Chapter 15
Latvian Practices for Protecting Water and Wastewater Infrastructure

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Technical Terms and Definitions

AMR	Automated meter reading
AOC	Assimilable organic carbon
BDOC	Biodegradable dissolved organic carbon
CEDM	Centre of emergency and disaster medicine
CERT	Latvian Information Technology Security Incidents Response Institution
CHA	Hydrophilic charged
CI	Cast iron
CPL	Civil Protection Law
DBP	Disinfection by-products
DOC	Dissolved organic carbon
DS	Distribution system
ESL	Epidemiological Safety Law
EU	European Union
GPRS	General packet radio service
GSM	Global system for mobile communications
HS	Humic substance
IC	Infectology Center
ICT	Information and telecommunication technology
IIS	Information systems
ISP	Internet service provider

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IT	Information technology
LD	Loose deposits
MW	Molecular weight
NEU	Hydrophilic neutral
NOM	Natural organic matter
NPOC	Non-purgeable organic carbon
NSL	National Security Law
NSSC	National State Security Council
OM	Organic material
PE	Polyethylene
PVC	Polyvinylchloride
RPM	Resuspension potential measurements
SHA	Slightly hydrophobic acids
SRD	Short range devices
TW	Talsi water
UDF	Unidirectional flushing
VHA	Very hydrophilic acids
WDN	Water distribution networks
WRT	Water retention time
WSN	Wireless sensor networks

15.1 Introduction

15.1.1 Government Policies Concerning the Protection of Critical Water and Wastewater Infrastructure

The Republic of Latvia has promulgated a number of laws that govern the national response to emergencies in water and wastewater. The Republic of Latvia has passed an Epidemiological Safety Law (ESL 1999) which describes the procedures for the evacuation and the isolation of patients during emergencies. If during routine analyses a company identifies a contamination event, it has to determine the preventive action to be taken. According to the Epidemiological Safety Law if smallpox, botulism, tularemia, plague or anthrax is identified in a person, the hospital is required to inform the Infectology Center (IC) of Latvia and isolate the patient until IC specialists take over the case. If additional infected persons are identified the Centre of Emergency and Disaster Medicine (CEDM) should be informed. CEDM is responsible for assessing the level of threat to the public (local, regional or national) and to take necessary actions.

The Civil Protection Law (CPL 2006) applies to disaster management, and the provision of legal and organizational support for the protection of public, property, and the environment in the cases of a disaster. The main tasks of the law are as follows: To carry out disaster management; to provide aid to victims of disasters;

to reduce the possible damage to property, and the environment caused by the disasters; and if a military invasion or war occurs—to support the National Armed Forces with resources.

A National Security Plan regulates the responsibility of involved authorities for carrying out disaster management plans. The State Cabinet of Ministers is responsible for risk management and remediation of the consequences from terrorist attacks.

Latvian legislation does not require every water supply company to have a plan in case of a terrorist attack. If a disaster occurs, the company would try to solve this problem using their own means. Should that prove to be impossible the company is obliged to inform the National or State Security Council (NSC), which consists of representatives of the Latvian Government and the President. The head of the NSC is the Prime Minister. If during a routine analyses a contamination event is identified a company has to decide which preventive action should be taken (e.g., closing a part of distribution system to prevent further contamination). All water supply companies must have an Action Plan for emergency situations in case of a limited water supply. No specific guidelines covering the technical measures to be taken for drinking water supply system decontamination are in existence. If the company cannot provide the necessary amount of drinking water to the customers from the water supply system, they must provide it in containers. An emergency technical council meeting is convened to identify the reasons for the emergency situation. The rapid involvement of the appropriate services to solve the accident is employed and the consequences of the incident are identified.

According to the National Security Law (2000) the Cabinet of Ministers is responsible for risk management and its aftermath. In case of a threat the crisis management council coordinates civilian-military cooperation, and directs the government institution's operational risk management measures.

From March 2001 the Law "On Pollution" has been in force. The purpose of the law is to prevent or reduce the impact of pollution on human health, to minimize property and environmental damage, and to prevent negative consequences. Based on the Pollution Law "Regulations on emissions of pollutants in water" was accepted by The Cabinet of Ministers in 2002. These Regulations prescribe effluent emission limits and prohibit pollutant emissions to water, including the order in which the operator controls the emissions of pollutants in water and so on.

15.1.2 Characteristics of the Water Utility Industry in Latvia

The Latvian Water Supply and Sewerage Enterprises Association (Krauze 2011) unites 27 enterprises, located mostly in former regional centers. An average amount of water supplied to a customer in 2010 was about 215 thou cu m (thousand cubic meters–7591.6 thou cu ft) per day, but the average amount of wastewater exceeded 260 thou cu m per day (9180.6 thou cu ft per day). The total length of water distribution pipe was 2965 km (1842.5 mi); the total length of sewer pipe was 2560 km (1590.8 mi). The members of the Association comprise 90 % of the Latvian water utility market, but the remaining 10 % is divided among small private companies. Over 71 % of water services are consumed by residents living in apartment buildings and individual houses, but the remaining 29 % are used by different industries and the public sector.

Table 15.1 indicates the large differences in water production among water utilities; therefore, the water volume processed by the Riga Water exceeds 60 % of the total association contribution, while the contribution of 14 water utilities is less than 1 %.

In 2009 Latvia moved from a two-level local governmental (regions, municipalities, and cities comprised the first level, but parish councils comprised the second-level of local government) structure to a local level—110 counties and 9 cities (Daugavpils, Jelgava, Riga, Jurmala, Liepaja, Rezekne, Riga, Valmiera, and Ventspils). Before the administrative reform (ATRL 2008) water management had been operating in each parish or town. Water infrastructure ownership has been shifted from the parish level to county and municipal ownership. Therefore,

Table 15.1 Supplied water and wastewater volumes distribution among Association's enterprises in the year 2009 (Krauze 2011)

Nr.	City	Water supply (thou cu m/day)[a]	Wastewater purification (thou cu m/day)[a]	W + WW (thou cu m/day)[a]	W + WW % of total volume
1.	Rīga	140,851	160,381	301,232	60.54
2.	Liepāja	10,654	26,760	37,414	7.52
3.	Daugavpils	15,604	13,898	29,502	5.93
4.	Jūrmala	10,160	9,832	19,992	4.02
5.	Jelgava	11,500	7,900	19,400	3.90
6.	Ventspils	7,632	10,342	17,974	3.61
7.	Rēzekne	4,520	7,297	11,817	2.38
8.	Valmiera	3,821	4,545	8,366	1.68
9.	Cēsis	3,017	3,805	6,822	1.37
10.	Jēkabpils	3,179	3,436	6,615	1.33
11.	Tukums	1,851	2,915	4,766	0.96
12.	Talsi	1,930	2,108	4,038	0.81
13.	Bauska	1,609	2,228	3,837	0.77
14.	Saldus	1,411	2,083	3,494	0.70
15.	Sigulda	1,647	1,750	3,397	0.68
16.	Aizkraukle	1,398	1,986	3,384	0.68
17.	Kuldīga	1,095	2,059	3,154	0.63
18.	Dobele	1,301	1,481	2,782	0.56
19.	Gulbene	711	1,429	2,140	0.43
20.	Līvāni	901	1,217	2,118	0.42
21.	Madona	930	791	1,721	0.35
22.	Alūksne	766	903	1,669	0.34
23.	Vangaži	500	500	1,000	0.20
24.	Limbaži	320	623	943	0.19
	Totals	227,309	270,268	497,577	100.00

[a] To convert from thou cu m/day to thou cu ft/day multiply by 35.31

counties have faced an important problem on how to organize water services throughout the county area. It has been found that when each parish administration deals with the problem itself (in rare cases getting contributions of budget and resources from the county), water quality is unacceptable, and financial and human resources are not used optimally. The majority of parishes do not have sufficient competence and lack the resources to maintain adequate water supply infrastructure even when built with the support of EU Funds. Therefore, the various county governments have started creating a single system for providing water services across the jurisdiction.

A study carried out by the authors covering three counties in the Kurzeme region revealed common problems (Zabašta 2010). Each parish independently performed water accounting and obtained payments from customers, so that the county administration did not have correct information concerning the overall situation in the county. Since each parish maintained its own customer billing and property accounting system, the county administration was not able to provide a common policy in relation to clients and debtors, due to a lack of timely information. A significant part of the municipal property was not equipped with water meters at the entrance to the building; thus, water consumption in many cases was determined by the consumption standards per person and sometimes by the number of animals owned by landlord. Different water tariffs were applied, which were not determined on the basis of actual costs. As a result of privatization formerly public water supply and sewerage infrastructure, in many parishes, ended up in private hands and the new owners were able to charge at any level they desired, because the actual cost burden was not corroborated in the Land Register.

In many cases water supply facilities and the trunk network (pumping stations, iron removal plants, water main, sewer pump stations, etc.) in parishes are not equipped with water supply monitoring and record keeping equipment; as a result leaks are detected with delay. In some counties water supply network depreciation has reached 70 % (Zabašta 2010).

There are several problems that are specific to both the county and urban water industry. Starting in 1990 both residential and industrial water consumption has been steadily decreasing. In the last 20 years water consumption has decreased significantly increasing the cost of supplied water per m^3 (Krauze 2011). Another problem is customers growing debt; however, current legislation does not permit disconnecting water, even if a subscriber does not pay their water bill. The existing legislation affecting water supply and sewer facilities regarding financing and construction is not conducive to the use of high-quality materials and advanced technologies, because only construction costs are taken into account and operating costs and facility life are neglected.

Since Latvian and Lithuanian and Estonian water utilities have encountered similar problems, the two countries have joined efforts in order to introduce information and telecommunication technology (ICT) solution for monitoring and controlling water distribution networks (WDN). For example in 2010, four Latvian and one Lithuanian counties initiated a project “Innovative e-services for water supply management” (E-Water 2010).

15.1.3 Primary Water Sources and Treatment

Due to a relatively cold climate and an abundance of soils rich in organic carbon (Broo et al. 1999), the concentration of raw water natural organic matter (NOM) in the Boreal region (Latvia) is high and its removal during conventional water treatment is complicated. The high concentration of NOM can be responsible for objectionable tastes, odors, and color in drinking water, and can be a factor in the formation of potentially carcinogenic disinfection by-products (DBPs) after reacting with disinfectants used in water treatment, and it affects biological stability and biological regrowth in distribution systems.

A water distribution system (DS) can be characterized as a biological and chemical reactor that interacts with water in the network (Gauthier et al. 2001) which results in water quality changes during its transport. These changes are dependent on many factors including the size and complexity of the DS, etc. (Servais et al. 1992). NOM's influence on water quality change is usually related to biodegradable organic carbon (BDOC) in drinking water. This may lead to the regrowth of microorganisms and coliforms, including opportunistic pathogenic bacteria in drinking water DS (Van der Kooij et al. 1982; Servais et al. 1992) and may increase the health risk for immunocompromised people. However, water with high levels of NOM contains humic substances (HS) and slowly degradable BDOC (Eikebrokk et al. 2007), which may influence water quality as well. It has been shown earlier that HSs absorb on the surface of corrosion products in iron pipes (Camper 1996), whereas slowly biodegradable compounds of NOM in water are used as substrate for bacteria. NOM constitutes a large fraction of loose deposits (LD) found in the distribution network (Gauthier et al. 2001).

15.1.4 The Problems of Monitoring Water Consumption and Identification of Leakages

Latvian water utilities are faced with growing operational and maintenance costs as a result of aging infrastructure. Leaks, ruptures in water supply pipelines, and water theft are very expensive, thus monitoring and repairing underground infrastructure presents a severe challenge.

During the Soviet period in which the economy was centrally planned, residential water consumption in Riga, Latvia, increased continuously. Water use for the population of 886,000 inhabitants was as high as 450,000 m^3 per day (15.9×10^6 ft^3 per day) at that time. The major drinking water consumption was for the vast industrial sector, which covered almost all of the expenses spent for water production and delivery of drinking water, including uncounted-for water. Household consumption was estimated according to inappropriate standards. The real cost of the water supplied for residential consumption was actually much

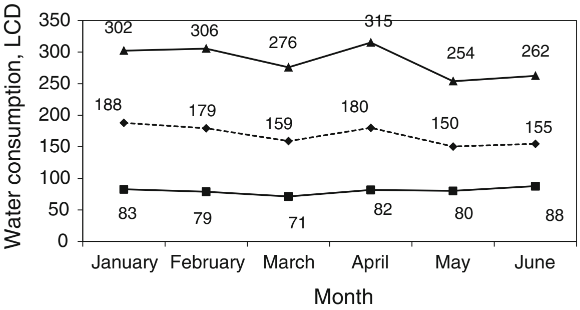


Fig. 15.1 Water consumption in liters per capita per day in apartment buildings in Riga in 1999. Water consumption is depicted: by consumers with individual meters (*solid line* with *squares*), by the municipal water supply company (*dashed line* with *diamond*) and by consumers which paid according to flat-rate tariffs (*solid line* with *triangles*)

higher than the cost charged to the household consumer, resulting in overuse by the consumer at the tap.

After Latvia achieved political independence, the market economy caused a recession in the country and industrial demand declined dramatically. As a result, the domestic sector became the major drinking water consumer. To ensure payments that covered the real cost of water, the municipal water supply enterprise of Latvia began installation of water meters in apartment buildings on the inlet pipes to buildings, while citizens were encouraged by the city council to install individual water meters in their flats. With this double accounting system (Fig. 15.1), it soon becomes clear that there was an enormous discrepancy between the volumes of water measured by the building water meter and that charged to residents with individual water meters.

Depending upon the building approximately 40–80 % of all consumers used apartment or flat meters (Rubulis et al. 2001). Even in a model apartment building in which all flats were supplied with impulse water meters together with accessories for data processing, utilizing ZENNER® interface and software products, there were discrepancies of 6–23 % between the total water amount measured by the building meter and that estimated by summing measurements from water meters in the apartments (Rubulis et al. 2001).

An inspection of water meters in apartments showed that 10 % of all the meters were installed on horizontal pipes with a horizontal clock-face, 15 % were installed on vertical pipes, and 75 % were installed on horizontal pipes with a tilted clock-face (Fig. 15.2). There are two main reasons why 75 % of water meters were installed on horizontal pipes with tilted clock-face:

1. Internal water pipes in apartment buildings which were built during the Soviet period were not suitable for the proper installation of water meters because the space between cold and hot water pipes as well as between the pipe and the wall was not sufficient for installation of water meters with a horizontal clock-face;

Fig. 15.2 Typical solution for installation of water meter with rotated clock face in internal piping

2. Easier access to the water meter (in most cases) occurs when it is located under the sink and it is also easier to record readings.

The performance of water meters on a special test-stand in the laboratory showed that the meters characteristics are significantly influenced by the type of installation (Fig. 15.3.) and all water meters met the Class A standard in cases when they were not installed on a horizontal pipe with a horizontal clock-face and minimal flow rate was 0.06 m^3/h (2.12 ft^3/h).

- The position of the meter clock-face is given as the angle (degrees) from the vertical axis of meter. Briliute et al. (2008) tested different types of water meters and concluded: similar to the results in Riga, the rotation around the pipe axis of the meter (single-jet or multi-jet vane wheel) at the 45° and 90° angle causes additional error which at the low flow range which may be as high as 30 %, whereas in the case with the volumetric meter it achieves (1.5…2.0) % in the worst case. After rotation the vane wheel meter even at the 45° angle, it is not able to meet the requirements of class A;

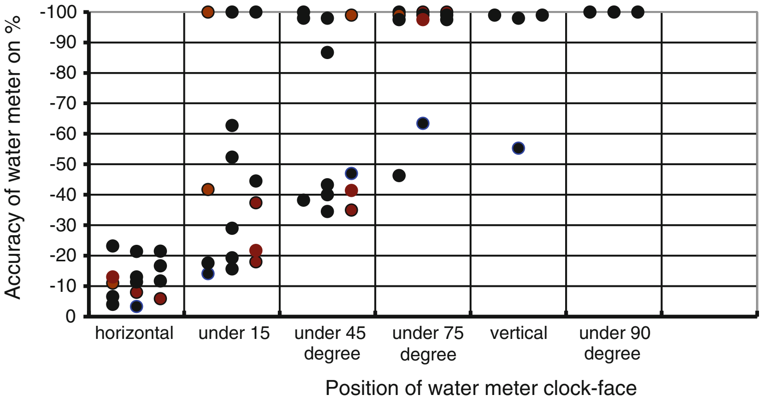


Fig. 15.3 Measurement accuracy in relation to installation style of the water meter

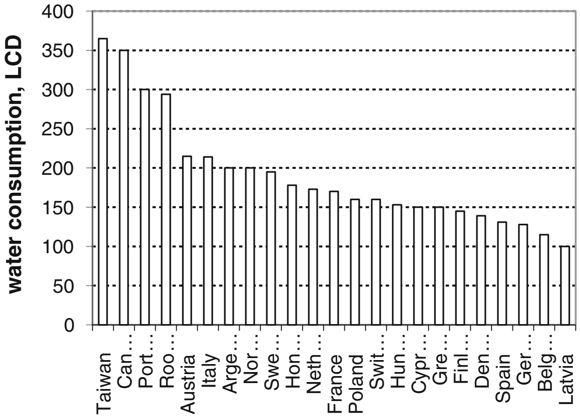


Fig. 15.4 Drinking water consumption worldwide

- when the meter is installed in the vertical pipe line, the additional error in the low flow range is almost as twice as great with the single-jet meter as compared to the multi-jet one, and may reach up to (25…27) %;
- installing the strainer upstream of the water meter has a minor influence (2 % at minimal flow), whereas when installing the strainer the bleeder plug should be directed downwards;
- installation of a strainer before the meter decreases the additional error (30…40) % of water meters due to particles which may interrupt rotation of the vane wheel;
- reducing the gasket bore inner diameter for the single-jet vane wheel meter installation always results in additional error. In the case analyzed, reducing of the gasket bore to 8.7 mm (0.03 in) led to an increase in the measurement error up to (20…21) %. The multi-jet concentric vane meters and the volumetric meters are not sensitive to reducing the gasket bore diameter (Briliute et al. 2008).

The usage of water meters with nominal capacity, 1.5 m^3/h (18.04 ft^3/h) led to water savings by consumers (Fig. 15.4) in Latvia and together with improper performance significantly decreased the total amount of measured drinking water (Fig. 15.5). As an example of the problem associated with correct meter reading is the fact that a water utility, which supplies drinking water to 16,000 householders in one Latvian city with 45,000 inhabitants, estimated its loss of revenue to be approximately 1,140,000 EUR in 2009 (Zabasta et al. 2011). Adding another 20–50 % to the consumed water volume shown on customer bills (IESM 2011) might be difficult. Currently, the absolute majority of water flow meters are still

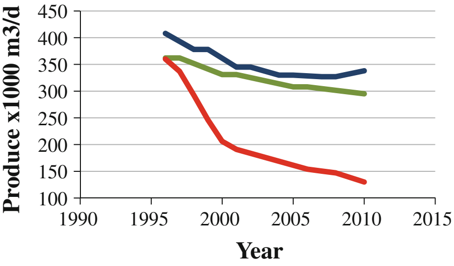


Fig. 15.5 The forecast of company “Rust VA-Projekt” (*blue line*) and “Sweden water” (*green line*) of produced drinking water amount in Riga city and actual delivered water to the city (*red line*)

monitored by visiting sites or by “walking-by”; clients frequently deliver metering data to water utilities by phone, by post, or provide them “in hand.”

Therefore, due to the lack of reliable data concerning the state of WDN it is difficult to identify local problems and to minimize losses caused by water leakage, illegal connections, and customer fraud (IESM 2011). Unfortunately utilities owned by municipalities, which suffer from an economic crisis, are reluctant to invest in the development of WDN monitoring tools and methods for leaks detection.

15.1.5 Cyber Security

Nowadays, in the water sector the internet is used mostly for customers’ information about tariff, emergency services, and customer services. Due to the installation of automated meter reading (AMR) systems in municipal WDN the role of ICT is growing rapidly. The internet is used not only to present the utility’s home page, but as a web interface for access to metering data and to services, and therefore the number of system users are growing dramatically. The other aspect of the growing use of the Internet is the increasing dependence from telecommunication and internet services providers (ISP) due to a growing volume of transmitted data. Therefore, data security and integrity has become a crucial aspect for Latvian utilities.

According to the Latvian IT Security Incidents Response Institution (CERT) about 3,300 IP addresses were infected (by bots) in the year 2011. In the year 2011 CERT dealt with more than 15,000 security incidents (Kaškina 2012). Websites of large state institution are compromised on a regular basis, for example: Latvian Health Emergency Service and Riga Municipal Police in October 2011, and energy monopolist Latvenergo in April 2011.

Internet and telecommunication security issues are regulated by the “Information technology security law” (promulgated in 2010) and by the government regulation “Information technology critical infrastructure security measures planning and implementing” which was promulgated in 2011. One of the security measures was creation of the state funded CERT in February 2011. The CERT responsibility is delegated to the Institute of Mathematics and Computer Science, University of Latvia. The scope of CERT's responsibilities covers public sector institutions, ISPs, and Critical IT infrastructure owners. These institutions are obliged to submit an "Action plan for continuous operations" and to report the major security incidents. CERT has the right to request IT security documentation, to initiate IT security audits and even to disconnect an end user (Andžans et al. 2012).

The National IT Security Council coordinations tasks and performance measures set by the IT Security Law. The Council is chaired by a representative of the Ministry of Transport and Communications. The members of the Council represent Latvian ministries, Bank of Latvia, CERT, and state security agencies. The application of security monitoring systems appears to be, that because of the quick acquisition of ICT tools water utilities will likely be able to meet new security challenges in the future.

15.1.6 Literature Review

NOM is one of the components connected with biofilm growth and heterotrophic bacteria proliferation, because it is a substrate for microorganism growth and regrowth. NOM is closely related to DOC and part of DOC supports exoenzymatic hydrolysis reactions and includes the biodegradable fraction (BDOC) which includes rapidly and slowly hydrolyzed classes of BDOC (Servais et al. 1992, 1995).

Many researchers have shown a correlation between assimilable organic carbon (AOC) and bacterial regrowth in distribution networks (see e.g., Van der Kooij and Hijnen 1991). AOC is related to coliforms and heterotroph regrowth in well-mixed system (Camper 1996). Fixed bacteria are linearly correlated to suspended bacteria in water (Servais et al. 1992) and regrowth cells and water residence time in the distribution network (Hammes et al. 2010).

The NOM fraction as humic substance (HS) can act as a substrate and an energy source for biofilm formation and the number of cultivable bacteria in biofilm have shown to be similar to that which was produced on an organic substrate as amino acids or carbohydrate (Camper 2004) and its concentration can be limiting for biofilm formation (Servais et al. 1995). Some researchers have observed a loss of cultivability at low DOC concentrations (Boualam et al. 2002). The BDOC fraction is a complex mixture of organic carbon and is available as substrate for bacteria. After the reaction with disinfectant it forms DBPs (Butterfield et al. 2002). Thus, BDOC is a major factor for control of bacterial growth (Servais et al. 1992, 1995) and for the biological stability of drinking water, especially in distribution networks with long WRT (Raczyk-Stanisławiak et al. 2004).

Drinking water contains organic and inorganic matter, which can accumulate at pipe surfaces in drinking water pipelines (Gauthier et al. 1999; Zacheus et al. 2001). After some years of use of distribution network, pipes are covered with deposits of corrosion products (Sarin et al. 2001) or soft and LD (Zacheus et al. 2001; Prevost et al. 2005). Changes of water flow or pressure in network can detach deposits which, in turn, increase turbidity, electrical conductivity, bacterial numbers in water; thus, deteriorating drinking water quality (Mustonen et al. 2008).

Some studies (Sarin et al. 2001, 2004) have shown that the structure of iron pipes deposits can be divided into four layers: Corroded floor, porous core, shell-like layer, and surface layer. A corroded "floor" forms on the metal surface during corrosion. A porous core layer is composed of small particles of different iron solids as iron (II) hydroxide, oxide, carbonate, or dissolved iron. A shell-like layer contains iron-oxidizing bacteria, and finally, the top surface layer is in contact with water and is largely influenced by the water quality. The top surface layer contains amorphous iron (III) hydroxide, silicate, phosphates, carbonates, and NOM molecules; thus, it can absorb bacteria from drinking water and form biofilms (Herro and Port 1993; Sarin et al. 2001, 2004; Prevost et al. 2005). The accumulation of bacteria and NOM on pipeline surfaces and the formation of deposits depends on the microbiological and chemical quality of drinking water in the distribution network: surface material, application of corrosion inhibitors at the water treatment plant, pH, alkalinity, mineral concentration, temperature, microbiological activity, as well as the type and concentration of NOM (Tuovinen et al. 1980; Zacheus et al. 2001; Sarin et al. 2001, 2004; Ndiongue et al. 2005; Prevost et al. 2005). In addition, biofilm may promote the deterioration of metallic pipes (bio-corrosion) and the dissolved organic compounds and humic colloids present in water act as catalysts in cast iron corrosion (Tuovinen et al. 1980; LeChevallier et al. 1993; Korshin et al. 2005). NOM interaction with pipe surfaces includes such processes as sorption, precipitation, dissolution, aggregation, comlexation, and degradation, which depend on different parameters, such as water pH, nutrient with electrolyte properties concentration (e.g., KNO_3), reaction time or WRT, carbonate, and calcium concentration (Ca^{2+} forms complexes with negative groups of NOM) (Day et al. 1994; Kaplan and Newbold 2000; Korshin et al. 2005). The reactivity of NOM depends on the physicochemical properties of organic matter such as molecular weight (MW), aromaticity, functional groups content, and hydrophobicity/hydrophilicity (Larson 1966; Sontheimer et al. 1981; Broo et al. 1999; Swietlik et al. 2004; Korshin et al. 2005). Many studies (Gruškeviča et al. 2008) have shown that non-humic hydrophilic NOM fractions are more corrosive than HS in copper and iron pipes at stagnant conditions and this effect is stronger in iron pipes.

The deployment of wireless sensor networks (WSNs) for monitoring water flow, pressure, and vibration at a large number of locations was proposed by (Lin et al. 2008). WSN can address the challenge of near real-time monitoring and eventually system control. The ability of a cross correlation algorithm to locate a leak in a pipeline when two sensors detect a leak was tested by Stoianov et al. (2007). Several leak detection methods are described by Hunaidi and Wang (2006), for example, water flow and pressure monitoring by measuring the minimum night flow rate on a continual basis and a system for locating pipe leaks based on the cross-correlation method. A pipe detection method based on the observation of abnormalities in water flow and pressure is presented by Bicik et al. (2011).

15.2 Research and Practices

15.2.1 Research on Control of Bacterial Regrowth

Drinking WDN consists of many different types of material (polyethylene—PE, polyvinylchloride—PVC, cast iron—CI) but water residence time depends on constant factors as pipe length and diameter, and also a variable factor—the water consumption. Networks contain different types of LD and biofilm depending on the age of the water supply system and its water quality; therefore, it can be defined as a chemical and biological system (Bose and Reckhow 2007). It is known that LD in a network also contains different concentrations of NOM (Amy and Her 2004), where bacterial regrowth in the distribution network takes place (Brandt et al. 2004). Therefore, the goals of this research were (i) to evaluate NOMs ability to accumulate in LD in different points in the distribution network and its influence on water quality in the distribution network; (ii) to evaluate the influence of NOM on water quality in the network.

The concentration of TOC and BDOC depending on WRT and the biodegradation kinetics of organic carbon in water samples from different points of the 1374 km (853.8 mi) distribution network in Riga city, Latvia (Fig. 15.6) was determined. The concentration of TOC ranged from 2.2 to 8.1 mg/l measured at different places ($n = 30$) in the network in Riga using a submersible, two beam spectrophotometer spectro::lyser™ (s::can Meßtechnik GmbH, Vienna, Austria) with on-line UV/Vis measurement. Results showed strong positive correlation between TOC and WRT in the distribution network (Moment Correlation coefficient, $r = 0.81$; Fig. 15.7a).

To assess BDOC changes in the drinking water distribution network data were collected during two sampling periods (Fig. 15.7b). The concentrations of BDOC ranged from 0.33 to 2.38 mg/l ($n = 25$) in all samples. Curve A displays BDOC changes in sample values for the April test series, when the water temperature ranged from 10 to 16 °C (50–61 °F). The exponential decay rate for BDOC in the network was equal to 0.05 h^{-1} in this period. Curve B shows the BDOC data from samples collected from different periods (February–July). Temperature changes during this period were greater from 9 to 21 °C (48.2–69.8 °F), and the biodegradation rate was higher also (0.31 h^{-1}). BDOC changes indicated that the biodegradation process in water during colder periods was slower than during the warmer periods. BDOC ranged from 0.85 to 1.79 and the degradation rate in the network was 6 times higher in seasons with high temperatures. Statistical data indicated that WRT determined by using hydraulic models can be divided in three phases, which display strong negative correlations with the concentration of BDOC in the distribution network for periods 2.82–13.72 h and 14.27–17.62 h ($r = -0.72$, $n = 8$ and -0.74, $n = 6$, respectively) and no correlation between BDOC values and WRT > 18.03 h ($n = 11$).

The biodegradation rates determined in samples taken at different places in the distribution network in Riga ranged from 0.24×10^{-2} to 3.15×10^{-2} min^{-1}

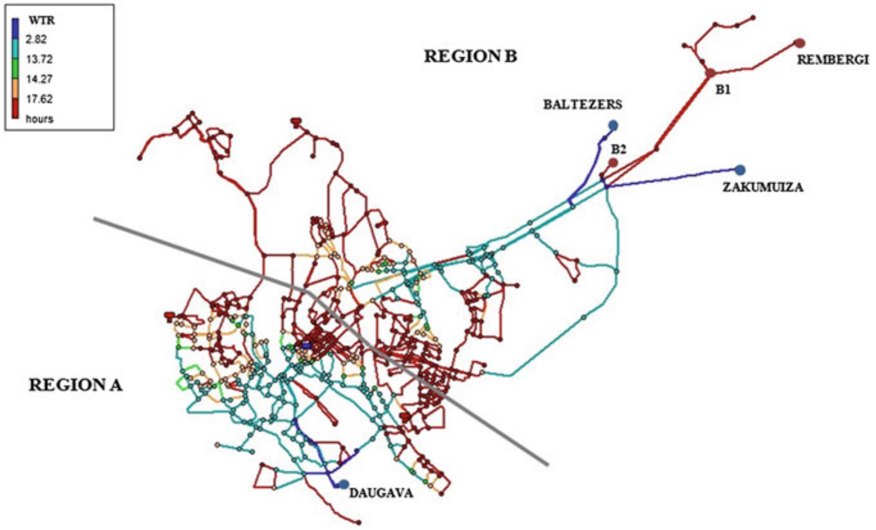


Fig. 15.6 Service areas of Riga water treatment plants in EPANET 2.0 with three reservoirs and WTP viz. Baltezers, Zakumuiza, Baltezers-1 (*B1*), Baltezers-2 (*B2*), Rembergi, and Daugava. *Region A* supplied by Daugava WTP, *region B* supplied by Baltezers, Zakumuiza, *B1*, *B2*, and Rembergi

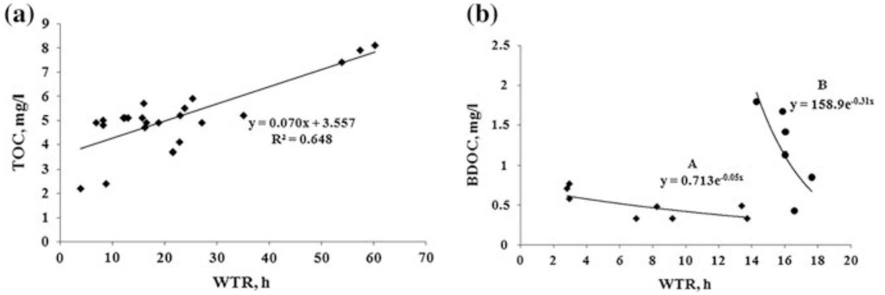


Fig. 15.7 TOC concentration in water samples correlation with WRT in distribution network (**a**); BDOC concentration changes in water samples depended on WRT (**b**)

($n = 13$) and there was a strong correlation with concentration of BDOC in these samples ($r = 0.78$).

The decrease in BDOC concentration for the first hours (<24 h) within distribution network can be explained by consumption of substrate by bacteria. For more distant areas in network (>24 h) the broad range of BDOC values and increases in TOC indicate the leaching of NOM from deposits within the distribution network. Results showed that DOM is an important parameter and can be used as indicator to evaluate drinking water quality depending on the WRT in distribution network.

The DOC concentration ranged from 2.5 to 7.7 mg/l in drinking water samples from the DS during the study period. To determine the NOM concentrations in LD, 38 samples were collected and the average amount of NOM measured as NPOC was determined. The NPOC in deposit samples collected from the DS supplied with groundwater varied from 0.18 to 21.01 mg/g ($n = 21$). In the samples collected from the DS supplied with surface water (River Daugava) NPOC ranged from 1.21 to 18.99 mg/g ($n = 12$). In the samples collected from different drinking water reservoirs in Latvia, NPOC values ranged from 0.20 to 3.11 mg/g ($n = 5$).

Results obtained from the study (Gruškeviča et al. 2009) did not show any significant relationship between NPOC and any other parameters (WRT in DS, diameter of pipe, source of raw water) studied, except for the pipe materials. PVC pipes showed an average 1.48 ± 1.77 mg/g (ranged from 0.18 to 3.50 mg/g); CI pipes—4.36 ± 3.13 mg/g (ranged from 1.83 to 14.33 mg/g); but PE pipes—14.29 mg/g (ranged from 9.99 to 21.01 mg/g). It appears that organic matter (OM) originates not so much from the source as from the pipe material, which leaches organic carbon substances. CI pipes are the oldest pipes (about 50 years) in the networks, whereas PE and PVC pipes are not older than 15 years. Thus, the NOM concentration in deposits depends on the pipe material itself, rather than the length of exposure to organics (PE and PVC).

Rapid fractionation results (Fig. 15.8) showed that the LD samples obtained from the DS which was supplied from groundwater OM were predominantly composed of VHA (44 %) and other fractions were distributed as follows: SHA—12 %, CHA—13 %, and NEU—31 %. In the samples obtained from surface water supply DS dominant NEU was the main fraction (41 %) and other fractions: VHA—24 %; SHA—22 %; and CHA—13 %. This can be explained by the fact that the VHA and SHA fractions were separated by 70 % (Fig. 15.8) during the water treatment process.

The NOM balance in the drinking water distribution network is described in Fig. 15.9, based on results presented in this research and published earlier (Servais et al. 1992; Frimmel 1998; Gauthier et al. 1999; Rubulis et al. 2007; Vreeburg 2007).

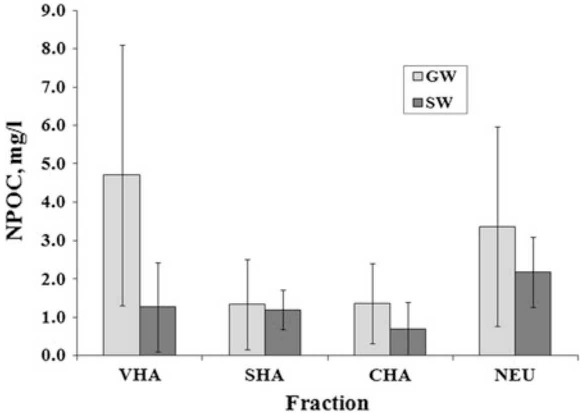


Fig. 15.8 RF results for isolated organic matter samples from the LD obtained from systems supplied by groundwater (GW, $n = 6$) and surface water (SW, $n = 5$)

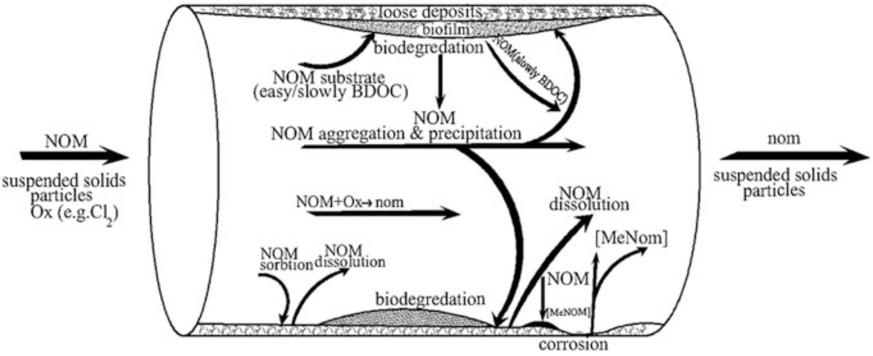


Fig. 15.9 NOM balance in drinking water distribution network

The network is the reactor where biological and chemical processes take place and pipes are covered with LD and biofilm in the distribution network. NOM molecules can be transported through the network. They have been involved in oxidation reactions (with disinfectants used in water treatment), corrosion processes (form complexes with metals) and can be used as substrate for microorganisms (biodegradation). Results showed that the TOC concentration increased in distribution network with increased WRT (caused by NOM dissolution, deterioration of the LD, and leaching from the pipe walls) and that BDOC concentration decreased with increased WRT (consumption of substrate by bacteria).

Hammes et al. (2010) showed that cell concentrations increased with increased WRT in the distribution network in Riga. Another study (Boualam et al. 2002) has shown the loss of cultivability of heterotrophic and coliform bacteria in water at low DOC concentrations (0.5 mg/l), suggesting that DOC could be the limiting factor for bacterial occurrence in drinking water. Thus, TOC concentrations (from 2.2 to 8.1 mg/l) determined at different places ($n = 30$) in the distribution network in this Chapter are high. There is a strong correlation between TOC and WRT which showed that substrate available for bacteria in the network increased with a decrease in BDOC suggesting that substrate was partially consumed.

A previous study (Gruškeviča et al. 2009) showed that LD samples collected from the DS contained goethite and quartz. NOM sorption isotherms for all media were not linear and the sorption rate was faster than desorption (Chi and Amy 2004), indicating that NOM forms relative strong bonds with iron surfaces. Thus, different amounts of nonpurgable organic carbon (NPOC) (from 0.18 to 21.01 mg/g, $n = 38$) in samples confirmed that NOM was accumulated in the LD. As the result of changes in hydraulic conditions or pressure shocks (Mustonen et al. 2008), NOM together with LD may be detached from the pipes leading to aesthetic complains of consumers.

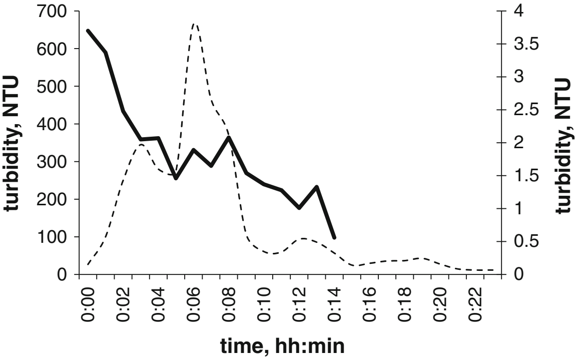
15.2.2 Practical Examples of Flushing a Water Distribution Network

Drinking water discoloration is the most reported complaint by consumers of drinking water supply companies (Vreeburg and Boxall 2007; Polychronopolous et al. 2003; Matsui et al. 2007) in regions where scarcity of drinking water is not so evident. In addition even in the centralized water supply systems of Latvia discoloration is quite often referred as a problem (Juhna 2007; Neilands et al. 2009). Unpleasant tastes and color of water significantly influences the confidence of consumer regarding the quality of tap water and the water company's service quality and causes consumers to want to pay less for their water (Kelay et al. 2008). Nevertheless, consumers in Latvia have fewer complaints with water suppliers (0.07 contacts/1000 pop/year) as compared with countries such as the Netherlands (0.5–1 contacts/1000 pop/year) and United Kingdom (4 contacts/1000 pop/year).

The accumulation and erosion of particles in drinking water system have been broadly described in the last years and there have been models developed models which describe the discoloration process (Ryan et al. 2008; Boxall et al. 2001). The main cause of particle accumulation in the drinking water network in Latvia is due to high iron concentrations in the source (HIL 2011) (background pollution) and inefficient treatment. Within the EU 6FP Techneua project the application of the resuspension potential method (RPM) developed in Netherlands (Vreeburg et al. 2004) for online turbidity monitoring in treatment plants and the unidirectional flushing (UDF) technique (Antoun et al. 1999; Friedman et al. 2002) for water quality control/improvement were carried out. These techniques were applied in several municipalities (population from >1,000–700,000; network length: 2–1,374 km; DN 100–DN 400). A mobile cart with installed online flow and turbidity meters and manometer, as well as a tap for grab samples (Fig. 15.10) was developed for this purpose.

Fig. 15.10 The mobile hand cart with equipment for UDF and RPM procedure in Latvia

Fig. 15.11 Application of RPM before (*solid line* with values on primer *y-axis*) and after (*dashed line* with values on secondary *y-axis*) the network flushing



Innovative approaches like RPM, UDF (Fig. 15.11), and online monitoring in water treatment plants could be used effectively to better understand the functioning of a water supply system and to help water utilities control water quality deterioration in WDN.

The case study showed that effective flushing is possible even in a big city such as the capital of Latvia—Riga (population 700,000) to eliminate discoloration problems. While comparing the UDF in a city with a population of 700,000 with the municipality with a population less than 10,000 it can be concluded that flushing is much more difficult in the larger city because of the intense traffic, limited space, and minimal capability to release the flushed water and because of the very complicated distribution network.

The pictures showing observed technical problems during the flushing program are presented (see Figs. 15.12, 15.13, 15.14).

Fig. 15.12 Flooded and filed with sand *Riga* type hydrant (2 m in deep) due to raised groundwater level

Fig. 15.13 By third person damaged manhole of hydrant in Riga case study

Fig. 15.14 By third person buried hydrants with clay cover

15.2.3 Wireless Sensor Networks Application at the WDN in Talsi

The system piloted in the municipality of Talsi consisted of 347 water flow meters 19 water pressure meters, metering data reading and transmitting equipment, server, software for network monitoring, and metering data analysis and reporting equipment. One of the project's tasks was to work out an interface between existing Talsi Water (TW) bookkeeping and billing information systems (IS) and a new metering data base. The pilot project was implemented in cooperation with the Talsi municipality and TW. After project completion incremental improvements have being made in order to introduce new elements of WDN management (CWDN 2010).

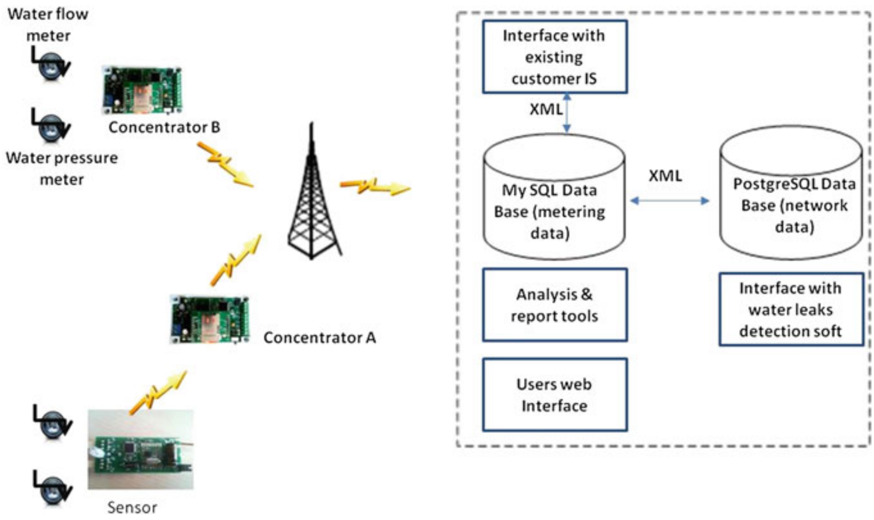


Fig. 15.15 A block scheme of a system for integrated water resources management (CWDN 2010)

A block scheme in Fig. 15.15 describes a system for integrated water resources management in a municipality.

Sensors—transmitters convert analog signals generated from water flow and water pressure meters into digital signals, process them into messages and send to gateways—concentrators using Short Range Devices (SRD) unlicensed telemetry band 868 MHz. Furthermore, a global system for mobile communication (GSM) network and a general packet radio system (GPRS) is used for data transmission between concentrators and a central server. MySQL database is used for metering data storage and processing, but the PostgreSQL database is used for WDN data storage and processing. The system's users: water utility staff, housing services providers, residents, and other clients accesses their data via a web interface.

A concentrator (gateway) shown in Fig. 15.16 periodically reads messages from meters and delivers data to the server via the GSM network using an IP protocol. The concentrator consists of: a microcontroller (Atmel), which controls the receiver and all concentrator operations, and stores metering data obtained from dedicated sensors. Receivers also use a short range devices (SRD) unlicensed telemetry band, 868 MHz. A TELIT GM864/865 is used as GSM modems for data exchange with the server. It has an internal processor and memory for programming in Python language.

In order to make the system more robust and to reduce power consumption the sensors—transmitters have only two regimes: registration of impulses from water meters and transmission of messages several times per hour; therefore, synchronization is not needed for the network's sensors. The approximate probability of message collision is about 1:10,000, so up to this point only a few cases have been

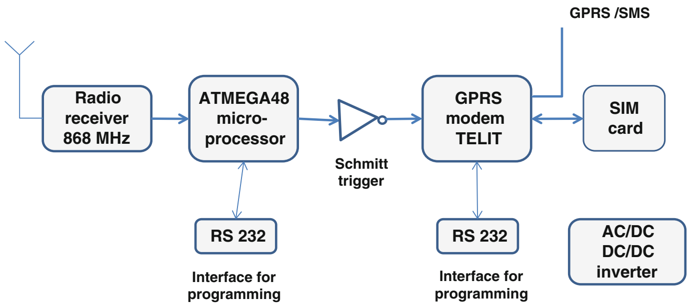


Fig. 15.16 A block scheme of A-type concentrator

noted. Such an approach has also helped to keep the cost of the system within the required boundaries, i.e., less than 35 euro per unit.

The power consumption of the sensors—transmitters was estimated to be capability to operate at least 10 years without battery replacement. Such an operational lifetime is achieved thanks to a 7,500 mAh battery (at the end of the project a new version of sensors—transmitters with 2500 mAh was created) and efficient operation of the transmitters. Depending on the settings a microprocessor switches on a transmitter two or more times per hour with a transmitting time of 20–50 ms. Between sessions the transmitter is switched off.

In order to diminish the risk of tampering with meters, which could be caused by magnets or other methods, a soft alert that occurs when hercon relay contacts show unusual behavior, was tested just after project completion.

Exploitation of GSM operator's networks helped to save capital investment and to achieve the best price. An agreement between the mobile operator and TW restricts a discounted volume of GPRS traffic for one concentrator by 10 Mbit per month. In order to reduce the traffic between concentrators and server text abbreviations and text cut are applied to data files, moreover files are split into short messages applying Md5 sum aiming to check integrity of files (MASOM 2010). Moreover, the initial TW requirement to transmit water pressure metering at 10 min intervals was revised; thus, data from the meters are now collected and transmitted each 30 min.

The system uses a Linux operational system, Ruby on Rails an open source full-stack web application framework and MyXQL database for storage and processing metering data. Free Open street map software is used for visualization of WDN topology. For the data integration with the third part IS systems (bookkeeping, billing, real estate management, etc.,) were used web-based XML requests.

The pilot project also had a target to create a framework for pinpointing leaks. This target was achieved by using hydraulic modeling tools that approximate defective sections of the water network. For this purpose a hydrodynamic model for network diagnostic application was created using a restricted number of nodes, pipes, and water flow and pressure meters. The model developed was linear, because there are no active elements such as pumps or tanks, which are depend on

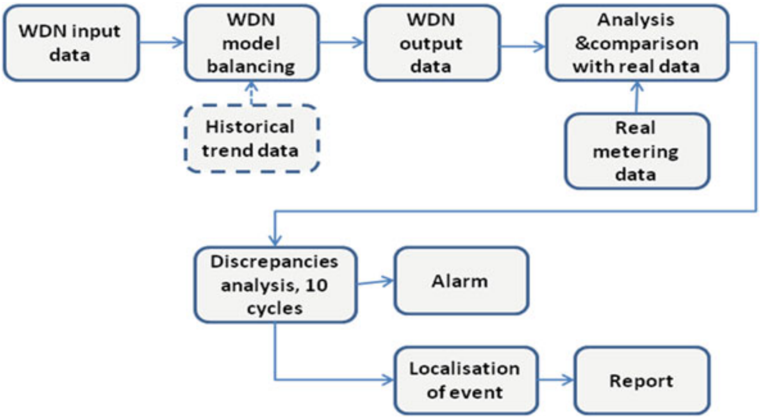


Fig. 15.17 An algorithm of network diagnostic

time or are caused by other nonlinearities; therefore, water flows freely from two reservoirs located at the highest points of the water network. The network structure was stored in a relational database as a directed graph. Using directed graphs allows for hydrodynamic model calculations and compares calculated and real metering data with the objective of identifying abnormities (for example, leakage events).

The diagnostic application calls on the WDN main application, which sends metering data as an XML file. The diagnostic application performs network modeling calculations and appropriate diagnostics and returns computational results as XML files, which is used by the network main program for visualization of results or for generation of alarms (for example SMS).

Figure 15.17 shows the WDN diagnostic algorithm, which comprises: metering data input, WDN model balancing, analysis and comparison with real data, and performs a discrepancies analysis providing for cycles, generation of alarms, identifying location of events, and reporting.

Due to the restricted scope and time of the project, the lack of historical records and due to the lack reliable data about WDN parameters, the diagnostic application was developed and tested as a trial model of the water distribution network. Although only approximate WDN parameters and conditional data were used for the simulation, the concept of diagnostic application proved its viability.

15.3 Discussions and Proposed Actions

15.3.1 Discussions About Results of Implemented Projects

The influence of high concentrations of NOM on the drinking water quality in the distribution network was examined in a project where the WRT in the supply system was determined using a hydraulic model, changes in the biological stability of water and NOM concentration changes in network, and in LD in the drinking water pipelines were taken into account.

Results suggest that NOM molecules are not simply transported through the network. Pipes are covered with deposits of corrosion products (Sarin et al. 2004) and NOM concentration in the deposits varies widely (Gauthier et al. 1999). Measurements of NOM concentration in the LD showed that it varies significantly, and its concentration level depends on the pipe material (e.g., PVC, PE, or CI) in the network. TOC concentrations increased in the distribution network with increased WRT indicating NOM dissolution, deterioration from the LD, and leaching process from the pipe walls. The BDOC concentration decreased with increased WRT indicating the consumption of substrate by bacteria. The BDOC reduction can be confirmed by previously published results (Van der Kooij and Hijnen 1991; Hammes et al. 2010) which have shown that the bacterial quantity in the distribution network increased with WRT as did the consumption of the AOC fraction. Simulated changes of water flow or pressure in network can detach deposits; therefore, result in increased turbidity, electrical conductivity, bacteria numbers in water (Mustonen et al. 2008) as well as TOC, thus deteriorating the drinking water quality.

The study has shown that grab sampling which is performed on a regular basis by water suppliers is not an accurate and effective method for determination of the risk of discoloration in the distribution networks. The resuspension of particles in distribution networks cannot be induced with current grab sampling procedures which use sampling from taps. Therefore, methodology of resuspension of particles like in RPM should be incorporated in the legislation.

The registration of complaints should be improved and consumers must always be informed about UDF.

The installation of telemetry at the Talsi WDN encouraged TW dispatchers to apply water flow and water pressure data monitoring in order to find abnormalities. They do it mostly at night-time, when the flow rate is minimal and any unusual event becomes more visible. TW dispatchers reported several cases, when water pressure meters incorporating remote monitoring helped them to identify pipe bursts and to identify local problem areas before leaks became visible. Water flow meter records also helped to explain to clients, why a particular monthly bill was larger than usually.

One of the problem issues is the reliability of the GSM network used for transmitting data between concentrators and a central server. Although the GSM network appears to have 100 % coverage and is transmitting almost 100 % of the time, delays in data transmission and unavailability of connections cause the system problems more frequently than other factors. A possible reason is the overload of the GSM network and lower priority of GPRS in comparison with voice and SMS traffic.

15.3.2 Suggestion for Standards and Legislations

The results showed that grab sampling alone in the distribution networks is not an adequate method for understanding discoloration problems, and tools such a RPM and UDF offers the possibility of evaluating and mitigating the turbidity risks in small and large cities.

The author of this chapter asked an officer of the Ministry of Environment Protection and Regional Development, which is the leading state administrative institution in the field of environment protection, about penalization utilities responsible for water loss in WDN. Since discussions regarding an emerging "Law on water services" have been started the issue of accountability for water loss could be one of the Law's topics. However, the Ministry still is reluctant concerning establishment of penalties due to monopolistic market for water supply services. Therefore, because customers are not able to change suppliers, losses, and penalties possibly would be assessed against clients as increasing tariffs for water supply services.

The following suggestions regarding the monitoring of drinking water consumption by residents should be considered:

- The application of impulse water meters or wireless sensor network together with data processing system;
- To overcome water theft due to usage of magnets the volumetric type of water meters should be used or alternatively vane wheel water meters with magnetic protection. Installing the water meters outside the flats could combat this problem as well as decrease the number of inaccurate readings;
- A solution against water theft could be the use of software to analyze the unusual behavior of meters;
- More sensitive water meters should be used (Class C).

15.4 Summary and Conclusions

NOM molecules are not simply transported through the network. The concentration of OC in the LD varies significantly, and its level depends on pipe material (e.g., PVC, PE, or CI) in the water distribution network. TOC concentrations in distribution networks increased with increased WRT indicating NOM dissolution, deterioration from the LD and leaching from the pipe walls. BDOC concentrations decreased with increased WRT indicating consumption of the substrate by bacteria.

The overall conclusion is that UDF is very effective method for reduction of turbidity and is more applicable in small communities then in large. In contrast to grab sampling, the RPM measurements showed the highest risk of discoloration risk in all municipalities.

The automatic wireless water meters reading system in Talsi town applies a two stage data collection and processing system; the sensors transmit data to the concentrators using SRD band 868 MHz, furthermore the traffic between concentrators and central server is ensured by GPRS. The system provides opportunities to collect data from difficult to access meters, to utilize existing mobile operator networks and to connect new customers without major investment. The increasing dependence on telecommunication and internet service providers (ISP), due to the growing volume of transmitted data, will force Latvian utilities to pay attention to data security and integrity aspects.

A hydrodynamic model for network diagnostic application has been created and simulated using an example model of a water distribution network. However, due to the limited scope of the project the network diagnostic application was tested using only a conditioned network segment, i.e., without application of historic and real data. Therefore, a new research project should be initiated in order to strengthen the initial research results and to make help make initial investments more effective.

References

Amy G, Her N (2004) Size exclusion chromatography (SEC) with multiple detectors: a powerful tool in treatment process selection and performance monitoring. Water Sci Technol: Water Supply 4(4):19–24

Andžāns M, Kaškina B, Teivāns V (2012) Situation regarding IT security in Latvia. The meeting with the State President in Riga Castle, 23 April 2012, pp 1–33

Antoun EN, Dyksen JE, Hiltebrand DJ (1999) Unidirectional flushing: a powerful tool. J AWWA 91(7):62–71

ATRL (2008) Administrative-Territorial Reform Law. “Administratīvi teritoriālās reformas likums”. http://www.likumi.lv/doc.php?id=51528/

Bicik J, Kapelan Z, Savić DA (2011) Challenges in the implementation of a DSS for real time WDS management. In: Proceedings of the CCWI 2011 conference, Exeter, UK, pp 1–7

Bose P, Reckhow DA (2007) The effect of ozonation on natural matter removal by alum coagulation. Water Res 41(7):1516–1524

Boualam M, Mathieu L, Fass S, Cavard J, Gatel D (2002) Relationship between coliform culturability and organic matter in low nutritive waters. Water Res 36(10):2618–2626

Boxall JB, Skipworth PJ, Saul AJ (2001) A novel approach to describing sediment movement in distribution mains, based on measured particle characteristics. Water Softw Syst 1:263–273

Brandt BW, Kelpin FDL, Van Leeuwen IMM, Kooijman SALM (2004) Modeling microbial adaptation to changing availability of substrates. Water Res 38(4):1003–1013

Briliute I, Bonckus A, Zygmantas G (2008) Influence of installation effects on the performance of residential water-meters. In: The 7th international conference environmental engineering, vol 2, pp 785–792

Broo AE, Berghult B, Hedberg T (1999) Drinking water distribution—the effect of natural organic matter (NOM) on the corrosion of iron and copper. Water Sci Technol 40(9):17–24

Butterfield PW, Camper AK, Ellis BD, Jones WL (2002) Chlorination of model drinking water biofilm: implifications for growth and organic carbon removal. Water Res 36(17):4391–4405

Camper AK (1996) Factors influencing microbial growth in the distribution system: laboratory and pilot experiments. American Water Works Association Research Foundation, Denver, p 60

Camper AK (2004) Involvement of humic substances in regrowth. Int J Food Microbiol 92 (3):355–364

Chi FH, Amy GL (2004) Kinetic study on the sorption of dissolved natural organic matter onto different aquifer materials: the effects of hydrophobicity and functional groups. J Colloid Interface Sci 274(2):380–391

CPL (2006) Civil Protection Law, Cabinet of Ministers Regulation No. 171, "Civilās aizsardzības likums". http://www.likumi.lv/doc.php?id=146474

CWDN (2010) Project computerized water distribution network control system for Talsi District. (Datorizētas ūdenssaimniecības vadības un kontroles sistēmas ieviešana Talsu novadā 2009–2010), EEA Grants program, Identification Nr. TNP 40/10. http://www.talsuudens.lv/arhivs_2009 (unpublished)

Day GMcD, Hart BT, Hart BT, McKelvie ID, Beckett R (1994) Adsorption of natural organic matter onto goethite. Colloids Surfaces A: Physicochem Eng Aspects 89(1):1–13

Eikebrokk B, Juhna T, Melin E, Osterhus SW (2007). Deliverable 5.3.2a. Water Treatment by Enhanced Coagulation and Ozonation-Biofiltration. Intermediate report on operation optimization procedures and trials. Report of Integrated Project TECHNEAU Funded by the European Commission under the Sustainable Development, Global Change and Ecosystems Thematic Priority Area. http://www.techneau.org/index.php?id=120

ESL (1999) Epidemiological Safety Law Republic of Latvia, "Epidemiologiskās drošības likums", http://www.likumi.lv/doc.php?id=52951

E-Water (2010) Innovative e-services for water supply management. Latvia—Lithuania Program, http://www.latlit.eu/eng/running_projects

Friedman MK, Gregory J, Antoun E (2002) Developing and implementing a distribution system flushing program. J AWWA 94(7):48–56

Frimmel FH (1998) Characterization of natural organic matter as major constituents in aquatic systems. J Contam Hydrol 35(1–3):201–216

Gauthier V, Gerard B, Portal JM, Block JC, Gatel D (1999) Organic matter as loose deposits in a drinking water distribution system. Water Res 33(4):1014–1026

Gauthier V, Barbeau B, Millette R, Block JC, Prevost M (2001) Suspended particles in the drinking water of two distribution systems. Water Sci Technol: Water Supply 1(4):237–245

Gruškeviča K, Tihomirova K, Osterhus S, Juhna T (2008) Influence of water velocity and NOM composition on corrosion of iron pipes. Programme and abstracts book, cost action 637 METEAU materials and related substances in drinking water. COST, Lisbona, pp 24–25

Gruškeviča K, Tihomirova K, Rubulis J, Juhna T (2009).Organic matter isolation from loose deposits in drinking water distribution system. In: Proceedings: 1st IWA East European regional young water professionals conference, Belarusian National Technical University, Minsk, pp 278–284

Hammes F, Vital M, Briedis A, Rubulis J, Juhna T (2010) Tracking bacterial growth in a full scale drinking water distribution network with a flow cytometry, ATP analysis and hydraulic modeling. In: Proceedings: The water research conference. COST, Lisbon

Herro HM, Port RD (1993) The Nalco guide to cooling water system failure analysis. McGraw-Hill, New York, 459 p

HIL (2011) Health Inspectorate of Latvia. An overview of drinking water quality in year 2011, http://www.vi.gov.lv/uploads/files/parskats_2011_2.pdf

Hunaidi O, Wang AA (2006) New system for locating leaks in urban water distribution pipes. Int J Manag Environ Quality 17(4):450–466

IESM (2011) Research on Justification of Development of the System for Monitoring and Control Water Resources, Latvia—Lithuania Cross-border cooperation program, project Innovative e-services for water supply management, LLIII-127 E-Water, Ventspils High Technology Park, 2011, 94 p (unpublished)

Juhna T (2007) Atdzelžošanas principi un to pielietojums dzeramā ūdens sagatavošana. Rīga, SIA Fotomart, p 40

Kaplan LA, Newbold JD (2000) Surface and subsurface dissolved organic carbon. In: Jones JB, Mulholland PJ (eds) Streams and ground waters. Elsevier, Academic Press, San Diego, 425 p

Kaškina B (2012) Dealing with the whole country: creating a National CSIRT. In: 35th TF-CSIRT and FIRST meeting, 31 January 2012, Rome, Italy, pp. 1–30. www.cert.lv

Kelay T, Vloerbergh I, Hagegård K (2008) Deliverable 6.1.3./6.2.3.) Interim Report: Consumer Focus Groups. Report of Integrated Project TECHNEAU Funded by the European Commission under the Sustainable Development, Global Change and Ecosystems Thematic Priority Area, http://www.techneau.org/index.php?id=120

Korshin GV, Ferguson JF, Lancaster AN (2005) Influence of natural organic matter on the morphology of corroding lead surfaces and behavior of lead-containing particles. Water Res 39(5):811–818

Krauze G (2011) Latvian Water Supply and Sewerage Enterprises Association. Presentation at international conference Baltic States in transition, Jurmala, Latvia, 16 September 2011, p 13 (unpublished)

Larson TE (1966) Chemical Control of Corrosion. J Am Water Works Assoc (AWWA) 58 (3):354–359

LeChevallier MV, Lowry CD, Lee RG, Gibbon DL (1993) Examining the relationship between iron corrosion and the disinfection of biofilm bacteria. J Am Water Works Assoc (AWWA) 85 (7):111–123

Lin M, Wu Y, Wassell I (2008) Wireless sensor network: water distribution monitoring system. In: Radio and wireless symposium 2008, IEEE 2008, pp 775–778

MASOM (2010) Mazzy Aquamet software operation manual, https://mazzy.basecamphq.com/login. Micro Dators ltd., IT Hous/ITH Group 2010. 52 p

Matsui Y, Yamagishi T, Terada Y, Matsushita T, Inoue T (2007) Suspended particles and their characteristics in water mains: development of sampling methods. J Water Supply: Res Technology—AQUA 56(1):13–24

Mustonen SM, Tissari S, Huiko L, Kolehmainen M, Lethola MJ, Hirvonen A (2008) Evaluating online data of water quality changes in a pilot drinking water distribution system with multivariate data exploration methods. Water Res 42(10–11):2421–2430

National Security Law (2000) “Nacionālās drošības likums”. http://www.likumi.lv/doc.php?id=14011

Ndiongue S, Huck PM, Slawson RM (2005) Effect of temperature and biodegradable organic matter on control biofilms by free chlorine in model drinking water distribution system. Water Res 39(6):953–964

Neilands K, Rubulis J, Juhna T (2009) Application of online monitoring, resuspension potential method and unidirectional flushing for control of drinking water quality in a distribution networks, Latvia. In: Proceedings 1st Eastern European regional young water professionals conference, Minsk, Belarus, p 6

On Pollution Law (2001) “Par piesārnņojumu likums”. http://www.likumi.lv/doc.php?id=6075

Polychronopolous M, Dudley K, Ryan G, Hearn J (2003) Investigation of factors contributing to dirty water events in reticulation systems and evaluation of flushing methods to remove deposited particles: a review. Water Sci Technol: Water Supply 3(1–2):295–306

Prevost M, Joret JC, Laurent P, Servais P (eds) (2005) Biodegradable organic matter in drinking water treatment and distribution. American Water Works Association, Washington, 300 p

Raczyk-Stanisławiak U, Świetlic J, Dabrowska A, Nawrocki J (2004) Biodegradability of organic by-products after natural organic matter oxidation with ClO_2-case study. Water Res 38 (4):1044–1054

Rubulis J, Šnīdere L, Briedis V (2001) Problems with drinking water metering in apartment buildings and flats in Riga city, Latvia. In: Ulanicki B, Coulbeck B, Rance J (eds). Research Studies Press, UK, pp 349–356

Rubulis J, Lukjaņeca I, Tihomirova K, Koliškins A, Nazarovs S, Vital M, Hammes F, Juhna T (2007) Simulation of bacterial regrowth in water networks by modeling of pseudomonas fluorescents growth in a lab biofilm reactor. In: CCWI2007 and SUWM2007 conference, water management challenges in global change, Leicester, pp 229–236

Ryan G, Mathes M, Haylock G, Jayaratne A, Wu J, Noui-Mehidi N, Grainger C, Nguyen BV (2008). Particles in water distribution systems, Tech. Rep. 33, Cooperative Research Centre for Water Quality and Treatment

Sarin P, Snoeyink VL, Bebee J, Kriven WM, Clement JA (2001) Physico-chemical characteristics of corrosion scales in old pipes. Water Res 35(12):2961–2969

Sarin P, Snoeyink VL, Lytle DA, Kriven WM (2004) Iron corrosion scales: model for scale growth, iron release, and colored water formation. J Environ Eng ASCE 130(4):364–373

Servais P, Billen G, Laurent P, Levi Y, Randon G (1992) Studies of BDOC and bacterial dynamics in the drinking water distribution system of the Northern Parisian suburbs. J Water Sci, Revue des science de L'EAU, 5(Special):69–89

Servais P, Laurent P, Billen G, Gatel D (1995) Development of a model of BDOC and bacterial biomass fluctuations in distribution systems. J Water Sci, Revue des science de L'EAU 8:427–462

Sontheimer H, Kolle W, Snoeyink VL (1981) The siderite model of the formation of corrosion-resistant scales. J Am Water Works Assoc (AWWA) 71(11):572–579

Stoianov I, Nachman L, Madden S (2007) PIPENET: a wireless sensor network for pipeline monitoring. In: Proceeding of IPSN '07; Proceedings of the 6th international conference on Information processing in sensor networks. ACM, New York, pp 264–273

Swietlik J, Dabrowska A, Raczyk-Staniskawiak U, Nawrocki J (2004) Reactvity of natural organic matter fractions with chlorine dioxide and ozone. Water Res 38(3):547–558

Tuovinen OH, Button KS, Vourinen A, Carlson A, Mair DM, Yut LA (1980) Bacterial, chemical, and mineralogical characteristics of tubercles in distribution pipelines. J Am Water Works Assoc (AWWA) 72(11):626–635

Van der Kooij D, Hijnen WAM (1991) Criteria for defining the biological stability of drinking water as determined with AOC measurements. In: Proceedings: water quality technology conference San Diego. American Water Works Association, Denver, pp 1281–1333

Van der Kooij D, Visser A, Hijnen WAM (1982) Determination the concentration of easily assimilable organic carbon in drinking water. J Am Water Works Assoc (AWWA) 74:540–545

Vreeburg JHG (2007) Discoloration in drinking water systems: a particular approach. Ph.D. thesis report

Vreeburg JHG, Boxall JB (2007) Discolouration in potable water distribution systems: a review. Water Res 41:519–529

Vreeburg JHG, Schaap P, van Dijk JC (2004) Measuring discoloration risk: resuspention potential method. In: IWA Leading Edge Conference, Prague, p 8

Zabašta A (2010) Ventspils region drinking water and sewage holding research and model development using information and communication technologies (ICT) solutions. Ventspils High Technology park, p 28 (unpublished)

Zabasta A, Kunicina N, Chaiko Y, Ribickis L (2011) Automatic meters reading for water distribution network in Talsi City. In: Proceeding of EUROCON 2011, April 2011, Lisbon, Portugal, IEEE 2011, pp 1–6

Zacheus OM, Lehtola MJ, Korhonen LK, Martikainen PJ (2001) Soft deposits, the key site for microbiological growth in drinking water distribution networks. Water Res 35(7):1757–1765