SMaRT-OnlineWDN deliverable 6.4: Identification of automatic countermeasures

Jochen Deuerlein, Nicolai Guth, Idel Montalvo Arango, Lea Meyer Harries,
Mathias Braun, Olivier Piller

To cite this version:

Jochen Deuerlein, Nicolai Guth, Idel Montalvo Arango, Lea Meyer Harries, Mathias Braun, et al.. SMaRT-OnlineWDN deliverable 6.4: Identification of automatic countermeasures. [Research Report] Irstea. 2015, pp.18. hal-03318603

HAL Id: hal-03318603
https://hal.inrae.fr/hal-03318603v1

Submitted on 10 Aug 2021

Berliner Wasserbetriebe

Fraunhofer
IOSB

DVGW TZW Technologiezentrum Wasser

3S Consult GmbH

irstea

VEOLIA
Eau d'Ile-de-France
Délégataire du SEDIF

VEOLIA
ENVIRONNEMENT
Recherche & Innovation

ENGEES
ÉCOLE NATIONALE DU GÉNIE DE L'EAU
ET DE L'ENVIRONNEMENT DE STRASBOURG

Strasbourg.eu
& COMMUNAUTÉ URBAINE

SPONSORED BY THE
Federal Ministry
of Education
and Research

PROJET FINANCÉ PAR L'ANR
ANR
PROJECT FUNDED BY THE ANR

Deliverable 6.4

Identification of automatic countermeasures

Dissemination level: Restricted

WP6

ONLINE-SOURCE IDENTIFICATION AND RISK MANAGEMENT

31st March 2015

SMaRT-Online WDN
Online Security Management and Reliability Toolkit
for Water Distribution Networks

ANR reference project: ANR-11-SECU-006

BMBF reference project: 13N12180

Contact persons

Fereshte SEDEHIZADE Fereshte.Sedehizade@bwb.de

Olivier PILLER Olivier.Piller@irstea.fr

WP 6 – ONLINE-SOURCE IDENTIFICATION AND RISK MANAGEMENT

D6.4 Identification of automatic countermeasures

List of Deliverable 6.4 contributors:

From 3S [WP6 leader]

Jochen Deuerlein (deuerlein@3sconsult.de)

Nicolai Guth (guth@3sconsult.de)

Idel Montalvo (montalvo@3sconsult.de)

Lea Meyer-Harries (meyer-harries@3sconsult.de)

From Irstea

Olivier Piller (olivier.piller@irstea.fr)

From IOSB

Mathias Braun (mathias.braun@isob-fraunhofer.de)

Work package number	6.4		**Start date:**	01/10/2014
Contributors	Irstea	3S Consult	IOSB	
Person-months per partne	6,25 15/15	2,75 10.5/10.5	1 1/5	

Keywords

Contaminant source, forward tracking, water quality model, look ahead, isolation, response time, sensor alarm

Objectives

To identify isolation valves that must be closed in order to separate the contaminated area from the rest of the system. After release of an alarm and identification of source candidates forward water quality modelling is used for look-ahead analysis of spread of contaminant. The simulation starts in the past and runs a reconstruction calculation until present time followed by look ahead analysis for the future. With an adequate choice of response time of the utility the spread of contamination can be calculated. The isolation valves that are reached after the response time are selected as isolation valves.

Summary

An effective and adequate response to a contamination event is one of the most important issues that are addressed by SMaRT-Online^{WDN} and can save lives of the population in case of a contamination event.

As soon as one of the sensors raises an alarm the online source identification algorithm delivers candidate nodes for the contamination source. The worst case node that explains the current alarms(s) is selected as source for an forward calculation of the spread of contaminant. The results shows how large the affected area is at present and how it will develop in the future.

In order to make optimal decisions for countermeasures the future spread of contamination is one of the most important information for the decision maker an therefore the basis for all response actions. For that purpose look ahead simulations are carried out that are based on the assumed source locations as well as the prognosis of the future flow velocities that are driven by the demands in the network.

With the so calculated contamination maps it is possible to select the population that must be informed first or the valves that have to be closed in order to isolate the contaminant and prohibit its further spreads through the network.

List of Figures:

Figure 1: Timeline of contamination event 6
Figure 2: Modified topology for exact allocation of valves and hydrants 8
Figure 3: Look ahead calculation 10
Figure 4: GUI of the SI and response software demonstrator 11
Figure 5: Graph decomposition results 12
Figure 6: Block graph tree 12
Figure 7: Response layer: contaminated pipes (blue) at earliest response time 13
Figure 8: Contamination layer: contaminated pipes (red) at current time 13
Figure 9: Source candidates layer: possible source locations as result of SI 14
Figure 10: Area observed by the four sensors 15
Figure 11: Control section overview (interactive mode only) 16

Contents:

1 Introduction 5
2 Response actions for mitigation of contamination events 5
2.1 Timeline of contamination event 5
2.2 Possible response actions 6
3 Online-Identification of isolation valves 8
3.1 Consideration of different network topologies 8
3.2 Brief description of the implemented algorithm 8
3.3 Outline for future improvements of the approach 10
  3.3.1 Neglecting impact of valve closure on flow distribution 10
  3.3.2 Neglecting changing demand characteristics 10
4 Software demonstrator overview 10
4.1 TreeView of layers 11
  4.1.1 Network graph 11
  4.1.2 Block graph tree 12
  4.1.3 Response Layer 13
  4.1.4 Look-Ahead Contamination Layer 14
  4.1.5 Contamination Layer 14
  4.1.6 Source Candidates layer 14
  4.1.7 Sensors layer 14
4.2 Timer and execution control panel 15
4.3 Controls for appearance of graphical elements in the map 15
4.4 Table views for sensors, sources and (isolation-) valves 16
4.5 Network map. 16
5 Conclusions 17
6 References 18

1 Introduction

Water quality monitoring combined with sophisticated alarm generation modules and online simulation and source identification (in the following also the abbreviation SI is used) techniques is an important step forward in order to reduce the risk of central water supply systems against deliberate or accidental contamination. However, solely the information about an event that can be gained from these systems is not sufficient for protection of the population and mitigation of the risk. The crucial part of the contamination warning systems is a sophisticated response plan. Roberson & Morley (2005, p. 3) state: "Clearly, no water utility should purchase any contamination monitoring technology without having a clearly defined response plan in place that has been tested and exercised. This response plan should detail how decisions will be made and what actions will be taken, by whom, when the alarm goes off."

To our knowledge there is no general agreement about the most appropriate countermeasures and response actions to contamination events. The overall objective is to save the life and health of the population. However, there is a number of different issues that make the definition of rules for an adequate response very difficult. The monitoring system is only part of a more comprehensive Contamination Warning System (CWS) that additionally includes management processes and uses all kind of available information for supporting the decision-making process in case of water network contamination thread.

Accordingly, the response plan has operational and technical aspects. The technical feasibility of efficient countermeasures is of course a necessary but not sufficient requirement for mitigation. Even more important is the implementation of the crisis management process within the utility. Crisis management is a native task of the utility and depended on multiple factors. It is not in the scope of this report to identify the necessary management issues. It rather addresses model based identification and decision support of technical actions that are appropriate for mitigation of the consequences of a contamination event. The tools can be used by the utility for planning and training in the context of crisis management. In addition, they are also designed for real-time use in combination with online monitoring and simulation.

2 Response actions for mitigation of contamination events

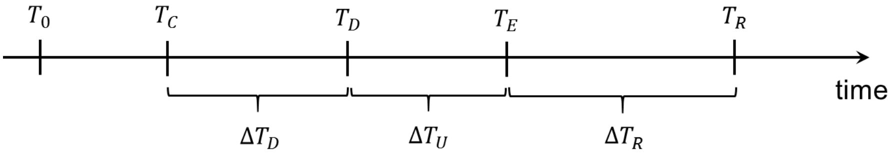
2.1 Timeline of contamination event

Once it is realized that a contamination event has happened, the utility needs to determine the appropriate actions according to the earlier developed response plan. The time needed to execute the required actions plays an important role to succeed on protecting the population and the water distribution infrastructure.

At each step of the process, starting from the sensor measurements to the actions to be taken, there are uncertainties that can delay the response of the water utility. There is uncertainty about the alarm itself. Even with the assumption of perfect sensors, there may be situations such as unusual operations where the early warning system releases an alarm although there is no real event. Therefore, the response is strongly related with the reliability of the sensors and the detection method for avoidance of false alarms.

After the first alarm there is a time of uncertainty. Is this a real event? What are the next steps? These are questions that have to be answered by the staff of the utility. The timeline of a contamination event is shown in Figure 1. After the contamination at time $T_{C,}$ it takes a time interval ΔT_D until the first sensor detects the contamination. This time span is called time to detection. The time to detection is dependent on the performance of the existing monitoring system and sensor network and the actual location of the injection. Minimizing time to detection is one of the performance measures in the sensor placement problem.

After the first sensor releases an alarm follows the period of uncertainty ΔT_U. During this time span it is not clear if the alarm is a false alarm or if there is really a problem with the water quality. If some monitored parameters continue to stay outside the normal range, and new alarms are raised the probability of a true contamination increased. Also, is there a normal water quality change in the system caused by new states of pumps and valves? Additionally, the utility proofs every additional information that is available (for example customer complaints, first aid actions, observation made by the police or citizens). If there is enough information that confirms the existence of a contamination at time T_E the response phase ΔT_R starts. At time T_R the utility is ready to react and to execute appropriate response actions.



Definitions:

- T_0: scenario start time (begin of observation)
- T_C: start time of contamination (unknown)
- T_D: time of detection (time of first sensor alarm)
- T_E: time of evidence (alarm(s) confirmed by utility)
- T_R: time of reaction (utility is ready to react)
- ΔT_D: time to detection (dependent on sensor network)
- ΔT_U: time of uncertainty (decision of utility)
- ΔT_R: response time (time interval that utility needs to react)

Figure 1: Timeline of contamination event

2.2 Possible response actions

The most appropriate way of response depends on a number of issues characterising the contamination event. Severity of the event, the already affected subsystem, the kind of contaminant, the technical possibilities of the utility, regulations and laws of the particular country and the qualification of the staff of the utility are only few examples for event characteristics.

Two main possibilities of technical reactions have been identified in the context of the project: In order to avoid the further spread of contamination for preventing the exposure of the population the contaminated water could be isolated by closing isolation valves. In this case the water remains in the pipes. The people that are connected to contaminated pipes have to be informed immediately and be prevented from consuming water. If the topology of the system allows a full separation of contaminated parts the supply in the rest of the system can be maintained. On the other hand if a very poisonous chemical agent was used the risk that people are not well informed and continue consuming the contaminated water might be too high if it remains too long in the pipes.

Another approach is trying to get the water out of the system as soon as possible. For that purpose all fire hydrants are opened at the same time and the water is let to the sewer system from where it flows to the central treatment plant. However, this approach has a number of problems. Dependent on the kind of contaminant very severe cascade effects can occur. For example, if a radioactive contaminant was used, most of the city would be contaminated for hundreds of years and could not be settled anymore.

There is a third possibility that combines the other two: manipulating valves for isolating the contaminated area and at the same time using specific hydrants to flush contaminated water in a controlled way (Poulin *et al.*, 2010). It is something in between the opening of all hydrants to flush immediately and isolating the contaminated area. Other researchers like (Preis & Ostfeld, 2008) have even considered the possibility to find a proper balance in reducing the impact of the contamination and the necessary amount of operations needed to accomplish it.

Besides the technical response actions there are a number of organisational issues that should be defined in the response plan of the utility including information of affected population, first aid logistics and combination of customer complaints with the more technical monitoring system.

Finding the best strategic response is a big challenge for water utilities. For mitigation of a contamination event technical and organisational aspects must be combined in order to strengthen the efficiency and effectiveness of the actions taken. Without adequate software tools it is almost impossible to foresee the impact of the decisions and its effectiveness. For instance, efficient and early enough information of the affected population is not possible without a well calibrated hydraulic model that forecasts the spread of contamination.

In the following a tool is presented that automatically identifies the valves that must be closed for isolation of contaminant in real-time. The tool uses the source candidates that are identified by the source identification algorithm (D 6.3). The (node, time) pair with the biggest negative impact is used (worst case assumption). Starting from this source node and the assumed time in the past when the contamination started, reconstruction calculation of the spread of contamination is carried out and the results are stored in the contamination layer. The contamination layer indicates how far the contamination has been spread probably over the network at current time.

Using the same source (node-time pair), in addition, combined reconstruction and look-ahead calculations are carried out. The results show the probable future spread of contamination. Using this information the utility can launch into response actions and counter-measures. For the look-ahead simulations the prediction model for the estimation of customer demands that was developed within the project (D 5.5, IOSB) can be used.

From the response actions described above the first approach, the online-identification of isolation valves, has been studied in detail within the project. The second approach requires the calculation of optimal flushing paths. In an earlier project (BMBF: STATuS, FKZ: 13N10623), the tool called “Flushing Planner” was developed (Deuerlein *et al.*, 2013). Therefore, within SMaRT-Online^{WDN} optimal flushing was not repeatedly studied. The results of both projects can be combined for the combination of isolation and flushing as described above.

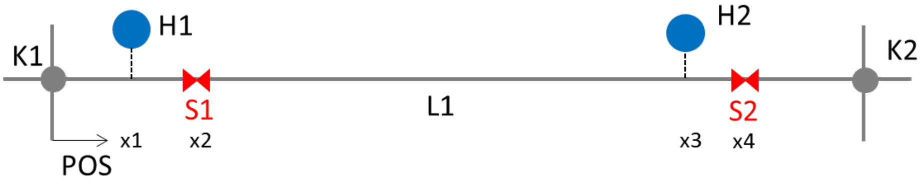
The method that has been implemented for the identification of isolation valves is described in more detail in the following section.

3 Online-Identification of isolation valves

3.1 Consideration of different network topologies

It is important to note that the common network topology of the hydraulic calculation model is not suited for the identification of isolation valves since the common node – arc network graph doesn't consider the exact locations of the isolation valves (Walski *et al.*, 2006). Available hydraulic simulation software tools normally use an approach where valves and hydrants are not modelled as nodes and links. They are special elements that are assigned to pipe links (see Figure 2, simplified topology). This approach has the advantage that the system to be solved in the hydraulic solver is much smaller. However, dependent on the length of the pipes and the level of aggregation, this method is not sufficiently accurate for the identification of isolation valves. In this case, the exact location must be considered because it can make an important difference if the valve is located at the front or at the end of the pipe. Two methods for tackling this problem have been identified. Either a modified topology model can be used as shown in Figure 2 (lower part) where the valves are modelled by extra links and the hydrants are nodes (Deuerlein *et al.*, 2013) or the response module must be able to consider the local location of valves and pipes within the link. For implementation the second approach has been used.

Simplified topology (hydraulic network simulation, GIS, …):



Exact topology (used by the response tool):

Figure 2: Modified topology for exact allocation of valves and hydrants

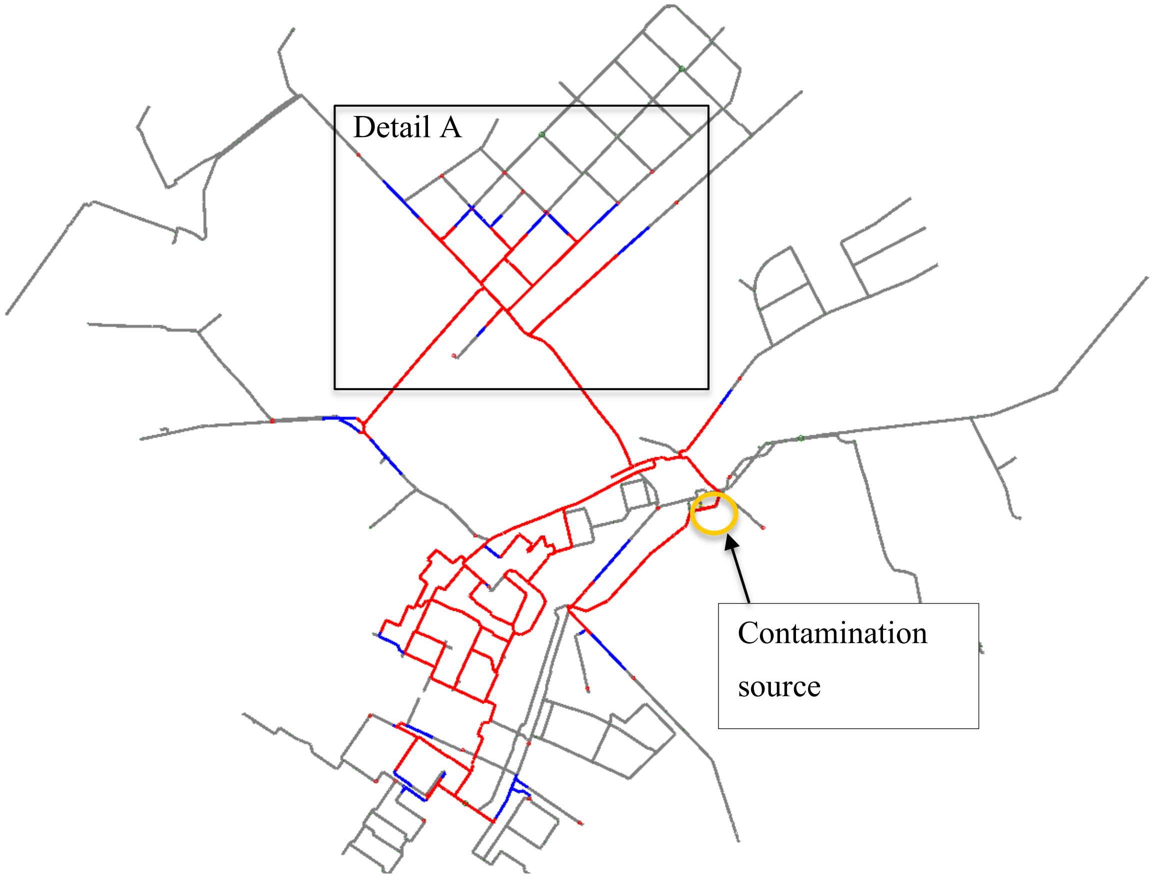
3.2 Brief description of the implemented algorithm

For decision support and response management, the online source identification module includes forward look-ahead calculation of the spread of contaminant. In case of a contamination alarm the look ahead simulation differs from common simulations of the future behaviour of the system. In this case, it is composed of a so called reconstruction calculation for the past and the look ahead simulation starting at present time. The reconstruction calculation is required since the origin of the contamination is generally in the past. Based on a worst case assumption the source node and the start time of contamination T_C (see Figure 1) are selected from the set of candidates that are delivered as result of the source identification algorithm.

Water transport calculation is then carried out for the time interval ΔT_D from start of contamination T_C to the time of detection T_D. As a result the spread of contaminant based on the assumed source is calculated and presented in the map (see Figure 3). Another calculation shows the probable spread of contaminant at the earliest time of reaction by the utility T_R that is defined as $T_R = T_D + \Delta T_U + \Delta T_R$.

For the look-ahead calculation the future demands are not well known and must be estimated by the demand prediction module. In a more simplified approach the current flow velocities that have been calculated by the online simulation module can be used. In this case an increased security factor for the response time should be applied.

The shut off valves are identified by running an extended look ahead simulation that doesn't stop at a certain time but runs until a state is reached where the transport of the particles is stopped. As described above the calculation uses a forward particle tracking. Each particle is moved forward until it reaches an isolation valve and, at the same time, the condition $T > T_R$ is true. The latter condition refers to the fact that a valve cannot be closed before the earliest time of reaction T_R. The valve is added to the list of isolation valves where also the latest time for closing the valve is stored. All the isolation valves and times are accessible via table-control in the software where the valves can be sorted through the latest shut-off time.



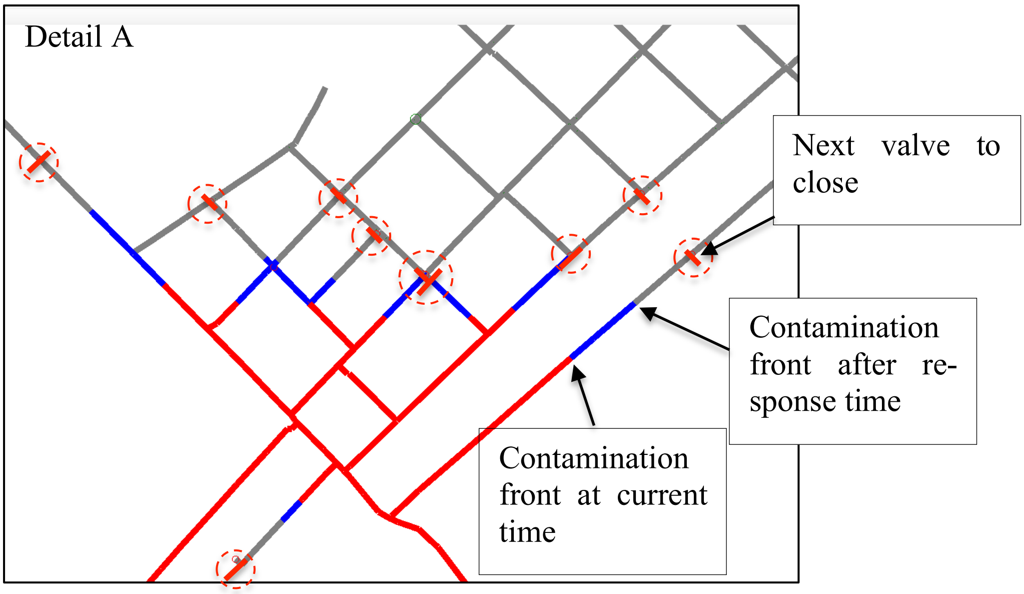


Figure 3: Look ahead calculation

3.3 Outline for future improvements of the approach

The implemented approach is based on simplifying assumptions. These simplifications have been necessary since the information and data needed for improvements is not available online. In future research projects the problem could be addressed by taking particularly care of the following issues.

3.3.1 Neglecting impact of valve closure on flow distribution

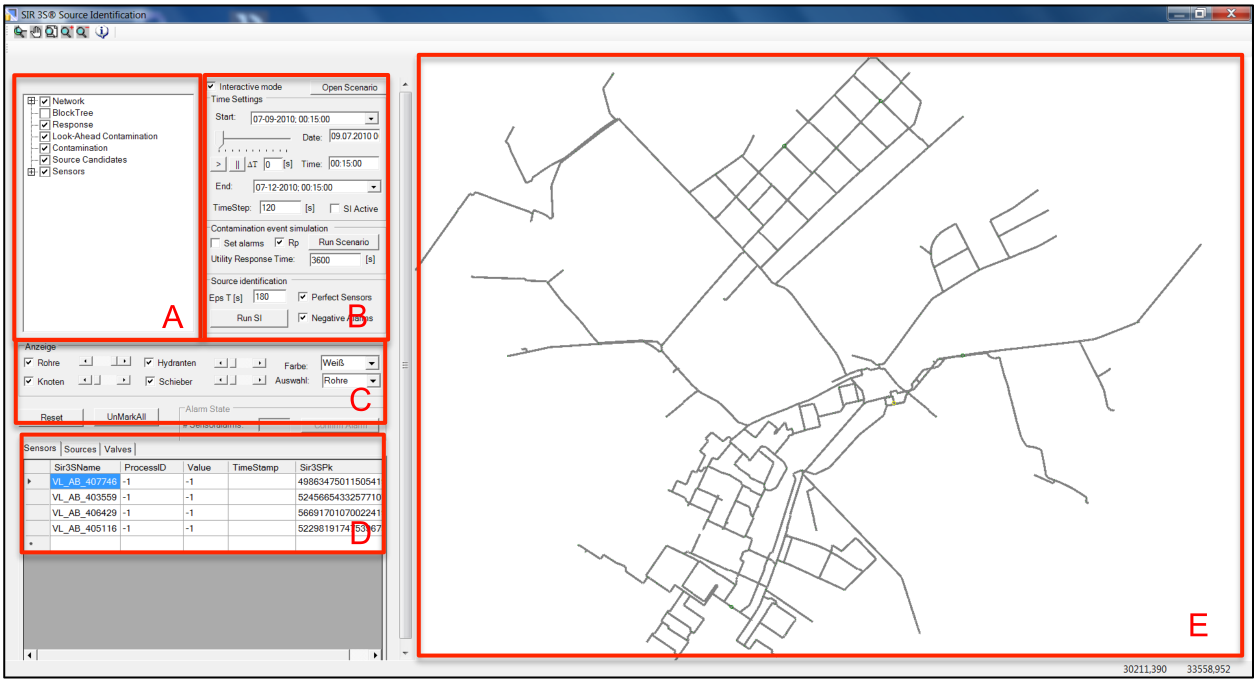
The actual time of closure of a valve in praxis is influenced by a number of (organizational) issues and might differ from the calculated time when the contamination passes the valve. The impact of the valve closure on the flow distribution is not considered in the software so far. A further step of development could consist of integrating valve state information in the SCADA system of the utility. In this case the information that a valve is closed could be transferred using for example mobile phone technology or real-time GIS. If the data are also integrated within the OPC-Server that is connected with the online-simulation model, the changed topology is automatically considered within the calculation of the next time step.

3.3.2 Neglecting changing demand characteristics

The information of the affected population about the contamination is also part of the response strategy of the utility. The effect that after this information the consumers will change their consumer behaviour has not been considered, neither in the valve identification tool nor in the demand forecast module. The difficulty is that data driven approaches for demand prognosis are not applicable in this situation due to missing comparable situations in the past.

4 Software demonstrator overview

Within the project a demonstrator for online source identification and response has been developed, implemented and tested for the example networks provided by BWB. The software can be used online as plugin of the SIR OPC integration platform or in interactive mode.



☑ Network
☐ BlockTree
☑ Response
☑ Look-Ahead Contamination
☑ Contamination
☑ Source Candidates
☑ Sensors

☑ Interactive mode

Time Settings

Start: 07-09-2010; 00:15:00
Date: 09.07.2010 0
ΔT 0 [s] Time: 00:15:00
End: 07-12-2010; 00:15:00
TimeStep: 120 [s] ☐ SI Active

Contamination event simulation

☐ Set alarms ☑ Rp
Utility Response Time: 3600 [s]

Source identification

Eps T [s] 180 ☑ Perfect Sensors
☑ Negative Alarms

Anzeige

☑ Rohre ☑ Hydranten Farbe: Weiß
☑ Knoten ☑ Schieber Auswahl: Rohre

	Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
▸	VL_AB_407746	-1	-1		4986347501150541
	VL_AB_403559	-1	-1		5245665433257710
	VL_AB_406429	-1	-1		5669170107002241
	VL_AB_405116	-1	-1		5229819174[illegible]
*					

Figure 4: GUI of the SI and response software demonstrator

An overview of the Graphical User Interface (GUI) of the software demonstrator is shown in Figure 4. The main partitions are:

A:	TreeView for selection of different layers of the map.
B:	Control options for interactive mode including timing and calculation parameters and execution buttons for different algorithms.
C:	Controls for appearance of graphical elements in the map.
D:	Table views for sensors, sources and (isolation-) valves.
E:	Network map.

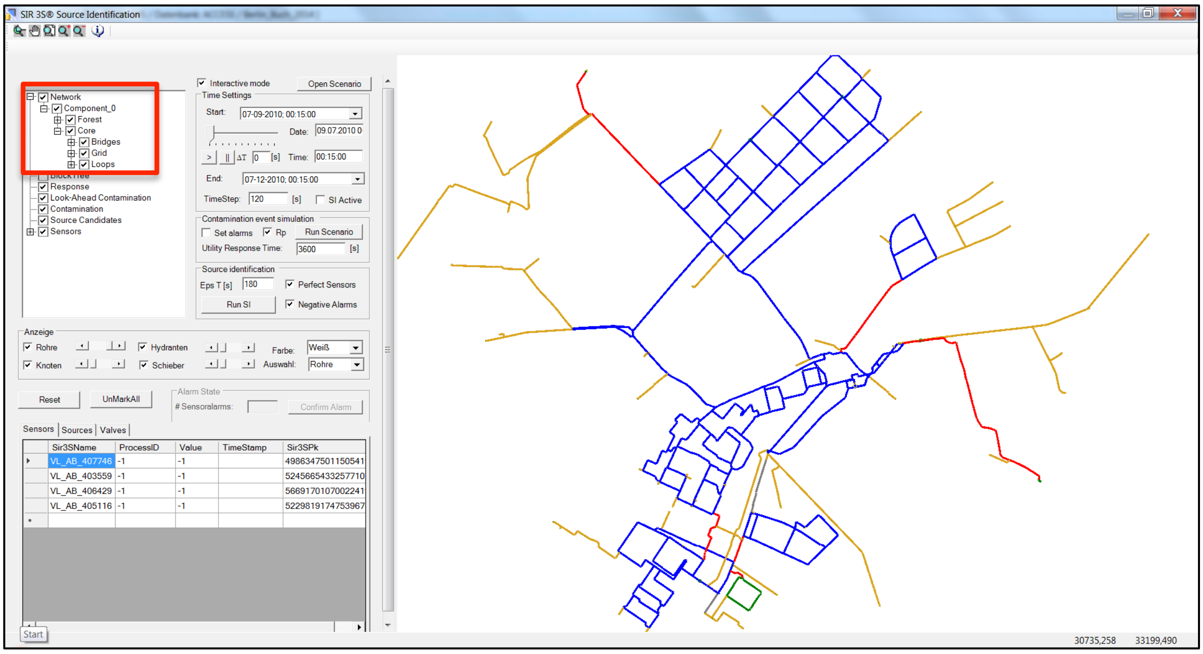
Each of the partitions will be explained in more detail in the following subsection

4.1 TreeView of layers

As a standard seven layers are included in the tree view:

4.1.1 Network graph

The first layer "Network" includes the network features of the hydraulic simulation model such as pipes, nodes and valves. Enlarging the tree view node shows the results of the decomposition of the network graph (Figure 5) into forest and 2-core where the forest (brown colour) consists of trees and the 2-core is composed of looped grid blocks (blue colour) and loops (green colour) that are connected by bridge components (red colour). The decomposition is used for enhancement of different algorithms in the context of SMaRT-Online^{WDN} and for an improved understanding of network connectivity (Deuerlein 2008).



☑ Network
☑ Component_0
☑ Forest
☑ Core
☑ Bridges
☑ Grid
☑ Loops
☐ BlockTree
☑ Response
☑ Look-Ahead Contamination
☑ Contamination
☑ Source Candidates
☑ Sensors

☑ Interactive mode
Start: 07-09-2010; 00:15:00
Date: 09.07.2010 0
ΔT 0 [s] Time: 00:15:00
End: 07-12-2010; 00:15:00
TimeStep: 120 [s] ☐ SI Active
☐ Set alarms ☑ Rp
Utility Response Time: 3600 [s]
Eps T [s] 180 ☑ Perfect Sensors
☑ Negative Alarms
☑ Rohre ☑ Hydranten Farbe: Weiß
☑ Knoten ☑ Schieber Auswahl: Rohre
Sensoralarms:

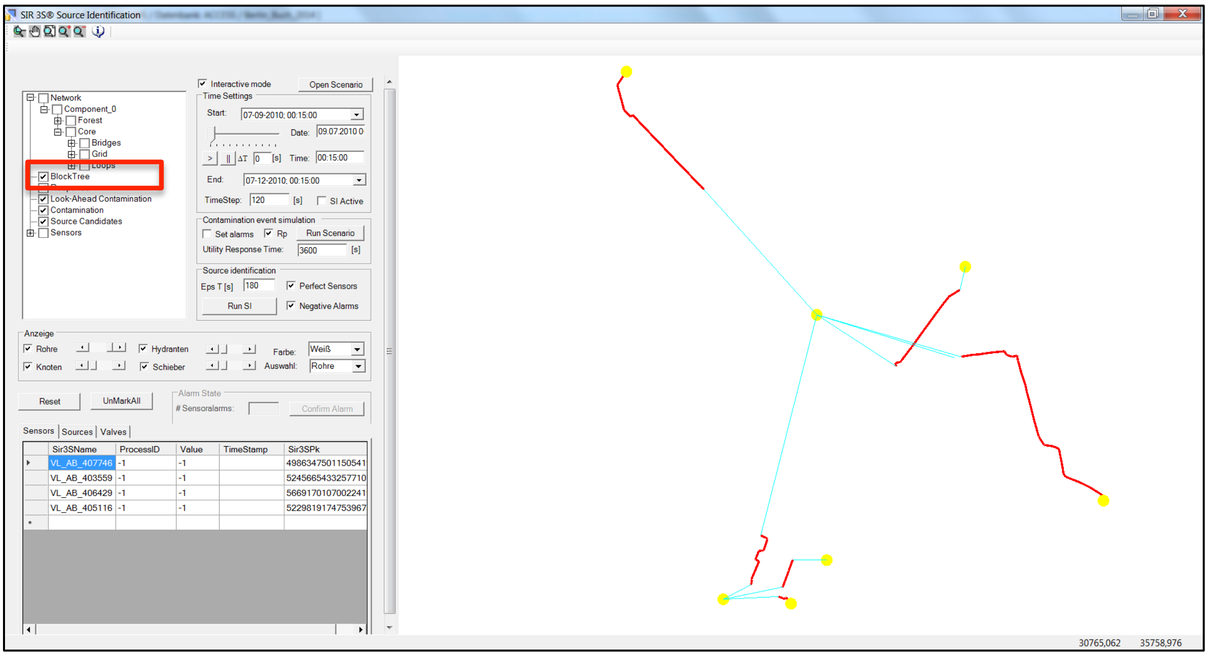
Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
VL_AB_407746	-1	-1		4986347501150541
VL_AB_403559	-1	-1		5245665433257710
VL_AB_406429	-1	-1		5669170107002241
VL_AB_405116	-1	-1		5229819174753967

30735,258 33199,490

Figure 5: Graph decomposition results

4.1.2 Block graph tree

The layer "Block Tree" (Figure 6) shows the connectivity of the main components of the graph and can be used for preselection of network components in the source identification and response tool. For instance, closing a valve on a bridge link subdivides the network into two disconnected subsystems. Therefore these links are particularly suitable for immediate response actions and placement of remote controlled valves.



☐ Network
☐ Component_0
☐ Forest
☐ Core
☐ Bridges
☐ Grid
☐ Loops
☑ BlockTree
☑ Look-Ahead Contamination
☑ Contamination
☑ Source Candidates
☐ Sensors

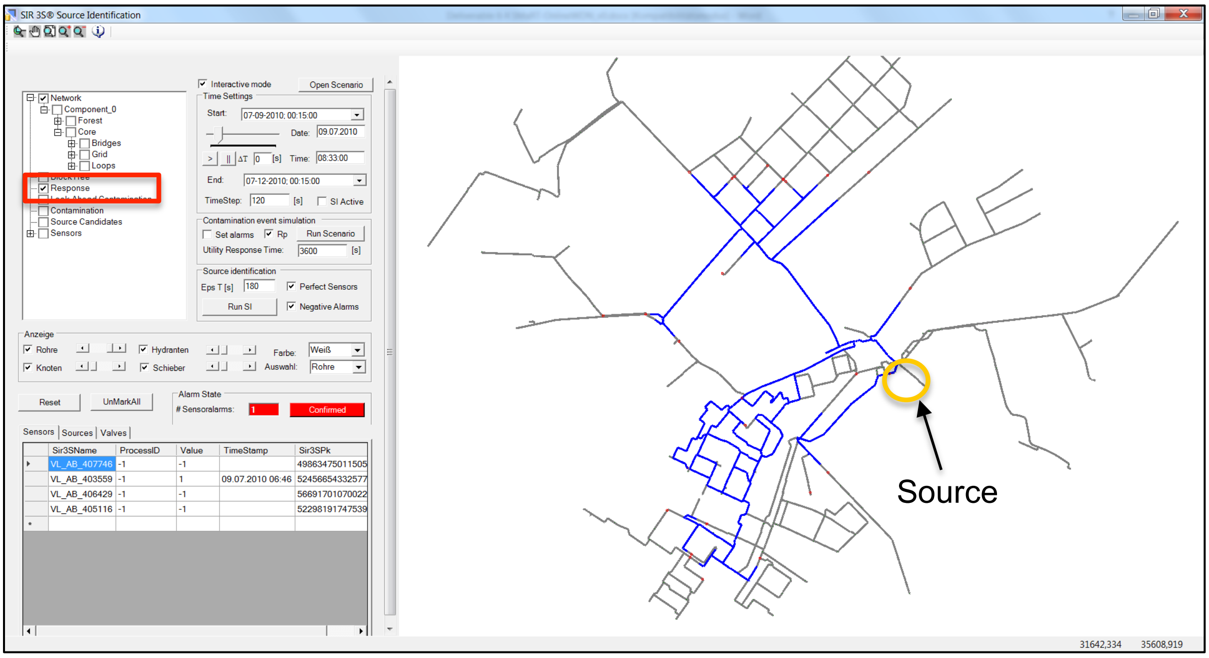
☑ Interactive mode
Start: 07-09-2010; 00:15:00
Date: 09.07.2010 0
ΔT 0 [s] Time: 00:15:00
End: 07-12-2010; 00:15:00
TimeStep: 120 [s] ☐ SI Active
☐ Set alarms ☑ Rp
Utility Response Time: 3600 [s]
Eps T [s] 180 ☑ Perfect Sensors
☑ Negative Alarms
☑ Rohre ☑ Hydranten Farbe: Weiß
☑ Knoten ☑ Schieber Auswahl: Rohre
Sensoralarms:

Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
VL_AB_407746	-1	-1		4986347501150541
VL_AB_403559	-1	-1		5245665433257710
VL_AB_406429	-1	-1		5669170107002241
VL_AB_405116	-1	-1		5229819174753967

30765,062 35758,976

Figure 6: Block graph tree

4.1.3 Response Layer


SIR 3S® Source Identification

☑ Network
☐ Component_0
☐ Forest
☐ Core
☐ Bridges
☐ Grid
☐ Loops
☐ BlockTree
☑ Response
☐ Look-Ahead Contamination
☐ Contamination
☐ Source Candidates
☐ Sensors

☑ Interactive mode

Time Settings
Start: 07-09-2010; 00:15:00
Date: 09.07.2010
ΔT 0 [s] Time: 08:33:00
End: 07-12-2010; 00:15:00
TimeStep: 120 [s] ☐ SI Active

Contamination event simulation
☐ Set alarms ☑ Rp
Utility Response Time: 3600 [s]

Source identification
Eps T [s] 180 ☑ Perfect Sensors
☑ Negative Alarms

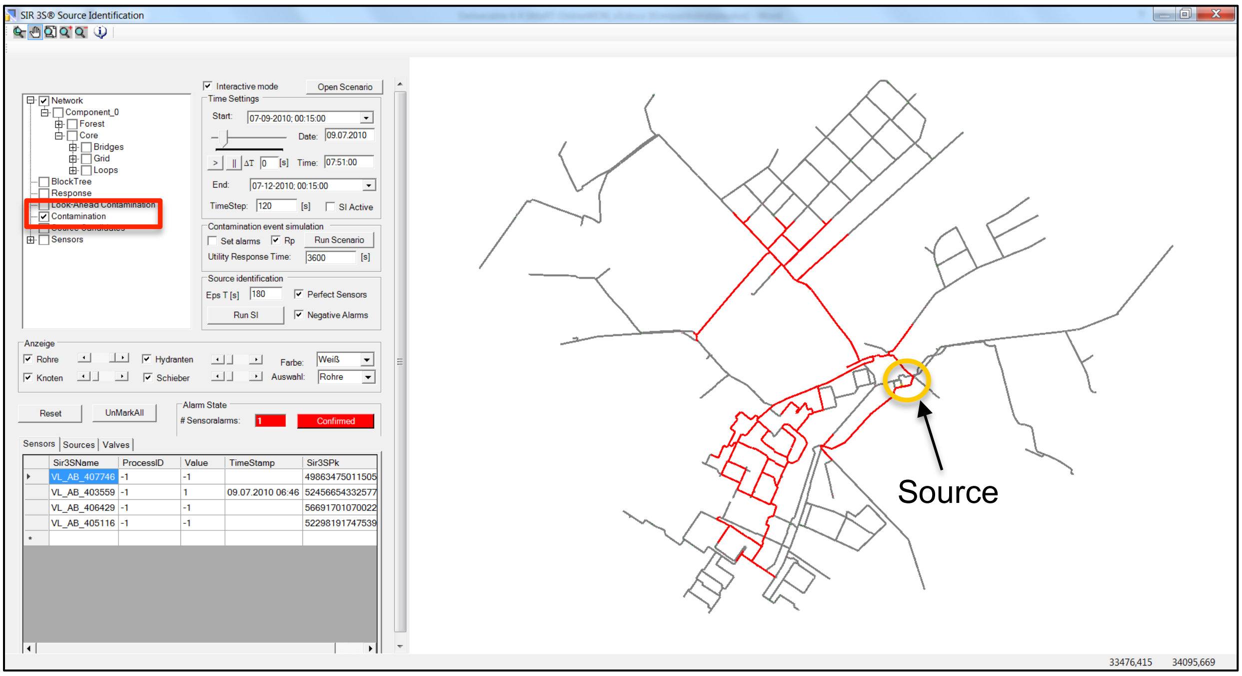
Anzeige
☑ Rohre ☑ Hydranten Farbe: Weiß
☑ Knoten ☑ Schieber Auswahl: Rohre

Alarm State
Sensoralarms: 1 Confirmed

Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
VL_AB_407746	-1	-1		49863475011505
VL_AB_403559	-1	1	09.07.2010 06:46	52456654332577
VL_AB_406429	-1	-1		56691701070022
VL_AB_405116	-1	-1		52298191747539

Figure 7: Response layer: contaminated pipes (blue) at earliest response time

Figure 7 shows the layer “Response” that includes the contaminated pipes and current selection of isolation valves at the earliest reaction time. In addition, in Figure 7 the layer “Network” is checked (grey pipes). After the pending sensor alarms were confirmed by the user the response look-ahead calculation is based on the assumption that shut-off valves are closed after the earliest response time. That means that the spread of contamination stops at the valves. After a certain time that depends on the flow velocities and the number and location of valves the contaminated subnetwork is bounded by closed isolation valves and rests in a steady-state.


SIR 3S® Source Identification

☑ Network
☐ Component_0
☐ Forest
☐ Core
☐ Bridges
☐ Grid
☐ Loops
☐ BlockTree
☐ Response
☐ Look-Ahead Contamination
☑ Contamination
☐ Source Candidates
☐ Sensors

☑ Interactive mode

Time Settings
Start: 07-09-2010; 00:15:00
Date: 09.07.2010
ΔT 0 [s] Time: 07:51:00
End: 07-12-2010; 00:15:00
TimeStep: 120 [s] ☐ SI Active

Contamination event simulation
☐ Set alarms ☑ Rp
Utility Response Time: 3600 [s]

Source identification
Eps T [s] 180 ☑ Perfect Sensors
☑ Negative Alarms

Anzeige
☑ Rohre ☑ Hydranten Farbe: Weiß
☑ Knoten ☑ Schieber Auswahl: Rohre

Alarm State
Sensoralarms: 1 Confirmed

Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
VL_AB_407746	-1	-1		49863475011505
VL_AB_403559	-1	1	09.07.2010 06:46	52456654332577
VL_AB_406429	-1	-1		56691701070022
VL_AB_405116	-1	-1		52298191747539

Figure 8: Contamination layer: contaminated pipes (red) at current time

4.1.4 Look-Ahead Contamination Layer

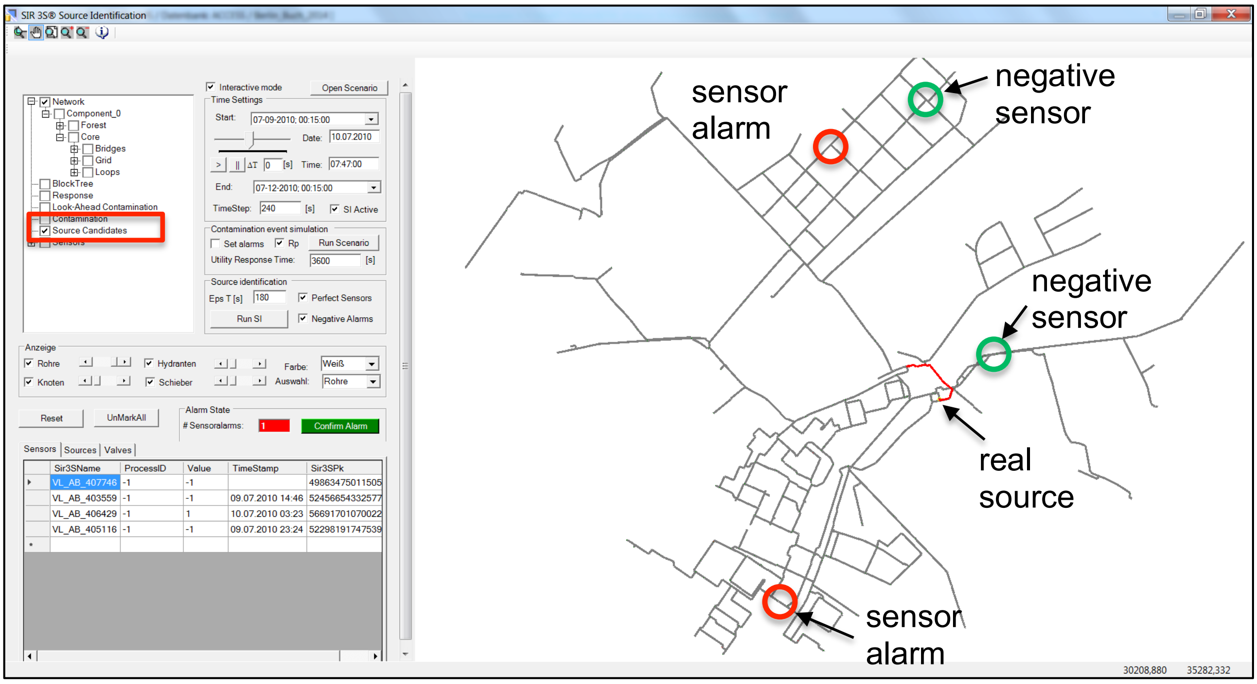
The layer “Look-Ahead Contamination” is exclusively used in the online case. It shows the spread of contamination at look-ahead time in the future. In contrast to the response layer, it is independent of the selection of response parameters. Furthermore, the spread of contamination is not restricted by isolation valves.

4.1.5 Contamination Layer

The layer “Contamination“ shows the estimated spread of contamination at current time based on the assumed location of the source (see red pipes in Figure 8).

4.1.6 Source Candidates layer

The layer “Source Candidates” presents the results of the last SI calculation. In general, there is no unique solution of the source identification problem. Therefore, the nodes and links that are possible sources are shown by this layer. Figure 9 shows the situation where two sensors have reported an alarm (red circles) and two sensors are in negative alarm state. There are only few source locations (red marled pipes) that can explain the appearance of these two alarms and their particular start times.



☑ Interactive mode

Time Settings
Start: 07-09-2010; 00:15:00
Date: 10.07.2010
ΔT 0 [s] Time: 07:47:00
End: 07-12-2010; 00:15:00
TimeStep: 240 [s] ☑ SI Active

Contamination event simulation
☐ Set alarms ☑ Rp
Utility Response Time: 3600 [s]

Source identification
Eps T [s] 180 ☑ Perfect Sensors
☑ Negative Alarms

Anzeige
☑ Rohre ☑ Hydranten Farbe: Weiß
☑ Knoten ☑ Schieber Auswahl: Rohre

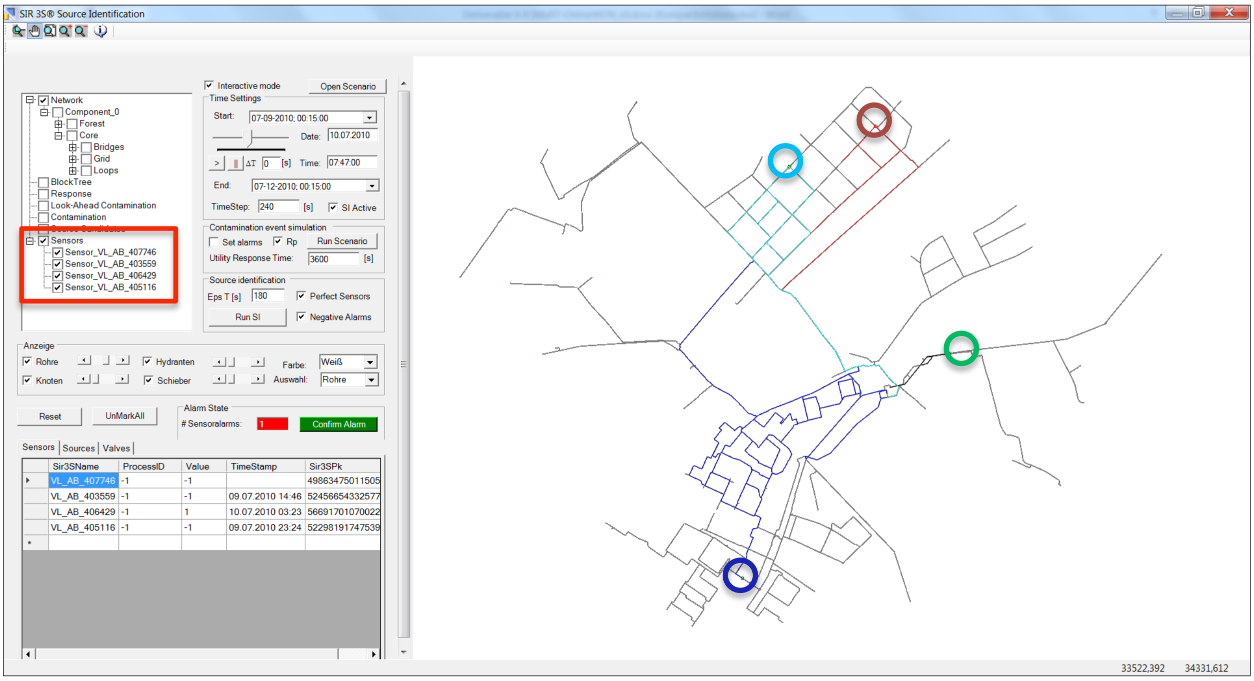
Alarm State
Sensoralarms: 1

Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
VL_AB_407746	-1	-1		49863475011505
VL_AB_403559	-1	-1	09.07.2010 14:46	52456654332577
VL_AB_406429	-1	1	10.07.2010 03:23	56691701070022
VL_AB_405116	-1	-1	09.07.2010 23:24	52298191747539

Figure 9: Source candidates layer: possible source locations as result of SI

4.1.7 Sensors layer

The last tree view node represents layer “Sensors” and has additional child nodes. The parent node is checked for drawing the location of sensors in the map whereas the child nodes show for each sensor the pipes that have been observed in the past by the sensor. The observed area is the result of a particle backtracking algorithm that is carried out for each sensor at every time step independent of the alarm state of the sensor. As a result, the current monitoring state of the entire network can be visualized (Figure 10).



☑ Interactive mode

Start: 07-09-2010; 00:15:00

Date: 10.07.2010

ΔT 0 [s] Time: 07:47:00

End: 07-12-2010; 00:15:00

TimeStep: 240 [s] ☑ SI Active

☐ Set alarms ☑ Rp

Utility Response Time: 3600 [s]

Eps T [s] 180 ☑ Perfect Sensors

☑ Negative Alarms

☑ Rohre ☑ Hydranten Farbe: Weiß

☑ Knoten ☑ Schieber Auswahl: Rohre

Sensoralarms: 1

Sir3SName	ProcessID	Value	TimeStamp	Sir3SPk
VL_AB_407746	-1	-1		49863475011505
VL_AB_403559	-1	-1	09.07.2010 14:46	52456654332577
VL_AB_406429	-1	1	10.07.2010 03:23	56691701070022
VL_AB_405116	-1	-1	09.07.2010 23:24	52298191747539

Figure 10: Area observed by the four sensors

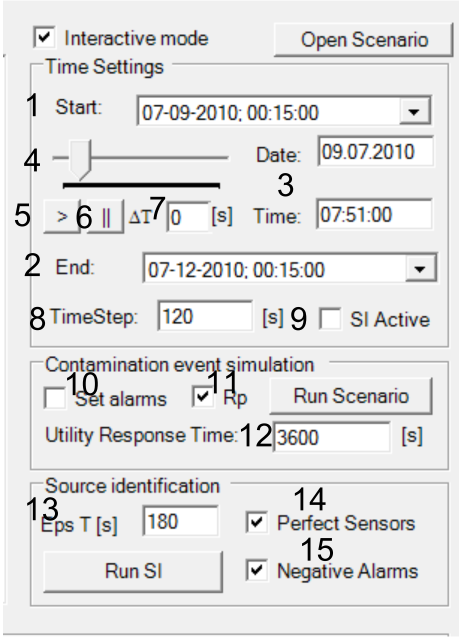
Please note that the backtracking algorithm uses the actual flow velocities that were calculated by the online simulation module in the past. In order to avoid memory leaks that could be caused by the fact that the number of time steps increases calculation by calculation a moving time window approach has been implemented where the time span of the window is only little longer than the maximum water age in the system.

4.2 Timer and execution control panel

The timer and execution control panel is applicable exclusively in interactive mode. For the online use of the software all the required parameters are defined in and transferred from the online integration platform SIR OPC. With the control panel the user can set the start time and end time of the simulation interval. The different calculation modes include forward transport calculation with response option or source identification. For “playing a movie” of the contamination scenario in the interactive mode, a track bar control or play and stop buttons are available. The playing speed can be defined by the choice of a sleep time value that stops the process after each time step for the selected timespan. Of course, also the internal time step can be defined in the control. Other parameters to be defined in the control are the response time of the utility and an epsilon threshold for the sensitivity of the SI algorithm.

4.3 Controls for appearance of graphical elements in the map

Controls are available for adjustment of line thickness (pipes, valve symbols) and circle diameter (nodes, hydrants). In addition, the background colour can be selected by the user. The standard is black providing the best contrast on the monitor. For printing out network maps, for instance, white background is preferable.



☑ Interactive mode

Start: 07-09-2010; 00:15:00

Date: 09.07.2010

ΔT 0 [s]

Time: 07:51:00

End: 07-12-2010; 00:15:00

TimeStep: 120 [s]

☐ SI Active

☐ Set alarms

☑ Rp

Utility Response Time: 3600 [s]

Eps T [s] 180

☑ Perfect Sensors

☑ Negative Alarms

1.) Scenario start time
2.) Scenario end time
3.) Current time
4.) Track bar
5.) Play button
6.) Stop button
7.) Sleep time
8.) Internal quality time step
9.) Check box for activating SI in play mode
10.) Set alarms: record alarm times during forward calculation for
11.) Check Box for activation of response calc
12.) Set utility response time
13.) Epsilon: sensitivity of SI
14.) Checked: assuming perfect sensors
15.) Checked: consider negative alarms

Figure 11: Control section overview (interactive mode only)

4.4 Table views for sensors, sources and (isolation-) valves

The table window consists of three tabs. The first tab shows the sensors and its actual alarm state. In addition, the different IDs used in the SCADA system and the hydraulic engine are mapped in the table. The TimeStamp column refers to the last change of alarm state.

The sources tab is either used for defining a known source for the forward calculation or as table that shows all the source candidates that are calculated by the source identification algorithm in the inverse case. Here, the time stamp designs the start of the contamination.

The valves table tab is filled by the response tool. It includes all the valves that have to be closed for isolation of contaminant. As long as the alarm is not confirmed by the user, the valves are continuously updated. As time progresses some of the valves are already passed by the contaminant or cannot be closed within response time.

The table content can be sorted (for example for finding the valve with shortest passing time) or copied into other post processing software or messaging systems.

For forward calculations in interactive mode the source must be defined in table D either manually by the user or by an earlier SI run. In contrast, for source identification calculation the sources must be removed from the table.

The sensor table not only includes information about the location of the sensors but also the full record of changes in the alarm state together with a valid time stamp. In the online use case, the change of alarm state is of course effectuated by the alarm generation module that is connected with the SIR OPC platform via OPC Server.

4.5 Network map.

The network map shows the graph of the network. As explained above, for visualization of the calculation results (SI, Forward Tracking, Identification of valves) different layers are used. The map of the software demonstrator includes only few interactive modes for user manipulations.

For instance, the sensor locations can be selected by mouse clicks as well as the location of the source for forward tracking.

5 Conclusions

The presented method for decision support and management of response actions proofed to work well for the test networks studied. It was shown for the two networks of BWB (Buch and Hochstadt Ost) that the spread of contamination always could be stopped by isolation valves. However, there are some weaknesses that one must be aware of and that should be improved in future research work:

- The assumption that all the response measures are potentially carried out all at the same time after the earliest reaction time is very crude and doesn't reflect the real situation at the utility that the resources for carrying out this actions is limited. A first attempt to solve this problem is included in the current approach by prioritization of valve closures. The valves are sorted by the time at that the contamination is expected to pass.
- Every newly closed valve has an impact on the flow distribution and therefore on the transport and spread of contamination. Theoretically the online simulation and source identification implementation is prepared for considering subsequent valve closures. If the information of closed valves is part of the online data and transferred to the OPC Server the calculation automatically considers the modified topology. Since the online source identification and response tools update the flow velocities before at the beginning of each time step from the simulator results the information is also existent in these tools. However, the problem is that normally the field actions are not immediately transferred to the SCADA system. Technically, this could be resolved by use of hand held or mobile phone devices. Transmission of information of valves closure should therefore be taken into account by the organizations preparedness and mitigation planning.
- At the moment there is no agreement at the side of the utilities about the best response actions. The isolation of contaminant on the one hand is able to prevent the further spread of contamination after a contamination event was detected. However, in this case, the contaminant remains in the system and can be possibly accessed by the customers that are connected to the isolated and contaminated part of the network. With regard to this massive flushing seems to be more appropriate in order to get rid of the contaminated water as fast as possible. A major disadvantage of flushing is that possible cascade effects resulting from further distribution of the contaminant in the sewer system or on the streets could be even worse.

In conclusion, the proposed methods represent a first step in the direction of online monitoring and online decision support for real-time response actions and mitigation in case of an contamination event. There still exist restrictions for the applicability of the methods. A strong response to an contamination must imperatively take into account the combination of different actions including valve closure, warning of the population, flushing and others. The tools can support this process but they are not able to deliver the one and only, most efficient reaction plan. In particular, the application of the software tools is recommended only in combination with a carefully elaborated response plan that is part of a more comprehensive contamination warning system that includes organisational issues and crisis management. Effective response imperatively requires preliminary studies for improved preparedness of the organisation.

6 References

Poulin, A., Mailhot, A., Periche, N., Delorme, L., & Villeneuve, J. P, (2010). "Planning unidirectional flushing operations as a response to drinking water distribution system contamination" Journal of water resources planning and management, 647-645.

Preis, A., & Ostfeld, A. (2008). Multiobjective contaminant response for water systems security. Journal of Hydroinformatics, 267-274.

Roberson, J. A., & Morley, K. M. (2005). Retrieved March 30, 2015, from Website of the American Water Works Association: http://www.awwa.org/Portals/0/files/legreg/security/ContaminationWarningSystems.pdf

Deuerlein, J.; Simpson, A. R. and Korth, A. (2013): „Flushing Planner: A Tool for Planning and Optimization of Unidirectional Flushing “, Computing and Control for the Water Industry 2013 (CCWI 2013), Perugia, 02.09 - 04.09.2013.

Walski, T., Weiler, J., and Culver, T. (2008) Using Criticality Analysis to Identify Impact of Valve Location. Water Distribution Systems Analysis Symposium 2006: pp. 1-9.