Monitoring of Targeted Works to Reduce Sediment Export to Waterways Entering Moreton Bay

September 2012

Authors: Belinda Thomson[2] Joadie Hardy[1] Nathaniel Parker[1] Britt Rogers[2]

On behalf of: SEQ Catchments

Acknowledgements
The authors wish to acknowledge the following individuals as co-contributors:
Amanda Bland, Matthew Bakker, Fiona Bengtsson, Jean Bray, Peter Pearce[1]
Ben Ferguson, Richard Gardiner, Jason Dunlop[2]

The authors wish to acknowledge the following people for their on-going support and guidance:
Rob Dehayr and the team at the Waters Laboratory, Chemistry Centre[2]
Noel Ainsworth, Tony McKew and Shannon Mooney[1]

1) SEQ Catchments Ltd
2) Department of Science, Information Technology, Innovation and the Arts

Citation: this report should be cited as:
Thomson, B., Hardy, J., Parker, N., Rogers, B. (2012). Monitoring of targeted works to reduce sediment export to waterways entering Moreton Bay. SEQ Catchments Ltd, Brisbane.

SEQ Catchments
PO Box 13204
George Street Qld 4003
www.seqcatchments.com.au

ISBN: 0-9872399-0-2
ISBN13: 978-0-9872399-0-7

Executive summary

In 2011 the Australian Government provided funding under the Caring for our Country (CfoC) program to undertake *Targeted Works to Reduce Sediment Exports to Waterways Entering Moreton Bay.* This report details the estimated sediment savings that were achieved from the various types of works using a range of monitoring strategies. The effectiveness of the various works' designs and monitoring approaches are considered and recommendations for future works and monitoring methods are included.

The CfoC project aimed to contribute to delivery of the CfoC Business Plan target to address threats contributing to poor or declining water quality of priority coastal hotspots by reducing the average annual sediment export load from selected sites by 3000 tonnes per year.

The works were undertaken in three focal catchments previously identified as contributing high sediment export loads to Moreton Bay, namely the Upper Bremer River, Blackfellow Creek (a tributary of Lockyer Creek) and Oaky Creek (a tributary of the Logan River). The works included leaky weirs, stream bank and gully repairs, flood plain and wetland reinstatement, hill slope reshaping and pasture renovation.

Six tailored monitoring strategies were implemented to assess the effectiveness of the works. They included assessments of the retention of source sediments (1), and diffuse sediments (2), bed load sediment movement using turf mats (3), water quality monitoring using automated samplers and rising stage samplers (4), digital elevation models, (5) and photopoint monitoring (6). Monitoring was undertaken at three project sites in the Bremer, two in the Lockyer and two in the Logan.

Monitoring indicated that all the on-grounds works implemented were effective in retaining sediments on site. Sediment savings were able to be quantified at all sites except 6a – the controlled grazing and creek fencing project which will require a longer period of monitoring to allow the site to stabilize and vegetate. Estimates of sediment savings varied across sites during the monitoring period (2011-12) with the greatest savings in sediment occurring on the three sites in the Bremer involving works to reinstate floodplain flows (3360 tonnes at site 1; 2906 tonnes at site 2; and 6864 tonnes at site 3). Across all seven sites, the monitoring strategies provided a total estimate of 14,330 tonnes of sediment retained during the monitoring period. It should be noted that the monitoring period included a well above average wet season.

Most of the sediment savings resulted from repairing and stabilising actively eroding gullies and stream banks (82%), rather than diffuse sedimentation across the landscape. Although diffuse sedimentation was only 18% of the total retained sediment, it is very likely to be composed of finer sediment particles (silts and clays) than the sediment eroding from gullies and stream banks, which consists of both coarse and fine sediment. It is the finer silts and clay particles that are mobilised over long distances which are important for water quality in Moreton Bay. In future monitoring, water quality monitoring should be accompanied by comprehensive soil sampling of both diffuse and source sediments.

Wetland reinstatement as occurred at site 1 was designed to reduce the flow velocity and spread water over a larger area allowing sediments to settle out. This strategy was proven effective and a unique dataset was gathered showing a significant reduction of TSS from the inflow to the outflow of the wetland system (59%).

The CfoC project enabled the six monitoring strategies to be evaluated. The strategy to assess retention of source sediment proved to be an inexpensive and effective way of assessing the direct benefit of repairing and stabilising actively eroding areas but the results do not provide an estimate of sediment volume transported to the local waterway and thus is not adequate by itself.

The strategy to assess retention of diffuse sediment is an inexpensive and effective way of assessing the ongoing benefit of implementing physical works which slow flow velocities over the landscape and thereby encourage diffuse sedimentation. However, the accuracy of this monitoring method is relatively low as deposition areas are hard to define accurately, and the method requires experienced and well trained staff. This method is able to give a snapshot of processes taking place but does not monitor the finer sediment particles and thus cannot be used to calculate an accurate TSS load reduction due to works.

Bedload sediment sampling using turf mats was unsuccessful and is not recommended for future monitoring.

Automated water samplers with continuous turbidity measurements proved successful and provided the most accurate calculations of sediment loads transported in overland flow. However, automated samplers are expensive, require a high level of technical skill to design, install and operate, and the data collected requires a well-developed system for data storage and analysis. They are also only useful in defined channels so that discharges and then loads can be calculated.

Rising stage samplers were not successful for paddock-scale monitoring because of difficulties in site selection. In addition, it proved very difficult to collect enough samples during a runoff event to adequately represent the TSS concentration. Collection of samples from rising stage samplers is highly labour intensive and often dangerous as bottles must be collected and replaced during rainfall events.

Surveys to develop digital elevation models and to compile photographic histories provided useful data, enabling the assessment of the stability of on-ground works. Further surveys will enable the calculation of any sediment losses over time, allow the identification of areas of instability and inform the direction of further management options.

The works undertaken as part of this CfoC project and the site specific monitoring strategies that were implemented have resulted in significantly reduced sediment exports from these sites. These works combined with the works implemented as part of other CfoC funding and State Government funding have allowed SEQ Catchments to develop, test and improve the design of works to reduce sediment export to waterways and to develop and implement paddock-scale monitoring to begin to quantify the volumes and costs. Fortuitously, the works and monitoring have been undertaken in two of the wettest seasons on record (comparable to the 1954-56 and 1974-76). This has allowed the works' designs and monitoring strategies to be tested under major flooding conditions.

Over the longer term (3-5 years) water quality monitoring at the paddock scale as demonstrated in this project will provide data that will enable the successful development of a water quality metric for SEQ and quantify the effectiveness of on-ground management actions.

Table of contents

List of tables

List of figures

List of units and acronyms

Ø	Diameter
ADM	Adams Bridge
cm	Centimetres
CfoC	Caring for our Country
DEM	Digital elevation model
DERM	Department of Environment and Resource Management
DNRM	Department of Natural Resources and Mines
DPI	Department of Primary Industries
DSITIA	Department of Science, Information Technology, Innovation and the Arts
ha	Hectares
km	Kilometres
km^2	Square kilometres
m	Metres
m^3	Cubic metres
mm	Milimetres
µm	Micrometres
MERI	Monitoring, Evaluation, Reporting and Implementation
ML	Megalitres
NATA	National Association of Testing Authorities
ntu	Nephelometric units
RF	Radio frequency
RSS	Rising stage sampler
SEQ	South East Queensland
SEQC	SEQ Catchments
t	Tonnes
TSS	Total suspended solids
USEPA	United States Environmental Protection Agency
WCM	Walloon Coal Measures
WQIP	Water Quality Improvement Plan

Glossary

Alluvium	Sediment deposited by flowing water.
Basalt	Dense volcanic rock.
Batter	An earthworks cut or a wall with a sloping face.
Bedload sediment	The sediment that is transported along the bottom of a water system (non-suspended sediment transportation).
Berms	A level area separating two sloping areas.
Bund	A long mound, built to hold back water or offer protection from it.
By-wash	The outlet/overflow from a weir or dam, which directs water over or around a dam in a controlled, low velocity manner.
Colluvia	Loose deposit of rock debris that accumulates at the foot of a steep slope.
Cracking clays	Clay that swells and shrinks as it wets and dries. Cracks form when dry.
Digital elevation model	A 3D representation of a terrain's surface.
Drowned gully head	A gully head cut that has been submerged, usually through the installation a dam across the gully.
Ephemeral watercourse	Contain water only after an irregular rainfall or flow event. .
Freeboard	The vertical distance between the top of the dam and the highest level of the water.
Friable soil	Crumbly soil considered ideal for plant root growth.
Gauging	Measurement of flow in a channel. At a well selected site, the flow has a constant relationship to water height.
Geofabrics	A fabric that can be used to restrain sediment movement and erosion.
Groyne	A low wall/obstruction that juts out into a water current (stream etc), to either divert strong flows away from vulnerable areas, capture sediment being washed downstream, or a combination of both.
Gully head cut	A situation, caused by erosion in a gully, in which there is a sudden change in depth of the gully. This step change in height often recedes back up the gully and is responsible for significant soil loss.
Hydrograph	Graph showing the rate of discharge versus time at a specific point in a river or other channel carrying flow.
Kikuyu	Exotic grass often planted for erosion control.

La Niña	The extensive cooling of the central and eastern Pacific Ocean that is generally associated with wetter conditions in eastern Australia.
Leaky weirs	An obstruction to the flow of a channel, designed to slow the flow and allow sediment to settle out as it moves at low velocities across the alluvial plain.
Loads	The mass of a given substance (eg. total suspended solids) that passes a given point in a river or stream measured over a period of time.
Loam	A fertile soil of clay, silt, sand and organic matter.
Logger	A programmable data recorder that is used to control measurement and sampling regimes at a site.
Nephelometric units	The units of measurement for suspended particulates – ie. measurement of turbidity. Measures the amount of light reflected from the particles.
Nikon Nivo 5.M Total Station	Digital surveying equipment.
Particle size analysis	Laboratory technique that determines the size range of particles in a sample.
Pressure transducer	A submerged depth sensor which generates an electrical signal as a function of the pressure of the water imposed on it. This is then related to the height of water above the sensor.
Rating curve	Curve expressing the empirical relationship between the height of the water and the flow.
Rill	A narrow, shallow incision into topsoil layers, resulting from erosion by overland flow.
Riparian	Of or inhabiting the banks of a natural course of water (eg. riparian vegetation).
Rising stage sampler	Fixed point automatic sampling devices with sample bottles set to specific heights above the normal water level.
Rock chute	A structure that allows for the safe flow of surface water from an outlet into a streambed, thereby preventing channel and bank erosion.
Sediment traps	Anything that reduces the amount of sediment in a water system (leaky weirs, swales, geofabrics, Groynes, etc).
Sodic soil	Soils characterised by a disproportionately high concentration of sodium (Na) ions compared to other cations.
Stoke's Law	Expression for the frictional force exerted on very small particles in a continuous viscous fluid.
Swale	A vegetated flow path, designed to encourage infiltration of water and settling of sediments.
Turbidity	A measure of the degree to which water loses its transparency due to suspended particles.

Turf mats	A simple form of sediment sampler, consisting of a square meter of fake turf pegged to the ground in an overland flow area, which can be collected after a flow event to determine sediment dropout.
Vertisol	A clay-rich soil in which deep cracks form during the dry season.
Walloon Coal Measures	A series of volcanolithic sandstones, coal, mudstones and siltstones with a max. thickness of about 250 m, extending over wide areas of the Surat Basin and the Clarence-Moreton Basin in southeastern Queensland.

Introduction

In 2011 the Australian Government provided funding under the Caring for our Country program to undertake the project *Targeted Works to Reduce Sediment Exports to Waterways Entering Moreton Bay* (henceforth the CfoC project). This report details some of the types of works undertaken during the project, the monitoring strategies used to assess their effectiveness including estimations of sediment retention by different on-ground works designs and makes recommendations on the improvement of works designs and monitoring methods.

The objective of the SEQ Catchments' CfoC project was to undertake rehabilitation works to reduce the sediment loads being exported from the Bremer, Lockyer and Logan catchments by ~3000 t/yr. Works undertaken included:

- stabilisation of gullies including fencing, porous/leaky weirs
- revegetation and stabilisation of tributary channels, stream banks and channel margins including riparian fencing and off-stream watering points
- engineered drainage improvements
- improved management practices such as:
  - use of minimum tillage, cover crops, contour banks and sediment traps on cropping land; and
  - improved ground cover on grazing lands by managing grazing pressure through rotational and cell grazing, fencing to land types, installation of watering points etc.

The project also aimed to build the awareness and capacity of landholders in implementing sustainable land management practices commenced under the Queensland State Government funded "Healthy Country Project 2007-2011".

A Monitoring, Evaluation, Reporting and Improvement (MERI) plan was prepared for the CfoC project. Its objectives were to assess whether the project achieved its stated outcomes and targets and how effectively, appropriately and efficiently it did this. In particular the MERI plan sought to develop knowledge on the efficacy of different management interventions in assisting to reduce sediment loads entering the receiving waters of Moreton Bay. In addition, the CfoC project sought to develop effective monitoring strategies to assess the effectiveness of works and collect valuable data at the paddock scale that could be useful in developing a water quality metric for South East Queensland (SEQ) (DERM 2010).

The project delivered against Caring for our Country 2010-11 Business Plan targets. Moreton Bay is a priority coastal hotspot under the Business Plan and the Business Plan identifies as a priority the undertaking of on-ground management actions identified in the Water Quality Improvement Plan (WQIP) – the SEQ Healthy Waterways Strategy 2007-12 (SEQHWP 2007). The principal WQIP target addressed by the project was:

"By 2026, non-urban diffuse loads entering receiving waters will be reduced by 50 per cent of the loads in 2006 and in-stream ecosystem health will improve in targeted catchments".

The activities were anticipated to contribute to the achievement of the WQIP targets as they focused on addressing processes that contribute significant sediment loads to the receiving waters of Moreton Bay.

Sediment movement from rural lands through flood plains and into rivers and ultimately into Moreton Bay has long been recognised as a key water quality issue. This sediment arises from a combination of processes:

- hill slope erosion where relatively minor losses of sediment over very large areas (primarily grazed and forested landscapes) ultimately can result in large volumes of sediment at the end of catchments. Some of this sediment is retained in the foot slopes stream banks and flood plains of the catchment as fertile soils.
- gully erosion produces larger volumes of sediment than the diffuse sources. Areas that are prone to gully erosion are located within the catchment foot slopes and flood plains. This form of erosion can mobilise large volumes of sediment from these otherwise landscape sediment sinks
- stream bank erosion plays a similar role to rill and gully erosion. The major difference is that stream bank erosion places previously stable, often highly fertile, sediments directly in the streams.

The previous Healthy Country Program introduced a proof of concept approach, where landholders in three focal SEQ catchments (i.e. Bremer, Lockyer and Logan) were engaged and encouraged to implement works which focuses on stabilising the landscape by reducing gully, hill slope and stream bank erosion. In 2010 SEQ Catchments (SEQC) and Catchment Water Sciences, Department of Environment and Resource Management (DERM) established a partnership to monitor the effectiveness of works under this CfoC project (Catchment Water Sciences are now part of the Department of Science, Information Technology, Innovation and the Arts, DSITIA). Due to the synergies between the projects and the inclusive nature of the extended works undertaken, sections of this monitoring and evaluation have included on-ground works from the Healthy Country Project. The objectives for the monitoring included the estimation of volumes of sediment retained by the on-ground works and recommendations regarding improvements to the design of the works.

The types of initiatives in the design of the works ranged from:

- construction of leaky weirs[1] - flood waters and levee breaches are retained by a small dam in a flood plain long enough for siltation to occur while allowing the flood plain to drain slowly over a period of days once the flood has passed
- stream bank repair - fencing off streams to encourage natural riparian revegetation, reshaping banks and revegetation and stabilising eroded stream banks
- flood plain and wetland re-instatement - diversion of overland flow away from gullied areas and the spreading of that flow across flood plains and wetlands by use of bunding[2]
- gully repair - gully heads drowned by dam structures or battered[3] where overland flow is diverted to stabilised flood plains or overland flow areas
- hill slope reshaping and pasture renovation – reshaping hill slopes to direct overland flow around gullies and encouraging perennial pastures to reduce rainfall erosion and runoff.

---

[1] Leaky weirs were tested at four previous sites in an earlier funding round.

[2] Bunds (sometimes in association with small detention dams), are used to spread overland flow water across an area and to slow the velocity of overland flow. These types of structures were used at a pilot scale in a highly erosive situation in Knapps Creek some three wet seasons ago and have proved very stable.

[3] Battering is the excavation of an eroding bank to decrease its angle of incline. The battered bank is then revegetated.

Rainfall

Successive La Niña events spanning 2010–12 were associated with record rainfall over much of Australia and some of the biggest floods in living memory.

- The 2010–11 La Niña event was one of the strongest on record, comparable in strength with the La Niña events of 1917–18, 1955–56 and 1975–76.
- 2010 was Australia's third-wettest calendar year on record.
- 2011 was Australia's second-wettest calendar year (with the wettest year since national rainfall records began in 1900 being 1974 – also a La Niña year).
- April 2010 to March 2012 was Australia's wettest two-year period on record (Commonwealth of Australia 2012).

See Appendix A for more detailed information on rainfall for the study area.

Methods used to assess the effectiveness of works

Six monitoring strategies were adopted to assess the effectiveness of works, however not all monitoring strategies could be adopted at all sites due to site constraints such as accessibility, channel shape, catchment size, the placement of works and limited budgets. The six monitoring strategies included:

1. assessment of the **retention of source sediment** in the landscape as a direct result of repairing expanding gullies and stream banks, thereby keeping sediment at its source
2. assessment of the **retention of diffuse sediment** in the landscape due to works by estimating the sediment accumulation before and/or after works
3. monitoring of **bedload sediment movement** using turf mats
4. **water quality monitoring** with monitoring stations that are able to determine the sediment load being transported in the catchment. Rising stage samplers were also installed at some sites to determine their effectiveness in monitoring water quality
5. construction of a **Digital Elevation Model (DEM)** using surveying techniques to determine soil and sediment erosion over time
6. **photographic evidence** displaying the stability of works through photographic records, post construction site visits and discussions with landholders

Retention of source sediment

For the projects aimed at stopping stream bank erosion or gully head retreat, the volume of sediment exported was estimated from design stage assessments where the length depth and widths of the erosion scar were measured (Appendix B). The rate of gully expansion or stream bank loss was estimated by discussion with the landholder to determine if the expansion rate was linear or exponential. Gully head retreat was linear where a similar amount of erosion was occurring each year, while an exponential rate was given to sites which produced higher levels of erosion each year than in the previous years. An annual sediment export rate (m^3/year) for each gully or stream bank was then calculated so that the impact of stopping further erosion at the site could be quantified.

Hence, by implementing works, sediment that would have been exported, was instead retained on site, and the expected annual sediment loss is realised as annual sediment retention (m^3) due to the physical works. Where cubic metres of soil are converted to tonnes in this report a conversion rate of 1.4 has been used (Australian Government 2009).

Retention of diffuse sediment

Deposition of diffuse sediment occurs before and after physical works, when the velocity of overland flow slows, allowing sediment to settle out (i.e. in front of a dam). The volume of diffuse sediment accumulated due to works was assessed by physically digging into the soil 20-30 cm and gently turning the soil over and assessing the depth of newly laid soil behind works, or in the case where works distributed water over floodplains or through wetlands, by assessing the depth and surface area of newly laid soil across the site. At each site eight random samples were taken over an area predetermined by visually assessing low areas before and after works where sediment would settle out. Newly laid soil was identified as fine, lighter or darker sandy soil that readily broke away from the underlying soil. Identification of the newly laid soils was also often aided by the presence of new root growth (fine white hairs) colonising the newly laid soil.

These assessments were made in June and July 2012 giving the soil approximately three months to settle after the main rainfall period in SEQ (Nov. to Mar.).

Bedload sediment movement

Bedload sampling with turf mats proved unsuccessful as the low friction surface of the turf mat did not give a representative measurement of the soil which had fallen in the area, which could be seen upon visual inspection. Furthermore, in areas with trees, often leaves and sticks would cover the mat making sediment build up assessments difficult. For future monitoring of sediment deposition, turf mats are not recommended. The United States Environmental Protection Agency (USEPA) approved Helley Smith bedload samplers (Helley and Smith 1971) were installed at two sites in May 2012 to assess their effectiveness in monitoring bed load movement before and after works. To date no results have been collected in these samplers.

Water quality monitoring

Water quality was monitored by installation of automated samplers at monitoring sites (Figure 1), one at the inflow and one at the outflow of the monitoring area. Water heights were recorded using depth sensors and discharge volumes were estimated using surveying and rating curve development techniques (DPI 1993, DNRM 2005). Water samplers were triggered when sensors detected the rise and fall of water. When triggered, water samples were automatically collected throughout the duration of the discharge events. These samples were then retrieved, processed according to quality assurance and quality control standards and submitted within a 24 hour period, to the Environment and Resource Sciences Chemistry Centre (NATA accredited) laboratory for analysis of total suspended sediments (TSS) and particle size. Sensors recorded turbidity readings (nephelometric units – ntu). Monitoring commenced in the last week of November 2011.

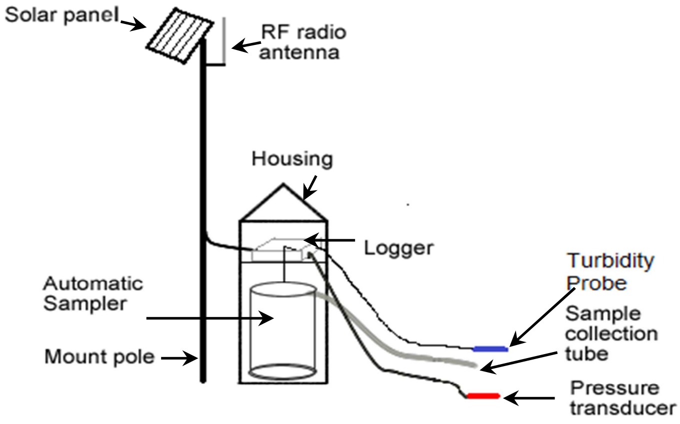


Figure 1 - Water quality monitoring station

Loads estimation

Samples collected and the hydrographs associated with them were reviewed to identify events (overland flow) with sufficient samples to reliably calculate loads. At least four samples over the rise and fall of the hydrograph were required to calculate a load (Thomson et al. *In Prep*) and loads of TSS were calculated using the Water Quality Analyser loads tool (eWater 2012) using discharge volume estimates and TSS concentration data from laboratory analysis results.

Turbidity measurements

Inflow turbidity readings were compared to outflow turbidity readings to identify if there was a reduction in turbidity between the two points as a result of works. Turbidity readings may in future be used to develop a regression equation between turbidity and TSS to enable the use of turbidity as a cost effective surrogate measure for TSS measurements. In order to accomplish this further monitoring is required to obtain enough data that will enable the development of reliable site specific flow/concentration/turbidity relationships.

Particle size analysis

Samples collected were analysed for particle size. The particle sizes analysed for included:

- very fine clay (0.24 to 0.5 µm)
- fine clay (0.5 to 1 µm)
- medium clay (1 to 2 µm)
- coarse clay (2 to 4 µm)
- very fine silt (4 to 8 µm)
- fine silt (8 to 16 µm)
- medium silt (16 to 31 µm)
- coarse silt (31 to 62 µm)
- very fine sand (62 to 125 µm)
- fine sand (125 to 250 µm)
- medium Sand (250 to 500 µm)
- coarse sand (500 to 1000 µm)
- very coarse sand (1000 to 2000 µm)

Particle sizes were grouped into four groups:

- clay (0.24 to 4 µm)
- silt (4 to 62 µm)
- fine sand (62 to 500 µm)
- coarse sand (500 to 2000 µm)

Samples over events were combined and the average proportion of each size class were graphed to determine if there was a specific particle size that was retained/exported due to works.

Digital Elevation Models (DEM)

Surveys were conducted on sites using a Nikon Nivo 5.M Total Station, which digitally records the changes in height over a survey site to an internally stored database. This database can then be downloaded to a computer for detailed analysis. For the analysis of the dataset and the creation of accurate DEMs of the survey site, the modelling software 12d Model version 9.0 (12d Solutions 2009) was used. These DEMs can then be analysed and graphically represented as contoured maps. In addition, models of the same site from different times can be overlayed on each other, to precisely examine and quantify changes in the survey site. It is planned that further surveys before and after the next wet season will determine the stability of works and also allow a precise calculation of sediment loss where works fail.

Photographic evidence

Photographic evidence of the stability of the works was collected by photo point monitoring from the same vantage point marked with star pickets to allow consistent photographic monitoring every one to two months, depending on the changes observed at each site. These site visits also allowed continuous visual assessment of the stability of the works and discussions with landholders to assess the operational effectiveness and efficiency of the works.

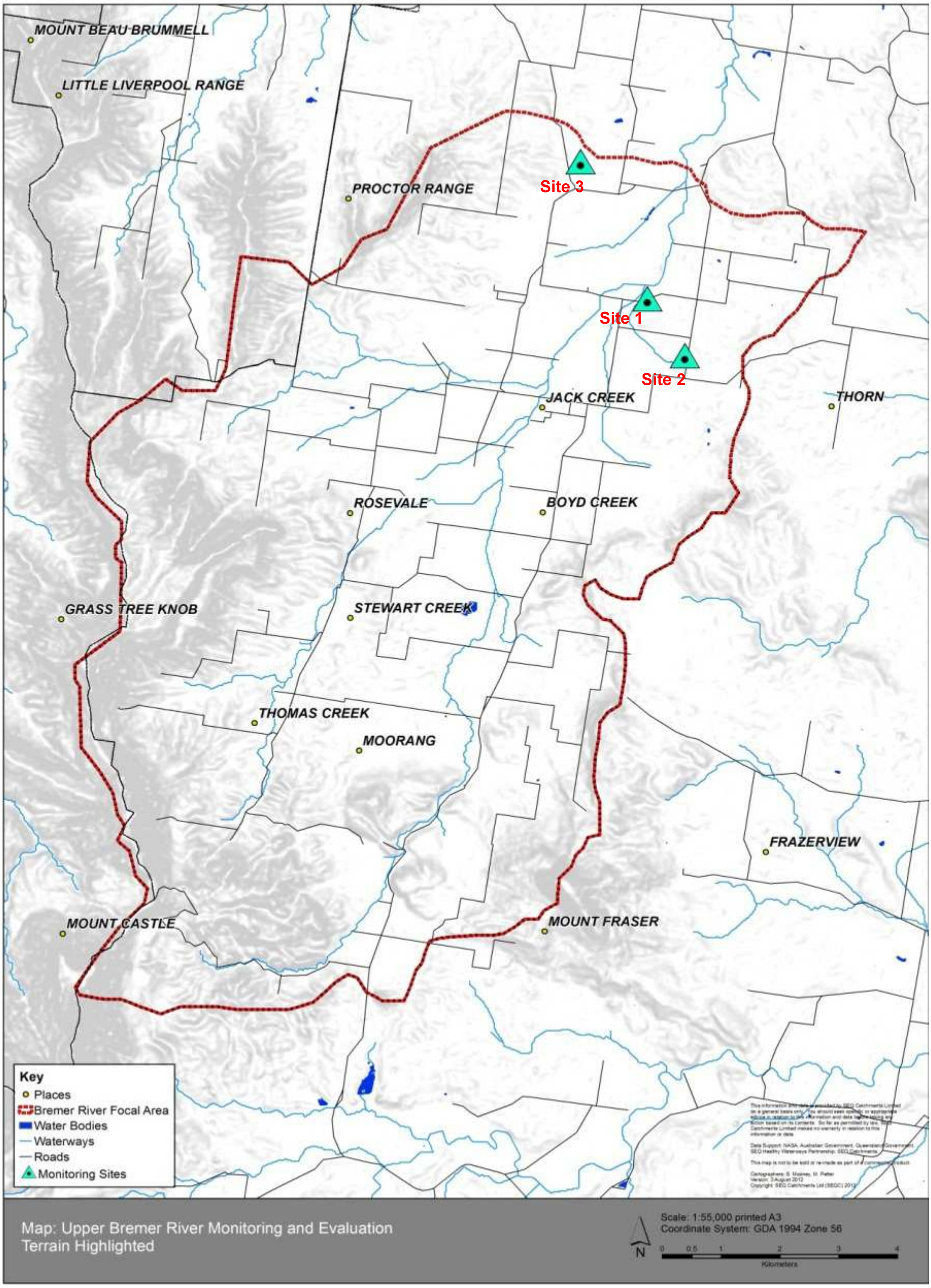
Focal area 1: Bremer catchment

The objective of this project was to improve water quality and address the interrelated water and land management issues that contribute to sediment entering the Bremer River from the upper Bremer focal catchment (Figure 2).

This catchment had been previously identified as one contributing high average annual sediment export loads (~ 4685 t/yr.) to Moreton Bay (Olley et al. 2010). The focal catchment is 127 km^2 and is extensively cleared with only 48% of the woody vegetation remaining. Clearing is most extensive in the lower parts of the catchment with grazing predominating in the upper steeper areas and cropping in the lower floodplain areas (Olley et al. 2010).

Three projects were undertaken in this focal catchment as part of the CfoC project to reduce sediment export. They included:

- Site 1 - Wetland reinstatement
- Site 2 - Gully battering and flow diversion
- Site 3 - Gully damming



Map courtesy of SEQ Catchments

Figure 2 - Monitoring locations located in the Bremer focal catchment

Site 1 – Hill slope erosion management and wetland reinstatement

The site

The site is on undulating country on a alluvial soil and sodic subsoil that are known to contribute high proportions of sediment to Moreton Bay (Thompson 2011). The area has been cleared of remnant vegetation and is dominated by grassland and has been historically used for cultivation, hence contour banks were installed to protect it from erosion. The contour discharge area developed into a gully which actively eroded during overland flow events (Figure 3).

This project is a key area in a landscape-scale wetland reinstatement project that involves links to hill slope erosion, gully erosion and flood plain processes and is managed as one project unit.

Figure 3 - Gully erosion at the reinstated wetland

Works undertaken

The following works were undertaken:

- the reinstatement of a wetland
- engineering works to address gully head erosion at the reinstated wetland
- installation of 2.8 km of exclusion fencing that encloses 4.89 ha of riparian vegetation
- fenced terrestrial native vegetation
- 3.5 ha fencing of an endangered regional ecosystem
- off-stream watering sites installation.

Area 1 Hill Stream bank, gully, hill slope and floodplain erosion management to support the reinstated wetland.

The hill slope has undergone contour reshaping to direct flow to a more stable location. Overland flow has previously directed runoff to a head cut running perpendicular to a naturally stabilizing gully. Works were enhanced by land type fencing and pasture revegetation with exotic perennial pastures of 79 ha to reduce runoff. This has allowed the landholder to manage stock grazing to maintain ground cover.

Sediment runoff is further reduced by the erection of exclusion fencing of an endangered regional ecosystem, which includes a major gully system that is undergoing natural repair. This will encourage natural regeneration of ground cover. A temporary diversion was constructed across the head of these works to exclude any overland flows.

Area 2 Wetland Reinstatement

The main on-ground works were undertaken as part of the initial Healthy Country Project and included the construction of a dam to close an eroding gully that drained the wetland directly into the Bremer River. The closure occurred at the top edge of the wetland and restored the original wetland overland flow pattern through a series of wetland communities (Figure 4). Similar works will continue on the neighboring property to maintain wetland connectivity across the landscape.

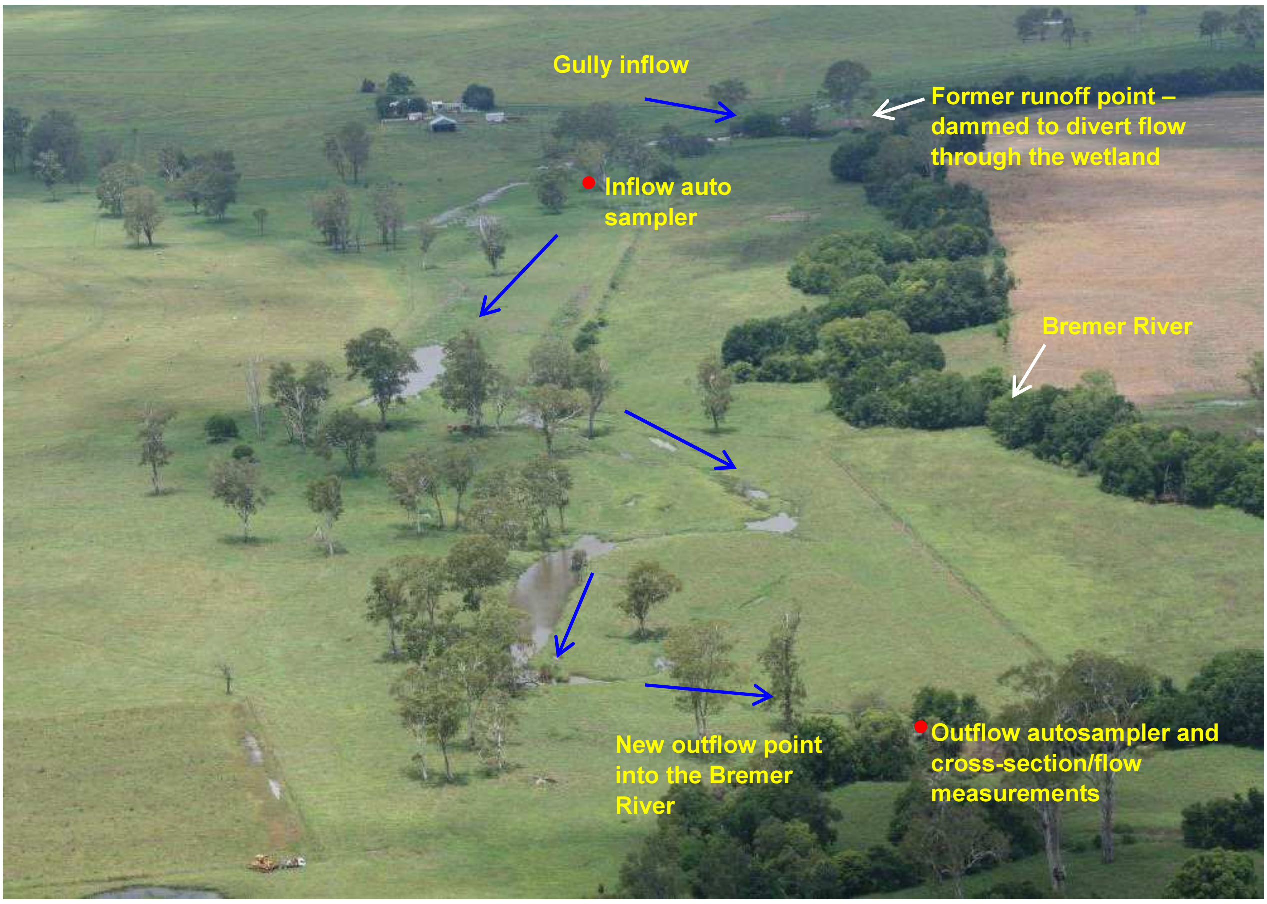


Figure 4 - Location of monitoring sites, gully erosion management site and direction of flow through the reinstated wetland (Photo, *courtesy of Nina Saxton*)

Results of hill slope erosion management and wetland reinstatement

Of the six methods used to assess the effectiveness of works, three were implemented at this site. These included:

- retention of source sediment
- retention of diffuse sediment
- water quality monitoring.

Retention of source and diffuse sediment

The gully at the inflow site expanded rapidly, retreating 30 m from 2010 to 2011. As the gully was 4 m wide and 4 m deep, approximately 480 m^3 of sediment moved directly into the Bremer River (Table 1).

At the outflow site a second gully, originating from the Bremer River, had cut back into grazing land and had moved approximately 375 m^3 of sediment into the Bremer River (Table 1).

Diffuse siltation monitoring was conducted near the inflow area (Figure 5) where the silted profile depth averaged 9.3 mm. Within the sample area of 3.8 ha, the estimated volume of sediment retention due to diffuse siltation was 354 m^3. At the outflow site sampling was conducted over 3.8 ha where the silted profile depth averaged less than half of that at the inflow being only 3.4 mm, which is consistent with water quality results presented in the next section. By averaging the siltation results of the inflow and outflow areas, an estimate could be made for diffuse siltation across the whole wetland, which was approximately 1545 m^3 or approximately 2000 tonnes (Table 1).

By combining the retention of source and diffuse sediment an overall sediment saving of 2400 m^3 was realised over the last year, as a result of the wetland reinstatement work.

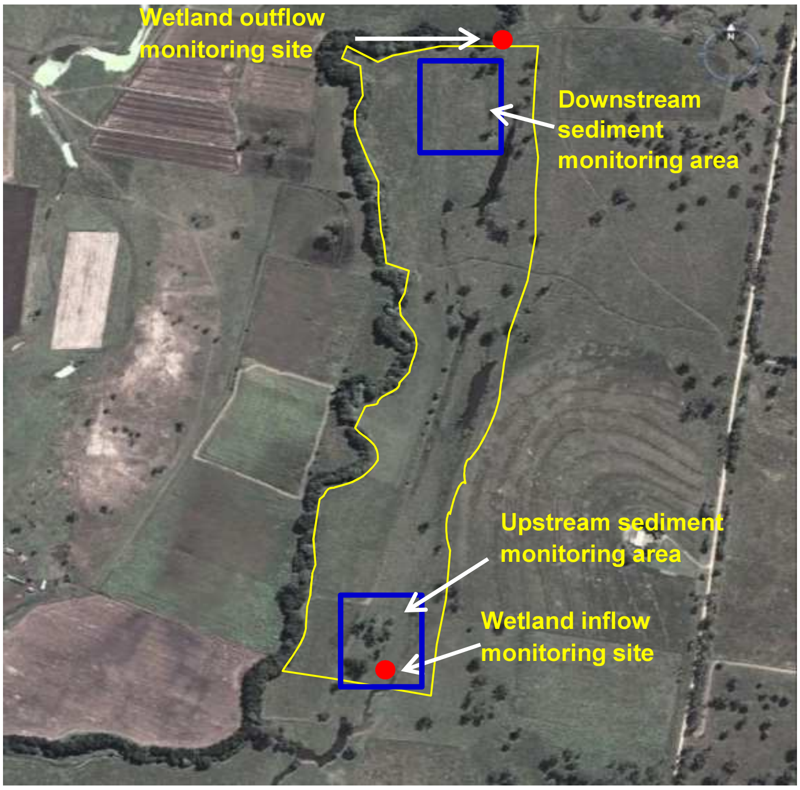


Figure 5 - The sediment monitoring area at the inflow and outflow of the wetland. The yellow boundary indicates the area used to estimate the sedimentation (m^3) over of the entire wetland

Table 1 - Calculated sediment savings from wetland reinstatement

		Site 1 - inflow	Site 1 - outflow	Wetland total
Erosion type addressed in project		Stream bank, gully and flood plain	Stream bank, gully and flood plain	Stream bank, gully and flood plain
Design approach		Leaky weir for bank repair and flood plain reinstatement	Bank repair and fencing for cattle management	Leaky weir for bank repair and flood plain reinstatement
Soil geology		Deep fertile alluvial soils, runoff from WCM areas	Deep fertile alluvial soils, runoff from WCM areas	Deep fertile alluvial soils, runoff from WCM areas
Source sediment	Source sediment retained (m^3/y)	480	375	855
	Source sediment loss (m^3/y)	0	0	0
	Net retention (m^3/y)	480	375	855
Diffuse sediment	Measured area (Ha)	3.83	3.83	24.48
	Silted profile depth (mm)	9.3	3.4	6.3
	Silted volume (m^3/y)	354	129	1545
Total volume of sediment retained (m^3/y)		834	504	2400

Water quality monitoring

Water quality monitoring was undertaken at the inflow and outflow of the reinstated wetlands (Figure 5).

Loads estimation

Eight runoff events were identified during the monitoring period (Nov. 2011-Mar. 2012), which is similar to the annual average for the Bremer River (nine events/year)[4]. Of these events, water quality samples were collected during four events at both the inflow site and outflow site (Table 2). Samples were collected during a further four events at the wetland outflow site but due to a failure of the radio communications system , samples were not collected at the inflow site and therefore loads of TSS retained in the wetlands could not be calculated.

Sampling was sufficient across the hydrographs (Appendix C) to ensure an estimate of TSS loads for the four events that were sampled at both the inflow and outflow sites. The total monitored discharge for the outflow site was 5309 ML (Table 2)[5].

---

[4] Average event number based on 6 years of event monitoring data at the DNRM gauging station on the Bremer River at Walloon.

[5] Discharge was estimated using a theoretical rating curve and not validated using flow gaugings. The discharge volumes are indicative only and therefore loads estimated are indicative only and may be underestimated.

For the four events where water quality samples were collected at both the inflow and outflow sites, the TSS loads at the outflow site were consistently less (Figure 6) than at the inflow site, with an average of 59% of the TSS being retained in the wetlands. Event two and three had the lowest discharge volumes of the monitored events but retained a greater percentage of sediments compared to the larger discharge events (Table 2).

A total of 1031 tonnes of sediment were retained in the wetlands, but this volume is underestimated for the entire period of monitoring due to four events not being sampled at the inflow site. Based on the trend of the monitored events the average retention of sediments within the wetland is 59% which means that sediment retention may have been higher than the 1031 tonnes estimated.

Table 2 - Discharge, total suspended solids (TSS) loads and % of TSS loads retained by the reinstated wetland

	Event								Total
	1	2	3	4	5	6	7	8	
	Nov 2011	Dec 2011	Dec 2011	Jan 2012	Jan 2012	Feb 2012	Feb 2012	Feb 2012	
Outflow discharge (ML)	297	93	147	696	422	154	97	3403	5309
Inflow TSS load (t)	28	8	13	-	-	-	-	1853	1902
Outflow TSS load (t)	18	2	4	68	12	7	6	847	964
TSS retained by wetland (t)	10	6	9	-	-	-	-	1006	1031
% of inflow TSS retained	36	75	69	-	-	-	-	54	59 (average)

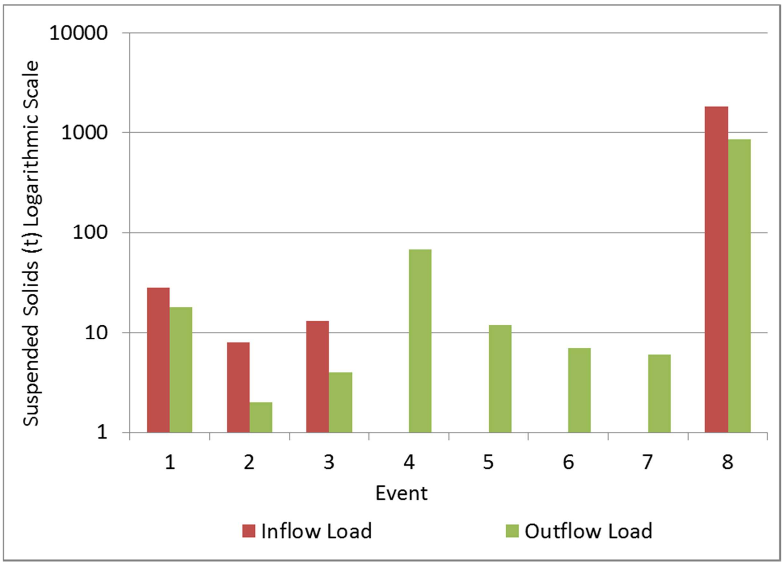


Figure 6 - Suspended solids loads (t) passing the inflow and outflow points of the reinstated wetland

Turbidity measurements

Turbidity was successfully measured during four of the eight events. The turbidity of the inflow site compared to the outflow sites shows a decrease in turbidity which supports the results of the reduction in TSS loads. Examples of turbidity at the inflow compared to the outflow for events where turbidity data were collected are included in Figure 7.

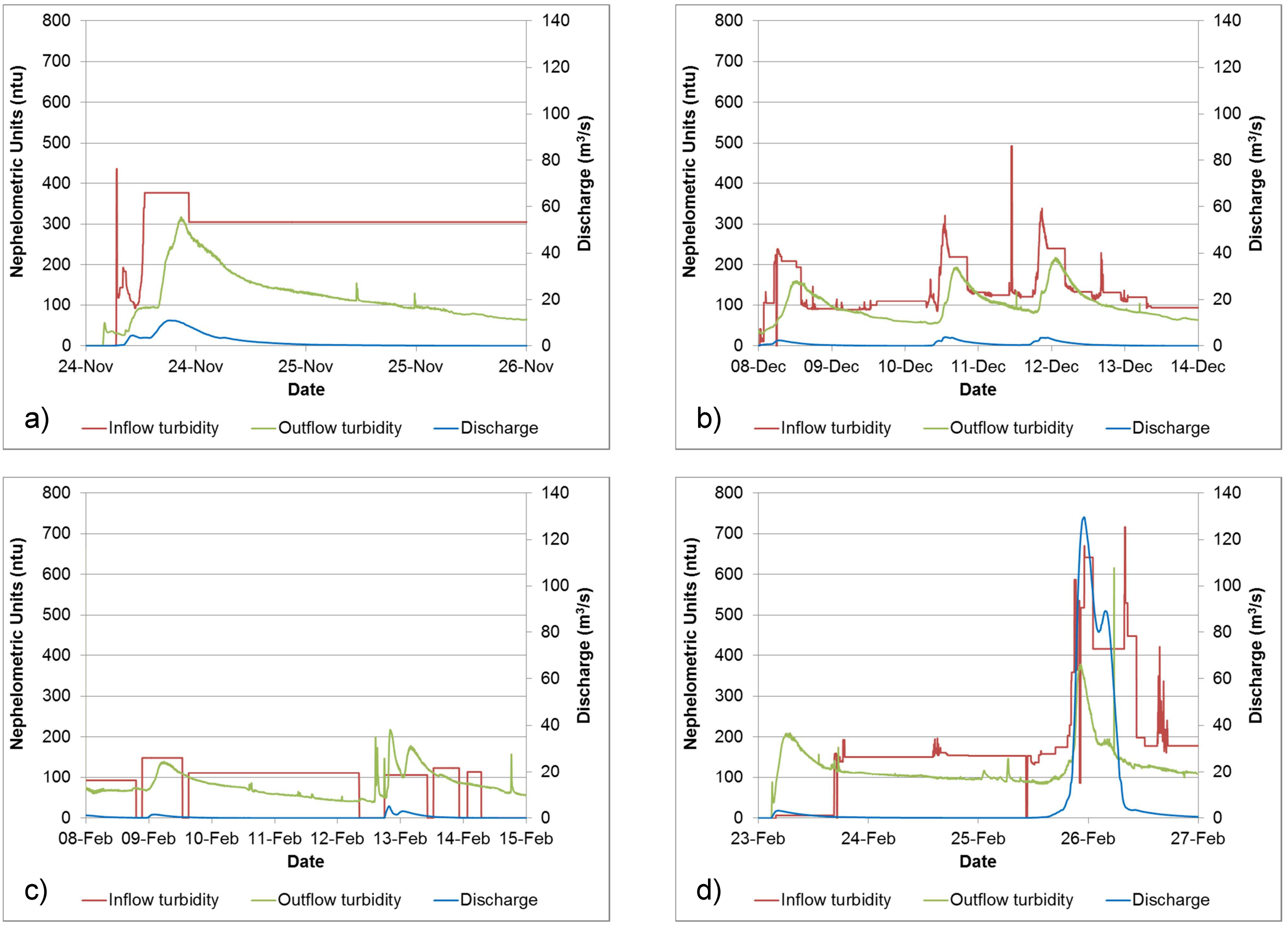


Figure 7 - a) Turbidity inflow and outflow, and discharge for November 2011 event. b) Turbidity inflow and outflow, and discharge for December 2011 event. c) Turbidity inflow and outflow, and discharge for first February 2012 event. d) Turbidity inflow and outflow, and discharge for second February 2012 event

Note: Straight lines on the graphs are a result of turbidity data not being collected due to either a technical communications issue or the site not experiencing sufficient water to trigger the inflow turbidity sensor.

Analysis of particle size

At the outflow sites the relative proportion of particle sizes remained the same as those for the inflow sites. This shows that all particle sizes were retained in the reinstated wetlands (Figure 8).

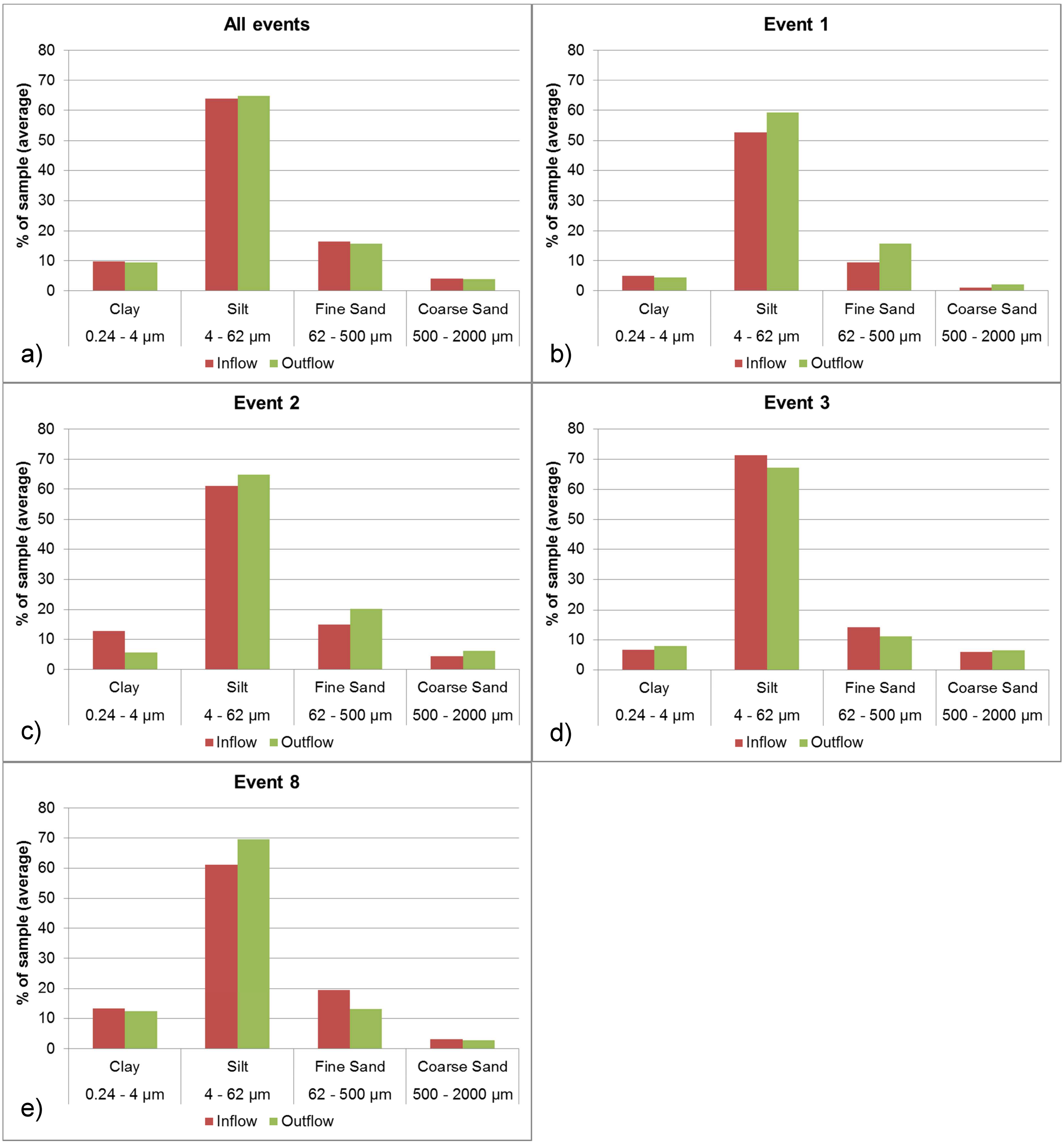


Figure 8 - Average percentage of samples based on the particle size range for: a) all events; b) Event 1; c) Event 2; d) Event 3; e) Event 8

Downstream monitoring

To give context to the discharge and loads being contributed by the wetland monitoring site, monitoring was also undertaken at a downstream site on the Bremer River at a Department of Natural Resources and Mines (DNRM) gauging station near Adams Bridge (ADM) (Figure 9). Water quality monitoring was conducted and total flow and loads of TSS were calculated using the previously outlined methodology (see “Methods to assess the effectiveness of works, Water quality monitoring” in this report).

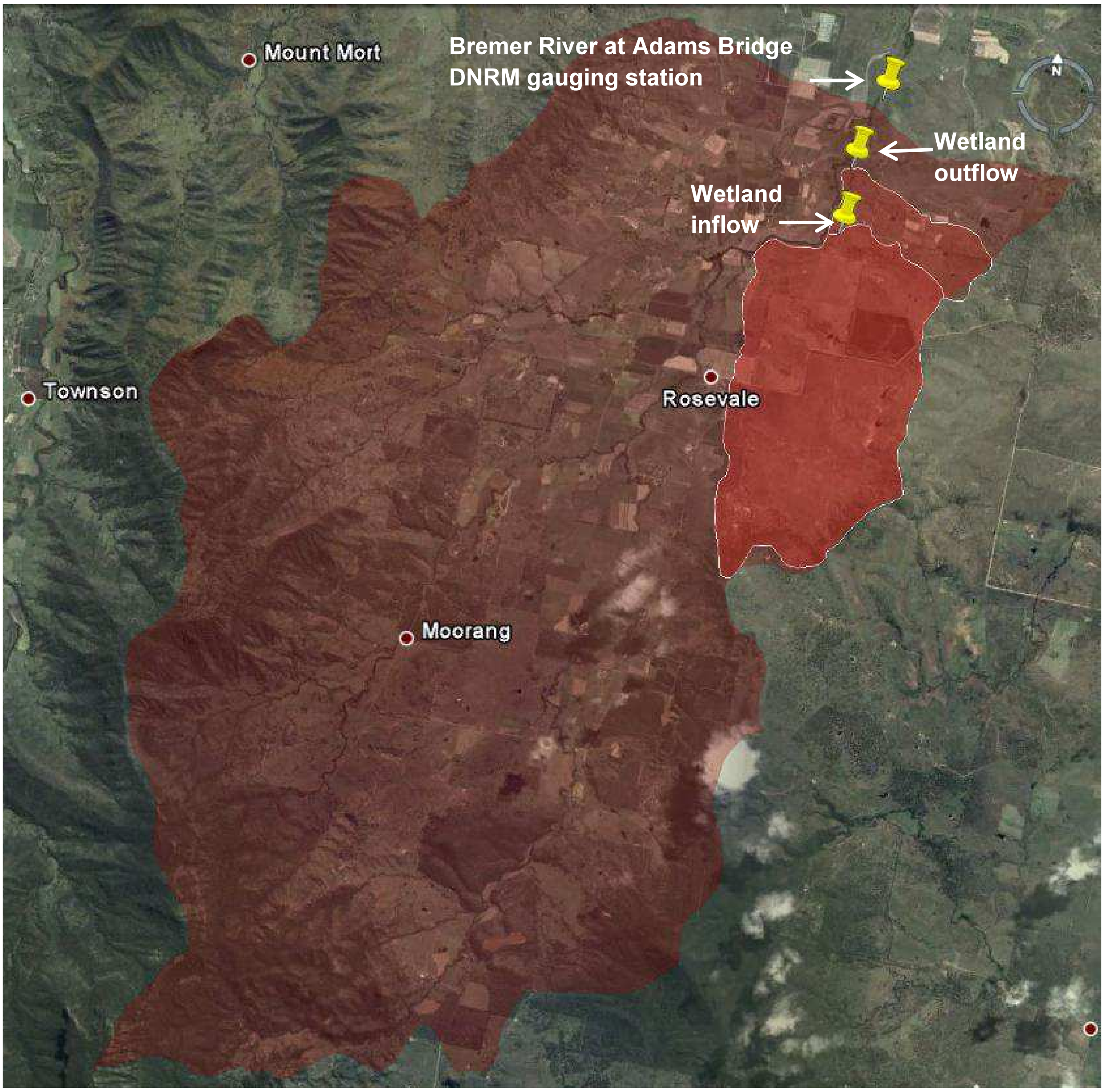


Figure 9 - Location of wetland inflow and outflow sites, Adams Bridge DNRM gauging station, and monitored sub-catchment outline for each site

Eight runoff events were identified at the ADM monitoring site and these coincided with the eight events from the wetland monitoring sites during the monitoring period (Nov. 2011-Mar. 2012). Of these, water quality samples were collected during six events (Table 3).

Sampling was sufficient across the hydrographs (Appendix C) to ensure a reliable estimate of TSS loads for the six events that were sampled.

The total monitored discharge for the ADM site was 14,847 ML (Table 3)[6]. The wetland monitoring site contributed an average of 37% of the discharge at the downstream ADM monitoring site (Table 3). It should be noted that the contribution of the wetland to discharge at ADM was not consistent, ranging from 11 to 80%. This is most likely to be correlated with the differences in where and how much rain fell in the ADM catchment. This finding calls into question methods often used to show the effectiveness of landscape repair works, where sediment yields are compared at a large catchment level such as the ADM site.

The variation in rainfall over the catchment, coupled with the placement of works in similar areas within a catchment, means that large scale monitoring has limited value to determine how effective works have been. Long term trend analysis and the calculation of catchment loads requires the installation of large scale monitoring sites. However, only small tributary or paddock scale monitoring will demonstrate the effectiveness of works, and importantly provide the information required to improve landscape restoration works into the future.

The ADM event loads were calculated and are displayed in Table 3. To give context to the outflow loads from the wetland, they were compared to the TSS loads from the ADM monitoring site (Figure 10). The wetland sub-catchment is 14% of the total area of the ADM site and the wetland sub-catchment outflow to the Bremer River, after works, contributes on average more than one third of the loads measured at the ADM site (Table 3).

Table 3 - Total suspended solids (TSS) loads and discharge volumes at the wetland outflow and Adams Bridge gauging station monitoring sites

	Event								Total
	1	2	3	4	5	6	7	8	
	Nov 2011	Dec 2011	Dec 2011	Jan 2012	Jan 2012	Feb 2012	Feb 2012	Feb 2012	
Outflow discharge (ML)	297	93	147	696	422	154	97	3403	5309
ADM discharge (ML)	523	116	403	2406	3293	1352	531	6223	14 847
Outflow discharge % of ADM	57	80	36	29	13	11	18	55	37 (Average)
Outflow TSS load (t)	18	2	4	68	12	7	6	847	964
Adams Bridge TSS load (t)	63	3	25	643	-	582	-	1588	2904
Outflow load % of ADM	29	67	16	11	-	1	-	53	30 (Average)

[6] Discharge was estimated using a theoretical rating curve and not validated using flow gaugings. The discharge volumes are indicative only and therefore loads estimated are indicative only and may be underestimated.

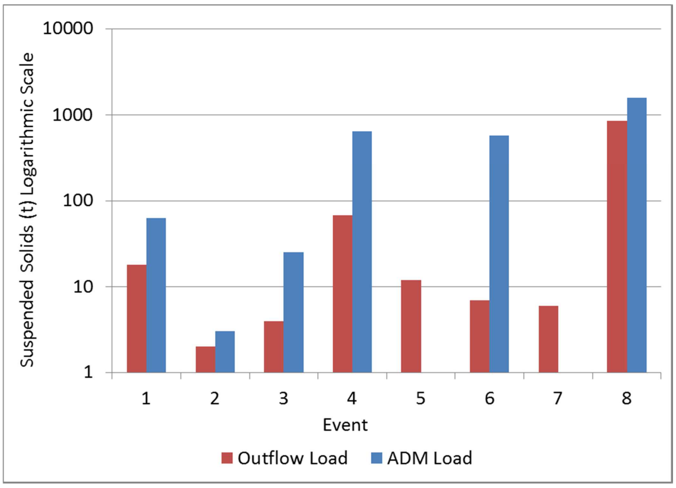


Figure 10 - Wetland outflow load compared to the Bremer River at Adams Bridge gauging station load estimates for 5 sites

Discussion

By repairing the gully at the inflow of the wetland, significantly more flow was directed through the wetland before entering the Bremer River. Importantly the outflow gully to the Bremer River was also fenced off to cattle and thick vegetation has been left undisturbed which minimised the erosive potential of the new discharge path. The large discharges that previously entered directly into the Bremer River though a eroded channel about 10 m wide were distributed at the new outflow through a densely grassed channel approximately 100 m wide, which significantly reduced the discharge velocity and its erosive potential. These design factors are essential for the long term stability of the outflow gully, which to date has remained stable. Even though the wetland is successful at reducing sediments and discharge velocities, large discharge events could still be responsible for the mobilisation and transport of large sediment loads. It is important to continue to monitor and manage the original gully erosion at the source.

The discharge rates of the inflow of water also influenced the time the water spent in the wetlands with lower discharge rates resulting in the greatest percentage of sediments being retained in the wetlands. The wetland is approximately 1 km long and provides adequate residence time for the removal of approximately half the TSS which enters the wetland. To further improve TSS removal the residence time for water in the wetland would have to be increased; this could be done by reducing the size of the outflow gully and allowing natural wetland revegetation. However, on grazing land (such as this wetland) production would be significantly reduced by increasing the residence time (as cattle could not enter the flooded area) and a balanced approach should be taken to prioritise the need for physical works, water quality improvement and the requirements for farming.

A unique dataset has been gathered from the sampling of four events in a large reinstated wetland in the Bremer catchment during the 2011-2012 wet season. Three of the events analysed were small events (one in one year events) while one was larger (one in two year event)[7]. The data for all events show that there is a significant reduction of TSS from the inflow to the outflow of the wetland system. Diffuse siltation due to sediment settling over the wetland means that the finer particle range has been captured, trapping the particle sizes that are most likely to reach Moreton Bay.

---

[7] Average Recurrence Intervals based on Adam's Bridge site downstream. To develop an accurate ARI for the wetland site, at least 10 years of flow data is required.

The estimates of sediment retained in the wetland as a result of water quality monitoring are less than the estimates of diffuse siltation results (1031 tonnes compared to 2000 tonnes). As only four events were monitored the estimate of sediment retention using water quality monitoring is an underestimation. The four events used account for 80% of the total flow during the sampling period. Therefore the total sediment load stored in the wetland could be estimated at between 1200 and 1370 tonnes. This is significantly less than the diffuse siltation results, however the two methods can't be compared directly as diffuse sedimentation monitoring measures sediment falling out of overland flow, while water quality monitoring measures sediment which stays suspended in overland flow.

Additional gauging's at the wetland outflow site are required before calculations of discharge (m^3/s) are within a tolerable error range. In the coming summer two additional gauging's at a medium and high flow are recommended for accurate discharge calculations. Until theoretical discharges are validated estimation of loads are indicative only.

There is also another small catchment that enters the wetland after the inflow measuring point, though small, the catchment characteristics and flow contribution needs to be assessed in the coming rainfall season to ensure the discharge estimates are accurate. The error associated with the loads estimations will be reduced when the confidence in discharge estimates increases. This will be a matter of priority if monitoring is to be continued at this site.

Despite the error associated with the calculation of TSS loads, the effectiveness of reinstating natural wetlands as a means of reducing sediment entering SEQ waterways was still able to be quantified using water quality monitoring. Reinstating the wetland along the Bremer River has proven to be a highly effective sediment management strategy.

The constant drying and wetting cycle of the wetland has proven challenging for the acquisition of consistent high quality turbidity data, particularly from the inflow site. More regular maintenance (from monthly to fortnightly) is required, and it is hoped that the recent remounting of the turbidity sensors will improve data consistency.

The data collected is only from November 2011 to March 2012 and for a more accurate understanding of the processes involved and verification of these early results, continued monitoring over the next few years is required.

Site 2 – Gully battering and flow diversion

The site

This site consists of low sloping ground forming the foothills of a steeper ridge to the east. The erosion site is on the flood plain. Soils are sandy loam over a heavy clay sub-soil. These soils are highly erosive. Most of the shallow hills have been cleared for cultivation and protected with contour banks. The erosion site has a fairly dense covering of grey box (*Eucalyptus microcarpa*).

Two dams have been constructed on the valley floor. The dams are holdings for a large upstream catchment (266 ha) that overflows frequently. Overland flows from the dam on the property, and stock access have contributed to highly erodible soils being exposed. The shoulders of the gully below the last dam are stable but discharge particularly to the north-west caused a long narrow gully to cut back from the adjacent property (Figure 11). This gully was 150 m long and contributed approximately 1764 m^3 of sediment (Table 4) further downstream.

Figure 11 - Gully erosion after construction of dams on the property

Works undertaken

The following works were undertaken:

- repair of the dam wall and receding gully head
- repair of the gully profile
- construction of a diversion bank to redirect water into the original system
- stock exclusion fencing
- seeding and mulching.

Gully and flood plain erosion management

The rehabilitation of these areas incorporated fencing of gullies and works to stabilise areas prone to erosion. Grazing management was also improved through fencing. The engineering works carried out in this project included the battering of newly formed gully heads and sides to halt erosion and the construction of bund walls to direct rainfall run off to stable ground to prevent further erosion (Figure 12).

Since the completion of the works, the landholder has implemented improved management practices for soil health outcomes by fencing the main creek/gully area to reduce the impact of continuous grazing.

Growth of native vegetation will be monitored with some thinning in localized areas to be done to reduce stems per hectare and to increase ground cover species to a satisfactory level. This will enhance the stability of the soil, particularly in places prone to gully erosion.

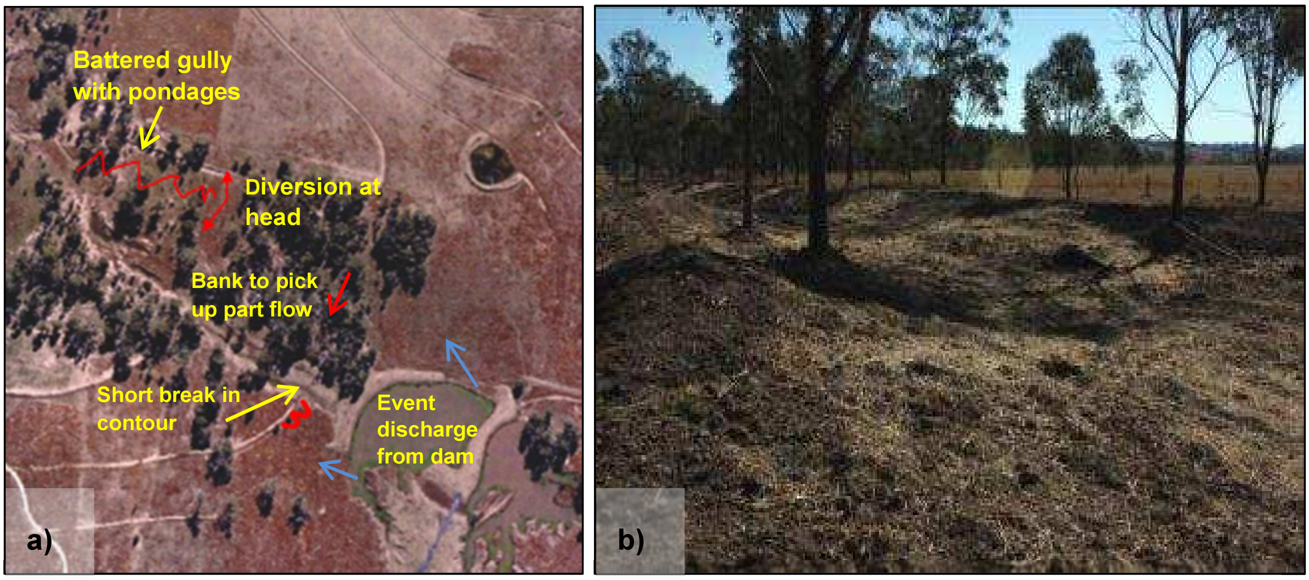


Figure 12 - Overview of the on-ground works to batter gully and divert flow (a). Image of gully battering works (b).

Results of gully battering and flow diversion

Of the six methods used to assess the effectiveness of works, all methods were implemented at this site. These included:

- retention of source sediment
- retention of diffuse sediment
- bedload sediment movement
- water quality monitoring
- digital elevation models
- photographic evidence.

Retention of source and diffuse sediment

Diffuse siltation monitoring was conducted behind and in front of the two contour banks installed to disperse water coming from the northern outflow of the dam. This monitoring showed there was significant sediment deposition occurring, with a 20 mm depth recorded 5-10 m from the contour banks. However, siltation depth dropped as distance increased from the contour banks and was only 6-10 mm at 50 m from the contour banks. The average siltation depth across the area sampled was 13 mm (Table 4). The volume of sediment retention, from siltation monitoring, was estimated at 312 m^3 (Table 4). The stability of the repaired gully, which had retreated approximately 150 m in the year preceding the installation of works (Appendix B – Sediment estimates), was successful with no flows entering the area. The estimated retention of source sediment is estimated at 1764 m^3. The combined estimate of source and diffuse sediment retained by the on ground works is 2076 m^3 over the last year, approximately 2906 tonnes (Appendix B – Sediment estimates).

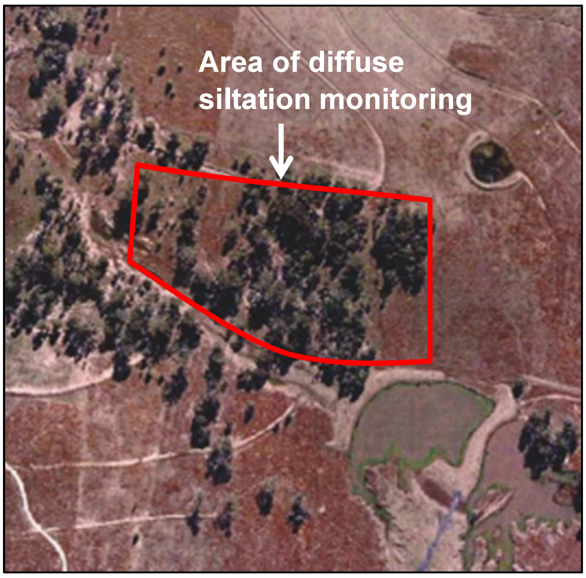


Figure 13 - Area of diffuse siltation/sediment monitoring. See Figure 12 (a) for location of targeted works

Table 4 - Summary information for Site 2 and calculated volumes of diffuse source sediment retained by the on-site works: measurements at Site 2

		Site 2
Erosion type addressed in project		Gully and flood plain
Design approach		Battering and flow redirection for bank repair and flood plain reinstatement
Soil geology		Low fertility, highly dispersive sodic soils from th Walloon Coal Measures
Source sediment	Source sediment retained (m^3/y)	1800
	Source sediment loss (m^3/y)	36
	Net retention (m^3/y)	1764
Diffuse sediment	Measured area (Ha)	2.4
	Silted profile depth (mm)	13
	Silted volume (m^3/y)	312
Total volume of sediment retained (m^3/y)		2076

Bedload sediment movement

Bedload sampling with turf mats proved unsuccessful. The low friction surface of the turf mat did not give a representative measurement of the soil that had fallen in the surrounding area, which could be seen upon visual inspection. For future monitoring of sediment fall, turf mats are not recommended.

Water quality monitoring

Rising stage samplers (RSS) were installed for the collection of total sediments; these were unsuccessful in the collection of water for analysis as the flows through the gully did not reach the required height for a sample to be taken. The RSS have been relocated to a lower section on the site and will remain in place to monitor future events. In addition to the RSS samplers, Helley Smith bedload samplers were installed at this site to replace the turf mats which were not suitable bedload sediment sampling.

Digital elevation models

Surveys were taken of the stable area where flows have been diverted to during the 2011-12 wet season and a DEM was produced (Figure 14). Further surveys will be taken after the 2012-2013 wet season and compared to the original survey. Comparisons will seek to confirm that the stable area into which flow has been diverted, remains stable and poses no further erosion risks.

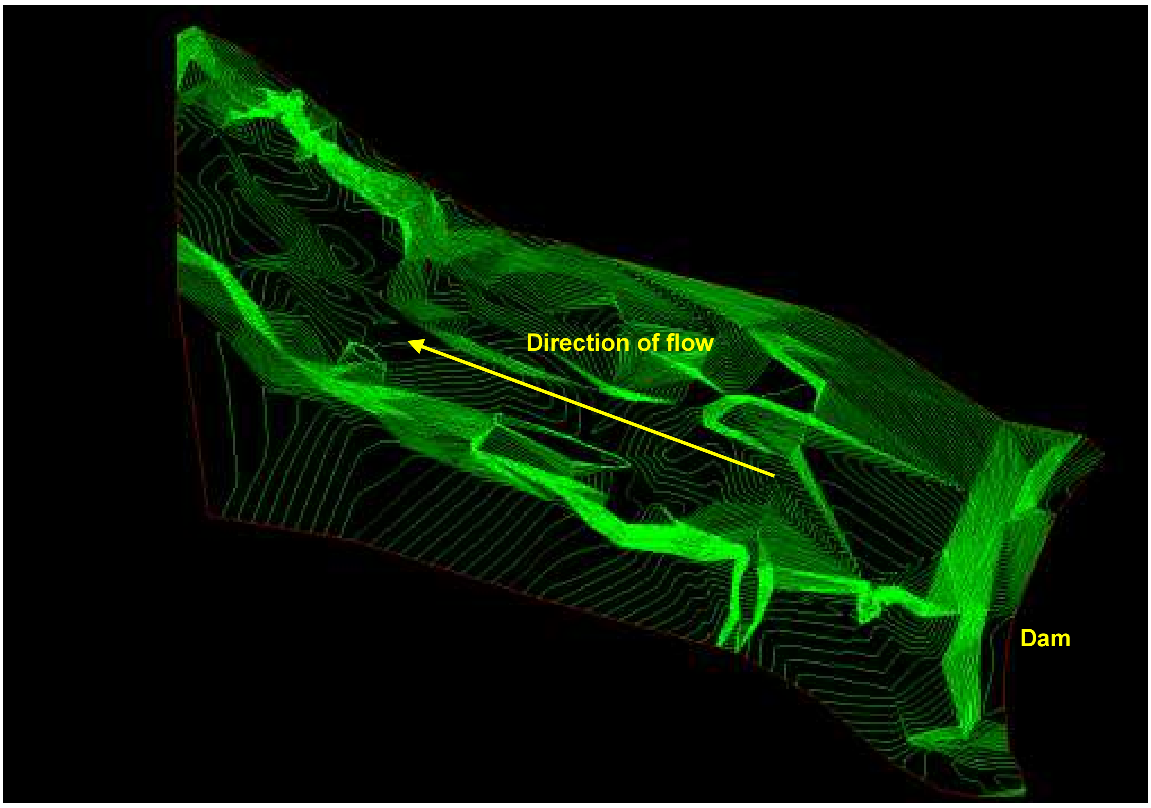


Figure 14 - Digital elevation map (2011-2012) of the stable area to which flow has been diverted (each line is a 5 cm change in elevation)

Photographic evidence

Photographic surveys will allow the tracking of natural revegetation of the battered gully and the stability of the diversion area (Figure 15). These surveys will also enable the documentation of any weak spots that may appear in the new diversion path, hydrological changes and sediment deposition over the survey period.

Long narrow gully to the north-west of the property before targeted on-ground works.

a) JUNE 2010

Gully after on-ground works of battering and bunding to redistribute flow to a stable area.

b) JUNE 2011

Revegetation of battered gully.

c) FEBRUARY 2012

Figure 15 - Original gully formed from dam overflows (a), and the stabilised gully following on-ground works (b and c)

Discussion

The battering and revegetation of the newly formed gully successfully stopped the export of sediment from the site. The diversion of discharge using contour banks also had the desired effect of directing the erosive potential of high velocity discharges into a more stable area. The new discharge path was prone to gully erosion, but has undergone a natural revegetation which stabilised the previous gullies. To determine the long term success of the works and the ability of the stable gully to allow sediments to settle out during high discharges, further monitoring of the stable gully is required. Surveying the area after the next wet season (Nov. 2012 – Mar. 2013) will result in identification of newly forming gullies or areas where further management may be directed.

The monitoring of water quality using RSS was not successful during the monitoring year due to placement in an area where water discharge was not constricted sufficiently to enable the collection of samples. The RSS has been relocated and for successful quantification of sediment retention by the stabilised gully, water quality monitoring should continue.

Site 3 – Gully damming

The site

This site's soil structure is deep black cracking clays associated with alluvial gullies. The commencement of rain causes immense soil loss through erosion, but follow up rains are less damaging, as the soil stabilises with water infiltration.

This gully system has three major head cuts that have retreated significantly in the six months from October 2010 to April 2011, with one head cut fall being over five metres (Figure 16). This, combined with a major bank slump retreating into valuable cultivation land, has contributed large volumes of sediment into the Bremer catchment and has the potential to contribute more.

Figure 16 - The major gully head cut which measured over five metres deep

The direct offsite sediment export for 2010-2011 was calculated at 5000 m^3, equivalent to a third of total sediment available at the upper site if all of the historic sediment load was mobilized by erosion (Thompson 2011). The historic sediment load at the site is on the order of 50 000 m^3. High value crop land is being lost and ultimately some housing infrastructure will be in danger.

Works undertaken

The following works were undertaken at the site:

- soil erosion control through extensive engineering works to dam the gully
- exclusion fencing of 12.5 ha of terrestrial vegetation
- stabilisation of 4.2 ha of stream banks through exclusion fencing.

Stream bank and gully erosion management

The rehabilitation of this site has incorporated earthworks to stop the retreat of the head cuts at the upstream site. The downstream site included diversion of the water flow and the stabilisation and protection of the bank slump. The gully walls have been battered and the water velocity has been decreased with the construction of a dam.

These works have been enhanced by strategic revegetation. To complement the project the landholder has implemented improved management practices for soil health outcomes by fencing the main creek/gully area to reduce the impact of continuous grazing.

Results of gully damming

Of the six methods used to assess the effectiveness of works, four were implemented at this site. These included:

- retention of source sediment
- retention of diffuse sediment
- digital elevation models
- photographic evidence.

Retention of source and diffuse sediment

This rapidly expanding gully retreated 100 m in one year (July 2010 - June 2011) and being 10 m wide and 5 m deep it released approximately 5000 m^3 of sediment downstream (Table 5), cutting into cropping land and endangering the landholder's house (Figure 17).

Diffuse siltation monitoring near the inflow to the dam showed there was significant sediment deposition with depths of 4 mm recorded 1 m from the inflow point over a nine month period. However, siltation depth quickly dropped and at 20 m from the inflow, no deposition was observable with the last two samples (furthest from the inflow to the dam) being 0 mm of sedimentation. Overall the sediment savings from these works was estimated at 4903 m^3, or approximately 6864 tonnes per year (Appendix B – Sediment estimates).

Table 5 - Summary information for Site 3 and calculated volumes of diffuse source sediment retained by the on-site works: measurements at Site 3

		Site 3
Erosion type addressed in project		Stream bank and gully erosion
Design approach		Dam for bank repair and flood plain reinstatement
Soil geology		Dark cracking clays derived from basalt colluvia
Source sediment	Source sediment retained (m^3/y)	5000
	Source sediment loss (m^3/y)	100
	Net retention (m^3/y)	4900
Diffuse sediment	Measured area (Ha)	0.07
	Silted profile depth (mm)	4.3
	Silted volume (m^3/y)	3
Total volume of sediment retained (m^3/y)		4903

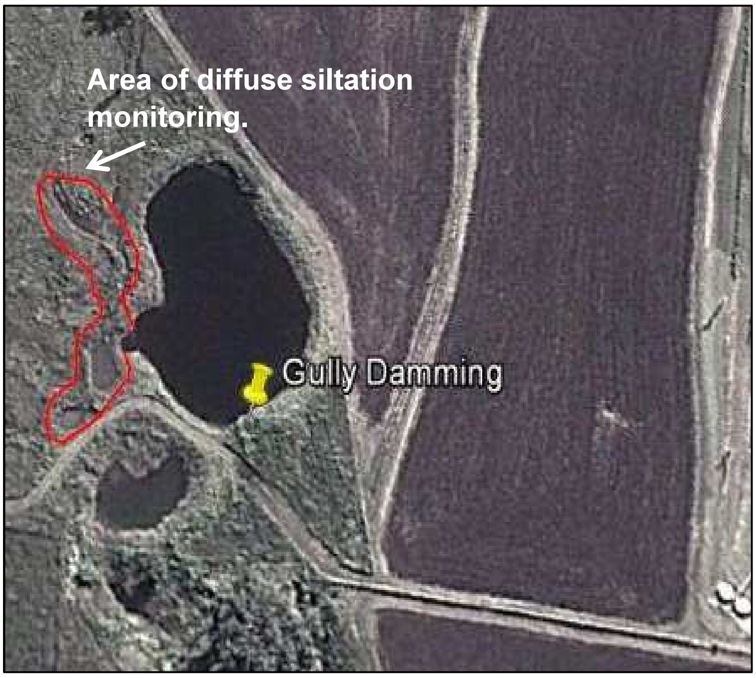


Figure 17 - Diffuse siltation monitoring area at Site 3

Digital elevation models

Surveys were conducted after the works were completed, mid wet season (2011-2012). The DEM produced from the surveys captured the finished works and highlighted areas where the stability of the works had been compromised (Figure 18). Follow up surveys after the wet season will show any further instability of the works and measure the volume of sediment lost.

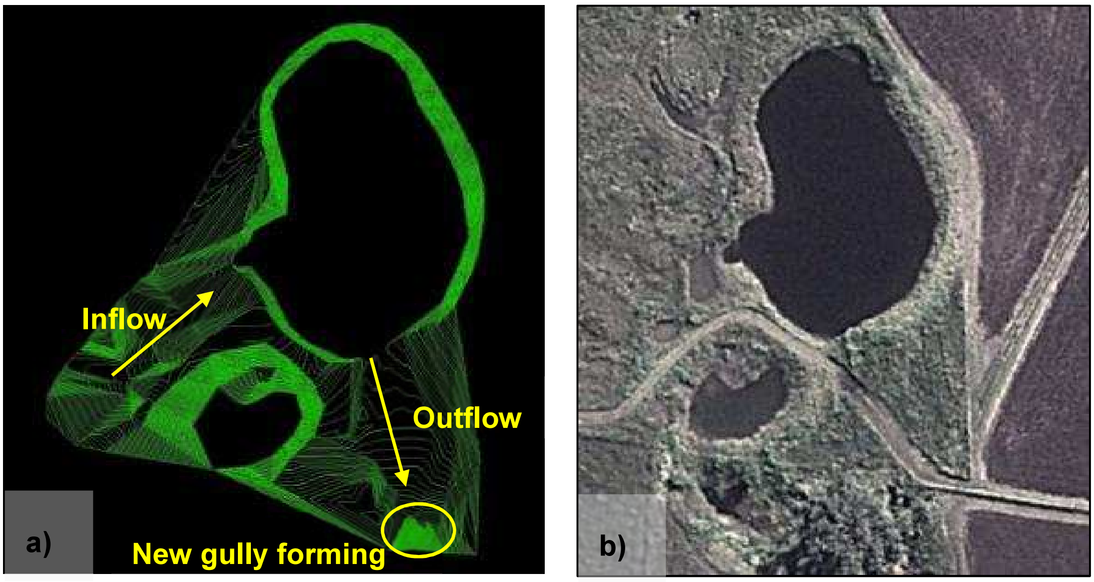


Figure 18 - (a) Digital elevation map (lines indicate 5 cm differences in elevation) and (b) overhead satellite picture of dammed gully

Photographic evidence

Photographs collected during the works and also over the monitoring period show the works remained stable (Figure 19).

a) December 2010

b) August 2011

c) November 2011

d) February 2012

Figure 19 - Eroding gully (a) and the dam built to halt further gully expansion (b). Photos c) and d) show later stages of the completed dam works

Discussion

The on-ground works to stabilise the downstream gully (the larger of the three head cuts) was successful in retaining sediments at the source. This will not only result in the retention of source sediment from the large head cut, but also aid in the capturing of diffuse sediment from sources upstream, including sediment resulting from the other two headcuts. The development of the dam has changed the original discharge path and as a result of the overflow of the dam (when the dam is full) there may be deleterious effects, e.g. formation of new gullies in the new discharge path.

The onset of a newly forming gully was identified during the surveying following completion of the on-ground works. The instability in the works was detected and repairs were applied to direct the discharge from the dam into an area of greater stability and less prone to erosion.

The continued monitoring of the works will ensure the works remain stable and allow the direction of management actions to other areas of erosive potential.

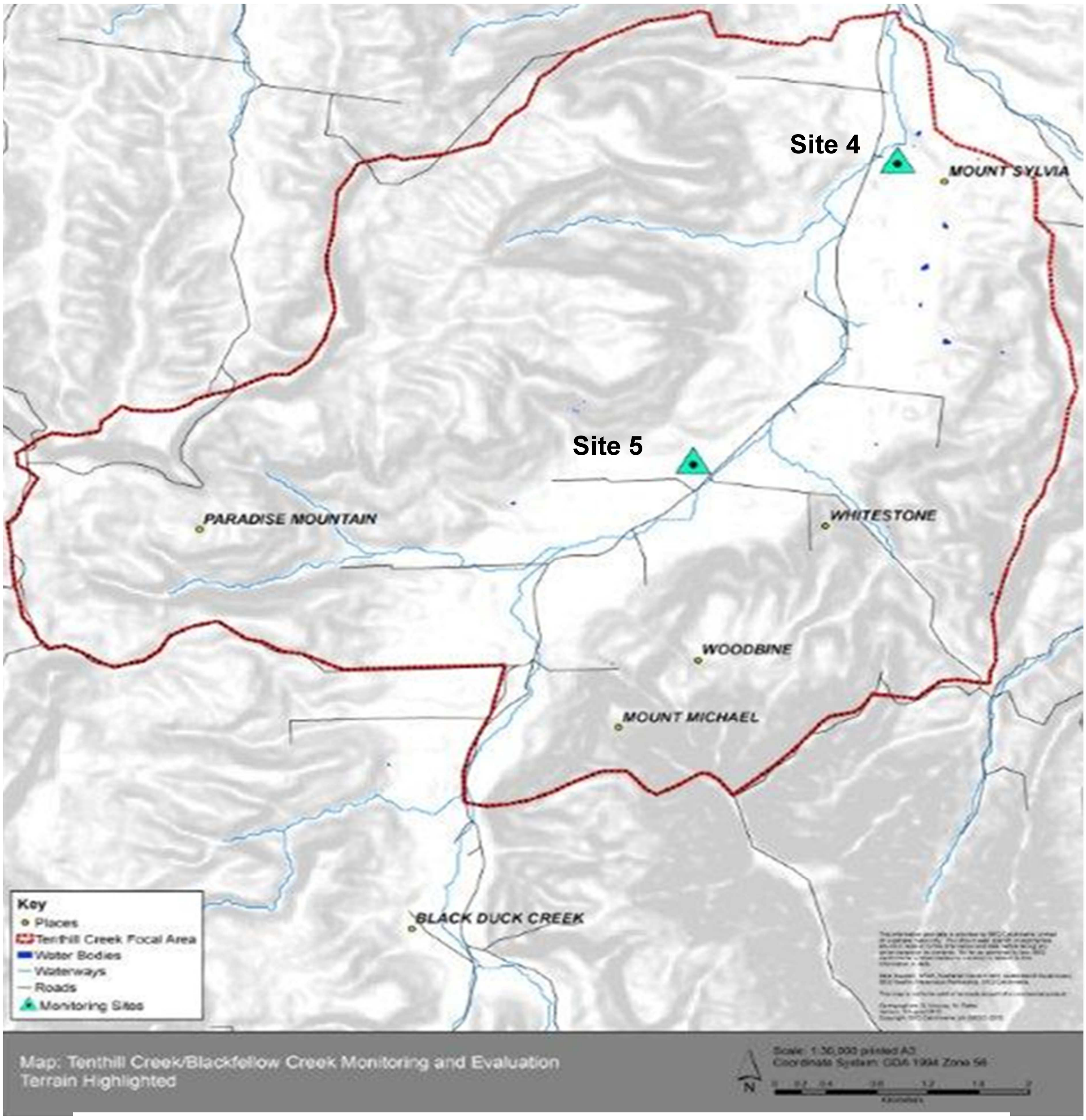
Focal area 2: Lockyer catchment – Blackfellow Creek

The objective of this project was to improve water quality by reducing erosion through repairing and reinforcing the discharge areas into Blackfellow Creek, by controlling erosion and sediment inputs, and to demonstrate techniques for erosion and sediment control to the local community.

This focal area is predominately cleared on the lower flood plains for extensive cropping and primary production with the higher areas used for grazing. The vegetation retention in this catchment is approximately 25%.

In the Blackfellow Creek catchment rehabilitation/remediation works were undertaken as part of initial Healthy Country Project and the CfoC project (Figure 20). The effectiveness of two of these projects were monitored. Remediation sites included:

- Site 4 - Gully stabilisation using rock chutes
- Site 5 - Water control and swales.



Map courtesy of SEQ Catchments

Figure 20 - Monitoring locations in the Lockyer catchment focal area of Blackfellow Creek

Site 4 – Gully stabilisation using rock chutes and groynes

The site

The property is 32 ha of an over 50 ha catchment of mainly horticulture and grazing land which drains directly into a bend on Blackfellow Creek, this entry point has exacerbated into a gully head and has caused erosion issues.

Erosion damage was caused by the floods in 1996. The local council repaired the receding gully head by replacing the alluvium of the gully mouth. Following rainfall events have undermined the gully head repair from 1996. The main problem over the last decade has been the expansion of Blackfellow Creek into the outer bend which is also the outlet of this drainage line. This has created a vertical bank which then cut back rapidly when runoff flowed down the gully (Figure 21).

The construction of the initial rock chute and the two initial rock groynes was undertaken as part of the Healthy Country Project, sections of the chute failed during the rainfall events of 2010 and the integrity of the structure was undermined during numerous rainfall events. Although the rock groynes had retained their structural integrity during this rainfall period, it was evident the velocity of the water required a greater resistance to decrease the flow velocity through the drainage system.

Figure 21 - Expansion of Blackfellow Creek into the bend

Works undertaken

The following works were undertaken:

- plantings of exotic perennial pastures – kikuyu (*Pennisetum clandestinum*)
- stabilisation of the stream bank through engineering works
- rock chute construction
- construction of two additional rock groynes.

Stream bank and gully erosion management

Post 1996 floods, rock deflection groynes were constructed to help protect the bank (Figure 22). A problematic head cut where the gully empties into the creek has been repaired with a rock chute trialing a number of techniques as part of the Healthy Country Project (Figure 23).

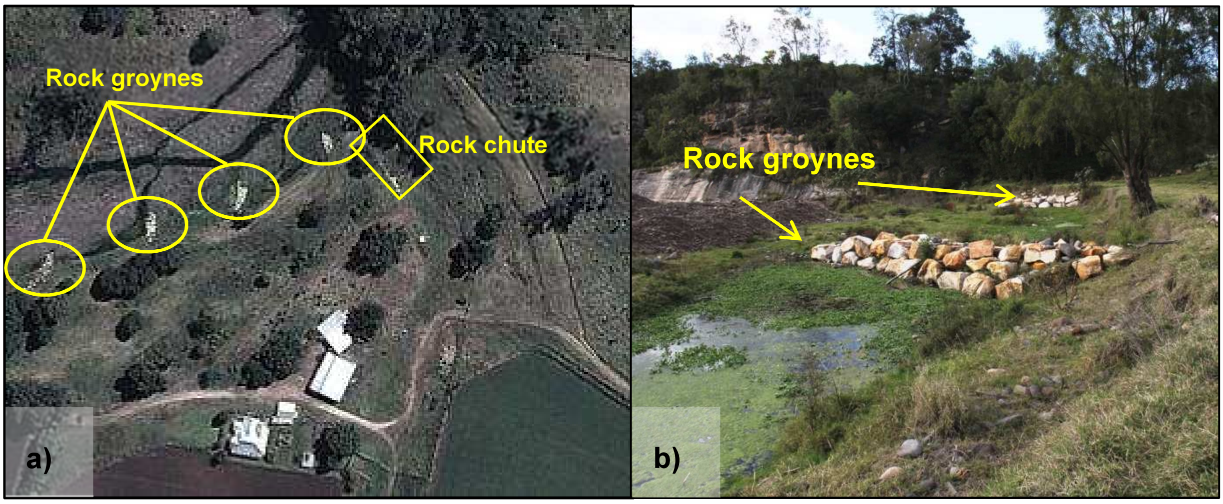


Figure 22 - Rock groynes (a and b) and chute (a) to reduce gully and bank erosion

The addition of two groynes will further reduced the velocity of the water flowing through the drainage system before the water renters the creek at the rock chute. The rock chute repairs included the placement of geofabric in the contour of the repaired alluvium and specific strategically placing rocks and boulders on the geofabric. The rock chute was then in-filled with soil and seeded with kikuyu.

Repairs will strengthen the chute using rock repositioning and vegetation, which will improve binding and reduce buoyancy during inundation.

Results of gully stabilisation using rock chutes and groynes

Of the six methods used to assess the effectiveness of works, three were implemented at this site:

- retention of source sediment
- retention of diffuse sediment
- photographic evidence.

Retention of source and diffuse sediment

Diffuse siltation monitoring found no evidence of sediment deposition 20 m before the rock chute (Figure 23). With an average depth of 0 mm recorded across eight samples (Table 6). Thus there is essentially no retention of diffuse sediment by the rock chute (Table 6).

The length (20 m) width (12 m) and depth (4 m) of the gully entering Blackfellow Creek, formed over a two year period (1994-1996) with approximately 960 m^3 of soil lost over this time. If the gully head retreated at a similar rate over the 2010 to 2011 period, the works would have prevented 480m^3 per annum (approximately 672 tonnes) of sediment moving into Blackfellow Creek (Table 6). The first repair, in 2009, had a 20% fail rate and approximately 96 m^3 of soil was washed out into Blackfellow Creek from the rock chute. If the same failure rate occurred with the current works, then the final estimate of soil retained and not discharged to Blackfellow Creek is 384 m^3 or 538 tonnes (Table 6). As seen in the photographic evidence (Figure 24), the new design held firm against an extreme event and it is likely the rock chute will remain stable in further high flow events.

Table 6 - Summary information for Site 4 and calculated volumes of diffuse source sediment retained by the on-site works: measurements at Site 4

		Site 4
Erosion type addressed in project		Gully, Stream Bank
Design approach		Rock chute for bank repair and gully stabilisation
Soil geology		Dispersive sandy loam soils near creek flats to fertile clays above derived from basalt colluvia
Source sediment	Source sediment retained (m^3/y)	480
	Source sediment loss (m^3/y)	96
	Net retention (m^3/y)	384
Diffuse sediment	Measured area (Ha)	0.02
	Silted profile depth (mm)	0
	Silted volume (m^3/y)	0
Total volume of sediment retained (m^3/y)		384

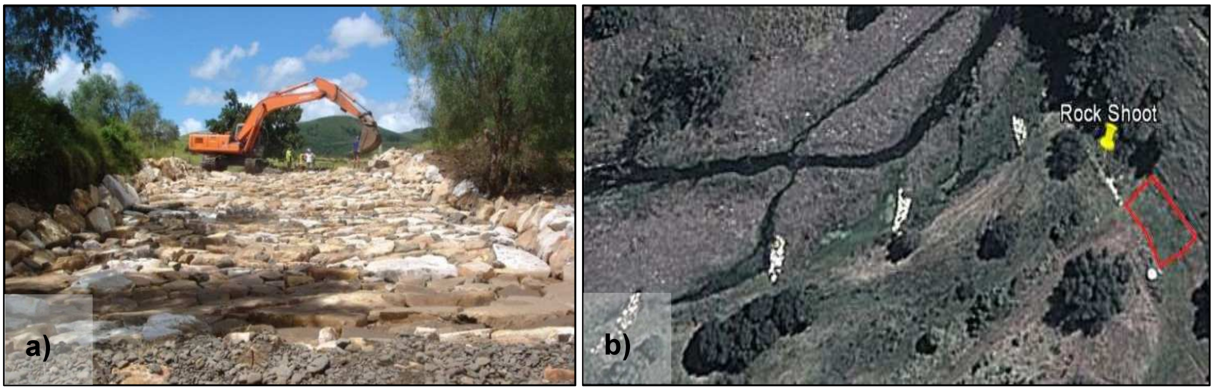


Figure 23 - Figure a) shows how a large excavator was required to place the last large rocks at the entry point of the rock chute. In figure b) the red boundary indicates the diffuse siltation area before the works

Photographic evidence

The first attempt at rock chute had an 8 m wide entry and blue metal rocks weighing 20-100kg.

Following 80 ml rainfall on the 6-8th November 2009 the rock chute failed and the gully started reforming.

The second attempt at the rock chute had a 12 m wide entry and used sandstone rocks weighing 100-500kg, which were individually placed so they could be interlocked and support one another.

The completed rock chute, showing interlocking design. Note the size difference of the old 'blue metal' rocks and the newly laid sandstone rocks.

Water spilling over the rock chute after 220 ml of rain from the 10th to 12th of January 2011.

Remarkably the rock chute sustained only minor damage from the January flood, estimated to be over a 1/100 year event.

Soil placed on top of the rock chute, into which kikuyu grass was planted to further stabilise the rock chute.

Completed rock chute. Kikuyu grass has spread roots over the rocks. This final design is a great model for high risk gully repairs adjacent to stream banks.

Figure 24 - Rock chutes designed to protect a gully from further expansion and stream bank erosion

Discussion

The improvement to the original rock chute appears to have successfully managed the erosion of the stream bank and gully. The rock groynes further reduce the effect of stream bank erosion by reducing the velocity of the water flowing into the stream bank bend.

These works will become more stable over time as natural revegetation takes place. Continued photographic monitoring will allow the identification of weak spots that may become a problem in the future.

Site 5 – Water control and swales

The site

The property is mainly a series of terraces separated by steep rocky hill slopes dropping to a creek flat. An ephemeral watercourse draining the hill slopes to the west runs to the southern side of the property. The catchment of this watercourse is about 140 ha.

There is a relic creek channel between the hill and the creek flat which drains overland and spring fed flows to Blackfellow Creek. Soils on the hill are predominately fertile friable 'scrub' soils and loam over cobble on the creek flat. Landslips, old and new, some quite large, are present.

Drainage of overland flows from 140 ha of mainly horticulture and grazing landuse into Blackfellow Creek had resulted in gully erosion (Figure 25). The erosion problem was in the cultivation area around the house and sheds and on the creek flats mainly due to water from the ephemeral watercourse in the gully.

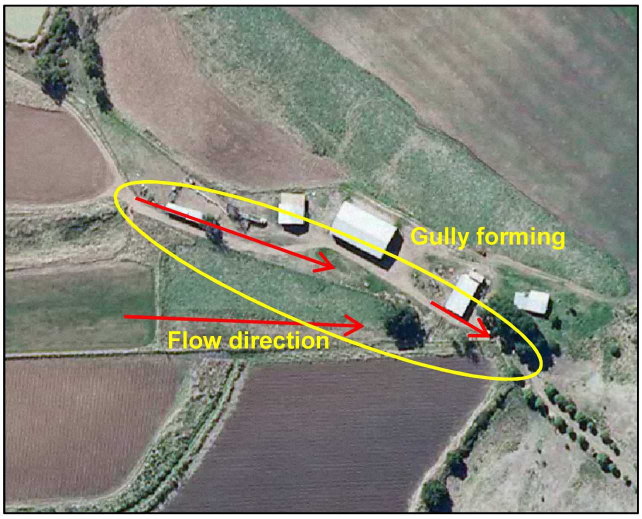


Figure 25 - Direction of flow and area of gully formation

Works undertaken

The following works were undertaken:

- soil erosion control through engineering works
- diversion bank construction
- revegetation with exotic vegetation kikuyu (*Pennisetum clandestinum*).

Gully Erosion Management

Drainage had been managed by constructing a series of sediment traps in the gully a few years ago but these were very constricted, intensifying runoff through the cultivation and around the house and sheds. A swale was constructed with an earth bank boundary that diverts gully and overland flows away from the buildings. The swale was heavily grassed to reduce the velocity and erosion risk and also the sediment content of the overland flow. The area of the creek flat most prone to erosion was also grassed.

Recent heavy rainfall events indicated that drainage along the boundary was of insufficient capacity to cope with the amount of water that moves through the area in heavier rainfall events. Works were designed to increase the drainage capacity, improve by-wash of the final sediment trap, improve the earth bank and maximize spread of flow at the outlet. An across- boundary agreement was entered into between the neighboring landholders detailing future management of overland flows.

This is an erosive gully, near sheds and the farm house, which has a historical cycle of scour and then repair by the farmer. A large vegetated grass swale was recently installed with significant width to reduce discharge energy and it is hoped that the gully will now be stable.

Results of water control and swales

Of the six methods used to assess the effectiveness of works, three were implemented at this site. These included:

- retention of source sediment
- retention of diffuse sediment
- photographic evidence.

Retention of source and diffuse sediment

Diffuse siltation monitoring found no evidence of sediment fall at the base of the swale. With an average depth of 0 mm recorded (Table 7). Therefore, it is estimated that the on-ground works will not have retained any diffuse sediment.

The length (50 m) width (6 m) and depth (1 m) of the gully formed over two years (2009-2011) so approximately 150 m^3 of soil was lost each year. If the gully head had retreated at the similar rate over the wet season of 2011-12, the attributed sediment savings to the works would be 150 m^3 which is approximately 210 tonnes.

Table 7 - Summary information for Site 5 and calculated volumes of diffuse source sediment retained by the on-site works: measurements at Site 5

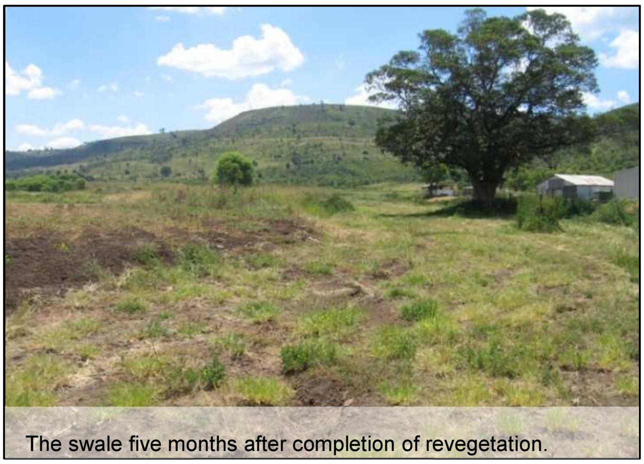
		Site 5
Erosion type addressed in project		Gully
Design approach		Large swale for gully repair
Soil geology		Dispersive sandy loam soils near creek flats to fertile clays above derived from basalt colluvia
Source sediment	Source sediment retained (m^3/y)	150
	Source sediment loss (m^3/y)	0
	Net retention (m^3/y)	150
Diffuse sediment	Measured area (Ha)	0.01
	Silted profile depth (mm)	0
	Silted volume (m^3/y)	0
Total volume of sediment retained (m^3/y)		150

Figure 26 - Large swale constructed to stop the gully head retreat. The red boundary shows the diffuse siltation monitoring area at the end of the swale

Photographic evidence

Photographic surveys were undertaken to track the natural regeneration of the grass swale and the stability of the area (Figure 27). Photographic monitoring will be continued to enable the documentation of any weak spots that may appear in the swale, hydrological changes and sediment deposition.

a) August 2011



b) January 2012

c) March 2012

Figure 27 - Newly excavated swale (a) and subsequent swale revegetation (b and c)

Discussion

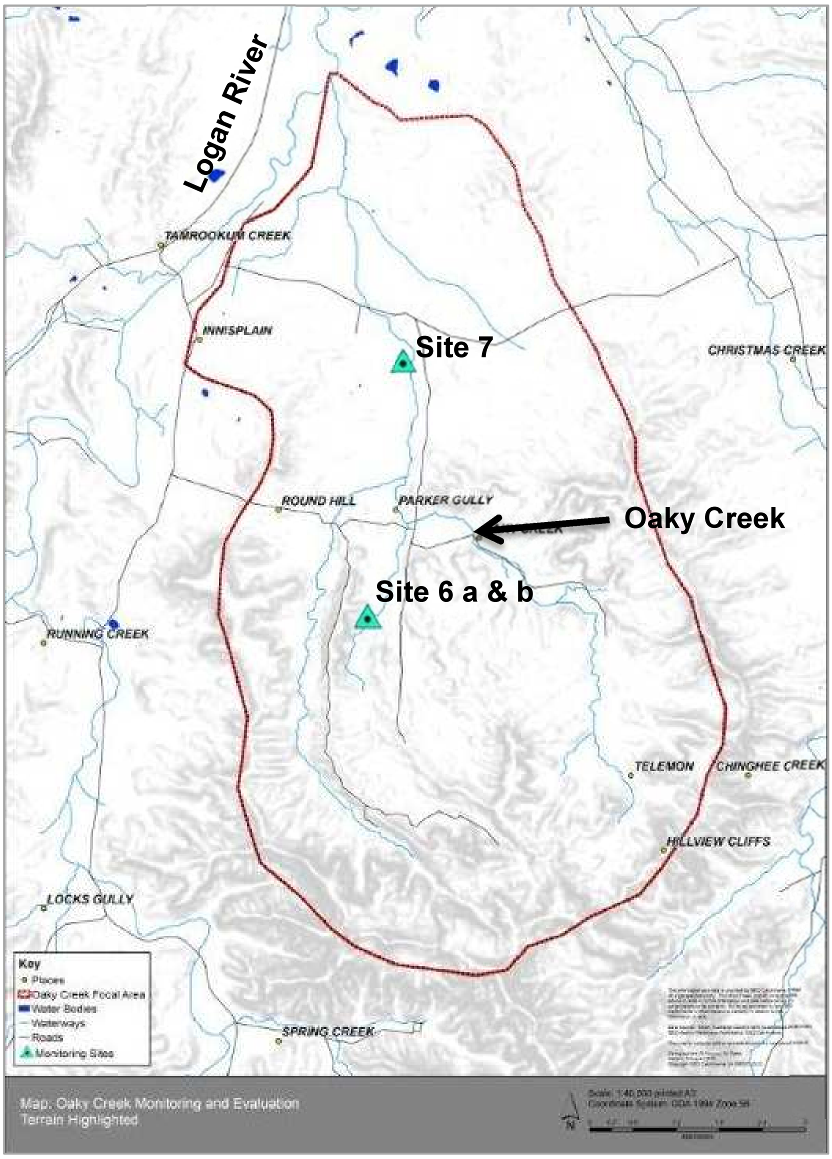
The construction of the grass swale to reduce flow velocity and gully erosion has been successful in retaining sediment at its source. Whether the works will be successful over time in capturing diffuse sediment from inflows remains to be quantified. The establishment of vegetation (kikuyu - *Pennisetum clandestinum*) was undertaken in an average wet year and the survival of this vegetation may be limited during dry years. To ensure the efficacy of the revegetated swale for the retention of both source and diffuse sediment, monitoring should also be conducted during dry years where the proportion of bare ground may increase and therefore also the erosive potential.

Focal area 3: Logan catchment – Oaky Creek

The objective of this project was to improve water quality and address the interrelated water and land management issues contributing to nutrients and sediment entering Oaky Creek. Oaky Creek forms the head waters of the Logan catchment and is subjected to high flow rainfall events and flash flooding. The catchment is predominantly pasture grazed by cattle for beef and dairy, with cultivated soils currently used for various crops (e.g. corn, sorghum, lucerne) on the lower alluvial plains. The country is basaltic in origin with the remaining 30% of vegetation cover dominated by woody vegetation.

In the Oaky Creek catchment rehabilitation/remediation works were undertaken for the CfoC project (Figure 28). The effectiveness of two of these projects were monitored. These included:

- Site 6a - Controlled grazing and creek fencing
- Site 6b - Gully damming and leaky weirs
- Site 7 - Gully diversion through wetland.



Map courtesy of SEQ

Figure 28 - Monitoring locations in the Logan catchment focal area of Oaky Creek

Site 6 (a & b) – Controlled grazing, creek fencing, gully damming and leaky weirs.

The site

Both sites are located on the same property. The property consists of cracking clays - described as vertisol. Early season rains cause significant soil loss through erosion, but follow up rains are less damaging, as the soil stabilises with water infiltration. This site was used for intensive grazing, and consists of one 300 ha paddock of mostly native pastures. Water from the stream is accessed by stock, which is causing significant erosion along the creek banks and exacerbating the retreat of gully head cuts (Figure 29).

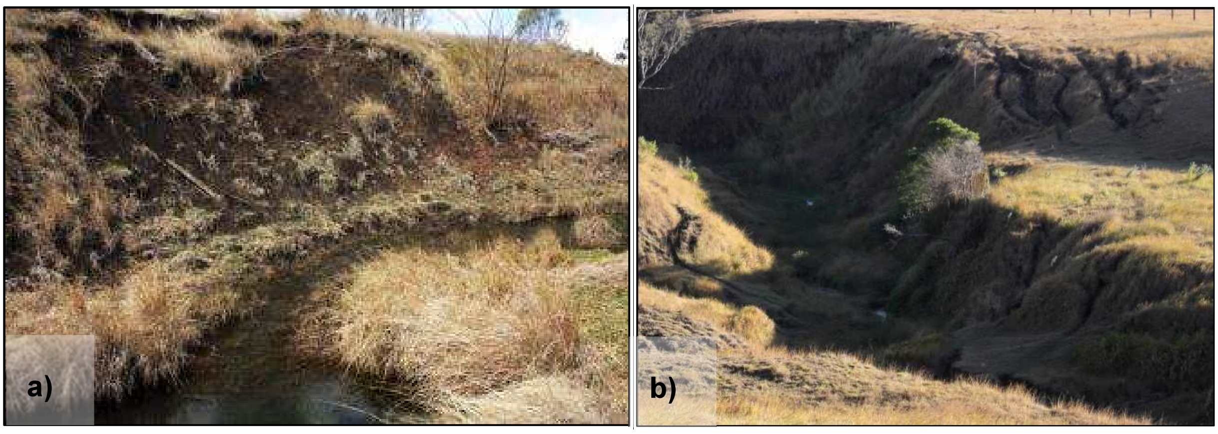


Figure 29 - Stream bank erosion caused by stock access

Works undertaken

The following works were undertaken:

Site 6 (a) Controlled grazing and creek fencing

- seeding of gully heads and improved pasture
- stream bank stabilisation through stock management (off-stream watering sites)
- stock control through exclusion fencing.

Site 6 (b) Gully damming and leaky weirs

- soil erosion control works to address gully head retreat
- construction of three leaky weirs.

Controlled grazing and creek fencing

Works for this project also included land type fencing, exclusion fencing and contour banks for erosion control.

Low diversion banks with leaky weirs were also constructed to direct water flow away from gully head cuts and slow the movement of water through the landscape (Figure 30).

To compliment this project the landholder implemented improved management practices for soil health outcomes by fencing off the main stream. In particular this should reduce the impact of continuous grazing by excluding stock from this area and allow for the regeneration of native vegetation.

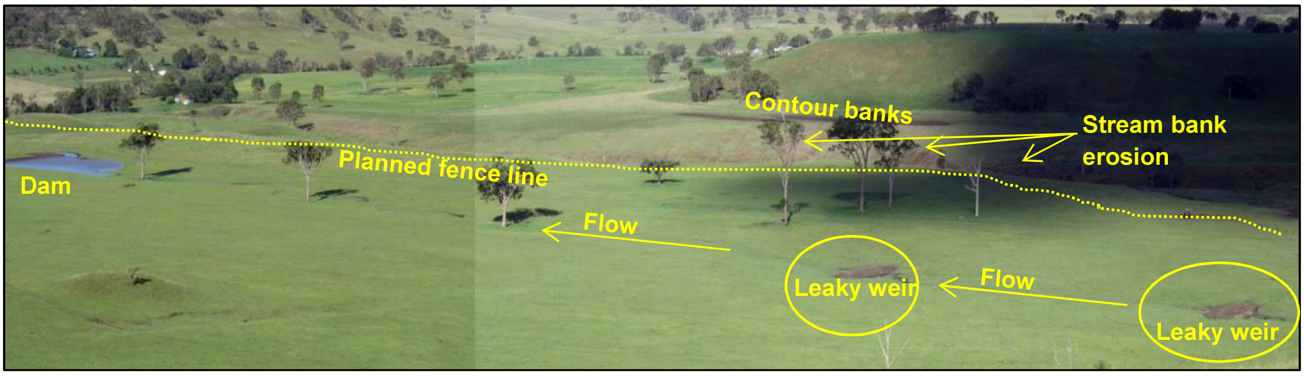


Figure 30 - Planned fencing to exclude cattle, contour banks to distribute flow away from stream bank erosion, constructed leaky weirs and a dam to hold back and distribute flow to stop head cutting and gully formation

Note that the third leaky weir is further up the catchment and not seen in the photo.

Gully damming and leaky weirs

A dam was constructed at the bottom of the works to drown another head cut developing at the receiving end of the works. Three leaky weirs were constructed to retain the flow and flood waters in the flood plain long enough for siltation to occur. The weirs also allowed the flood plain to drain slowly over a period of days.

Site 6 (a) Results of controlled grazing and creek fencing

Of the six methods used to assess the effectiveness of works, four were implemented at this site. These included:

- retention of source sediment
- retention of diffuse sediment
- water quality monitoring
- photographic evidence.

Retention of source and diffuse sediment

The gully head retreat at this site was the most difficult to estimate as there were numerous stream bank gully heads retreating at different rates, estimated at 2-10 m per year. For an indicative estimate the five main gullies below the contour bank were chosen (Figure 31) with a conservative estimate of gully head retreat being 5 m per year (Appendix B). Assuming the on-ground works are 100% effective, the total volume of sediment estimated to be saved for the five gully heads would be 13 m^3 per year (Table 8), approximately 20 tonnes.

Measurements of diffuse sediment retention carried out above the contour bank showed no evidence of sediment accumulation. Thus, at this point, the diffuse sediment retention associated with on-ground works is zero. This is largely because the contour banks were only finished in March 2011, and few runoff events have passed along the banks (Table 8).

Table 8 - Summary information for Site 6(a) and calculated volumes of diffuse source sediment retained by the on-site works: measurements at Site 6(a)

		Site 6(a)
Erosion type addressed in project		Stream bank, gully and flood plain
Design approach		Contour bank for stream bank protection, fencing for cattle management
Soil geology		Deep fertile dark cracking clays derived from basalt colluvia
Source sediment	Source sediment retained (m^3/y)	13
	Source sediment loss (m^3/y)	0
	Net retention (m^3/y)	13
Diffuse sediment	Measured area (Ha)	0.26
	Silted profile depth (mm)	0
	Silted volume (m^3/y)	0
Total volume of sediment retained (m^3/y)		13

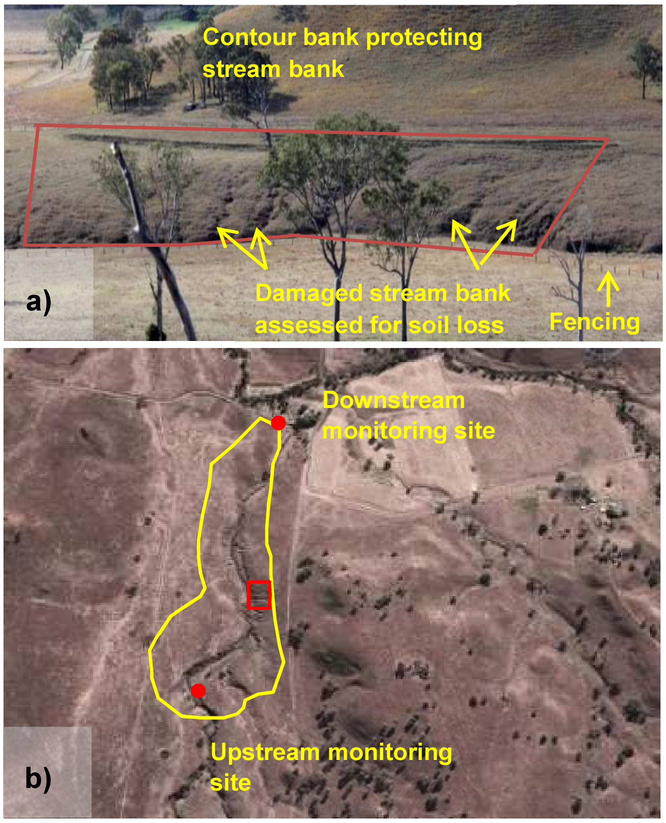


Figure 31 - Damaged stream bank and the gullies chosen for sediment reduction estimates in figure a). The fenced off area of the creek is outlined in yellow in figure b). The red outline shows the area of the on-ground works as outlined in a)

Water quality monitoring

Two water quality monitoring sites were installed, one at the inflow to the fenced off area and one at the outflow (flowing into Oaky Creek further downstream) (Figure 32).

Rising stage samplers (RSS) were installed for the collection of total sediments; these have been unsuccessful in the collection of water for analysis due to discharge events being of insufficient height to trigger sample collection. The RSS will remain in place to monitor for future events of sufficient height.

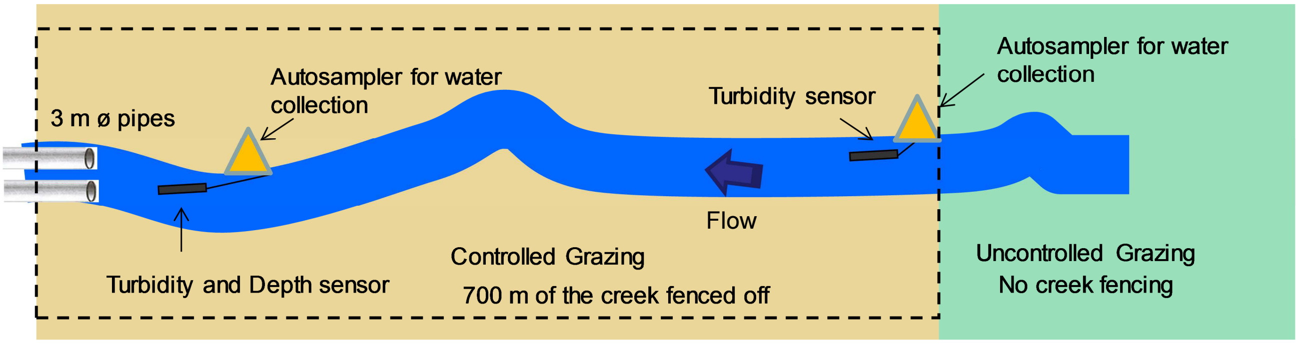


Figure 32 - Controlled grazing creek fencing monitoring design

Loads estimation

Eight events were identified during the monitoring period (2011 to 2012). Of these events, water quality samples were collected during three events at both the inflow site and outflow site (Table 9). For the events that weren't sampled, the height of the water did not reach the heights to trigger the automatic sampler or events were so small that fewer than three samples were taken and loads could not be calculated. Sampling was sufficient across the hydrographs (Appendix C) to ensure a reliable estimate of TSS loads for the three events that were sampled at both the inflow and outflow sites. The total monitored discharge for the outflow site during the monitored period (2011 to 2012) was 685 ML[8].

For the first two events where water quality samples were collected at both the inflow and outflow sites, the TSS loads at the outflow site were larger than at the inflow site by approximately 7 and 44%, respectively (Table 9). For the third event monitored (three months after the commencement of monitoring) the outflow loads were approximately one third of the TSS load at the inflow site (i.e. 63% of TSS was retained) (Table 9). The TSS loads decreased with the increase of natural regeneration of vegetation along the tributary banks. The natural regeneration of vegetation increased after the initial rain events, during the first two months of monitoring.

[8] Discharge was estimated using a theoretical rating curve and not validated using flow gaugings. The discharge volumes and loads estimates are indicative only.

Table 9 - Inflow and outflow, indicative discharge and indicative total suspended solids (TSS) loads

Event no. and date of occurrence	1	2	3	4	5	6	7	8	Total
	(Nov 11)	(Dec 11)	(Dec 11)	(Jan 12)	(Jan 12)	(Jan 12)	(Feb 12)	(Feb 12)	
Inflow Discharge (ML)	41	139	-	346	94	10	5	-	635
Outflow Discharge (ML)	45	150	-	373	101	11	5	-	685
Inflow TSS load (t)	-	463	-	85	40	-	-	-	588
Outflow TSS load (t)	-	495	-	122	15	-	-	-	632
TSS retained across works (t)	-	-32	-	-37	25	-	-	-	-44
% of Inflow TSS retained	-	-7	-	-44	63	-	-	-	-7

Turbidity measurements

Turbidity was successfully measured during four of the eight events. The turbidity of the inflow site compared to the outflow sites shows a decrease of turbidity even for the events where the calculated TSS loads increased. Further monitoring will allow the construction of a site specific turbidity/TSS relationship which will help explain the differences in turbidity measurements compared to the TSS concentrations. Examples of turbidity at the inflow compared to the outflow for events where turbidity data were collected are included in Figure 33.

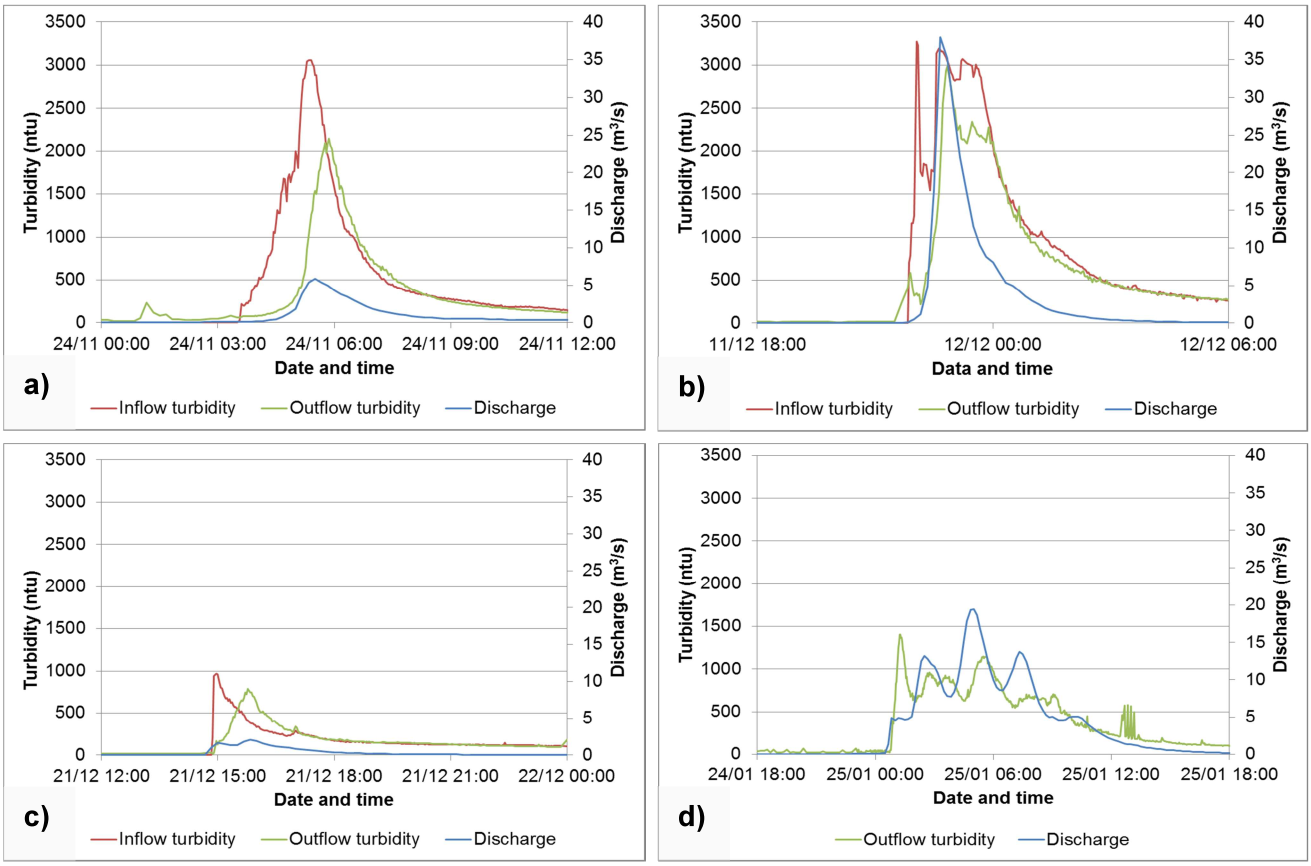


Figure 33 - Discharge and inflow/outflow turbidity measured at Site 6(a) over four events; November 2011 (a), December 2011 first event (b), December 2011 second event (c), and January 2012. There was insufficient turbidity data (due to a radio communication breakdown) at the inflow monitoring site in January 2012

Particle size analysis

At the outflow sites, the relative proportion of particle sizes differed with the fine sand particle size (62-500 µm) making up a greater proportion of particles within samples compared to clay particles (Figure 34).This may have been due to inputs of sediment from stream bank erosion upstream of the outflow site, before the regeneration of vegetation along the stream banks. The clay particles (0.24-4 µm) made up less of the percentage of samples at the outflow compared to the inflow, which may mean that the in-stream vegetation is acting as a filter for small particle sizes. To enable a greater understanding of particle size distribution and the effectiveness of vegetation regeneration on the composition of particles being transported, further monitoring is necessary.

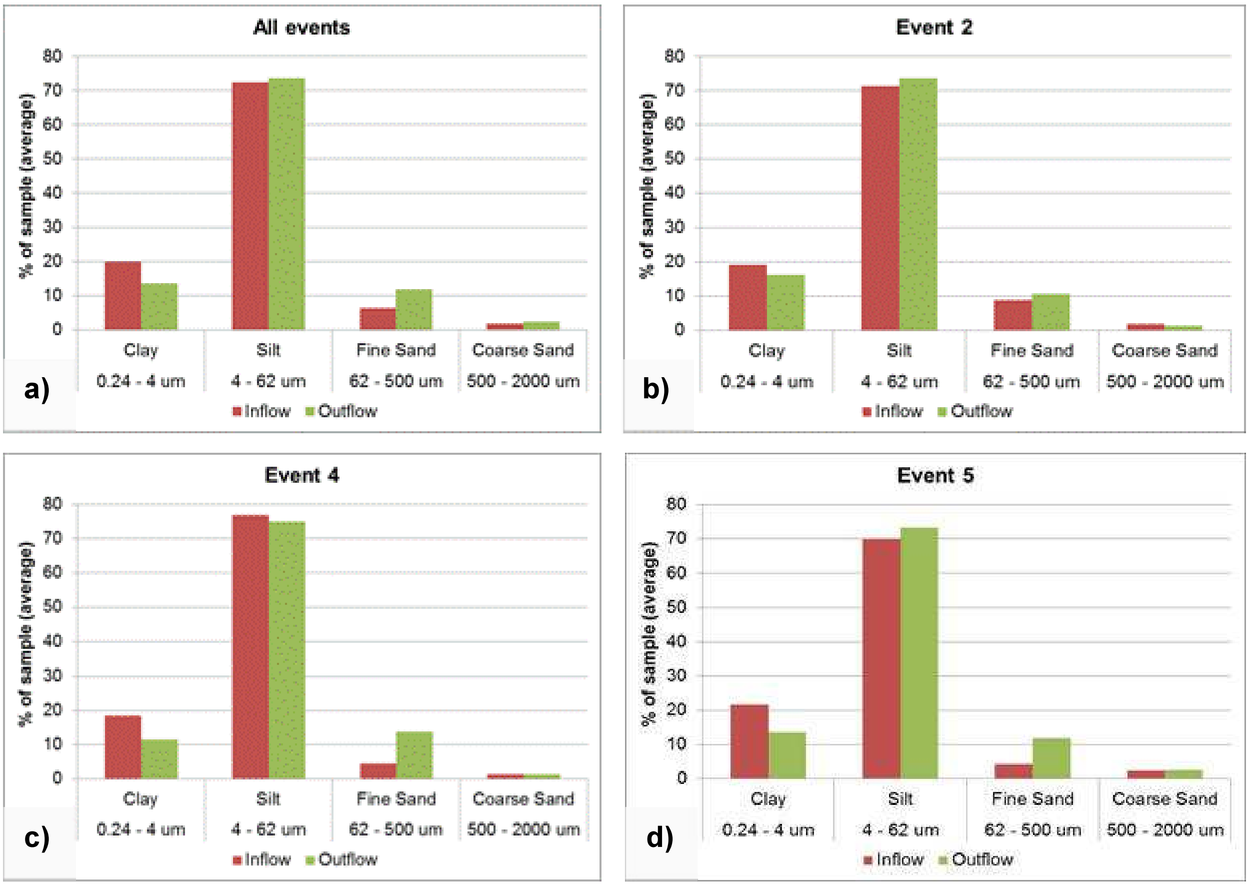


Figure 34 - The particle size distribution of suspended sediment collected from the inflow and outflow of the fenced off section of Oaky Creek for three events (b, c and d). An average particle size distribution for the three events is also presented (a)

Photographic evidence

The photographs in Figure 35 show an increase in stream bank vegetation during the monitoring period. To determine if this vegetation remains and is efficient at stabilising the stream bank, photographic monitoring should continue during the dry season.

Bank erosion before stock exclusion fencing

a) August 2011

Three months after the beginning the wet season, stock still accessing site

b) November 2011

Three months after stock exclusion fencing and three months into monitoring

c) February 2012

Figure 35 - Natural revegetation of stream banks following stock exclusion from the creek

Discussion

The works on this site aimed to exclude livestock from eroding areas and foster natural regeneration of the area. In contrast to other the sites monitored, management actions undertaken at this site did not have an immediate saving on source sediment as the interventions did not immediately stop gully or stream bank erosion. Hence, the sediment savings were not shown in the water quality monitoring results. The benefits of the exclusion fencing will become apparent when the natural vegetation has had sufficient time to establish itself and remain stable. Stream bank and riparian vegetation will assist in the stabilisation of the banks and also aid in filtering of diffuse sediment from other sources in the sub-catchment. The exclusion of livestock will also encourage in-stream vegetation to establish itself which should aid in the reduction of the erosive high velocity discharges.

To determine the cost effectiveness and sediment savings resulting from the on-ground actions at this site, monitoring and evaluation should continue over a longer period after the re-establishment of vegetation and the stabilisation of erosion sources.

Site 6 (b) Results of gully damming and leaky weirs

Of the six methods used to assess the effectiveness of works, three were implemented at this site. These included:

- retention of source sediment
- digital elevation models.
- retention of diffuse sediment

Retention of source sediment

The main gully below the dam had retreated 30 m during the July 2010- June 2011 period, with three smaller gullies retreating approximately 10 m during the same period (Figure 36). The average width of the gullies was 3 m, with an average measured depth of 1 m. Assuming a linear expansion rate and 100% effectiveness of the on-ground works, the total volume of sediment retained as a result of this project was 180 m^3 per year (Table 10), approximately 253 tonnes per year.

Digital elevation models

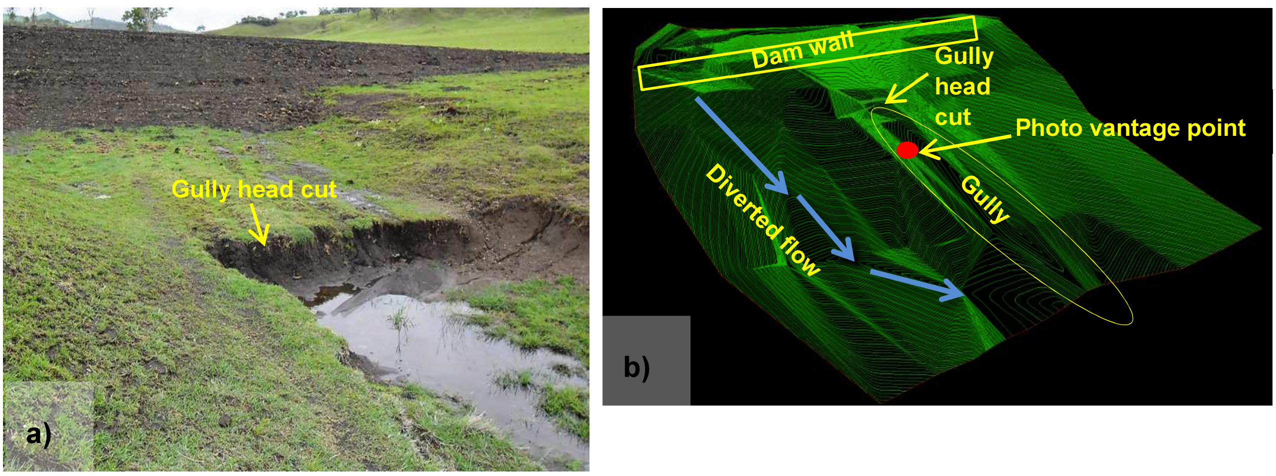


Figure 36 - Newly constructed dam wall and retreating gully head (a). Digital elevation model surveying results from February 2012 (b). Red dot indicates photo vantage point for figure a)

Retention of diffuse sediment

Diffuse siltation monitoring was conducted 10 m behind each leaky weir; no diffuse siltation monitoring was conducted behind the dam wall, as it was heavily disturbed by cattle footprints. It should be noted that diffuse siltation monitoring directly behind the dam would significantly underestimate the volume of sediment retained by the works because any sediment that flows into the dam would be covered by water and could not be measured.

Diffuse siltation monitoring showed that near the leaky weirs there was significant sediment fall, with depths of 12 mm recorded 1 m from the weir over a period of nine months. However, siltation depth sharply decreased with increasing distance from the weir and, at 10 m from the weir, was just observable at 1-2 mm over the same period (Table 10).

Table 10 - Summary information for Site 6(b) and calculated volumes of diffuse source sediment retained by the on-site works: measurements at Site 6(b)

		Site 6(b)
Erosion type addressed in project		Gully and floodplain
Design approach		Three leaky weirs and dam gully repair
Soil geology		Deep fertile dark cracking clays derived from basalt colluvia
Source sediment	Source sediment retained (m^3/y)	180
	Source sediment loss (m^3/y)	0
	Net retention (m^3/y)	180
Diffuse sediment	Measured area (Ha)	0.01
	Silted profile depth (mm)	5.5
	Silted volume (m^3/y)	1
Total volume of sediment retained (m^3/y)		181

Discussion

The construction of the dam wall appears to have effectively diverted flow around the original gully erosion problem towards a more stable area. The leaky weirs installed above the dam wall have also been successful in the retention of water for a longer period of time to encourage siltation over a larger expanse. Over a longer period of time the silt that accumulates behind the leaky weirs may redirect the discharge path and this will need to be monitored and evaluated.

The new discharge path around the original gully may also pose threats to other areas that may not be stable. As such, monitoring of these discharge paths should continue so that flow-on effects can be managed. Further regeneration or revegetation may assist in stabilising the area. However the requirement for physical works for water quality improvement and increased sediment savings will need to be balanced against the economic loss to the landholder that results from removing land from production.

Site 7 – Gully damming and flow diversion through wetland

The site

This alluvial gully site is located on the edge of a hillside, on slightly sloping country to the west of the Oakey Creek flood plain. The erosion was cutting back along a broad drainage line and just below the junction of two catchments with a total area of 94 ha (Figure 37). The soils are cracking clay of reasonable depth.

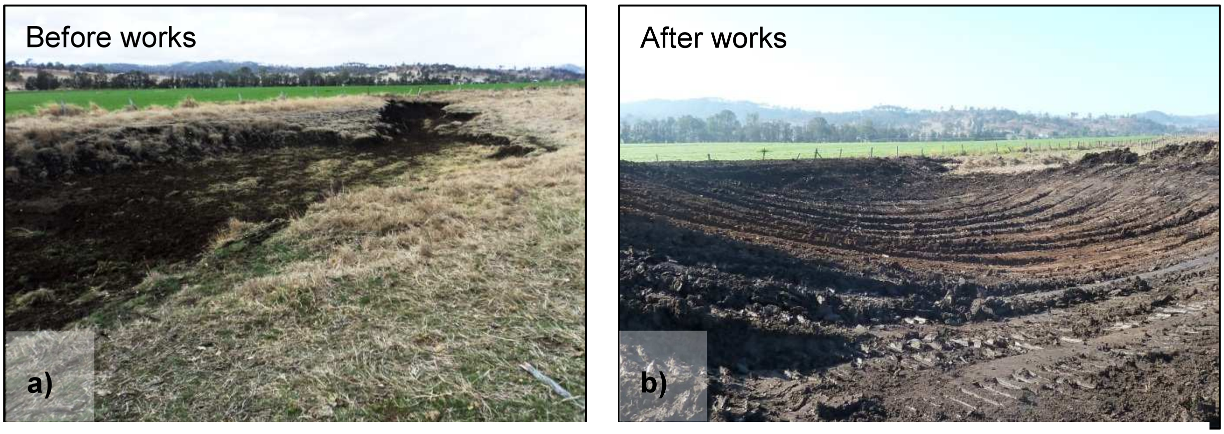


Figure 37 - The gully before (a), and after (b) construction of the dam to drown the gully head

Works undertaken

The following works were undertaken:

- soil erosion control works to address the retreating gully head
- construction of a dam above the gully head but below the catchment junction
- construction of a dam with a 1 m freeboard (bank built 1 m above spillway height)
- construction of a by-wash with a 10 m flat bottom, extending far enough out into the paddock to avoid further retreat from the gully before the timbered section of the paddock
- stabilisation with grass.

Gully and flood plain erosion management

The gully had a strong head cut, and was dammed to flood the head cut and stop erosion. The by-wash was constructed to spread the overflow from the dams (with the assistance of berms) over the surrounding paddocks and down into an area of natural wetland. The wetland was enhanced to increase the capacity and stability of the system, to improve the quality of the water it provides.

Results of gully damming and flow diversion through wetland

Of the six methods used to assess the effectiveness of works, four were implemented at this site. These included:

- retention of source sediment
- retention of diffuse sediment
- bedload sediment movement
- water quality monitoring.

Retention of source and diffuse sediment

The gully had increased 20 m from 2010 to 2011, and was approximately 3 m wide and 2 m deep through sections. Stabilising this expanding gully saved 120 m^3. Stopping any further expansion was critical as it would have resulted in the loss of cropping land and once the gully head reached unprotected areas, gully expansion would likely have increased exponentially if works were not undertaken.

A low-lying section before the drowned head had dried out and was monitored for diffuse siltation. The average depth was 7.3 mm over the area shown in Figure 38 with a total volume of 9 m^3 calculated. This is a conservative estimate as it is unknown what volume of additional sediment has been carried into the drowned gully, which is covered by water. The volume of sediment deposited in the drowned gully could be significant as runoff entering this region would have the slowest velocity, and hence the most sediment fall. Overall the sediment retained on site due to the works was calculated at 129 m^3 (Table 11), approximately 181 tonnes per year.

Table 11 - Summary information for Site 7 and calculated volumes of diffuse source sediment retained by the on-site works: measurements and estimates at Site 7

		Site 7
Erosion type addressed in project		Gully, floodplain reinstatement
Design approach		Dam for bank repair and floodplain reinstatement
Soil geology		Deep fertile dark cracking clays derived from basalt colluvia
Source sediment	Source sediment retained (m^3/y)	120
	Source sediment loss (m^3/y)	0
	Net retention (m^3/y)	120
Diffuse sediment	Measured area (Ha)	0.13
	Silted profile depth (mm)	7.3
	Silted volume (m^3/y)	9
Total volume of sediment retained (m^3/y)		129

Figure 38 - Location of dammed gully and area of diffuse siltation monitoring (outlined in red)

Bedload sediment movement

Bedload sampling with turf mats proved unsuccessful as the low friction surface of the turf mat did not give a representative measurement of the soil which could be seen to have fallen in the surrounding area. For future monitoring of sediment fall, turf mats are not recommended.

Water quality monitoring

Rising stage samplers (RSS) were installed for the collection of total sediments; these have been unsuccessful in the collection of water for analysis.

Discussion

The battering and revegetation of the newly formed gully successfully stopped the export of sediment from the previously retreating gully head and stabilised the area. The construction of the dam was also successful in retaining diffuse sediments from inflow. The new discharge path is effectively diverting water through a natural wetland which will enable a larger percentage of sediments to settle out before reaching Oaky Creek. To determine the long-term success of the on-ground works and the ability of the wetland to filter out sediments during high discharges, further monitoring and evaluation of the site should be undertaken. Further regeneration of the discharge path and the wetlands will aid in reducing the erosive velocity of water and aid in reducing the volume of sediments exported to Oaky Creek.

The monitoring of water quality using RSS was not successful during the monitoring year due to placement in an area where water discharge was not constricted enough to enable the collection of samples. The RSS has been relocated and for successful quantification of sediment retention by the dam and wetland, monitoring and evaluation should continue over time.

Evaluation of monitoring strategies

Retention of source sediment

This is a cost effective way of assessing the direct benefit of repairing and stabilising actively eroding areas in the landscape. However, the results do not give an estimate of sediment volume which will be transported to the local waterway. Hence, this monitoring will not provide the necessary information to estimate the benefits that the physical works will have on aquatic ecosystems, be they the local waterways or Moreton Bay.

Retention of diffuse sediment

This is a cost effective way of assessing the ongoing benefit of implementing physical works which slow flow velocities over the landscape and thereby encourage diffuse sedimentation. However, the accuracy of this monitoring method is relatively low as deposition areas are hard to define accurately, and require experience and visual cues. Also, when measuring 1mm to 2mm of sediment deposition the error is likely to be high as it is hard to differentiate newly laid soil on top of the soil profile. Over a large area this would translate to large errors in sediment volumes. Similarly, when newly laid sediment can’t be seen clearly on top of the soil profile, deposition is still present; in general this monitoring method will significantly underestimate diffuse sedimentation. Diffuse sampling fails to measure the fraction of sediment which remains suspended in overland flow and then flows into creeks and rivers and to estuaries and bays. Figure 8 and 34 show that 80-90% of the sediment collected in the automated water quality stations was fine sediment (less than 62 µm), much of which would not settle out as it passed through the wetland. This is because even in completely still conditions it is unlikely that particles less than 10 µm will settle out discretely according to Stoke’s Law (1851). Hence, though the diffuse sampling method may give a snapshot of processes taking place, it does not monitor the finer sediment and therefore cannot be used to calculate an accurate TSS load reduction due to the works.

Bedload sediment movement

Bedload sampling with turf mats proved unsuccessful as the low friction surface of the turf mat did not give a representative measurement of the soil which had fallen in the surrounding area, which could be seen upon visual inspection. Furthermore in treed areas, leaves and sticks would often cover the mat making sediment build up assessments difficult. For future monitoring of sediment deposition, turf mats are not recommended. The USEPA-approved Helley Smith bedload samplers were installed at two sites in May 2012 to assess their effectiveness in monitoring bed load movement before and after works. To date, no results have been collected in these samplers.

Water quality monitoring

Automated water monitoring stations

The use of automated water monitoring stations with continuous turbidity measurements has proven successful in showing the effectiveness of water quality improvement in this project. Limitations of this approach are that these are expensive monitoring systems which require a high level of technical skill to design, install and operate, also, the data collected requires a well-developed system for data storage and analysis. When measuring wetland areas for sediment deposition and sediment movement out of the system it is important that the discharging water passes through a channelled point to enable the measurement of the loads passing through and out of the measured area. Many of the sites where works were implemented were not able to be monitored via automated water quality stations as they had no defined channel, or could not be

accessed during runoff events. However, of the monitoring techniques trialled in this project, this method provided the most accurate calculation of the load of sediment transported in overland flow.

The constant drying and wetting cycle of the Bremer wetland has proven challenging for the acquisition of consistent high quality turbidity data, preventing an assessment of the relationship between turbidity and TSS for the inflow and outflow water quality monitoring stations. Similarly, more data needs to be collected from the monitoring stations on Oaky Creek before a site specific TSS\Turbidity relationship can be developed for continuous sediment load monitoring.

Rising Stage Samplers

In total eight samples were collected from rising stage samplers (RSS),from seven RSS stations, six of these from Site 8. The best collection achieved was 2 bottles at the upstream station and 2 bottles at the downstream station during one event. However, TSS and particle size distribution concentration of all four bottles was highly variable, and was not useful in assessing the effectiveness of works. Over a number of wet seasons (approximately 10) RSS sampling may give results that can represent the concentration and the particle size of sediments in surface flow; however for short-term monitoring programs they are not recommended.

Using RSS for paddock scale monitoring presents the following challenges:

1. There is often no clearly defined channel (i.e. wetlands) and knowing where to place the RSS sampler so it will be submerged and take even one sample during a runoff event can be problematic.
2. Similarly, for paddock scale monitoring surface flow is often dispersed across the paddock after the implementation of works to encourage sediment settling. The resulting shallow water flow across the paddock makes it difficult to collect more than 2 bottles using a RSS system, which is inadequate to properly represent of the TSS concentration of the event.
3. When trying to determine sediment loads, samples must be collected on the rising and falling limbs of the hydrograph, this is highly labour intensive as bottles need to be replaced during the event, and for smaller catchments (such as in paddock scale monitoring) or wetland monitoring this is dangerous and unrealistic.

Digital Elevation Models (DEM) and photographic evidence

Surveys, both to develop DEMs and compile photographic history of the effectiveness of works, provided informative data that enabled the assessment of the stability of on-ground works. Further surveys to develop DEMs will enable the calculation of any sediment losses over time, allow the identification of areas of instability and inform the direction of further management options.

Conclusion and recommendations

The monitoring of targeted rehabilitation works, aimed at reducing sediment export to waterways entering Moreton Bay, set out to quantify sediment savings as a result of these works. The works were aimed at reducing erosion and sediment transport from hill slopes, gullies and stream banks in three focal catchments. Monitoring also aimed at developing knowledge in the efficacy of different management actions to assist in the reduction on sediment loads entering Moreton Bay. Collecting paddock scale data of this kind can be used to develop models that will be invaluable in the development of a water quality metric for South East Queensland.

Various forms of monitoring and the estimation of retention of source and diffuse sediment, permitted the estimation of total sediment savings as a result of works. A total of 8366 m^3/y of sediment was estimated to be retained at its source from repairing and stabilising actively eroding areas. A further 1870 m^3/y of diffuse sedimentation of finer silts and clays settled out from overland flow before and after works. This equates to approximately 14,330 tonnes of sediment that was saved from exportation to waterways in SEQ from the sites monitored in this report.

Table 12 - Proportion of sediment retained at its source due to the implementation of works compared to the volume of sediment which settled out from overland flow before and after works

Sediment retention due to implementation of works	
Source sediment *resulting from stopping gullies and streambanks from further erosion due to implementation of physical works*	8366 m^3/y
Diffuse sediment *resulting from finer sediment settling out from overland flow before and after works*	1870 m^3/y
Total sediment retention for the projects assessed	**10,236 m^3/y**
Total sediment retention for the projects assessed	***14,330 t**

***Conversation factor of 1.4 used to convert cubic metres to tonnes**

Note: The above sediment retention figures refer to the mentioned projects in this report, which are both CfoC and Healthy Country works.

The findings from the sedimentation assessments showed that most of the sediment saving is likely to arise from repairing and stabilising actively eroding gullies and stream banks (82%), rather than diffuse sedimentation across the landscape. Though diffuse sedimentation was only 18% of the total retained sediment, it is more likely to be composed of finer sediment particles (silts and clays) than the sediment eroding from gullies and stream banks, which consists of both coarse and fine sediment. It is reduction of the finer silts and clay particles, which can be mobilised over long distances, that is more important for water quality in Moreton Bay. In future monitoring, water quality monitoring should be accompanied by comprehensive soil sampling of both diffuse and source sediments.

These findings assume that the erosion scars would have continued at a similar rate, and indeed it is highly like that for the following year or two a similar rate of expansion would have occurred (depending on rainfall). However, gullies generally head toward a more stable state as source material is exhausted and the sides of the channel become less steep, slowing the rate of erosion and loss of sediment (Hughes et al. 2001). Hence, in the short term, the effectiveness of the physical works is largely dependent on the success of the works in repairing and stabilising fast moving gully heads and stream banks. However, in the long term it is the ability of the works to enable diffuse sedimentation to occur over the landscape which will improve water quality as it targets the range of particle sizes that impact river and marine ecosystems (Lewis et al. 2009).

Therefore, where the project goal is to protect estuaries and bays, physical works that encourage diffuse sedimentation should be prioritised when implementing works in the landscape.

The reinstated wetland at the Bremer catchment site has proven the value of this approach to sediment management and provides a great example of the above discussion. Stabilisation of the gully and stream bank occurred as a one-off sediment saving. However, the diffuse siltation occurring across the wetland will continue into the future and this ongoing sediment capture is likely to consist of the finer particle size ranges that are most likely to reach Moreton Bay.

By repairing the source of sediment gully at the inflow of the wetland, significantly more flow was directed through the outflow of the wetland. Importantly the outflow gully was fenced off to cattle and thick vegetation has been left undisturbed. It also allows the large flows to enter the Bremer River as distributed flow over approximately 100 m and therefore the discharge velocity is significantly reduced, minimising its erosive potential.

The design of rehabilitation works (to reduce sediment export to waterways) should ideally include the facility to reduce anthropogenic disturbance, with an emphasis on reducing the erosive velocity of high flows by targeting their source. Design factors that also ensure repairs are stable in the long-term will reduce the cost of ongoing maintenance.

Water quality monitoring has validated the sediment savings estimates but quantification of loads of contributed sediment (on the Bremer Wetland) from monitoring sites was only successfully undertaken after the targeted works were completed. It would be beneficial for future monitoring to obtain a baseline understanding of the quality of water flowing into the sites. This would allow a complete understanding of the sediment composition, mobilisation and transport from other areas of the sub-catchment that may have contributed to the sediment loads. The use of automated water sensors with continuous turbidity measurements has also proven successful in showing the effectiveness of water quality improvement in two of the targeted works projects and can be further refined to allow a cost effective monitoring strategy that can be deployed over a longer period.

The sediment retention and water quality monitoring results presented in this report are useful in determining the volume of sediment that has been retained at a site. However, additional information which includes particle size distribution of the eroded and deposited material would be useful in estimating what proportion of sediment may be transported into Moreton Bay.

The establishment of works to reduce the export of sediment were conducted during an average wet year and the revegetation of these works was stable over all sites with ground cover fairly consistent over all areas. This vegetation will be reliant on the average rainfall during a year and in times of drought the vegetative ground cover may reduce. A reduced vegetation cover may result in further erosion and the stability of works should be monitored through wet and dry years to determine if the reduction of sediments remains consistent.

Over the long term (3-5 years) water quality monitoring at the paddock scale will provide data which will aid the successful development of a water quality metric for SEQ (DERM 2010) and quantify the effectiveness of on-ground management actions. Additional paddock scale assessments should be made on different soil types, current land management practises and novel management actions that will allow the generation of informative data. In conjunction with the data from the event monitoring system already in place in SEQ, this data will support the development of models that simulate processes involved in sediment export from landscapes, further quantify the effectiveness of targeted on-ground actions, improve farming management practises and inform cost benefits analyses The information gathered will also lead to the enhancement of monitoring and evaluation programs in SEQ to better inform adaptive management strategies, government policy and legislative development.

References

12d Solutions Pty Ltd. 2009 12d Model software (version 9.0). Sydney, NSW, Australia.

Australian Government 2009. Appendix 2. Australian Soil Resources Information System. Retrieved September 2012 from Australian Agricultural Assessment. http://www.anra.gov.au/topics/soils/pubs/national/agriculture_asris_density.html.

Commonwealth of Australia 2012a. *Record-breaking La Niña events. An analysis of the La Niña life cycle and the impacts and significance.* Melbourne VIC 3001: Bureau of Meteorology, July 2012.

Commonwealth of Australia 2012b. *Climate Data Online*. Retrieved September 13, 2012, from

Bureau of Meteorology : http://www.bom.gov.au/climate/data/

DERM 2010. Development of a water quality metric for south-east Queensland: To enable effective policy and program design and the use of market-based instruments in the Lockyer, Bremer and Logan catchments, Department of Environment and Resource Management, Brisbane.

DNRM 2005. Hydrographic operational procedures – Rating, Version 1.30, Department of Natural Resources and Mines, Brisbane.

DPI 1993. Hydrographic procedure No. 7 – Rating curves: a practical approach to preparation, Data Acquisition Group, Water Resources Division, Water Resources Group, Department of Primary Industries, Brisbane.

eWater 2012. Water Quality Analyser, eWater Limited Canberra, Australia, <http://www.ewater.com.au/products/ewater-toolkit/eco-tools/water-quality-analyser/>.

Helley, E.J. and Smith, W. 1971. Development and Calibration of a Pressure-Difference Bed Load Sampler. U.S. Geological Survey Open File Report, Washington, USA.

Hughes A., Prosser I., Stevenson J., Scott A., Hua L., Gallant J., and Moran C. 2001. Gully Erosion Mapping for the National Land and Water Resources Audit Technical Report 26/1, Commonwealth SIRO Land and Water.

Lewis, S. E., Bainbridge, Z. T., Sherman, B. S., Brodie, J. E. and Cooper, M. 2009. The trapping efficiency of the Burdekin Falls Dam: Estimates from a three-year monitoring program. Report to the Marine and Tropical Sciences Research Facility, Reef and Rainforest Research Centre Limited, Cairns and Australian Centre for Tropical Freshwater Research (ACTFR), Townsville, 31pp.

Olley, J., McMahon, J., Ward, D., Saxton, N., Pietsch, T., Laceby, P., Bland, A., Rose, C. & Pantus, F. 2010. 'Healthy Country Project Phase 2b Report: Rehabilitation Priorities Upper Bremer River". eWater Cooperative Research Centre in SE Queensland, Brisbane.

SEQHWP 2007. South East Queensland Healthy Waterways Strategy 2007-2012. South East Queensland Healthy Waterways Partnership, Brisbane. <http://www.healthywaterways.org/TheStrategy/ActionPlanLinks.aspx>

Thompson, W.P. 2011. Design Notes: 2pp. SEQ Catchments Project 2011, Land Resources Assessment and Management Pty Ltd.

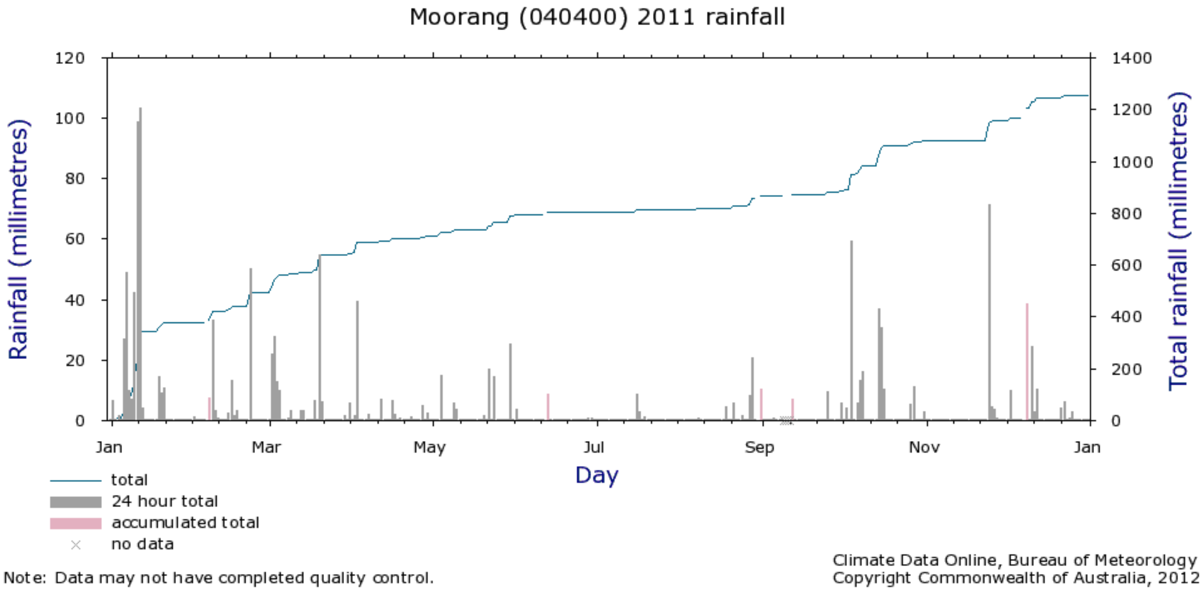
Thomson B., Rogers B., Dunlop J., Ferguson B., Marsh N., Vardy S. and Warne M. St. J. In Preparation. A framework for selecting the most appropriate load estimation method for events based on sampling regime, Department of Science, Information Technology, Innovation and the arts, Brisbane.

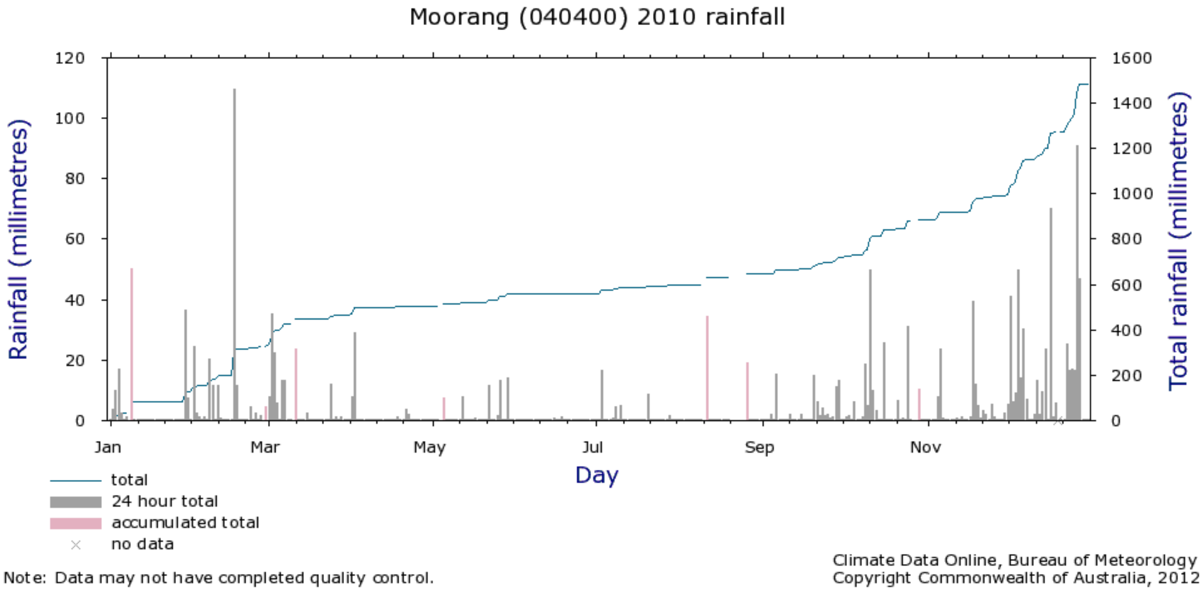
Appendices

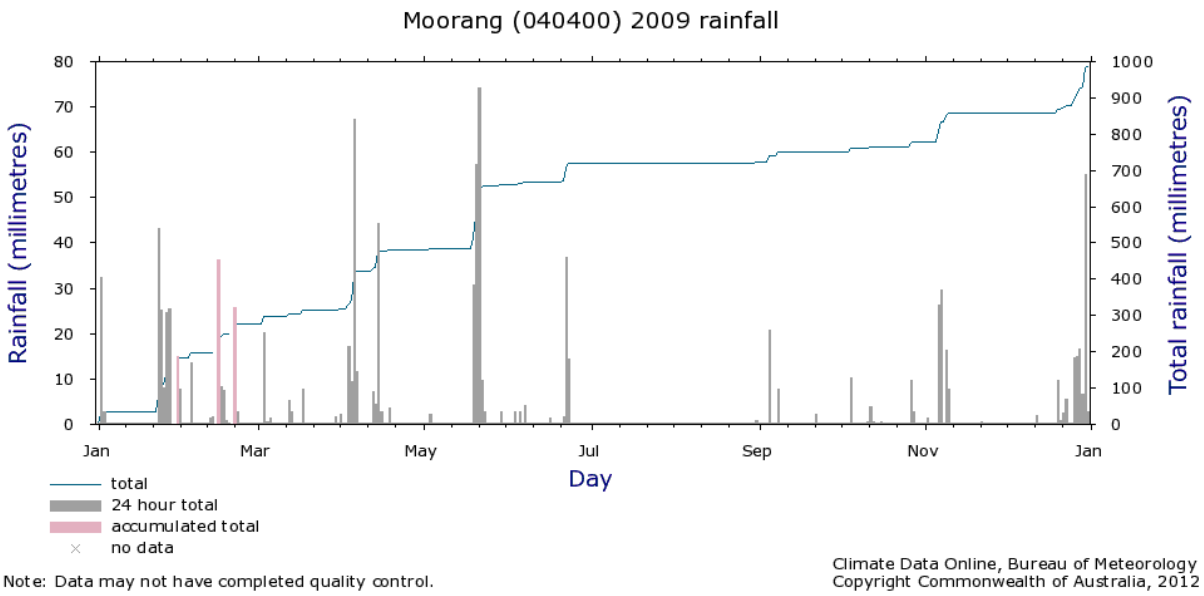
Appendix A – Rainfall Data

The following data were retrieved from the Bureau of Meterology online climate database (Commonwealth of Australia 2012b).

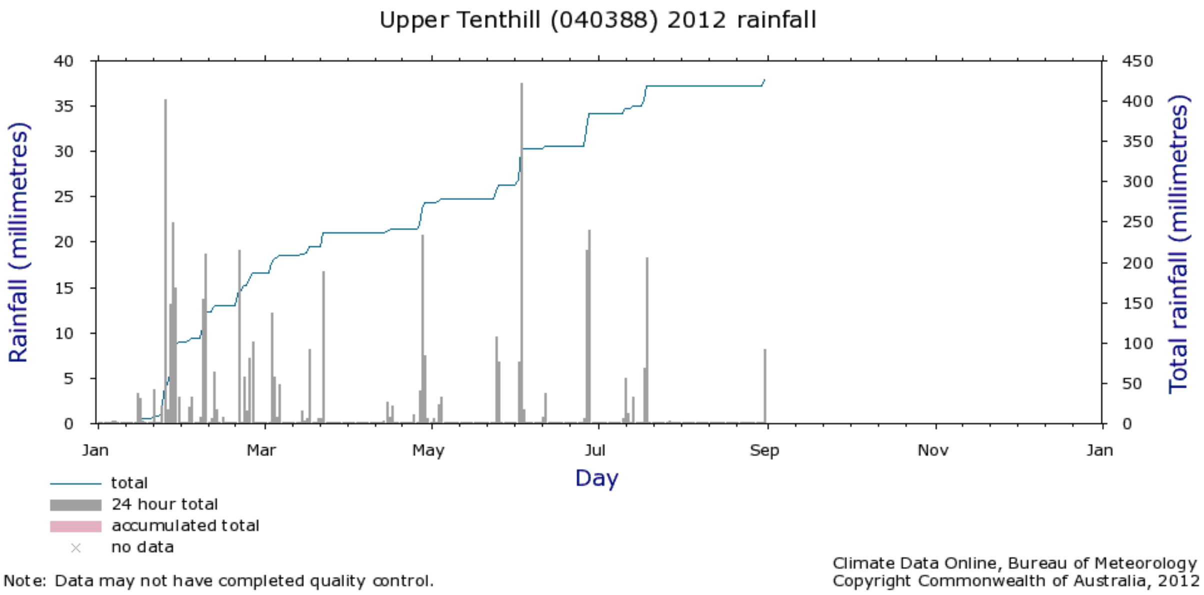
Rainfall Data: Bremer

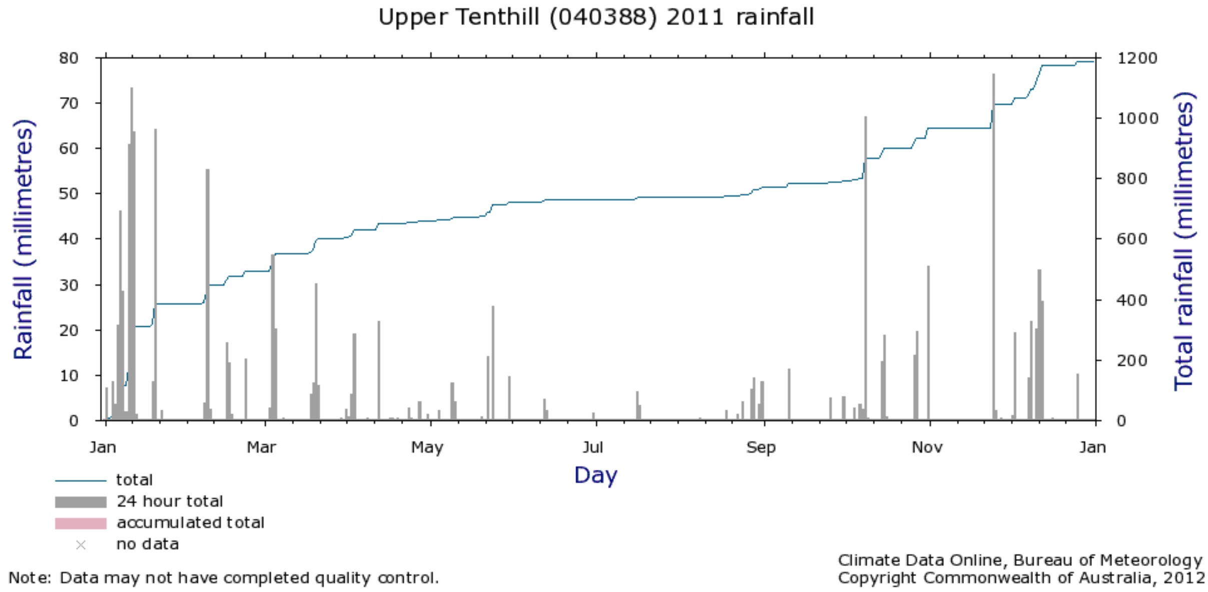


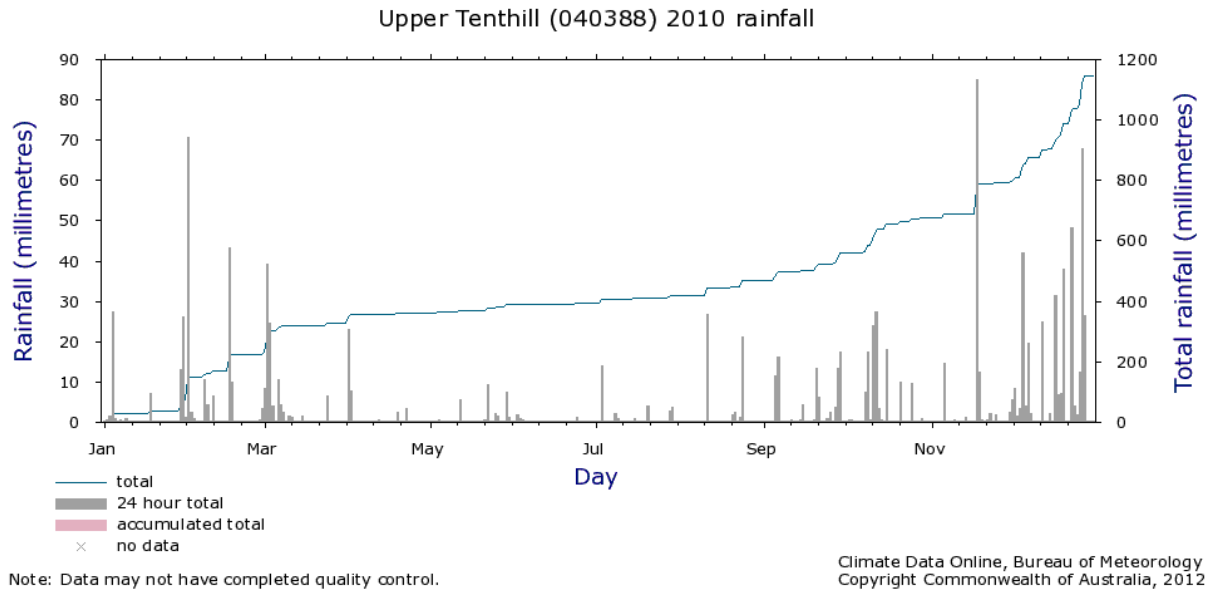


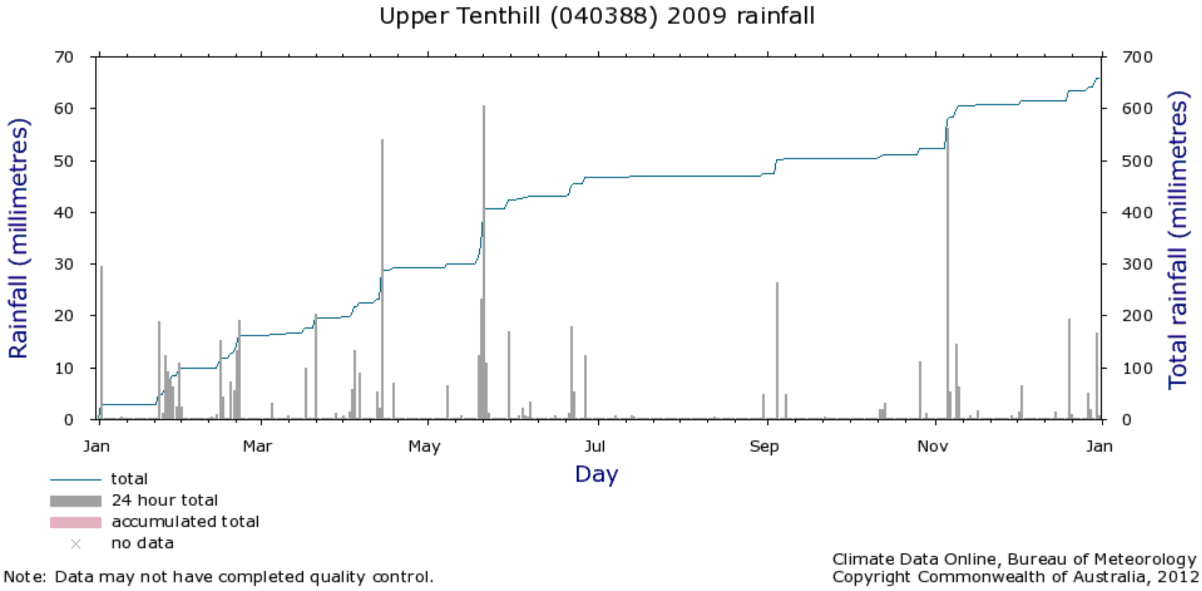


Rainfall Data: Lockyer

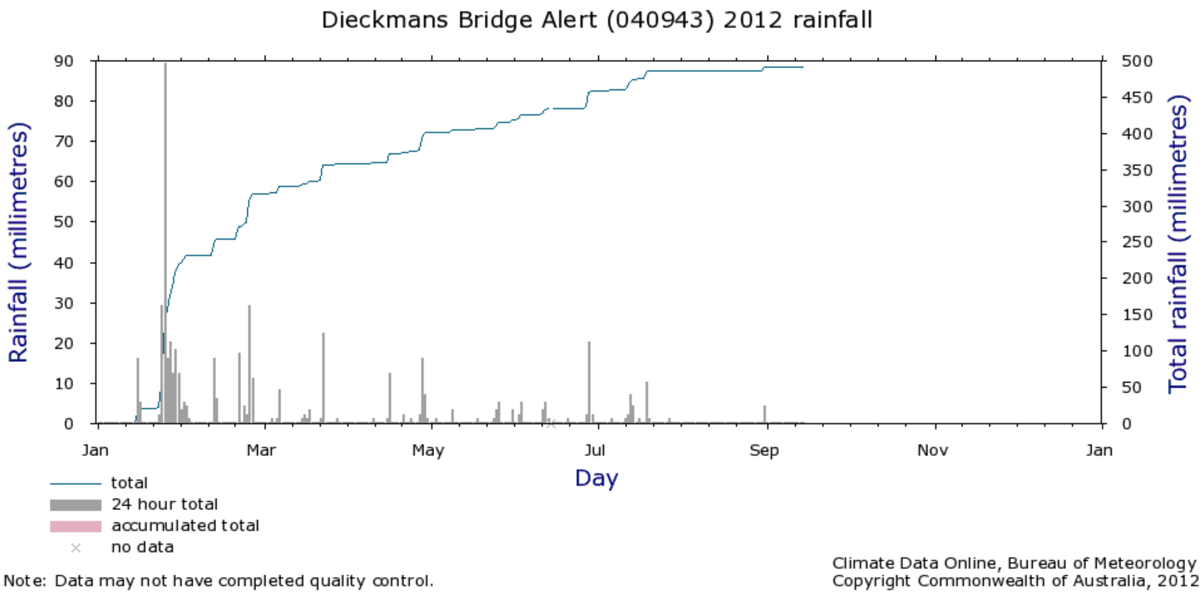


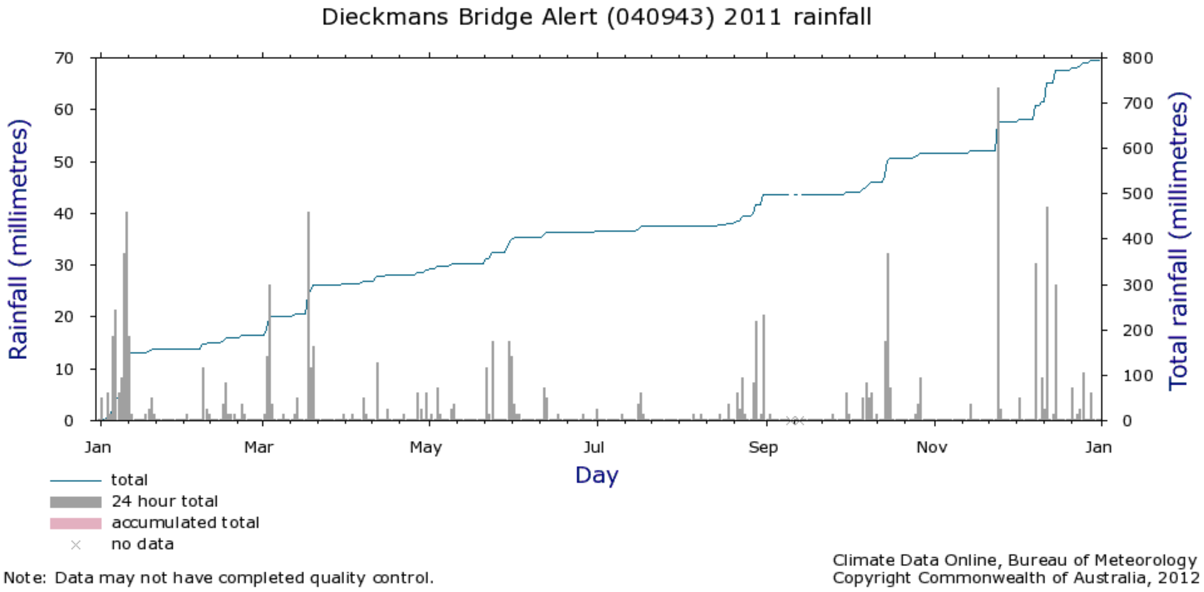

Upper Tenthill (040388) 2011 rainfall
Rainfall (millimetres)
Total rainfall (millimetres)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
Jan
Mar
May
Jul
Sep
Nov
Jan
Day
total
24 hour total
accumulated total
no data
Note: Data may not have completed quality control.
Climate Data Online, Bureau of Meteorology
Copyright Commonwealth of Australia, 2012

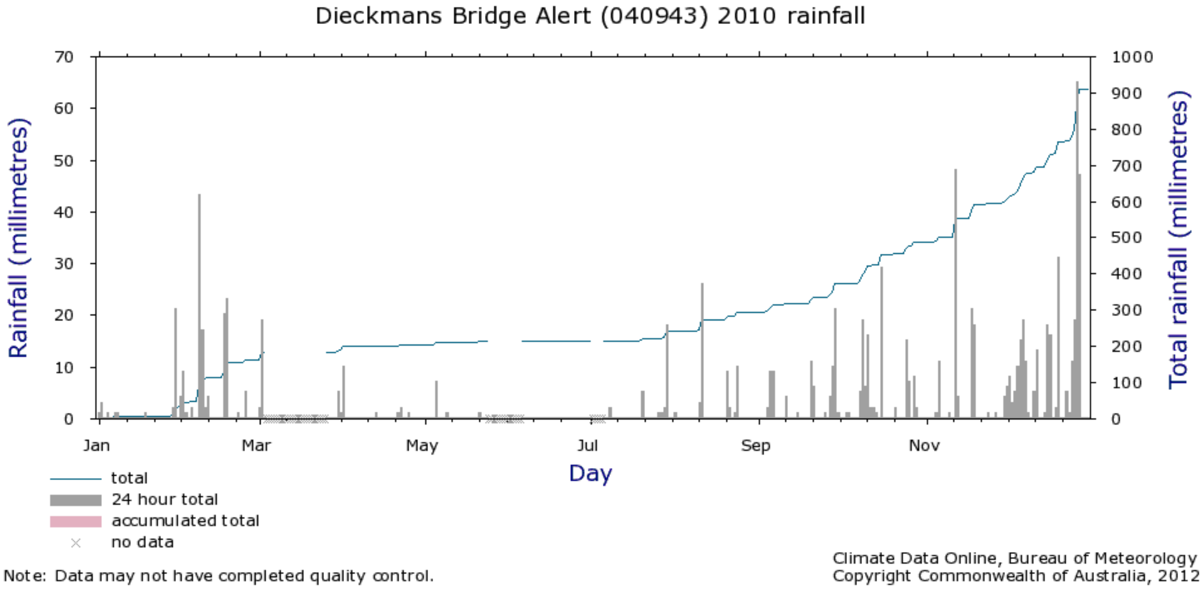

Upper Tenthill (040388) 2010 rainfall
Rainfall (millimetres)
Total rainfall (millimetres)
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200
Jan
Mar
May
Jul
Sep
Nov
Day
total
24 hour total
accumulated total
no data
Note: Data may not have completed quality control.
Climate Data Online, Bureau of Meteorology
Copyright Commonwealth of Australia, 2012



Rainfall Data: Logan




Dieckmans Bridge Alert (040943) 2011 rainfall
Rainfall (millimetres)
Total rainfall (millimetres)
Day
Jan
Mar
May
Jul
Sep
Nov
Jan
total
24 hour total
accumulated total
no data
Note: Data may not have completed quality control.
Climate Data Online, Bureau of Meteorology
Copyright Commonwealth of Australia, 2012


Dieckmans Bridge Alert (040943) 2010 rainfall
Rainfall (millimetres)
Total rainfall (millimetres)
Day
Jan
Mar
May
Jul
Sep
Nov
total
24 hour total
accumulated total
no data
Note: Data may not have completed quality control.
Climate Data Online, Bureau of Meteorology
Copyright Commonwealth of Australia, 2012

Appendix B – Sediment estimates

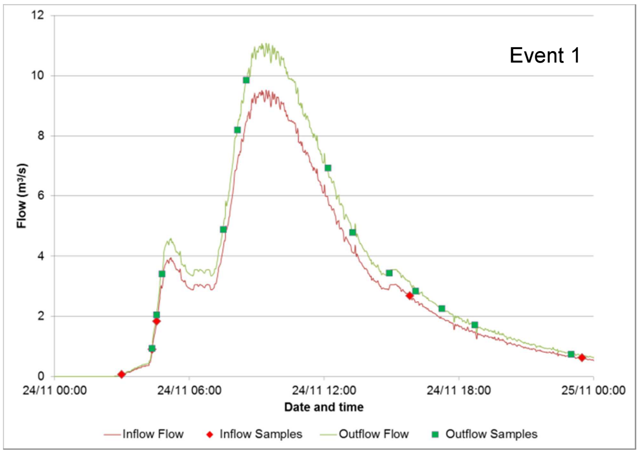
		Site 1- Inflow	Site 1 - Outflow	Wetland Total	Site 2	Site 3	Site 4	Site 5	Site 6 (a)	Site 6 (b)	Site 7	Totals
Site Characteristics	Erosion Type Addressed in Project	Steam Bank, Gully and Flood Plain	Steam Bank, Gully and Flood Plain	Steam Bank, Gully and Flood Plain	Gully and Flood Plain	Stream Bank and Gully	Gully, Stream Bank	Gully	Steam Bank, Gully and Flood Plain	Gully and Flood Plain	Gully, flood plain reinstatement	
	Design Approach	Leaky weir for bank repair and flood plain reinstatement	Bank repair and fencing for cattle management	Leaky weir for bank repair and flood plain reinstatement	Battering and flow redirection for bank repair and flood plain reinstatement	Dam for bank repair and flood plain reinstatement	Rock shoot for bank repair and gully stabilisation	Large swale for gully repair	Contour bank for stream bank protection, fencing for cattle management	Three Leaky weirs and dam for gully repair	Dam for bank repair and flood plain reinstatement	
	Soil Geology	Deep fertile alluvial soils, runoff from WCM area's	Deep fertile alluvial soils, runoff from WCM area's	Deep fertile alluvial soils, runoff from WCM area's	Low fertility, highly dispersive sodic soils from WCM	Dark cracking clays derived from basalt colluvia	Dispersive sandy loam soils near creek flats to fertile clays above derived from basalt colluvia	Dispersive sandy loam soils near creek flats to fertile clays above derived from basalt colluvia	Deep fertile dark cracking clays derived from basalt colluvia	Deep fertile dark cracking clays derived from basalt colluvia	Deep fertile dark cracking clays derived from basalt colluvia	
	Time (yrs) of expansion	3	3	3	1	1	3	2	2	2	2	22
	Estimated length increase	90	75	165	150	100	30	50	50	120	40	870
Retention of Source Sediment (m^3/y) *Resulting from stopping gullies and streambanks from further erosion due to implementation of physical works*	Percent of Works Pass	100	100	100	98	98	80	100	100	100	100	
	Percent of Works Fail	0	0	0	2	2	20	0	0	0	0	
	Length Increase (m)	30	25	55	150	100	10	25	25	60	20	
	Width Increase (m)	4	5	9	6	10	12	6	1	3	3	
	Depth Increase (m)	4	3	7	2	5	4	1	0.5	1	2	
	Vol Retention to Date (Pass)	480	375	855	1800	5000	480	150	12.5	180	120	**8598**
	Vol Export to Date (Fail)	0	0	0	36	100	96	0	0	0	0	**232**
	Expansion Type	Expon	Linear	Expon	Expon	Expon	Linear	Linear	Linear	Linear	Linear	
	Net Retention (m^3/y)	**480**	**375**	**855**	**1764**	**4900**	**384**	**150**	**13**	**180**	**120**	**8366**
Retention of Diffuse Sediment (m^3/y) *Resulting from finer sediment settling out from overland flow before and after works*	Direct to Stream		Y		Y	Y	Y	Y	Y	Y		
	Direct to Floodplain	Y		Y							Y	
	Area (Ha)	3.825	3.825	24.48	2.4	0.0732	0.024	0.01	0.26	0.01	0.1276	
	Silted profile depth (mm)	9.3	3.4	6.3	13	4.25	0	0	0	5.5	7.25	
	Silted Vol (m^3/y)	**354**	**129**	**1545**	312	3.111	0	0	0	0.55	9.251	**1870**
	Total volume of sediment retained (m^3/y)	**834**	**504**	**2400**	**2076**	**4903**	**384**	**150**	**13**	**181**	**129**	**10236**
	***Total volume of sediment retained (Tonnes per year)**	**1167**	**706**	**3360**	**2906**	**6864**	**538**	**210**	**18**	**253**	**181**	**14330**

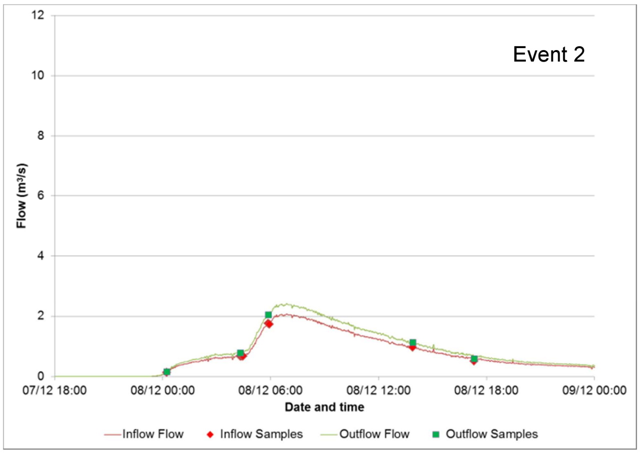
WCM denotes Walloon Coal Measures. *Conversation factor of 1.4 used to convert cubic metres to tonnes

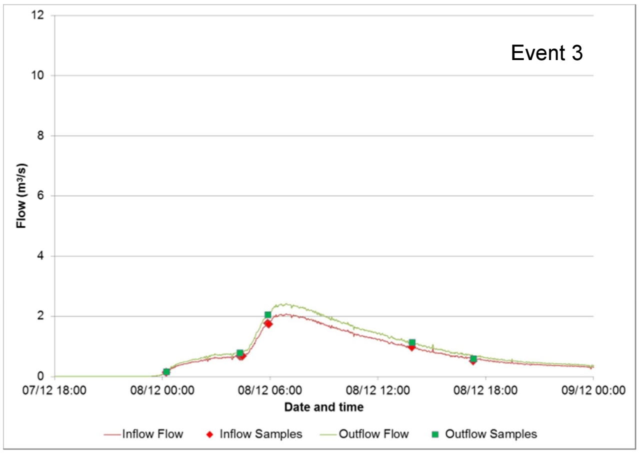
Appendix C – Sample distribution over the hydrograph

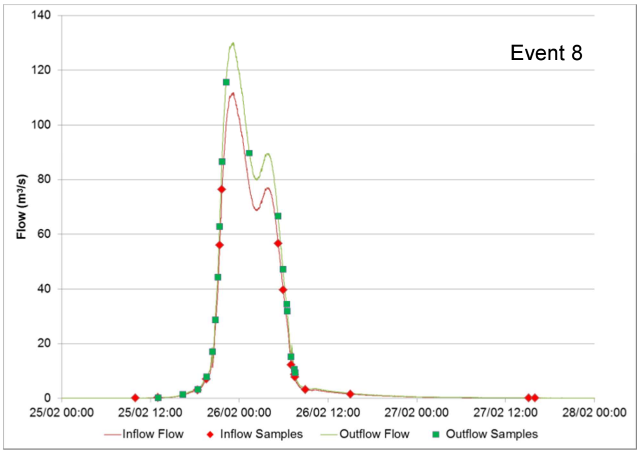
Site 1 – Wetland reinstatement

Wetlands inflow and outflow

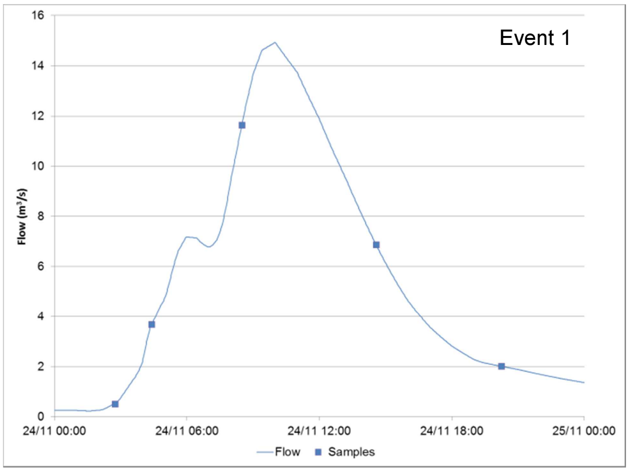


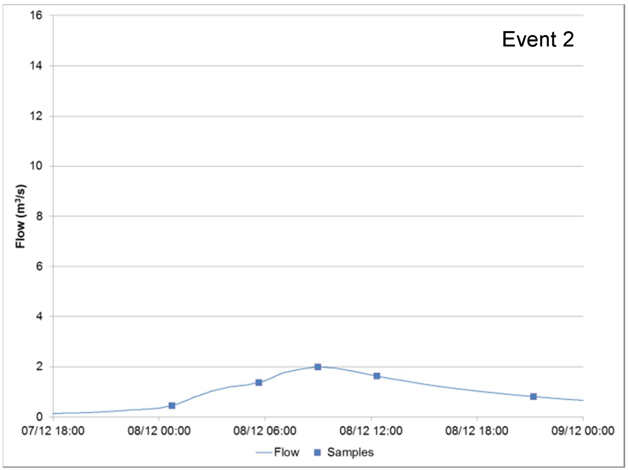


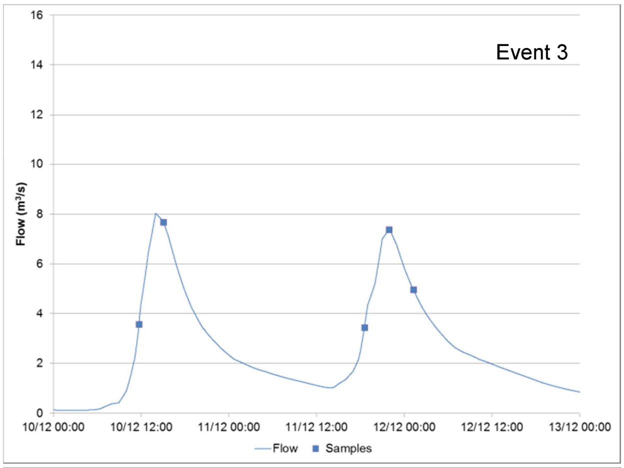


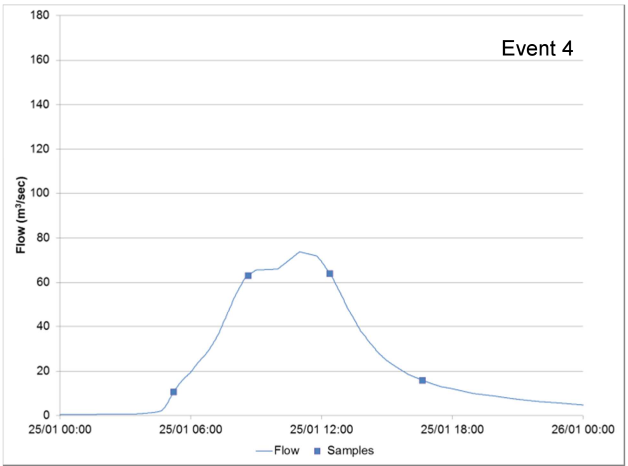


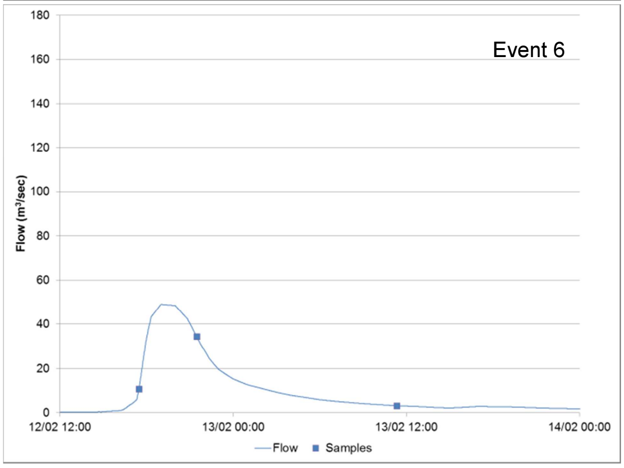
Bremer River at Adams Bridge

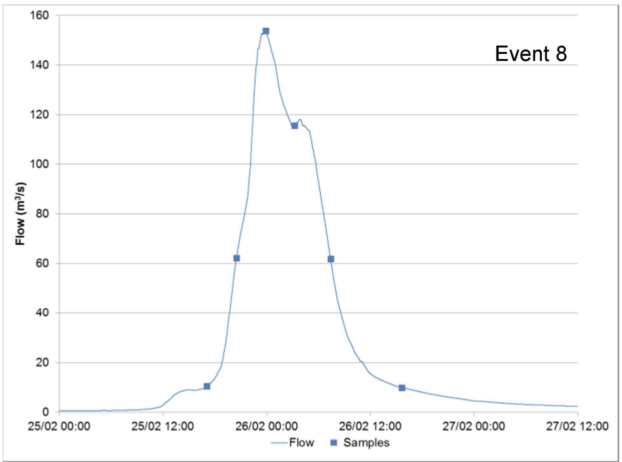












Site 6 (a) – Controlled grazing and creek fencing