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COMPARISON OF RAINGAUGE & CALIBRATED RADAR DATA USING GIS BASED SEWER MODELLING

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ABSTRACT

Accurate real-time rainfall measurement is an important aspect in sewer network modelling. Weather Radio Detection and Ranging (RADAR) can give a good estimate of precipitation as compared to Tipping Bucket data. The RADAR data should be properly processed to make it usable for calibration purposes. This paper presents ways in which the discrepancies in RADAR data can be minimised by determining a relationship between RADAR and Tipping Bucket raingauge data.

The models have been simulated with rainfall data generated from RADAR data using various random reduction factors, point raingauge data and calibrated RADAR-raingauge derived precipitation. The paper reports on the results of these trials, indicating the differences in using the above methods. Results show that the calibrated RADAR-raingauge derived precipitation can give a better representation of the timing of flow response, total volume and peak depth in sewer networks.

Keywords : *RADAR; Rain gauge; Rainfall; Geographic Information System (GIS); Flow Monitor; Infoworks.*

I. INTRODUCTION

The Barrhead model, a part of Shieldhall West catchment located within the Greater Glasgow area (UK) was used for this study. This model was taken as a part of model maintenance for Q&S III carried out by Scottish water under the SR10 programme in 2008 for update and verification purpose.

It was decided during the initial stages of the project to use RADAR rainfall data for the project. A small number of rain gauges were installed from 22nd Feb 08 to 7th Aug 08 for calibration of RADAR rainfall. Flow Monitors were also installed during the same period at various locations in the catchment.

The study was conducted based on three objectives:

- Use of RADAR data using Tipping Bucket data for urban drainage modelling.
- An appropriate method for calibrating RADAR rainfall data
- Studying the effect of spatial variation observed between Tipping Bucket and RADAR data.

II. STUDY AREA

The Barrhead catchment covers an area of around nine sq. km. RADAR data was available for each one sq.km. grid and was collected at 5 minutes intervals and converted pro rata to 2 minutes intervals. Barrhead catchment was covered by twelve RADAR grids and additionally our Tipping Bucket rain gauges (RG108, RG086, RG087 and RG080) were installed in the study area. However, data was returned for two rain gauges (RG108 and RG080) as the other two rain gauges were stolen early on in the survey (refer to Figure 1 which shows the RADAR grid reference numbers and the location of rain gauges). It also shows the location of nineteen standard flow Monitors for flow survey data with Thiessen polygons based on rain gauge location.

From Figure 1, it can be seen that the density of rain gauges was significantly less when compared with the RADAR grid within the catchment.

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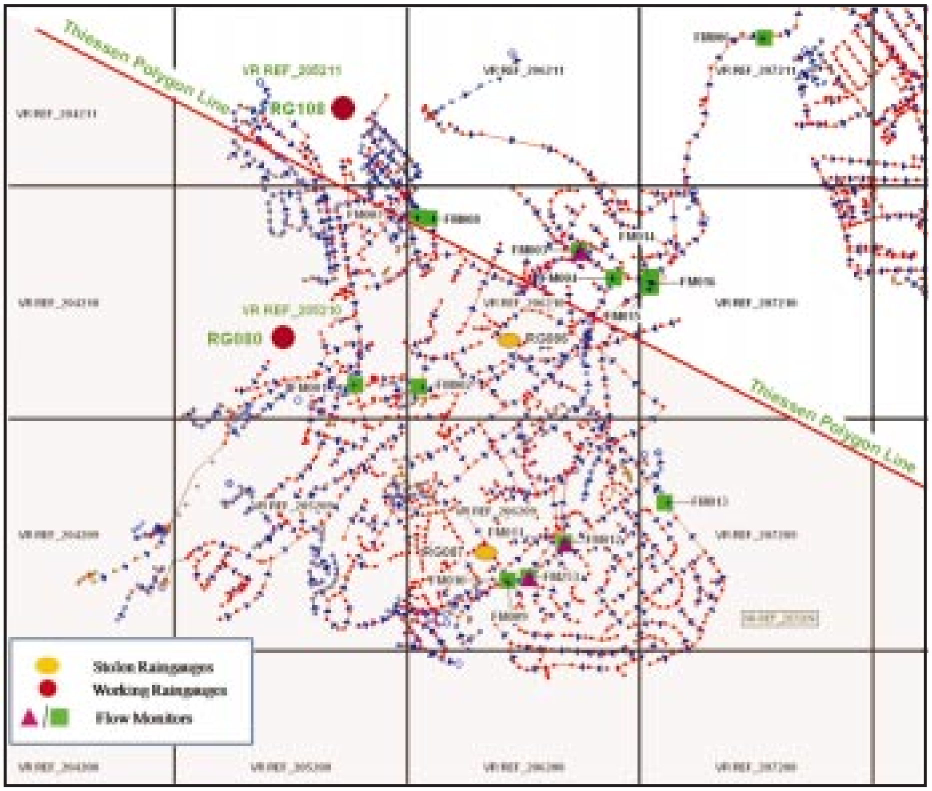

Figure 1 : RADAR grid reference number and the location of raingauges.

III. REVIEW OF INPUT DATA

RADAR data suffers from various errors. The RADAR records rainfall that may fall on the catchment, whereas the Tipping Buckets record data that has fallen. Hence in order to determine the relationship between rain gauge and RADAR data, it was assumed that data recorded by a rain gauge located in that particular RADAR grid represents actual rainfall on the ground.

From the data available, two storm events shown in Table I was selected based on WaPUG criteria.

Table II : Storm events consider for study

Event Reference	Date & Start Time	Date & End Time
Storm 1	21/06/2008 00:02:00	24/06/2008 00:02:00
Storm 2	08/07/2008 12:00:00	10/07/2008 00:02:00

The graphs were plotted to represent time versus cumulative intensity of both RADAR and Tipping Bucket rain gauge data for the two selected storms with different grids. A sample graph is shown in Figure 2 representing storm event 1.

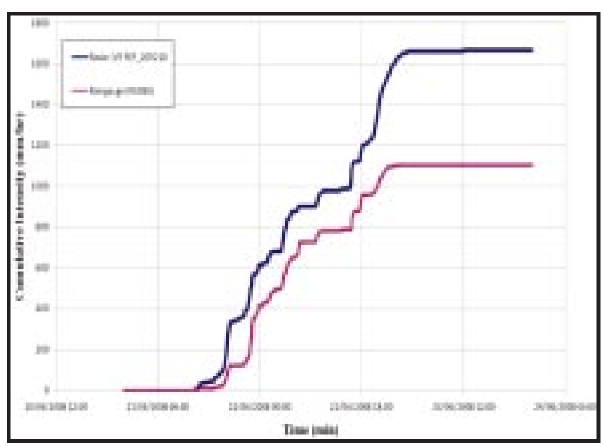

Figure 2 : Cumulative Intensity versus time for Storm 1

Analysis of the graph shows, the RADAR data had higher a cumulative intensity than the tipping bucket data, inferring that there could be some error during the measurement of either RADAR or Tipping Bucket data or both at few instances. The quality and consistency of a grid RADAR data were checked by comparing the graphs between cumulative intensity vs. time with the adjacent grids RADAR data. Similar procedures were applied for Tipping Bucket data. It was concluded that it could be due to some erroneous data points in Tipping Bucket data. This error was also confirmed by comparing the observed flow taken from installed flow Monitors and predicted model simulation flow graphs (from Infoworks model) obtained by using corresponding rainfall and RADAR rainfall data. The results from the model show higher flow and depths for some of Tipping Bucket rainfall data.

The results analyses for Storm 2 (Refer Figure 3), i.e. the rain gauge RG080 show higher cumulative intensity than the RADAR data for a time interval of 15:00 Hrs to 15:14 Hrs on Date 08-07-2008. This shows that the cumulative intensity of Tipping Bucket (colour: pink) was greater than RADAR data (colour: blue) between time interval as specified above. This could be influenced by the trees seen in the background of rain gauge RG080 (Refer Figure 4).

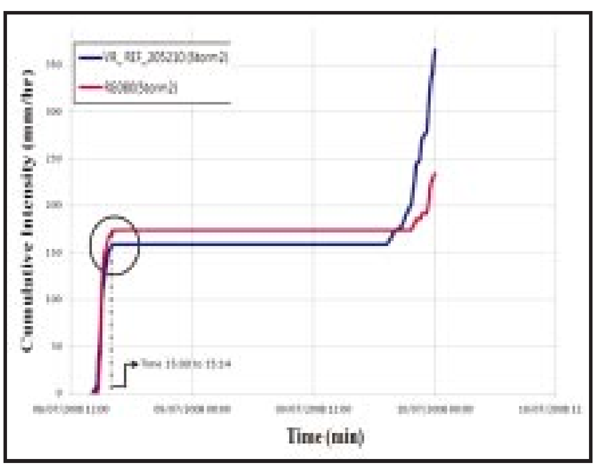

Figure 3 : Cumulative intensity vs. time for storm event 2

Hence the error was corrected by making a comparison with the adjacent rain gauges data. Therefore, the Tipping Bucket data of RG080 has been replaced by RG108 for the above time interval. The Figure 5 shows the cumulative intensity of Tipping Bucket (colour: pink) was less than RADAR data (colour: blue), after correcting the data between time interval as specified above.

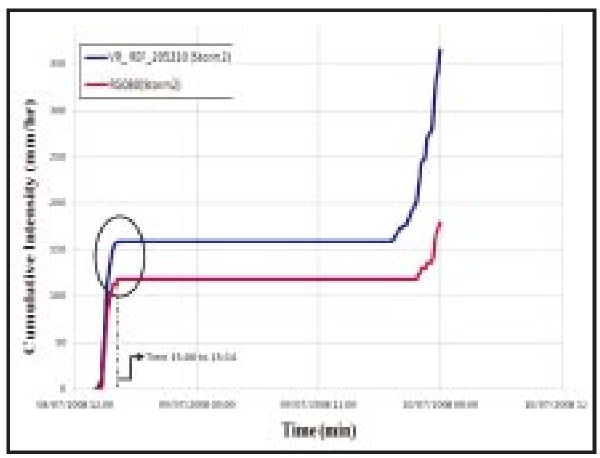

Figure 5 : Cumulative intensity vs. time for storm event 2 after revised intensities.

IV. METHODS FOR CALIBRATING RADAR RAINFALL

The following methods were used for calibrating RADAR data

- Method 1: Applying a calibration factor of 0.8 to RADAR data (this method was used during verification previously).

- Method 2: Obtaining a mathematical relationship between RADAR rainfall and Tipping Bucket rainfall data.

A. Method 1

1) *Methodology :* Jordon (2000) and Vinux (2002) attempted to classify RADAR gauge errors in the two broad categories

- ***Systematic Errors***

Systematic errors are associated with specific problems such as incorrect RADAR reflectivity-rainfall (Z-R) relationship (Marshall – Palmer's equation) which causes systematic underestimation/ overestimation by RADAR and which can be removed by adding a multiplicative constant in the Z-R relationship.

To eliminate the Systematic error, Wilson and Brandes (1979) proposed to compute multiplicative 'mean field bias' using RADAR and gauge measured rainfall. The 'mean field bias' (B) is computed by the following equation

$$B = \sum_{i=1}^{n}(G_i) / \sum_{i=1}^{n}(R_i) \quad (1)$$

Where G is the gauge rainfall, R is the RADAR estimated rainfall, and n is the number of observations. The calculated bias is then multiplied with RADAR data of each grid.

- ***Random Error***

Even after removing systematic errors, RADAR measured data may contain a number of random errors.

1) *Application to study :The Barrhead model has* been verified using the RADAR data. It was observed that the simulated results (peak Depth, Peak flow and Total volume) are not within the UK Wastewater Planning Users Group (WaPUG) criteria. Hence the bias factor has been calculated using equation 1 for both the storm events. Also the statistical analysis has been carried out between revised RADAR data and rain gauge. It has been observed that the Root Mean Square Deviation (RMSD) for storm event 1 is 0.66 while for storm event 2 is 0.87 with bias factor of 0.80 and 0.64 respectively. Hence in order to obtain better fits and to meet the WaPUG criteria, various factors (0.6, 0.7 and 0.8) were used for RADAR data. The fits from the 0.8 factor were well within the WaPUG criteria but the shape of simulated curve did not match the observed curve as required. This further indicates that the revised RADAR data contains random error as well and will need to be addressed. Hence, an attempt has been made as a part of this study to generate a better method to get more accurate results.

B. Method 2

1) *Methodology :To mitigate l*arge discrepancies which at times are seen in the RADAR data, rain gauge data can be utilised to calibrate the RADAR data using the method given below. It was necessary to find out a relationship between them for all storms. An assumption has been made that if a rain gauge is located in particular RADAR grid, represents rainfall of RADAR grid data on ground. Hence, the graph has been generated between cumulative RADAR data on X- Axis and cumulative rain gauge data on Y- Axis. Then the dynamic equation has been generated between them using Polynomial option given in Format trendline tool in MS Excel™. Polynomial option applies a curved line to display fluctuating data values. It will determine how many bends (hills and valleys) appear in the curved line based on the value (2 to 6) enter in order box. This type of trendline uses equation (2) to calculate the least squares fit through points.

$$Y = b + c_1 X x + c_2 X x^2 + ... + c_6 X x^6 \quad (2)$$

Where, b and $C_1 .... C_6$ are constants. e.g. Figure 6 shows the equation (relationship) generated for storm event1 which is

$$Y = 3.22 X 10^{-10} X x^4 - 1.50 X 10^{-6} X x^3 + 2.03 X 10^{-3} X x^2 + 1.86 X 10^{-3} X x$$

Where, X = RADAR data given for each Grid
Y = Calibrated RADAR data close to ground measured data

1) *Application to the study*: The RMSD for the above equation is 0.99. This equation has been applied to the each RADAR grid using Thiessen's polygon based on Tipping Bucket location in order to calibrate the RADAR data. This calibrated RADAR data has been used for simulations of Barrhead model.

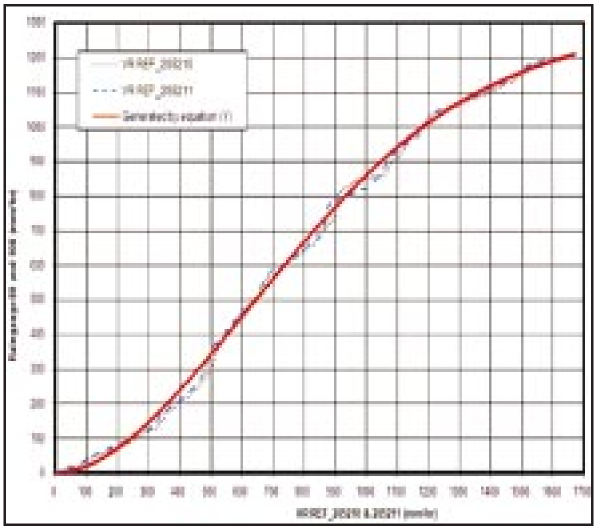

Figure 6 : Cumulative intensity of RADAR vs. rain gauge data for storm event 2

V. RESULTS

Figure 7, 8 & 9 shows, the simulation graphs obtained using Method 1 (Color: cyan), Method 2 (Color: Blue), Tipping Bucket (color: Green) and observed data (color: Red). It also shows, ratio of volume, flow and depth for data obtained from tipping bucket, method 1 and method 2 against measured data for flow Monitors No. 003, 012 and 253.

VI. RESULTS DISCUSSION

A. Tipping Bucket

It was observed that the simulation graphs for the model using Tipping Bucket rainfall data produce better results for storm event 1 as compared to Method 1. On the other hand simulation graph for storm event 2 shows higher peak, depth and volume due to the error in measurement e.g. flow Monitor FM253 (refer Figure 9), storm event 1 shows the total volume for Tipping Bucket was 10 % more than observed data, while in method 1 it was 78 %. Similarly, peak flow is 1% more in case of the Tipping Bucket while it reduces to 14% for method 1.However for storm event 2, the Tipping Bucket shows 18% more total volume while the method 1 predicted only 6% greater than the observed data. Similarly, the peak depth is 2.54 times more than the observed data in the case of the Tipping Bucket data. It has also been observed that results obtained using Tipping Bucket rainfall data predicted depth and flow, where there is possible error in the measurement of RADAR data. e.g. for storm event 1 the RADAR data was unable to predict the observed results by the flow Monitors FM03 between the time intervals of 07:00 Hrs to 08:50 Hrs on Date 22-06-2008.

B. Method 1

It has been observed that the simulated graph generated from the calibrated RADAR data using Method 1 was unable to reduce the peak depth, flow and volume up to the mark when compared with observed flow Monitor data. e.g. flow Monitor FM012 (refer to Figure 8), storm event 1 shows that the total volume for method 1 was 73 % more than the observed data, while for the tipping bucket, it was 12 % and for method 2 it was 8 %. However storm event 2 shows that the total volume for method 1 was 58 % and in method 2 predicted 47 % more than observed data. Similarly, peak depth is 17 % less than the observed data in case of method 1. It was also noted that due to the application of symmetrical bias factor, the simulation graphs are under-predicting at some places while over-predicting at others when compared with observed flow Monitor data. The accuracy of the revised RADAR data with method 1 can be directly identified from the cumulative intensity vs. time graph between the RADAR and Tipping Bucket data. Figure 10 shows the relationship between the analysis carried out in MS Excel™ and the simulation graph of the model. The solid color at the bottom side of Figure 10 shows the observed data of flow Monitor FM003 while the orange color represents the simulation results which is over-predicting .This over-prediction can be directly identified between the magenta color (Tipping Bucket data) and green color (calibrated RADAR data with method 1) line on the top portion of Figure 10.

C. Method 2

It has been observed that the simulated results generated from the calibrated RADAR data using Method 2 showed good prediction of peak depth, flow and volume as per the criteria specified by WaPUG, when compared to observed flow Monitor data for all storm events. It can also been observed that at some flow Monitors, the simulation results are more accurate than the Tipping Bucket as well as method 1. e.g. flow Monitor FM003 (refer Figure 7), storm event 1 shows that the total volume for method 2 was 4% more than the observed data, while in Tipping Bucket it was 6 % and in method 1 it was 41 %. On the other hand, storm event 2 shows that the total volume for method 2 was 11 % and method 1 predicted 40 % more than observed data. Similarly, peak depth is 4 % more than the observed data in the case of method 2. It can also been observed that at some flow Monitors, the timing of peaks are exactly matching with the time of observed peak when compared with typing bucket results.

A comparison of predicted peak depth, peak flow and total volume obtained by using calibrated RADAR data and Tipping Bucket data was done. It was observed that (e.g.FM0253 – refer Figure 9) for flow Monitors away from the Tipping Bucket raingauges, higher level of accuracy was obtained in calibrated RADAR data. This could be due to the high density of RADAR data over the Tipping Bucket data measured in that part of the catchment.

The accuracy of the revised RADAR data with method 2 can be directly identified from the "cumulative intensity vs. time graph between RADAR and Tipping Bucket data". Figure 10 shows the relationship between the analysis carried out in MS Excel™ and the simulation graph of the model. The solid color at the bottom side of figure shows the observed data of flow Monitor FM003 while the yellow color represent the simulation results obtain from method 2 .The top portion of Figure 10 also shows the calibrated RADAR data from method 2 (color: orange) more or less overlapping with the measured ground data i.e. Tipping Bucket (color : Green).

VII. Conclusion

- It is recommended to check the discrepancies of RADAR data with Tipping Bucket data before it is used for verification of urban drainage models.
- The study also shows that the discrepancies in RADAR data have been minimised by using a calibration factor derived from the RADAR data and rain gauge data in the catchment.
- The simulated results obtained by using method 2 are statistically closer to the observed data as compared to method 1 & tipping bucket.
- The results from the comparisons conclude that calibrated RADAR data (method 2) provides a clear advantage in representing total volume, peak flow and peak depth over other methods for flow monitors which are not near to the rain gauges.
- The study also shows that usage of the calibrated RADAR data (method 2), model predicts more accurate timing of peaks when compared to Tipping Bucket data based on flow monitor data.
- The investigation on RADAR data, its applicability and performance as input to urban drainage models was made on the basis of its comparison to Tipping Bucket data. RADAR rainfall data has a clear advantage in representing spatial variation of rainfall over the catchment.

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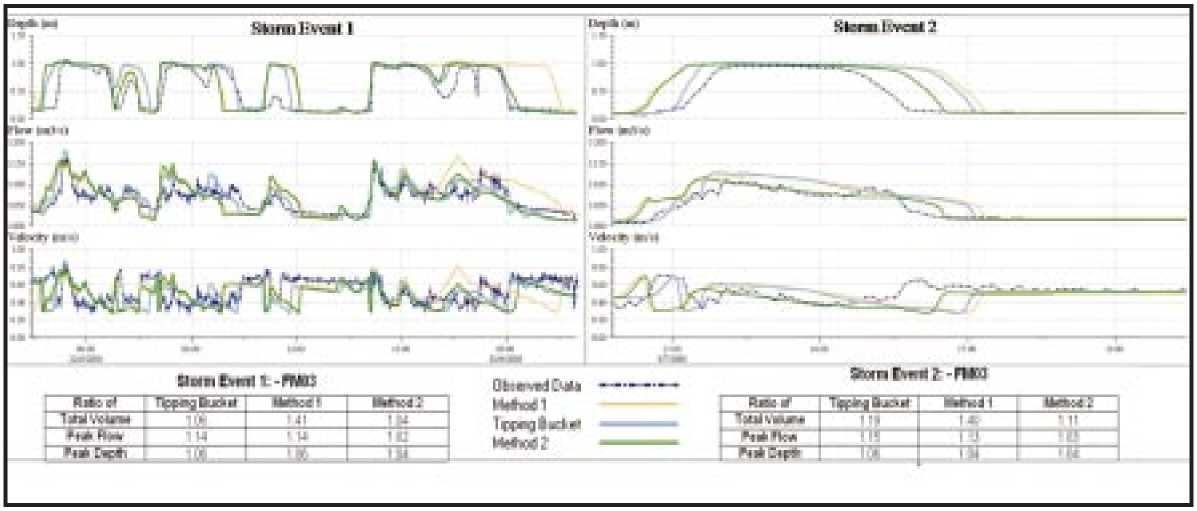

Figure 7 : (FM003)

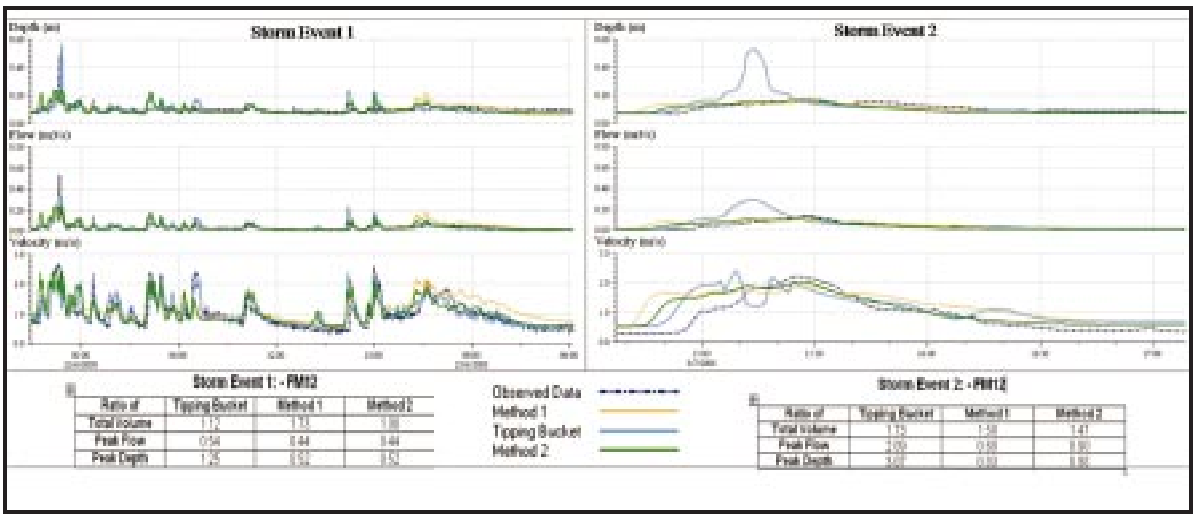

Figure 8 : (FM012)

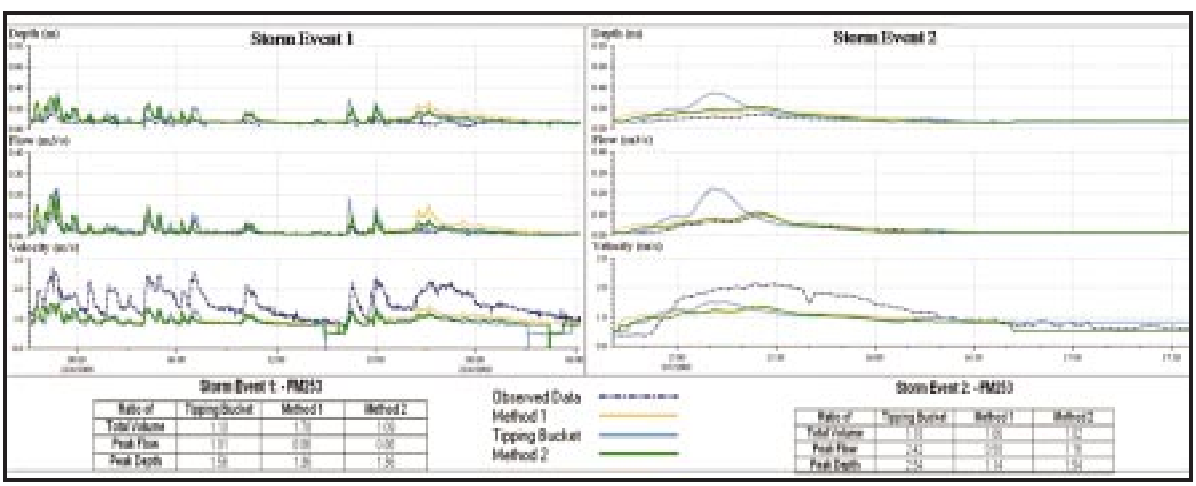

Figure 9 : (FM253)

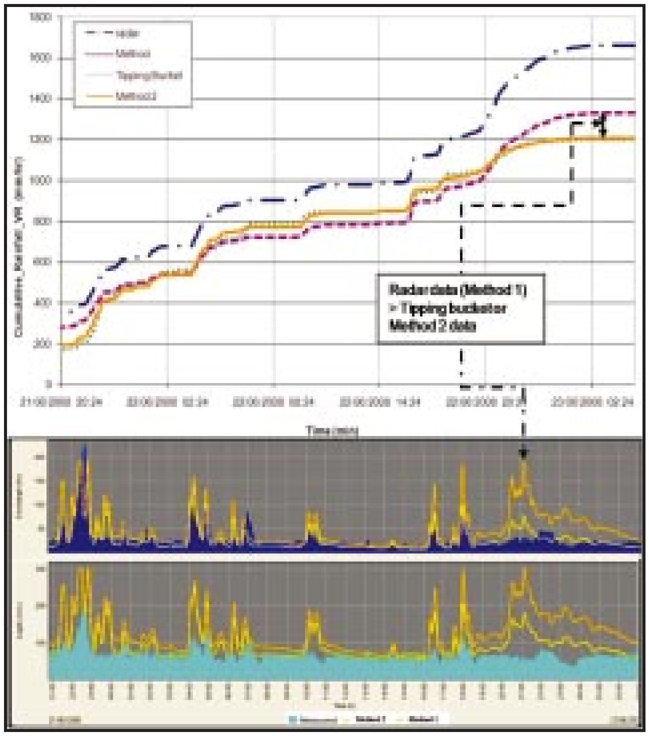

Figure 10 : Shows excel and simulated graph

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