Mosbaek CEV flow regulator

Verification Report

Verification Report
February 2015

This report has been prepared under the DHI Business Management System
certified by DNV to comply with ISO 9001 (Quality Management)

Approved by Sten Lindberg (Head of department, DHI)	Approved by Peter Fritzel (Verification responsible, ETA Danmark)

Mosbaek CEV flow regulator

Verification Report

Test facility

Prepared for **Mosbaek A/S**

Represented by **Torben Krejberg, Technical Director**

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Archiving: All standard project files (documents, etc) are archived at ETA Danmark. Any other project files (set-up files, forcing data, model output, etc.) are archived with the institute performing the tests or analysis.

1 Introduction

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application under defined conditions and quality assurance.

The objective of this verification is to evaluate the performance of a vertical centrifugal flow regulator for storm water.

This Verification Report and the verification of the technology are based on the Specific Verification Protocol, Test Plan and Test Report for the Mosbaek CEV flow regulator, included as Appendix B, D and E.

1.1 Name of technology

Vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical), produced by Mosbaek A/S.

Mosbaek produces CEVs for flow capacities from 0.2 l/s to 80 l/s. The verification will cover verification test of four specific CEV dimensions within this range.

Mosbaek have selected four specific CEV-models to represent their CEV technology, namely:

- CEV 1.4l/s @ 1.00m – 100%
- CEV 4.9l/s @ 1.50m – 100%
- CEV 10.5/s @ 2.00m – 78%
- CEV 10.5l/s @ 2.00m – 100%

The name of the CEV indicates the designed maximum flow of for example 1.4 l/s and the correlating maximum pressure height of for example 1.00 m. The percentage (100% and 78%) indicates the percentage of the design flow at the point/bump where the vortex is formed.

1.2 Name and contact of proposer

Mosbaek A/S
Værkstedsvej 20
4600 Køge
Denmark

Contact: Torben Krejberg, e-mail: tk@mosbaek.dk, phone: +45 5663 8580

Mosbaek website: www.mosbaek.dk

1.3 Name of verification body and responsible of verification

ETA Danmark A/S
Göteborg Plads 1
2150 Nordhavn
Denmark

Verification responsible:
Peter Fritzel (PF), email: pf@etadanmark.dk, phone +45 7224 5900

Appointed verification expert:
Mette Tjener Andersson (MTA), e-mail: mta@dhigroup.com, phone: +45 4516 9148

1.4 Verification organisation including experts

The verification was conducted by ETA Danmark A/S in cooperation with Danish Centre for Verification of Climate and Environmental Technologies, DANETV, which performs independent verification of technologies and products for the reduction of climate changes and pollution.

The verification is conducted to satisfy the requirements of the ETV scheme established by the European Union (EU ETV Pilot Programme) [1].

The verification was coordinated and supervised by ETA Danmark, assisted by an appointed verification expert, while tests were coordinated and supervised by DHI with the participation of the proposer, Mosbaek. The testing was conducted at the premises of Mosbaek in Køge, where a test facility has been constructed.

An internal and an external expert are assigned to provide independent expert review of the planning, conducting and reporting of the verification and tests:

- Internal technical expert: Morten Just Kjølby (MJK), DHI, Urban and Industry Dept., e-mail mjk@dhigroup.com
- External technical expert: Verification protocol: Professor Torben Larsen (TL), Aalborg University, Department of Civil Engineering, e-mail tl@civil.aau.dk. Verification Report: Ian Walker (IW), WRc plc, e-mail Ian.Walker@wrcplc.co.uk

The tasks assigned to each expert are given in more detail in section 4 Quality assurance.

The relationships between the organisations related to this verification and test are given in Figure 1-1.

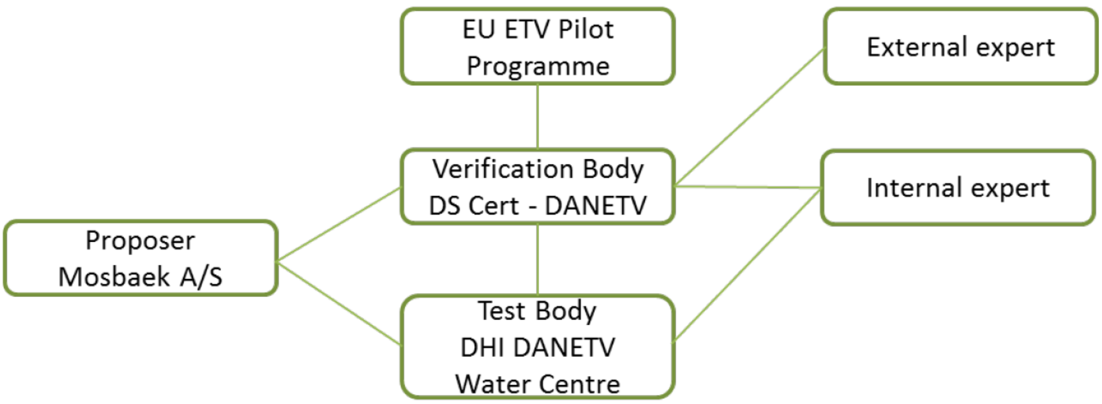


Figure 1-1 Organisation of the verification and test.

1.5 Verification process

The principles of operation of the DANETV verification process are given in Table 1-1. As it can be seen, verification and testing are divided between the verification and the test body.

Table 1-1 Simplified overview of the verification process.

Phase	Responsible	Document
Preliminary phase	Verification body	Quick Scan
		Contract
		Specific verification protocol
Testing phase	Test body	Test plan
		Test report
Assessment phase	Verification body	Verification report
		Statement of Verification

Quality assurance is carried out by an expert group of internal and external technical experts. Two audits of the test system were performed, starting with an internal audit by the test body followed by an external audit by the DANETV verification body under ETA Danmark. Reference for the verification process is the EU ETV General Verification Protocol [1] and ETA Danmarks internal procedure [2]. A Statement of Verification will be issued by ETA Danmark after completion of the verification. This verification report will include the other documents prepared as appendices.

1.6 Deviations from the verification protocol

There were no deviations to the verification protocol.

2 Description of technology and application

2.1 Summary description

The flow regulator technology for extreme rainfall events is based on quickly reaching the maximum discharge flow and staying at or below this value. The maximum discharge flow is the allowable amount of water passing through the regulator without causing any problems to the downstream pipe network.

The technology verified is the vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical) from Mosbaek. It is a wet mounted vortex flow regulator for storm water with design flows between 0.2 and 80 l/s.

The CEV regulates the water due to the vortex created when sufficient water flow is going through the unit. The vortex is created when the water flow reaches a certain flow rate. The vortex slows down the water flow through the CEV. In this way the water is stored in the well and the water flow is then kept almost constant. A schematic view of the CEV in operation is shown in Figure 2-1.

The CEV can be designed to fulfil different design criteria. The specific design criteria are defined by the client and Mosbaek in cooperation according to the design of the existing or planned piping network.

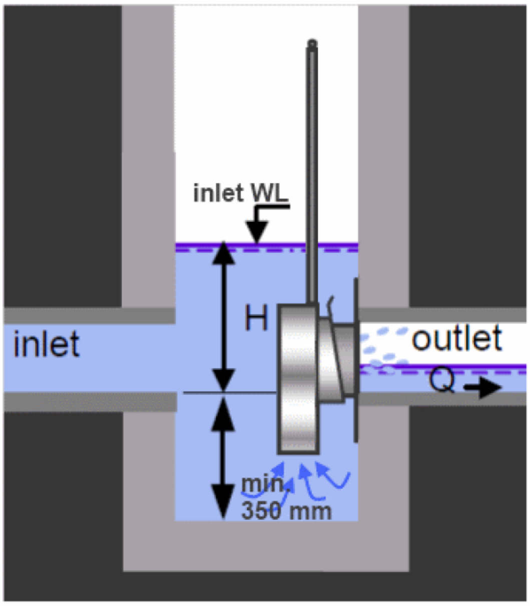


Figure 2-1 Sketch of CEV flow regulator installed in well. Sketch provided by Mosbaek.

The CEVs verified have inflow in the bottom of the regulator, as shown in Figure 2-1. This is to ensure proper and equal hydraulic conditions. Furthermore, in a standard installation Mosbaek will ensure that inlet and outlet are located at the same level in the well (as depicted on Figure 2-1) in order to be able to control the water level rise in the well optimally.

Figure 2-2 shows the flow through a CEV. In the 100% case the maximum outlet (Q_{design}) is met twice - first where the vortex is formed (the bump on the graph) and then at the specified H_{design}, where H_{design} is calculated from the invert of the discharge pipe to the maximum water level in the well. A 78% case (a smaller CEV in a well with same height) with the same H_{design} is also shown; here the bump occurs at a flow of 78% of Q_{design}.

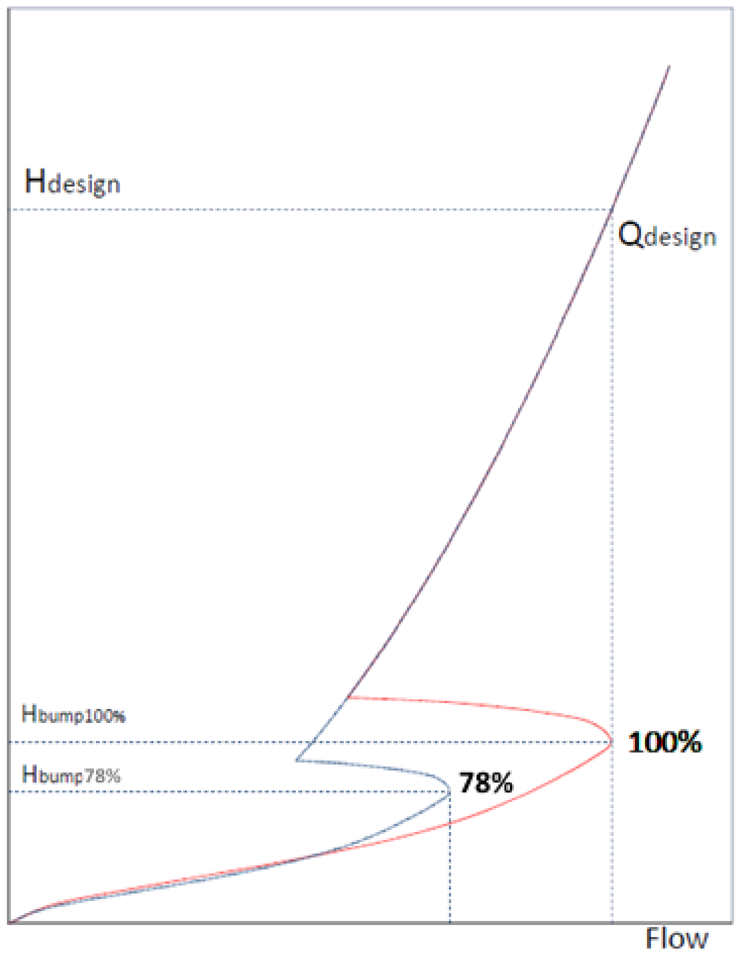


Figure 2-2 Graphic showing the general vortex brake effect on water outflow, with CEVs operating at 78% and 100% efficiency and water inflow to well larger than outflow though CEV (well is filling up). Graph provided by Mosbaek.

The optimal solution (100%), where Q_{bump} equals Q_{design}, gives less restriction at low heads allowing a better flow during normal operating situations and thereby less risk of blocking downstream.

2.2 Intended application

The intended application of the technology for verification is defined in terms of the matrix and the purpose.

2.2.1 Matrix/matrices

The CEV is for storm water and certain types of industrial wastewaters. The CEV is installed before the combined system (with storm water and wastewater), and is thereby restricting the amount of storm water into the combined system. The verification therefore only covers the matrix storm water.

2.2.2 Purpose(s)

The purpose of the technology is to store storm water at appropriate places before entering the piping system during storm water events. The CEV is installed in wells and basins depending on the piping network.

2.3 Verification parameters definition

There is no regulation to fulfil for this technology. The initial claims from the proposer are matching the claims from other vendors. No need has been found to add any additional performance parameters to those initially selected by the proposer.

Mosbaek has two types of claims for their CEVs, both described below.

2.3.1 Flow at H_{bump} and H_{design}

Mosbaek has specified the performance of four selected models of the CEV through performance graphs and specified the following specific claims (for details, please consult Appendix B):

100% model: **Q_{design} ±5% is met at H_{bump} and H_{design}**

X% model: **X% of Q_{design} ±5% is met at H_{bump}**
Q_{design} ±5% is met at H_{design}

Specific values for each of the four selected CEVs are listed in Table 2-1.

Table 2-1 Specific performance claims from the proposer on Q_{bump} and Q_{design}.

CEV model	Q_{bump} (l/s)	Q_{design} (l/s)
CEV 1.4l/s @ 1.00m – 100%	1.4 ±5%	1.4 ±5%
CEV 4.9l/s @ 1.50 m – 100%	4.9 ±5%	4.9 ±5%
CEV 10.5l/s @ 2.00m – 78%	8.2 ±5%	10.5 ±5%
CEV 10.5l/s @ 2.00m – 100%	10.5 ±5%	10.5 ±5%

2.3.2 Flow reduction at H_{design}

Mosbaek has further specified their claimed reduction of the flow at H_{design} compared to a well with no flow regulator (equal to a hole in a straight wall, with no additional piping).

Mosbaek claims the following:

A Mosbaek CEV 100% model can reduce the flow by a factor of 4.25 at Q_{design}

Performing tests where the test well is filled up to H_{design} with no CEV will require very high water flow. Therefor this claim will be verified using only the smallest of the four CEVs used in the tests. Specific performance claim is listed in Table 2-2.

Table 2-2 Specific performance claims by the proposer on flow reduction compared to no CEV installed in well.

CEV model	Orifice diameter (Ø) (mm)	Flow reduction factor at H_{design}
CEV 1.4l/s @ 1.00m – 100%	Diameter corresponding to CEV 1.4l/s @ 1.00m – 100% outlet	4.25

3 Evaluation

Detailed descriptions of the test design and test results are found in the Test Plan (Appendix C) and Test Report (Appendix D).

3.1 Calculation of verification parameters performance

Detailed information on how to calculate the verification parameters are included in the Specific Verification Protocol in Appendix B.

3.2 Evaluation of test quality

3.2.1 Control data

Test system control included leakage test and for CEV1.4l/s @ H=1.00m – 100% investigation of the variation was included for tests carried out with identical inlet flows. The variation was minimal and far less than 10 %, which means - according to the Verification Protocol (Appendix B), section 5.1.4 - that triplicate tests were not needed for the remaining CEVs.

Test performance audit included review of calibration certificates for pressure transducers and flowmeters. They are valid and can be found in Appendix to the Test Plan (Appendix C). In addition calibration tests were performed of pressure transducers on both inlet and outlet side.

The outflow could not be measured directly due to air and circulation in the outlet. Instead measurement of head in the outlet tank and of the overflow from the outlet tank where measured. The calculation two different methods were listed , see Appendix B section 6.1 Calculation of performance parameters. Method 2 was expected to most precise, while method should be used for control. For method 1the time series had to be subjected to intensive averaging to get readable results. A comparison between the results obtained by means of method 1 and method 2 for one of the model tests has been performed. The results are shown in the Appendix D of the Test Report (Appendix D to this report). It appears that there is, apart from the fluctuations, a good agreement between the two methods. However, since the quality of the results with method 2 was very reliable and, while the results obtained by means of method 1 are subject to large fluctuations, it was chosen to use method 2 only.

3.2.2 Audits

During testing and internal test, a system audit was performed by Jesper Fuchs from DHI on 29 September 2014. The verification body ETA Denmark, represented by Peter Fritzel, performed a test system audit on 2 October 2014.

Conclusions of the internal audit (Jesper Fuchs):

“The test is performed in accordance with the test plan and carried out in a safe manner. Handling and storage of data is safe”.

Conclusions of the audit by ETA Denmark (Peter Fritzel):

“There is consistency with the test plan and handling of measurements is carried out in a safe manner”.

The full audit reports can be found in Appendix E.

3.2.3 Deviations

There were four deviations to the test plan. The description of these can be found in full in Appendix C of the Test Report included as Appendix E to this report. A summary of the deviations is as follows:

1. Instead of establishing the zero level in the inlet tank for each test, a common zero scan was performed for each CEV type. This zero scan was carried out as an individual test instead of an integrated part of each test.

2. The lowest inflow in the tests with CEV 1.4l/s @ 1.0m was carried out with too low inflow, 1.79l/s instead of 1.9l/s. With good accuracy the inlet flow, which will result in a water level rise of 0.5mm/s, can be found by interpolation. Such interpolation shows that an inflow of approximately 2.8l/s will result in a water level rise of 0.5mm/s. The corresponding Qbump would be approximately 1.28l/s (see Figure 3.8 in Test Report (Appendix E)).

3. For all 100% CEVs the largest inflows gave larger water level rise than 1.5mm/s, which was the largest water level rise to be tested and a predefined operational parameter. During the test attempt was made to come close to 1.5 mm/s, but due to the character of the curve, with the rapid bump, it was difficult in advance to estimate the water level rise. With good accuracy the inlet flows, which will result in a water level rise of 1.5mm/s, can be found by interpolation. Doing this is it nice to have a measured values of water level rise is above 1.5 mm/s. Interpolations show for:

   - CEV 1.4l/s @ 1.0m that such a water level rise would be obtained for an inflow of approximately 6.1l/s. The corresponding Qbump would be approximately 1.44l/s (see Figure 3.8 in the Test Report (Appendix E))

   - CEV 4.9l/s @ 1.5m that such a water level rise would be obtained for an inflow of approximately 9.2l/s. The corresponding Qbump would be approximately 4.93l/s (see Figure 3.12 in Test Report (Appendix E))

   - CEV 10.5l/s @ 2.0m that such a water level rise would be obtained for an inflow of approximately 13.9l/s. The corresponding Qbump would be approximately 10.4l/s (see Figure 3.16 in Test Report (Appendix E))

4. The test with the orifice was carried out with a larger inflow than predefined. This was done, as the Q – H relation for an orifice is independent of the water level increase, which also is documented by comparing with the theoretical relation, see Figure 3.23 in the Test Report (Appendix E).

3.3 Verification results

3.3.1 Performance parameters

The verified performance for the two parameters is listed below. The results are transferred directly from the Test Report (Appendix E).

3.3.2 Flow at H_{bump} and H_{design}

Specific performance for each of the four selected CEVs is listed in Table 3-1 and Table 3-2.

Table 3-1 Verified performance on Q_{bump}. +) Be aware that the results of Q_{bump} are uniquely influenced by Q_{inflow}, see later.*) For this flow the water level rise was only 0.19 mm/s, while the operational requirement was >0.5 mm/s, this is an explanation for the deviation from the expected.

CEV model	Inflow in test (l/s)	Q_{bump} (l/s)	Deviation from model characteristics (%)

		Mean+	Range	
CEV 1.4l/s @ 1.00m – 100%	1.79 to 6.31	1.34	1.22* – 1.45	-4.3 (-13* – 3.6)
CEV 4.9l/s @ 1.50 m – 100%	5.89 to 9.99	4.74	4.50 – 5.04	-3.3 (-8.2 – 2.9)
CEV 10.5l/s @ 2.00m – 78%	8.60 to 12.97	8.17	7.57 – 8.74	-0.2 (-7.6 – 6.7)
CEV 10.5l/s @ 2.00m – 100%	11.32 to 15.24	10.18	9.75 – 10.67	-3.0 (-7.1 – 1.6)

Table 3-2 Verified performance on Q_{design}. *) based on two tests only.

CEV model	Inflow in test (l/s)	Q_{design} (l/s)		Deviation from model characteristics (%)
		Mean	Range	
CEV 1.4l/s @ 1.00m – 100%	1.79 to 6.31	1.43	1.42 – 1.45	2.1 (1.4 – 3.6)
CEV 4.9l/s @ 1.50 m – 100%	5.89 to 9.99	4.78	4-76 – 4.80	-2.4 (-2.9 – (-2.0))
CEV 10.5l/s @ 2.00m – 78%	8.60 to 12.97	10.11	10.09 – 10.12*	-3.7 (-3.9 – (-3.6))
CEV 10.5l/s @ 2.00m – 100%	11.32 to 15.24	10.56	10.55 – 10.56	0.6 (0.5 – 0.6)
Orifice	13.72	6.36	N/A	N/A

Please be aware that there is a unique influence of Q_{bumb} by Q_{inflow}, see Figure 3-1.

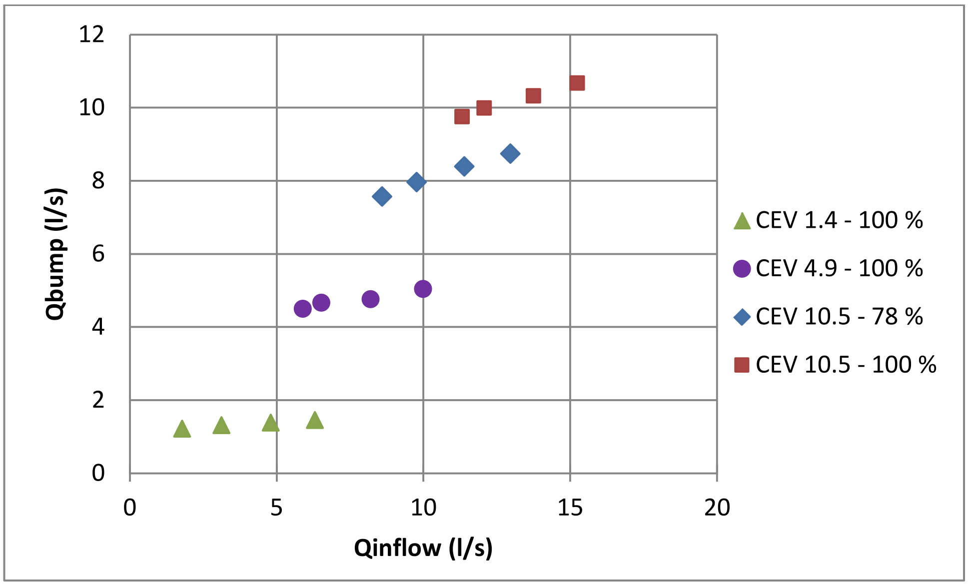


Figure 3-1 Correlation between Q_{inflow} and Q_{bump} given for all tested CEVs.

3.3.3 Flow reduction at H_{design}

Performance compared to a well with no flow regulator is listed in Table 3-3.

Table 3-3 Verified performance on flow reduction compared to no CEV installed in well.

CEV model	Orifice diameter (Ø) (mm)	Flow reduction factor at H_{design}
CEV 1.4l/s @ 1.00m – 100%	Diameter corresponding to CEV 1.4l/s @ 1.00m – 100% outlet	4.45

Mosbaek CEV 1.4l/s@1.00m - 100 % is verified to reduce the flow by a factor of 4.45 at Q_{design}.

3.3.4 Operational parameters

During operation the following parameters were measured:

- Inflow (l/s)
- Water level/pressure in regulator well (mH_2O/Pa)
- Water level/pressure in the outlet tank (mH_2O/Pa)
- Outlet from the outlet tank (l/s)

These data have created curves shown in the Test Report, section 3 Test results (Appendix E).

During the test the average water level must be within 0.5 and 1.5mm/s, since this is common values in runoff systems.

3.3.5 Additional parameters

3.3.5.1 User manual

The verification criterion for the user manual is that the manual describes the use of the equipment adequately and is understandable for the typical test coordinator and test technician. This criterion was based on a number of specific points of importance, see Table 3-4 for the parameters to be included.

A description is complete if all essential steps are described, if they are illustrated by a figure or a photo, where relevant, and if the descriptions are understandable without reference to other guidance.

Mosbaek has provided:

- Centrifugal valve CE/V wet mounted (General information)
- Installation Instruction. Mosbaek Flow Regulators. Type CEV-KPS – Sealing
- Maintenance and Inspection Instructions. Mosbaek Flow Regulators. Type CEV-KPS – Sealing

Table 3-4 Evaluation of user manual.

Parameter	Complete description	Summary description	No description	Not relevant
Product				
Principle of operation		√		
Intended use		√		
Performance expected	√			
Limitations		√		
Preparations				
Unpacking			√	
Transport			√	
Assembly	√			
Installation	√			
Function test	√			
Operation				
Steps of operation		√		
Points of caution		√		
Accessories		√		
Maintenance	√			
Trouble shooting		√		
Safety				
Chemicals				√
Power				√

3.3.5.2 Required resources

The capital investment and the resources for operation and maintenance could be seen as the sustainability of the product and will be itemized based upon a determined design [3], see Table 3-5for the items that will be included.

The design basis consists of one installed CEV in an existing well. All cost items relevant for the Mosbaek CEVs are listed. Note that the actual cost for each item is not compiled and reported.

Table 3-5 List of capital cost items and operation and maintenance cost items per product unit.

Item type	Item	Number/duration
Capital		
Site preparation	None	
Buildings and land	None	
Equipment	The CEV and mounting from Mosbaek Tightening material and bolts	1
Utility connections	Rain water sewer system and wells	1
Installation	To be installed by sewer contractor	1 day
Start up/training		
Permits	None	
Operation and maintenance		
Materials, including chemicals	None	
Utilities, including water and energy	None	
Labor	Regular inspection and drainage of sump/sand catcher	1 day
Waste management	Sump/sand	As for other wells with no CEV
Permit compliance	None	

Evaluation of the following subjects has been performed based on information gained from Mosbaek:

- <u>*Resources used during production of the equipment in the technology*</u>

  The CEV and their mounting are produced from stainless steel, grade 1.4404/316L.

  For the tested products incl. mounting the weights are:

  CEV 1.4l/s@1.0m 100% : 5.9 kg

  CEV 4.9l/s@1.5m 100%: 11.5kg

  CEV 10.5l/s@2.0m 78%: 21.5kg

  CEV 10.5l/s@2.0m 100%: 25.1kg

  80% of the steel on the world market is reused material. The main part of the steel in Denmark is imported from other European countries, while the rest is mainly from Taiwan, India and China. Depending on the distance the freight is by ship or by truck. For the European marked the transport is mainly by truck. Mosbaek purchases steel from Danish distributors such as: Dacapo Stainless, Lemvigh-Müller, Sanistål and Dam-stahl.

  The average energy consumption for the final product is 4.1kWh/kg.

- <u>*Longevity of the equipment*</u>

  The regulators are designed to last as long as the other components in a sewage system, approx. 50 years. A regulator will not need to be replaced unless inspection shows considerable wear and tear.

- <u>*Robustness/vulnerability to changing conditions of use or maintenance*</u>

  The regulator is robust to changes in temperature and environment. A steeper slope on the characteristic curve gives robustness towards changes in pressure head. Larger orifice opening, compared to other competing solutions, give robustness with respect to clogging. Maintenance scheme should be adjusted according to changes in condition concerning the quality of the water. Maintenance is a visual check of the condition of the regulator and to remove signs of clogging.

- *Reusability, recyclability (fully or partly) and end of life decommissioning and disposal*

  A regulator can be reused in another location with similar conditions or adjusted to fit other conditions. If reuse is not possible, the regulator can be sold as scrap and molten into new steel. It is 100% is recyclable.

3.3.5.3 Occupational health and environmental impact

The risks for occupational health and for the environment associated with the use of the products will be identified. A list of chemicals classified as toxic (T) or very toxic (Tx) for human health and/or environmentally hazardous (N) (in accordance with the directive on classification of dangerous substances [4]) will be compiled. The tightening material used for installation is chosen by the sewer contractor. The mainly used material is sealant tape or waterproof silicone, which are both unclassified.

All operations in wells are subject to safety risk, and standard safety precautions have to be taken accordingly.

3.4 Recommendation for the Statement of Verification

3.4.1 Technology description

The technology verified is the vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical) from Mosbaek. The flow regulator technology for extreme rainfall events is based on quickly reaching the maximum discharge flow, where it creates a vortex making it stay at or below this discharge flow while the remaining water is stored in the well. A schematic view of the CEV with inflow in the bottom is shown in Figure 3-2a.

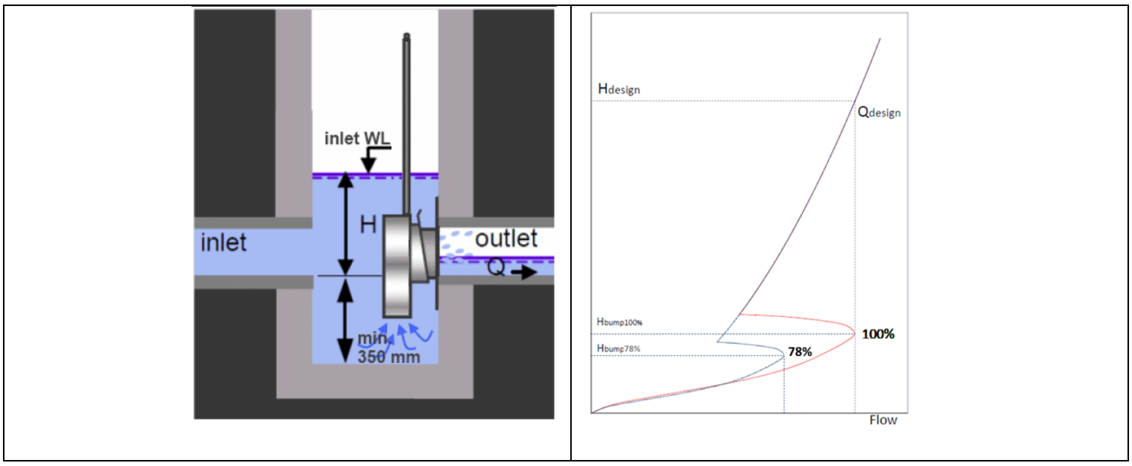


Figure 3-2 A) Sketch of CEV flow regulator installed in well. B) Graphic showing the general vortex brake effect on water outflow, with CEVs operating at 78% and 100% efficiency and water inflow to well larger than outflow though CEV (well is filling up). Both provided by Mosbaek.

Figure 3-2b shows the flow through a CEV. With a 100% model, the maximum outlet (Q_{design}) is met twice, first where the vortex is formed (the bump on the graph) and then at the specified H_{design}, where H_{design} is calculated from the invert of the discharge pipe to the maximum water level in the well. A 78% model is also shown; here the bump occurs at a flow of 78% of Q_{design}.

Mosbaek has selected four models to represent their CEV-series. The models are;

- CEV 1.4l/s @ 1.00m – 100%
- CEV 4.9l/s @ 1.50 m – 100%
- CEV 10.5l/s @ 2.00m – 78%

- CEV 10.5l/s @ 2.00m – 100%

3.4.2 Application

3.4.2.1 Matrix

The CEV is installed before the combined system (with storm water and wastewater) and is restricting storm water inflow to the combined system. The verification covers storm water.

3.4.2.2 Purpose

The purpose of the technology is to store storm water at appropriate places before entering the piping system during storm water events. The CEV is installed in wells and basins depending on the piping network.

3.4.2.3 Conditions of operation and use

Maintenance is needed regularly as a visual check of the condition of the regulator and to remove signs of clogging.

3.4.2.4 Verification parameters definition summary

Two types of parameters have been verified:

1. Outflow (l/s) at H_{bump} and H_{design}
2. Flow reduction at H_{design}

3.4.3 Test and analysis design

The test was designed for this verification. No existing data have been included.

3.4.3.1 Laboratory or field conditions

The test was performed at a test set-up at Mosbaek's premises in Koege, Denmark, see Figure 3-3.

The figure is suggested to be an appendix to the Statement of Verification.

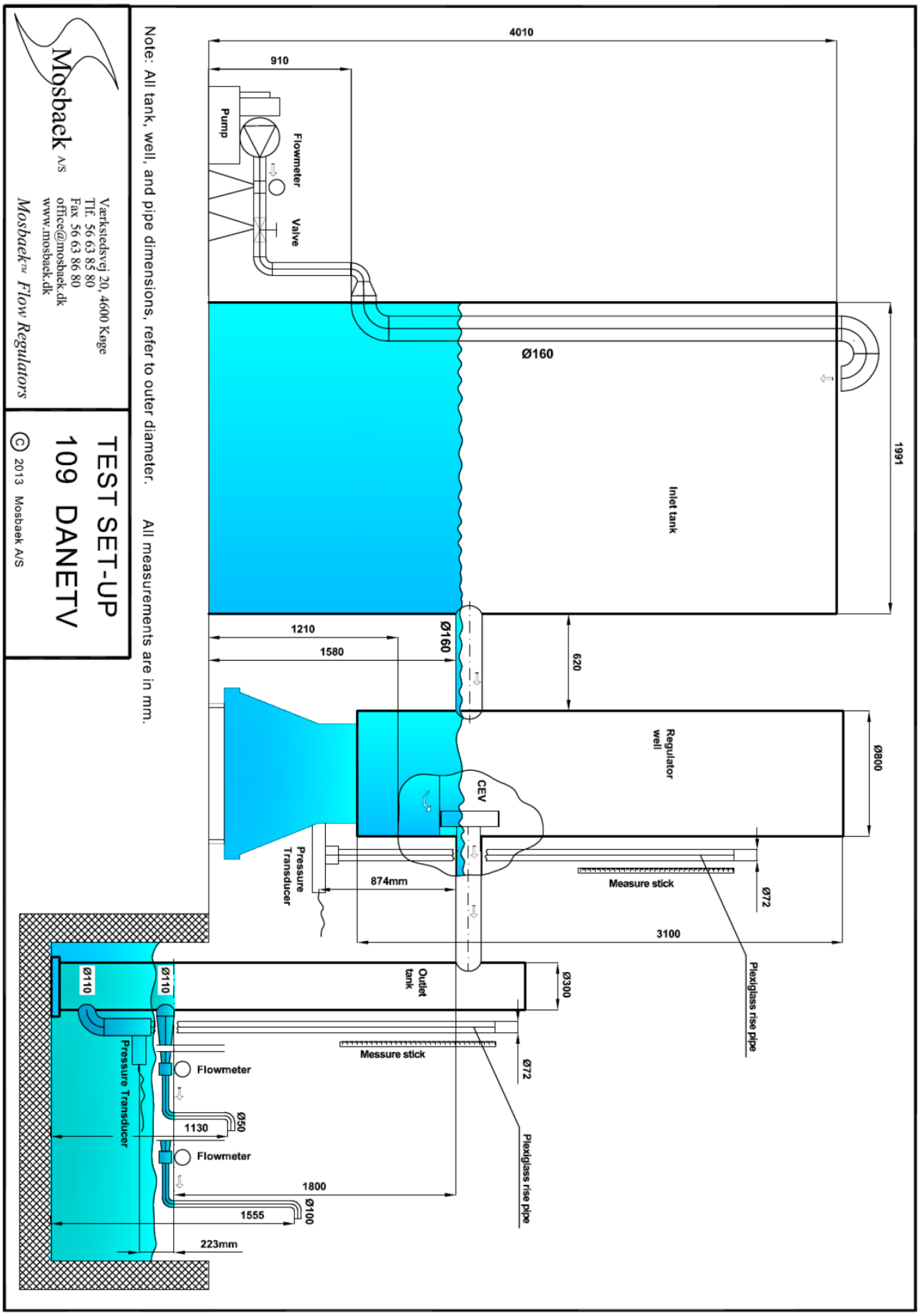


Figure 3-3 Sketch of test set-up.

The set-up consists of a well (regulator well) placed on a base; the CEV regulator is mounted in this well. The regulator well is in direct connection with a large diameter tank (inlet tank), through a pipe, positioned just opposite the CEV outlet. The water levels in the regulator well and the inlet tank are accordingly identical. This set-up is established in order to secure that the increase of the water level in the regulator well can be controlled and limited still with a reasonable high flow rate to the well. The outlet connection goes through the CEV in the regulator well to the outlet tank. A pressure transducer is mounted in the base of the regulator well. On the base of the regulator well, a Plexiglas riser is mounted in order to follow the water level in the well during testing.

The flow to the inlet tank is fed at the top of the tank through a pipe placed internally in the tank by means of a pump, which is pumping water from a feeding tank. The flow from the feeding tank to the inlet tank is measured by means of the flowmeter. The water level in the feeding tank is kept constant by pumping water from a central reservoir to the feeding tank; an overflow weir ensures that the water level in this tank is kept almost constant. In this way, it is possible to keep an almost constant pressure head at the pump and thus an almost constant flow.

From the regulator well, the water flows through the CEV to the outlet tank. The outlet tank has a pressure transducer monitoring the water level in this tank. The outlet flow from the outlet tank is measured by means of a flowmeter.

3.4.3.2 Matrix composition

The used water is from an outdoor reservoir.

3.4.3.3 Test and analysis parameters

The following test-runs were performed.

CEV model	Flow 1	Flow 2	Flow 3	Flow 4	Flow 4'	Flow 4"
CEV 1.4l/s @ 1.00m – 100%	1.79	3.12	4.80	6.31	6.18	6.25
CEV 4.9l/s @ 1.50 m – 100%	5.89	6.52	8.20	9.99		
CEV 10.5l/s @ 2.00m – 78%	8.60	9.77	11.40	12.97		
CEV 10.5l/s @ 2.00m – 100%	11.32	12.07	13.75	15.24		
Orifice	13.72					

Tests of the performance at H_{bump} and H_{design} are marked in light orange.

Test of the flow reduction at H_{design} is done by comparing the results from the hatched test runs.

The repetition of CEV 1.4l/s @ 1.00m – 100% (dark blue marking) is done to see if there is more than 10 % variation between runs with the same flow. There was very limited variation; therefore the repetition was not done for other test runs.

3.4.3.4 Test and analysis methods summary

The inflow and outflow from the CEV was measured by the use of flowmeters and pressure transducers as described above.

3.4.3.5 Parameters measured

- Inflow (l/s)
- Water level/pressure in regulator well (mH_2O/Pa)
- Water level/pressure in the outlet tank (mH_2O/Pa)
- Outlet from the outlet tank (l/s)

Outflow from CEV is calculated by using the following equation:

$$Q_{outflow} = Q_{overflow} + \frac{\Delta Hout \times Aout \times 1000}{\Delta t}$$

$Q_{outflow}$: Flow out of CEV (l/s)
$Q_{overflow}$: Overflow from the outlet tank (l/s)
A_{out}: Surface area in the outlet tank+riser (m^2)
H_{out} : Pressure head in the outlet tank (mH_2O)
Δt: Time for changing H_{out} with ΔH_{out} (s)

3.4.4 Verification results

3.4.4.1 Performance parameters

The results of the verification with regards to flow at H_{bump} (Q_{bump}) and at H_{design} (Q_{design}) are listed in the table.

Based on the results from a test with 1.4l/s@1.00m - 100 % and a corresponding orifice, it can be stated that Mosbaek CEVs are verified to reduce the flow by a factor of 4.45 at Q_{design}.

CEV model	Q_{bump}		Q_{design}	
	Mean+ and range (l/s)	Deviation from model charac-teristics (%)	Mean and range (l/s)	Deviation from model character-istics (%)
CEV 1.4l/s @ 1.00m – 100%	1.34 (1.22* – 1.45)	-4.3 (-13* – 3.6)	1.43 (1.42 – 1.45)	2.1 (1.4 – 3.6)
CEV 4.9l/s @ 1.50 m – 100%	4.74 (4.50 – 5.04)	-3.3 (-8.2 – 2.9)	4.78 (4.76 – 4.80)	-2.4 (-2.9 – (-2.0))
CEV 10.5l/s @ 2.00m – 78%	8.17 (7.57 – 8.74)	-0.2 (-7.6 – 6.7)	10.11 (10.09 – 10.12)#	-3.7 (-3.9 – (-3.6))
CEV 10.5l/s @ 2.00m – 100%	10.18 (9.75 – 10.67)	-3.0 (-7.1 – 1.6)	10.56 (10.55 – 10.56)	0.6 (0.5 – 0.6)
Orifice	N/A	N/A	6.36	N/A

+) Be aware that the results of Q_{bump} are uniquely influenced by Q_{inflow}

*) For this flow the water level rise was only 0.19 mm/s, while the operational requirement was >0.5 mm/s, this is an explanation for the deviation from the expected.

#) Based on two tests only.

3.4.4.2 Operational parameters

No additional operational parameters than the performance parameters were measured.

This subchapter will therefore not be included in the Statement of Verification.

3.4.4.3 Environmental parameters

No additional environmental parameters than the performance parameters were measured.

This subchapter will therefore not be included in the Statement of Verification.

3.4.4.4 Additional parameters

The user manual and other descriptions were described as complete.

Application of the CEV does not give rise to any special risk or contact to hazardous substances. Though installation in the well is subject to safety risk as all operations in wells, and standard safety precautions therefore have to be taken accordingly.

The CEVs are produced of stainless steel. Today 80 % of the stainless steel on the marked is re-cycled. It is imported from Europe and certain places in Asia. The tested CEVs contain from 6-25 kg stainless steel, and 4.1kWh/kg steel is used in the production. The CEVs are reusable or 100 % recyclable. They have a lifetime of 50 years. The above information is obtained from Mosbaek A/S.

3.4.5 Additional information

The CEV is designed to be effective within a flow range until a certain amount of water is stored in the connected well or basin. This means that if a storm water event exceeds the design criteria, the well or basin where the CEV is located will float over. This situation is not included in the verification.

The CEV is designed with the largest possible opening at the given hydraulic situation. The CEV is most often installed as detachable and if required, obstacles can be removed in this way. At locations with many obstacles in the water, the CEV can be equipped with a grid. All tests are carried out with water without obstacles.

Industrial wastewater and backwater (backwards flow through the CEV) are not included, nor are rapid changes in head and flow. Such changes may occur in special situations (e.g. if pumps are started or stopped).

Characteristics obtained from the experiments are only 100 % valid for applications which have full geometric similarity with the set up defined in Figure 3-2a. For applications with geometries which differ from this figure, the actual characteristic can deviate from the characteristic found from the verification experiment.

3.4.6 Quality assurance and deviations

Prior to testing was performed leakage test and review of calibration certificates for pressure transducers and flowmeters. In addition, calibration tests of pressure transducers were performed on both inlet and outlet side. During testing, internal and external test system audits were performed by DHI and ETA Danmark.

4 Quality assurance

The personnel and experts responsible for quality assurance as well as the different quality assurance tasks can be seen in Table 4-1. All relevant reviews are prepared using the DANETV review report template [5]. Audit during testing has been performed.

Table 4-1 QA plan for the verification

	Internal expert	Verification body		Proposer	External experts
Initials	MJK	MTA	PF	Mosbaek	TL/IW
Tasks					
Specific verification protocol	Review			Review and approve	Review
Test plan		Review	Approve	Review and approve	
Test system at test site			Audit		
Test report		Review		Review	
Verification report	Review			Review	Review
Statement of Verification				Acceptance	Review

Internal review was conducted by Morten Just Kjølby (MJK) and a test system audit was conducted following general audit procedures by certified auditor Peter Fritzel (PF).

Only the verification protocol and verification report require external review according to EU ETV pilot programme GVP [1]. For the verification protocol, external review was performed by Torben Larsen (TL), while the verification report and Statement of Verification have been reviewed by Ian Walker (IW).

The verification body has reviewed and approved the test plan and reviewed the test report. The reviews were performed by Mette Tjener Andersson (MTA), while the approval was given by Peter Fritzel (PF).

5 References

1. EU Environmental Technology Verification pilot programme. General Verification Protocol. Version 1.1 – July 7th, 2014.
2. ETA Danmark. ETV – Verifikation. I30.11, Environmental Technology Verification. 20-11-2013.
3. Gavaskar, A. and Cumming, L.: Cost Evaluation Strategies for Technologies Tested under the Environmental Technology Verification Program. 2001. Battelle.
4. European Commission: Commission Directive on classification, packaging and labelling of dangerous substances. 2001/59/EC. 2001.
5. DANETV Test Centre Quality Manual, 2013.08.13

APPENDICES

APPENDIX A

Terms and definitions

The terms and definitions used by the verification body are derived from the EU ETV General Verification Protocol, ISO 9001 and ISO 17020.

Term	DANETV	Comments on the DANETV approach
Accreditation	Meaning as assigned to it by Regulation (EC) No 765/2008	EC No 765/2008 is on setting out the requirements for accreditation and market surveillance relating to the marketing of products
Additional parameter	Other effects that will be described but are considered secondary	None
Amendment	Is a change to a specific verification protocol or a test plan done before the verification or test step is performed	None
Application	The use of a product specified with respect to matrix, purpose (target and effect) and limitations	The application must be defined with a precision that allows the user of a product verification to judge whether his needs are comparable to the verification conditions
DANETV	Danish centre for verification of environmental technologies	None
Deviation	Is a change to a specific verification protocol or a test plan done during the verification or test step performance	None
Evaluation	Evaluation of test data for a technology product for performance and data quality	None
Experts	Independent persons qualified on a technology in verification	These experts may be technical experts, QA experts for other ETV systems or regulatory experts
General verification protocol (GVP)	Description of the principles and general procedure to be followed by the EU ETV pilot programme when verifying an individual environmental technology.	None
Matrix	The type of material that the technology is intended for	Matrices could be soil, drinking water, ground water, degreasing bath, exhaust gas condensate etc.
Operational parameter	Measurable parameters that define the application and the verification and test conditions. Operational parameters could be production capacity, concentrations of non-target compounds in matrix etc.	None
(Initial) performance claim	Proposer claimed technical specifications of product. Shall state the conditions of use under which the claim is applicable and mention any relevant assumption made	The proposer claims shall be included in the ETV proposal. The initial claims can be developed as part of the quick scan.

Term	DANETV	Comments on the DANETV approach
Performance parameters (revised performance claims)	A set of quantified technical specifications representative of the technical performance and potential environmental impacts of a technology in a specified application and under specified conditions of testing or use (operational parameters).	The performance parameters must be established considering the application(s) of the product, the requirements of society (legislative regulations), customers (needs) and proposer initial performance claims
Procedure	Detailed description of the use of a standard or a method within one body	The procedure specifies implementing a standard or a method in terms of e.g.: equipment used
Proposer	Any legal entity or natural, which can be the technology manufacturer or an authorised representative of the technology manufacturer. If the technology manufactures concerned agree, the proposer can be another stakeholder undertaking a specific verification programme involving several technologies.	Can be vendor or producer
Purpose	The measurable property that is affected by the product and how it is affected.	The purpose could be reduction of nitrate concentration, separation of volatile organic compounds, reduction of energy use (MW/kg) etc.
(Specific) verification protocol	Protocol describing the specific verification of a technology as developed applying the principles and procedures of the EU GVP and the quality manual of the verification body.	None
Standard	Generic document established by consensus and approved by a recognised standardization body that provides rules, guidelines or characteristics for tests or analysis	None
Test/testing	Determination of the performance of a product for measurement/parameters defined for the application	None
Test performance audit	Quantitative evaluation of a measurement system as used in a specific test.	E.g. evaluation of laboratory control data for relevant period (precision under repeatability conditions, trueness), evaluation of data from laboratory participation in proficiency test and control of calibration of online measurement devises.
Test system audit	Qualitative on-site evaluation of test, sampling and/or measurement systems associated with a specific test.	E.g. evaluation of the testing done against the requirements of the specific verification protocol, the test plan and the quality manual of the test body.
Test system control	Control of the test system as used in a specific test.	E.g. test of stock solutions, evaluation of stability of operational and/or on-line analytical equipment, test of blanks and reference tech-

Term	DANETV	Comments on the DANETV approach
		nology tests.
Verification	Provision of objective evidence that the technical design of a given environmental technology ensures the fulfilment of a given performance claim in a specified application, taking any measurement uncertainty and relevant assumptions into consideration.	None

APPENDIX B

Specific Verification Protocol

Mosbaek CEV flow regulator

Specific Verification Protocol

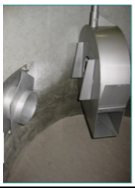
Specific Verification Protocol
February 2015

This report has been prepared under the DHI Business Management System certified by DNV to comply with		
Quality Management		
ISO 9001		
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S		

Approved by Sten Lindberg (Head of department, DHI)	Approved by Peter Fritzel (Verification responsible, ETA Danmark)

Mosbaek CEV flow regulator

Specific Verification Protocol



Prepared for **Mosbaek A/S**
Represented by **Torben Krejberg, Technical Director**

CEV flow regulator

Project No	11530013
Classification	Restricted
	Final version, rev. 3

Authors	Mette Tjener Andersson, DHI

Contents

Figures

Tables

Appendices

Archiving: All standard project files (documents, etc) are archived at ETA Danmark. Any other project files (set-up files, forcing data, model output, etc) are archived with the institute performing the tests or analysis.

1 Introduction

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application under defined conditions and quality assurance.

The objective of this verification is to evaluate the performance of a vertical centrifugal flow regulator for storm water.

1.1 Name of technology

Vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical), produced by Mosbaek A/S.

Mosbaek produces CEVs for flow capacities from 0.2 l/s to 80 l/s. The verification will cover verification test of four specific CEV dimensions within this range.

1.2 Name and contact of proposer

Mosbaek A/S
Værkstedsvej 20
4600 Køge
Denmark

Contact: Torben Krejberg, e-mail tk@mosbaek.dk, phone +45 5663 8580

Mosbaek website: www.mosbaek.dk

1.3 Name of verification body/verification responsible

ETA Danmark A/S
Göteborg Plads 1
2150 Nordhavn
Denmark

Verification responsible:
Peter Fritzel (PF), email: pf@etadanmark.dk, phone +45 7224 5900

Appointed verification expert:
Mette Tjener Andersson (MTA), e-mail mta@dhigroup.com, phone +45 4516 9148

1.4 Verification organisation including experts

The verification will be conducted by the ETA Danmark A/S in cooperation with Danish Centre for Verification of Climate and Environmental Technologies, DANETV, which performs independent verification of technologies and products for the reduction of climate changes and pollution.

The verification is planned and conducted to satisfy the requirements of the ETV scheme established by the European Union (EU ETV Pilot Programme) [1].

The verification will be coordinated and supervised by ETA Danmark, assisted by an appointed verification expert, while tests will be coordinated and supervised by DHI with the participation of the proposer, Mosbaek. The testing will be conducted in the workshop of Mosbaek in Køge, where a test facility has been constructed.

An internal and an external expert are assigned to provide independent expert review of the planning, conducting and reporting of the verification and tests:

- Internal technical expert: Morten Just Kjølby (MJK), DHI, Urban and Industry Dept., e-mail mjk@dhigroup.com
- External technical expert: Professor Torben Larsen (TL), Aalborg University, Department of Civil Engineering, tl@civil.aau.dk

The tasks assigned to each expert are given in more detail in section 8 Quality assurance.

The relationships between the organisations related to this verification and test are given in Figure 1-1.

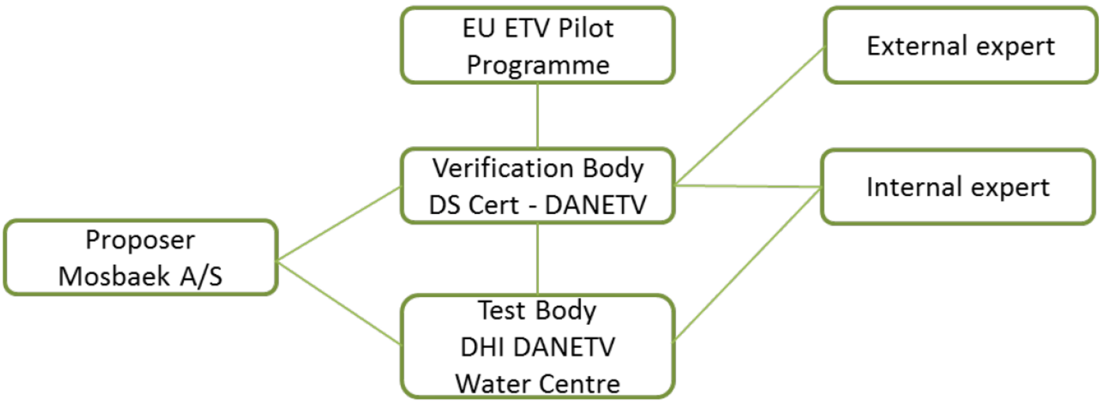


Figure 1-1 Organisation of the verification and test.

1.5 Verification process

The principles of operation of the DANETV verification process are given in Table 1-1. As it can be seen, verification and testing are divided between the verification and the test body.

Table 1-1 Simplified overview of the verification process.

Phase	Responsible	Document
Preliminary phase	Verification body	Quick Scan
		Contract
		Specific verification protocol
Testing phase	Test body	Test plan
		Test report
Assessment phase	Verification body	Verification report
		Statement of Verification

Quality assurance is carried out by an expert group of internal and external technical experts. Two audits of the test system will be performed, starting with an internal audit by the test body followed by an external audit by the DANETV verification body under ETA Danmark. Reference for the verification process is the EU ETV General Verification Protocol [1] and ETA Danmarks internal procedure [2]. A Statement of Verification will be issued by the DANETV verification body after completion of the verification. The final verification report will include the other documents prepared as appendices

2 Overall description of technology group/technology type

Extreme rainfall events are often characterised by being short and local, and for short periods causing full-flowing pipes conditions and surcharges to the surface or the recipients. The overload of the systems hydraulic capacity is expected to increase due to climate changes. One way of solving the problem can be to retain the excess water in other places of the system during the relevant time interval.

A flow regulator is efficient in most precipitation situations and does not require any installation of larger pipes or basins.

The flow regulator technology is based on quickly reaching the maximum discharge flow and staying at or below this value. The maximum discharge flow is the allowable amount of water passing through the regulator without causing any problems to the downstream pipe network.

Generally speaking, the purpose of a flow regulator is to protect the low-lying parts of the sewage system (downstream) against overloading and flooding. One of the specific qualities of the flow regulator is that it allows liquid to pass further down in the sewage system at a predetermined maximum amount per time unit, regardless of the variation in feed flow and the water level immediately before the regulator. Flow regulators can be applied inline in combined systems or before, restricting the amount of storm water before it enters the system, see Figure 2-1 for more details.

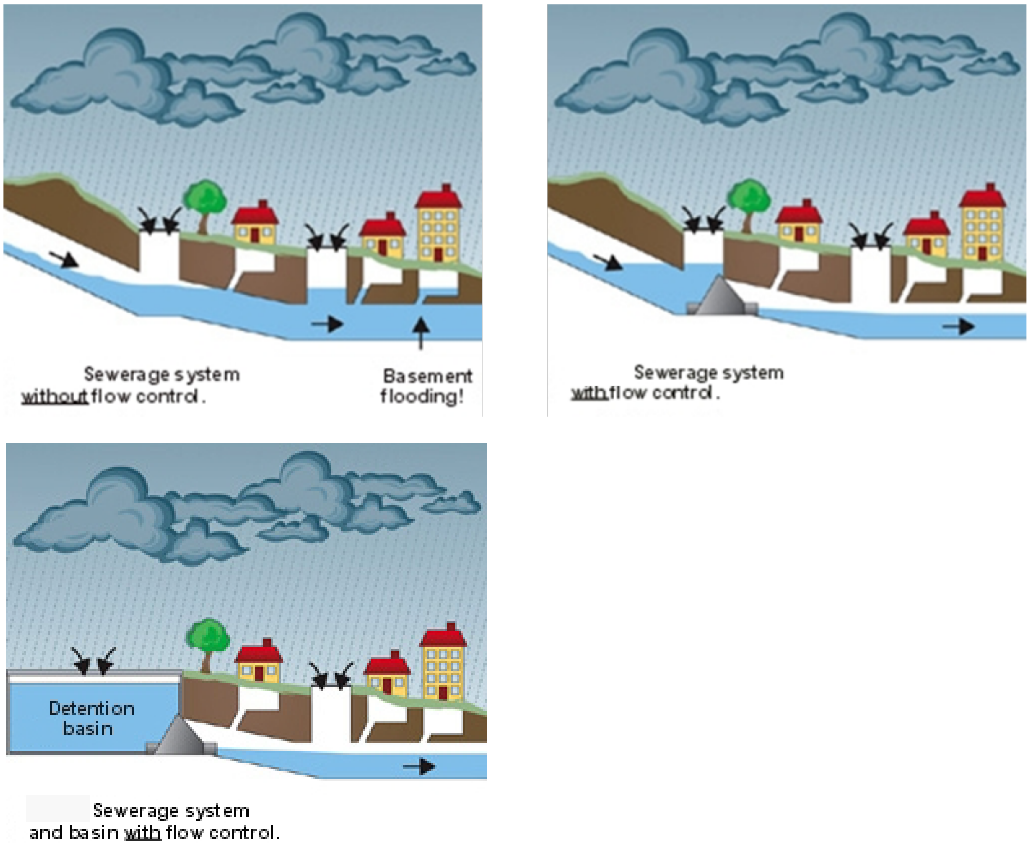


Figure 2-1 Sketch of sewerage system without and with flow regulator. Figures provided by Mosbaek.

3 Description of the specific technology for verification

The technology to be verified is the vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical) from Mosbaek. It is a wet mounted vortex flow regulator for storm water with design flows between 0.2-80 l/s.

The CEV regulates the water due to the vortex created when sufficient water flow is going through the unit. The vortex is created when the water flow reaches a certain flow rate. The vortex slows down the water flow through the CEV. In this way the water is stored in the well and the water flow is then kept almost constant. A schematic view of the CEV in operation is shown in Figure 3-1.

To avoid the risk of blocking and to minimise the need for service and maintenance the CEV is designed to have no moving parts. Furthermore, its passageway is large in order to minimise its resistance in normal, daily runoff situations.

During low flow conditions, water entering through the inlet of the CEV passes through the valve with negligible pressure drop. During high flow conditions, a vortex flow pattern develops within the CEV creating an air filled core. This phenomenon restricts and throttles flow through the device, creating back pressure immediately upstream of its discharge.

The CEV can be designed to fulfil different design criteria. The specific design criteria are defined by the client and Mosbaek in cooperation according to the design of the existing or planned piping network. The creation of the vortex in the CEV causes a speed reduction of the outflow, Q in Figure 3-1, allowing the well to be used for water storage during a storm event.

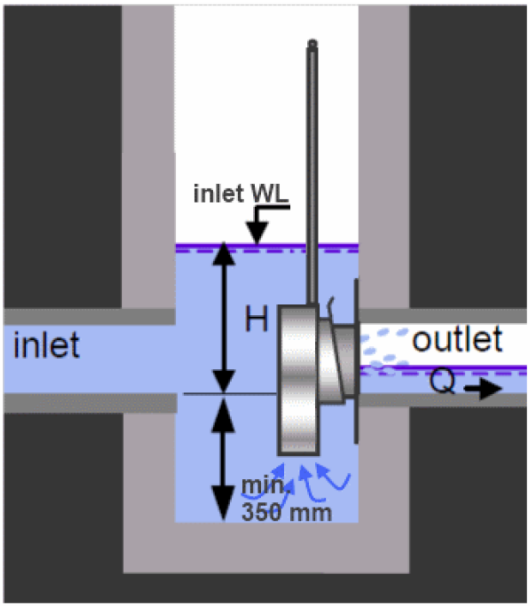


Figure 3-1 Sketch of CEV flow regulator installed in well. Sketch provided by Mosbaek.

The CEVs to be verified will have inflow in the bottom of the regulator, as shown in Figure 3-1, this is to ensure proper and equal hydraulic conditions. In addition Mosbaek will in a standard installation ensure that inlet and outlet are located at the same level in the well (as depicted on Figure 3-1). In order to be able to control the water level rise in the well optimally, the regulator well is connected to an inlet tank, so that the main part of the inlet flow is lead to the inlet tank, see also the sketch in Figure 3-2. As the regulator well and the inlet tank are direct connected the heads in the two compartments will be the same. This is done to ensure that the average increase of water level is kept within 0.5 and 1,5mm/s, which are common values in runoff systems. These conditions shall be used during testing.

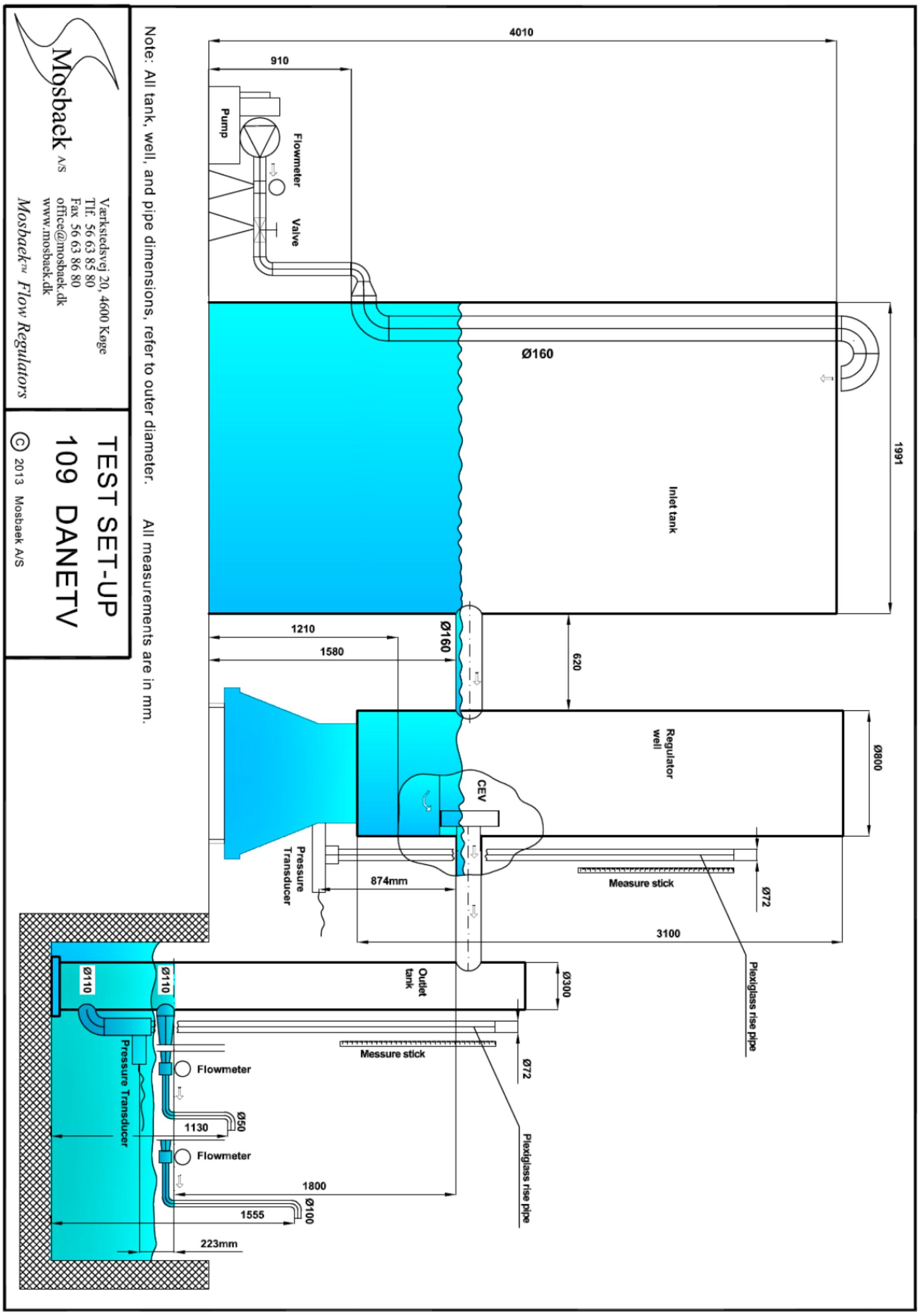


Figure 3-2 Schematic test set-up

Figure 3-3 shows the flow through a CEV. In the 100% case the maximum outlet (Q_{design}) is met twice, first where the vortex is formed (the bump on the graph) and then at the specified H_{design}, where H_{design} is calculated from the invert of the discharge pipe to the maximum water level in the well. A 78% case (a smaller CEV in a well with same height) with the same H_{design} is also shown; here the bump occurs at a flow of 78% of Q_{design}.

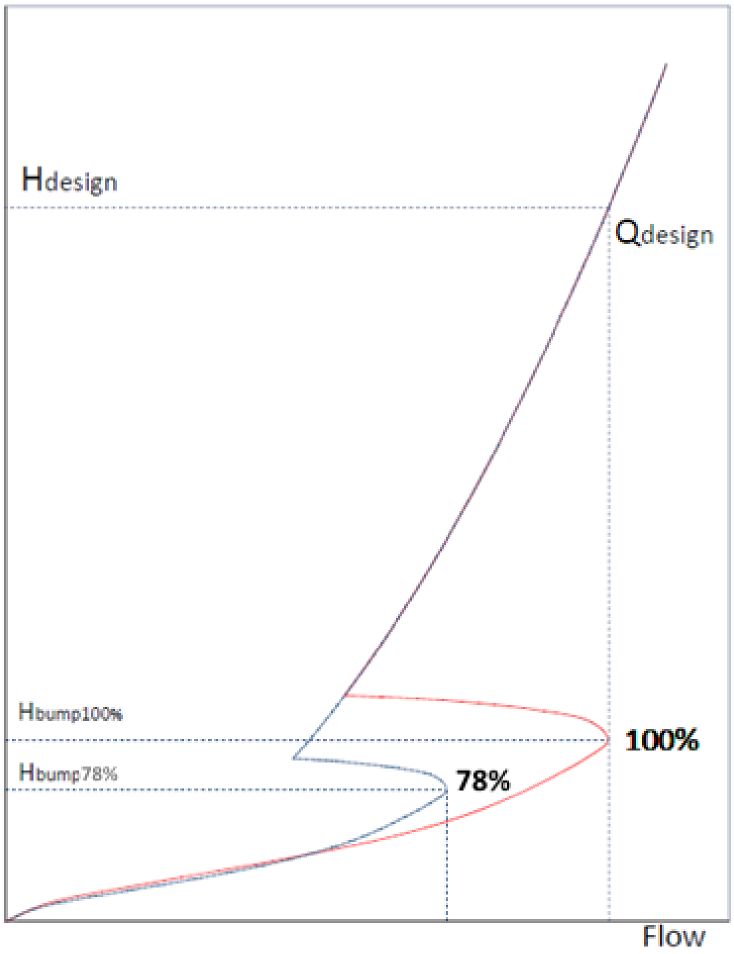


Figure 3-3 Graphic showing the general vortex brake effect on water outflow, with CEVs operating at 78%and 100% efficiency and water inflow to well larger than outflow though CEV (well is filling up). Graph provided by Mosbaek.

The optimal solution (100%), where Q_{bump} equals Q_{design}, gives less restriction at low heads allowing a better flow during normal operating situations and thereby less risk of blocking downstream.

Mosbaek have selected four specific CEV-models to represent their CEV technology, namely:

CEV 1.4l/s @ 1.00m – 100%
CEV 4.9l/s @ 1.50m – 100%
CEV 10.5/s @ 2.00m – 78%
CEV 10.5l/s @ 2.00m – 100%

The name of the CEV indicates the designed maximum flow of for example 1.4l/s and the correlating maximum pressure height of for example 1.00 m. The percentage (100% and 78%) indicates the percentage of the design flow at the point/bump where the vortex is formed.

In Figure 3-4 is shown the coverage of Mosbaeks CEVs, while the three selected flows and pressure heights for verification testing are pointed out.

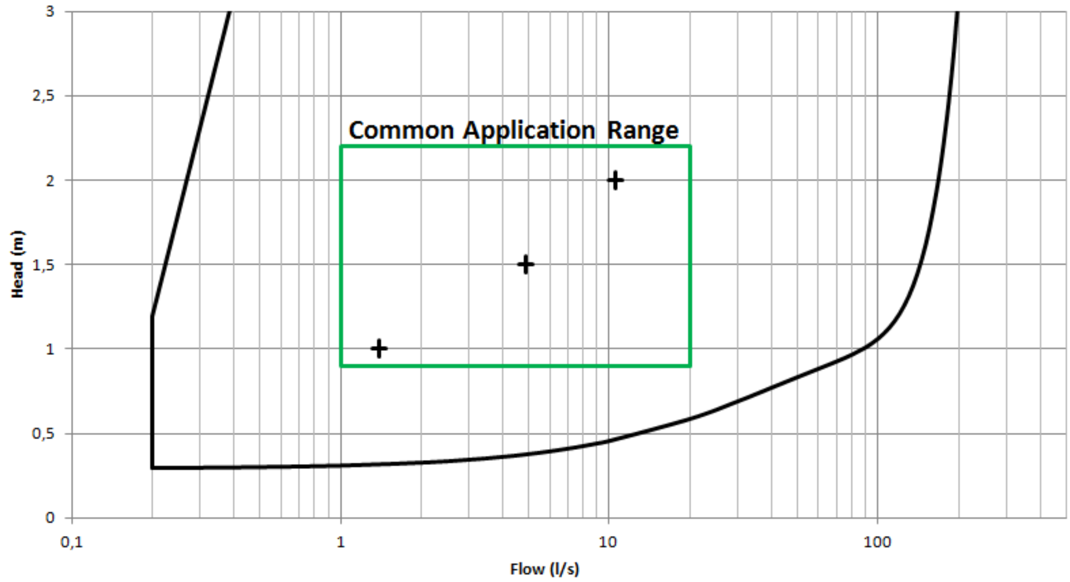


Figure 3-4 Coverage range of Mosbaek CEVs. The crosses mark the selected CEVs for verification testing CEV 1.4l/s @ 1.00m, CEV 4.9l/s @ 1.50m and CEV 10.5l/s @ 2.00m. Graph provided by Mosbaek.

3.1 Application and performance parameter definitions

The intended application of the technology for verification is defined in terms of the matrix and the purpose.

3.1.1 Matrix/matrices

The CEV is for storm water and certain types of industrial wastewaters. The CEV is installed before the combined system (with storm water and wastewater), and is thereby restricting the amount of storm water into the combined system. The verification therefore only covers the matrix storm water.

3.1.2 Purpose(s)

The purpose of the technology is to store storm water at appropriate places before entering the piping system during storm water events. The CEV is installed in wells and basins depending on the piping network.

3.1.3 Exclusions

The CEV is designed to be effective within a flow range until a certain amount of water is stored in the connected well or basin. This means that if a storm water event exceeds the design criteria, the well or basin where the CEV is located will float over. This situation is not included in the verification.

The CEV is designed with the largest possible opening at the given hydraulic situation. The CEV is most often installed as detachable and if required obstacles can in that way be removed. At locations with many obstacles in the water the CEV can be equipped with a grid. All tests are carried out with water without any obstacles.

As mentioned, industrial wastewater as matrix is not included, further is backwater (backwards flow through the CEV) not included nor is rapid changes in head and flow. Such changes may occur in special situations (e.g. if pumps are started or stopped).

Characteristics obtained from the experiments are only 100 % valid for applications which have full geometric similarity with the verification set up defined in figure 3–1. For applications with geometries which differs from this figure the actual characteristic can deviate from the characteristic found from the verification experiment.

3.2 Performance parameters for verification

The performance parameters for the verification comprise parameters describing for example the regulatory requirements or assessing the equipment performance, water quality and so on. Performance or quality parameters may include chemical, physical and biological parameters.

3.2.1 Initial vendor claims

Mosbaek has two types of claims for their CEVs.

3.2.1.1 Flow at H_{bump} and H_{design}

Mosbaek has specified the performance of four selected model of the CEV through performance graphs and specified the flowing specific claims[1]:

100% model: **Q_{design} ±5% is met at H_{bump} and H_{design}**

X% model: **X% of Q_{design} ±5% is met at H_{bump}**
Q_{design} ±5% is met at H_{design}

The graphs are included in Appendix B. Specific values for each of the four selected CEVs are listed in Table 3-1.

Table 3-1 Specific performance claims from the proposer on Q_{bump} and Q_{design}.

CEV model	Q_{bump} (l/s)	Q_{design} (l/s)
CEV 1.4l/s @ 1.00m – 100%	1.4 ±5%	1.4 ±5%
CEV 4.9l/s @ 1.50 m – 100%	4.9 ±5%	4.9 ±5%
CEV 10.5l/s @ 2.00m – 78%	8.2 ±5%	10.5 ±5%
CEV 10.5l/s @ 2.00m – 100%	10.5 ±5%	10.5 ±5%

3.2.1.2 Flow reduction at H_{design}

Secondly Mosbaek has specified their claimed reduction of the flow at H_{design} compared to a well with no flow regulator (equal to a hole in a straight wall, with no additional piping). The method to determine the reduction of the flow is shown in Figure 3-5.

[1] For details on the parameters Q_{design}, H_{bump} and H_{design} consult Figure 3-3 and the describing text.

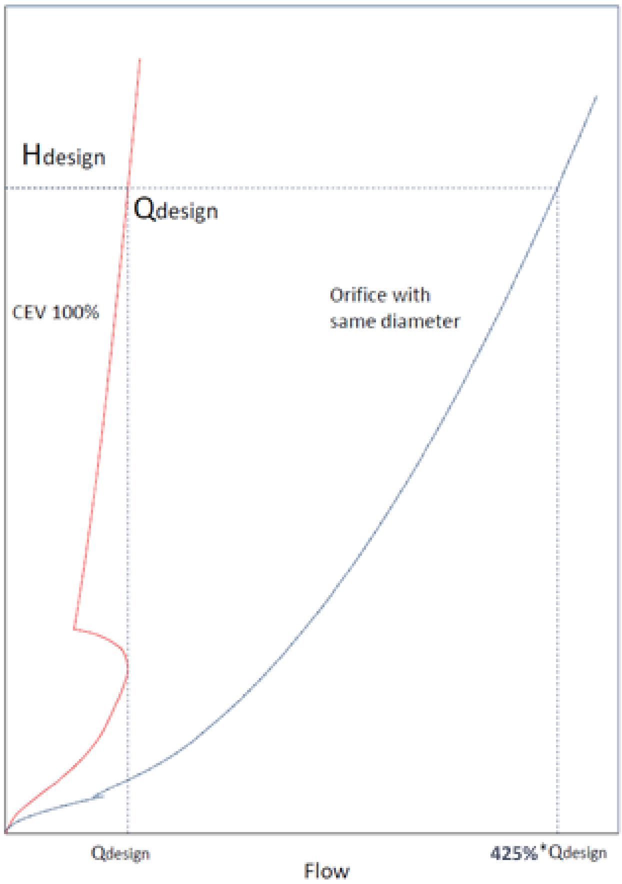


Figure 3-5 Outlet flow from well. Red curve is outflow through a 100% Mosbaek CEV, while dark blue line is outflow through an orifice with the same outlet diameter as the CEV. The curl on the dark blue line is the transition point from partly filled pipe to full pipe. Graph provided by Mosbaek.

Mosbaek claims the following:

A Mosbaek CEV 100% model can reduce the flow by a factor of 4.25 at Q_{design}

Perform tests where the test well is filled up to H_{design} with no CEV will require very high water flow which are not possible to have in the test set-up, except for the smallest of the CEVs to be tested. Therefor this claim will be verified using the smallest of the four CEVs used in the tests, specific performance claim is listed in Table 3-2.

Table 3-2 Specific performance claims by the proposer on flow reduction compared to no CEV installed in well.

CEV model	Orifice	Flow reduction factor at H_{design}
CEV 1.4l/s @ 1.00m – 100%	Diameter corresponding to the smallest opening of CEV 1.4l/s @ 1.00m – 100%	4.25

3.2.2 Regulatory requirements

There are no regulatory requirements for flow regulators.

3.2.3 Application based needs

For the user of the CEV it is important that the outflow is kept below a maximum flow rate (Q_{design}) for as long time as possible during a storm event.

According to Mosbaek pressure heights in standard well is between 1.1-2 m, while typical flows for such wells are 1-20 l/s, as indicated in Figure 3-4.

3.2.4 State-of-the-art performance

On the market there are several types of similar vertical flow regulators for storm water. Only one of the vendor homepages consulted have specified the performance towards Q_{design} for specific CEV models like Mosbaek has in Table 3-1. Umwelt und Fluid-Technik claims a precision of ±5 % on Q_{design} at the specified H_{design} [6].

Furthermore, two similar technologies have stated that they have been WRc approved [7,8]. The WRc-approval process includes [9]:

- A review of hydraulic performance, including hydraulic testing and Computational Fluid Dynamics (CFD).
- A review of the design procedure, including the suitability assessment of the mathematical modelling.
- An audit of production facilities, including a review of quality control procedures.
- An audit of installation procedures for flow regulator, including witnessing of installation and collection of feedback from end users.

One of the tests is described to be performed at flow rates of 5 and 20 l/s [9]. The WRc certificate states that the product meets the requirements - but unfortunately there is no reference to the requirements [7].

In addition, one of these technologies is BBA approved under the development phase [8,10]. None of the references include any specifications on the requirements for obtaining this approval.

Both WRc and BBA are national British approval programmes.

A few flow regulator producers have claimed that they have a larger outlet diameter than an orifice plate reducing the risk of blockage [11,12,13]. These numbers are ranging from a 200 to a 600% larger opening. However, the producers have not specified the corresponding flow reduction, compared to no flow regulator.

3.2.5 Selected performance parameters

There is no regulation to fulfil for this technology and no need has been found to add any additional performance parameters to those initially selected by the proposer. The initial claims from the proposer are matching the claims from other vendors. The performance claims are therefore selected to be the claims provided by the proposer and listed in Section 3.2 Performance parameters for verification.

3.3 Operational parameters

During operation the following parameters shall be measured:

- Inflow (l/s)
- Water level/pressure in regulator well (mH_2O/Pa)
- Water level/pressure in the outlet tank (mH_2O/Pa)
- Outflow from the outlet tank (l/s)

These data will be used to create curves similar to the claimed performance, included in Appendix B.

During the test the average water level must be within 0.5 and 1.5mm/s, since this is common values in runoff systems.

3.4 Additional parameters

Besides the performance parameters obtained by testing, a compilation of parameters describing the ease of understanding the user manual, required resources, and occupational health and environmental issues of the Mosbaek CEV is included in the verification.

4 Existing data

No existing CEV test data has been provided by Mosbaek for evaluation under this verification.

5 Requirements on test design and data quality

Based on the identification of application and performance parameters the requirements for the test design have been set. A detailed test plan will be prepared separately based on the specifications of the test requirements presented below. The test plan shall be prepared in accordance with the requirement and test plan template in the EU General Verification Protocol [1] and the DANETV Centre Quality Manual –Water technology [3].

5.1 Test design

At an early stage it has been considered whether the test should be performed in an existing well or in a designed well. It has been decided to construct designed wells where the testing can take place.

The test design is divided into five tasks. These are listed with objectives and overall work plan in Table 5-1 and detailed in section 5.1.1-5.1.5.

Table 5-1 Test design for this verification

Task Objective	1 Design of test facility	2 Installation of facility	3 Pre-testing	4 Verification testing	5 Documentation
Work plan	Determination of location	Installation of test wells	Test of facility	Test of CEV performance	Data management
	Identification of needed equipment and measurements devises	Installation of measuring devises	Test and calibration of measuring devises	On-line flow and water pressure measurements	Data quality

5.1.1 Task 1 - Design of test facility

Objective: The objective of this task is to determine where the test facility shall be located and to describe the test facility and the needed measuring devises.

Work plan: The design of the test facility comprises the following work items:

- Determination of the location of test wells
- Description of the equipment to be used during construction of the wells
- Description of the needed measuring devises
- Pattern of operation of the water pumping system, CEV and water outlet
- Pattern of operation of the measuring devises.

5.1.2 Task 2 - Installation of facility

Objective: The objective of this task is to have the wells and the measuring devices installed at the location.

Work plan: The installation of the test facility comprises the following work items:

- Installation of test wells
- Ensuring that water inlet and outlet is connected
- Installation of measuring devises and data-logging.

5.1.3 Task 3 – Pre-testing

Objective: The objective of this task is to have the regulator well and the measuring devises tested and ready for operation under the actual test.

Work plan: The pre-testing of the test facility comprises the following work items:

- Testing the regulator well filled with water for detection of possible leakages
- Testing operation of inlet and outlet water
- Control of and - if required - calibration of measuring devises
- Control that all four CEV-models can be installed correctly in the well
- Implementation of a test run of the planned verification test
- Final adjustments of the test facility.

5.1.4 Task 4 – Verification testing

Objective: The objective of this task is to test four selected CEVs. Based on on-line measurements of flow and water pressure (height) the performance is evaluated and verified.

Work plan: The verification testing of the CEVs comprises the following work items:

- Verification testing, including
  - 3 to 4 runs for each CEV-model, these shall be performed at different average rise of water level in the regulator well. The average rise in head in the test well shall be between 0.5 to 1.5 mm/s (which are common values in run off systems). To ensure a stable rise in head an inlet tank is installed parallel to the regulator well (see Figure 3-2).
  - To show variation one of the runs for one of the CEV-models must be repeated 3 times. If the variation of the triplicates is more than 10 % (e.g. in the bump), triplicate runs have to be made for the remaining CEV-models too.
  - A reference test with no CEV must be performed, see further information in Section 5.2.
  - The inflow is started in an empty regulator well. The inflow and outflow must continue until the design head, H_{design} for the actual CEV is reached, thereafter the well shall run empty.
- Online measurement and evaluation of the flows and water pressure during the test runs. The monitoring of outflow (e.g. as water pressure in collection tank), inflow and water pressure (height) in test manhole shall as far as possible continue through the whole test run.

5.1.5 Task 5 – Documentation of verification

Objective: The objective is to ensure proper documentation and data management during the verification testing.

Work plan: The documentation of the verification testing comprises the following work items:

- Use of amendment and deviation forms in case of changes to the developed test plan. Templates to be found in [3].

- Creation and use of a field logbook, where also deviations from the stated operating conditions (e.g. flow, pressure) must be documented.

- Appropriate storage of data from on-line measurements of flow and water pressure.

5.2 Reference analysis and measurements

A test run should be performed as a reference with only an orifice and no CEV at the outlet. This shall be done for an orifice diameters corresponding to the smallest tested CEV, see Table 3-2. To show variations the run with this orifice test must be repeated 3 times.

The calibration of measuring devises must be documented either by certificates or details of calibration and listed in the field logbook, where the calibration is performed prior to testing.

5.3 Data management

Data storage, transfer and control must be in accordance with the requirements of the DANETV Centre Quality Manual [3] and the quality manual of the test body, enabling full control and retrieval of documents and records. The requirements to filing and archiving of the quality manual of the test body must be followed.

On-line measurements are expected to be recorded and stored by means of a data-logger and retrieved by the test personnel. The data can then be transferred for instance to Excel files for evaluation. The actual data handling must be specified further in the test plan.

The data from the tests will be stored under a name, which are self-explanatory.

5.4 Quality assurance

The quality assurance of the tests must include test system control, test system audit, performance evaluation audit and control of the data quality and integrity. Details are specified below and for several of them detailed definitions can also be found in Appendix A:

- Test system audit: Physical audit by an auditor from the verification body during the actual testing of the technology.
- Performance evaluation audit: Calibration or control of calibration on monitoring equipment. For some instruments the calibration is done by the manufacturer and a valid certificate is required. Other instruments need regular calibration that has to be performed as required and documented.
- Test system control: Control of the test system used in the actual test for instance by testing whether the equipment is measuring as expected. This could be implemented as:
    - Control measurements before and after testing, the test body must consider if a static control measurement is sufficient or if also a dynamic measurement is required.
    - An inspection for possible leakages in the test set-up e.g. between the two parts of the CEV.
    - Control of relation between inflow and pressure height by performing measurement with closed CEV.
    - Control of data logging by using two parallel data loggers
    - Define boundary conditions on outlet side, to ensure it does not affect determination of outflow.
- Data quality and integrity: The test body is responsible for high quality test data and must ensure proper and traceable handling of the test results.

The test plan and the test report must be subject to a review by an internal expert. Furthermore, test plan and test report must be subject to a review by the verification body, which will be performed by an appointed verification expert (MTA). The test plan needs an approval by the verification body, which will be given by the verification responsible (PF).

The test plan must be approved by Mosbaek before the test is initiated.

The test body is obliged to have an internal test system audit performed. In addition, a test system audit will be performed by the verification responsible (PF) during the verification testing.

5.5 Test report requirements

The test data and records from the verification testing must be reported in a test report following the principles and template in the General Verification Protocol [1].

6 Evaluation

6.1 Calculation of performance parameters

The results from the verification testing should be shown graphically and specific performance parameters must be calculated.

For each of the four CEV-models as well as for the run without CEV the test report should include graphs, including all test runs on:

A. Relation between inflow (l/s) and time (s)
B. Relation between time (s) and head in regulator well (mH_2O)
C. Relation between calculated outflow (l/s) and time (s)
D. Relation between outflow (l/s) and head in regulator well (mH_2O)

The outflow cannot be measured directly due to air and circulation in the outlet. However, measurements of the head in the outlet tank and of the overflow from the outlet tank will be measured/registered. The $Q_{outflow}$ will be calculated in two ways:

1) by using the following equation:

$$Q_{outflow} = Q_{inflow} - \frac{\Delta Hwell \times Awell \times 1000}{\Delta t}$$

$Q_{outflow}$: Flow out of CEV (l/s)
Q_{inflow}: Flow into inlet tank (l/s)
A_{well}: Surface area in inlet tank+regulator well+riser (m^2)
H_{well}: Pressure head above outlet invert level in the regulator well (mH_2O)
Δt: Time for changing H_{well} with ΔH_{well} (s)

2) by using the following equation:

$$Q_{outflow} = Q_{overflow} + \frac{\Delta Hout \times Aout \times 1000}{\Delta t}$$

$Q_{outflow}$: Flow out of CEV (l/s)
$Q_{overflow}$: Overflow from the outlet tank (l/s)
A_{out}: Surface area in the outlet tank+riser (m^2)
H_{out} : Pressure head in the outlet tank (mH_2O)
Δt: Time for changing H_{out} with ΔH_{out} (s)

The equitation 2) will be used as in the performance evaluation, while 1) will only be used as indication and control of the result in 2).

6.1.1 Flow at H_{bump} and H_{design}

The performance parameters regarding the claim: Q_{design} is met at H_{bump} and H_{design} must be evaluated in the verification report based on the results shown in the prepared graph D. For each test run, the flow at the bump (Q_{bump}') and at H_{design} (Q_{design}') is derived[2].

[2] Apostrophes indicated that the numbers are based on measurements.

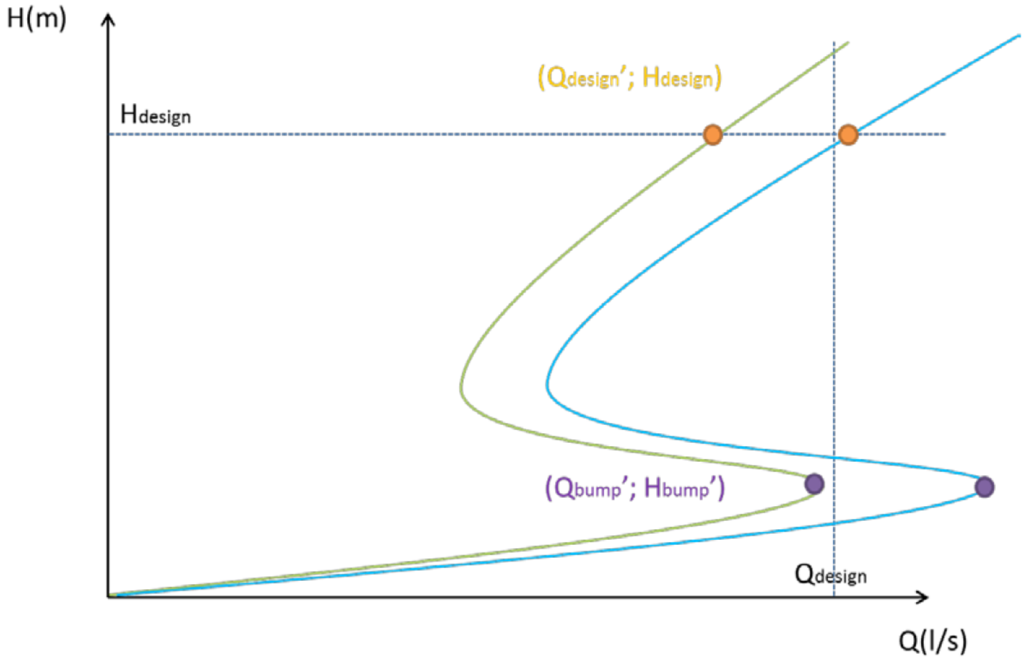


Figure 6-1 Points to be identified during evaluation of results.

Based on the values, average and precision for Q_{bump}' and Q_{design}' for each of the four CEV-models will be calculated. These calculations are performed according to the following equations:

Average:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$\bar{X}$: average of values
n: number of data points
X_i: individual value

Precision:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}$$

$$RSD = \frac{SD}{\bar{X}}$$

SD: standard deviation
RSD: relative standard deviation
n: number of data points
X_i: individual value
$\bar{X}$: average of values

6.1.2 Flow reduction at H_{design}

The reduction in flow is calculated for H_{design} by comparing these values with the test run for CEV 1.4l/s @ 1.00m – 100% with test runs with only an orifice plate with diameter corresponding to the CEV. The reduction flow caused by the CEVs will be calculated as shown in Figure 3-5. Precision as relative standard deviation will also be calculated.

6.2 Evaluation of test quality

The information in the test report on the test system control, test system audit, performance evaluation audit and control of the data quality and integrity should be evaluated against the requirements set in this protocol and the objectives set in the test plan.

Spread sheets used for calculations must be subject to control on a sample basis (spot validation).

The internal audit report and the external audit report prepared by ETA Danmark will be evaluated and major findings complied and reported.

6.3 Operational parameter summary

Test data on operational parameters must be summarised in the test report.

6.4 Additional parameter summary

6.4.1 User manual

The verification criterion for the user manual is that the manual describes the use of the equipment adequately and is understandable for the typical test coordinator and test technician. This criterion is assessed through evaluation of a number of specific points of importance, see Table 6-1 for the parameters to be included.

A description is complete if all essential steps are described, if they are illustrated by a figure or a photo, where relevant, and if the descriptions are understandable without reference to other guidance.

Table 6-1 Criteria for evaluation of user manual.

Parameter	Complete description	Summary description	No description	Not relevant
Product				
Principle of operation				
Intended use				
Performance expected				
Limitations				
Preparations				
Unpacking				
Transport				
Assembly				
Installation				
Function test				
Operation				
Steps of operation				
Points of caution				
Accessories				
Maintenance				
Trouble shooting				
Safety				
Chemicals				
Power				

6.4.2 Required resources

The capital investment and the resources for operation and maintenance could be seen as the sustainability of the product and will be itemized based upon a determined design [4], see Table 6-2 for the items that will be included.

Table 6-2	List of capital cost items and operation and maintenance cost items per product unit.

Item type	Item	Number	None
Capital			
Site preparation			
Buildings and land			
Equipment			
Utility connections			
Installation			
Start up/training			
Permits			
Operation and maintenance			
Materials, including chemicals			
Utilities, including water and energy			
Labor			
Waste management			
Permit compliance			

The design basis will be described and the cost items relevant for the Mosbaek CEVs will be listed. Note that the actual cost for each item is not compiled and reported.

Evaluation will also be done on the following subjects:

- Resources used during production of the equipment in the technology
- Longevity of the equipment
- Robustness/vulnerability to changing conditions of use or maintenance
- Reusability, recyclability (fully or in part)
- End of life decommissioning and disposal

Information on these subjects will be gained from Mosbaek.

6.4.3 Occupational health and environmental impact

The risks for occupational health and for the environment associated with the use of the products will be identified. A list of chemicals classified as toxic (T) or very toxic (Tx) for human health and/or environmentally hazardous (N) (in accordance with the directive on classification of dangerous substances [5]) will be compiled. The information will be given as amount used per product unit (sample), see Table 6-3 for format.

Table 6-3	Compilation of classified chemicals used during product operation.

Compound	CAS number	Classification	Amount used per product unit

Additional risks from installing, operating and maintaining the product will be evaluated, compiled and reported, if relevant. In particular, risks for human health associated with power supply and danger of infections will be considered.

7 Verification schedule

The verification was initiated in the late spring 2012. The testing facility was constructed during winter 2012-2013 and testing is planned to take place in the summer/fall 2013. A detailed schedule is given in Table 7-1.

Table 7-1 Verification schedule.

Task	Verification Body	Test Body
Specific verification protocol	October 2012	
External review of specific verification protocol	October/November 2012	
Testing incl. test planning, testing and reporting		August-October 2013
Test system audit	September 2013	
Assessment and verification reporting	November-December 2013	
External review of verification report	January 2014	
Issuing of Statement of Verification	January 2014	

8 Quality assurance

The personnel and experts responsible for quality assurance as well as the different quality assurance tasks can be seen in Table 8-1. All relevant reviews will be prepared using the DANETV review report template [3]. An audit of the test will be performed.

Table 8-1 QA plan for the verification

	Internal expert	Verification body		Proposer	External experts
Initials	MJK	MTA	PF	Mosbaek	TL
Tasks					
Specific verification protocol	Review			Review and approve	Review
Test plan		Review	Approve	Review and approve	
Test system at test site			Audit		
Test report		Review		Review	
Verification report	Review			Review	Review
Statement of Verification				Acceptance	Review

Internal review is conducted by Morten Just Kjølby (MJK) and a test system audit is conducted following general audit procedures by certified auditor Peter Fritzel (PF).

Only the verification protocol and verification report require external review according to EU ETV pilot programme GVP [1]. External review will be performed by Torben Larsen (TL).

The verification body will review and approve the test plan and review the test report. The review will be performed by Mette Tjener Andersson (MTA), while the approval will be given by Peter Fritzel (PF).

9 References

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APPENDICES

APPENDIX A

Terms and definitions

The terms and definitions used by the verification body are derived from the EU ETV General Verification Protocol, ISO 9001 and ISO 17020.

Term	DANETV	Comments on the DANETV approach
Accreditation	Meaning as assigned to it by Regulation (EC) No 765/2008	EC No 765/2008 is on setting out the requirements for accreditation and market surveillance relating to the marketing of products
Additional parameter	Other effects that will be described but are considered secondary	None
Amendment	Is a change to a specific verification protocol or a test plan done before the verification or test step is performed	None
Application	The use of a product specified with respect to matrix, purpose (target and effect) and limitations	The application must be defined with a precision that allows the user of a product verification to judge whether his needs are comparable to the verification conditions
DANETV	Danish centre for verification of environmental technologies	None
Deviation	Is a change to a specific verification protocol or a test plan done during the verification or test step performance	None
Evaluation	Evaluation of test data for a technology product for performance and data quality	None
Experts	Independent persons qualified on a technology in verification	These experts may be technical experts, QA experts for other ETV systems or regulatory experts
General verification protocol (GVP)	Description of the principles and general procedure to be followed by the EU ETV pilot programme when verifying an individual environmental technology.	None
Matrix	The type of material that the technology is intended for	Matrices could be soil, drinking water, ground water, degreasing bath, exhaust gas condensate etc.
Operational parameter	Measurable parameters that define the application and the verification and test conditions. Operational parameters could be production capacity, concentrations of non-target compounds in matrix etc.	None
(Initial) performance claim	Proposer claimed technical specifications of product. Shall state the conditions of use under which the claim is applicable and mention any relevant assumption made	The proposer claims shall be included in the ETV proposal. The initial claims can be developed as part of the quick scan.

Term	DANETV	Comments on the DANETV approach
Performance parameters (revised performance claims)	A set of quantified technical specifications representative of the technical performance and potential environmental impacts of a technology in a specified application and under specified conditions of testing or use (operational parameters).	The performance parameters must be established considering the application(s) of the product, the requirements of society (legislative regulations), customers (needs) and proposer initial performance claims
Procedure	Detailed description of the use of a standard or a method within one body	The procedure specifies implementing a standard or a method in terms of e.g.: equipment used
Proposer	Any legal entity or natural, which can be the technology manufacturer or an authorised representative of the technology manufacturer. If the technology manufactures concerned agree, the proposer can be another stakeholder undertaking a specific verification programme involving several technologies.	Can be vendor or producer
Purpose	The measurable property that is affected by the product and how it is affected.	The purpose could be reduction of nitrate concentration, separation of volatile organic compounds, reduction of energy use (MW/kg) etc.
(Specific) verification protocol	Protocol describing the specific verification of a technology as developed applying the principles and procedures of the EU GVP and the quality manual of the verification body.	None
Standard	Generic document established by consensus and approved by a recognised standardization body that provides rules, guidelines or characteristics for tests or analysis	None
Test/testing	Determination of the performance of a product for measurement/parameters defined for the application	None
Test performance audit	Quantitative evaluation of a measurement system as used in a specific test.	E.g. evaluation of laboratory control data for relevant period (precision under repeatability conditions, trueness), evaluation of data from laboratory participation in proficiency test and control of calibration of online measurement devises.
Test system audit	Qualitative on-site evaluation of test, sampling and/or measurement systems associated with a specific test.	E.g. evaluation of the testing done against the requirements of the specific verification protocol, the test plan and the quality manual of the test body.
Test system control	Control of the test system as used in a specific test.	E.g. test of stock solutions, evaluation of stability of operational and/or on-line analytical equipment, test of blanks and reference tech-

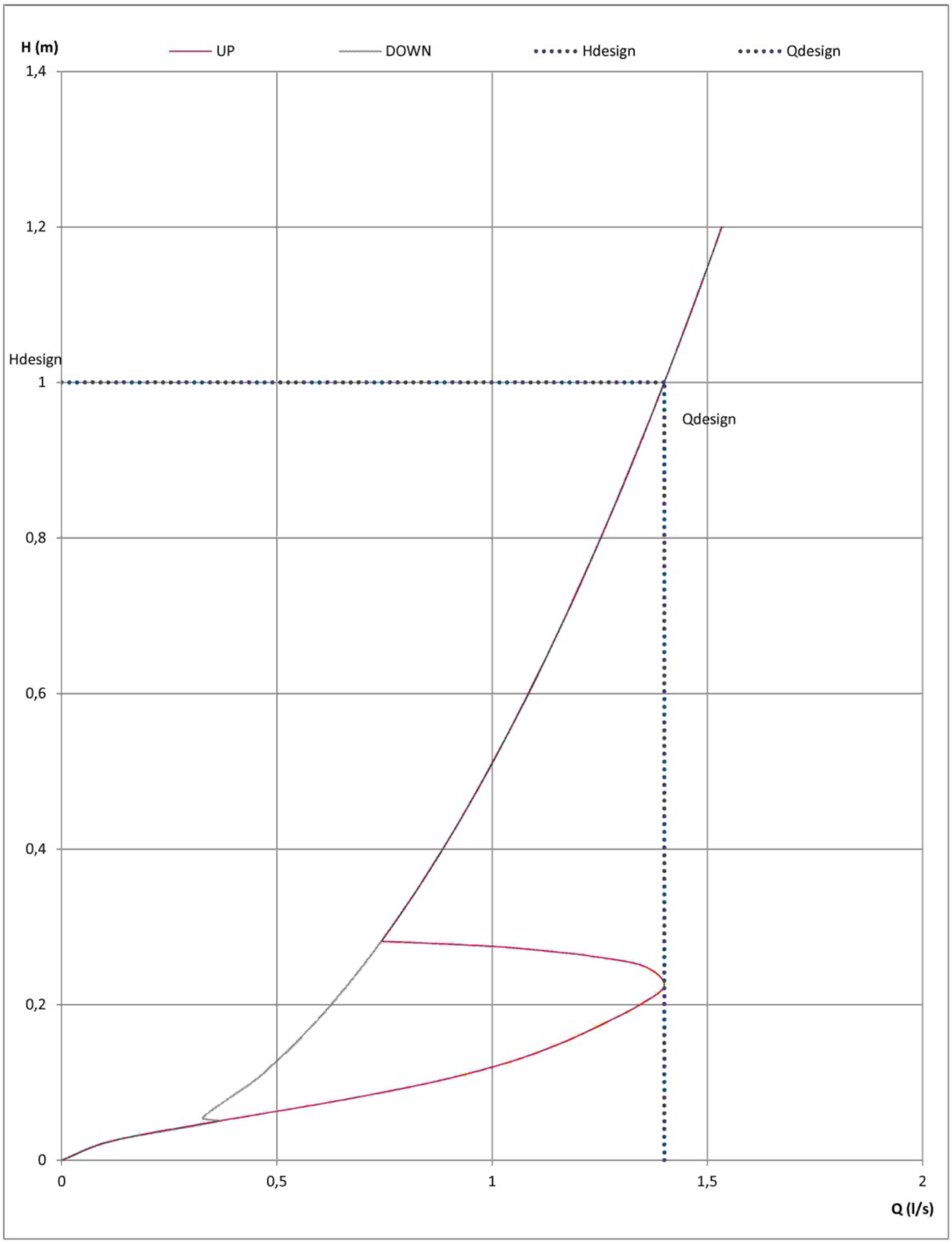
Term	DANETV	Comments on the DANETV approach
		nology tests.
Verification	Provision of objective evidence that the technical design of a given environmental technology ensures the fulfilment of a given performance claim in a specified application, taking any measurement uncertainty and relevant assumptions into consideration.	None

APPENDIX B

Claimed performance of Mosbaek CEVs

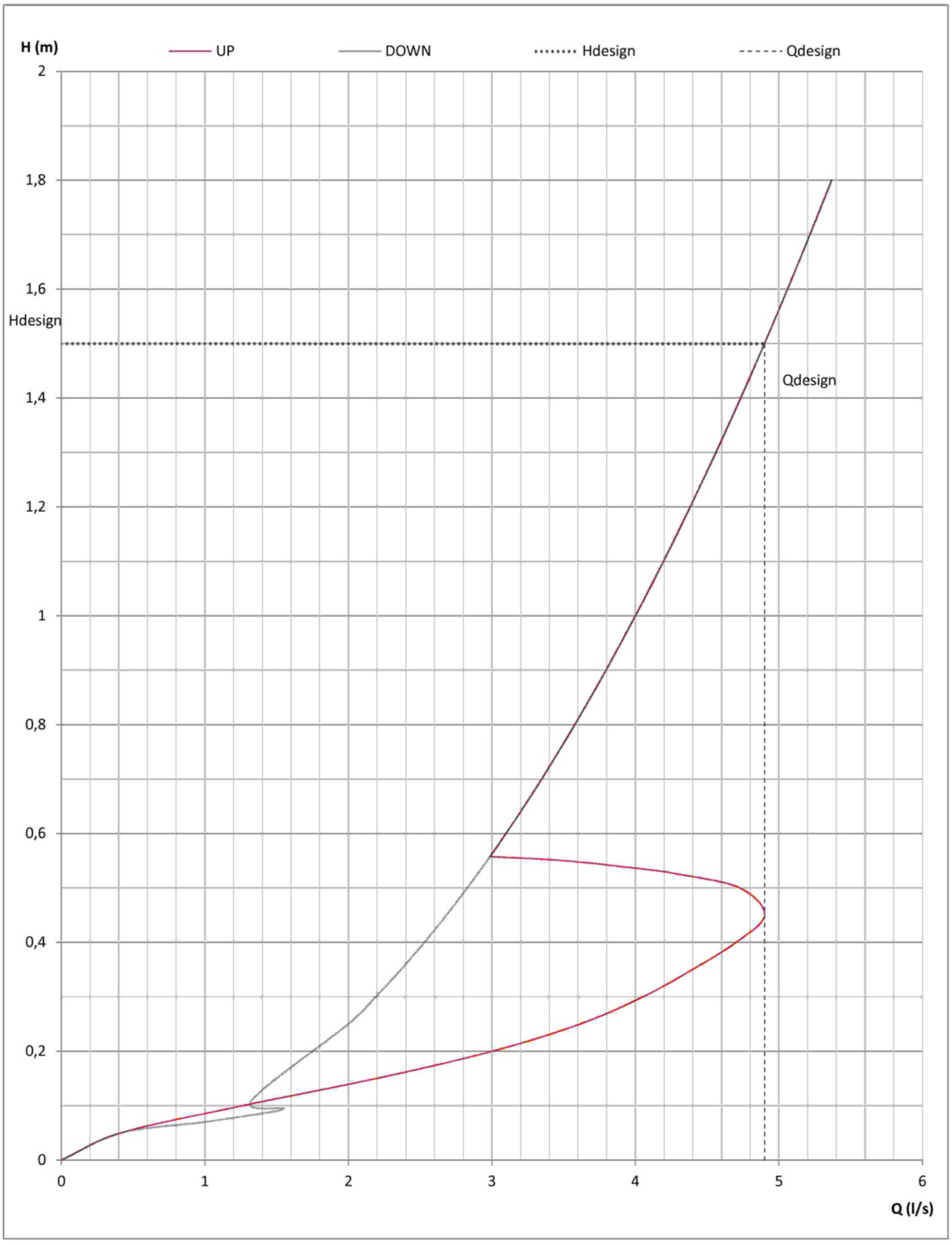
Ref: 109.1.1
Date: 29-10-2012
Design: Q=1,4l/s
H=1m

CEV 1.4 l/s@1.0m - 100%



Ref: 109.4.1
Date: 29-10-2012
Design: Q=4,9l/s
H=1,5m

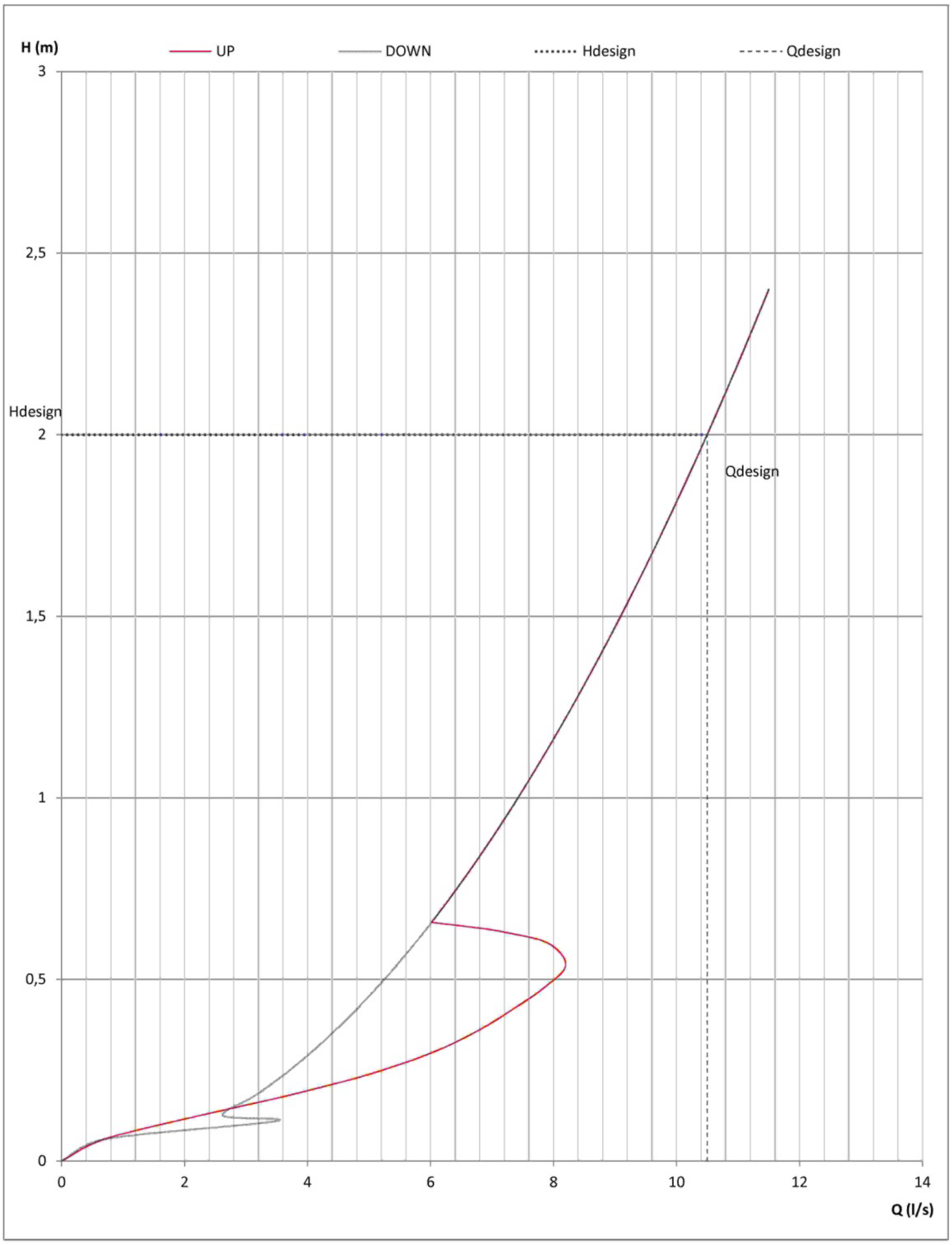
CEV 4.9l/s@1.50m - 100%



Mosbaek A/S

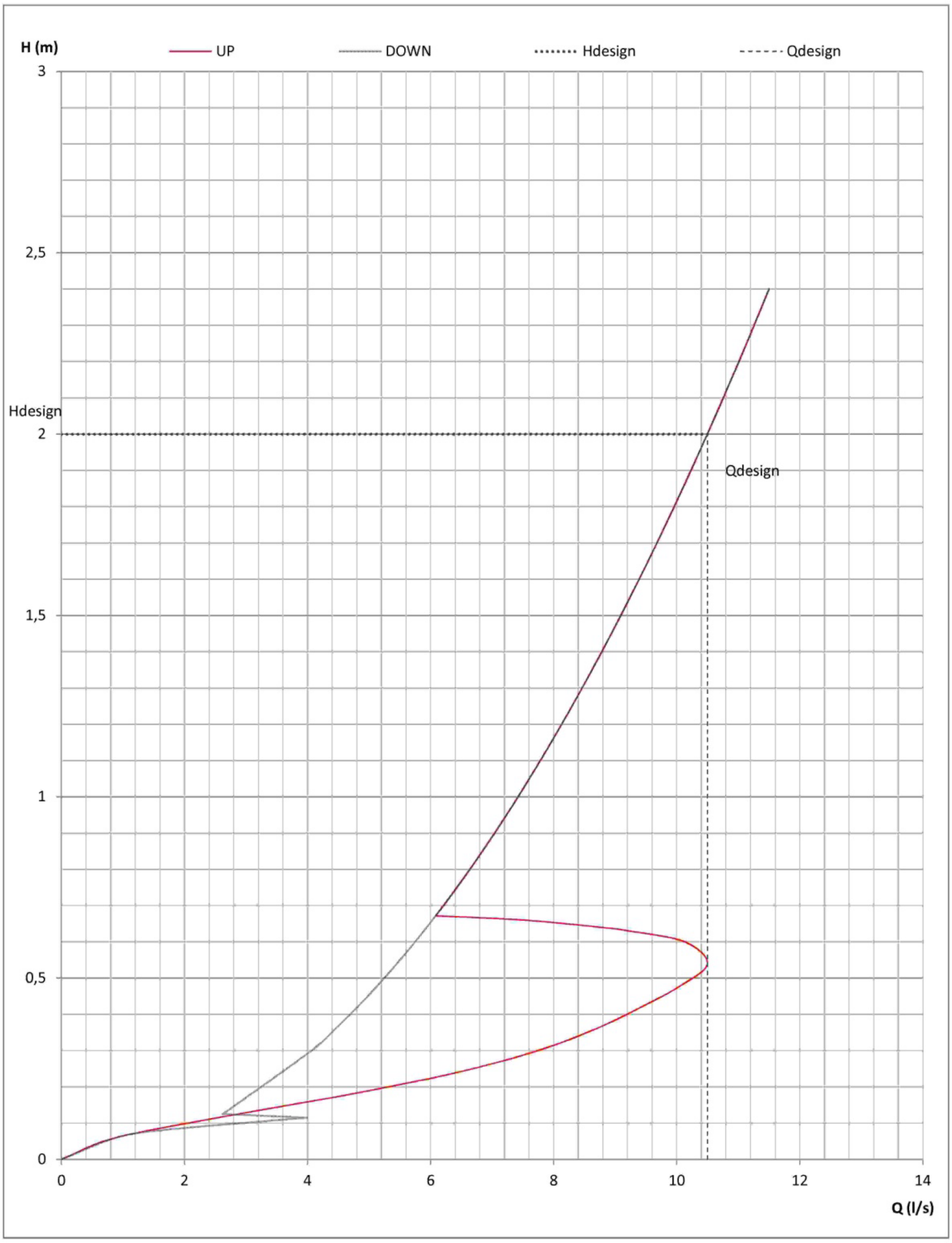
Ref: 109.6.2
Date: 29-10-2012
Design: Q=10,5l/s
H=2m

CEV 10.5l/s@2.00m - 78%



Ref: 109.3.1
Date: 29-10-2012
Design: Q=10,5l/s
H=2m

CEV 10.5l/s@2.00m - 100%

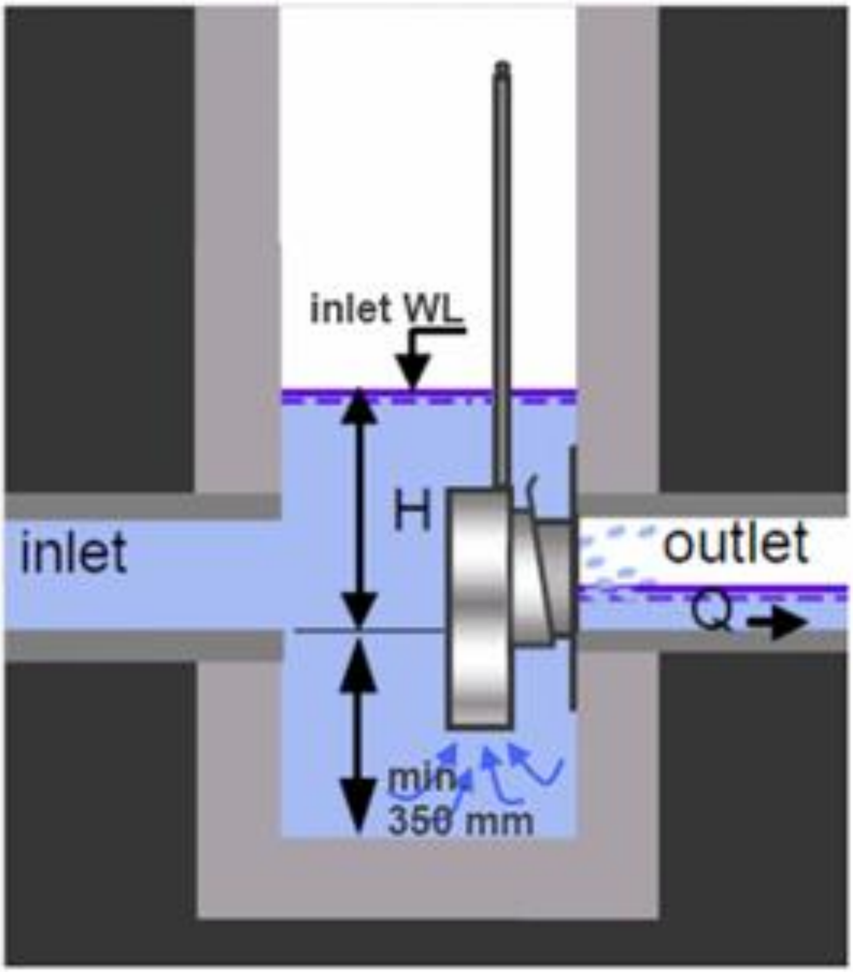


APPENDIX C

Test Plan

Mosbaek CEV Flow Regulator

Test Plan



Test Plan

January 2015

The expert in **WATER ENVIRONMENTS**

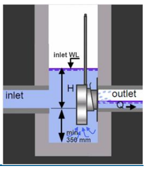
This report has been prepared under the DHI Business Management System certified by DNV to comply with ISO 9001 (Quality Management)

Approved by
Jesper Fuchs, Head of Projects, POT

Mosbaek CEV Flow Regulator

Test Plan

Prepared for	Mosbaek
Represented by	Mr Torben Krejberg, Technical Director



Sketch of CEV flow regulator in well

Project manager	Mette Tjener Andersson
Author	Mogens Hebsgaard
Quality supervisors	Jesper Fuchs – Mette Tjener Andersson
Approver	Jesper Fuchs, Head of Projects, Ports & Offshore Technology

Project number	11811720
Approval date	09 January 2015
Revision	Final 2.0
Classification	Restricted

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1 Introduction

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and quality assurance.

The objective of this verification and the testing is to evaluate the performance of a vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical) for storm water pipes.

1.1 Short description of the CEV regulator

The technology to be verified is the vertical centrifugal flow regulator, CEV (**CE**ntrifugal **V**ertical) from Mosbaek. It is a wet-mounted vortex flow regulator for storm water drainage system with design flows between 0.2-80ℓ/s.

The CEV regulates the water due to the vortex created when a certain water flow is going through the unit. The vortex slows down the water flow through the CEV. As a consequence, water is detained and stored upstream of the CEV, for example in a well, and the water flow rate is then kept almost constant.

1.2 Verification protocol reference

This test plan is prepared in response to the test design established in the Mosbaek CEV flow regulator verification protocol /1/.

1.3 Name and contact of proposer

Mosbaek A/S
Værkstedsvej 20
4600 Køge
Denmark

Contact: Torben Krejberg, e-mail: tk@mosbaek.dk, phone +45 5663 8580

Mosbaek website: www.mosbaek.dk

1.4 Name of test body/test responsible

DHI DANETV Test Centre
Agern Alle 5
DK-2970 Hørsholm
Denmark

Test responsible:
Mogens Hebsgaard, email: mhe@dhigroup.com, phone +45 4516 9414

2 Purpose and Functioning of the Flow Regulator

This section gives a short description of CEV flow regulators and the purpose of the regulators. For further information, see /1/.

Extreme rainfall events are often characterised by being short and local, and for short periods causing full-flowing pipes and surcharges to the surface or to the recipients. The frequency of over-loads on the system's hydraulic capacity is expected to increase in future due to climate changes. In such situations, it may be advantageous to be able to delay the excess water upstream for a certain period of time until the pipe system downstream will be able to receive and deal with the water.

The delay of water may take place by means of a flow regulator, which will be efficient in most precipitation situations. The delay of water means that installation of larger pipes or basins downstream may be avoided.

The flow regulator technology is based on quickly reaching the maximum discharge flow of the regulator and then staying at or below this value, when the pressure increases. The maximum discharge flow is chosen such that the amount of water passing through the regulator does not cause problems to the downstream pipe network.

Generally speaking, the purpose of a flow regulator is to protect the downstream parts of the drainage system against overloading and flooding. One of the specific qualities of the flow regulator is that it allows liquid to pass the drainage system at a pre-determined maximum discharge rate (amount per time unit), regardless of the variation in feed flow and in the water level (up to design water level) immediately upstream the regulator.

A schematic view of the CEV in operation in a well is shown in Figure 2.1.

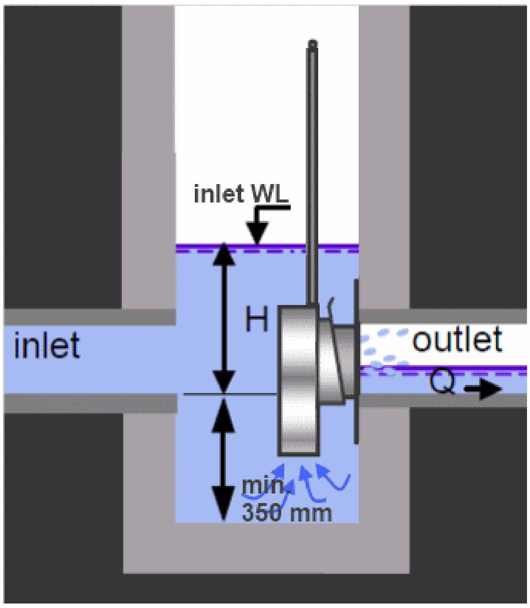


Figure 2.1 Sketch of CEV flow regulator installed in well. Sketch provided by Mosbaek

To avoid the risk of blocking and to minimise the need for service and maintenance, the CEV is without moving parts. Furthermore, its passageway is large in order to minimise its flow resistance during normal, daily runoff situations.

During low flow conditions, water entering through the inlet of the CEV passes through the well with negligible pressure drop. During high flow conditions, a vortex flow pattern develops within the CEV creating an air-filled core. This phenomenon restricts and throttles flow through the device, creating back pressure immediately upstream of the device.

The CEV can be built to fulfil different design criteria. The specific design criteria are defined by the client and Mosbaek in cooperation according to the design of the existing or planned piping network.

The creation of the vortex in the CEV causes a speed reduction of the outflow, Q, allowing the well to be used for water storage during a storm event. Figure 2.2 shows the flow through a CEV. In the 100% case, the maximum outlet (Q_{design}) is met twice, first where the vortex is formed (the bump on the graph) and then at the specified H_{design}, where H_{design} is calculated from the invert of the discharge pipe to the maximum water level in the well. A 78% case (a smaller CEV in a well with same height) with the same H_{design} is also shown; here the bump occurs at a flow of 78% of Q_{design}.

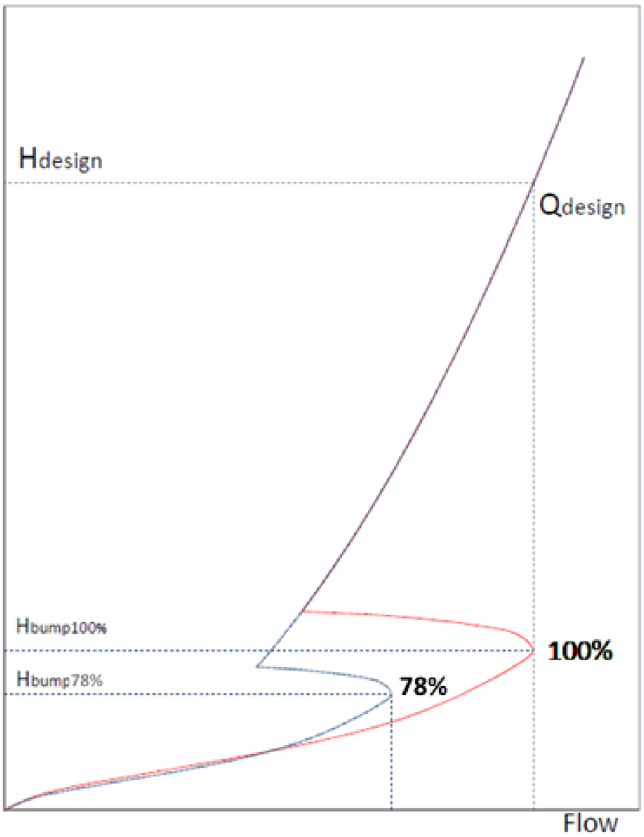


Figure 2.2 Graphic showing the general vortex brake effect on water outflow, with CEVs operating at 78% and 100% efficiency and water inflow to well larger than outflow though CEV (well is filling up). Graph provided by Mosbaek

The optimal solution (100%), where Q_{bump} equals Q_{design}, give less restriction at low heads allowing a better throughput during normal operating situations and thereby less risk of blocking downstream.

The regulators are designed to function optimal at a rate of increase of the water levels approximately between 0.5 and 1.5mm/s.

3 Test Design

The test design in the test plan is based on the requirement in the Specific Verification Protocol, /1/.

3.1 Test site

The verification of the CEV flow regulator will be carried out at a test site established at Mosbaek A/S, Køge, Denmark.

3.1.1 Type

The tests comprise field tests with data collection.

3.1.2 Addresses

The tests will be performed at

Mosbaek A/S
Værkstedsvej 20
4600 Køge
Denmark

3.1.3 Descriptions

Descriptions of the test design and model set-up are included in Section 3.2.

3.2 Test design and model set-up

The test design for the CEV flow regulators is described in the following sub-sections.

In accordance with the verification protocol /1/, the test design has been divided into five tasks:

1. Design of test facility
2. Installation of facility
3. Test of facility
4. Verification testing
5. Documentation

3.2.1 Task 1 – Design of test facility

Objective: The objective of this task is to determine where the test facility shall be located and to describe the test facility and the required measuring devices.

Work plan: The design of the test facility comprises the following work items:

- Determination of the location of test set-up
- Description of the equipment to be used during construction of the test set-up
- Description of the required measuring devices
- Method of operation of the water pumping system, CEV and water outlet
- Method of operation of the measuring devices.

Location and set-up of test facility

The test facility is set up at Mosbaek's workshop facilities in Køge.

The set-up of the test facility is shown in the drawings in Figure 3.1. The set-up consists of a well (ø800mm with inner diameter 785mm, see also Appendix C) with top level 4.01m above ground level. The test well is placed on a 1.21m high base; the CEV regulator is mounted in this well, which therefore is denoted the regulator well. The regulator well is in direct connection with a large diameter tank, called the inlet tank (ø1991mm), through an ø160mm pipe, positioned just opposite the CEV outlet. The water levels in the regulator well and the inlet tank are accordingly identical. The CEV invert level is positioned 1.58m above the ground level. This set-up is established in order to secure that the increase of the water level in the regulator well can be controlled and limited to 0.5-1.5mm/s still with a reasonable high flow rate to the well. The inlet of water takes place directly to the inlet tank and leads to the regulator well (ø800mm with inner diameter 785mm). The outlet connection is through the CEV in the regulator well to the outlet tank. A pressure transducer is mounted in the base of the regulator well. On the base of the regulator well, a Plexiglas riser is mounted in order to allow for check of the calibration of the pressure transducer and in order to be able to follow the water level in the well during testing.

The flow to the inlet tank is fed at the top of the tank through an ø160mm pipe (which is placed internally in the tank) by means of a pump, which is pumping water from a feeding tank. The flow from the feeding tank to the inlet tank is measured by means of the flowmeter. The water level in the feeding tank is kept constant by pumping water from a central reservoir to the feeding tank; an overflow weir ensures that the water level in this tank is kept almost constant. In this way, it is possible to keep an almost constant head at the pump and thus an almost constant flow.

From the regulator well, the water flows through the regulator to the outlet tank through an ø160mm pipe. The outlet tank (ø300mm with inner diameter 294mm, see also Appendix C) is equipped with a pressure cell, which monitors the water level in this tank. The outlet flow from the outlet tank is measured by means of a flowmeter. The outlet flow is thus measured by a combination of pressure change during time in the outlet well and discharge from the outlet well.

A schematic impression of the flow through the test set-up is shown in the following Figure 3.1.

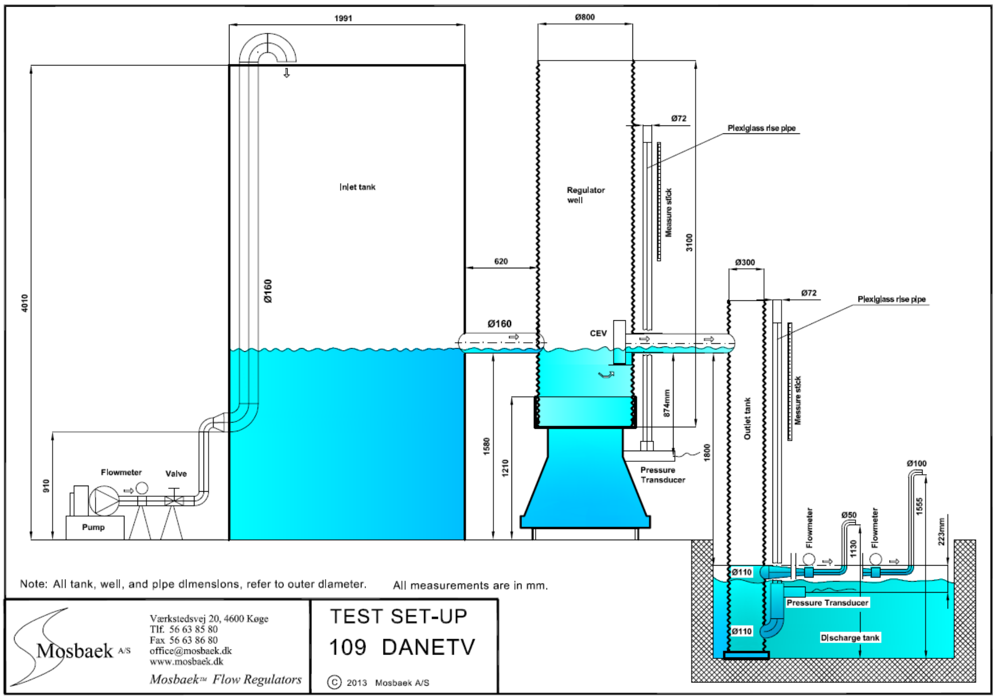


Figure 3.1 Model set-up

Equipment summary

The following equipment will be used for the tests:

Intake connections

- Submersible pump with capacity 0-20ℓ/s delivering water flow from the feeding tank (constant head tank)
- Connection from the pump to the inlet tank by means of an ø100mm tube and pipe. The pipe is placed inside the inlet tank (outside diameter of pipe is 160mm)
- A flowmeter (ø100mm) and adjustment valve on the intake pipe. Flowmeter measuring range: 0-69.4444ℓ/s, for description see Appendix B

Regulator well

- Foundation of well, 1.21m high
- Upper part of the well, top level 4.01m above ground level, ø785mm with inlet pipe (DN ø160mm) and outlet pipe through the CEV regulator and an ø160mm pipe to the outlet tank, invert level 1.58m above ground level
- One pressure transducer, measuring the pressure close to the bottom of the regulator well (placed 0.874m below the invert of the outlet pipe); measuring range: 0-3.5mH_2O; for description, see Appendix B
- The upper part of the well can be removed so that it is possible to shift CEV's and access pressure transducer if needed. The connection between the well and its base is sealed water tight. The CEV is mounted with the inlet opening pointing downwards. H=0m corresponds to the invert level of the CEV outlet pipe. The CEV is installed in the regulator well by a socket
- A riser, in the shape of an ø72mm (inner diameter) Plexiglas tube, is connected to the lower part of the regulator well. Manual readings of the water level in the riser are used to verify the calibration of the pressure transducer. Furthermore, it is used for observing the water level in the well during the tests. The riser is equipped with a scale showing the pressure in mH_2O.

Outlet connection

- The water discharges from the CEV through the outlet tank to the discharge tank. The outlet from the outlet tank takes place through an ø100mm pipe with an ø100/ø50mm flowmeter mounted. For the smaller CEV regulator (1.4ℓ/s), a flowmeter with measuring range 0-17.5ℓ/s (ø50mm) will be used and for the larger, a flowmeter with measuring range 0-69.4444ℓ/s will be used; for descriptions see Appendix B. The discharge pipe can be equipped with a plug for closure of the outlet
- One pressure transducer, measuring the pressure close to the bottom of the outlet tank; (0.223m below the outlet level) measuring range: 0-3.5mH_2O; for description, see Appendix B
- A riser, in the shape of an ø72mm (inner diameter) Plexiglas tube, is connected to the lower part of the outlet tank. Manual readings of the water level in the riser are used to verify the calibration of the pressure transducer. The riser is equipped with a scale showing the pressure in mH_2O.

The outlet flow from the outlet tank to the discharge tank takes place by means of an elevated outlet pipe. This is done to avoid air entrainment at the flowmeter and thus to ensure that the flowmeter measures correctly. As mentioned above, two different flowmeters and thus outlet pipes are used.

The test set-up is furthermore equipped with the following measuring devices:

- Datalogging equipment; for description, see Appendix B
- Rulers, calipers to be used for control dimensions of CEV's, etc.

Test operation description

This subtask is described in details later in Tasks 3 and 4.

Operation of measuring devices

This subtask is described in details later in Tasks 3 and 4.

3.2.2 Task 2 – Installation of facility

Objective: The objective of this task is to have the wells and the measuring devices installed at the location.

Work plan: The installation of the test facility comprises the following work items:

- Installation of test set-up as described under Task 1
- Ensuring that water inlet and outlet is connected correctly according to the drawing and descriptions given in Task 1; check positions of intake and outlet pipes
- Installation of measuring devices and data-logging equipment
- Control dimensions of well, riser, outlet pipe, CEV

3.2.3 Task 3 – Pre-testing

Objective: The objective of this task is to have the wells and the measuring devices tested and ready for operation and undertaking of the actual tests.

Work plan: The pre-testing of the test facility comprises the following work items:

- Testing the regulator well filled with water
- Check of calibration of pressure transducers
- Control that the CEV-models are installed correctly in the well
- Implementation of a trial run of the planned verification tests
- Final adjustments of the test facility as required

Testing the well filled with water

The purpose of this test is to check if any leakages are present and if all connections are water tight. For this purpose, the discharge line is closed by closing the outlet through the CEV, and the well is slowly filled with water. The water remains in the well for at least 10min and the pressures are recorded. The amount of water lost from the well per time unit is recorded. The amount of water lost is calculated as:

$$Q_{lost} = 1000*\Delta p_{rw}*\pi*(R_{rw}^2 + R_{it}^2 + r_{rw}^2 - r_{ind}^2) / \Delta t$$

Q_{lost} (ℓ/s)
Δp_{rw} is the pressure difference (mH_2O) in the regulator well during the time Δt
R_{rw} is the radius of the well (0.3925m)
R_{it} is the radius of the inlet tank (=0.9955m). The dimension is to be verified during pre-testing
r_{rw} is the radius of the Plexiglas riser (=0.036m)
r_{ind} is the radius of the feeding pipe (=0.080m)

$\pi*(R_{rw}^2 + R_{it}^2 + r_{rw}^2 - r_{ind}^2) = 3.58m^2$

Check of pressure transducer calibration, regulator well

The check of the pressure transducer in the regulator well is carried out according to the following procedure:

- The CEV outlet is closed
- Water is filled in the well until the invert level of the outlet pipe; level above the pressure transducer is registered
- The water level is read in the riser and the output from the pressure transducer is logged
- Water is filled to about 1m, 2m and 3m above the pressure transducer
- For these water levels, the riser water level (mH_2O) is read and the output from the pressure transducer is logged

The calibration can now be calculated as 1mA = xxmH_2O, assuming a linear relationship between output and water level. The found relation is compared to the theoretical calibration (1mA=0.21857mH_2O).

This calibration procedure is carried out at the same time as the testing of well filled with water.

Check of pressure transducer calibration, outlet tank

The check of the calibration of the pressure transducer in the outlet tank is performed in a similar way:

- The outlet from the outlet tank is closed
- Water is filled in the well until the pressure gauge is covered; level above the bottom is registered
- The water level is read in the riser and the output from the pressure transducer is logged
- Water is filled to about 0.5m, 1m and the highest possible level above the pressure transducer
- For these water levels, the riser water level is read and the output from the pressure transducer is logged

The calibration can now be calculated as 1mA = xxmH_2O, assuming a linear relationship between output and water level. The found relation is compared to the theoretical calibration (1mA=0.21857mH_2O).

Check of water surface area inlet side

The diameter of the inlet tank is varying somewhat over the height of the tank. The average inner diameter of the regulator well is given by the manufacturer (=785mm). The inner diameter of the inlet tank is determined from the tests carried out at the same time as testing of well filled with water and check of pressure cell calibration.

The radius of the inlet tank is determined from the expression:

$$Q_{inflow} * \Delta t = -1000 * \Delta p_{rw} * \pi * (R_{rw}^2 + R_{it}^2 + r_{rw}^2 - r_{ind}^2)$$

Where all dimensions except R_{it} are known

Flowmeter calibration inlet flow

The flowmeter is pre-calibrated from the factory, and further check of the flowmeter calibration will not be performed. The calibration factor is 1mA = 4.340ℓ/s.

Flowmeter calibration outlet flow

The flowmeters are pre-calibrated from the factory, and further check of the flowmeter calibrations will not be performed. The calibration factor for the 100mm flowmeter is 1mA = 4.340ℓ/s. The calibration factor for the 50mm flowmeter is 1mA = 1.094ℓ/s.

Control of CEV models

The CEV models to be used in the verification tests are selected and the following noted:

- Identification numbers, if any
- Dimensions are measured: inlet and outlet openings
- Photos are taken
- Check that CEVs can be mounted in the well and fit tightly

Trial runs

A few trial runs are carried out with one of the CEVs to be tested in order to see if everything works as planned. The results of the trial runs are processed as relationships between outflow, $Q_{outflow}$ (ℓ/s) and pressure above the invert of outlet opening, H (m).

$$Q_{outflow,1} = Q_{inflow} - 1000 * \Delta p_{rw} * \pi * (R_{rw}^2 + R_{it}^2 + r_{rw}^2 - r_{ind}^2) / \Delta t \qquad [1]$$

and

$$Q_{outflow,2} = 1000 * \Delta p_{ot} * \pi * (R_{ot}^2 + r_{ot}^2) / \Delta t + Q_{overflow} \qquad [2]$$

Δp_{ot} is the pressure difference in the outflow tank during the time Δt. When the inflow is kept constant, the water level in the outlet tank will be constant after a while ($\Delta p_{ot} = 0$)
R_{ot} is the radius of the outlet tank (=0.147m)
r_{rw} is the radius of the Plexiglas riser (=0.036m)
Q_{inflow} is the measured inflow (ℓ/s) to the inlet tank
$Q_{overflow}$ is the measured flow (ℓ/s) from the outlet tank

The performance is compared to the theoretical one, and possible deviations between the two performance curves are analysed. Are possible deviations caused by

- inaccurate measurements such as fluctuations in the signals?
- errors in the model set-up?
- other reasons?

Formula [2], which is based on the measurements on the outflow side, will be used to calculate the Q–H relationship. Formula [1] will be used to support these calculations, but due to the large surface area of the inlet tank and of the regulator well, even small disturbances of the surface areas will be registered by the pressure transducer. This may reveal large fluctuations in the calculated outflow. The time series of the flow based on the inflow conditions may thus need to be low-pass filtered with rather low cut-off frequency. This may cause that some information will be lost around the bump on the relation.

It should be noted that it may be necessary to approximate the time series from the flowmeters and pressure transducers to fitted polynomials as the fluctuations, which are unavoidable, may make it difficult to interpret the results otherwise.

Final adjustments of test set-up

Does the calibration and test run give rise to any problems?

- Is it possible to run at an acceptable flow rate?
- Are the fluctuations in the measurement time series acceptable?
- Is the Q-H relationship almost as expected?
- Any problems at the outlet? Should it be adjusted?
- Well stability?
- Miscellaneous?

3.2.4 Task 4 – Verification testing

Objective: The objective of this task is to test four selected CEVs. Based on electronically-recorded (logged) measurements of flow and water pressure (height), the performance is evaluated and verified. The following CEVs have been proposed for testing:

1. CEV 1.4ℓ/s @ 1.00m – 100%
2. CEV 4.9ℓ/s @ 1.50m – 100%
3. CEV 10.5ℓ/s @ 2.00m – 78%
4. CEV 10.5ℓ/s @ 2.00m – 100%

The name of the CEV indicates the design maximum flow, for example Q_{design}= 1.4ℓ/s (CEV no 1), and the correlated maximum pressure height for this CEV is H_{design}= 1.00m. The percentage (100% and 78%) indicates the percentage of the design flow at the point/bump, where the vortex is formed.

Work plan: The verification testing of the CEVs comprises the following work items:

- Verification testing, including
  - 3-4 runs at specified pump flows for each CEV model; see Table 3.1. The following inflows (Flows 1 to 4) are proposed for the CEVs to be tested. Note that Flow 1 is proposed to be slightly higher than the design flow, as it may be necessary in order to pass the bump. The inflows are proposed in order to achieve an average water level rise in the regulator well, which is less than approximately 1.5mm/s. This average water level rise is a design criterion.
  - Although desirable, it is not required that the flow is completely constant during each test.

Table 3.1 Proposed test programme

CEV type	Design flow (ℓ/s)	Flow 1 (ℓ/s)	Flow 2 (ℓ/s)	Flow 3 (ℓ/s)	Flow 4 (ℓ/s)
CEV 1.4ℓ/s @ 1.00m – 100%	1.4	1.9	3.1	4.8	6.3
CEV 4.9ℓ/s @ 1.50m – 100%	4.9	5.9	6.6	8.3	10
CEV 10.5ℓ/s @ 2.00m – 78%	10.5	9.2	9.9	11.6	13.3
CEV 10.5ℓ/s @ 2.00m – 100%	10.5	11.5	12.2	13.9	15.6

- To demonstrate the variability, one of the runs for one of the CEV-models must be repeated 3 times. If the variation of the triplicates is more than 10% (eg in the bump), triplicate runs have to be made for all the other CEV models too.
- In addition to the tests with the CEVs, a reference test with no CEV shall be performed; this test will be carried out with an inflow of around 5ℓ/s. During this test, the CEV is replaced by an orifice with diameter corresponding to the smallest tested CEV.
- The inflow is started with water level in the regulator well corresponding to the invert level in the CEV. The inflow should continue until the design H is passed or the water level is stagnant, which is assumed to take place for design flow. When the design water level is reached, the inlet valve is closed, the inflow is stopped, and the well for one test shall drain until empty (to the invert level of the CEV). For the other three tests the inlet tank and the regulator well will just be emptied using the evacuation valve.
- Electronically-recorded (logged) measurement and evaluation of the flows and water pressure during the test runs. The logging of inflow, outflow and water pressures (mH_2O) should continue throughout the entire test run.

3.2.5 Task 5 – Documentation of verification

Objective: The objective is to ensure proper documentation and data management during the verification testing.

Work plan: The documentation of the verification testing comprises the following work items:

- Use of amendment and deviation forms in case of changes to the developed test plan. Templates to be found in /3/.
- Creation and use of a test logbook, where also deviations from the stated operating conditions (eg flow, pressure) must be documented. The test logbook (see also Appendix D) contains:
  - Results of review of test set-up, instrument positions, etc
  - Notes on instrument calibration/verification tests, date and time
  - Notes on CEVs tested, serial numbers, dimensions, (photos)
  - Description of each verification test with indication of test number, CEV type, target inflow conditions, realised inflow conditions
  - Notes on adverse conditions during the tests such as change of inflow conditions, malfunction of instruments, etc
  - Name/initial of person(s) undertaking the activity and date and time of activity

Operation conditions

The operational conditions for each verification tests are summarized as follows:

- Check instruments
- Fill water in the inlet tank and regulator well until CEV invert level
- Wait until water level is stable
- Close inlet adjustment valve
- Start data logging, logging of zero level
- Wait 5 minutes
- Start submersible pump
- Open valve until target flow is reached
- Proceed at least until design H is reached
- Close inlet valve
- Stop pump
- Proceed until well is empty for one test with each CEV
- Stop data logging
- For remaining three tests, empty the inlet tank and regulator well with evacuation valve
- Check results

Operation measurements

The measurements carried out are:

- Inlet flow (ℓ/s) measured by means of flowmeter
- Pressure (mH_2O) at a position in the lower part of the regulator well
- Pressure (mH_2O) at a position in the lower part of the outlet tank
- Run off from outlet tank (ℓ/s), measured by means of flowmeter

3.2.6 Appropriate storage of data from on-line measurements of flow and water pressure – Test staff

The data from the tests are logged by means of a data logger (Type: National Instruments, NI cDAQ-9171 with NI9203 analogue module). The data contain time series from the flowmeters (inflow to the inlet tank and outflow from the outlet tank) and from two pressure transducers mounted in the lower part of the regulator well and in lower part of the outlet tank respectively. The data are sampled with a frequency of at least 10Hz, but up to 1000Hz is possible. A sampling frequency of 10Hz is regarded adequate to obtain a good and sufficient resolution.

The file names are denoted (italics to be changed):

Calibration tests: **Cal test no_*x*_*instrument*.extension**

Production tests: **Test no_*x*_*CEVtype*_*target flow*.extension**

Test staff

Jesper Fuchs (JUF)	Quality Control, test set-up and test execution
Mogens Hebsgaard (MHE)	Project Manager

3.2.7 Test schedule

The tentative test schedule is:

• Model set-up and function tests estimated finalised during	Week 40/2014
• Calibration/verification of test instruments	Week 40/2014
• Verification tests	Week 40-42/2014
• Report	Week 50/2014

3.2.8 Health, safety and waste

Work at the test site by DHI staff will be done according to the DHI rules for safe field work included in the DHI safety rules.

4 Measurements and Data Analyses

4.1 Measurement parameters and methods

In this section, a summary of the measured data and the analytical methods to be used for calculation of the final results is given, see also Figure 3.1.

- Q_{inflow} is the inlet flow; it is measured by means of the flowmeter; unit: ℓ/s, specifications for the instrument are attached in Appendix B
- $Q_{outflow}$ is the outlet flow; $Q_{outflow}$ is calculated in two ways, see Section 3.2.3 and summary below it is calculated from 1) the inflow and the pressure in the regulator well and 2) from the pressure in the outlet tank and the measured overflow ($Q_{overflow}$) from the outlet tank; see Section 3.2.3
- H is the water level above the invert of the regulator, H is derived from the pressure measurements carried out by the pressure sensor placed in the lower part of the well at a distance a below the regulator invert level, H_{rw} = P-a (a is the vertical distance from the pressure transducer to the invert level, a = 0.874m); unit of H and P is mH_2O, specifications for the instrument are attached in Appendix B
- Filtering or approximation (by polynomial) of the time series of the inflow, outflow and pressures as necessary
- $Q_{outflow}$–H relationships are found and presented and compared to the theoretical relationships

Summarising the two methods for calculations of $Q_{outflow}$:

1) by using the following equation:

$$Q_{outflow,1} = Q_{inflow} - \frac{\Delta Hrw \times Ain \times 1000}{\Delta t}$$

$Q_{outflow,1}$: Flow out through CEV (ℓ/s)
Q_{inflow}: Flow into the inlet tank (ℓ/s)
A_{in}: Surface area in inlet tank, regulator well and inlet riser pipe ($3.38m^2$)
H_{rw}: Pressure head above outlet invert level in the regulator well (mH_2O)
Δt: Time for changing H_{well} with ΔH_{well} (s)

2) by using the following equation:

$$Q_{outflow,2} = Q_{overflow} + \frac{\Delta pot \times Aout \times 1000}{\Delta t}$$

$Q_{outflow,2}$: Flow out of CEV (ℓ/s)
$Q_{overflow}$: Overflow from the outlet tank (ℓ/s)
A_{out}: Surface area in the outlet tank and outlet riser pipe ($0.075m^2$)
p_{ot}: Pressure head in the outlet tank (mH_2O)
Δt: Time for changing H_{out} with Δp_{ot} (s)

Method 2 will be used in the calculation of the relation between $Q_{outflow}$ and H. Method 1 will be used to support quantitatively the results derived by Method 2.

The following procedure is anticipated to take place in the processing of data:

- Data are recorded (logged) with a frequency of 10Hz (0.1s)
- Data are calibrated (to ℓ/s for Q_{inflow} and $Q_{overflow}$ and mH_2O for p_{rw} and p_{ot})
- The calibrated time series are used to find $Q_{outflow1}$ and $Q_{outflow2}$
- $Q_{outflow,2}$ is low-pass filtered using a cut-off frequency of 0.1Hz

- The relation between $Q_{outflow,2}$ and H_{rw} is drawn and compared to the theoretical relation (it may be needed to approximate the relations by means of polynomials in order better to describe the details at the bump)
- $Q_{outflow,1}$ and $Q_{outflow,2}$ are low-pass filtered using a cut-off frequency of 0.001Hz and compared quantitatively

4.2 Analytical and measurement performance requirements

Described under Section 3.2.

4.3 Data management

Data management by DHI will follow the filing and archiving rules described in DHI's quality system. All relevant project documents, e-mail communication and data will be stored on the DHI project SharePoint site.

4.4 Data storage, transfer and control

The Table below shows a summary of the type of data and recording/storage for the data from the verification tests. Immediate check of data will be performed after the tests with each CEV in order to determine if the quality of the data is acceptable. Final data control will be performed as part of the test report review.

The test plan and test report will be compiled as protected PDF files and will be stored on the DHI project SharePoint Site. Data from on-line measurements will be stored locally on a PC by the data-logger. After completion of the testing, the on-line measurement data will be transferred to DHI and will be stored on the project SharePoint site. The handwritten logbook and completed data report forms will be scanned as PDF documents and stored at the project SharePoint Site.

Any deviation from the test plan will be recorded into the logbook – with date, time, initials and description of reason/event for deviations and action taken.

Data Type	Data Media	Responsible for recording/storage of data	Timing of data recording/storage	Data Storage
Test plan and report	Protected PDF files	Test responsible, DHI	When approved	Files and archives at DHI
On-line measurements	Text, (dsf0) and Excel files	Test responsible and technician, DHI	During testing	Files and archives at DHI
Test and set-up details	Logbook and pre-prepared forms	Test responsible, DHI	During testing	Files and archives at DHI
Calculations	Excel files, MIKEZero files	Test responsible, DHI	During testing	Files and archives at DHI

5 Quality Assurance

5.1 Test plan review

Internal review of the test plan will be carried out by Jesper Fuchs (JUF), DHI. The proposer, represented by Mr Torben Krejberg will also carry out a review of the test plan. The test plan must be approved by the proposer and the Verification Body before tests are initiated.

5.2 Performance control – analysis and measurements

The performance of the set-up will be checked during the calibration/documentation. The model set-up will be checked for leakages. The dimensions of the well, the CEVs, the inlet and outlet tubes, the positions of the measurement instruments will be checked before verification tests are initiated.

The calibration of the pressure sensors will be documented and checked before the verification tests are initiated.

5.3 Test system control

The test system will be controlled during the calibration/documentation phase. The data from the data-logger will be checked after each test. If the results are markedly different from the expected values, the system will be checked for possible errors. Depending on this check, the test may be re-run.

5.4 Data integrity check procedures

Deviations from the target value of Q_{inflow} will be documented in the logbook and in the test results. Target results do not need to be reproduced exactly as shown in Table 3.1, as the $Q_{outflow}$–H relationships should be independent of Q_{inflow}.

5.5 Test system audits

An internal audit of the test system will be performed by Jesper Fuchs (JUF), DHI. An external test system audit will be performed by Peter Fritzel from the Verification Body.

5.6 Test report review

The test report will be reviewed by Jesper Fuchs, DHI, the Proposer represented by Mr Torben Krejberg and by the Verification Body.

6 Test Report

The test report will be based on the template that can be found in the DANETV quality manual. The test report will refer to the test plan, and a summary of any amendments to and deviations from the test plan recorded during test from the plans will be included. Templates for reporting amendments and deviations are found in the DANETV quality manual.

The test data report will include all analytical and calculated data as well as a reference to the staff performing the test. The methods of calculation, test measurement and performance parameters from raw data shall be described, unless they are given in the analytical and test methods used. If relevant, details on equipment and software used will be included.

The test report will be reviewed by the test center internal expert and the Proposer and shall be approved by the verification responsible before the verification report is prepared.

6.1 Amendment report

The test report section on amendments will compile all changes to the test plan occurring before testing and will contain justifications of amendments and evaluation of any consequences for the test data quality.

6.2 Deviations report

The report section on deviations will compile all deviations from this test plan occurring during testing with justification of deviations and evaluation of any consequences for the test data quality.

7 References

/1/ Mosbaek CEV flow regulator verification protocol. DHI. September 2014.

/2/ EU Environmental Technology Verification pilot programme. General Verification Protocol. Version 1.1. 2014.07.07.

/3/ DANETV Test Centre Quality Manual, 2013.08.13.

APPENDICES

APPENDIX A

Terms and Definitions

Appendix A – Terms and Definitions

The terms and definitions used by the test body are derived from the EU ETV General Verification Protocol, ISO 9001 and ISO 17020.

Term	DANETV	Comments on the DANETV approach
Accreditation	Meaning as assigned to it by Regulation (EC) No 765/2008	EC No 765/2008 is on setting out the requirements for accreditation and market surveillance relating to the marketing of products
Additional parameter	Other effects that will be described but are considered secondary	None
Amendment	Is a change to a specific verification protocol or a test plan done before the verification or test step is performed	None
Application	The use of a product specified with respect to matrix, purpose (target and effect) and limitations	The application must be defined with a precision that allows the user of a product verification to judge whether his needs are comparable to the verification conditions
DANETV	Danish centre for verification of environmental technologies	None
Deviation	Is a change to a specific verification protocol or a test plan done during the verification or test step performance	None
Evaluation	Evaluation of test data for a technology product for performance and data quality	None
Experts	Independent persons qualified on a technology in verification	These experts may be technical experts, QA experts for other ETV systems or regulatory experts
General verification protocol (GVP)	Description of the principles and general procedure to be followed by the EU ETV pilot programme when verifying an individual environmental technology.	None
Matrix	The type of material that the technology is intended for	Matrices could be soil, drinking water, ground water, degreasing bath, exhaust gas condensate etc.

Term	DANETV	Comments on the DANETV approach
Operational parameter	Measurable parameters that define the application and the verification and test conditions. Operational parameters could be production capacity, concentrations of non-target compounds in matrix etc.	None
(Initial) performance claim	Proposer claimed technical specifications of product. Shall state the conditions of use under which the claim is applicable and mention any relevant assumption made	The proposer claims shall be included in the ETV proposal. The initial claims can be developed as part of the quick scan.
Performance parameters (revised performance claims)	A set of quantified technical specifications representative of the technical performance and potential environmental impacts of a technology in a specified application and under specified conditions of testing or use (operational parameters).	The performance parameters must be established considering the application(s) of the product, the requirements of society (legislative regulations), customers (needs) and proposer initial performance claims
Procedure	Detailed description of the use of a standard or a method within one body	The procedure specifies implementing a standard or a method in terms of e.g.: equipment used
Proposer	Any legal entity or natural, which can be the technology manufacturer or an authorised representative of the technology manufacturer. If the technology manufactures concerned agree, the proposer can be another stakeholder undertaking a specific verification programme involving several technologies.	Can be vendor or producer
Purpose	The measurable property that is affected by the product and how it is affected.	The purpose could be reduction of nitrate concentration, separation of volatile organic compounds, reduction of energy use (MW/kg) etc.
(Specific) verification protocol	Protocol describing the specific verification of a technology as developed applying the principles and procedures of the EU GVP and this quality manual.	None

Term	DANETV	Comments on the DANETV approach
Standard	Generic document established by consensus and approved by a recognised standardization body that provides rules, guidelines or characteristics for tests or analysis	None
Test/testing	Determination of the performance of a product for measurement/parameters defined for the application	None
Test performance audit	Quantitative evaluation of a measurement system as used in a specific test.	Eg evaluation of laboratory control data for relevant period (precision under repeatability conditions, trueness), evaluation of data from laboratory participation in proficiency test and control of calibration of online measurement devises.
Test system audit	Qualitative on-site evaluation of test, sampling and/or measurement systems associated with a specific test.	Eg evaluation of the testing done against the requirements of the specific verification protocol, the test plan and the quality manual of the test body.
Test system control	Control of the test system as used in a specific test.	Eg test of stock solutions, evaluation of stability of operational and/or on-line analytical equipment, test of blanks and reference technology tests.
Verification	Provision of objective evidence that the technical design of a given environmental technology ensures the fulfilment of a given performance claim in a specified application, taking any measurement uncertainty and relevant assumptions into consideration.	None

APPENDIX B

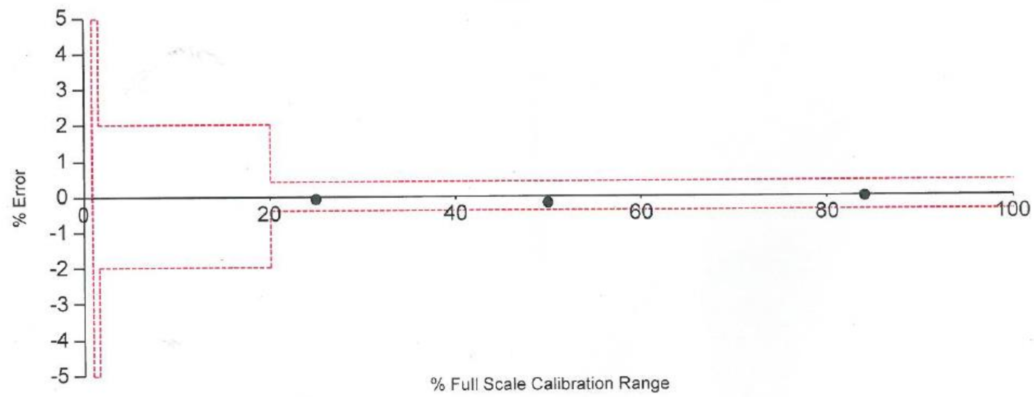
Instrument Specifications:
Flowmeters and Pressure Transducers
Data Logging Equipment

ABB

CERTIFICATE OF CALIBRATION

Customer Name:	ABB A/S - DKABB	Certificate Number:	13/1/4/002759
Customer Ref:	234-4500267382	Accreditation Number:	
Tag Number:		Calibration Date:	28 Aug 2013
Serial No:	3K220000190399	Calibration Location:	ABB Stonehouse U.K.
ABB Order Ref:	0000473641	Test Rig:	Rig 4
Meter Type:	WaterMaster	Fluid:	Water
Meter Code:	FEV111100V1S1S2B1A1A0A1A1A1	Calibration Range:	83.33 m3/hr
Meter Options:	.V0.CWA	Calibration Type:	Comparison
Meter Bore:	100 mm	Sensor Factor Ss:	169.4773
		Sensor Factor Ss(t):	0.0000
		Sensor Factor Sz:	-2.1181
		Sensor Factor Sz(b):	0.0000
		Accuracy Specification:	Class 2

		Reference						Meter Under Test		
Test Run number	Run Time sec	Water Temp °C	Stream 1 m3/hr	Stream 2 m3/hr	Stream 3 m3/hr	Stream 4 m3/hr	Ref-Lab Flow m3/hr	Test Meter Flowrate m3/hr	% Cal. Range	% Error
1	60.000	27.200	20.824	0.000	0.000	0.000	20.824	20.808	24.970	-0.08
2	48.000	27.200	41.696	0.000	0.000	0.000	41.696	41.617	49.941	-0.19
3	48.000	27.200	70.022	0.000	0.000	0.000	70.022	69.999	83.999	-0.03



This flowmeter has been wet calibrated at ABB Stonehouse Calibration Facility and is traceable to some/all of the International Standards detailed below ISO 4185, ISO 7278 Part 2, ISO 8316 and ISO 17025

Note, these are the main calibration standards, but due to the complex nature of fluid flow calibration, other standards will apply to parts of the system

ABB Limited Oldends Lane, Stonehouse Gloucestershire, GL10 3TA ENGLAND Tel: +44 (0) 1453 826661 Fax: +44 (0) 1453 829671 e-mail: flow@gb.abb.com	**ABB Engineering Shanghai Limited** No.5, Lane 369, Chuangye Road, Kangqiao Town Pudong District, Shanghai, 201319, PRC Tel: +86 (0) 21 61056666 Fax: +86 (0) 21 61056992 e-mail: china.instrumentation@cn.abb.com	**ABB Limited** 32 Industrial Area NIT, Faridabad - 121001, Haryana, India Tel: +91 129 2448100 Fax: +91 129 4023006 e-mail: abb.instrumentation@in.abb.com
ABB Automation Bapaume Rd Moorebank, NSW 2170 AUSTRALIA Tel: +61 2 9821 0111 Fax: +61 2 9821 0950	**ABB Automation GmbH** Dransfelder Str. 2 D-37079 Göttingen GERMANY Tel: +49 (0) 551 9050 Fax: +49 (0) 551 905711	**ABB Automation Inc.** 125 East County Line Road Warminster, PA 18974 U.S.A Tel: +1 215 674 6000 Fax: +1 215 674 6394

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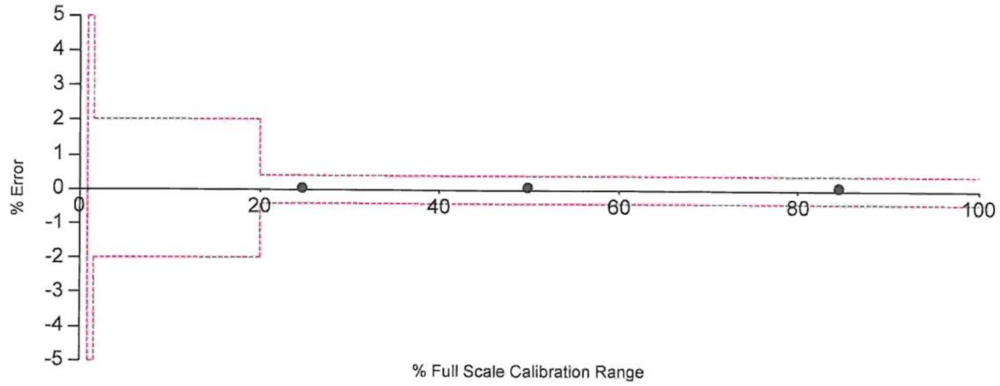
ABB

CERTIFICATE OF CALIBRATION

Customer Name:	ABB A/S - DKABB	**Certificate Number:**	13/1/4/002989
Customer Ref:	234-4500270862	**Accreditation Number:**	
Tag Number:		**Calibration Date:**	15 Oct 2013
Serial No:	3K220000194712	**Calibration Location:**	ABB Stonehouse U.K.
ABB Order Ref:	0000487769	**Test Rig:**	Rig 4
Meter Type:	WaterMaster	**Fluid:**	Water
Meter Code:	FEV111100V1S1S2B1A1A0A1A1A1	**Calibration Range:**	83.33 m3/hr
Meter Options:	.V0.CWA	**Calibration Type:**	Comparison
Meter Bore:	100 mm	**Sensor Factor Ss:**	172.1297
		Sensor Factor Ss(t):	0.0000
		Sensor Factor Sz:	-2.8350
		Sensor Factor Sz(b):	0.0000
		Accuracy Specification:	Class 2

	Reference							*Meter Under Test*		
Test Run number	*Run Time sec*	*Water Temp ° C*	*Stream 1 m3/hr*	*Stream 2 m3/hr*	*Stream 3 m3/hr*	*Stream 4 m3/hr*	*Ref-Lab Flow m3/hr*	*Test Meter Flowrate m3/hr*	*% Cal. Range*	*% Error*
1	60.000	23.00	20.568	0.000	0.000	0.000	20.568	20.578	24.694	0.05
2	48.000	23.00	41.496	0.000	0.000	0.000	41.496	41.531	49.837	0.08
3	48.000	23.00	70.320	0.000	0.000	0.000	70.320	70.380	84.456	0.09



This flowmeter has been wet calibrated at ABB Stonehouse Calibration Facility and is traceable to some/all of the International Standards detailed below
ISO 4185, ISO 7278 Part 2, ISO 8316 and ISO 17025
Note, these are the main calibration standards, but due to the complex nature of fluid flow calibration, other standards will apply to parts of the system

ABB Limited Oldends Lane, Stonehouse Gloucestershire, GL10 3TA ENGLAND Tel: +44 (0) 1453 826661 Fax: +44 (0) 1453 829671 e-mail: flow@gb.abb.com	**ABB Engineering Shanghai Limited** No.5, Lane 369, Chuangye Road, Kangquiao Town Pudong District, Shanghai, 201319, PRC Tel: +86 (0) 21 61056666 Fax: +86 (0) 21 61056992 e-mail: china.instrumentation@cn.abb.com	**ABB Limited** 32 Industrial Area NIT, Faridabad - 121001, Haryana, India Tel: +91 129 2448100 Fax: +91 129 4023006 e-mail: abb.instrumentation@in.abb.com
ABB Automation Bapaume Rd Moorebank, NSW 2170 AUSTRALIA Tel: +61 2 9821 0111 Fax: +61 2 9821 0950	**ABB Automation GmbH** Dransfelder Str. 2 D-37079 Göttingen GERMANY Tel: +49 (0) 551 9050 Fax: +49 (0) 551 905711	**ABB Automation Inc.** 125 East County Line Road Warminster, PA 18974 U.S.A Tel: +1 215 674 6000 Fax: +1 215 674 6394

Calibration / Test Certificate

ABB

Customer: ABB A/S - DKABB		Test Description	144003 337011
		Certificate Number	2/1/D&D/1980
		Equipment Used	ID No / Cal Due
		Timer	KEN 1239 / 27/10/12
		Scale 1	KEN 2544 / 17/08/12
Calibration Type:	Gravimetric	Scale 2	KEN 2130 / 15/11/12
Meter Type:	WaterMaster V, Class 2	W. Temp	Ken 1845 / 22/11/12
Sensor Serial No:	3k220000144003	Sensor Span:	-195.23
Transmitter Serial No:	KEN3049	Sensor Zero:	-1.48
Sensor DN:	50 mm	Drive Mode:	
Q3:	63.0 m3/hr	Slurry Fact:	
Calibration Date:	12-Jul-12	Sc, Sv	-2, -11
Operator:	Marc Henderson		
Ambient:	20C, 75%		

Run	Reference Weight kg	Run Time seconds	Temp °C	Volume litres	Flowrate l/s	Meter Under Test Pulse Factor	Pulses	Flowrate l/s	Error %	Comments
1	1001.1	650.71	27.1	1005.680	1.546	70	70574	1.549	0.25%	
2	1001.4	359.87	27.0	1005.953	2.795	40	40287	2.799	0.12%	
3	1004.3	182.17	26.9	1008.839	5.538	20	20186	5.540	0.05%	

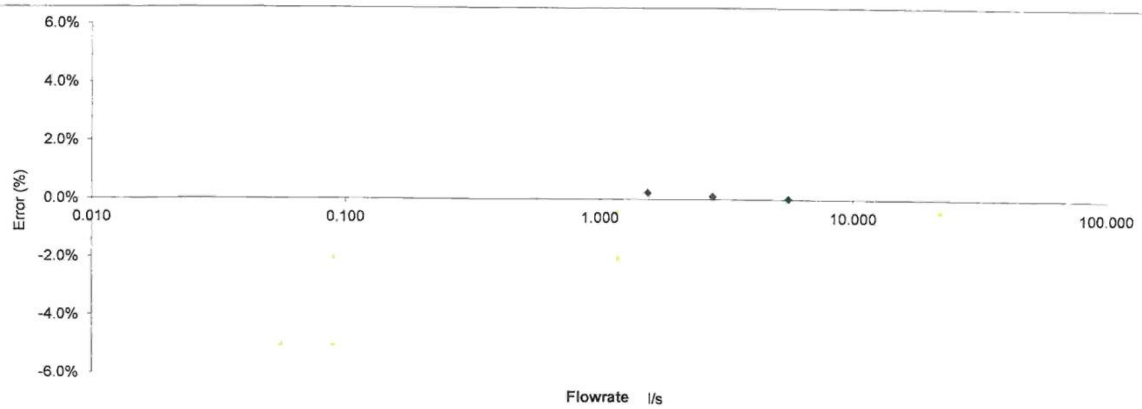


ABB Limited
Oldends Lane
Stonehouse,
Glos, GL10 3TA

The Measurement Uncertainty is +/- 0.083%

The reported expanded Uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Signed Calibrator

Approved Signatory ANDREW PAUL BENT

Approved Signatory Name

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to recognised national standards, and to the units of measurement realised at the National Physical Laboratory or other recognised national standard laboratories. This certificate may not be reproduced, other than in full without the written approval of the issuing laboratory.

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LT100

Submersible transmitter for level measurement in liquids

Level transmitter with submersible probe in stainless steel for level measurement in vessels where pressure connection in the bottom of the vessel is not possible or desirable. For exampel pump pits, reservoirs or plastic tanks.

- LT100 has microcomputer based electronics.
- HART communication.
- Accuracy 0,1 %.
- Configuration through HART communication from PC with the program PI100 or with a standard hand held HART terminal.
- Withstands mediatemperatures up to 80 °C continuously.
- Well tested and approved for EExia according to ATEX and CE (EMC and PED).
- Lightning protected (option). Fullfills the demands for Class 1 testing according to IEC61643-1, 5 kA (10/350 uS).
  This means that the transmitter can withstand a stroke of lightning close to the supply/signal cables. (Not available togheter with EExia approval.)
- Stainless steel measurment probe with a rugged Hastelloy C 276 diaphragm (others on request).
- Embossed diaphragm, insensitive to particles and contact. Can easily be cleaned without deformation.
- Big span turn down ratio. Down to 1/30 of sensor limit.

PONDUS INSTRUMENTS

DANETV

DHI

Types and order codes:

The transmitters order codes for different configurations can be found from the table below.

LT100XX-XXXX

Electronic	Design	Diaphragm	Connection	Pressure range	Measuring principle
H = Hart	E= Explosion-proof Exia L= Lightning protected	4= Hastelloy C-276	0= Submersible	2= 3,5 mH2O 4= 20 mH2O 6= 200 mH2O	0= Gauge pressure

Ordering example

Lightning protected level transmitter with submersible measuring probe, 10 m cable and calibrated range 0-1,5 m water level will have the order code: **LT100HL-4020** with calibrated range 0-1,5 mH2O

Description

LT100 is a level transmitter for applications where pressure connection in the bottom of the vessel is not possible or desirable, for exampel pump pits. LT100 consists of a measure-ment probe with the diameter 31 mm. The probe has a Hastelloy C-276 measuring diaphragm for highest corrosion resistance (other material as options). The probe are suspended in its connection cable. Standard lenght for the probe cable is 10 m, but can on be delivered in lenght up to 500 m, max range 200 mH2O (cable lenght over 500 m on request).
Connection of the probe cable can be done in optional connection box. A specially designed connection box can be delivered as an accessorie. This box is equiped with an appropriate connection for the probe cables atmoshperic vent tube.
Its also possible to equip this box with a local display.
LT100 can as an option be delivered with a good lightning protection (see next page for description).
LT100 can as an option also be delivered in intrinsic safe design, EExia.

Function

LT100 has a piezoresistive sensor connected to the media by means of a diaphragm and a capillary tube. The media pressure acts on the diaphragm and is tranfered to the sensor through a pressure intermediate oil. Since this oil completely fills the volume between the diaphragm and the sensor the diaphragm movement is very small when the pressure changes. Since the diaphragm are embossed to the surface underneath it is very insensitive to particles and contact. The capillary tube protects the sensor from high overloads because of short pressure shocks. To obtain atmospheric pressure on the back side of the sensor (for reference pressure) it is connected to the surrounding through a capillary tube inside the probe cable.
LT100 has microcomputer-based electronics, which communicate with the outside world with 4 to 20 mA signal as well as HART communication. The electronics measure and converts the output signal from the pressure dependent sensor bridge to digital values. Furthermore, the total resistance of the sensor bridge is measured and these values are converted to digital temperature values.
The electronics perform compensation for temperature drift of the sensor by means of compensation values entered at the factory calibration and at the same time the temperature measurement is also calibrated. Compensation for the non-linearity in the sensor is done in the same manner.
Different kinds of transfer functions, such as linear, square root, curves..., can be selected. The electronics perform the calculation for the selected transfer function and then the digital value is converted to analogue for the 4 to 20 mA current loop. The digital value can also be read via HART communication in optional engineering units, percentage or current.
LT100 can be configured/ calibrated fully by means of a hand terminal or a PC via HART communication.

To consider

Dont expose the diaphragm to unnecessary damage (even though its very robust and insensitive).
Dont descend the probe so that it stands on the bottom of the vessel.
Highest media temperature is +80°C.
Make sure that the vent tube is connected to the surrounding atmosphere without the risk for plugging.
If the media are turbulent or flowing fasten the probe appropriately.

Lightning protection

As an option LT100 can be equiped with lightning protection. The transmitter will then have the code LT100HL where L indicates "Lightning protected". This option can not be combined with the

Technical specification LT100:

Type:	Electronic submersible level transmitter with microcomputer based electronics	**Series resistance:**	R kohm = (Supply voltage - 11)/20. For HART communication min 250 ohm
Function:	Directly connected transmitter with piezoresistive sensor	**Series resistance dependance:**	Better than +/- 0,1%
Operating range:	From -100% to 100% of upper sensorlimit	**Supply voltage dependance:**	Better than +/- 0,1%
Span:	Adjustable between upper sensor limit and 1/30 of this.	**Temperature dependance:**	Better than +/- 0,1% of max range. (From -10 to +70 degrees C.)
Zero:	Adjustable between -100% and 100% of upper sensor limit	**Long time stability:**	Better than 0,08 % per year.
Overload: 3,5 mH2O:	Max 25mH2O	**Vibration dependance:**	
20 mH2O:	Max 60 mH2O	Perpendicular to the diaphragm:	Max +0,3 kPa/G
200 mH2O:	Max 600 mH2O	Parallell to the diaphragm:	Max +0,02 kPa/G
Material: Diaphragm:	Hastelloy C-276 (certain coatings on request)	**Repeatability:**	Better than +/- 0,1% of max range.
Other media tuched parts:	Stainless steel SS2353	**Accuracy:**	Better than +/- 0,1% of max range (including nonliearity, hysteresis and repeatability).
Cable:	Polyurethane	**Electrical connection:**	Lose wires
Ambient temperature:	-20 to +80 degrees C	Wire area:	0,75 mm2
Damping:	0,1-10 sec. At delivery 1 sec	**Encapsulation:**	IP68
Media temperature:	Max 80 degrees C	**Electrical safety:**	According to EN 60204-1
Output:	4-20 mA, two wire connection, signal proportional to the pressure. Max current at overload 22,5 mA. HART communication	**EMC:**	According to EN 61326-1-2-3
Supply:	9-55 V DC	**Intrinsic safety (option):**	EExia IIC T4 (NEMKO) according to ATEX
Filling liquid:	AK100, food approved siliconoil (FDA approval)	**PED:**	According to 97/23/EG
Weight:	700 g including 10 m cable.	**Lightning protection (option):**	Class 1 testing according to IEC61643-1. 5kA (10/350 uS).

PONDUS INSTRUMENTS

Internet: www.pondus-instruments.com
Product home page: www.etp90.com/LT100

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LT100_EN_0902_ABB

Typically, when a system is in sleep mode, you cannot communicate with the modules. In sleep mode, the system consumes minimal power and may dissipate less heat than it does in normal mode. Refer to the *Specifications* section for more information about power consumption and thermal dissipation.

Specifications

The following specifications are typical for the range –40 to 70 °C unless otherwise noted. All voltages are relative to COM unless otherwise noted.

Input Characteristics

Number of channels .... 8 analog input channels

ADC resolution .... 16 bits

Type of ADC.................................... Successive approximation register (SAR)

Nominal input

- Unipolar.................................... 0 to 20 mA
- Bipolar....................................... ±20 mA

Minimum overrange

- Unipolar 6.5%
- Bipolar 5.5%

Overvoltage protection .... ±30 V Ch-to-COM max

Sample rate

- R Series Expansion chassis .... 192 kS/s max
- All other chassis .... 200 kS/s max

Conversion time

- R Series Expansion chassis .... 5.2 µs min
- All other chassis .... 5 µs min

Unipolar accuracy

Measurement Conditions	Percent of Reading (Gain Error)	Percent of Range* (Offset Error)
Calibrated max (–40 to 70 °C)	±0.18%	±0.06%
Calibrated typ (25 °C, ±5 °C)	±0.04%	±0.02%
Uncalibrated max (–40 to 70 °C)	±0.66%	±0.54%
Uncalibrated typ (25 °C, ±5 °C)	±0.49%	±0.46%
* Range equals 21.5 mA.		

Bipolar accuracy

Measurement Conditions	Percent of Reading (Gain Error)	Percent of Range* (Offset Error)
Calibrated max (–40 to 70 °C)	±0.20%	±0.09%
Calibrated typ (25 °C, ±5 °C)	±0.05%	±0.02%
Uncalibrated max (–40 to 70 °C)	±0.74%	±0.66%
Uncalibrated typ (25 °C, ±5 °C)	±0.54%	±0.55%
* Range equals 43 mA (±21.5 mA).		

Scaling coefficients

Unipolar....................................330 nA/LSB typ

Bipolar......................................660 nA/LSB typ

Unipolar stability

Offset drift.................................63 nA/°C

Gain drift ....±14 ppm/°C

Bipolar stability
- Offset drift .... 286 nA/°C
- Gain drift .... ±17 ppm/°C

Input bandwidth (–3 dB).................. 850 kHz

Input impedance
- Resistance.................................. 138 Ω
- Capacitance .... 20 pF

Input noise (code-centered)
- RMS .... 1 LSB_{rms}
- Peak-to-peak.............................. 7 LSB

No missing codes............................. 16 bits

INL... ±3 LSB max

Crosstalk (at 1 kHz).......................... –100 dB

Settling time (to 2 LSB)................... 5 µs

APPENDIX C

Specifications of
300mm and 800mm WAVIN Pipes

Spildevand / Gravitation / Dobbeltvæggede rør - X-Stream /

300mm sort PP X-Stream regnvandsrør m/muffe sn8 3m

2531014

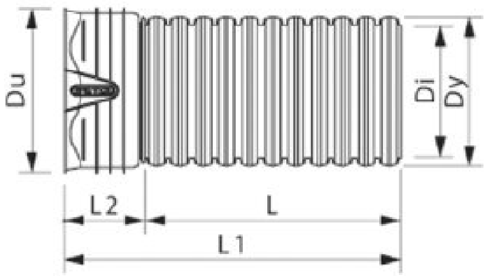
Generel information

EAN	5708525374860
Varenummer	2531014
VVS nr.	198863300
DB nr.	1443417

Beskrivelse

Produkttype	Rør
Materiale	Polypropylen
Farve	Sort
Ø	300

Teknisk information



L = 3000 mm,Dimension = 300 ,L2 = 154 mm,Di = 294 mm,Dy = 338 mm,L1 = 3154 mm,Du = 371 mm

Spildevand / Gravitation / Dobbeltvæggede rør - X-Stream /

800mm sort PP X-Stream regnvandsrør m/muffe sn8 3m

2531029

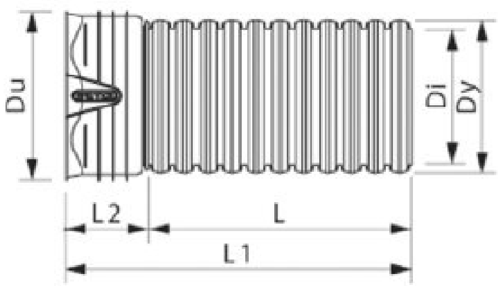
Generel information

EAN	5907444018026
Varenummer	2531029
VVS nr.	198863800
DB nr.	1443425

Beskrivelse

Produkttype	Rør	**Stivhedsklasse**	0
Materiale	Polypropylen		
Farve	Sort		
Ø	800		
Indvendig diameter	785		
Længde	3 M		

Teknisk information



Di	785mm
Du	985mm
Dy	895mm
L1	400mm
L2	3400mm
L	3000mm

APPENDIX D

Check Lists, Pre-tests and Verification Tests

Appendix D – Check Lists, Pre-tests and Verification Tests

Model tests with CEV Flow Regulators

Check of calibration of pressure transducer in the regulator well

Procedure

This procedure describes the way used to verify the calibration of the pressure transducers.

1. Close the outlet from the regulator well
2. Fill in water until outlet invert level
3. Start recording
4. Close the inlet valve and let the water level be undisturbed for at least 5min
5. Read also the constant water level at the measure stick by video or at least each minute
6. Fill in water until about 1m above pressure transducer
7. Repeat 4 and 5
8. Fill in water until about 2m above pressure transducer
9. Repeat 4 and 5
10. Fill in water until about 3m above pressure transducer
11. Repeat 4 and 5, but 4 with a duration of at least 10min
12. Stop recording

Manual readings

Water levels	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
At CEV invert level for outlet pipe					
~+1m					
~+2m					
~+3m					

Date:

Test No:

Test id:

Model tests with CEV Flow Regulators

Check of calibration of pressure transducer in the outlet tank

Procedure

This procedure describes the way used to verify the calibration of the pressure transducer.

1. Close the outlet from the outlet tank
2. Fill in water until the pressure transducer is covered
3. Start recording
4. Let the water level be undisturbed in 5 minutes
5. Read the constant water level at the measure stick by video or at least each minute in 5 minutes
6. Fill in water until about 0.6m above pressure transducer
7. Repeat 4 and 5
8. Fill in water until about 1.2m above pressure transducer
9. Repeat 4 and 5
10. Fill in water until about 1.8m above pressure transducer
11. Repeat 4 and 5
12. Stop recording

Manual readings

Water levels	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
Transducer covered					
~+0.6m					
~+1.2m					
~+1.8m					

Date:

Test No:

Test id:

Model tests with CEV Flow Regulators

Execution of zero scan

Procedure

This procedure describes the way used before start of a series of tests with a new CEV.

Date:

Test No: **CEV model and id:** **Target flow:**

Test id:

Action	Check	Time	Signature
Check instruments		N/A	
Fill tanks with water until CEV invert			
Close inlet adjustment valve			
Wait until water level is stable			
Start data logging (at zero level)			
Wait 10 minutes			
Stop data logging			

Model tests with CEV Flow Regulators

Execution of verification tests

Procedure

This procedure describes the way used during execution of the tests.

Date:

Test No: **CEV model and id:** **Target flow:**

Test id:

Action	Check	Time	Signature
Check instruments		N/A	
Close inlet adjustment valve			
Fill or empty tanks with water just below CEV invert			
Start data logging (at level just below zero)			
Wait 5 minutes			
Start submersible pump			
Open valve until target flow is reached			
Proceed at least until design H is reached			
Close inlet valve			
Stop pump			
Proceed until well is empty for one test per CEV			
Wait 5 minutes			
Stop data logging			
Empty the inlet tank and regulator well by evacuation valve in three of the four tests			
Check results roughly			

APPENDIX D

Test Report

Mosbaek Verification

Tests with CEV Flow Regulators

Mosbaek A/S

DHI DANETV Test Report

February 2015

The expert in **WATER ENVIRONMENTS**

This test plan has been prepared under the DHI Business Management System certified by DNV-GL to comply with ISO 9001 (Quality Management)

Approved by
Jesper Fuchs, Head of Projects, POT

Mosbaek Verification

Tests with CEV Flow Regulators

Prepared for	Mosbaek A/S
Represented by	Mr Torben Krejberg, Technical Director

Test set-up at Mosbaek

Project manager	Mette Tjener Andersson
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Approver	Jesper Fuchs, Head of Projects, Ports & Offshore Technology

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Approval date	18 February 2015
Revision	Final : 2.0
Classification	Restricted

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Symbol	Description	Unit
Q_{inlet}	The inlet flow pumped into the inlet tank	[ℓ/s]
$Q_{overflow}$	Overflow from the outlet tank	[ℓ/s]
Q, $Q_{outflow}$	Flow out of the CEV	[ℓ/s]
Q_{bump}	Maximum flow out of the CEV at the bump	[ℓ/s]
Q_{design}	Design flow out of the CEV (at H_{design})	[ℓ/s]
R_{rw}	Radius of regulator well	[m]
R_{it}	Radius of inlet tank	[m]
r_{rw}	Radius of inlet riser pipe	[m]
r_{in}	Radius of inlet pipe	[m]
A_{in}	Surface area of the inlet side (inlet tank, regulator well, riser and inlet pipes)	[m^2]
A_{out}	Surface area of the outlet tank and outlet riser pipe	[m^2]
p_{ot}	Pressure head in the outlet tank	[mH_2O]
p_{rw}	Pressure head in the regulator well	[mH_2O]
H	Water level above CEV invert level in the regulator well	[mH_2O]
H_{out}	Water level in the outlet tank	[mH_2O]
H_{design}	Design water level above invert level for actual CEV	[mH_2O]
RSD	Relative standard deviation	[%]
g	Acceleration due to gravity	[m/s^2]

1 Introduction

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and quality assurance.

The objective of this verification and the testing is to evaluate the performance of a **vertical centrifugal flow regulator, CEV** (**Ce**ntrifugal **V**ertical) for storm water pipes.

1.1 Name of technology

Vertical centrifugal flow regulator, CEV (**Ce**ntrifugal **V**ertical), produced by **Mosbaek A/S**.

Mosbaek produces CEVs for flow capacities from 0.2 to 80ℓ/s. The verification covered four CEVs within the range of 1.4 to 10.5ℓ/s.

1.2 Name and contact of proposer

Mosbaek A/S
Værkstedsvej 20
DK-4600 Køge
Denmark

Contact: Mr Torben Krejberg, Technical Director, e-mail tk@Mosbaek.dk, phone +45 5663 8580

Mosbaek website: www.mosbaek.dk

1.3 Name of centre/test responsible

DHI DANETV Test Centre
Agern Alle 5
DK-2970 Hørsholm
Denmark

Test responsible:
Mogens Hebsgaard, email: mhe@dhigroup.com, phone +45 4516 9414

1.4 Reference to test plan and specific verification protocol

This test report is prepared in response to the test design established in the Mosbaek CEV flow regulator Test Plan, /1/, and the Verification Protocol, /2/. The project was carried out in accordance with EU Environmental Technology Verification program, /3/ and DANETV Test Centre Quality Manual, /4/.

2 Test Design

The design of the test set-up is thoroughly explained in the Test Plan (/1/).

The tests were divided into five tasks:

1. Design of test facility
2. Installation of facility
3. Test of facility (pre-testing)
4. Verification testing
5. Documentation

The test facility was set up at the premises of Mosbaek A/S.

The pretesting contained a check of the pressure transducers mounted in the inlet and outlet side, see also /1/.

The verification testing comprised tests with four CEVs and with one orifice. The test programme and conditions are shown in Table 2.1. The final test programme was carried out with flow rates very close to target rates (see Test Plan, /1/).

Table 2.1 Test programme; the flow conditions are the measured average inflow through the tests

CEV type	Design flow (ℓ/s)	Flow 1 (ℓ/s)	Flow 2 (ℓ/s)	Flow 3 (ℓ/s)	Flow 4 (ℓ/s)	Flow 4 (ℓ/s)	Flow 4 (ℓ/s)
CEV 1.4ℓ/s @ 1.00m – 100%	1.4	1.79	3.12	4.80	6.31	6.18	6.25
CEV 4.9ℓ/s @ 1.50m – 100%	4.9	5.89	6.52	8.20	9.99	-	-
CEV 10.5ℓ/s @ 2.00m – 78%	10.5	8.60	9.77	11.40	12.97	-	-
CEV 10.5ℓ/s @ 2.00m – 100%	10.5	11.32	12.07	13.75	15.24	-	-
Sharp edged orifice	N/A	13.72	-	-	-	-	-

3 Test Results

3.1 Test data summary

This section contains a summary of the results of all tests which were carried out. For a more detailed description of the test methodology, refer to /1/ and /2/. The raw data files are listed in Appendix B.

This section includes:

- Results of pre-testing
- Results, CEV 1.4ℓ/s @ 1.00m – 100% (six tests)
- Results, CEV 4.9ℓ/s @ 1.50m – 100% (four tests)
- Results, CEV 10.5ℓ/s @ 2.00m – 78% (four tests)
- Results, CEV 10.5ℓ/s @ 2.00m – 100% (four tests)
- Results, Sharp edged orifice (one test)

3.1.1 Brief summary of the test results

The test result summary is shown in Table 3.1.

Table 3.1 Summary of test results

CEV type	Inflow in tests (ℓ/s)	Q (outflow, ℓ/s) at bump		Q (outflow, ℓ/s) at H_{design}	
		Claimed	Measured	Claimed	Measured
CEV 1.4ℓ/s @ 1.00m – 100%	1.79 to 6.31	1.40	1.22 – 1.45	1.40	1.42 – 1.45
CEV 4.9ℓ/s @ 1.50m – 100%	5.89 to 9.99	4.90	4.50 – 5.04	4.90	4.76 – 4.80
CEV 10.5ℓ/s @ 2.00m – 78%	8.60 to 12.97	8.19	7.57 – 8.74	10.50	10.09 – 10.12[*)]
CEV 10.5ℓ/s @ 2.00m – 100%	11.32 to 15.24	10.50	9.75 – 10.67	10.50	10.55 – 10.56

[*)] based on two tests only

The tests with the 100% CEV have shown that there is an almost linear relation between Q_{inflow} and Q_{bump} and between Q_{inflow} and the water level rise in the regulator well. This allows interpolations of the results, which may give estimates of Q_{bump} for other Q_{inflow} than tested. The tests indicate that the claimed values of Q_{bump} generally are obtained for a water level rise of ~1.5mm/s. For lower water level rise, Q_{bump} will be slightly smaller, and for higher water level rise Q_{bump} will be slightly larger.

The tests showed that $Q_{outflow}$ at H_{design} is independent of the inflow for the inflows tested.

Tests with identical inflow conditions were carried out (repeated) with CEV 1.4ℓ/s @ 1.00m – 100%. These tests showed almost identical Q – H relationships.

Tests with the orifice, which had a diameter equal to the outlet diameter of the CEV 1.4ℓ/s @ 1.00m, showed that the outflow through the orifice was 6.36ℓ/s at H=1m or 4.45 times the outflow through the CEV.

3.1.2 Results of pre-testing

This subsection includes results of the calibration check of the pressure transducers and estimation of the diameter of the inlet tank. The procedures are described in /1/.

3.1.2.1 Test of inlet side

The pre-testing of the inlet side were carried out to

- Check the calibration of the inlet pressure transducer
- Estimate the diameter of the inlet tank
- Determine whether there was any leakage in the intake system

These items were investigated in one test where:

1. The outlet from the inlet well was closed off by means of a plug
2. Water was pumped into the inlet well at a constant flow rate in 5 steps with approximately 0.5m between the steps. The time between the steps was minimum 5 minutes
3. During the 5-minute pauses, the water level in the well was read with time intervals of 1 minute on a ruler attached to the riser pipe in the well. Also video recordings of the water level were made
4. The time series of inlet flow and pressure during the test was recorded in a file with sampling frequency of $0.1s^{-1}$

Calibration of inlet pressure transducer

The relation between the water level (mm) in the regulator well and output from the pressure transducer (mA) is shown in Figure 3.1.

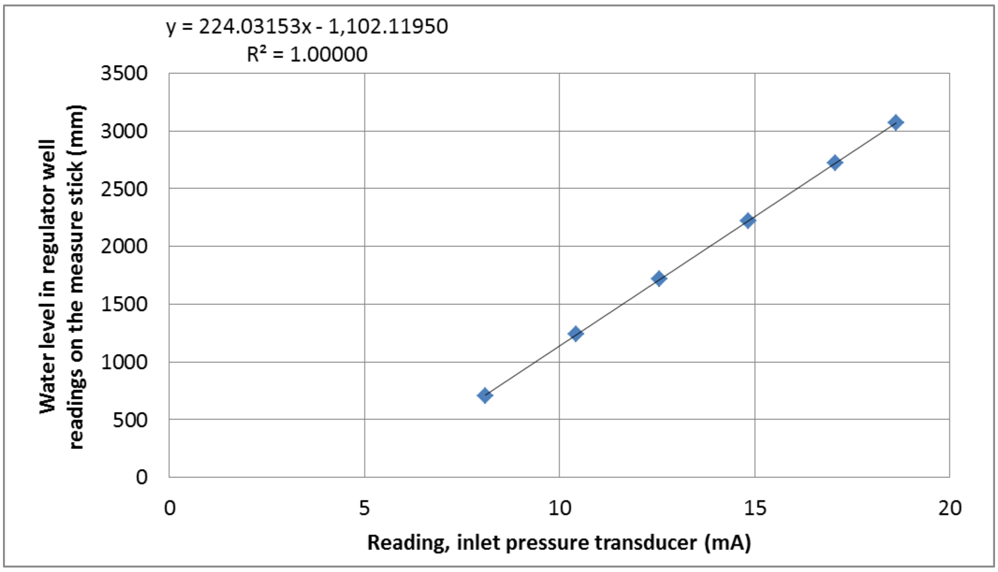

Figure 3.1 Relation between output from pressure transducer and water level, regulator well

It appears the relation between the transducer output and the water level is virtually linear and hence very good. The following relation will be used in all results: 1mA = 0.224mH_2O, which is slightly different (2.5%) from the theoretical calibration: 1mA = 0.21857mH_2O.

Investigations of leakages in the inlet side

This calibration revealed the following relation between the time and H, see Figure 3.2. H is the calibrated water level in the regulator well above the pressure cell.

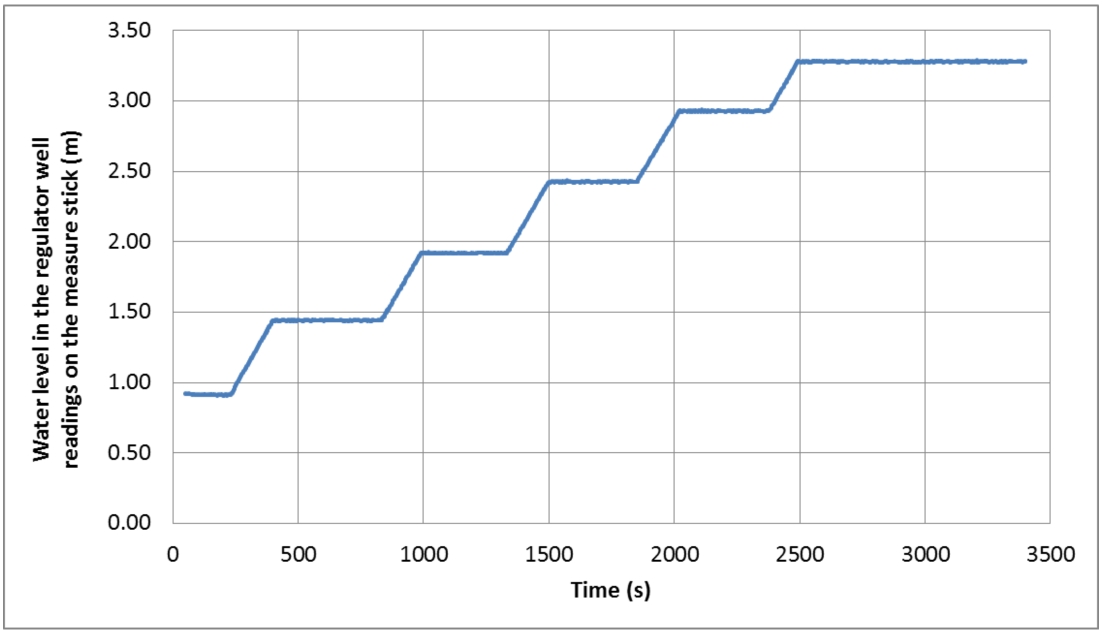

Figure 3.2 Relation between time and H, calibration tests with inlet pressure transducer

Closer analysis of the periods with no inflow showed that the levels were constant during these periods and thus, it was concluded that there was no leakage on the inflow side of the set-up.

Estimation of the inlet tank diameter

The diameter of the inlet tank was estimated from the following formula, see also /1/.

$$Q_{inflow} * \Delta t = -1000 * \Delta p_{rw} * \pi * (R_{rw}^2 + R_{it}^2 + r_{rw}^2 - r_{in}^2) = 1000 * \Delta p_{rw} * A_{in}$$

Q_{inflow} is the measured inflow (ℓ/s)
Δp_{rw} is the pressure difference (mH_2O) in the regulator well during the time Δt
R_{rw} is the radius of the regulator well (0.3925m)
R_{it} is the radius of the inlet tank (m)
r_{rw} is the radius of the Plexiglas riser (=0.036m)
r_{in} is the radius of the feeding pipe (=0.080m)
A_{in} is the area of the inlet side

R_{it} is the only unknown in the expression. On the basis of the five inflow situations, the dimension of the inlet tank was estimated.

The diameter of the inlet tank was estimated at D_{it} = 1.904m, RSD (Relative Standard Deviation) = 0.3%.

3.1.2.2 Test of outlet side

The pre-testing of the outlet side were carried out to

- Check the calibration of the outlet pressure transducer

The relation between the water level (mm) in the outlet tank and output from the pressure transducer (mA) is shown in Figure 3.3.

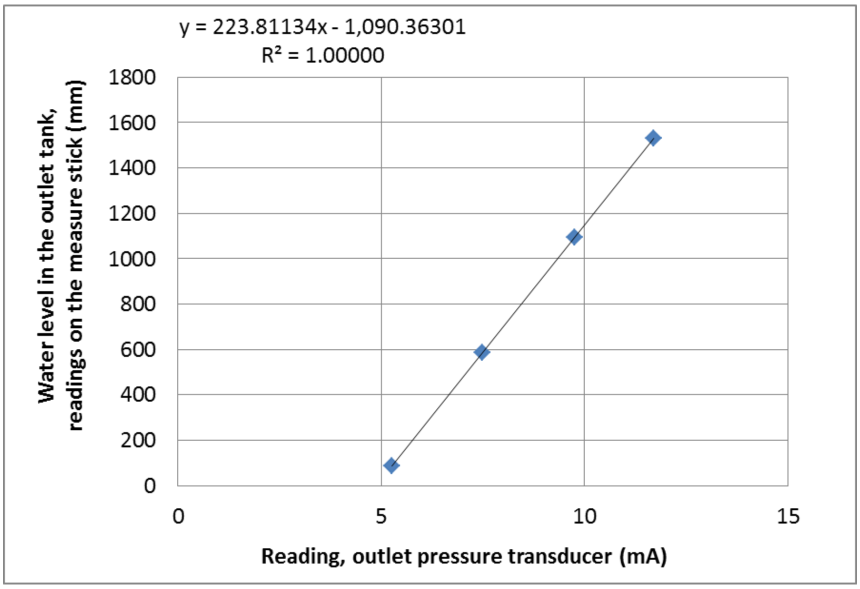

Figure 3.3 Relation between output from pressure transducer and water level, outlet tank

It appears that the relation between the transducer output and the water level is virtually linear and hence very good. The following relation has been used in all results: 1mA = 0.224mH_2O, which is slightly different (2.5%) from the theoretical calibration: 1mA = 0.21857mH_2O.

3.1.2.3 Calibration of flowmeters

The flowmeters were pre-calibrated from the factory, and any further check of the flowmeters calibration was not performed. The calibration factor was 1mA = 4.340ℓ/s for the 100mm flowmeters at the inlet and outlet. The calibration factor for the 50mm flowmeter, which was used for the smallest CEV, was 1mA = 1.094ℓ/s.

3.2 Test results verification tests

This section contains the results of all tests carried out with the CEVs and the orifice.

3.2.1 Short description of methodology

The tests with the individual CEV's were carried out in the following sequence:

Mounting the CEV

The regulator well was lifted off its base and the CEV was identified and mounted at the outlet connection. The outlet of the CEV was an orifice mounted in an Ø160mm pipe with a rubber gasket to secure that the connection was water tight. A photo of one of the tested CEV's is shown in Figure 3.4.

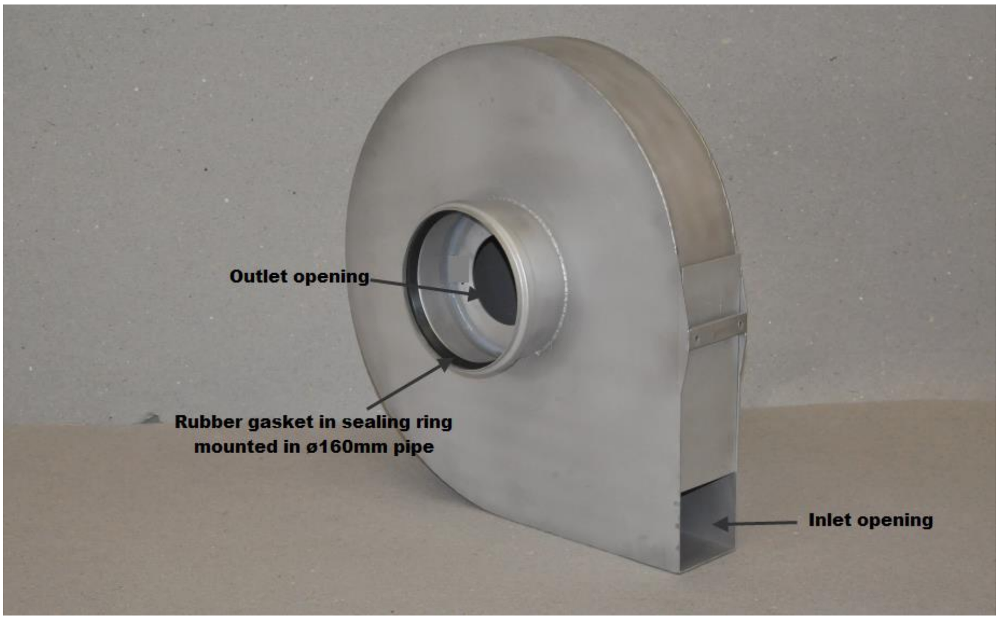

Figure 3.4 Photo of one of the tested CEV's (CEV 4.9ℓ/s @ H=1.50m) showing inlet and outlet openings

Zero test

This test lasted for approximately five minutes, and the purpose was to identify the inlet pressure level for a water level in the regulator well corresponding to the invert level in the outlet opening of the CEV.

Before the zero test was initiated, water was filled into the intake tank to a level slightly above the invert level. The zero test was initiated when the outlet from the regulator well was zero.

The inlet pressure average in the zero test was used as the zero (reference) level in the documentation tests with the mounted CEV.

Verification tests

Four tests (six tests with CEV 1.4ℓ/s @ 1.00m) with different inflows were carried out with each CEV, while one test was performed with just an orifice. For CEV 1.4ℓ/s @ 1.00m, the same flow was repeated three times to document the variation. During the tests, time series of the inflow and outflow and pressure in regulator well and outlet tank were recorded, see also /1/.

Data processing

The data from the tests were processed in order to achieve a relation between H (mH_2O), which is the head in the inlet tank, relative to the invert level of the CEV outlet opening and Q (ℓ/s), which is the outlet flow.

H is measured directly by means of the inlet pressure transducer. Q is expressed by the measured outflow and the pressure in the outlet tank:

The relations between Q = $Q_{outflow}$ and H have been calculated using Method 2, see /1/:

$$Q_{outflow} = Q_{overflow} + \frac{\Delta pot \times Aout \times 1000}{\Delta t}$$

$Q_{outflow}$: Flow out of CEV (ℓ/s)
$Q_{overflow}$: Overflow from the outlet tank (ℓ/s)
A_{out}: Surface area in the outlet tank and outlet riser pipe (0.075m^2)
p_{ot}: Pressure head in the outlet tank (mH_2O)
Δt: Time for changing H_{out} with Δp_{ot} (s)

Q was calculated for time steps of 0.1s. Fluctuations in the signals made it necessary to average the signals, and accordingly the time series for Q underwent a 20s moving averaging. In order to determine the Q value in the bump and at design H, averaging was made by a moving averaging over 100s (CEV 1.4ℓ/s @ 1.00m and CEV 4.9ℓ/s @ 1.5m) and over 60s (CEV 10.5ℓ/s @ 2.00m – 78% and 100%).

Method 1 (see /1/) was generally abandoned. Small and unavoidable fluctuations in the intake pressure caused by the water inflow resulted in large fluctuations in the estimated flow, due to the large surface areas at the inlet side. The time series had to be subjected to intensive averaging to get readable results. A comparison between the results obtained by means of Method 1 and Method 2 for one of the model tests has been included. The results are shown in Appendix D. It appears that, apart from the fluctuations, there is a good agreement between the two methods. However, since the quality of the results with Method 2 was very reliable, while the results obtained by means of Method 1 are subject to large fluctuations, it was chosen to use Method 2 only.

3.2.2 Test results CEV1.4ℓ/s @ 1.00m – 100%

Description of the CEV

The identification number of this CEV was: **109.1.1**

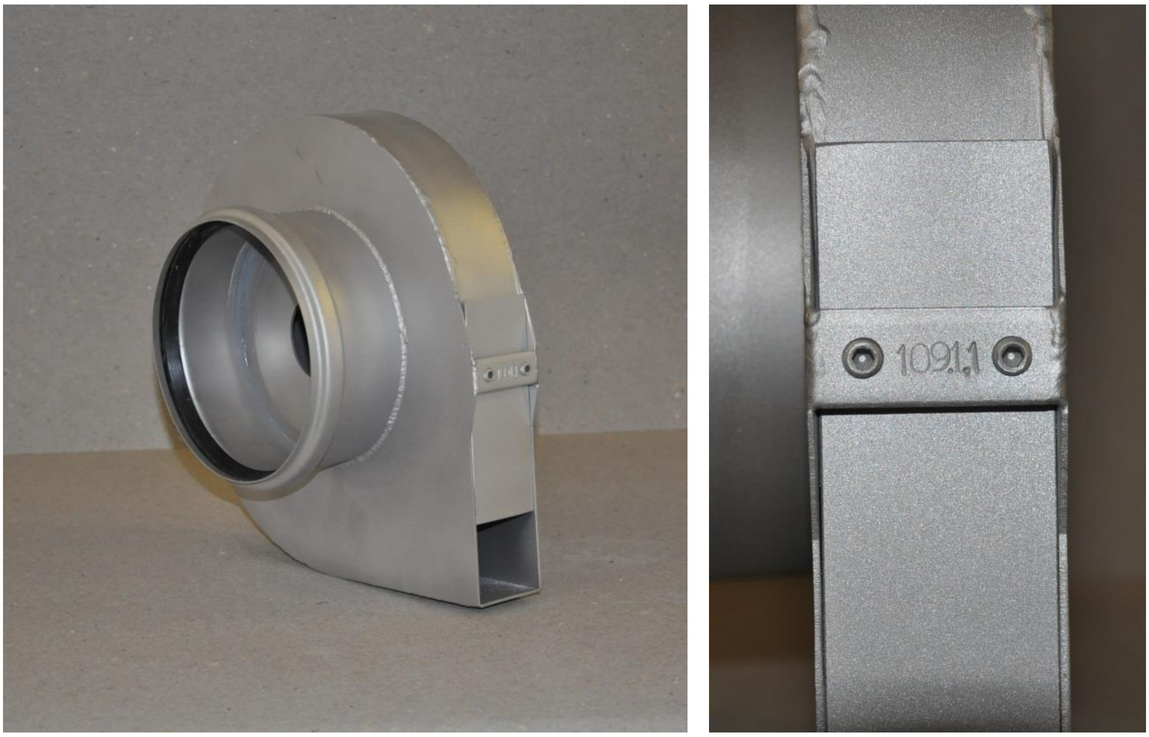

Figure 3.5 Photos of CEV 1.4ℓ/s @ 1.00m – 100%

The dimensions of the CEV were checked and found to be in accordance with specifications.

Test conditions
Table 3.2 shows the test conditions for this CEV.

Table 3.2 Test inflow conditions, CEV 1.4ℓ/s @ 1.00m – 100%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4	Flow 4	Flow 4
Inflow (ℓ/s)	1.4	1.79	3.12	4.80	6.31	6.18	6.25
Test no	-	1	4	3	2	5	6

For CEV 1.4ℓ/s @ 1.00m, three tests were carried out with Flow 4 to determine the variation.

Results
The relations between Q and H for the three tests with the same inflow conditions (Flow 4) are shown in Figure 3.6 and Figure 3.7.

- Figure 3.6: Results of tests 2, 5 and 6, moving averaging over 20s used
- Figure 3.7: Results of tests 2, 5 and 6, moving averaging over 100s used

Table 3.3 Test results, CEV 1.4ℓ/s @ 1.00m – 100%, investigation of variation

	Design flow	Flow 4	Flow 4	Flow 4
Inflow (ℓ/s)	1.4	6.31	6.18	6.25
Test no	-	2	5	6
Q_{bump} (ℓ/s)	1.4	1.45	1.43	1.43
Q at H_{design} (ℓ/s)	1.4	1.45	1.43	1.43
Average water level increase (mm/s)		1.54	1.53	1.53

The variations of Q_{bump} and Q at H_{design} are seen to be less than 10 %, and according to the verification protocol, /2/, section 5.1.4, this is then meant that triplicate tests were not required for the remaining CEVs.

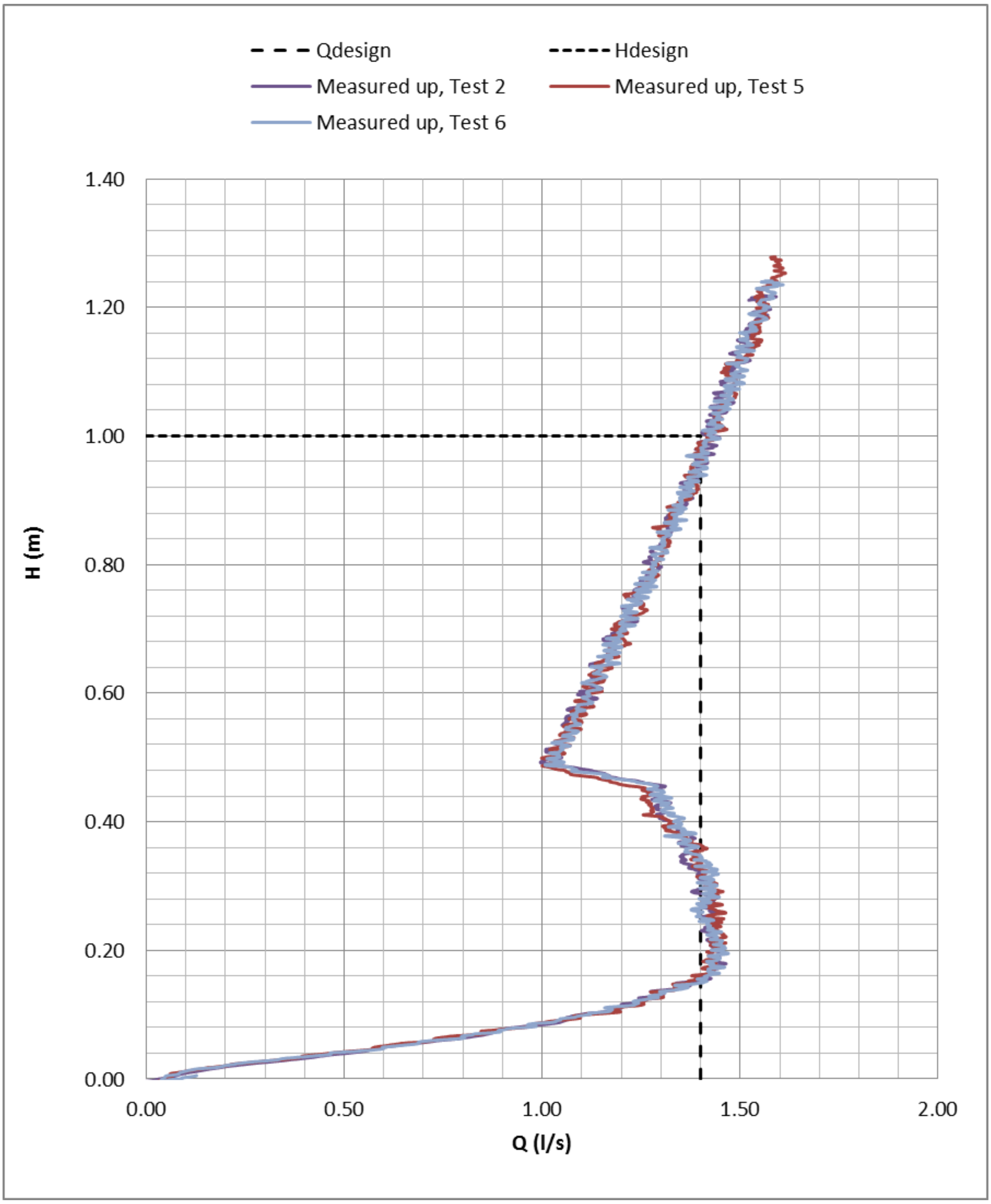

Figure 3.6 Results of tests 2, 5 and 6, moving averaging over 20s used, CEV 1.4ℓ/s @1.00m

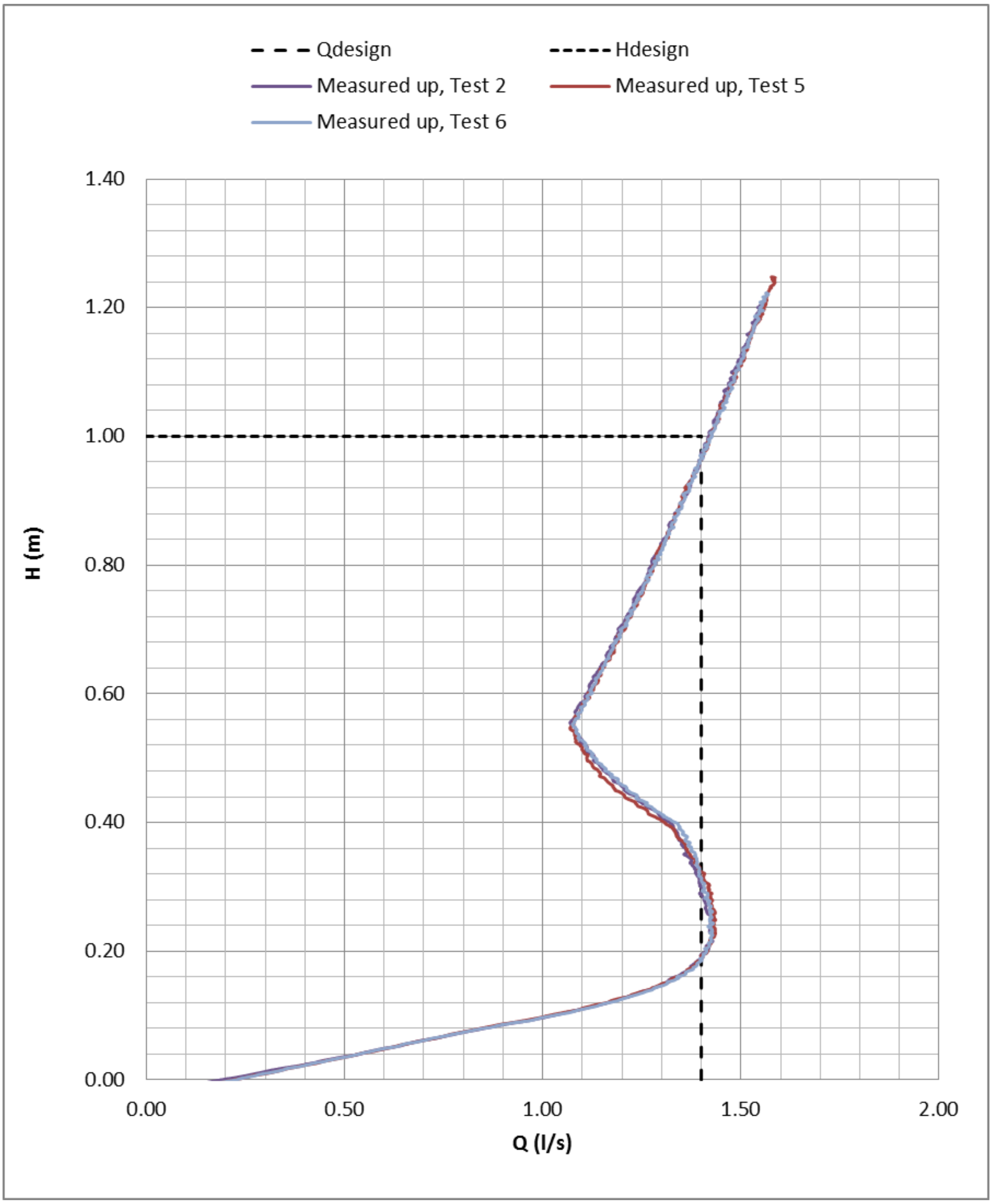

Figure 3.7 Results of tests 2, 5 and 6, moving averaging over 100s used, CEV 1.4ℓ/s @1.00m

In the remaining evaluation of this CEV model, the results from test 2 have been used.

The relations between H and Q are shown in the following figures:

- Figure 3.9: Results of tests 1, 2, 3 and 4 moving averaging over 20s used
- Figure 3.10: Results of tests 1, 2, 3 and 4 moving averaging over 100s used

The tests showed the following values of Q at the bump and at H_{design}. The Q value at the bump and at design H was derived using the results from the moving averaging over 100s.

Table 3.4 Test results, CEV 1.4ℓ/s @ 1.00m – 100%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	1.4	1.79	3.12	4.80	6.31
Test no	-	1	4	3	2
Q_{bump} (ℓ/s)	1.4	1.22	1.31	1.38	1.45
Q at H_{design} (ℓ/s)	1.4	1.42	1.43	1.43	1.45
H at end of bump (m)	-	0.40	0.45	0.50	0.55
Average water level increase (mm/s)		0.19	0.61	1.09	1.54

It is seen that at **the bump** the average flow was:

- Average, tests 1, 2, 3, 4: Q_{bump} = 1.34ℓ/s, RSD = 6.8 % [1]

It is seen that at $\mathbf{H_{design}}$ the average flow was:

- Average, tests 1, 2, 3, 4: $Q_{Hdesign}$ = 1.43ℓ/s, RSD = 0.4 %

The measured relations between Q_{inflow} and Q_{bump} are illustrated in Figure 3.8.

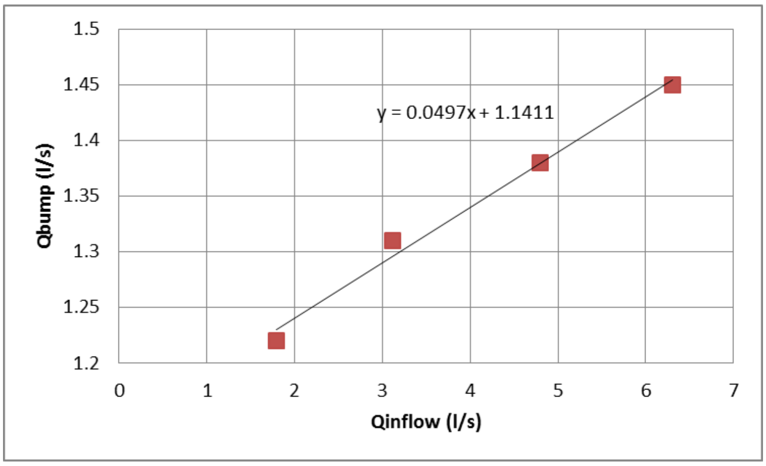

Figure 3.8 Measured relations between Q_{inflow} and Q_{bump}, CEV 1.4ℓ/s @ 1.00m – 100%

The run-off relation is seen to follow the same relation as during run-up until the end of the bump. A small bump is seen at H≅0.05m (Figures 3.9 and 3.10), where the rotation in the CEV stops and the outlet opening begins to act as an orifice.

[1] Please be aware that the results of Q_{bump} are uniquely influenced by Q_{inflow}, see Figure 3.8

Conclusions

The following conclusions could be drawn:

- The repetition of identical test input (tests 2, 5 and 6) gave almost identical results
- Q_{bump} increases with increasing Q_{inflow}
- The end of the bump takes place for H = 0.40-0.55. The higher inlet flow, the higher H at the end of bump
- Q_{max} at the bump takes place for H = 0.15-0.25m

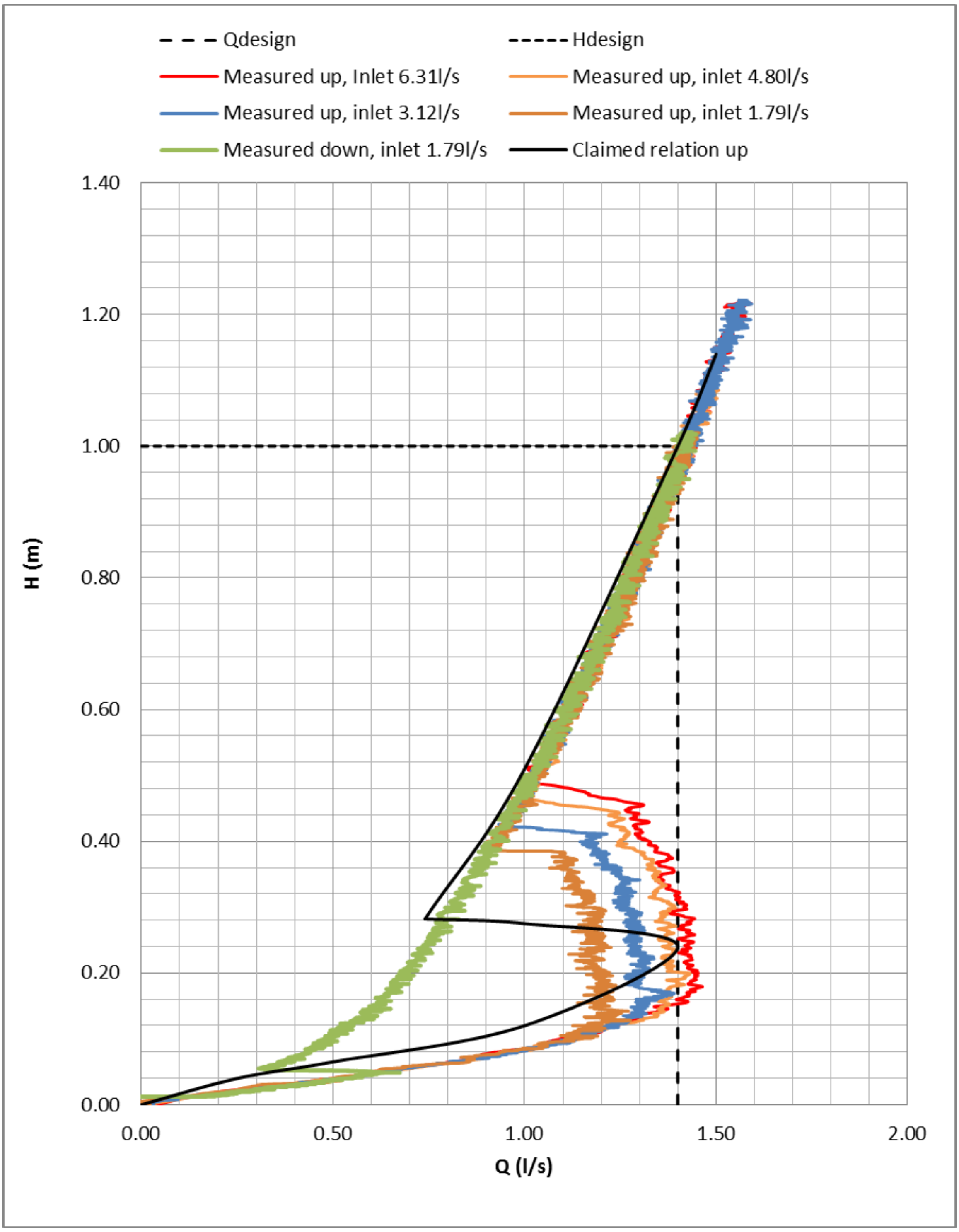

Figure 3.9 Results of tests with CEV 1.4ℓ/s @ 1.00m – 100%, moving averaging over 20s used

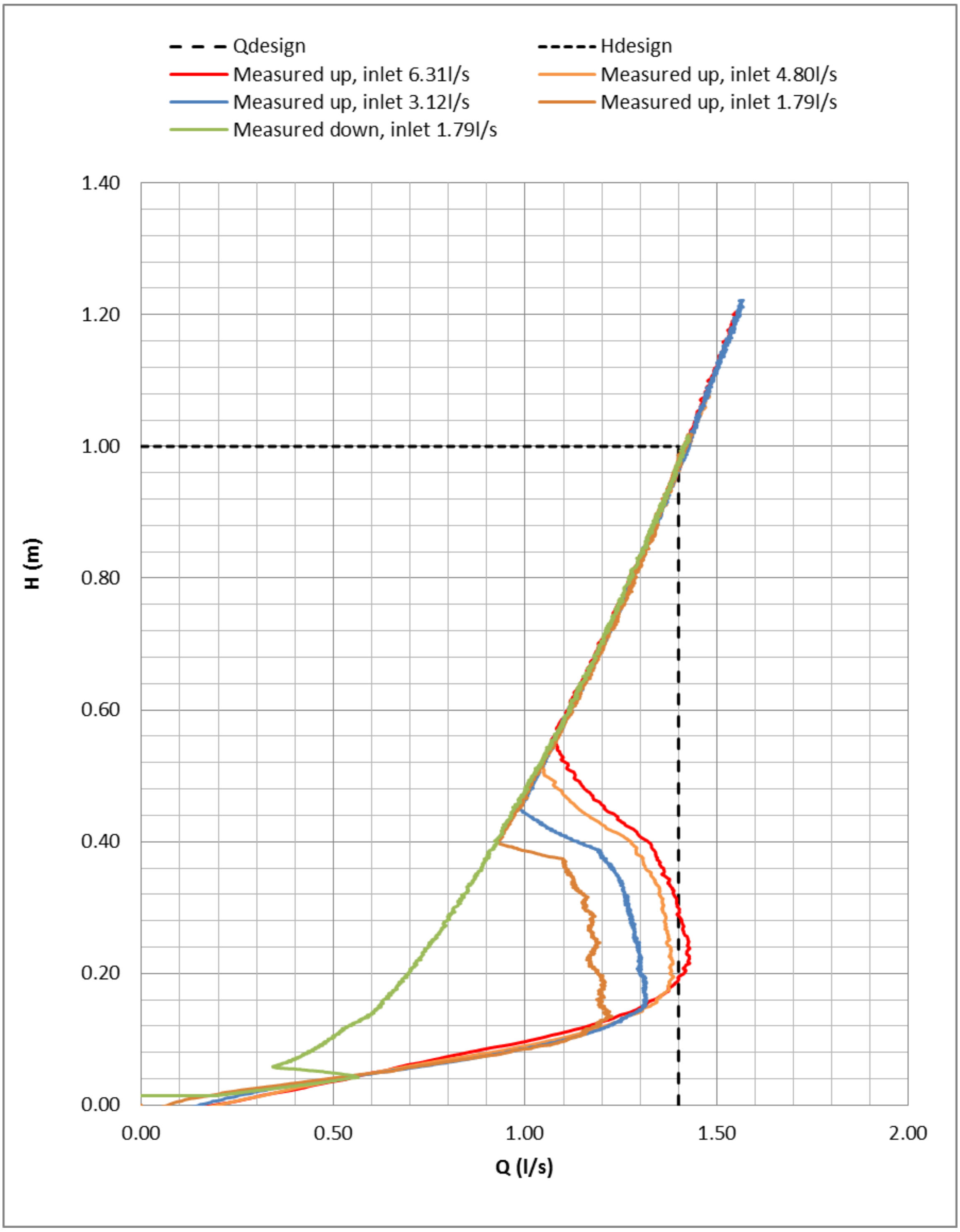

Figure 3.10 Results of tests with CEV 1.4ℓ/s @ 1.00m – 100%, moving averaging over 100s used

3.2.3 Test results CEV4.9ℓ/s @ 1.50m – 100%

Description of the CEV

The identification number of this CEV is: **109.4.1**

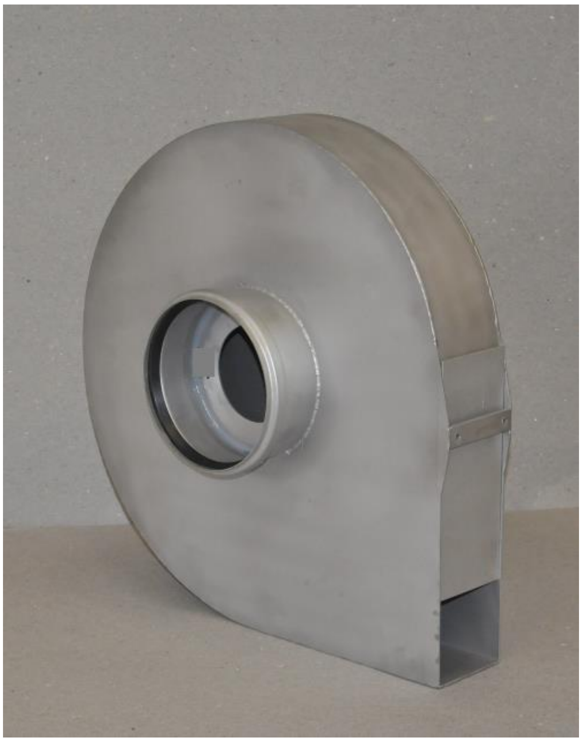

Figure 3.11 Photos of the CEV 4.9ℓ/s @ 1.50m – 100%

The dimensions of the CEV were checked and found to be in accordance with specifications.

Test conditions

Table 3.5 shows the test conditions for this CEV.

Table 3.5 Test conditions, CEV 4.9ℓ/s @ H=1.50m – 100%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	4.9	5.89	6.52	8.20	9.99
Test no	-	9	10	8	7

Results

The relations between H and Q are shown in the following figures:

- Figure 3.13: Results of tests 7, 8, 9 and 10, moving averaging over 20s used
- Figure 3.14: Results of tests 7, 8, 9 and 10, moving averaging over 100s used

The tests showed the following values of Q at the bump and at H_{design}. The Q value at the bump and at design H has been derived using the results from the moving averaging over 100s.

Table 3.6 Test results, CEV 4.9ℓ/s @ 1.50m – 100%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	4.9	5.89	6.52	8.20	9.99
Test no	-	9	10	8	7
Q_{bump} (ℓ/s)	4.9	4.50	4.66	4.76	5.04
Q at H_{design} (ℓ/s)	4.9	4.77	4.76	4.78	4.80
H at end of bump (m)	-	0.70	0.73	0.80	0.86
Average water level increase (mm/s)		0.53	0.71	1.21	1.71

It is seen that at **the bump** the average flow was:

- Average, tests 7, 8, 9, 10: Q_{bump} = 4.74ℓ/s, RSD = 4.8 %[2]

It is seen that at $\mathbf{H_{design}}$ the average flow was:

- Average, tests 7, 8, 9, 10: $Q_{Hdesign}$ = 4.78ℓ/s, RSD = 0.4 %

The measured relations between Q_{inflow} and Q_{bump} are illustrated in Figure 3.12.

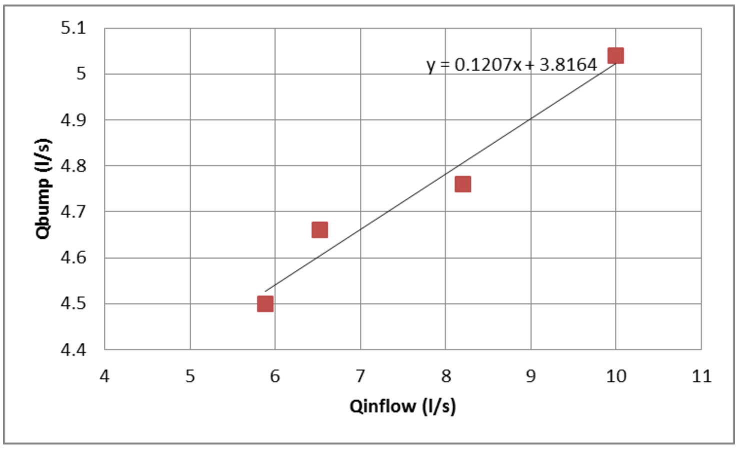

Figure 3.12 Measured relations between Q_{inflow} and Q_{bump}, CEV 4.9ℓ/s @ 1.50m – 100%,

The run-off relation is seen to follow the same relation as during run-up until the end of the bump. A small bump is seen at H≅0.10m (see Figure 3.13 and Figure 3.14), where the rotation in the CEV stops and the outlet opening begin to act as an orifice.

2 Please be aware that the results of Q_{bump} are uniquely influenced by Q_{inflow}, see Figure 3.12

Conclusions
The following conclusions can be drawn:

- Q_{bump} increases with increasing Q_{inflow}.
- The end of the bump takes place for H = 0.70-0.85. The higher inlet flow the higher H at the end of bump
- Q_{max} at the bump takes place for H = 0.25-0.30m

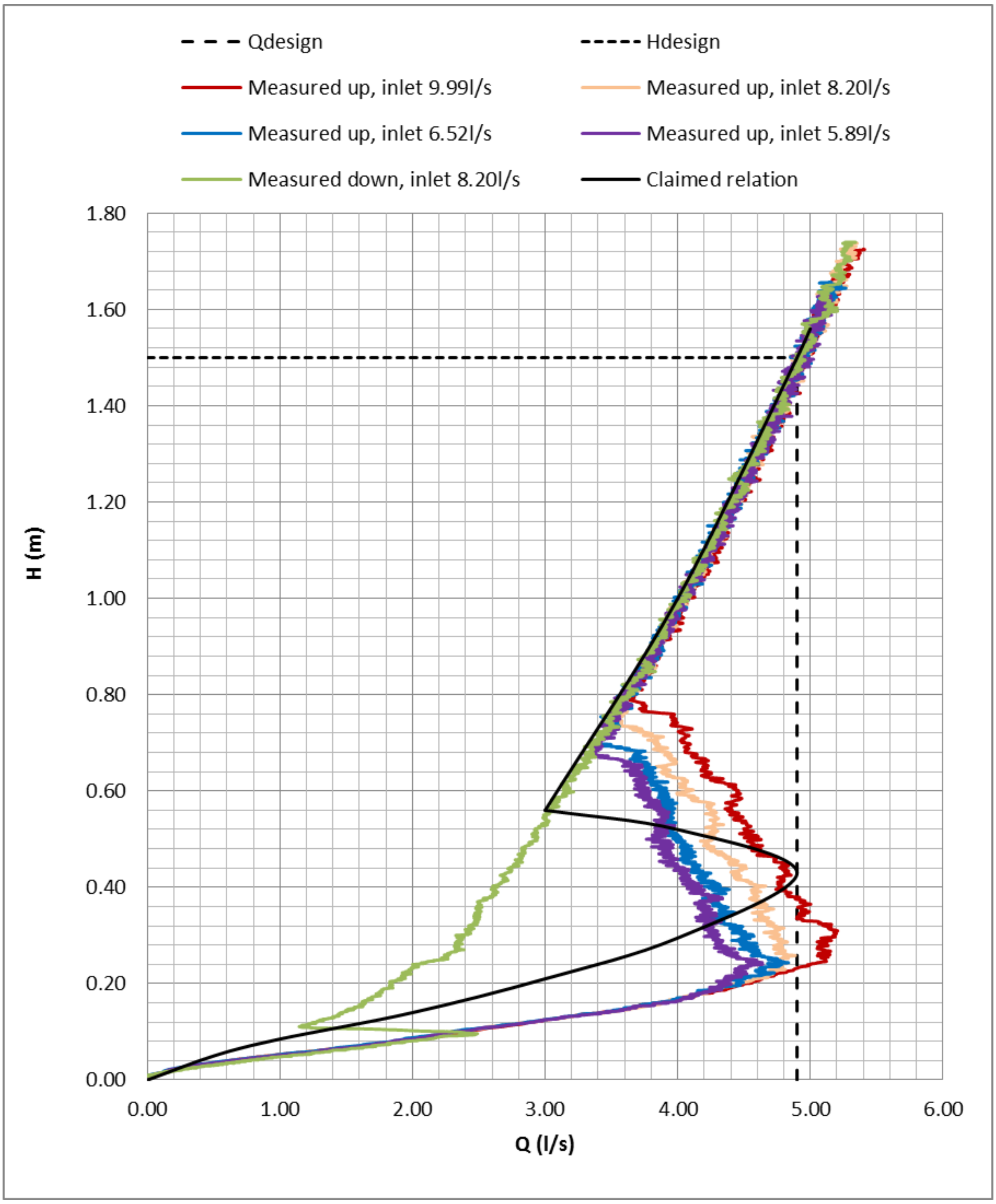

Figure 3.13 Results of tests with CEV 4.9ℓ/s @ 1.50m – 100%, moving averaging over 20s used

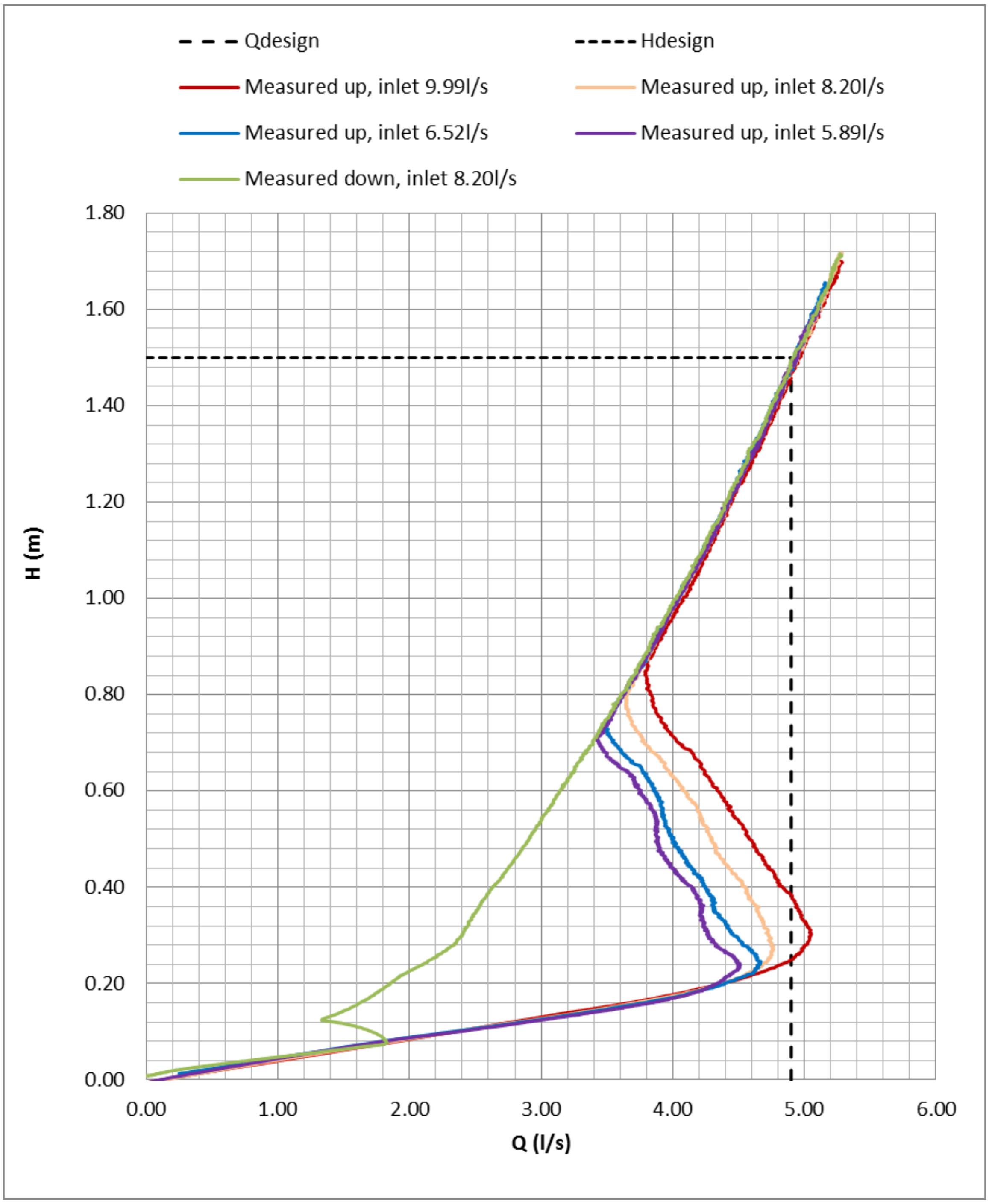

Figure 3.14 Results of tests with CEV 4.9ℓ/s @ 1.50m – 100%, moving averaging over 100s used

3.2.4 Test results CEV10.5ℓ/s @ 2.00m – 100%

The identification number of this CEV is: **109.3.1**

Figure 3.15 Photos of the CEV 10.5ℓ/s @ 2.00m – 100%

The dimensions of the CEV were checked and found to be in accordance with specifications.

Table 3.7 shows the test conditions for this CEV.

Table 3.7 Test conditions, CEV 10.5ℓ/s @ 2.00m – 100%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	10.5	11.32	12.07	13.75	15.24
Test no	-	14	13	12	11

Results
The relations between H and Q are shown in the following figures:

- Figure 3.17: Results of tests 11, 12, 13 and 14, moving averaging over 20s used
- Figure 3.18: Results of tests 11, 12, 13 and 14, moving averaging over 60s used

The tests showed the following values of Q at the bump and at H_{design}. The Q value at the bump and at design H has been derived using the results from the moving averaging over 60s.

Table 3.8 Test results, CEV 10.5ℓ/s @ 2.00m – 100%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	10.5	11.32	12.07	13.75	15.24
Test no	-	14	13	12	11
Q_{bump} (ℓ/s)	10.5	9.75	9.99	10.32	10.67
Q at H_{design} (ℓ/s)	10.5	10.55	10.55	10.56	10.56
H at end of bump (m)	-	0.75	0.75	0.85	0.85
Average water level increase (mm/s)		0.71	0.99	1.43	1.90

It is seen that at **the bump** the average flow was:

- Average, tests 11, 12, 13, 14: Q_{bump} = 10.18ℓ/s, RSD = 3.9 %[3]

It is seen that at $\mathbf{H_{design}}$ the average flow was:

- Average, tests 11, 12, 13, 14: $Q_{Hdesign}$ = 10.56ℓ/s, RSD = 0.1 %

The measured relations between Q_{inflow} and Q_{bump} are illustrated in Figure 3.16.

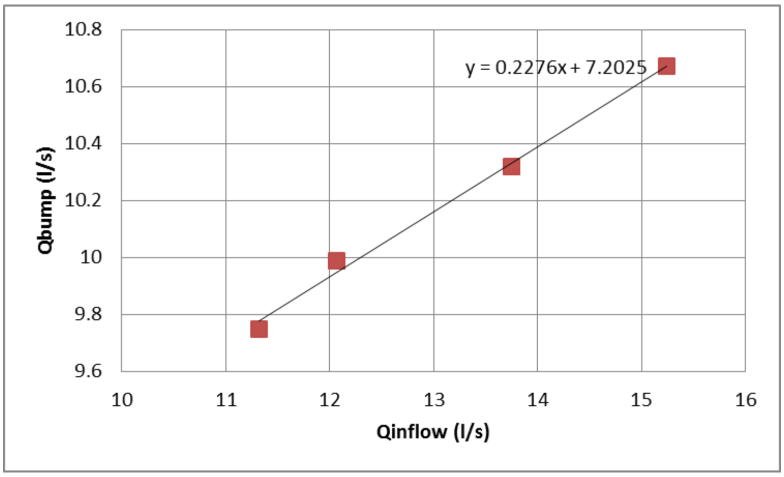

Figure 3.16 Measured relations between Q_{inflow} and Q_{bump}, CEV 10.5ℓ/s @ 2.00m – 100%

The run-off relation is seen to follow the same relation as during run-up until the end of the bump. A small bump is seen at H≅0.12m (see Figures 3.17 and 3.18), where the rotation in the CEV stops and the outlet opening begins to act as an orifice.

3 Please be aware that the results of Q_{bump} are uniquely influenced by Q_{inflow}, see Figure 3.16

Conclusions

The following conclusions can be drawn:

- Q_{bump} increases with increasing Q_{inflow}.
- The end of the bump takes place for H = 0.75-0.85m. The higher inlet flow the higher H at the end of bump
- Q_{max} at the bump takes place for H = 0.30-0.35m

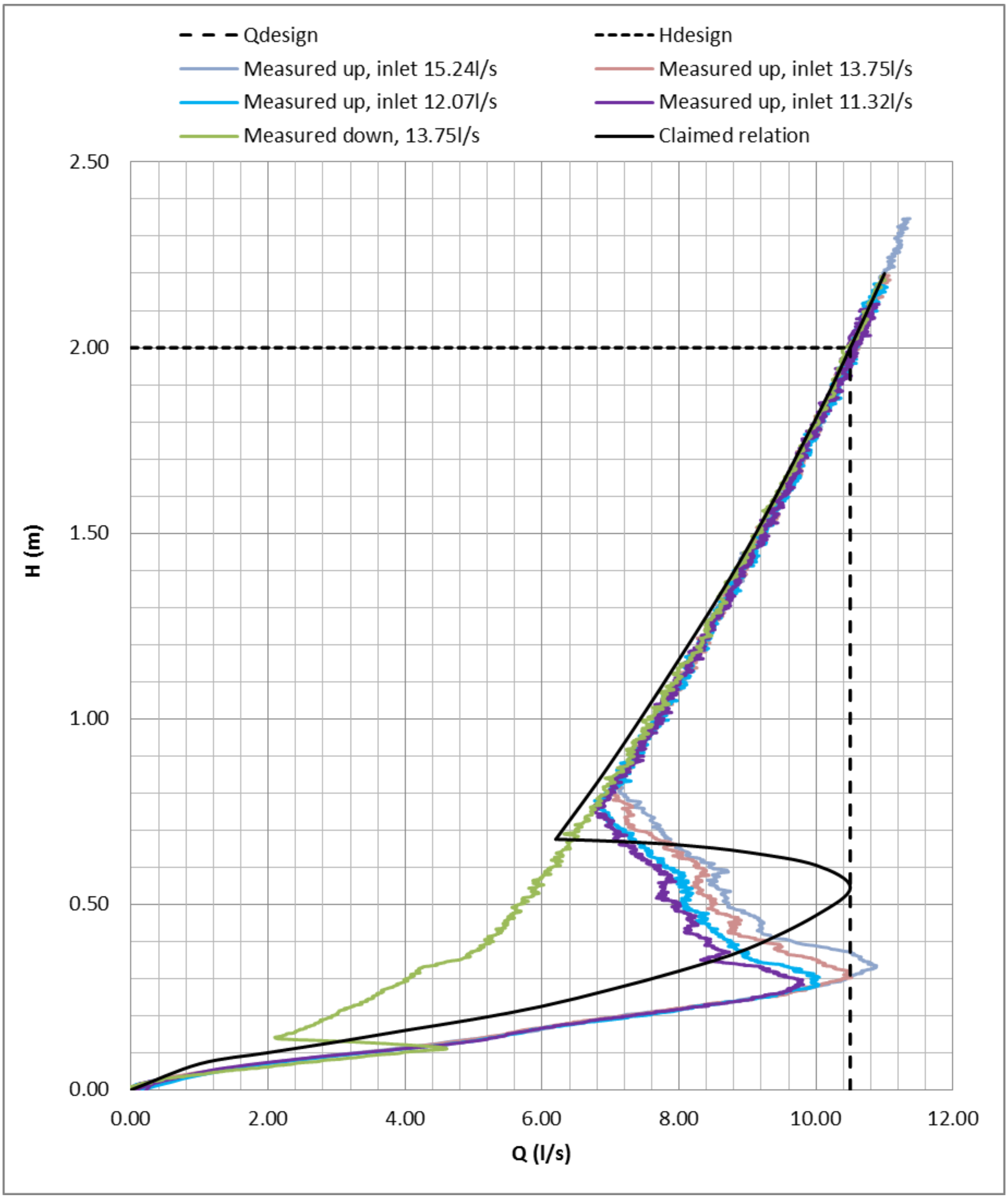

Figure 3.17 Results of tests with CEV 10.5ℓ/s @ 2.00m – 100%, moving averaging over 20s used

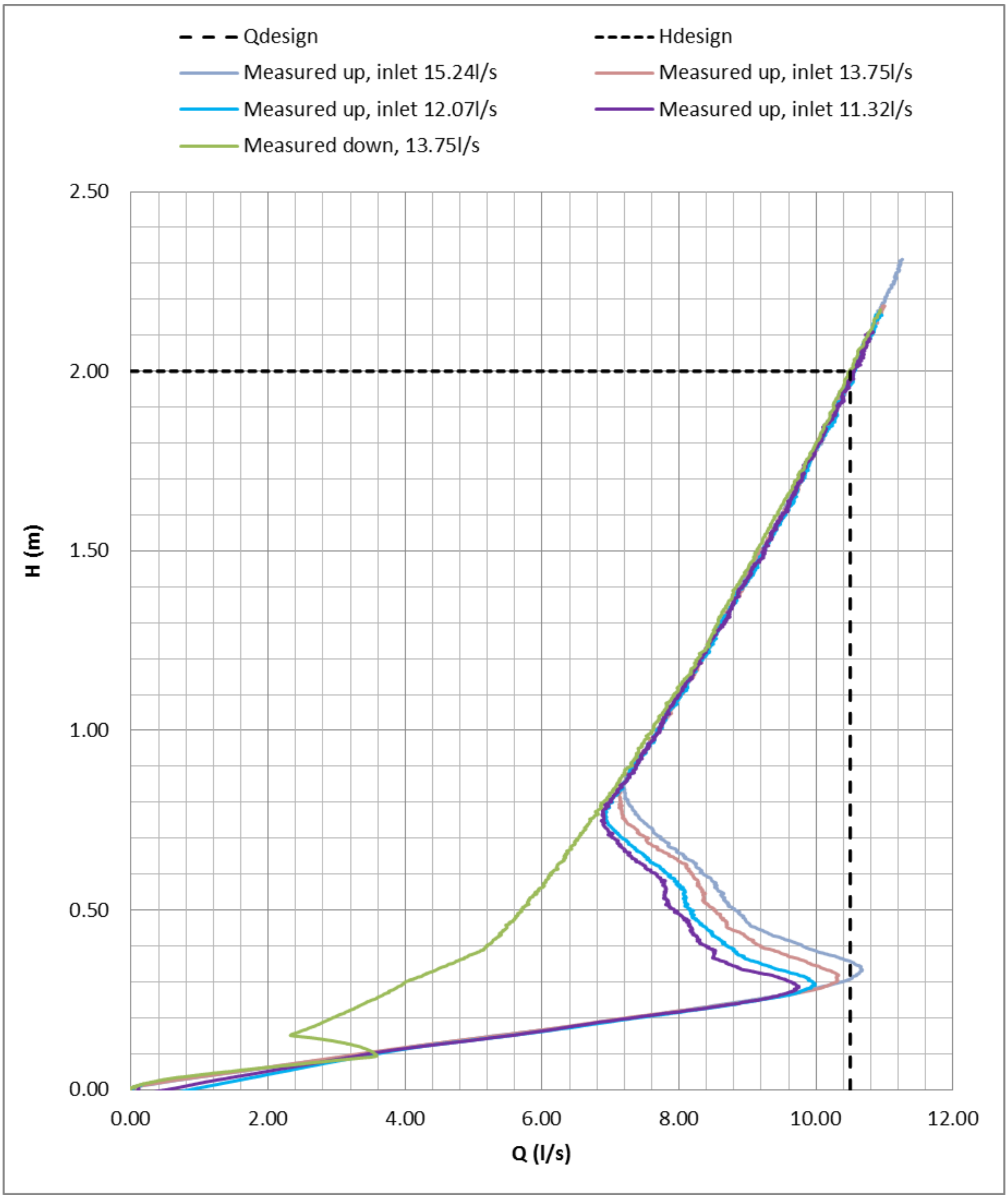

Figure 3.18 Results of tests with CEV 10.5ℓ/s @ 2.00m – 100%, moving averaging over 60s

3.2.5 Test results CEV10.5ℓ/s @ 2.00m – 78%

The identification number of this CEV is: **109.6.2**

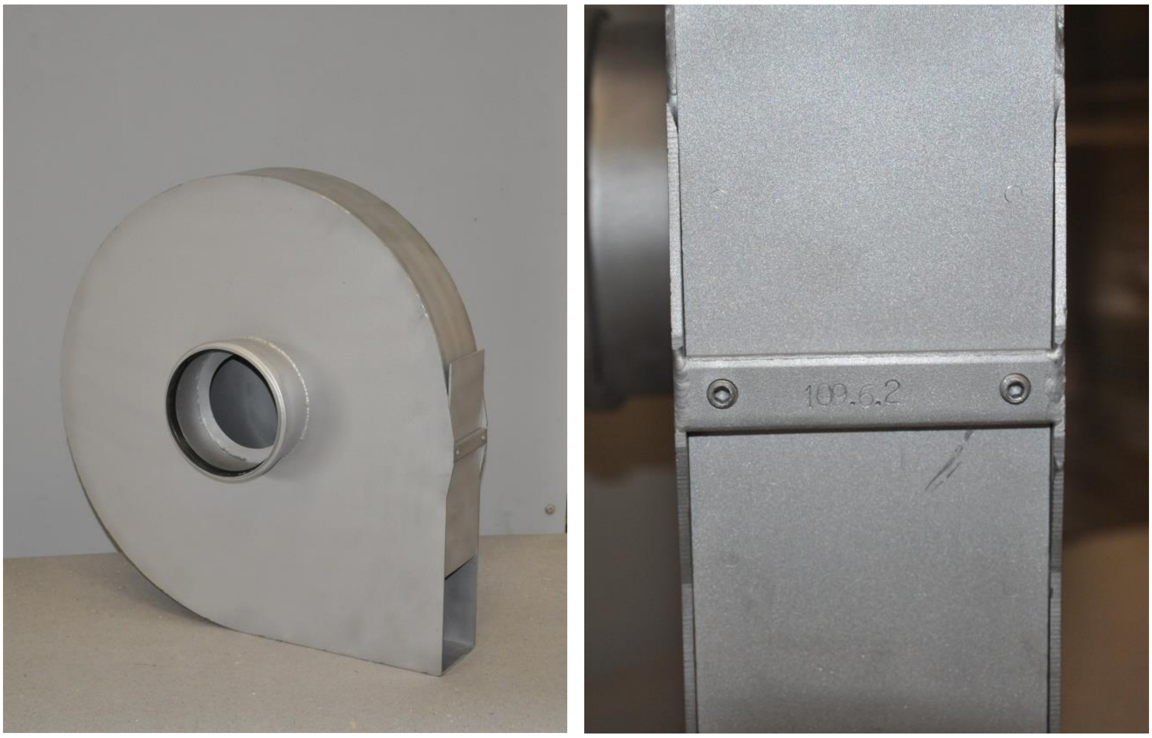

Figure 3.19 Photos of the CEV 10.5ℓ/s @ 2.00m – 78%

The dimensions of the CEV were checked and found to be in accordance with specifications.

Table 3.9 shows the test conditions for this CEV.

Table 3.9 Test conditions, CEV 10.5ℓ/s @ 2.00m – 78%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	10.5	8.60	9.77	11.40	12.97
Test no	-	21	23	22	20

Results

The relations between H and Q are shown in the following figures:

- Figure 3.21: Results of tests 20, 21, 22 and 23, moving averaging over 20s used
- Figure 3.22: Results of tests 20, 21, 22 and 23, moving averaging over 60s used

The tests showed the following values of Q at the bump and at H_{design}. The Q value at the bump and at design H has been derived using the results from the moving averaging over 60s.

Table 3.10 Test results, CEV 10.5ℓ/s @ 2.00m – 78%

	Design flow	Flow 1	Flow 2	Flow 3	Flow 4
Inflow (ℓ/s)	10.5	8.60	9.77	11.40	12.97
Test no	-	21	23	22	20
Q_{bump} (ℓ/s)	8.2	7.57	7.96	8.39	8.74
Q at H_{design} (ℓ/s)	10.5	-	-	10.09	10.12
H at end of bump (m)	-	0.70	0.70	0.80	0.80
Average water level increase (mm/s)		-	-	0.89	1.38

H_{design} could not be reached for Flows 1 and 2 as the inlet flows were smaller than the design flow.

It is seen that at **the bump** the average flow was:

- Average, tests 20, 21, 22, 23: Q_{bump} = 8.17ℓ/s, RSD = 6.2 %[4]

It is seen that at **H_{design}** the average flow was:

- Average, tests 20, 22: $Q_{Hdesign}$ = 10.11ℓ/s, RSD = 0.2 %

The measured relations between Q_{inflow} and Q_{bump} are illustrated in Figure 3.20.

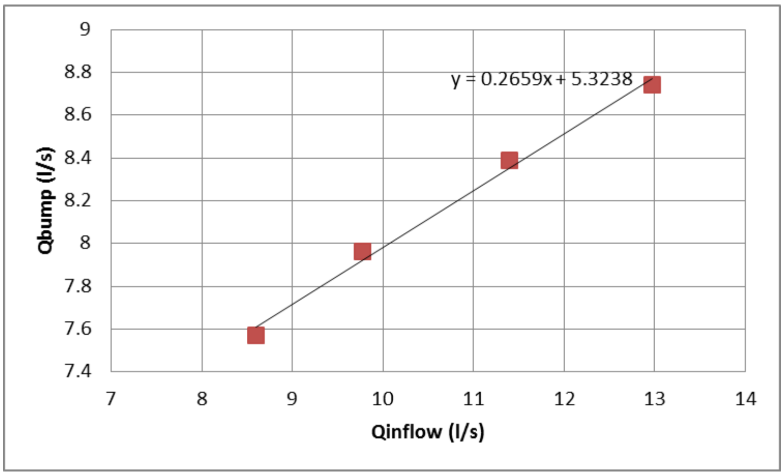

Figure 3.20 Measured relations between Q_{inflow} and Q_{bump}, CEV 10.5ℓ/s @ 2.00m – 78%

The run-off relation is seen to follow the same relation as during run-up until the end of the bump. A small bump is seen at H≅0.12m (see Figures 3.21 and 3.22), where the rotation in the CEV stops and the outlet opening begins to act as an orifice.

4 Please be aware that the results of Q_{bump} are uniquely influenced by Q_{inflow}, see Figure 3.20

Conclusions

The following conclusions can be drawn:

- Q_{bump} is increasing with increasing Q_{inflow}.
- The end of the bump takes place for H = 0.70-0.80. The higher inlet flow the higher H at the end of bump
- Q_{max} at the bump takes place for H = 0.25-0.35m

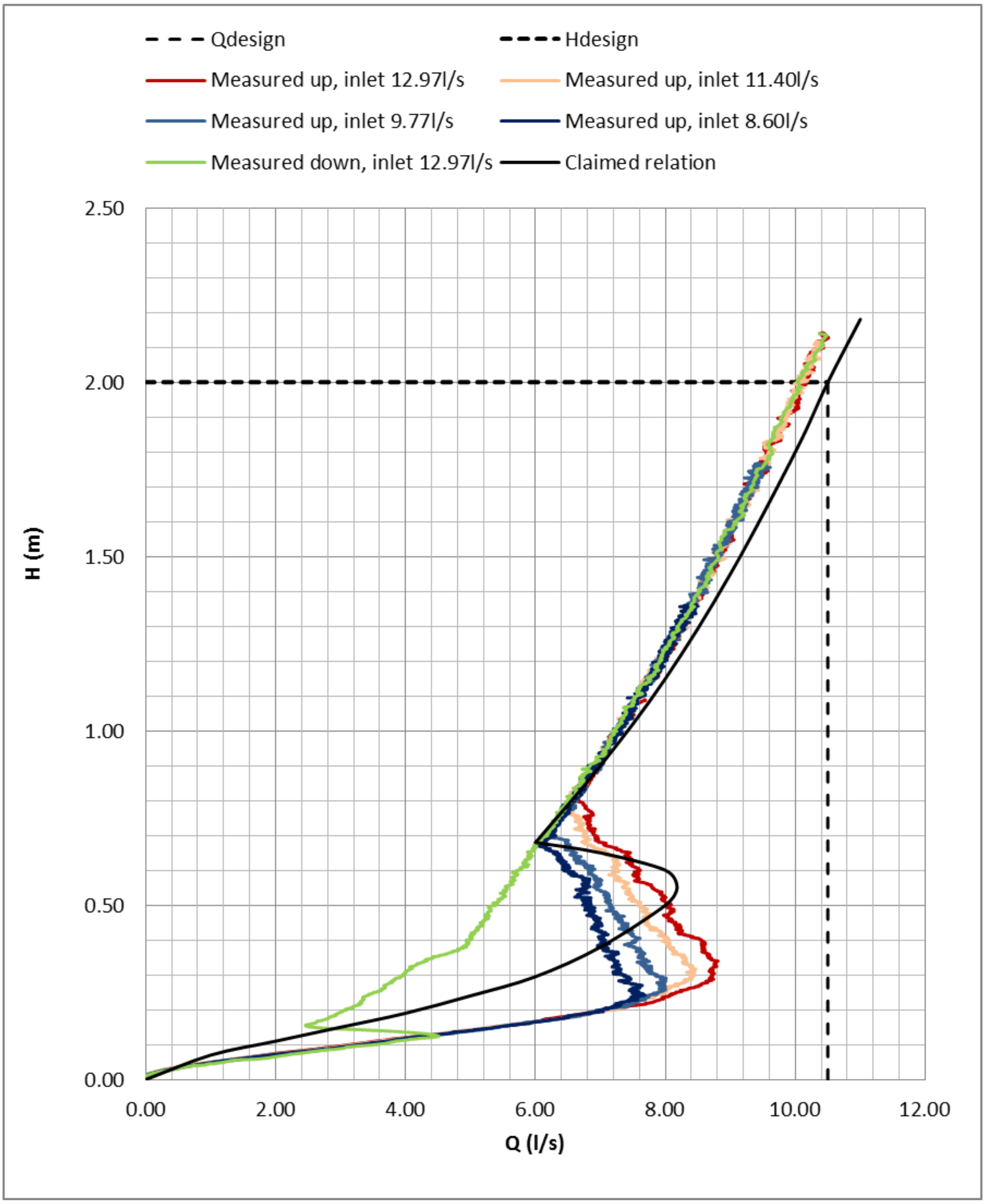

Figure 3.21 Results of tests with CEV 10.5ℓ/s @ 2.00m – 78%, moving averaging over 20s used

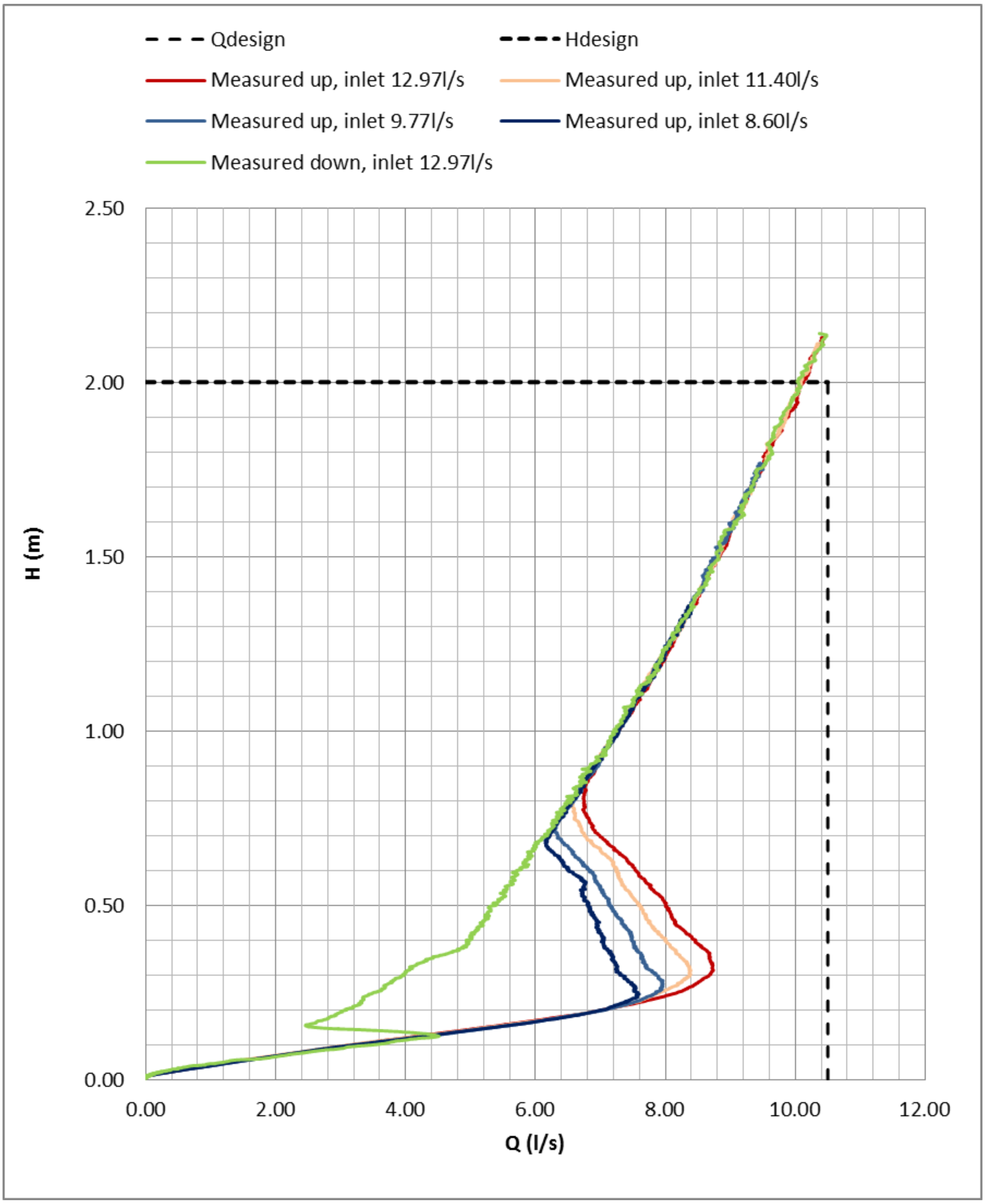

Figure 3.22 Results of tests with CEV 10.5ℓ/s @ 2.00m – 78%, moving averaging over 60s used

3.2.6 Test results sharp edged orifice

The dimension of the orifice has been checked to be same as the opening of CEV 1.40ℓ/s @ 1.0m.

Table 3.11 shows the test conditions for this orifice. For comparison, the Q-H relation for one of the tests with the CEV 1.40ℓ/s @ 1.0m, which has the same opening as the orifice, is also plotted in the figure.

Table 3.11 Test conditions, sharp edged orifice

	Design flow	Flow 1
Inflow (ℓ/s)	N/A	13.72
Test no	-	15

Results

The relations between H and Q are shown in the following Figure 3.23:

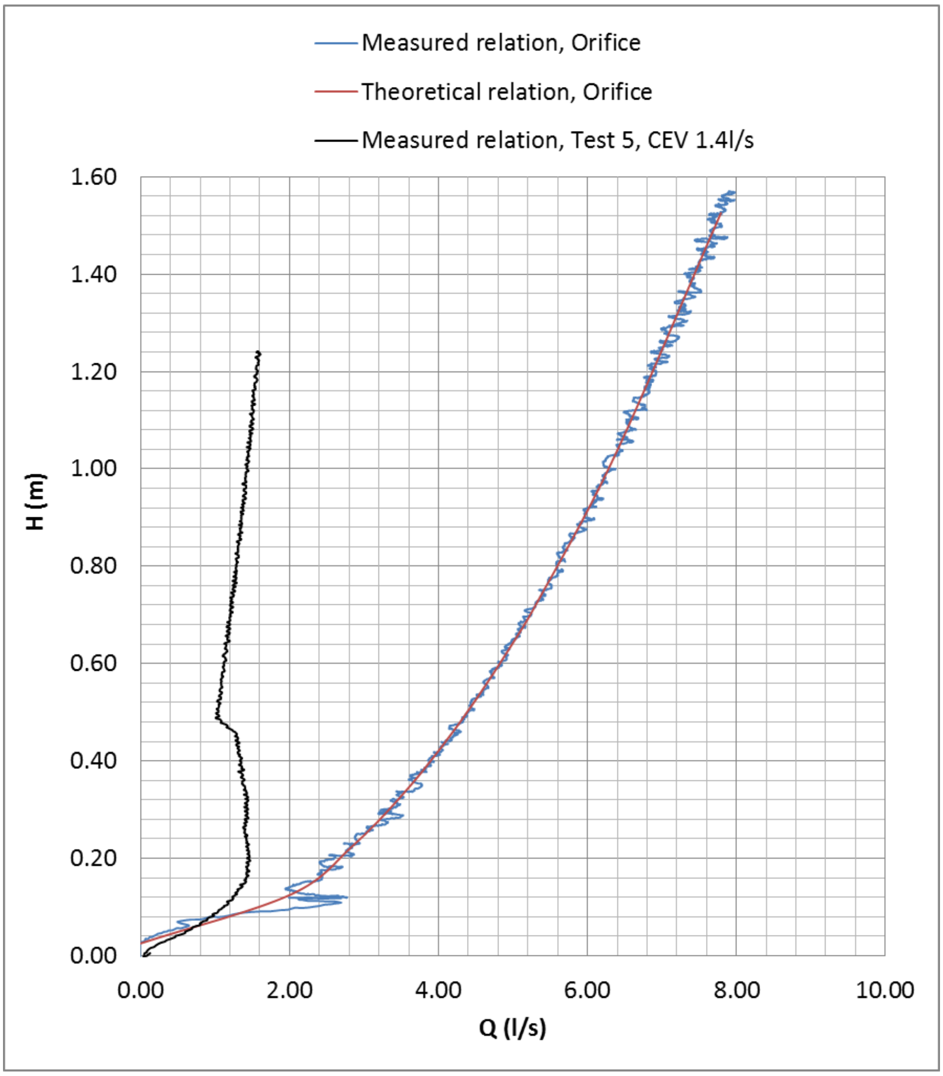

Figure 3.23 Measured and theoretical Q - H relations

The theoretical relation has been derived from the formula

$$Q = 1000\ \mu\ A_o\ \sqrt{2g\ h_0}$$

- Q is the calculated flow (ℓ/s)
- μ is the outlet coefficient for circular and sharp edged orifice ($\mu \cong 0.607$ for the present size)
- A_o is the orifice area ($A_o = \pi\ (d_o/2)^2\ m^2$)
- g is the acceleration of gravity ($9.82 m/s^2$)
- h_0 is the head relative to the centre of the orifice, $H = h_0 + d_o/2$ (m)
- d_o is the diameter of the orifice

Figure 3.23 shows that the measured relation for the sharp edged orifice is almost identical to the theoretical. Comparing the outlet flow at $H_{\text{design for CEV}}$ (1.0m) obtained with the orifice with the outlet flow obtained with the CEV 1.4ℓ/s @ 1.00m, the following results are obtained:

- Q_{CEV} = 1.43ℓ/s
- $Q_{Orifice}$ = 6.36ℓ/s

This means that $Q_{Orifice}$ = 4.45 times Q_{CEV} at H = 1.0m.

3.3 Test performance observation

Generally no major problems were observed during the tests. The equipment functioned well during all tests. Different floating stuff (especially leaves) passed sometimes through the flowmeters giving odd results, but due to the relative small recording frequency, it was easy to detect these incidents and correct for them.

It was noted that determination of flow by means of the head (measured by means of pressure transducers) and cross-sectional areas of the tanks was very difficult. Small fluctuations in the water level (pressure head) resulted in very large fluctuations in the flow. This was the reason why the estimation of the Q – H relation by means of Method 1 (see /1/) was abandoned. Method 2 did also include an estimate of the outflow partly by regarding the measured water level in the outlet tank. However, due to the limited size of the outlet tank, the influence was small, and almost negligible. In a possible future test set-up, it may be advantageous to reduce the diameter of the outlet tank and neglect the contribution arising from the water level variation in the outlet tank to the outlet flow.

3.4 Test quality assurance summary, including audit result

Results of test system control including leakage test and calibration tests of pressure transducers can be found in Section 3.1.2.1 (inlet side) and Section 3.1.2.2 (outlet side).

The documentation tests can be found in Section 3.2:

- Section 3.2.2 describes test results with **CEV1.4ℓ/s @ 1.00m – 100%.** The tests included investigation of the variation for tests carried out with identical inlet flows

- Section 3.2.3 describes test results with **CEV4.9ℓ/s @ 1.50m – 100%**

- Section 3.2.4 describes test results with **CEV10.5ℓ/s @ 2.00m – 100%**

- Section 3.2.5 describes test results with **CEV10.5ℓ/s @ 2.00m – 78%**

- Section 3.2.6 describes test results with a **sharp edged orifice**

Test of variation can be found in Section 3.2.2.

During testing and internal test, system audit was performed by Jesper Fuchs from DHI on 29 September 2014. The verification body ETA Denmark, represented by Peter Fritzel, did test system audit on 2 October 2014.

Conclusions of the internal audit (Jesper Fuchs):

"The test is performed in agreement with the test plan and carried out in a safe manner. Handling and storage of data is safe"

Conclusions of the audit of ETA Denmark (Peter Fritzel):

"There is consistency with the test plan and handling of measurements are carried out in a safe manner"

The full audit reports are available at DHI.

3.5 Details on amendments to and deviations from test plan

Four deviations from the original test plan were performed:

Deviation 1
Instead of establishing the zero level in the inlet tank for each test, a common zero scan was performed for each CEV type. This zero scan was carried out as an individual test instead of an integrated part of each test.

Deviation 2
The lowest inflow in the tests with CEV 1.4ℓ/s @ 1.0m was carried out with too low inflow, 1.79ℓ/s instead of 1.9ℓ/s. The inlet flow, which will result in a water level rise of 0.5mm/s can with good accuracy be found by interpolation. Such interpolation shows that an inflow of approximately 2.8ℓ/s will result in a water level rise of 0.5mm/s. The corresponding Q_{bump} would be approximately 1.28ℓ/s (see Figure 3.8).

Deviation 3
The largest inflows gave for all 100% CEV's larger water level rise than 1.5mm/s, which was predefined as being the largest water level rise to be tested. The inlet flows, which will result in a water level rise of 1.5mm /s, can with good accuracy be found by interpolation. Such interpolations show for:

- **CEV 1.4ℓ/s @ 1.0m** that such water level rise would be obtained for an inflow of approximately 6.1ℓ/s. The corresponding Q_{bump} would be approximately 1.44ℓ/s (see Figure 3.8)
- **CEV 4.9ℓ/s @ 1.5m** that such water level rise would be obtained for an inflow of approximately 9.2ℓ/s. The corresponding Q_{bump} would be approximately 4.93ℓ/s (see Figure 3.12)
- **CEV 10.5ℓ/s @ 2.0m** that such water level rise would be obtained for an inflow of approximately 13.9ℓ/s. The corresponding Q_{bump} would be approximately 10.4ℓ/s (see Figure 3.16)

Deviation 4
The test with the orifice was carried out with a larger inflow than predefined. This was done, as the Q – H relation for an orifice is independent of the water level increase, which also is documented by comparing with the theoretical relation, see Figure 3.23.

4 References

/1/ Mosbaek CEV flow regulator test plan. DHI, September 2014

/2/ Mosbaek CEV flow regulator verification protocol. ETA Danmark, September 2014

/3/ EU Environmental Technology Verification Programme. General Verification Protocol Version 1.1, 2014.07.07

/4/ DANETV Test Centre Quality Manual, 2013.08.13

APPENDICES

APPENDIX A

Terms and Definitions

A Terms and Definitions

Term	Definition	Comments
Accreditation	Meaning as assigned to it by Regulation (EC) No 765/2008	EC No 765/2008 is on setting out the requirements for accreditation and market surveillance relating to the marketing of products
Additional parameter	Other effects that will be described but are considered secondary	None
Amendment	A change to a specific verification protocol or a test plan done before the verification or test step is performed	None
Analytical laboratory	Independent analytical laboratory used to analyse test samples	The test centre may use an analytical laboratory as subcontractor
Application	The use of a technology specified with respect to matrix, purpose (target and effect) and limitations	The application must be defined with a precision that allows the user of a technology verification to judge whether his needs are comparable to the verification conditions
CEV	CEntrifugal Vertical	
DANETV	Danish centre for verification of environmental technologies	None
Deviation	A change to a specific verification protocol or a test plan done during the verification or test step performance	None
Environmental technologies	Environmental technologies are all technologies whose use is less environmentally harmful than relevant alternatives	The term technology covers a variety of products, processes, systems and services
Evaluation	Evaluation of test data for a technology for performance and data quality	None
General verification protocol (GVP)	Description of the principles and general procedure to be followed by the ETV pilot programme when verifying an individual environmental technology	None
Innovative environmental technologies	Environmental technologies presenting a novelty in terms of design, raw materials involved, production process, use, recyclability or final disposal, when compared with relevant alternatives	None

Term	Definition	Comments
Matrix	The type of material that the technology is intended for	Matrices could be soil, drinking water, ground water, degreasing bath, exhaust gas condensate etc.
Method	Action described by e.g. generic document that provides rules, guidelines or characteristics for tests or analysis	An in-house method may be used in the absence of a standard, if prepared in compliance with the format and contents required for standards, see e.g. /4/
Operational parameter	Measurable parameters that define the application and the verification and test conditions	Operational parameters could be flow, pH, temperature, production capacity, concentrations of non-target compounds in matrix etc.
(Initial) performance claim	Proposer claimed technical specifications of technology. Shall state the conditions of use under which the claim is applicable and mention any relevant assumption made	The proposer claims shall be included in the ETV proposal. The initial claims can be developed as part of the quick scan.
Performance parameters (revised performance claims)	A set of quantified technical specifications representative of the technical performance and potential environmental impacts of a technology in a specified application and under specified conditions of testing or use (operational parameters)	The performance parameters must be established considering the application(s) of the technology, the requirements of society (legislative regulations), customers (needs) and proposer initial performance claims.
Potential environmental impacts	Estimated environmental effects or pressure on the environment, resulting directly or indirectly from the use of a technology under specified conditions of testing or use	None
Procedure	Detailed description of the use of a standard or a method within one body	The procedure specifies implementing a standard or a method in terms of e.g.: equipment used
Product	Ready to market or prototype stage product/technology, process, system or service based upon an environmental technology	Technology is used instead of the term product
Proposer	Any legal entity or natural person, which can be the technology manufacturer or an authorised representative of the technology manufacturer. If the technology manufactures concerned agree, the proposer can be another stakeholder undertaking a specific verification programme involving several technologies	Can be vendor or producer

Term	Definition	Comments
Purpose	The measurable property that is affected by the technology and how it is affected	The purpose could be reduction of nitrate concentration, separation of volatile organic compounds, reduction of energy use (MW/kg) etc.
Ready to market technology	Technology available on the market or at least available at a stage where no substantial change affecting performance will be implemented before introducing the technology on the market (e.g. full-scale or pilot scale with direct and clear scale-up instructions)	None
Specific verification protocol	Protocol describing the specific verification of a technology as developed applying the principles and procedures of the EU GVP and this quality manual	None
Standard	Generic document established by consensus and approved by a recognised standardization body that provides rules, guidelines or characteristics for tests or analysis	None
Test body	Unit that that plans and performs test	None
Verification body	Unit that plans and performs the verification	None
Test/testing	Determination of the performance of a technology for measurement/para-meters defined for the application	None
Test performance audit	Quantitative evaluation of a measurement system as used in a specific test	E.g. evaluation of laboratory control data for relevant period (precision under repeatability conditions, trueness), evaluation of data from laboratory participation in proficiency test and control of calibration of online measurement devises.
Test system audit	Qualitative on-site evaluation of test, sampling and/or measurement systems associated with a specific test.	E.g. evaluation of the testing done against the requirements of the specific verification protocol, the test plan and the quality manual of the test body.
Test system control	Control of the test system as used in a specific test	E.g. test of stock solutions, evaluation of stability of operational and/or on-line analytical equipment, test of blanks and reference technology tests.
Vendor	The party delivering the technology to the customer. Here referred to as proposer	Can be the producer

Term	Definition	Comments
Verification	Provision of objective evidence that the technical design of a given environmental technology ensures the fulfilment of a given performance claim in a specified application, taking any measurement uncertainty and relevant assumptions into consideration	None

APPENDIX B

Test Data Report

B Test Data Report

A list of the raw data files for the tests carried out is shown in Figure B1.

Name	Date modified	Type	Size
CAL No 1 PC INLET 20040929 115528-01.txt	02-10-2014 14:15	Text Document	1628 KB
CAL test 1 inlet pressure cell.txt	30-09-2014 08:46	Text Document	1628 KB
CAL test 2 outlet pressure cel.txt	30-09-2014 08:46	Text Document	886 KB
Test no 1 CEV1.4@1.0 q=1.9lps.txt	30-09-2014 08:44	Text Document	4743 KB
Test no 2 CEV1.4@1.0 q=6.3lps.txt	01-10-2014 08:55	Text Document	824 KB
Test no 3 CEV1.4@1.0 q= 4.8lps.txt	01-10-2014 08:55	Text Document	857 KB
TEST no 4 CEV 1.4@1.0 Q=3.1lps.txt	01-10-2014 08:55	Text Document	1503 KB
TEST No 5 CEV1.4@1.0 Q=6.3lps.txt	01-10-2014 08:55	Text Document	709 KB
TEST No 6 CEV1.4@1.0 Q=6.3lps.txt	01-10-2014 08:55	Text Document	800 KB
TEST No 7 CEV 4.9@1.5 Q=10.0lps.txt	01-10-2014 08:56	Text Document	843 KB
TEST No 8 CEV 4.9@1.5 Q=8.3lps.txt	02-10-2014 08:16	Text Document	2039 KB
TEST No 9 CEV4.9@1.5 Q=5.9lps.txt	02-10-2014 08:17	Text Document	1834 KB
TEST No 10 CEV 4.9@1.5 Q=6.6lps.txt	02-10-2014 08:16	Text Document	1389 KB
TEST No 11 CEV 10.5@2.0 Q=15.6lps.txt	02-10-2014 08:16	Text Document	814 KB
TEST No 12 CEV10.5@2.0 Q=13.9lps.txt	02-10-2014 08:17	Text Document	1939 KB
TEST No 13 CEV10.5@2.0 Q=12.2lps.txt	02-10-2014 08:17	Text Document	1441 KB
TEST No 14 CEV10.5@2.0 Q=11.5lps.txt	06-10-2014 08:37	Text Document	1814 KB
TEST No 15 Orifice Q=14.0lps.txt	06-10-2014 08:37	Text Document	738 KB
TEST No 16 CEV 10.5@2.0 78% Q=13.3lps.txt	06-10-2014 08:38	Text Document	2058 KB
TEST No 17 CEV 10.5@2.0 78% Q= 11.6lps.txt	06-10-2014 08:38	Text Document	1465 KB
TEST No 18 CEV10.5@2.0 78% Q=9,9lps.txt	06-10-2014 08:38	Text Document	2207 KB
TEST No 19 CEV 10.5@2.0 78% Q=9.2lps.txt	06-10-2014 08:38	Text Document	2551 KB
Test no 20 CEV 10.5@2m 78% Q=13.3lps + D...	31-10-2014 08:55	Text Document	2269 KB
Test no 21 CEV 10.5@2m 78% Q=8.7lps.txt	31-10-2014 08:55	Text Document	2326 KB
Test no 22 CEV 10.5@2m 78% Q=11.6lps.txt	31-10-2014 08:55	Text Document	1542 KB
Test no 23 CEV 10.5@2m 78% Q=9.9lps.txt	31-10-2014 08:55	Text Document	2393 KB
ZERO test 1 CEV 1.4@1.0.txt	30-09-2014 08:44	Text Document	365 KB
ZERO test 2 CEV 4.9@1.5.txt	01-10-2014 08:56	Text Document	321 KB
ZERO test 3 CEV4.9@1.5.txt	02-10-2014 08:16	Text Document	704 KB
ZERO test 4 CEV10.5@2.0.txt	02-10-2014 08:16	Text Document	398 KB
ZERO test 5 CEV10.5@2.0.txt	06-10-2014 08:37	Text Document	355 KB
ZERO test 6 Orifice.txt	06-10-2014 08:37	Text Document	752 KB
ZERO Test 7 CEV10.5@2.0 78%.txt	06-10-2014 08:38	Text Document	298 KB
ZERO test 8 CEV 10.5@2m 78%.txt	31-10-2014 08:55	Text Document	302 KB

Figure B1 Overview of the tests carried out

Tests with the CEV 10.5 @ 2.0m, 78% were repeated, as the inlet opening was set erroneously. Accordingly, the data obtained in Tests 16 to 19 (incl.) have not been processed.

The files are stored centrally at DHI and will remain there until end of 2024.

APPENDIX C

Test Plan Deviation Reports

C Test Plan Deviation Reports

DHI DANETV Test Plan Deviation Report

PLAN DOCUMENT TITLE AND DATE:	Mosbaek CEV Flow Regulator, Test Plan, September 2014
DEVIATION NUMBER:	1
DATE OF DEVIATION:	2014.09.30
DESCRIPTION OF DEVIATION:	The test plan demanded that each test should include logging of zero level for 5 minutes. Instead a common zero tests was carried out for each CEV prior to the tests with this CEV
REASON FOR DEVIATION:	This change provided a unique determination of the zero level, and each test can be initiated at a lower level than zero and thus ensured that the inflow is adjusted when the outflow starts
IMPACT OF DEVIATION:	None
CORRECTIVE ACTION:	No corrective action required
PREVENTIVE ACTION:	Not relevant
ORIGINATED BY:	Mogens Hebsgaard
Test responsible	Mogens Hebsgaard
DATE:	2014.09.30

DHI DANETV Test Plan Deviation Report

PLAN DOCUMENT TITLE AND DATE:	Mosbaek CEV Flow Regulator, Test Plan, September 2014
DEVIATION NUMBER:	2
DATE OF DEVIATION:	2014.09.30
DESCRIPTION OF DEVIATION:	The first test with the CEV 1.4ℓ/s @ 1.0m, 100% was carried out with an inflow of q = 1.79ℓ/s instead of 1.9ℓ/s as prescribed in the test plan
REASON FOR DEVIATION:	This change was caused by the difficulties in adjusting the small inlet flow
IMPACT OF DEVIATION:	The average increase of water level was less than the prescribed 0.5mm/s. The test showed, however, that the performance of the CEV was as expected also for this low flow, and the results showed that it will be possible with good accuracy to predict the results in the form of inlet flow for any water level rise between 0.5 and 1.5mm/s by interpolation
CORRECTIVE ACTION:	No corrective action was performed
PREVENTIVE ACTION:	It was ensured that the lowest inflow with the other CEV's was adjusted in a way securing that the average increase of water level was above 0.5mm/s
ORIGINATED BY:	Mogens Hebsgaard
Test responsible	Mogens Hebsgaard
DATE:	2014.09.30

DHI DANETV Test Plan Deviation Report

PLAN DOCUMENT TITLE AND DATE:	Mosbaek CEV Flow Regulator, Test Plan, September 2014
DEVIATION NUMBER:	3
DATE OF DEVIATION:	General
DESCRIPTION OF DEVIATION:	The tests with the highest inflow for all 100% CEV's were carried out giving higher water level rise in the regulator tank than 1.5mm/s, which was aimed at as the largest increase in the tests. During the test, attempt was made to come close to 1.5mm/s, but due to the character of the curve, with the rapid bump, it was difficult in advance to estimate the water level rise.
REASON FOR DEVIATION:	The deviation was caused by the calculation method used to determine the maximum flow: $Q_{inflow, max} = Q_{design} + I_{max} * A_{in}$ (ℓ/s), • Q_{design} is the design flow for the actual CEV • I_{max} is the maximum water level increase (1.5mm/s) • A_{in} is water surface area of the inlet side As the $Q_{outflow}$ always should be less than or equal to Q_{design} until H_{design} is reached, the water level rise for this inflow will always be larger than 1.5mm/s
IMPACT OF DEVIATION:	The results of the tests showed that the performance of the CEV was as expected also for water level rise larger than the design conditions. The results showed that it will be possible with good accuracy to predict the results in the form of inlet flow for a water level increase of 1.5mm by interpolation. Doing this, it is even advantageous to have measured values of water level rise above 1.5mm/s.
CORRECTIVE ACTION:	No corrective action was performed
PREVENTIVE ACTION:	None
ORIGINATED BY:	Mogens Hebsgaard
Test responsible	Mogens Hebsgaard
DATE:	2014.12.11

DHI DANETV Test Plan Deviation Report

PLAN DOCUMENT TITLE AND DATE:	Mosbaek CEV Flow Regulator, Test Plan, September 2014
DEVIATION NUMBER:	4
DATE OF DEVIATION:	2014.10.02
DESCRIPTION OF DEVIATION:	The tests with the orifice were carried out with higher inflow than prescribed in the test plan
REASON FOR DEVIATION:	The prescribed inflow was too low to reach the prescribed level in the regulator well
IMPACT OF DEVIATION:	The deviation has no impact on the results. The Q – H relation followed the theoretical relation as expected and this will be irrespective of the inflow value
CORRECTIVE ACTION:	No corrective action was performed
PREVENTIVE ACTION:	None

ORIGINATED BY:	Mogens Hebsgaard
Test responsible	Mogens Hebsgaard
DATE:	2014.10.02

APPENDIX D

Comparison between Method 1 and Method 2 for Calculation of Outlet Flow

D Comparison between Method 1 and Method 2 for Calculation of Outlet Flow

The outflow from the CEV's can, with the applied measurement set-up, be calculated in two different ways, see also /1/.

The two methods are:

Method 1

The following equation is used in Method 1:

$$Q_{outflow,1} = Q_{inflow} - \frac{\Delta Hrw \times Ain \times 1000}{\Delta t}$$

$Q_{outflow,1}$: Flow out through CEV (ℓ/s)
Q_{inflow}: Flow into the inlet tank (ℓ/s)
A_{in}: Surface area of inlet tank, regulator well and inlet riser pipe (3.315m^2)
H_{rw}: Pressure head above outlet invert level in the regulator well (mH_2O)
Δt: Time for changing H_{well} by ΔH_{well} (s)

Method 2

The following equation is used in Method 2:

$$Q_{outflow,2} = Q_{overflow} + \frac{\Delta pot \times Aout \times 1000}{\Delta t}$$

$Q_{outflow,2}$: Flow out of CEV (ℓ/s)
$Q_{overflow}$: Overflow from the outlet tank (ℓ/s)
A_{out}: Surface area of the outlet tank and outlet riser pipe (0.075m^2)
p_{ot}: Pressure head in the outlet tank (mH_2O)
Δt: Time for changing H_{out} by Δp_{ot} (s)

The comparison is presented for the test carried out with CEV10.5ℓ/s @ 2.00m – 100% (Test 11). The results of the comparison are shown in Figure D1. Both time series for Q underwent a 60s moving averaging.

It is seen that the relations derived by Method 1 and Method 2 are generally very similar apart from the fluctuations in the Method 1 results.

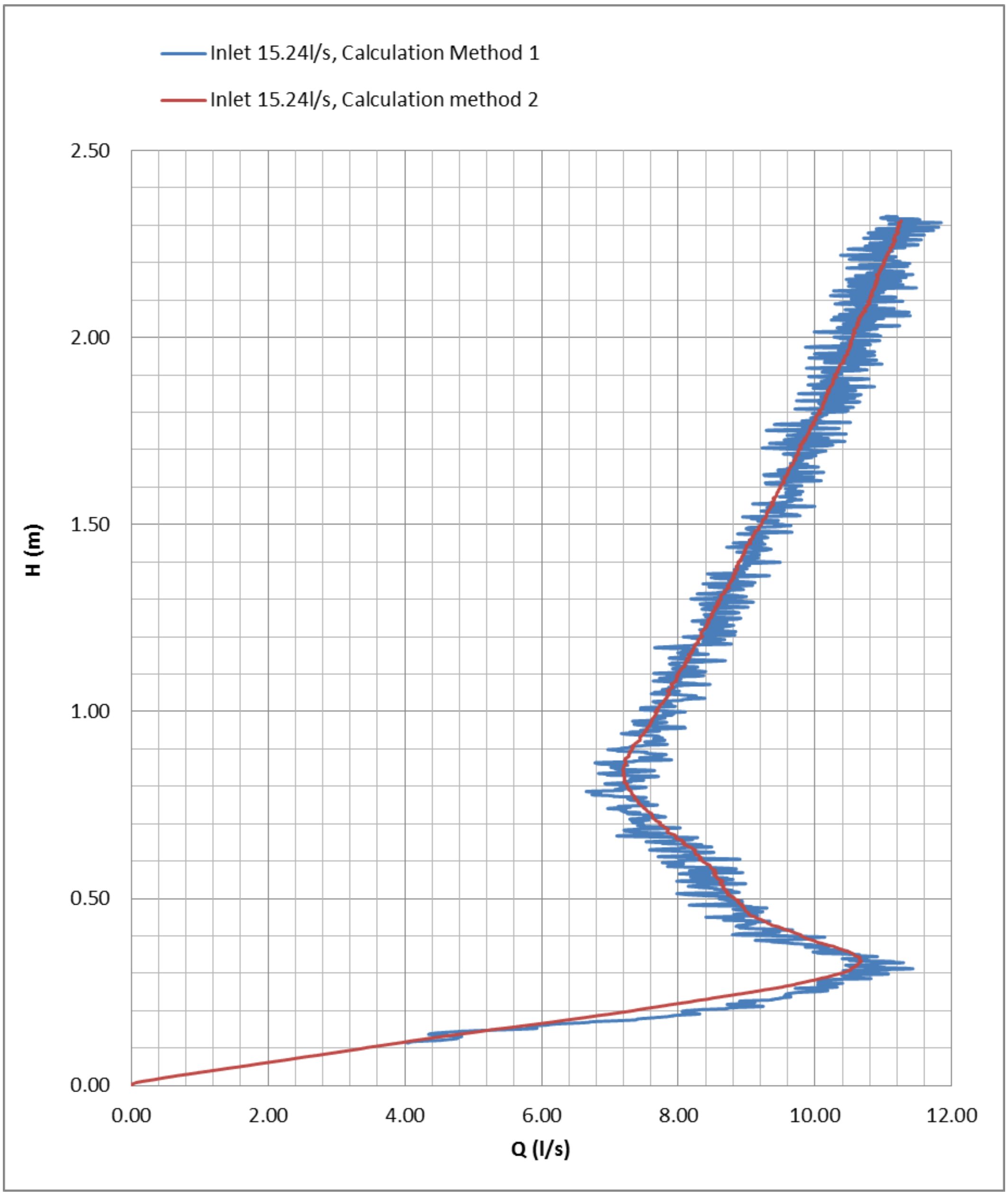

Figure D1 Comparison of calculation method (Method 1 and Method 2), test conditions: CEV 10.5ℓ/s @ 2.00m – 100%, Q_{inflow}=15.24ℓ/s moving averaging over 60s

APPENDIX E

Audit reports

Audit Report

DHI Project No	11811720
Testing project	Mosbaek CEV Flow Regulator
Date of audit:	29 September 2014
Test & audit site:	Mosbaek A/S, Værkstedsvej 20, 4600 Køge

Present during audit:	Jesper Fuchs,	Auditor, DHI
	Torben Krejberg,	Technical director, Mosbaek
	Mogens Hebsgaard,	Test responsible, DHI

During the audit the first test (Test id: Test 1, CEV1.4 @ 1.0m 100%, q=1.9l/s) was initiated and running. A copy of the test plan, dated September 2014 was available at the site.

Compliance with Test Plan:

Test set-up
The test set-up as described in the test plan has been followed.

Test execution
The auditor suggested the original test procedure changed: It was suggested initiating the test series with each CEV with a common zero reference test instead of initiating each individual test with 5 minutes at zero level without flow. This change provided a unique determination of the zero level, and each test can be initiated at a lower level than zero and thus ensure that the inflow is adjusted when the outflow starts.

Calibration of Instruments
The calibration check of the pressure cells was performed earlier that day, and according to the notes and videos this was carried out as described in the test plan.

The flowmeters are pre-calibrated and certificates available in an appendix to the test plan.

Test execution
The test was carried out in accordance with the test plan. A list covering the test period is filled in. A test scheme is available in an appendix in the test plan.

Data logging and processing
All data are logged and stored. Each day raw data files will be sent to DHI for storage and processing. The raw data will be stored at the DHI project Sharepoint site. A copy of the data files will be stored at Mosbaek.

Other issues identified
The test arrangement is set up outdoor, which makes it sensitive to weather conditions; wind may affect the open tanks both with respect to oscillations of the tanks and oscillation of the water levels in the tanks. Tests in strong winds cannot be recommended.

Non-compliance noted
None

Auditor's conclusions
The test is performed in agreement with the test plan ~~and carried out~~ in a safe manner.
Handling and storage of data is safe.

Date: 3 October 2014 Signature: ____________________

ETA Danmark Test System Audit Report

Project no.: 011987-01	Date of audit: 20014.10.02
Testing project: Mosbaek CEV flow regulator	Site: Mosbaek A/S, Værkstedsvej 20. 4600 Køge

Test system audit – Storm water

Present during audit:

Auditor: Peter Fritzel

Other: Torben Krejberg, Mosbaek
Mogens Hebsgaard, DHI

Checklist

Conformity with test plan:
Test method in general
Section 2.1.1.: Test set up is as described in test plan. Test plan dated 2014.09.10, available at site
Operation of technology:
Section 2.1.1.: Filling of tanks is handled manually.
Operation conditions, and measurements for monitoring them
Section 3.3.: A check list covering a measuring session is filled out. Viewed list for Test no. 8 with Id CEV4,9@1,5m100%, see page 2.
On-line measurements and sampling for performance parameters
Section 4.2.: Flow meters are calibrated and certificates are shown in an appendix to the test plan. Pressure meters is checked. Calibration test viewed, see page 3.
Data logging and retrieval
Section 3.2.: All data are logged and stored. After the daily session, data is sent to DHI a version is also stored at Mosbaek.

Other issues identified by auditor*:*
The tent used for covering the measuring equipment is sensitive to the weather conditions. An indoor set up could be an idea – it requires only longer cords to the sensors.

Non-conformities noted by auditor
None

Auditor's conclusions
There is consistency with the test plan and handling of measurements are carried out in a safe manner

Date: 2014.11.19 Signature: Peter Fritzel

Model tests with CEV Flow Regulators

Execution of verification tests

Procedure

This procedure describes the way used during execution of the tests.

Date: 1-10-14

Test No: 8 **CEV model and id:** CEV 49l/s @1.5m **Target flow:** 8.3 l/s

Test id: Test no 8 CEV49l/s@1.5_9 = 8.84 l/s

Action	Check	Time	Signature
Check instruments	✓	N/A	[illegible]
Close inlet adjustment valve is closed	✓	11.05	[illegible]
Fill or empty tanks with water just below CEV invert	✓	11.05 Start	[illegible]
Start data logging (at level just below zero)	✓	11.05	[illegible]
Wait 5 minutes	✓	11.10	[illegible]
Start submersible pump	✓	11.07	[illegible]
Open valve until target flow is reached	✓	11.07	[illegible]
Proceed at least until design H is reached	✓	11.35	[illegible]
Close inlet valve	✓	11.35	[illegible]
Stop pump	✓	11.35	[illegible]
Proceed until well is empty for one test per CEV	✓	12.10	[illegible]
Wait 5 minutes	✓	12.15	[illegible]
Stop data logging	✓	12.15	[illegible]
Empty the inlet tank and regulator well by evacuation valve in three of the four tests	N/A		[illegible]
Check results roughly			[illegible]

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Model tests with CEV Flow Regulators

Check of calibration of pressure transducer in the regulator well

Procedure

This procedure describes the way used to verify the calibration of the pressure transducers.

1. Close the outlet from the regulator well ✓
2. Fill in water until outlet invert level ✓
3. Start recording ✓
4. Close the inlet valve and let the water level be undisturbed for at least 5min
5. Read also the constant water level at the measure stick by video or at least each minute
6. Fill in water until about 1m above pressure transducer
7. Repeat 4 and 5
8. Fill in water until about 2m above pressure transducer
9. Repeat 4 and 5
10. Fill in water until about 3m above pressure transducer
11. Repeat 4 and 5, but 4 with a duration of at least 10min ✓
12. Stop recording ✓

Manual readings

Water levels	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
At CEV invert level for outlet pipe	71.0	71.0	71.0	71.0	71.0
~0.5 ~~~+1m~~	123.8	123.9	123.8	123.8	123.8
~1.0 ~+2m	171.4	171.4	171.7	171.5	171.5
~1.5 ~+~~3~~m	222.0	222.0	222.0	221.9	[illegible]
~ +2.0m	272.2	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	306.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Date: 9

Test No:

Test id: