

Rehabilitation of pipelines, an evaluation method with application to 3 trenchless technologies

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In the Netherlands the drinking water distribution network contributes to about 120.000 km underground pipelines. In the 1950's to the 1970's the network expanded rapidly due to the expansion of urbanized areas and connecting the rural areas. Many of these pipes are expected to be in need of replacement in the next decades.

Traditionally pipes are replaced by using open trenches. However, in the light of the increase in replacements this may change. To ensure current service levels, replacement techniques will have to be balanced for relevant elements such as effectiveness, nuisance to the environment and costs. Dutch drinking water companies want to know when to use which technique, but currently have too few experiences with trenchless techniques to allow for a detailed analysis. Experiences are usually limited to a few kilometers or locations that are not representative for larger parts of the network. In addition, each company evaluates projects differently and relevant aspects such as environmental impact or nuisance were difficult to quantify, making it difficult to compare experiences.

We developed an evaluation method for rehabilitation techniques for all relevant aspects in an asset management decision. This evaluation method quantifies these aspects as much as possible and allows for comparison between different techniques. The evaluation method was tried and tested on several pilot projects each with a different trenchless rehabilitation technique. Results from the pilots were used to improve the evaluation method.

This paper describes the evaluation method and the results of the pilot projects with the different techniques. In addition, we discuss current developments towards a knowledge base for comparing techniques for pipeline renovation or renewal.

1. Introduction

In the Netherlands the drinking water distribution network contributes to about 120.000 km underground pipelines. In the 1950's to the 1970's the network expanded rapidly due to the expansion of urbanized areas and connecting the rural areas. With an estimated average life time of around 70 years many of these pipes are expected to be in need of replacement in the next decades. This may lead to an increase in replacement activities, which in turn may lead to an increase in nuisance and costs. The drinking water companies want to ensure current service levels, both in terms of costs and nuisance, and are looking for alternatives to the traditional techniques.

In the Netherlands most pipes are traditionally replaced with an open cut approach. No-dig technologies are used sparsely and only in those situations where no other options exist. However, the country's urbanisation has grown significantly over the past decades [1]. At the same time, the use of the subsurface in the urbanized areas has increased. Cables, pipes from other utilities, aquifer thermal energy storage (ATES), parking garages etc. occupy more and more space. In addition, the traffic

intensity has increased. This results in more nuisance, costs and risks when applying an open cut approach.

Dutch drinking water companies want to know when to use which technique, but currently have too few experiences with trenchless techniques to allow for a detailed analysis. Experiences are usually limited to a few kilometers or locations that are not representative for larger parts of the network. In addition, each company evaluates projects differently and relevant aspects such as environmental impact or nuisance were difficult to quantify, making it difficult to compare experiences.

In 2015 WML, Brabant Water, Vitens, Heijmans, BAM Infra Energy & Water, and KWR started a project to provide insight in the applicability of trenchless technologies in the drinking water distribution networks. An important revenue of this project an evaluation method for rehabilitation techniques. This evaluation method was specifically designed to quantify aspects as costs, environmental impact and nuisance. During the project, the evaluation method was tried and tested for three pilot projects each with a different rehabilitation technique. The evaluation results were used to improve the evaluation method itself and to assess applicability of the different techniques in the drinking water network.

With this evaluation method we can for the first time compare projects with different techniques and drinking water companies. As such, we are now in a position to share and compare knowledge between the companies. The drinking water companies can include the knowledge in their decision support systems and base their decisions on transparent, uniform information, validated by science and practice.

2. Drinking water pipes in The Netherlands

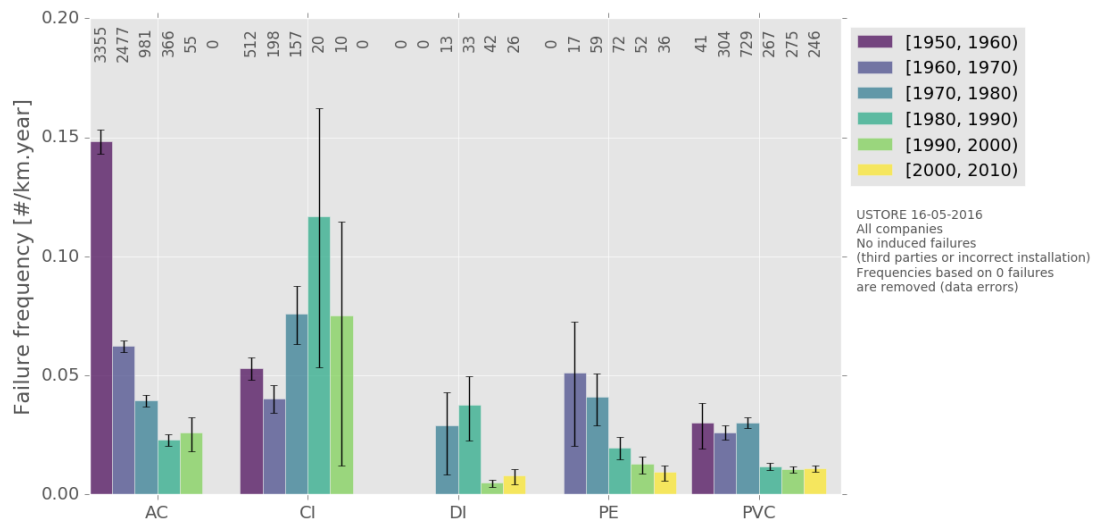
In the Netherlands, the drinking water distribution network comprises of approximately 120.000 km of pipelines [2]. This network consists of different diameters and materials of different ages. Until the 1950's the pipe material used was primarily cast iron (CI). During the 1950's asbestos cement (AC) rapidly took over the role of dominant material. Since 1993 the construction of new AC pipes is prohibited, since the 1990's the amount of AC is therefore steadily decreasing. From the early 1960's PVC entered the system. In the 1950's to 1970's the network expanded with 7 to 8% each year due to expansion of the urbanized areas and connecting the rural areas. Currently, there is an increasing role for materials as PVC and PE, and a decreasing role of AC and CI. However, AC still consists of around 30,000 km and CI around 9,000 km of pipes.

In the Netherlands 8 out of 10 drinking water companies register their failure data according to uniform standards in a central web based database (USTORE) [3]. The failure frequencies of the different materials as a function of the period of installation are shown in Figure 1. Clearly, AC and CI show on average higher failure frequencies. The early asbestos cement pipes tend to fail in higher numbers than the younger pipes. As most of the failing pipes are not repaired, but replaced in the Netherlands, the low failure rate of the old cast iron pipes is due to replacing the bad quality pipes in the total cohort cast iron. The focus on replacement in the Netherlands is therefore on old AC and CI pipes.

The two different materials suffer of different degradation processes. AC will lose its strength while CI tends to cause discolored water, reduced hydraulic capacity, local

leakages and loss of strength due to corrosion of the iron wall (in the case of uncoated CI or when the coating is in bad condition).

Figure 1 Failure frequencies of the different materials over the period of installation. The black line shows the error margin, based on the number of failures the analysis was based on compared to the total length of pipe for that material of that age. The numbers above the bars show the number of failures the analysis was based on.



3. Description of evaluation method

Within the project we developed an evaluation method and applied the method on three pilot projects with different rehabilitation techniques. In addition, two more pilots are currently being evaluated with the same method. The method was developed to evaluate all relevant aspects of pipeline rehabilitation and to quantify these aspects as much as possible.

Relevant aspects for evaluation of rehabilitation techniques are those aspects that play a role in asset management decisions. From literature review and the experiences of drinking water companies from the Netherlands and abroad, we concluded that the most relevant aspects are [4, 5, 6, 7, 8]:

- Technical aspects: is the technique performed to specifications and how complex is the techniques in practice?
- Process: how did the preparations compare to a traditional approach with open trenches? Did the technique solve the problem?
- Environment (nuisance, sustainability and safety):
- Costs: all direct investment and operational costs during the entire lifetime of the pipe and liner.

All techniques are compared with a traditional approach using an open cut approach.

We quantified all aspects as much as possible:

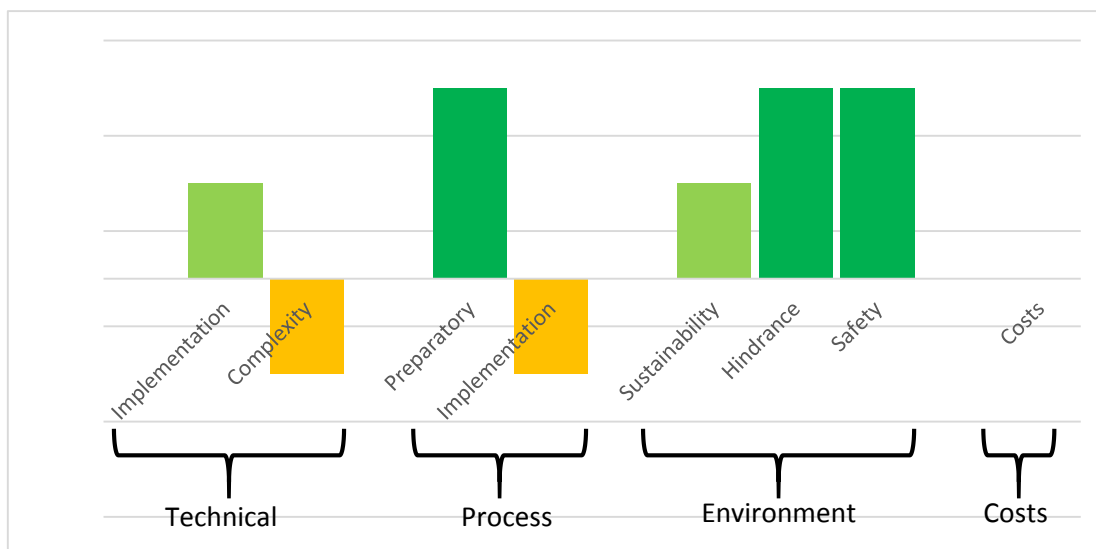
- Technical specifications are compared to the characteristics of the pilot site. Particularities are investigated.
- The decision to use which technique for the specific problem to be solved is analyzed and discussed.

- The sustainability is investigated with a generalized Life Cycle Analysis approach.
- Nuisance is quantified in terms of:
 - Accessibility of houses or commercial plots during the work;
 - Noise levels during a specified period and at certain times (i.e. working hours or day-round);
 - Visual nuisance by square meters and height of equipment;
 - Smell if relevant.
 - Safety:
 - Traffic measures during a specified period;
 - Vicinity of other utility pipes and cables;
 - Vicinity of objects that require caution, such as railroads, highways or monumental buildings.

In addition, a risk analysis is performed for all 4 aspects (technical, process, environmental and costs) using the experiences from the pilot projects and a literature review. Each risk is accompanied with the measures that are or can be taken as prevention or mitigation.

The experiences with individual pilots have shown that for a single pilot location a rating of environmental aspects and costs leads to unwanted results, because these elements are very much locally determined. Therefore, individual pilot locations were rated only for technical and process related aspects and analyzed, but not rated for environmental aspects and costs. The full rating is therefore only possible when evaluating several projects at once or for scenario calculations. The full rating is presented in an effect-diagram, with different colors representing performance. An example is shown in Figure 2.

Figure 2 Example of effect diagram, with red indicating the technique performs poor compared to a traditional open-cut approach, orange (moderate), yellow (equivalent), light green (reasonable) and dark green (much better).



3. Evaluation results for 3 pilot projects

During the project 3 pilots have already been evaluated, a fourth pilot is currently in the process of evaluation. In addition, an independent pilot of a fourth water company with pipe cracking is currently being evaluated with the same method. Within the

framework of this project, the following techniques were performed in a pilot, each with its own innovations and research required.

Hydrofit, Heijmans

This is a Cured in Place Pipe (CIPP) in which a resin impregnated liner (Figure 3) is pulled into a pipe after which the liner is cured using high temperatures that initiate and maintain a chemical reaction turning the liner and resin into a fully constructive new pipe. This type of trenchless technology is quite common in sewers since decades, but until recent no Dutch certified technology was available for drinking water. To obtain the required certification a new resin was developed that does not impact the drinking water quality and still maintains the required characteristics to ensure a strong liner.

The evaluation was carried out for the first pilot in an actual operational network in Sittard, Limburg (November, 2014). (<http://www.heijmans.nl/nl/nieuws/wereldprimeur-kousmethode-voor-ondergrondse-drinkwaterleidingsanering/>). Simultaneously tests were carried out for the best procedure to apply the liner (specifically use of a pressure vessel or water pressure) and possibilities to work without end-supports.

In the pilot project a section of 550 meters of 400 mm diameter AC pipe was rehabilitated. It's condition was estimated beforehand as in need of replacement. Condition assessment by means of a non-destructive assessment in combination with an exit assessment revealed that the pipe actually would have had a remaining service life of about 25-30 years.

Figure 1 Impregnating a liner with resin.



Compact Pipe, BAM

This is a close-fit technique in which a fully constructive, pre-folded PE-liner is pulled through an existing pipe and then reshaped back into its original shape. This technique was applied to a 300 mm CI pipe in Zwaagwesteinde (June 2016, Figure

4) (<http://nl.wavin.com/web/oplossingen/drinkwater/hoofdnetwerk/close-fit-lining-compact-pipe-3.htm>). The pipe is a bitumen coated CI pipe to ensure continuous supply in situations with increased demand or problems with the regular supply route. The water in this specific pipe remains still for extended periods of time. During these periods PAH's were released from the bitumen coating. To ensure water quality the pipe needs extensive flushing before operational use. The Compact Pipe should resolve this problem. A specific research question in this pilot concerned whether the permeable PE liner would sufficiently reduce the water quality problem.

Subline, BAM

This is a close-fit technique in which a semi-constructive, folded PE liner is pulled through an existing pipe. So far, only the preparatory stage of this technique was carried out and evaluated for a pilot to reinforce a PVC 500 mm pipe in Maarssebroek, The Netherlands. During this preparation the following questions were investigated:

- Required strength of the original PVC-pipe during the actual relining;
- The total strength of the PVC-pipe and liner after the works are complete.

Figure 2 Application of Compact Pipe in Zwaagwesteinde, Friesland.



Trenchless pipe removal, BAM

In this technique pipes are pulled out of the ground over lengths up to tens of meters from one pit. This technique had before been applied to steel pipes, but during this project the technique was redeveloped to pull AC pipes including the connections, which is a worldwide innovation. This technique is carried out in an area where the pipes were hard to reach due to above-ground obstacles, for example trees. Prototyping has taken place in 2015 and a pilot has successfully removed pipes in 2016. This pilot is currently being evaluated. A specific research question is how much pulling force the ageing AC can endure against the various subsurface adhesive forces. This technique removes all the old building materials from the ground. On the location of the old pipe a completely new pipe can be installed.

6.1 Results of the generalized Life Cycle Analysis (LCA)

To assess and quantify the sustainability of different trenchless technologies compared to a traditional open-cut approach, we performed a generalized LCA (SimaPro 8.0/EcolInvent 3.0). A LCA determines sustainability of products in terms of Ecopoints and takes into account aspects as energy use, loss in biodiversity, toxicity, depletion of materials and acidification. As such, it is far more comprehensive than for example a CO₂ footprint, which only takes into account emissions.

A full LCA requires detailed information with knowledge on local circumstances. This information was not completely available for the pilot projects, so instead we have performed a generalized study to the most dominant elements governing sustainability from studies to applications of trenchless techniques in sewers [a. o. 9]. From this study was concluded that the most dominant elements governing sustainability are:

- Material of the liner or new pipe: we assumed that in most situations, an open cut approach uses PVC as material for the new pipe. Trenchless technologies most often use PE or in the case of CIPP glass-fiber or glass reinforced felt [8]. Of these materials PVC is the most sustainable material, with PE coming in at a close second and glass-fiber or felt last (especially the resin causes this material to be the least sustainable). Differences in sustainability compared to PVC depend on the diameter of the pipe, but range from differences of 24% (PE) to 440% in Ecopoints (glass reinforced felt) for a 100 mm diameter pipe to 27% (PE) to 28% (glass reinforced felt) for a 400 mm pipe. Differences are therefore smaller for larger pipes.
- Traffic diversions: We assumed that traffic diversions are usually related to an open-cut approach and are less or not needed in trenchless technologies. How much difference in sustainability results from having to use traffic diversions or not depends very much on the amount of vehicles involved, the length of the diversion and the type of vehicles involved (heavy traffic has more influence on sustainability than cars or scooters). We used examples of 100 meters pipe replacement and different traffic diversions to estimate the potential. The conclusion is that when there are substantial traffic diversions (hundreds of vehicles or more over distances of 1 km or more) especially in areas with a lot of heavy traffic, the effects on sustainability are potentially as large or much larger than the effect of material use.
- Uncertainties in service life of a product. We assumed in the analyses that each product has a similar service life. Actual service life varies greatly and is dependent on materials, but also on local circumstances, such as the soil composition and groundwater, local loads and water quality. Therefore, any calculation should be regarded as providing insight in the order of magnitude of specific aspects, but no more specific than that.

Compared to an approach using CO₂ footprints only, the CO₂ footprint method overestimates the sustainability effects of traffic diversions and digging as only emissions are taken into account.

6.2 Evaluation results Hydrofit [10]

Technical aspects

During this pilot Hydrofit showed its ability to rehabilitate an AC pipe and produce a fully operational drinking water pipe.

Results from this pilot showed the importance of applying continuous pressure throughout the application and curing procedure. In one section, the pressure dropped during the insertion of the liner resulting in displacement of the resin. The resulting liner was deemed insufficiently strong. As a result the procedure has been set to using scaffolding to maintain a continuous water pressure rather than relying on pressure vessels.

The option to work without end-supports required the development of new connections allowing for connection of liners and pipes using less force. This reduces the possibility of damaging the liner.

Process

The preparation for rehabilitation using Hydrofit is in general less complex and time-consuming than using a traditional open-cut approach. There is less need for digging and nuisance measures, which reduces the number and complexity of permits.

The implementation is more complex than a traditional open-cut approach, because of the specialized nature of the works. Several companies work together, which requires precise procedures and communication. The companies have prevented risks arising from this complexity by having strict working procedures in which the communication is documented in progress reports.

Environment

For the pilot site nuisance was no actual problem in absence of houses, commercial centers, roads etc. However, the analysis did show that trenchless techniques do have a potential to reduce nuisance when these elements are present. This depends very much on local circumstances. This has to be evaluated locally per technique.

Costs

Costs were not determined for this pilot. During the pilot many innovations and working procedures were tested and evaluated, making it too difficult to deduce the actual operational costs and compare it against a standard open-cut approach.

6.3 Evaluation results Compact Pipe [11]

Technical aspects

The application of Compact Pipe showed that the technique can successfully rehabilitate operational drinking water pipes.

We concluded that the liner would solve most of the problems of PAH's by isolating the coating from the drinking water. Only the permeation of PAH's through the liner itself cannot be excluded, but will most likely be slow and of a small magnitude [12]. It is advised to flush the pipe before using the pipe for water supply, but this is already standard procedure and does not require the amount of flushing as in the original situation.

Particularities of the Compact Pipe pilot included:

- Location on private property;
- Proximity of a high-pressure gas pipe and proximity of the private property to the working pit;
- Railroad-crossing.

Process

In general the preparation stage for Compact Pipe is less complex and time-

consuming for the same reason as Hydrofit, namely the reduced number and complexity of permits. The implementation is more complex than a traditional open cut approach, due to the specialized nature of the works.

The proximity of the high-pressure gas pipe led to delay of the works, indicating the importance of the reliability of data. Test trenches were dug beforehand, but these did not show the location of the pipes also with respect to the property with enough precision to judge that this would not be a problem in the working pits. This however is of general concern for any replacement or renovation technique, including an open-cut approach and not distinctive for trenchless technologies.

The railroad crossing was not a problem, the licensee was informed and agreed with the approach.

Environment

The location on private property was handled with communication measures both from the drinking water company and the contractor. The owner was fully satisfied with the proceedings.

The location was not vulnerable for nuisance or traffic.

Costs

Costs were not part of the assessment which technique to use for this pilot location and were left out of the evaluation.

6.4 Evaluation results Subline

Technical aspects

While a pipe remains pressurized PVC derives strength from its round shape (rerounding effect). Once the pressure of the water is removed, this increases the tension in the PVC, making the pipe more vulnerable to loads from for example traffic, but also the works themselves. After the works during a certain period (at least order of magnitude of weeks) the liner expands to fit with the original PVC pipe, which means that the original PVC pipe still shows this reduced strength as the rerounding effect is not present during this time. After this period of expanding, the total strength of PVC pipe and liner combined can be calculated by assuming that loads are carried proportionally to their flexural rigidities by PVC pipe and liner. Depending on the thickness of the liner, the total combination is then stronger than the original PVC pipe alone.

To make sure that the resulting liner PVC combination has the required strength it is very important to have information on the actual remaining strength of the PVC pipe. This strength however, is often poorly known and requires tests on the resistance to slow crack propagation on a removed pipe segment.

We conclude that:

- it is advisable to test a pipe segment for its resistance to slow crack propagation before application to make sure the liner-PVC combination has the required strength.
- due to the removal of the rerounding effect, it is important both during works and the period in which the liner expands to fit with the original pipe to limit the loads (for example traffic).

Process

The preparations for Subline are in general less complex and time-consuming than for a traditional open-cut approach, because of the reduced number and complexity of permits.

Environment

The environmental aspects were not evaluated as the pilot was only prepared, not (yet) carried out. The expectation is that Subline will give less nuisance to traffic, because of the proximity to a busy asphalt road. The nuisance because of sound levels and visual nuisance will be of less importance, because of the lack of proximity to houses.

Costs

The costs were not evaluated as the pilot was only prepared, not carried out.

7. Applicability to drinking water distribution pipes

Techniques with liners which require activities to acquire the required strength or shape are more complex to apply than a traditional open-cut approach or a trenchless slip-lining approach. If the likelihood of failure to achieve the required strength is as low as from a prefabricated pipe, the effect of this failure is much larger. A failed pipe from a factory can be immediately replaced, while a failed liner is already in position in the subsurface. The execution requires trained staff and the techniques cannot be performed by any contractor or the drinking water company itself. This is not a problem as long as attention is given to

- communication between all parties involved;
- reliability of information on local network and site specific conditions (such as the occurrence of repair sections with different diameters or materials, vicinity of utility cables and pipes, remaining strength of host pipe, groundwater levels, existing contaminations). This demands accuracy of data from both drinking water companies and appropriate local preliminary inquiries.

Of course, some of this information is also of importance to an open-cut approach, but often this is less critical for the success of the renewal.

Trenchless technologies have a great potential in reducing nuisance in areas busy with traffic, commercial centers, historical buildings, valuable trees etc. For pipes that are located deeply below the surface trenchless technologies provide a means to greatly reduce digging costs. The same goes for pipes beneath paved roads. In the case of soil and groundwater contaminations trenchless technologies are able to work more around the contaminated areas reducing the need for digging in contaminated soils.

There are a few areas in which care is required (specifically for the application of PE liners and CIPP as these are the only techniques evaluated for this paper):

- We advise against using PE liners in areas with groundwater contaminations as this contamination has the potential to permeate into the drinking water in case of leakage of the original pipe. This means that not only at the actual location of the liner there should not be any contaminations, also in the surrounding areas as penetrating groundwater has the ability to travel along the pipe.

- When using semi-structural liners, it is very important to make sure that the liner provides enough strength to make sure the liner-pipe combination can withstand the applied loads.
- Any trenchless technique that requires working without water pressure In the pipes should be handled with care when applied to PVC pipes:
 - During the works the absence of the rerounding effect makes the pipe more vulnerable to loads (for example from traffic, but also the work itself and equipment used on-site
 - In the case of PE liners, after the works there may be a period in which the liner has not fully expanded. During this period it is important to limit the applied loads.
- It is important to make sure the water coming from a CIPP pipe (Hydrofit) does not contain any chemical residues from excess resin [13] especially when this water is directly released to surface water or sewers.

8. Conclusions

During this project we developed an extensive evaluation method which has been applied to several pilots with trenchless technologies. The results show that the evaluation method is able to evaluate individual pilot projects and can be used to compare different trenchless techniques for comparable circumstances. The evaluation results allow for a review of the method to decrease the complexity, providing easier and faster application.

We are currently setting up a knowledge base in which large numbers of projects and techniques are evaluated and compared using the reviewed evaluation method. When more pilots become available for single techniques, the full rating can be applied which gives the possibility to include ratings on nuisance and costs. The goal for the knowledge base is that users can filter for relevant local circumstances and get an overview of the possible techniques complete with advantages and disadvantages, costs and individual experiences of other users. We also include a discussion forum to get into contact with other users.

This evaluation method is currently used for applications in the drinking water sector, but is equally applicable for projects with trenchless technologies in other infrastructure sectors, such as waste water or gas pipes.

9. Acknowledgements

This project was funded by the Dutch government within the policy on “topsectoren”. In the Netherlands the government stimulates the development and implementation of innovations in the so called “topsectors”, acknowledged areas of expertise. For each of these topsectors consortia consisting of private companies, knowledge institutes and end users work together to generate innovations (TKI: (<http://www.tkiwatertechnologie.nl>)).

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