4 Determination of parameters for SIBERIA

4.1 Overview

The parameter estimation of the hydrology and sediment transport models described in the previous section provide the basis for estimation of the parameters for SIBERIA. SIBERIA is a model of the long-term erosional behaviour of landscapes. Thus the parameters of SIBERIA characterise the average properties of the landscape and its processes, not the instantaneous or point values as calibrated in the hydrology and erosion studies above. However, there is very good reason to believe (Willgoose et al 1989, Huang & Willgoose 1992) that the requisite average parameters can be obtained from the hydrology and erosion models calibrated in previous sections. The parameters in SIBERIA can be considered in two groups.

The first group of parameters in SIBERIA define how the erosion varies with time, over periods of many years. This involves the averaging of the erosion that occurs in each runoff event, calibrated in section 3, to give the mean annual sediment yield. This mean annual sediment yield is not simply dependent on the sediment transport rate for a particular discharge and slope but also the range of discharges occurring during individual runoff events and the frequency at which these runoff events occur. Willgoose et al (1989) has shown that the simple concentration-discharge-slope dependence calibrated above in equation 3.4.2 is maintained in the mean annual formula but that the discharge used in the equation changes from being the discharge at that time to the mean peak discharge obtained from a frequency analysis of runoff events. This peak discharge can in turn be related to the contributing area to that point. This mean peak discharge is very similar in interpretation to the dominant discharge, or channel forming discharge, commonly used by river engineers in river sediment transport studies. The process that is followed in this report will be to simulate, using the hydrology model and observed pluviograph records for Jabiru, a runoff and erosion time series. The resulting erosion series will be averaged over the simulated record and the average sediment transport rate will be related to the mean peak discharge estimated by the hydrology model.

The second group of parameters define how the hydrology changes at different points within the catchment and, in particular, how the mean peak discharge varies with area—the scale dependence of the runoff hydrology. The hydrology model will use the digital terrain map of the proposed mine sites to simulate the variation of discharge with area for specified rainfall data. This model will then be used below to predict the scale dependence of the mean peak discharge; the variation of the discharge with increasing area and slope.

Finally, to predict the extent of potential gullying a gully threshold for the gully development module of the SIBERIA model is required. Data for a nearby natural site with similar regolith properties are used to estimate the magnitude of this threshold and its dependence on hillslope gradient and area.

This calibration process is summarised in figure 4.1.

4.2 Scale dependence of the hydrology

Some of the most important parameters in SIBERIA are those that define how the discharge used in the calculation of the sediment transport rate varies with catchment area. The general form of the relationship between discharge and area used in SIBERIA is given in equation 1.3.3. This relationship has been widely used in empirical studies of catchment hydrology and is the basis of mainly regional relationships for flood frequency.

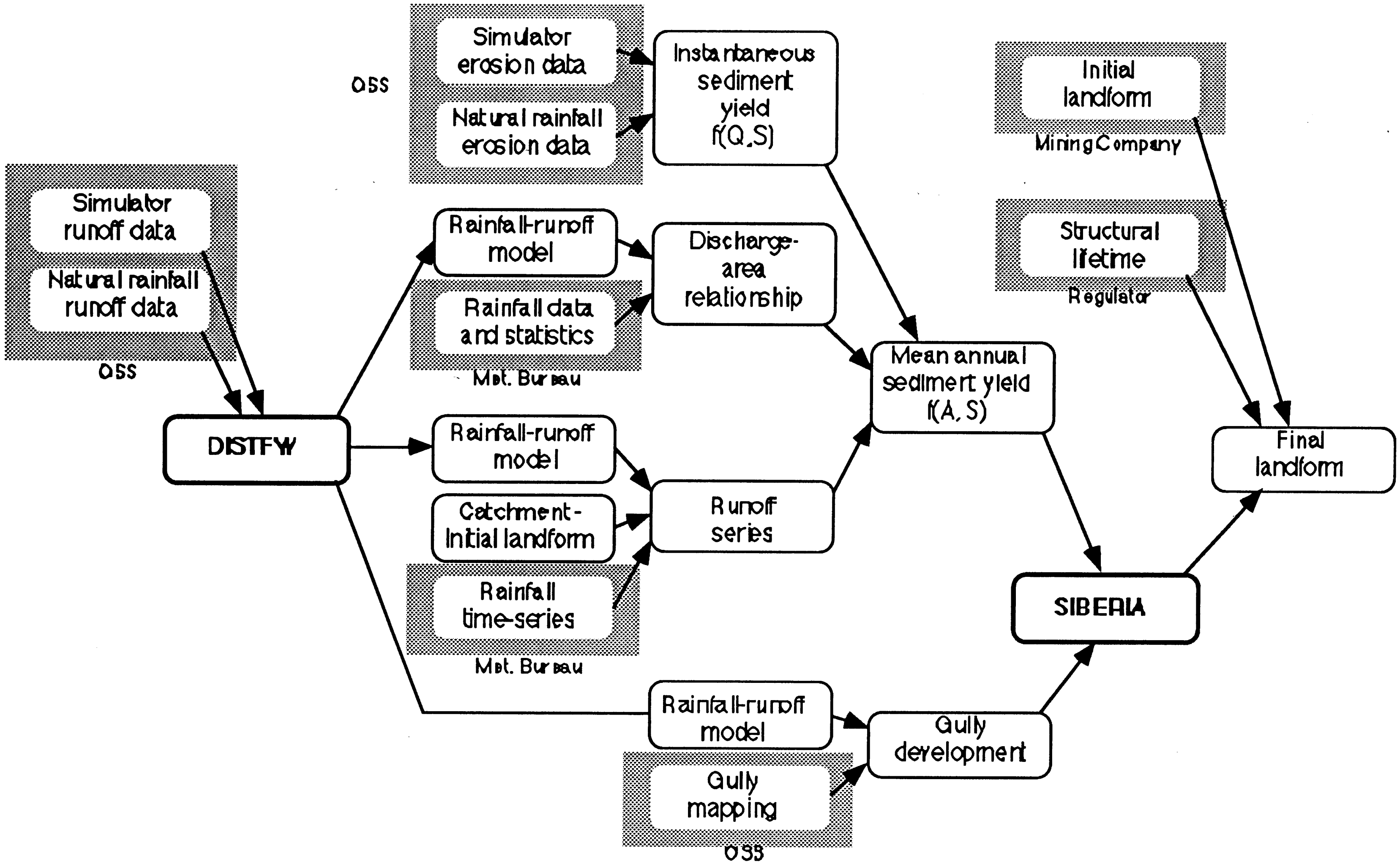


Figure 4.1 Schematic of the calibration process and use of SIBERIA

Recently, Huang and Willgoose (1992, 1993) have studied how the DISTFW rainfall-runoff model may be used to determine this relationship. This process is only valid for small catchment where it is reasonable to assume that the rainfall in all parts of the catchment are the same.

The process is as follows

1 Calibrate or select the parameters for the DISTFW model.

2 From Intensity-Frequency-Duration (IFD) curves of rainfall the 2 year storms of various durations are selected. Using the rainfall temporal patterns from Australian Rainfall and Runoff each of these storms is applied to the catchments and the peak discharge for every node in the catchment is noted for each storm.

3 The peak discharge at each node from the various duration 2 year storms is determined (smaller areas have highest discharge from short storms, larger from longer storms). These peak discharges are then plotted against area and the coefficients of the discharge-area relationship in SIBERIA are directly fitted from the graph. Huang and Willgoose (1992) have found that the correlation coefficient of this relationship is very high, and that the parameters in the relationship are a function primarily of the conveyance parameters in the rainfall-runoff model.

This process was followed to determine the area dependence of the discharge at RUM. It might be noted that equation 1.3.3 allows a slope dependence on discharge. Functionally, this dependence is only of importance when there are wholescale changes in the average slope of the catchment with time. This is not the case in this study so this dependence is ignored (ie n_3=0) and the discharge-area relationship is calibrated for the initial slopes.

Using the 30 m digital terrain map of the proposed rehabilitation strategy for the above-grade option the largest single catchment was defined (approx 1.6 km^2). This catchment was believed to have a hydrologic response typical of the other catchments on the rehabilitated area and is outlined in figure 4.2.

This digital terrain map was used as input to the digital terrain based version of DISTFW and a number of 1 in 2 year storms of different duration were simulated using IFD data for Jabiru. The 1 in 2 year storm was used because it is of about the same return period as the mean annual discharge (1 in 2.33 years), the discharge required by SIBERIA. The parameters used in DISTFW were those calibrated in section 2 with the exception of kinematic wave rate parameter as discussed below. For any node in the catchment the maximum peak discharge simulated from the different duration storms was calculated. This peak discharge was then plotted against area (fig 4.3) and the parameter m_3 calibrated. The adopted relationship for the 1 in 2 year discharge is

$$Q_2 = 0.000114\ A^{0.88} \qquad 4.2.1$$

The coefficient on this relationship, β_3, is not important as it only appears in SIBERIA in conjunction with the erosion rate parameter, β_1. These two parameters will be calibrated together in the next section where the mean annual erosion rate is determined.

As noted one parameter was changed from that in the calibrations of section 2. This was the kinematic wave rate parameter. This parameter is a function of the width of flow occurring (as well as Manning n). It was assumed in the work above that the width of flow in one node was half the grid spacing; ie 15 m. That is, that half of the surface area is flooded in a storm. For a rilled surface this is considered more reasonable than assuming that everywhere is flooded (ie classical overland sheet flow). Recent research in the US (Abrahams & Parsons 1991) has established that the classical model of overland sheet flow is unreasonable. The effect of this on the calibrated parameter, m_3, is relatively small as seen in figure 4.4. The general question of what proportion of the surface provides significant downslope flow (the so called rill area, as opposed to the remaining areas called interrill areas) is a major focus of research at this time (Willgoose & Riley 1993, Moore pers comm).

4.3 Long-term erosion rate and timescales for the simulation

For the determination of the long-term erosion rate a runoff series is created using the historical rainfall records at Jabiru and the calibrated rainfall-runoff model. Using the sediment transport equation previously calibrated and this runoff time-series an erosion time-series is generated and the average sediment transport per year can be determined.

The exceptionally large computational demands of generating a runoff series of sufficient accuracy for determining the average sediment transport rate from the engineered landform necessitated a multi-stage process for the generation of the runoff and erosion time-series.

1 The 1.6 km^2 catchment used in the hydrologic study of the previous section was used here for the sediment transport study.

2 This digital terrain map was used as input to the digital terrain based version of DISTFW and using a measured rainfall event a runoff event was simulated. Parameters used were those calibrated for the hydrology model in the previous section.

3 Using the plan of the catchment from the digital terrain map the conceptual subcatchment version of DISTFW with 10 subcatchments was calibrated to the simulated runoff event at the catchment outlet. Only one parameter was calibrated—the kinematic wave rate parameter; all other parameters are independent of whether the DTM or subcatchment version of DISTFW is used.

4 The subcatchment based model calibrated in 3 was then used to generate a 5 minute resolution runoff series for the catchment outlet from the 20 years of 30 minute pluviograph data for Jabiru.

5 Using the runoff data a time-series of the sediment yield from the catchment was then generated and averaged for each year. These results were then correlated to area and used as input to SIBERIA.

The key simplification in this process is in stage 3 which was required because to simulate the runoff data using the DTM rainfall-runoff model at 5 minute intervals would have required about 60 CPU hours per year on a high performance HP 710 workstation (about 3 times faster than a SUN SparcStation II workstation). The simplification of the runoff model did not significantly affect the accuracy and reduced the required computer time for the simulation of the 20 year runoff series to about 25 CPU minutes per year.

Figure 4.5 is a map based on the digital terrain map for the above-ground option. It shows the drainage network for the region including the engineered containment structure. The approximate boundary of the rehabilitated area is outlined on the map. The region selected for the hydrologic modeling is outlined on this figure. This region consists of 1773 nodes with area of 900 m^2 each for total catchment area of 1.6 km^2. The flow paths and the slopes were calculated by SIBERIA.

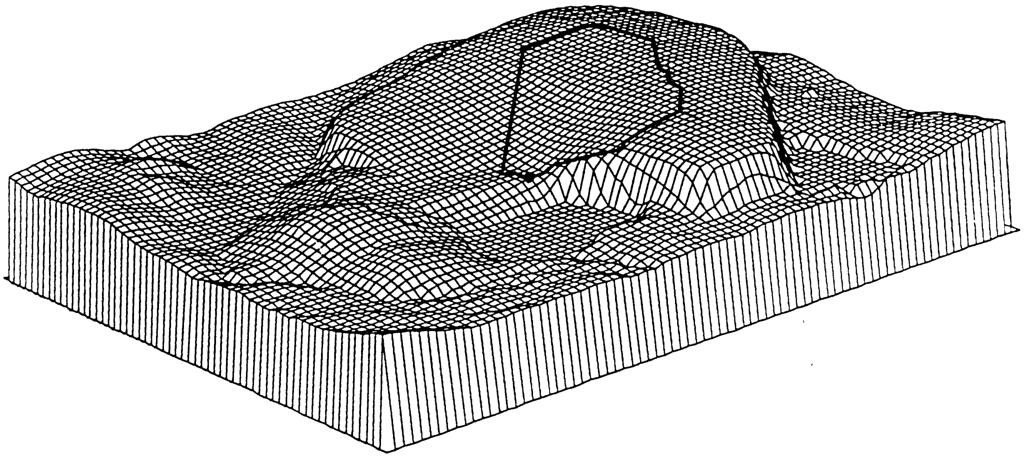


Figure 4.2 Perspective of the study catchment used for the hydrology study

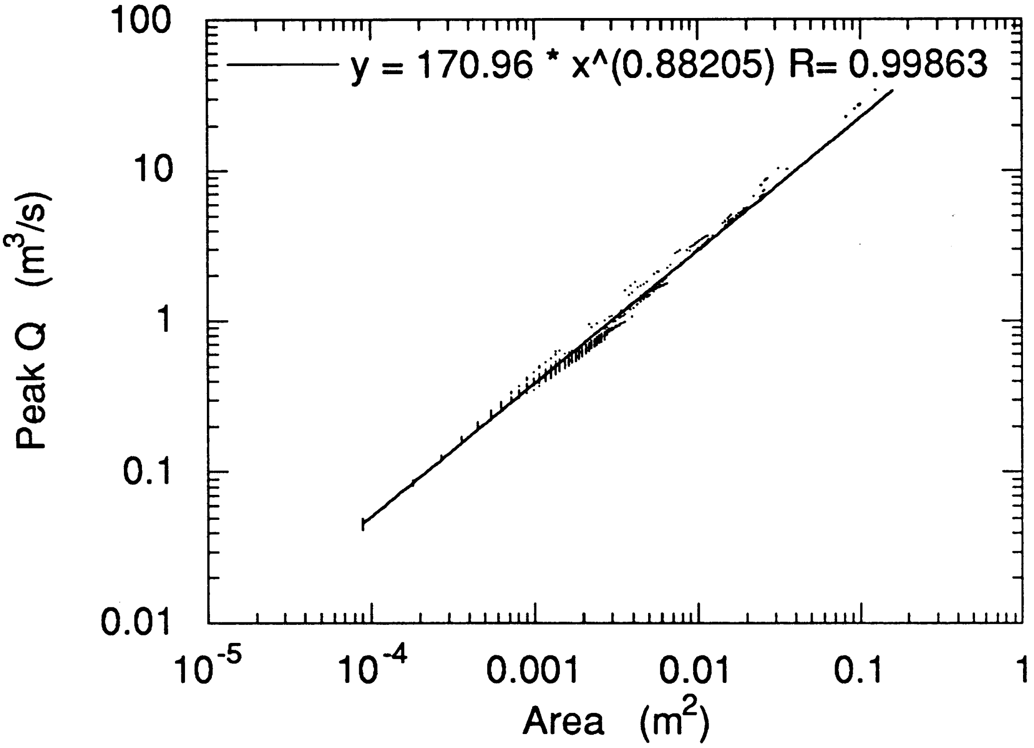


Figure 4.3 Discharge-area relationship for the 1 in 2 year storm for each node in the study catchment

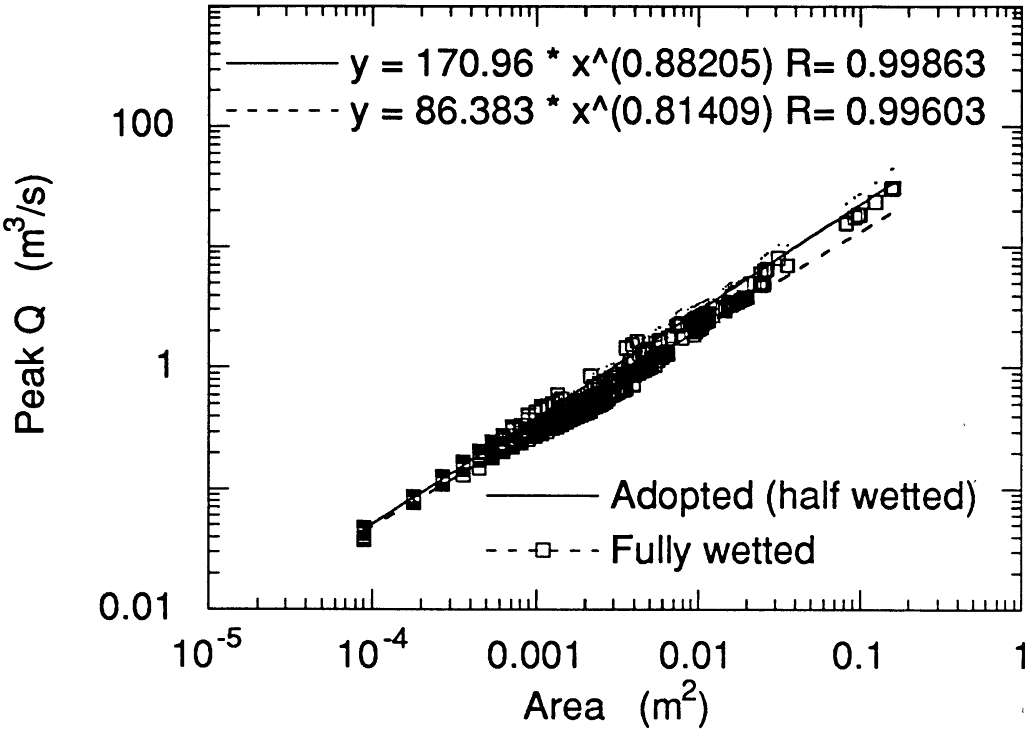
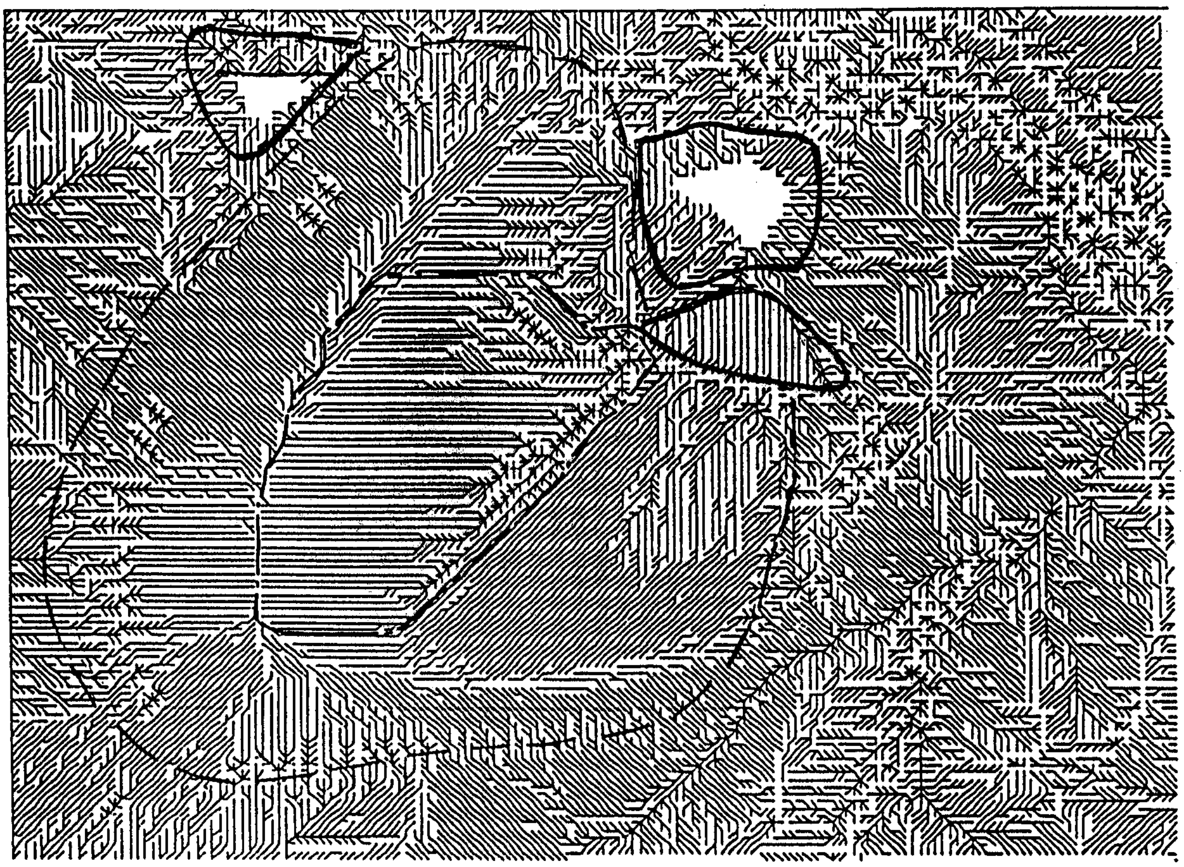


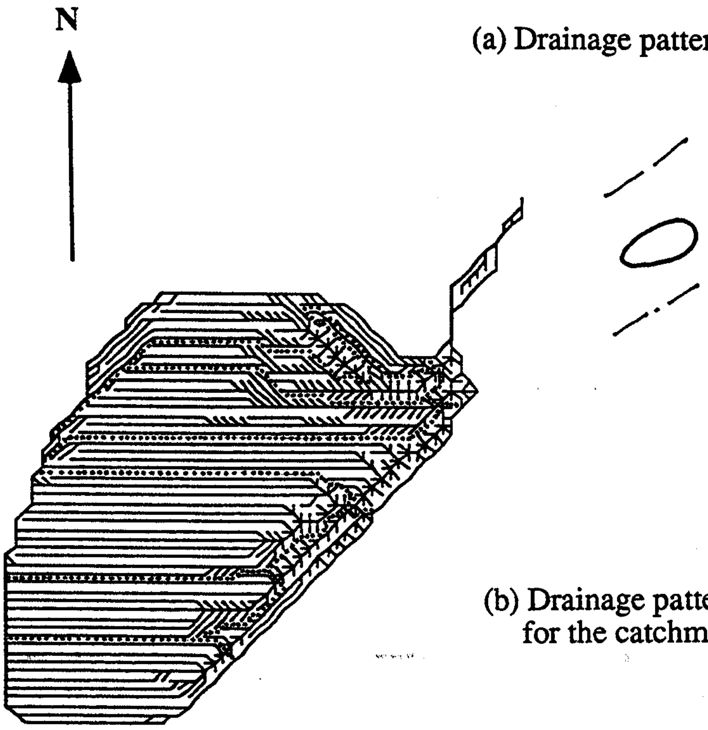
Figure 4.4 Sensitivity study on the discharge-area relationship for the 1 in 2 year storm for each node in the study catchment

The next stage was the calibration of the subcatchment model to the DTM model output. It was found on the work in the section 4.2 that the approximate time of concentration of the selected catchment was 60 minutes. The rainfall events that were collected and discussed as part of the calibration work (table 2.2) were examined and a storm that was close to the time of concentration was selected. The selected storm was the batter gauge on 21/1/91. The hydrograph from the catchment is shown in figure 4.6. The parameters used for this hydrograph are those for the adopted case used in the previous section with the exception of the sorptivity and the steady state infiltrations rate which were set to 0. The drainage paths within the catchment were then examined to select the 10 subcatchments for the subcatchment model. The selected subcatchments, together with the drainage pattern for the DTM model are shown in figure 4.5. As previously noted the only parameter that needed to be calibrated was the conveyance rate parameter, all others do not change (eg infiltration rates) from that in the DTM model. Figure 4.6 shows the satisfactory result of the calibration of the subcatchment model.

The final stage in the hydrology calculation was the simulation of the runoff time-series. For this ***eriss*** provided a pluviograph record for Jabiru at 30 minute resolution. This data series began in mid–1971 and ended in mid–1990. It is not possible to use the longer-term rainfall records at Darwin because it has significantly different rainfall statistics from Jabiru (Riley 1991). There is no evidence to suggest that the record at Jabiru is statistically different from that expected at the mine site. While individual storms may vary substantially from Jabiru to the mine-site, passing over one but not the other, it is the statistical characteristics of the rainfall and runoff series that are important in determining the mean runoff and sediment transport rates.



(a) Drainage pattern for above-grade option



(b) Drainage pattern and adopted subcatchments for the catchment used in the hydrology study

Figure 4.5 The drainage pattern of the study catchment used in the hydrology study

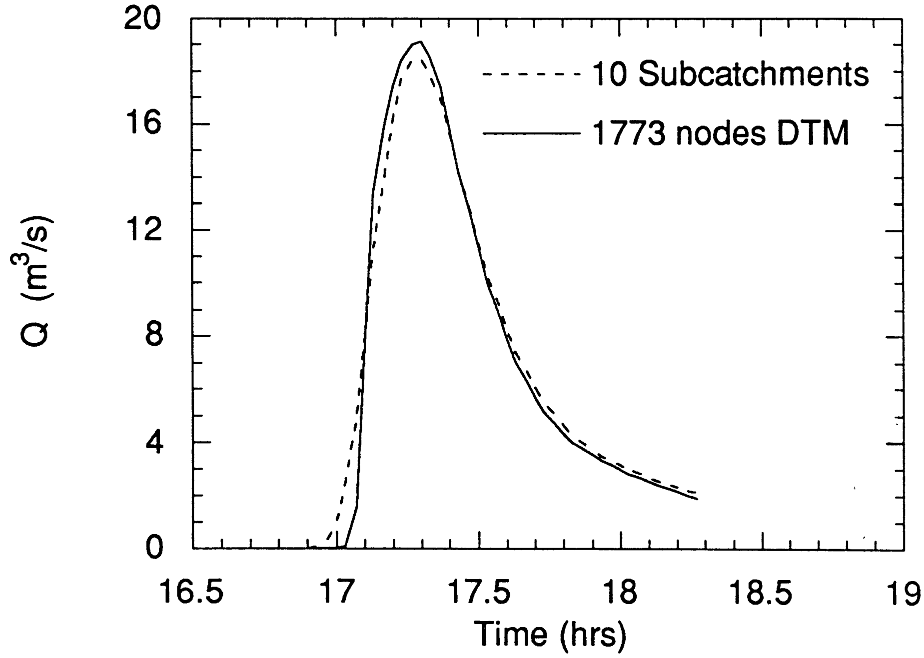


Figure 4.6 Calibration of the 10 subcatchment runoff model to the output of the 1773 node DTM runoff predictions for the event of 22/1/91

The Jabiru record is separated into two halves by a 3 year gap from 1980–1983. Data recovery from the early period was poor with substantial gaps in both the Dry and Wet seasons but data recovery is considerably better in the second half. It was necessary to simulate this runoff series at 5 minute intervals for almost 20 years of data. It was assumed that where rainfall data were missing during the Dry season rainfall did not occur.

Finally, this runoff series was used to simulate the erosion series. The adopted erosion model of equation 3.4.2 was used for this purpose. This erosion loss is considered to be indicative of losses that will occur from the cap of the engineered landform when it is in the unvegetated state. Losses from the batters are expected to be considerably higher because of the higher slopes. That there are higher losses on the batter compared with the caprock will be confirmed in the analysis of section 5.

4.4 Gully thresholds

One of the novel features of SIBERIA is its ability to model the dynamic development of gullies in response to hydrologic and erosional characteristics of the surface. Using a user-defined threshold, a gully occurs when that threshold is exceeded by a function called the channel initiation function (CIF). This CIF is a function of the hydrology upstream of the gully head. This hydrology is, in turn, a function of upslope area and slope. The CIF can be a function of the velocity of the overland flow, the shear stress of the overland flow, or, in areas dominated by groundwater flow, various functions of the groundwater head gradient. Most importantly, these functions are positively correlated with runoff and rainfall, area upstream of the gully head and the slope at the gully head (Willgoose et al 1989). Everything else being equal increases in rainfall, runoff, area and slope increase the tendency for a gully to erode at any given point in a catchment. This threshold behaviour based on area, slope and runoff has been widely observed in natural catchments (Patton & Schumm 1975, Montgomery & Dietrich 1988). At this time there is some inconclusive data for mine spoils (eg Elliott 1988) but the natural data suggest that similar mechanisms will occur in mine rehabilitation sites.

SIBERIA requires that this area-slope-runoff relation be determined *a priori* from field data and used as input parameters to the model. Once a gully is triggered, by exceeding the channel initiation threshold, the excavation of that channel proceeds using the sediment transport physics calibrated in section 3 of this report.

No data exist for the RUM rehabilitation site at this stage to allow the calibration of such a relationship. However, Williams and Riley (1992) have examined a natural area (Tin Camp Creek) derived from similar geologic material, schists. These data could be expected to be *reasonably indicative* of gullying behaviour of the mine site at some time in the future when the spoil site has developed a natural soil profile. However, without matching hydrologic data any conclusions on gully development on RUM must be made with extreme caution. Since the soils at both sites will be largely derived from the fast weathering schists in the outcropping rocks then it is likely that the soil profile will be similar. The main difference between the sites is that Tin Camp Creek is underlain at a relatively shallow depth by bed rock while the waste rock dump is not. This may affect the hydrology (and through it the channel initiation behaviour). The shape and size of the gullies will probably be only slightly different because it appears that most of the gullies at Tin Camp Creek do not excavate down to bedrock and where they do the bedrock is heavily weathered and friable; gully depth at Tin Camp Creek is not constrained by bedrock levels.

The form of the channel initiation function, $\boldsymbol{a}$, and its threshold, $\boldsymbol{a}_t$, used by SIBERIA is

$$\boldsymbol{a} = \beta_5\, \boldsymbol{q}^{m_5}\, \boldsymbol{S}^{n_5} \overset{<}{>} \boldsymbol{a}_t \qquad 4.4.1$$

This function is both consistent with field data (Willgoose et al 1990) and justified from theoretical considerations (Willgoose et al 1989, Dietrich pers comm). If the discharge-area-slope relation of equation 1.3.3 ($\boldsymbol{q} = \beta_3 \boldsymbol{A}^{m_3} \boldsymbol{S}^{n_3}$) is adopted, then this relation can be re-expressed as

$$\boldsymbol{a} = \beta_5\, \boldsymbol{A}^{m_5} \boldsymbol{S}^{n_5} \overset{<}{>} \boldsymbol{a}_t \qquad 4.4.2$$

where the primed variables are functions of the parameters of the CIF and the discharge relationships. Williams and Riley (1992) used discriminant analysis to identify two relationships, each with a threshold, that defined the transition from ungullied to knickpoint, and from knickpoint to gullied. The general form of their recommended relationship was of the form

$$\boldsymbol{a} = \beta_6 + \boldsymbol{AS} + l \overset{<}{>} \boldsymbol{a}_t \qquad 4.4.3$$

where l was the slope length, which can be considered a surrogate of area (ie $l \sim A^{1/2}$). For this study it was necessary to reinterpret their data to develop a relationship of the form of equation 4.4.2.

Discriminant analysis (Mosteller & Tukey 1977) was used to identify the threshold between gully and ungullied. For this purpose, those points that were ungullied were given a discriminant value of 1, knickpoint 2, and gullied 3. A knickpoint is a gully head. At a gully head the channel initiation function equals the threshold (if it were less than the threshold then it would not be a gully, if it were greater than the threshold then it would not be the gully head—some point upstream with less area would be). Thus the line with discriminant value 2 defines the threshold between gullied and ungullied. The data analysis is plotted in figure 4.7 and the resulting channel initiation function is given as

$$\boldsymbol{a} = \boldsymbol{A}^{2.27} \boldsymbol{S} \overset{<}{>} 23.6 \text{ x } 10^6 \qquad 4.4.4$$

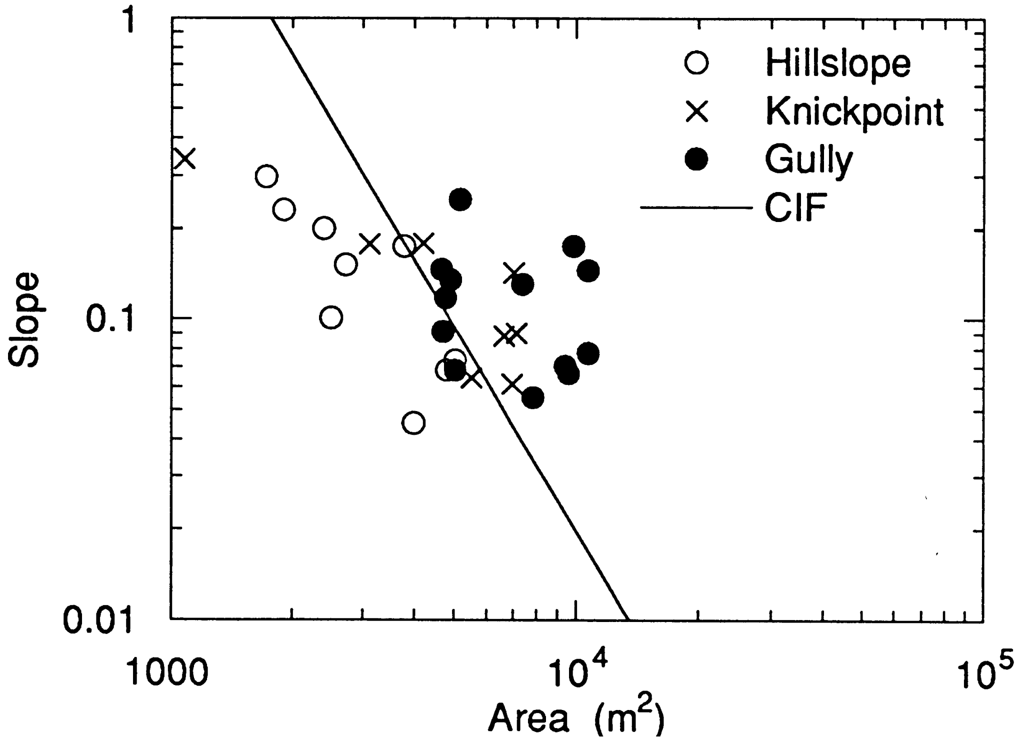


Figure 4.7 Adopted threshold for distinguishing gully from hillslope (data from Williams & Riley 1992)

The power on area in the above expression is in the range of values that have been observed for natural catchments and within the range of values predicted from theory. For a slope of 0.15 (approximately that of the waste rock batters) it predicts an area of about 4000 m^2 which for a planar slope is a slope length of about 65 m. For a slope of 0.02 (approximately that of the waste rock cap) it predicts an area of about 10 000 m^2 which for a planar slope is a slope length of about 100 m. It appears that the discriminating power of equation 4.4.4 and that of Williams and Riley (1992) are similar.

5 Assessment of proposed RUM landforms

5.1 Overview

The relationships that have been developed in the preceding sections were used to determine the parameters to be used by SIBERIA for the assessment of the various cases to be studied in this project. Two potential baseline designs were examined for the extent and location of erosion and deposition at the end of the design lifetime of 1000 years. They were the so-called above-grade and below-grade options as proposed by RUM where the tailings were stored above-grade and below-grade in a mine-pit, respectively.

A number of sensitivity studies have been carried out to assess the reliability of the predictions for the baseline above- and below-grade options.

Most importantly, the effect of settlement of the landform was examined. Richards (1987) believes that settlements of up to 1 m can be expected, randomly distributed in space. Random fluctuations on the initial elevations were imposed and the effect on the erosion was examined.

The gully threshold information from Tin Camp Creek is used to predict the extent of the gully erosion that will occur. The effect of gully erosion is to incise a localised gully into the