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# Sand and Gravel Transport Rates in Queensland Rivers

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## SUMMARY

Understanding modern riverine sediment transport processes is essential for approaching sustainable management practices in water courses. Sediment transport behaviour is an important influence on channel morphology and stability, and water and habitat quality.

Most studies into bed material load (sand and gravel supply) have been conducted in Europe and North America. It has been questioned whether the laboratory flume based empirical formulae developed at these locations can adequately describe the sediment transport processes operating in Queensland.

As a result, the Department of Natural Resources has undertaken a major program to assess sand and gravel supply rates in Queensland rivers based on direct flood measurements. So far, flood events have been sampled on the Balonne, Black, Brisbane, Condamine, Comet, Don, Fitzroy, Herbert, Logan, Maranoa, and Mary Rivers.

The program has helped to more accurately describe the quantity and variability of sediment being transported by Queensland rivers. The results are currently being used to calculate Average Material Transport Rates (AMTR's). This helps provide a more accurate indication of sustainable sand and gravel extraction quantities and determine the siltation potential of existing and proposed water storages. In the future, it is likely that this program will contribute to the Queensland Government's Water Allocation Management Plan (WAMP) processes.

**THE MAIN POINTS OF THIS PAPER**

1. In Queensland, fluvial sand and gravel supply rates are not well described using traditional empirical formulae.
2. Supply rates are being measured directly during flood events in Queensland rivers.
3. Flood based measurements are now used for management of sand and gravel operations.

## INTRODUCTION

Understanding modern riverine sediment transport processes is essential for approaching sustainable management practices in water courses. Sediment supply and removal have an important influence on channel morphology and stability, and water and habitat quality.

The Department of Natural Resources (DNR) has responsibility for determining quantities of material that sand and gravel operators may remove from Queensland river systems. The Department considers these quantities should be sustainable in relation to fluvial sediment delivery. To help achieve this, the Department is developing a new methodology for assessing riverine quarry material operations (see Boon, this volume).

Difficulties arise in establishing the sustainable sand and gravel transport rate in a particular river reach. It has been found that the traditional approach of basing extraction policy on either demand driven criteria, or at best empirical sediment transport rate formula, may have resulted in approving unsustainable operations in some areas.

Most studies of sediment transport behaviour have been conducted in Europe and North America. It has been questioned whether the commonly used, laboratory flume-based empirical formulas derived overseas for bed material transport ie. Van Rijn, Ackers and White, Engelund and Hansen, Zanke etc. can adequately describe sediment transport processes occurring in Queensland[2]. Inaccuracies result because of the different particle size distributions, bed slopes, channel configurations and stabilities and flow variability.

Consequently, a major program commenced in 1994 to directly measure bed material load transport rates during flood events. As part of the program, wash loads are also determined. So far, 25 major flood events have been sampled on the Balonne, Black, Brisbane, Condamine, Comet, Don, Fitzroy, Herbert, Logan, Maranoa and Mary Rivers.

The primary function of the program is to support the Department's sand and gravel management role. In addition, other evaluations have been undertaken including the assessment of possible storage siltation rates for existing and proposed dams. In the future, it is likely that this program will contribute to the Queensland Government's Water Allocation Management Plan (WAMP) processes.

## METHODOLOGY

Sampling is conducted during flood events from boats, cableways and bridges, using Helley-Smith samplers to collect bed load material, and P61 samplers to collect suspended load material. Significant development of field and laboratory methodologies (based on Wong et al. 1992) has been undertaken.

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Where possible, samples are taken at several distinct stages (river heights) of the flood (hydrograph), ideally to cover a range of higher flows. Samples are usually collected over a period of several minutes. Normally, five points are sampled along a cross-section of the river. These sampling points are spaced so that each represents approximately an equal discharge component. Consequently, the points in the mid-channel area are closer together as the discharge is higher. Flow velocities are measured simultaneously with the collection of all sediment samples. **Figure 1.** illustrates the field program in operation.

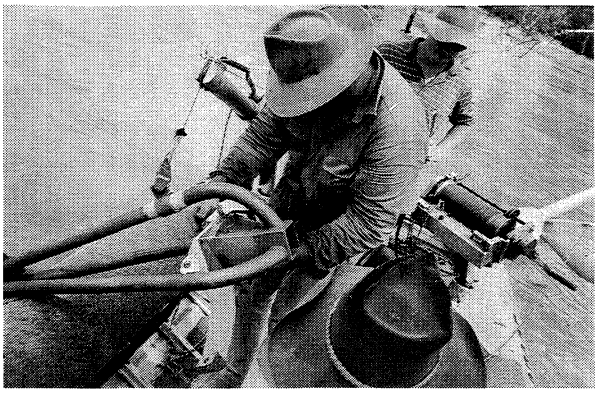

**Figure 1: Fitting a sample collection bag to the Helley-Smith bed load sampler. Maranoa River at Old Cashmere, February 1997 (note: P61 suspended load sampler at far right of photo).**

For the suspended and bed load samples, particle size distributions, size fraction percentages and concentrations are determined. The concentrations are flow weighted for each of the cross-sectional areas to give compartment loads. The compartment loads are then combined to give instantaneous: bed load, suspended load, bed material load and wash load quantities[3].

Sediment transport *vs.* discharge functions are calculated and sediment rating curves (log log plots of the total sediment load components against discharge) are determined[4]. These functions are then applied to the complete river flow record to provide an indication of the historical sediment loads transported over the period of record.

Approximate average yearly sediment transport rates are determined from historical sediment transport loads and have been calculated for several Queensland rivers.

The sediment rating curves and average annual tonnages from the direct flood measurements are compared to results from empirical formulae for the Logan, Mary and Brisbane Rivers.

The formulae include Van Rijn, Ackers and White, Engelund and Hansen, Zanke etc., and results were determined using bed load particle size distribution data collected during low flow conditions. The formulae also required specific river hydraulic data, such as depth, cross sectional, area, and flow velocity.

Empirically based results for the Logan River, were derived during this program. Results for the Brisbane and Mary Rivers are from Wong (1993, 1995), which were determined during the feasibility studies for this program. All of the empirical results were derived using the same methodology (see Poplawski, 1985).

## RESULTS AND DISCUSSION

Since 1994, 11 rivers have been tested. However, because of access difficulties, only six rivers have been comprehensively sampled for at least one flood event. These include the Brisbane, Fitzroy, Herbert, Logan, Maranoa and Mary Rivers. It is only in these rivers that any specific assessments about sand and gravel supply rates can be made at this stage. However, to accurately gauge supply rates several flood events will need to be sampled in a particular river. Consequently, the results presented here can only be considered preliminary.

The data for all rivers sampled in the program is summarised in Horn et al. (1998). An example, using the summary for the Logan River, includes the sediment rating curve and average annual sediment transport loads, and appears in **Figure 2**. Additionally, the historical flow pattern and the timing of sediment collection during each flood sampled are shown.

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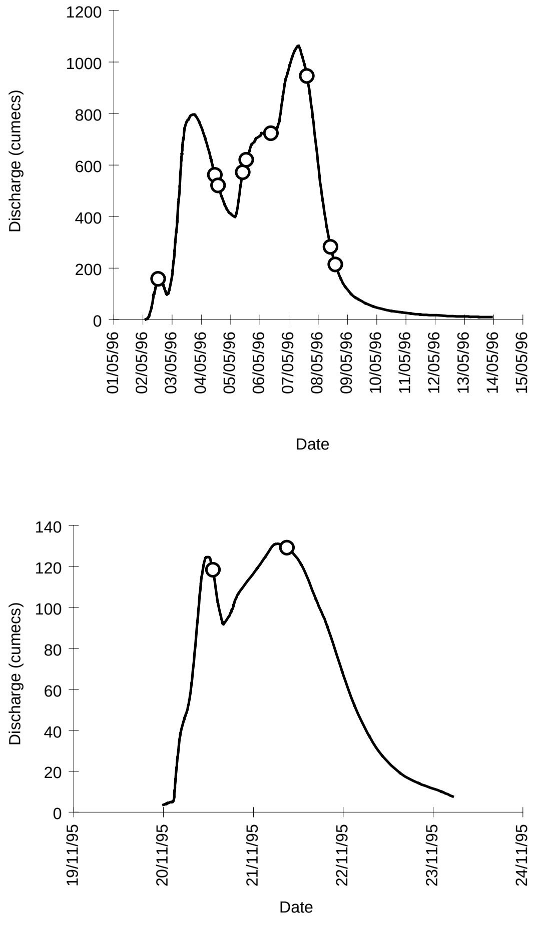
[3] The bed load plus the suspended load equal the total sediment load, as does the bed material load plus the wash load. The bed material load contains the bed load and the sand fraction (>0.063 mm) of the suspended load, whereas the wash load consists of the clay plus silt fraction (<0.063 mm) of the suspended load. Normally, the bed material load is used for sand and gravel extraction rates.

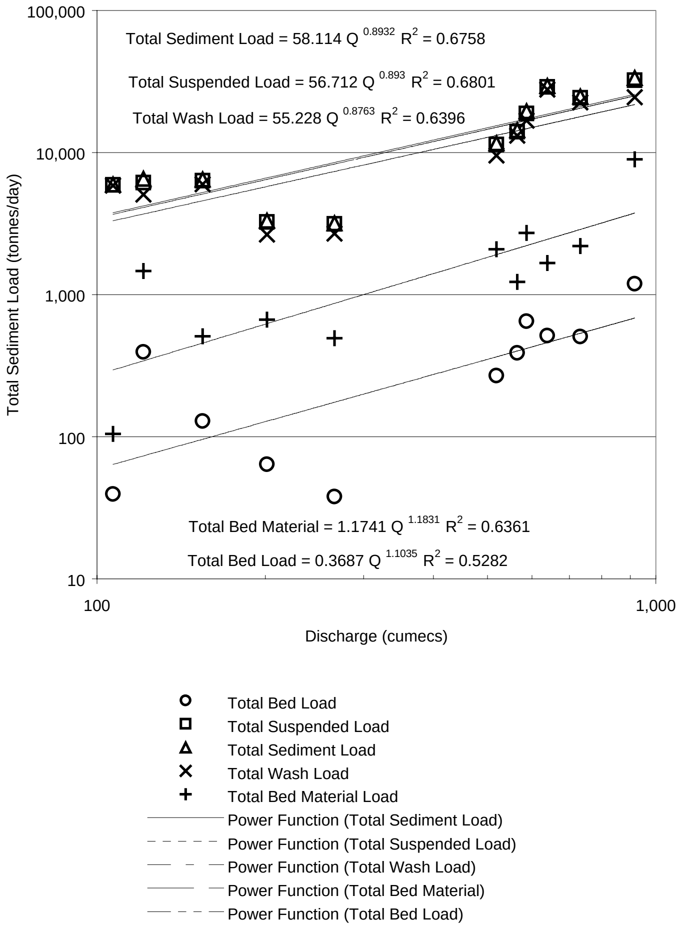
[4] However, it is worth noting that these relationships for wash load and suspended load are generally not considered to be reliable.

| Average Bed Material Load (tonnes/year) | Average Wash Load (tonnes/year) | Average Suspended Load (tonnes/year) | Average Bed Load (tonnes/year) |
|---|---|---|---|
| 15 000 | 170 000 | 190 000 | 3 000 |

**Hydrograph of Flood Events with Sampling Points**



**Sediment Loads vs. Discharge (All Floods)**



**Flow Record 1969 – 1997 (Limit of Record), GS 145014A Logan River @ Yarrahappini**

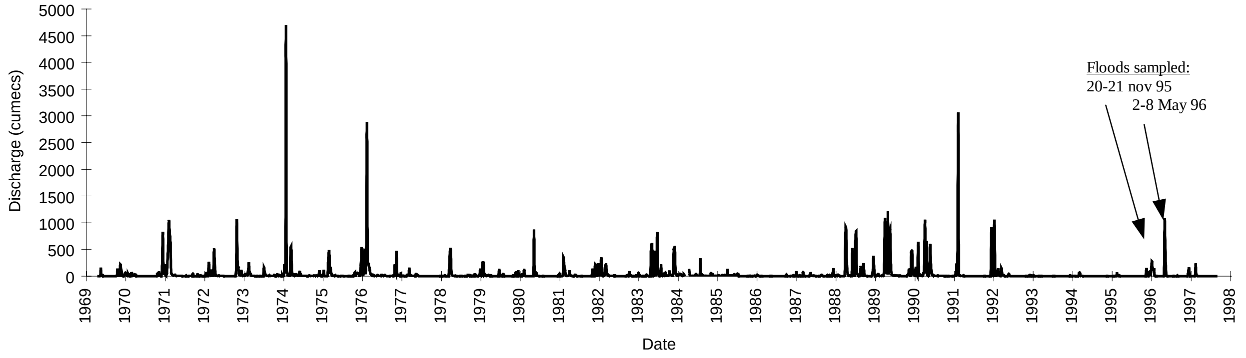


**Figure 2. Summary of sediment transport rates, Logan River at Yarrahappini GS 145014A (AMTD 77.7 km), based on one minor and one moderate flood during November 1995 and May 1996, and the flow record from 1969 -1997**

Theoretically, the bed material load plus wash load should equal the bed load plus suspended load and indicate the total sediment load. However, there is some slight variation in the implied total sediment load, as the above components are derived from their own separate rating curves.

Estimates of average annual bed material supply rates based on direct flood data for those six rivers with reasonable data are provided in **Table 1**. The table also shows that the larger floods possible in these systems have not yet been sampled and these floods are the most important for evaluating sand and gravel transport behaviour. This is a reflection of the generally dry climatic conditions that have occurred since the commencement of the program.

The relationship between the bed material load and discharge for these rivers, based on the direct flood results, is indicated in **Figure 3**.

As part of the program, it is intended to compare the results from the direct flood measurements with results from the empirical formulae, as sufficient flood based data becomes available. Such a comparison is presented for the Logan, Mary and Brisbane Rivers.

For these three rivers, the bed material load rating curve derived from the direct flood measurements is compared to rating curves derived from empirical formulae (**Figures 4, 5, 6**). These formulae include Ackers and White, Engelund and Hansen, Van Rijn, and Simplified Van Rijn, and additionally, Ranga Raju and Zanke[5] for the Mary River.

Since the start of the sediment sampling program, only small floods[6] have occurred in these rivers and consequently these comparisons are indicative only.

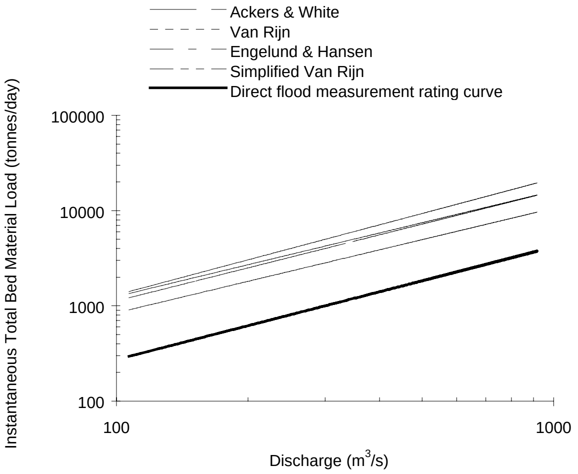


**Figure 4: Sediment rating curves, Logan River at Yarrahappini, GS 145014A (AMTD 77.7 km).**

| River | AMTD<br>(km) | Catchment Area<br>(km$^2$) | Maximum Discharge Sampled<br>(m$^3$/s) | Peak Discharge Recorded<br>(m$^3$/s) | Maximum Discharge able to be Sampled<br>(m$^3$/s) | Sampled discharge/maximum measurable discharge | Average Bed Material Load<br>(tonnes/year) |
|---|---|---|---|---|---|---|---|
| **Brisbane** | 130.8 | 10 180 | 2 000 | 7 400 | 7 400 | 0.27 | 20 000 |
| **Fitzroy** | 75.7 | 140 000 | 3 800 | 15 000 | 8 000 | 0.48 | 72 000 |
| **Herbert** | 30.3 | 8 805 | 1 800 | 10 000 | 4 000 | 0.45 | 81 000 |
| **Logan** | 77.7 | 2 435 | 900 | 4 700 | 4 700 | 0.19 | 15 000 |
| **Maranoa** | 29.3 | 19 490 | 450 | 1 700 | 1 700 | 0.26 | 5 000 |
| **Mary** | 204.7 | 2 110 | 630 | 5 000 | 3 400 | 0.19 | 71 000 |

**Table 1: Average annual bed material load transport rates for selected rivers.**

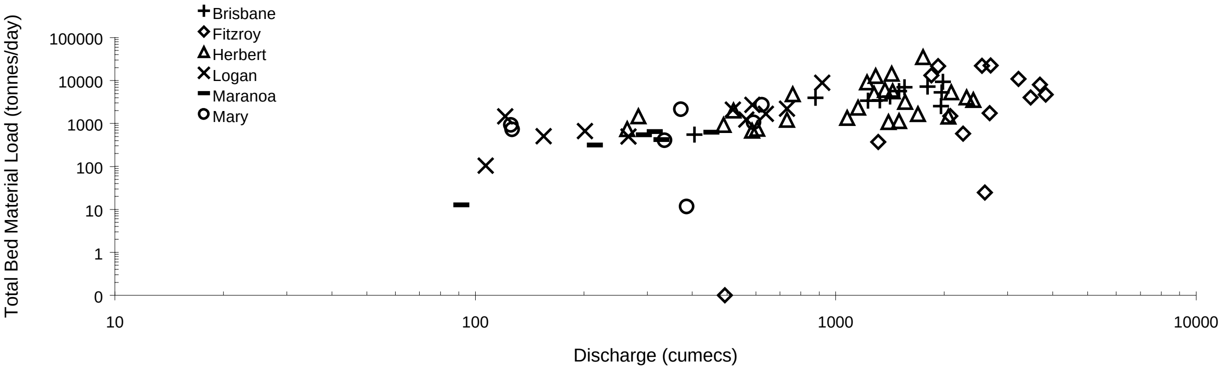


**Figure 3: Total bed material load *vs.* discharge for selected rivers.**

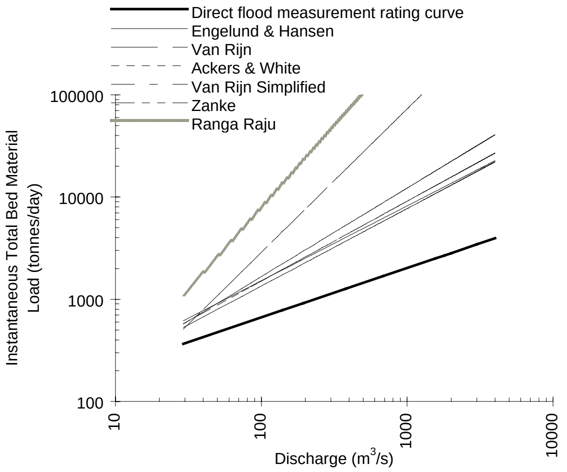


**Figure 5: Sediment rating curves, Mary River at Dagun Pocket, GS 138109A (AMTD 204.7 km).**

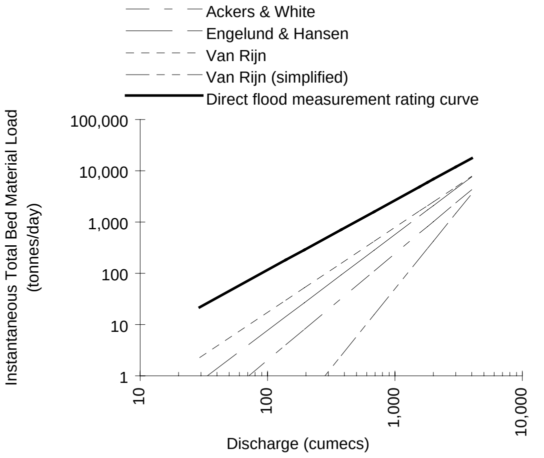


**Figure 6: Sediment rating curves, Brisbane River at Savages Crossing, GS 143001C (AMTD 130.8 km)**

An illustration of the difference in the average annual bed material supply rates, calculated using the direct flood measurements and empirical equations, where the necessary data was available, appears in **Table 2**.

| **Methodology** | **Total Bed Material Load (tonnes/year)** | | |
|---|---|---|---|
| | **Logan** | **Mary** | **Brisbane** |
| Ackers and White | 45 000 | 120 000 | 3 900 |
| Engelund and Hansen | 66 000 | 130 000 | 7 400 |
| Van Rijn | 60 000 | 110 000 | 8 900 |
| Simplified Van Rijn | 73 000 | 130 000 | 3 100 |
| Direct flood data | 15 000 | 71 000 | 20 000 |

**Table 2: Annual average bed material loads from direct flood measurements and empirical equations.**

In the Logan River and Mary River, the empirical equations appear to greatly overestimate the sand and gravel supply tonnages, relative to the direct flood measurement figures. However, preliminary direct flood results for the Brisbane River indicate that the empirical formulae results (Wong 1995) may be underestimating the rate of bed material supply.

Considering the differing results, it is difficult to generalise on the predicted relative loads from the two techniques (ie. direct flood measurement and empirical formula) at this stage. Although, the differences may, in part, is due to the empirical formulae having been developed to describe fluvial processes, where there are smaller coefficients of variation of flow, and significantly different particle size distributions to Queensland rivers.

Results from the formulae are strongly dependent on the $d_{50}$ value. In this example, when the $d_{50}$ is low the empirical formulae appear to over-estimate bed material supply rates, and where the $d_{50}$ is high the formulae appear to under-estimate supply rates[7]. Certainly, the issue of particle size distributions do warrant further investigation.

Both, the empirical formula approach and the flood based measurements show that there is significant variability between catchments regarding sand and gravel supply rates. Of the empirical formulae, it is of Ackers and White that best describes bed material transport for the Logan and Mary Rivers, and Van Rijn for the Brisbane River. While results of the flood based program are still preliminary, they help provide a better description of sand and gravel replenishment rates in Queensland than is available from the empirical formulae.

The results presented here should be regarded as indicative only, as several factors limit their accuracy. Additional information is still needed to adequately determine sediment behaviour in these highly variable river systems:

- Several flood events need to be sampled at each site; depending on the variability of processes, up to six events may need to be recorded. The Fitzroy River is the only site to have been comprehensively sampled for more than one flood event.
- Many of the floods sampled so far have not been large events. It is critical to obtain information from large floods in each system, as these are the real drivers of the bed material transport processes.
- It has proven difficult to capture the critical rising limb of the flood events because of access times.

Additionally, significant bed load sample variation may be occurring in streams with faster bed movement rates. Depending on the precise timing of sample collection, the bed load sampler may be lowered either on top of a bar or immediately in front of a migrating dune. These two situations may yield quite different sample quantities.

The next stage of data collection will concentrate on capturing large events and identifying technologies that will help understand rising stage processes. The relationship between wash load and discharge will be evaluated more fully, and an error analysis of results from both, the direct measurements and the empirical formulae will be made. Additionally, key relationships between catchment, fluvial and hydrological processes with the measured transport rates will be explored.

From this, it is anticipated that a better generalised description of sediment transport rates in Queensland rivers will be obtained than is currently available through the traditional empirical approaches.

This description may be in the form of a series of relationships (formulae) pertaining to different river conditions or may ultimately be developed into several ‘rules of thumb’ or guidelines. It is expected that such a description may have some application to other highly episodic tropical and sub-tropical rivers, where no direct measurements are available.

## CONCLUSION

Direct flood measurements appear to provide a better description of sediment transport rates in Queensland rivers than the traditional empirical equations. Preliminary results indicate that the traditional empirical approach may be up to an order of magnitude out when tested against direct measurements.

Results from the direct flood measurement program are being used to provide a more realistic appraisal of sand and gravel supply rates in Queensland rivers. This will assist sand and gravel operations approach sustainable levels in regards to material availability.

## ACKNOWLEDGEMENTS

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