Local Area Weather Radar (LAWR) System to Validate Drainage Systems Capacity - Case Study from Egedal - Denmark

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ABSTRACT

In autumn 2008 Egedal Supply (EF) decided to implement a LAWR system due to future challenges of climate change and elevated number of rainfall-flood events. The objective was to provide modellers and operatives with better quantitative and qualitative data of local rainfall patterns in order to monitor, evaluate and validate the hydraulic capacity of drainage systems in accordance with the national service level, guidelines and requirements.

The LAWR in Egedal, which was under construction, was tested for the first time in summer 2009 with a 36-hour rainfall event on 11 June 2009 with an average accumulation of 111 mm. Catchments were visualized on a web site with dynamic monitoring of the event, tabular data and time series plots were produced and analysed. Up to 3 µm/s recorded average intensity and locally up to 8 µm/s were observed. Accumulation varied between 79 mm and 150 mm. Data were calibrated with local rain gauges.

Floods could be related directly to local intensity and accumulation. Publicly made reports eased the communication with costumers. A warning system can be realized. A procedure of screening drainage systems in flooded areas was established in EF.

Forecasting rainfall events and online connection of LAWR data with hydrological and hydraulic simulations can be the prospects of implementation.

KEYWORDS

Drainage system, floods, LAWR, rainfall intensity, return period, service level.

INTRODUCTION

During the summers of 2005 and 2007 Egedal Municipality in Northern Zealand (Figure 1) was exposed to two storm events that caused flooding in the urban drainage system and along the rivers and stream banks in the region. Flooding resulted in damages in both urbanised and rural areas.

A hydrological-hydraulic analysis of the drainage system catchments and network has since then been implemented. From the beginning lack of rain gauges was identified as a general problem, as there were just two rain gauges available to provide data. Studying the flood events and the capacity of the drainage system has shown that there is generally a significant variation in the rainfall depth and intensity over Egedal. Based on this, EF had the options of either installing and maintaining a net of rain gauges or implementing a LAWR system (Figure 2) that covers the western region of Northern Zealand too, which represents rain data in the form of time series for each spatial pixel (100x100 m) in the area covered by the radar up to 15 km range, 250x250 m pixel size up to 30 km range and 500x500 m pixel size up to 60 km. The latter was decided and an X-band type radar was chosen to be implemented for this task.

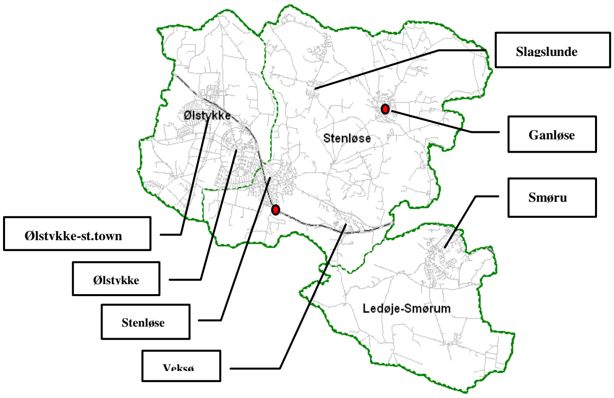

Figure 1: Towns in Egedal and locations of the two implemented rain gauges in this case study (red dots).

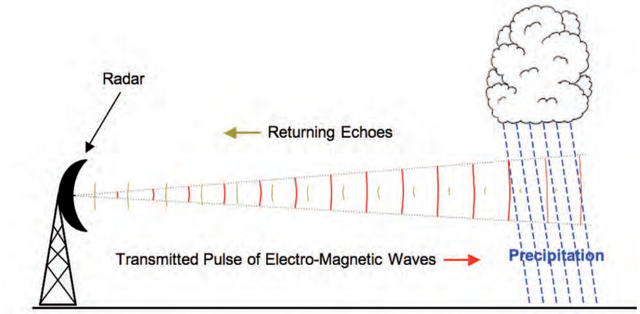

Figure 2: How radar works (Met Office, 2009).

On 11 June 2009 at 12:30 pm a storm event hits for the next 36 hours with a low pressure concentrated upon Northern Zealand, which is the case study of this paper. This event has once more flooded Egedal. The data of the rain event was covered by LAWR of type X-band radar located in DHI – Hørsholm more than 20 km to the northeast of Egedal. The paper is a review of implementing X-band radar technology during the event and an evaluation of advantages and challenges of this experience in a water company.

RAIN EVENT 11-13 JUNE 2009

The average depth of this rain event was 111 mm. The depth varied between 79 mm and 150 mm measured by the radar in different catchments in Egedal.
Figure 3 presents the rain event.

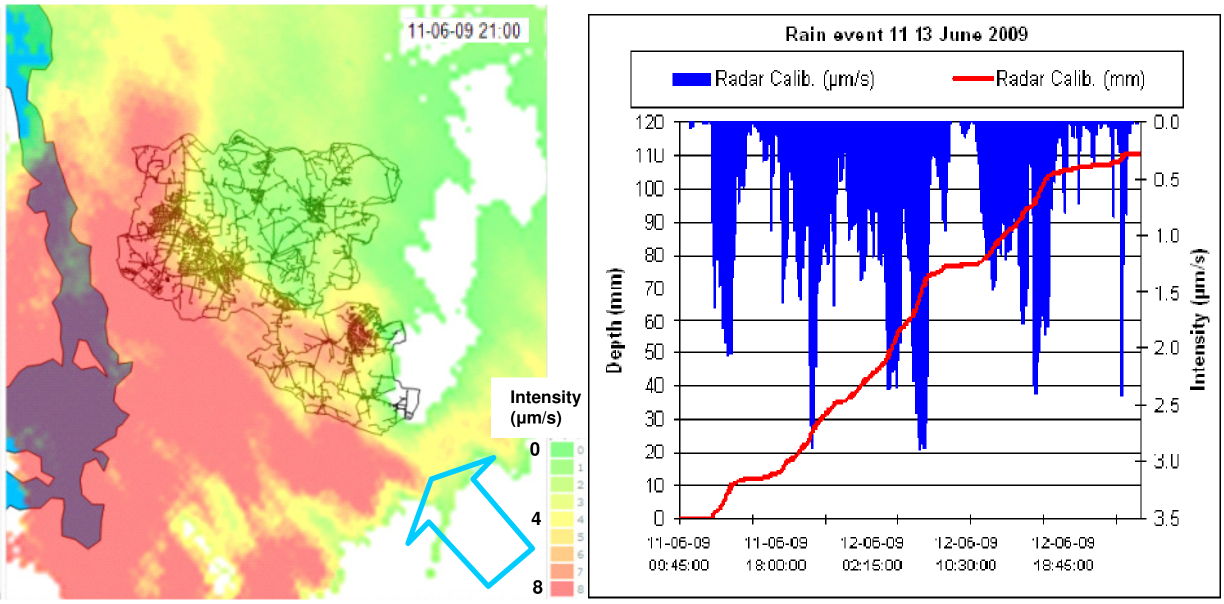

Figure 3: Rain event on 11-13 June 2009 in Egedal – Radar data.

This rain event has a return period equivalent to more than 100 years (T≥100). T estimation is illustrated in Figure 4.

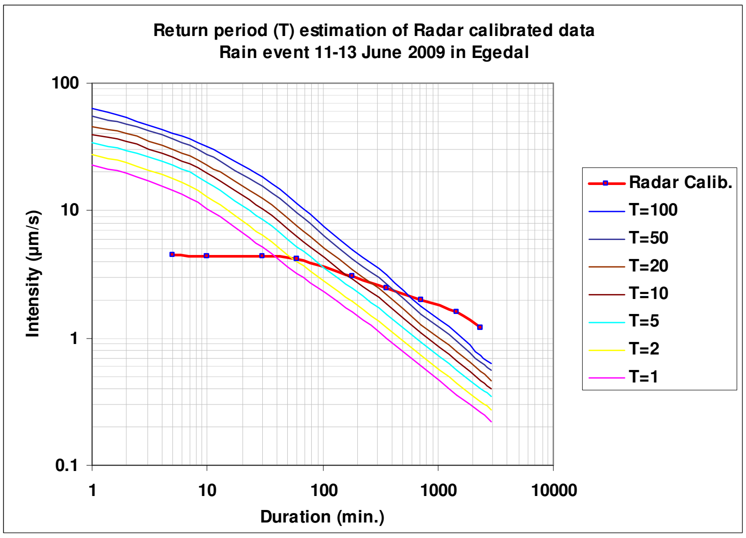

Figure 4: Return period estimation of the rain event 11-13 June 2009 in Egedal

DATA CALIBRATION

Data from the only two functional local rain gauges at the time of the storm event were used for radar data calibration. The two rain stations are the rain gauge located in Stenløse wastewater treatment plant (SG) and the rain gauge located in Ganløse town (GG). See Figure 2. SG has registered a total rainfall depth of 115.8 mm during the event and GG has registered 73.2 mm during the same event from 11-06-2009 9:45 to 13-06-2009 01:15. SG is located in the radar catchment ST1, which has an area of 23.7 ha and GG is located in the radar catchment GA4, which has an area of 25.9 ha. A linear relationship between rain gauge counts of intensity and radar counts of intensity for the corresponding catchment is assumed, based on 5 minutes log data. The linear relationship can be described as in equation 1

$$I = C \times R \qquad \text{eq. 1}$$

Where I is calibrated radar count of intensity (µm/s), C is calibration factor and R is radar count of intensity (µm/s). C value for all the catchments in Egedal was found to be 0.655 in this case study. The results of calibration are presented in Figure 7.

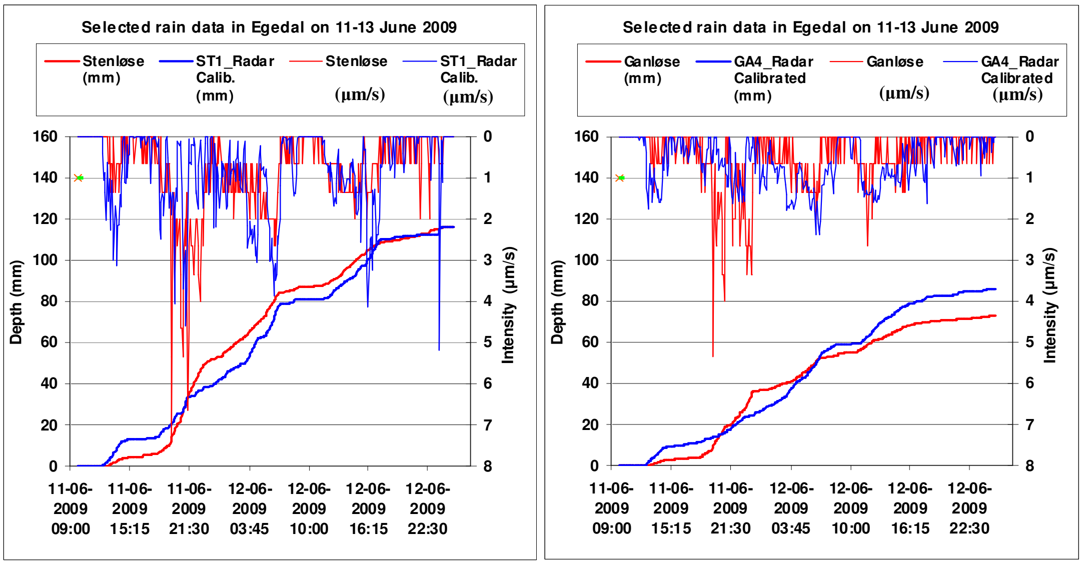

Figure 7: Calibration results of radar catchment ST1 compared to Stenløse-SG (Left). Calibration results of radar catchment GA4 compared to Ganløse-GG (Right).

However, calibration of spatial pixel data 250X250 m from the radar in the same location of each rain gauge could have been even better characterized. Such pixel data were not available at the time of the rain event, as the radar was under construction and such points of data were not established in the set up of the data. Hence, catchments ST1 (23.7 ha) and GA4 (25.9 ha), where rain gauges SG and GG are respectively located, were selected for calibration in this case study.

Evaluation of the calibration is presented in Figure 8. R^2 is greater than 0.9. The tangent of the relationship is between 0.9 and 1.1, which are the criteria set chosen for the calibration.

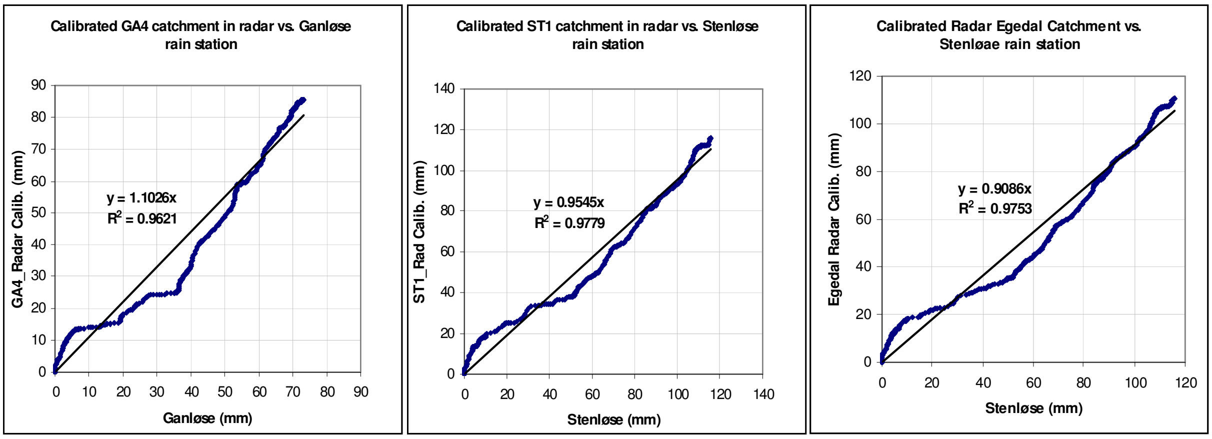

Figure 8: Evaluation of the calibration.

Return period (T) estimation of the calibrated data from the radar together with the data from the rain gauges SG and GG are presented in Figure 9.

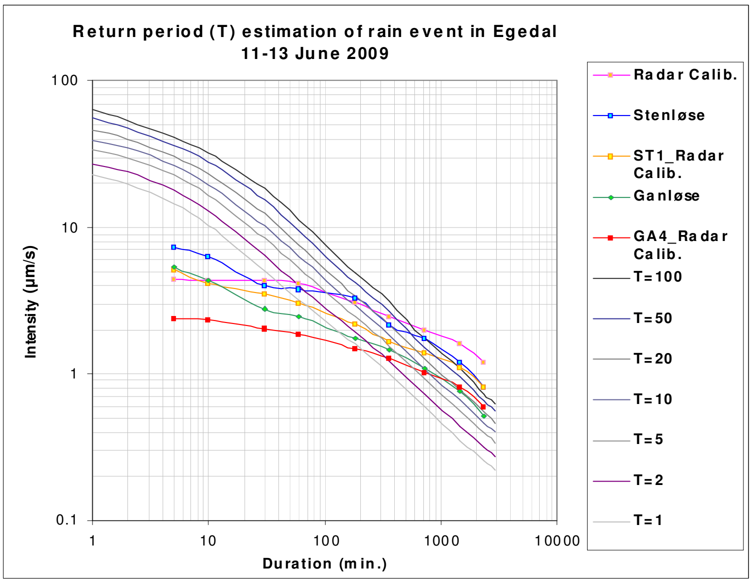

Figure 9: Return period (T) estimation of the calibrated radar data together with the data from the rain gauges in Stenløs-SG and Ganløse-GG compared to T estimations from the Wastewater Committee in Denmark (SVK28, 2005).

Based on the above calibration and T-estimation, other catchments radar data could be calibrated and T-estimated. The overall accumulation after the rain event can be seen in Figure 10.

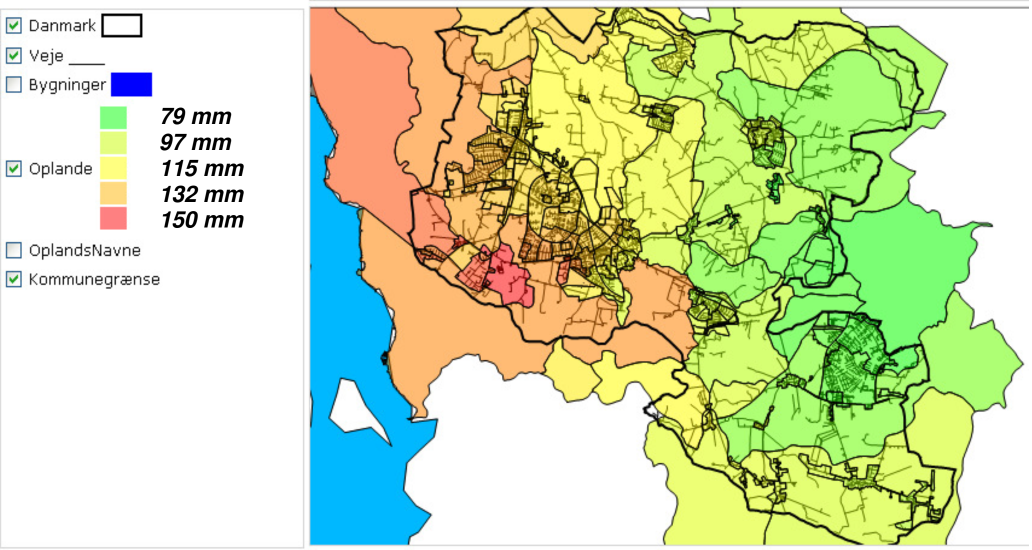

Figure 10: Distribution of rainfall depth in Egedal on 13-06-2009 at 01:15am at the end of the event.

WHAT IS REALLY HAPPENED IN EGEDAL ON 11-13 JUNE 2009

At the end of week 24, Egedal was suffering the damages of approximately 36-hour rain event of a return period of more than 100 years. Examples of the damages are presented in Figure 11.

Figure 11: Aspects of the physical damages in Egedal on 13-06-2009.

82 observations of flooding have been registered in the records of EF during and after the event. It took EF and Local Civil Emergency Force more than 3 days to control hazard flooding and more than one week to treat the aftermath damages of the event. However, no estimation of damage cost has been documented in EF.

Service level guidelines of drainage system capacity defined by Document 27 (SVK27) of the Wastewater Committee in Denmark is illustrated in Figure 12 (SVK27, 2005).

According to SVK27 a drainage system is supposed to contain a rain event of a return period up to T=5 and T=10 without flooding for rainwater sewer systems and combined sewer systems respectively. The average return period of the event of 11-13 June 2009 in Egedal catchment was T≥100 year. The minimal effect was T=20 on catchments in the eastern parts of Egedal such as in Smørum and Ganløse. Se Figure 10 and then Figure 13.

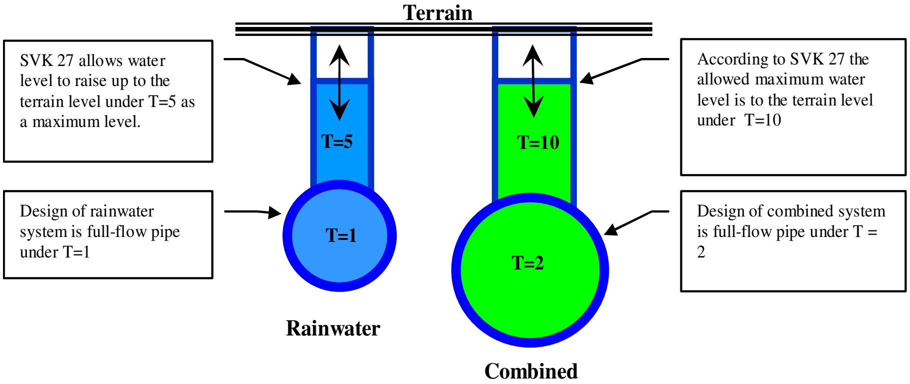

Figure 12: Illustration of service level guidelines for hydraulic design of separate and combined drainage systems according to SVK 27 (Al-Shididi, 2008).

This explains why floods in Egedal were unavoidable as it appears in Figure 11. Figure 13 presents the volume of rainwater precipitated on a square meter on 11-13 June 2009 compared to the expected capacity of the sewer system.

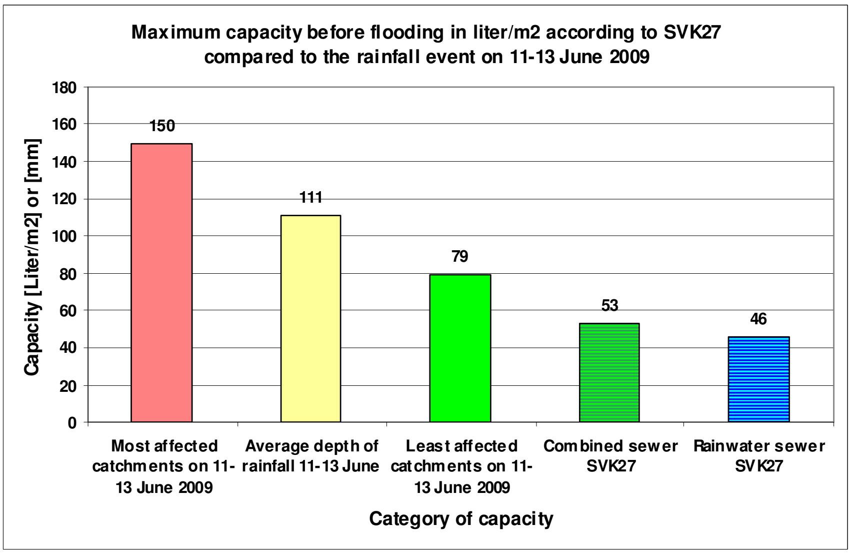

Figure 13: Comparison between expected capacity of the sewer system in Egedal according to SVK27 (Striped columns) and the volume of rainwater precipitated on Egedal catchments.

Figure 13 demonstrates that the whole sewer system even in the least affected catchments has suffered a lack of capacity to contain the amount of rainwater precipitated during this event without flooding. The rainwater volume was much beyond the volume of the service level capacity defined by SVK27. All catchments in Egedal were exposed to flooding. Catchments located in the eastern parts of Egedal were the least affected, while catchments in the western part of Egedal were the most affected. See also Figure 10.

THE AFTERMATH OF THE RAIN EVENT

A publically made report by EF has been the major element in public communication, which has presented the size of the event and explained why the sewer system in Egedal could not protect properties from the flooding damages.

Online monitoring of the radar website, fast decision making, and forwarding information to the maintenance operatives in EF and the Local Civil Emergency Force has effectively coordinated their efforts, which became a future work plan. Local flood events could be related directly to local intensity and depth of rain.

CATCHMENT VALIDATION

After this rain event EF began to implement radar data to validate the service level capacity of every catchment in the urbanised areas of Egedal. It is used as a fast preliminary risk assessment tool before making further decisions. This can be accomplished by comparing calibrated radar data under certain rain events and using information from level and flow meters installed in the catchments to evaluate flooding in the catchments. Validation is based on the following decision criteria:

1. In rainwater catchments, where floods do not happen under rain events T≥5, the catchment is identified as approved to live up to the service level of the guidelines of SVK27. Calibrated hydraulic models verify the drainage system in the catchment.
2. The same is valid for combined sewer catchments under T≥10.
3. Based on climate change certainty factors of Wastewater Committee (SVK 29, 2008), future service level and future T-numbers can be identified for each catchment too.
4. The above tool can yet be further verified in the decision making process by calibrated hydraulic modelling of each identified catchment implementing calibrated radar data. Investigation of the correlation between service level estimation from radar data and service level estimation from hydraulic modelling can be done.

UNCERTAINTIES OF THIS CASE STUDY

Although EF has implemented simplified linear calibration in this case study, the radar was distinctly well in detecting the distribution of rainfall intensities. This has been practiced during the storm by estimating the impact time and location, while online monitoring radar data during the rain event on 11-13 June 2009. However, uncertainties in this case study can be accounted on the following:

1. The data source LAWR is located more than 20 km to the northeast of the centre of Egedal and therefore the pixel resolution provided was of 250x250 m (DHI, 2010, Table 1.1). The opportunity of 100x100 m resolution pixel of the under construction LAWR installed locally in Egedal was absent during this rain event.
2. Simplified linear and static calibration rather than online dynamic calibration.
3. Data calibration of large area catchments (23.7 ha ST1 and 25.9 ha GA4) against only two rain gauges (SG and GG respectively) represented by two spatial points. Pixels of 100x100 m (rather than 250x250 m) in the locations of the two rain gauges could have presented even more accurate calibration.
4. Using the same factor of calibration on all catchments without considering the differences in catchment areas, location from radar antenna, etc. are factors of uncertainty in this case study that need to be explored and defined

Radar signal errors are presented in

5. Figure 14, which can be summarized in the following:
    a. Permanent echoes caused by buildings, hills, trees, windmills, high voltage electricity power supply towers and other permanent obstacles that generate clutters and magnetic fields that cause propagation, which was relevant in this case study, as the source LAWR was located more than 20 km from the centre of Egedal.

b. Spurious echoes caused by airplanes, birds, insects or other moving objects at the site of the radar. This error is always possible and hard to register from its first use. However, observing and gaining knowledge about the routes of routine flights, birds' seasonal immigration and birds' local flying patterns within the LAWR site can help avoiding such signal errors in cooperation with LAWR developers through signal noise rinsing techniques.

c. Technical problems or interfering from other radars can create false echoes. Locating the radars operative in the LAWR site can help analyzing such echoes.

d. Overshooting: The radar beam is above the precipitation at long distances. This error can be minimized, if the source LAWR was locally installed in Egedal.

e. Bright band by reflects from snow particles on an altitude before precipitating down to rain drops. Investigation to determine seasonal and type of rain related to this error can be conducted.

f. Drop size can be overestimated for above average sized drops (defined by radar set up) and it can be underestimated for below average sized drops.

g. Anomalous propagation, where radar beam will be bent, when passing through different density air due to temperature change. The worst case scenario is when the beam bends towards the terrain surface, where strong echoes can be generated back to the radar antenna. Propagation is expected to occur often during convictive rain events rather than frontal rain events.

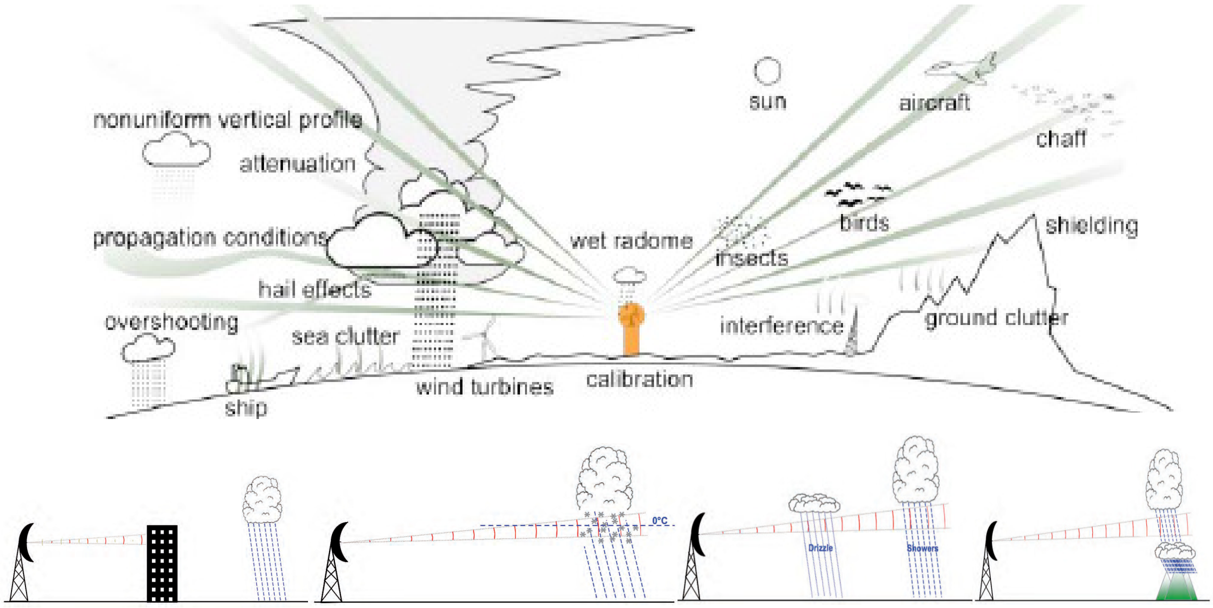

Figure 14: Illustration of signal errors in weather radar (Rossa, 2010 & Met Office, 2009).

ADVANTAGES OF THE CASE STUDY

The first use of radar in EF could support decision making in dealing with the rain event. It helped identifying the problem faster. It explained why the drainage system could not contain the rain event as it is presented in this paper. As for the technical advantages, the following were gained:

1. Detailed, instantaneous and integrated rainfall intensities for all catchments in Egedal.
2. Data in 5-minute real time, which can be optimised to 1-minute real time.

3. Spatial rainfall estimates over all Egedal instead of relying on just two rain gauges.
4. First time privilege of monitoring dynamic precipitation areas during the event.
5. Online high resolution detection of locations of frontal showers.

FUTURE PERSPECTIVES

Although the first use of radar technology in Egedal is considered to be functional, future performance of radar and objectives of implementation formulate a list of perspectives, which can be summarised as follows:

1. Numerical forecast models are an essential function that has to be developed for future implementation of drawing scenarios of events from flooding down to the outlet of the catchment.
2. Developing warning systems and at the same time reducing false warnings.
3. Dynamic online calibration is a necessary integration with online data validation from flow and level meters.
4. Extracting rain data from radar counts in order to use in hydraulic modelling is relevant to the catchment rather than using data from a rain gauge in an adjacent location that might not describe the rain event on the modelled catchment. This would be reliable, when radar data are well calibrated.
5. Integrating data from a net of LAWR radars can be more reliable than data from single radar. Thus, organising radar data administration is a future task for optimizing local and regional radar data system.

CONCLUSIONS

Calibrated radar data helped preliminarily to identify the capacity problems in accordance with the service level standards. Online data from radar supported effectively decision making during the storm event. Local flood events could be related directly to local intensity and depth of rain. Overall image of the event created and explained why flooding had happened. Calibrated data supported risk analysis and provided the basis of decision making. Radar is an instantaneous spatially integrated data source that needs to be optimized to be reliable for more accurate estimations in comparison to data from rain gauges.

REFERENCES

Al-Shididi, Sabah (2008). Implementation of MIKE URBAN and MOUSE to Support Sustainable Economic and Quality Assurance in the Municipal Water Company in Egedal – Denmark. Paper & presentation. The 2nd European MIKE by DHI Software Conference. 13-15 Oct. 2008. Dubrovnik. Croatia.

DHI (2010). Local Area Weather Radar. LAWR Documentation. Version 3.2. Danish Hydraulic Institute. 21-06-2010. http://radar.dhigroup.com, http://radar.dhigroup.com/publications/LAWR_manual.pdf

Met Office (2009). Radar - National Meteorological Library and Archive Fact sheet 15 — Weather radar. version 01. UK. www.metoffice.gov.uk

Rossa. Andrea M. (2010). How to represent uncertain radar observations and weather forecasts. Presentation. Contribution from the COST 731 and MAP D-PHASE community. BALTRAD End User Workshop, 26 October 2010, Aalborg, Denmark. http://baltrad.eu/sites/default/files/presentation%20of%20uncertainty%20COST%20731.pdf.

SVK 27 (2005). Funktionspraksis for afløbssystemer under regn. October 2005. Skrift nr. 27. IDA spildevandskomiteen.

SVK 28 (2006). Regional variation af ekstremregn i Danmark – ny bearbejdning. 1979 – 2005. October 2006. Skrift nr. 28. IDA Spildevandskomiteen.

SVK 29 (2008). Forventede ændringer i ekstremregn som følge af klimaændringer. August 2008. Skrift 29. IDA Spildevandskomiteen.