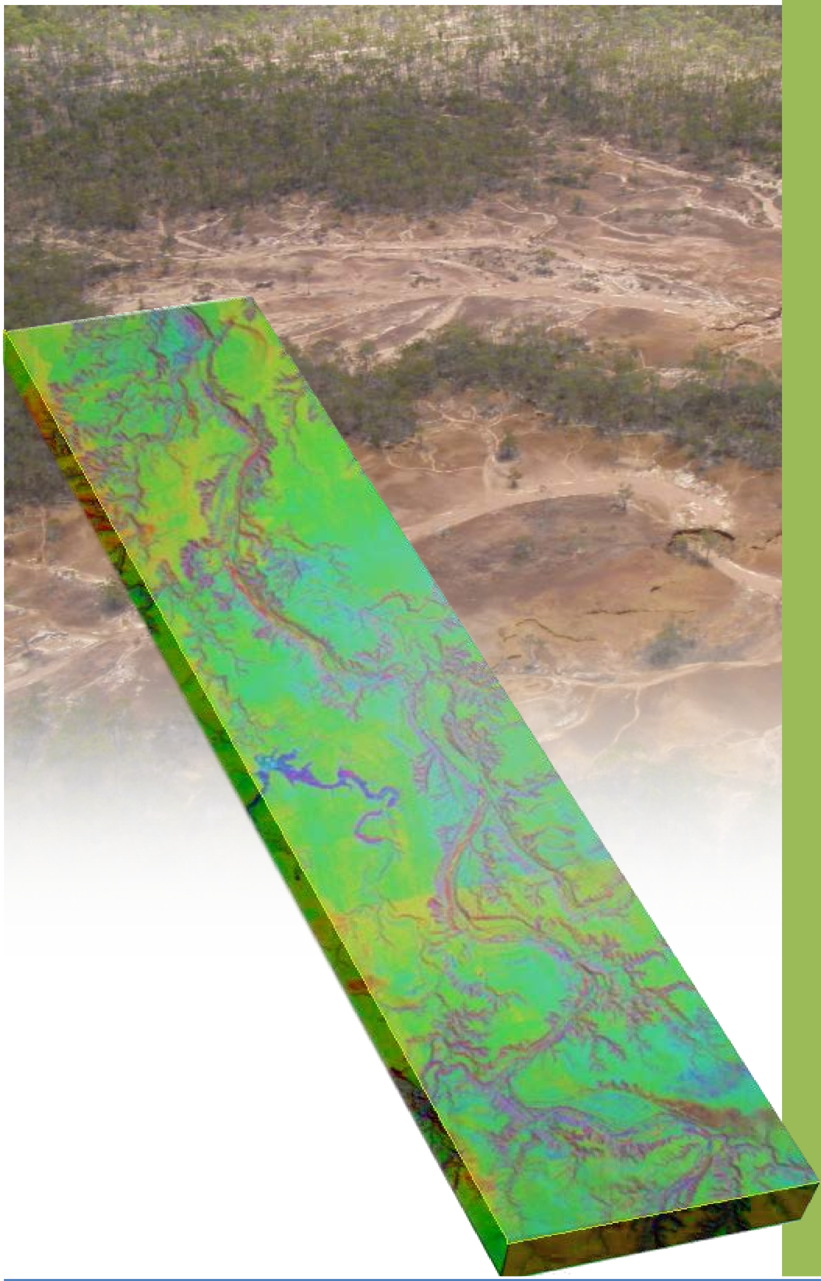

An Empirically-based Sediment Budget for the Normanby Basin

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Appendix 05: Hillslope Sediment Trap – Design and Evaluation

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This Version: 3/03/2013

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

CAPE YORK WATER QUALITY

Appendix 05: Hillslope Sediment Trap – Design and Evaluation

Prepared by: Andrew Brooks*, Daniel Borombovits, John Spencer, Timothy Pietsch and Jon Olley

DRAFT for PUBLICATION

Abstract Sediment budget modeling has become a widely used management tool for natural resource management prioritization in Australia and globally. Two of the most widely used models in Australia, SedNet, and its more recent successor Source Catchments, rely on the Revised Universal Soil Loss Equation (RUSLE) to predict sediment production from hillslope erosion. However, very few empirical data exist in Australia with which to test hillslope sediment yields predicted by the RUSLE, particularly in the more remote unimproved savannah woodlands of northern Australia that are utilized by the cattle grazing industry. These savannah woodland landscapes comprise the vast majority of the catchment area draining into key ecological assets such as the Great Barrier Reef. An increasing number of sediment tracing studies suggest that hillslope erosion is not the dominant sediment source in most tropical savannah environments, which calls into question the validity of the modeling studies that have predicted a dominance of hillslope erosion. In this paper we present a design and evaluation of a simple, low cost Hillslope Sediment Trap (HST) that requires little to no maintenance across an entire wet season in low sediment yield environments dominated by sheet flow transport of sand, silt and clay. It can consequently be deployed in remote, inaccessible areas of Australia to collect data on hillslope sediment production as a means of testing predictions of

erosion. Using these traps, it is possible to develop locally calibrated hillslope erosion models that will provide far more realistic predictions of erosion than have previously been employed. Laboratory flume evaluations of the HSTs also show that the traps will accurately sample the full particle size distribution of sediment mobilised on a given hillslope, with a suspended sediment (<63μm) trapping efficiency conservatively estimated to be 50%.

Keywords: hillslope sheet erosion, sediment trap, tropical Australia, sediment yield, RUSLE

1. Introduction

Sediment budget models are widely used in Australia and worldwide for the purpose of determining catchment scale sediment pollutant loads and for prioritizing management of the key sources contributing to these loads (Prosser et al., 2001; Brodie et al., 2003; 2009). In countries like Australia where much of the landscape is sparsely populated, with large areas that are remote and inaccessible, models are often applied over vast areas with very scant empirical data used as inputs to the models or as regional validation for model predictions, particularly for some of the more difficult to measure sediment sources. In Australia, the sediment budget model SedNet and SedNet/Annex (Prosser et al., 2001; Lu et al., 2003) and its more recent successor Source Catchments (http://www.ewater.com.au/products/ewater-source/for-catchments/), have identified hillslope erosion as being the dominant sediment source in many regions, particularly the tropical savannah landscapes of northern Australia. Such models rely on predicting hillslope erosion rates using the Revised Universal Soil Loss Equation (RUSLE) (Rennard et al., 1993, 1997) often under conditions that are well outside those for which the RUSLE was developed. In the tropical savannah landscapes of northern Australia only a handful of studies have measured hillslope erosion rates, and from a very limited range of soils, slopes and climatic regimes (e.g. McIver et al., 1995; O'Reagain et al., 2005; Bartley et al., 2010; Hawden et al., 2008; Silburn., et al., in review). These few studies currently provide the only means of testing hillslope sediment production rates predicted by the RUSLE across vast areas that have been modeled in tropical Australia.

The validation of the modeled sediment yields in these more remote savannah landscapes currently relies on sediment loads measured within the stream network (usually at official gauging stations), and as such, cannot isolate the hillslope sediment contribution from other sources within the catchment (e.g. channel erosion, gully erosion, road erosion), unless by a process of elimination when accurate data exist on all other sources (i.e. which is very rare), or by sediment tracing (Walling and Woodward, 1992; Wallbrink et al., 1993, 1998; Olley et al., 1993). The mismatch between sediment loads measured within the stream network and the sediment yield predicted by RUSLE on hillslopes, is currently assumed to represent ineffective sediment delivery and is dealt with solely through the application of a hillslope sediment delivery ratio (HSDR) (Prosser et al., 2001) to balance the sediment budget.

In the studies cited above that have measured hillslope sediment production rates, instrumented experimental hillslope plots with flumes were used to determine sediment yields. Such an approach is both expensive and labour intensive, and most importantly generally requires ongoing access throughout the sampling period to maintain the equipment and collect samples. This makes it difficult to replicate, with the site locations biased towards sites easily accessible in all weather and at all times of the year. Alternative approaches utilizing detailed Cs137 inventories have been used to quantify hillslope sediment production in remote savannah landscapes (e.g. Hancock et al., 2008). However as with the instrumented flumes, to accurately determine annual sediment production rates from a given hillslope requires extensive sampling, which is also expensive and time consuming. Hancock et al., (2008) also successfully used an inexpensive erosion pin approach to determine net sediment yields from a savannah hillslope. However, as with the Cs137 inventory approach, neither of these approaches can differentiate between the suspended and bedload fraction of the sediment yield, something that is critical for factoring into catchment scale sediment budget models.

To date the particle size fraction of sediment delivered from hillslopes has not generally been clearly articulated, and there is now considerable confusion as to what particle size fraction are being predicted by RUSLE based models, despite the fact that model is intended to predict total load. Many of the previous SedNet modeling exercises have dealt with the issue by not explicitly stating what sediment size fraction are being delivered, but after applying the HSDR it is assumed that only suspended sediment load remains, which is generally referred to as being the sediment <63μm. Rustomji et al. (2010) stated however that the gross hillslope erosion predicted by the RUSLE was explicitly referring to the <63μm fraction derived from hillslopes, excluding the sand and gravel bedload fraction. While this erroneous distinction will not have changed the outcome of the model, given that the mismatch between predicted gross hillslope erosion is dealt with by the HSDR, without explaining the particle size composition of the non-delivered sediment, or even where this sediment is stored, it makes a significance difference for comparison with predictions of gross hillslope erosion by the RUSLE model at the hillslope scale. Hence, it is critical to understand what the particle size distribution of hillslope sediment looks like for a model validation data set, and as such we need methods for measuring hillslope sediment production from which we can glean this information.

Given that fully instrumented experimental sites are only ever going to be established at a few highly accessible locations, a new approach is required that is cheap and easy to install and manage in order to enable the collection of much larger data sets on hillslope sediment yields within a more representative sample of soils and soil landscape conditions, particularly in remote inaccessible areas. It would appear likely that the dearth of available empirical hillslope erosion data in Australia with which to parameterize, and test the outputs of, broader scale sediment budget models, is in large part due to the expense and human resources required to run such experiments.

In this paper we present a design for a low budget and low maintenance hillslope sediment trap (HST) that has successfully been deployed to measure gross annual hillslope sediment production (suspended and bedload) across two wet seasons in the Normanby catchment, Cape York, North Queensland, Australia. The results of the sediment trap deployments over two wet seasons and their implications for sediment budget modeling are reported in the companion paper (Brooks et al., this vol). This paper is intended to provide a detailed outline of the trap design and to report on the results of laboratory flume experiments undertaken to assess the performance of the trap.

1.1 Design Requirements

To enable the deployment of a sufficient number of samplers in the field within the life of a typical three year research project tasked with quantifying sediment sources from a large catchment, the following design requirements were imposed:

1) The sampler should not cost more than about $AUD 500 in materials
2) The sampler can be constructed from materials that can be easily purchased
3) The sampler can be readily transported in a 4WD vehicle and constructed by two people within a day (or less).
4) The sampler only requires an initial setup and then a single return visit for sample and data recovery at the end of the sampling period (in this case the end of the wet season). This is to ensure that data collection is not biased to sites that are readily accessible during the wet season (which in northern Australia limits you to a very small proportion of the landscape).

Given these constraints a sampler was designed that is based on the same principle used in the design of silt fences for erosion control. The only departure from the design requirements outlined is that we were required to source commercial quantities of high grade geofabric (i.e. not typically available in large quantities from a hardware store). Additional monitoring equipment was also installed to quantify total rainfall, rainfall intensity and total erosivity during the sampling period. We used Onset tipping bucket rain gauges (0.2mm/tip with Hobo data logger) at each site, along with a Moultrie i60 camera set to take 3 photographs of the trap site per day. The camera images are useful for observing runoff conditions during some of the recorded events, and are particularly useful for monitoring ground cover change across the monitoring period. A single rising stage sampler (*sensu* Colby, 1961, Graczyk et al., 1993) was also incorporated in each trap as a single sample validation for the event concentration of an early wet season runoff event.

As shown in Table 1 the *material* cost of the traps were under $AUD 500, with the associated monitoring equipment comprising the bulk of the cost. It should be pointed out that the full complement of monitoring equipment may not be necessary for all traps deployed once the regional rainfall run-off characteristics have been characterized and the general performance of the traps determined. The extent of additional monitoring equipment will depend on the overall objectives of a given study. Ideally a pressure transducer stage recorder would be added in the apex of each trap to measure trap backwater across the monitoring period, but this would more than double the monitoring equipment budget.

Table 1 Material costs for a single hillslope sediment trap. Note the costings are in $AUD as at August 2009

Hillslope Sediment traps	units	# units	unit cost	total
geofabric Bidim CP320	linear m (x 2.2m wide)	16	$ 5.30	$ 85.00
star pickets 6'	ea	11	$ 6.00	$ 66.00
star pickets 2'	ea	5	$ 2.50	$ 12.50
plain fencing wire 3.15 mm	m	68	$ 0.50	$ 34.00
Iowa barbed wire 2.5 mm	m	46	$ 1.00	$ 46.00
steel pegs	ea	60	$ 1.50	$ 90.00
Jambro C clip pliers (prod code A10855)	ea	1	$ 70.00	$ 70.00
C clips (Jambro prod code 12301)	ea	160	$ 0.20	$ 32.00
			sub-total - trap only	$435.50
rain gauge mount				
star pickets 6'	ea	3	$ 6.00	$18.00
star pickets 2'	ea	3	$ 2.50	$ 7.50
plain fencing wire 3.15 mm	m	12	$ 0.50	$ 6.00
tie wire (high tensile)	m	10	$ 1.00	$10.00

other monitoring equipment				
rising stage sampler	ea	1	$ 20.00	$20.00
tipping bucket rain gauges	ea	1	$ 535.00	$535.00
data loggers ML1 Mini logger	ea	1	$ 265.00	$265.00
time lapse camera (Moultrie Game i60)	ea	1	$ 300.00	$300.00
sub-total - monitoring equipment only				$1,161.50
Total Trap + monitoring equipment				***$1,597.00***

1.2 Trap Design & Construction

As shown in Figure 1, the trap is essentially a robust star picket fenced enclosure from which a geofabric fence is hung and attached to the ground. Plain wire strands are used for the lower three strands to support the geofabric. The barbed wire strand is used for the top wire and across the front (upslope opening) of the trap to exclude cattle and other large stock. The geofabric used was a high grade non-woven product known as Bidim (product code CP320), manufactured by Geofabrics Australasia. The selection of the geofabric for this application is a trade-off between its capacity to pass water through the fabric and its ability to trap as much sediment as possible, of all particle sizes. If the geofabric is too fine, insufficient water will pass through the trap causing it to back up and overtop (thereby losing an unknown amount of the delivered sediment). Hence, there is no way to achieve a perfect trap, in which all sediment is trapped, so the challenge is to quantify the HSTs trapping efficiency and what size fractions are likely to be passing through.

Two variants of the trap have been built and deployed; a U shaped variant as per the diagram in Figure 1, where the trap wings are bent upslope for deployment on lower slope sites; and a V shaped variant with straight wings for higher slope sites. The operational principles of each trap variant as outlined below are essentially the same, however the selection of either variant depends on the slope of the site.

A key consideration of the design is that the elevation difference between the ground surface at the trap apex (i.e. the centre post) and the upslope post of each trap wing must be greater than the elevation difference between the ground surface at the apex post and the top of the geofabric at the apex post (typically 0.5m). This prevents the backwater within the trap from spilling around the sides of the wings. Hence, the need for the bent wing variant for lower slopes. Given these constraints on design and deployment, the traps are only appropriate for hillslopes with gradients ranging from 7 to 25%. For a slope any lower than 7% it is not possible to attain sufficient fall within the trap to prevent backwater spillover. Any steeper than 25% reduces the volume of water stored, and the effective filtration surface area of the geo-fabric, thereby increasing the likelihood of overtopping due to the reduced infiltration rates through the reduced area of effective geofabric filter. Steeper slopes also would be likely affected by additional hillslope erosion processes beyond sheet flow, such as landslides, debris flows, rock fall, dry ravel, etc.

The traps are designed to be a standard length of 16m (8m per wing), whether the arms are of the bent or straight wing variant. This was a trade-off between cost, sufficient trap width and length to sample a reasonable area of hillslope, and the likely volume of material to be trapped and then processed. The geofabric is supplied in rolls 2.25m wide; thereby with the trap height being around 0.5m from the ground, and a 100mm fold over on the top wire, an apron of around 1.5m perpendicular from the base of the fence is formed on the ground on the inside of the trap. The top edge of the geofabric is secured to the plain wire strand 0.5m above ground level by folding it over the wire and stapled in place using wire netting C clips (Jambro product code 12301). The leading edge of the apron is folded over and pinned flush to the ground, through the geofabric, using Supapeg 6.3mm x 300mm chisel point tent pegs. It is critical that the geofabric is pulled taught and pegged at least every 30cm so that there is no space for water to flow under the leading edge of the apron. A line of clean rocks are placed on the surface of the geofabric at the base of the fence line, to both pull the fabric taught and to prevent it from blowing up during storms and disturbing the sediment sample (Figures 1 and 2).

1.3 Trap Operating Principle

The trap is designed to collect all sediment runoff from the trap's contributing catchment area for the entire period that it is deployed. In this study the traps were deployed for the entire period of the summer monsoon period (November to April), during which 90% or more of the annual runoff and sediment supply is contributed. As outlined further below, the traps do not however, have a 100% trap efficiency. Hence a key objective of this study was to quantify the trap efficiency.

The traps were located on hillslopes upslope of any drainage lines to ensure that only hillslope surface sediment is delivered to the trap (i.e. no channel or gully erosion). Hence traps were placed in zero-order channeless-hollows or on concave hillslopes. They were positioned toward the bottom of the hillslope where coarse sediment naturally would begin to accumulate. It is acknowledged that exact location positions on a hillslope either longitudinally (up and down slope) and laterally (convex, planar or concave) could have significant effects on the collected sediment, trap efficiency and local sediment delivery ratio.

The ideal catchment area for any given trap will vary with slope, soil type and soil hydraulic conductivity, given that the trap needs to filter the total volume of water delivered, ideally without overtopping. The trap can store a significant volume of water without overtopping, but once full it must be able to transmit water through the geofabric at the same rate as the water coming in if it isn't to overtop. According to the manufacturer's specifications, the Bidim CP320 has an infiltration rate of 8 $l/min/m^2$ of fabric with a 100mm head. Determining the actual infiltration rate under field conditions was difficult given that it was not possible to predict what the head would be at any given time (without adding a stage recorder to every trap), nor the performance of the fabric under different head conditions or once sediment had begun to clog the pores of the fabric.

At the end of the sample period, all of the material captured on the geofabric apron and face was then swept up and placed in samples bags for transport to the lab, with the remaining fines collected with a Miele S2120 1600W vacuum. The vacuum bags were taken with the swept samples to the lab for processing for total load, which was differentiated between fines (<63μm), silt/sand, sand/gravel and removal of organics. Sub-samples of fractions were analysed in a Malvern Mastersizer 2000 at the Department of Science, Information Technology, Innovation and the Arts (DSITIA) Laboratories, EcoSciences Precinct, Dutton Park, Queensland, to derive a complete particle size distribution. Representative samples of the geofabric after cleaning were then collected to determine the mass and particle size distribution of the sediment retained within the fabric. These data were used to correct for the suspended fraction of the sediment load retained in the trap fabric.

As outlined below, a series of laboratory flume experiments were undertaken to quantify the characteristics of the fabric, both from the perspective of its infiltration characteristics, particularly after it has begun to accumulate sediment, as well as the particle size distribution of the trapped and throughput sediment (i.e., its trapping efficiency). The fabric is rated to trap sediment with a minimum particle size of less than 75μm . The precise minimum particle size transmitted through the material has been established experimentally as outlined below.

The particle size distribution of sediment passed through the geofabric, as established experimentally, represents the "worst case scenario" for the proportion of the sediment that is not being trapped, given that sediment is also deposited upon the trap apron out of suspension, when the trap experiences backwater conditions. Time lapse cameras set up at the traps in the field indicate that this condition occurs commonly during storm events. Some of the sediment that is dropped out under these conditions will clearly be deposited off the trap apron, however, it is assumed that during subsequent events across the wet season that such material will be reworked onto the geofabric, and as such is ultimately collected within the trap. Given that ground cover increases dramatically across the wet season in the savannah landscapes where the traps have been deployed, it is likely that most suspended sediment is delivered to the trap in the early wet season events. Late wet season events will have lower suspended sediment concentrations (SSC) and hence are more likely to rework the material deposited in the trap backwater zone by earlier events. It is recognized that this may represent one source of error in the trap design, and could be rectified by installing geofabric across the entire area of the trap.

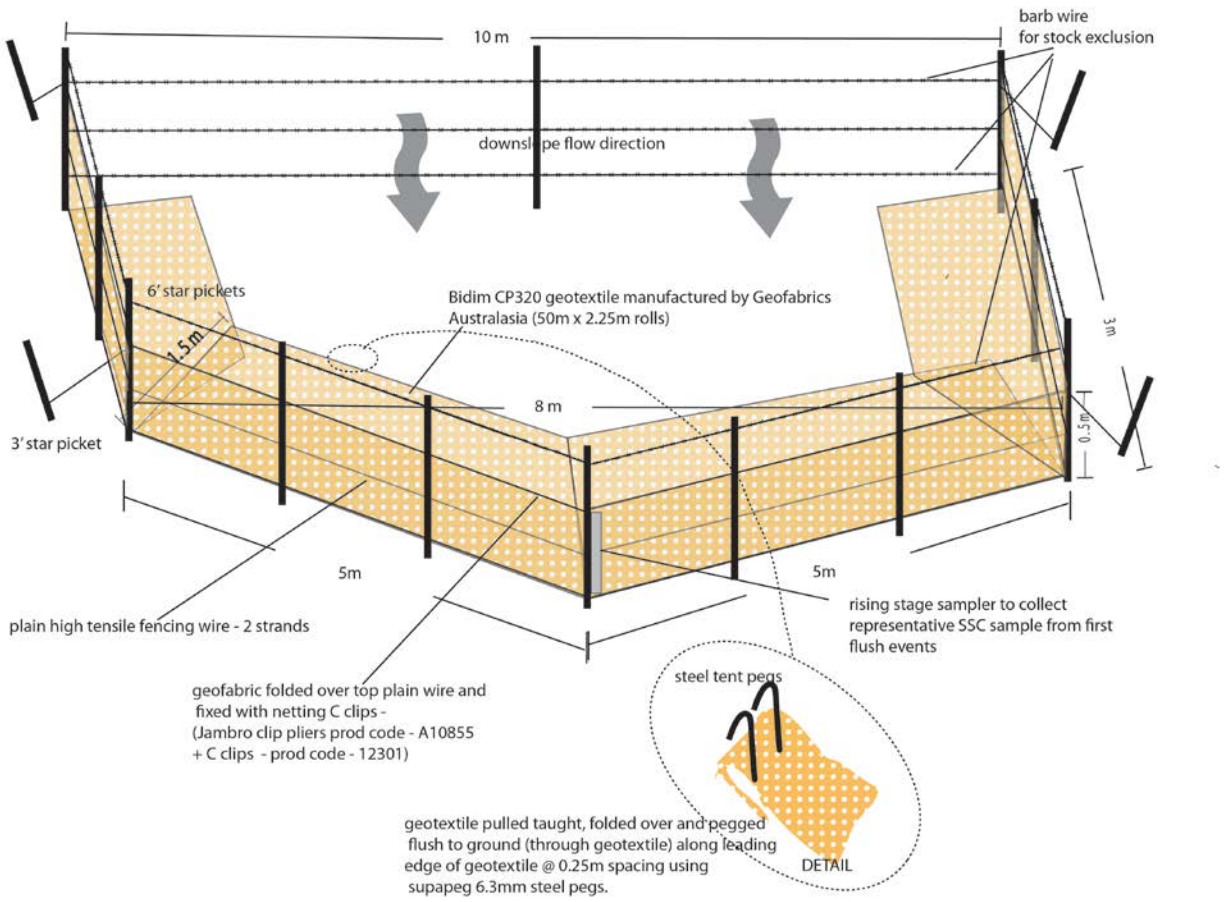

Figure 1 Design specifications for the bent wing variant of the Hillslope sediment trap

Figure 2 Examples of the two trap variants as deployed in the Normanby catchment; straight wing V shaped variant left; U shaped variant right

Figure 3 Examples of the tipping bucket rain gauge setup (left) and one of the traps in operation under backwater conditions during a rain event (right) in the middle of the wet season.

2. Laboratory evaluation of flume trap efficiency

The high porosity of nonwoven geotextiles allows water through-flow while at the same time trapping fine sediment. Under field conditions it is possible that variations in particle shape, mean particle size, particle size range and sediment concentrations will affect the flow rate and trap efficiency of the geofabric. In order to assess possible experimental error in the Normanby HSTs it is necessary to determine the effective filtration threshold and the overall sediment retention of the geofabric, under conditions simulated to replicate those in the field. To test the effective particle size filtration threshold (and hence trap efficiency) of the BIDIM CP 320 geofabric, a laboratory flume was constructed to test the infiltration rate and sediment retention characteristics of the material.

A series of replicated experiments were then run to establish the infiltration rates under clearwater conditions, and with SSCs at similar or higher levels than those experienced in the field trials. A full explanation of the measured loads is provided in the companion paper (Brooks et al., this vol.). A SSC of 400 mg/l was used as a standard in the flume experiment, mixed from soil samples collected and derived from the Hodgkinson Formation metasedimentary rock which comprise a significant proportion of the upper Normanby catchment, and which typically produce finer grained soils than the sandstone and granitic geologies that comprise the majority of the rest of the upper catchment. The standard concentration was 1 – 2 orders of magnitude greater than the typical "event mean concentrations" (EMCs) back calculated for the 11 HSTs deployed in the Normanby catchment over the 2009-10 and 2010-11 wet seasons (Brooks et al., this vol.). We elected to use a single standard SSC solution from a single soil type in order to keep the experimental design to a manageable level.

Given that under field conditions the traps experience a variable head, depending on the extent of backwater ponding at any one time, it was decided to replicate these conditions, rather than run the experiments at a consistent head. Under field conditions the head various from 0-500mm, but in the lab flume we were only able to replicate a maximum head of 165mm. Hence the experimental infiltration rates will be conservative compared to the field conditions.

The objectives of the flume experiments were: 1) to determine the nominal flow rate of clean water through the geofabric; 2) to measure the trapping efficiency of the geofabric using the <63μm 400mg/l standard SSC solution (i.e. worst case scenario – with no bedload); 2) to measure the trapping efficiency of the geofabric using a bulk sediment sample that includes both suspended load and bedload); 4) to determine how the trapping efficiency of the geofabric changes after multiple events – i.e. simulating the potential clogging of the pores after multiple events; and 5) to simulate the effect of late season flows with clearwater conditions on top of previous high concentration flows – i.e. to assess the potential for the flushing of the trap with late season events – once cover factor has increased to such an extent that SSCs are reduced to a minimum.

2.1 Experimental Methods

2.1.1 Flume setup

A two-sectioned angled flume was constructed from two polypropylene crates. The top section consisted of a 70 l crate with an opening cut across one end, surrounded by a plastic housing containing an aluminium grill to support the wall section of the geofabric, and an internal watertight clamp structure that also extends along the base of the crate. The clamp structure allowed a 670mm x 330mm piece of geofabric to be securely fastened across the front wall of the flume, with a proportional extent of geofabric fastened along the bottom of the crate to simulate the apron.

The bottom section of the flume consisted of a 40 l crate which provided a support for the top section and facilitated collection of the filtered sample through the drainage tap. The rear end of the top section is supported by an adjustable base structure that allows the angle of the flume to be modified, which was set at 9% during laboratory trials to match the mean slope of the traps deployed in the field. This way the flume tested the combined trap efficiency of the near vertical trap wall under a head of up to 165mm, as well as the backwater deposition characteristics of the apron.

The effective wetted area of the geofabric (including the wall and apron) was 0.05 m^2, and each experiment used a new piece of fabric cut from a sample of the same roll used for the traps in the field.

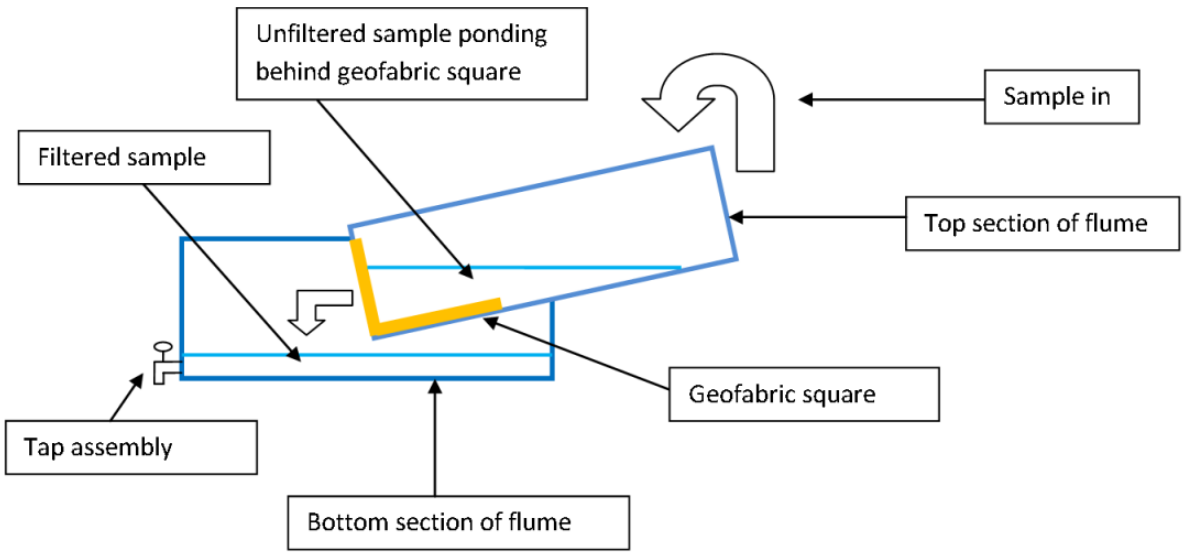

Figure 4 Schematic of flume setup

Figure 5 Photo of flume setup in the laboratory

2.2 Flume Experiments

In order to enable sufficient experimental replication, the flume experiments were standardized as much as possible while still enabling the five key characteristics of the geofabric to be determined. Individual experiments consisted of 5 or 7 runs, which were sequential treatments of either 30 l of clear water or 30 l of water made to a standard concentration of 400 mg/l of sediment. Two different sediment treatments were used 1) a bulk sample of Hodgkinson Formation soil, made up to 400 mg/l, and 2) a solution comprising only the <63µm fraction of the same parent soil material. The former represented the full particle size distribution of surface soils, and is considered to be the most representative of the material delivered to the HSTs in the field. We focused on the Hodgkinson Formation soil material because it was one of the more abundant soil types, and we had set up a series of replicated traps at the same location on Hodgkinson soils to test the local variability of erosion rates. The time and expense involved in running replicated experiments precluded us from running the same set of experiments for each soil type. The pre-sieved <63µm was considered to test the geofabric under worst case conditions with no bedload or coarser fractions that would provide additional clogging of the geofabric. It was assumed that a greater proportion of the fines would pass through the geofabric with only fines present, and hence provide the basis for the most conservative estimate of the HST trapping efficiency.

For most experiments two clear water runs were undertaken first, before the soil solution runs. This was both to establish the flow rate without any sediment and because it was thought to better reflect the conditions in the field where initial rainfall would wet up the geofabric prior to the initiation of overland flow. A further three clear water runs were then undertaken after the sediment laden runs to simulate late season sediment starvation on the hillslopes following the initial flush and the extensive growth of grass cover that occurs on savannah hillslopes. These runs were to measure the potential for additional sediment loss through the geofabric under clear water conditions. While it is acknowledged that true clear water conditions are unlikely to occur late in the wet season, even with the extensive grass cover, that again this situation represents that worst case condition in terms of the trapping efficiency of the HST, and as such the final trapping efficiency figures will be conservative.

Specific steps involved in this experiment are:

1) Load a new piece of geofabric into the housing of the top section of the flume. Tighten the clamps firmly and ensure that geofabric is securely locked into position along the front wall and base of the flume
2) Lock top section of the flume onto the bottom section and place over the support structure at the back of the flume. Ensure angle of top section is set to 9%
3) Prepare two 30 l soil solutions at 400 mg/l concentration (either as a bulk soil treatment, or as a <63µm treatment)
4) Undertake two sequential clear water runs, recording time for top section of the flume to empty completely
5) Undertake two sequential 400 mg/l soil solution runs, recording time for the top section of the flume to empty completely. Store output sediment solution samples for further processing, separating intermediate sub-samples at 6 minute intervals if required
6) Undertake a further one to three sequential clear water runs (depending on total number of runs required), recording time for the top section of the flume to empty completely. Store output sediment solution samples for further processing, separating intermediate sub-samples at 6 minute intervals if required

7) Allow flume to drain completely, remove clamps and take geofabric out of the housing. Thoroughly clean all surfaces and repeat steps 1-7.

A set of volumetric flow experiments were also conducted to determine the change in flow rate through the geofabric over time. Three sequential 30 l runs of clear water were passed through a fresh square of geofabric, with time taken to fill a 1 l graduated cylinder recorded repeatedly until the top section of the flume was empty. Stage height was also recorded for each 1 l increment.

2.3 Particle Size Analysis for Flume Experiments

All particle size distribution analysis was carried out using a Malvern Mastersizer 2000 at the Department of Science, Information Technology, Innovation and the Arts (DSITIA) Laboratories, EcoSciences Precinct, Dutton Park, Queensland. A 0.5g sub-sample of the material that had passed through the trap, as well as the input material was taken and wet-sieved using a 1.0mm mesh sieve, then mixed with approximately 1000ml of de-ionised water to provide a suspended sample for analysis by a Malvern Mastersizer 2000 particle size analyser. The wet-sieved samples were then mechanically dispersed in a cut-bottle using a screw propeller attached to the Mastersizer.

The dispersed sample was then left to soak in the bottle for a minimum of 12 hours. The soaked sample was once again mechanically dispersed by the screw propeller, which also served to homogenise the suspended sample as it is pumped through the measurement cell in the Mastersizer. With the laser obscuration level on the Mastersizer set to 5-15%, the suspended sample was continuously pumped through the measurement cell, and particle size measurements taken for 15 seconds providing 15000 measurement snaps per cycle, with a total of 15 measurement cycles per sample. Initial measurements were taken for each sample, with results reported for pre-dispersion (W_PSD_PRED) and mechanical dispersion (W_PSD_MECD). A subsequent set of measurements were taken following further dispersion of the sample by immersion in an ultrasonic bath (processed internally within the Mastersizer), and the results reported (W_PSD_ULTD).

3. **Results**

3.1 Trapping Efficiency and Infiltration - Sub 63µm Experiments

The experiments using the sub-63µm input sediment were considered to be the most extreme test for the geofabric, and consequently the greatest effort was directed into replicating these experiments as a basis for deriving a conservative trapping efficiency correction factor that can be applied to the field data set. As can be seen in Figure 4 and 5, the cumulative trapping efficiency for a single run with an input suspended sediment concentration of 400mg/l is in the order of 60%, which declines marginally with the subsequent sediment laden run, and by a further 10 % following an additional 3 clear water runs. Given that true clear water input conditions are unlikely to occur in the field it is reasonable to assume that the final trapping efficiency of 50% represents a sufficiently conservative estimate of gross HST efficiency.

Geofabric infiltration rates are reduced as sediment loads stored within the trap increase (Figure 6), seemingly stabilising at around 1 l/sec/m^2 at the peak sediment concentration. While only two sediment load runs were undertaken as part of the experiment, the load runs were at concentrations typically twenty times greater than the event mean concentrations experienced in the field experiments (Brooks et al. this vol). Furthermore, given that across the wet season there were on average around 30-40 run-off generating events that delivered sediment to the traps at lower concentrations than the flume experiments, it is considered unlikely that the geofabric would be “clogged” to a greater extent than experienced in these flume experiments. Hence it is reasonable to assume that the minimum infiltration rates indicated here are unlikely to be significantly less than this in the field experiments (Brooks et al., this vol.).

Based on the average trap volume at full capacity of the 11 traps deployed in the field (Brooks et al., in prep) of 11.6 m^3 , and the average wetted surface area of the vertical face being of 4.2m^2, then the trap would on average take around 46mins to completely drain (using an average infiltration of 1 l/sec/m^2). However, it needs to be remembered that the experimental infiltration rates reported here are the time integrated average with a variable head from 165mm to zero. The drainage rate in the experimental flume is, however, non-linear through time, with the rates changing according to a third order polynomial function of water depth in the trap, as shown in Figure 7. The reason for this non-linear relationship between infiltration rate and backwater depth in the experimental flume trap is that the apron of the trap comes into play at intermediate water depths. At maximum depth, the vertical pressure exerted on the trap apron seals it to the ground, or in this case, the base of the plastic flume, and under these conditions the infiltration rate is purely a function of the flow through the vertical wall of the trap. As the flow depth within the experimental flume trap declines, the seal on the fabric on the base of the trap is released, and some flow can now pass through the basal apron as well as the vertical face of the trap. Whether the basal apron of the trap in the field seals to the same extent is unknown, but it may well not seal completely due to the hydraulic conductivity of the soil beneath the trap (compared to the impermeable plastic flume base). Hence we can assume that the infiltration rates in the field version of the trap will have higher infiltration rates than those reported here, and that with depths greater than those achieved in the flume experiment that the downward trending rate with increasing depth is unlikely to continue on the same trajectory. It is not clear whether with the greater depths in the field traps (which can achieve a maximum head of 0.5m), that the pressure may not force water through the apron. We would certainly expect increased infiltration through the wetted vertical face with greater depth. Hence, for a variety of reasons, the infiltration rates recorded in the flume experiments can be assumed to represent the absolute minimum rate, none the least due to the fact that the time to drain calculations take no account of the apron surface area.

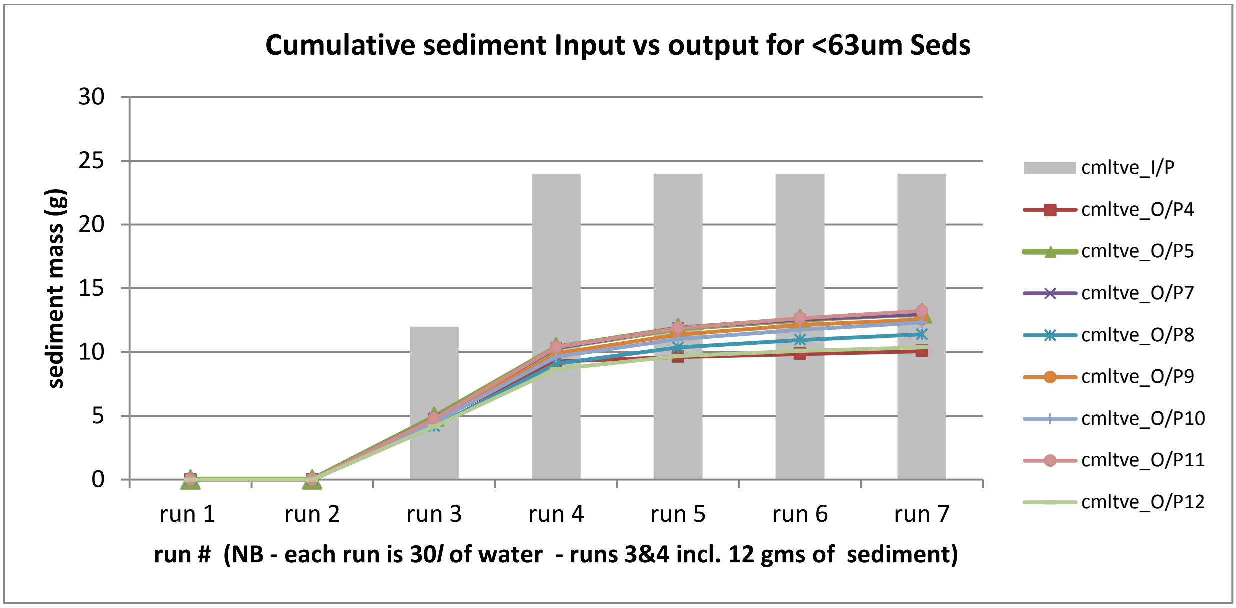

Figure 6 Results of the eight experiments run using the <63µm Hodgkinson soil material. The grey bars represent the cumulative mass of sediment input across the 7 runs – while the coloured lines represent the cumulative sediment output for the eight experiments. Note the first 2 runs are clear water runs (run 1 and 2), followed by 2 runs at 400mg/l (runs 3 and 4), then followed by a further 3 clear water runs (runs 5, 6, 7).

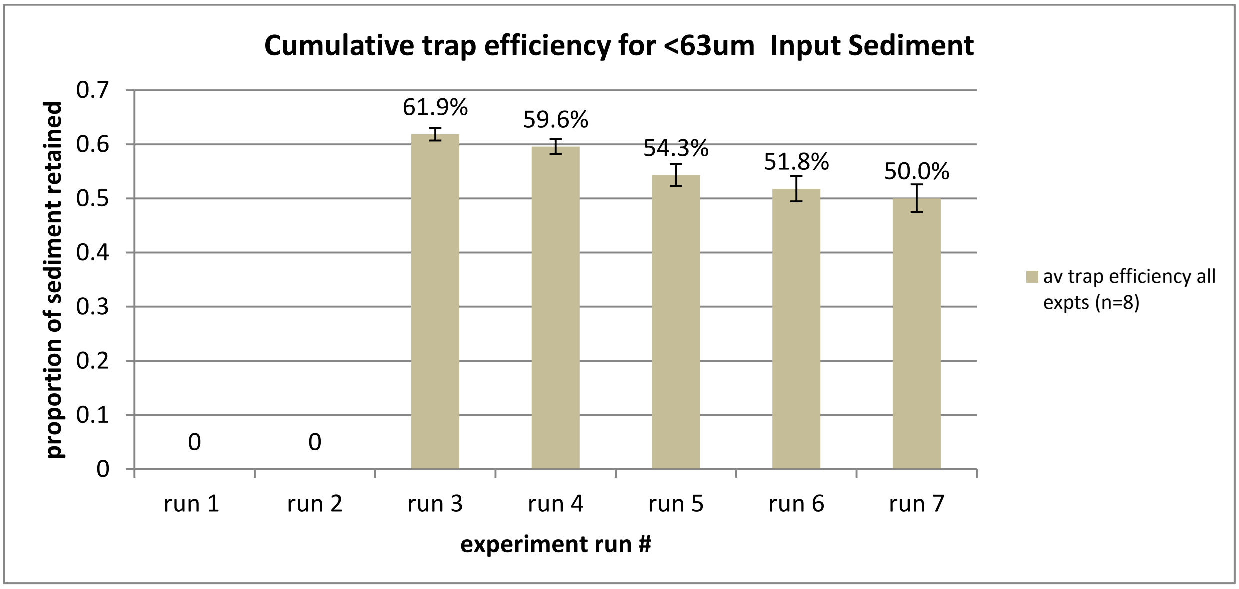

Figure 7 Cumulative trap efficiency results across the seven runs from the eight experiments replicates. Error bars represent one standard deviation. Note the first 2 runs are clear water runs (run 1 and 2), followed by 2 runs at 400mg/l (runs 3 and 4), then followed by a further 3 clear water runs (runs 5, 6, 7).

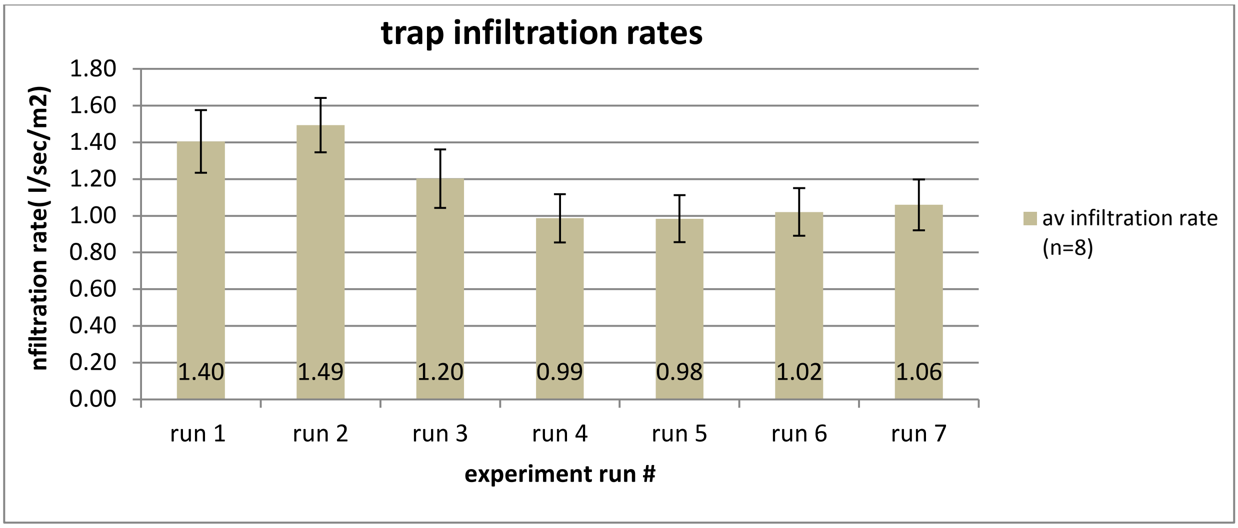

Figure 8 Average Geofabric infiltration rates (until all solution is run through) for the full set of <63μm Hodgkinson soil runs including the two initial clear water runs. Error bars represent one standard deviation. Note the first 2 runs are clear water runs (run 1 and 2), followed by 2 runs at 400mg/l (runs 3 and 4), then followed by a further 3 clear water runs (runs 5, 6, 7).

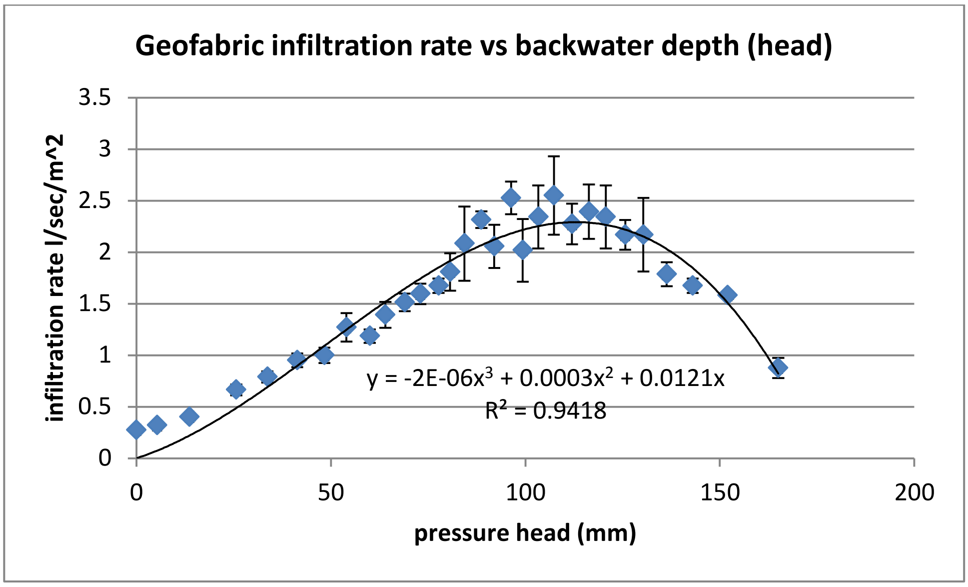

Figure 9 Infiltration rates with varying head for the clear water input condition.

3.2 Trapping Efficiency and Infiltration- Bulk Soil input Experiments

The same set of experiments as run for the sub-63μm sediment input experiments were also run using bulk soil material as the input, typical of the soils found on the Hodgkinson Formation metasediments. In this case only a single clear water run was undertaken following the soil solution runs, given that the clear water response was well established in the <63μm experiments. As would be expected, the data shown in Figures 8 and 9 indicates that gross trap efficiency using the bulk soil material as the input solution is significantly greater than that just for the fine suspended fraction of the input load. In this case the total trap efficiency is in the order of 90%, although we would expect that trap efficiency for the <63μm of the total load will still be similar to those outlined for <63μm experiments alone. Infiltration rates (Figure 10) would appear to be marginally quicker than those with the fines only experiment. This would be expected given that the total amount of fines that could potentially clog the pores of the geofabric is substantially less than in the fines only experiments.

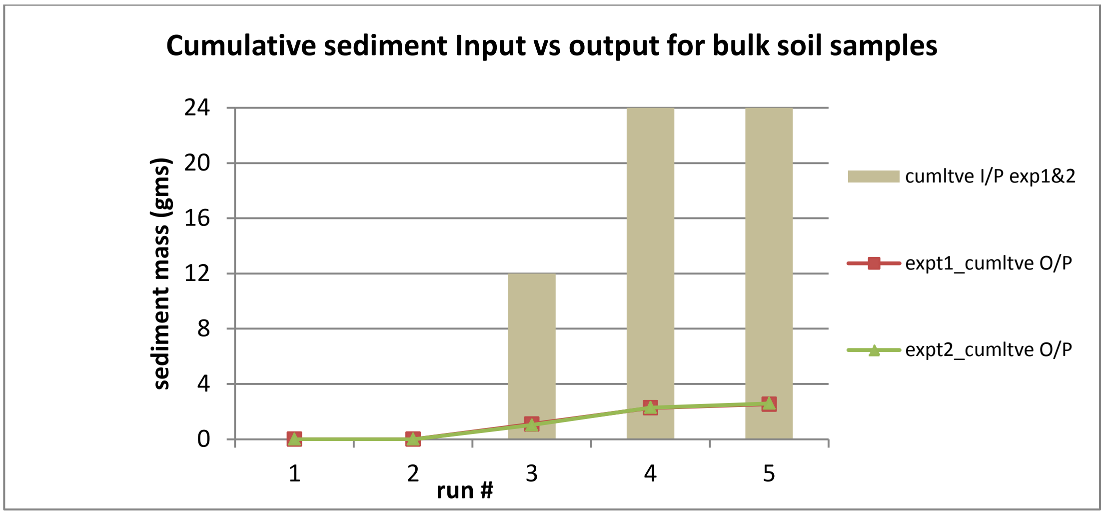

Figure 10 Results of the two experiments (multiple runs each) using the bulk sample Hodgkinson soil material. Each experiment had two initial clear water runs followed by 2 runs at 400mg/l, and a final clear water run.

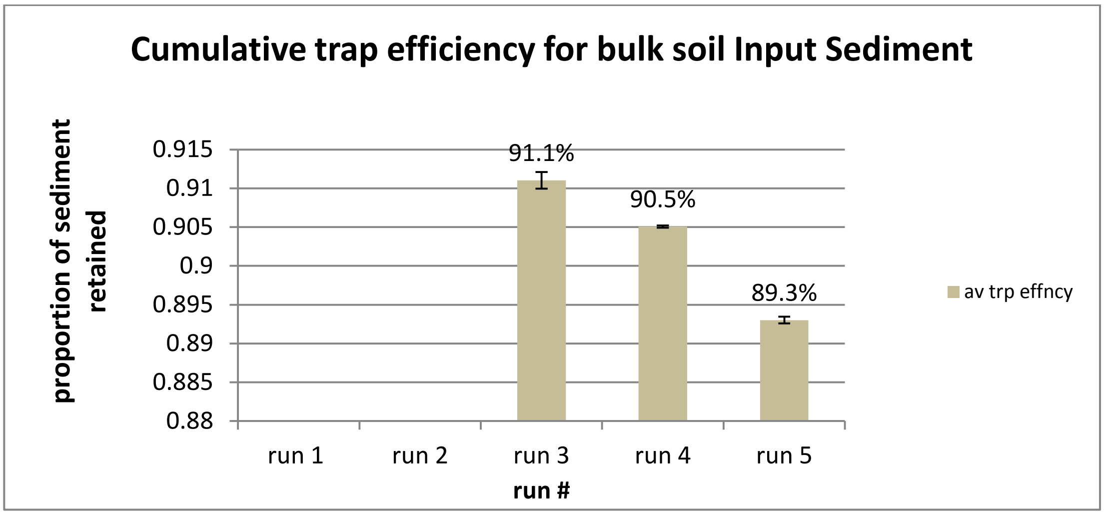

Figure 11 Cumulative trap efficiency results with bulk soil as the input load at a concentration of 400mg/l. Error bars represent one standard deviation. Each experiment had two initial clear water runs followed by 2 runs at 400mg/l, and a final clear water run.

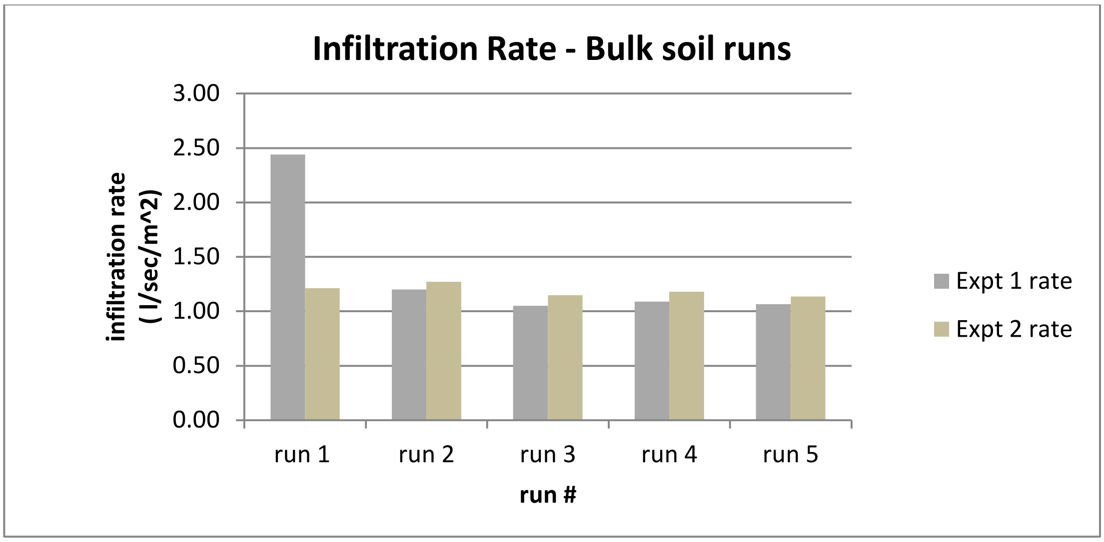

Figure 12 Infiltration rates for the geofabric with bulk soil as the input. Each experiment had two initial clear water runs followed by 2 runs at 400mg/l, and a final clear water run.

4. Particle Size Characteristics

4.1 Fines Only Experiments.

The primary descriptive statistics of the particle size data, for both the fines only and bulk soil experiment runs are shown in Figure 11. As outlined in the methods section above, three separate analyses were performed on each sample: 1) in the un-dispersed state (indicated by the code PRED); 2) with mechanical dispersion (MCED); and 3) with both mechanical and ultrasonic dispersion (code ULTD). All three data sets are presented because they provide an indication of the extent to which the sediment in question is likely to be transported as soil aggregate or otherwise. The undispersed sample might be expected to be more representative of what is likely to be transported on the hillslope.

The data presented in Figure 11A shows that the geofabric certainly seems to be filtering effectively at the 63μm level, although given that the input material was wet sieved to less than 63μm to prepare the input sediment mix, it is somewhat surprising to see that there is 10-20% of the sediment mix that is > 63μm in the solution that was thought to be < 63μm. This could be explained either by the fact that wet sieve used is slightly worn and is passing sediment >63μm; or it may indicate that there are some inconsistencies between the two methods, with the Mastersizer "seeing" coarser particles than are in fact there. It could also indicate that the sediment in question has asymmetrical particles and that this is unavoidable measurement error, or it could also indicate that the particles are re-aggregating while in solution, after the wet sieving. Regardless, even with the fines only data, it is apparent that the geofabric trap is effectively trapping particles that are less than or equal to 63μm. What is evident from these data is that the clear water runs, which follow the sediment laden runs, are flushing some coarser particles through the geofabric, as the total proportion of sample that is < 63μm declines slightly with each clear water run. The difference between the un-dispersed and ultrasonically dispersed sample, indicates that at least 10% of the suspended load could be expected to be transported as a mud aggregate on the hillslopes with this soil type.

The D_{90} data shown in Figure 11B, highlights even further the disparity between the dispersed and undispersed samples, indicating that the mud aggregate particles are almost double the size of the fully disaggregated sample. More significantly, however, these data show that under normal operating conditions (i.e. no subsequent clear water flushing), that the trap is effectively filtering to around 30μm, as indicated by the undispersed sample. Note also, an additional sample (GF13 run 4.612 O/P) is included in this data set. This was an intermediate sub-sample taken from run 4, towards the later stages of this run, when most of the material had already passed through the trap (i.e. after 6 minutes). This sub-sample is notably finer than the sample average (which is collected after the full trap run is complete), and highlights the fact that the coarser fractions will pass through in the initial phase of the run, when the trap or flume is full and under maximum hydraulic head.

4.2 Bulk Soil Experiments.

The results of the bulk soil experiments shown in Figure 11C & D and Figure 12 further highlight the trapping efficiency of the geofabric for the bulk soil sample runs, with the output D_{90} being < 50μm regardless of the dispersion method or the degree of clear water flushing. Figure 12 clearly shows that there is very pronounced differentiation between the particle size distribution of the trap input and output material for both the undispersed and mechanically dispersed samples, with even the ultrasonically dispersed samples showing a clear difference. It is interesting to note that there is an extremely large disparity in the D_{90} of the input material depending on dispersion method used (Figure 11D), indicating that more than 20% of the sample is being transported as mud aggregates in the <63μm material. Complete dispersion in this case results in a three-fold reduction in particle size of the D_{90} of the bulk soil input material. It is also interesting to note that even the fine fraction passing through the geofabric is passing to some extent as aggregates, with a similar three-fold differentiation in the D_{90} in some of the output samples. This would suggest that particle aggregation is a phenomenon across the full spectrum of particle sizes in these soils.

5. **Discussion**

The laboratory flume simulations undertaken in this study are critical for establishing the sediment trapping characteristics of the geofabric and hence the performance of the proposed hillslope sediment traps. While it is clear that it is not possible to design cheap, low maintenance instrument such as this that will trap ***all*** sediment coming off a given hillslope, if the particle size characteristics and proportion of the input load that passes through the trap are known, then it is possible to correct for this in the sediment collected within the trap, and thereby account for the total sediment production for the catchment feeding each of the sediment traps. The results of these experiments demonstrate that it is only a portion of the <63μm sediment load that is passing through the traps, and under what can be regarded as worst case conditions, at most only 50% of the fine suspended load is passing through the trap. It is safe to assume that most of the coarse fraction is retained, unless the trap is overtopped, in which case it is unlikely that there would be a significant loss of coarse load, as much if this would settle out in the trap backwater, before the flow overtopped.

It is important to note that the trap does not behave like a sieve, where all of the fines are transmitted, and only the coarse fraction remains in the trap reservoir. There are two reasons for this; the first being that as the flume experiments demonstrate, even when 100% fine suspended sediment is used as the input to the trap, followed by several clearwater runs that are intended to flush as much of the sediment through as possible, that only around 50% of the material is being transmitted through the trap. Secondly, the backwater conditions that prevail in the trap reservoir during major events causes much of the fine sediment to settle out onto the trap apron before it has an opportunity to impinge on the trap face. Presumably much of the material in the former scenario is actually retained within the fabric pores. In the field experiments, this material was also collected and has been added to the transmitted load.

In lieu of an *in-situ* full scale field experiment of the trap on a representative hillslope, in which all sediment entering the trap is sampled along with all sediment transmitted through the trap, perhaps the next best test of the performance of the trap in the field is to compare the particle size distribution of the sediment retained within the trap with the hillslope parent material. If a systematic bias in the particle size distribution of the fine sediment fraction was evident compared to the parent material, this would provide evidence that perhaps the trap was not performing quite as expected. Some bias in the coarse fractions may be expected, because not all of the coarse particle fraction found on the hillslope would be expected to be transported downslope.

Borrowing from the results presented in the companion paper (Brooks et al., this vol.) (Figure 13) which is a subset of the results just taken from the trap material within the Hodgkinson Formations soils, it is apparent that the sub-63μm fraction from the trap material tracks the parent material extremely well. Such a close fit would not be expected if the fines were disproportionately passing through the trap. Hence, it is reasonable to conclude that a good approximation of the total load at a given site can be reproduced by the measurement of all material retained with the trap reservoir, with a conservative correction factor of two made to the sub-63μm fraction retained within the trap, due to 50% trapping efficiency for fines. A correction also needs to be made for the sub-63μm fraction retained with the geofabric itself. This is determined from representative samples collected from the trap fabric at the end of the wet season.

5.1 Other Sources of Error in the field HST

It is recognized that there are other sources of potential error than those already outlined. Perhaps the most significant is the potential overtopping or bypassing of the trap, which will result in sediment lost that is not accounted for in the two primary compensation factors already accounted for (i.e. loss through the trap and material retained within the geofabric). The experimental infiltration rates derived from the flume experiments provide the means for calculating the total trap drainage rate, which can be compared against the predicted runoff generation rates determined from the rainfall intensity data. These rates have been determined for each trap, which were then compared against the hillslope discharge to determine whether the trap storage and infiltration capacity is ever exceeded. While there is inherent error in the determination of the overland flow generation rates because we do not know the hydraulic conductivity of the soils and hence the runoff coefficients, conservative coefficients have been assumed. These data suggest that over topping is rare, but probably did occur a few times on several of the traps (see Brooks et al., this vol). In addition, it is possible the geofabric hydraulic conductivity may decline further than documented in our flume experiments due to additional clogging of the geofabric associated with the growth of algal mats on the fabric. Such mats were observed on several traps when we collected the trap samples in the early dry season, however it is not known at what point during the wet season that these algal mats developed, or indeed if they developed after the wet season. On the upside, the reported mean infiltration rates are almost certainly conservative because the additional depth of the backwater is likely to increase the vertical face infiltration rates above those values determined in the experimental flume. Added to this is the fact that the apron is unlikely to seal under pressure to the same extent as it did in the flume. The combined effect of loss due to overtopping or bypassing under or around the trap might account for further 20% error in the calculated suspended loads.

5.2 Conclusion

The experimental results presented here, coupled with the field data collected over two wet seasons of HST deployment in Normanby catchment as presented in the companion paper (Brooks et al, this vol), demonstrate that this cheap low maintenance sediment trap can provide extremely valuable data in total hillslope sediment production rates in remote locations. These data are crucial for validating sediment budget models that are increasingly being relied upon as a basis for major investments of government funds and human effort directed at reducing sediment yields to critical environmental assets such as the Great Barrier Reef. With low budget, low maintenance sampling equipment such as this, there is much greater scope for directing more effort into the actual measurement of erosion data in a broader range of sites. This will help with the validation of erosion models across a broader number of landscape units, but it will also help to reduce the reliance on modeled data alone, particularly in remote areas.

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