

CARPE DIEM  
CENTRE FOR WATER RESOURCES RESEARCH  
DELIVERABLE 10.3  
ASSESSMENT OF FACTORS AFFECTING FLOOD  
FORECASTING ACCURACY AND RELIABILITY  
DRAFT

by

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# Chapter 1

## Introduction

In Deliverable 10.1, an optimal methodology for combining precipitation information from rain gauges, radar and NWP models (in this case HIRLAM) was described. It was based on an artificial neural network combination model, fitted to historic data, and operating on one-dimensional time-series of discharges. In this report, this new methodology is tested by applying it to (i) a rural catchment (Dargle) and (ii) a small urban catchment (CityWest). The results are compared with measured discharge series in both cases. Various measures of performance, applied to both the entire discharge series and also to the peaks-only, are reported for various combinations of lead-time, spatial resolution and numbers of neurons in the hidden layer of the ANN model.

# Chapter 2

## THE DARGLE CATCHMENT

### 2.1 General

The Dargle is a short river of approximately 15 km length, which, together with a number of tributaries, drains a 122  $km^2$  catchment on the eastern side of the Dublin Mountains. It flows into the Irish Sea through the large town of Bray. Although small, the catchment has great variety. Its elevation varies from close to sea level to over 700 m above sea level, Figure 2.1. Land use comprises urban areas in the lower coastal areas of the catchment, tillage, pasture/sheep farming, forestry and peaty scrubland in the headwater areas. In particular, the catchment can be divided into twelve sub-catchments, each with one of these land-uses predominant, as seen on Table 2.1. This makes it a good catchment for comparative studies of the effects of land use. Because it flows into the sea at a scenic location near a number of beaches there is concern that it may affect bathing water quality, especially just after floods.

Annual rainfall amounts varies with altitude and increases from less than 1000 mm at the coast to over 2000 mm on the peaks towards the western side of the catchment. The Dargle is subject to flash floods that can have peaks of well over  $100m^3/s$ . It has predominantly a gravel or rocky bed. Twelve (12) electronic recording water level recorders have been installed at the outlets of most of the sub-catchments and 4 tilting bucket recording rain gauges within the catchment (see Figure 2.2). One rain gauge is at sea level, one at above 350 m altitude and the remaining two at intermediate altitudes.



Rating curves have been established and are being updated for the water level recorders, by current meter flow gauging, ultrasonic flow measurement and hydraulic computer simulation.

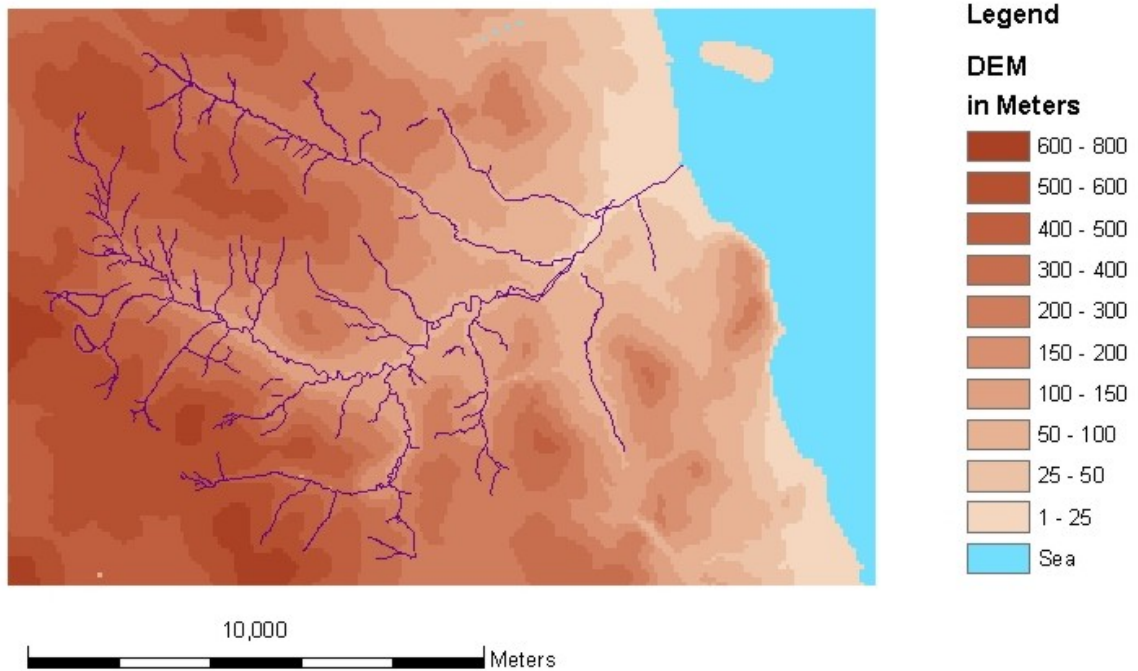


Figure 2.1: Digital elevation model of the Dargle catchment

## 2.2 Rainfall data

Three RainLog tipping-bucket automatic recording rain gauges were installed within the rural part of the catchment, (i) near Djouce Wood, (ii) in Powerscourt Demesne and (iii) at the Stone Quarry in Glencullen valley. A fourth one was installed at the sewage pumping station in Bray (see Figure 2.2). These have a resolution (bucket capacity) of 0.2 mm and record the time (to within a minute) and date of every bucket tip. The sites were chosen to give a distribution covering a range of altitudes, and both north-south and east-west axes within the catchment to establish any spatial variation in the overall rainfall pattern. FORTRAN programs were written to extract rainfall time series for any specified time-interval, e.g. daily, hourly, minutely, etc, from the recorded data. As expected, there is considerable variation in rainfall amounts with altitude, decreasing from west to east. The totals recorded during the period

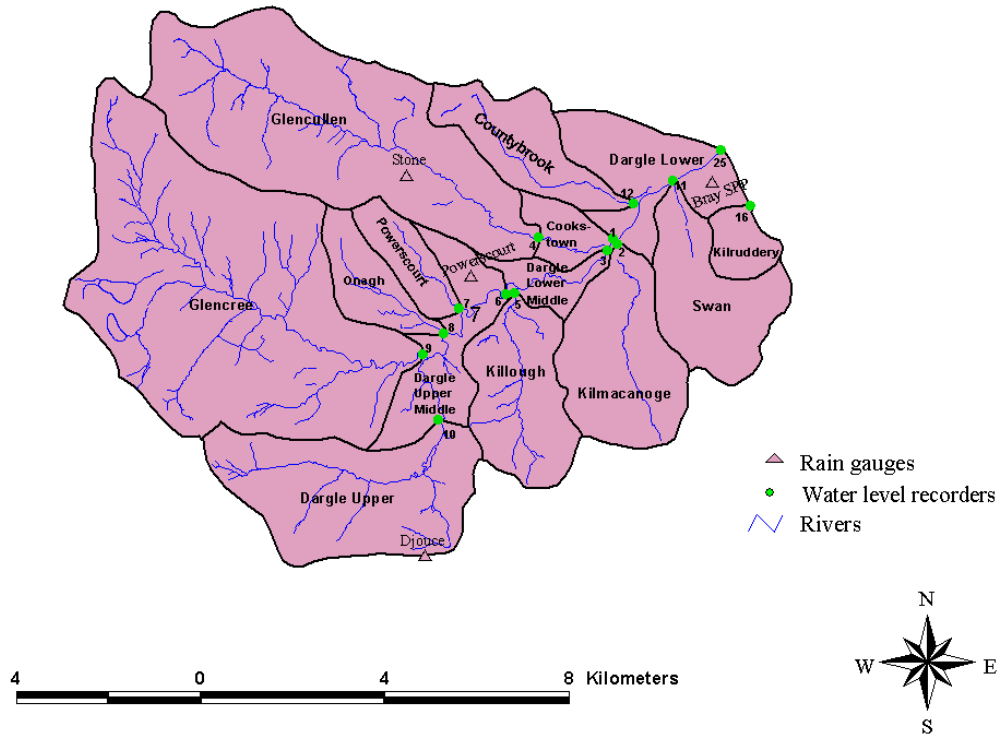


Figure 2.2: Locations of instruments in the Dargle catchment (level recorders locations similar to biological quality points; points 16 and 25 only used for water quality sampling)

22 July 2000 to 13 Nov 2000 were Djouce (618 mm), Stone Quarry (534 mm) and Powerscourt Demesne (515 mm). The correlation of daily rainfall totals between Stone Quarry (Glencullen valley) and Powerscourt Demesne (Dargle valley) was quite close (Figure 2.3). The correlation between the higher Djouce values and the others was still good but with more scatter for the higher rainfall amounts (Figure 2.4).

## 2.3 Water levels and flows

Eleven OTT Thalimedes and one OTT Opthalimedes bubble automatic recording water level recorders were installed in the catchment. In all, 12 different sites are used: see Table 3 and Figure 4. All instruments recorded water levels to a precision of 1 mm and, for the period of study, were set to record the water level every five

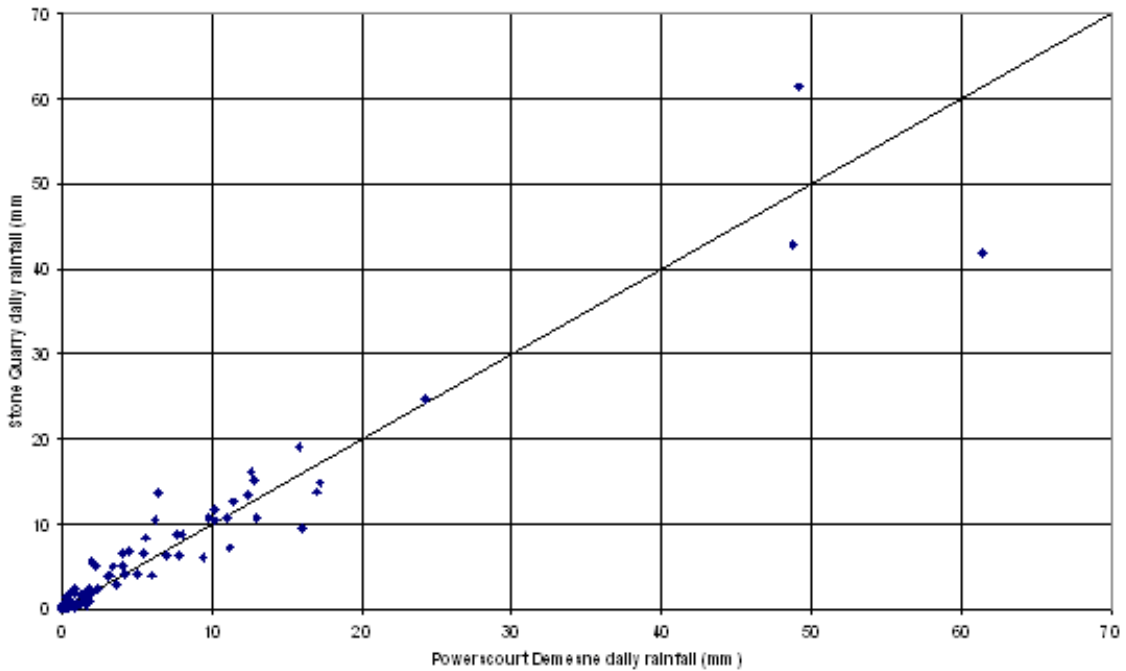


Figure 2.3: Correlation of daily rainfall amounts in middle Dargle catchment (Powerscourt) with middle Glencullen catchment (Stone Quarry).

minutes.

The sites were chosen with a number of objectives in mind. They had to be secure and safely accessible at all times, day or night, during high flows. They also had to offer a reasonable prospect of establishing a rating relationship between water levels and flows, especially high ones. The sites chosen reflect a balance between these objectives. Accessibility and safety requirements often dictated the choice of sites near existing bridges. Accurate measurement of low flows was not a priority and was not feasible within the parameters of this project as it requires the construction of control structures in the channels.

The establishment of rating curves takes many years and requires spot gauging at a wide range of different flows. Such work has begun during this project and will be continued by UCD. For the purposes of this project, preliminary rating relationships were established by surveying the channel in the vicinity of the gauge and for some distance downstream and using a steady-flow computer program (HECRAS) to simulate water levels for different discharges through the reach. This establishes

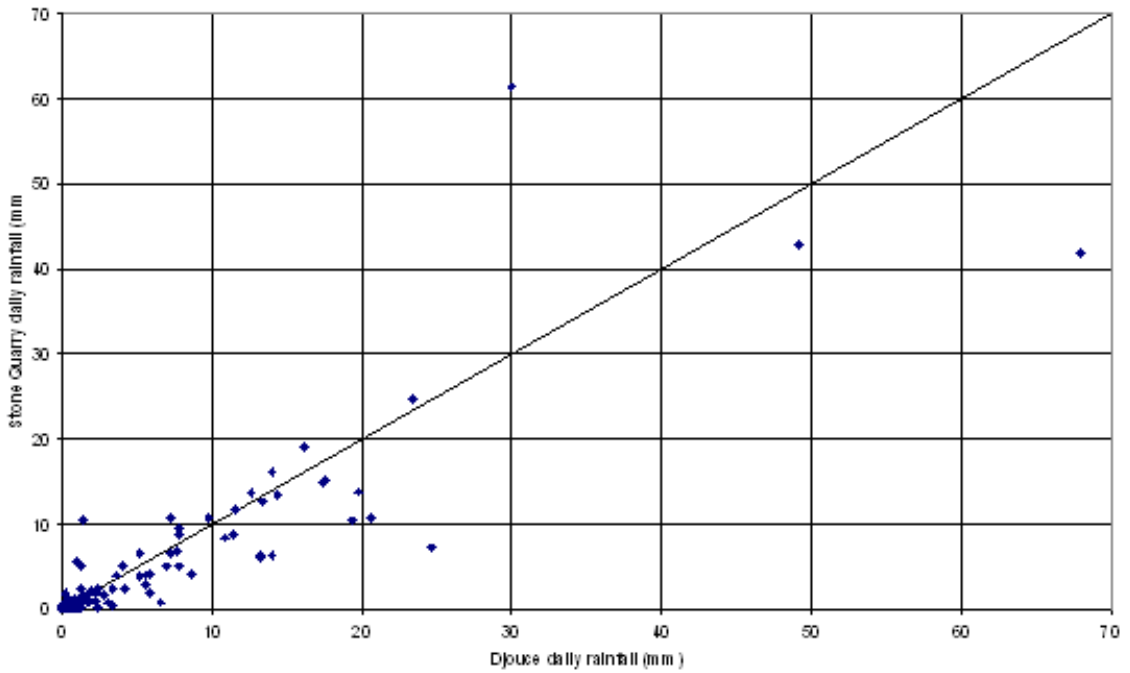


Figure 2.4: Correlation of daily rainfall amounts in high Dargle catchment (Djouce) with middle Glencullen catchment (Stone Quarry).

first estimates of a rating relationship which can be refined as more spot-flow measurements are taken with a current meter for medium-range flows and an ultrasonic time-of-travel device for high flows. The spot-flow measurements taken as part of this study were used to help calibrate the rating relationships. The preliminary rating curves are very sensitive to the choice of Manning's coefficient for the reaches and of the downstream boundary conditions. A number of the gauging sites offered a reasonable expectation of producing critical flow conditions a short distance downstream of the site during high flows, while "uniform" flow sections were assumed at other sites. The gauge on the Kilmacanogue site is just upstream of a culvert entrance that is expected to offer an inlet control during high flows.

Subcatchment	percentage of area under land use						Area ( <i>km</i> <sup>2</sup> )
	Arable	Built-up	Forest	Lake & Rock	Pasture	non-agric veg.	
Waterfall - North	0.00	0.67	29.70	0.00	7.16	62.47	12.95
Onagh (Glencree)	0.07	0.78	29.50	1.23	12.94	55.48	33.87
Onagh Stream	4.92	3.28	33.34	3.99	45.54	8.92	3.34
Powerscourt Stream	24.91	5.49	38.18	0.06	28.77	2.60	2.69
Tinnahinch Bridge	2.41	2.19	30.62	0.94	16.79	47.04	52.85
Killough Bridge	6.35	5.97	5.97	4.40	53.83	23.49	7.27
Dargle at Dublin Road Bridge	3.07	3.23	27.69	1.29	21.41	43.31	60.12
Cookstown River at STP	14.18	10.69	8.96	7.05	50.84	8.28	24.05
Dargle at N11 Bridge	2.85	4.78	25.58	1.29	23.88	41.62	86.17
Kilmacanogue at N11 Bridge	4.19	19.66	8.68	6.05	30.03	31.39	8.74
County Brook (at Dargle)	11.95	11.78	17.38	2.07	48.30	8.52	5.51
Swan at Dargle	16.54	33.57	20.38	1.27	13.60	14.64	7.10
Harbour Mouth	4.37	8.57	23.08	1.68	25.49	36.81	114.15

Table 2.1: Water Level recorder sites (12)

Recorder Site	River	Type of Hydraulic Control for High Flows
Waterfall Bridge	Dargle	Channel
Onagh Bridge	Glencree	Channel
Dudley's Wood	Onagh Stream	Critical flow
Tumble Bay	Powerscourt Stream	Critical flow
Tinnahinch Bridge	Dargle	Channel
Boat Bridge	Killough	Channel
STP	Cookstown/Glencullen	Critical flow*
Dublin Road Bridge	Dargle	Critical flow
N11 Bridge	Dargle	Channel
Church	Kilmacanogue	Culvert entrance
Bray	County Brook	Pool
Bray	Swan River	Channel

*\*This*

*was not obvious from a visual inspection, however it matched the flow gauging and modelling more closely than an equation based on uniform flow.*

# Chapter 3

## Forecasting in the Dargle catchment

### 3.1 25 km resolution

Note that, at 25km resolution, only one HIRLAM grid point is in, or bordering, the Dargle catchment.

#### 3.1.1 ANN combinations with 2 hidden layer neurons

Figure 3.1 shows the variation of mean forecast bias with lead time for the various data sources and their combination. Note that the proposed optimum combination forecast is unbiased, while all the individual forecasts have a negative mean bias, i.e. an overall tendency to under predict the flows. Note also that, of the individual forecasts, HIRLAM has the least mean bias and it doesn't change much with forecast lead time. This is likely to be a consequence of less variation in the HIRLAM forecasts in precipitation (smoothed by the hydrological model SMAR). Note the bias in the radar and raingauge based forecasts worsens with forecast lead time.

Figure 3.1 shows the variation of the variance of the forecast residuals with lead time for the various data sources and their combination. Note that the optimal neural network combination is better (lower residual variance) than any of the individual forecasts. The forecast steadily worsens after the lead time of 12 hours.

If we ignore the overall performance and concentrate on how the method does at forecasting the peaks, a somewhat different picture emerges. Figure 3.3 shows the

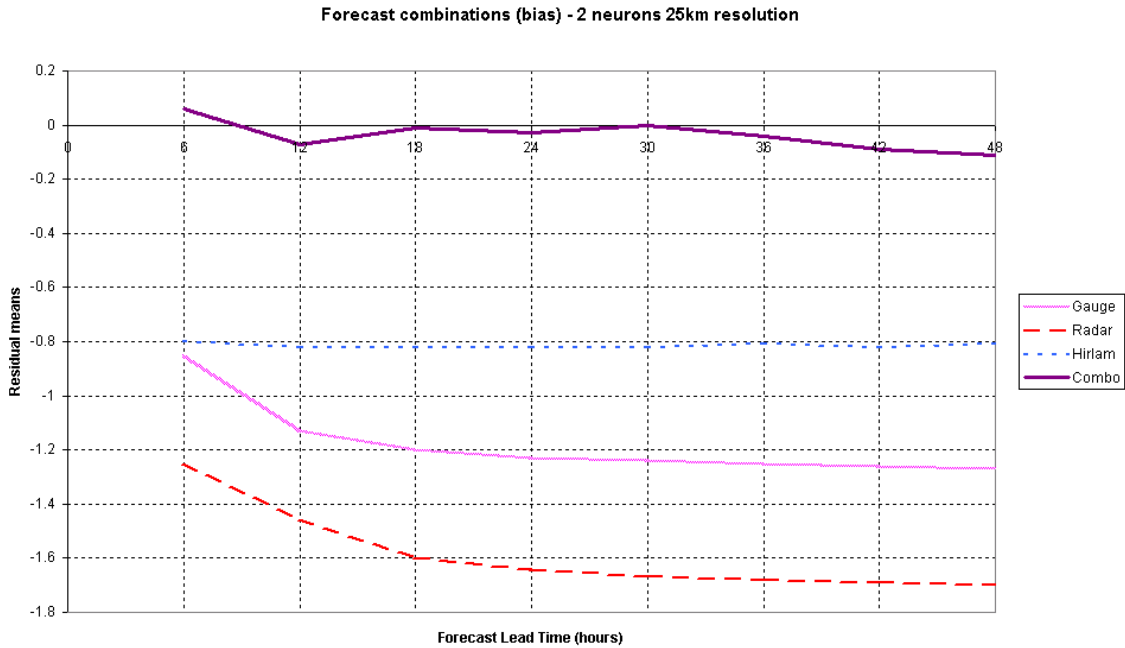


Figure 3.1: Mean Forecast bias vs lead time for 2 neuron model 25km resolution

mean bias (over the peak values only). In this case the mean bias, for all method, worsens rapidly as lead time increases up to approx. 20 hours and is relatively constant for longer leads. The optimal combination methods has the least bias up to a lead time of 20 hours and thereafter is comparable with HIRLAM, which is better than either the raingauge or radar results.

### 3.1.2 ANN combinations with 3 hidden layer neurons

The corresponding results for a more complicated neural network model, with 3 hidden neurons, were similar. Figure 3.4 shows the variation of mean forecast bias with lead time for the various data sources and their combination. Note that the proposed optimum combination forecast is unbiased, while all the individual forecasts have a negative mean bias, i.e. an overall tendency to under predict the flows. Note also that, of the individual forecasts, HIRLAM has the least mean bias and it doesnt change much with forecast lead time. This is likely to be a consequence of less variation in the HIRLAM forecasts in precipitation (smoothed by the hydrological model SMAR). Note the bias in the radar and raingauge based forecasts worsens with forecast lead



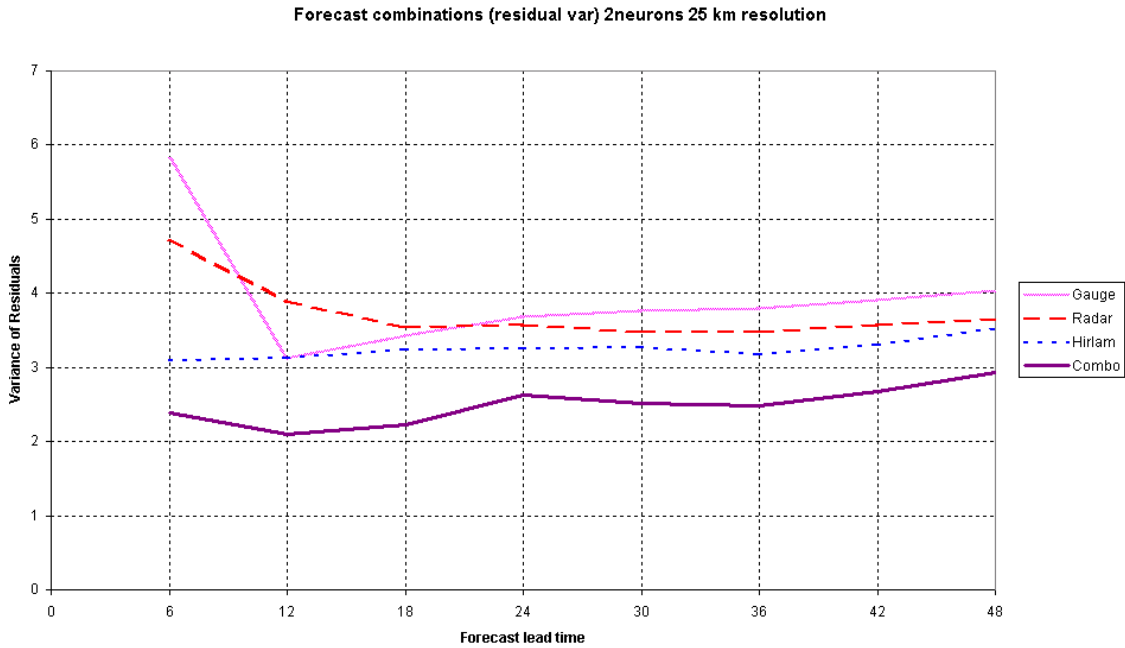


Figure 3.2: Mean Forecast residual variance vs lead time for 2 neuron model 25km resolution

time.

Figure 3.4 shows the variation of the variance of the forecast residuals with lead time for the various data sources and their combination. Note that the optimal neural network combination is better (lower residual variance) than any of the individual forecasts. The forecast steadily worsens after the lead time of 12 hours.

If we ignore the overall performance and concentrate on how the method does at forecasting the peaks, a somewhat different picture emerges. Figure 3.6 shows the mean bias (over the peak values only). In this case the mean bias, for all method, worsens rapidly as lead time increases up to approx. 20 hours and is relatively constant for longer leads. The optimal combination methods has the least bias up to a lead time of 20 hours and thereafter is comparable with HIRLAM, which is better than either the raingauge or radar results.

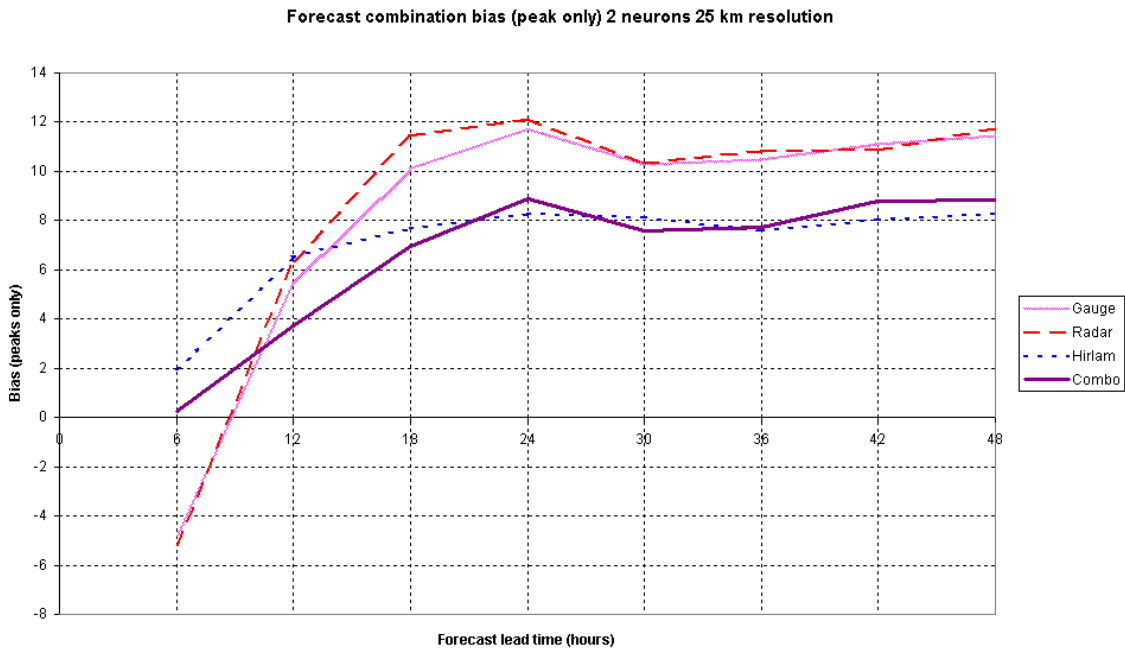


Figure 3.3: Mean Forecast peak-only bias vs lead time for 2 neuron model 25km resolution

## 3.2 15 km resolution

An analogous series of tests were done with the HIRLAM 15 km resolution output. There were 6 HIRLAM grid points either in or adjacent to the catchment. Because of the higher resolution and greatly increased computation time, the HIRLAM forecasts were made up to a lead time of 18 hours only. In general, similar trends were observed in that the optimum combination was better than forecasts based on any individual precipitation data source. Of interest is a direct comparison between the 25 km and 15 km resolution runs, Figure 3.7. Note that the combination using the higher resolution HIRLAM model is uniformly better than the combination with the coarser HIRLAM output. While generally expected, these results should be treated as indicative only as they use data series taken within the 3 year project period. Ideally, tests and comparisons should be done over a much longer data record, to increase the confidence in the results.

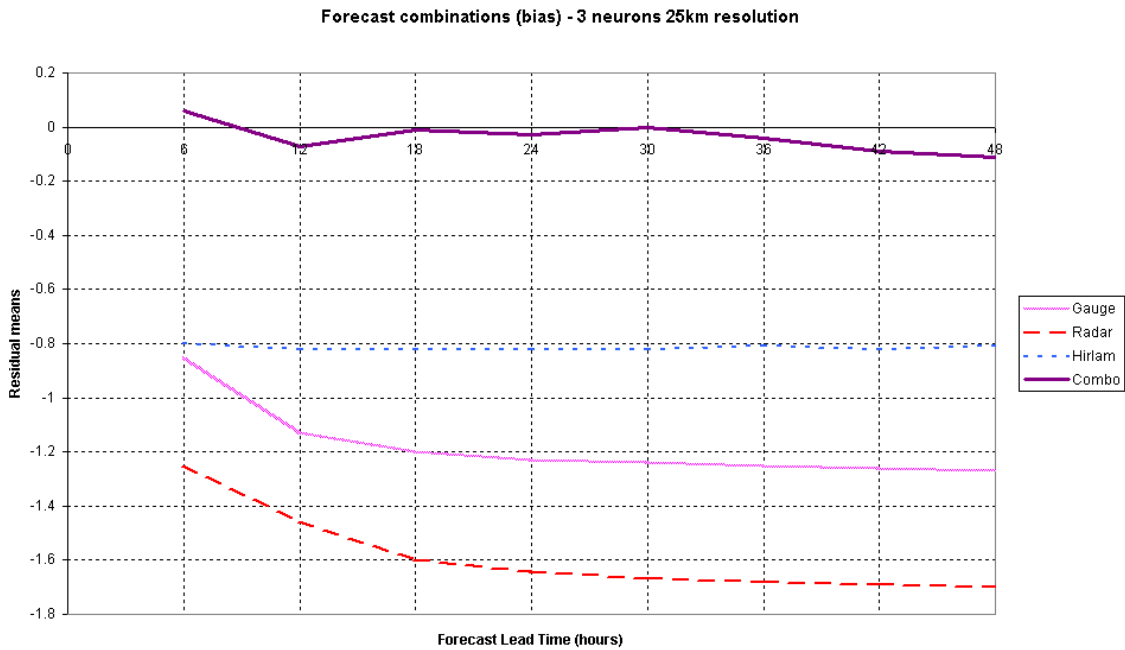


Figure 3.4: Mean Forecast bias vs lead time for 3 neuron model 25km resolution

### 3.3 5 km resolution

Given the success of the 15 km resolution model, we tested the 5 km HIRLAM model. In this case the higher resolution and increased computer time involved required us to analysis only predictions for individual storm events, not the entire record. An initial correlation between forecast precipitation amounts for all grid points in or adjacent to the catchment showed a high degree of scatter, such that the range of precipitation totals exceeded the mean. No correlation was apparent between adjacent points, nor with topography (altitude). The conclusion is that the patterns individual values are not physically realistic/representative and should not be used as input a forecasting model. This may thus be the forecasting resolution limit with the HIRLAM model. It is an hydrostatic model and it may be that, in future, when a non-hydrostatic version is produced, improved precipitation patterns and values will be produced.

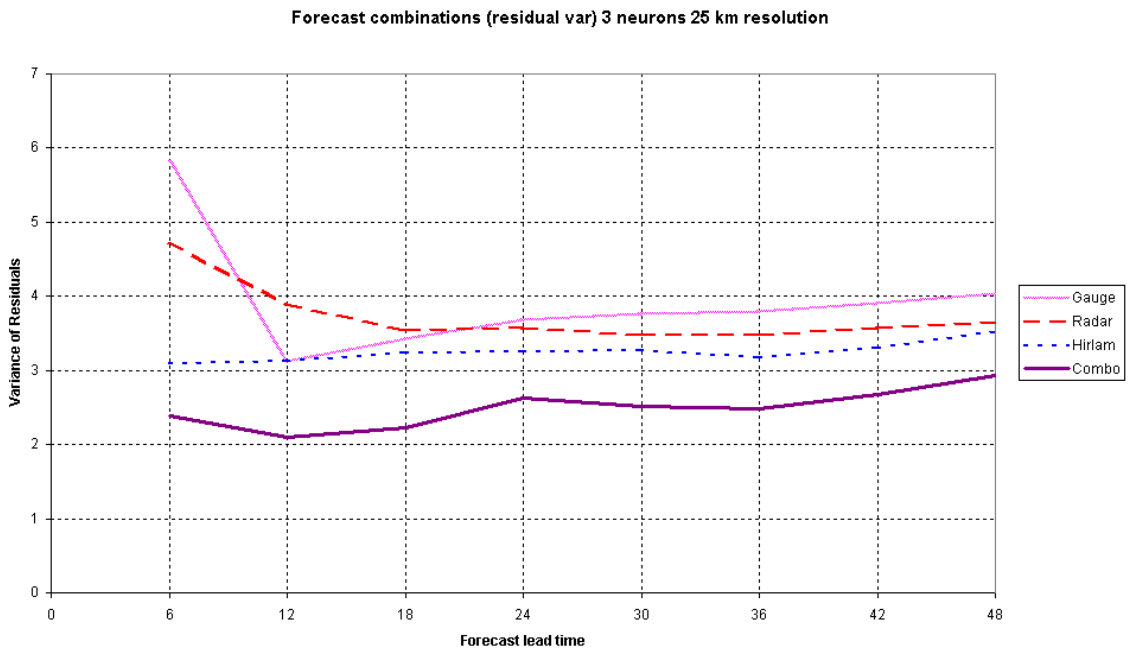


Figure 3.5: Mean Forecast residual variance vs lead time for 3 neuron model 25km resolution

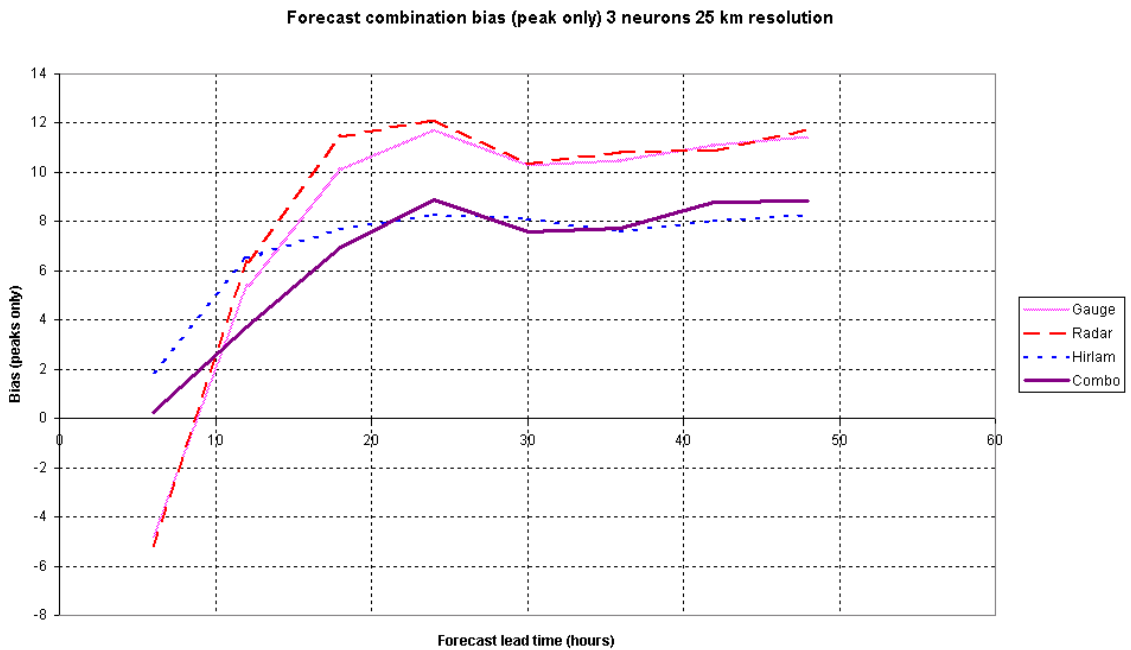


Figure 3.6: Mean Forecast peak-only bias vs lead time for 2 neuron model 25km resolution

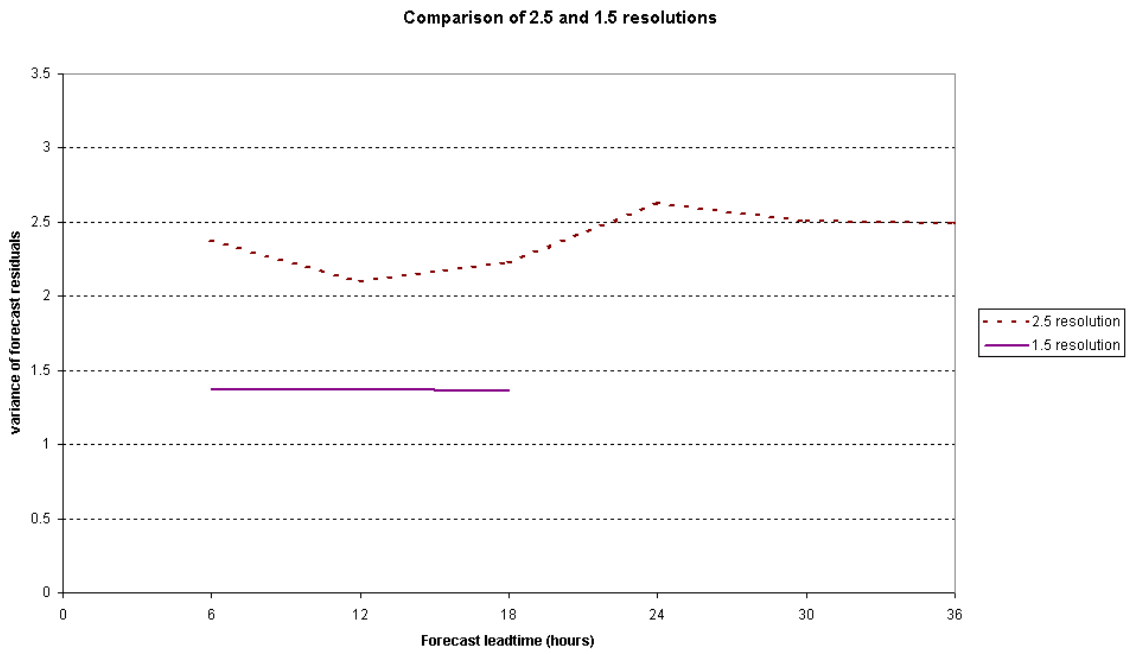


Figure 3.7: Comparison of combination forecasts with 2.5 and 1.5 degree resolution HIRLAM

# Chapter 4

## Urban catchment, Citywest

### 4.1 Catchment description

The study catchment, Citywest development, is a small rapidly urbanising catchment located in the Southwest of Dublin City, Ireland, Figure 3.1. As a new development, the land-use of the catchment is currently a mixture of a newly constructed business campus including the National Digital Park, residential areas, car-parking, roads, and large areas of farmland awaiting new plans, as well as a centre lake, a cascade of attenuation ponds, and both underground pipes and above ground open channels for drainage. The catchment is approximately 25.4% urbanised at present. This rate is expected to increase due to the ongoing construction throughout the catchment.

The catchment has an area of 183ha. It is approximately 1.8km long in the south-north direction, and 1km wide in east-west direction. The elevation varies from approximately 145m (O.D) in the south to about 95m (O.D) in the north, with an average slope of 2.6%. An open channel runs through the centre of Citywest development. At the very far northern end, the channel drains into the Camac River. Due to the effect of the Dublin Mountains at the Southwest of the catchment, the catchment has a quick response to rainfall and can produce flash floods. The remainder of the study area is at the west-side of Citywest development, where a small river, Brownsbarn, serves a large rural area and drains to the N7 road site at Citywest. The Citywest catchment and flow monitoring sites are shown in Figure 4.1. Figure 4.2 shows the Citywest ground surface elevations.

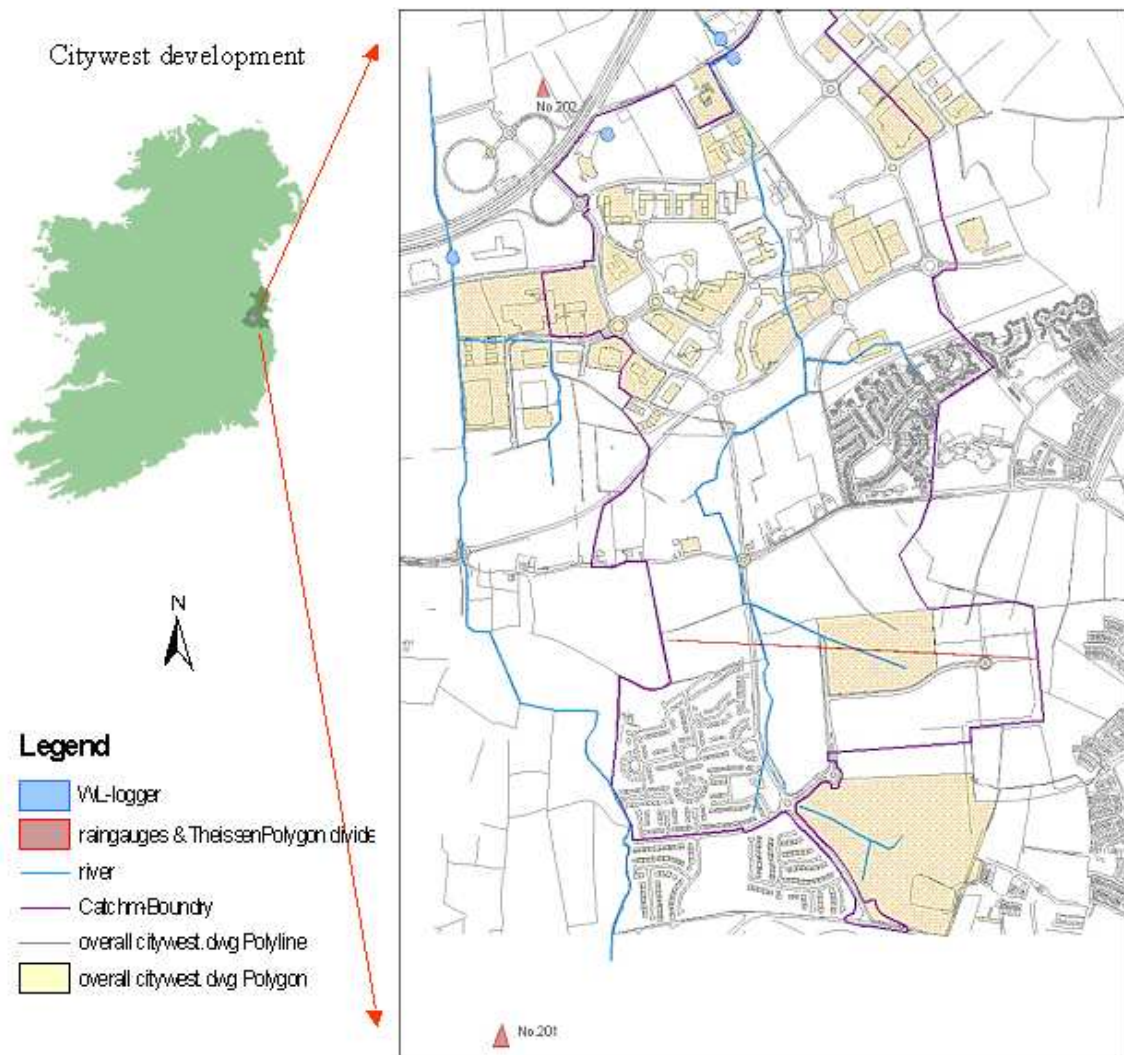


Figure 4.1: Citywest development and flow monitoring sites

## 4.2 The existing Citywest stormwater drainage system

In 1999, Dublin Corporation implemented a new stormwater management policy (Dublin Corporation, 1999) based on a review of current regulatory practice in Europe and North America. The new policy aims to minimise the flood impact in urban areas, and a separate surface water drainage system is required for all new developments in order to provide sufficient drainage. All surface water from the development area must be controlled by means of Best Management Practices (BMPs), e.g., attenuation and retention ponds, so that the peak flow from the developed area will not exceed

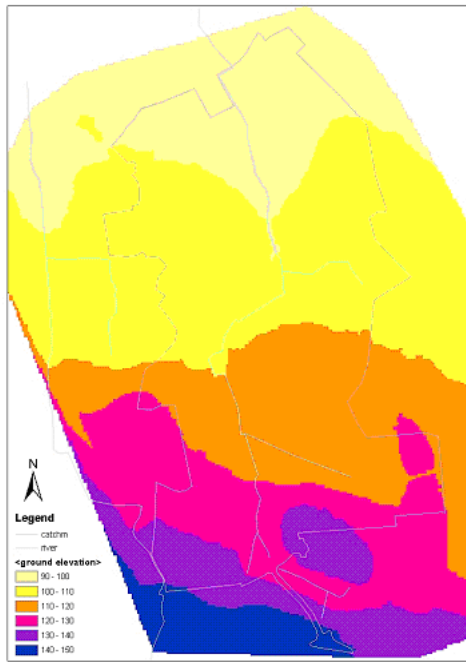


Figure 4.2: Citywest topology

that of the original undeveloped lands. The intention is that new developments will thus pose no flooding threat to the downstream areas.

As a result of this policy, Citywest development has separate surface stormwater and sewage drainage systems. The surface drainage system collects the drainage from paved areas such as residential areas, business campus, and roads. These are mainly the pipe-based systems that drain to the open channel. The open channel was artificially improved, and new weirs and culverts were constructed in connection with the pipes. The cascade wet ponds were constructed and connected to the center existing lake in the business park. The ponds provide attenuation as well as being a pleasant landscape feature. Being a new developing area, there still remains large area of farmland inside the catchment, and much of this will eventually be developed.

The surface drainage system is composed of a number of individual networks, each draining to the open channel with its own outlet. The southern part of the catchment is a residential area, while the business campus is in the north. The wet ponds are cascaded and located in the northern catchment within the business campus. There is a large amount of pervious area in the central part of the catchment. The individual



networks are connected by the open channel which outfalls at Kingswood Bridge in the north where the flow leaves the Citywest property. The whole drainage system therefore comprises both the underground pipe networks and the aboveground open channels. The existing surface stormwater drainage system is shown in Figure 4.3

### **4.3 The monitoring system and database**

The Citywest data monitoring system, which was installed for this study, collects rainfall, flow and water quality variables. Three rain-gauges and four water-level loggers are installed in the catchment. In order to provide sufficient information for analysis, both rainfall and water level data are recorded at one-minute time steps. The recorded data can be converted into time series for selected time increments, e.g. every minute, hourly or daily. The water quality samples are collected manually at selected sites and analysed in the laboratory, and are reported in chapter 10. The radar rain data is also used for the study, and is discussed in chapter 9. All the monitoring raw data and the generated new series are collected and stored in PC forming a database for the Citywest development.

#### **4.3.1 Rain-gauges**

The rain-gauges are of the tipping-bucket type (resolution 0.2mm) with an integral logger. Tipping bucket pluviometers are widely used to monitor the temporal pattern and the magnitude of storm events. Since this type of pluviometer records the time at each tip of the bucket, it gives a good representation of the temporal distribution of rainfall. Furthermore, battery power and memory space are efficiently utilised, since no recordings are taken during dry-weather periods (Maheepala et al., 2001). The date and time of each tip, which corresponds to its resolution of 0.2mm of rain, are recorded to the nearest minute. The raw event-based data are downloaded to a portable PC and processed by specific software to produce rainfall time-series at required time intervals.

The rain-gauge locations were chosen to provide information on rainfall both in

the Citywest area itself and in the higher catchment, which drains through it. This choice of locations also provides measurements of rainfall at different altitudes along the north flank of the Dublin Mountains, which drains through Citywest. The highest rain-gauge (310m, O.D) is on the Mountain along the Mount Seskin Road outside the catchment. The next is near the Blessington road outside the catchment, closing to the southernmost part of the main Citywest area, Figure 3.4a. The third is the lowest and most northerly of the rain-gauges near the N7 road inside the catchment, Figure 3.4b. Table 4.1 lists the sites of three rain gauges across the Citywest development. The number of rain-gauges and their siting were chosen to characterise rainfall in the Citywest area and to identify any spatial variation in the rainfall which might affect flood design calculations. The steep slope and proximity of the Dublin Mountains were expected to affect the rainfall distribution.

Table 4.1: Citywest rain-gauge locations

Gauge Location	Gauge ID. No	Elevation(m, O.D)	Main characteristic
Mount Seskin Road (stables)	203	310	0.2mm tipping-bucket
Blesington Road	201	150	0.2mm tipping-bucket
N7 (near Citywest Bridge )	202	100	0.2mm tipping-bucket

### 4.3.2 Water level loggers

Sites for stilling wells for four water-level recorders were selected. Four OTT thalimedes water-level recorders were installed

1. on both sides of bridge at Kingswood where flow leaves the Citywest property,
2. at the downstream outlet of the attenuation ponds,
3. at the entrance to culvert under N7 road site where an upstream rural area (Brownsbarn stream) drains through the N7 road site.

The Ott Thalimedes is a float-operated shaft encoder with a data logger, used to continuously measure water levels. The unit is mounted in a 6inch vertical steel

pipe. It has a resolution of 1mm and a maximum measuring error of 2mm. The data storage time-intervals may be pre-set to suit the hydrological system and the study objectives. The stored values may be read by a portable computer with either an infra-red or RS-232 interface. The HYDRAS3 software, loaded on a PC, facilitates the display, tabulation and management of the data.

### **4.3.3 Data analysis for the Citywest development**

Both rainfall and water level data recorded in-situ are analysed to provide an overview of the hydrologic situation on the Citywest development. Before analysis, the recorded data are examined for possible errors and the gross errors are corrected where possible. If the gross-error cannot be corrected then the data for that period is discarded. The analysis is then carried out and comparison between different sites is made to provide spatial and temporal vision of the catchment.

However, due to occasional problems such as battery failure, the clogging of the gauges, etc, the record at each site was interrupted at different periods. Therefore, the analysis is made only for the data recorded at compatible time period for all sites. The data record availability for the gauges is shown in Figure ??.

### **4.3.4 Analysis of the rainfall data recorded**

The total amount of rainfall recorded for their compatible time periods (20 months) by each gauge is shown in Table 3.2. Clearly, there is a striking difference of the total rainfall for the gauge near the N7 Dual Carriageway (Gauge202) which is much lower than the other two gauges, i.e., gauge 201 at Blessington road site, and gauge 203 at the Mount Seskin road site, for all the record periods. This may not be explained entirely by the difference in altitude. The effect of Dublin mountains on the quantity, direction, and shape of storms, particularly for short duration storms cannot be neglected. The site of gauge 202 at the north side of the Citywest property shows that the total rainfall is 24.0% (419.0 mm) lower than gauge 203 on Dublin mountains, and is about 18.6% (303.0 mm) lower than the gauge 201 at the south

side of Citywest.

Table 4.2: Summary of total rainfall amount recorded at different periods

Site	Gauge ele.(m, O.D)	Total rainfall (mm)
Mount Seskin Road (stables)-203	558.8	1749.0
Blessington-201	150	1633.0
N7 Dual.C-202	100	1330.0

The difference in total amount of rainfall recorded between gauge 203 and gauge 201 is about 6.6% for the whole record period. The difference between these two rain-gauges is 116.0 mm for an altitude change of approximately 160 m. The discrepancy in rainfall between these two sites is small compared to the difference of their attitudes. This is in contrast with the difference between the gauge 202 and gauge 203 of an increase in 419.0mm for an altitude increase of 50m.

Close examination for the data recorded between gauges show that their patterns are consistent throughout the record despite the differences in absolute values. That is, a heavy storm recorded at one rain-gauge will always be recorded at the others although the recorded amount may vary temporally. Cumulative curves of the rainfall record show that this difference in rainfall is consistent throughout the periods of record.

The north part of the catchment receives less rainfall than the south part. Thus, the analysis from the recorded data suggests a consistent pattern of significant spatial variation of rainfall severity across the Citywest area, which has important consequences for the design of appropriate storm water management systems. This north-south gradient in rainfall across the Citywest area has a number of important implications, particularly for the areas that are still waiting for construction. For example, if the more northerly parts of the campus receive less rainfall than expected when designed, thus may have spare capacity in their stormwater drainage and attenuation systems to accommodate the possible future increased runoff from sites developed in future. On the other hand, if the southerly parts of the site were to receive more

rainfall than expected then, as this would impede drainage in the northerly part of the campus, it would eventually cause flooding problems there. Therefore the design of drainage in areas developed in future should take account of this information.

### **4.3.5 Analysis of the water level data recorded**

As a main part of the Citywest monitoring system, the water levels are recorded at the selected key outlets of the drainage systems. The recorder at the attenuation pond outlet monitors the flow changes from the ponds. Because of their functioning as the wet ponds, the water level at this site varied relatively slowly, within a range of 0.2m (maximum value 0.624m on 29/12/02, and minimum value 0.431m on 30/5/03), despite some severe rainfall events. The recorder at the N7 road site monitors the flow regime of the stream Brownbarn. The Kingswood Bridge has water level recorders on its upstream and downstream sides. Two recorders were thought necessary because a stable hydraulic control could not be guaranteed at this location (which is where the stream leaves Citywest property), and the analysis is then focused on this site.

## **4.4 Catchment lag-time**

Catchment parameters such as lag time and time of concentration are important information for hydrological modelling and forecasting. These parameters are related to physical features of the watershed such as drainage area, channel length and channel slope. An estimated watershed lag time is useful for the choice of suitable time increment in stormwater drainage system modelling. Lag time is related to the speed of travel of the flood wave. In flood hydrology, the lag time of a catchment are sometimes considered as constant, independent of the magnitude of the flood (NOAA, 2003). In practice, in urbanising areas, the catchment lag time varies with the period and magnitude of the storms.

Lag time ( $T_{lag}$ ) has been defined in several different ways. A common definition for lag time is the time difference from the centroid of the net rainfall to the centroid of the direct-runoff hydrograph (McEnroe and Zhao, 1999). Another definition used

by SCS (1972) is the time difference from the centroid of the net rainfall to the peak discharge at the watershed outlet.

Catchment lag time can be estimated directly using rainfall and runoff data. However, many streams may be ungauged at the time of modelling. In practice, the lag time of an ungauged stream is estimated from physical characteristics of the catchment. There are several formulas available for the lag time estimation, each has limited range of application. A commonly used formula developed by the U.S. Soil Conservation Service (SCS) estimates the lag time directly using an empirical approach. The SCS lag equation (SCS, 1972) is given as:

$$T_{lag} = 0.0057 * \left( \frac{100}{CN} - 9 \right)^{0.7} * \frac{L^{0.8}}{\sqrt{S}} \quad (4.1)$$

(3.4)

where :  $T_{lag}$  = lag time in hours L = Length of the longest drainage path in kilometers S = the average watershed slope in m/m CN = the SCS curve number (here taken as 86 for developing urban area)

The runoff curve number depends on the soil type, surface cover and antecedent moisture conditions. The formula was developed from rainfall and stream flow data from agricultural catchments in the USA.

Nash (1958, 1959) suggested the use of the statistical moments of the Instantaneous Unit Hydrograph (IUH) to determine the parameters of the unit hydrograph where the first moment is equal to the lag of the IUH . Nash (1960), Dooge (1973) demonstrated that the lag of the output of a system is equal to the lag of the input plus the lag of the impulse response, expressed as their first moment

The Citywest catchment is an urbanising catchment containing both pervious and impervious areas. The response to long duration rainfall is usually dominated by the pervious areas of the catchment which may give longer lag times than that of short storms which are mostly dominated by the impervious areas. Since urban drainage systems usually have quick response to impervious area during a storm, to estimate

the lag time using recorded storm data, it is necessary to distinguish between the short and long period storms. Therefore, the available storms are tentatively divided into the short period thunderstorms (with apparent single peak) of duration less than 5hours and the long period storms (more likely winter storms) of duration greater than 5hours. Results estimated using the method of moments are shown in Table 3.4.

Table 4.3: Lag time estimation using the method of moments

Item	Event	Rain duration(hrs)	Lag (minutes)	Standard deviation
Minimum lag-time	E030922	2.7	24.5	—
Maximum lag-time	E021229	17.0	186.5	—
Averages short storms	7 storms	3.2	39.7	12.9
Averages long storms	8 storms	7.8	120.2	35.0

The result provides useful information on the overall catchment response from different storm events. Examination of the result shows that, the difference between shortest and longest time lags of the assessed storm events is large. However, this discrepancy is consistent with the difference of the average lag time from short and long period storms. Results also indicate that the long period storms and short period thunderstorms are likely dominated by different response mechanisms of the catchment.

While, in applying the SCS method to Citywest development, according to Rawls et al. (1993), the hydrologic condition and cover type is the "developing urban area" and is of the soil group B, the SCS Curve number CN=86. The catchment length is approximately 1.8Km, and the average slope is 2.6%. When used in the above equation 3.4, the lag time can then be estimated Tlag=40.0 minutes. This value is much comparable to the above estimation from the short period storms (39.7 minutes) using the method of moments.

Naturally since 39.7 minutes is from measured storms, and the quick response from urban areas is the most concern for a drainage system, this value is thus used as the approximate lag time of the Citywest catchment.

## 4.5 Discussion

The data monitoring system and data collection is an important part of the overall modelling strategy (WaPUG (W01), 1998). High quality rainfall-runoff data is essential for river impact modelling at all times, but particularly for a small catchment with fast response time. However, there will be always unavoidable uncertainties involved in the field monitoring system. For example, it is very frequent that flow rates in sewer systems are known with an error of 50 to 100%, because even the minimum amount of calibrations and verifications are not carried out, and because inappropriate sensors are used in inadequate measurement locations (Bertrand-Krajewski et al., 2000). It is also possible that bias in the gauging data, due to the changes in equipment-performance with time, will have significant effect on the conclusions drawn from that data (Whalley et al., 2001). In this study, a number of rainfall-runoff events were recorded at the Citywest catchment, but some were also missed because of the recorder problems or discarded because of poor data quality. Rainfall events used in this analysis are those believed to be reliable and to allow the correct reproduction of hydrographs. For these storm events, there are simultaneous rainfall and discharge measurements at each site. The available data patterns, particularly those of moderate to heavy storms are important in the modelling tests for the study.



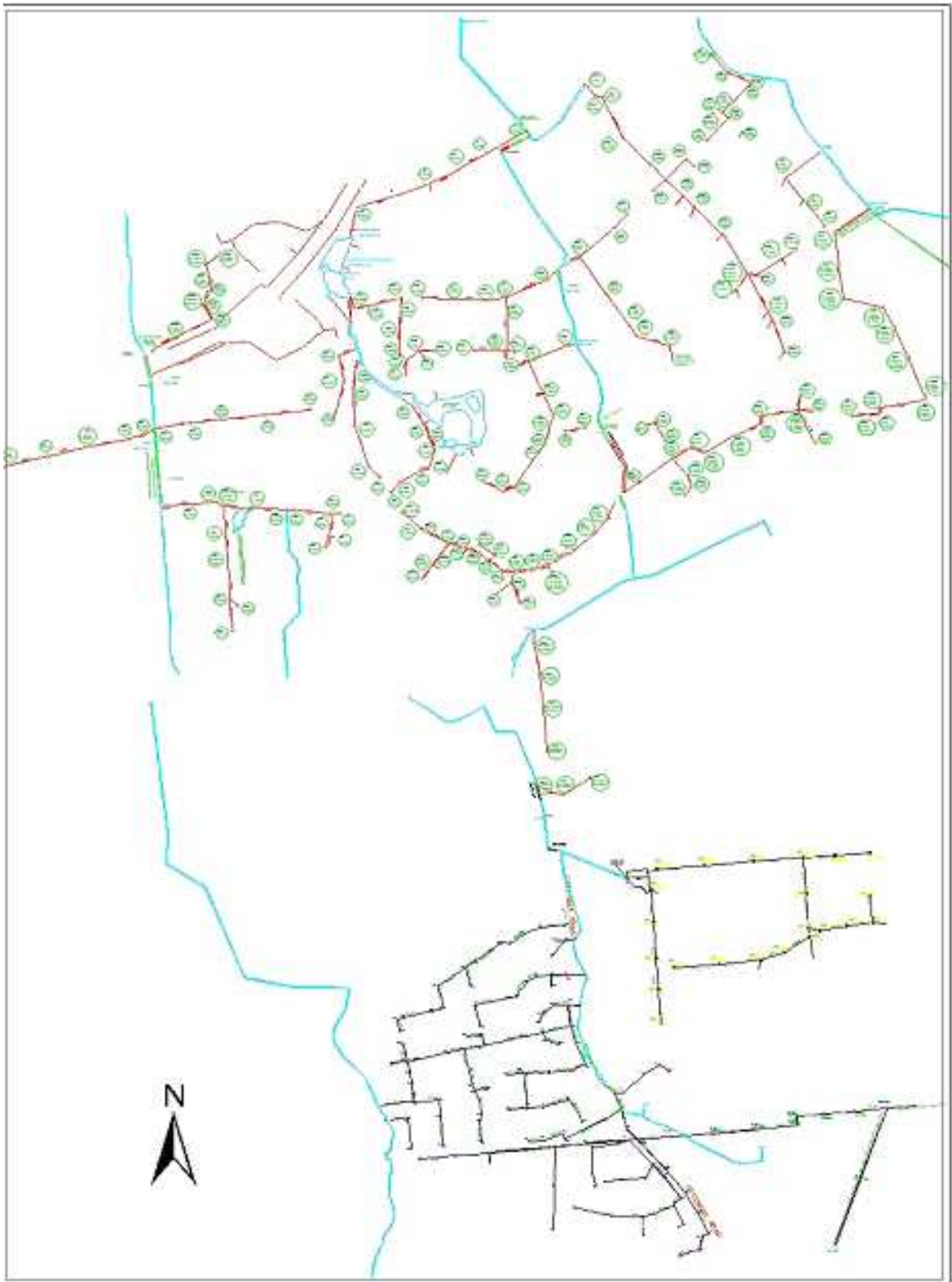


Figure 4.3: Citywest surface water drainage system

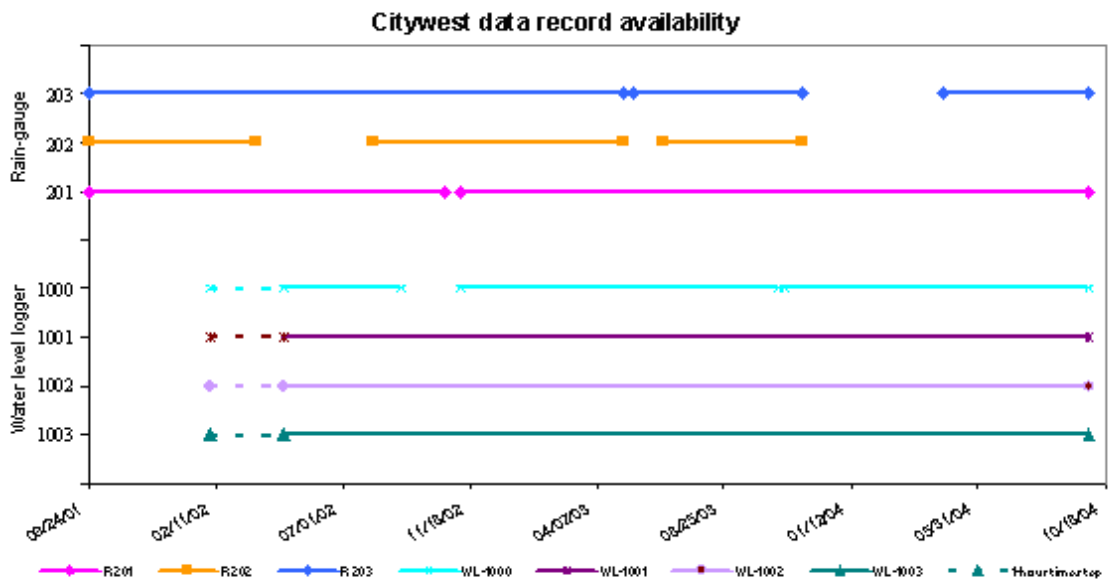


Figure 4.4: Data record availability at Citywest development

# Chapter 5

## Forecasting in the Urban, CityWest, catchment

### 5.1 Introduction

Radar rainfall data have good spatial coverage, but contain many and complex sources of error when compared with rain-gauge data. To make use of radar data for mathematical modelling, the radar estimations of the on-ground rainfall rate are usually obtained by an empirical relationship between the radar reflectivity,  $Z$ , and actual rainfall rate  $R$ . A commonly used conversion equation is of the exponential type , where constants , , are the most widely accepted values. The accuracy of estimates based on the  $Z$ - $R$  relationship is highly affected by measurement errors in the reflectivity values, propagation clutter, and uncertainties in the translation of reflectivity values. Alberoni et al. (2003) provided an up-to-date overview of processing techniques and limitations of the radar data. The abilities and limitations of the weather radar operation are well described in the literature (e.g. Serafin and Wilson, 2000).

Radar is a widely used tool, and becomes an important source of precipitation information in the countries like UK. Weather radar data measures the reflectivity, from which one can estimate atmospheric variables like vertically integrated liquid (VIL) water content close to surface layers (Rogers and Yau, 1989). Golding (2000) demonstrated the quality of the radar processing analysed by Driscoll (1998), and the probability of detection of precipitation as a function of the range, which confirmed the capability of radar in observing moderate to high precipitation rates and for flood

prediction, at ranges up to about 100km. Radar and rain gauge are complementary in providing the rainfall information. In contrast to the good spatial coverage as well as the poor estimation accuracy of the radar rain data, rain gauge measures rainfall at specific location representing the on-ground values at that point. Rain gauges can generally provide high quality point measurements of significant rainfall amounts. However, the major problem of rain-gauge networks is the lack of provision of sufficient density of spatial distribution.

The impacts of the spatial and temporal resolution of rainfall data on the performance of meteorological and hydrologic modelling have been studied in the last years. For example, Woolhiser et al. (1996) demonstrated the effects of spatial variability of saturated hydraulic conductivity on Hortonian overland flow. The study showed the sensitivity of runoff models to the factors such as spatial variability of rainfall and interaction of infiltration are dependent on the magnitude of the runoff event, with less sensitivity being exhibited for large events. Johann and Verworn (1997) investigated the influence of various time/space resolutions of radar rainfall data with hydrodynamic model for a small urban catchment. Results show that the rainfall runoff simulation is very sensitive to the resolution of the input data. The effects of radar precipitation data with various time/space resolutions on rainfall runoff models are dependent on the characteristic of the catchment studied and the structure of the considered rain event. The lowest discretisation level provides small precipitation errors. Koren et al. (2004) combined physically-based and conceptual features into a hydrology laboratory research modelling system (HL-RMS) in flow forecasting where high-resolution (1km and 4km grid cell) radar-based precipitation data over a large region were used. Study shows that HL-RMS is comparable to well-calibrated lumped model in several headwater basins, and it outperforms a lumped model in basins where spatial rainfall variability effects are significant. Morena et al. (2002) studied the influence of spatial rainfall variability on the hydrological behaviour of urban basins based on weather radar data. They proposed a preliminary approach for adjusting model parameters to account for spatial and temporal variation in rainfall

input. Quirnbach and Schultz (2002) reported that radar data should be used in urban hydrology where there is more than 4km between rain-gauges for catchments with rain-gauge densities less than 1 rain gauge per 16km<sup>2</sup>. In hydrologic modelling, previous studies have suggested that the combination of rain-gauge and radar rainfall as input can improve the modelling results (c.f. Sun et al., 2000).

The response of an urban catchment system to rain storms is complex due to its complexity and speed of the drainage network. Runoff prediction errors in urban area resulting from rainfall spatial and temporal resolution errors depend on various factors. These include the interaction of watershed topography and geomorphology, the runoff producing mechanism, the rainfall rate to the soil saturation hydraulic conductivity (Saghafian et al., 1995), and the spatial and temporal variability of the rainfall field (Ogden et al., 2000).

To date, much work has been done to assess the use of radar for flow forecasting in an urban context. Bruen (2000) outlined the work on hydrological/hydraulic models for flow forecasting in urban catchment involved in the study of WG1-4, which was part of the COST-717 Action entitled "Use of Radar Observations in Hydrological and NWP models (Rossa, 2000)". Yuan, et al. (1999) introduced an urban drainage system modelling approach to predict flows throughout pipe networks in real-time. The approach utilised quantitative distributed rainfall input derived from weather radar. In urban stormwater flood forecasting, the speed and direction of the rainstorms can have significant effects on the hydrographs at the catchment outfall. This is particularly obvious when the storm events are localised or of short duration, and where the watersheds are small. For instance, Cluckie et al. (1994) assessed the influence of the temporal and spatial resolution of radar rainfall information on the resulting flood forecast from an urban storm sewer model. Stellman et al. (1999) examined the improvement of the spatial rainfall distribution within a basin on the stream flow forecasting by dividing a large basin into small sub-catchments, and then using either rain-gauge or radar-derived rainfall. A more accurate stream flow forecast result was obtained by dividing a lumped basin into semi-distributed basins. Giannoni et al.

(2003) applied the high-resolution radar rainfall estimates of 1km horizontal scale and 5minute time scale to a distributed hydrologic model for analysis and monitoring of extreme floods. The information from weather radar is often thought to be more directly relevant to distributed quantitative precipitation forecasting (Ganguly, 2002). In flood forecasting, using radar rain data has the potential benefit that the rain data derived from radar scan of the storm reflectivity may contain dynamic predictive information (Tsanis et al., 2002). Therefore, forecasting using radar data can be informative for short lead-times.

## **5.2 Radar rainfall data for Citywest development**

The radar rainfall used in this study is provided by Met Eireann, Ireland, who operate the radar in Dublin Airport. It is a C-Band (5640MHz) radar with a maximum range of 600km and a useful range of 250km. The Dublin radar collects 10 elevations of rainfall intensity every 15 minutes at 240km and 10 elevations of Doppler rainfall and wind every 15 minutes at 120km and 1 elevation of rainfall intensity at 480 km (Bruen, 1999). In this study, the high radar spatial resolution of Km radar grids as well as the relatively high temporal resolution of 15 minutes time step data are used. Nine pixels of the Dublin radar, arranged in a grid, are sufficient to cover the Citywest catchment, Figure 5.1 The data is for the period January 2001 December 2003. These 9-grid radar data cover all Citywest area in order to consider the rainfall variability in the whole catchment. The storm events were abstracted from both radar data and rain-gauge record. The corresponding flow data converted from water level records at the catchment outfall were used for the assessment.

## **5.3 Methodology**

There are a number of ways in which the performance of radar system may be evaluated. One of the important elements is the accuracy in estimating the quantity of rainfall and the ability in forecasting flow using radar rain data.

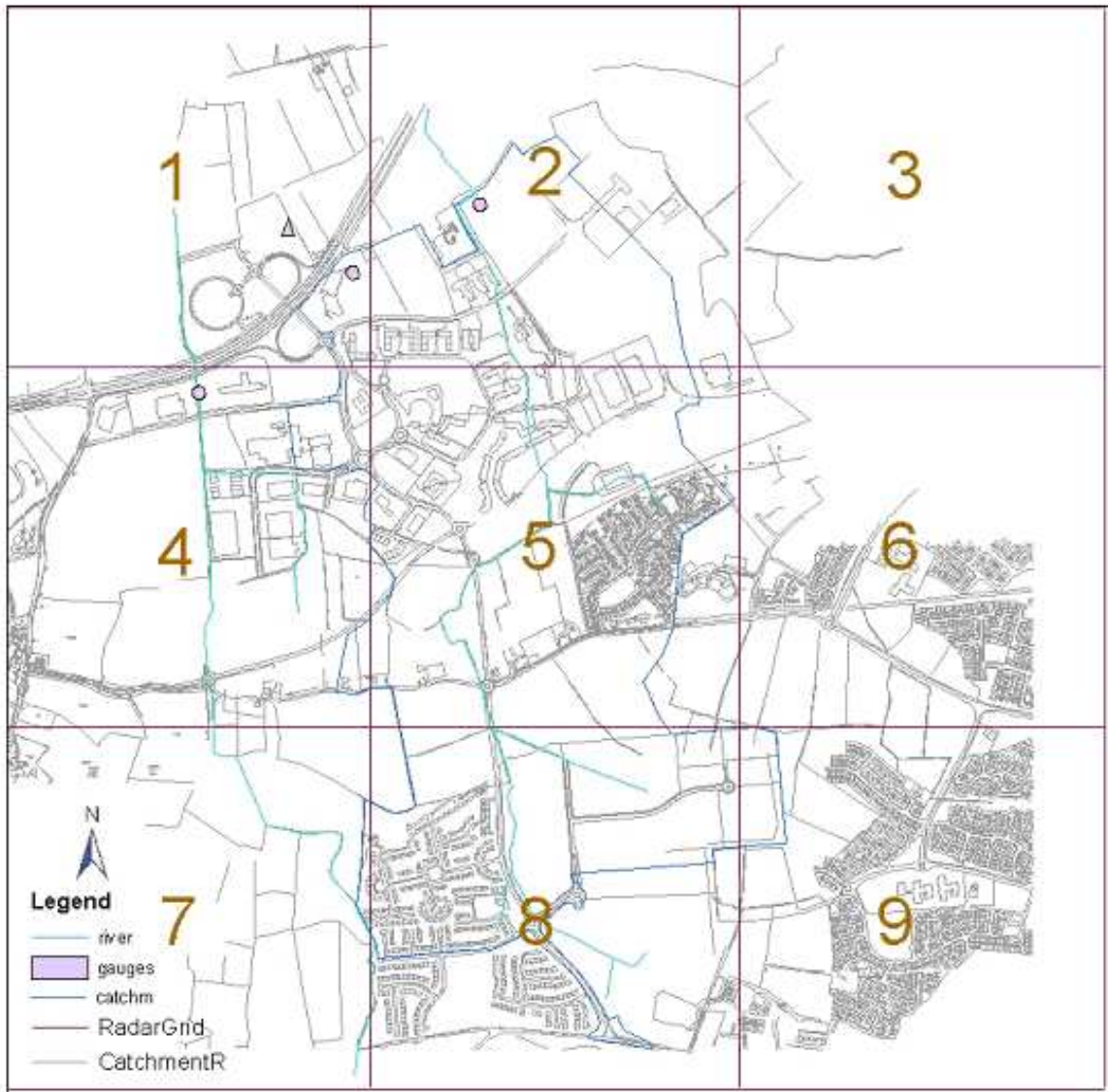


Figure 5.1: Citywest catchment and the Dublin radar grid image (9 radar grids)

When compared with rainfall measured in gauges, radar generally underestimates the rainfall, in particular, at the nearby and at the far ranges from the radar. Smith et al (1996) reported that, using the NEXRAD (WSR-88D) radar system of the USA, underestimation occurred at all radar coverage at the rate ranging 14

In this study, a systematic approach is used to assess the value of radar estimates of precipitation based on on-ground rain-gauge at Citywest development. The main objective is to investigate the radar rain data uncertainties in comparison with the rain-gauge record, and to assess the potential use of radar rain data in high spatial and temporal resolutions on small urban catchment in flow simulation and forecasting

using either black-box or physically-based hydraulic models.

The study has the following steps:

- Assessment of the radar-gauge rainfall estimates. Starting with the simplest modelling method and adding complexity one step at a time, assessment of the correlation of gauge rainfall and radar rain estimates are made by comparing their corresponding values.
- Rainfall-runoff simulation using radar rainfall estimates. The best estimates from the radar rainfall data are used for the flow simulation test at Citywest catchment outfall. The artificial neural networks (ANN) model is used for the modelling tests.
- Flood forecasting using radar rainfall estimates. The ability of short lead-time flood forecasting using radar rain data is assessed. The ANN model is used for short lead-time flood forecasting.
- Modelling with stormwater drainage system. The weather radar storm event data are tested for the urban stormwater drainage system using physically-based hydraulic model.

The storm event data extracted from series are used for the assessment. A split-sample framework, where one part of the data is used for radar adjustment and model calibration and the other part of the data is used for independent verification.

## **5.4 Results and discussions**

The results are evaluated using a number of criteria, including the Nash-Sutcliffe R<sup>2</sup> efficiency (1970), mean square error (MSE) fitness criterion, model bias, and model-gain. The performance of the HydroWorks stormwater drainage system model were evaluated by comparing with the observed storms flows in terms of the peak discharge, storm volume and the hydrograph shape.



The bias measures how far the sample statistic lies from its estimates in average, which also refers to the error that arises in the quantity estimation. While the model-gain defined here calculates the values of model parameters (coefficients), and is determined through model calibration. Examination of whether the gain value is equal to one provides the test of model variability or fitness.

#### 5.4.1 Assessment of the radar -gauge rainfall estimates

In this assessment, 27 storm events with a total of 1930 data points were used, of which 14 storms were for calibration and 13 for verification.

(i) The radar rainfall for each individual grid was used to estimate the on-ground rain-gauge at the catchment outfall. The possible modelling equations are as follows,

Model 00:

$$g_t = r_{i,t} \tag{5.1}$$

(i.e., the radar pixel value is an estimate of the rain-gauge record)

Model 01:

$$g_t = \alpha p_{gari,t} \tag{5.2}$$

(i.e., the radar pixel value has constant correlation with the rain-gauge record)

Model 02:

$$g_t = \alpha_0 + \alpha_t R_{i,t} \tag{5.3}$$

(i.e., the radar pixel value has a linear correlation with the rain-gauge record)

Table 5.1 shows the fit of the individual radar grid data to the on-ground rain-gauge at the catchment outfall. Unfortunately, no strong direct correlation was found between rain-gauge and individual radar grid. In model00, since the predicted value is the actual radar rainfall at each grid, the results show the positive bias values for all radar grids, which indicate that the radar data underestimates the gauge measurement

at all the grids. The poor R2 efficiency in both calibration and validation for the models in table 9.1 suggest weak performances for all these models even when the model-gain (parameters for each grid) for some grids were at the level close to one. This may also indicate a considerable discrepancy between radar estimates and the rain-gauge records. In comparison with different models, results show that there were generally constant improvements in particular at the calibration, when the model complicity was increased.

(ii) The linear methods are used to assess the relationship of the combined radar rainfall for all grids, and the on-ground rain-gauge at the catchment outfall.

Model 03:

$$g_t = \frac{1}{k} \sum_{i=1}^k r_{i,t} \quad (5.4)$$

(i.e., the average of radar pixel values is an estimate of the rain-gauge record)

Model 04:

$$g_t = \frac{1}{k} \alpha \sum_{i=1}^k r_{i,t} \quad (5.5)$$

(i.e., the average of radar pixel values has constant correlation with the rain-gauge record)

Model 05:

$$g_t = \alpha_0 \frac{1}{k} \alpha_i \sum_{i=1}^k r_{i,t} \quad (5.6)$$

(i.e., the average of radar pixel values has linear correlation with the rain-gauge record)

Model 06:

$$g_t = \sum_{i=1}^k \alpha_i r_{i,t} \quad (5.7)$$

(i.e., the sum of fractional radar pixel values of the current time step is an estimate of rain-gauge record)

Model 07:

$$g_t = \sum_{i=1}^k \alpha_i r_{i,t-1} \quad (5.8)$$

(i.e., the sum of fractional radar pixel values of previous one time step is an estimate of rain-gauge record)

Where,  $k$  is the total number of radar grids. As in the first stage, the assessment in this stage starts from assuming a simple relationship between the radar and gauge record at the catchment outfall. Starting from a non-parametric model, then add parameters step by step. Finally, the linear regressions of all rain radar grids covering the catchment area, at current time step and at previous time step, are used to fit the rain-gauge record.

The results of combined effect of the radar grids rainfall from linear methods were presented in Table 5.2. The combined results showed a better performance than the individual radar grid fitting. However, no satisfactory correlation between radar rainfall and rain-gauge record were obtained from the simulations. It is clear, however, that the model performances were generally improved when the model complexity was increased.

#### **5.4.2 Modelling with urban stormwater drainage system using radar rainfall**

Finally, the radar rainfall data are used to simulate the flow through an urban stormwater drainage system.

In drainage system modelling, various limitations for using radar rainfall data in sewage system management have been reported. For instance, Faure et al. (1999) concluded that despite the ability of radar data in spatial rain structure, the rainfall variability in space and time restricts the accurate forecasting period. They reported that the forecasting range limits for typical urban catchment areas are greatly depended on the rainfall conditions (type of rain events). Koishikawa et al. (1999) also examined radar rain data for the application of operational support systems in urban drainage facilities. They found that, for effective operation, sufficient radar rain data

must be derived accurately and in high temporal and spatial resolutions.

Here, the Citywest stormwater drainage system is developed using a physically-based hydraulic model, HydroWorks. The HydroWorks model is calibrated using the on-ground rain-gauge storm events as described in previous chapter. The calibrated model is then used to test the performance of rain radar data. In this case, five storm events were tested for flow throughout the drainage network. Previous sections showed that weather rain radar constantly underestimates the gauge rainfall and so does the flows when they are used for flow simulation. In this test, both the radar rainfall and the gauge-adjusted rainfall data are used as the input to HydroWorks model in two separate simulations.

An overall acceptable performance was obtained from the simulations using either radar rain input or gauge-adjusted radar rain input. Results also showed that simulations using radar data generally underestimate the hydrographs. However, it is clear that, overall, the gauge-adjusted radar rain input gave considerable better results than that from radar rain input for all the events. When compared with the rain-gauge results, the predicated storm volumes from radar rainfall input were smaller than that from rain-gauge input for most of the storm events used, the differences were ranged -22.4% 0.71%. While gauge-adjusted radar input produces storm volume -16.01% +3.11% difference from that of gauge rainfall input. Examining the hydrographs in the figures also show that the radar rainfall input tended to predict storm peaks ahead of the recorded ones.

In dynamic management of urban catchment, rainfall runoff simulations are sensitive to the resolution of the input data (Johann and Verworn, 1997). The recorded rainfall data in HydroWorks model is recommended at a maximum time step of five-minute in order to give adequate resolution of the changing rainfall conditions. Due to the small catchment size and the quick catchment response, as shown in previous chapter, the Citywest storm drainage system was simulated at two-minute time step. While the time resolution used for radar data is 15 minutes. Therefore, the systematic errors caused by the spatial resolution in such case are unavoidable. This may

also suggest that the discrepancy between gauge-adjusted radar input and gauge rain input is more likely due to the different time-steps used.

Table 5.1: Results on individual-radar grid fitting rain-gauge at catchment outfall

Model00	Criteria	Grid1	Grid2	grid3	Grid4	Grid5	grid6	grid7	grid8	grid9
Cal Bias	0.122	0.14	0.145	0.115	0.106	0.145	0.103	0.115	0.106	
Cal	MSE 0.19	0.2 0.19	0.18	0.17	0.19	0.19	0.16	0.16		
Cal	Nash-R2 11.9	7.3 11.3	16.3	18.8	10.1	11.8	25	25.7		
Val Bias	0.112	0.126	0.125	0.1 0.094	0.128	0.09	0.107	0.098		
Val	MSE 0.21	0.22	0.24	0.21	0.21	0.24	0.21	0.24	0.22	
Val	Nash-R2 (%) 13.8	8.5 2.5 14.6	12.7	2.6 13.8	3.6 11.2					
Model01	Criteria	Grid1	Grid2	grid3	Grid4	Grid5	grid6	grid7	grid8	grid9
Cal Model-gain 1.24	1.102	1.129	1.28	1.081	1.191	1.028	1.129	0.995		
Cal	Bias	0.081	0.125	0.126	0.066	0.091	0.117	0.097	0.093	0.107
Cal	MSE 0.18	0.2 0.19	0.17	0.17	0.19	0.19	0.16	0.16		
Cal	Nash-R2 (%) 13.9	7.8 12 19.2	19.1	11.4	11.8	25.9	25.7			
Val	Model-gain	1.24	1.102	1.129	1.28	1.081	1.191	1.028	1.129	0.995
Val	Bias	0.072	0.11	0.106	0.051	0.079	0.099	0.085	0.085	0.099
Val	MSE 0.22	0.23	0.25	0.22	0.21	0.25	0.21	0.24	0.22	
Val	Nash-R2 (%) 11.3	6.9 -1.9	11.9	12 -3.8	13.7	0.9 11.2				
Model02	Criteria	Grid1	Grid2	grid3	Grid4	Grid5	grid6	grid7	grid8	grid9
Cal	Model-gain	0.939	0.791	0.846	1.026	0.85	0.882	0.76	0.922	0.809
Cal	Model-constant	0.132	0.172	0.168	0.111	0.133	0.162	0.148	0.129	0.142
Cal	Bias	0	0	0	0	0	0	0	0	0
Cal	MSE 0.17	0.17	0.17	0.16	0.16	0.17	0.17	0.15	0.14	
Cal	Nash-R2 (%) 19.0	17.9	21.9	22.6	24.8	20.3	18.6	31.5	32.8	
Val Model-gain	0.939	0.791	0.846	1.026	0.85	0.882	0.76	0.922	0.809	
	Model-constant	0.132	0.172	0.168	0.111	0.133	0.162	0.148	0.129	0.142
	Bias	-0.01	-0.014	-0.019	-0.015	-0.012	-0.017	-0.013	-0.009	-0.009
	MSE	0.2	0.2	0.21	0.2 0.2	0.21	0.2	0.22	0.2	
	Nash-R2 (%)	19.7	18.6	14.1	18.3	18.2	13.1	19.3	10.3	17.5

Table 5.2: Results on combined-radar grid fitting rain-gauge at catchment outfall using linear methods

Model	Nash-R <sup>2</sup> (%)		MSE	
	Cal	Val	Cal	Val
Model03	22.2	16.0	0.17	0.21
Model04	25.9	13.1	0.16	0.21
Model05	28.1	14.3	0.15	0.21
Model06	36.6	19.2	0.13	0.20
Model07	51.2	31.2	0.10	0.17

# Chapter 6

## Conclusions

The radar rainfall data was analysed on the basis of the on-ground rain-gauge record using individual storm events for a small urbanising catchment. The high temporal and spatial resolutions of the radar grid data were used for the analysis. A systematic approach was developed to assess the value of radar estimates of precipitation, which were later used for the hydrological models in rainfall-runoff modelling and forecasting for the urban application. A black-box model, artificial neural network, was used for real-time flood forecasting using the radar rainfall as input. The radar rainfall events were finally used to forecast the flow from urban stormwater drainage system. The physically-based hydraulic model, HydroWorks, was used to carry out the flow simulation. The hydraulic model was calibrated using the on-ground rain-gauge data, in order to provide a perceived radar-gauge assessment.

The following conclusion may be drawn from this study,

- A poor correlation between rain radar grids and rain-gauge record was found on the small urbanising catchment. The possible reasons are (i) the high temporal and spatial resolution data used, (ii) the small catchment size, (iii) the effect of the Dublin Mountains beside the catchment on the storm data.
- There is a considerable discrepancy in the quantity of precipitation between the gauge and radar grids. This may also due to the high-resolution radar data used since the low discretisation level usually provides small precipitation errors. The radar data overall underestimates the rain-gauge record. This is expected, and



for that reason, the radar is normally "gauge-adjusted" before being used.

- The radar data are useful for urban stormwater drainage system modelling. However, when compared with rain-gauge record, radar rain data tends to underestimate the flow from drainage network constantly. The gauge-adjusted radar rainfall input provide more reasonable simulation results than that of radar rain input, and this can be used for small urban drainage system modelling.
- The assessment in this study suggest that the hydrological response (both from black-box and physically based Hydraulic models) as well as the radar-gauge correlation, are sensitive to the high temporal and spatial resolutions of radar data input, and to the small size of catchment analysed. For a small urban catchment, not only the quantity of the storms but also their direction and shape affect the catchment response significantly. In such case, care should be taken in using radar data where there are no rain-gauge references.
- Because of the poor performance of a normal (1 km grid) radar with this small urban catchment, it was not considered useful to also use the coarser resolution NWP output in this catchment. The Citywest catchment was both smaller and had too fast a response for the currently available NWP output to be of practical quantitative use. This again is a question which may be re-opened when non-hydrostatic NWP model output becomes available.

# Chapter 7

## References

**Alberoni, P.P., Ducrocq, V., Gregoric, G., Haase, G., Holleman, I., Lindskog, M., M**

Quality and assimilation of radar data for NWP: Working Group3- A review.  
Cost Action 717: Use of radar observation in hydrological and NWP models. European cooperation in the field of scientific and technical research, EUR 20600.

**Bertrand-Krajewski, J., Barraud, S., Chocat, B., 2000.** Need for improved methodologies and measurements for sustainable management of urban water systems. *Environmental Impact Assessment Review* 20: 323-331.

**Dooge, J.C.I., 1959.** A general theory of the unit hydrograph. *Journal of Geophysical Research* 64 (2): 241-256.

**Driscoll, S., 1998.** Variations in the probability of detecting precipitation with range. Observation Based Products Technical Report No. 12. Unpublished report from the National Meteorological Library, London Road, Bracknell, Berks RG12 2SZ, UK.

**Dublin Corporation, 1999.** Stormwater management policy for developers. Dublin Corporations.

**Johann, G., and Verworn, H-R., 1997.** Requirements for radar rainfall data in urban catchment modelling and control. *Water Science and Technology* 36 (8-9): 13-18.

- McEnroe, B.M., Zhao, H., 1999.** Lag times and peak coefficients for rural watersheds in Kansas. Final Report, report No. K-TRAN: KU-98-1. University of Kansas, Lawrence, Kansas.
- Maheepala, U.K., Takyi, A.K., Perera, B.J.C., 2001.** Hydrological data monitoring for urban stormwater drainage systems. *Journal of Hydrology* 245 (1-4): 32-47.
- Morena, F., Andrieu, H., Rodriguez, F., Creutin, J-D., 2002.** Effect of Rainfall Variability on the Hydrological Behavior of Urban Basins: A Simulation Study Based on Weather Radar Data. In: E.W. Strecker, and W.C. Huber, (Edt.), Proc. Global Solutions for Urban Drainage: 9ICUD. Portland, Oregon.
- Nash, J.E., Sutcliffe, J.V., 1970.** River flow forecasting through conceptual models, part I- a discussion of principles. *Journal of Hydrology* 10: 282-290.
- Nash, J.E., 1958.** The form of the instantaneous unit hydrograph. *Intl. Assoc. Sci. Hydrology, Pub 42, Cont. Rend.* 3 114-118.
- NOAA, 2003.** Unit Hydrograph (UHG) Technical Manual. National Weather Service Office of Hydrology, Hydrologic Research Laboratory, and National Operational Hydrologic Remote Sensing Centre, USA available online [[http://www.nohrsc.nws.gov/technology/gis/uhg\\_manual.html](http://www.nohrsc.nws.gov/technology/gis/uhg_manual.html)].
- Quirnbach, M, Schultz, G.A., 2002.** Comparison of rain gauge and radar data as input to an urban rainfall-runoff model. *Water Science and Technology* 45 (2): 27-33.
- Rawls, W.J., Ahuja, L.R., Brakensiek, D.L., Shirmohammadi, A., 1992.** Infiltration and soil water movement. In: Maidment, D.R. (Editor in chief), *Handbook of Hydrology*. McGRAW-HILL, INC. New York.
- SCS (Soil Conservation Service), 1972.** National Engineering Handbook, Section 4, U.S. Department of Agriculture, Washington, D.C.

**Serafin, R.J., Wilson, W., 2000.** Operational weather radar in the United states:  
Progress and Opportunity. Bull. Amer. Meteor. Soc. 81: 501-518.

**WaPUG** Autumn Meeting. Wastewater Planning Users Group.

**Whalley, N., Iredale, R.S., Clare, A.F., 2001.** Reliability and uncertainty in  
flow measurement techniques - some current thinking. Phys. Chem. Earth (C)  
26 (10-12): 743-749.