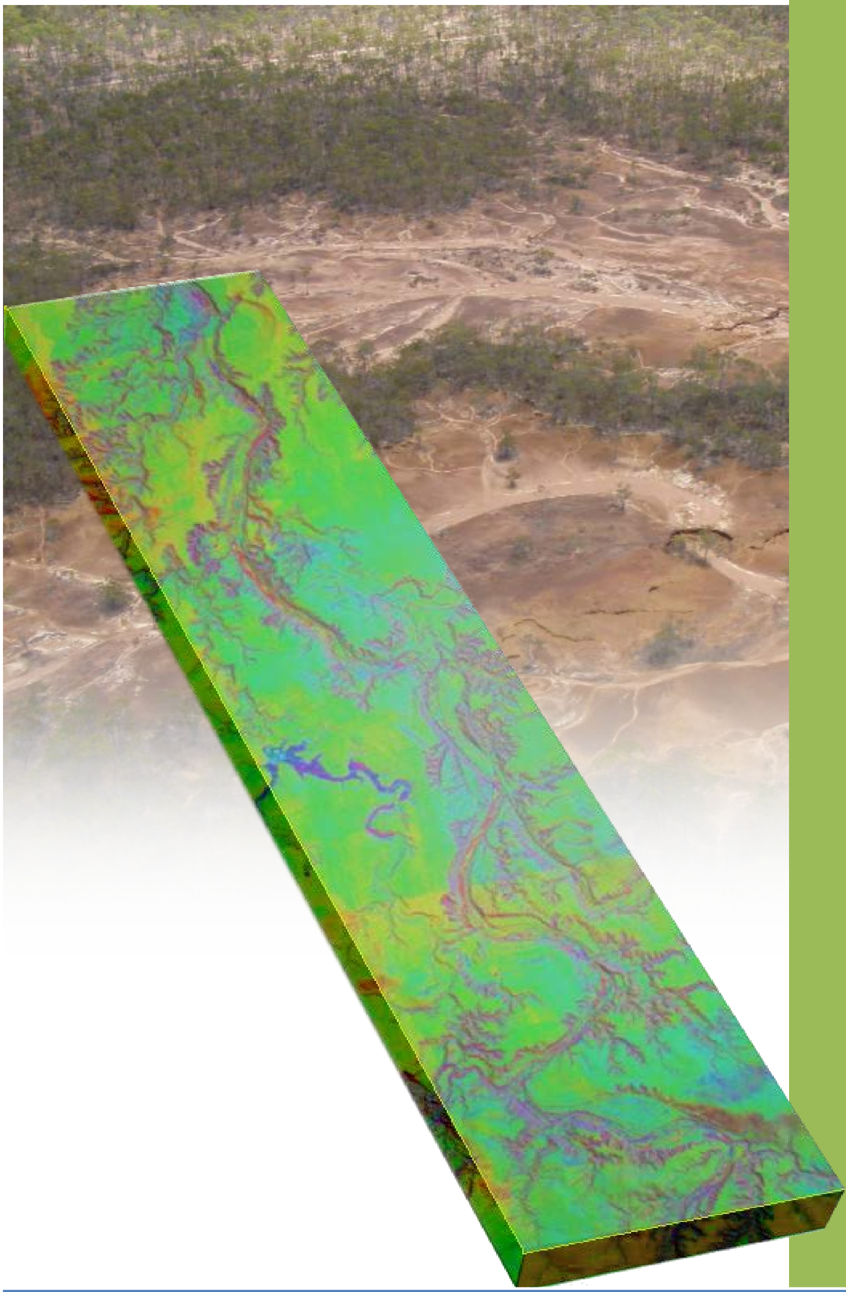

An Empirically-based Sediment Budget for the Normanby Basin

Andrew Brooks, John Spencer, Jon Olley, Tim Pietsch, Daniel Borombovits, Graeme Curwen, Jeff Shellberg, Christina Howley, Angela Gleeson, Andrew Simon, Natasha Bankhead, Danny Klimetz, Leila Eslami-Endargoli, Anne Bourgeault

Australian Rivers Institute

Griffith University

Appendix 17: The Sediment Budget Model

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CARING FOR OUR COUNTRY

Appendix to the Final Report prepared for the Australian Government's Caring for our Country - **Reef Rescue initiative**

CAPE YORK WATER QUALITY

Appendix 17: The Sediment Budget Model

Prepared by: John Spencer

The model developed for this project uses the stream segments as the primary modelled unit within a yearly time step and covers a 24 year (1986 – 2009) period of synthetic hydrologic data. The stream network consists of 9635 segments. The model calculates suspended sediments inputs and outputs for all stream segments, starting at each headwater segment and progressing downstream carrying surplus sediment to the next downstream segment. The model is a steady state model that assumes all suspended sediment not deposited is transport to the receiving water body (Princess Charlotte Bay). The network contains and the model deals with bifurcations and distributaries, partitioning flow and suspended sediment. Figure 1 and table 1 show the sediment components included in this model.

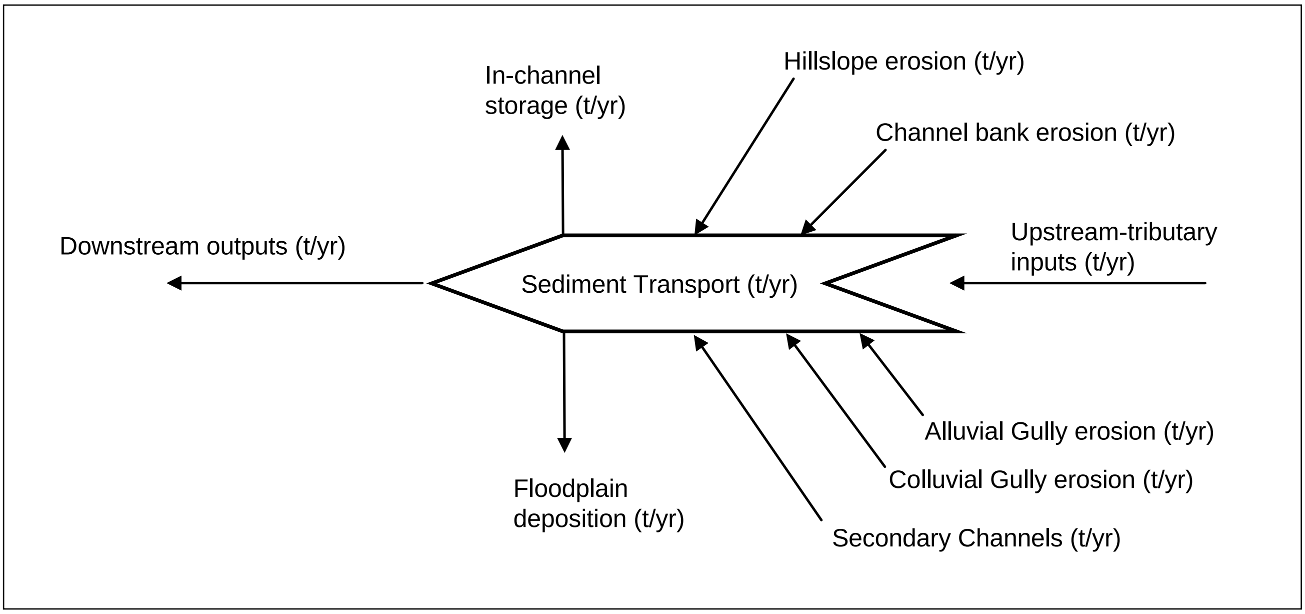


Figure 1: Schematic of stream segment suspended sediment inputs and outputs.

Table 1: Suspended sediment components included in model.

Sediment sources	
	Hillslope (calculated as long term yearly average)
	Alluvial Gullies (calculated as long term yearly average)
	Colluvial Gullies (calculated as long term yearly average)
	Secondary Channels (calculated as long term yearly average)
	Bank Erosion (calculated each time step)
Sediment Sinks	
	Floodplain Deposition (calculated each time step)
	In-channel Deposition (calculated as long term yearly average)

The calculation of the suspended sediment being passed to the downstream segments becomes;

$$Segment_{Yield} = FractionUpstreamNode + Bank\,Erosion + Gully_{Colluvial} + Gully_{Alluvial} + SecondaryChannel + Hillslope - InChannel - FPDeposition$$

(Equation 1)

1.1 Stream Network

A common method, and used here, to represent a river basin is a network built up from a system of nodes, segments, and sub-catchments. As shown in figure 2, the segments represent the streamlines, the nodes represent the beginning and end of each segment and the sub-catchments represent the catchment area of each segment. This data structure maintains relationships between the areal (hillslope erosion) variables attached to the sub-catchments, the longitudinal variables (stream length) attached to the segments, and the point variables (channel dimensions, discharge) attached to the nodes. In this study a segments downstream node variables are used to represent a segment.

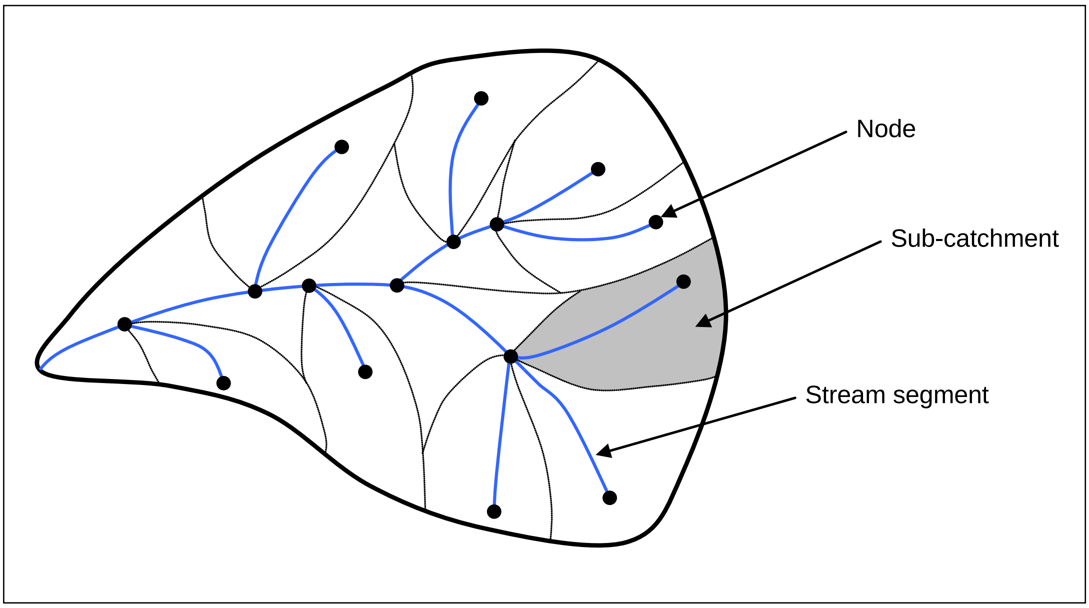
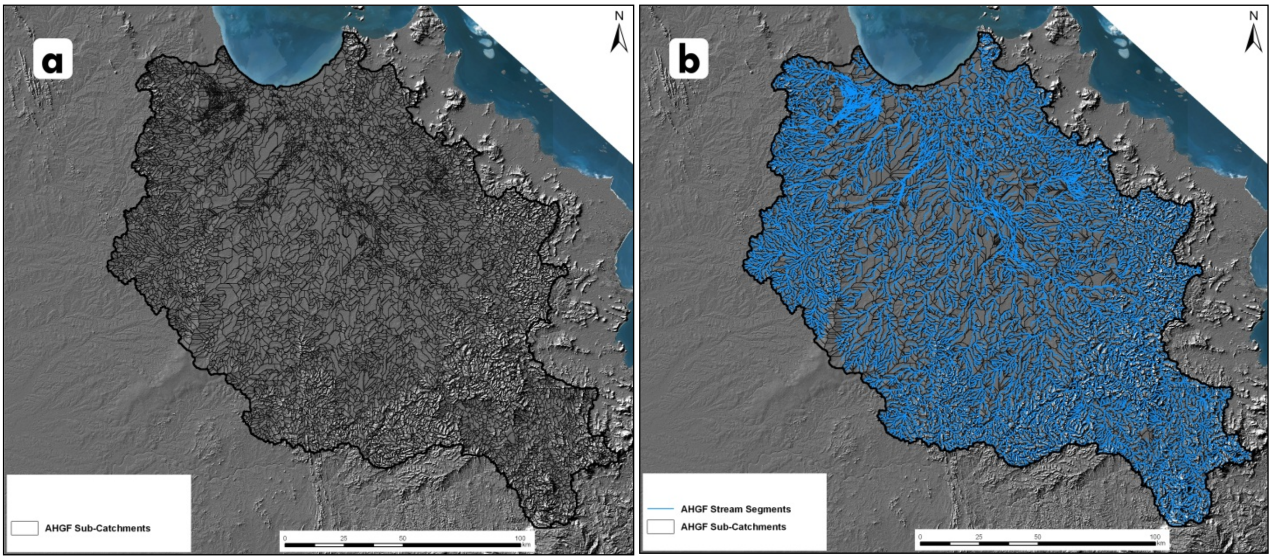


Figure 2: Node, Segment, and Sub-Catchment schematic.

The stream network used here is part of the Australian Hydrologic Geospatial Fabric (AHGF) which is available from the Bureau of Meteorology (http://www.bom.gov.au/water/geofabric/index.shtml). It is derived from the 9 second DEM of Australia. The Normanby Basin consists of 9621 sub-catchments, 9635 segments, and 8782 nodes, as shown in figure 3.



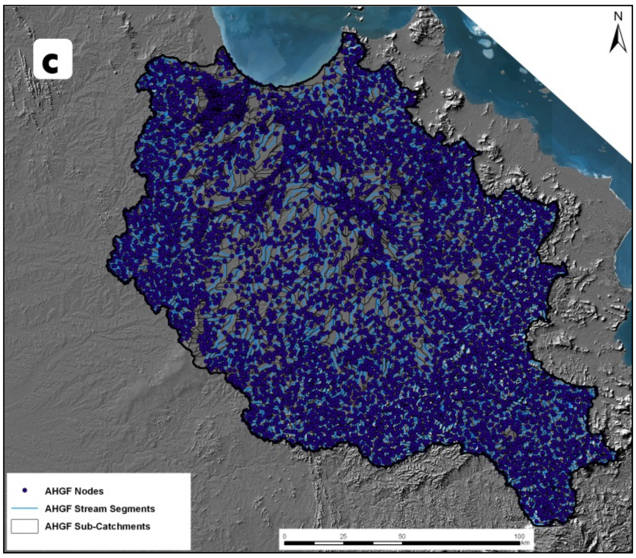


Figure 3: Australian Hydrologic Geospatial Fabric (AHGF) Normanby Basin. a) Sub-Catchments, b) Segments, and c) Nodes.

The AHGF network contains data on upstream catchment area for nodes in the data set, but does not distribute upstream catchment area at bifurcations within the network, i.e. when a stream divides into two streams both are labelled with the same upstream catchment area. Upstream catchment area is required to provide modelled estimates for variables such as stream segment discharge or channel depth. Therefore to parameterise segments within multi-channel and distributive areas of the network it was necessary to develop algorithms to apportion upstream catchment area at each bifurcation in the network.

1.2 Hydrology

Queensland DNRM has created a synthetic hydrograph dataset for, amongst other, the Normanby Basin. It consists of daily discharge data for the period 1986 to 2009. It was based on a stream network developed by DNRM and not the AHGF network. The DNRM network consisted of 361 nodes for the Normanby basin (figure 4). Twenty four years of daily data for 361 nodes adds up to over 3 million rows of data. This data was used as the base to interpolate hydrologic data for the 8782 nodes of the Normanby AHGF network. This required the mapping of the nodes in both datasets into approximately homogenous geomorphic zones, figure 4 and figure 5.

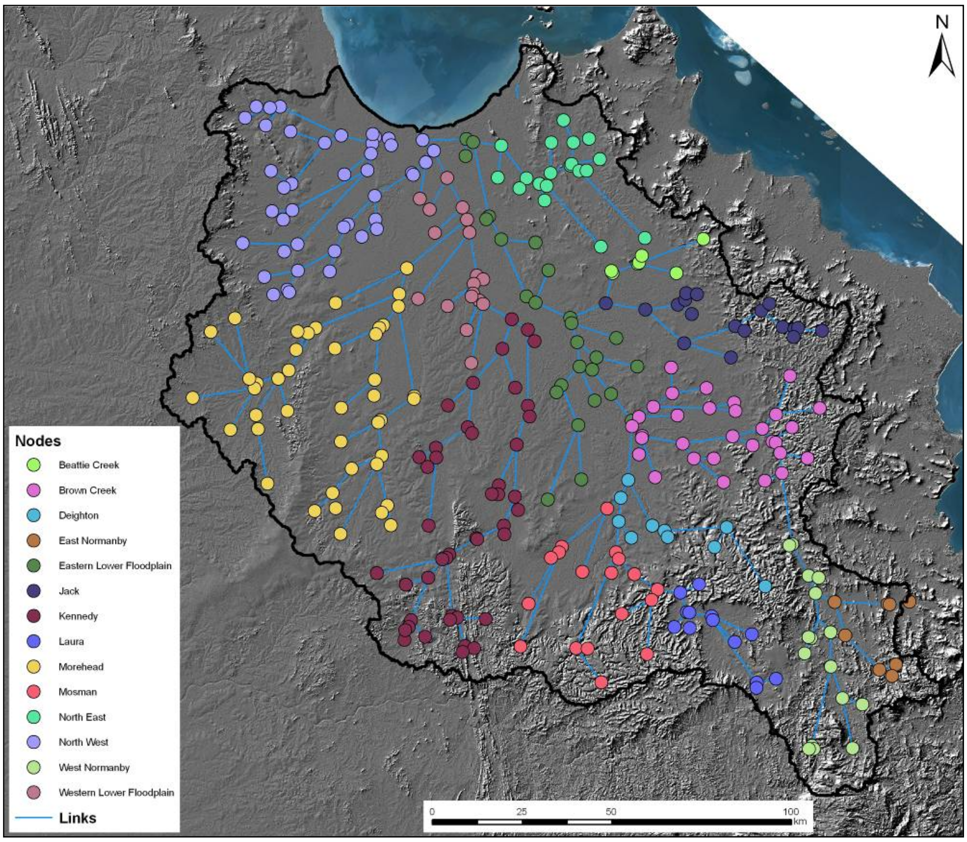


Figure 4: DNRM generate nodes and links shown divided into hydrologic interpolation zones.

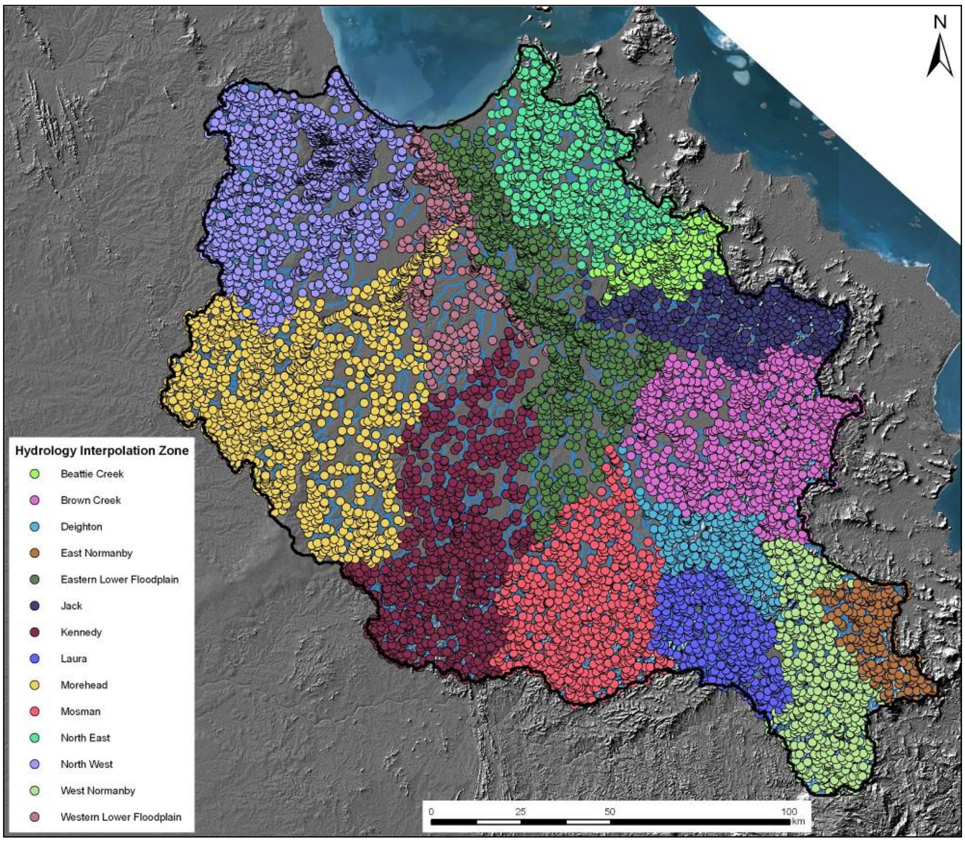


Figure 5: AHGF nodes divided into hydrologic interpolation zones.

The hydrologic parameters used in this model are total annual discharge, annual overbank discharge and annual in-channel flow. Linear regression was used to estimate these parameters for each node. The total annual discharge for each DNRM node was calculated as the summation of daily discharge. The regression for each of the 24 years, for each of the interpolation zones, for DNRM node total annual discharge and DNRM node catchment area produced good R^2 values, Table 2. These regression equations were used to calculate the total annual discharge of the downstream node of each stream segment of the AHGF network.

We did experiment with monthly and daily regressions, producing nearly 500,000 regression equations, but correlations at those temporal scales were low. The lowest values always being associated with high magnitude flows which are the most important flows in regards to sediment transport.

As a back check on this procedure we plotted the yearly discharge of the set of stream segments entering PCB from the DNRM network and the AHGF network (figure 6) and found there is excellent agreement. The set of streams entering PCB was chosen simply because it is easy to define these segments in both datasets.

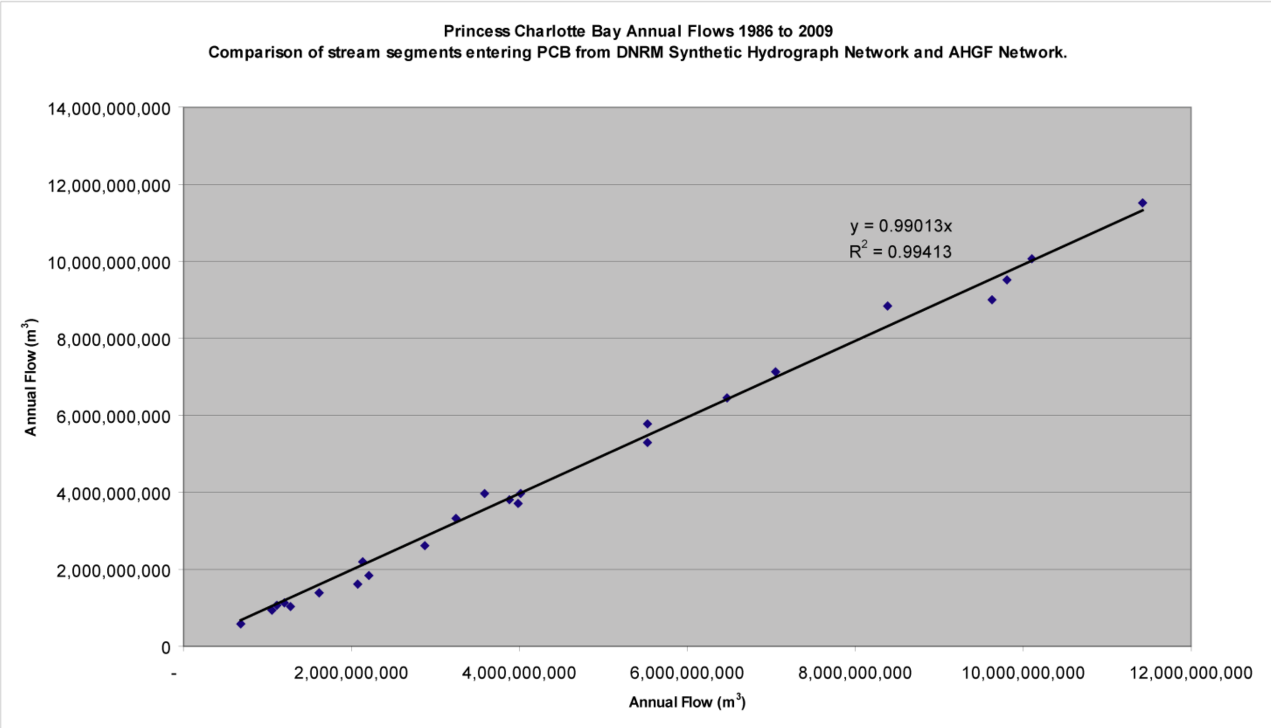
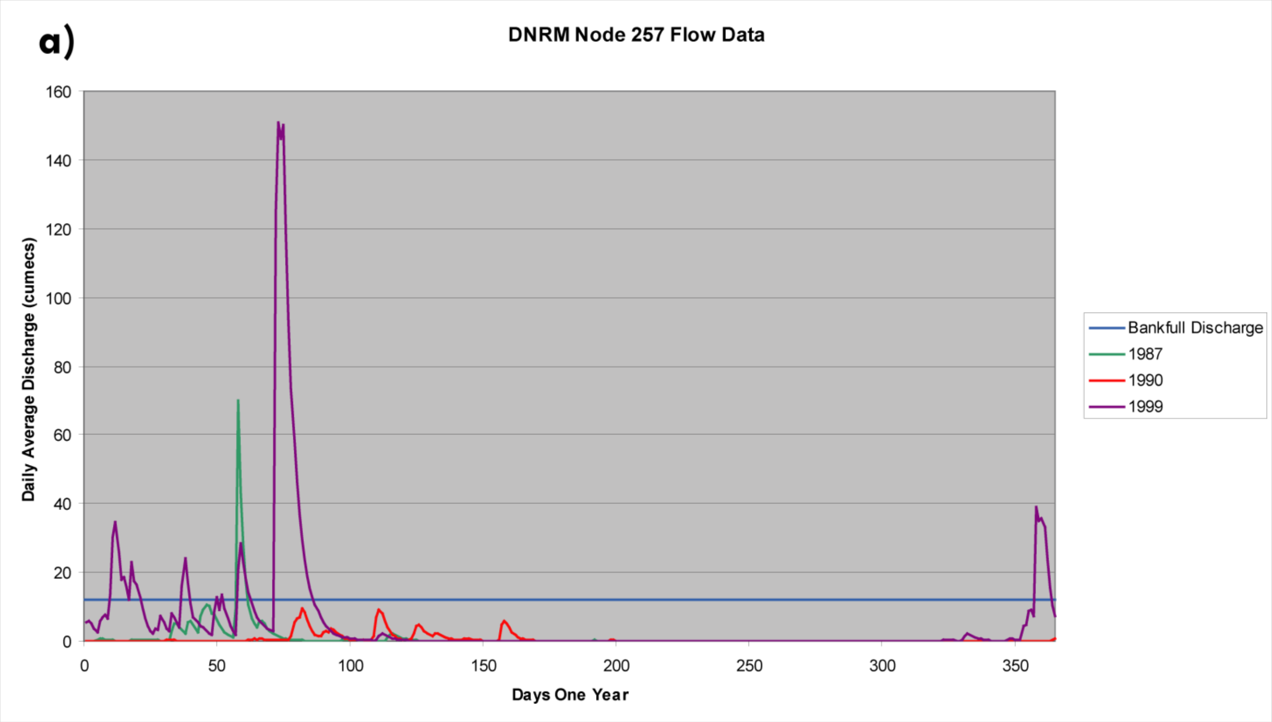
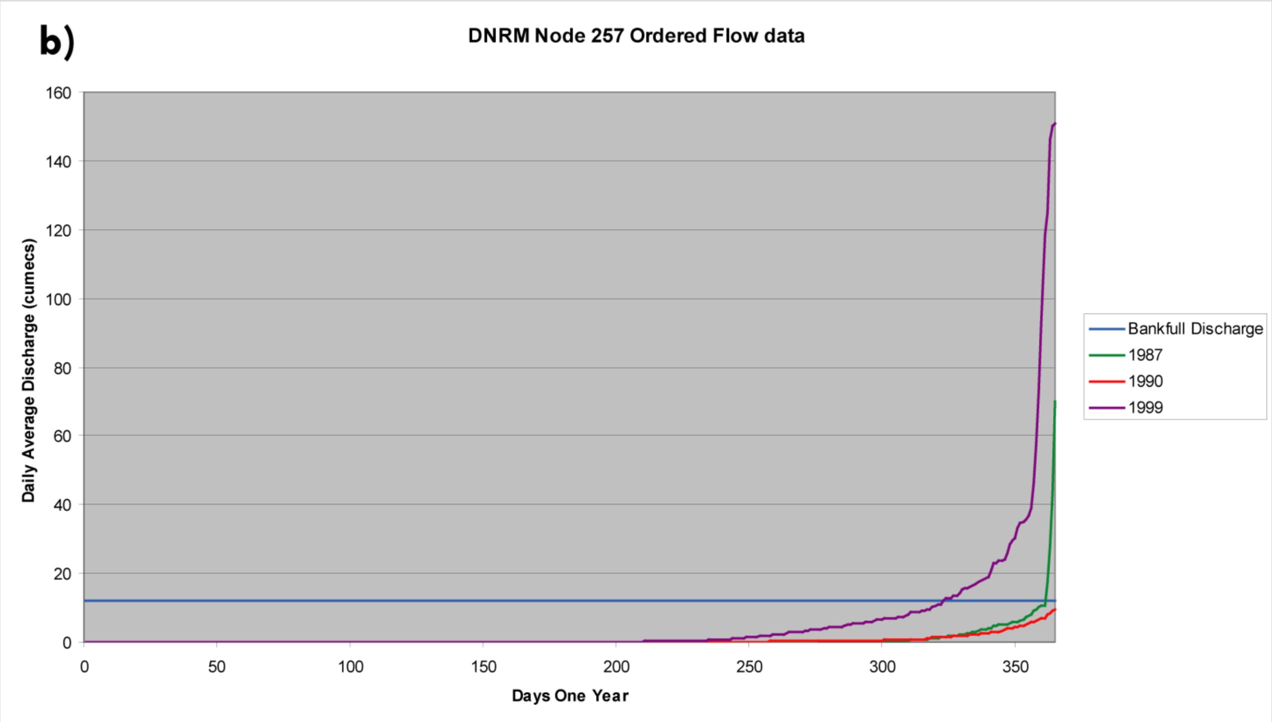


Figure 6: DNRM and AHGF inflows into PCB.

To estimate the portion of the total annual discharge that is overbank discharge require the development of a method applicable to the data available. Figure 7a shows the daily discharge of a DNRM node (chosen as an example) for a selection of years. As can be seen the variations of magnitude and timing of flows between years is significant. Extracting information from this yearly data in a form that can be used to extrapolate from the DNRM network to the AHGF network begins with transforming the yearly flow data into an order set (figure 7b), which simply means the 365 discharge values for a year in order from lowest to highest.



a)
DNRM Node 257 Flow Data
Daily Average Discharge (cumecs)
Days One Year
Bankfull Discharge
1987
1990
1999



b)
DNRM Node 257 Ordered Flow data
Daily Average Discharge (cumecs)
Days One Year
Bankfull Discharge
1987
1990
1999

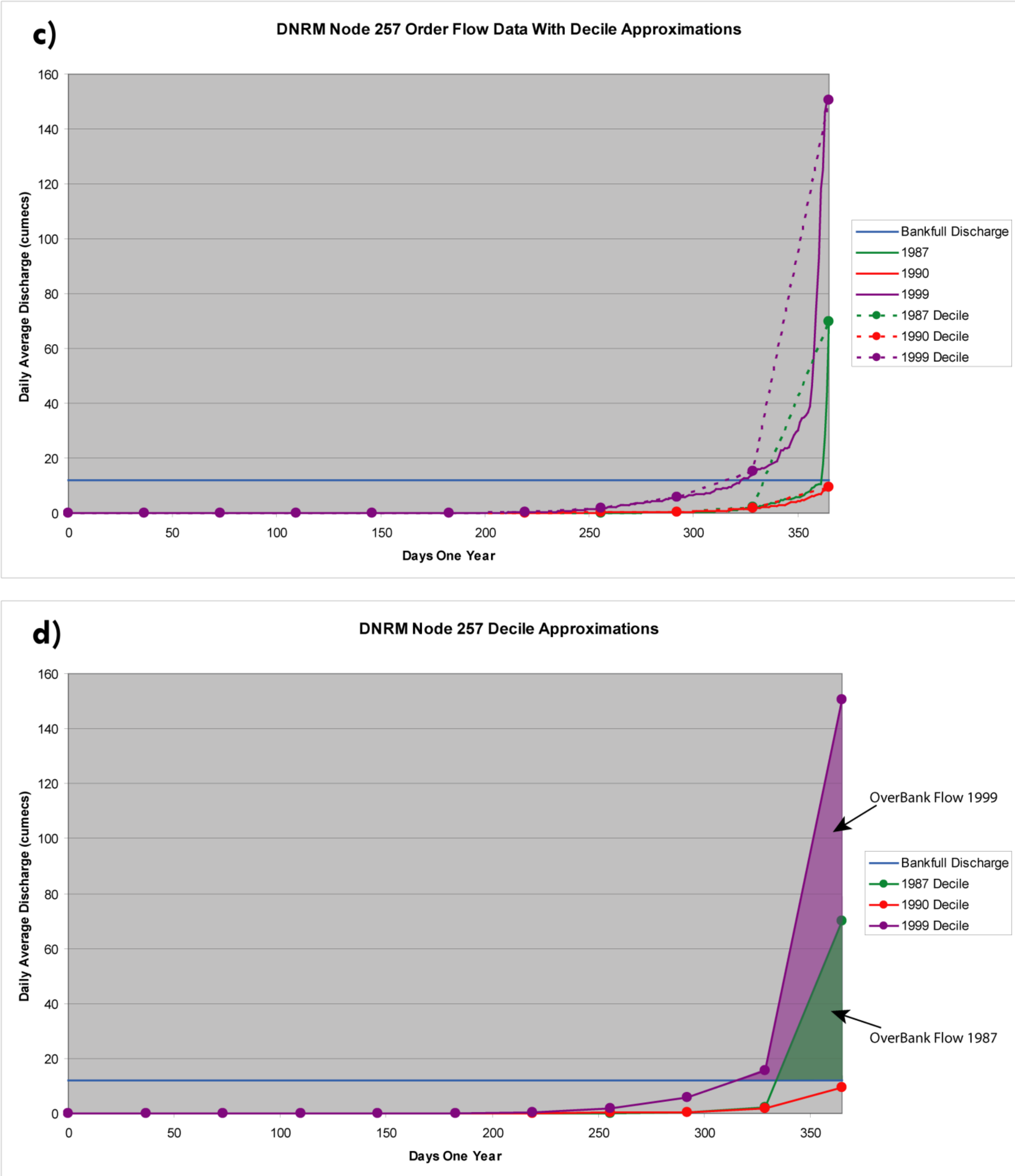


Figure 7: Example of over bank discharge estimation procedure.

The ordered set can be approximated by the maximum, minimum, and 9 intervening equal intervals (1 to 9 deciles), figure 7c. That is, the ordered set is broken into 10 equal divisions. The ordered set were generated for each DNRM node for each year and used to generate regression equations for each interpolation zone for minimum, 1 to 9 deciles, and maximum discharge values using catchment area as the independent variable. These regression equations were used to produce an approximation of a yearly ordered set of daily average discharge for each AHGF node. The overbank discharge for a year is the area under the decile approximation curve but above the bankfull discharge (described below), as shown in figure 7d. This procedure does not describe on which days overbank flows occurred, but on how many days of a year there was overbank flow.

As can be seen in figure 7c, the decile curve approximation is over estimating the original curve. There is the potential to further develop this procedure and improve the approximation and reduce the over estimation. This over estimation creates a discrepancy between the total annual discharge calculated as the total area under the decile approximation curve and the total annual discharge calculate from the regression equations of the sum of discharge of each DNRM node, the decile approximation curve value being higher. As regression equations for the sum of discharge of each DNRM node each year for each interpolation zone had high R^2 values (table 2), the annual overbank discharge as calculated from the decile approximation curve was scale to the total annual discharge calculate from the regression equations of the sum of discharge of each DNRM node.

Table 2 shows the range of R^2 values for the 4368 regression equations that describe the descriptive statistics of annual average, sum, minimum, 1 to 9 deciles, and maximum of daily discharge for each year for each DNRM node for each interpolation zone for the 24 years.

Table 2: R^2 values over 24 years for each hydrologic interpolation zone for average, sum, minimum, 1 to 9 deciles, and maximum of daily discharge data.

Interpolation Zone	Yearly average daily average discharge			Yearly sum daily average discharge			Yearly minimum daily average discharge			Yearly 1st decile daily average discharge			Yearly 2nd decile daily average discharge		
	Max R^2	Min R^2	Ave R^2	Max R^2	Min R^2	Ave R^2	Max R^2	Min R^2	Ave R^2	Max R^2	Min R^2	Ave R^2	Max R^2	Min R^2	Ave R^2
Beattie Creek	0.9999	0.8944	0.9845	0.9999	0.8944	0.9845	0.9774	0.8768	0.9530	0.9828	0.8784	0.9591	0.9863	0.9104	0.9676
Brown Creek	0.9981	0.8095	0.9336	0.9981	0.8095	0.9336	0.9775	0.7127	0.8993	0.9748	0.7731	0.8717	0.9771	0.7676	0.8484
Deighton	0.9984	0.9554	0.9829	0.9984	0.9554	0.9829	0.9867	0.9524	0.9755	0.9842	0.8731	0.9677	0.9844	0.8966	0.9616
East Normanby	0.9983	0.9188	0.9777	0.9983	0.9188	0.9777	0.9818	0.3620	0.4825	0.8393	0.3620	0.5473	0.8414	0.4192	0.6088
Eastern Lower Floodplain	0.9987	0.8533	0.9797	0.9987	0.8533	0.9797	0.9952	0.9046	0.9773	0.9972	0.9371	0.9788	0.9949	0.9269	0.9731
Jack	0.9969	0.6600	0.9257	0.9969	0.6600	0.9257	0.9737	0.7901	0.9203	0.9853	0.8275	0.9367	0.9889	0.8505	0.9452
Kennedy	0.9975	0.8652	0.9680	0.9975	0.8652	0.9680	0.9982	0.9243	0.9765	0.9970	0.7688	0.9686	0.9979	0.8116	0.9695
Laura	0.9991	0.9202	0.9706	0.9991	0.9202	0.9706	0.9897	0.9324	0.9538	0.9984	0.9235	0.9592	0.9987	0.9268	0.9669
Morehead	0.9972	0.8689	0.9519	0.9972	0.8689	0.9519	0.7664	0.5942	0.6421	0.7790	0.6033	0.6354	0.7802	0.6062	0.6409
Mosman	0.9965	0.7916	0.9465	0.9965	0.7916	0.9465	0.9555	0.8852	0.9265	0.9518	0.8681	0.9148	0.9487	0.8750	0.9197
North East	0.9999	0.9396	0.9888	0.9999	0.9396	0.9888	0.7326	0.5406	0.6072	0.7261	0.5676	0.6424	0.7673	0.6105	0.6893
North West	0.9989	0.9462	0.9827	0.9989	0.9462	0.9827	0.8974	0.8257	0.8374	0.9269	0.8256	0.8440	0.9583	0.8257	0.8542
West Normanby	0.9988	0.8959	0.9768	0.9988	0.8959	0.9768	0.7190	0.7041	0.7075	0.7234	0.7038	0.7081	0.7478	0.7037	0.7130
Western Lower Floodplain	0.9986	0.8933	0.9668	0.9986	0.8933	0.9668	0.7491	0.6390	0.6534	0.7716	0.6386	0.6605	0.8416	0.6408	0.6770
Interpolation Zone	**Yearly 3rd decile daily average discharge**			**Yearly 4th decile daily average discharge**			**Yearly 5th decile daily average discharge**			**Yearly 6th decile daily average discharge**			**Yearly 7th decile daily average discharge**		
	Max R^2	**Min R^2**	**Ave R^2**	**Max R^2**	**Min R^2**	**Ave R^2**	**Max R^2**	**Min R^2**	**Ave R^2**	**Max R^2**	**Min R^2**	**Ave R^2**	**Max R^2**	**Min R^2**	**Ave R^2**
Beattie Creek	0.9864	0.9282	0.9719	0.9848	0.9065	0.9682	0.9886	0.9124	0.9584	0.9920	0.9075	0.9585	0.9924	0.9172	0.9608
Brown Creek	0.9240	0.7407	0.8300	0.9703	0.7325	0.8303	0.9844	0.7493	0.8351	0.9769	0.7477	0.8575	0.9827	0.7804	0.8974
Deighton	0.9852	0.9054	0.9593	0.9821	0.9011	0.9580	0.9873	0.9038	0.9570	0.9865	0.8494	0.9599	0.9931	0.7463	0.9523
East Normanby	0.8048	0.4555	0.6415	0.8705	0.4982	0.6892	0.9001	0.5424	0.7532	0.9629	0.6052	0.7907	0.9826	0.6901	0.8570
Eastern Lower Floodplain	0.9963	0.8453	0.9637	0.9969	0.8862	0.9716	0.9962	0.8165	0.9559	0.9949	0.7806	0.9541	0.9959	0.7392	0.9185
Jack	0.9948	0.8694	0.9525	0.9833	0.7967	0.9439	0.9887	0.7539	0.9226	0.9884	0.7669	0.8949	0.9981	0.7418	0.8914
Kennedy	0.9982	0.8476	0.9708	0.9978	0.8903	0.9757	0.9976	0.9046	0.9780	0.9974	0.9125	0.9819	0.9991	0.8492	0.9793
Laura	0.9989	0.9436	0.9749	0.9987	0.9485	0.9837	0.9980	0.9634	0.9900	0.9981	0.9707	0.9913	0.9971	0.9117	0.9868
Morehead	0.7913	0.6013	0.6493	0.8452	0.6010	0.6615	0.8949	0.6051	0.6915	0.9722	0.6127	0.7394	0.9932	0.6546	0.8257
Mosman	0.9487	0.8748	0.9228	0.9580	0.8450	0.9117	0.9567	0.7627	0.8862	0.9544	0.7116	0.8849	0.9567	0.7296	0.8991
North East	0.8136	0.6140	0.7139	0.8457	0.6307	0.7429	0.8510	0.5824	0.7472	0.9674	0.5319	0.7114	0.9863	0.5251	0.7172
North West	0.9659	0.8326	0.8672	0.9966	0.8294	0.8893	0.9893	0.8384	0.9123	0.9998	0.8619	0.9372	0.9988	0.8760	0.9588
West Normanby	0.7764	0.7041	0.7215	0.8071	0.7036	0.7341	0.8407	0.7071	0.7504	0.8817	0.7133	0.7741	0.8852	0.7146	0.8074
Western Lower Floodplain	0.8669	0.6491	0.7028	0.9619	0.6526	0.7498	0.9884	0.6767	0.8101	0.9956	0.7399	0.8703	0.9935	0.7864	0.9199

Interpolation Zone	Yearly 8th decile daily average discharge			Yearly 9th decile daily average discharge			Yearly maximum daily average discharge		
	Max R^2	Min R^2	Ave R^2	Max R^2	Min R^2	Ave R^2	Max R^2	Min R^2	Ave R^2
Beattie Creek	0.9952	0.9309	0.9688	0.9990	0.9163	0.9790	0.9966	0.6225	0.9454
Brown Creek	0.9909	0.8503	0.9416	0.9932	0.8369	0.9385	0.9802	0.6416	0.8384
Deighton	0.9918	0.8898	0.9709	0.9963	0.9394	0.9768	0.9930	0.7442	0.9321
East Normanby	0.9937	0.6813	0.9181	0.9992	0.8491	0.9594	0.9842	0.5316	0.9027
Eastern Lower Floodplain	0.9985	0.6373	0.9354	0.9974	0.8222	0.9629	0.9946	0.7761	0.9529
Jack	0.9946	0.7165	0.9319	0.9980	0.8207	0.9346	0.9942	0.2848	0.8499
Kennedy	0.9980	0.9086	0.9694	0.9969	0.7973	0.9638	0.9733	0.4001	0.8038
Laura	0.9938	0.9536	0.9846	0.9952	0.9492	0.9795	0.9941	0.7454	0.9187
Morehead	0.9916	0.8462	0.9376	0.9972	0.9210	0.9733	0.9836	0.5364	0.8649
Mosman	0.9675	0.7562	0.9224	0.9951	0.8417	0.9398	0.9622	0.3880	0.7326
North East	0.9906	0.5389	0.8478	0.9972	0.6721	0.9423	0.9878	0.5090	0.8885
North West	0.9983	0.8688	0.9720	0.9979	0.9266	0.9792	0.9904	0.6293	0.8869
West Normanby	0.9932	0.7412	0.8648	0.9898	0.8349	0.9327	0.9812	0.8260	0.9134
Western Lower Floodplain	0.9955	0.8115	0.9441	0.9982	0.8797	0.9577	0.9945	0.8037	0.9255

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1.3 Banks

The LiDAR data collected for this project provided a unique opportunity to use a spatially distributed modelled bank height and depth based on an extrapolation of channel cross section data extracted from the LiDAR. The distribution of the LiDAR blocks is shown in figure 8. Approximately 300 cross sections were extracted from these LiDAR blocks at locations proximal to network nodes. Some of these cross sections were not used as they were considered not representative. The remaining 220 cross sections were divided into channel dimension interpolation zones (figure 9) that approximately represent zones of similar geomorphology. The east side of the catchment is not well represented within the LiDAR blocks. The node network was divided into the same channel dimension zones, figure 8.

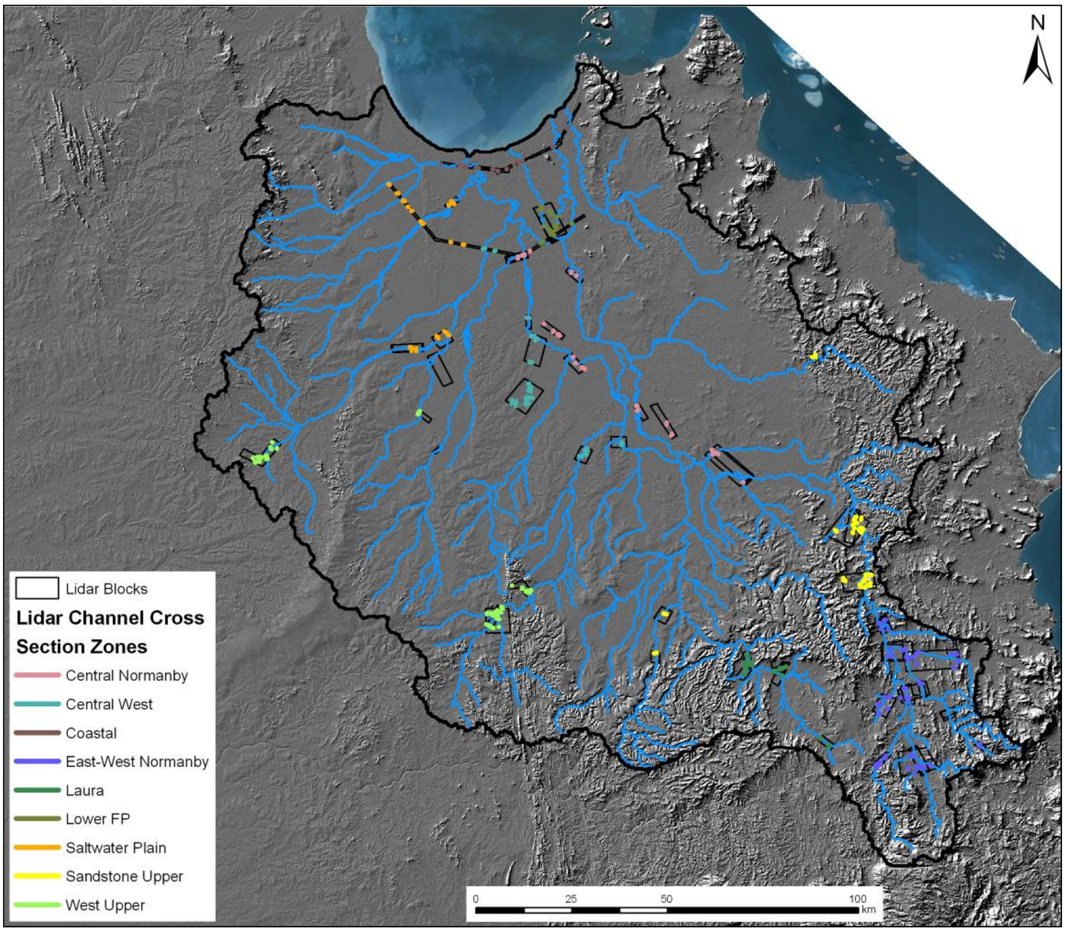

Figure 8: Location of LiDAR blocks and channel cross sections shown divided into channel dimension interpolation zones.

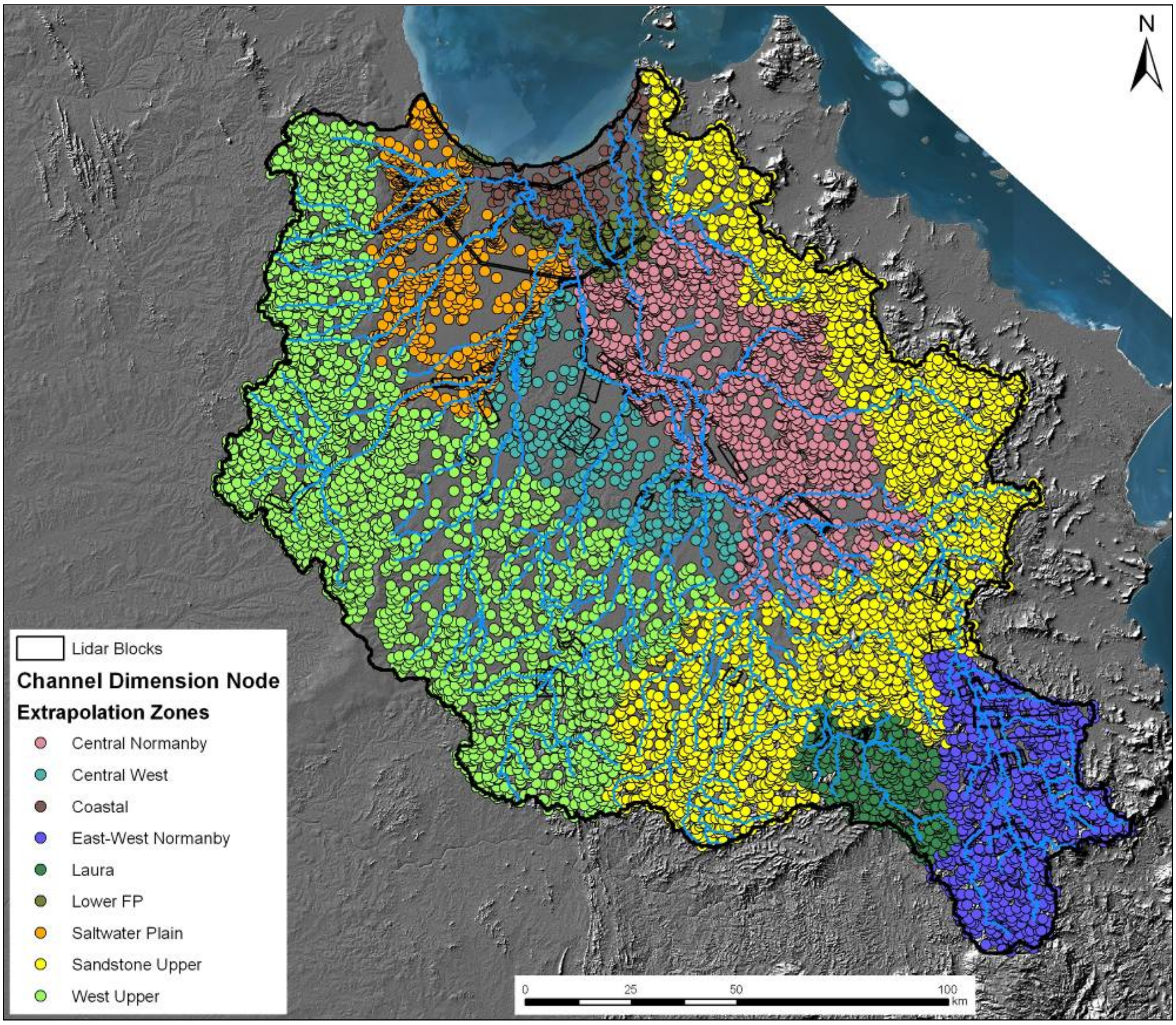

Figure 9: AHGF node network shown divided into channel dimension interpolation zones.

Approximations of the downstream patterns of channel dimensions were modelled using polynomial regression equations. The dependent variable was catchment area at each node. The R^2 values and the polynomial equations are shown in Table 3. The coastal zone depth equation was not used as the water surface is captured in the LiDAR data and not the channel depth. The channel depth in the coastal zone was modelled using the Lower FP zone depth equations or manually edited. The resulting modelled channel depth is shown is figure 10.

Table 3: Regression equations used in channel dimension interpolation.

Zone		R^2	Equation
Central Normanby	Depth	0.73	$y = 7.74E\text{-}21x^2 + 3.93E\text{-}10x + 1.31E{+}00$
	Width	0.69	$y = 2.53E\text{-}18x^2 + 2.07E\text{-}09x + 2.71E{+}01$
Central West	Depth	0.74	$y = -1.47E\text{-}18x^2 + 5.00E\text{-}09x + 1.14E{+}00$
	Width	0.65	$y = -2.11E\text{-}16x^2 + 5.39E\text{-}07x$
Coastal	Depth	0.24	$y = -7.47E\text{-}30x^3 + 9.32E\text{-}20x^2 - 2.009E\text{-}10x + 1.22E{+}00$
	Width	0.76	$y = 1.30E\text{-}27x^3 - 1.06E\text{-}17x^2 + 2.30E\text{-}08x + 4.16E{+}01$
East–West Normanby	Depth	0.60	$y = 2.65E\text{-}26x^3 - 8.35E\text{-}17x^2 + 7.76E\text{-}08x$
	Width	0.74	$y = 3.28E\text{-}25x^3 - 9.511E\text{-}16x^2 + 8.54E\text{-}07x$
Laura	Depth	0.64	$y = 1.37E\text{-}25x^3 - 1.97E\text{-}16x^2 + 8.70E\text{-}08x$
	Width	0.69	$y = 1.28E\text{-}24x^3 - 1.83E\text{-}15x^2 + 8.45E\text{-}07x$
Lower FP	Depth	0.72	$y = 1.73E\text{-}28x^3 - 1.95E\text{-}18x^2 + 5.25E\text{-}09x + 1.46E{+}00$
	Width	0.70	$y = -1.87E\text{-}28x^3 - 2.23E\text{-}18x^2 + 2.25E\text{-}08x + 4.03E{+}01$
Saltwater Plain	Depth	0.83	$y = -3.86E\text{-}28x^3 - 1.16E\text{-}20x^2 + 2.62E\text{-}09x + 8.59E\text{-}01$
	Width	0.79	$y = -2.54E\text{-}25x^3 + 7.37E\text{-}16x^2 - 2.90E\text{-}07x + 4.91E{+}01$
Sandstone Upper	Depth	0.62	$y = 6.31E\text{-}27x^3 - 2.59E\text{-}17x^2 + 3.58E\text{-}08x$
	Width	0.66	$y = 9.74E\text{-}26x^3 - 3.33E\text{-}16x^2 + 4.73E\text{-}07x$
West Upper	Depth	0.73	$y = -1.55E\text{-}17x^2 + 3.06E\text{-}08x$
	Width	0.75	$y = -2.95E\text{-}16x^2 + 4.99E\text{-}07x$

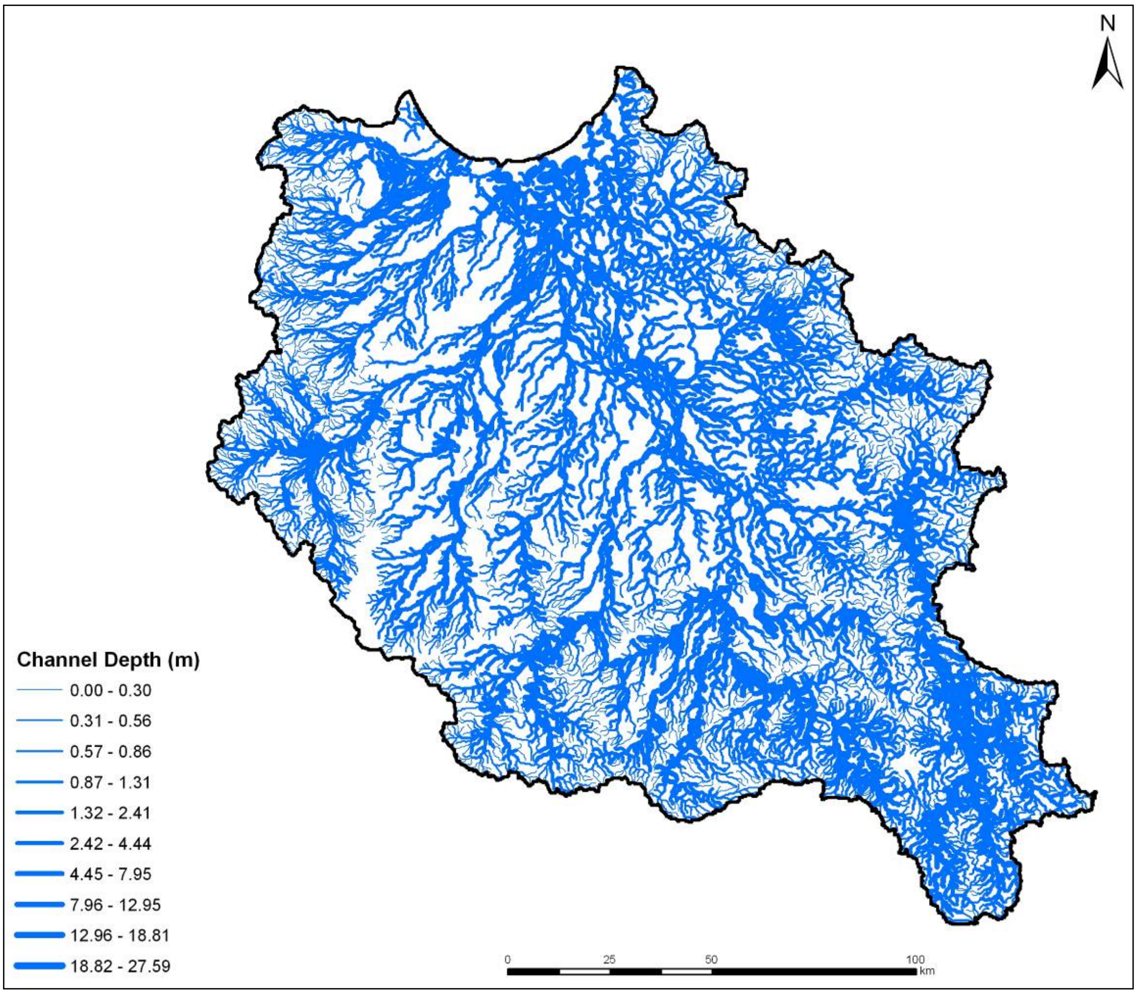

Figure 10: Stream network channel depth.

The modelled channel width and depth were used to calculate the channel cross sectional area (CSArea) and the wetted perimeter (WP) of each stream segment. Bank full velocity was calculated using the Chezy-Manning equation.

$$Vel_{BF} = \frac{R^{2/3} S^{1/2}}{n}$$

(Equation 2, Chezy-Manning Equation)

Vel_{BF} = average velocity, m/s

S = slope

R = hydraulic radius (= CSArea / WP), m^2/m

n = roughness coefficient (Manning's n)

The channel slope was used as a proxy for the water surface slope and was calculated with the 9 second DEM elevation of the upstream and downstream node and length of each stream segment. Manning's n was simply estimated using text book values of different channel descriptions, the spatial distribution of n values are shown in figure 11.

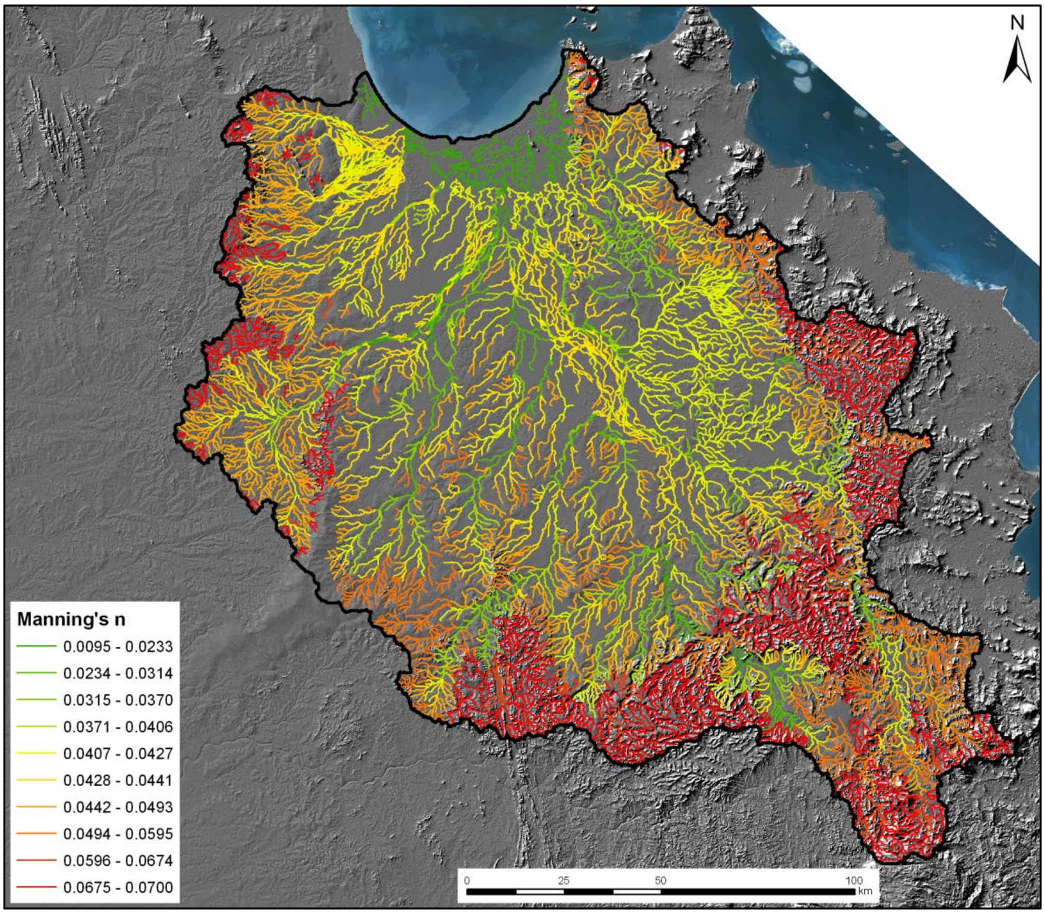

Figure 11: Manning's n estimation.

Then bank full discharge (Q_{BF}, cumecs) is calculated using;

$$Q_{BF} = CSArea \times Vel_{BF}$$

(Equation 3)

For this iteration of the model, we have used the standard SedNet equation (equation 4) to estimate the rate of bank erosion (BE_{Rate}), Whilst we acknowledge the inherent weakness of this approach, as outlined in Rustomji et al. (2010), an improved understanding of bank erosion processes is the subject of ongoing research and will be updated in the future.

$$BE_{rate} = 0.008 Q_{BF}^{0.60}$$

(Equation 4, Prosser et. al.(2001))

The following step (equation 5) which converts the bank erosion rate to t/yr of bank erosion is the same as that used in Prosser et al (2001).

$$SusBE_{t/yr} = BE_{rate} \times Bank\ Height \times Segment\ Length \times Bulk\ Density \times Portion\ Suspended\ Load$$

(Equation 5)

Bulk Density = 1.66, Portion Suspended Load = 54.3 %

1.4 Floodplains

The delineation of an approximate floodplain extent consisted of three steps. Using the alluvial geology as the first approximation, then removing 9 second pixels according to the degree of variation (roughness) of the elevation values of the 1 second pixels within the 9 second pixel, and lastly several sections were manually edited. The very flat nature of the landscape in some parts of the catchment was best addressed with manual editing. The floodplain extent is shown in figure 12. The AHGF sub-catchments were overlain on the floodplain extent and the amount of floodplain within each sub catchment was calculated. It is acknowledged that this method is likely to have over-estimated the area of “effective” floodplain, so further work looking at flood inundation patterns using MODIS imagery or analysis of DEM datasets is required to characterise the area actually inundated.

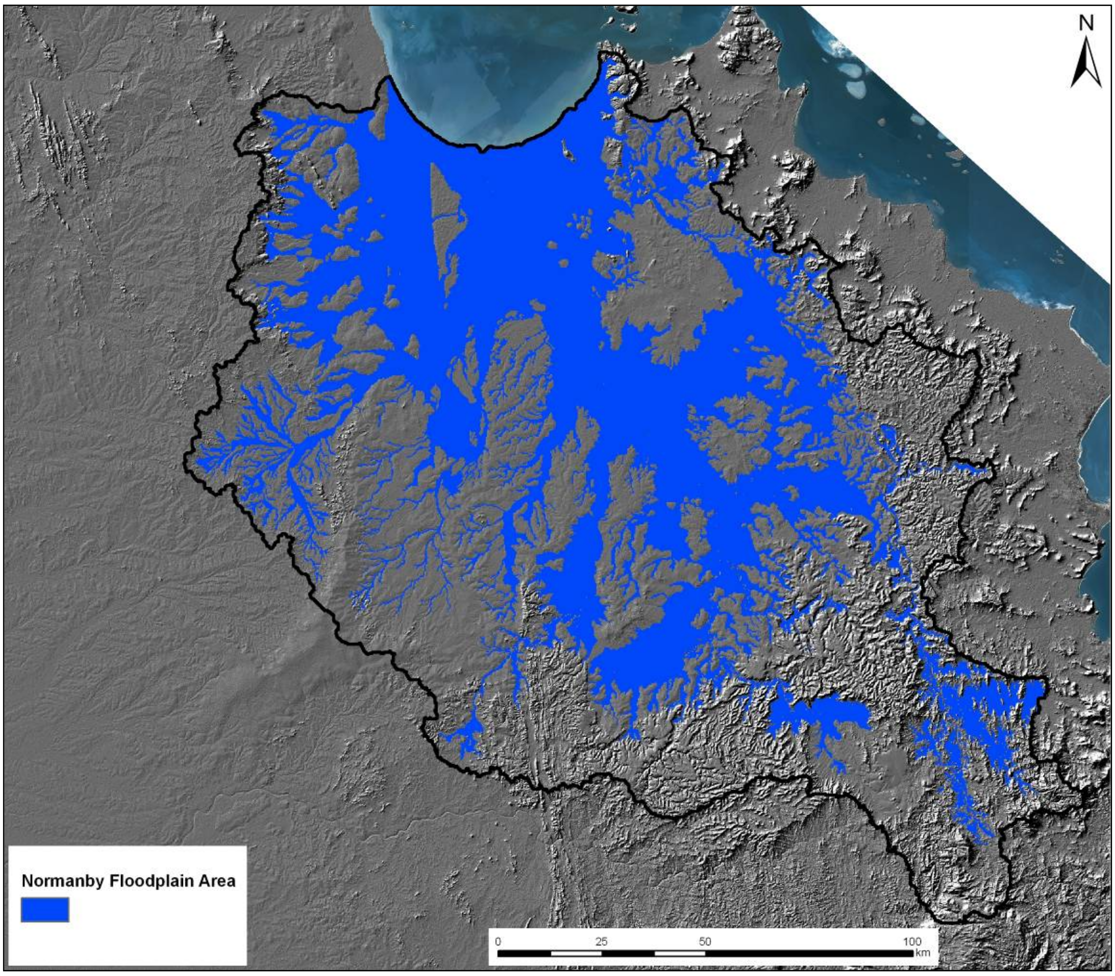

Figure 12: Floodplain area used for model parameterisation.

Two methods of calculating floodplain deposition were used in this study. The standard method (equation 6) was used for sub-catchments outside the zones of floodplain accretion shown in figure 13. The OSL sampling component of this study defined 5 floodplain accretion rates. These 5 sample sites were grouped into 3 zones of floodplain accretion. The extent of each zone was determined by an examination, in combination, of longitudinal profiles of the main streamlines, Spot satellite imagery and the 1 second DEM and hillshade. The coastal zone was defined as having no floodplain accretion within the model, for reasons explained elsewhere.

$$FPDeposition = \frac{Q_{OverBank}}{Q_{Annual}}(Suspended\ Load)\left(1 - e^{-\left(\frac{vA_f}{Q_f}\right)}\right)$$

(Equation 6, Prosser et. al.(2001))

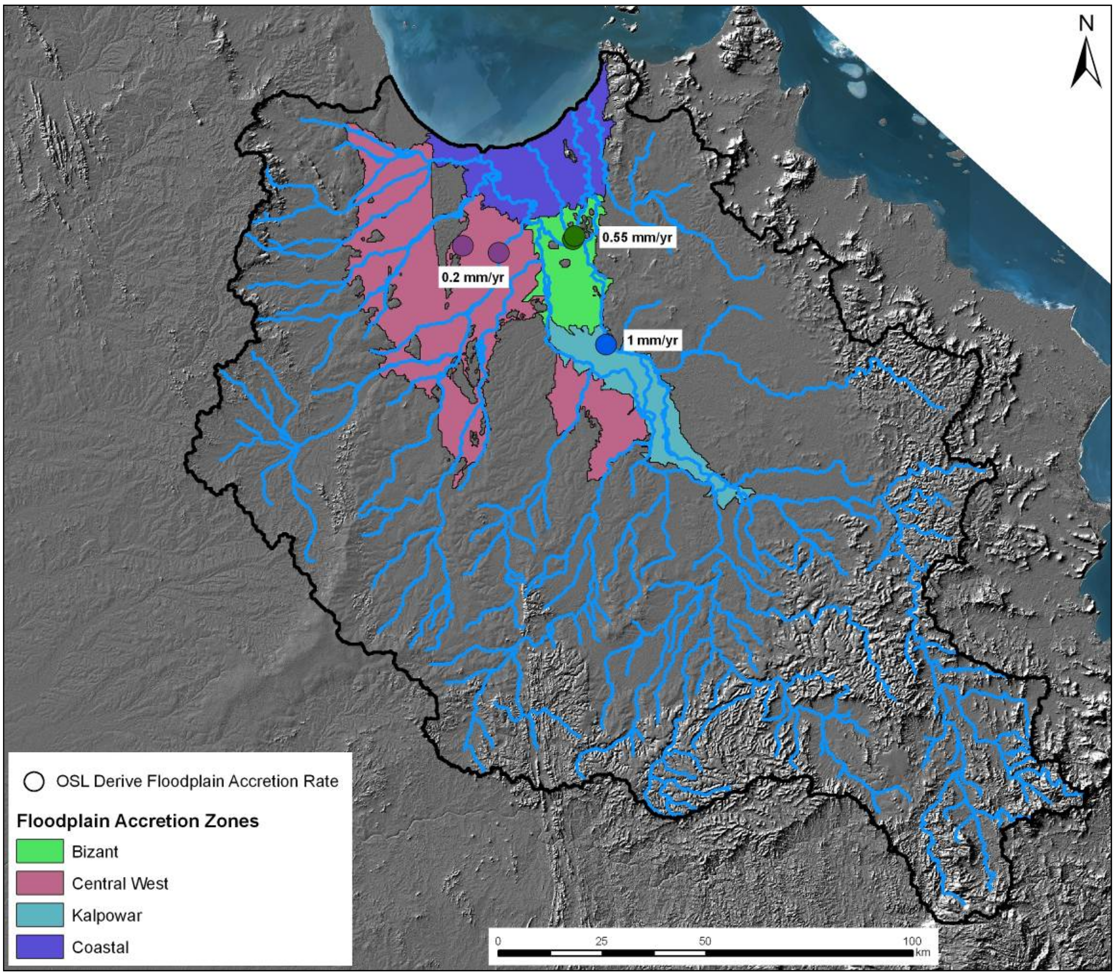

Figure 13: Floodplain zones with floodplain accretion OSL sampling sites.

Within the floodplain accretion zones suspended sediment was deposited onto the area of floodplain within each sub-catchment to equal the measured floodplain accretion rate. Where there was insufficient suspended sediment supply to equal the floodplain accretion rate the floodplain deposition was capped at the amount of suspended sediment available.

1.5 Hillslope Erosion

The area of hillslope within the catchment was calculated as in equation 7. The modelled channel width (mentioned above) provided the opportunity to exclude the channel area.

$$\textit{Hilslope Area} = \textit{Total Catchment Area} - \textit{Floodplain Area} - \textit{Channel Area}$$

(Equation 7)

Hilllslope erosion was determined using RUSLE. The datasets used were as follows;

- R-factor – dataset developed for the NLWRA
- C-factor and S-factor – datasets developed by Queensland DNRM. DNRM supplied us with a time series of C-factor data covering the period 1986-2010. For the purposes of this model we used the average C-factor over this period, given that it varied little between years, and there were pixels with no data within the annual layers.
- L-factor – assume to be 1.
- K-factor and the Hillslope Sediment Delivery Ratio (HSDR) – these were determined for 4 main geologic zones of the catchment from field data collected at sites that had hillslope sediment traps installed for two wet seasons. The values were extrapolated to the whole catchment based on the catchments geology, figure 14, figure 15, and figure 16.

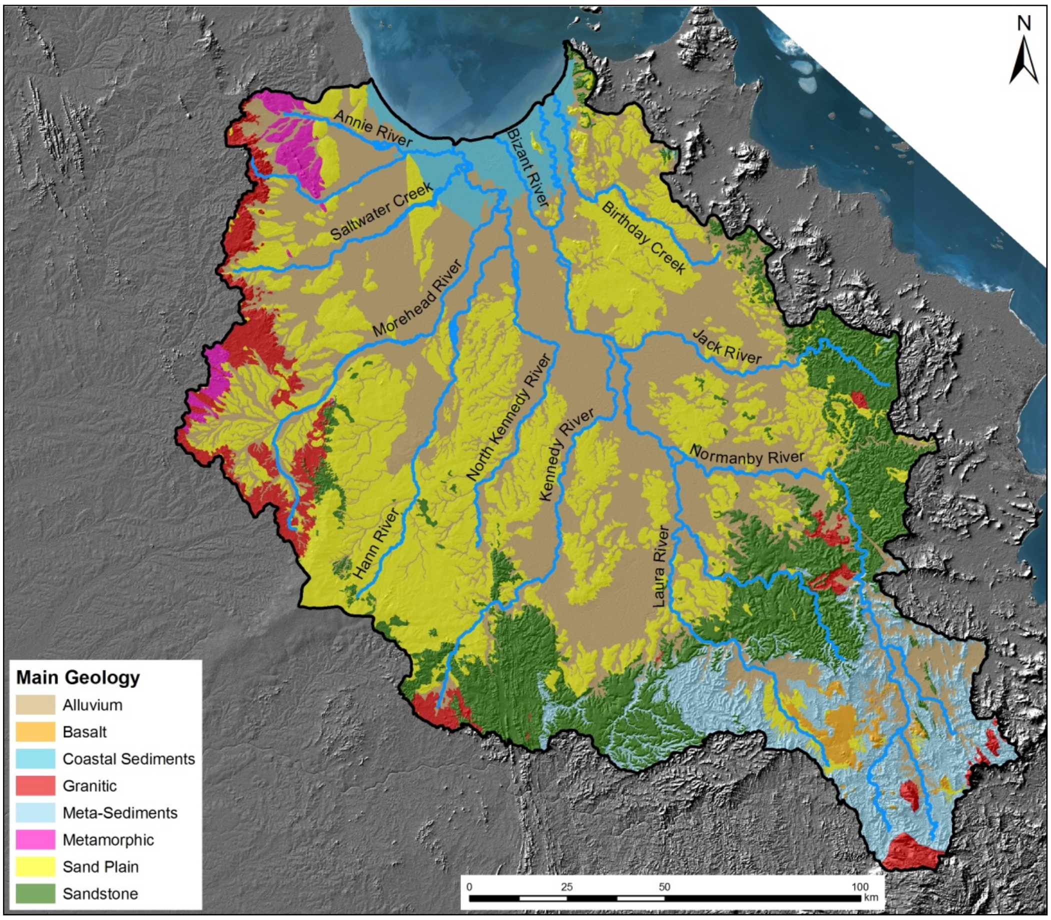

Figure 14: Catchment Geology.

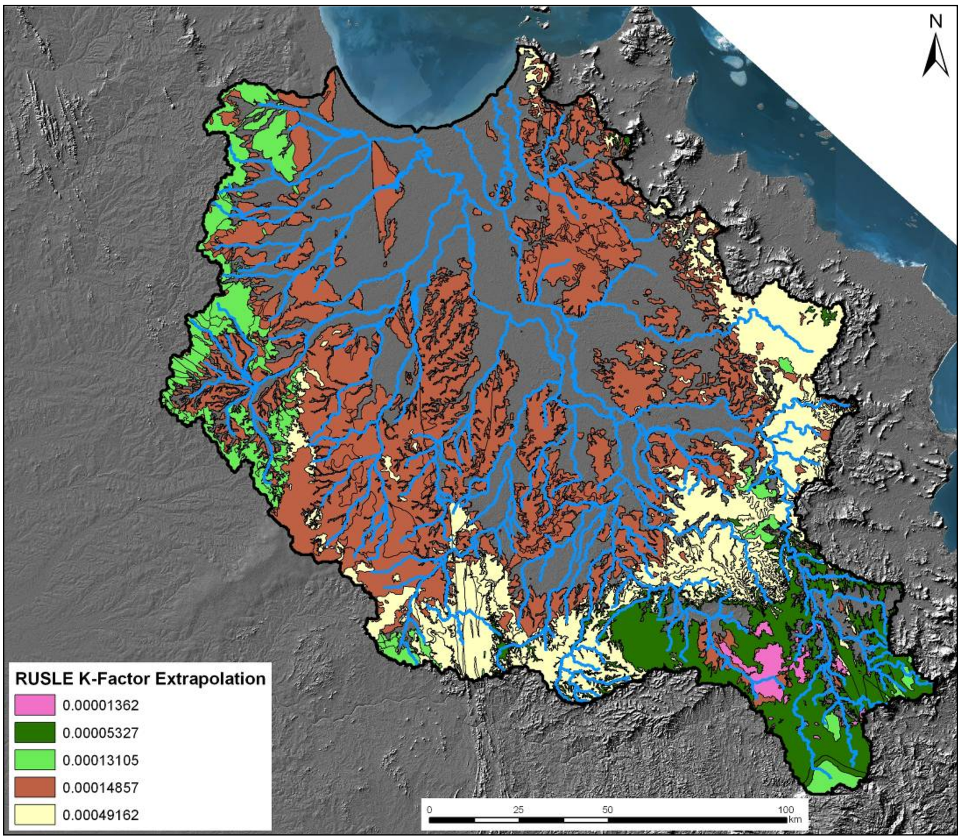

Figure 15: K-factor extrapolation.

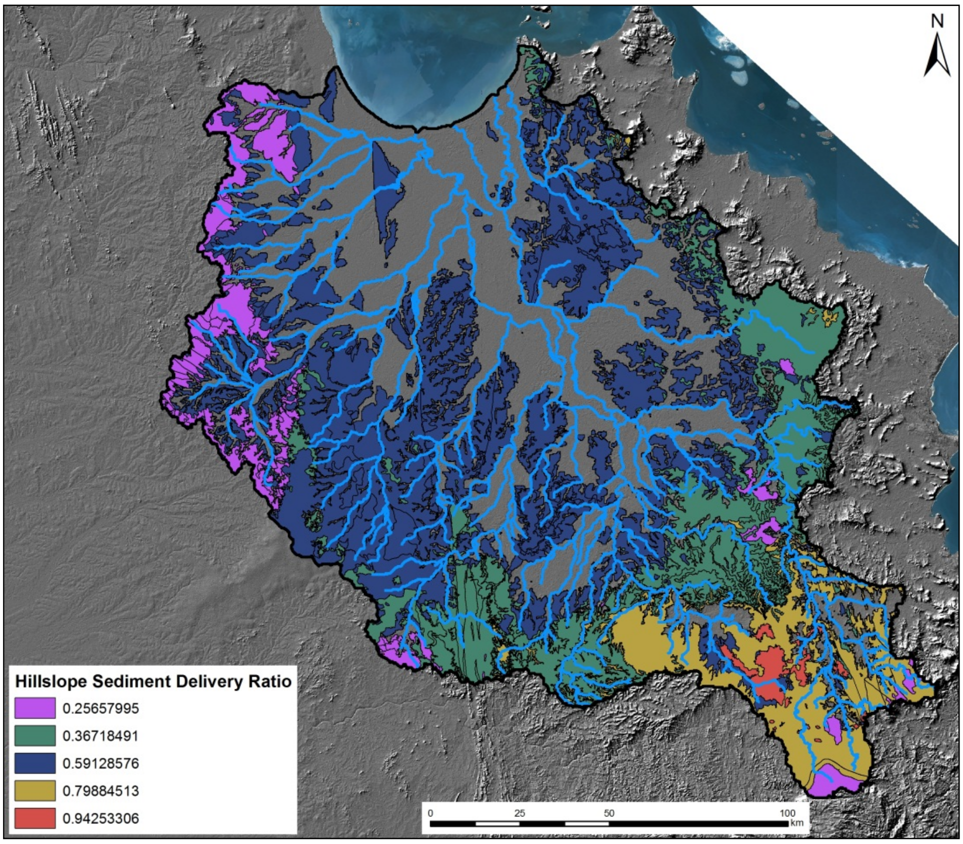

Figure 16: Hillslope sediment delivery ratio extrapolation.

1.6 Secondary Channels

Significant amounts of erosion were observed between LiDAR data collected in 2009 and 2011 that was associated with small streams that are not represented in the modelled network. The volume of this erosion was calculated and summed for each LiDAR block were repeat LiDAR was available. This was plotted against the length of AHGF stream segment length within each LiDAR block to give the regression in figure 17.

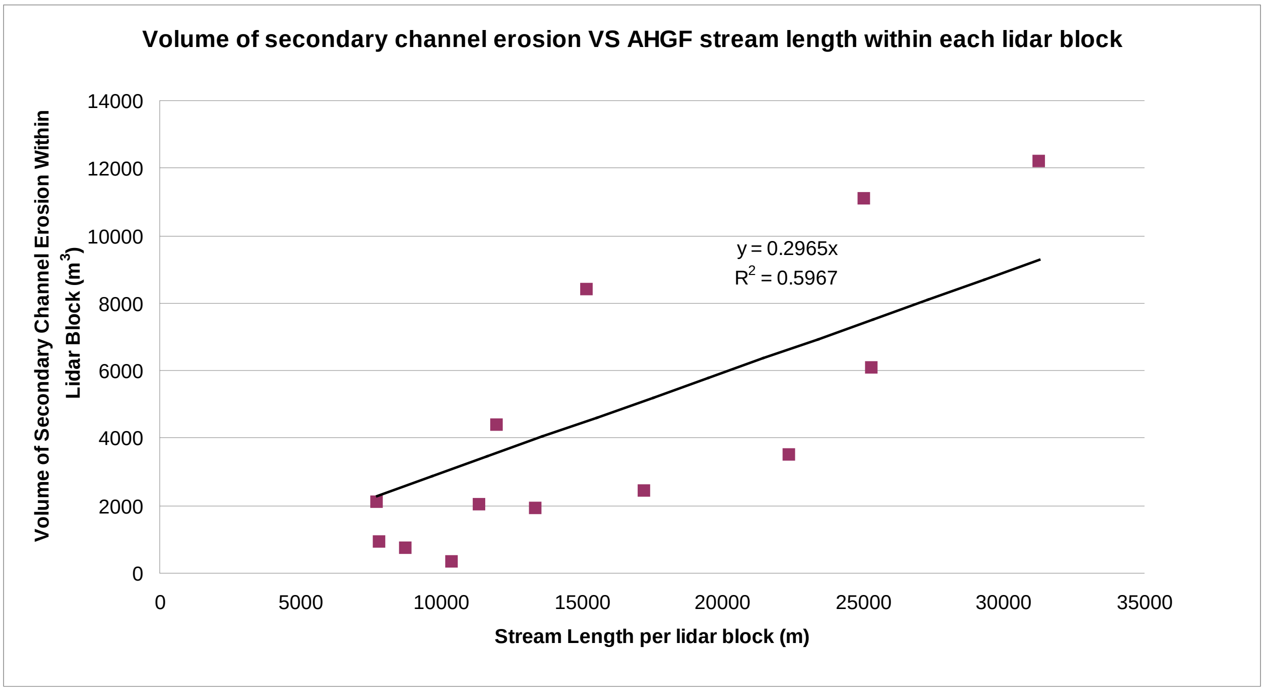

Figure 17: Volume of secondary channel erosion plotted against AHGF stream length within each LiDAR block.

This regression was used with the length of stream segment within each sub-catchment to parameterise each sub-catchment with an amount of secondary channel erosion. A bulk density value of 1.6 and a portion of suspended sediment of 33.7 % were then applied to give tons per year of suspended sediment for each sub-catchment.

1.7 Channel aggradation

In-channel deposition was determine within LiDAR blocks and extrapolated to the AHGF network. The amount of in-channel deposition of suspended sediment was subtracted from the suspended sediment moving through a stream segment. Where there was insufficient suspended sediment supply to equal the amount of expected in-channel deposition, in-channel deposition was capped at the amount of suspended sediment available.

1.8 Gully Erosion

Amounts of gully erosion were determined using a dataset of volumes of gully erosion measured between LiDAR data collected in 2009 and 2011 and a dataset of gullies mapped on Google Earth imagery. Both gully datasets were separated into alluvial and colluvial gullies according to the extent of alluvial geology (figure 14). The distribution of Google Earth gullies can be seen in figure 18. The area of alluvial and colluvial gully within each sub catchment (figure 19) was extracted.

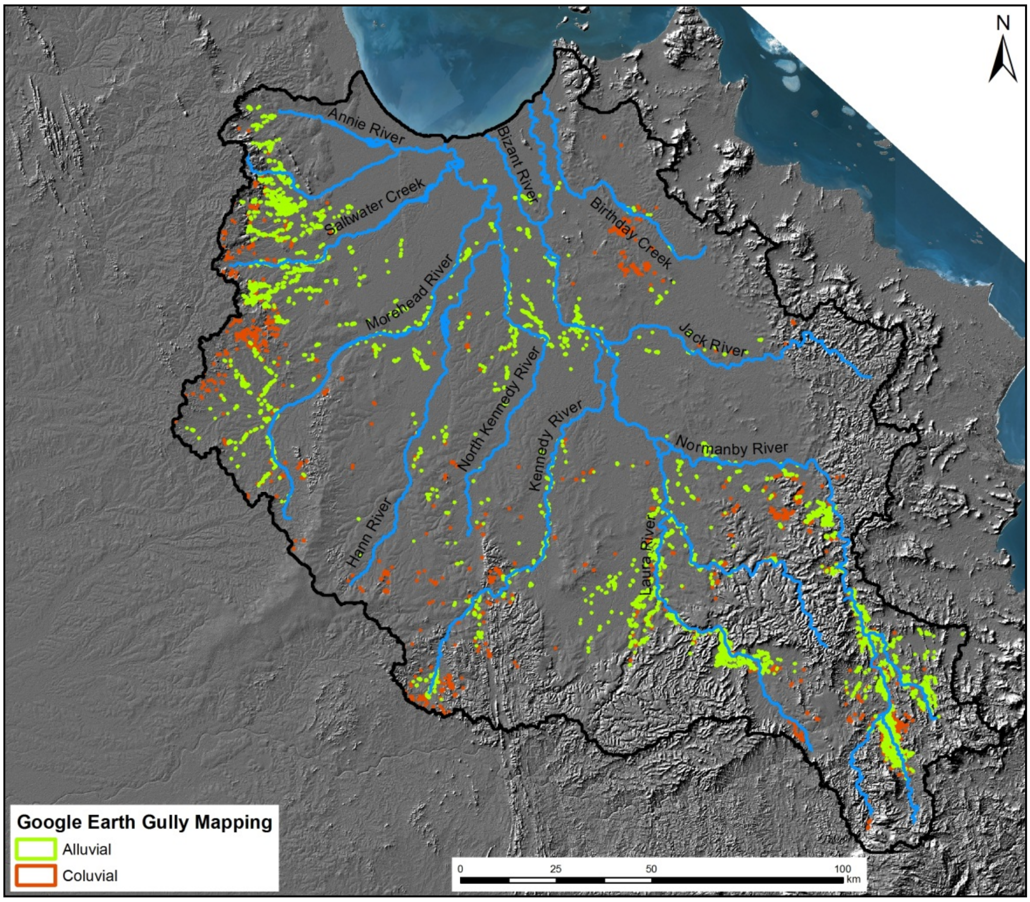

Figure 18: Distribution of colluvial and alluvial gullies mapped in Google Earth.

Table 4: Area of Google Earth mapped gullies.

Catchment total alluvial gully area =	10,746,706 m²	69 %
Catchment total colluvial gully area =	4,920,377 m²	31 %
Catchment total gully area =	15,667,084 m²	

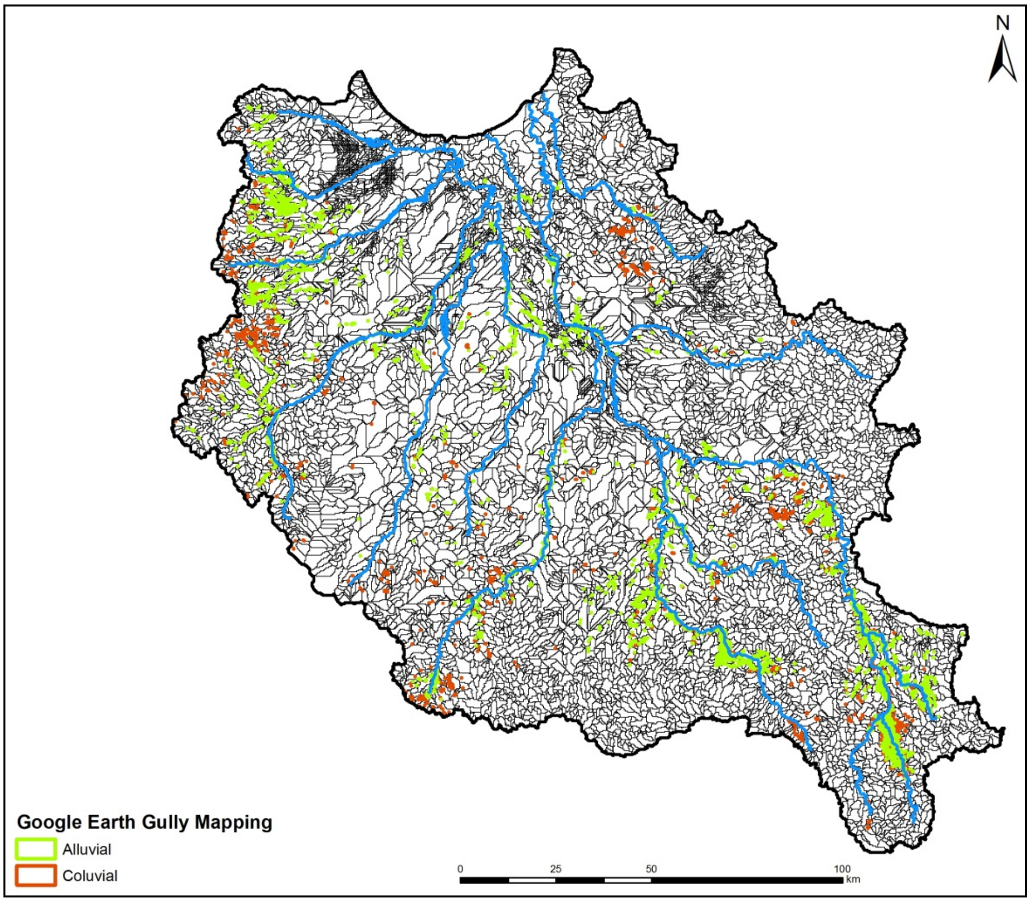

Figure 19: Google Earth mapped gullies overlain on AHGF sub-catchments.

The volume of gully erosion observed in each LiDAR block was plotted against the ratio of Google Earth gully area within a LiDAR block and LiDAR block area for alluvial (table 5 and figure 20) and colluvial (table 6 and figure 21) gullies.

Table 5: Alluvial gully erosion volume and the ratio of alluvial Google Earth gully area and LiDAR block area.

LiDAR Block	Alluvial LiDAR Gully Erosion (m^3/yr)	Alluvial Google Earth Gully Area / LiDAR Block Area
norm 4	1629	0.0179
norm 5	2955	0.0189
norm 7	7014	0.0634
norm 9	723	0.0119
norm 10	1352	0.0105
norm 13	637	0.0160
norm 16	3818	0.0430
norm 17	602	0.0060
norm 20	1021	0.0177
norm 21	1196	0.0012
norm 25	79	0.0001
norm 40	0	0.0003

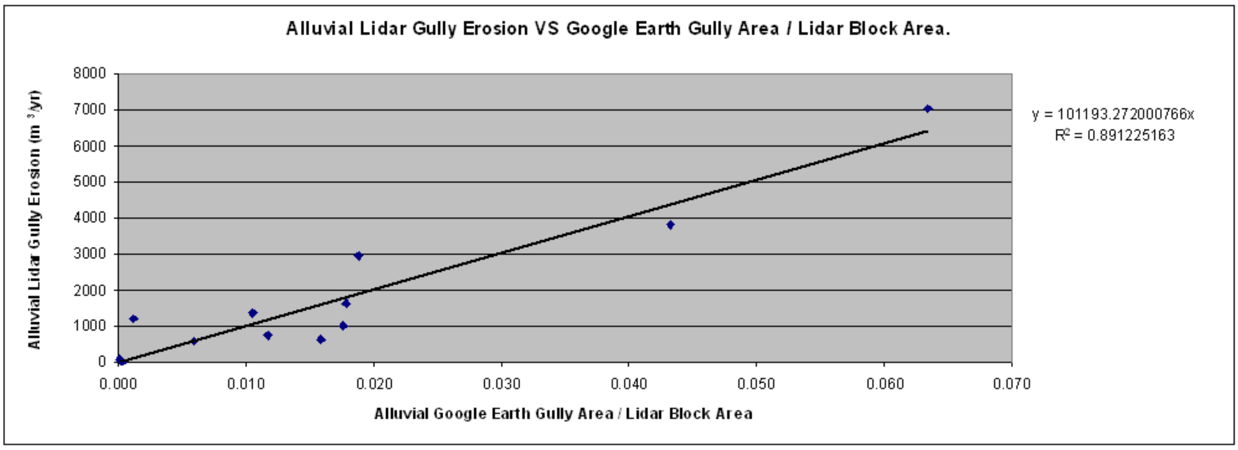

Figure 20: Relationship between alluvial gully erosion volume and the ratio of alluvial Google Earth gully area and LiDAR block area.

Table 6: Colluvial gully erosion volume and the ratio of colluvial Google Earth gully area and LiDAR block area.

LiDAR Block	Colluvial LiDAR Gully Erosion (m^3/yr)	Colluvial Google Earth Gully Area / LiDAR Block Area
norm 4	214	0.001200
norm 5	224	0.000790
norm 7	277	0.001300
norm 9	0	0.000510
norm 10	18	0.000000
norm 13	61	0.001230
norm 16	4	0.000000
norm 17	0	0.000000
norm 20	0	0.000076
norm 21	5	0.000000
norm 25	0	0.000000
norm 40	0	0.000000

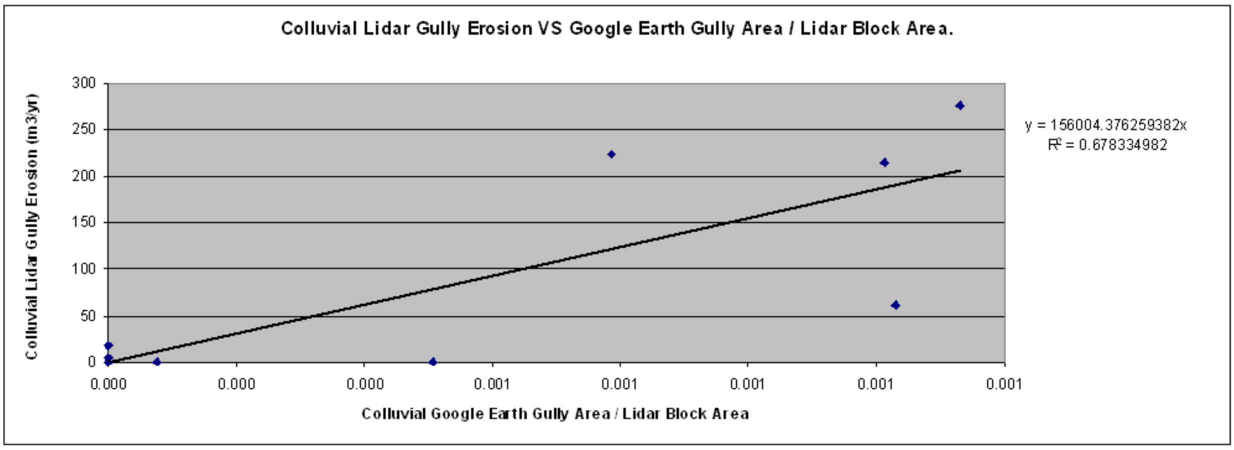

Figure 21: Relationship between colluvial gully erosion volume and the ratio of colluvial Google Earth gully area and LiDAR block area.

The ratio of Google Earth area of alluvial and colluvial gully in each sub catchment and the sub catchment area was converted to m^3 of erosion with the above regression equations. These volumes were converted to tons per year of suspended sediment using values of bulk density = 1.94 and portion of suspended sediment = 61.9 %

Table 7: Tons per year of gully erosion.

Catchment total alluvial gully erosion =	733,195 t/yr	63 %
Catchment total colluvial gully erosion =	433,830 t/yr	37 %
Catchment total gully erosion =	1,167,026 t/yr	

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Rustomji, P., Shellberg, J., Brooks, A., Spencer, J., Caitcheon, G., 2010. A catchment sediment and nutrient budget for the Mitchell River, Queensland. A report to the Tropical Rivers and Coastal Knowledge (TRaCK) Research Program. CSIRO Water for a Healthy Country National Research Flagship. Available at: http://track.gov.au/publications/registry/876, Canberra, Australia.