

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

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Abstract

To assist for flood managers and operational hydrologists and to monitor a current situation of the river network, various data visualizations are required in real-time. Flow maps may be one of such helpful visualizations. By representing the quantities of river discharge using the line width of a specific river stretch, quick overviews of the river network are possible. The present paper discusses ideas and concepts of such a flow map for parts of the Swiss 1:200,000 river network. Additionally, remarks are made, and examples are presented, as to the pre-processing, processing and presentation of the data in a web-based flow map.

1. Introduction

The technique of flow maps are appropriate when the movement of goods or ideas between places are to be shown. Particularly, flow maps intend to show interaction between places. More specifically, network flow maps, to which river flow maps are counted, attempt to reveal the interconnectivity of places (DENT 1999). Lines seem to be the most logical network elements (by being the medium of a movement or not, or by being directed or undirected). However, aside from lines, also points or polygons may constitute network elements as RUGGELS and ARMSTRONG (1997) discuss. Points for example must be further differentiated into origin or destination points and polygons such as the basin

area may be a factor that influences the network's extent. Most of the examples of network flow maps found in literature deal with transportation and various forms of traffic as well as with international trade volumes. Only few realizations of hydrographical flow maps exist, predominantly in national atlas systems as shown in Fig. 1 (a and b). In such atlases, however, the short-term or even real-time dynamics are not shown, because the river discharge data is averaged over a considerable long-time span.

In the present paper and in the on-going project "Real-time Cartography in Operational Hydrology" (RETICAH) flow maps are developed for the purpose of monitoring the dynamics of the hydrographical network and to anticipate potential hazards at an early stage. Additionally, the prototype application will also feature visualizations to retrace short-term an ongoing event and in order to compare ongoing events with high-resolution archive data. In this paper, we stick to three layers of the monitoring component. The overall concept is further described in LIENERT et al. (2007).

Aside from point, graph and areal symbolization, the realization of the real-time flow map is an attempt to visualize line symbols dynamically. Moreover, it can also be stated that virtually no application exists so far that deals with dynamic real-time river visualizations. Nonetheless, several cartographic research projects deal with real-time thematic content. The following undertakings – limited to those in

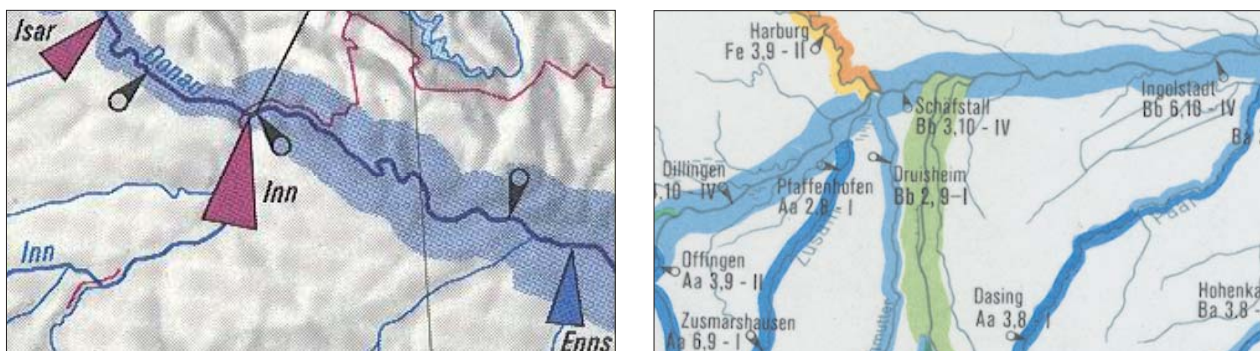


Fig. 1a and 1b: Flow maps of mean annual river discharge (HADES 1992-2007; HAD 2000).

the natural hazard domain – are worth mentioning: In Switzerland, a national information system for avalanches exists which is fed by an automatic network measuring meteorological and snow parameters. This information is stored in a central database and is available to safety services over the internet in form of overview maps with bulletins and measurement graphs (BRÜNDL et al. 2004). A similar system for avalanches has been implemented and tested in Austria (KINBERGER et al. 2007). In hydrology, efforts were made by AL-SABHAN et al. (2003), to interface hydrological models in a GIS combined with real-time rainfall data to users. The authors developed a Java-Applet interface that mostly uses raster visualizations for interpolated parameters (soil-moisture, rainfall) and time-series data. Other projects in the hydrological hazard and risk management focus rather on integration of real-time data into now-casting and forecasting models (e.g., TODINI 2004; FORACI et al. 2005; D-PHASE 2007; ROMANG et al. 2007) than on cartographic visualizations models. Thus, despite the availability of huge amounts of hydro-meteorological measurement and modeled data, the current situation is not fully satisfying as more can be done in order to suitably interface these data with the user in a sound cartographic, interactive and more usable way.

2. Goals

Consequently, two major goals are set for this paper: 1) Presenting real-time river discharge data in an interface and 2) find appropriate, quickly legible cartographic visualization for this purpose, with emphasis on a dynamically

generated flow map that represents real-time discharge values of selected parts of the 1:200,000 river networks.

3. Methods

Theoretically, natural hazard management nowadays is viewed as a cyclic activity. Four main activities are centered on the hazardous event: After it, regeneration activities takes place which are then replaced by a new risk assessment of the given situation. The following prevention activities comprise taking measures and enhancing the preparedness. The hazardous event takes place and event management must put in place both as the event evolves and as it ceases (KIENHOLZ 2005). Different methods exist and are used to enhance prevention and event management. Focusing on flood events, a few options, its advantages and disadvantages are briefly outlined.

3.1. Radar and satellite techniques

Areas indicate the extent of an inundation. Imagery of such areas is created during the flood event and then overlaid by a high-resolution digital elevation model (DEM). Advantage: the areal extent of the inundation can be very well captured this way. Using software such as e-cognition (www.definiens.com), a classification of these images may be carried out and certain areas may be automatically segregated. Disadvantage: The water quantities can merely be estimated and flying over the inundated area several times is a financial and logistic strain. An example of this technique is shown in DLR-ZKI (2006).

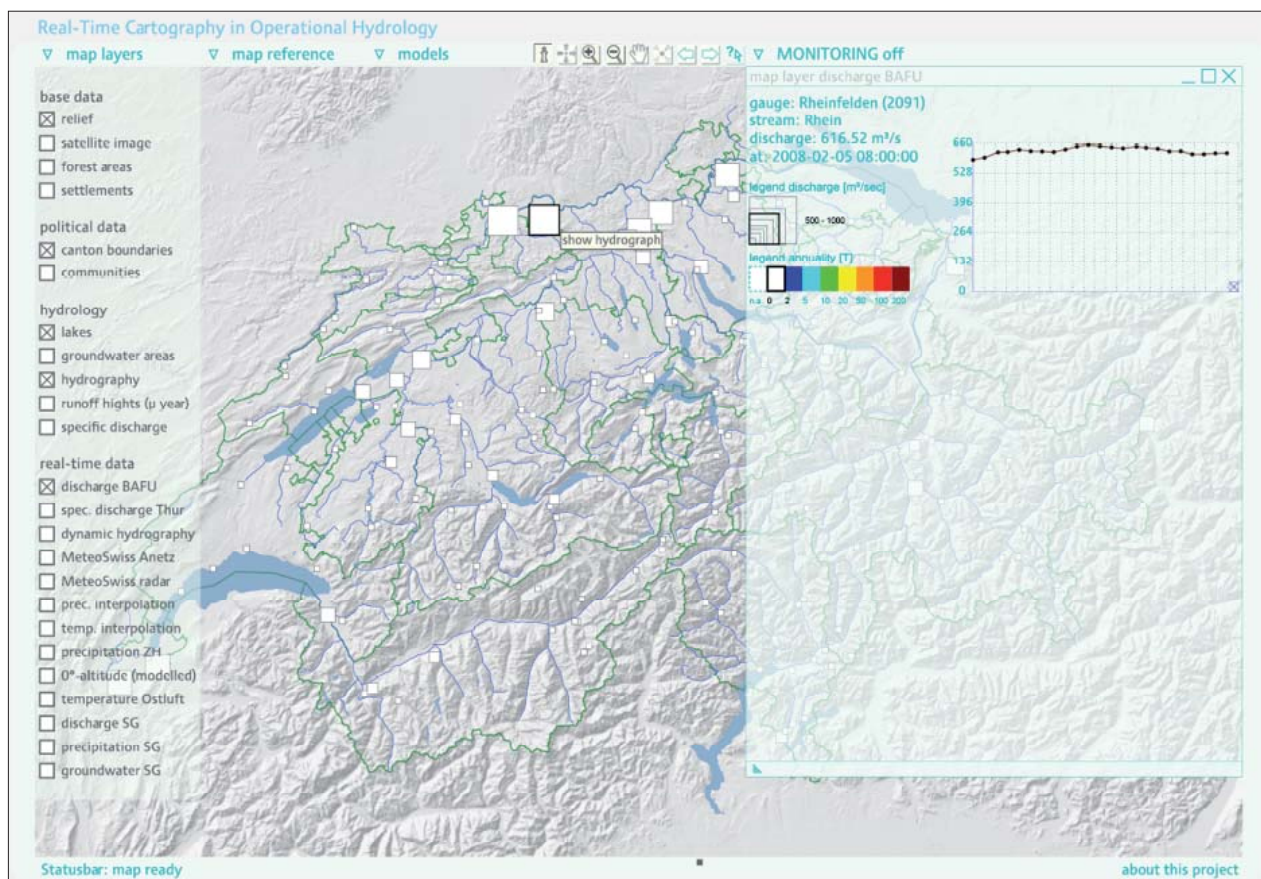


Fig. 2: Point location map representing real-time discharge (own representation).

3.2. Measurement networks on the ground (the approach pursued in this paper).

Point location maps: point sizes indicate real-time discharge quantities. Advantage: in general, such maps are easy and quickly readable and comprehensible. Disadvantage: the map may become difficult to read. Also, points may not be appropriate symbolizations of lines structures such as river networks but they might act as a supplementary visualization option.

3.3. Flow maps

The line width stands for the real-time discharge quantities between two measurement points. Advantage: sound readability, especially interesting as animated sequence which may allow observing the flood wave moving downstream. Disadvantage: the generation of such real-time maps is quite difficult and data intensive. Those rivers of which no measurements exist must be left with a standard line width on the map.

3.4. Choropleth maps of the specific discharges [liter/sec*km²]

The basin area above a river outlet is colored according to a pre-defined classification of the specific discharge. Advantage: such maps can be depicted well and are easy to read. They also integrate those rivers of which no measurement is available. Disadvantage: Having said that, they integrate unmeasured tributaries and geographical in-situ knowledge of the basin might be needed (i.e., about the geology, veg-

etation, settlements) due to the difficulty interpreting such maps.

In Fig. 2 and 3, realizations of a point location and choropleth map representation are shown. In Fig. 2, a classification has first been created. Then the sizes of each of the rectangles are assigned on-the-fly according to the real-time value of the data. This provides a very quick look of where values are high in absolute terms. To know what the data at each respective station means in relative terms, colors are used to classify the real-time value into a pre-defined classification scheme denoting annualities of discharge. In case the actual discharge value is in the range of high annualities (i.e., within rare recurrence intervals), an eye-catching color is used in the map. This information is shown on the map without user interaction. However, if a user moves the mouse over a point location, additional information is shown in the monitoring window such as the name of the location, the exact measurement value and measurement time. If the point location is clicked, a hydrograph is shown, rendered on the fly with the data of the past 24 hours. The hydrograph itself has interactive features. For example, each measurement point on the graph can be queried for its value and each gradient between these points may also be queried. If a user clicks on another point symbol, an additional graph is shown. Up to four graphs may be added to the monitoring window. In this way, users can also instantly compare the situation at different gauging locations.

Fig. 3 shows an example of areal discharge data. The amount of outflow of a certain balance area is related to the area

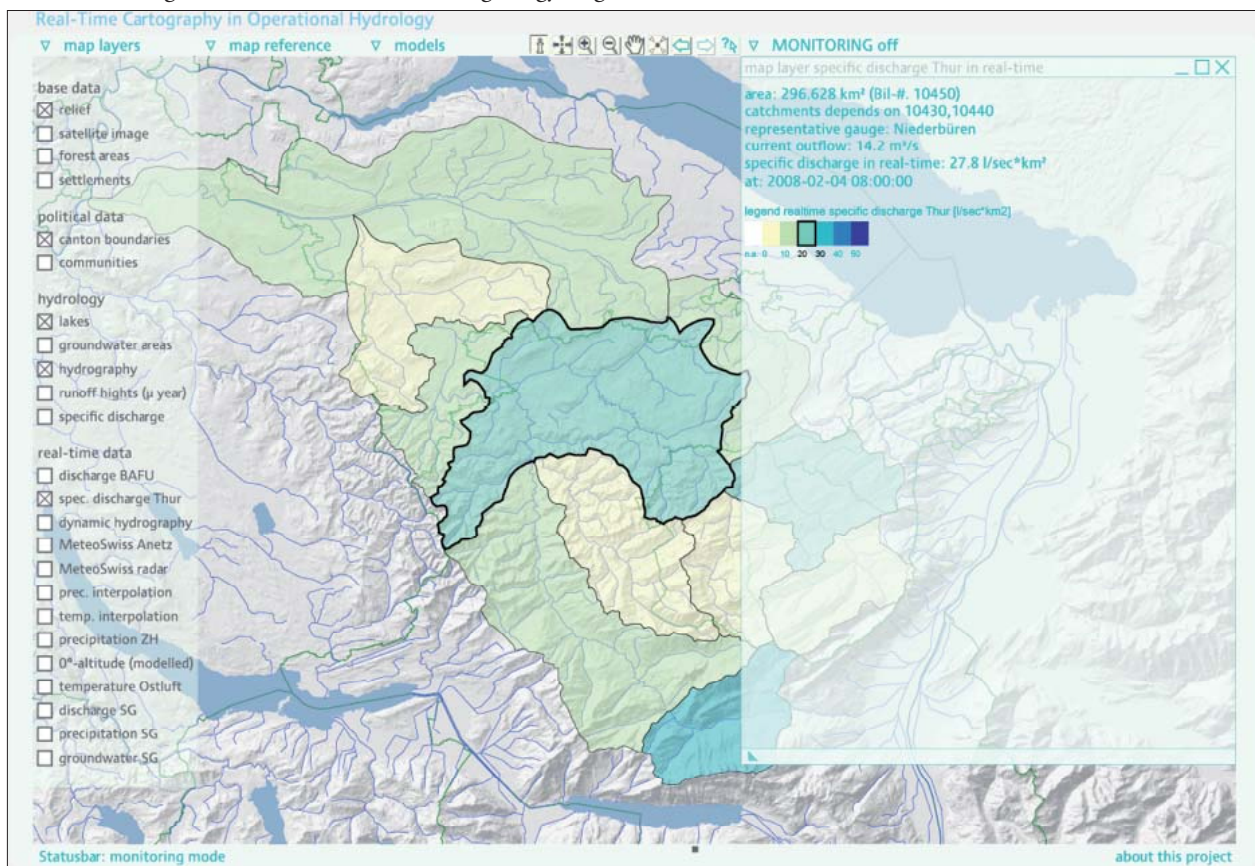


Fig. 3: Choropleth map representing real-time specific discharge (own representation)

itself, preparing the ground for a choropleth map showing the specific discharge [liter/sec*km²]. Creating this map requires real-time data at or reasonably close to the outlet of a balance area. However, creating this map also involves a data model that accounts for the dependency of the different balance areas. The outflow generated from balance area A is a sum of the discharge generated by A itself and the discharge generated from the upstream areas B and C (unless A is headwater). Thus, the data model contains for each balance area not only the foreign key of the representative real-time discharge station but also the foreign key of the real-time discharge stations representing areas B and C. The discharge values for these two upstream areas have to be processed before the specific discharge and the respective color of the area A are determined. The outflow of value of area A must be subtracted from the sum of these two upstream values. Only this way, the correct specific discharge for area A can be calculated and correctly colored. For both maps in Fig. 2 and 3, the legends are created on-the-fly.

The real-time measurement data is stored in, or loaded from, a huge spatial database. Presently, new hydro-meteorological measurement data is acquired hourly from remote servers of various data providers, among them the Swiss Federal Office of the Environment (BAFU). These data are joined together with static spatial data sets, such as the river gauge network or the balance areas in the two examples above. Both the real-time measurement data tables and the static network tables share the same foreign keys in order that the joining can be accomplished. In most cases, station numbers act as foreign keys. These have already been determined by the data provider. Vigorously simplified, the following work steps are passed through when real-time data are visualized:

- Clicking on a map layers checkbox in the *Scalable Vector Graphic* (SVG) map viewer releases a uniform resource locator (URL) string concatenation
- To this URL various GET parameters are passed (such as the specific layer name, the current width and height of the view box, the time stamp of the request, etc.)
- Using the prepared URL string, either a `XMLHttpRequest()` for standard conform browsers such as *Firefox* and *Opera* browser, or a `getURL()` for *Internet Explorer* is released.
- The URL string locates to a file that retrieves the desired data out of the database and does the desired preprocessing of the data and the data formatting.
- The requested data is pre-processed using PHP and returned as SVG-readable XML format and then appended to, and rendered in, the SVG application

It should be noted that this workflow only applies to vector data stored in the database. For raster data visualizations, the procedure is entirely different and involves geo-processing tools and services such as *UMN Mapserver*, *GDAL* and *R-spatial*. The raster data processing is not part of this paper.

4. Data and materials

The data for mapping discharge data involves river network data, data about the gauging locations and measured river discharge data. Scripting programs were written that fetch real-time discharge data from remote servers to our own server infrastructure and that read these data automatically into a database. By now, the database contains several thousand data records of hourly discharge for each of the 200 gauges in Switzerland. Each gauge is combined in a database schema. Within this schema, each gauge is represented as a table. Using schemas proved to be very helpful for managing the huge amount of data in the database.

The river network origins from Federal Office of Topography (swisstopo) and is suited for maps of the scale of 1:200,000. The gauging location data has been compiled independently. Although the data is available for whole of Switzerland, the geographical focus will be on the Thur basin in north-eastern Switzerland. It is the largest Swiss basin contributing to the Rhine and does not contain lakes that could retain or attenuate flood waves.

The technical environment is built around the database which is managed by a *PostgreSQL/PostGIS* database management system. It stores all vector and measurement data (either real-time or archived). Incoming data are inserted into the database only, if the data's timestamp is different from the previous timestamp. Technically speaking, the timestamp is chosen as the unique identifier. This way, data can be fetched from remote servers at an arbitrary small interval, but only if new data is available will they be inserted into the database. Archived measurement data and topographic vector data (as the above mentioned river network or gauging locations) are inserted into the database as well. Various PHP scripts act as the interpreter of the system. These scripts run periodically and either pre-process the data themselves (such as the width of the river sections of the flow map; see below) or release additional tools that further process the data. After processing, visualizations are accomplished using the *UMN MapServer* (raster data) or *SVG* technology (vector). Both kinds of visualizations are distributed over the internet and sent to the browser. The data interface itself is developed entirely with *SVG*, making use of additional *PHP* and *JavaScript/AJAX* technology. Further details are given in LIENERT et al. (2007).

5. Approaches, questions and problems

The remainder of this paper deals with realization of the real-time flow map integrated in the web-based project prototype. However, it should be noted, that there is also a variant to produce flow maps offline (e.g., for printed maps), making use of in-house Adobe *Illustrator* plug-ins developed at the Institute of Cartography, *ETH Zurich* (see www.ika.ethz.ch/plugins/).

For the sake of clarity, the following two definitions are made: (1) *river sections* are paths between two data points and are the smallest unit of the 1:200,000 river network. They are not modified when creating the flow map. (2) A

river leg is the stretch of a river between two gauges. The rendered width of the river sections between these legs are determined by the upper and the lower gauge.

Stored in the spatial database, the river geometries and certain attributes can be selected using *Structured Query Language* (SQL). Out of over 10,000 river section records, the main SQL statement selects the geometries, the SVG code of the rivers, the river name, and a so-called *code200* attribute. The selection is limited to river name Thur and seven of its tributaries. The resulting data set is sorted in descending order by the *code200*. The sorting is important because this way, objects with low *code200* numbers denote the end section of a river while high *code200* number stands for the river's source section. The sorting also assures that we can fetch the resulting data set – for each river separately – row by row and build an algorithm that adds for each river sections a supplementary rendering width and discharge quantity. For each river leg, a “discharge per section” is calculated using the difference of the real-time value (“rt_val”) of the downstream gauge and the upstream gauge divided by the number of sections in that leg, like so:

```
disch_per_section = (rt_val_downstream -
rt_val_upstream) / num_of_sections;
```

If the river leg is the first from the source, the real-time value at the upstream gauge is set to zero or any other arbitrary starting value. The discharge values within gauges are interpolated linearly. The starting discharge value is the one measured by the gauge upstream. A newly established counter starting from zero adds the “discharge per section” to each river section. The pseudo code looks like this:

```
rt_val_modeled = rt_val_upstream + (count *
disch_per_section)
```

The starting rendering width value is the width that has been calculated for the upstream gauge. It is the maximum width of all the river sections belonging to the river leg above. The same counter just mentioned adds for the new river section the supplementary width. The width is directly calculated from the “discharge per section” value. Eventually, the width is rendered in accordance with the map scale (i.e., with its inverse value). Expressed in pseudo code, the line may look like this:

```
width_modeled = max_width_upstream + (count *
disch_per_section * mapscale)
```

For the river leg between source and the first downstream gauge, the starting rendering width and discharge values are set to zero (although other values could be set here, see below). In Fig. 4, an implementation of the discussed ideas and of the pseudo-codes is shown. The application is extended so that when the user clicks over a river section the modeled discharge is shown (and so is the discussed “discharge per section” value). Two dynamically created legends are displayed when moving the mouse over these sections. The upper of the two legends shows river width unclassified, related to an arbitrary set upper bound of 400 m³/sec. The overall bar represents 400 m³/sec while the filled bar is the

absolute discharge value. The legend below relates the colors of the river network to whether data is supported by two gauges (i.e., interpolated) or if the data for the (inexistent) gauge has been estimated. At the moment, such estimations are based on the long-term data provided in HADES (1992-2007). Estimating such missing values in real-time is a problematic challenge (see below). The current solution is to color estimated river legs with a weaker color than those of interpolated river legs.

Undoubtedly, many questions and associating problems remain to be discussed and solved: They can roughly be divided into points such as (1) *cartographic visualization* problems and (2) *hydrological/data-related* problems. In the following, a non-exhaustive list for each point is discussed.

(1.1) The river sections of a main river, just after a confluence of a tributary, is visually not considered. It is logic that these sections should appear wider than the upstream sections. Hard-coding the program using estimated discharge quantities for unmeasured river legs could do this job. Doing this for the complete 1:200,000 river network is both laborious and will inevitably lead to wrong results in real-time mode.

(1.2) Depending on the “discharge per section” value that is being dynamically calculated, the visibility of the rendered width of a starting river might be very poor or not even existing. For rivers that start with considerable quantity of discharge (such as rivers that appear out of karst areas), the starting width and starting discharge quantity can adjusted (though manually if no measurement exist).

(1.3) Given the fact that the rendering width of the network is depending on the scale, the flow map may look very bloated if both the map scale is small and the real-time discharges are high. This means that other map objects are wrongfully overlaid by the flow map and that topographical conflicts occur (even with the same river). This problem may be encountered by multiplying the scale with a certain factor. The better option, however, is to zoom into the map which results in a more clear layout of the flow map.

(1.4) The river network that is not considered for the flow map due to the lack of measurement data is visualized in form of paths with a constant width. This may be confusing for the map reader but can be diminished or even avoided if the separate map layer for the overall river network 1:200,000 is clicked off.

(2.1) The distribution of river gauge stations delivering real-time data are in most of the cases not located at key locations (= location where a river ends or starts or where two rivers join; see also point 1.1). The only option may be to integrate missing data from a hydrological model output. Work is in progress that deals with the integration of now-casting data generated by a semi-distributed hydrological model.

(2.2) In the existing model shown in Figure 4, interpolation of discharge within a river leg is solely depending on the

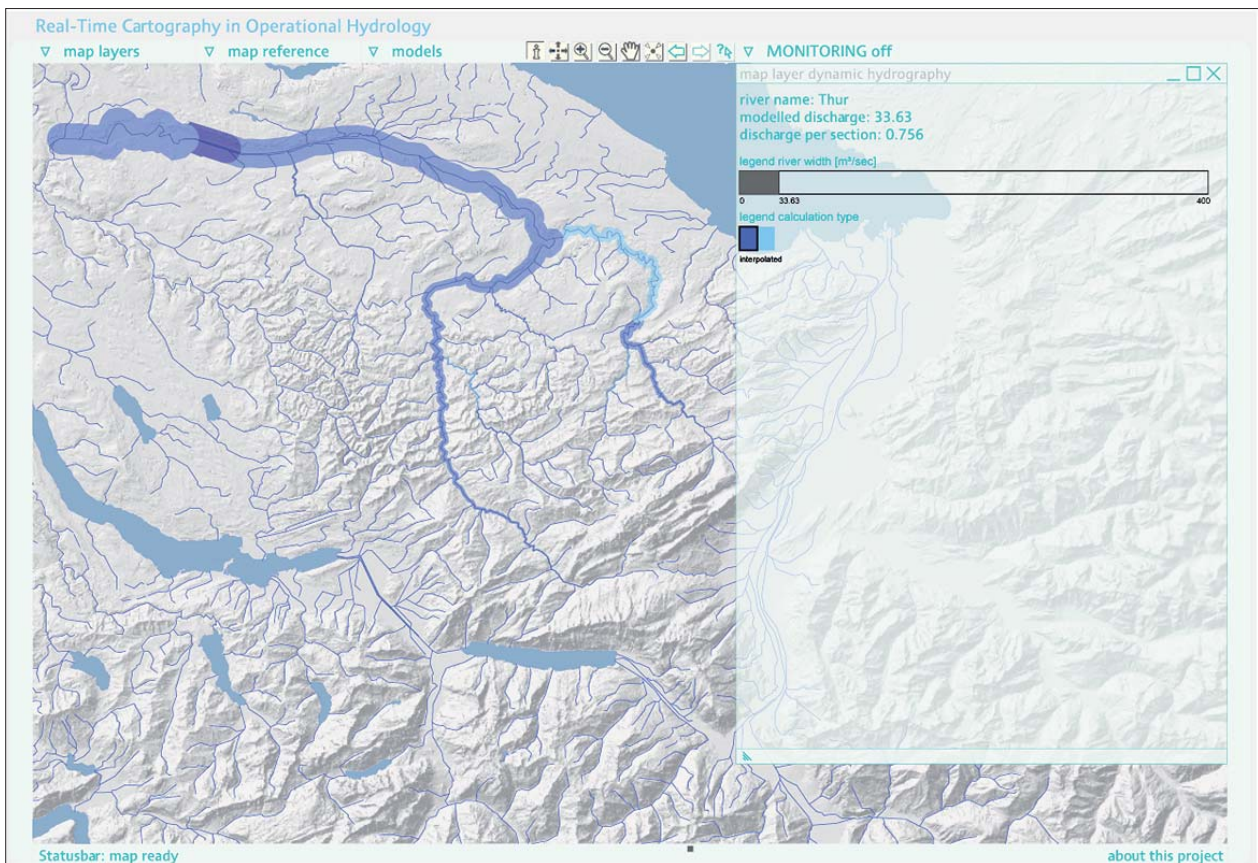


Fig. 4: Flow map representing real-time discharge by line width (own representation).

number of river sections within that leg. The river sections are predefined but often exhibit varying length. This means that interpolated values should not be considered accurate but an approximation to the real, unmeasured value of this river section.

(2.3) The term „Real-time“ in our project means „near real-time“. The gauges providing data for the flow map have a temporal offset between 10 minutes and several hours. This must be considered when viewing the map.

6. Conclusion

First attempts show that rendering a real-time flow map with real-time discharge data fetched from a database is feasible. Based on the existing 1:200,000 river network data model, it is demonstrative view of river discharge data for the purpose of monitoring in flood management. The generated flow map, however, is simplified as it does not take into account all rivers. Also, from a cartographic and hydrological point of view it is still objectionable at some points.

Unsurprisingly, the existence and the availability of real-time data, i.e., the density of the measuring network, is decisive for the map quality. Due to the lack of data at key locations of the river network, many parts of the workflow from raw data to the usable map have to be hard-coded. Many aspects, some have been mentioned above, remain to be researched. From a hydrologist' perspective, flow maps certainly hold the potential to support flood risk management for quick overviews. However, they can hardly be the sole means but must be complemented by additional maps such as point location or choropleth maps.

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