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# Report

## *SMS from OSLO VAV - Secure and Monitored Service from Oslo VAV*

**First periodic progress report**
**Project objectives,  work progress and achievements,  project management**


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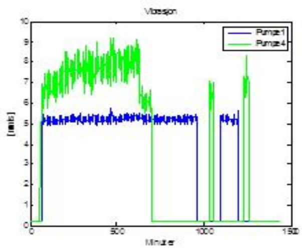


**SINTEF Building and Infrastructure**
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# Report

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**ABSTRACT**
This report summarises the goals, results achieved and deviations from the plan of the SMS from OSLO VAV project after 8 months of activity. The report is meant as a summary for the Regionale forskningsfond's board committee. Technical details will not be included in this report, but will be provided if requested.
The project work is overall well on track. A main challenge, however, was related to the quality of the information system and data to be used in one of the statistical models applied and the selection of the case studies for three research activities that took longer time than expected, however the research activity is now in line with the plan.
About 67 % of the budget has been spent up to now, since the start of the feasibility studies in the selected case studies was postponed requiring a consequent shift in the use of the resources.
The project team has been very active during the first 8 months and collaboration has been very good, as also confirmed via letter by the personnel of Oslo VAV.
The project will continue for 2 more years. One priority for 2013 will be to develop a strategic plan for involvement of industries to implement the projects results.

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# Table of contents

# 1 SUMMARY

This report summarises the goals, results achieved and deviations from the plan of the SMS from OSLO VAV project after 8 months of activity. The report is meant as a summary for the RFF Hovedstaden's board committee. Technical details will be not included in this report, but will be provided if requested.

***The project aims to improve the efficiency and the security in monitoring and control of the urban water and wastewater system of Oslo Vann og Avløp (VAV).***

The project works in 4 parallel and integrated directions, corresponding to 5 projects work packages, WP1-WP5:

- Condition assessment of wastewater pipes promoting the application of an innovative model for deterioration analysis to identify pipes in worst conditions. The model acts as basic tool for proactive rehabilitation planning, by providing adequate information on the current and future structural state of the network to support rehabilitation decisions (WP1) also including risk analysis (WP2).
- Feasibility analysis of new wireless communication technology for monitoring and control of water and wastewater infrastructures carried out by pilot installations at two selected sites (WP3).
- Improvement of the security of interconnected process control systems with carefully designed security architecture and establishing a sector-specific scheme for incident response management (WP4).
- Evaluation of how to extract and use data collected by the SCADA system for generation of condition monitoring information to detect equipment and component degradation at an early stage (WP5).

The project also includes 2 additional WPs, number 6 for dissemination and 7 for management.

The first period of the project focused on the first work package (WP1) that is a direct follow up of the pre - project *Deterioration of wastewater pipes in Oslo VAV* (DetWast) financed by RFF in 2011.

WP1 aims to provide *Oslo Vann og Avløp* (VAV) with the analysis of current and future level of deterioration of the wastewater pipes and the estimation of the resources required to improve the system conditions with rehabilitation actions (both information are important for master planning (*hovedplan*) and for rehabilitation schemes (*saneringsplan*)). The research activity started with intense data management and analysis: the screening exercise of the data showed that the quantity of data stored is sufficient for running advanced analysis, as summarised in this report, however a lot still needs to be done to improve the quality of data in the VAV information system.

The project also highlighted a major issue: the need to review the Norwegian standard (Norsk Vann) on visual inspection. One result of the first year of the WP1 is to recommend a revision of this standard. A dialogue has started with Norsk Vann on this issue. This result is relevant for the whole water industry in Norway, given that most of the Norwegian water utilities bases the rehabilitation scenarios on calculations made by using those standard.

A second activity partially completed by this WP1 has been to model the deterioration process of inspected pipes in concrete material and for all the inspected wastewater pipes of Oslo and, given the available data, interpret the results and evaluate the level of credibility and of significance.

WP3-4 activity started with the selection of the application areas that may benefit from wireless communication and the area including Voksenåsen water tank and Voksenlia pumping station has been selected as first-year pilot.

The challenge here is to establish a reliable and secure direct communication link between the water tank and pumping station, enabling Oslo VAV to maintain an appropriate water tank level even though the main control system should temporarily fail (WP3). Based on the identified requirements, the project team has selected a wireless technology that is to be further evaluated both by technical studies and field tests. Included in this work is an evaluation of the security measures provided by the selected technology (WP4).

Also the research activity of WP5 mainly dealt with the selection of the case study.
The chosen first case is "Frognerparken wastewater pumping station" that has demonstrated the value of process data in providing several types of condition information to be utilized directly and indirectly using model based techniques (Kalman-filtering). The WP5 has then focused the attention on proposing a method to aggregate the information "hidden" in the process data in order to inform the user on the overall level of condition of the system under analysis. A first version of "Functional specification" for condition monitoring system has been also defined.

The project work is well on track. A main challenge, however, is related to the quality of the information system and data to be used in WP1, and the selection of the case studies for WP3-4-5 took longer time than expected, however the research activity is now in line with the plan.

## 2 BACKGROUND OF THE PROJECT

Water and wastewater systems are critical infrastructures which can benefit from condition monitoring and control of its equipment, pipelines and operating status. Improving the knowledge about the system functionality can increase the economic efficiency related to maintenance and investment planning, and also protect the environment from system malfunctions and improve the system safety and security.

Oslo VAV has in the last years faced malfunctions, accidents, or system failures with impacts to environment, service and loss of reputation. The incidents in addition to the alarm highlighted by national reports (RIF, 2010), that point at the need for the water and wastewater sector to be prepared and to better adapt to the negative effects of climate change and deterioration, have been inspiring realities for the research team in proposing this project to Oslo VAV first, and then together to the RFF.

SMS from OSLO VAV project is a 3 years project financed 75% by RFF and 25% by Oslo Waterworks. The project is divided in 7 work packages, of those 5 are research work packages (WP1-5), one is meant for dissemination activities (WP6) and one for project management (WP7).

***The project aims to improve the efficiency and the security in monitoring and control of the urban water and wastewater system of Oslo VAV.***

# 3 PROJECT OVERALL OBJECTIVES AND OBJECTIVES FOR THE PERIOD, PARTNERS AND BUDGETING

## 3.1 Project objectives in total and for the period

The objectives of the overall 3 years project are:

- **Assessment of current and future conditions of the wastewater pipes** to reduce the probability of structural failures from the system
- **Smart condition monitoring system** - evaluate how to extract and use these data for generation of condition monitoring information to detect equipment and component degradation at an early stage.
- Feasibility analysis of **new wireless communication technology for monitoring and control** of water and wastewater infrastructures.
- **Improvement of the security of interconnected process control systems** with carefully designed security architecture and establishing a sector-specific scheme for incident response management.

For each objective a list of challenges and proposed solutions is described in the project application. The activities enabling the proposed solutions have been organized in a list of work package tasks. Each task has a scheduled budget and duration.

This report provides information only for the tasks planned for this first period of reporting (April – December 2012), that means for the tasks expected to be completed by month 8 (December).

### 3.1.1 The list of those tasks is given below for each WP

For **WP1** dealing with wastewater pipes condition monitoring, assessment and rehabilitation planning
Task 1.1 - Criteria for inspection prioritization – within 2012 (M1-M4)
Task 1.2 - Deterioration modeling (data from 10 catchments) – within 2012 (M1-M6)
Task 1.3 - Cost functions for rehabilitation modeling – within 2012 (M1-M5)
Task 1.4 - Rehabilitation scenarios – within 2012 (M6-M8)
For **WP3 - Wireless Communication**
Task 3.0 – Pilot selection (M0)
Task 3.2 – Pilot system specification and requirements (M1 – M3)
Task 3.3 – Pilot technology evaluation and selection (M3 – M5)
Task 3.4 – Pilot installation (M5 – M7)
For **WP4 – Information Security**
Task 4.1 A Security Requirements first draft (M1-M4)
For **WP5 – Control Systems**
Task 5.1 - Feasibility study (M1-M6)
Task 5.2 - Condition monitoring function specification (M8-M12)
Task 5.3 - Prototype implementation of core algorithms (M13-M19)

### 3.2 Project team

This project includes interdisciplinary research collaboration between the following project partners:

Oslo Water and sewerage works department (Oslo VAV)
SINTEF Building and Infrastructure, Dept. of Water and Environment
SINTEF ICT Dept. of Communication Systems
SINTEF ICT Dept. of Software Engineering, Safety and Security
SINTEF ICT Dept. of Applied Cybernetics
IRSTEA – international partner.

The participants and their contribution to the project are listed in the following table (table 1).

**Table 1 List of project participants as for 2012**

| Partner | Key Personnel | Competence | Challenge |
|---|---|---|---|
| Oslo Water and Wastewater Works (VAV) | Eng. Arnhild Helene Krogh, Eng. Ragnar Dehli, Eng. Harald Rishovd | Public Sector | (Providing data and feedback on solutions proposed to all challenges). |
| SINTEF Building and Infrastructure Dept. of Water and Environment | Senior Scientist, Prof II Rita Ugarelli<br>Senior Scientist Jon Røstum<br>Research Engineer Ingrid Selseth | Condition assessment, risk analysis for water cycle, generic knowledge in water and wastewater, generic ICT in water sector | WP 1 and 2 (will also contribute in WP3-4-5) |
| SINTEF ICT Dept. of Communication Systems | Research Scientist Stig Petersen<br>Research Scientist Bård Myhre | Wireless communication | WP3 |
| SINTEF ICT Dept. of Software Engineering, Safety and Security | Research Scientist Martin Gilje Jaatun | ICT security | WP4 |
| SINTEF ICT Dept. of Applied Cybernetics | Senior Scientist Berit Floor Lund<br>Senior Scientist Svein Peder Berge | Condition monitoring, process control, model based measurements | WP5 |
| IRSTEA, Bordeaux, France | Senior Researcher Yves Le Gat | Infrastructure deterioration and failure process modeling | WP 1 and 2 |

The competences of the different partners are included in the project application.

The project from year 2 will develop a strategic plan for involvement of industries to implement the projects results. SINTEF and VAV have identified together a list of industries that will be involved in the SMS VAV project from 2013, to ensure cooperation in the territory between VAV and companies and to create market opportunities thanks to the project.

The strategic plan will consist on defining when and how to integrate one or more of the companies and then update the partner agreement.

Some of the companies listed are already involved with VAV in other projects, while others will be new.

As companies related to WP3-4-5 ABB has been already approached: interest and availability to provide to this project (for free) wireless sensors to be tested. The wireless sensors will be useful to collect data on temperature and vibration of pumps to support the studies performed in WP5, as described further in the report; as technology provider the selection is on Phoenix and Last Mile Communication in Asker; for various wireless solutions (point-to-point, point-to-multipoint) the selection is for Radiocrafts, in Oslo that are proprietary of wireless sensor network radio modules; the list also includes Leif Kølner Ingeniørfirma, Nøtterøy that is the Norwegian distributor of Yokogawa wireless instrumentation and InstrumentTeam, in Bærum that are the Norwegian distributor of Honeywell wireless instrumentation.

The companies related to WP1 to be contacted are GEODATA: already involved in the pre-project and POWEL. The reason for the selection of POWEL is related to the issue of improvement of the information system of Oslo (as shown by the project) since Gemini VA (by Powel) is the main database used in Oslo and by most of Norwegian water utilities.

## 3.3 Project budgeting

In the following table a comparison between the budget planned at the beginning of the project in April and the budget spent until 26.11.2012 is provided.

**Table 2 overview of the budget spent until end of November in each WP.**

| | Budget Planned | Budget SPENT (PERSONNEL + DIRECT) | % of spent versus planned |
|---|---|---|---|
| | [NOK] | [NOK] | |
| **WP1** | 745000 | 638 537 | 86 % |
| **WP3** | 458400 | 134 350 | **29** % |
| **WP4** | 250000 | 175 260 | 70 % |
| **WP5** | 191600 | 82 379 | 43 % |
| **WP6** | 105000 | 11 800 | **11** % |
| **WP7** | 125000 | 123 672 | 99 % |
| **TOT** | 1875000 | 1165998 | 62 % |

The main deviations are found in WP6, where budget was initially planned for 2012, to leave open the option to organize a workshop for dissemination of results before the end of the first year. As described in the conclusions, the project team has already prepared an ambitious plan for workshops for 2013 and therefore this budget will be used in 2013.

Regarding WP3, the initial planned budget was of NOK 305 000, but due to a re-distribution of budget between WP3 and 5, caused by a wrong registration of hours of the colleagues of WP5, more budget was allocated in WP3 from the resources provided by RFF; the same amount was taken from WP3 and given to WP5 in the resources financed by VAV. The budgets financed by RFF and VAV are registered in SINTEF as 2 different projects. The use of 2 project numbers created errors in hour's registration that is now fixed.

# 4 WORK PROGRESS AND ACHIEVEMENTS IN WP1 – *WASTEWATER PIPES: CONDITION MONITORING, ASSESSMENT AND REHABILITATION PLANNING*

The tasks to be fulfilled by WP1 by the end of 2012 are list in chapter 3.1.1.
The work flow is proceeding as planned and not major deviations are higlighted.
An overview of the research work is provide in the following chapters.

## 4.1 Work progress and achievements as for now

The WP1 deals with the application of a statistical model called GompitZ to the wastewater pipes of Oslo for deterioration analysis. The results are used for knowledge based MASTER PLAN and INVEST-MENT PLAN.

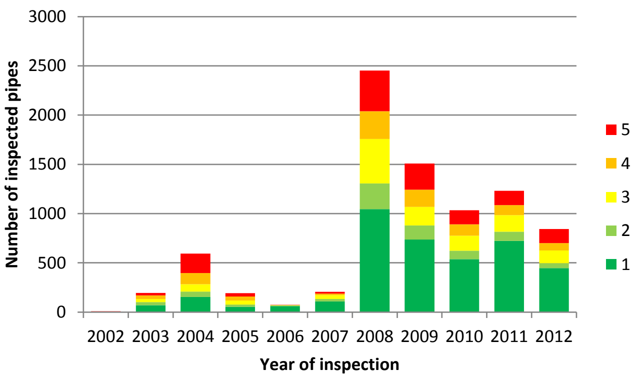
The non – homogeneous Markov chain GompitZ (Le Gat, 2008) model, combined with Closed-Circuit TV (CCTV) inspections data, enables a water utility to predict the deterioration process in a wastewater system. This is, however, dependent on reasonable assumptions, sufficient amount and precise enough data and that the data describes the deterioration process to a sufficient degree.

Most research of the first 8 months focused exactly on a data analysis procedure including data collection, filtering and adaption, calibration of the model, stability testing of results versus data available, feedback to Oslo VAV, collection of new data or improvement of existing ones, new calibration and so on.

### 4.1.1 Data collection

Data from a total of 8333 inspected pipes in Oslo VAV was delivered to SINTEF by VAV personnel. Due to a change in system in 2008, the datasets lack some data before 2007. These data might be available later in the project. Oslo VAV inspected the sewer network area by area following the river basins. The inspections were carried out from 2002 to 2012, but mainly concentrated in 2008-2012. None of the pipes were subject to repeated inspections. The inspected pipes are considered by VAV to be representative for the whole network.

According to the classification method applied, pipes have been grouped in 5 classes of level of deterioration, where 1 stands for pipe as good as new and 5 to pipe close to collapse. The amount of pipes in each class at the time of inspection is shown in Figure 1.



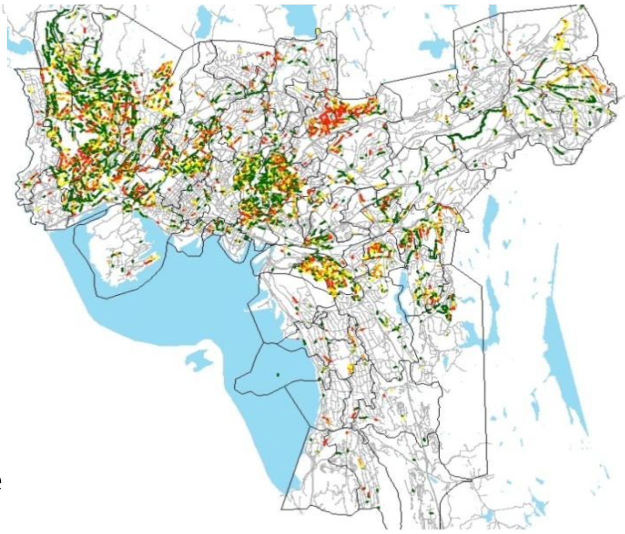
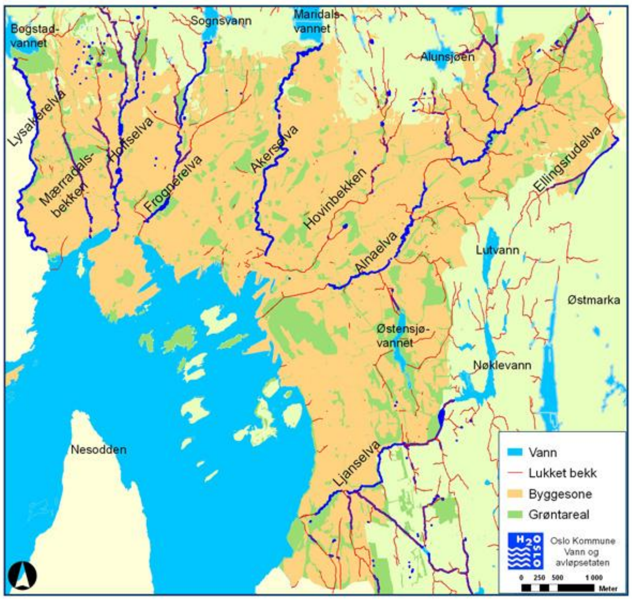



**Figure 1 The number of inspected pipes within each year classified using condition class 1-5 where 1 is the best.**



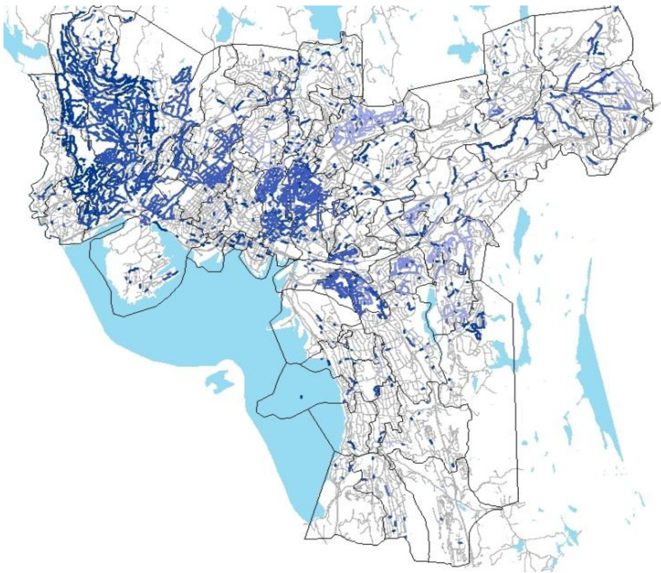



**Figure 2 River basins in Oslo (left) and when the different areas were inspected (right) from light blue in 2002 to dark blue in 2012**

The main focus of the analysis in these 8 months has been on concrete pipes. Almost 80 % of the sewer pipes in Oslo are concrete pipes. Models have been calibrated for concrete pipes with pipe diameter less than 600 mm ("BET"), concrete pipes bigger than 600 mm ("cBET") and for all the inspected pipes ("ALL"). These three models can be applied for the whole network using a model that we called "BET" for small concrete pipes, "cBET" for concrete culvert and "ALL" for the remaining pipes. An extensive data cleaning has been carried out. The available data was delivered from different sources: Gemini VA, RioGIS, manual lists of rehabilitation works carried out etc.

### 4.1.2 Calibration

The GompitZ program needs pipe data and inspection data, both should be available at pipe level. Data are used for a model parameter calibration module in order to identify what factors (co-variates) has influenced the process of deterioration of the inspected pipes and how the deterioration will continue in time.

The following explanatory factors have been tested as covariates in the deterioration model:

- Pipe diameter (mm),
- Effluent type (combined versus waste water),
- Tramway proximity (yes / no),
- Presence of trees close to the sewer (yes / no),
- Construction period (1850-1929, 1930-1945, 1946-1969, or 1970-2011),
- Road traffic (0, 1-500, 501-5000, 5001-15000 vehicles / day),
- Type of bedding soil (marine deposits, detritus material, fillers, or rock)

**Goodness of fit**

The goodness of fit, between observations and the model, groups pipes in classes of successive age of 5 years; it allows to graphically assessing the model goodness of fit by comparing for each age group, the condition distributions observed versus the modelled one. The observed frequency in each age group is displayed on the bottom bar chart (Figure 3).

In our study, the agreement between observed and modelled condition distributions is satisfactory, except for youngest and oldest age groups where observed sample sizes are too small. The reason for that can be related to replacement of the oldest pipes and missing collected information about conditions of new installed pipes.

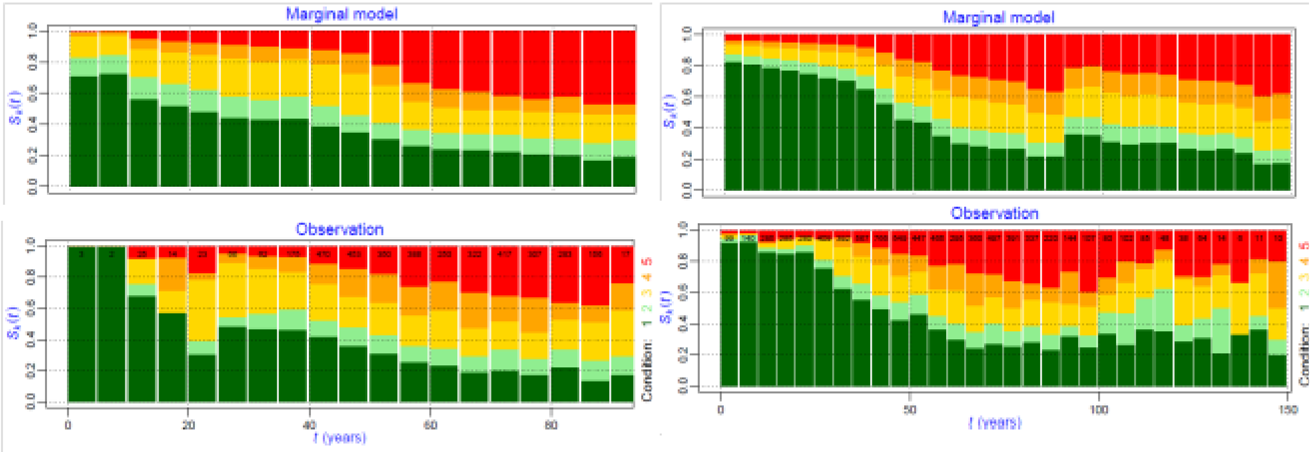



Figure 3

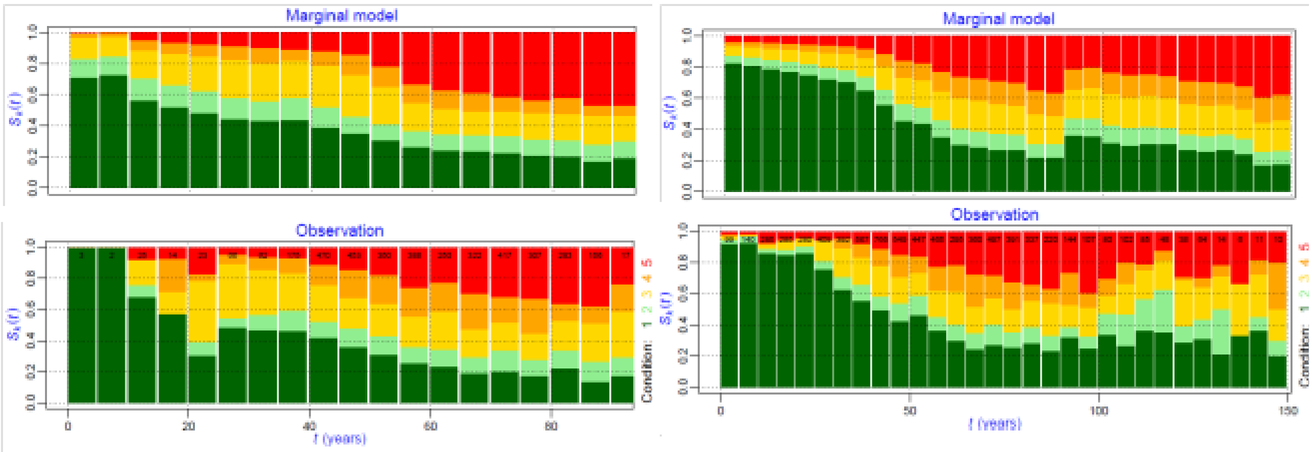



**Figure 3 The goodness of fit for model "BET" (left side) and model "ALL"(right side)**

### Prediction of future condition classes

This step of the analysis focuses on the prediction of the expected deterioration process of the network. This can done for both pipes with and without previously inspections. First it is important to define a baseline by predicting how the system will deteriorate if no rehabilitation actions are performed. The results of the "do nothing scenario" can be then compared with the results of different rehabilitation strategies: for a given period of time, a certain deficiency (e.g. pipes in worst condition class) shall be reduced, in order to achieve a certain level of service that shall be kept in the long – term. The selection of the criteria to be tested as rehabilitation scenarios is the current focus of the dialogue with Oslo VAV, in order to produce useful results for the Oslo VAV Master Plan. Attention is on calculating the trade off between the costs of a given rehabilitation option and the benefit achievable in terms of improved conditions in the system for a period of time of 15 years.

The global deterioration condition of the network is defined by the set of maximum tolerable proportions of the total network length in each condition state. The set of pipes to be annually rehabilitated is chosen by ranking the pipes in descending order according to a deterioration score; this deterioration score is defined in the current version of GompitZ as the sum over the condition states of the products of the condition probability by a condition specific score equal to 0 for the best condition, 1 for the next deteriorated, 2 for the next and so on.

## Do-nothing scenario

Figure 4 displays the “natural" evolution of the network condition distribution in the absence of rehabilitation (“do nothing scenario”) for the period 2012-2060. The clear worsening of the network is visualized if interventions are not planned by the increase of the size of stock of pipes in condition class 4- 5 and the decrease of the size of the stock of pipes in condition class 1 and 2.

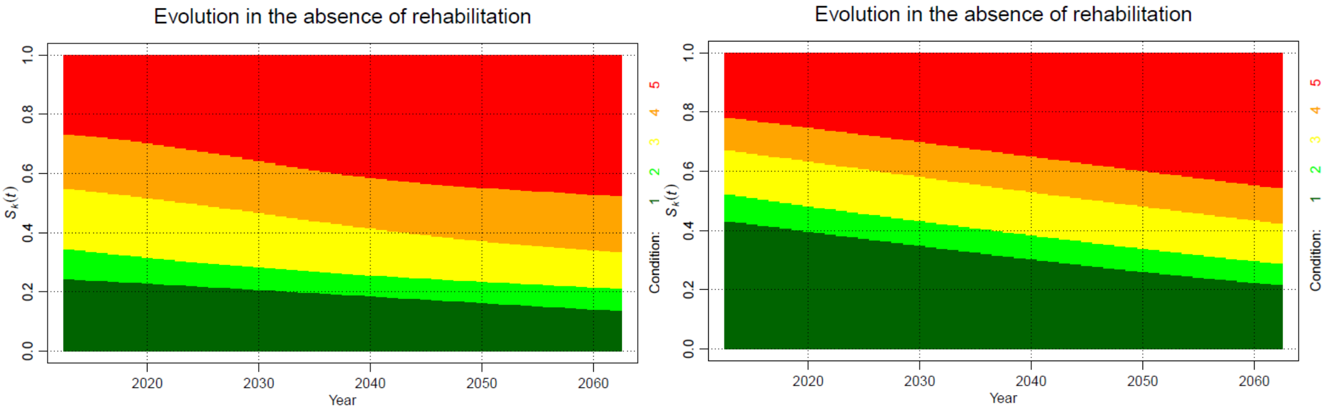



**Figure 4 Do-nothing scenario for 50 years prediction of the model "BET" and "ALL"**

## Optimized scenario

Figure 5 shows the evolution of the network condition by applying an optimized strategy of rehabilitation (2015-2040) aiming at reaching a given objective at horizon 2030; the objective is to have proportions of the network length in condition states 1 to 5 respectively less than 100%, 80%, 60%, 40% and 1%.

By comparing Figure 4 and Figure 5 it is possible to see (and calculate) the benefit in terms of improvement of the network conditions obtained by applying a given rehabilitation strategy, instead of “doing nothing”.

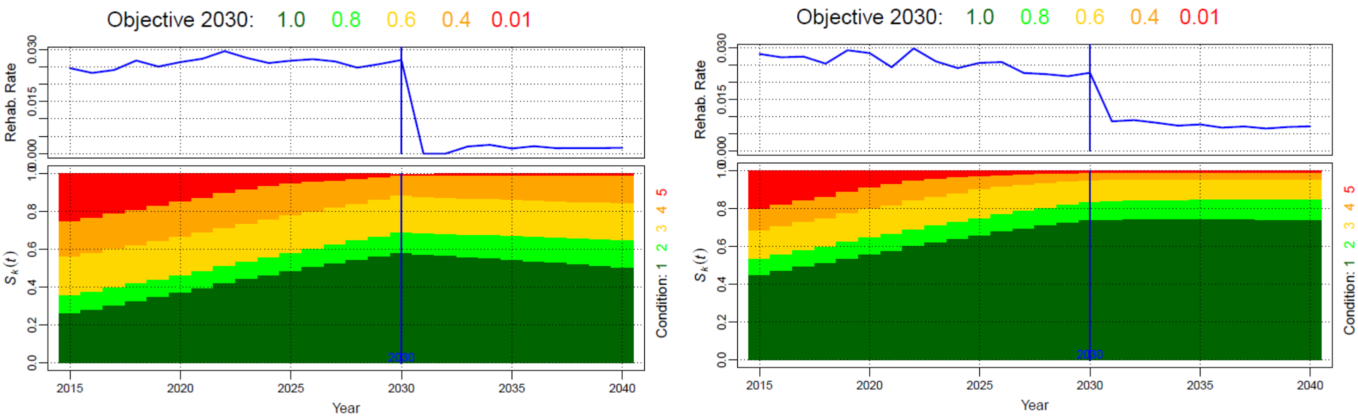



**Figure 5 Optimized scenario for 25 years prediction of the model "BET" and "ALL"**

Particularly useful information is provided for rehabilitation planning when the results of the inspections and of the predictions are visualized on a GIS platform (a map). The user can enjoy the benefit of visualizing the output of the different simulations and also of linking the level of deterioration of the pipes with the characteristics of the external environment (Figure 6).

**Figure 6 Visualization of pipes conditions with a GIS system (red = class 5, orange = class 4, yellow = class 3, dark green = class2, light green = class1)**

## 4.2 Planned activities to fulfill the objectives by the end of the project

The work plan to fulfil the objective of the WP1 includes:

By end of 2012
Complete the calibration of the dataset "ALL", this activity will include:
To refine the input data including pipes those after inspection have been rehabilitated
To run the final calibration

By end of January 2013:
Create input data files for inspected and non - inspected pipes (intense new data cleaning will be needed), grouped in the classes

- BETtot
- cBETtot
- Alltot

By mid-January
The international advisor will complete some programming issues especially related to the need to include into the model the real costs in use in Oslo VAV.

By March 2013:
The focus from January will be on predicting the future system conditions as effect of selected rehabilitation options. The activity will include:

- Selection of the prediction period and strategy (VAV)
- Run the simulations
- Present the result.

# 5 WORK PROGRESS AND ACHIEVEMENTS IN WP3/WP4 – WIRELESS COMMUNICATION AND INFORMATION SECURITY

The tasks to be fulfilled by WP 3 and 4 by the end of 2012 are listed in chapter 3.1.1.
The work flow is proceeding as planned and no major deviations are higlighted.
An overview of the research work is provide in the following chapters.

## 5.1 Work progress and achievements as for now

The overall objectives according to the revised project plan for 2012 are threefold:

- Pilot selection – select one pilot for wireless communication (Task 3.0)
- Pilot installation with appropriate wireless technology (Tasks 3.2 – 3.4)
- Security requirements study (Task 4.1 A)[1]

Note: As there are important security aspects within the two first activities ("Pilot selection" and "Pilot installation") the Security requirements study (Task 4.1 A) has been integrated into these activities for the first year of the project.

### 5.1.1 Pilot selection

The WP3-4 activity started with identifying application areas within Oslo VAV that may benefit from wireless communication.

At the start of the project, four areas with possible benefit for wireless technologies were considered:

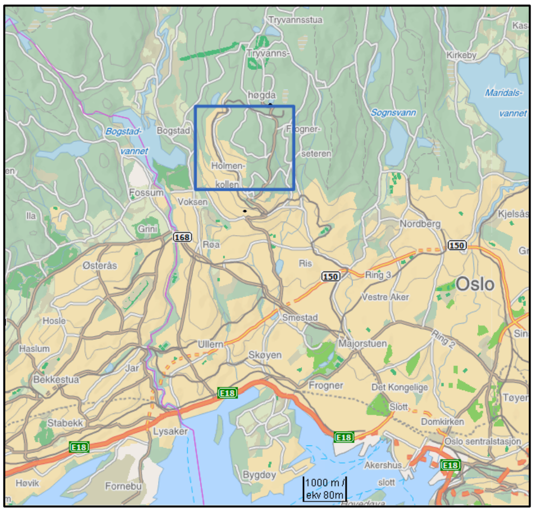
- Oset water treatment plant
- Voksenlia pumping station and Voksenåsen water tank
- Monitoring of wastewater tunnels
- Bekkelaget wastewater treatment plant

**Oset water treatment plant**
The new Oset water treatment plant was completed in 2008, and provides about 90 % of Oslo's population with water. It consists of two separate water treatment facilities, and has a total capacity of 390 000 $m^3$ per day.

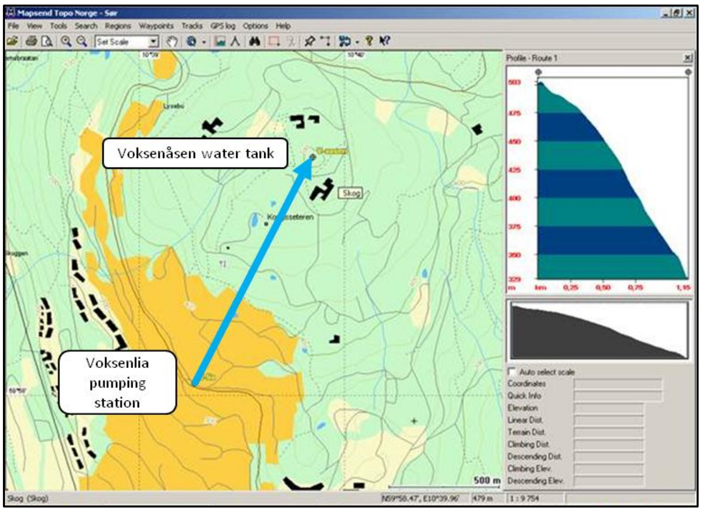
During the project activity, the plant was analyzed in order to identify whether wireless technologies could be beneficial for retrofitting with new sensors or when installing temporary measurement points. In both cases wired sensors seemed to be beneficial over wireless ones, as there already exists a wired infrastructure at the plant. Also, as introducing wireless systems would increase complexity without bringing any substantial benefits, no immediate uses of wireless technologies were identified.

**Voksenlia pumping station and Voksenåsen water tank**
In order to secure a stable water supply for Oslo's population, the Oslo municipality has established 18 water tanks. One of these is the Voksenåsen water tank, receiving water from the Voksenlia pumping station (see Figure 7).

[11] A first draft security checklist is presented in Appendix A.2.




Map data: Norkart (kart.finn.no)




Source: Vann- og avløpsetaten i Oslo

**Figure 7. Voksenlia pumping station and Voksenåsen water tank**

The pumps at Voksenlia pumping station are controlled based on the water level at Voksenåsen water tank. Today the water level information is transmitted either via the Oslo VAV remote control system, with a direct wired communication link (made by copper) as backup. *The latter link is however very unstable, making this a relevant case by replacing an unreliable wired link with a more reliable wireless link.*

**Sewer tunnel**

The Oslo wastewater infrastructure consists of about 2220 km of wastewater pipes and 33 km wastewater tunnels. There is a need for reliable data with regard to level and velocity of wastewater transport in the tunnels, but there seems to be some challenges with acquiring these data. The project has not yet identified whether the problem lies in the sensor readings or the communication infrastructure, but aims to complete this analysis by the end of 2012.

**Bekkelaget wastewater treatment plant**

The Bekkelaget wastewater treatment plant is one of two wastewater treatments plant in Oslo, and it receives wastewater from Oslo East, Oppegård and Nittedal.

The following three topics might be relevant for the SMS VAV project:

- The Bekkelaget wastewater plant is planned to be extended in order to increase its capacity. When making changes to existing facilities that already are in service, extra care is needed to avoid introducing errors that will reduce the current service level. In such cases a wireless infrastructure will potentially be more resilient and robust than a wired infrastructure.
- In order to increase the probability of detecting unfortunate incidents, one might consider introducing a redundant set of sensors at critical measurement point. If these extra sensors are wireless, they could also provide a redundant infrastructure.
- There are some indications that process information security is not fully adressed at the Bekklaget wastewater plant. An internal Oslo VAV process has been carried out to deal with this issue.

**Significant results**

The Voksenlia-Voksenåsen case was selected for a pilot installation, as this case demonstrated an immediate need for a new communication solution between the water tank and the pumping station. There also seems to be other areas where wireless technologies could be beneficial, and these will be further analyzed until the end of 2012.

### 5.1.2 Pilot installation with appropriate wireless technology

The objective of the pilot installation has been to establish a wireless link between the Voksenåsen water tank and the Voksenlia pumping station, enabling Oslo VAV to maintain an appropriate water tank level even though the main control system should temporarily fail.

**Requirements specification**
The overall requirements were defined as follows:

- The wireless solution should:
  - not require any third-party infrastructure
  - provide appropriate encryption
  - have a range of at least 1,5 km
  - not require line-of-sight between transmitter and receiver
  - be able to transmit analogue sensor values conforming to 4-20 mA
- The transmitter unit should:
  - be able to run on batteries
- The receiver unit should:
  - be able to detect and report when failing to receive data
  - be able to receive data from several transmitter units

**Technology selection**
Based on both the requirement specification and product availability, the radio ELPRO 105-U (see Figure 8) was selected for the pilot. Strictly speaking, this radio is not conforming to all the requirements, as it is not designed to run on batteries. Also, its encryption level is below than what is considered state-of-the-art in 2012 (see Appendix A.3). However, these drawbacks were considered as acceptable for the pilot, as long as they are treated with appropriate consideration.

**Figure 8. ELPRO 105-U**

**Pilot installation and evaluation**
The pilot will be installed at Voksenlia/Voksenkollen by November/December 2012. Preliminary laboratory tests indicate that it should work adequately.

## 5.2 Planned activities to fulfill the objectives by the end of the project

The following activities are planned to run until end of 2012:

- Complete report on Pilot selection
- Complete Pilot installation and Pilot experience report

# 6 WORK PROGRESS AND ACHIEVEMENTS IN WP5 – CONDITION MONITORING, PROCESS CONTROL AND MODEL BASED MEASUREMENTS

The tasks to be fulfilled by WP 5 by the end of 2012 are listed in chapter 3.1.1.
The work flow is proceeding as planned and not major deviations are higlighted.
An overview of the research work is provide in the following chapters.

## 6.1 Work progress and achievements as for now

### 6.1.1 Main Objectives

The main objectives in WP 5 is to evaluate how to extract and use data for generation of condition monitoring information to detect equipment and component degradation at an early stage.

The activities planned and performed in 2012 in order to achieve the objectives are presented in the following chapters.

### 6.1.2 Task 5.1 - Feasibility study

The feasibility study was performed in the wastewater pumping station of Frognerparken in Oslo.
Based on the report "Feiltreanalyse for Frognerparken avløpspumpestasjon " by Ugarelli et al. (2010), that refers to a fault analysis of a wastewater pumping station, some initial brainstorming about the technical solution was produced in order to identify the potential system fault modes. The analysis looked at answering specific questions also with the collaboration of VAV personnel.
**Progress: 90 %**

### 6.1.3 Task 5.2 - Condition monitoring function specification

The following ideas and principles for condition monitoring were presented to the Oslo personnel (16 of November 2012):

- Aggregate condition information to determine overall condition "at a glance"
- Provide information drill down capabilities
- Example tool: TeCoMan from Marintek.

The selected case "Frognerparken avløpspumpestasjon" was presented as example of use of the condition monitoring ideas, including the presentation of a way to aggregate information from each critical component (pump, PLS, electrical power supply) and get immediate understanding of the overall system status. At each level a green, yellow or red light can be used to indicate level of failure or degradation.

This exercise can be performed in other locations/cases as well. This is supposed as an activity for next year.
**Progress: 90 %.**

### 6.1.4 Task 5.3 - Prototype implementation of core algorithms

There are different methods for detecting failures and degradation:

1. Model based estimation – Kalman filtering (augmented with unknown parameters) using first principles models, but often simplified.
2. Signal processing
3. Statistics
4. Voting

For the selected case "Frognerparken avløpspumpestasjon" including 6 pumps in parallel, the model based estimation (extended Kalman-filter) was used to estimate unknown process parameters using available measurements. Since both the response and final temperature in the bearings will be different for Pump #1 and Pump #4, it is possible to detect failures/malfunction even if absolute temperature limits are not reached. The extended Kalman-filter will detect deviation in the dynamic response during heating and cooling phase.
Other algorithms can be used for other cases. Each case must be evaluated to find the suitable algorithms for failure and degradation detection.
**Progress: 80 %.**

### 6.1.5 Requirement for industrial solution

As presented at the workshop in Oslo (16 November 2012), SINTEF ICT proposed to use the "use case"-technology to describe what information shall be available for which user(s). The use case consists of different written scenarios that will be a good starting point to make a requirement specification of an industrial solution. The "use case" exercise must be done in cooperation with the users (VAV-owner and/or VEAS- operator) to have a common understanding what is expected to be the end result.

Based on the required information needed from the "use-case" study versus available information we already have, then the requirement specification can be finalized.
**Progress: 50 %.**

## 6.2 Planned activities to fulfill the objectives by the end of the project

The activities to be planned in order to fulfil the objective of WP5 include the full definition of the use-cases with the operator and owner.

Link the research performed in WP5 also with WP3 and 4.

Investigate other pumping stations in Oslo (both water and wastewater), as for instance the high pressure drinking water pumping station from Oset to Årvoll.

# 7 CONCLUSIONS

This report summarises the goals, results achieved and deviations from the plan of the SMS from OSLO VAV project after 8 months of activity. Technical details are not included in this report, but will be provided if requested.

The project SMS from OSLO VAV aims to improve the efficiency and the security in monitoring and control of the urban water and wastewater system of Oslo Vann og Avløp (VAV).

The first period of the project focused on the first work package (WP1) aiming at providing *Oslo Vann og Avløp* (VAV) with the analysis of current and future level of deterioration of the wastewater pipes and the estimation of the resources required to improve the system conditions with rehabilitation actions (both information are important for master planning (*hovedplan*) and for rehabilitation schemes (*saneringsplan*)).
This work package has also highlighted a major issue in the Norwegian standard (Norsk Vann) used to classify pipes from visual inspection. The problem consists on the standard being too pessimistic in the pipe classification leading to a much more negative figure of the overall network need for rehabilitation that it is in reality. By classifying the pipes as much more close to collapse than thy actually are, brings also to a too high estimation of the investment needs for rehabilitation plans. One result of the first year of the WP1 is to recommend a revision of this standard and a dialogue has already started with Norsk Vann. This result is relevant for the whole water industry in Norway, given that most of the Norwegian water utilities bases the rehabilitation scenarios on calculations made by using those standard. The results from WP1 will be presented in January 2013 in Trondheim at the national conference – Kursdagene organised by Tekna. The presentation will be held as a duet/dialog presentation by representative from both SINTEF and VAV, inspired by the good working atmosphere in the SMS for VAV project.

The research activity performed until now by WP3 dealt with a feasibility analysis of new wireless communication technology for monitoring and control of the *Voksenlia water tank* and *Voksenåsen pumping station* including the identification of a wireless technology that will be further evaluated both by technical studies and field tests.

For the same pilot the improvement of the security of interconnected process control systems with carefully designed security architecture is the current focus for WP4.

"Frognerparken wastewater pumping station" has been the pilot for WP5 until now. The experience has demonstrated how to extract and use data collected by the process data for generation of condition monitoring information to detect equipment and component degradation at an early stage.

The project work is overall well on track. A main challenge, however, is related to the quality of the information system and data to be used in WP1, and the selection of the case studies for WP3-4-5 took longer time than expected, however the research activity is now in line with the plan.

The project team has been very active during the first 8 month and collaboration has been very good, as also confirmed via letter by the Oslo VAV (*Kari Elisabeth Fagernæs, Avdelingsdirektør and Arnhild Krogh, seksjonsleder):*
*"Oslo Water and Sewerage Works (VAV) as end user and partner in the project "Secure and monitored service from VAV" are satisfied with the work carried out by SINTEF in this project.*
***VAV are revising the master plan for waste water and water environment and the results from WP1 and WP2 in this project will be useful in calculating the investments needed in the future for the waste water***

***network if we proceed with the project.*** *Also for WP3 Wireless communications we have had good results and are satisfied with the results so far.*
*The collaboration between the partners has been good and the discussions in the workshops have been constructive and interesting for VAV personnel."*

The project from year 2 will develop a strategic plan for involvement of industries to implement the projects results. SINTEF and VAV have identified together a list of industries that will be involved in the SMS for VAV project from 2013, to ensure cooperation in the territory between VAV and companies and to create market opportunities thanks to the project. The strategic plan will consist on defining when and how to integrate one or more of the companies and then update the partner agreement.

The interactions and the dialogue established between the project participants in the different WPs have also highlighted the possibility to link the findings and to test alternative methods instead of using the traditional ones. For instance, we would like to investigate if the stochastic approach used in WP1 for pipes can be applied to manholes.

Or the risk analysis planned for WP2 could also include those manholes in which the pipes of clean drinking water are installed just beside the pipes of sewer/wastewater.

Or what about planning investment needs for system equipments as pumps, predicting the deterioration process with the WP5 algorithms? Can the work presented for WP5 be used to support the investment plan/Master plan/Rehab plan?

Can the finding of WP5 may be useful case input to WPs 3 and 4 aiming at finding good cases for remote, wireless monitoring?

At the beginning of year 2, we will also start the WA6 dealing with workshops to be organized at VAV.

After the first 8 months of project we identified the benefits of arranging 3 specific workshops:

1) A creative workshop for a wider SINTEF and VAV group, not only personnel involved in SMS for VAV. The aim of the workshop will be in generating ideas based on VAV needs by merging research expertise from different background (material and chemistry, water engineers and ICT scientists)!
2) Looking at the whole flow from data to master plan, we want to identify where the weak points for uncertainty are and create expert groups in Oslo VAV that, by collaborating, can reduce the uncertainty that propagates from data to the master plan. We would like to organize one workshop for each weak point where experts in VAV also external to the SMS project are invited. The goal of these series of workshops is to facilitate the improvement of the data quality towards condition monitoring.
3) One example of course highly needed for the water industry is IT security and SCADA systems. Knowledge and experience from other sectors which are at a more advanced stage (e.g. oil and gas, electricity) might be relevant to include. To ensure that the proposed security solutions reflect the needs of VAV, combined training and requirements elicitation workshops will be organized with key VAV personnel. These workshops will help increase information security awareness, and will later in the project also provide an opportunity to pre-test solutions with respect to acceptability and benefit.

# 8 REFERENCES


Le Gat, Y. 2008. Modelling the deterioration process of drainage pipelines. Urban Water Journal, 5, 10.

RIF, 2010. Norwegian Association for chartered engineers 2010; State of the nation, a report on Norwegian public infrastructure.

Ugarelli, R., Selseth, I. and Røstum J. (2010). Feiltreanalyse for Frognerparken avløpspumpestasjon. SINTEF rapport: SBF IN F10313.

# A APPENDIX

## A.1 Security requirements

The following is a draft checklist that can be used as a basis for security requirements in Oslo VAV:

- Is information security in process control systems sufficiently anchored in VAV management?
- Is information security awareness implemented throughout the organization?
- Are personal user name and passwords used to logon to all process control systems?
- Is there two-factor authentication for remote access to process control systems (VPN, terminal server)?
- Are there procedures for authorization control (joining, leaving, changing jobs)?
- Has there been performed a risk analysis covering remote administration (from home) of process control systems?
- Are there separate PCs, tablets etc which are used only for maintenance and remote operation of process control systems?
- Have technical measures been implemented to ensure security of such equipment (restrictions on program selection, no access to the internet other than process control systems)?
- Have different levels of access rights (access, modification) been specified for remote operation?
- Has separation or alternatively security barriers between the administrative and process control systems network been considered?
- Has separation or alternatively security barriers between the process control systems network and the internet been considered?
- Has VAV ranked the criticality / importance of the various field stations / VA systems?
- Are there separate process control systems networks for water and wastewater, respectively (Zone partitioning)?
- Is geographical partitioning of the process control systems network performed?
- Is it possible to access other parts of process control systems from any out-station?
- Is there a system for recording security incidents and deviations?
- Is there a system for recording incidents and deviations (failures) for process control systems?
- Are there written procedures for handling incidents and deviations in process control systems?
- Is it easy for intruders to gain access to information about the geographical location of VA infrastructure?
- Have a redundancy of critical systems / components ensured (two servers, communications, power supplies, computer)?
- Are there any plants that cannot be operated in manual mode when you lose contact with out-stations (water treatment)
- Are there arrangements for information security toward external service providers?
- Are there systems for intrusion detection (IDS)?
- Has VAV conducted an analysis of process control systems links with other systems (Internet, administrative system etc) that might pose a danger?
- Do contingency plans also cover process control systems events?
- Has the contingency plan been updated during the last year?
- Is there adequate perimeter protection of VAV infrastructure so that it is not too easy to get physical access to infrastructure?
- Is the physical security of VAV facilities commensurate with their importance?
- Are there routines to ensure adequate training and retraining of personnel in information security?

- Are there periodic risk analysis in VAV that adequately covers information security and process control systems?
- Do VAV crisis exercises also cover ICT / process control systems events.
- Does VAV have sufficient in-house expertise in information security and process control systems, or are they totally dependent on vendors and consultants?
- Does VAV have an agreement covering a full backup of the configuration of all process control systems?
- Does the VA itself sufficient technical expertise for acquisitions of new process control systems?
- Are there stated requirements for uptime of process control systems?
- Are all system solutions and descriptions of process control systems well documented?
- Are periodic tests of DKS performed to check that the system works as intended?

## A.2 Security assessment of radio link

The security solution of the ELPRO 105-U device is described in a high-level manner in the user manual[2], but no details are given. The manual states that a 64-bit security key that can be used to encrypt data that is sent over the radio interface. The algorithm used is not specified, and also not which encryption mode is used (if the algorithm is a block cipher).

No modern encryption solutions today use less than 128-bit keys. There are also few examples of well-known older algorithms that use a 64-bit key; we can mention LOKI91 (considered "broken") and the stream cipher RC2 (also considered "broken"). The previously best-known algorithm, DES, had a key-size of 56 bit, and can today be cracked by exhaustive search in a matter of a few hours. As an aside, DES keys were usually stored as a 64-bit quantity, where every 8th bit was used for parity.

The time required to perform an exhaustive search on a 64-bit key for any given algorithm will be proportional with available computing power, and will thus be reduced for each passing year. We have no updated test results readily available, but even 12 years ago cryptographers[3] stated that a 64-bit algorithm would not have been secure after1992 (i.e. 20 years ago).

It is worrisome that no mechanisms for key administration have been specified; with such a short key it must be changed very frequently: and if this must be done manually, it will not be workable in practice.

[2] ELPRO 105U-3-LW439 user manual

[3] Arjen K. Lenstra1, Eric R. Verheul: "Selecting Cryptographic Key Sizes", http://www.win.tue.nl/~klenstra/key.pdf

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