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Article

# Sediment Modelling of a Catchment to Determine Medium-term Erosional Trends

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**Abstract:** This study is part of a project designed to simulate the long-term landform equilibrium of a rehabilitated mine site. The project utilizes event fine suspended sediment (FSS) fluxes in a receiving stream following a rainfall event as an indicator of landform stability. The aim of this study was to use HEC-HMS to determine sediment and discharge quantity upstream to determine how it affects the downstream development of the catchment landform, in terms of sediment changes and geomorphology. Thus, the study focused on hydrology and sediment modelling of the upper catchment with HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) to determine daily discharge and sediment output at the catchment outlet. HEC-HMS was used to calibrate the stream discharge and FSS quantities at the catchment outlet to observed continuous discharge and FSS values. Calibration of the HEC-HMS model was done for two water years and then the same model parameters were used to validate the model for a third water year. Catchment discharge and FSS were calibrated and validated for continuous rainfall events against observed discharge and FSS data at the catchment outlet. The model was then run for a projected rainfall of 50 years. The denudation rate predicted by the model falls in the range previously determined for the region. The simulated sediment output was compared to the rainfall trends over the years. As a result, the sediment spikes following a rainfall-runoff event gradually decreased over time. Reducing FSS spikes indicate that the landform gradually attains stability. This modeling study can be used for long-term simulations to determine erosion equilibrium over the years and to quantify sediment yield in catchments for projected wet and dry rainfall scenarios.

**Keywords:** catchment hydrology; erosion modeling; stream sediment transport

## 1. Introduction

Soil erosion in tropical countries is triggered due to geologically weathered soils, intensive rainfall, inappropriate soil and land management practices, and mining activities. Where mining activities cause disturbance in catchment stream ecosystems, they are impacted by heavy loads of eroded material entering the streams [1] if not managed correctly. Transport of hydrophobic pollutants and heavy metals is often facilitated by suspended sediment particles eroded and taken down-stream during heavy discharge events [2]. Thus, suspended sediments correspond to particle-related pollutant transport from the catchment across the river reaches.

Stream-suspended mud also acts as an indicator of post-mining landform stability. During landform disturbance such as mining, fine suspended sediment (the silt and clay components of suspended sediment - FSS) spikes have been observed in the receiving waters following the disturbance. As the landform is rehabilitated and reaches equilibrium with the surrounding catchment, FSS spikes following rainfall events return to pre-mining levels [3]. The magnitude of FSS spikes following a known rainfall event can be a tool to measure landform stability [3]. Since FSS is highly mobile, many contaminants released by the catchment disturbance attach themselves to FSS

and are transported downstream [4]. Thus, erosional trends of a catchment imply associated sediment and pollutant transfer within the river reaches.

Quantification of stream sediments at the catchment outlet using gauging stations is a time-consuming process. It involves collecting water samples at high-discharge events which are then dried, sieved, and weighed to quantify sediments of different particle sizes. However, there is a strong correlation between turbidity (NTU) and mud concentration (silt and clay component of suspended sediment) [5]. Thus, continuous turbidity (NTU) data collected with turbidimeters at the catchment outlet of a stream can be used to measure changes in FSS load exiting the catchment.

Continuous discharge and FSS data measured at the catchment outlet facilitates catchment hydrology and erosion modeling. Modelling also requires knowledge of model input parameters that depict the catchment characteristics, such as transpiration and surface roughness. This provides an avenue to comment on dynamics of landform stability through simulated erosional trends and catchment erosion quantification based on rainfall events. Hydrology and sediment modelling of the catchment enables simulations by the model for projected future rainfall events. This provides medium-term and long-term erosional trends of the catchment under different rainfall scenarios.

The broader objective of the project is to validate an approach using an event-based stream FSS discharge relationship in combination with a landform evolution model (LEM) to determine when erosion of a rehabilitated landform is at equilibrium with the surrounding catchment [6]. A rainfall event-based stream FSS/discharge relationship was developed using continuous receiving stream monitoring data in which a catchment disturbance caused a change in this relationship [3]. To evaluate the change in event stream FSS on account of a probable disturbance due to mining in the catchment, CAESAR-Lisflood LEM is calibrated and validated for the mining catchment. It is then run for future rainfall simulations to show changes over time and changes in response to differences in those rainfall scenarios [7]. It was found that CAESAR Lisflood accurately predicts event FSS for a specific discharge for early wet season but underpredicts for the later wet season. To run the LEM for a 1000-year period and to investigate how the event FSS/discharge relationship changes across the years, upstream continuous stream discharge and sediment input to the catchment is required. Therefore, the upstream catchment needs to be calibrated and modelled with the help of HEC-HMS to simulate future continuous discharge and sediment input to the lower catchment where the mine resides. The aim of this study was to use HEC-HMS to determine sediment and discharge quantity upstream of a catchment with mining to determine how those upstream inputs affect the downstream development of the catchment landform, in terms of sediment changes and geomorphology.

This study focusses on hydrology and sediment modeling of a catchment with HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System). The Hydrologic Modeling System (HEC-HMS) is designed to simulate the complete hydrologic processes and soil erosion of dendritic watershed systems [8]. The application is used to model the catchment by adjusting the parameters of the model such that an input like an observed rainfall event will give discharge and sediment output at the catchment outlet similar to that measured at the site. In this study, HEC-HMS was calibrated for two individual water years and the same model parameters were used to validate the model for a third water year. Observed discharge, fine suspended quantities and rainfall used for calibration and validation of the model were obtained from gauging stations. Rainfall for future simulations was computed with the help of a weather generator incorporating climate change factors. The model was then run for a time period of 50 years to explore the medium-term erosional trends of the catchment. The application also facilitates quantification of sediment mobilized and eroded from the catchment for different wetter and drier rainfall scenarios.

Previous studies indicate that the parameters that influence the erosion rate likely to occur on the landform will change in time. A study that focused on temporal trends in hydrology and erosion for the post-mining landform at Ranger mine, Alligator Rivers Region, Northern Territory, Australia, indicates that the amount of sediment transported from the rehabilitated landform at Ranger will decrease with time, particularly during the first 50 years after rehabilitation [9]. The SIBERIA Landform Evolution Model (LEM) was used to predict medium-term erosional characteristics for another site in the same region, the Scinto 6 site, and results shows that erosion in gullies reduces

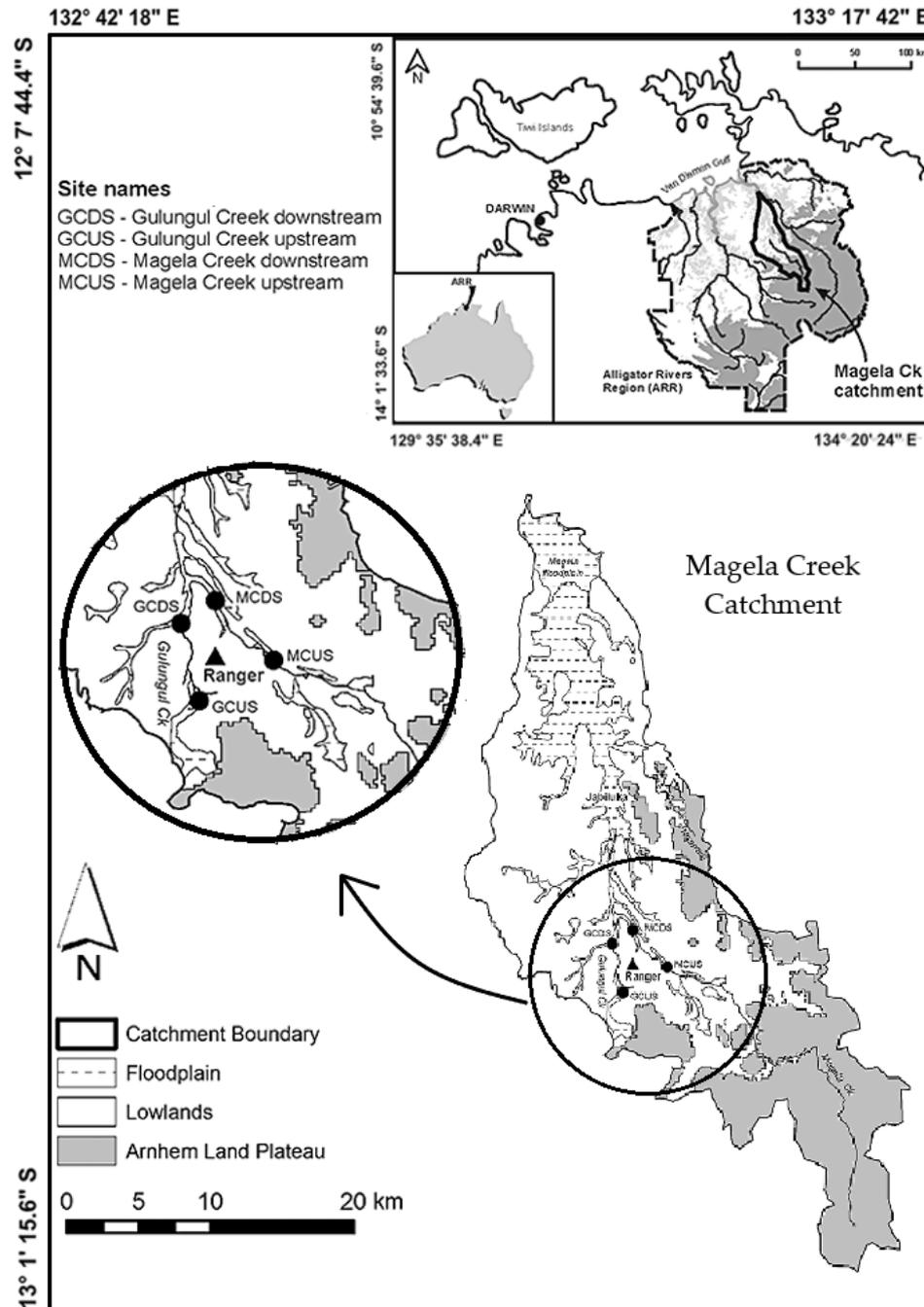
over time [10]. The catchment under consideration in this study for more detailed modeling of discharge and sediment quantification is the upper Gulungul Catchment in the Alligator Rivers Region.

## 2. Materials and Methods

### 2.1. Study Site

Ranger Mine (12°41' S, 132°55' E) is an open cut uranium mine operated by Energy Resources of Australia Ltd. (ERA) in Northern Territory, Australia. The mine is located 8 km east of the township of Jabiru in the Alligator River Region (ARR) and within the 78 km<sup>2</sup> Ranger Project Area which is surrounded by, but separate from, the World Heritage-listed Kakadu National Park. It has been producing uranium oxide (U<sub>3</sub>O<sub>8</sub>) since 1981 and is presently undergoing rehabilitation and closure. Mining ceased in 2012, milling of the mined ore ceased in early 2021 and work is now focused on rehabilitation [11]. The regional geology, climate and the location significance are detailed in [7]. ERA is responsible for the rehabilitation of Ranger Mine based on laid out principles called Environmental Requirements (ERs). The Australian Commonwealth Government Supervising Scientist has a supervisory role. ERs pertaining to erosion equilibrium of the landform require erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas. It is expected that the erosion rates will initially be high then tend slowly towards the natural rates. These timeframes are expected to be quite long so the outcome is to use the best available modelling to demonstrate that the erosion characteristics of the final landform will eventually be comparable to natural landscapes.

The Ranger Mine is adjacent to Magela Creek, a left-bank tributary of the East Alligator River [11]. Gulungul Creek is a small tributary of Magela Creek that is adjacent to the tailings dam. It is one of the tributaries that would be the first to receive sediment generated from the mine site during and after rehabilitation [12]. Gulungul and Magela Creeks are ephemeral, braided, sand-bed streams which carry very large sand loads (bed and suspended bed) and small FSS (fine suspended sediment) loads. The Environmental Research Institute of the Supervising Scientist (eriss) monitored sites in Gulungul Creek downstream (GCDS), Gulungul Creek upstream (GCUS), Magela Creek downstream (MCDS), and Magela Creek upstream (MCUS) of the mine (Figure 1). The data obtained from eriss for this study were continuous discharge (m<sup>3</sup>s<sup>-1</sup>), and turbidity (NTU) and FSS (<63 μm fraction of sediment samples collected in the auto-samplers; mg). Data were from August 2004 to August 2015 measured at a frequency of 6 min for Gulungul Creek GCDS and GCUS. Rainfall data for GCDS and GCUS at 10 min intervals were also obtained for modelling Gulungul catchment in CAESAR-Lisflood.



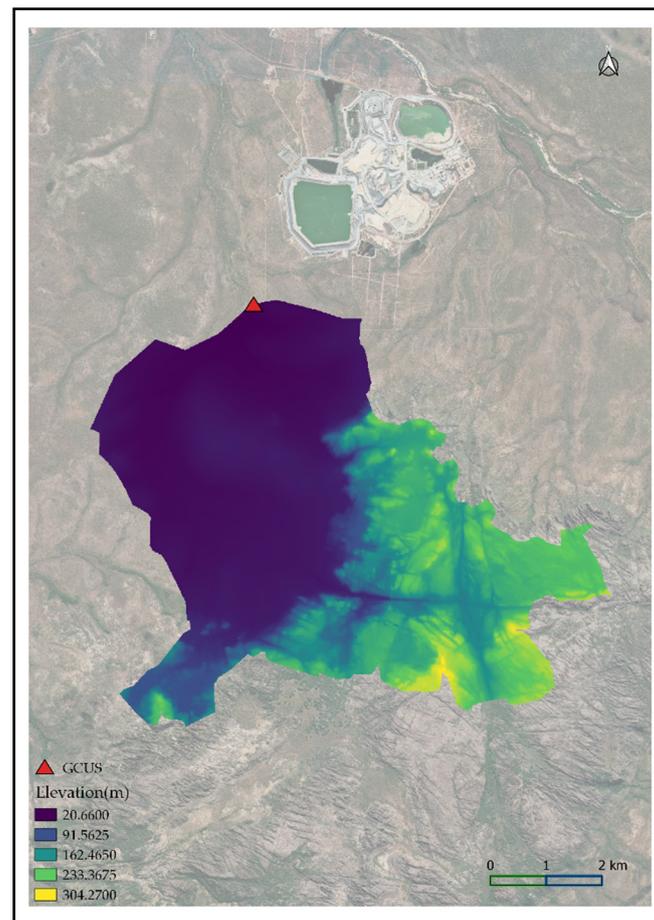
**Figure 1.** Location of gauging stations at Ranger. Adapted from [13]; copyright Commonwealth of Australia.

## 2.2. HEC-HMS Model

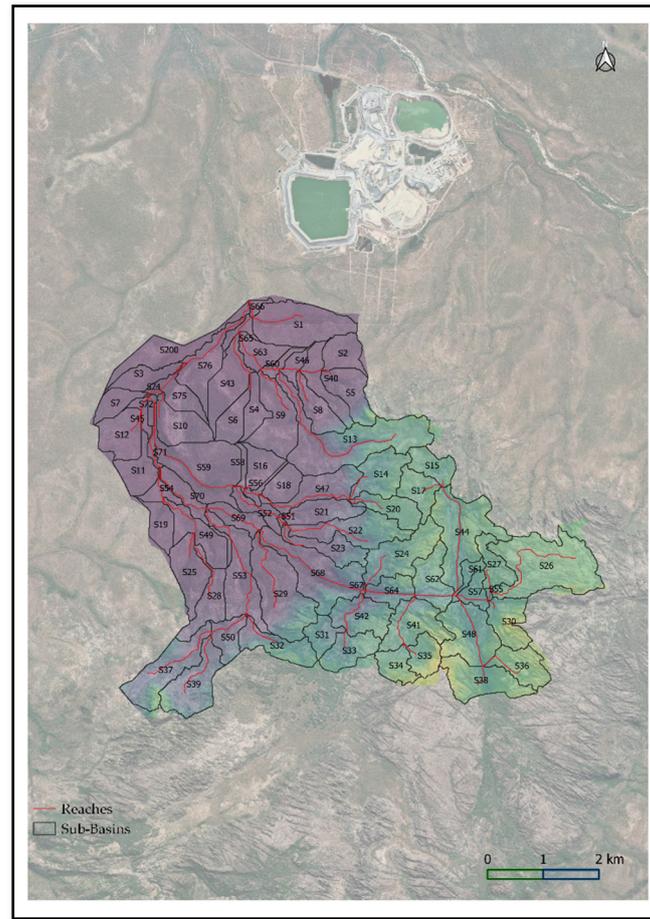
HEC-HMS is designed to simulate complete hydrological processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. It also includes procedures necessary for continuous simulation including evapo-transpiration, snowmelt, and soil moisture accounting. The physical representation of a watershed is accomplished with a basin model. Hydrologic elements are connected in a dendritic network to simulate runoff processes. Available elements include sub basins, reaches, junctions, reservoirs, diversions, sources, and sinks. Computation proceeds from upstream elements in a downstream direction [8]. Modeling of the Upper Gulungul Catchment involved the following components:

1. Precipitation methods which can describe an observed (historical) precipitation event or a frequency-based hypothetical precipitation event.
2. Evapotranspiration methods
3. Loss methods which can estimate the amount of precipitation that infiltrates from the land surface into the soil. By implication, the precipitation that does not infiltrate becomes surface runoff.
4. Direct runoff methods that describe overland flow, storage, and energy losses as water runs off a watershed and into the stream channels generally called transform methods.
5. Baseflow methods that estimate the amount of infiltrated water returning to the channel.
6. Hydrologic routing methods that account for storage and energy flux as water moves through stream channels.
7. Models of naturally occurring confluences (junctions) and bifurcations (diversions)
8. Basin and stream erosion methods [14].

The hydrology, soil erosion and sediment routing capabilities of HEC-HMS were applied to the Upper Gulungul catchment (UGC) (Figure 2) an area of 39.1 km<sup>2</sup> which drains to an imaginary outlet at GCUS. Thus, the catchment modelling is done such that the continuous discharge and sediment output of UGS is similar to the observed values at gauging station GCUS (Figure 2). For this study, a 10m resolution DEM of UGC (Figure 3) was used in HEC-HMS and the watershed was divided into 77 sub-watersheds/basins and 38 reaches for modelling. The sub-basins and reaches were delineated by HEC-HMS based on DEM data.



**Figure 2.** Digital Elevation Model of Upper Gulungul Catchment.



**Figure 3.** Basins and reaches identified in HEC-HMS for Upper Gulungul Catchment.

### 2.2.1. Parameters

The parameters used for modelling are tabulated in Table 1 below and a detailed description of the same follows.

**Table 1.** Parameters used in HEC-HMS for Calibration.

Parameter	Method		Value	Source
Canopy	Simple	Maximum Storage	175mm	Field Data*, Calibrated Value
		Initial Storage	0%	Field Data*
		Crop Coefficient	1	
		Evapotranspiration	only dry periods- 0.005m/day	
		Uptake method	Simple	
Loss	Deficit and Constant	Maximum Storage	175mm	Field Data*, Calibrated Value
		Initial Deficit	175mm	Field Data*, Calibrated Value
		Constant Rate	0.175 to 0.225 mm/hr	ARR Data Hub, Calibrated value
		Imperviousness	10 to 60%	Field Data*, Calibrated value
Transform	SCS Unit Hydrograph	Graph Type	Standard (PRF 484)	

Baseflow	Recession	Lag Time	30-150 min	[15]
		Initial Discharge	0	Field Data*
		Recession Constant	0.8	Calibrated Value
Erosion	Modified USLE	Threshold Type: Ratio to Peak	0.3	Calibrated Value
		Erodibility Factor	0.03	[16]
		Topographic Factor	0.22-2.82	
		Cover Factor	0.01-0.03	
		Practice Factor	1	
		Threshold	1	Calibrated Value
		Exponent	0.56	Calibrated Value
Routing	Muskingum Cunge	Gradation Curve	Sub-basin Particle size distribution	[17]
		Initial Type	Discharge=Inflow	
		Length	Reach length characteristics	HEC-HMS
		Slope	Reach slope characteristics	HEC-HMS
		Manning's n	0.07	Calibrated Value
		Space-Time Method	Auto DX Auto DT	
		Index Method	Flow	
		Index Flow	1.7m <sup>3</sup> /s	Average annual flow
		Shape	Trapezoid	Reach Profile in GIS
		Width	50m	Reach Profile in GIS
Sediment	Volume Ratio	Initial Bed Curve	Stream Particle size distribution	[7]
		Bed Width	10m	IR574
		Bed Depth	2m	IR574
		Active Bed Factor	1	IR574
Transport Potential Method	Wilcock & Crow			
Fall Velocity Method	Van Rijn			

\*Field data obtained from eriss.

Rainwater is infiltrated until rainfall exceeds the infiltration capacity of the soil after which excess precipitation formed on the surface that contributes to the run-off. Deficit and constant loss method was used to compute precipitation losses in this study since this allows for continuous simulation when used with a canopy method that will extract water from soil in response to potential evapotranspiration computed in meteorological model [18]. Since the watershed in the study has distinct wet and dry seasons and model calibration is done for water years from the start of wet season, initial storage was 0% and initial deficit equals maximum storage in deficit and constant loss method. The initial deficit, constant loss and imperviousness for basins were attained from ARR data hub and calibrated accordingly [19]. The calibrated value of initial deficit was 175mm and constant loss rate varied from 0.175 to 0.225 mm/hr. The evapotranspiration value for the catchment was taken as 5mm/day [20].

The actual surface runoff calculations for a sub basin element are performed by a Transform method. SCS (Soil Conservation Service) unit hydrograph was used as a transform method in this study. The unit hydrograph is a technique for modeling the transformation of excess precipitation to runoff at the watershed scale. The SCS unit hydrograph method defines a curvilinear unit

hydrograph by first setting the percentage of the unit runoff that occurs before the peak flow. The percentage of runoff occurring before the peak is reflected in the Peak Rate Factor (PRF). The default unit hydrograph has a PRF of 484 which is used in this study [21]. The catchment lag time is calculated from equation 1 [15].

$$\begin{aligned} \text{Lag Time (min)} &= \text{Time of Concentration} / 1.67, \\ \text{Time of Concentration (min)} &= (107nL^{0.333}) / S^{0.2} \end{aligned} \quad (1)$$

where, n= roughness value (n=0.035 for bushland)

L=overland sheet flow path length (m)

S=slope of surface (%) = [m/km]/10

L and S are attained from sub-basin characteristics in HEC-HMS

Recession Baseflow method is used to compute baseflow contributions to sub-basin outflow. The two constants, namely Recession constant and Ratio to peak constant used in the method can vary from 0 to 1. The calibrated constant values for this study were 0.8 and 0.3 respectively.

Surface erosion can be computed at sub-basin elements using the MUSLE approach. It computes the total sediment load transported out of the sub-basin. Sediment yield using MUSLE is calculated using equation 2 [22].

$$\text{Sediment yield (tons)} = 95(Q_{\text{surf}} \times q_{\text{peak}})^{0.56} \times K \times LS \times C \times P \quad (2)$$

where  $Q_{\text{surf}}$  is the surface runoff volume (acre feet),  $Q_{\text{peak}}$  is the peak runoff rate (cubic feet per second), K is the soil erodibility factor, LS is the topographic factor, C is the cover and management factor, and P is the support practice factor. The erodibility factor K describes the difficulty of eroding the soil. The topographic factor LS describes the surface's susceptibility to erosion due to length and slope. The practice factor P describes the effect of specific soil conservation practices. The cover factor describes the influence of plant cover on surface erosion. The values for K, LS, C and P for the watershed were determined from CSIRO (Commonwealth Scientific and Industrial Research Organisation) data raster maps [16,23]. The threshold factor is the peak flow less than which there will be no erosion or sediment yield. The calibrated value of threshold factor in this study was  $1 \text{ m}^3/\text{s}$ . The exponent is used to distribute the sediment load into a time-series sedigraph which was 0.56 in this study. Gradation Curve is the sub-basin sediment particle size distribution of the watershed area where the catchment belongs [24].

The transport potential of the watershed specifies which method to use to calculate the stream flow sediment carrying capacity for non-cohesive sediments. The transport potential method used in this study was the Wilcock and Crow method [25] and the fall velocity method which determines the time required for the deposition of sediment from water column to the stream was the Van Rijn method [26].

While a reach element in HEC-HMS conceptually represents a segment of stream or river, the actual calculations are performed by a Routing Method contained within the reach. The routing method used in this study was Muskingum Cunge. The initial type of method was selected as assuming that the initial inflow is the same as the initial outflow to the reach from upstream elements. The length and slope of the reach were taken from reach characteristics in HEC-HMS. The Manning's n roughness coefficient value was a calibrated value of 0.07. For the space-time method, Auto DX Auto DT Method was selected so that the program will automatically select space and time intervals that maintain numeric stability. The Index flow was taken as the average value of hydrograph under consideration. The reach cross section shape was given as trapezoid and the corresponding parameters of width and side slope were attained from Digital Elevation Model (DEM) reach profiles using GIS (Geographic Information System).

Sediment processes within a reach are directly linked to the capacity of the stream flow to carry eroded soil. The volume ratio method links the transport of sediment to the transport of flow in the reach using a conceptual approach. The bed width was the width of the sediment bed which is used in computing the volume of the upper and lower layers of the bed model. Bed depth is the total depth

of the upper and lower layers of the bed. The active bed factor is used to calculate the depth of the upper layer of the bed model. The values for bed width, bed depth and active bed factor for the catchment were taken as 10m, 0.2m and 1 respectively [27]. The initial bed curve defines the distribution of the bed sediment by grain size at the beginning of the simulation. The computed particle size distribution of different grain sizes at GCUS was used as input [7].

### 2.3. Rainfall

The rainfall gauging station at GCUS (figure 1) gives continuous rainfall data at 10 min intervals. Since GCUS lies at the outlet of the Upper Gulungul catchment, using the same data to account for daily rainfall in the whole catchment was not accurate for calibration and validation of the HEC-HMS model. Thus, daily rainfall data were attained for water years 2012-13, 2013-14 and 2014-15 for modeling purposes from SILO which is a database of Australian climate data from 1889 to the present [28]. SILO gives rainfall point data at 5 km intervals. SILO data from points available across and near the catchment were considered and Voronoi polygons were drawn in QGIS [29] to determine the area of the catchment influenced by each rainfall point data [7]. Daily rainfall data from six such data points were sorted to determine the rainfall that influences respective sub-basins of the catchment.

Area Reduction Factors (ARF) were then applied to the rainfall data. The point data gives rainfall intensity at a single point. For large catchments, the rainfall intensity is always not constant across the whole of the catchment during a storm. To account for this, an ARF is included to estimate the average rainfall over the whole of a large catchment [30]. The equation for ARF is given in equation 3. Computed ARF value of 0.89 for the catchment was then multiplied with the point data rainfall intensity available at six SILO points to account for the whole catchment. This data was used as rainfall input for respective sub-basins in the model for calibration and validation.

$$\text{ARF} = [1 - a(\text{Area}^b - c \log_{10} \text{Duration}) \text{Duration}^{-d} + e \text{Area}^f \text{Duration}^g (0.3 + \log_{10} \text{AEP}) + h 10^{i \text{Area} \text{Duration} / 1440} (0.3 + \log_{10} \text{AEP})] \quad (3)$$

where a, b, c, d, e, f, g, h and i are ARF parameters specific to the region under study [19].

For future simulations of over 50 years, simulated rainfall data needs to be used as input with adequate climate change factors incorporated. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change [31]. CSIRO and the Australian Bureau of Meteorology (BOM) prepares tailored climate change projection reports for Australia which provides guidance on climate changes that needs to be considered in planning and projections [32]. The projections are based on the outputs from the ensemble of model simulations brought together for the Coupled Model Inter-comparison Project phase 5 (CMIP6) [33]. Coupled Modeling has facilitated using eight different models for climate projections in four greenhouse gas emission criteria [34]. It provides future rainfall dataset available for discrete 30-year future periods and not continuous time series data over 100 years. Each future time series data is regarded as representative of the mean state of future climate for specified time period. Multiple future time series cannot be joined to make longer continuous time series.

Future rainfall simulations for this study shown in Figure 4 are taken from a project on Tom's Gully which is 100 km away from Ranger mine [35]. The study uses WGEN weather simulator [36] to generate 1000 year continuous daily rainfall series from year 2025. WGEN is a stochastic weather generator which uses monthly and annual statistics to generate daily time series of precipitation, minimum temperature, maximum temperature, and solar radiation. In the absence of on-site observation data, long-term daily climate data from 1957 to 2019 was sourced from the SILO Australian climate online database and used as reference in WGEN.

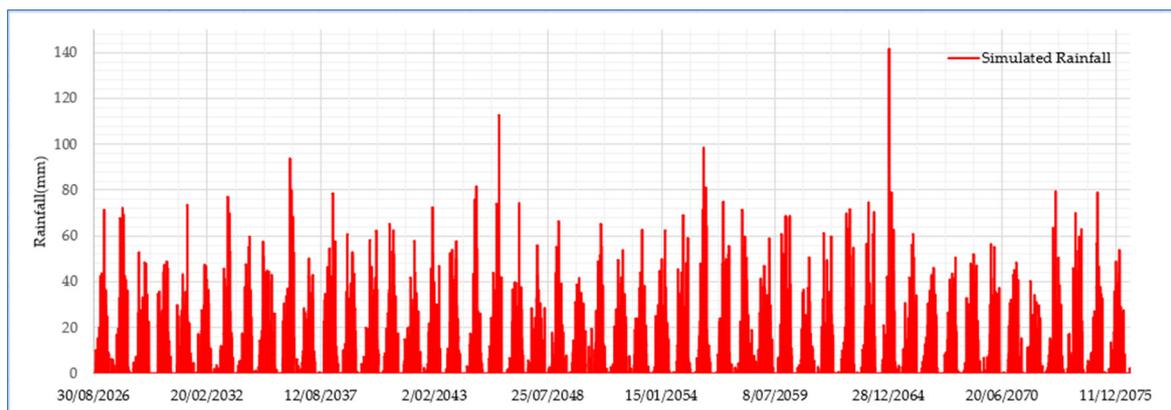


Figure 4. Simulated Daily Rainfall[35].

### 3. Results

#### 3.3.1. Model Calibration & Validation

The HEC-HMS model was calibrated with parameters given in Table 1 and described in the previous section. Calibration was done for two water years (31<sup>st</sup> August to 31<sup>st</sup> August) of 2011-12 and 2012-13. Daily rainfall point data from SILO improvised with area reduction factor was used as input for respective sub-basins. The model was run for each water year to obtain daily output of discharge ( $\text{m}^3\text{s}^{-1}$ ) and sediment (tonnes) at model output which is GCUS (Figure 3). The continuous discharge and turbidity data at 6 min intervals obtained from eriss from their monitoring station at GCUS was used to compare the simulated output with the observed site data (Figure 6a & 6b). Observed discharge at 6 min intervals was averaged to hourly discharge and turbidity data (NTU) at GCUS was converted to continuous FSS hourly data in tons (Table A1 in Appendix A) using equation 3 [3].

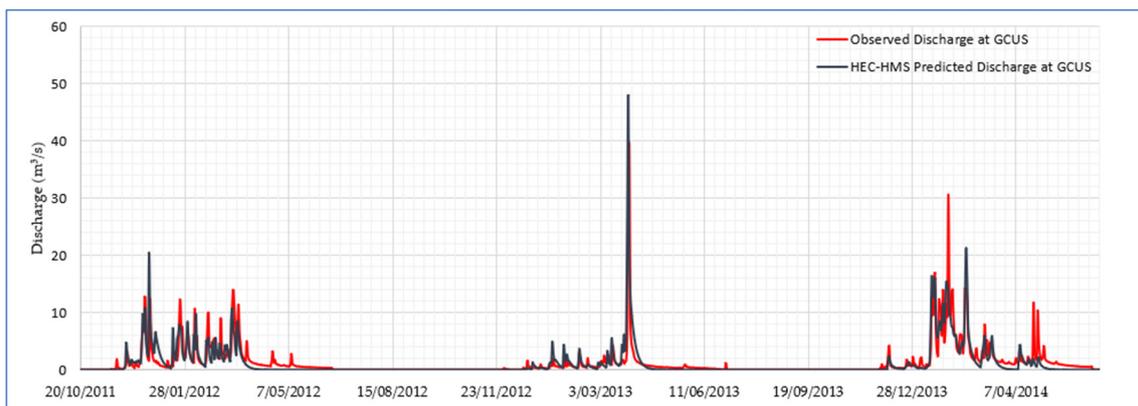
$$\text{FSS} = 0.52 * \text{NTU} \quad (2)$$

Figures 5 and 6 thus compare the calibrated model output to the observed data for discharge and FSS respectively. The efficiency of the calibrated model to match the observed values is determined by Nash-Sutcliffe efficiency (NSE) number generated at the end of each simulation. The NSE value is computed as in equation 4.

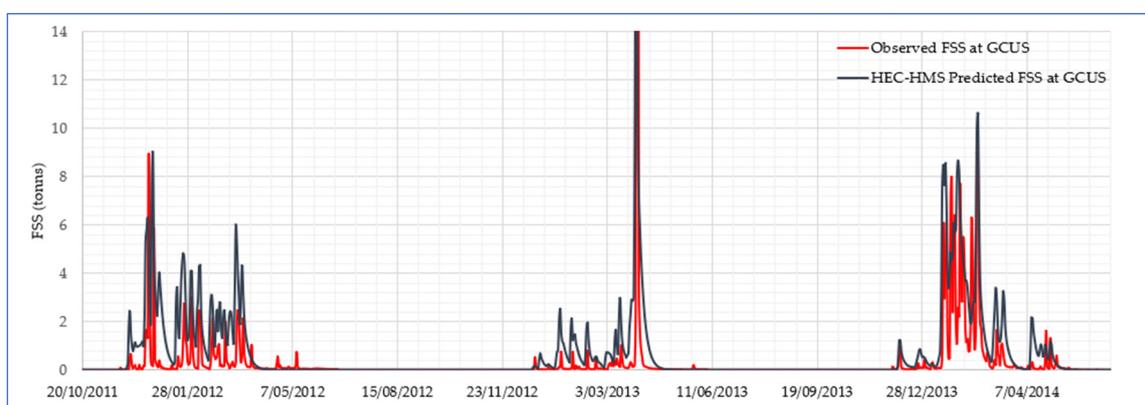
$$\text{NSE} = 1.0 - \frac{\sum_{t=1}^T (y_t - f_t)^2}{\sum_{t=1}^T (y_t - \bar{y})^2} \quad (2)$$

where  $y_t$  is the observed data values for time period  $t$ ,  $f_t$  is the simulated data values for the same period,  $\bar{y}$  is the mean observed data values per time period and  $T$  is the number of time periods [37]. The maximum NSE value possible is 1.0 and occurs if simulated values perfectly match observed values. Larger NSE values denote better model performance. The NSE values for 2011-12 and 2012-13 hydrology calibration in this study are 0.5 and 0.6 respectively. Since the turbidity values give the quantity of FSS using equation 3 which is the combined clay and silt component, the clay and silt quantities from the model output are summed up and compared to the observed values in Figure 6.

Since the model performs well for each calibration simulation, it was run for another water year of 2013-14 with the same model parameters used for the calibration study, for model validation. Comparison between observed values and the simulated output for hydrology and FSS are shown in Figure 5a and 5b respectively. The NSE value for hydrology simulation was found to be 0.7 which was a good fit.



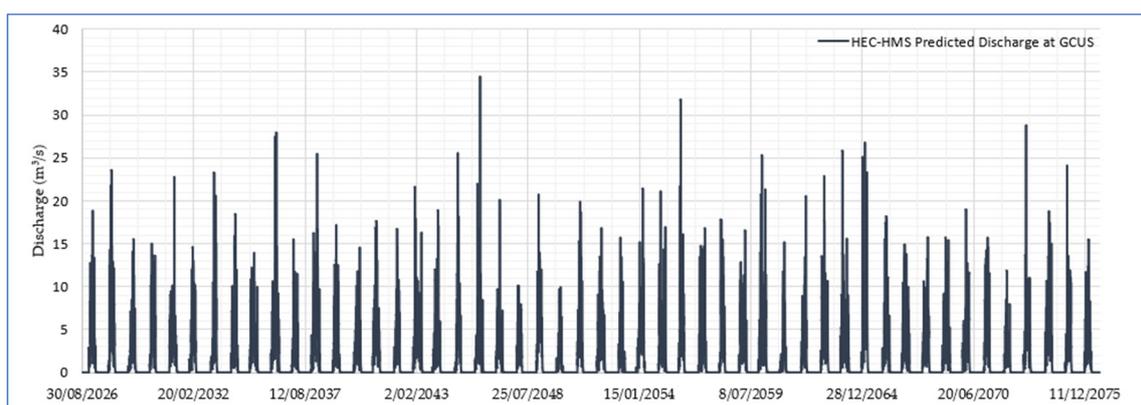
**Figure 5a.** Calibration & validation results comparing the observed output discharge with model outputs.

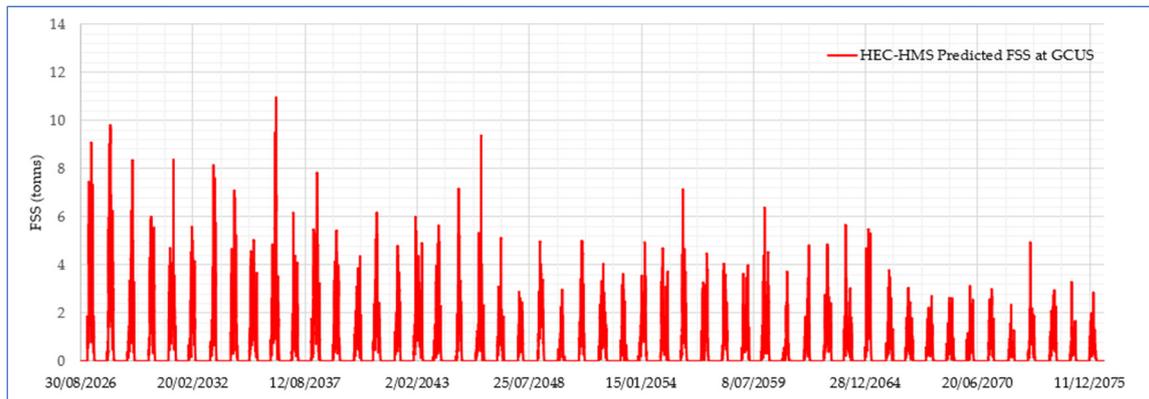


**Figure 5b.** Calibration and validation results comparing the observed FSS quantities with model outputs.

### 3.3.2. Medium Term Erosional Trends

Long-term rainfall simulations obtained from WGEN were used to run the calibrated and validated model for 50 years. The rainfall generated had a uniform average value across the years as shown in Figure 4. The corresponding simulated discharge at GCUS for 50 years is shown in Figure 6a which also exhibits a uniform trend. Unlike the rainfall and discharge, the simulated FSS quantities across the years decrease gradually (Figure 6b). Thus, the FSS output of the Upper Gulungul Catchment decreases over the years for a corresponding uniform rainfall event in UGC and corresponding discharge at GCUS.



**Figure 6a.** HEC-HMS simulated daily discharge at GCUS till 2075.**Figure 6b.** HEC-HMS simulated daily FSS output at GCUS till 2075.

### 3.3.3. Sediment Quantification and Total Denudation Rate

The FSS sediment output for each water year from HEC-HMS simulations were 296 tonnes, 172 tonnes and 287 tonnes at GCUS for 2011-12, 2012-13 and 2013-14 respectively. The total denudation rate of the Upper Gulungul catchment after 50 years of simulations was found to total 1.2269 mm. This accounts to 0.0245 mm year<sup>-1</sup> of denudation rate in the catchment as predicted by HEC-HMS. The long term average total denudation rate calculated from the available observed data at lowlands near Ranger mine is 0.075 ± 0.013 mm year<sup>-1</sup> [38]. As per CSIRO data, the denudation rates in the upper Gulungul catchment varies from 0.576 tonnes ha<sup>-1</sup> year<sup>-1</sup> to 19.923 tonnes ha<sup>-1</sup> year<sup>-1</sup> for different basins [16,23]. This equates to 0.0217mm year<sup>-1</sup> to 0.727mm year<sup>-1</sup> for the denudation rate of basins across the catchment. Annual denudation rate predicted by HEC-HMS from 50-year simulations is 0.0245mm which is thus within the bounds of these estimates.

## 4. Conclusion

This study showed that HEC-HMS was effectively calibrated and validated as a catchment model for observed rainfall and it quantified discharge and sediment output from the catchment over 50 years. The model output proved to be a good fit to the observed data. The output from the HEC-HMS model showed that the erosional trends tended to decrease over time which is in concordance with the previous studies which states that parameters that influence the erosion characteristics of a post-mining landform decreases over time, especially in the first 50 years after rehabilitation. The annual denudation rate of the study catchment predicted by the model after the 50-year simulation is in the same order of magnitude of the natural denudation rate of the area calculated in previous studies. It also falls in the range of denudation rates determined by CSIRO for the catchment area. Thus, the methodology and selection of parameters for calibration and validation of the model in this study seems adequate to predict discharge and sediment output from the catchment in concordance with the field observed data and thus enabling it to predict future erosional trends.

Previous studies on the Ranger Mine site have evaluated landform stability and temporal changes in erosional trends based on gully erosion and incision depths. This study enables modelling of continuous discharge and FSS output from the catchment and enables the evaluation of event FSS output for a specific discharge event. Thus, it enables the use of the output for evaluating FSS following specific rainfall events as an indicator of disturbance and achieving equilibrium. While this was previously carried out within a catchment [3] the use of HEC-HMS enables upstream inputs to be included. HEC-HMS also allows hourly rainfall inputs, and easily enables differing wet and dry season rainfall scenarios to be included. This was important for its use in tropical regions with highly seasonal rainfall conditions. In contrast the CAESAR-Lisflood LEM was modelled [7] but while the annual simulations gave event FSS output matching the observed site values for the early wet season,

they underpredicted the FSS output for the later part of the wet season. HEC-HMS modelling simulations of FSS gave uniform comparison to observed values throughout the wet season. HEC-HMS also runs faster than CAESAR-Lisflood to predict event discharge and FSS quantities. Moreover, HEC-HMS predicted output can be used to run CAESAR-Lisflood LEM for the mine site to determine how the mine site affects the downstream development of the catchment landform, in terms of sediment changes and geomorphology.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Calculations to determine daily FSS output (tonnes) from observed turbidity data at GCUS.

Date	Daily Turbidity in NTU (Observed data)	Daily Turbidity in mg/L (using turbidity-FSS relationship)	Daily discharge in m <sup>3</sup> s <sup>-1</sup> (observed data)	Daily discharge in L	Daily sediment output in mg (Daily discharge in L*Daily Turbidity in mgL <sup>-1</sup> )	Daily sediment output in tonnes
1/09/2011	0	0	0	0	0	0
2/09/2011	0	0	0	0	0	0
3/09/2011	0	0	0	0	0	0
4/09/2011	0	0	0	0	0	0
5/09/2011	0	0	0	0	0	0
6/09/2011	0	0	0	0	0	0
7/09/2011	0	0	0	0	0	0
8/09/2011	0	0	0	0	0	0
9/09/2011	0	0	0	0	0	0
10/09/2011	0	0	0	0	0	0
11/09/2011	0	0	0	0	0	0
12/09/2011	0	0	0	0	0	0
13/09/2011	0	0	0	0	0	0
14/09/2011	0	0	0	0	0	0
15/09/2011	0	0	0	0	0	0
16/09/2011	0	0	0	0	0	0
17/09/2011	0	0	0	0	0	0
18/09/2011	0	0	0	0	0	0
19/09/2011	0	0	0	0	0	0
20/09/2011	0	0	0	0	0	0
21/09/2011	0	0	0	0	0	0
22/09/2011	0	0	0	0	0	0
23/09/2011	0	0	0	0	0	0
24/09/2011	0	0	0	0	0	0
25/09/2011	0	0	0	0	0	0
26/09/2011	0	0	0	0	0	0
27/09/2011	0	0	0	0	0	0
28/09/2011	0	0	0	0	0	0
29/09/2011	0	0	0	0	0	0
30/09/2011	0	0	0	0	0	0
1/10/2011	0	0	0	0	0	0
2/10/2011	0	0	0	0	0	0

3/10/2011	0	0	0	0	0	0
4/10/2011	0	0	0	0	0	0
5/10/2011	0	0	0	0	0	0
6/10/2011	0	0	0	0	0	0
7/10/2011	0	0	0	0	0	0
8/10/2011	0	0	0	0	0	0
9/10/2011	0	0	0	0	0	0
10/10/2011	0	0	0	0	0	0
11/10/2011	0	0	0	0	0	0
12/10/2011	0	0	0	0	0	0
13/10/2011	0	0	0	0	0	0
14/10/2011	0	0	0	0	0	0
15/10/2011	0	0	0	0	0	0
16/10/2011	0	0	0	0	0	0
17/10/2011	0	0	0	0	0	0
18/10/2011	0	0	0	0	0	0
19/10/2011	0	0	0	0	0	0
20/10/2011	0	0	0	0	0	0
21/10/2011	0	0	0	0	0	0
22/10/2011	0	0	0	0	0	0
23/10/2011	0	0	0	0	0	0
24/10/2011	0	0	0	0	0	0
25/10/2011	0	0	0	0	0	0
26/10/2011	0	0	0	0	0	0
27/10/2011	0	0	0	0	0	0
28/10/2011	0	0	0	0	0	0
29/10/2011	0	0	0	0	0	0
30/10/2011	0	0	0	0	0	0
31/10/2011	0	0	0	0	0	0
1/11/2011	0	0	0	0	0	0
2/11/2011	0	0	0	0	0	0
3/11/2011	0	0	0	0	0	0
4/11/2011	0	0	0	0	0	0
5/11/2011	0	0	0	0	0	0
6/11/2011	0	0	0	0	0	0
7/11/2011	0	0	0	0	0	0
8/11/2011	0	0	0	0	0	0
9/11/2011	0	0	0	0	0	0
10/11/2011	0	0	0	0	0	0
11/11/2011	0	0	0	0	0	0
12/11/2011	0	0	0	0	0	0
13/11/2011	0	0	0	0	0	0
14/11/2011	0	0	0	0	0	0
15/11/2011	0	0	0	0	0	0
16/11/2011	0	0	0	0	0	0
17/11/2011	0	0	0	0	0	0
18/11/2011	0	0	0	0	0	0
19/11/2011	0	0	0	0	0	0
20/11/2011	0	0	0.228465208	19739394	0	0
21/11/2011	0	0	0.060598125	5235678	0	0
22/11/2011	0	0	0.04175725	3607826.4	0	0
23/11/2011	0	0	0.163358708	14114192.4	0	0
24/11/2011	0	0	0.10550275	9115437.6	0	0
25/11/2011	1.057083333	0.549683333	1.834947292	158539446	87146491.14	0.087146491
26/11/2011	1.6375	0.8515	0.446017	38535868.8	32813292.28	0.032813292
27/11/2011	1.320416667	0.686616667	0.242510708	20952925.2	14386627.66	0.014386628
28/11/2011	1.305	0.6786	0.235214917	20322568.8	13790895.19	0.013790895
29/11/2011	1.2475	0.6487	0.185182458	15999764.4	10379047.17	0.010379047
30/11/2011	1.382916667	0.719116667	0.143461625	12395084.4	8913511.777	0.008913512
1/12/2011	1.50875	0.78455	0.12129625	10479996	8222080.862	0.008222081
2/12/2011	1.5975	0.8307	0.21388775	18479901.6	15351254.26	0.015351254
3/12/2011	1.46	0.7592	0.401550125	34693930.8	26339632.26	0.026339632
4/12/2011	9.36625	4.87045	1.246408708	107689712.4	524497359.8	0.52449736
5/12/2011	4.515	2.3478	3.164770917	273436207.2	641973527.3	0.641973527
6/12/2011	3.014583333	1.567583333	1.519958458	131324410.8	205861957.6	0.205861958
7/12/2011	2.12625	1.10565	0.696604917	60186664.8	66545385.94	0.066545386

8/12/2011	3.07666667	1.59986667	0.961137417	83042272.8	132856564.2	0.132856564
9/12/2011	2.675833333	1.391433333	1.569808792	135631479.6	188722161.8	0.188722162
10/12/2011	1.521666667	0.791266667	0.695273167	60071601.6	47532655.96	0.047532656
11/12/2011	1.358333333	0.706333333	0.473957292	40949910	28924286.43	0.028924286
12/12/2011	1.45875	0.75855	0.374008542	32314338	24512041.09	0.024512041
13/12/2011	3.23625	1.68285	1.422329458	122889265.2	206804199.9	0.2068042
14/12/2011	1.93375	1.00555	0.750662208	64857214.8	65217172.34	0.065217172
15/12/2011	1.808333333	0.940333333	0.744352667	64312070.4	60474783.53	0.060474784
16/12/2011	1.446666667	0.752266667	0.507747917	43869420	33001502.35	0.033001502
17/12/2011	2.74625	1.42805	1.275893208	110237173.2	157424195.2	0.157424195
18/12/2011	2.141666667	1.113666667	1.749059333	151118726.4	168295888.3	0.168295888
19/12/2011	6.977083333	3.628083333	4.988017792	430964737.2	1563575980	1.56357598
20/12/2011	5.639166667	2.932366667	6.524772125	563740311.6	1653093298	1.653093298
21/12/2011	4.447916667	2.312916667	6.7368665	582065265.6	1346268454	1.346268454
22/12/2011	15.57416667	8.098566667	12.78070996	1104253340	8942869294	8.942869294
23/12/2011	6.292916667	3.272316667	8.428586333	728229859.2	2382998705	2.382998705
24/12/2011	2.542083333	1.321883333	3.234033125	279420462	369361251.7	0.369361252
25/12/2011	2.247916667	1.168916667	1.884673667	162835804.8	190341486.2	0.190341486
26/12/2011	2.4975	1.2987	1.606975042	138842643.6	180314941.2	0.180314941
27/12/2011	10.50458333	5.462383333	12.43176388	1074104399	5867169966	5.867169966
28/12/2011	2.355	1.2246	4.149364375	358505082	439025323.4	0.439025323
29/12/2011	1.98125	1.03025	3.080770708	266178589.2	274230491.5	0.274230492
30/12/2011	2.013333333	1.046933333	1.868403125	161430030	169006479.4	0.169006479
31/12/2011	1.876666667	0.975866667	1.493171417	129010010.4	125896568.8	0.125896569
1/01/2012	6.310416667	3.281416667	1.366722125	118084791.6	387485403.2	0.387485403
2/01/2012	3.0225	1.5717	1.505556958	130080121.2	204446926.5	0.204446926
3/01/2012	2.069166667	1.075966667	1.078669167	93197016	100276882.6	0.100276883
4/01/2012	2.053333333	1.067733333	1.246226458	107673966	114967082.6	0.114967083
5/01/2012	1.705	0.8866	0.846677375	73152925.2	64857383.48	0.064857383
6/01/2012	1.56375	0.81315	0.722855042	62454675.6	50785019.46	0.050785019
7/01/2012	1.643333333	0.854533333	0.649962292	56156742	47987807.93	0.047987808
8/01/2012	1.576666667	0.819866667	0.597723167	51643281.6	42340605.14	0.042340605
9/01/2012	1.574166667	0.818566667	0.548501125	47390497.2	38792281.32	0.038792281
10/01/2012	1.6325	0.8489	0.495839083	42840496.8	36367297.73	0.036367298
11/01/2012	1.555	0.8086	0.446725292	38597065.2	31209586.92	0.031209587
12/01/2012	1.575	0.819	0.436580667	37720569.6	30893146.5	0.030893147
13/01/2012	2.81125	1.46185	1.560139167	134796024	197051567.7	0.197051568
14/01/2012	1.58125	0.82225	0.72043625	62245692	51181520.25	0.05118152
15/01/2012	1.562083333	0.812283333	0.699027208	60395950.8	49058624.24	0.049058624
16/01/2012	1.65	0.858	0.5799705	50109451.2	42993909.13	0.042993909
17/01/2012	1.723333333	0.896133333	0.688882125	59519415.6	53337332.3	0.053337332
18/01/2012	1.760416667	0.915416667	0.646783167	55882065.6	51155374.22	0.051155374
19/01/2012	3.924583333	2.040783333	3.118488958	269437446	549863449.2	0.549863449
20/01/2012	2.195	1.1414	1.911158417	165124087.2	188472633.1	0.188472633
21/01/2012	1.597916667	0.830916667	1.815980375	156900704.4	130371410.3	0.13037141
22/01/2012	2.001666667	1.040866667	1.686906833	145748750.4	151705016	0.151705016
23/01/2012	2.85625	1.48525	3.180722833	274814452.8	408168166	0.408168166
24/01/2012	4.08625	2.12485	8.406660333	726335452.8	1543353887	1.543353887
25/01/2012	4.962916667	2.580716667	12.26780504	1059938356	2735400580	2.73540058
26/01/2012	3.835416667	1.994416667	7.247807	626210524.8	1248924708	1.248924708
27/01/2012	3.1075	1.6159	7.489754792	647114814	1045672828	1.045672828
28/01/2012	2.5275	1.3143	3.051238625	263627017.2	346484988.7	0.346484989
29/01/2012	2.3475	1.2207	2.170032292	187490790	228870007.4	0.228870007
30/01/2012	2.683333333	1.395333333	2.129102708	183954474	256677809.4	0.256677809
31/01/2012	4.396666667	2.286266667	4.4826005	387296683.2	885463496.9	0.885463497
1/02/2012	10.27791667	5.344516667	6.520981292	563412783.6	3011169012	3.011169012
2/02/2012	3.531666667	1.836466667	5.836933042	504311014.8	926150368.3	0.926150368
3/02/2012	2.098333333	1.091133333	3.210332875	277372760.4	302650664.6	0.302650665
4/02/2012	1.124166667	0.584566667	2.168608875	187367806.8	109528974.3	0.109528974
5/02/2012	1.104583333	0.574383333	1.60080925	138309919.2	79442912.42	0.079442912
6/02/2012	1.131666667	0.588466667	1.762203875	152254414.8	89596647.96	0.089596648
7/02/2012	1.042916667	0.542316667	1.26181225	109020578.4	59123676.68	0.059123677
8/02/2012	5.104583333	2.654383333	10.59284963	915222207.6	2429350574	2.429350574
9/02/2012	8.995833333	4.677833333	5.292572792	457278289.2	2139071624	2.139071624
10/02/2012	5.865416667	3.050016667	5.848525083	505312567.2	1541211752	1.541211752
11/02/2012	2.55	1.326	2.125671542	183658021.2	243530536.1	0.243530536

12/02/2012	2.2675	1.1791	1.6064485	138797150.4	163655720	0.16365572
13/02/2012	2.3875	1.2415	1.311686833	113329742.4	140698875.2	0.140698875
14/02/2012	2.492083333	1.295883333	1.120730792	96831140.4	125481861	0.125481861
15/02/2012	1.918333333	0.997533333	1.009130333	87188860.8	86973794.94	0.086973795
16/02/2012	1.818333333	0.945533333	0.915646	79111814.4	74802857.58	0.074802858
17/02/2012	1.681666667	0.874466667	0.881567625	76167442.8	66605889.81	0.06660589
18/02/2012	1.137916667	0.591716667	0.799305458	69059991.6	40863948.03	0.040863948
19/02/2012	3.37625	1.75565	1.829516125	158070193.2	277515934.7	0.277515935
20/02/2012	3.59	1.8668	6.579386625	568459004.4	1061199269	1.061199269
21/02/2012	4.765416667	2.478016667	9.993038083	863398490.4	2139515849	2.139515849
22/02/2012	3.055416667	1.588816667	4.721255458	407916471.6	648104488.7	0.648104489
23/02/2012	2.934583333	1.525983333	4.115818125	355606686	542649876.1	0.542649876
24/02/2012	2.677916667	1.392516667	3.819696583	330021784.8	459560835.7	0.459560836
25/02/2012	3.0225	1.5717	4.156761417	359144186.4	564466917.8	0.564466918
26/02/2012	4.127083333	2.146083333	5.199721208	449255912.4	964140626	0.964140626
27/02/2012	4.297083333	2.234483333	5.447390792	470654564.4	1051669780	1.05166978
28/02/2012	1.442916667	0.750316667	2.809767875	242763944.4	182149833.5	0.182149834
29/02/2012	1.422916667	0.739916667	3.44752425	297866095.2	220396088.3	0.220396088
1/03/2012	1.4425	0.7501	2.203969375	190422954	142836257.8	0.142836258
2/03/2012	1.884583333	0.979983333	2.030587833	175442788.8	171931009	0.171931009
3/03/2012	1.909583333	0.992983333	1.961053875	169435054.8	168246185.5	0.168246185
4/03/2012	4.902916667	2.549516667	8.999992833	777599380.8	1982502581	1.982502581
5/03/2012	2.805833333	1.459033333	3.860733042	333567334.8	486685860.4	0.48668586
6/03/2012	2.240416667	1.165016667	2.71657675	234712231.2	273443661.2	0.273443661
7/03/2012	1.70875	0.88855	2.956050417	255402756	226938118.8	0.226938119
8/03/2012	0.939583333	0.488583333	1.9216965	166034577.6	81121727.37	0.081121727
9/03/2012	1.14875	0.59735	2.3526545	203269348.8	121422945.5	0.121422946
10/03/2012	1.8025	0.9373	2.97758775	257263581.6	241133155	0.241133155
11/03/2012	2.042916667	1.062316667	3.506452583	302957503.2	321836804.9	0.321836805
12/03/2012	1.577916667	0.820516667	2.375770542	205266574.8	168424645.7	0.168424646
13/03/2012	1.387916667	0.721716667	2.293133958	198126774	142991394.9	0.142991395
14/03/2012	2.091666667	1.087666667	3.279834833	283377729.6	308220510.6	0.308220511
15/03/2012	3.819583333	1.986183333	11.24753758	971787247.2	1930147634	1.930147634
16/03/2012	3.945	2.0514	13.94577246	1204914740	2471762098	2.471762098
17/03/2012	3.89	2.0228	11.08535533	957774700.8	1937386665	1.937386665
18/03/2012	2.536666667	1.319066667	7.577065083	654658423.2	863538104.1	0.863538104
19/03/2012	1.711666667	0.890066667	3.965737292	342639702	304972177.4	0.304972177
20/03/2012	2.759583333	1.434983333	5.832349083	503914960.8	723109570.2	0.72310957
21/03/2012	4.159166667	2.162766667	11.3885755	983972923.2	2128103839	2.128103839
22/03/2012	2.301666667	1.196866667	6.511953083	562632746.4	673396379.7	0.67339638
23/03/2012	1.734166667	0.901766667	4.694357208	405592462.8	365749763.2	0.365749763
24/03/2012	1.48375	0.77155	2.9314655	253278619.2	195417118.6	0.195417119
25/03/2012	1.310833333	0.681633333	2.374086417	205121066.4	139817356.2	0.139817356
26/03/2012	1.257916667	0.654116667	1.982300833	171270792	112031079.6	0.11203108
27/03/2012	1.638333333	0.851933333	1.752770917	151439407.2	129016279	0.129016279
28/03/2012	1.970416667	1.024616667	1.600279792	138264174	141667777.1	0.141667777
29/03/2012	4.6025	2.3933	4.990607042	431188448.4	1031963314	1.031963314
30/03/2012	1.900416667	0.988216667	2.501158208	216100069.2	213553690.1	0.21355369
31/03/2012	1.422083333	0.739483333	1.816911292	156981135.6	116084933.4	0.116084933
1/04/2012	1.1825	0.6149	1.546442417	133612624.8	82158402.99	0.082158403
2/04/2012	1.15625	0.60125	1.397847083	120773988	72615360.29	0.07261536
3/04/2012	1.28125	0.66625	1.2805035	110635502.4	73710903.47	0.073710903
4/04/2012	1.289583333	0.670583333	1.203315833	103966488	69718194.08	0.069718194
5/04/2012	1.22	0.6344	1.136012875	98151512.4	62267319.47	0.062267319
6/04/2012	1.26	0.6552	1.067628333	92243088	60437671.26	0.060437671
7/04/2012	1.296666667	0.674266667	1.007954667	87087283.2	58720052.15	0.058720052
8/04/2012	1.24125	0.64545	0.965996208	83462072.4	53870594.63	0.053870595
9/04/2012	1.236666667	0.643066667	0.921714	79636089.6	51211314.69	0.051211315
10/04/2012	1.20375	0.62595	0.869973167	75165681.6	47049958.4	0.047049958
11/04/2012	1.415833333	0.736233333	0.833352375	72001645.2	53010011.25	0.053010011
12/04/2012	1.773333333	0.922133333	0.873184708	75443158.8	69568651.5	0.069568652
13/04/2012	1.615833333	0.840233333	0.796236958	68794873.2	57803745.63	0.057803746
14/04/2012	1.443333333	0.750533333	0.786376458	67942926	50993430.73	0.050993431
15/04/2012	1.36	0.7072	0.763117833	65933380.8	46628086.9	0.046628087
16/04/2012	1.330833333	0.692033333	0.730961542	63155077.2	43705418.59	0.043705419
17/04/2012	1.422083333	0.739483333	0.688425417	59479956	43984436.13	0.043984436

18/04/2012	1.351666667	0.702866667	0.656823667	56749564.8	39887377.45	0.039887377
19/04/2012	1.484583333	0.771983333	0.635524292	54909298.8	42389063.52	0.042389064
20/04/2012	1.489166667	0.774366667	0.678654083	58635712.8	45405541.47	0.045405541
21/04/2012	1.649166667	0.857566667	0.645536125	55774321.2	47830198.72	0.047830199
22/04/2012	3.558333333	1.850333333	1.617385792	139742132.4	258569525.7	0.258569526
23/04/2012	3.80375	1.97795	3.200284583	276504588	546912249.8	0.54691225
24/04/2012	2.175416667	1.131216667	1.273644	110042841.6	124482296.5	0.124482296
25/04/2012	2.349166667	1.221566667	1.731303583	149584629.6	182727597.4	0.182727597
26/04/2012	2.059166667	1.070766667	1.093058	94440211.2	101123430.1	0.10112343
27/04/2012	2.060833333	1.071633333	0.931715875	80500251.6	86266752.96	0.086266753
28/04/2012	1.803333333	0.937733333	0.852574833	73662465.6	69075749.41	0.069075749
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30/04/2012	2.12875	1.10695	0.75134325	64916056.8	71858829.07	0.071858829
1/05/2012	2.051666667	1.066866667	0.718458333	62074800	66225534.96	0.066225535
2/05/2012	2.03625	1.05885	0.685400875	59218635.6	62703652.31	0.062703652
3/05/2012	3.289166667	1.710366667	0.8104395	70021972.8	119763248.2	0.119763248
4/05/2012	3.08375	1.60355	0.811166792	70084810.8	112384498.4	0.112384498
5/05/2012	2.13375	1.10955	0.687214625	59375343.6	65879912.49	0.065879912
6/05/2012	2.400833333	1.248433333	0.624613083	53966570.4	67373665.37	0.067373665
7/05/2012	2.757916667	1.434116667	0.595935833	51488856	73841026.54	0.073841027
8/05/2012	2.819583333	1.466183333	0.582127375	50295805.2	73742871.32	0.073742871
9/05/2012	2.887916667	1.501716667	0.568508958	49119174	73763082.25	0.073763082
10/05/2012	4.417083333	2.296883333	0.831191583	71814952.8	164950568.2	0.164950568
11/05/2012	5.948333333	3.093133333	2.758289833	238316241.6	737143910.8	0.737143911
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13/05/2012	1.804166667	0.938166667	0.813831375	70315030.8	65967218.06	0.065967218
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15/05/2012	1.582083333	0.822683333	0.661920167	57189902.4	47049179.54	0.04704918
16/05/2012	1.786666667	0.929066667	0.605832375	52343917.2	48630988.67	0.048630989
17/05/2012	1.9825	1.0309	0.585537167	50590411.2	52153654.91	0.052153655
18/05/2012	2.0875	1.0855	0.570115625	49257990	53469548.15	0.053469548
19/05/2012	2.035416667	1.058416667	0.548264875	47370085.2	50137287.68	0.050137288
20/05/2012	2.019583333	1.050183333	0.527347708	45562842	47849337.29	0.047849337
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22/05/2012	1.8575	0.9659	0.491946708	42504195.6	41054802.53	0.041054803
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24/05/2012	1.712916667	0.890716667	0.461519792	39875310	35517603.21	0.035517603
25/05/2012	1.70625	0.88725	0.46319275	40019853.6	35507615.11	0.035507615
26/05/2012	2.182916667	1.135116667	0.462014667	39918067.2	45311663.38	0.045311663
27/05/2012	2.6825	1.3949	0.446289417	38559405.6	53786514.87	0.053786515
28/05/2012	2.698333333	1.403133333	0.430412875	37187672.4	52179262.73	0.052179263
29/05/2012	2.82375	1.46835	0.412768583	35663205.6	52366067.94	0.052366068
30/05/2012	3.226666667	1.677866667	0.409872375	35412973.2	59418247.3	0.059418247
31/05/2012	3.20875	1.66855	0.416677875	36000968.4	60069415.82	0.060069416
1/06/2012	2.8375	1.4755	0.412269958	35620124.4	52557493.55	0.052557494
2/06/2012	2.56875	1.33575	0.406913042	35157286.8	46961345.84	0.046961346
3/06/2012	2.535833333	1.318633333	0.402872167	34808155.2	45899193.72	0.045899194
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5/06/2012	3.026666667	1.573866667	0.364896042	31527018	49619322.73	0.049619323
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7/06/2012	2.563333333	1.332933333	0.351803583	30395829.6	40515614.47	0.040515614
8/06/2012	2.4725	1.2857	0.34884875	30140532	38751681.99	0.038751682
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10/06/2012	2.285833333	1.188633333	0.337013167	29117937.6	34610551.23	0.034610551
11/06/2012	2.3175	1.2051	0.331817875	28669064.4	34549089.51	0.03454909
12/06/2012	2.33125	1.21225	0.326213083	28184810.4	34167036.41	0.034167036
13/06/2012	2.36375	1.22915	0.322456542	27860245.2	34244420.39	0.03424442
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