-making under uncertainty: An application to real-time forecasting in the river Rhine. *Journal of Hydrology* 356(1-2): 56-69.

SLOCUM, T. A. (2005). Thematic cartography and geographic visualization. Upper Saddle River, N.J.: Pearson-Prentice Hall.

USGS. (2002). "Near-Real-Time Simulation and Internet-Based Delivery of Forecast-Flood Inundation Maps Using Two-Dimensional Hydraulic Modeling -- A Pilot Study for the Snoqualmie River, Washington". Retrieved 13. Aug., 2008, from http://pubs.usgs.gov/wri/wri024251/pdf/wri024251.pdf.

VALPREDA, E. (2004). GIS and Natural Hazards. IN: CASALE, R., MARGOTTINI, C. (Eds.). Natural disasters and sustainable development. Berlin, Springer: 397.

VERBUNT, M., ZAPPA, M., GURTZ, J., KAUFMANN, P. (2006). Verification of a coupled hydrometeorological modelling approach for alpine tributaries in the Rhine basin. *Journal of Hydrology* 324(1-4): 224-238.

ZILLMAN, J. W. (2003). Meteorlogical and Hydrological Early Warning Systems. IN: ZSCHAU, J., KÜPPERS, A. N. (Eds.). Early warning systems for natural disaster reduction. Berlin, Springer: 135-166.