The influence of subsurface heat sources on the drinking water temperature

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Sam van der Zwan (Deltares)
Mirjam Blokker (KWR)
Claudia Agudelo-Vera (KWR)
David Nugroho (Deltares)

Deltares

Title
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Keywords
Drinking water, temperature, district heating

Summary
This report summarizes the research which has been performed to determine a recommended distance between drinking water pipelines and heat sources in the subsurface.

In the research a coupling of 4 different models has been performed to come to a recommended distance between the subsurface heat sources and drinking water pipelines. These models were:

1 1D soil model in the vertical
2 2D soil model in a vertical plane in the soil
3 2D drinking water model, along the pipeline taking into account a small section of the soil around it.
4 1D drinking water distribution model along the pipelines.

The results of these coupled models could not be validated yet with measurement data. Therefore, it was not yet possible to give a recommended distance between the drinking water pipeline and the subsurface heat source. This will be investigated in future research.

References
TKI

Version	Date	Author	Initials	Review	Initials	Approval	Initials
2.0	Feb 2020	Sam van der Zwan Claudia Agudelo-Vera David Nugroho		Mirjam Blokker		Bas van Vossen	

Status
final

Contents

1 Preface

This report provides the results of the research project into the influence of sub surface heat sources on the drinking water temperature. This research has been funded by the Raad voor ondernemend Nederland (RVO) under the Topsectoren voor kennis en inovatie (TKI) program Water Technology. The research proposal can be found in Appendix A. The following parties contributed to this research:

- Waternet
- PWN
- Oasen
- WMD
- Evides
- Dunea
- Energie Nederland
- Alliander

The research has been performed by Deltares and KWR. This report first describes the background and main research question. Then the approach is explained. The main results are summarized, detailed results can be found in the appendices the memo reporting the results of the different work packages which have been sent to the participants.
This report is written in English for consistency with the previously reported work.

2 Background

The reduce the effect of climate changes CO_2 emissions need to be reduced. To do this an energy transition is required. Other source of energy need to be used, like geothermal wells, solar power, wind power etc. This also required more energy to be transported from the sources to users. This will result in more heat sources (district heating, higher capacity electricity cables) in the subsurface. This will lead to an increased temperature of the subsurface. Consequently, this might lead to an increase of the drinking water temperature. In order to be able to control the influence of district heating networks and electricity cables in the soil on the drinking water temperature, the question was raised what the minimum recommended distance should be between a drinking water pipeline and a source of heat in the subsurface. Since this is a very wide topic this research is limited to a source (district heating system or electricity cable) which runs parallel to a drinking water pipeline. Furthermore, climate change influences have not been researched, this has already been done in the following work:

1. Agudelo-Vera, C. M., Blokker, E. J. M., van der Wielen, P. W. J. J. en Raterman, B. (2015). "Drinking water temperature in future urban areas." *BTO 2015.012*, KWR, Nieuwegein.
2. Agudelo-Vera, C. M. en Fujita, Y. (2017). "Hotspots in het leidingnet " *BTO 2017.023*, KWR, Nieuwegein.
3. Agudelo-Vera, C. M. (2018). "Aanpak om de hotspots in het leidingnet terug te dringen " *BTO 2018.024*, KWR, Nieuwegein.

3 Approach

To answer the research question, a simulation model was developed. This model also needs to be validated against measurement data. Development of a fully coupled model, which takes into account above ground influences and the subsurface heat source to calculate the drinking water temperature would be too costly. Therefore, it was decided to use existing models, extend them and couple them offline, validate these coupled models to try and answer the research question.
The aim was to simulate what the drinking water temperature in a city is going to be when there is a district heating pipe network (or electricity cable network) next to the drinking water network. This can be done with the KWR drinking water temperature model created in EPANET MSX, see Figure 3.4.This model needs as input a.o. for every pipe a soil temperature and a thickness of the influential ground layer, for each scenario of the distance between the two networks. These input data result from a detailed drinking water temperature model, which subdivides every pipeline into elements and also subdivides the subsurface into elements, see Figure 3.3, so that it can calculate the drinking water temperature along the pipeline. The temperatures at the boundary of the subsurface region included in the 2D drinking water temperature model are the results of the 2D soil temperature model, see Figure 3.2. This 2D soil temperature model requires a boundary condition on the surface, and at both sides of the soil domain. For this the 1D soil temperature model developed by KWR was used. This is a micrometeorology model that calculates the subsurface temperature based upon above ground parameters, like surface coverage, building level, solar influx etc. and soil parameters.

Summarizing, to simulate the drinking water temperature the following models are run successively:

1. 1D Soil temperature model taking into account above ground influences as well as soil parameters, Figure 3.1. This model is in the vertical direction from the surface into the soil.
2. 2D soil temperature model using 1D model as boundary condition, Figure 3.2. The model is in a vertical plane in the soil.
3. 2D drinking water temperature model using 2D subsurface model as boundary, Figure 3.3. This model is along the pipeline and at every element of the pipe it takes into account a small part of the soil surrounding the pipe
4. Simplify the 2D drinking water temperature model results to a 1D drinking water temperature model. The direction of the 1D drinking water model is along the pipeline.
5. City drinking water distribution network model using results of 1D drinking water temperature model as input parameters, Figure 3.4.

The work was split into the following work packages

1. Development of the 2D soil temperature model (in Plaxis) and comparison of the 1D soil temperature model with the 2D soil temperature model.
2. Sensitivity analysis of the 2D soil temperature model.
3. Development of the 2D drinking water temperature model (in Wanda) and sensitivity analysis with the 2D drinking water temperature model. Simplifying this model to a 1D drinking water temperature model.
4. Validation of the models.
5. Simulating the influence of a heat source for an entire city.

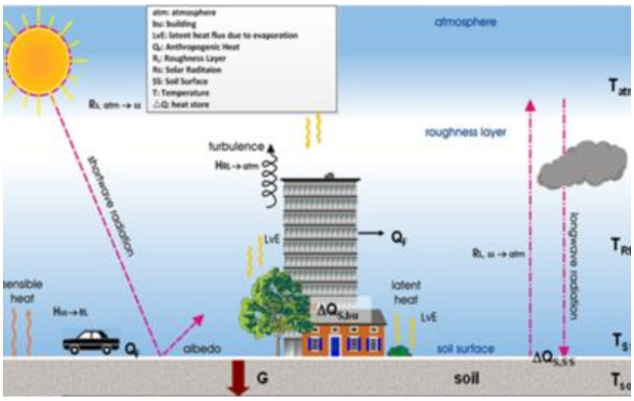

Figure 3.1 Overview of the 1D Subsurface temperature model

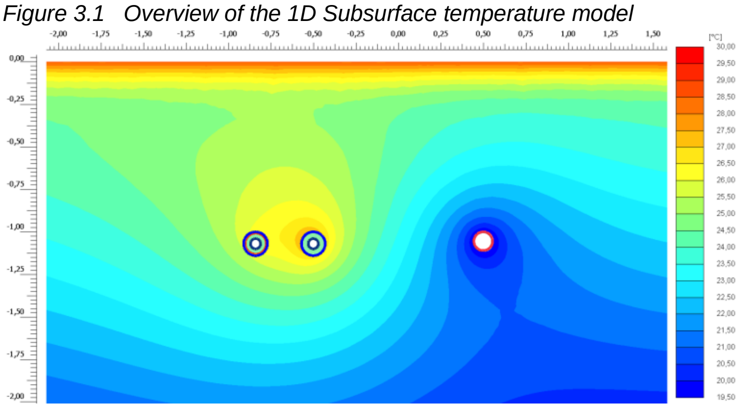

Figure 3.2 Example of results of the subsurface temperature model

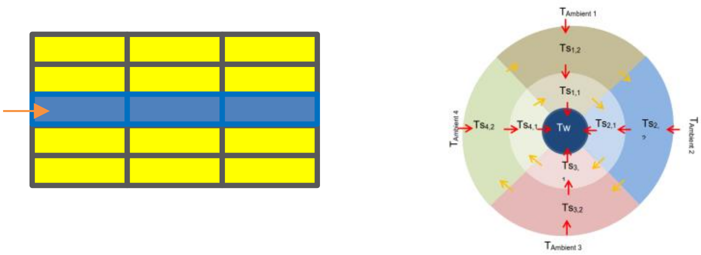

Figure 3.3 Overview of how the drinking water pipeline and subsurface are divided into elements (left) and section right

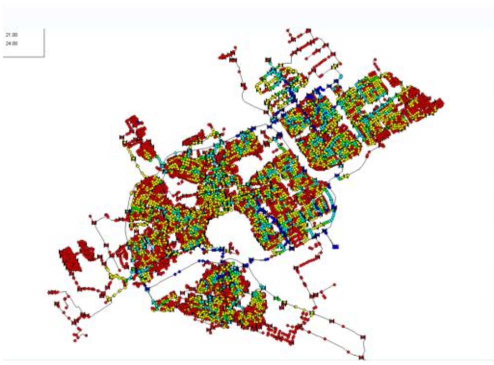

Figure 3.4 Overview of example results of the KWR drinking water temperature model

4 Results

The results of the different work packages are reported in memos and presented during the progress meetings. The memos and presentation are added as appendix to this report. The main findings are summarized in this section.

Work Package 1 2D soil temperature model
The memo's describing the results can be found in Appendix A. In this work package a comparison is made between the 1D and 2D model. This has been done the make a first validation of the 2D soil model. The main conclusions were:

1. The results of the 1D soil temperature model and the 2D soil temperature model match.
2. Plaxis can be used to model the thermal processes in the subsurface.

Work Package 2 Sensitivity analysis of the soil temperature model
The memo's describing the results can be found in Appendix A. For this work package, many parameters were varied to investigate the sensitivity of them on the soil temperatures. These parameters where chosen in cooperation with the project partners. Parameters investigated are a.o. soil properties, type of heat source (none, district heating system, electricity cable), ground coverage, burial depth of drinking water pipes, pipe diameters. The results have been used as boundary conditions for work package 3 in which the drinking water temperature is calculated.

Work Package 3 Sensitivity analysis of the drinking water temperature.
The memo describing the results can be found in appendix A. The soil temperature is used as boundary condition in a Wanda model which can simulate the drinking water temperature along the pipe. Al simulations were done for weather data of the year 2016. The maximum average soil temperature was used as boundary resulting in the highest possible drinking water temperature. The main finding for the scenarios investigated was:

1. the maximum temperature the drinking water can reach is limited by the soil temperature, which for the year 2016 in most scenarios was lower than 25^{o}C.
2. The residence time is the major factor which influences the drinking water temperature.
3. An electricity cable results in a smaller increase of the drinking water temperature than a district heating pipe parallel to the drinking water pipe.
4. A comparison between stationary (no variation in time) and transient (variation in time) simulation showed that the drinking water temperature might be determined based on the residence time in with stationary simulations. This needs to be verified with measurements.

TNO reviewed the different work packages see appendix A. Based on this review, and a comparison of the model results with results from previous projects, it was decided not to make a table with recommended distances. The main reasons for this are:

1. No measurement data available to validate the complete model train
2. The fixed drinking water temperature boundary in the 2D soil temperature modelling can lead to an underestimation of the soil temperature around the drinking water pipe.

To get an insight into the effect of item 2 some additional simulations were performed. The results can be found in Appendix A.The main conclusion is that the fixed drinking water temperature boundary which was used in the 2D soil temperature model simulations can lead to an underprediction of the rate at which the drinking water temperature increases. It did not influence the maximum potential drinking water temperature. Meaning that if the soil temperature is below the maximum allowed drinking water temperature, the drinking water temperature will not reach this limit. If the soil temperature is above this limit, then the drinking water temperature might reach it, but this will depend upon the residence time and the rate at which the temperature changes.

Work Package 4 Measurements and validation
The memo describing the results can be found in appendix A. Measurements were performed around the drinking water network of Oasen. Soil temperature sensors were installed which measured the temperature next to drinking water pipes at several locations in Krimpen aan den IJssel. However, drinking water temperature was not recorded. Based on this the following can be said on validation of the models:

1. 1D soil temperature model: it was already validated
2. 2D soil temperature model (in Plaxis): with the measurement data from Krimpen aan den IJssel it was shown that the physics are correctly taken into account. A further validation is required, where boundary conditions are better known (not just estimated) and where also the influence of hot water pipes can be validated. It is expected that this is possible with measurement data from the University of Sheffield.
3. 2D drinking water temperature model (Wanda): this could not be validated with the measurement data from Krimpen aan den IJssel, since the drinking water temperature was not measured. Measurements from the University of Sheffield are probably not enough due to the limited size of the setup.
4. Model of the entire city cannot be validated since there are no drinking water temperatures available.

Work Package 5 Simulating the influence of a heat source for an entire city
As described above it was decided not to create tables with the drink water temperature as function of the distances for different. The main reason for this is the lack of validation data to verify of the followed approach does produce acceptable results. Furthermore, some concerns were raised on the constant drink water boundary used in the Plaxis calculations. To investigate the effect of this boundary condition additional simulations have been performed. These have been reported in a separate memo, which is included in Appendix A.
The main conclusion was the additional simulations with varying drinking water temperature in the subsurface show that keeping the drinking water temperature constant leads to an underprediction of the rate at which the drinking water increases in temperature. The maximum drinking water temperature is not underpredicted.

Recommendations for future work
Based on the outcome of this research project, it is recommended to continue the research. The following steps need to be taken to come to a table with a drinking water temperature as function of the distance for different scenarios.

1. Validation of the model train to assess which approach (if any) fits best with measurements.
2. If no approach fits with measurements develop a fully coupled model. Otherwise use the approach which best fits the measurements.
3. Then use the best model (from step 1 or 2) to simulate scenarios for an entire city.
4. From the results create tables with the drinking water temperature as function of the distance for different scenarios. This can be used by the NEN committee to determine what acceptable distances are.

A Memo's work packages

The memo's describing the work can be found in separate pdf's documents. The following documents are part of this reports:

1. Research proposal: Annex A - 11200634-001-GEO-0003-m-TKI 2017 Warmteoverdracht leidingen-def.pdf
2. Work package 1: 11201825-000-HYE-0003a-m-Comparison of 1 dimensional heat transfer calculation between Calorics and Plaxis thermal_def.pdf
3. Work package 2: 11201825-000-HYE-0004-m-WP2_def1.pdf
4. Work package 3: 11201825-000-HYE-0006 v1.0 - Wanda simulations_def.pdf
5. Work package 4: 07082018 Conceptmemo_TKI_validation Results mesaurements Oasen 1D and 2D.pdf
6. Review TNO: R11779_Deltares_TAA_LNS report-1.pdf
7. Additional simulations: 11201825-000-HYE-0013 v0.1 - Effect of the constant drinking water temperature in sub-surface simulations.pdf

List of deliverables according to the research proposal

1 Tables and rules of thumb to determine the minimal distance between drink water pipelines and parallel heat sources. If possible, in the form of an excel spreadsheet.
2 Powerpoint presentation to share within partner companies.
3 Wanda Heat extension with the new heat pipe for a test period of 1 year
4 Journal article about the research and the implication of it.
5 Popular press paper on the 1D and 2D modelling of the subsurface and the sensitivity analysis and guidelines on the minimum distances between drinking water pipelines and parallel heat sources.
6 Concept NTA on the minimum acceptable distance between drinking water pipeline and district heating pipeline.

Ad 1. Cannot be delivered yet, since the models need to be validated first. If an excel spreadsheet tool will be made available will be decided in the continuation of the project.

Ad 2. Powerpoint presentation of the meetings have been distributed among the partners.

Ad 3. Wanda heat with new heat pipe can be delivered upon request

Ad 4. Is in progress

Ad 5. Cannot yet be done since the models have not yet been validated

Ad 6. It was decided to drop this and to produce tables with the drinking water temperature as function of the distance for different scenarios.