# Implementation of Hydraulic Modelling to Support Sustainable Economic and Quality Assurance in the Municipal Water Company in Egedal - Denmark

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## *Abstract*

Climate change is an extensive challenge for water companies to optimize drainage systems capacity. Publications of The Wastewater Committee in Denmark no. 27, no. 28 and no. 29 are the recently updated guidelines for hydraulic design of drainage systems in Denmark. Private housing developments are the most typical means of drainage systems expansion. Renovation and reconstruction projects consider higher capacity in drainage systems due to future scenarios of climate change, continuous expansion of impermeable urban quarters and increased restriction on discharge permission according to new water plans in Denmark.

The Municipal Water Company in Egedal (MWCE) implemented Hydraulic modelling successfully for quality assurance of private housing development projects. Hydraulic modelling helped to obtain sustainable economic measures in renovation projects in accordance with the water company perspective. The MWCE has saved 17 million DKK (€ 2.3 million) during the period 2007 to 2009.

## *Key words*

Egedal, Hydraulic modelling, MIKE URBAN-MOUSE, SVK, housing development projects, renovation projects, Water Company, MWCE.

## Introduction

Egedal Forsyning A/S (Egedal Supply Ltd.) was established on June the 1st 2009 as a private company and extension to the MWCE. Egedal Municipality was born on January the 1st 2007 by merging the three previous municipalities Stenløse, Ølstykke and Ledøje-Smørum. The population concentration of Egedal is 320 people per km$^2$. The approximate population is 40,000 people and the area is approximately 125 km$^2$. The recent technological developments in the water sector are implemented in Egedal. In the last 4 years, Egedal was exposed to three rainfall events in the summers of 2005, 2007 and 2009, which caused flooding in some areas. Hydraulic modelling has been implemented since then for analysis, design, planning, solutions and to support economic optimization of the drainage system in Egedal. This paper is a review and study of the hydraulic modelling experience of the MWCE. Furthermore, the paper presents case studies, results, conclusions, decisions and future plans for implementing hydraulic modelling in the WMCE.

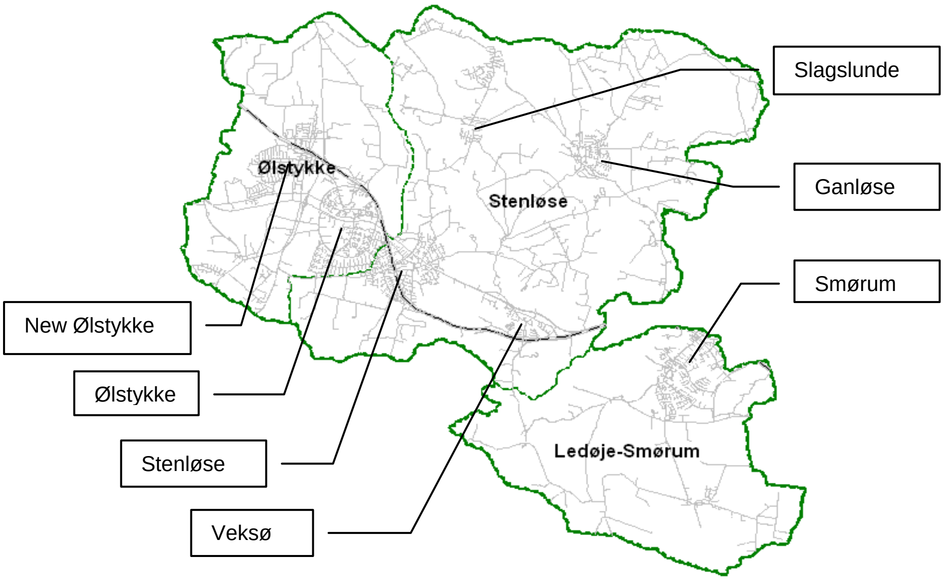

***Figure 1:*** *Map of Egedal showing the borders and names of the old municipalities and towns.*

## Guidelines of hydraulic design of drainage systems in Denmark (SVK 16)

Publication no. 16 of The Wastewater Committee in Denmark (SVK 16) of 1974 for determination of rain series has classified rainfall events in Denmark of 1 year, 2 years, 5 years, ...etc. rain events [SVK 16, 1974]. The letter “T” was given to refer to the rain event. For example, T=20 is a 20 year rainfall event, which statistically is expected every 20 years [Winther et.al, 2005, p87]. Curves of certain precipitation events of different durations from SVK 16 are shown in Figure 2.

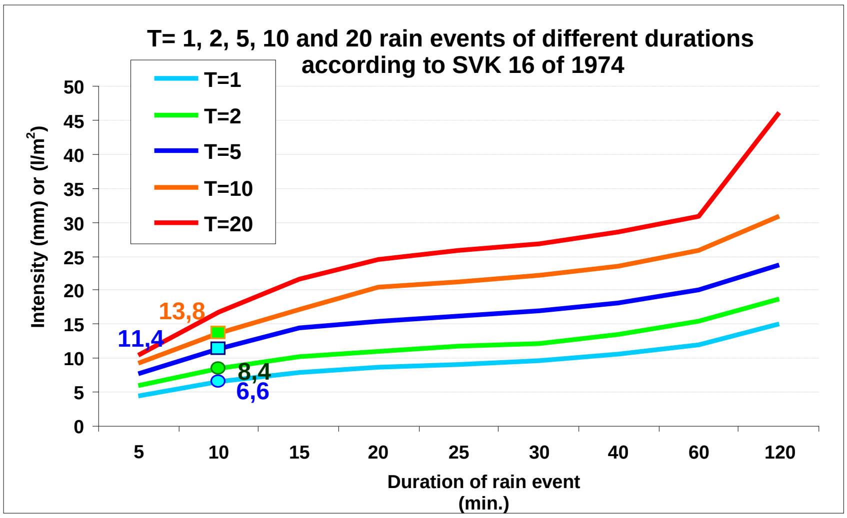

***Figure 2:*** *Curves of rainfall events of different durations based on observation period 1933-62 from SVK 16 [Al-Shididi, 2008].*

The rain event of T=1 (6.6 mm) and T=2 (8.4 mm) in 10 minutes were typically used to design full-flow sewer pipes of separate system and combined systems respectively [Winther et.al, 2005, p224; DS 432, 1994]. This hydraulic capacity should live up to all events with maximum precipitation of T=1, and T=2 respectively.

Due to climate change, SVK 27 of October 2005 defines additional guidelines [SVK 27, 2005].

## Guidelines due to climate change (SVK 27)

Higher intensity of rainfall events has been observed in the last 10 years up to 2005. Due to this fact SVK 27 defines an allowed maximum level of water above the sewer pipes as an additional guideline for drainage systems hydraulic design as is shown in figure 3.

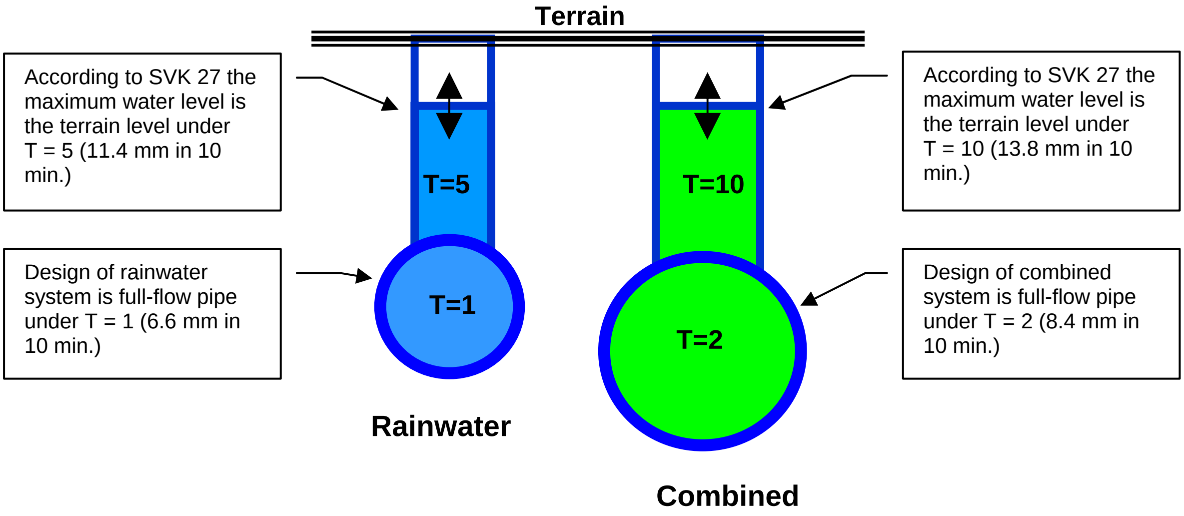

***Figure 3:*** *Illustration of guidelines for hydraulic design of separate and combined drainage systems according to SVK 27 [Al-Shididi, 2008a].*

SVK 27 also discusses factors of safety in future sewer systems due to different scenarios of climate change, increase in percentage of impermeablity and possible inaccuracy in calculation. Estimation of the safety factor takes into consideration the economic aspect. The economic aspect is discussed as a balance between cost of executing/operating and cost of renovation (See figure 5). The safety factor can fluctuate between 1.2 and 1.7. SVK 29 of August 2008 suggests a total safety factor between 1.45 and 1.7, where the part of climate factor represents 1.2, 1.3 and 1.4 of respectively 2, 10 and 100 years' scenario or lifetime of drainage system.

Determination of the safety factor depends on the following [SVK 27, 2005]:

1. Type of chosen climate scenario.
2. Level of calculation (Level 1 based on block rain, level 2 based on CDS-rain[1] and historical rain or level 3 based on verified model).
3. Expected growth in the impermeable areas of catchments during life time of design.
4. Chosen level of service that the water company provides in terms of definition of terrain level (critical level) especially in modelling of existing drainage system.

In addition to this, SVK 28 of 2006 has included rainfall of 97 stations registered until 2005. An increase has been observed in rainfall intensity up to 20% in the past 10 years [SVK 28, 2006, p22-25], which added an extra safety factor. Figure 4 illustrates this relation.

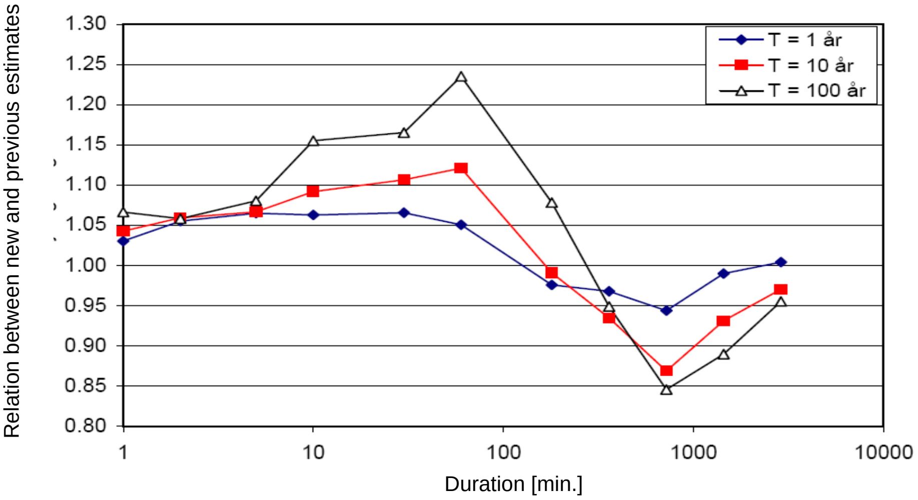

***Figure 4:*** *Regional estimate of T-year intensity in a location in Region East with average annual precipitation of 600 mm based on the data from SVK 28 (1979-2005) and the data from SVK 26 (1979-1997) [SVK 28, 2006, p25] .*

The art of planning and management engineering is to provide not less than the minimum level of service that complies with guidelines and at the same time to achieve the lowest point in the curve of the total cost in figure 5. This is a strategic goal the MWCE has adopted as a management policy in drainage systems projects.

In order to realize this policy, the MWCE has chosen the hydraulic modelling analysis as a tool to support decision-making processes in planning, designing and choice of solution of specific projects and thus to facilitate economic optimization.

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[1] CDS-rain is Chicago Design Storm [SVK 28, 2005]

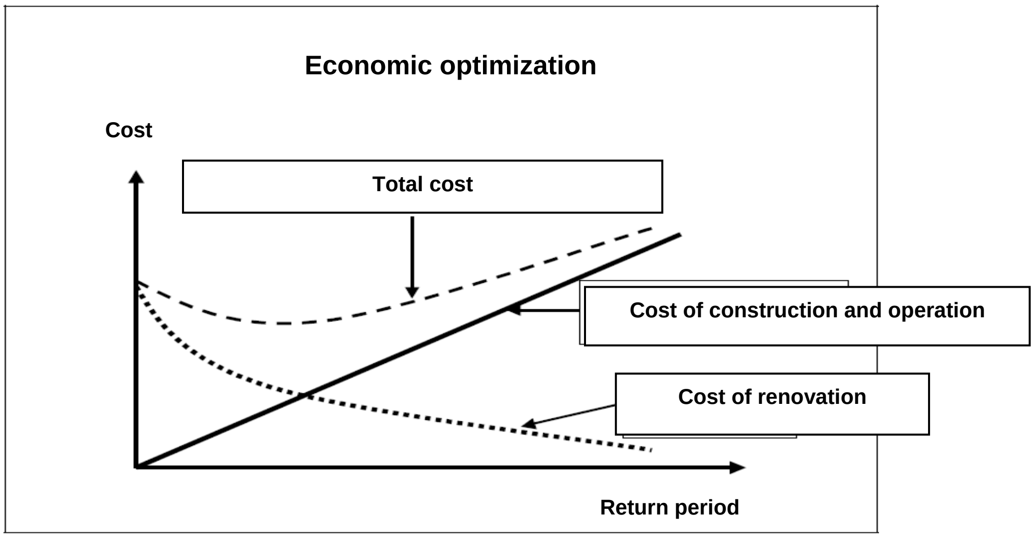


***Figure 5:*** *The basic principle of economic optimization regarding the relation between the construction and renovation cost converted to an average annual cost as a function of return period [SVK 27, 2005, p16; Winther et.al., 2006, p228].*

### Fields of implementation

Hydraulic modelling has been implemented primarily to focus on implementing hydraulic modelling in specific projects planning rather than in general planning. The decision-making was based on the economic significance of specific projects that can economically be estimated by such analysis as hydraulic evaluation.

The MWCE has hydraulically analyzed two types of the above-mentioned projects:

1. Private housing development projects

   This type of project is the typical mean of expansion of drainage systems. In development projects the client the housing project constructs the drainage system on behalf of and according to the specifications of the MWCE. The cost of construction is paid by the MWCE. The process starts with sending the project to the MWCE for examination, assessment and approval of project plans, structural design, rational method hydraulic calculations, quantities and economic compensation based on the above approvals. This is supported by a hydraulic evaluation carried out by the MWCE on level 2 calculation of SVK 27.

2. Renovation projects

   This type of project is carried out by the MWCE. The project starts with investigations, evaluation, solution proposal, bidding, contracting, construction and the handover. The solution proposal is usually based on hydraulic evaluation. The MWCE carries out or orders hydraulic model and then performs a quality check on the model before it is implemented in solution proposal.

### Case studies

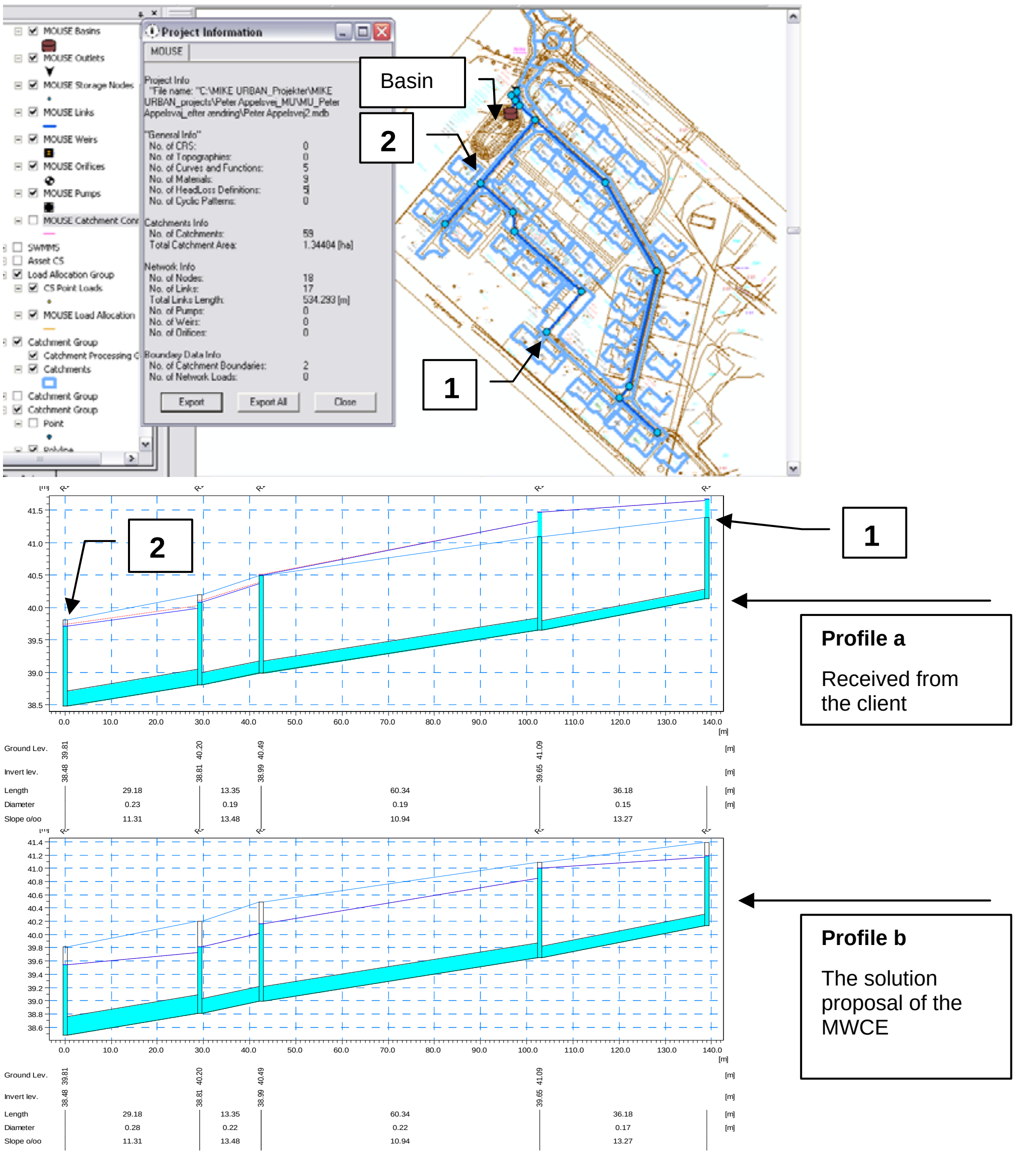
Case studies from five projects will be presented in this review from both housing development and renovation projects such as the following:

1. Housing development projects: Peter Appelsvej and Stenløse Syd.
2. Renovation projects: Flooding control in Ganløse, Renovation project in Smørum.
3. New rainwater drainage system for the road Krogholmvej.

*Peter Appelsvej*

A 42 house development project with separate drainage system with a 345 m$^3$ rainwater detention basin was executed on the north-western edge of Ganløse town. The client's consultant has estimated initial cost of the project to about 3 million DKK (€ 0.4 million) [Stenløse, 2006, p6]. By revaluating the project hydraulically (level 2), qualitatively and quantitatively, the cost of the project was reduced to less than 1.7 million DKK (€ 0.23 million). The project and one of the solutions are illustrated in figure 6.

The evaluation showed that the project was exposed to flooding during T=5, minimum guideline requirements level. The project was optimised by MWCE through necessary adjustments of pipe dimensions, reduction of the number of manholes from 32 to 28, change of the structure design of the inlet/outlet of the basin, removal of tide flex valve and flexibility was given to the contractor to choose the approved environmentally-friendly materials.



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  No. of Cyclic Patterns:            0

Catchments Info
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  Total Catchment Area:              1.34404 [ha]

Network Info
  No. of Nodes:                      18
  No. of Links:                      17
  Total Links Length:                534.293 [m]
  No. of Pumps:                      0
  No. of Weirs:                      0
  No. of Orifices:                   0

Boundary Data Info
  No. of Catchment Boundaries:       2
  No. of Network Loads:              0
```

**Profile a**

Received from the client

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ground Lev. | 39.81 | | 40.20 | | 40.49 | | 41.09 | | [m] |
| Invert lev. | 38.48 | | 38.81 | | 38.99 | | 39.65 | | [m] |
| Length | | 29.18 | | 13.35 | | 60.34 | | 36.18 | [m] |
| Diameter | | 0.23 | | 0.19 | | 0.19 | | 0.15 | [m] |
| Slope o/oo | | 11.31 | | 13.48 | | 10.94 | | 13.27 | |

**Profile b**

The solution proposal of the MWCE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ground Lev. | 39.81 | | 40.20 | | 40.49 | | 41.09 | | [m] |
| Invert lev. | 38.48 | | 38.81 | | 38.99 | | 39.65 | | [m] |
| Length | | 29.18 | | 13.35 | | 60.34 | | 36.18 | [m] |
| Diameter | | 0.28 | | 0.22 | | 0.22 | | 0.17 | [m] |
| Slope o/oo | | 11.31 | | 13.48 | | 10.94 | | 13.27 | |

***Figure 6:*** *An example from the housing development project Peter Appelsvej, Ganløse. The pipe series 1-2 was exposed to flooding during rain event T=5 (Profile a). The design was adjusted by The MWCE (Profile b). Level 2, CDS-rain according to SVK27 was used in modelling.*

The following results were achieved by the optimization:

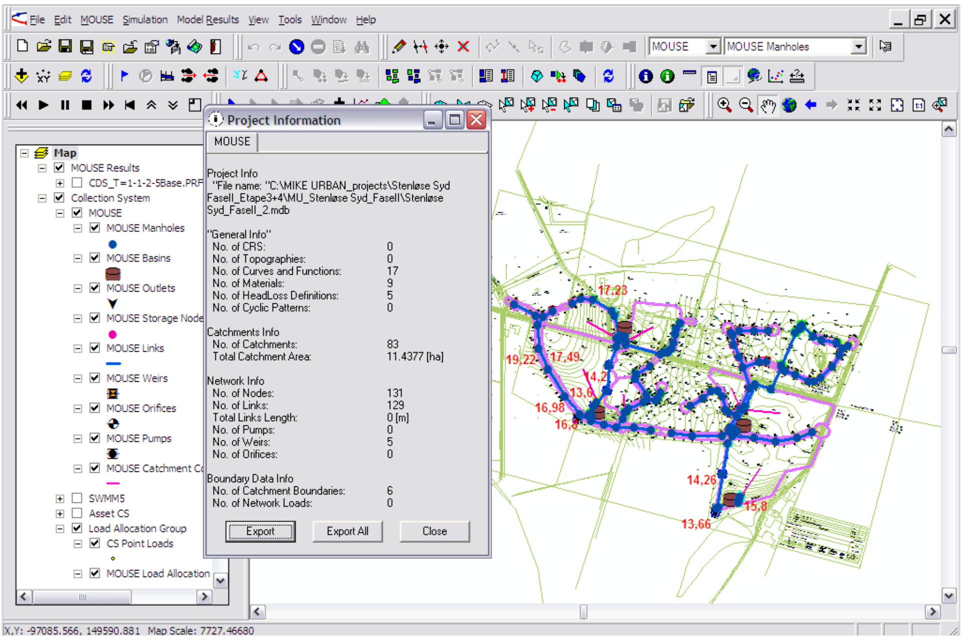
- The project lived up to the guidelines of SVK 27 with no flooding under T=5.
- 55 m3 extra volume capacity gained the in basin without extra excavation works.

- The discharge of the catchment adjusted to 2.5 l/s below the allowed maximum annual average discharge of 2.7 l/s or 2 l/s/red.ha [Stenløse, 2006, p3].
- 1.3 million DKK (€170,000) was saved.

*Stenløse Syd (Stenløse South) - phase II*

The project was a housing development project of approximately 500 houses on 30.2 ha (11.5 red. ha) with 5 detention tanks [Stenløse, 2004]. Egedal Municipality was the client of the project, which was under the supervision of the MWCE. Allowed maximum annual average discharge from the catchment is 2 l/s/red.ha (24 l/s) [Stenløse, 2004].

A new concept of reusing the roof water (Rain water) in the household was implemented by the client proactively to deal with the climate change. Only road water (Rain water) is discharged into the drainage system [Stenløse, 2004]. The project is presented in figure 7.



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Catchments Info
 No. of Catchments:                   83
 Total Catchment Area:                11.4377 [ha]

Network Info
 No. of Nodes:                        131
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 No. of Pumps:                        0
 No. of Weirs:                        5
 No. of Orifices:                     0

Boundary Data Info
 No. of Catchment Boundaries:         6
 No. of Network Loads:                0
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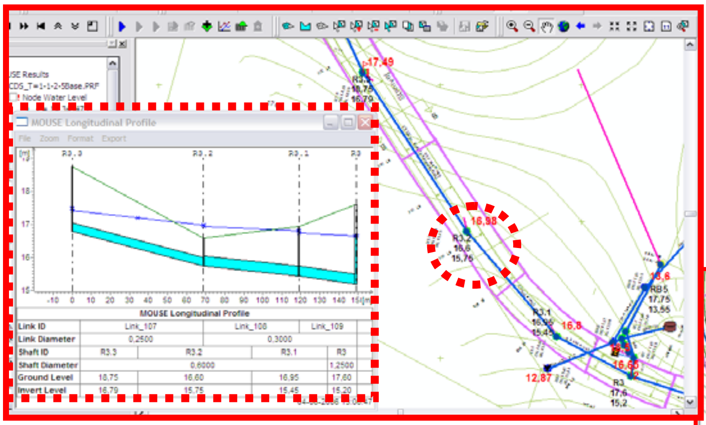
***Figure 7:*** *Project information of Stenløse Syd (Stenløse South) – phase II from MIKE URBAN-MOUSE.*

The MWCE has examined the project on level 2 calculation, CDS-rain [SVK 27, 2005]. During T=5, the location marked with the dotted circle in figure 8 was 38 cm (level 16.98 m) below water. It was significant to avoid flooding in this particular location, because a heating power station was scheduled to be constructed just to the south west of the location.

While the project was under construction a solution was proposed by the MWCE to overcome the problem. At the time of modelling all pipes upstream of manhole R3.2 were constructed in contrast to the project plans executed to 300 mm instead of 250 mm, which resulted in an even higher level of water (52 cm over manhole R3.2 at 17.12 m). The MWCE suggested a second alternative solution, which was to raise the ground level of manhole 3.2 and the surrounding terrain to 17.15 m, which was approved. Figure 9 illustrates the eventual solution. Furthermore, the second alternative included making flooding paths from the road towards terrain away from the power station.

Moreover, the allowed annual maximum average discharge of the whole catchment of Stenløse Syd – phase II was found to be 15 l/s, which is within the allowed discharge of 24 l/s.



MOUSE Longitudinal Profile

| | | | | |
|---|---|---|---|---|
| Link ID | Link_107 | Link_108 | Link_109 | |
| Link Diameter | 0,2500 | 0,3000 | | |
| Shaft ID | R3.3 | R3.2 | R3.1 | R3 |
| Shaft Diameter | 0,6000 | | | 1,2500 |
| Ground Level | 18,75 | 16,60 | 16,95 | 17,60 |
| Invert Level | 16,79 | 15,75 | 15,45 | 15,20 |

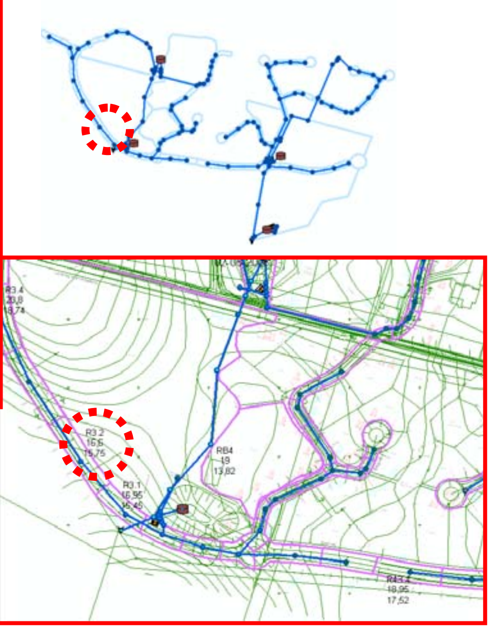
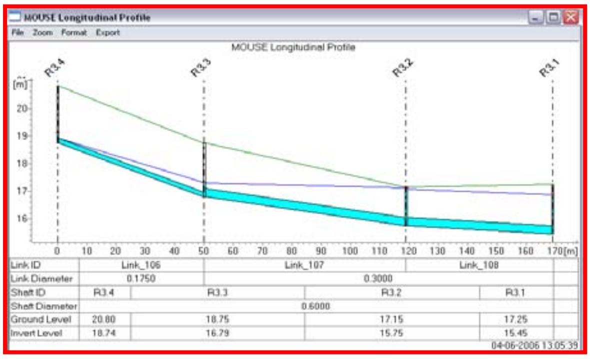


***Figure 8:*** *Hydraulic analysis by MIKE URBAN – MOUSE of StenløseSyd (Stenløse South) – Phase II project has shown that Manhole R3.2 (Ground level 16.6 m) in the road Stamvej becomes flooded by 38 cm (Level 16.98) water level during a T=5 rain event. Level 2, CDS-rain according to SVK27 was used.*



| | | | | |
|---|---|---|---|---|
| Link ID | Link_106 | Link_107 | Link_108 | |
| Link Diameter | 0.1750 | 0.3000 | | |
| Shaft ID | R3.4 | R3.3 | R3.2 | R3.1 |
| Shaft Diameter | 0.6000 | | | |
| Ground Level | 20.80 | 18.75 | 17.15 | 17.25 |
| Invert Level | 18.74 | 16.79 | 15.75 | 15.45 |

***Figure 9:*** *The eventual solution Stenløse Syd (Stenløse South), where ground level at manhole 3.2 in the road Stamvej is lifted up from level 16.6 to 17.15 that the water level became lower than the ground level during the rain event T=5.*

## Flooding control in Ganløse

A storm of 30 mm precipitation in 40 minutes (equivalent to T=20) on 2 June 2005 caused flooding in private properties in the combined sewer catchment GA4 in Ganløse. Blue circles in figure 10 are water at ground level and red circles are water in basements. A longitudinal profile of an externally ordered hydraulic model of the area in figure 10 shows a bottleneck of flooding in the most affected spot on the trunk sewer of the catchment [Al-Shididi, 2006].

The flooding data in figure 10 was collected from the locals in catchment GA4. The calibration of the model was based on this data. The model was based on catchment impermeability of 35% and initial concentration time of 7 minutes. The requirement of the guidelines for this combined catchment was to prevent flooding during a 10 year rain event [SVK 27, 2005]. Terrain level is road level in this case. The status and the solution models were tested under both CDS-rain of T=10 and historical rain series.

The solution, which was also externally ordered, was reported in 2006, which included a combination of several solutions, which is listed below and as it is numbered in figure 14:

1. Capacity optimization of an existing detention tank.
2. New underground detention tank of 750 $m^3$.
3. Increasing the dimension of an existing pipe.
4. Reorienting the outlet of 1 ha from catchment GA4 towards another catchment that has sufficient capacity.

The solution project was executed in fall 2006 and handed over in summer 2007.

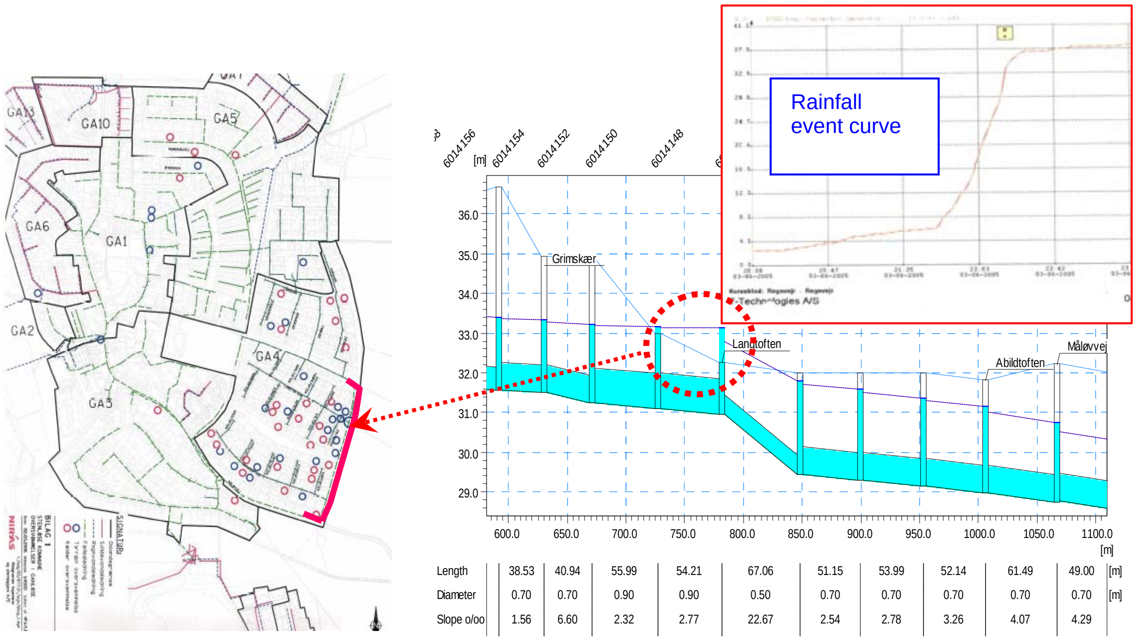


***Figure 10:** Illustration of flooding in catchment GA4 in Ganløse, Egedal on 2 June 2005 of 30 mm in 40 min. (T=20). Longitudinal profile from MOUSE model shows the flooding in the trunk sewer of the catchment. A hydrograph shows the rainfall event [Al-Shididi, 2006].*

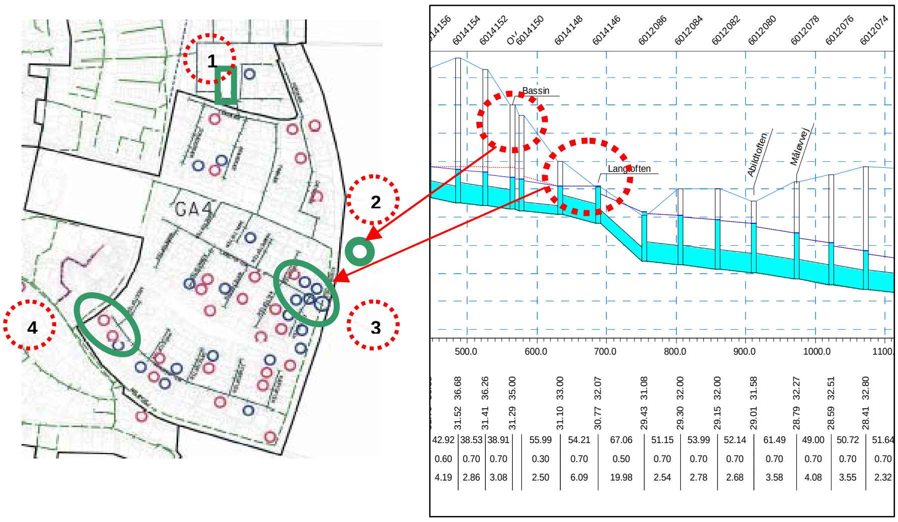


***Figure 11:** The locations of the 4 solutions to overcome the flooding problem of June 2005 in catchment GA4 in Ganløse. A longitudinal profile of the solution shows that the flooding disappears above the trunk sewer [Al-Shididi, 2006].*

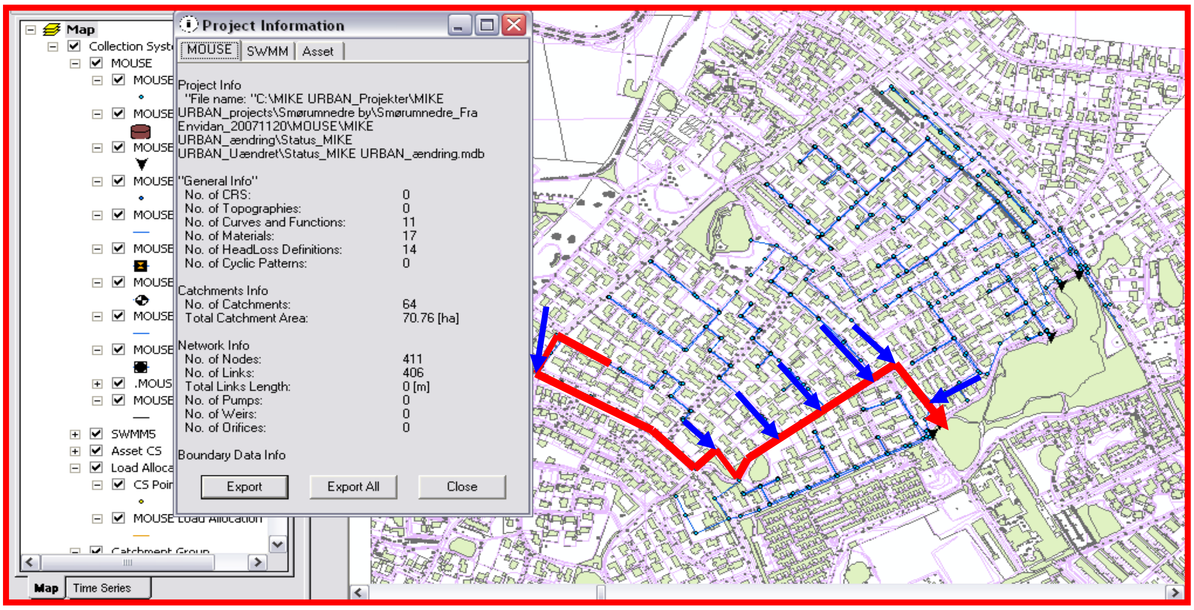
### <u>Renovation project in Smørum</u>

Planning of a renovation project Tulipanhave (figure 15) was started in May 2007. The planning started by ordering externally a non-calibrated MOUSE model to investigate whether the catchments satisfies the requirements of SVK 27. The catchments are separate system and therefore the focus in the hydraulic model would be on the rainwater system.

The focus in this case study will be on a 1100 m trunk rainwater sewer pipe that is highlighted in figure 12.

The model was based on calculation level 2, CDS-rain (T=5) from SVK 28. The permeable area was calculated on the basis of 100% roof area of all houses in the catchment added to 90% of the road area in the catchment. The safety factor was equal to 1.44 and based on 1.2

climate safety factor and 1.2 modelling uncertainty. No expansion in permeable area in the future was taken into consideration for the safety factor determination [Envidan, 2007].



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Catchments Info
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  No. of Weirs:                        0
  No. of Orifices:                     0

Boundary Data Info
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***Figure 12:*** *Model information of the catchment Tulip Garden (Tulipanhave) in Smørum illustrated together with the main trunk rainwater pipe.*

The longitudinal profile in figure 13a is the status calculation and in figure 13b is the solution proposal that was delivered to MWCE in November 2007. The solution suggested replacing the mentioned trunk sewer with bigger diameter pipes, which meant that the solution incurred costs of excavation work and replacement along almost the entire pipe [Envidan, 2007].

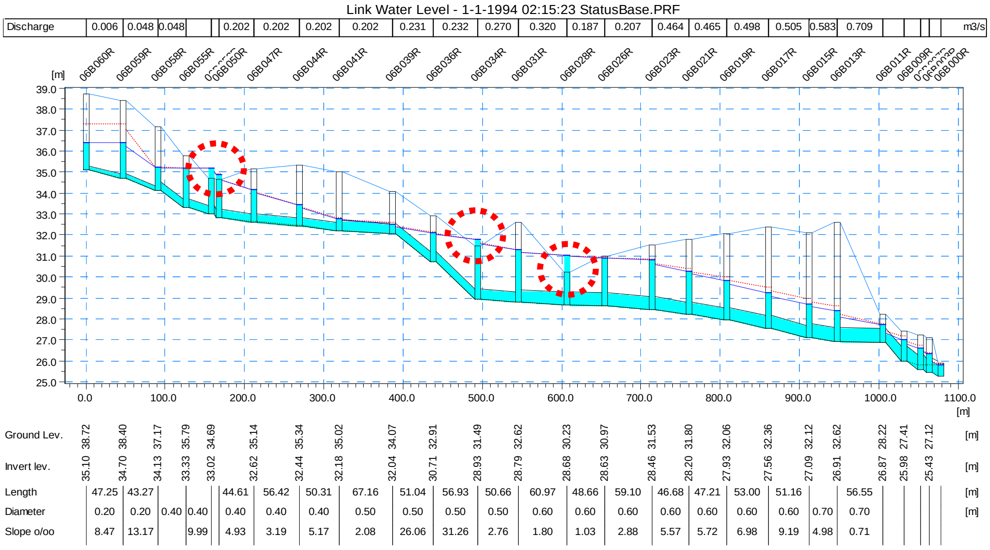
However the model was received and discussed internally. A priority of excavation works were given by the MWCE to locations of defective pipes need to be replaced, which at the same time need hydraulic capacity optimization. The solution model was re-evaluated. The re-evaluation resulted in an alternative solution that is illustrated in figure 13c.

The alternative solution proposed by the MWCE recommends I stead a partial replacement of the trunk sewer pipe in the form of two detention pipes, moving the one manhole to a higher level of terrain, as it is presented in figure 14 and the dimension reduction or throttling of two pipes. This solution means that the excavation work is significantly reduced, flooding as in figure 13b is eliminated and the rest of the pipeline is left to no-dig renovation methods, which are much cheaper.

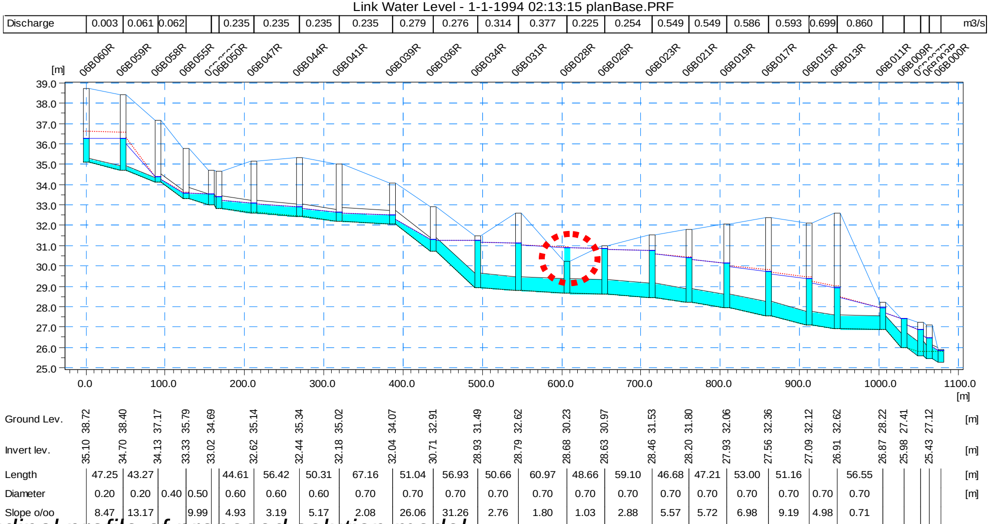
The MWCE has decided to calibrate and verify the model. This decision was taken against the background of achieving a model with smaller degree of incertitude. This can result in a solution with more precise economic outcome. Therefore a flow survey program was carried out in summer 2008 and the results were anticipated in spring 2009.

It has also been decided to carry out TV-inspection on especially unclear observations that need to be confirmed such as either pipe settling or sediments that create the appearance of standing water in pipes. This can also have a hydraulic effect. Besides a decision should be made whether excavation should be done or a no-dig renovation is sufficient to restore the system to a functional level.

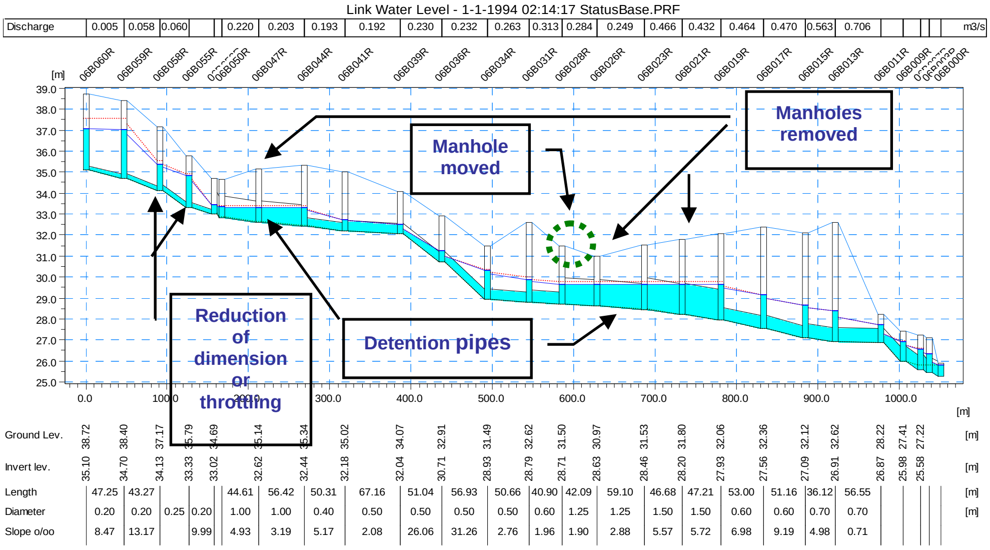
However until this time a temporary saving of about 9 million DKK (€ 1.2 million) was achieved by the alternative solutions.



*a) Longitudinal profile of status model.*



*b) Longitudinal profile of proposed solution model.*



*c) Longitudinal profile of alternative solution model by MWCE.*

***Figure 13:*** *Three longitudinal profiles of the trunk sewer in Tulipanhave (Tulip Garden) catchments in Smørum. Profile (a) shows the status model with 3 locations of flooding along the profile. Profile (b) shows the proposed solution that delivered to the MWCE still with flooding in one location. Profile (c) shows the alternative solution that suggested detention in two places, moving one manhole to a higher level, reducing or throttling the dimension of two pipes and removing 3 manholes.*

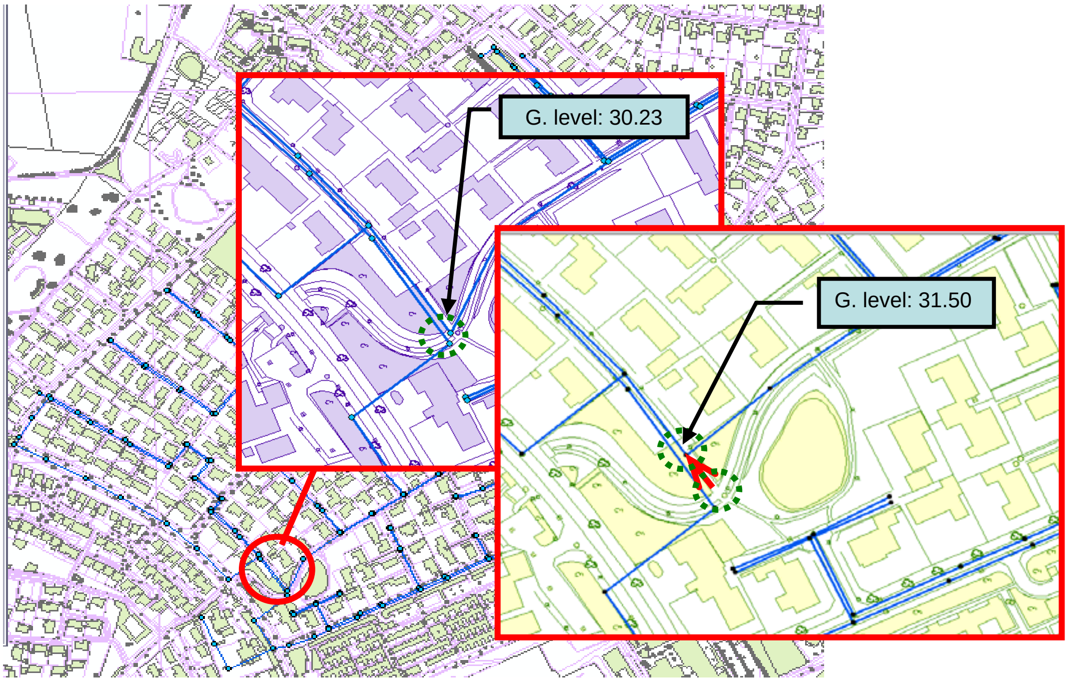


***Figure 14:*** *A description of the achievement of a higher terrain level by moving a manhole on the rainwater main trunk sewer in Tulipanhave (Tulip Garden) catchment to a higher ground level in order to avoid flooding.*

*<u>New rainwater drainage system for the road Krogholmvej</u>*

The expansion of the road Krogholmvej that connects Stenløse town towards west has been an economic challenge. The designed project has suggested a detention pipe system connected to the northern side of the system as it is shown in the upper part of figure 19. According to the design, the total pipe volume of the project was suggested to be 434 m$^3$.

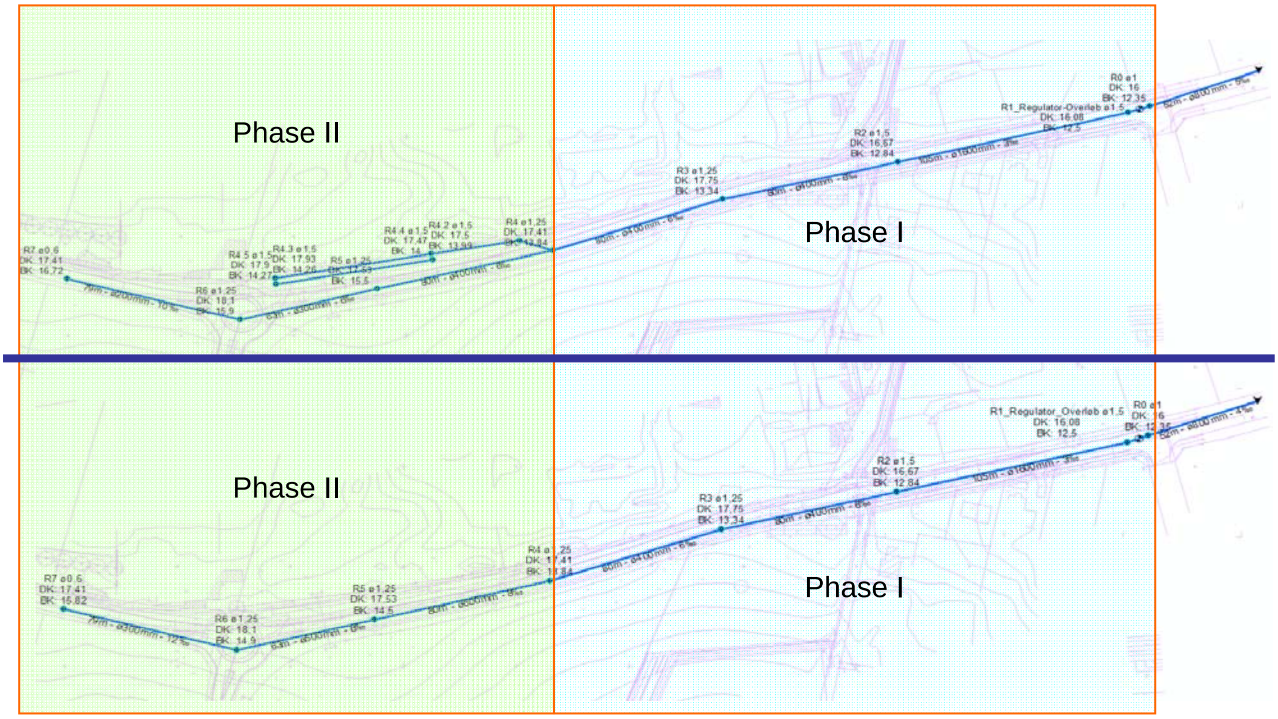


***Figure 15:*** *Expansion of the road Krogholmvej. Phase I of the project was executed in spring 2009. The designed rainwater drainage system with extra detention pipes (above). The modelled drainage system with reduced detention pipes (Below).*

The design was optimised through hydraulic modelling by reducing the unnecessary volume of the detention pipe system and a new solution was suggested. The model indicated that 122 $m^3$ of the designed pipe system would be empty volume during operation. Therefore the pipe volume reduced to 312 $m^3$. The pipe system reduced to what it can be seen in the lower part of figure 15. The following amounts and works were saved in this project:

1. Reduction of five concrete pipes of 1m diameter with total length of 206 m. According to the designed project these pipes should be laid down 3.6 m beneath the road surface. This means a reduction of approx. 2225 $m^3$ in excavation works.
2. Reduction of a concrete pipe of 400 mm diameter with total length of 15 m that should be laid down 3.55 m beneath the road surface. This means a reduction of approx. 160 $m^3$ in excavation works.
3. In total, 14 pipes reduced to 8 and 6 detention pipes reduced to 3.
4. Five Manholes of 1.5 m diameter. In total 13 manholes reduced to 8.
5. A reduction in the amount of surplus soil resulted from excavation work as 122 $m^3$ (approx. 244 tons) reduced in the pipe system volume.

Approximately 4 million DKK (€0.53 million) saved in this project due to the optimisation.

### Assessment

The hydraulic modelling in the past four years has optimized the decision-making process towards focused decisions in the direction of qualitative and economically sustainable projects. The following was achieved in renovation and development projects:

1. Quality control of the rational method hydraulic design by modelling, which gave a better overall hydraulic evaluation of the development and renovation projects.
2. Hydraulic capacity of the drainage system compatible with the service level and requirement of the guidelines of SVK 27 in both renovation and development projects.
3. Reordering of the priority of renovation projects towards economically sustainable solutions on the basis of hydraulic evaluation.
4. Large savings by implementing hydraulic modelling.

### Decisions

On the basis of the experience with hydraulic modelling by implementing MIKE URBAN-MOUSE in drainage projects, the MWCE has taken a decision to implement hydraulic modelling using one dimensional (1-D) drainage systems modelling of MIKE URBAN-MOUSE combined with 1-D river modelling of MIKE 11 and connected to two dimensional (2-D) modelling of MIKE 21 through MIKE FLOOD. Modelling will be utilized as a support tool to establish and develop long term strategic plans, short term strategic plans and detailed plans for renovation and development projects. A decision was taken to either build up models and/or externally order models based on the following lines:

1. Calculation level 2, CDS from SVK 28 and CDS of local rain gauges.
2. Calculation level 2, historical rain from SVK 28 and from local rain gauges.
3. Calculation level 3, flow survey program for calibration and verification.
4. Testing the hydraulic systems with CDS and then historical rain.
5. Testing detention systems (tanks, basins, lagoons, lakes and detention pipes) with historical rain for catchments of more than 10 ha.
6. Testing the stability of the model under different historical rain series.
7. Using a safety factor equal to 1.45 in future scenarios for verified models. This factor consists of climate change factor equal to 1.2, condensation factor equal to 1.1 and model uncertainty factor equal to 1.1. For unverified models a total safety factor equal to 1.6 is used, which includes a model uncertainty factor equal to 1.2 [SVK 27, 2005].

8. However, SVK 29 has suggested a climate safety factor equal to respectively 1.2, 1.3 and 1.4 for 2, 10 and 100 years' scenario or lifetime [SVK 29, 2008]. This is currently a matter for internal discussion.
9. In the case of an unverified model, determined reduction factors equal to 1.0 for roofs, 0.1 for green areas and 0.9 for roads to be implemented in modelling.
10. Using the land register map as catchments boundary basis in urban areas with initial concentration time based on mean surface velocities of 0.3 m/s from roof to the nearest manhole in the main sewer pipe, 0.5 m/s runoff for impermeable catchments up to 0.2 ha, 0.5-1 m/s for impermeable catchments between 0.2 ha and 1 ha and 1 m/s for catchments from 1 ha and bigger.
11. New catchment borders, discharge values, permeability percentage to be calculated with a view to implementation in strategic planning.
12. Establishing local key values for time-area parameters of modelling in Egedal regarding concentration time, impermeability percentage of classified types of catchments, discharge values of different types of catchments and infiltration to the drainage system.

**Long term plans**

On the basis of the achieved results in hydraulic modelling using MIKE URBAN-MOUSE the following procedures have been adopted in the MWCE:

1. Gradual connection of all models of MIKE URABN-MOUSE together to attain better overview regarding flooding and hydraulic difficulties in the system. A terrain model and MIKE FLOOD will be implemented to further optimize this task.
2. Creation of scenarios for extreme situations to predict and handle flooding in such scenarios.
3. The initiation of a basis of effective management and operation of the drainage system under extreme weather events based on results from hydraulic modelling.
4. Implementation of modelling to establish a foundation for emergency plans.
5. Establishing a network of local rain gauges, flow survey programs and online data to implement in models verification and calibration.
6. Taking a next step, which is combining MIK URBAN-MOUSE modelling with two dimensional (2-D) hydraulic modelling implementing MIKE 21 to be connected with 1-D river modelling of MIKE 11 through MIKE FLOOD in order to obtain as credible scenarios as possible that can achieve integration with other hydraulic bodies, such as streams, rivers, lakes and coastal water.
7. The initiation of radar and early warning system implementation to prepare the drainage system in extreme weather in order to minimize or avoid damage by flooding. Besides, forecast radar system can be implemented for collecting rain data, support emergency procedures and updating calculations of hydraulic modelling.

**Conclusions**

After 4 years of hydraulic modelling in the projects of the MWCE, the following can be concluded in regard to hydraulic modelling:

1. It is an effective tool to ensure a quality of drainage systems to live up to guideline requirements of SVK 27, SVK 28 and SVK 29.
2. It is a successful support to reduce project costs and carrying out economically sustainable projects. Sustainable cost-benefit management achieved. In total 17 million DKK (€ 2.3 million) saved in 2007-2009.

3. It is a means to handle the challenge of climate change and imminent higher level of intensity in future storms, which helps a sustainable economic investment.
4. However, building up expertise and know-how within the MWCE in modelling is an assignment that needs a thorough plan. This includes tasks supporting modelling such as updating the databases of the pipe system registration, GIS-systems, surveying, flow survey programs, rain gauges and online data.
5. To expand the frontiers of implementing hydraulic modelling in areas of analysis, control and overall planning beyond current implementation of modelling in specific projects in the MWCE, modelling should be presented to the organization as a modern support aid for decision-making processes rather than a complicated high-tech tool. This requires facilitating the use of modelling, training specialist personnel and presenting transparent results to support decision-making. This support must always be available during the process of reaching decisions.

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