Floodplain management in the Burnett Catchment

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In January 2013, ex-tropical cyclone Oswald traveled south just inland of the coast of Queensland causing widespread impact including flooding and tornados. Coastal regions of Queensland were the most impacted with Mundubbera, Eidsvold, Gayndah and Bundaberg severely affected. In many places the rainfall total for January set new records. In Mundubbera, the Burnett River peaked at 22.9 meters at 1 am on 28 January while at Bundaberg the Burnett River reached a new recorded height of 9.53 meters on 29 January. The floods in the Burnett Catchment during the 2013 summer period caused extensive damage to infrastructure, housing, land, economic productivity and the environment.

In rural areas (non-urban), damage was widespread and included lost productivity from crop damage; severe flood scouring with loss of top soil and associated nutrients, organic matter and biological activity; severe sand/silt deposition impacting on land productivity and machinery use; water logging with loss of crops and soil health; loss and damage to farm infrastructure particularly roads and access, irrigation equipment, fences and farm machinery; bank erosion and loss of productive land; debris deposition in cropping lands affecting crop production and possible contamination; debris deposition in stream channels threatening infrastructure and natural assets such as agricultural lands and riparian ecosystems; and the spread of weeds due to the floods. The heavy rains also caused severe hill slope erosion on cultivated lands due to the failure of some soil conservation works and agronomic measures (minimum tillage, crop residue retention, controlled traffic) unable to cope with the severe event. Activation of gully erosion was also widespread. Environmental damage included sediment and nutrient deposition to water ways and the Great Barrier Reef lagoon; loss of riverine, estuary and marine habitat and biodiversity; reduced water quality, and loss and damage to terrestrial and riparian ecosystems. The widespread damage to our natural assets has highlighted many aspects of floodplain management that need improvement.

This report identifies recent damage caused by the 2013 floods, the main processes and consequences. The report also identifies aspects of floodplain management in rural areas that require improvement:

- Landscape management
- Riparian management
- Riparian risk assessment
- Run-off control
- Restoration of stream bank erosion
- Technical support
- In-stream management
- Emergency works
- Land use planning
- Training in floodplain management
- Coordination and agency responsibilities
Floodplain damage

The whole Burnett catchment (figure 1) was affected by the extreme events of ex-cyclone Oswald through extensive rainfall and flooding in all creeks and rivers in the catchment. The flood extent map for Bundaberg is currently not publically available (as at July 2013) but will be available on the Government website late 2013, however the map is currently available for BMRG use for flood recovery works and other resource management activities. Flood extent maps of other areas of the Burnett Catchment inundated by the 2013 floods are not available. Rural damage mainly affected crop losses and associated soil health/productivity, floodplain and hill slope erosion, debris deposition, loss of farm infrastructure, and loss/damage to ecosystems. Other losses/damage to urban and commercial related infrastructure (roads, bridges, buildings, power, communications, dams/weirs, port facilities, etc), private property, recreation facilities and scenic amenity are not covered in this report.

The Burnett Mary Regional Group contracted the acquisition of post flood imagery of the Burnett River and major tributaries to map floodplain scouring, floodplain sand/silt deposition, river bank scouring and river bank slumping. The information was also used to identify the flood dynamics and geomorphic processes that caused the flood damage and therefore help identify the “practicality” and benefit/costs of undertaking flood recovery works. All works aim to stabilise and rehabilitate the damaged areas and to ensure our natural resources are more resilient against future floods.

Rural production losses
Crop and land productivity losses occurred on all lands inundated by the flood waters. The floodplains on the Kolan Burnett Rivers and the major tributaries of Three Moon Creek, lower Splinter Creek, Barambah Creek, Reid Creek and Barker Creek were the most severely affected particularly the summer grain and forage cropping areas in the inland Burnett, cotton and summer crops at Byee, sugar cane in the lower Burnett, horticultural small crops, and tree crops particularly in the central Burnett.

Losses were due mainly to physical damage/removal by flowing water, waterlogging of soils and associated soil health and disease issues, silt/sand deposition damaging/killing crops and restricting machinery use, and flood damage from inundation of the crops/plants for extended periods.

Rehabilitation will concentrate on supporting landholders to restore productivity by providing agronomic advice on crop management, erosion control and rejuvenation of soil health damaged by waterlogging/inundation and erosion/scouring. This support is to be integrated with floodplain management, riparian management and infrastructure planning mentioned below.
Floodplain scouring and sand/silt deposition occurred throughout the catchment (Figure 2) with the most severe damage on recently cultivated lands in the Three Moon Creek area at Monto (photo 1), Barambah floodplains at Byee near Murgon.
(photo 5), and on the lower Burnett and Kolan River floodplains at Bundaberg (photo 2, 3, 4). Damage on other rivers and creek floodplains was generally minor to moderate (photo 6).

Figure 2. Extent of Burnett Catchment post 2013 floodplain erosion and silt/sand deposition
Floodplain scouring was most severe where flood water energy (velocity, depth, duration) was concentrated, usually adjacent to high velocity channel waters flowing...
over natural levees and onto adjacent floodplains, on scroll plains where flood waters natural take “short cuts” from an upper section of the river to a lower elevation, and where flood waters are naturally or artificially concentrated or diverted. All scouring was most severe where land was recently cultivated or had insufficient crop cover to protect the soil surface, with up to two metres lost in some areas (photo 1, 3, 4). A severely affected area on the lower Kolan River had approximately 30 ha affected (photo 2) with loss of up to two metres of soil removed together with loss of cane rail infrastructure (photo7). Dense weed infestation of stream channels limiting flood flows also contributed to deviation of floods out of the channel onto floodplains (photo 8).

![Photo 7. Damaged can rail infrastructure, Bundaberg](image)

![Photo 8. Severe weed infestation choking channel and causing floodplain scouring, Barker Creek](image)

Floodplain damage associated with the scouring included wash-out of council and Main roads, causeways and farm access; and damaged irrigation infrastructure, farm machinery, fencing and farm buildings.

Associated with any scouring is the deposition of sand and silt usually where the flood waters los energy (photo 9, 10). Sand deposits are particularly troublesome as they are difficult and costly to remove, can cause “droughty” soils, and severely restrict machinery access and harvesting. Silt deposits can usually be incorporated with existing soils relatively quickly and can help rejuvenate soils to improve soil fertility.

Table 1 lists the areas affected by floodplain scouring and sand deposition. As indicated in figure 2, Three Moon Creek at Monto had 786 ha severely affected by floodplain scouring, while Byee had 126 ha and the lower Burnett and Kolan catchments had 185 ha. The remainder of the catchment had 45 ha severely affected. Associated with the scouring was sand/silt deposition on 77 and 820 ha in the Monto and lower Burnett/Kolan areas respectively. A total of 127 ha was affected by sand deposition elsewhere in the catchment.
Table 1. Areas (ha) affected by severe floodplain scouring and sand/silt deposition

<table>
<thead>
<tr>
<th>Areas (ha)</th>
<th>Monto</th>
<th>Byee</th>
<th>Lower Burnett/Kolan</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floodplain scouring</td>
<td>786</td>
<td>126</td>
<td>185</td>
<td>45</td>
</tr>
<tr>
<td>Floodplain sand/silt</td>
<td>77</td>
<td>0</td>
<td>820</td>
<td>127</td>
</tr>
</tbody>
</table>

Any rehabilitation and stabilisation works are to concentrate on farm layout and agronomic management to improve surface cover and reduce risk in flood prone times; adoption of controlled traffic techniques to limit soil compaction and reduce soil loss from scouring; improving and coordinating flood channel stabilisation and drainage works; appropriate modelling/planning for the maintenance or removal of structures (levees, diversion banks\(^1\)) that affect flood dynamics and concentrate flood energy; coordinating floodplain management with road infrastructure; locate on-farm infrastructure in stable areas; create vegetative buffers in unstable areas to reduce flood energy and reduce sand/silt deposition; appropriate weed management to ensure stream channels operate as they should.

\(^1\) Constructed levees are designed to exclude flood waters from land for a certain flood level (e.g. a 1:20 flood event). A diversion bank is designed to divert waters away from or around important assets (e.g. diverting “high” velocity flood water to avoid scouring soils on cropping lands).
Gully erosion on floodplains and associated river and creek bank was activated throughout the catchment resulting in slight to severe loss of soil, and damage to on-farm infrastructure such as fences and access (photo 11, 12). Environmental damage included sediment and nutrient deposition to water and reduced water quality. With any gully erosion, stabilisation is difficult, costly and unreliable. Prevention is more effective.

River bank scouring and slumping

River bank scouring and associated collapse and slumping occurred on all rivers and tributaries throughout the Burnett Catchment (Figure 3). Bank scouring was most severe on “outside bends” of channels corresponding to high energy flood waters and lack of vegetation particularly the diverse vegetation that provides surface cover against removal of soil by fast flowing water, root proliferation to hold the soil and dense vegetation to slow the velocity of the water. Due to the record flood height, all vegetation particularly in the lower one third of the stream banks was damaged or removed (photo 13) and bank collapse usually occurred where significant portions of the lower banks were eroded (photo 14, 15) particularly on the “out-side” bends of the stream channels. The 2010-11 floods removed large amounts of vegetation and acted to destabilise these areas prior to the 2013 flood. Bank scouring was particularly
severe in the estuarine sections of the Burnett and Kolan Rivers where normal tidal movements and lack of marine vegetation destabilised the banks (photo 16).

Figure 3. Extent of Burnett and Mary Catchment post 2013 river bank scouring and slumping
Photo 13. Severe scouring and vegetation loss on lower bank, Burnett River

Photo 14. Severe creek bank scouring, Gin Gin

Photo 15. Bank scouring and collapse, Three Moon Creek, Monto

Photo 16. Naturally unstable lower bank, estuarine section Kolan River

River bank slumping is restricted to “high”, “steep” banks with certain soils. Approximately 80% of all slumps occurred on banks >5 m high and slopes > 25°. Very few slumps occurred on slopes < 20° while banks higher than 10 m and > 25° were at high risk. Slumps typically occur as the flood recedes or even days after the flood have receded (photo 17, 18). Banks steepened by bank scouring are at most risk. The resultant slump delivers “huge” amounts of sediment to the river. Remnant vegetation is very effective at reducing the risk.
Table 2 lists the areas affected by river bank scouring and slumping. As indicated in figure 3, the main areas affected by banks scouring and bank collapse are below the confluence of the Burnett, Auburn and Boyne Rivers above Mundubbera to Gayndah (172 ha over ...km of stream channel), from Paradise Dam to Bundaberg (61 ha over ...km), and in the lower Kolan Rivers (5 ha over ...km). The stream channels in the Burnett, Auburn and Boyne above Mundubbera and other tributaries of the Burnett have relatively intact remnant vegetation or hard rock geologies in the bed and banks which appears to have significantly reduced bank scouring to 94 ha over the remainder of the catchment. Associated with the bank scouring was bank slumping on 18 ha in the Mundubbera-Gayndah stretch of the river and 42 ha in the lower Burnett stretch. A total of 16 ha was affected by bank slumping elsewhere in the catchment.

Table 2. Areas (ha) affected by severe bank scouring and collapse, and bank slumping

<table>
<thead>
<tr>
<th>Areas</th>
<th>Mundubbera-Gayndah</th>
<th>Lower Burnett</th>
<th>Lower Kolan</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank scouring and collapse</td>
<td>172</td>
<td>61</td>
<td>5</td>
<td>94</td>
</tr>
<tr>
<td>Bank slumping</td>
<td>18</td>
<td>42</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

Due to the slow natural recovery of natural vegetation on river banks, bank scouring and bank slumping destabilises the banks against future floods in the short to medium term. Associated with the scouring is the loss of productive cropping lands; loss of infrastructure; loss of riverine, estuary and marine habitat and biodiversity; reduced water quality; and loss and damage to terrestrial and riparian ecosystems.

Some weeds, such as cat’s claw, are very effective at protecting the soil against scouring. Any removal of weeds on “high” risk areas of river banks needs to be followed by revegetation with suitable diversity of species and density to avoid destabilisation of the banks.
River bed scouring and sand deposition
River bed scouring and sand deposition occurred in all rivers and tributaries in the Burnett and Kolan Catchment. Due to the record flood levels, river bed and banks deepen and widen naturally to cater for the increased flows. Associated is the removal of vegetation, scouring of the banks and relocation of sediments and deposition of sand in the “inside” bend of the river channels as the meanders migrate out and downstream and deposition of sediments over the floodplains. Based on the post flood image 666 ha of the stream channel had active sand deposition. Due to the hard rock geologies controlling stream bed gradients throughout the catchment and water storages controlling bed scouring in the storages, future “low” levels floods will redistribute sediments and deposit sediments and tend to infill the channel. River geomorphology indicates a continuous and adequate supply of sediments throughout the catchment except below the storages of Paradise Dam and the weirs at Gayndah and Walla. These natural dynamic areas will stabilise naturally over time assuming sediment has not decreased through water storages or removed from the system (such as sand/gravel extraction). As a result of stable river geomorphology, channels have not been straightened and channel gradient has not changed significantly except for the areas immediately below the storages mentioned earlier. Stream “roughness” from natural bed and bank barriers (rock, riffles, rapids, sand bars), sediment bed-load, meanders and vegetation is critical to maintain “natural” stream dynamics and stability. Long term catchment management and development history has changed catchment runoff, vegetation cover and type, bank stability and stream dynamics through sand/gravel extraction and water storages. The resultant un-natural stream dynamics are resulting in destabilisation of the bed and banks.

River realignment occurred in several localities where channels removed in-stream vegetation and islands to allow channel straightening and in-filling of old channels, all indicating relatively stable sediment delivery throughout the catchment. Sand and gravel extraction has also destabilised the bed and banks in some areas. This geomorphic process increases the hydraulic gradient (steeper channel), deepens and widens channels, and increases flood energy. Flood waters may also be diverted to previously “stable” areas, and therefore destabilise river banks.

Severe stream bed scouring is most apparent immediately below water storages (for example Paradise Dam and to a lesser extent below the weir at Gayndah) where sediment bed loads are reduced due to sediment deposition in the storages. Stream bed lowering (for example deeper channels in the estuarine section of the Burnett River) due to lack of bed load or sand/gravel extraction in the upper catchment may further destabilise river geomorphology.

Debris deposition
Debris deposition of vegetative material (grass, branches, logs, etc.) and man-made materials (plastic containers, fuel tanks, farm equipment, etc.) occurred in cropping lands on floodplains throughout the catchments (photos 19, 20, 21). As stated above, all river channel and banks showed severe loss of vegetation. A majority of this debris remained in-place or was deposited a short distance downstream. However, a significant amount of vegetative debris was deposited in farm paddocks, in native vegetation communities and riparian areas (photos 22), and against infrastructure such as fences, machinery and bridges (photos 23, 24). This debris can severely interfere with normal farm operations such as cultivation, harvesting and pest control. Man-
made materials were also deposited in paddocks, further restricting normal farm operations (photos 19, 20, 21, 25).

**Photo 19.** Trees deposited in cultivation, Ban Ban Springs

**Photo 20.** Boat in cane, lower Burnett, Bundaberg

**Photo 21.** Debris in cane, Burnett River

**Photo 22.** Vegetative debris in riparian areas

**Photo 23.** Debris on fences, Bundaberg
Vegetative debris normally provides river bank stability and protects against scouring as it reduced water velocity. Debris should only be removed where it threatens natural geomorphic processes, threatens natural assets such as agricultural land stability and riparian ecosystems or where it threatens infrastructure.

**Loss of infrastructure**

Loss of infrastructure, both on-farm and community, occurred throughout the catchment. On-farm infrastructure damage included the loss of fencing; loss /damage to irrigation infrastructure such as pumps, irrigation pipes and irrigators; farm access; causeways; machinery and sheds; cane railways; and on-farm water storages (photo 7, 26, 27, 28, 29). Other losses/damage to urban and commercial related infrastructure (roads, bridges, buildings, power, communications, dams/weirs, port facilities, etc.), private property, recreation facilities and scenic amenity are not covered in this report.

Rehabilitation will concentrate on supporting landholders to improve infrastructure resilience by locating and constructing infrastructure in stable areas, and designing farm layout and infrastructure appropriate to flood prone lands.

**Photo 24.** Debris accumulation on irrigation pump, Burnett River

**Photo 25.** Man-made debris in citrus orchard, Gayndah

**Photo 26.** Damaged machinery, Isis Mill area, Burnett River

**Photo 27.** Dam wash-out, Burnett River floodplain
Damage to riparian and stream/estuary/marine ecosystems
Damage to riparian and stream/estuary/marine ecosystems have occurred throughout the catchments but no assessment of damage has been conducted. As mentioned above, severe scouring of riparian lands and floodplains particularly in the Burnett and Kolan Rivers caused loss and damage to riverine, estuary (photo 30) and marine habitats; sediment and nutrient deposition to water ways and the Great Barrier Reef lagoon (photo 31); reduced water quality, and expected loss and damager to terrestrial and riparian ecosystems.

As stated above, rehabilitation and stabilisation of riparian lands and floodplains to make these lands more resilient against future flood events will help restore and stabilise the riparian and water based ecosystems. Stabilisation of river banks with marine vegetation in estuarine sections of the Burnett and Kolan Rivers may be appropriate to protect floodplain and terrestrial bank stability.

Processes
The severe weather event in January to March 2013 resulted in record flooding, particularly in the coastal and north Burnett region. Most of the damage was a result of record flood levels and the associated energy. The 2010-11 flood also helped to destabilise the floodplains.

**River bank scouring and slumping**

As discussed, all creek and river channels and lower banks (particularly the lower one third) were severely scoured as rivers deepened and widened to cater for the extreme flows. The amount of widening and deepening of the channel is determined by the amount of energy (water velocity as determined by hydraulic head and channel gradient, water depth, and flow duration), sediment load, channel geomorphology, resistance of the channel material, roughness of the channel (smoothness increases velocity/roughness reducing velocity, but localised turbulence can cause local high energy flows), and ability vegetation to protect and “hold” the channel and bank material. The physical removal of channel material by suspended debris (rock, sand, vegetation) is also a factor. The natural river dynamics over extended periods allows meanders to migrate towards the mouth and for the meander to enlarge as sediment loads increase as the river matures (lower gradient). These geomorphic principles make river channels and floodplains in general naturally dynamic and subject to change over long periods. Therefore, extreme events are a natural part of landscape development and may result in changes in river course.

The “outside” bend of channels are the most severely affected due to the energy (velocity, depth and duration) of the flood waters, resulting in severe scouring, undercutting of the lower bank and bank collapse. This contributes considerable sediment and nutrients to the river system, considerable destruction of the vegetation communities and delivery of vegetative debris to the flood waters. The natural widening and deepening of the channel and relocation/redistribution of sediments during extreme events, particularly on the “outside” bend of the channel, automatically makes the bank higher and steeper. Steep high banks with a lack of remnant vegetation to protect the soil surface, decrease water velocity and roots stabilising the soil, and together with unstable soils are at most risk. Hard rock geologies are stable and generally contribute little sediment to the streams. The long term histories of bank and bed disturbance including clearing, grazing, burning, weeds and sand/gravel extraction have all helped to destabilise the bed and banks.

Due to the hard rock geologies controlling stream bed gradients throughout the catchment and water storages controlling bed scouring in the storages, future “low” levels floods will redistribute and redeposit sediments and tend to infill the channel. These natural dynamic areas with stabilise naturally over time assuming sediment or bed loads in the channels has not changed. Changes in bed load may result in straightening of channels, or removal of natural stream bed barriers. Removal of sediments through sand/gravel extraction or deposition in water storages can reduce bed loads and destabilise the channels and river geomorphology resulting in accelerated bed and bank erosion. Stream “roughness” from natural bed and bank barriers (rock, riffles, rapids, sand bars), meanders and vegetation is critical to maintain “natural” stream dynamics and stability. Long term catchment management and development history has changed catchment runoff, vegetation cover and type, bank stability and stream dynamics through sand/gravel extraction and water storages.
The resultant un-natural stream dynamics are resulting in destabilisation of the bed and banks.

Severe stream bed scouring is most apparent immediately below water storages (for example Paradise Dam and Gayndah weir) where sediment bed loads are reduced due to sediment deposition in the storages. Stream bed lowering may further destabilise river geomorphology downstream as bed loads gradually move downstream.

River realignment occurred in several localities where channels removed in-stream vegetation and islands to allow channel straightening and in-filling of old channels. This is a natural process associated with channel aggregation. Sand and gravel extraction has also destabilised the bed and banks in some areas. This geomorphic process increases the hydraulic gradient (steeper channel), deepens and widens channels, and increases flood energy. Flood waters may also be diverted to previously “stable” areas, and therefore destabilise river banks. Current Government legislation under the Water Act 2000 limits disturbance in the bed and banks.

Very unstable soils on stream banks, such as sodic soils, are very erodible and difficult to stabilise with vegetation due to their dispersive nature and hostile subsoil. These eroded banks are usually not practical to stabilise.

The “in-side” bend of rivers are naturally more stable with low bank slope and height and tendency to accumulate sand, silt and debris corresponding to a “low” energy environment. Post flooding erosion mapping supports these geomorphic principles with large sand and gravel deposits, and a lack of bank scouring.

In “low” flows, the channels are expected to redistribute bed load and in-fill channels and vegetation re-establish. However, in the short to medium term (<10 years) until management practices are implemented and suitable vegetation is established, beds and banks will remain unstable and may be subject to further erosion. The ability to rehabilitate and stabilise banks is very dependent on understanding the river and flood dynamics, river geomorphology, soil type and “practicality” of establishing cost effective stabilising techniques. The 2010-11 floods appear to have destabilised the lower banks contributing to severe damage in the 2013 flood.

Bank slumping is associated with steep high banks and bank scouring where soils become saturated during flooding, the soils consistency reduces significantly (ability to hold together), and the bank rotates out delivering large amounts of bank material into the channel. Any standing vegetation ends up pointing back towards the bank. Approximately 80% of all slumps occurred on banks >5 m high and slopes > 25°. Very few slumps occurred on slopes < 20° while banks higher than 10 m and > 25° were at most risk. The slumping occurs as the flood waters recede and may occur days after the floods. The resultant semicircular steep bank is unstable and can be subject to further slumping and scouring. The alluvial soils of the Burnett River are particularly unstable. In all cases of bank slumping, historical land use has cleared to the top of the high bank and the resulting slump has rotated back from the edge of the high bank into the adjacent flats, often resulting in severe loss of crops and land productivity.
While vegetation is generally essential for stabilisation of banks, isolated large trees such as forest red gum (*Eucalyptus tereticornis*) can create localised turbulence exposing supporting roots resulting in tree collapse especially on saturated unstable soils during windy conditions. Any tree collapse in high risk areas can destabilise the bank causing further turbulence, scouring and banks collapse. If trees collapse into the river channel, it may initiate debris accumulation, reduce channel flow and alter normal flood dynamics.

Vegetation removal/damage during flood events is normal, and the deposition of debris on river banks can help reduce water velocities and therefore protect the banks. As described above, isolated trees and fallen trees can create turbulence and create problems. As with any unstable area, any debris removal needs to consider flood dynamics, river geomorphology, soil stability and vegetation type/cover. Debris should be only removed if it threatens natural geomorphic processes, natural assets such as agricultural lands and important ecosystems, and infrastructure.

Floodplain management needs to consider all aspects of flood dynamics, river geomorphology, existing land uses and infrastructure requirements. Any rehabilitation and stabilisation works are to concentrate on maintaining stream bed and bank stability. All works require a “risk” assessment of river geomorphology and dynamics, geotechnical assessment of soil stability, bank height and slope, and foliage cover of riparian vegetation. This information together with the floodplain erosion mapping will help identify priority areas and practicality and cost/benefit of rehabilitation/stabilisation works.

Existing techniques predominantly involve the maintenance and rehabilitation of riparian vegetation on the banks and adjacent high banks. Where bank scour/collapse or slumping is practical to repair, works can involve stabilisation of the toe of the bank with engineering works (such as rock batters) and/or reshaping the banks to a “stable” angle which is around a batter of 1:2 (vertical:horizontal) or <25° for moderately stable soils or around 1:3 batter for less stable soils. A batter of 1:4 or lower is recommended for unstable soils, such as sodic soils. During battering any topsoil is stockpiled for topdressing later; the upper bank is excavated and filled to the lower bank (where practical) and any fill compacted in 0.2-0.3 layers; top dressed; mulched if practical to prevent surface run-off and scouring from rain and improve soil moisture retention for vegetation growth; grassed with a creeping “deep rooted” grass; fertilised where appropriate; and revegetated with suitable vegetation comprising ground covers, shrubs and trees to give suitable diversity and density. Vegetation is critical to provide soil surface protection against scouring, root proliferation for soil stability, and vegetation cover to slow down water velocities. Any weed management on steep high banks needs to be followed by bank vegetation rehabilitation works to ensure stream remain stable.

Other engineering solutions involve rock battering, groins, gabions, log structures, bank diversions, in-stream rock structures, etc. These engineering structures are generally expensive and require appropriate design.

**Floodplain scouring and sand/silt deposition**
Damage on floodplains (excluding bed and banks) is very dependent on flow dynamics and river geomorphology as described above. Under natural undisturbed
environments, flood waters overtop natural levees thereby loosing energy by spreading out over a large area. Natural vegetation helps to slow water velocities and protect the soil surface. Coarse material is deposited first resulting in “elevated” levees. Back plains have the lowest energy resulting in fine silt and clay deposition. Scroll plains develop due to meander migration but during floods, waters take a “short cut” across the in-side bend of the floodplain resulting in “high” and “low” energy flow paths. Natural vegetation would help to protect the soil from scouring and encourage deposition of sediment.

Historical development of the highly fertile floodplains has removed the protective natural vegetation thereby reducing roughness and increasing water velocities. This together with soil cultivation “loosening” the soil has resulted in severe floodplain scouring. Soil loss is most severe adjacent to the high energy flows adjacent to stream channels, on unstable soils particularly “low” coherent alluvial soils, and where recently cultivated and/or immature crop cover is low. The severe scouring is most prevalent on scroll plains adjacent to the “in-side” bends of rivers. Sand and gravel extraction on scroll plains has destabilised the channel and adjacent land in some situations potentially resulting in stream realignment and changes to river bed gradient and geomorphology.

Associated is the deposition of sand as the flood waters lose energy over the broad plains. Silt deposition in the low energy back plains are a natural rejuvenation process for the floodplain soils.

Clearing and cropping of natural flood channels on the floodplains has increased water velocities with scouring potentially making the flood channels wider and deeper, and reducing stability of the floodplains. Future major flood events may result in new river channels.

Historical diversion banks and artificial levee banks have been constructed for various reasons, mainly to protect crops from inundation. These banks may work effectively in low flood events, but during the extreme event of 2013, all artificial diversion and levee banks created problems by concentration water or diverting water to other sensitive areas. The results were severe scouring of productive cropping lands, loss of crops, damaged irrigation infrastructure and damaged public infrastructure such as roads. Liability with private or public property damage may be an issue. Any construction, maintenance or removal of artificial levees needs to consider the natural flood dynamics and river geomorphology to ensure the floodplain operates as naturally as possible.

State and local roads have aggravated floodplain scouring in some areas, particularly Three Moon Creek where road design has concentrated flood flows onto cropping lands.

Floodplain management needs to consider all aspects of flood dynamics, river geomorphology, existing land uses and infrastructure requirements. The aim is to help stabilise the floodplains to reduce future risk while still utilising these highly productive lands. Integration of on-farm paddock layout, flood control measures and regional infrastructure is essential to avoid /limit future damage. Any rehabilitation and stabilisation works are to concentrate on soil levelling, sand removal, soil health
(rehabilitation of soil organic matter, soil physical and nutrient properties, soil biology, and drainage for water logging), farm layout and agronomic management to improve surface cover and reduce risk in flood prone times; adoption of controlled traffic techniques to limit soil compaction and reduce soil loss form scouring; improving and coordinating flood channel stabilisation and drainage works; appropriate modelling/planning for the maintenance or removal of structures (levees, diversion banks) that affect flood dynamics and concentrate flood energy; coordinating floodplain management with road infrastructure; locate on-farm infrastructure in stable areas; create vegetative buffers in unstable areas to reduce flood energy and reduce sand/silt deposition; appropriate weed management to ensure stream channels operate as they should.

Weeds, particularly Chinese celtis, have caused severe problems in some floodplains by choking the river channel and reducing the flow capacity. The result is frequent overtopping and failure of natural and artificial levees and severe scouring of soils on the adjacent cropping lands. With any weed control on floodplains and river channels, the river geomorphology and flood dynamics need to be considered. Any weed removal needs to be followed by immediate revegetation to ensure stability.

**Gully erosion**
Gully erosion on floodplains occurs when concentrated flow detaches soil particles from unstable subsoils resulting in “under cutting” of the subsoil at the vertical gully head and collapse of the relatively stable surface. Gullies on floodplains are particularly troublesome on unstable soils adjoining deeply incised stream channels where gullies extend upslope until a new stable gradient is achieved or a restrictive layer is reached such as bedrock. Gullies are steep sided water courses that affect soil productivity, restrict land use and can threaten roads, fences and buildings. Consequences include silt deposition on fence lines, roads and in water ways. Sediment and attached nutrients can affect water quality and ecosystem health.

Gully prevention is the best solution. The amount of runoff depends on the catchment area, soil type, vegetation cover/type and slope. Clearing or poor crop/pasture cover usually increases runoff while removal of deep rooted vegetation can increase deep drainage and cause rising water tables, reducing the capacity of the soil to store water and therefore promote runoff. Dense tree vegetation can also reduce surface cover through shading and competition for available soil moisture and nutrients.

Management options include restricting stock movement and grazing pressure; controlling erosion in cropping lands with appropriate agronomic measures (crop residue retention, minimum tillage, controlled traffic, strip cropping) and construction/maintenance of appropriate soil conservation measures; filling and reshaping and stabilising; stabilising the gully bed and sides; stabilising the gully head; reducing seepage; and diversion of runoff away from the gully. Concentrated flows from culverts and road table drains can be particularly difficult to control without engineering solutions. Numerous Department of Natural Resources and Mines factsheets are available for general advice.
Landscape management

The principle of landscape management over the whole catchment is to reduce runoff to streams by slowing down overland flow by good surface cover, and improve soil health to increase soil infiltration and moisture water storage. This also reduces sediment, nutrient and chemical delivery to water ways. Slowing overland flow potentially reduces flood peaks but may extend flood duration as a consequence.

The exceptional seasonal conditions in 2010-12 leading up to the summer floods in 2013 resulted in “good” land cover and it was only the dry seasonal conditions from July to mid-January that reduced cover through grazing and possible fire. Therefore, improvement in landscape management this year probably had minimal benefits. Landscape management still needs to be improved in “normal” years and is especially important in “drier” years where land cover is reduced through increased grazing pressure reducing pasture and land cover, or reduced cropping increasing bare fallow or reduced plant/residue cover. In many cases, soil health has decreased over time through reduced soil organic, pH and nutrient levels; secondary salinization and waterlogging; reduced surface infiltration; and soil compaction reducing subsurface permeability and plant rooting depth.

Management options are best dealt with through implementation of best management practices by landholders with support from rural industries and agencies such as DAFF, DNR&M, BMRG and BSES.

The national and state programs for Sustainable Landscapes and the Reef Water Quality Improvement Plan in cooperation with the grazing, sugar and horticulture industries support the adoption of management practices to improve soil health and farm productivity while reducing off-site degradation such as sediment and nutrient loss to waterways, particularly to the reef lagoon.

Riparian management and restoration

Extensive stream bank slumping and scouring of riparian areas occurred along all water ways, especially in the lower Burnett and Kolan Catchments. The resulting sediment and nutrient loads to streams and the Great Barrier Reef Lagoon caused significant environmental and infrastructure damage. Historic and current management in riparian areas has aggravated the amount and severity of damage.

The severity of scouring occurred mainly due to the exceptional volume and velocity of waters with most damage occurring on the lower one third of banks on “outside” bends of streams with poor vegetation cover or inappropriate vegetation types and unstable soil types.

Slumping was most severe in the Mundubbera-Gayndah and lower Burnett stretches of the Burnett River. Areas most at risk are high (> 10 m) steep (> 25°) banks with susceptible soils and poor vegetation cover. Scouring of the lower bank in the 2010-11 and 2013 floods often aggravated the instability due to an increase in bank height (deeper channel) and steepness.
Natural rehabilitation occurs slowly and sometimes not at all, resulting in continued destabilisation and progressive damage of stream banks downstream. Best management includes maintaining a healthy vegetation cover of suitable diversity and density, restricting stock movements through fencing and off-stream watering, restricting sand/gravel extraction to appropriate areas, and reducing runoff through landscape management. A wide range of information (fact sheets) is available to landholders but on-going technical advice and funding/incentives (see below) are lacking. DNRM traditionally provided advice in the past but technical support is currently limited (see below).

Due to the instability of riparian areas in high risk areas, particularly the steep high banks, development on the high bank adjacent to the steep banks needs to be reassessed and cropping possibly removed to be replaced with suitable vegetation to ensure long-term stability.

As discussed above, vegetation removal/damage during flood events is normal, and the deposition of debris on river banks can help reduce water velocities and therefore protect the banks. As with any unstable area, any debris removal needs to consider flood dynamics, river geomorphology, soil stability and vegetation type/cover. Debris should be only removed if it threatens natural geomorphic processes, natural assets such as agricultural lands and important ecosystems, and infrastructure.

In estuaries, riparian management is difficult where normal tidal movements and lack of marine vegetation destabilise the banks. In these areas, maintenance or establishment of terrestrial vegetation is critical. In some areas, establishment of marine vegetation may be possible to help reduce water velocities and roots protect the soil from scouring.

Any dense weed infestation in stream channels may limit the capacity of the channels and may contribute to deviation of floods out of the channel onto floodplains. These areas require special consideration to ensure that the weeds are killed and the upper part of the tree (trunk and branches) removed from the downstream part of the channel first. The weed roots are retained to help stabilise the banks while suitable replacement vegetation establishes. On-going weed control follows.

As a result of state and national flood recovery funding, the BMRG have initiated a two year program to stabilise and rehabilitate “high risk” riparian areas. “High risk” is assessed on river geomorphology (out-side/in-side banks and curvature), bank height and steepness, soil stability, geology (hard rock) and amount of remnant vegetation. On-going management of the riparian areas is essential to ensure controlled stock movement, weed control, limited burning, restricted clearing and debris removal, and controlled sand/gravel extraction. On-going awareness and education programs are essential.

Riparian areas are managed by the landholder often on behalf of the Government. Funding for restoration works are expensive, the rehabilitation of riparian vegetation is preventative and cost per linear length of bank is “low”, but funding is generally lacking. Any works are a direct cost to the landholder through lost production; reduced access to the river; contributions for labour and machinery use, purchase and
planting of vegetation; loss of crop production, and ongoing maintenance and management costs.

Incentives are a direct benefit to the landholder, the community and the environment through reduced sediment and nutrients in our waterways. Any restoration or rehabilitation works need to be allocated on priority (see above) based on a risk assessment, practicality and cost/benefits.

The limited funding available through the 2013 flood recovery program is insufficient to address all riparian management issues. Another possible funding source is through local government rates or government taxes where the whole community are levied a small amount to fund land holders to provide these ecosystem services on behalf of the whole community.

One consequence of increased vegetation cover in riparian areas is to slow down flood velocity and a possible increase in flood duration. However, if this is achieved over the whole catchment, flood heights are potentially reduced throughout the catchment. While farming operations on floodplains may be affected, the natural benefits of floods to regeneration soils and replenish ground water generally outweigh the disadvantages.

**Riparian risk assessment**

As stated above, scouring and slumping occur under certain circumstances. Assessment of stream geomorphology, bank height and steepness, soil type, geology and vegetation type and cover will help identify areas at risk and help prioritise rehabilitation and allocation of funding and/or incentives.

Post flood imagery has been used to map extent and severity of bank scouring, bank slumping, floodplain scouring, floodplain sand deposition, and stream bed sand deposition. Stream channel scouring has not been mapped as all stream channels had severe scouring resulting in the deepening and widening of the channel and removal of vegetation particularly in the lower one third of the bank. This is a natural process associated with major events. With lower floods, the channel will tend to in-fill and vegetation establish naturally. These natural dynamic areas with stabilise naturally over time assuming channels have not been straightened, or natural stream bed barriers or sediments (sand/gravel) have been removed. Stream “roughness” from natural bed and bank barriers (rock, riffles, rapids, sand bars), meanders and vegetation is critical to maintain “natural” stream dynamics and stability.

This erosion mapping has been used to identify erosion processes and together with river geomorphology, bank height and steepness, soil type, geology and remnant vegetation has been used to identify “high” risk areas. This information in conjunction with community and industry consultation, an assessment of practicality for restoration and cost/benefit assessment were used to identify priorities for bank and floodplain restoration/rehabilitation and appropriate management practices.
Run-off and flood drainage coordination

Coordinated flood run-off and cross-country flows, and stabilisation of flood channels are necessary to reduce the effects on floodplain scouring, inundation, damage to crops, damage to on-farm and public infrastructure, and reduce effects on downstream land uses. Similar plans operate on the Darling Downs where erosion control plans and floodplain management plans are integrated with council controlled infrastructure (such as roads). Government infrastructure (roads, railways, irrigation, etc.) needs to be integrated in any run-off control.

As stated above, the main areas affected are the cropping lands on the floodplains of Three Moon Creek at Monto, Barambah Creek floodplains at Byee and the floodplains in the lower Burnett and Kolan Rivers. Other floodplain damage associated with the scouring included wash-out of council and Main roads, causeways and farm access; and damage to irrigation and transport infrastructure, farm machinery, fencing and farm buildings. Associated with any scouring is the deposition of sand and silt.

Any rehabilitation and stabilisation works are to concentrate on farm layout and agronomic management to stabilise the soil surface, improve surface cover and reduce risk in flood prone times; adoption of controlled traffic techniques to limit soil compaction and reduce soil loss form scouring; improving and coordinating run-off, drainage and flood channel stabilisation and drainage works; appropriate modelling/planning for the maintenance or removal of structures (artificial levees and diversion banks) that affect flood dynamics and concentration of flood energy; coordinating floodplain management with road infrastructure; locate on-farm infrastructure in stable areas; create vegetative buffers in unstable areas to reduce flood energy and reduce sand/silt deposition; appropriate weed management to ensure stream channels operate as they should while maintaining bank stability.

All works described here require coordination and cooperation between landholders to ensure that the rights and interests of landholders are protected while on-farm works avoid adverse consequences to downstream users. Integration of infrastructure (on-farm and public) into the coordinated planning is critical.

In the Monto, Byee and lower Burnett floodplains, severe flood scouring on cropping lands has created deeper and wider or even new flood channels. These channels operate over multiple properties and will continue to act as flood ways/channels in future flood events. If not stabilised, these flood ways may become new stream channels. To avoid on-going production losses and damage to infrastructure, new and existing flood over-flow channels require survey to identify flow direction and energy, suitable design, cooperation between landholders (including council and government) to meet on-farm layout and property rights, appropriate stabilisation and ongoing maintenance. Any coordinated drainage and flood ways will influence farm paddock layout and infrastructure design, and may result in some loss of cropping lands. Any works needs to be assessed in relation to short term and long term costs and benefits.
Artificial levees and flood diversion banks have long been contentious in relation to benefits and adverse impacts. Artificial levees have been constructed over time usually to protect crops from inundation and production losses from “low” to “moderate” floods. Some levees have been authorised by government or local authorities through legislation and planning provisions, while other have been constructed to meet local needs. The severe weather event and resultant record floods in 2010-11 and 2013 has highlighted the need for a coordinated and uniform policy on levees and diversion banks to avoid/reduce the effects of concentration or diversion flood waters. One good example of appropriate design is on the Byee floodplain where the previous Murgon Council required levees, diversion banks, head ditches and irrigation channels to not restrict flood flows. This was achieved by restricting height with the ability to “fail” when over-topped allowing flood water to flow/spread-out over the floodplain. Any removal or maintenance of levee or diversion banks needs to meet the requirements of any coordinated floodplain run-off and drainage plan. Any new artificial levees require approval under the Water Act 2000.

Technical support

Engineering solutions to design, repair or prevent damage to infrastructure is generally readily available to the controlling agency but technical support to landholders and other land managers for “low” cost or “soft” solutions (such as vegetation rehabilitation) is generally lacking or unavailable. Government technical support to landholders through technical advisory services was generally available in the past for riverine and stream channel management, crop agronomy and associated land management and soil conservation survey, design and advice but these government services are now noticeably unavailable.

Some advisory services are provided by industry to various extents in sugar, horticulture, grains and dairy, while other services are provided by private consultants. These services predominantly cater for agronomic and marketing advice, while engineering services are provided by private consultants. Support and advice to landholders on land management such as soil management, soil conservation design and control, floodplain and riparian restoration and management are not readily available especially at “low” cost to support landholders under severe financial stress from the floods.

All works implemented after the floods to make the landscape more resilient against future damage requires appropriate planning, design, application and on-going management. All this requires appropriate technical support for the short and long term. Short term government funding for flood recovery has allowed industry and community organisations to provide technical services in the short term. Long term strategies need to be developed.
In-stream management

In-stream and floodplain extraction of sand and gravel in some cases has resulted in aggravated channel and bank erosion due to removal of bed loads, removal of vegetation, altering the hydraulic gradient of the stream bed and destabilising the stream bed. Some restoration/rehabilitation works under the control of government may have been ineffective resulting in significant loss to landholders and environmental damage.

Although extraction in streams and on floodplains is regulated by government under the Water Act 2000, the lack of historic management is still resulting in damage. Any restoration will be very expensive probably at government and community expense. Some sort of assessment is required to ensure in-stream management is effective.

Emergency works

Emergency works after the floods are seen as necessary to quickly restore important infrastructure. However, any works need to ensure that flood dynamics and river geomorphology are maintained in a stable state and all works are coordinated with industry plans, run-off and flood drainage plans and community bodies to ensure any community based projects are not destroyed or aggravated in future floods. Any works that destabilise the stream or floodplain may need immediate attention and further rehabilitation.

Agencies undertaking future emergency works need to follow appropriate restoration and rehabilitation guidelines and integrate works with other relevant agencies.

Emergency work in the catchment has concentrated on infrastructure repairs and removal of sand and artificial debris particularly where it potentially affects infrastructure or the environment. Works that potentially modify flood dynamics (such as levee construction or repairs, removal of in-stream vegetation/debris, straightening stream channels, implementing engineered bank stabilisation measures, sand/gravel extraction) require appropriate planning.

Land use planning

Effective land use planning is essential on floodplains to limit inappropriate development and the affects of development on flood dynamics. Regional government planning needs to be coordinated with all designated agency responsible including natural resource managers such as BMRG (see below). Future changes in floodplain management, urban and infrastructure development may change flood dynamics. Therefore, catchment modelling and monitoring needs to be undertaken to identify possible risks.

Levee construction has been under the control of government and regional councils but recent historical authorisation has been lacking. Rejuvenation of government responsibility and control after the recent 2011 and 2013 flood are obvious
developments in the authorisation mechanism. Other needs for land use planning is the coordination of any floodplain run-off and flood drainage planning with local authority plans to ensure appropriate planning and integration of infrastructure works.

Other examples include the removal of riparian/floodplain vegetation and vegetation off-sets; urban development and design including flood protection/mitigation; appropriate buffers; infrastructure design including irrigation supply and storage in flood prone areas; industry development including transport infrastructure and processing plants that may affect flood dynamics; rock embankments or other engineered solutions to protect private property and infrastructure; state owned infrastructure such as roads, bridges, rail, port facilities, dams and irrigation; sand and gravel extraction in water courses and floodplains; protection and appropriate development/management of valuable agricultural lands; and appropriate habitat protection and management.

Training in floodplain management

After the extreme flood events in the Burnett and Kolan Catchments in 2010-11 to 2013, the community is highly aware of the consequences of flooding, particularly in urban environments. As a result, the rural and urban communities are requesting information and technical support on floodplain management. Various organisations including industry, DAFF and DNRM have limited available expertise in various fields to help landholders with improved land management. In general, there is a lack of expertise in fluvial hydrology, land management and riparian/floodplain restoration methods. Specific and specialised technical advice is available for engineering works through private consultants and business. Community based NRM organisations are attempting to address some of these deficiencies in the short term.

Various training opportunities are available from government and regional councils, a range of private experts, and some industries especially on-ground support in crop agronomy and associated land management. Some community based organisations such as BMRG have implemented programs post 2013 floods to improve community capability by providing awareness and training in floodplain management, flood dynamics and causes of damage, identification of geomorphic processes and identification of risk, general advice on stabilization and restoration, and providing appropriate information products and contacts for specific advice.

Community awareness is essential to the community to understand the benefits, consequences and management associated with floods.

Coordination and agency responsibilities

There is no central agency to take responsibility for controlling and coordinating all floodplain management, planning and operations. At present, there is an obvious lack of coordination for floodplain management, particularly between urban and rural landscapes where floods affect infrastructure, housing, land management, economic productivity and environment protection and management. Various government
departments, local authorities, emergency services, industry and community organisations all have a range of roles with some overlap of responsibilities and activities.

An obvious coordinating body is lacking and it is left up to the good will and cooperation of the various organisations to keep each other informed of various planning and operational decisions.

**NRM Plan**

The NRM Plan identifies a wide range of activities, projects and strategies that indirectly deal with floodplain management. These including riparian rehabilitation and wildlife corridors for biodiversity; improved land management for the Reef Water Quality Improvement Plan; sustainable landscapes for adoption of improved land management practices; wetland identification and management; soil health and improved land management; Regional Council planning schemes; Government legislation, regulation and policy development; community capacity building, awareness and education; industry research and development; and information management and information availability.

The discussion above provides opportunities to improve floodplain management through integrated projects and programs in the NRM Plan. The Plan also identifies funding strategies while the Monitoring and Evaluation Plan provides a mechanism for monitoring the health of the natural resources, evaluating the success of investment and management strategies to improve resource health, and therefore allows for review of resource condition targets.

Although the NRM Plan does not specifically deal with flood management, the Plan is flexible enough to cater to modification where necessary and more importantly, allows for the integration of strategies to improve floodplain management.