Progress report: contemporary erosion sources supplying sediment to Lake Wivenhoe

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1. Executive summary

This document reports on progress in identifying contemporary erosion sources supplying sediment to Lake Wivenhoe, a project being conducted on behalf of Seqwater as part of the research agreement with Griffith University.

The dominant erosion process generating the sediment delivered to Lake Wivenhoe has been assessed by comparing concentrations of $^{137}$Cs on sediment samples collected from Lake Wivenhoe with those on the surface soil and channel source end members. Activity concentrations of $^{137}$Cs in 53 of the 55 samples collected from the lake fall within the concentration range of the channel source samples (< 7.21 Bq kg$^{-1}$) and we have estimated the relative contribution of surface erosion to the group of samples as 0.04 ± 0.04. This result is consistent with channel erosion (stream bank and gully) being the dominant source of sediment to Lake Wivenhoe.

The type and extent of channel erosion along the Upper Brisbane River has been assessed using repeat LiDAR surveys captured before and after the 2011 flood. The before-flood LiDAR was commissioned by DERM and was captured in 2001, while the after-flood LiDAR was commissioned by the current project and was captured in 2011. The January 2011 flood event caused substantial erosion which we estimate to be equivalent to 2,640,000 ± 610,000 m$^3$. Currently there is no way to determine how much of the sediment eroded from the macro channel banks was deposited underneath the water surface in the channel further downstream. However, given that the flows were largely confined to the macro-channel and the relatively short transport distance it is considered likely that a substantial amount of this eroded sediment was transported to Lake Wivenhoe. This preliminary analysis, which will be refined over the coming months, also indicates that erosion was greater in areas with low woody vegetation cover. The section of river surrounding Harlin was particularly badly eroded.

The extent of gully erosion was mapped for the first time using SPOT5 and Google Earth Imagery. The linear extent of gullies in this catchment is approximately 384 km. The total linear extent of actively eroding gullies in south-east Queensland is approximately 715 km. Analysis of the gully distribution in association with the catchment geology shows that the highest gully extents are associated the Neara Volcanics and the alluvium category (Qa-SEQ) made up of Quaternary, Tertiary and Pleistocene material and includes floodplain, lower and second level river terraces and high level alluvium in the landscape. The Esk Formation and Eskdale Granodiorite geologies also show significant totals of eroding gully length.

The management implications of this study are that conservation works aimed at reducing the supply of sediment to Lake Wivenhoe should focus primarily on stabilization and rehabilitation of the gully and channel network.
2. This document

This document reports on progress in identifying contemporary erosion sources supplying sediment to Lake Wivenhoe, a project being conducted on behalf of Seqwater as part of the research agreement with Griffith University. It is delivered as part of Research Program 2: Optimising Multi Barrier Treatment. The aim for this program is to understand processes within Seqwater catchment’s (source, store, supply) that influence water quality, and to identify ways to assess, investigate and improve treatment barriers for enhanced water quality outcomes. The study is part of sub-project 2 with the overall objective:

Understand the spatial sources and active erosion processes (e.g. extent of channel erosion) which generate sediments under events of varying magnitudes and under differing dam management scenarios, and understand how these sources and processes may influence future sediment delivery to reservoirs and water treatment plants.

This report delivers on milestone: A report and maps which identify the major contemporary erosion sources supplying sediment to Lake Wivenhoe, the primary erosion processes for responsible generating the sediment, and key management actions which could be taken to decrease the impact of future similar events on water quality and storage capacity in Wivenhoe

3. Background

The January 2011 flood event in SEQ resulted in extensive erosion across the Upper Brisbane River (confirmed from visual assessments from aerial surveys) and significant declines in water quality in the Reservoirs. A key question from this event is how much sediment eroded from the Upper Brisbane River Catchment, and was this deposited in Seqwater storages or transported downstream? The results from this study will relate specifically to the January 2011 event and this information will be used to target and prioritise catchment management actions.

3.1 Overview of the study and methods

There are four components to this study:

Determine the dominant erosion process generating the sediment delivered to Lake Wivenhoe.

This has been assessed by comparing concentrations of $^{137}\text{Cs}$ on sediment samples collected from Lake Wivenhoe with those on the surface soil and channel source end members. This shows whether the sediments are derived primarily from erosion of surface soils or from channel erosion (stream-banks and gullies).
Determine the extent of erosion along the main channel of the upper Brisbane River. The type and extent of channel erosion has been assessed using repeat LiDAR surveys captured before and after the 2011 flood. The before-flood LiDAR was commissioned by DERM and was captured in 2001, while the after-flood LiDAR was commissioned by the current project and was captured in 2011.

Determine the extent of gully erosion in the Wivenhoe catchment. The extent of both historical and active gully erosion was digitised from Google Earth Images. A stream order layer (100m resolution) was used to initially determine drainage lines across the catchment. Stream orders of <4 were then assessed as to whether they were gullies.

Determine the spatial sources of sediment delivered to Lake Wivenhoe. Sediment tracing techniques are being used to determine the spatial sources of the sediment delivered to Lake Wivenhoe. Sediment cores collected from Lake Wivenhoe have been analysed for their geochemistry as have samples collected from the various potential source areas. Initially these source samples were collected primarily from hillslope areas with uniform underlying geologies. Given the findings reported below we are currently sampling the potential alluvial sources along the stream network. This component of the study is not complete and is not reported on here.
4. The dominant erosion process generating the sediment delivered to Lake Wivenhoe.

The fallout radionuclide $^{137}$Cs has been widely used to determine the relative contributions of surface soil and channel erosion to stream sediments (Wallbrink et al., 1994, 1998; Walling and Woodward, 1992; Olley et al., 1993; Everett et al., 2008; Caitcheon et al., 2012; Olley et al., in press). It is a product of atmospheric nuclear weapons testing that occurred during the 1950-70s. Initially the distribution of this nuclide in the soil decreased exponentially with depth, with the maximum concentration at the surface. However, due to processes of diffusion the maximum concentration is now generally found just below the surface in undisturbed soils. The bulk of the activity of this nuclide is retained within the top 100 mm of the soil profile. In subsoils recently exposed by erosion $^{137}$Cs is virtually absent (Wallbrink and Murray 1993). As it is concentrated in the surface soil, sediments derived from sheet and rill erosion will have high concentrations while sediment eroded from gullies or channel banks have little or no fallout nuclide present.

Previous studies in the South-east Queensland region using fallout radionuclide concentrations to determine the relative contribution from surface soil and channel sources have shown a dominance of channel erosion (Wallbrink 2004; Hancock and Caitcheon, 2010; Olley et al., in press). Here we use $^{137}$Cs concentrations in sediments collected from Lake Wivenhoe to test if they are consistent with those derived from channel erosion. The distribution of $^{137}$Cs concentrations in the surface soil and channel end members are used in a mixing model to provide a best estimate of the relative contribution of these two components to the lake sediments.

4.1 Methods

Determining the source distributions

Source end members: To characterise the $^{137}$Cs activity distributions in both the surface-soil and channel erosion end members we have used a subset of the data from Olley et al., in press. Samples were collected from each of the major landuse areas (grazing, forest; including natural bush and managed forest). Each sample was made up of twenty subsamples collected using a ring 5 cm diameter by 1 cm deep. Spatially random samples were collected from a sampling quadrant of ~300 m$^2$ and composited to make one sample. Most surface soil samples were collected from the steeper hillslopes as it is expected that this is where soil mobilisation and transport is greatest. In total, composite samples were collected from 71 sites in the Wivenhoe catchment (Figure 4.1).

Channel bank: Profiles of channel bank material were collected by taking many small subsamples down the actively eroding bank face in fourth or higher order stream channels. These were then composited. Samples were collected from a total of 21 sites to characterise the $^{137}$Cs activity concentration of sediment derived from channel erosion (Figure 4.1).
Figure 4.1: Map of South-east Queensland showing the location of the Wivenhoe catchment and the surface soils sampling sites and the channel bank sampling sites.
Lake sediment sampling

A total of 55 sediment samples were collected from the bottom of Lake Wivenhoe in April and May 2011 using an Eckmann grab sampler and gravity core sampler. Samples were collected from along 10 cross-sectional transects of the lake. These transects were approximately evenly spaced along the length of the lake starting at the point where the Brisbane river channel flows into the full lake to the dam wall.

Sample Treatment and Measurement

Upon deposition onto the soil surface fallout $^{137}$Cs binds strongly to soil particles, mostly in the upper 10-15 cm of soil profiles. Since the radionuclide binds preferentially to fine-grained particles it is necessary to fractionate soils and sediments to minimise variations in concentrations due to differences in particle size distributions within samples (Walling, 2005; Wallbrink et al., 1999). In this study we only analysed the clay and fine silt fraction (<10μm) of soils and sediments to minimize particle size effects. We also corrected for variations in organic matter and interstitial water content by using “mineral” concentrations determined from loss-on-ignition measurements. Activity concentrations are expressed in terms of the weight of the mineral fraction. All sediment and source area samples were pretreated by individually slurrying with water and subsequent settling (based on Stokes’s Law) to the point where the fine fraction (less than 10μm) was decanted, and then dried at 105°C.

Radionuclide analysis: Analysis of the samples for gamma emitting radionuclides was undertaken at the CSIRO radionuclide laboratory. Samples were pressed into sealed containers for radionuclide analysis following the procedures described in Leslie (2009).

Determining the source distributions

To determine the distributions of the fallout radionuclide activity concentrations in the surface-soil and channel end members we followed a similar procedure to Caitecheon et al., 2012 and Olley et al., in press. The data related to the surface soil and channel samples were used to derive probability distributions describing their distributions. The probability distributions were created for each sample using the following:

$$P(a \leq X \leq b) = \frac{1}{n} \sum_{j=1}^{n} \frac{1}{\sqrt{2\pi\sigma_j^2}} \int_{x=a}^{b} e^{-\frac{(x-\mu_j)^2}{2\sigma_j^2}} dx$$  \hspace{1cm} (Equation 1)

Probabilities were summed using bin width (b-a) of 0.05 Bq kg$^{-1}$; $a$ and $b$ are the lower and upper limits of the individual bins; $\mu_j$ is the jth individual sample activity concentration and $\sigma_j$ its uncertainty. The bins covered the full range of measured values. Total probability for each distribution summed to one. These resultant summed probability plots were then fitted using standard probability functions (e.g. Lorentzian; Gaussian).
**Mixture modelling**

We have made the assumption that individual Lake samples represent a discrete mix of surface soil and channel material, with \(x\) being the relative proportion of surface material and \(1-x\) the proportion derived from channel erosion, with \(0 \leq x \leq 1\). The modelled surface soil (A) and channel distributions (B) were used to determine the concentration distributions that could be expected in mixtures ranging for 0 to 100% of surface soil. Such that:

\[ A \cdot x + B \cdot (1-x) = C, \]  

(Equation 2)

where \(C\) is the resultant distribution and \(x\) is the relative proportion of surface soil contributing to river sediment. For a group of samples \(x\) can be expected to vary from sample to sample such that \(x\) will have mean value (\(\mu_m\)) and a standard deviation (\(\sigma_m\)). The distribution of \(x\) will be truncated such that \(0 < x < 1\). Following Caiccheon et al., (2012) we have assumed that \(x\) is normally distributed. The best estimate of the relative contribution from each source to the Lake samples is obtained when the absolute difference in the means \(|\mu_c - \mu_m|\) and the standard deviations \(|\sigma_c - \sigma_m|\) of the generated ‘mix’ distributions and the Lake samples distributions are at a minimum. Here \(\mu_c\) and \(\sigma_c\) are mean and standard deviation of the activity concentrations in the samples collected from the Lake.

### 4.2 Results

**\(^{137}\text{Cs concentrations in the source samples}**

Table 4.1 presents relevant statistics on the distribution of \(^{137}\text{Cs}\) concentrations in samples collected to characterise the channel and hillslope source end members. The \(^{137}\text{Cs}\) data overlap between 1.1 and 7.2 Bq kg\(^{-1}\). Figure 4.2a shows the \(^{137}\text{Cs}\) probability plots for both the surface soil and channel source end members and shows the samples from which they were derived in ranked order. The surface soil and channel source probability distributions overlap by ~25\% (by area). Both distributions are asymmetric.

<table>
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<th>Statistic</th>
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<th>Lake sediments</th>
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<tr>
<td>Mean</td>
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<td>9.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.4</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Median</td>
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<td>8.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Standard Deviation</td>
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<td>5.7</td>
<td>1.8</td>
</tr>
<tr>
<td>Skewness</td>
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<td>1.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Range</td>
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</tr>
<tr>
<td>Minimum</td>
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<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.2</td>
<td>35.6</td>
<td>9.5</td>
</tr>
<tr>
<td>Count</td>
<td>21</td>
<td>71</td>
<td>55</td>
</tr>
</tbody>
</table>
Figure 4.2: The $^{137}$Cs probability plots: a) data from samples collected to characterize the surface-soil (grey closed circles) and channel (black closed circles) sources in the Wivenhoe catchment shown in ranked order. The black solid line and the solid gray line are the respective probability plots; b) the probability function for the Lake samples (dashed line) and the samples used to derive it in ranked order; the end member probability distributions (as in Figure 4.2a) are shown. In both figures the error bars are equivalent to one standard error on the mean and are derived from the analytical uncertainties.
**137Cs concentrations in the Lake samples**

Activity concentrations of $^{137}$Cs (Figure 4.2b) in the sample collected from the Lake samples range from $1.0 \pm 0.4$ to $9.5 \pm 0.7$ Bq Kg$^{-1}$ with a mean and standard deviation of $3.0$ and $1.8$ Bq Kg$^{-1}$ respectively. Concentrations of 53 of the 55 samples fall within the concentration range of the channel source samples ($< 7.21$ Bq kg$^{-1}$) (Table 4.1). Using equation 2 we have estimated the relative contribution of surface erosion to the group of samples as $0.04 \pm 0.04$. This result is consistent with channel erosion being the dominant source of sediment. This finding is consistent with previous studies in the region (Wallbrink 2004; Hancock and Caitcheon, 2010; Olley et al., in press) which concluded that channel erosion (gully and river bank) dominated the supply of sediment in the region.

### 4.3 Management implications

It is widely accepted that subsoils are the dominant sediment source in southern temperate grazing lands (Wasson, 1994; Olley and Wasson, 2003). It is clear that this source is also dominant in Australia’s wet/dry tropics (Bartley et al., 2004; Caitcheon et al., 2012; Hughes et al., 2009; Tims et al., 2010; Wasson et al., 2002; Wasson et al., 2010; Wilkinson et al., in press). The current study, and those by Wallbrink (2004), Hancock and Caitcheon (2010), and Olley et al., (in press) indicate that this is also the case in the sub tropical region of SE Queensland.

Effective management of sediment delivery in water supply catchments depends in part on the identification of the primary erosion process generating the sediment. The results presented here are consistent with channel and gully erosion being the dominant source of sediment to Lake Wivenhoe. The management implications of this study are that conservation works aimed at reducing the supply of sediment to Wivenhoe should focus primarily on stabilization and rehabilitation of the gully and channel network.

### 4.4 Conclusions

Our results are consistent with channel erosion being the dominant source of sediment to the Wivenhoe during the January 2011 floods. It shows that conservation works aimed at reducing the supply of sediments in the catchments should focus on stabilization and rehabilitation of the channel network. This finding is consistent with other similar studies in tropical Australian.
5. Erosion along the main channel of the upper Brisbane River

In this section hydrological information and repeat LiDAR surveys are used determine the extent of erosion and to infer bank erosion processes occurring in the main stem of the Upper Brisbane River (Figure 5.1). Different bank erosion processes usually produce distinctive shapes visible in the LiDAR imagery. For example, large planar failures of banks are generally the result of fluvial undercutting and/or the development of a near-vertical tension crack in the upper part of the bank leading to gravitational failures, and wet earth flows generally have a lobate form (see Figure 5.2) (Lohnes and Handy, 1968; Thorne et al., 1981; Watson and Basher 2006).

Figure 5.1: Upper Brisbane River Catchment showing the extent of LiDAR coverage (dark blue) along the main channel
5.1 Methods

Hydrological Data
Hydrological data for the two gauges along the main stem of the Upper Brisbane (see Figure 5.1) was extracted from the Department of Environment and Resource Management (DERM) water monitoring website (http://watermonitoring.derm.qld.gov.au/host.htm).

LiDAR
LiDAR surfaces of the Upper Brisbane River from upstream of the confluence with Cooyar Creek to Wivenhoe Dam have been captured before and after the January 2011 flood (see Figure 5.1). The pre-flood LiDAR was commissioned by DERM and was captured in 2001, while the post-flood LiDAR was commissioned by the current project and was captured in 2011. Details of the LiDAR captures are described below.

The DERM LiDAR was captured in May 2001 by Gunn Resources Pty Ltd using an Optech Airborne Laser Terrain Mapper (ALTM) 1020 system. A flying height of 400m and a swathe width of 150m were used. The accuracy of the capture was ±0.15m in the z direction and ±0.4m in the x and y directions. The accuracy of the digital elevation model (DEM) was verified through survey data collected in the field. The results of this comparison showed that the DEM was accurate to within 30cm for at least 80% of the data.

Terranean captured LiDAR on the 14th of June 2011 using a Toposys Harrier 68i/G1 LiDAR system. A flying height of 700m and a swathe width of 730m were used. The accuracy of the capture was ±0.15m at one sigma (67% confidence level). In lieu of a ground survey, the DERM DEM was used to test the LiDAR accuracy and provide additional adjustment values. OrthoPhotograph was captured simultaneously with the LiDAR using the scanner’s integrated camera.
Comparison of LiDAR Surfaces

To compare the two LiDAR surfaces, elevation values from the two DEM’s were extracted from 414 digitised points on bitumen road surfaces throughout the catchment. These surfaces are expected to have zero elevation difference between the surveys. The 2011 LiDAR DEM was found to be consistently different to the 2001 LiDAR DEM. Across the digitised points the elevation difference oscillated around a mean of 1.94m (see Figure 5.3); there was no systematic trend with elevation and this value was subtracted from the 2011 LiDAR derived DEM to align it with the 2001 LiDAR derived DEM. The residual difference had a standard deviation around zero of 0.096 m this has been used to estimate a limit of detection (LoD) at 95% confidence limit of ± 0.19m (Milan et al., 2011). This has been applied uniformly across the difference layer and we have only included changes greater than ± 0.19m in our assessment of difference between the LiDAR surfaces. The magnitude of the average vertical deviation from zero is 0.075m and we have assigned this uncertainty to each 1 x 1m grid cell used to estimate the changes between the surfaces.

Figure 5.2: Deviation between the between 2001 and 2011 LiDAR surfaces for 414 points on hard surface expected to have zero elevation change. The adjusted 2011 DEM was subtracted from the 2001 DEM to determine the relative change between the LiDAR surveys. Figure 5.4 shows an example of
the resulting layer, with red indicating positive change (or erosion) and blue indicating negative change (or deposition).

![Figure 5.4: Example of the difference between 2001 and adjusted 2011 Layers (red indicates erosion and blue indicates deposition)](image)

Estimating the total volume of change was complicated by the differing water levels at the times of the LiDAR captures. LiDAR cannot penetrate water (Mosaic Mapping Systems Inc. 2001) and the river height was at different stages for the two captures. Additionally the scale of the 2011 flood event changed the river morphology so that the location of water in the channel also differed.

To reduce the error introduced by this, it was necessary to exclude those sections of the LiDAR affected by water surfaces. The water extent in both LiDAR captures were digitised and merged into one polygon, and the macro channel banks were digitised. The combined water extent polygon was merged with the macro channel banks polygon then removed, creating a mask covering areas within the macro channel not affected by water (see Figure 5.5). This layer was then used for the zonal statistics tool in ArcGIS to estimate the total value of the DEM difference layer within this mask. This value sums positive (erosion) and negative (deposition) change in the DEM difference layer, so a positive number indicates net erosion and a negative number indicated net deposition.
Figure 5.5: Procedure for Removing Water from Volume of Change Estimate; Top - The water extent in both LiDAR captures were digitised and then merged into one polygon (bottom left), and the macro channel banks were digitised (blue in middle and right figure). The combined water extent polygon was merged with the macro channel banks polygon then removed, creating a mask covering areas within the macro channel not affected by water (right bottom).

5.2 Results

Hydrological data

Over the period of record (1965-2012) the January 2011 event was the third largest in terms average daily discharge at the Linville and Gregors Creek gauges (Figure 5.6). In terms of maximum daily discharge however this event was the largest in the gauge record, reaching a flow rate of just under 700,000 ML/d (Figure 5.7). The time period between the repeat LiDAR surveys was relatively dry, with only small events occurring in 2001, 2004, 2008 and 2010 (Figure 5.8 and Figure 5.9). This gives confidence to the assumption that the majority of geomorphic activity visible in the channel between the LiDAR surveys was due to the January 2011 event. Figure 5.10 and Figure 5.11 show that two small events in late December 2010 would most likely have resulted in significant wetting of the catchment before the large January 2011 event. Additionally the hydrograph at the Linville gauge shows a smaller peak before the largest and final peak.
Figure 5.3: Average daily discharge for gauges on Upper Brisbane River

Figure 5.4: Maximum daily discharge for gauges on Upper Brisbane River
Figure 5.5: Average daily discharge between LiDAR Surveys

Figure 5.6: Maximum daily discharge between LiDAR Surveys
LiDAR Comparison

The LiDAR difference layer highlights several different erosion processes occurring throughout the main stem of the Upper Brisbane River catchment. The dominant processes include fluvial scour on the inside and outside banks of bends, semi-circular bank failures and localised scour around trees.
Fluvial scour on the outside bank of river bends is by far the most widespread source of difference between the repeat LiDAR surveys. Examples of the largest such failures are detailed in Figures 5.12-5.15. Large amounts of fluvial scour also occurred on the inside of bends in some locations. The largest examples are shown in Figures 5.16-5.17 (note: in all figures red polygons relate to channel bank erosion and yellow polygons relate to scour around vegetation). Semi-circular bank failures are also present in the LiDAR however only two could be identified in the lower reaches of the Upper Brisbane River (see Figure 5.18-5.19). Some sections of the river were particularly active between 2001 and 2011 with erosion occurring on the inside and outside of bends, and bank scouring around trees (Figures 5.20-5.21).

The sum of the DEM difference values within the macro channel mask which excludes parts of the LiDAR influenced by water or below the detection limit we estimate to be equivalent to 2,640,000 ± 610,000 m$^3$ net erosion. It is important to view this estimate in light of the many possible sources of error in the analysis. The possible sources of error are:

- There was a reasonably consistent two metre difference on hard surfaces across the catchment. Although the 2011 LiDAR surface was corrected for this, further analysis would be needed to determine any spatial pattern in this difference away from hard surfaces.
- No aerial photography was available from the time of the DERM LiDAR capture making defining the exact water extent difficult in some cases.
- Inevitably there will be some errors defining the water surface edge. This part of the channel directly adjacent to the water surface is likely to be the area of greatest change between the LiDAR DEM's. Additionally, as the length of channel captured by the LiDAR is approximately 80km these errors may cumulatively add.
- In some areas the LiDAR surfaces did not extend to cover the entire macro channel.
- There is no way of determining how much erosion or deposition occurred under the water surface, adding further uncertainty to any estimate.
Figure 5.9: Outside Bank Erosion Site 1

Figure 5.10: Outside Bank Erosion Site 2
Figure 5.11: Outside Bank Erosion Site 3
Figure 5.12: Outside Bank Erosion Site 4
Figure 5.13: Inside Bank Erosion Site 1

Figure 5.14: Inside Bank Erosion Site 2
Figure 5.15: Wet Earth Flow Site 1

Figure 5.16: Wet Earth Flow Site 2
Figure 5.17: Heavily Eroding Site 1

Figure 5.18: Heavily Eroding Site 2
5.3 Discussion

Characteristics of the January 2011 Flood Event
Several characteristics of the January 2011 flood event combined to result in significant erosion occurring in the main stem of the Upper Brisbane River. For example the January 2011 event had the highest maximum discharge in the gauge record, it had a relatively rapid rate of rise with two peaks, and the event was preceded by two small events.

For any event, the peak discharge reflects the maximum force exerted on the banks caused by a flow during a storm event (Hooke 1979; Lawler et al. 1999). The size of January 2011 event is therefore likely to have resulted in some of the largest shear stress exerted on the Upper Brisbane River channel banks over the gauge record due to the very high maximum discharge (approximately 700,000 ML/d). Hooke (1979) suggested the rate of rise of discharge affects the rate of wetting of the bank material, and the development of turbulence. This turbulent flow behaviour (such as spiral vortices and circular upwellings) is thought to be an important factor related to the distribution, type and extent of fluvial erosion (Hooke 1979; Knighton 1998). The January 2011 event rose rapidly to its maximum flow, so not only would the maximum discharge have caused substantial shear stress on the bank, the characteristics of the flood peak hydrograph would most likely have resulted in substantial eddying and turbulence leading to further bank erosion.

The two small preceding events in addition to the multi-peaked nature of the hydrograph in the upper part of the catchment near Linville, would have weakened the banks and made them more susceptible to erosion. Prolonged inundation of channel banks can lead to bank failure through: 1. increase in soil unit weight; 2. decrease or complete loss of matric suction, and, therefore, apparent cohesion; 3. generation of positive pore-water pressures, and, therefore loss of frictional strength; 4. entrainment of in situ and failed material at the bank toe; and 5. loss of confining pressure during recession of stormflow hydrographs (Cassagli et al. 1999; Hooke 1979; Lawler et al. 1997; Rinaldi et al. 2004; Simon et al. 1999; Simon et al. 2000; Simon and Collison 2001; Springer Jr et al. 1985; Thorne 1982; Twidale 1964). Consecutive smaller floods and multi-peaked floods can produce more extensive and severe erosion due to combinations of the above processes (Hooke 1979; Rinaldi et al. 2004; Watson and Basher 2006).

Although substantial variation would have occurred over the approximately 80km of the Upper Brisbane River LiDAR coverage, without observed data on the exact processes occurring at discrete locations only assumptions can be made in light of the above principles of bank erosion processes. It is highly likely the preceding events wet the lower section of the channel banks increasing their soil unit weight and positive pore-water pressure, and decreasing their cohesion and frictional strength. The first peak of the hydrograph around Linville may have entrained in situ and previously failed
material at the toe of the banks. Loss of confining pressure on the already weakened banks during the falling limb of the first peak may have led to bank slumping. The substantial force associated with the largest peak would have then entrained previously failed material and further eroded the weakened banks. Therefore the particular combination of factors surrounding the January 2011 event seems like a worst case scenario for bank erosion in that the channel banks were already weakened through previous events and a preliminary flood peak, before the largest flood peak in the gauged record further eroded the system.

**Outside Bank Erosion**

From the LiDAR difference layer it appears the force generated by the discharge of the January 2011 event overcame the resistance of the channel banks in many locations. This was particularly true for the outside of meanders bends where velocities, velocity gradients and shear stresses are generally higher (Watson and Basher 2006). Those areas of high erosion on the outside of channel meanders identified in Figures 5.12-5.15 also appear to have had relatively sparse vegetation. Figures 5.22-5.25 show aerial photographs, sourced from Google Earth, of the four outside bank erosion sites from May 2010.

Vegetation is one part of the complex number of factors influencing bank erosion, and consequently reports vary in the literature on whether the effects of vegetation are stabilising or destabilising (Stott 1997). Vegetation absorbs the forces exerted by flowing water, provides mechanical reinforcement to the soil matrix which transfers stress to the roots during loading of the soil, and increases the tensile and shear strength of the bank (Greenway 1987; Lawler et al. 1997; Thorne 1990; Watson and Marden 2004). Vegetation increases the roughness of channel banks which reduces flow velocity, stream power and shear stress along the bank and directs flow towards the centre of the channel (Hupp 1999; Kouwen 1987; Kouwen and Li 1979; McKenney et al. 1995; Simon and Darby 1999; Smith 1976; Thorne and Furbish 1995; Tsujimoto 1999; Zaimes et al. 2006). Vegetation has also been found to reduce near bank turbulence and secondary currents, leading to further reduction in fluvial entrainment (Abernethy and Rutherfurd 1998; Thorne and Furbish 1995). Vegetation also leads to better drained and drier bank conditions through plant evapotranspiration (Watson and Marden 2004). Vegetation may also have destabilising effects due to locally severe scour of the bed and banks, loosening of bank soils due to roots, increased loading due to surcharging effects of the biomass and wind throw force of trees on the bank, and because root reinforcement is ineffective below the rooting depth of plants (McKenney et al. 1995; Lawler et al. 1997; Thorne 1990). The specific effect of vegetation will also vary with season, stream stage, stream width to depth ratio, and its spacing along a waterway which will determine the distribution of hydraulic stresses (Abernethy and Rutherfurd 1998; Gregory and Gurnell 1988; Masterman and Thorne 1992; Pizzuto and Meckelnburg 1989; Thorne et al. 1997; Thorne and Osman 1988b; Wynn 2004). Clearly more research is needed to
quantify the stabilising or destabilising effects of vegetation of particular species in particular soil types and discharge regimes (Lawler et al. 1997).

Given that hydrological and remotely sensed data are the only tools available for this analysis, variations in soil-vegetation complexities are unable to be ascertained. Therefore bank erosion processes related to vegetation can only be inferred from the presence or absence of vegetation at key points in the river. Keeping these assumptions in mind there appears to be a correlation between erosion on outside meanders, which would higher forces exerted on them, and sparse vegetation (see Figures 5.22-5.25).

Figure 5.19 Aerial Photograph (14-5-2010) of Outside Bank Erosion Site 1
Figure 5.20 Aerial Photograph (14-5-2010) of Outside Bank Erosion Site 2

Figure 5.21 Aerial Photograph (14-5-2010) of Outside Bank Erosion Site 3
Inside Bank Erosion

The occurrence of erosion on the inside bends of meanders can be described through patterns of force and resistance. At inside bank erosion site 1 (Figure 5.16), the outside bank is more vegetated and has a higher slope than the inside bank (Figure 5.26-5.27). These factors appear to have combined to increase the resistance of the outside bank enough to protect it from significant erosion and redirect the flow into the inside bank. The outside bank also appears to be on the macro channel banks, while the inside bank runs along what appears to be an inset floodplain. Although no soil data was collected, it is feasible that this inset floodplain would be comprised of more erodible material and therefore be more susceptible to erosion. At inside bank erosion site 2 (Figure 5.17), although both inside and outside banks appear to have sparse vegetation (Figure 5.28) the outside bank has a much steeper slope and similar to the pattern mentioned above appears to be on the bank of the macro channel (Figure 5.29).

In these examples, the consequence of flow hitting a relatively resistant outside bank appears to be greatly increased rates of erosion on the comparably erodible inside bank. Allen (1985) described how flow through river meanders must be accompanied by secondary flows due to friction between the flow and the river bed. When the flow through a meander runs into a particularly resistant bank, the helicoidal and secondary flows appear to dramatically increase. Consequently erosion appears to
increase in parallel on more easily erodible sections of the channel downstream. This concept echoed in channel restoration theory, namely that if stream power is not reduced in conjunction with bank protection then the channel will erode from other subreaches to maintain the channel equilibrium model of Lane (1965)(Zaimes et al. 2006).

Figure 5.23 Aerial Photograph (14-5-2010) of Inside Bank Erosion Site 1
Figure 5.24 Slope and Cross Sections (based on 2001 DEM) for Inside Bank Erosion Site 1

Figure 5.25 Aerial Photograph (14-5-2010) of Inside Bank Erosion Site 2
Semi-Circular Bank Failures

The semi-circular failures shown in Figure 5.18 and 5.19 are unlikely to be caused by direct fluvial erosion and have a lobate form which Watson and Basher (2006) suggest is typical of wet earth flow failures. It is possible that at these locations the banks were sufficiently wetted to overcome soil strength and critical shear stress and gravitational failure, that was not necessarily a wet earth flow, occurred along a semi-circular weakness in the bank. Anderson et al. (2004) found that gravitational mass failure was dominant in the lower reaches of the Latrobe, and interestingly the only easily identifiable semi-circular failures found in the main stem of the Upper Brisbane River were in the lower reaches close to Lake Wivenhoe (see inset map in Figures 5.18 and 5.19). Although technically this is still the upper reaches of the Brisbane River catchment, Lake Wivenhoe acts as a receiving water for the Upper Brisbane River catchment. Therefore it most likely imparts characteristics of the lower reaches of non-impounded rivers to the lower sections of the Upper Brisbane River, such as lower velocities and greater volumes of overbank flow. This may explain the pattern of this type of erosion found in the current study.
**Heavily Eroding Sites**

Two sites suffered particularly heavy erosion between the LiDAR surveys due to an apparent combination of several processes. Heavily eroding site 1 had erosion on the inside and outside of the bend and scour related to trees (Figure 5.30). Aerial Photograph taken in 2010 (Figure 5.31) shows the outside bend to have sparse medium sized vegetation with a small number of well established trees. It appears the force of the January 2011 flood was sufficient to overcome the resistance of the bank and its vegetation. Interestingly the outside bank erosion is in discrete sections around the remaining established trees (see Figure 5.30).

The erosion occurring on the inside of the bank at this site appears to be related to the size of the January 2011 event. For example the inside bank has established vegetation around the low flow channel. When viewed across the whole macro channel, which was most likely inundated given the size of the January 2011 event, the vegetation is densest in the centre. In processes similar to those outlined above in relation to vegetation, this would have increased roughness and reduced flow velocity, stream power and shear stress in this section. However due to its location in the centre of the macro channel, instead of redirecting flow towards the centre of the channel it redirected flow into the inside bank. It is likely this redirected flow would also be highly turbulent causing further erosion of the inside bank.

This site is part of a tight meander loop in the upper sections of the Upper Brisbane River (Figure 5.32) and it is possible that the above factors combined with less resistant bank material at this site to result in the erosion. Although local scour occurred around the stand of established trees just downstream of this site, large scale erosion did not occur and the trees remain on the bank. Despite the force of the turbulent water likely to be exiting this meander, the trees apparently combined with soil properties of the bank to provide sufficient resistance to maintain the stability of the bank. As vegetation is an effective trap of washload, sediment associated with future floods may negate the localised scour caused by this vegetation (Hickin 1984; Hupp 1999; McKenney et al. 1995; Thorne 1990).
Figure 5.27 Heavily Eroding Site 1

Figure 5.28: Aerial Photograph (14-5-2010) of Heavily Eroding Site 1
Heavily eroding site 2 stretches for approximately five kilometres around the town of Harlin in the middle of the Upper Brisbane River catchment (Figure 5.33). Several processes appear to be operating around this site and therefore it has been broken into sections from upstream to downstream. Section A is dominated by inside bend erosion apparently due to a lack of vegetation to increase the resistance of the inside banks on an inset floodplain (Figure 5.34) and the outside bank being along the much higher macro channel banks (Figure 5.35).

Section B has erosion on the outside bank most likely due to high velocities, velocity gradients and shear stresses caused by the flow and sparse vegetation leading to less resistant bank (Figure 5.36). Inside bank erosion also occurs opposite the confluence of Ivory and Maronghi Creeks, most likely due to increased flow and turbulence caused by this flow confluence. A stand of established trees just downstream of this confluence appears to have increased the resistance of the bank sufficiently to stabilise this section of bank. Although established vegetation was also present on the outside of the bend further downstream it appears that the force of the water overcame the resistance of the bank in this location and eroded a large section of arable land. Established vegetation in the macro channel

Figure 5.29: Tight Meander Surrounding Heavily Eroding Site 1
opposite may have been a factor in the increased force at this location by redirecting some flow into
this bank.

Section C (Figure 5.37 and 5.38) has inside bank erosion occurring apparently due to similar
processes as stated above: the outside bank is reinforced either through established vegetation, being
against the macro channel banks or a combination of both; and the inside bank is relatively sparsely
vegetated, and appears to be an inset floodplain of lower slope and height.

Section D has large scale inside bank erosion occurring over a section with bank completely free of
vegetation, while the outside bank has stands of established vegetation (Figure 5.39). Interestingly
however the slope difference between the inside and outside banks is minimal except for the most
downstream section (Figure 5.40). Given the scale of erosion occurring in this section, it appears
another erosion mechanism may be operating that cannot be inferred from the LiDAR data alone.

One possible explanation for the severity of erosion around Harlin is adjustments of the fluvial system
to sand and gravel extraction. Sand and gravel extraction can cause local bed slope and stream power
to increase upstream of the extraction site, which in turn may lead to channel incision progressing
upstream (Galay 1983; Kondolf 1994; Shellberg and Brooks 2007). Downstream of the extraction site
the supply of material has been reduced due to extraction, yet the force of the water has not,
commonly leading to bed degradation progressing downstream as the fluvial system attempts to
regain dynamic equilibrium (Galay 1983; Kondolf 1994; Shellberg and Brooks 2007). The cumulative
total of discrete sand and gravel extraction throughout a fluvial system can add to a large percentage
or exceedance of the total annual bed load and result in significant impact to it’s geomorphology and
ecology (Kondolf et al. 2001; Kondolf and Swanson 1993; Shellberg and Brooks 2007).

Sand and gravel extraction has occurred along the Upper Brisbane River for over a century, with
significant large-scale commercial extraction occurring over the last 50 years (Waye 1997; Shellberg
and Brooks 2007). Downstream of Harlin appears to be the location of the majority of this extraction
with the greatest number of sand and gravel extraction permits (Figure 5.41). The magnitude of the
impact of sand and gravel extraction is related to the magnitude of the extraction relative to bed load
sediment supply and transport through a reach (Kondolf et al. 2001; Shellberg and Brooks 2007).
Although bed load supply and transport data is not available on this section of river, it is reasonable to
assume that given the scale of extraction at this site some off-site consequences may result. This may
partly explain not only the degree of erosion in Section D but also across the entire heavily eroding
site 2.

Harlin is also situated roughly in the centre of the catchment and this position may make it
particularly susceptible to fluvial erosion. Abernethy and Rutherford (1998) suggest that mid basin
areas are particularly prone to fluvial erosion due to a confluence of factors producing the highest
stream power. For example in upper reaches the slope is high yet discharge is small, and in lower reaches the slope is low yet discharge is high. However in the middle reaches, comparatively high slope and discharge result in the highest stream power in the catchment. The shape of the Upper Brisbane River catchment and distribution of its tributaries also magnifies this effect (see Figure 5.1). For example approximately 3,800 km² of the 5,500 km² catchment (70%) is draining into the main stem of the river at this location, further increasing the stream power.

The section of the Upper Brisbane River surrounding Harlin was identified by Prosser et al. (2003) as a high priority sediment source area leading to it being targeted for erosion control measures under the Queensland Western Catchments Resource Investment Strategy (RIS) (SEQWCG 2005; Shellberg and Brooks 2007). It is unclear from the LiDAR where these erosion control measures were situated and whether they were sufficient to withstand the significant force of the January 2011 event, however SEQCatchments is preparing restoration plans of the reach in conjunction with local landholders and DERM staff (pers. comm. Bruce Lord, SEQ Catchments, Community Partnerships Manager, Upper Brisbane and Stanley Catchments).

Figure 5.30 Heavily Eroding Site 2
Figure 5.31 Aerial Photograph (14-5-2010) of Heavily Eroding Site 2, Section A

Figure 5.32 Slope and Cross Sections (based on 2001 DEM) for Heavily Eroding Site 2, Section A
Figure 5.33 Aerial Photograph (14-5-2010) of Heavily Eroding Site 2, Section B

Figure 5.34 Aerial Photograph (14-5-2010) of Heavily Eroding Site 2, Section C
Figure 5.35 Slope and Cross Sections (based on 2001 DEM) for Heavily Eroding Site 2, Section C

Figure 5.36 Aerial Photograph (14-5-2010) of Heavily Eroding Site 2, Section D
Figure 5.37 Slope and Cross Sections (based on 2001 DEM) for Heavily Eroding Site 2, Section D
Figure 5.38 Locations of Sand and Gravel Extraction Permits (from Shellberg and Brooks 2007)
**Volume of Change Estimate**

There was net erosion between the LiDAR surveys which we estimate to be equivalent to $2,640,000 \pm 610,000$ m$^3$. Currently there is no way to determine how much of the sediment eroded from the macro channel banks was deposited underneath the water surface in the channel further downstream. However given that the flows were largely confined to the macro-channel and the relatively short transport distance it is considered likely that a substantial amount of this eroded sediment was transported to Lake Wivenhoe.

**5.4 Conclusion**

The January 2011 flood event caused substantial and widespread erosion in the main stem of the Upper Brisbane River eroding $2,640,000 \pm 610,000$ m$^3$. This preliminary analysis, which will be refined over the coming months, indicates that erosion was greater in areas with low woody vegetation cover. The section of river surrounding Harlin was particularly badly eroded. A number of factors potentially contributed to this: Firstly, it is in the middle of the catchment where stream power is highest, due to the characteristics of the catchment the stream power is this section is particularly high; and secondly, the cluster of sand and gravel extraction permits just downstream potentially primed the area for erosion. It is clear that the middle of the catchment is actively and severely eroding due to a combination of inherent catchment characteristics and river management. As this area is prone to erosion, it is advisable to cease sand and gravel extraction in this reach immediately and conduct a study to determine sustainable rates of extraction for the rest of the river.

Please note that this research is on-going and these conclusions are preliminary.
6. The extent of gully erosion in the Wivenhoe catchment.

Gully and channel erosion have been identified as major source of sediment to Wivenhoe Dam (section 4 above; Olley et al, in press). Here for the first time we develop a map of the distribution of gully erosion in the Wivenhoe catchment.

A recent study in the upper Brisbane River catchment showed that gully initiation in this region was post European settlement (N Saxton et al., in press). Results from this catchment were consistent with a single inception date of 1949±9. Gully erosion rates in the upper Brisbane River catchment ranged from 14 to 444 m²/y. Erosion rates were positively correlated with contributing catchment area and slope ($r^2=0.67$) and linear regression analysis showed an increasing erosion rate with increasing catchment area and slope for all of the gullies studied.

6.1 Method

SPOT5 imagery (2.5m pan sharpened multi-spectral datasets, 2006) was used to visualise the landscape and gully features were digitised using ArcGIS (v9.3) software. A stream order layer (100m resolution) was used to initially determine the distribution of drainage lines across the catchment. Stream orders of $\geq 4$ were discounted as gully structures. Features that included drainage lines of order $\leq 3$ and not a named waterway were included in this study. Areas of gully erosion were determined using a combination of the SPOT5 imagery and Google Earth Imagery. The distribution of gullies in relation to the underlying geology is also examined.

6.2 Results

Figure 6.1 shows the extent of actively eroding gullies in the Wivenhoe Dam catchment; by visual inspection actively eroding gullies were categorised as those containing areas of bare ground within the SPOT/google imagery. The linear extent of gullies in this catchment is approximately 384 km. In comparison, the total linear extent estimated by the same method of actively eroding gullies in south-east Queensland is approximately 715 km.
Figure 6.1: A map of actively eroding gullies in the Wivenhoe Dam catchment (note this map is available to Seqwater as ARCGIS layers)
6.3 Gully extent mapping and landscape geology

Analysis of the gully distribution in association with the catchment geology has shown that the highest gully densities are associated with particular geologies in the catchment. Figure 6.2 shows the distribution of actively eroding gullies in association with particular geology types in the Wivenhoe Dam Catchment.
Figure 6.3 shows the total linear extent of gullies associated with specific geologies; the greatest length of gullies occurs in the Neara Volcanics and the alluvium category (Qa-SEQ) made up of Quaternary, Tertiary and Pleistocene material and includes floodplain, lower and second level river terraces and high level alluvium in the landscape. The Esk Formation and Eskdale Granodiorite geologies also show significant totals of eroding gully length.

![Graph showing total gully length by geology](image)

Figure 6.3: Sum of eroding gully length within a given geology in the Wivenhoe Dam Catchment

**6.4 On-going Research**

While we now have a clear understanding of the spatial distribution of gullies across the Wivenhoe catchment we have no information on their form or volume. In the next phase of this study 100 gullies across the upper Brisbane River Catchment will be survey in the field. This project aims to repeat the work carried out by Rustomji (2006) in the Sydney Water supply catchments to assess cross sectional dimensions and sediment texture for gullies in south-east Queensland. These data along with historical gully erosion rates will be used to improve the parameterization of gully erosion in the development of sediment budgets for the catchment to aid in the targeting of rehabilitation works. Further work will build on the relationships between the spatial extent of actively eroding gullies and landscape features such as the geology, soil type, topography and vegetation to improve our knowledge of gully processes.
7. References


Caitcheon, G., Olley, J., Pantus, F., Hancock, G., and Leslie, C., 2012. The dominant erosion processes supplying fine sediment to three major rivers in tropical Australia, the Daly (NT), Mitchell (Qld) and Flinders (Qld) Rivers. Geomorphology, doi:10.1016/j.geomorph.2012.02.001


Olley, J.M., Burton, J., Smolders, K., Pantus, F., and Pietsch, T., (in press) The application of fallout radionuclides to determine the dominant erosion process in water supply catchments of subtropical South-East Queensland, Australia. Hydrological Processes


Simon A 2011 Lecture notes from Stream Restoration Short Course, July 2010, Whitsundays, QLD


Twidale, C. R. (1964), "Erosion of an Alluvial Bank at Birdwood, South Australia ", *Zeitschrift fur Geomorphologie*, **8**: pp. 189-211


Waye, K.J. 1997. *An Inventory of Riverine Quarry Material in the Upper Brisbane River: Monsildale Creek to Lake Wivenhoe Headwaters*. Queensland Department of Natural Resources, Geotechnical Services Group, Brisbane, Qld, Australia
