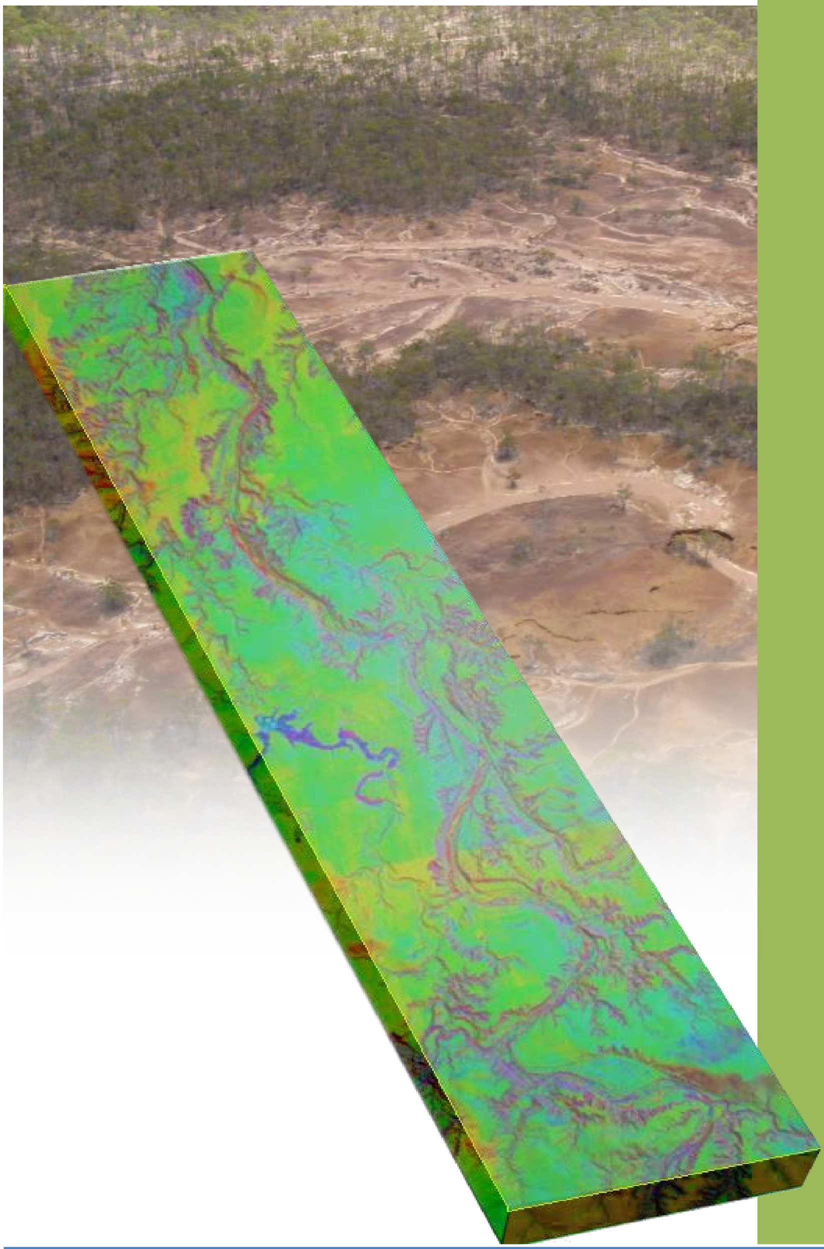

An Empirically-based Sediment Budget for the Normanby Basin

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

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Appendix 11: Suspended Sediment Data at River Gauges

IMPORTANT

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Griffith UNIVERSITY

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 11: Suspended Sediment Data at River Gauges

Prepared by: Jeff Shellberg, Andrew Brooks, John Spencer, and Christina Howley

1. Review of Laboratory Protocols to Measure Suspended Sediment

There are currently two main laboratory methods for measuring the concentration (mg/L) of suspended sediment. The suspended sediment concentration (SSC) method analyses whole water bottle samples (typically > 400 mL) to retain and weight all sediment collected for a given water volume (ASTM 2002). The total suspended solid (TSS) method analyses sub-samples (typically 100 mL) extracted from bottle samples (typically > 300 mL) to estimate sediment concentrations from a portion of the total water and sediment (APHA 1995). While both methods provide an estimate of the concentration of suspended sediment (mg/L), the data results are not necessarily equal or interchangeable due to bias in measurement technique. The TSS protocol is known to bias against sand sized particles (>63 μm) during sub-sampling (Gray et al. 2000), while the SSC protocol is a less biased estimate of sediment concentration. The TSS protocol is generally not appropriate to use for fluvial sediments, especially where the suspension of sand particles (>63 μm) occurs during floods (Edwards and Glysson 1998; Gray et al. 2000). Unfortunately, the TSS protocol remains the predominant method used for fluvial sediment analysis in Queensland, contributing an unknown degree of bias into suspended sediment load estimation to receiving waters like the GBR.

For fluvial sediment analysis in the Normanby catchment, the TSS data should be utilized and interpreted with caution due to the potential bias against suspended sand (Gray et al. 2000). However due to the dearth of data in the Normanby, these historic TSS data are utilized along with more recent SSC data to develop sediment rating curves. While not best practices for multiple reasons, the combined data do provide an initial estimate of concentrations of suspended sediment and fine suspended sediment loads in the Normanby catchment.

2. Review of Field Protocols to Measure Fluvial Suspended Sediment

It is generally known that concentrations of suspended sediment vary considerably with width and depth across a given cross-section at a particular point in time. Detail field measurement protocols and equipment have been developed to measure this variability and determine integrated or average concentrations for a given cross-section at a point in time (Edwards and Glysson 1998; Wong et al. 2003). In addition, the exact method of water collection can influence the resultant concentration, depending on whether the sample is collected isokinetically or non-isokinetically with respect to actual surrounding ambient concentrations. Generally, grab samples using water bottles or pump samplers are non-isokinetic and introduce bias, while collection using isokinetic samplers ensures that the water velocity and sediment concentration entering a bottle is the same as the surrounding environment (Edwards and Glysson 1998).

In the Normanby catchment, collection of TSS sediment samples has historically been conducted using non-isokinetic surface grab samples typically from the water edge along a bank. Recent SSC samples using rising stage samplers (RSS, see below) are also non-isokinetic and typically collected near the water edge.

No isokinetic width- or depth-integrated suspended sediment samples have been collected to date in the Normanby to determine the true average concentration for a given discharge or correct data from surface grab samples.

Surface water grab samples from river banks most likely contain the least amount of suspended sediment in a cross-section, especially for suspended sand. This bias, along with the use of the TSS laboratory protocol, suggests that these samples most likely represent fine suspended sediment dominated by silt and clay, or washload (<63 μm). However data from the 75 RSS SSC samples collected in this study indicate that suspended sand (>63 μm) averages 11% of the total concentration and can range from 0 to 64%. Therefore, interpretation and utilization of these existing data should be done with caution until improved measurement and analysis techniques are conducted to improve data quality and quantity (Lewis 1996; Edwards and Glysson 1998; Wong et al. 2003; Gray and Gartner 2009).

3. Existing TSS Data in the Normanby

Historic total suspended solid (TSS) concentration (mg/L) data were obtained from DERM and AIMS databases from all of the current and historic stream gauges in the Normanby catchment. Upon review, most of these data were collected at low stages and discharges, and were concentrated at some gauge sites more than others. The exception was the Normanby River at Kalpowar gauge where significant surface TSS data collection has occurred in recent years across a range of discharges (Joo et al. 2012 in press). Samples were collected at the water surface typically near the water edge using non-isokinetic grab sample methods and processed using the TSS protocol (APHA 1995; Gray et al. 2000). Hence a key component of this study was to collect additional suspended sediment concentration (SSC) data at higher stages at 4 gauge sites in the upper catchment (Laura @ Coalseam, East Normanby, West Normanby, Normanby @ Battle Camp). Lack of historic and current TSS and SSC data at other key gauges sites like the Hann River prevented the development of additional sediment load calculations.

4. Existing Turbidity Data and Correlations with TSS and SSC

At DERM gauge sites, turbidity (NTU) data were also collected periodically in concert with or absence of TSS data. These data also were collected predominantly at low stages and discharges, with the exception of the Kalpowar gauge. Samples were collected at the water surface typically near the water edge using non-isokinetic grab sample methods.

Howley (2010) also collected turbidity data at DERM gauge sites monthly between 2006 and 2010. Samples were collected at the water surface typically near the water edge using non-isokinetic grab sample methods. Additional paired samples of turbidity and suspended sediment concentration (SSC) were collected periodically through 2012 to help develop a relationship between sediment concentration and turbidity (Howley, unpublished data).

Despite the differences in the laboratory analysis protocols between TSS and SSC measurement (sub-sampling vs. whole bottle sampling), both provide an estimate of the concentration of suspended sediment (mg/L). Both paired DERM data of TSS (mg/L) and turbidity (NTU) and data of SSC (mg/L) and turbidity (NTU) from Howley (2010; unpublished) were pooled to create a correlation relationship. This relationship was used to predict the concentration of suspended sediment from turbidity values, and effectively add to the overall data set for sediment rating curve development at key gauge sites.

5. New Rising Stage Samplers (RSS)

Due to the remote location and difficulty in timing field sampling in association with flood peaks, rising stage samplers (RSS) were used to automatically collect suspended sediment concentration (SSC) samples during the rising stages of flood events from specific points in a cross-section (Edwards and Glysson 1998). Sample analysis followed the SSC protocol and particle size analysis was conducted on the samples to determine percent sand versus silt/clay (><63 μm). RSS design followed that of Colby (1961; U.S. U59C single stage sampler) and were mounted in protective housings following the design of Graczyk et al. (2000) (Figure 1a; Figure 2a). Samplers were deployed at staggered elevations along one bank of a cross-section (Figure 1b; Figure 2b).

Samplers are designed to collect a suspended sediment sample during the first inundation incident for a given peak event. Following sampling, an air lock should prevent the re-sampling or re-circulation of the sampler during subsequent inundation episodes. RSS design with an increased exhaust tube length minimized the potential for re-circulation during deep inundation and high velocity heads. However completely ensuring that re-sampling or re-circulation does not occur remains problematic, especially for deep or fast flows, prolonged inundation, or repeat inundation. Use of several samples was rejected due to possible contamination by re-circulation. Additional manually collected field data are needed on the rising limbs of first flush events to confirm or refute some of these questionable data (which have been excluded from the load calculations).

During WY 2010 to WY 2012, a series of 5 staggered rising stage samplers were each deployed at or near three operating gauges (Laura @ Coalseam, East Normanby, Normanby @ Battle Camp) and one discontinued gauge (West Normanby). Where practical, samplers were replaced during the wet season to try to isolate specific flood events or early vs. last season events. In total for the 4 gauge sites over three wet seasons, 75 RSS SSC samples were collected in total, average 18 samples per site.

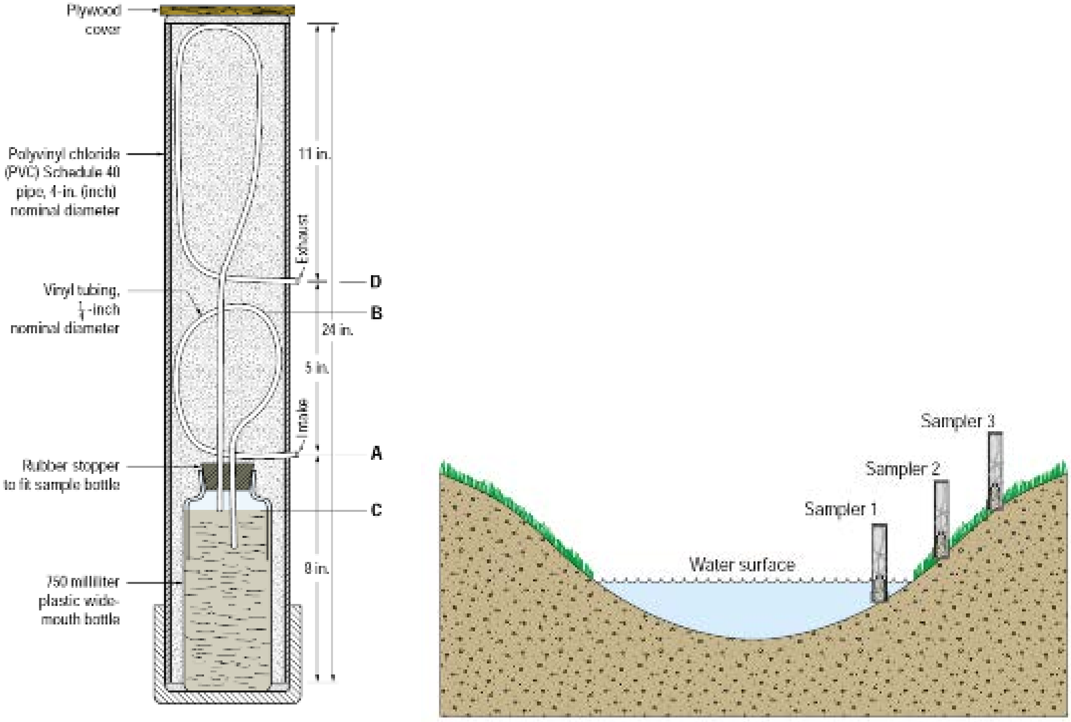


Figure 1 – Left: Schematic design for a passive rising stage sampler (RSS) that forms the basis for the samplers used in this study. Right: The typical manner in which they are deployed within a stream (after Graczyk et al. 2000).

Figure 2 – Left: Rising stage sampler production line – September 2009. Right: Rising Stage Sampler array in the West Normanby River. These samplers collect a suspended sediment sample during the first inundation incident for a given stage. Subsequent inundation episodes are not collected and should not affect the existing sample. A pressure transducer stage recorder at the site allowed the identification of the precise point in the hydrograph that the sample was collected, which was correlated to nearby gauge discharge data.

6. Stage and Discharge Data

At current operational DERM gauges where RSS equipment was installed (Laura @ Coalseam, East Normanby, Normanby @ Battle Camp), continuous stage (m) and water discharge (m^3/sec) data were obtained at 15-minute intervals for the period of record, continuing through the period of this study. These data were used to calculate the stage and discharge at which the rising stage samplers (RSS) were first inundated and filled, for use in suspended sediment rating curves. They were also used to estimate the length of time and number of events that the samplers were inundated, which provides an indication of the potential for sample contamination from prolonged or multiple events. Once suspended sediment rating curves were developed, the 15-minute discharge data were used to calculate suspended sediment loads at this time step as the product of water volume per unit time and sediment concentration.

At the East and West Normanby gauges, RSS equipment could not be installed at the gauge cross-section due to logistical constraints, but rather were installed on banks up or downstream within the same river reach. At these locations, stage recorders (pressure transducers) were also installed to identity the local cross-section hydrograph and determine the point at which samplers were filled. These local stage data were correlated to stage data at adjacent gauge sites in the same reach at the same time intervals, in order to estimate the discharge at which RSSs filled.

At the discontinued West Normanby gauge, continuous stage also was recorded at the old gauge infrastructure using a pressure transducer. These data were used to correlate to stage data at the RSS equipment location, and estimate the corresponding gauge stage at which RSSs filled. Since discharge data are not currently available at this site and the current stage-discharge rating curve is unknown for the gauge cross-section, historic stage-discharge rating curves were relied upon to estimate the discharge at a given stage. Analysis of the historic stage-discharge rating curves indicated that the ratings would still likely be applicable for medium to high stages and discharges, but that the low flow rating curve would likely be affected by shifting sedimentation. Therefore, discharge estimates were likely reasonable for the medium discharge events that RSS equipment sampled at during the study period.

6.1 Discharge vs. TSS/SSC Suspended Sediment Rating Curves at 5 Gauges

Five (5) gauge sites in the catchment were utilized for empirical suspended sediment load determination (Laura @ Coalseam, East Normanby, West Normanby, Normanby @ Battle Camp, Normanby @ Kalpowar) to compare to model estimates. Due to the lack of high quality and quantity sediment concentration data at 4 of the gauges, excluding Kalpowar, all available data types and sources were pooled together for each site to develop suspended sediment rating curves. This included TSS data from DERM, SSC data from Griffith RSSs, and estimated sediment concentration (mg/L) data predicted from turbidity (NTU) data using relationships from data collected by DERM and Howley (2010, unpublished) at sites across the Normanby catchment. These data were matched to the estimated water discharge at the nearest 15-minute time interval when the sediment water sample was created.

Due to the questionable quantity and quality of the sediment concentration data at the 4 upper catchment gauge sites, simple sediment rating curves correlating discharge to sediment concentration were created. Rating curves were not developed for specific events or different parts of the hydrograph (rising vs. falling stage, or early vs. late wet season) to address the issue of event or seasonal hysteresis. Nor were any shift corrections applied to the data. In the future, additional data exploration and statistical techniques could be used to analyse the data variability and potential causative factors influencing concentration in *these* data (Kuhnert et al. 2012). However, overall more rigorous data collection techniques and surrogate technologies are needed in the future to properly measure suspended sediment loads over time (Lewis 1996; Edwards and Glysson 1998; Wong et al. 2003; Gray and Gartner 2009).

For each of the 4 upper catchment gauge sites, discharge vs. concentration data were filtered to isolate data above 1 m^3/sec for rating curve trends. Sediment concentration data below this value were highly variable for each gauge site. Therefore a constant or average concentration value was used for these low discharges. At the upper end of the rating curve beyond the limit of data availability, a constant maximum concentration value was used for the highest discharges rather than extending out the rating prediction into unknown territory. This is a conservative load approach. Once suspended sediment rating curves were developed, the 15-minute discharge data were used to calculate suspended sediment loads at this time step as the product of water volume per unit time and sediment concentration. These data were summed to estimate annual suspended sediment load (tonnes/year).

For the Normanby River at Kalpowar gauge, the suspend sediment load data estimated by Joo et al. (2012 in press) were utilized for water years (WY) 2007, 2008, and 2009. They used near daily TSS grab samples from the river bank during flood events through the wet seasons and gauge discharge data to estimate instantaneous loads, as well as specific event loads through non-linear interpolation of the available data at the event scale. This is a preferred method of rating curve development, at the event scale, where the frequency of data collection is moderately high and correlate well to water discharge, in contrast to other surrogate correlates such as turbidity. For the other water years in the Kalpowar gauge record (WY 2006, 2010, 2011, 2012), the analysis techniques of Joo et al. (2012 in press) were not repeated for this study due to the limited availability of TSS data for these years and time constraints. Such an analysis should be conducted in the future with available data. For this study, a more simplified rating curve approach was used with the same DERM TSS data by pooling all data for the period of record into one rating curve, similar to other gauge stations. This approach was used along with 15-minute discharge data to estimate annual suspended sediment loads for WY 2006 to 2012. These data can be compared to 3 years estimated by Joo et al. (2012 in press).

6.2 Catchment Correlations Between Turbidity (NTU) and TSS / SSC

Across the Normanby catchment, paired data of surface water turbidity (NTU) and either TSS or SSC sediment concentrations displayed a strong correlation (Figure 3). This relationship was highly influenced by recent data collection efforts at higher discharges (Howley, unpublished data). Available DERM data were typically collected during low to moderate discharges. Additional data need to be collected at high discharges at gauge sites across the catchment to improve this relationship and develop individual relationships for each gauge site. While DERM data at Kalpowar were collected through a full range of discharges, the resultant low turbidity and sediment concentrations measured there constrained their use for predication elsewhere. Furthermore, the turbidity data at Kalpowar are influenced by biological factors (i.e., algae, plankton) that also cause turbidity in addition to suspended sediment. This biological influence is less evident at upstream gauge sites, especially during larger discharges when turbidity is dominated by suspended sediment.

The relationship in Figure 3 was used to predict the concentration of suspended sediment from turbidity values, and effectively add to the overall data set for sediment rating curve development at key gauge sites.

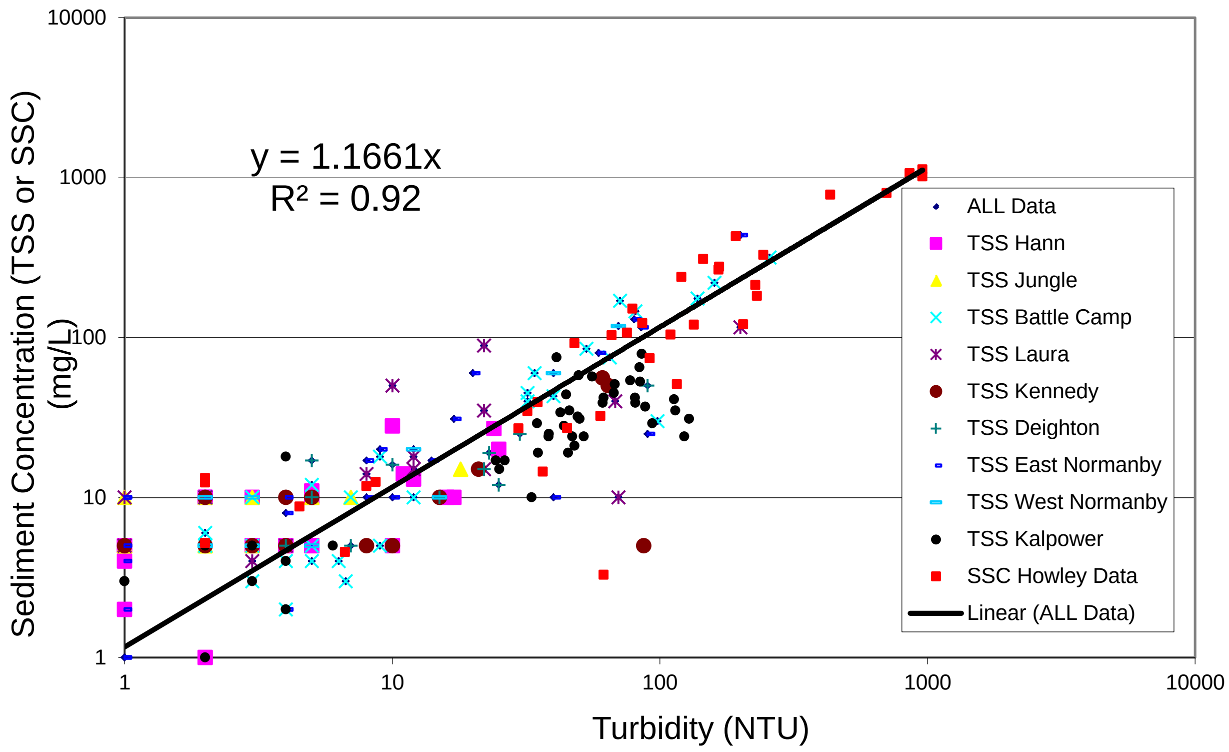
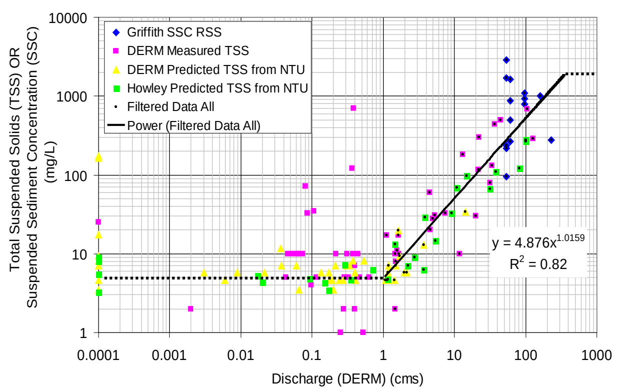


Figure 3 Catchment wide relationship between surface water turbidity (NTU) and either total suspended solid (TSS) or suspended sediment concentration (SSC) data from either DERM or Howley (2010, unpublished).

6.3 Discharge vs. TSS/SSC Suspended Sediment Rating Curves at 5 Gauges

At the four gauge sites in the upper catchment (Laura @ Coalseam, East Normanby, West Normanby, Normanby @ Battle Camp), all available suspended sediment data types and sources for each site were pooled to develop suspended sediment rating curves (Figure 4). This included TSS data from DERM, SSC data from Griffith RSSs, and estimated sediment concentration (mg/L) data predicted from turbidity (NTU) data and relationships. Due to the questionable quantity and quality of the sediment concentration data at these sites, simple sediment rating curves correlating discharge to sediment concentration were created using power equations. A 1 m^3/sec lower threshold was utilized along with not extending the curve much beyond the upper limits of the data, with estimated constant values for lower and upper extreme concentration values (Figure 4).

These rating curves are useful for rough suspended load calculations. However considerable variability in the relationships indicates the potential for influence from both measurement error from field and laboratory procedures and natural hysteresis between concentration and discharge. Additional data exploration and statistical analysis techniques will be needed to analyse these data in more detail (e.g., Kuhnert et al. 2012), as well as develop improved data collection techniques and surrogate technologies to measure suspended sediment loads into the future (Lewis 1996; Edwards and Glysson 1998; Wong et al. 2003; Gray and Gartner 2009).



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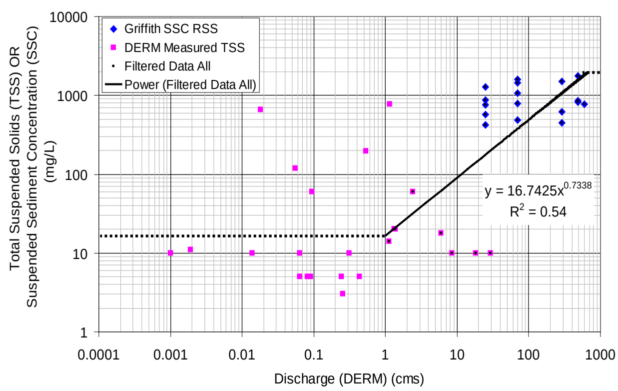

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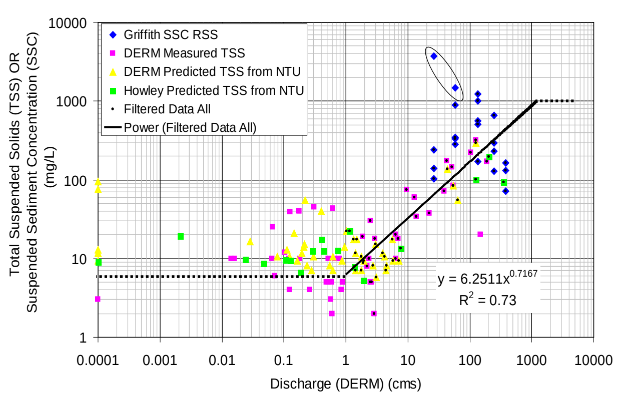

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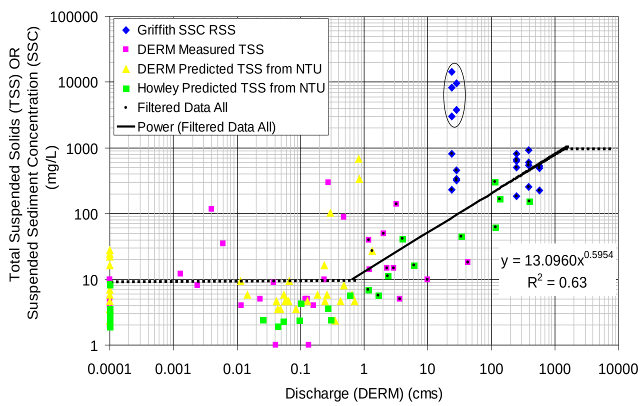

d)

Figure 4 Suspended sediment rating curve for a) the East Normanby River gauge (105105A), b) West Normanby River gauge (105106A), c) Normanby River at Battle Camp gauge (105101A), and d) Laura River at Coalseam gauge (105102A). Note circled GU RSS data points have been excluded from the load calculations due to the fact that we cannot rule out contamination due to recirculation of the instruments during subsequent events.

For the Normanby River at Kalpowar gauge, the overall sediment rating curve using pooled TSS data between WY 2006 and 2012 indicated that sediment concentration varied by an order of magnitude between moderate (>100cms) to high (<2000cms) discharges. This indicates significant hysteresis over event cycles and is best addressed by high frequency data collection for calculation of loads at the event scale (Joo et al. 2012 in press) or use of surrogate technologies for correlation and load determination (Gray and Gartner 2009). The other interesting feature of the Kalpowar rating curve is the overall very low sediment concentrations measured there, typically < 100 mg/L. It is unknown whether this is a partial artefact of collecting sediment samples from the water edge at the bank where concentrations would expected to be the lowest in the cross-section. Future width and depth integrated samples will be needed at this gauge during flood to reveal this variability. This would also highlight any influence of using the TSS protocol for laboratory analysis. Alternatively, the low concentrations could be due to sediment dilution from high discharges contributing from low yielding parts of the catchment, and/or loss of upper catchment suspended sediment into floodplains, lagoons, and channel storages above the Kalpowar gauge, or due to complete bypass of flow around the gauge reach. A combination of factors is likely responsible for the low measured concentrations at Kalpowar compared with the upstream gauges.

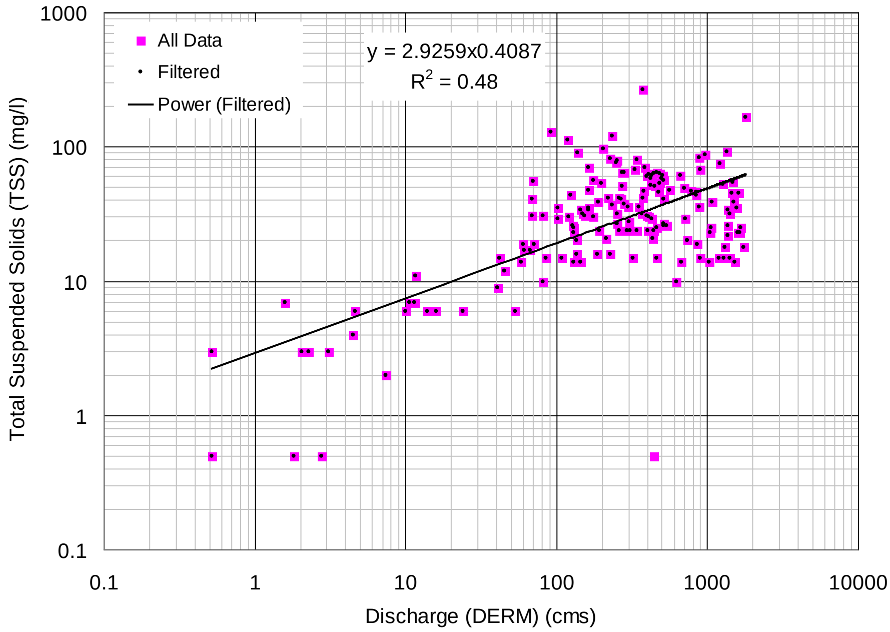

Figure 5 Suspended sediment rating curve for the Normanby River at Kalpowar gauge (105107A) using pooled TSS data from WY 2006 to 2011.

7. Annual Suspended Sediment Load at 5 gauges

Once suspended sediment rating curves were developed, the 15-minute discharge data were used to calculate suspended sediment loads at this time step as the product of water volume per unit time and sediment concentration. These data were summed to estimate annual suspended sediment loads for each gauge for their period of record (tonnes/year).

Summary statistics are included in Table 1. Annual suspended sediment yield were highest at the West Normanby and Normanby at Battle Camp gauges and intermediate for the Laura and East Normanby gauges (Table 1; Figure 7). The lowest yields were estimated at the Normanby at Kalpowar gauge. The methods used in this study and those of Joo et al. (2012), using the same data, returned generally similar estimates of annual suspended sediment yield (Table 2). If the Kalpowar loads during 2006-2012 are compared to the two main tributary gauges (Laura and Normanby at Battle Camp) that deliver water and sediment to this reach, than the suspended sediment loads estimate at Kalpowar only represent 29% on average of the combined total loads estimated at Laura and Battle Camp (Figure 8). This also does not include additional tributary inputs between Battle Camp and Laura gauges and Kalpowar.

The reduction in annual suspended sediment load downstream could be a result of three main factors:

1) errors inherent in the sediment concentration data and sediment rating curves at each gauge sites;
2) unmeasured water and sediment discharge around the Kalpowar gauge through distributaries and across floodplain during major flood events, and;
3) downstream loss of suspended sediment through the deposition of sediment in channels, benches, floodplains, and wetlands.

The first issue, regarding inherent data and load estimate errors was discussed above and can only be addressed by more rigorous sediment gauging techniques (Edwards and Glysson 1998; Gray and Gartner 2009). The second issue is also a known major factor at the Kalpowar gauge (local observations; Wallace et al. 2012) and will be discussed further below. The third issue is addressed elsewhere in this report in terms of the potential for sedimentation with channel beds, benches, floodplains, and wetlands.

Reductions in specific suspended sediment yield ($t/yr/km^2$) in the downstream direction with increasing catchment area (Table 1; Figure 9) are influenced by: 1) the reduced effective contributing catchment area of suspended sediment, 2) actual sediment deposition onto channel beds, benches, floodplains, and wetlands, and 3) unmeasured water and sediment discharge due to floodwater bypassing the Kalpowar gauge (see below). The decline in specific sediment yield with increasing catchment area is common in global rivers (Wasson, 1994;FAO, 2010). This can largely be attributed to the increasing percentage of low elevation lands as catchment area increases, which are largely ineffective at producing and delivering sediment to adjacent rivers compared to higher elevation catchment headwaters. However, real sedimentation can also occur on bottomlands as catchment area increases, as floodplains and low gradient river channels can effectively buffer sediment throughput to receiving waters.

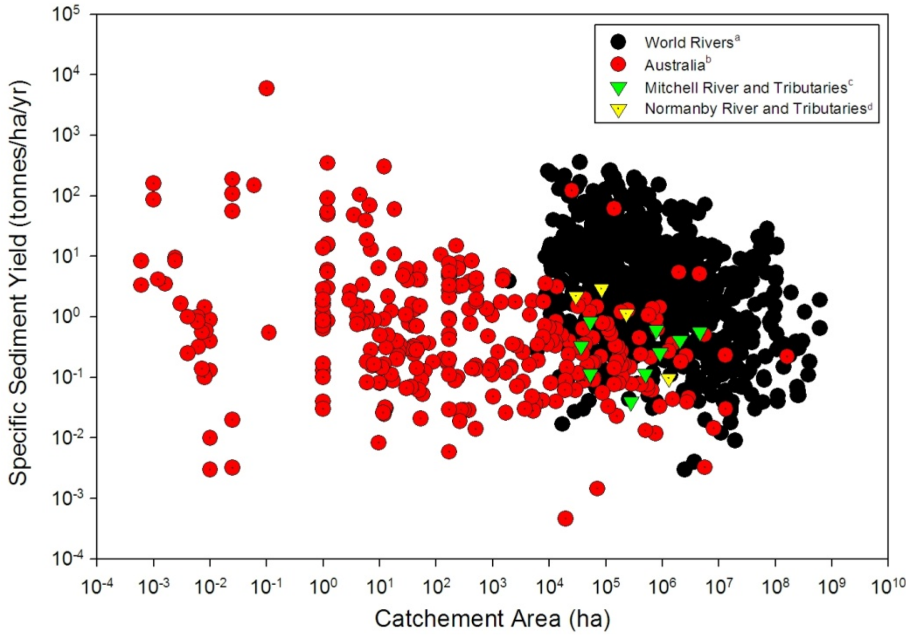

Figure 6 Declining specific sediment yield for Australian and World Rivers with increasing catchment area. Note that the specific yield in the Normanby mid and upper catchment gauges are above average for Australian Rivers.

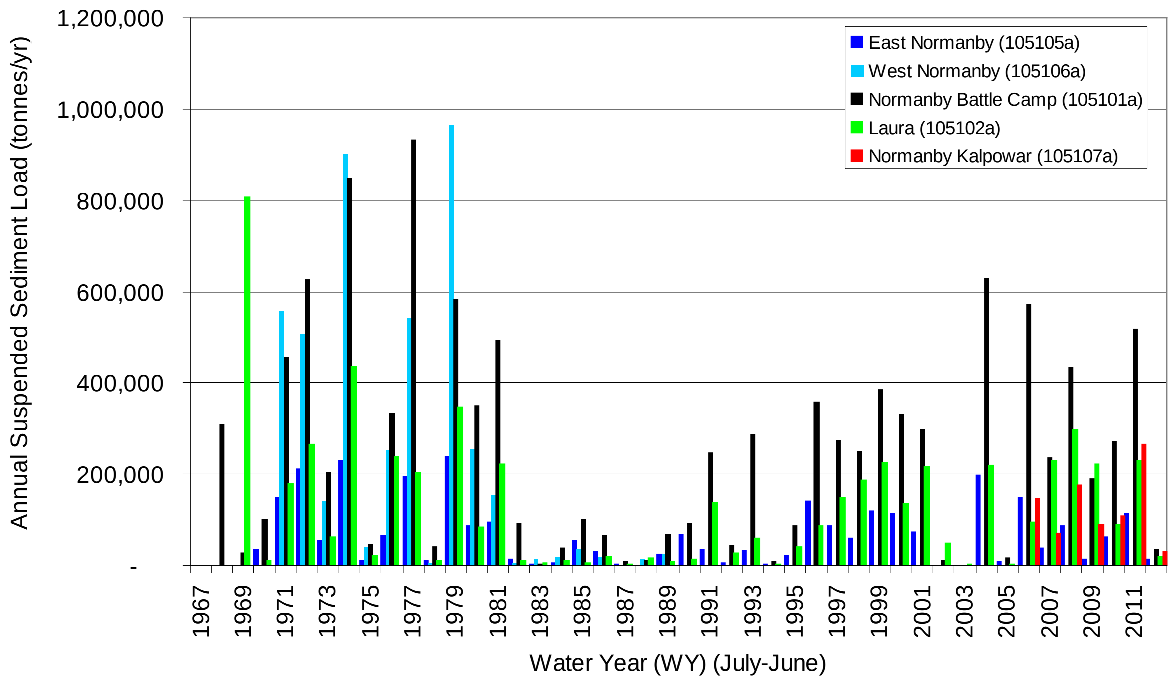

Figure 7 Estimated annual suspended sediment loads (tonnes/year) for each water year (WY, July–June) for 5 DERM gauge sites in the Normanby catchment.

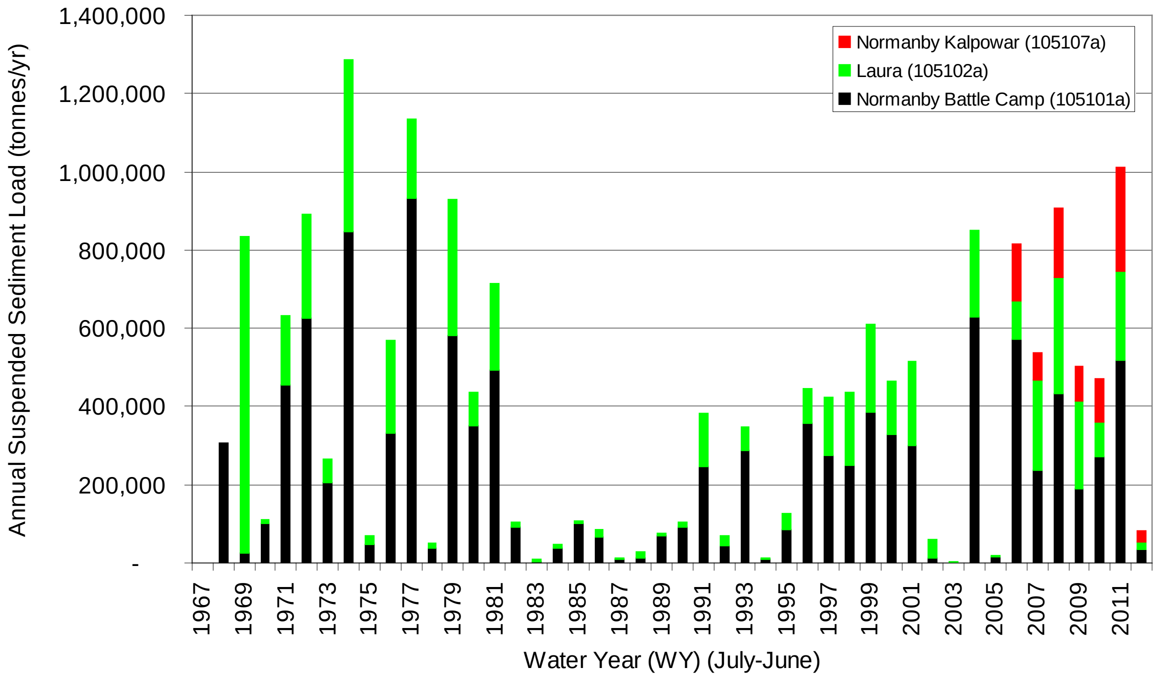

Figure 8 Estimated annual suspended sediment loads (tonnes/year) for each water year (WY, July–June) for the Normanby at Kalpowar gauge (2006–2012; 105107a) and its two main tributary sources upstream represented by the Normanby at Battle Camp gauge (1968–2012, 105101a) and Laura at Coalseam gauge (1969–2012, 105102a). For the period of common record on average only 28% of the combined load from the two upstream gauges (Coalseam Creek and Battle Camp) is recorded at the Kalpowar Gauge.

Table 1 Estimate Annual Suspended Sediment Loads at Selected Gauges in the Normandy

Gauge Site #	**River**	**Site**	**Catchment Area (km^2)**	**Total Record Annual Suspended Sediment Load (tonnes)**	**Total Record Average Specific (LHS) Common Record (WY 2006-2012) (RHS) (t/yr/km^2)**		**Common Record (WY 2006-2012) Annual Suspended Sediment Load (tonnes)**	**model**
105105A	East Normanby	Mulligan Highway	297	**Ave: 65,732** Median: 46,545 StDev: 67,115	221.3	230.6	**Ave: 68,483** Median: 63,068 StDev: 51,788	**53,000**
105106A	West Normanby	Mulligan Highway	839	**Ave: 247,070** Median: 90,004 StDev: 314,478	294.5	N/A	N/A	**450,000**
105101A	Normanby	Battle Camp	2302	**Ave: 261,751** Median: 240,807 StDev: 238,737	113.7	140.0	**Ave: 322,325** Median: 270,380 StDev: 192,636	**738,000**
105102A	Laura	Coalseam Creek	1316	**Ave: 135,482** Medium: 88,468 StDev: 154,118	102.9	128.8	**Ave: 169,485** Median: 222,754 StDev: 100,990	**190,000**
105107A	Normanby	Kalpowar Crossing	12,934	**Ave: 126,015** Median: 109,165 StDev: 77,465	9.7	9.7	**Ave: 126,015** Median: 109,165 StDev: 77,465	**650,000**

Table 2 Estimates of annual suspended sediment loads at the Kalpowar gauge between 2006 and 2012 using DERM TSS data different analytical methods (this study, Joo et al., 2012).

Water Year (WY, July-June)	**Annual Total Suspended Sediment Load (tonnes/yr)** This Study, Pooled DERM TSS Data, One Rating Curve	**Annual Total Suspended Sediment Load (tonnes/yr)** Joo et al. (2012), DERM TSS Data, Loads Interpolated and Calculated at Event Scale
2006	145,270	N/A
2007	70,355	59,000
2008	175,037	211,000
2009	89,184	104,000
2010	109,165	N/A
2011	264,125	N/A
2012	28,967	N/A

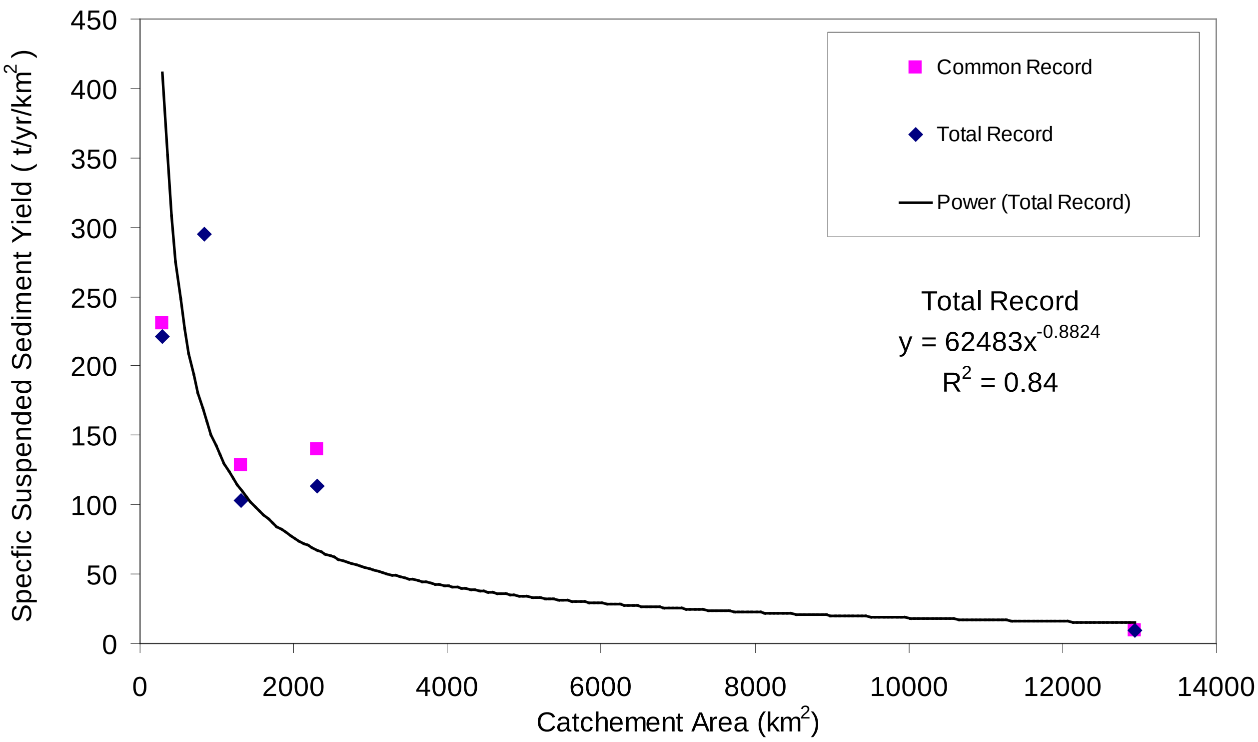

Figure 9 Decline in specific suspended sediment yield (t/yr/km²) with increasing catchment area in the Normanby, which is a combined function of 1) a reduction in the effective contributing catchment area of suspended sediment from low gradient lands, 2) actual sediment deposition onto channel beds, benches, floodplains, and wetlands, and 3) unmeasured water and sediment discharge due to floodwater bypassing the lowest Kalpowar gauge.

8. Suspended Sediment Loss Around or Above Normanby at Kalpowar

The Normanby River at Kalpowar gauge (105107A) is located in the centre of the large Normanby River floodplain along the main channel of the Normanby River. This gauge is located downstream of several major distributaries, notably Two-Mile Creek located 1.5 km upstream of the gauge and Catfish Creek and associated distributary channels originating from the Kennedy River 20–25 km above the gauge (Figure 10). These distributary channels route water and sediment onto and through the floodplain and into the North Kennedy River, bypassing the Kalpowar gauge (Figure 10). The water and sediment discharged through these distributaries and across the floodplain are unmeasured. There are no gauges on the North Kennedy River near Kalpowar. Therefore, water and sediment measurement at Kalpowar are an absolute minimum estimate of discharges onward toward Princess Charlotte Bay.

Locally, the Kalpowar gauge only estimates water and sediment discharge within the bankfull channel at the gauge site. Once water reaches initial flood levels and eventually the height of the banks (bankfull), water will begin flowing onto the floodplain and into local distributaries on both sides of the river (i.e., Two-Mile Creek; Figure 10) and further upstream. This overbank floodwater is not measured locally or upstream during standard water gauging procedures. In a preliminary analysis for the Normanby at Kalpowar gauge, Wallace et al. (2012) estimated that 43% of the mean annual water discharge is bypassed around the Kalpowar gauge during floods. This estimate was based on the duration of time that floodwaters were above minor flood stages at the gauge site. This estimate does not necessarily include the water lost into distributaries or the floodplain many kilometres upstream (i.e., Catfish Creek; Figure 10). Future analysis of the floodplain topography via LiDAR, along with floodplain hydraulics and water conveyance measurement and modelling, will be needed to assess the full potential for water and sediment bypassing the Kalpowar gauge.

In summary from an empirical viewpoint, the amount of water and suspended sediment actually being discharged into Princess Charlotte Bay from the Normanby catchment remains unknown due to insufficient measurement locations and gauging efforts in a complex floodplain environment. The Normanby at Kalpowar gauge only measures a fraction of this discharge.

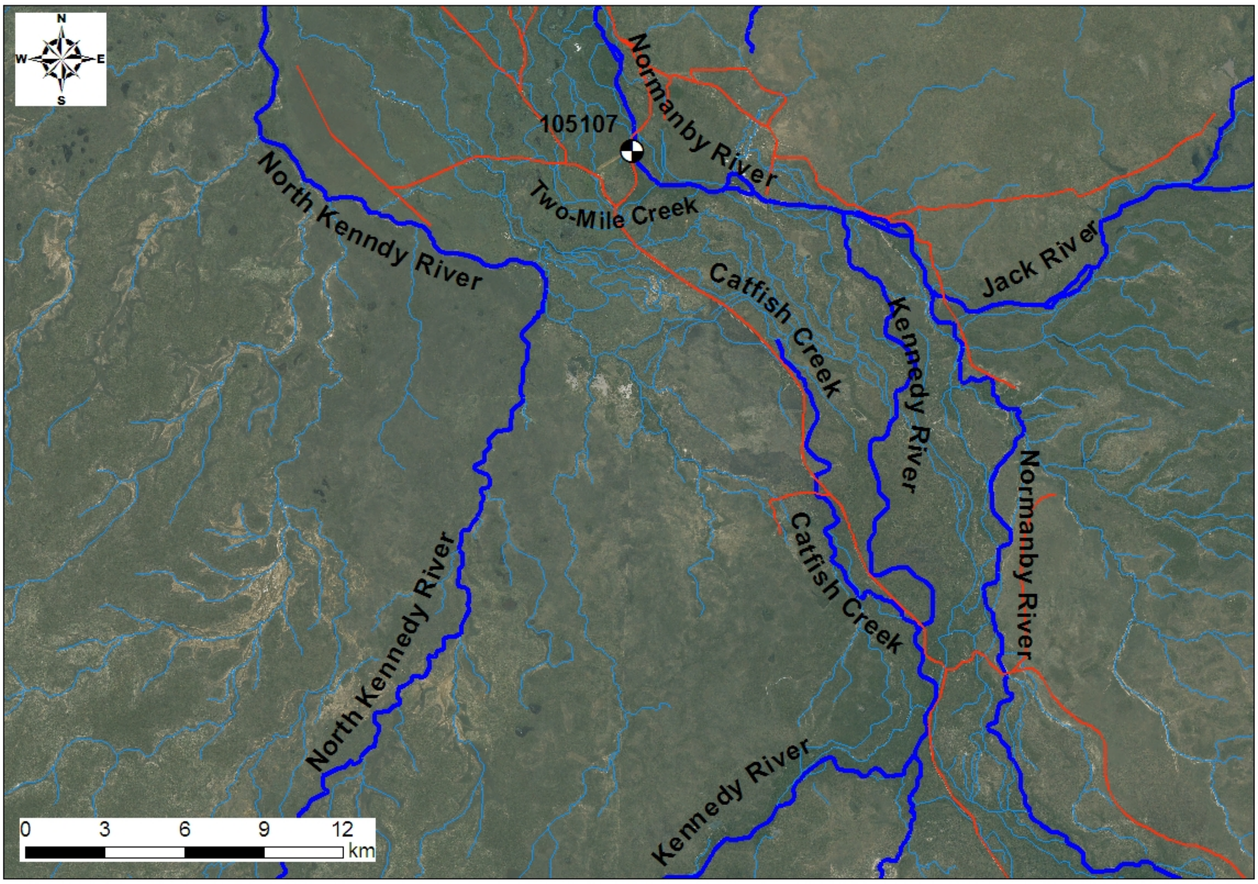

Figure 10 Map of main river channels and floodplain distributaries upstream of the Kalpowar gauge (105107A) indicating the potential flow paths of water and sediment bypassing the Kalpowar gauge.

References

Please also see main document, or visit the website: **http://www.capeyorkwaterquality.info**