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Hydrological Sensor Networks in Germany - Introducing SensorWeb-WSV

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Abstract: Sensor networks are important infrastructures for monitoring environmental systems on a routine basis. In response to climate change and adaptation strategies, environmental monitoring data is becoming increasing valuable as a mean for observing the impact on natural systems. Recent flood events in Europe (e.g. the Elbe floods in 2002 and 2006) show that environmental monitoring and subsequent data analysis lack standardized procedures for data availability and system interoperability. The existing systems do not fully meet the demands for in-time warning, efficient alerting and informing the public.

One of the major hydrological monitoring networks in Germany is operated by the Federal Waterway and Shipment Administration, which belongs to the Ministry of Transport, Building and Urban Affairs. Additional hydrological monitoring systems are operated on state and local water board level. The analysis of the different networks shows that a common architecture and a system interoperability using standardized data description and data servicing is missing. In most cases, the monitoring data is exchanged via E-mail or ftp in different data formats. Different web service solutions are just developing. Global climate change research projects as well as increasing natural hazards (see the mentioned Elbe floods) have put an additional pressure on the different stakeholders to closely line up recent environmental monitoring systems with emerging technologies.

In 2007, the Federal Waterways Engineering and Research Institute started the "SensorWeb-WSV" project with the goal to develop guidelines for future internet-enable architectures and the transition of the existing networks. This project shall implement a service orientated architecture (SOA) using international standards for geo and sensor data. It focuses on the guidelines of the German geo data infrastructure (GDI-DE, depending on W3C, ISO and OGC standards) and the "Sensor Web Enablement" initiative of the Open Geospacial Consortium (OGC SWE). In this paper, the first results of the project are presented, discussing the usability of the OGC SWE components (O&M - Observations and Measurements, SensorML – Sensor Model Language, SOS - Sensor Observation Service, WNS - Web Notification Service and SAS - Sensor Alert Service) in different monitoring networks.

The major challenge of the project is to implement the sensor web standard in all monitoring networks of the Federal Waterway and Shipment Administration ranging from smaller networks over control infrastructure elements along rivers and canals, local groundwater measurement networks and the federal hydrometric network. In doing so, "SensorWeb-WSV" shall open a path for a much more efficient use of existing environmental information and risk management systems in the context of the climate change debate.

Keywords: *OGC SWE, Sensor Web, O&M, SensorML, SOS, SAS, WNS, geo data infrastructure, INSPIRE*

1. INTRODUCTION

Hydrology data-sampling networks operated by German federal government, state governments and reservoir management boards play a major role in water resources management. These networks collect most of the needed data and rely on tested telemetry and IT infrastructure. They provide the data source for further data analysis and modeling as well as environmental information and risk management systems. The nationwide network providers in water resources management are the Federal Waterway and Shipment Administration (WSV - operator of the federal hydrometric network) and the German Weather Service (DWD) for all climate-meteorological data collection.

The WSV is in charge of different monitoring networks for hydrological data, which operate nationwide, regional or local. The different network types can be summarized as follows:

- Federal hydrometric network (nationwide): This network consists of about 1.600 monitoring stations (all measuring water level; some also provide information on discharge, water temperature, pH and other water quality parameter). The data is collected with a temporal resolution ranging from one minute (stations with tidal influence) to five minutes (stations without tidal influence). About 550 stations have online data access.
- Groundwater monitoring networks (regional): Some 10.000 groundwater sites positioned along the federal waterways (mostly channels) provide information on groundwater level and some additionally on groundwater quality with a temporal resolution ranging from one minute to 24 hours. The sites are grouped into smaller networks which are operated by the regional offices. Some networks offer online data acquisition.
- Monitoring and surveillance of deformations at waterway structures (local): Surveillance systems to monitor extension of dam constructions, alteration at gaps and joints and groundwater levels are existing at most waterway structures (about 700 locks and weirs, four lift locks, 15 canal bridges and two reservoirs). Most data is available with a temporal resolution of one minute. The networks are set up for each structure or structure complex (like a lock) individually and operated by the local or regional office. Some online data is available.

These networks use incompatible data loggers, data formats and data transmission techniques. Lack of standardization complicates the data exchange, limits the availability of the real-time data and increases the total cost of data distribution and data archiving.

OGC Sensor Web Enablement (SWE) promise standardized Service Orientated Architecture (SOA), web-enabled services and data encodings for Environmental Information Systems (EIS). OGC SWE components can be either used to build EISs from scratch, or as an compatibility layer for web-enabling and exchange of data between existing networks (BOTTS et.al. 2007).

The WSV sees in SWE technology a high potential to create compatibility between the internal networks (federal hydrometric network, groundwater monitoring networks and surveillance networks) and enforce their data integration into SWE OGC standardized systems. OGC SWE shows the path to a more effective, innovative and interoperable data exchange which can be (if consequently applied) less cost intensive.

In order to achieve these goals the WSV has set up the research project “SensorWeb-WSV”. In this paper first results are shown how (i) OGC SWE standards were integrated into an existing monitoring and surveillance system of a water log and how (ii) a sensor observations service (SOS) was developed for the nationwide federal hydrometric network using the IT infrastructure of PEGELONLINE (www.pegelonline.wsv.de).In both cases experiences with SWE are discussed to improve their interoperability.

2. RESEARCH PROJECT SENSORWEB-WSV

The research project “SensorWeb-WSV” was started in 2007 by discovering that many standardizing processes concerning sensor and data interoperability which were carried out by different working groups of the WSV did not satisfied the proposed goal (“interoperability”). By using the experience of the X-Hydro project (internal project of the WSV) which developed a XML-standard for hydrometric data description and using WSDL and SOAP for data communication., “SensorWeb-WSV” was set up to develop a general sensor and data model. The tasks of the project were to use a standardized Service Orientated Architecture (SOA), to rely on international standards, to integrate experience from X-Hydro, to deliver solutions for all sensor types and to minimize the impact on existing monitoring strategies and IT-systems. Technological “SensorWeb-WSV” is using the OGC SWE sensor web specifications (O&M - Observations and

Measurements, COX 2007 – Part 1 and 2 and SensorML- Sensor Model Language, BOTTS and ROBIN 2007) and services (SOS - Sensor Observation Service, NA and PRIEST 2007; WNS - Web Notification Service, SIMONIS and ECHTERHOFF 2006 and SAS - Sensor Alert Service, SIMONIS 2006). Additionally the project follows the guidelines of the German geo data infrastructure (depending on W3C -, ISO - and OGC standards) to assure the interoperability of sensor -, geo- and meta data.

Using the technical guidelines, the overall aim of "SensorWeb-WSV" is:

- Analyzing, customizing and implementing sensor web specifications and services: This task applies SWE OGC specifications and services in different case studies to test the suitability of,sensor and measurement descriptions given by O&M and SensorML for the networks and sensors of the WSV and to test the performance and stability of services and clients. It is mainly technical orientated.
- Linking OGC SWE with the German geo data infrastructure (GDI-DE): This tasks focuses on the interoperability of a common data access for sensor, geo and meta data. Besides the technical evaluation of standards the task is generally strategic and is followed up by the management.
- Defining standards and general procedures for the future design or the restructuring of monitoring networks in the WSV: This task is outcome focused and should deliver standard procedures for sensor data handling according to the case studies. Examples are a SensorML based sensor dictionary to describe sensors. Products of this task will be mandatory elements for future developments.

The research project "SensorWeb-WSV" is based on a project plan with two milestones. The first milestone is presented in this paper and covers the research work till end 2008. In milestone one, two case studies (Sülfeld lock and PEGELONLINE-SOS) were completed. Their focus was to analyse, customise and implement sensor web specifications and services. Till the end of 2010 the second milestone has to be completed. A positive outcome will result in implementation specifications for the networks and further research activities.

3. CASE STUDY SÜLFELD LOCK

3.1. Overview

The first case study of "SensorWeb-WSV" was carried out at the site 'Sülfeld lock'. The research was done in a master thesis (KLIPP 2008) supervised by scientific staff and supporting technicians. The site was chosen because the monitoring network of the lock was updated due to its reconstruction. A surveillance monitoring system is always required by federal law to monitor deformations and hydrological impacts over a time of at least 10 years after construction.

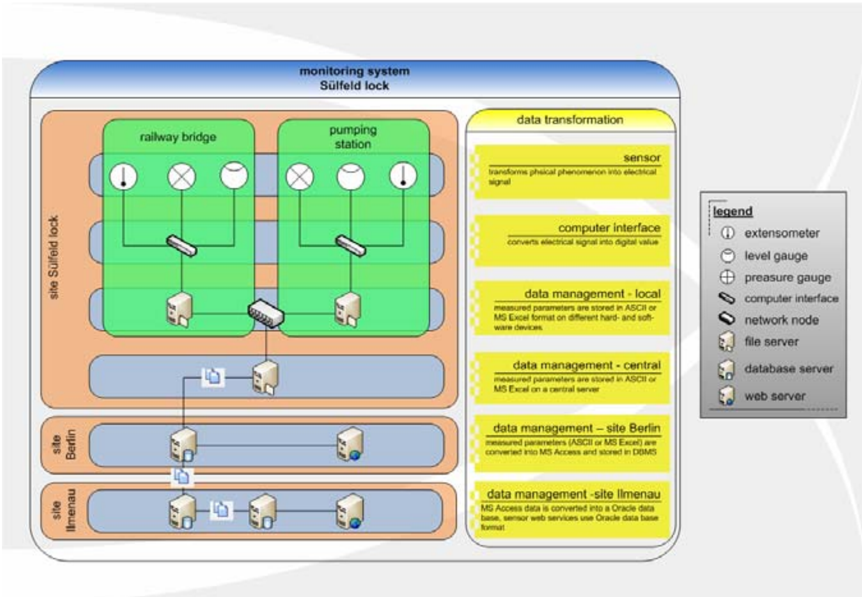

Figure 1. The surveillance monitoring network of the Sülfeld lock showing the different IT infrastructures and the data handling concept

The set up of the system and how "SensorWeb-WSV"is linked is shown in Figure 1. At the lock site two measurement stations (railway bridge and pumping station) are operated with several sensors measuring groundwater levels (level gauge), deformations of the structure (extensiometer) and soil water influence (pressure gauge). The data is stored at each sites in ASCII and MS Excel format and transferred to a central server for backup and data transfer. From the central server the data is transferred via ftp to a data base server of a private company in Berlin who constructed the surveillance monitoring system before “SensorWeb-WSV” was started. The server in Berlin stores the data in a MS Access DBMS and uses the Internet Map Servers ArcIMS from ESRI for data visualization. With the start of “SensorWeb-WSV”, it was decided to keep the setup of the monitoring network as it is. At the current stage “SensorWeb-WSV” connects to the DBMS in Berlin however that will be switched from Berlin to Sülfeld at the time the contract with the company in Berlin runs out.

3.2. Aim of the experiment and technical approach

Software used in the Sülfeld lock experiment includes the 52°North implementations of the SOS, SAS and WNS services and for the WNS the Open Source Native XML Database Exist and the mail server Mercury. As a data base system for “SensorWeb-WSV” an Oracle DBMS is used. It is the standard system for the entire Ministry of Transport, Building and Urban Affairs which is centrally operated in the city of Ilmenau. Oracle was used in the experiment to allow the future transition of any surveillance monitoring network within the WSV. The Oracle DBMS was implemented using the SOS Feeder and a JDBC–ODBC connection to synchronize it with the MS Access.DBMS. O&M and SensorML specifications were used to describe measurements and sensors.

The aim of this experiment was to show that “SensorWeb-WSV” is suitable to represent all functions of the surveillance monitoring network using standardized SWE specifications and services. Their main functions are:

- Processing sensor meta and time series data for reporting,
- Generalization of time series data for visualization and download,
- Implementation of alert messaging for threshold values.

3.3. Results

The achieved results were quiet promising and are summarized as follows:

<u>Processing sensor meta and time series data -</u>

The operations “GetObservation (O&M)” and “DescribeSensor (SensorML)” were used for general description. The key issue was to show the possible processing options. With the Apache Cocoon framework it could be achieved to transform the XML data (O&M and SensorML) into all data formats (word, excel, pdf) used by the local shipment offices (see Figure 2). Using this setup all reporting functions of the surveillance monitoring network could be met.

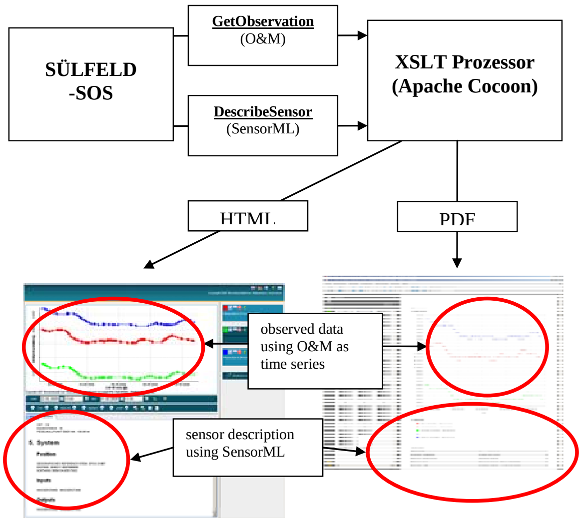

Figure 2. Processing the “GetObservation” and the “DescribeSensor” operations using the XSLT Prozessor Apache Cocoon

<u>Generalization of time series data -</u>

The generalization of time series data was the principal part of the experiment. The main reason therefore is that in the different WSV networks the resolution of time series data may vary from seconds to days. The focus was only on continuous time series. The used SOS implementation offered the following four generalization methods (i) skipping every second value, (ii) selecting every xx value, (iii) skipping values within a certain tolerance and (iv) skipping values within a certain tolerance (request time period dependant). In the experiment the aim was to visualize a time series of one month with a resolution of one second. First tests showed that the SOS client was not able to handle the data volume. Only a reduction to three days of data lead to stable condition of the client. The test results let conclude that only the generalization method (iv) could be used to reduce the data volumes. The main disadvantage of the used SOS was that the generalization methods had to be configured for the entire SOS service. The use of different methods depending on the time resolution of the data or on their further processing (download or visualization) was not possible. Based on that experiment one option could be to add to the „ GetObservation“ operation a generalization parameter (e.g. simplest case: generalisization=[activ | inactiv]).

Implementation of alert messaging for threshold values:

Using SAS and WNS an alert messaging system was set up to report threshold values via Email and SMS. The “AdvertiseSOS“ operation of the SAS is shown in Figure 3. The response is a SAS internal „SensorID“ which is stored with the response of the “AdvertiseSOS“ request in the SAS data base. The “SensorID” is further used in the SAS operations “Subscribe”, “Cancel- und Renew Subscription”. In the SAS client the user defines the threshold values for the sensor. By calling the “Subscribe" operation (SAS) and the “RegisterUser” operation (WNS) a link between sensor (targeted threshold) and messaging (Email or SMS) is established. By calling the „GetObservation“ operation of the SOS, the SAS compares the actual data with the threshold and notifies by calling the “DoNotification “ operation of the WNS the subscriber. Our experience with that setup was that connecting the services and clients for SOS, SAS and WNS was very complex and that the demand for configuration very high. Following are two examples. The „AdvertiseSOS“ operation has to be done manually by a service administrator for every sensor which is not feasible in an operating environment. Secondly the “SensorID” is just an internal ID for the SAS and does not refer to the actual ID of the sensor.

```
<?xml version="1.0" encoding="UTF-8"?>
<AdvertiseSOS
xmlns="http://www.opengis.net/sas/0.0"
xmlns:sml="http://www.opengis.net/sensorML/1.0"
xmlns:swe="http://www.opengis.net/swe/1.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/sas/0.0        ../sasAdvertise.xsd"
service="SAS" version="1.0.0">
<SOSInformation>
  <SOSURL>http://il431.ik.ilmenau.baw.de:8080/52nSOS_Oracle/sos</SOSURL>
    <offering>baw-offering-1</offering>
    <procedure>baw-sensor-101@22</procedure>
    <observedProperty>baw-phenomenon-1</observedProperty>
</SOSInformation>
<RetrievalFrequency>PT6H</RetrievalFrequency>
</AdvertiseSOS”>
```

Figure 3. “AdvertiseSOS” XML-Request (SAS)

The experiment showed that the functions of the surveillance monitoring using “SensorWeb-WSV” can be modeled. To use the approach in a reliable operating sensor network system further research needs to be carried out in terms of data generalization. This also addresses the problem of performance and stability (see case study PEGELONLINE-SOS). Also a practicable linking of different services like SOS, SAS and WNS with is minimizing the configuration work is required.

4. CASE STUDY PEGELONLINE-SOS

4.1. Overview

Using the experiences of the Sülfeld lock experiment we started a second “SensorWeb-WSV” application. This case study had the aim to implement the SOS from 52°North for the internet portal of the federal hydrometric network PEGELONLINE (www.pegelonline.wsv.de). PEGELONLINE was launched in 2002 to improve the data availability for flood forecasting and to develop a general platform for exchanging hydrometric data between different stakeholders. It integrates the hydrometric data of the federal hydrometric network (mainly water level). PEGELONLINE receives the data from regional data centers using SODA (Simultaneous Online Data Acquisition, retrieval system with software and hardware to connect to different telemetry systems) and WISKI (Wasserwirtschaftliches Informationssystem KIsters, software for water resource management by the company ‘Kisters’) which are organized in a Citrix server network..

PEGELONLINE uploads simultaneously the raw data retrieved from the monitoring stations by SODA and the analyzed time series data on demand from WISKI. Via PEGELONLINE the following services are available for different users (government and non-government institutions as well as public):

- Ftp and sftp data download in different formats: This interface was introduced with the launch of the system and allows additionally for users a station and time based automatic download of data. It is still used by most users to integrate the data into their systems (e.g. flood forecasting systems of the different German states).
- Online data visualization: Every time series is described via an URL. The URL can be easily customized using a parameter description on the PEGELONLINE website. The online data visualization was developed for users (e.g. city councils, industry) to display data of relevant water level stations in their internet representation (see example:

http://www.pegelonline.wsv.de/charts/OnlineVisualisierungGanglinie?pegelnummer=2430060&pegelnummer=23700205&imgBreite=450&pegelparameter=HSW,GLW,ZS_I,ZS_II,M_I,M_II,M_III&dauer=300).

- SOAP-Webservices: This service provides a WSDL conform description of all PEGELONLINE stations and data. It allows customers to integrate PEGELONLINE functionality into their systems.
- Mapping Services: PEGELONLINE offers an OpenLayers Map Client based on an Open Source Ajax-Client to integrated map images (map file of UNM map server) and stations (dynamically generated by PEGELONLINE DBMS). Additionally a PEGELONLINE WMS interface provides information for the operations “GetCapabilties“, „GetMap“ und „GetFeatureInfo“ for external OGC Web Mapping Services.. The operation “GetMap“ delivers information about the station as well as the actual water level and the trend of the time series..

4.2. Aim of the experiment and technical approach

The aim of the second case study was to find an efficient way (technical and economical) to publish PEGELONLINE data by an OGC SWE SOS. Given the fact that (i) the PEGELONLINE DBMS already hosts the complete hydrometric network data and (ii) a SOAP-Webservice already exists, the most promising approach was to use the SOAP-Webservice as data source for the SOS. By starting this experiment, we addressed the following questions:

- How can we design the operational steps for the implementation?
- What are available options to publish our service?
- How can we measure performance and stabilize the services for complex SOS queries and the huge amount of data transport (see generalization of time series data in the Sülfeld lock experiment)?

4.3. Results

In our experiment we achieved the following results:

<ins>How can we design the operational steps for the implementation?</ins> Using the SOS software the operations “GetObservation”, “GetCapabilities”, “DescribeSensor” and “GetFeatureOfInterest” were retrieving the sensor and observation data from the SOAP WS-Client (see Figure 4). In case of the operation "GetFeatureOfInterest" a geographic coordinate transformation was additionally implemented into the SOS software. This technical approach allowed the communication to stay internally SOAP and WSDL based. Externally the customers are offered an additional interface which relies on O&M and SensorML.

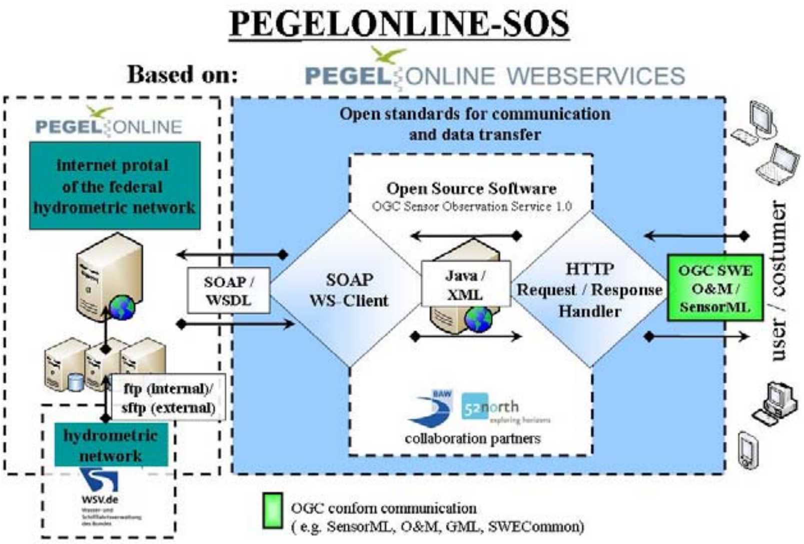

Figure 4. Technical implementation of the PEGELONLINE-SOS using the SOAP WS-Client as data source

<ins>What are available options to publish our service?</ins> The PEGELONLINE SOS is published on the GEOSS website (Global Earth Observation System of Systems): http://geossregistries.info/geosspub/service_details_ns.jsp?serviceId=urn:uuid:36e8f654-17ec-4ae7-8d67-80110b61a273. Further publishing will be carried out as part of our cooperation with 52°North.

<ins>How can we measure performance and stabilize the services for complex SOS queries and the huge amount of data transport (see generalization methods of time series data in the Sülfeld lock experiment)?</ins> The results from the Sülfeld lock experiment already showed that data generalization is a main issue to assure performance and stability of the SOS. A possible solution was suggested. To monitor and compare performance of the SOAP web service and the SOS the OpenSource tool JMeter was used

(http://jakarta.apache.org/jmeter/). Performance was defined as time between the executed request and the received response. Comparing the SOS „GetObservation“ and the SOAP/XML-RPC request in different scenarios (number of threads ranging from 100 to 1000) the following results were achieved. The SOAP web service had for the same request a higher data volume. Executing both requests in our intranet the SOAP web service was about three times faster. Looking at the internet performance both services performed equally. With the gained experience we aimed at more complex test scenarios to evaluate the performance of request chains such as combining a WMS, SOS and SAS. With performance data of the SWE services we are able to get valuable information for the further service integration into our information systems. Additionally we see a major improvement in stability of the services by code review.

The PEGELONLINE-SOS experiment showed how an existing information system could be easily extended by an OGC sensor observation service. To use the SOS in an operating information system such as PEGELONLINE it can be concluded from our studies that data generalization, performance and stability are three major issues for further investigation. Sensor resource discovery and semantics of observed properties were not deeper addressed in this study.

5. DISCUSSION AND CONCLUSIONS

In this paper the first results of the research project “SensorWeb-WSV” by the Federal Waterway and Shipment Administration were presented. The key issues of the research were (i) to test the SWE sensor web specifications and services for their suitability in different administration network types and (ii) to elucidate future research needs when applying the SWE services in an operating environment.

In two case studies the suitability, the benefits and arising problems by using sensor web were demonstrated. As benefits “SensorWeb-WSV” has provided (i) a standard procedure to describe sensors, (ii) a technical framework to standardize smaller networks and (iii) an operating SOS based on an available SOAP web service for the information system PEGELONLINE. Also SWE problems were addressed and evaluated. Main future research demands are to apply SWE in the “real” world and therefore further work is required on generalization methods, performance and stability issue and the orchestration (service interaction at the message and at the execution level) of services.

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