A web system for display and analysis of real-time monitoring observations of small urbanized catchments in Lahti, Finland

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Introduction

The hydrological cycle in urban areas is strongly affected by urbanization process (Lee et al. 2003). Urbanization leads to an increase of impervious surfaces (such as asphalt roads or car parks) with high runoff to rainfall ratios (Schueler 1994). Water flowing from these impervious surfaces is known as stormwater runoff. In Finland, stormwater runoff is typically not treated by wastewater treatment plants. Instead, it flows through a separate network of pipes and culverts directly into receiving water bodies and lakes (Valtanen et al. 2013).
The city of Lahti (population: 100 000) is situated in southern Finland on the shore of Vesijarvi. The lake (area: 121 km^2, maximum depth: 41 m) belongs to the Finnish Lake district area and it provides many important ecosystem services: recreation, fishing, swimming, sailing, water sports, ice-skating, skiing and others (Lehtoranta 2013). Every year, extensive lake treatment activities (oxygenation and intensive fishing) are carried out in order to keep the lake water nutrients at satisfactory levels and to prevent excessive algal blooms (Kuoppämäki et al 2013). However, lake treatment activities must be accompanied with mitigating incoming nutrient load from the catchment area (Valtanen et al. 2013). A significant part of the lake catchment land area is urbanized (10 % of the area). The remaining area is forest (67%) and agricultural 17%). Experience from other Nordic countries (Modaresi et al. 2010, Nordeidet et al. 2004), show that the stormwater runoff from urban areas may have important effect on nutrient transport to receiving lakes. To be able to predict the effect of urban development on the total volume of stormwater runoff and on the water parts of the city quality, it is important to establish a systematic monitoring network of experimental areas and quantify their hydrological response in different rainfall-runoff or snowmelt events. This paper introduces three study areas in Lahti (Figure 1), describes a new web system for the management and visualization of hydrological observations, and shows a case-study of the impact of urbanization on the runoff hydrograph in the catchments.

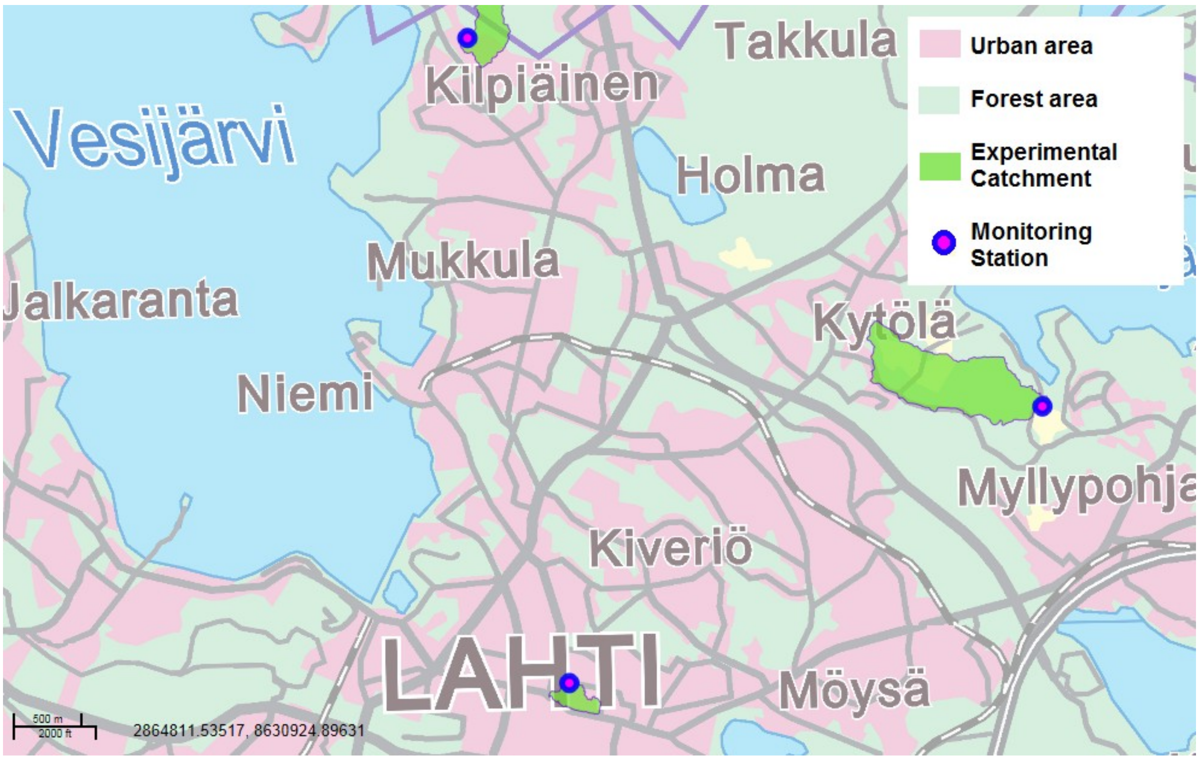

Figure 1: Locations of the experimental catchment study areas in Lahti

Study Areas

Table. 1 shows the overview of the experimental watersheds from Figure 1. The first area (Ainonpolku) is located in the city centre. It consists of a high density residential and commercial land use. 20% of the area is covered by asphalt roads or car parks. The second area (Kilpiäinen) is a suburban area where a forest was partially replaced by low-density residential housing. Although over 60% of the Kilpiäinen area is still covered by urban forest, the impervious parts of the area are mostly located near the catchment outlet. The third area (Kytölä) consists of forest and abandoned agricultural fields. It is the largest of the three study areas. In the year 2013, a change of the urban plan was approved by the Lahti city council. According to the urban planning document, 30% of the catchment will be changed to low and medium density residential housing. It is expected that the disturbance of soil caused by the construction activities will have measurable impact on the hydrology of the Kytölä catchment area.

Table 1: Properties of the experimental catchments in Lahti

	Ainonpolku (city centre, highly urbanized)	Kilpiäinen (suburban area, medium urbanized)	Kytölä (forest area, not urbanized)
Area (ha)	22.2	51.1	127.0
Impervious area percent	78.4%	25.6%	7.2%
Runoff coefficient in summer	0.87	0.27	0.19
Changes in the catchment	No major changes	No major changes	New construction will start in 2014
Monitoring periods	2008 – 2011, 2012 - 2014	2009 – 2011, 2012 - 2014	2012 - 2014

Observation data management system

The observation stations at Ainonpolku, Kytölä and Kilpiäinen are located inside underground pipes to protect the equipment from extreme weather conditions. They are equipped by the Labkotec (Labkotec, 2014) instrumentation device. Discharge (l/s) is measured at a one-minute time step using a pressure-based sensor. Turbidity (NTU) is measured by the turbidimeter connected to labkotec unit. Each station is also equipped with an automated grab sampler. When discharge or turbidity exceeds a threshold level, the sampler is activated and a water sample is retrieved and stored for further laboratory analysis of nutrients and other pollutants. All 3 stations are connected by a GSM mobile unit to the Labkonet mobile network (Labkotec, 2014). The observations data are temporarily stored at a logger at the station. At hourly intervals, the data from the logger are sent to a central Labkonet server (www.labkonet.fi). Authorized users may log-in to the server and examine the most recent data from each sensor (Figure 2).

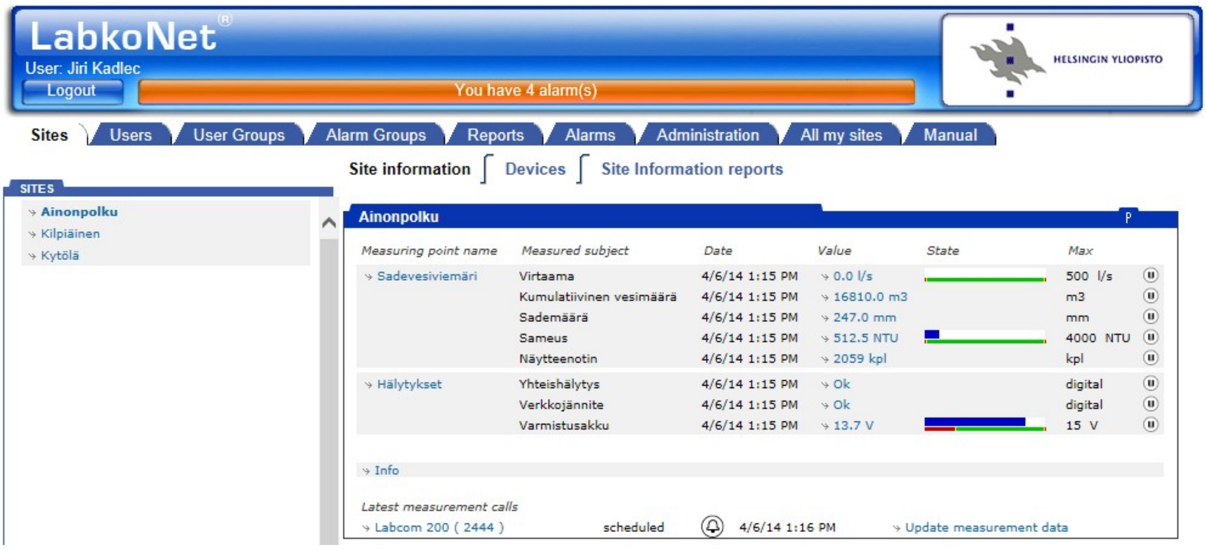

Figure 2: The default LabkoNet interface for monitoring observations from the experimental sites

Web System for Real-Time visualization

The Labkonet server (Figure 2) has only provided limited data access and visualization tools for examining the current and historical situation in the catchments. A survey of requirements of researchers, Lahti city officials, and the public, showed that a more interactive interface that includes the spatial view (location of study areas in the map) was needed. Also, users required the functionality to compare time series at different stations, and download any combination of parameters from any site and time period. To meet the requirements, a data management and visualization system was built using free and open-source software components (Figure 3). The time series data from field sensors are transmitted to a relational database, and then served using the Sensor Observation Service (SOS), Javascript Object Notification (JSON), WaterML or text file format. The open-source matplotlib toolkit is then used to display the one, two or three time series of precipitation, discharge or turbidity in a dynamic interactive chart.

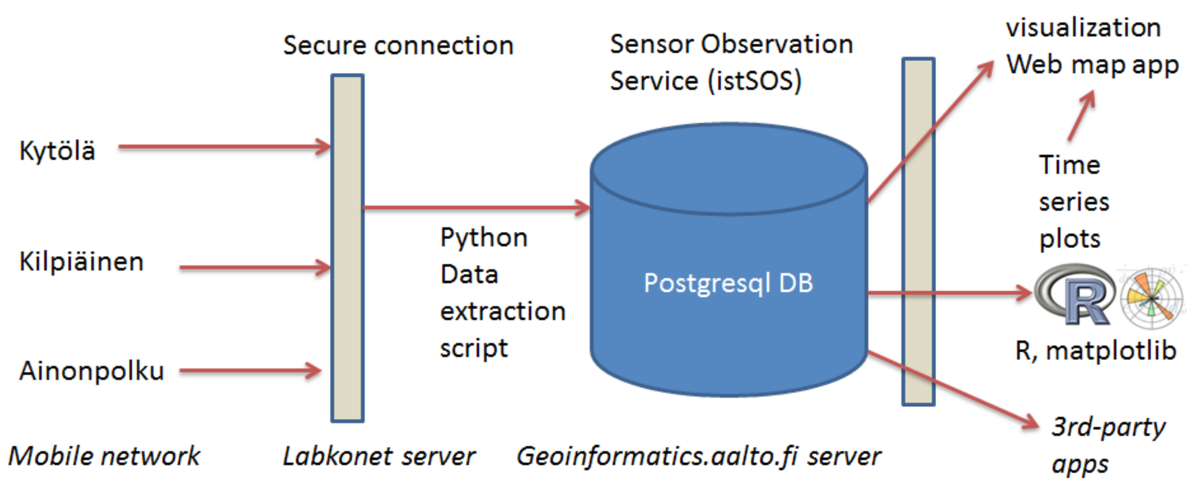

Figure 3: Transfer of real-time observations from experimental stations to the end user interface

The first component of the web-based data management and visualization system is a custom data extraction script written in the python programming language. The script logs-in to the LabkoNet interface with a user name and password, and simulates the action of the user for retrieving most-recent data from the sensors. It saves these observations to a relational database. The relational database uses the PostgreSQL database management system. The database schema is a simplified version of the ODM schema (Observations Data Model, Horsburg et al 2009) and consists of 5 tables: *catchments, stations, variables, sensors and observations*.

The **catchments** table contains geographic information on the catchment boundaries. The **stations** table contains the name, coordinates, elevation, identifier and photograph of each station. The **variables** table contains the English and Finnish names, units, scale, time step, time units, no data value, and explanation associated with each measured variable parameter (such as discharge, turbidity, precipitation, sampling operation). The **sensors** table is a look-up that shows which variables are measured at which station. It also contains technical information on each of the field sensor and the Labkonet sensor identifiers. Finally, the **observations** table stores the time, value, version and qualifier of each observation. The qualifier may be used by the data manager to record additional information (for example notification of outlier value due to sensor malfunctioning) associated with each individual observation. The database schema is shown in Figure 3.

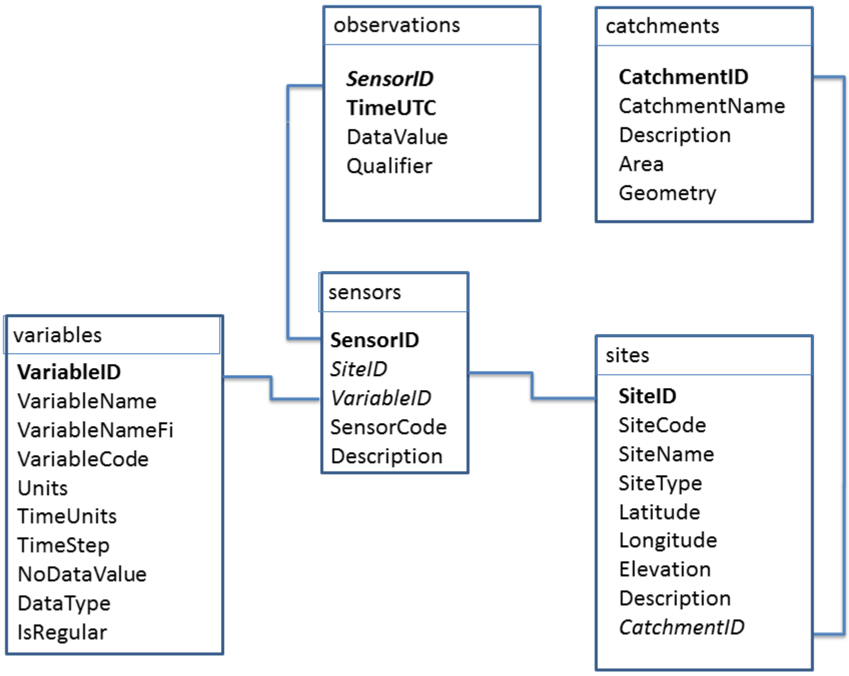

Figure 4 Database schema (PostgreSQL) for management of the hydrological observations

The observation time series from the database are re-published using 4 available formats: Text file (tab-delimited), Sensor Observation Service (SOS), WaterML data format, and time-series chart. All 4 formats can be retrieved by a web request with the following parameters: site, variable, begin date and end date. If the site is not specified, then time serieses for all sites that match the variable and time period are returned. This component has been built by customizing the open source istSOS tool (Cannata et al, 2013)

The final part of the interface is an interactive map application for exploring the experimental sites. The map shows the Lahti area with available background layers: topographic map, orthophoto, and general map. It also shows the experimental catchment areas and sites. Extra project-specific map layers (such as the land cover survey or runoff coefficient) may be added to the map. When the user clicks on a site in the map, a site info window with the last seven days time series chart is opened. Users can change the variable (default variable is discharge) and change the time period using a calendar selection or by using the time navigation button. The site information window also contains the „show data from all stations“ option for comparison with neighbouring sites. Finally, it has a „data download“ link for downloading the raw data corresponding to the chart in a text file format. The interactive map application has been built using the OpenLayers javascript library (OpenLayers, 2014).

Figure 5 shows the map interface with time series chart (discharge) from the Kytölä forest site, compared with the two other urban sites sites for the period 6.1 – 13.1.2014. The highest runoff volume at Kytölä is given by the largest area of the catchment. The time of peak flow in the Kytölä forest catchment is delayed by several hours compared to the urban sites. Figure 6 shows an example of the enlarged station info window at the Ainonpolku site and other sites with turbidity for the same period.

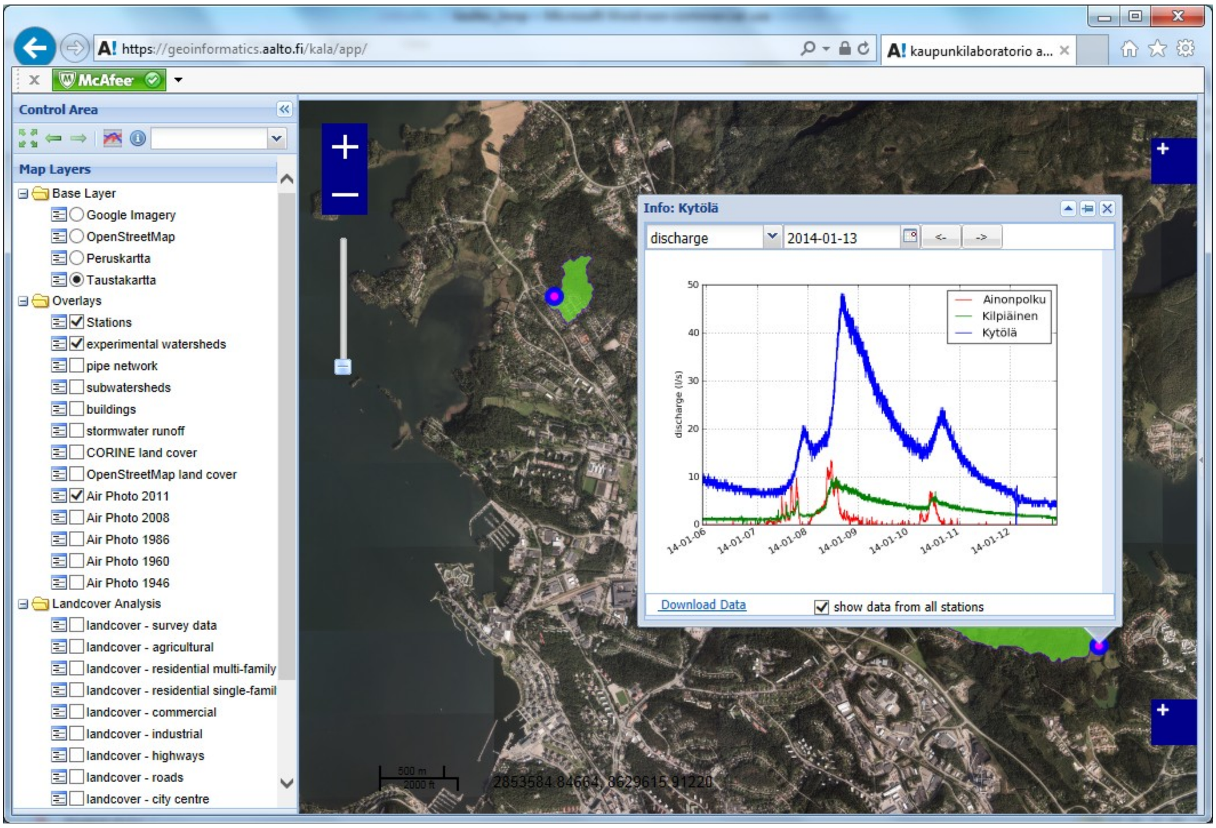

Figure 5: Web based interactive map with discharge time series from the catchments (January 2014)

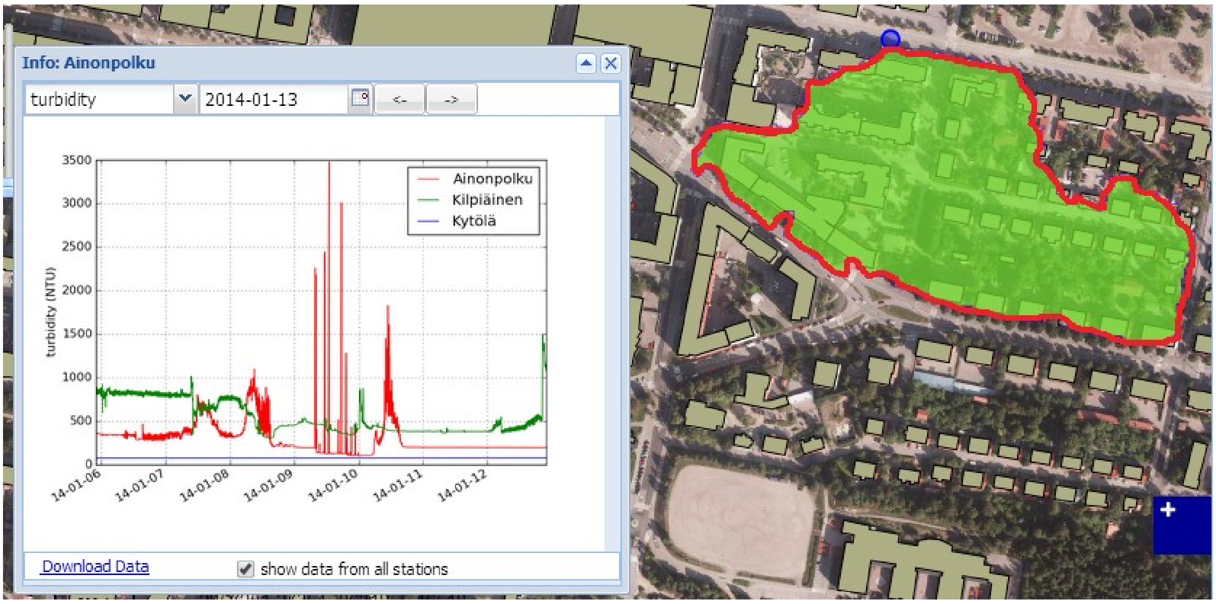

Figure 6: The info window for Ainonpolku urban site showing the turbidity in January 2014

Conclusions

By implementing the interactive web map interface, the large volume of near real-time and historic data from the experimental sites has become more simple to visualize and compare for students, city officials, researchers, and all interested public in Lahti. The whole end-user interface and web service has been designed using open-source software. The source code (in python and javascript) is available free of charge at the address: *geoinformatics.aalto.fi*.

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