

# **THE RATIONAL METHOD IN INTERMEDIATE SIZED CATCHMENTS**

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Floating down a beautiful river on a tube is a wonderful experience especially popular these days at company team-building breakaways. A typical scene of tubers on the river is shown in Figure 1. However, it can also lead to disaster. On the evening of 25 March 2000, the media (Eastern Province Herald, Eastern Cape Weekend) reported the unfolding drama of a number of people missing, feared dead, in a tubing accident in the narrow Storms River gorge in the Tsitsikamma Mountain Range, on the border between the Eastern and Western Cape Provinces. In total, thirteen people lost their lives turning a fun company breakaway into a tragedy.



Photo by Euan Waugh

Figure 1 Tubers enjoying the Storms River.

Hogan (2002) undertook a hydrological study of this and surrounding rivers, to obtain an understanding of what happened in the Storms River during this accident period, in hydrological terms. While there is no river gauging station in the Storms River, there are gauging stations in three of the surrounding rivers. The Rational method was used to determine the runoff in the Storms River during this accident period, based on the very good correlation between the calculated and the recorded runoff in the surrounding rivers, even though the catchments are larger (up to 100 km<sup>2</sup>) than what is conventionally considered the limiting size for the Rational method (10 - 15 km<sup>2</sup>). From this study an MSc project has developed, in which the accuracy of the Rational method will be tested in further catchments the size of the Storms River and somewhat larger (20-250 km<sup>2</sup>), using net rainfall instead of average rainfall.

In this paper, the initial study of the Storms River accident is described as background information and to illustrate the procedure that is being adopted in the MSc project.

## **LOCALITY**

A schematic layout of the Storms River catchment is shown in Figure 2. The river rises in the Tsitsikamma Mountains, cuts deeply into the coastal plateau, across which the N2 national road is constructed, discharging into the Indian Ocean at the popular Storms River Mouth resort. A large tributary of the Storms River, the Witteklip River, also rises in the Tsitsikamma Mountains and joins the Storms River fairly near the sea. River tubers traditionally enter the Storms River at the point shown in the figure, and continue down through the narrow gorge section, ending at the river mouth. If the water level is high, the narrow gorge section is extremely dangerous and tubing down that section of the river is prohibited. An escape route has been provided about 600m below the confluence of the Witteklip and the Storms River itself, and is just above the narrow gorge section. The accident on 25 March 2000 occurred while the tubers were between the confluence of the Witteklip and the narrow gorge.

## RAINFALL DATA

Rainfall was recorded at a number of stations in the Storms River area over the accident period, namely at the Lottering, Witelsbos, Blueilliesbush, Storms River Village, and Tsitsikamma stations (South African Weather Bureau). The Storms River Village rainfall station is on the plateau near the Tsitsikamma Mountains and lies between the Lottering and Witelsbos / Blueilliesbush rainfall stations while the Tsitsikamma station is located at the Storms River Mouth on the coast. The positions of the rainfall stations closest to the Storms River can be seen in Figure 2. The Storms River Village station is the closest gauge to the upper catchments of the Storms River, as there are no rain gauges in the mountains.

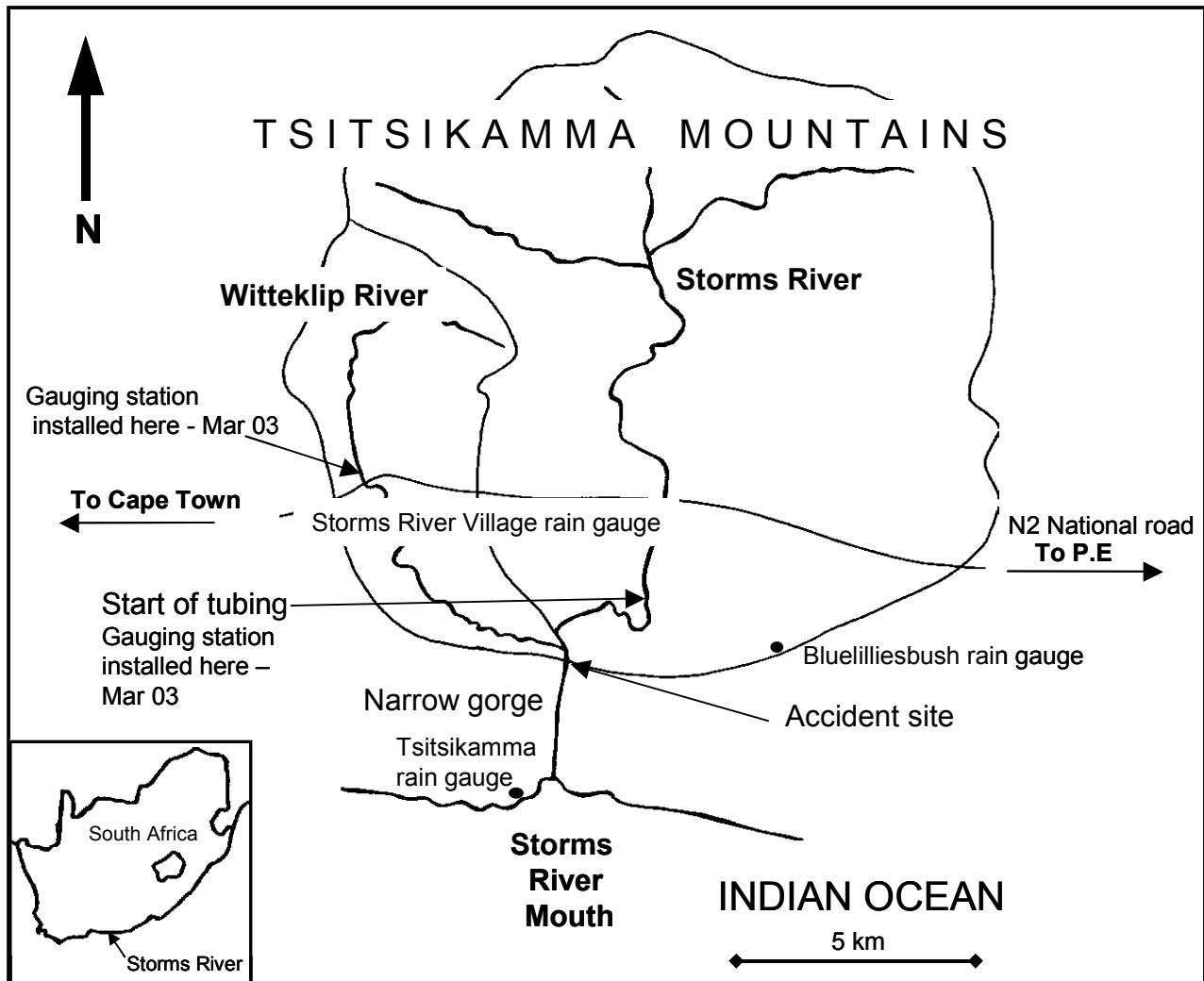


Figure 2 Locality of the Storms River catchment area

Based on the rainfall data from Storms River Village station (South African Weather Bureau, Weather Office: Port Elizabeth), 25mm of rain fell on Friday/ Saturday to 8am Saturday 25 March, and a further 51,2mm fell on Saturday/ Sunday to 8am Sunday 26 March. The total recorded rainfall for the period 24-26 March was thus 76,3mm. According to the Storms River Forestry Officer, most of the 25mm of rain that fell in the Friday/ Saturday to 8am period, fell in the early hours of Saturday morning (Report on the Storms River Tubing Accident), (Storms River Forestry Officer) . A similar rainfall record was recorded at the Tsitsikamma station with 13,8mm of rain recorded on Friday/ Saturday to 8am Saturday 25 March, and a further 54mm fell on Saturday/ Sunday to 8am Sunday 26 March. The total rainfall for the period

24 - 26 March was 80.5mm. The corresponding rainfall records for Bluelilliesbush, Witelsbos, and Lottering showed that 71.9mm\*, 66.6mm\*, and 73mm\* of rain respectively, fell over the combined period 24-26 March to 8 am. (\* Indicates only cumulative rainfall recorded over the period 24-26 March at these stations.)

It can therefore be appreciated that there is a good correlation between all the rainfall records, indicating that the rainfall was widespread over the period and of a similar intensity, in the order of 70-80mm over the two-day period. (It is necessary to consider the two day records as rainfall was only recorded over the period 24-26 March at some of the gauges.)\*

The Tsitsikamma rain gauge at the mouth of the Storms River is the only hourly recording gauge. Figure 3 shows graphically the hourly rainfall recorded at this gauge over the accident period.

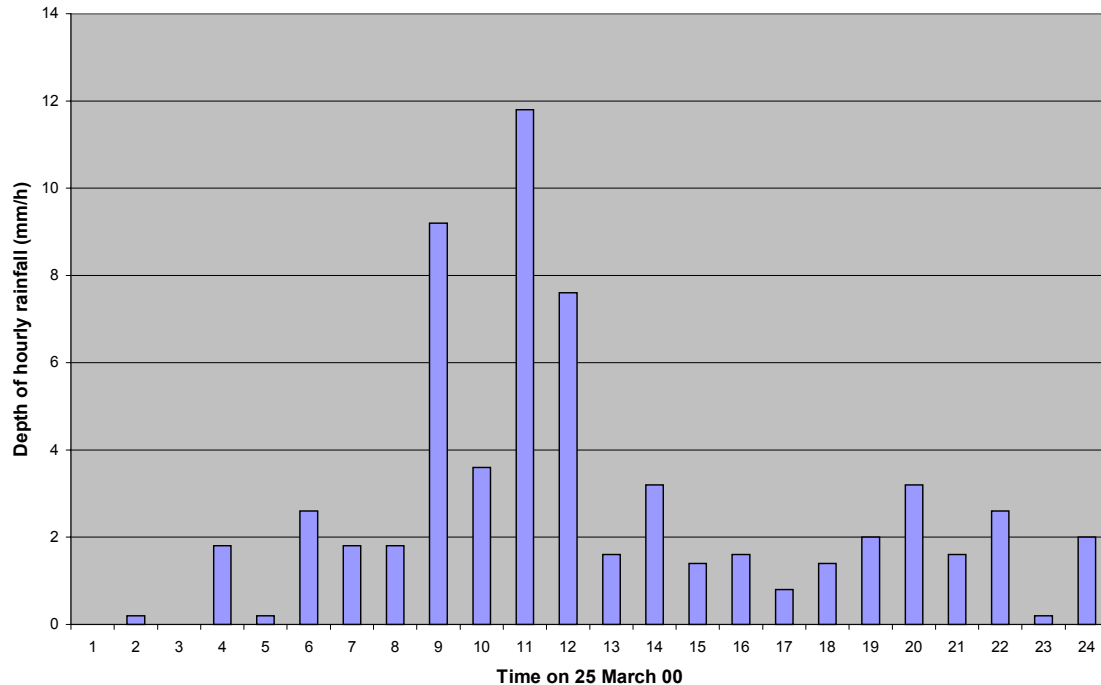


Figure 3 Tsitsikamma gauge hourly rainfall on 25 March 2000

Records also show that the previous rainfall in the area during the period 13-17 March, was sporadic light rain measuring in total 20,7mm at Storms River Village, 19,6mm at Tsitsikamma, 16,7mm at Witelsbos, 23,3mm at Bluelilliesbush, and 35mm at Lottering. For the period 18-24 March the records showed that no rain fell in this area. This means that the ground was not saturated from a previous rainfall before the rainfall on 24-26 March occurred. However, the rain falling in the early morning of 25 March would have wet the ground significantly, but may not have resulted in a noticeable rise in water level in the rivers, but would have had the overall effect of increasing the runoff from rain falling later in the day.

The historic rainfall records from these rainfall stations indicated that rainfall of the magnitude experienced over the accident period had a recurrence interval (RI) of three times a year.

## RUNOFF DATA

The Department of Water Affairs and Forestry (DWA&F) has a number of water level weir gauging stations located on rivers around the country. Three such gauging stations are located in the vicinity of the Storms River, namely on the Bloukrans, Kruis and Elands Rivers. The Bloukrans River is 25km west of the Storms River while the Kruis and Elands Rivers are the next two adjacent river catchments to the east, respectively 9 and 13km east of the Storms and Witteklip Rivers. The catchments of these stations are shown in Figure 4.

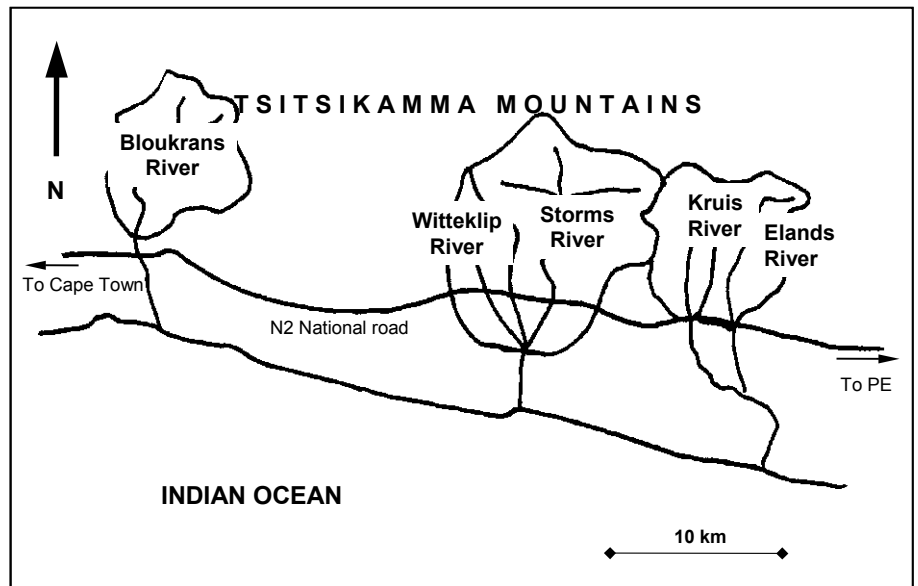


Figure 4 Locality plan of river catchments.

There are no DWA&F gauging stations on the Storms or Witteklip Rivers. From the DWA&F data, (Department: Water Affairs and Forestry, Cradock), (Department: Water Affairs and Forestry, Western Cape Region), it was observed that all three gauges recorded a flood peak in the afternoon of the accident day, in line with the widespread rainfall recorded, as discussed above. There was a good correlation of the rise in water level of these three rivers as can be seen in Figure 5. The recorded peak discharge in the Bloukrans River was 23,8 m<sup>3</sup>/s while it was 17,7 and 17,9 m<sup>3</sup>/s in the Kruis and Elands Rivers respectively. The catchment areas of these rivers are 57km<sup>2</sup>, 25,5km<sup>2</sup>, and 34,5km<sup>2</sup>, in the Bloukrans, Kruis and Elands Rivers respectively.

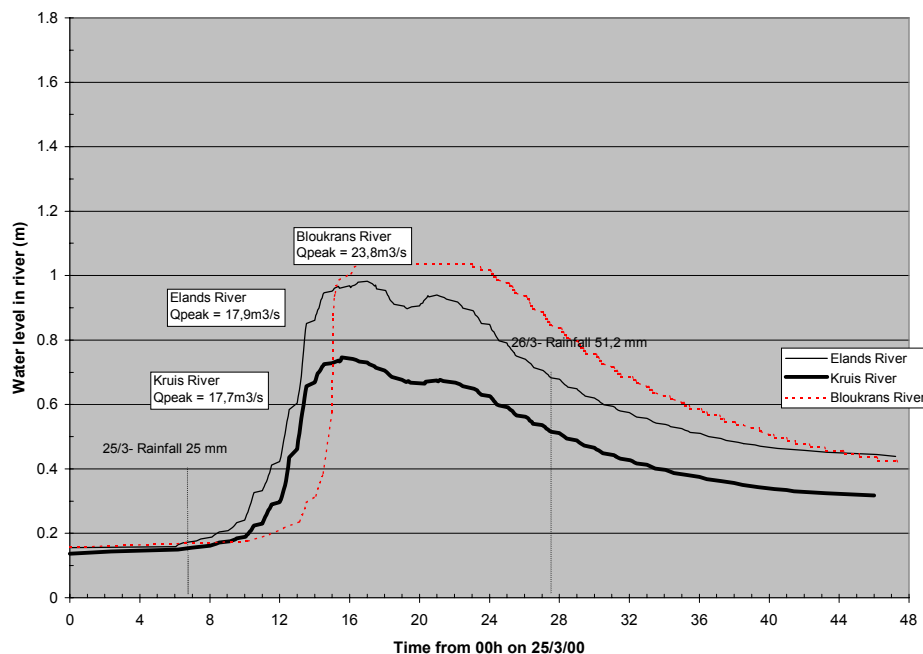


Figure 5 Water level in the Bloukrans, Kruis and Elands Rivers over the accident period.

In a study of the Bloukrans, Elands and Kruis River gauging station records for the period June 1961 to August 2002, flood events of the magnitude of that recorded on 25 March 2000 or greater, have occurred 92 times in the Elands River, 178 times in the Kruis River, and 149 times in the Bloukrans River. This is in the order of two to three times a year on average for the Elands River and more than four times a year on average for the Kruis River, and in the order of three to four times a year on average for the Bloukrans River.

During March 2003, water level recorders were installed by Professor Basson (2003) in the Storms River and the Witteklip River. The locality of these rivers gauges is shown in Figure 2. Figure 6 shows the good correlation in water level between these two gauging stations and the DWA&F stations in the Elands, Kruis and Bloukrans Rivers.

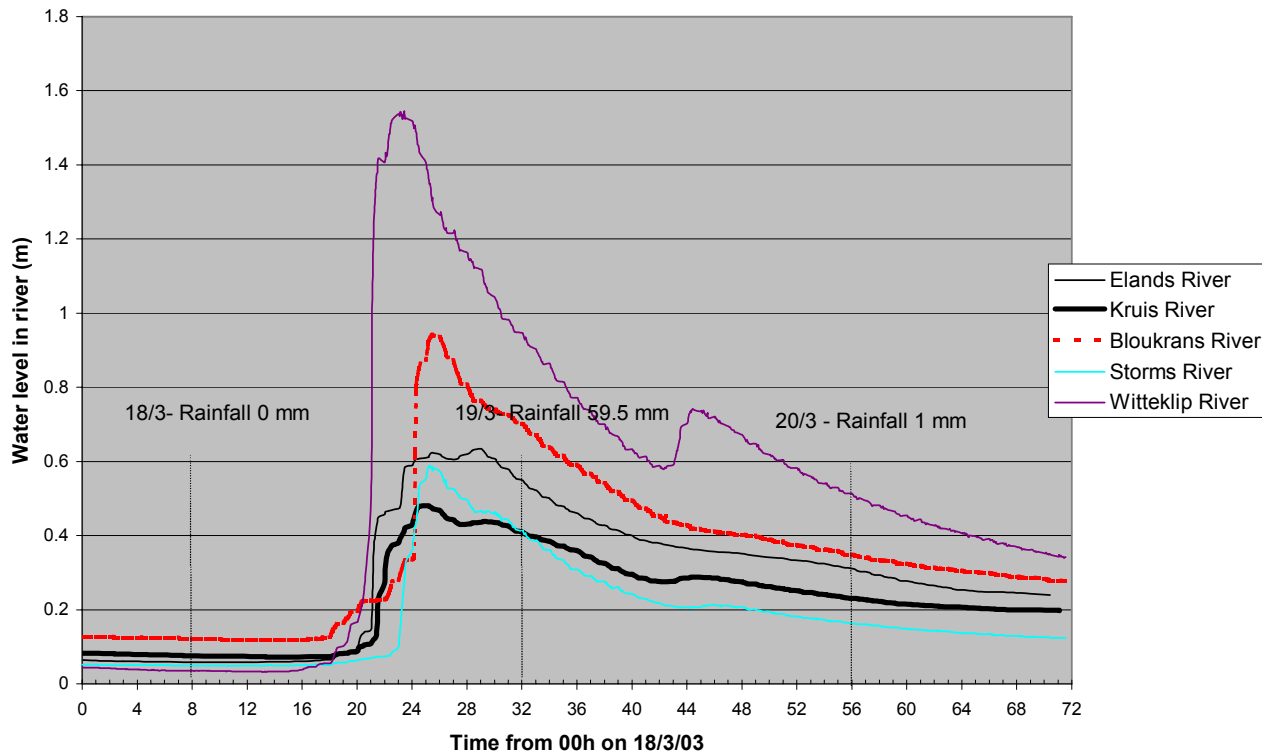


Figure 6 Water level in Kruis, Elands, Bloukrans, Storms and Witteklip Rivers during 18 to 20 March 03.

The question however still remained, "What was the magnitude of the runoff in the Storms River itself during the accident period?" To obtain this estimate, the Rational Method was used, assuming a direct relationship between the un-gauged catchments of the Storms and Witteklip Rivers and the gauged catchments of the Kruis, Elands and Bloukrans Rivers. The good correlation in Figure 6 confirms this relationship is valid.

### **THE RATIONAL METHOD**

The Rational method as proposed by Mulvaney in 1851 (Design Flood determination in South Africa, Report No.1/72), (Water Engineering III, Stormwater Design course notes), is widely used by Civil Engineers in everyday practice, to determine the stormwater runoff quantities from "small" catchments, generally assumed to be areas up to 10 - 15 km<sup>2</sup>. This method therefore finds application mostly in urban township developments.

The greatest shortcomings of this method is that

- It is generally limited to small catchments in application,
- Its accuracy cannot be assured and
- It does not provide an understanding of the mechanics of the runoff process,

but it is widely used by Civil Engineers as it uses the average rainfall intensity, which is easily available information. This method generally gives good results when compared with other studies.

This method is not usually recommended for use in “intermediate” (10 – 5 000 km<sup>2</sup>) or “large” (> 5 000 km<sup>2</sup>) sized catchments, but in some cases it can be used by experienced Engineers for these larger sized catchments. The catchments studied in this investigation all fall within the intermediate sized area range.

For intermediate sized catchments, the Unitgraph method is suggested for determining the design flood peak. This method finds application for Engineers in the hydrological designs for bridges, culverts, spillways and canalization projects. The shortcoming of this method is that a unitgraph is not always available for the catchment and the methods of synthesizing a unitgraph requires an in-depth hydrological analysis, which is not always within the Engineering budget for a project.

The Unitgraph method requires the application of the net rainfall to the unit hydrograph. The net rainfall is the recorded rainfall less the losses for infiltration, detention, interception etc. The determination of these losses is a complex procedure and is not generally easily determined by the average Engineer, as it varies significantly from area to area and from rainfall event to event. If a hydrograph is available, the net rainfall can be determined using the base flow separation technique.

### **USE OF THE RATIONAL METHOD OVER THE STORMS RIVER ACCIDENT PERIOD**

When using the Rational Method, average rainfall intensity is usually used instead of net rainfall. This average rainfall intensity is generally readily obtainable for storms of RI of 1 in 2 years intervals or greater using the HRU reports. However over the Storms River accident event, the RI is two or four times in a year, which falls outside of this readily available information. Instead, a base flow separation technique (a semi – empirical technique) was applied to the runoff records of the three adjacent river gauging stations; from which an average net rainfall intensity during the accident period was determined.

Details of the calculations for the different catchments are given below.

#### **Bloukrans River.**

As previously stated, the catchment area of this River, to the gauging station is 57 km<sup>2</sup> and the MAP in the area is greater than 900mm per annum. The upper reaches of the river are very steep, with an average slope of 33 %, which reduces to 2,65 % in the lower reaches. The vegetation varies from generally light to thick bush on the very steep slopes to thick bush and indigenous forests on the lower, flatter slopes. The geology in the area is Table Mountain Sandstone and these mountains form part of the Cape fold belt. The upper slopes of the catchment were assumed to be semi-permeable, while the lower areas, which are covered in indigenous forest, were considered to be permeable. An adjustment factor of 0,6 was used in the determination of the runoff coefficient C, as the return period of this storm event was less than 1 : 1. An average C value of 0,24 was used for this catchment.

The time of concentration  $T_c$  of this river was determined to be about 45 minutes of overland flow and about 2,5 hrs of river flow, giving a total  $T_c$  of 3,25 hrs. No allowance has been made for time to infiltrate the upper strata of the soil or the filling of detentions, as the 25 mm of rain that fell in the early hours of Saturday would

have had the effect of saturating the soil, with the result that all the rain that fell later in the morning of 25 March 00 became runoff.

The base flow separation technique applied to the recorded hydrograph in the Bloukrans River gave an average depth of net rainfall of 6,5 mm/h, assuming the peak discharge occurred after a storm of  $T_c$  duration.

Using these values as detailed above, the Rational method predicts a peak discharge of 24,7 m<sup>3</sup>/s. The recorded peak discharge in this river during this event was 23,8 m<sup>3</sup>/s.

### Kruis River

The catchment area of the Kruis River is 25,5 km<sup>2</sup> and the  $T_c$  is about 2,5 hrs, calculated in a similar manner as described above. The catchment basin has similar slope, vegetation and geology characteristics; except that part of the basin had been recently burn. The runoff coefficient was therefore increased to 0,3.

The base flow separation technique applied to the recorded hydrograph in the Kruis River gave an average depth of net rainfall of 8,9 mm/h, assuming the peak discharge occurred after a storm of  $T_c$  duration.

Using these values, the Rational method predicts a peak discharge of 18,9 m<sup>3</sup>/s. The recorded peak discharge in this river over the event was 17,7 m<sup>3</sup>/s.

### Elands River

The catchment area of the Elands River is 34,5 km<sup>2</sup>, and the  $T_c$  was determined to be 2,75 hrs. The basin characteristics are similar to the Kruis River in that a large part of this area had also been burnt the preceding year. The runoff coefficient was taken as 0,3.

The base flow separation technique gave an average depth of net rainfall of 6,3 mm/h, assuming the peak discharge occurred after a storm of  $T_c$  duration.

Using these values, the Rational method predicts a peak discharge of 18,1 m<sup>3</sup>/s. The recorded peak discharge in this river during this event was 17,9 m<sup>3</sup>/s.

In all three cases the Rational method predicted a peak runoff remarkably similar to what was recorded at the river gauges over the event. Comparing the intensity of the hourly-recorded rainfall at the Tsitsikamma rain gauge (Figure 3), with net rainfall as determined using the base flow separation technique, shows that these net rainfall intensities are the correct order of magnitude.

### Storms River

Applying similar catchment characteristics to the Storms and Witteklip River catchments, where the total effective catchment area is about 92 km<sup>2</sup> (a portion of the Storms River catchment is very flat and covered in thick indigenous forest, it was assumed that this area would not contribute much runoff during this flood event), the  $T_c$  is about four hours and the average depth of net rainfall is assumed to be in the order of 7,5 mm/h, the average C is 0,30, as some parts of the catchment had been burnt, the peak runoff for the whole catchment would have been in the order of 58 m<sup>3</sup>/s.

## **MASTERS PROJECT**

This Masters project will then focus on the rainfall–runoff relationship, as defined by the Rational method, using net rainfall instead of average rainfall in intermediate sized catchments (up to about 250 km<sup>2</sup>), using data from a number of additional stations around the Eastern Cape. The selected gauging sites are shown in Figure 7. The requirements for the selection of the sites are,

- A river gauging station with no large dam upstream,
- Catchment in the lower intermediate size,
- Good rainfall record(s) from a nearby gauge(s).

The runoff as predicted by the Rational method will also be compared with other methods of predicting runoff, as reflected in the present day literature. Cognisance will also be taken of other similar studies that have been under taken in the recent past.

A desirable by-product of this study would be to develop an easily usable method of predicting runoff from rainfall records that the everyday Civil Engineer may use with confidence in intermediate sized catchments.

## **CONCLUSIONS**

When analysing the Rainfall – Runoff relationship, as expressed by the Rational Method, over the Storms River accident period, a good relation was found between the predicted runoff and the recorded runoff.

It is anticipated that this good correlation will also be found for the other selected catchments of the Masters project.



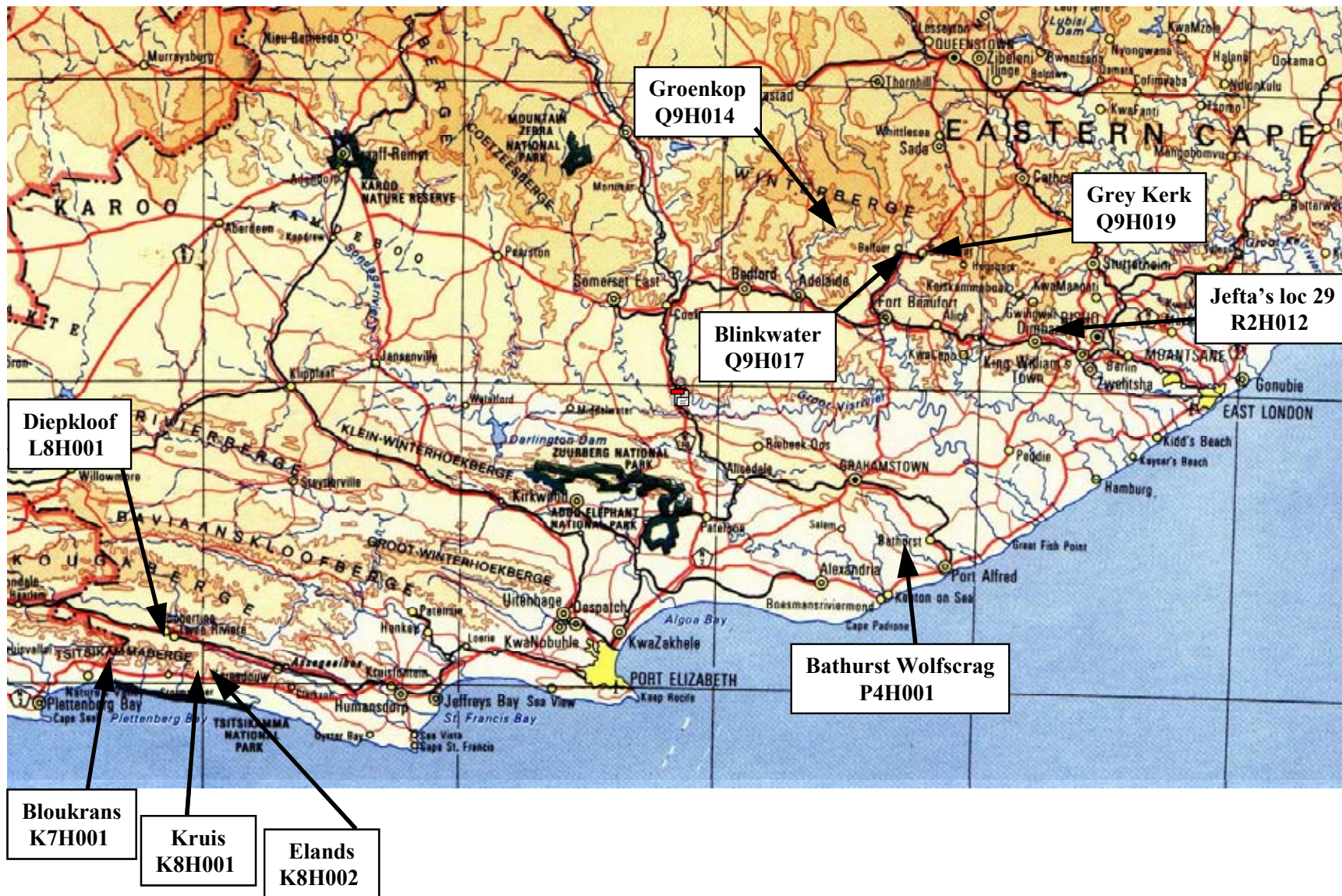


Figure 7 Locality plan of MSc river gauges selected

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