IN THE MATTER OF
THE QUEENSLAND FLOODS COMMISSION OF INQUIRY

A COMMISSION OF INQUIRY UNDER THE COMMISSIONS OF INQUIRY ACT 1950

AND PURSUANT TO COMMISSIONS OF INQUIRY ORDER (No. 1) 2011

STATEMENT OF DR BRUCE ABERNETHY

On the 7th day of October 2011, I, **Dr Bruce Abernethy**, c/- Floor 11, 452 Flinders Street, Melbourne in the State of Victoria, state on oath:

1. I am currently employed by Sinclair Knight Merz (***SKM***) as Manager, Water and Environment, South East Australia.

2. Attached to this statement and marked "BA-1" is a copy of a document entitled "Brisbane River Flood: Report on River Bank Erosion" (***Report***).

3. The Report was prepared by SKM at the request of Seqwater.

4. I believe the contents of the Report are true and correct.

5. The opinions expressed in the Report are opinions which I hold.

Filed on behalf of: Queensland Bulk Water Supply Authority trading as Seqwater

Allens Arthur Robinson
Lawyers
Riverside Centre
123 Eagle Street
Brisbane QLD 4000

DX 210 Brisbane
Tel (07) 3334 3000 Fax (07) 3334 3444
Ref MGI:120128021

[redacted]

jzhb A0118962886v1 120128021

[redacted]

6. Attached to this statement and marked "BA-2" is a copy of my curriculum vitae.

SWORN by **DR BRUCE ABERNETHY** on the 7 day of October 2011 at Melbourne in the presence of:

[redacted]

Deponent

[redacted]

Barrister/Solicitor/Justice of the Peace/Commissioner for Declarations

[redacted]

52 Flinders St, Melbourne 3000
An Australian Legal Practitioner
within the meaning of the
Legal Profession Act 2004

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3A-1

Brisbane River Flood, January 2011

REPORT ON RIVER BANK EROSION

- Final
- 6 October 2011

Brisbane River Flood, January 2011

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Sinclair Knight Merz
ABN 37 001 024 095
Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
Tel: +61 3 8668 3000
Fax: +61 3 8668 3001
Web: www.skmconsulting.com

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1. Introduction

Sinclair Knight Merz was engaged by Allens Arthur Robinson to investigate bank erosion on the Brisbane River following the January 2011 flood. Two days of field inspection were undertaken on 25 August and 14 September 2011, with sites observed at various locations above and below Wivenhoe Dam. Considerable evidence of bank erosion remains along the river with the erosion apparently caused by a variety of mechanisms.

Specific questions posed by the brief were as follows.

1) What is fluvial geomorphology?
2) What can cause or contribute to river bank instability, slumping or erosion in the Brisbane River?
3) Did the operation of Wivenhoe and Somerset dams during the January 2011 flood event (6 to 17 January 2011) cause or contribute to bank instability, slumping or erosion in the Brisbane River upstream or downstream of Wivenhoe and Somerset dam?
4) Would the bank slumping or erosion on the Brisbane River during the January 2011 flood event have been reduced or increased if Wivenhoe and Somerset dams did not exist?
5) Did the operation of Wivenhoe and Somerset dams cause or contribute to river bank damage referred to in:
   a) the statement of Ms Jenny Moore dated 14 April 2011;
   b) the statement of Mr Russell Burnitt dated 15 April 2011;
   c) the submission to the Commission of Inquiry of Mid-Brisbane River Irrigators dated 11 March 2011; and
   d) the submission to the Commission of Inquiry of Ms Jocelyn Bailey?

Answers to the above questions rely on my observations of the Brisbane River's banks and my understanding of river bank erosion processes. My report does not consider whether dam operations during the flood were or were not in accordance with the "manual" (Seqwater, 2009).

2. Fluvial geomorphology

Newson and Sear (1998) define fluvial geomorphology as the science that seeks to investigate the complexity of behaviour of river channels at a range of scales from cross-sections to catchments; it also seeks to investigate the range of processes and responses over a very long timescale but usually within the most recent climatic cycle. Much of the recent research effort in the discipline has sought to explain (and offer improved management of) human impacts on fluvial systems. These impacts are now well understood and are the subject of an extensive body of literature (*e.g.* Boon *et al.*, 1992).

Human intervention in river processes generally takes two forms: direct and indirect. Direct impacts include river engineering works such as channelisation, reservoir construction and so on. Indirect impacts take the form of catchment modification where human landuse affects sediment and water delivery to the channel (Leopold, 1997). Of particular interest to fluvial geomorphologists is the impact of impoundments on the flow regime and its subsequent effects on sediment movement and channel morphology. Underlying the study of the downstream impact of reservoirs is the assumption that scientists understand the range of flows, both spatial and temporal, that maintain the floodplain, macrochannel and active channel in a 'natural' or equilibrium state (Dollar, 2000). Although major strides have been made in this regard, our knowledge is still fragmentary and frequently based on observed empirical relationships rather than demonstrated causal mechanisms.

3. Brisbane River

The Brisbane River rises on the Brisbane Range near Nanango some 140km northwest of Brisbane. The river flows for 344km to drain a catchment area of 13,600km^2 before debouching into Moreton Bay at Brisbane. The river is characterised by its long meandering low gradient course, a relatively stable channel and a low ratio of bedload to total sediment load within a catchment of low rainfall and runoff. Landuse of the catchment is dominated by open forests, grazing, irrigated and dryland cropping and urbanisation. For descriptive purposes, the river can be thought of in three broad reaches: up stream of Wivenhoe Reservoir (upper), downstream from Wivenhoe Dam to the tidal extent (mid); and the tidal, urbanised lower reach (lower).

Beckmann and Stevens (1978) noted that very little had been written on the geological history of the Brisbane River with even fewer papers on the river and catchment's geomorphology. This is still true today. However, O'Flynn and Thornton (1990) summarised the history of the ancestral Brisbane River to show that the river has followed its present course since late Miocene times (approximately 10 million years ago) and probably earlier. In addition, Neil (1998) provided a comprehensive review of pre-historic landscape, climate and vegetation changes and environmental degradation following European development of the catchment.

According to Brizga and Finlayson's (1996) interpretation of the geomorphology of the upper Brisbane River, the river is incised and underfit. An underfit stream occupies a palaeochannel that was formed by a flow regime disproportionate to contemporary hydrology. The implications of this degree of underfitness concern the dynamics of the sediment body which fills the palaeochannel and makes up the modern active floodplain in the upper reaches. Brizga and Finlayson argued that this sediment body is fossil and does not represent the material being supplied to the modern channel from the catchment.

The surface of the active floodplain is subject to stripping during floods, resulting in the exposure of gravels and cobbles in many places. Historical evidence of stripping is cited by Brizga and Finlayson —1951 aerial photographs that show unvegetated patches on the floodplain surface, and nineteenth century survey plans that note conspicuous gravelly areas— supports the view that the active floodplain is a high energy environment subject to active deposition and erosion. Confinement of even large flows within the palaeochannel gives rise to high energy conditions on the active floodplain and, hence, episodic floodplain stripping and later re-deposition is a natural part of the upper Brisbane River's accommodation to floods and downstream sediment movement. However, it is likely to have been exacerbated by landuse changes (*i.e.* clearing, grazing, extractive activities) which exposed the surface sediments and retarded the recovery of vegetation.

Sea level during the Pleistocene is thought to have been up to 200m below present, placing the coastline some 40km to the east of Moreton Island (Hydrobiology Pty Ltd, 2003). Sea level changes during the Pleistocene produced a history of valley fill and erosion. The ice ages saw periods of rapid downcutting of the river to 45m below present sea level in the lower reaches of the Brisbane River (Stevens, 1990). During the interglacial periods the valley was refilled by alluvium transported by the river down from the upper catchment. Sea level is estimated to have been about 2m higher than the present level between 140,000 and 120,000 years ago, which resulted in some gravel infilling in higher terraces. Gradual downcutting and erosion of the terraces occurred until approximately 18,000 years ago. Since then, sea level has progressively risen to that of the present day, resulting in new deposition of coarse material, gradually covered by silt and clay.

Hydrobiology (2003, after Brizga and Finlayson, 1996; Department of Mines and Energy, 2000) documented a sequence of terraces evident along much of the Brisbane River:

1) low terrace – comprising the active floodplain and likely to be inundated by floods with an average recurrence interval (ARI) of approximately 1:10;
2) intermediate terrace – likely to be inundated during ARI 1:100 year events and subject to limited deposition of flood-borne silt.; and
3) high terrace – thought to be of Pleistocene age, formed during past regimes of greater flow, and not inundated by modern floods.

The intermediate terrace supports limited grazing and cropping but is the focus of most extractive industry operations. It the terrace in which the main river channel is now incised and is thought to have formed during the present high sea-level phase of the last 6,500 years.

4. Bank erosion processes

Rivers change through time as their channel evolves naturally or responds to the impacts of imposed management. The cause of bank instability (Figure 1) can be difficult to isolate and identify, and results from a variety of geomorphological processes, some operating locally, others at reach scale, and some associated with catchment-wide adjustments. The wider geomorphological context notwithstanding, the nature and extent of local bank erosion are controlled by:
1) local stream discharge;
2) channel shape (cross-section and planform);
3) location of eroding bank section (*e.g.* inner or outer bank);
4) bank geometry; and
5) bank material properties (geotechnical and hydrological).

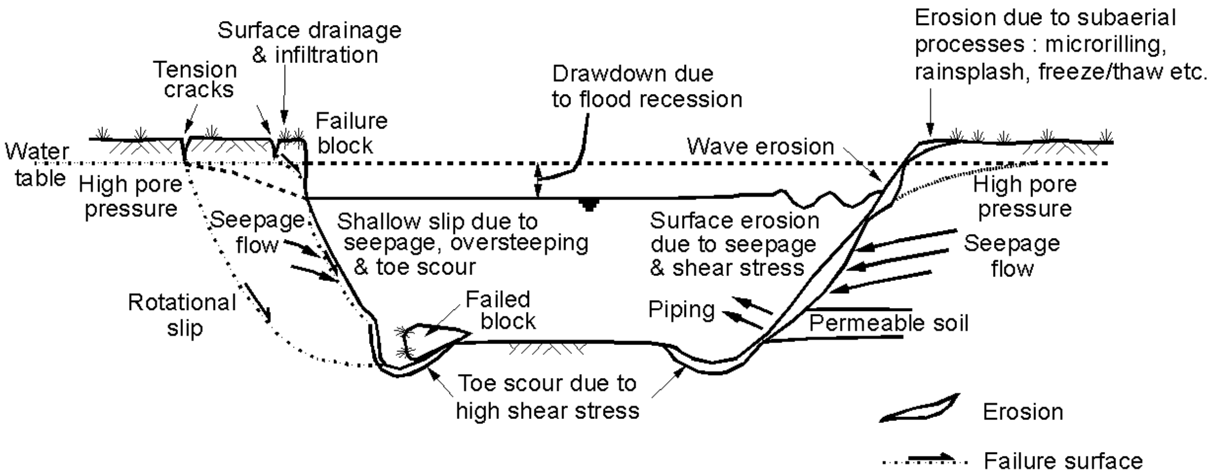

Figure 1: Processes of riverbank erosion (after Abernethy and Rutherfurd, 2000).

The mix of local conditions determines which of the erosion processes dominates the site and all are subject to the moderating influence of vegetation. Lowland riverbanks generally retreat by cyclical combination of fluvial scour of the bank toe followed by mass failure under gravity, followed then by removal of the failed material by further scour. All components of the cycle are affected somewhat by bank material loosening or weakening due to subaerial weathering processes. Mass failure is usually triggered when a critical stability condition is exceeded, either by reduction of the internal strength of the bank (often due to subaerial processes) or a change in profile geometry (typically the result of scour). The rate at which the failed material is transported away ultimately controls the rate of bank retreat over time (Thorne, 1982).

Scour occurs when the force applied to a bank by flowing water exceeds the resistance of the bank surface to withstand those forces. Particle by particle entrainment is usually limited as most alluvial bank materials exhibit some cohesion. Cohesion is the result of either capillary suction, the binding effect of plant roots or the presence of silt and clay fractions within the bank sediment. The bonding strength, between particles and aggregates, and hence the bank's erosion resistance, depends on the physio-chemical properties of the material and the chemistry of the pore and eroding fluids (Partheniades, 1965; Arulanandan *et al.*, 1980).

In floodplain reaches, banks are usually formed in cohesive material and are eroded primarily by mass failure under gravity, during discrete events, (Thorne, 1982). Mass failures occur when a critical stability condition is exceeded and whole blocks of material slide or topple from the bank into the channel. The shape and extent of mass failures are controlled by the geometry of the bank section, the geotechnical properties of the bank material and the type and density of the riparian vegetation (see Appendix A).

The soil water regime of a riverbank is very variable. It fluctuates with both rain infiltration and recharge from and discharge to the channel as the stage rises and falls in response to passing floods. Soil water plays an important role in determining the strength of the bank material. Any increase in pore-water pressure within the voids will reduce the grain to grain contact stresses, the effective stress, and hence the ability of the material to resist deformation. Often, bank failure occurs during flood recession when the river stage lowers sufficiently quickly that the pore pressures in the bank do not have time to reach equilibrium with the new stage. At the same time that the pore pressures are increased, the stabilising influence of the water pressure on the bank face is lost and the bank is less stable (Fell *et al.*, 2005). Faster rates of drawdown generally give rise to greater destabilising effects than slower rates.

In reality, riverbanks are almost always made up of a range of materials that occur in discrete and discontinuous layers. Under these conditions, mass failures typically reflect the combination of processes and failure modes of each of the bank material types. Bank material is also subject to marked variations over short reach lengths and a number of studies note the variety of failure modes occurring in close proximity to each other (*e.g.* Hubble and Hull, 1996).

5. 2011 flood damage

5.1. Upper Brisbane

The width of the upper Brisbane River's active floodplain is variable: in most places it is only about 150m to 200m, but occasionally it is more than 400m wide. The active floodplain is composed of alluvial sediments, mainly sand and gravel overlying coarser bed-material. The active floodplain is not flat; topographic features include natural levees and benches with the lower parts inundated frequently and the higher parts less frequently. Aggradation of the floodplain, and its stabilisation by vegetation, controls the position of the low-flow channel. The active floodplain is vegetated with grasses, shrubs and trees; grazing is carried out on most properties, and in some cases the floodplain is cultivated.

Dramatic channel change occurred as a result of the 2011 flood at Harlin. Comparison between a photo tendered to the Commission by Jenny Moore and Figure 2 shows dramatic stripping of the active floodplain and channel metamorphosis. Where previously a narrow sinuous channel meandered from side to side within the palaeochannel, depositing an alternating active floodplain within the confines of the channel, there now exists a wide shallow channel that almost fills the breadth of the palaeochannel.

Figure 2: Channel at Harlin, post flood.

Figure 3: Channel downstream from Harlin, showing active floodplain aggradation.

Over time, the channel will re-create its former pattern but there are no guarantees that floodplains will be aggraded in their former locations and the process will take a very long time – assuming there are no intervening large floods capable of further floodplain stripping. Ironically, the active floodplain renewal process was initiated elsewhere in the upper Brisbane by the same flood in January 2011 that scoured the floodplain at Harlin. Downstream (near Gregors Creek Road), the active floodplain has been aggraded by sand transported to the site from upstream during the flood (Figure 3).

Brizga and Finlayson (1996) noted a number of factors instrumental in causing the historical stripping of the floodplain surface in the upper Brisbane River. Firstly, landholders own to the bank of the river channel and have right of access over the river channel – there is no Crown frontage along the waterways. This, coupled with the extensive grazing regime used particularly by the early settlers, has meant that stock have been allowed free access to the stream riparian zone and have caused extensive damage to the vegetation and the banks. The river flats have also been selectively cleared for grazing and cultivation, a further factor modifying the nature of these areas. Finally, the river channel and floodplain deposits have been seen historically by local landholders, other residents and the shire councils as cheap and convenient sources of sand and gravel and there is a tradition of sourcing these materials from any conveniently accessible spot along the river.

Harlin is upstream from the Gregors Creek gauge which in turn is some 83km upstream from the Wivenhoe Dam wall. Base flow at the Gregors Creek gauge is some 10m higher than the peak water level recorded at the dam in January. Regardless of the processes of channel change, the hydrographs presented in Figure 4 show clearly that flow in the River at Harlin was controlled by local channel conditions alone and was not under the influence of Wivenhoe Dam. Between 9 and 13 January, the river stage at the Gregors Creek gauge rose and fell, completely independently of the steady rise in stage in the Wivenhoe Reservoir. In other words, operation of the dam during the flood had no bearing at all on the flow behaviour of the river at Harlin.

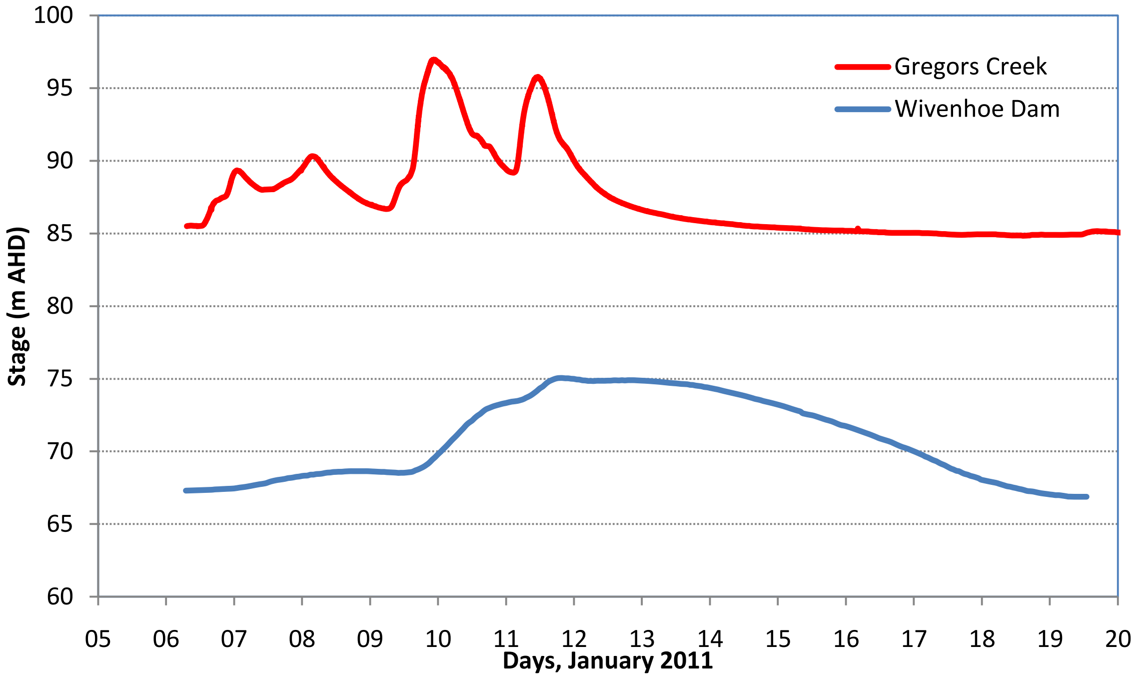

Figure 4: Stage heights at Gregors Creek and Wivenhoe Dam gauges.

5.2. Mid-Brisbane

I inspected a number of sites on the mid-Brisbane River (between Wivenhoe Dam and Mt Crosby Weir) and saw evidence of numerous bank erosion processes that had given rise to almost all of the failure modes described in Appendix A. Indeed, signs of bank erosion from the January flood are a ubiquitous feature of the whole mid-Brisbane reach. Flood debris is still apparent in many places along the river and, where it is caught up in high trees, it remains a constant reminder of the enormity of the flood and its power to rework the channel's boundary.

At Noel Schmidt's place at Fernvale the valley bottom is wide and the river runs in high banks though a broad floodplain. Downstream from the site, the terrain closes in again and probably produces a backwater effect over the floodplain during flood flows. At any rate, at Noel Schmidt's property, the flood well and truly inundated the higher terrace and deposited a swathe of sand over the floodplain. River bank erosion that resulted from the flood is still very clearly evident with large slumps and downed trees all along the reach (Figure 5 and Figure 6). The bank material is fine sandy loam (field estimate) and only weakly cohesive.

Figure 5, particularly, shows the complexity of process that occurs at any given point. Here, there is a very large failure (shown to the left of the photograph) and large overbank deposits of fine sand (foreground and right, where the people are standing) that all resulted from the same flood. Figure 6 depicts the left bank cut into the higher terrace on the outside of a right-hand bend. Seen in the foreground are uprooted trees aligned downstream on the toe of the bank and a series of shallow failures on the bank face. Even though the trees have been downed, they and the coarse material they are rooted in (gravels and cobbles) have protected the toe of the bank and have likely prevented the deep-seated failures observed just upstream (Figure 5).

At Jocelyn Bailey's place at Pine Mountain the river is confined within a narrow valley. Here the river generally flows at the base of the valley sides but the occasional small alluvial flat is apparent, typically only developed on one side or other of the river. Again, a variety of processes have given rise to bank erosion. Figure 7 shows an intact bank section on Jocelyn Bailey's property where the bank has been protected by a bed-rock outcrop. Elsewhere along this reach minor failures have occurred but the banks had been re-battered prior to my visit, so it was difficult to infer process or extent of failure.

Figure 8 shows a very dramatic failure that occurred on Graham Bell's property. (Graham Bell is Jocelyn Bailey's downstream neighbour). It is difficult to hypothesise what occurred here, as the original topography cannot be inferred but there was certainly an interaction between hillslope and river processes. It is likely that this failure occurred on the falling limb of the flood as the soil water drained back towards the river. Perhaps the incipient failure resulted from a concentration of flow through convergent topography.

The above are just a few examples of the multitude of bank erosion examples that I observed through the reach. However, they serve to illustrate the effect of the flood on the banks. All the property owners above remarked to me that they believed a contributing cause of the erosion was the operation of Wivenhoe Dam. They believe that the flood's peak could have been reduced by storing more of the flood waters within Somerset and Wivenhoe Dams and that the recession was unnaturally fast and that this led to drawdown induced failures of the banks.

I have relied on the gauge data at Mt Crosby Weir to characterise the hydrology of this reach. This is the first gauge that the hydrodynamic model lends reliable predictions of water levels and velocities and offers a credible no-dams scenario (Sinclair Knight Merz, 2011).

Figure 5: Mass failure of right bank at Fernvale and overbank deposition.

Figure 6: High outer left bank at Fernvale.

Figure 7: Relatively intact right bank section at Pine Mountain.

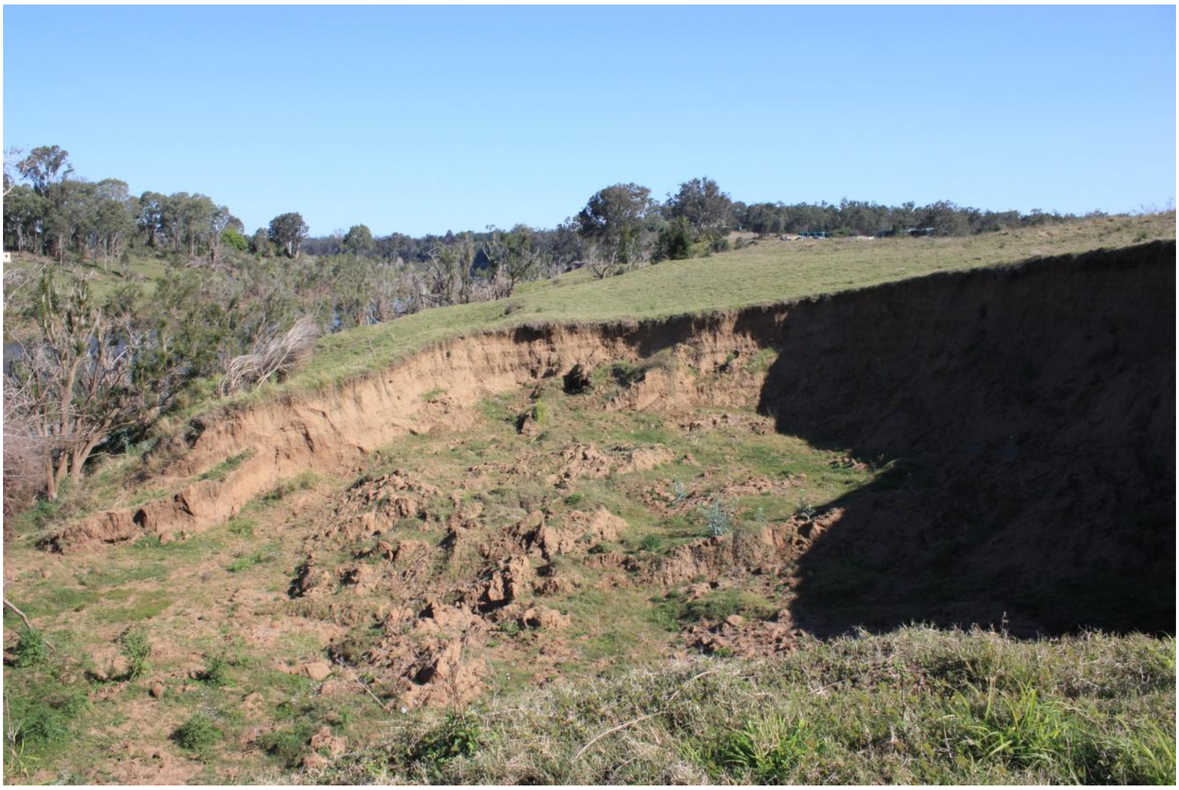

Figure 8: Massive failure on right bank at Pine Mountain.

The hydrographs presented in Figure 9 show that, in comparison to the 1974 flood, the January 2011 flood had quite different attributes. Although the peak stage was similar, at 26.1mAHD compared to the 1974 peak of 26.7mAHD, the floodwaters remained above 18mAHD for 75 hours and 55 hours in 1974 and 2011 respectively. This against a potential peak (modelled) of 29.3mAHD at the Mt Crosby Weir gauge and high floodwaters, above 18mAHD, for 82 hours if the dams weren't used to moderate the downstream flow.

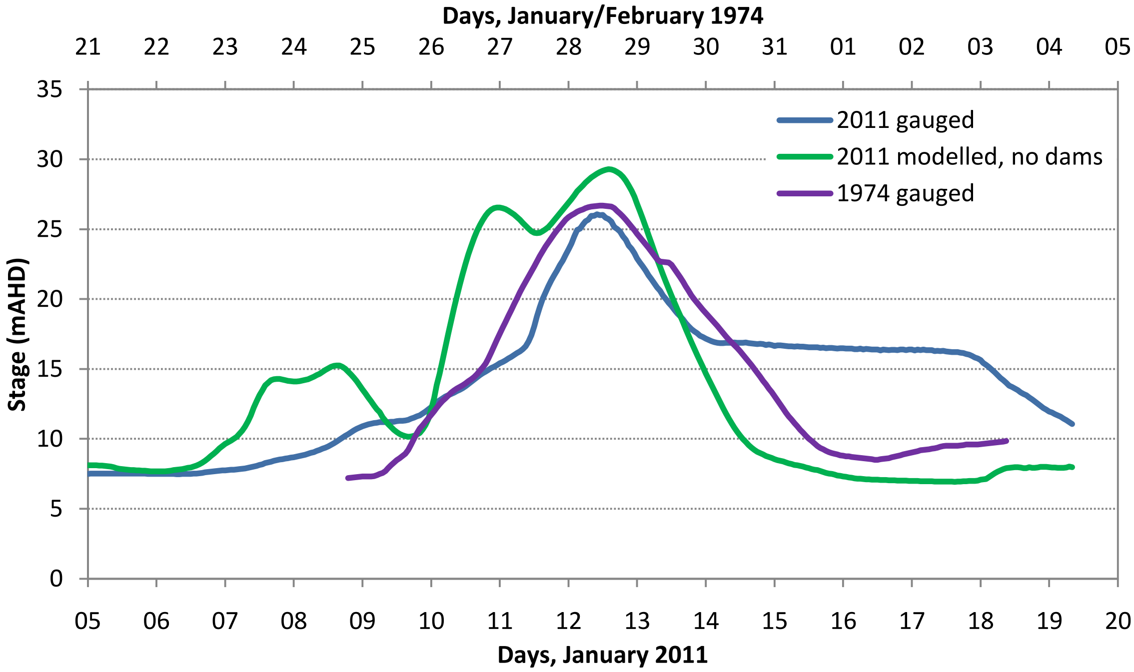

Figure 9: Modelled and gauged hydrographs at Mt Crosby Reservoir.

In 2011 river stage was maintained above 16.5 m at Mt Crosby Weir (level prior to a second drawdown) for 106 hours. In 1974, the river remained above 16.5 m for 85 hours. And according to SKM's (2011) modelled scenario would have stayed up above 16.5 m for some 87 hours if Wivenhoe and Somerset Dams had not existed during the 2011 flood. Hence dam operations kept the stage at that point for some 20% longer than might have happened without them.

Turning now to the question of drawdown rates, Table 1 presents a range of gauge data that compares the drawdown rates of the 1974 flood recession with the two drawdown phases of the January 2011 flood releases from Wivenhoe Dam (see also Appendix B). The context for these drawdown values is that post-peak, releases from Wivenhoe Dam were essentially matched to

Table 1: Stage recession (drawdown) rates at Brisbane River Gauges.

Stream gauge	2011 first drawdown			2011 second drawdown			1974		
	Δ Stage (m)	Time (hr)	Rate (m/hr)	Δ Stage (m)	Time (hr)	Rate (m/hr)	Δ Stage (m)	Time (hr)	Rate (m/hr)
Lowood							11.88	44	0.27
Savages	8.34	27	0.31	7.41	51	0.15	9.20	35	0.26
Mt Crosby	8.56	34	0.25	4.76	34	0.14	12.79	50	0.26
Ipswich	8.81	36	0.24	4.52	36	0.13	15.83	59	0.27
Moggill	7.27	31	0.23	4.11	31	0.13			
Jindalee	6.13	35	0.18	2.99	29	0.10	9.10	38	0.24

inflows to the reservoir (Appendix C). In other words, the data presented in Table 1 represent essentially natural rates of recession for the first drawdown period of the 2011 flood and the 1974 flood. The second period recession, following a sustained release from the dam (c. 3,500 m^3/s for nearly four days) was controlled through the dam at a much lower rate of drawdown than the otherwise natural values. Modelled drawdown for a "2011, no dams" scenario gives rates of 0.26 m/hour and 0.40 m/hour at Mt Crosby Weir and Moggill, respectively.

6. Conclusion

Stock (1990) noted that the early pioneers would not recognise today's Brisbane River. Post-settlement modifications —clearing, pastoralism, sand and gravel extraction, urbanisation and river impoundments, for example— have changed the hydrological condition of the catchment and generated increased loads of fine sediment. Removal of riparian vegetation and stock access have particularly contributed to bank degradation with marked changes to channel form apparent at local scales. This transformation of the catchment and the river has led to channel changes and instability that cannot be reversed over human timescales. Even so, restoration of riparian vegetation will strengthen riverbanks, resist erosion, and help maintain aquatic and terrestrial ecosystem function.

Following the January 2011 flood, bank failure and channel change are ubiquitous features of the Brisbane River. It is particularly noteworthy that the flood was large and would have caused considerable channel change regardless of dam operations. Indeed, dam operations had no effect on channel process above the reservoir's backwater and could not have contributed to bank erosion or floodplain stripping in the upper Brisbane River. Downstream, dam operations significantly reduced the flood peak and shortened the duration of overbank flows, thus reducing the period and depth of floodplain inundation. In all likelihood, then, Wivenhoe Dam operations mitigated some of the potential effects that an otherwise uncontrolled "natural" flood that may have inflicted on downstream reaches. Certainly the deeper flows and higher velocities that could have occurred within the channel and across the floodplain were avoided and this alone would probably have saved some property and river bank damage.

The reservoir drain-down phase (with a sustained release of c. 3,500 m^3/s from Wivenhoe) did give rise to a prolonged elevated flow within the channel. It may be that the extended period of this flow allowed many bank sections to become saturated and more prone to erosion when the stage eventually dropped. However, the drawdown rate at this phase of the flood was maintained at much lower than natural rates by the dam operation.

In my opinion, the operation of Wivenhoe and Somerset dams did not cause or contribute to the river bank damage referred to in the statement of Ms Jenny Moore dated 14 April 2011.

In my opinion, the operation of Wivenhoe and Somerset dams during the period of 7 to 14 January did not exacerbate and probably mitigated bank erosion processes that occurred as the result of the January 2011 flood in the mid-Brisbane River as referred to in:

a) the statement of Russell Burnitt dated 15 April 2011;
b) the submission to the Commission of Inquiry of Mid-Brisbane River Irrigators dated 11 March 2011; and
c) the submission to the Commission of Inquiry of Ms Jocelyn Bailey.

In my opinion, the operation of Wivenhoe and Somerset dams during the period of 14 to 18 January maintained a flow (between base flow and bankfull) within the mid-Brisbane River channel that extended the period of inundation of the lower portions of the river's banks. This extended period of inundation would have provided for greater recharge of those bank portions below the river stage.

In my opinion, the operation of Wivenhoe and Somerset dams during the period of 18 to 19 January drew down the river stage within the mid-Brisbane River channel at a slower rate than might otherwise have occurred naturally.

It is not possible to determine whether the combination of the prolonged flow during the period of 14 to 18 January combined with the later drawdown of 18 to 19 January gave rise generally to conditions that resulted in widespread drawdown induced mass failures of the mid-Brisbane River's banks. All bank erosion on the mid-Brisbane River, that I observed, varied greatly and appeared to be the result of the particular bank and flow conditions apparent locally at each site. Amongst a number of seemingly drawdown induced failures, I also observed all of the failure types (and local variants) described in Appendix A.

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Appendix A Bank failure modes

The following descriptions of failure modes are based on idealised descriptions found in the literature, reconciled against my own observations in the field.

A.1 Shallow failure

This type of failure occurs on a variety of bank angles. Failure by shallow slip has less impact on a riverbank than deep-seated failure, but the high frequency of shallow slips makes them important. Failure takes place along a surface that is generally parallel to the bank face. Theoretically this type of failure should be confined to banks formed in cohesionless material because the shear strength of non-cohesive material increases more quickly with depth than does the shear stress (Terzaghi and Peck, 1948; Carson and Kirkby, 1972).

Although deep-seated failures of non-cohesive material should be rare, there are many instances where banks formed in predominantly cohesive materials are subject to shallow failures. In well-drained banks, failure occurs when the bank slope angle exceeds the friction angle. This can result from over-steepening of the bank angle by basal scour (Thorne, 1991).

A.2 Planar failure

Plane slip failures are usually observed on steep bank slopes. In nearly vertical cohesive banks, there is little change in the orientation of the principal stresses with depth and the failure surface is almost planar (Carson and Kirkby, 1972). Field observations show that the planar failures tend to occur on high angled banks and that the failure surface generally passes through the toe of the bank. Lower-angle banks tend to fail along a circular arc or logarithmic spiral (Taylor, 1948; Lohnes and Handy, 1968).

A.3 Slab failure

Low, steep banks fail by sliding. Usually, the sliding mass is projected downwards and outwards along an almost planar surface and the failure block topples forward into the channel. This is termed slab or toppling failure by Thorne (1990). Behind steep banks, significant tensile stress can be generated adjacent to the upper part of the bank. This leads to the development of vertical tension cracks, which in riverbanks may occupy a significant proportion of the bank height (Alonso and Combs, 1990).

In situations where the bank has yet to fail, deep cracks can be seen running parallel to the bank face. These cracks deepen and widen as the failure develops until the block is completely separated from the bank and topples into the channel. I have only observed this type of failure at locations where the vegetation cover consisted of grass alone.

A.4 Rotational failure

High, less steep banks fail by rotational slip along a curved surface; the failure block is back-tilted away from the channel. Although the failure surface often passes through the toe of the bank, this is not always the case, and the possibility of failure surfaces extending beyond the toe, or intersecting the bank face above the toe, must not be overlooked (Hemphill and Bramley, 1989).

For the most part, rotational failures occur on banks with slopes less than 60° along a circular arc or logarithmic spiral (Lohnes and Handy, 1968; Thorne, 1990). Because they usually occur in cohesive material, rotational failures are generally deep seated. Terzaghi (1943) explained that the circular slip surface in sloping cohesive banks is due to the change in the orientation of the principal stresses with depth.

A.5 Translational failure

Very few of the mass failures that I have inspected could be considered to be truly rotational. Some deep-seated failures display minimal signs of rotation and are more correctly termed translational failures. The upper surfaces of translational failures retain their previous orientation with respect to the former bank top. Other deep-seated slips observed in the field tended to break up on failure, resulting in a confused morphology. These appear to be the result of a number of failure mechanisms acting simultaneously.

A.6 Cantilever failure

When a stream bank is subject to undercutting as the result of seepage, wave action, or basal erosion an overhang or cantilever can develop in the upper bank. Detailed analysis of cantilever failure was undertaken by Thorne and Tovey (1981) who describe three principal failure modes.

Shear failure occurs when the cantilever simply fails along a vertical plane, most probably an interped fissure, and drops straight down. Failure comes about because the shear stress due to the weight of the block overcomes the shear strength of the soil. Alternatively, tensile failure across a horizontal plane occurs at some height above the base of the cantilever and causes the lower part of the block to fall away. The third failure mode is beam failure, which is brought about as the cantilever rotates forward about a horizontal axis somewhere in the block. Above the axis, failure is in tension but below it is in compression. Failure occurs because the moment of the weight of the block about the neutral axis overcomes the resistive moments of the soil’s strength in tension and compression (Thorne and Tovey, 1981).

A.7 Tension cracks

Tension or desiccation cracks formed in cohesive soils reduce the stability of the bank, particularly if they are subsequently filled with water. For most failure analyses, Terzaghi (1943) maintained that it is important to account for the effects of cracks and fissures in the soil. Cracks may be inherent, like inter-ped fissures found in clay soils due to desiccation, or may develop to relieve tensile stress at the top of a steep slope.

Tension cracks open when the horizontal tensile stresses in the upper layers of a riverbank exceed the tensile strength of the soil. Since the tensile stress is a maximum at the soil surface, tension cracks usually propagate from the surface downward (Baker, 1981; Darby and Thorne, 1994). Vertical tension cracks at the surface of the bank reduce its overall stability by decreasing the cohesion that can be mobilised along the upper part of a potential failure surface (Bradford and Piest, 1977; Baker, 1981). Within the zone of tensile stress the strength of the soil cannot be relied upon to resist failure (Thorne, 1982).

Appendix B Flood hydrographs

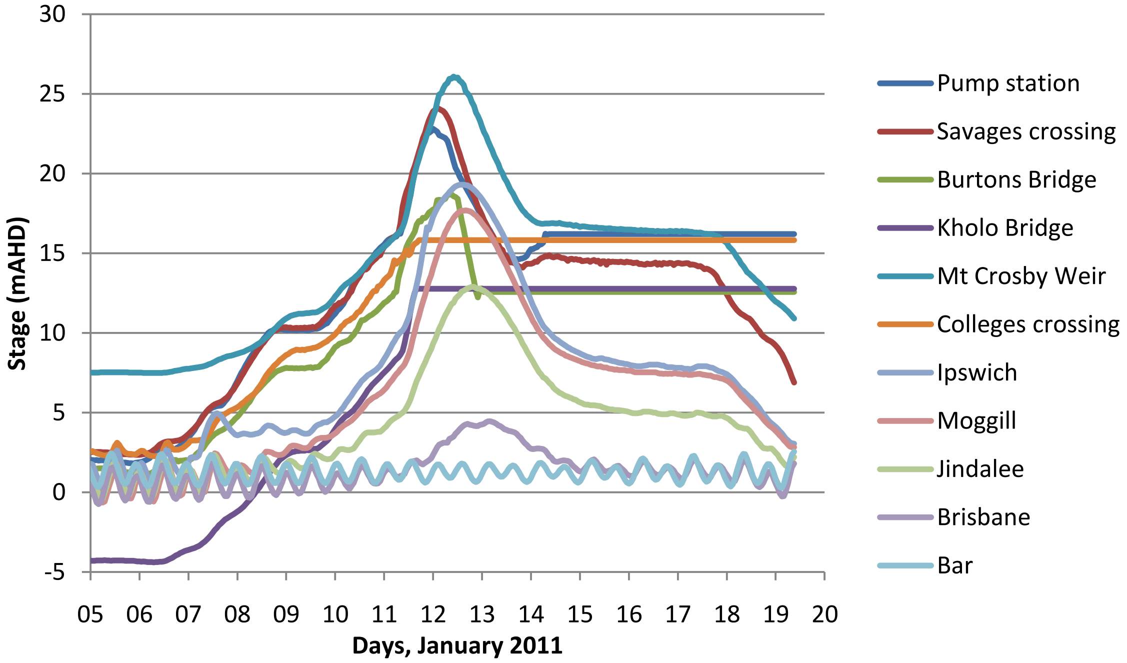

Figure 10: 2011 gauge hydrographs.

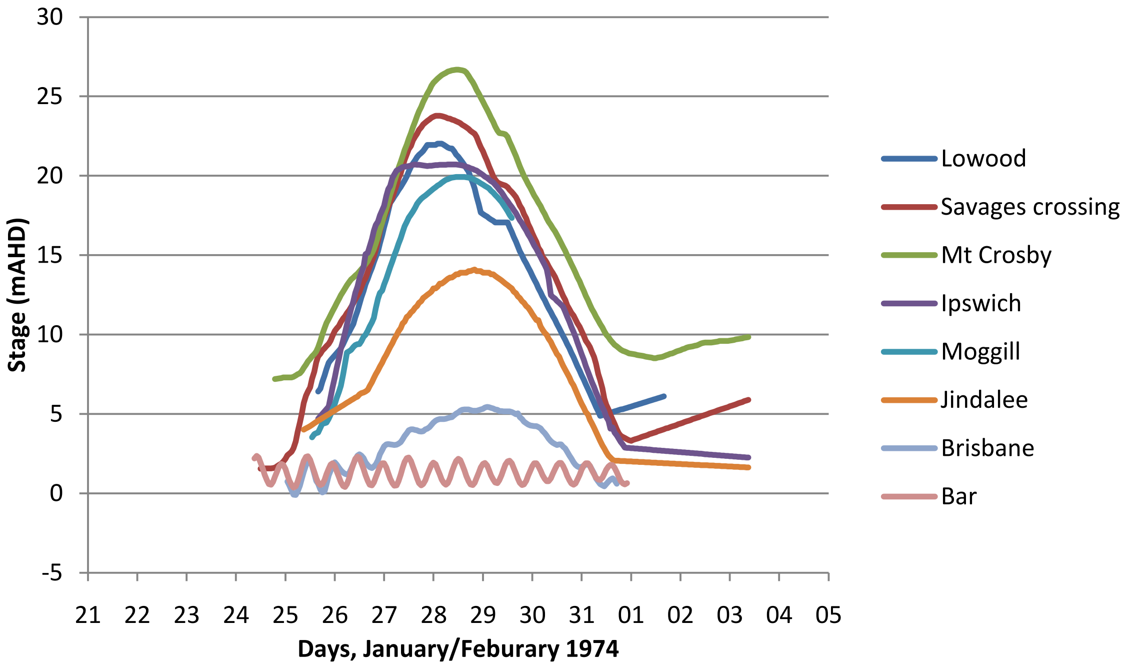

Figure 11: 1974 gauge hydrographs.

Appendix C Wivenhoe Dam inflows and releases

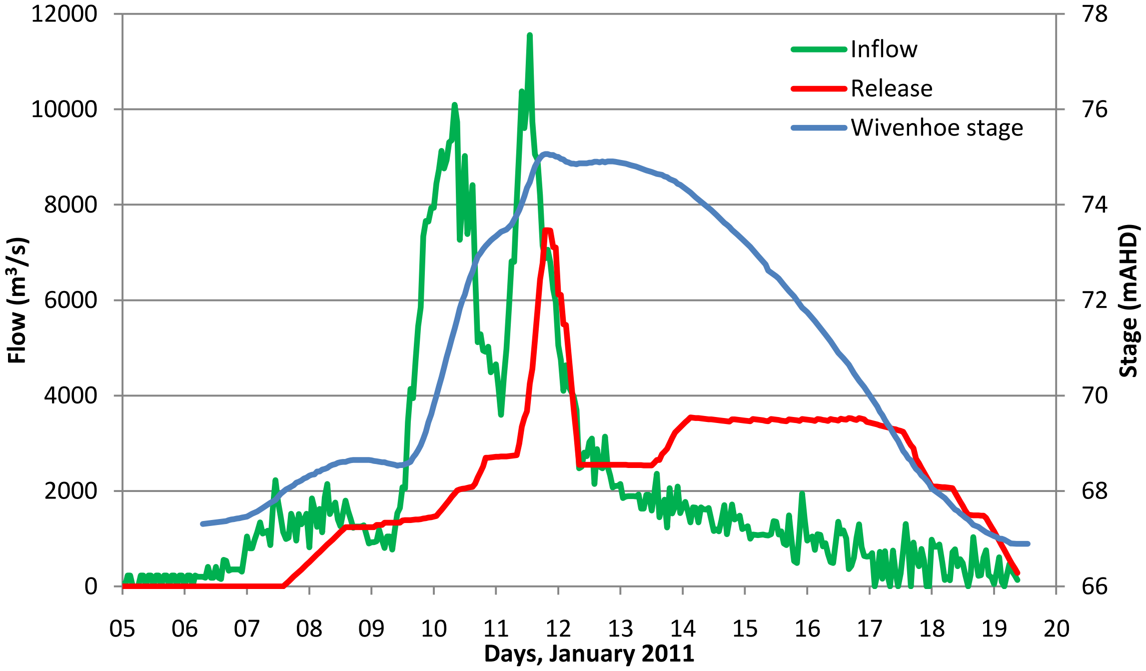

Figure 12: Wivenhoe Dam inflow and release during the January 2011 flood.

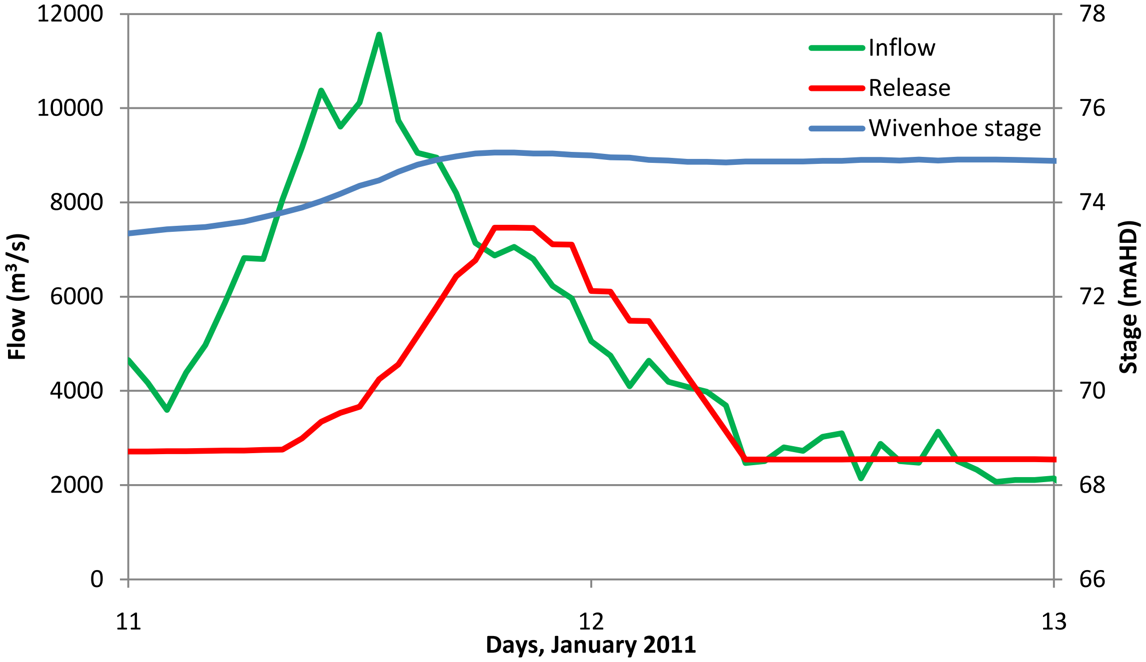

Figure 13: Wivenhoe Dam inflow and release during peak of the January 2011 flood.

BA - 2

CV

SKM

Dr Bruce Abernethy

Qualifications

Doctor of Philosophy
Department of Civil Engineering
Monash University, 1999

Bachelor of Science (Honours Class 1)
School of Geography
University of New South Wales, 1994

Affiliations

Member of the River Basin Management Society

Fields of special competence

- Regional strategic planning
- Natural resource management planning
- Strategic sustainability planning
- Fluvial geomorphology
- Role of vegetation in river channel processes
- River bed and bank erosion
- Hillslope and gully erosion processes
- Environmental flows

Relevant experience

I have sixteen years experience in riverine investigations and catchment management. My career has exposed me to a broad range of catchment, waterway and floodplain management issues. My work has variously involved: fluvial investigations; river rehabilitation strategies; catchment sediment budgeting; investigations of the impacts from riverine quarrying; extraction site closure and rehabilitation; environmental flow assessments; regional planning; and strategic sustainability planning. Through this experience, I have developed a number of techniques to assess and report the social, economic and environmental requirements of contemporary natural resource management.

In addition to my technical roles, I have managed many multidisciplinary projects. My project management relies on my practical knowledge of natural and social processes combined with proactive risk management and successful community and stakeholder consultation.

My corporate roles have included people, commercial and strategic management. I currently manage SKM's southeast Australian Water and Environment Operations. The business spans Victoria, Tasmania and the ACT and is comprised of some 300 engineers, scientists, planners and spatial analysts engaged in a variety of potable and wastewater engineering, surface water, groundwater and land management projects and environmental impact assessments.

Previously, I managed our New Zealand Water and Environment Operations. Before that, I managed our US Water and Environment Operations, where my role was to foster client relationships, build business and strengthen SKM's global alliance with our North American partners. Recently, I also lead SKM's global sustainability strategy. This role necessitated framing and implementing a range of initiatives to reduce the company's environmental footprint and oversee a change management process that introduced sustainability to all SKM project delivery. The execution of the strategy saw a number of profound changes in the company's operations and staff outlook.

Sinclair Knight Merz
November, 1999 to date

Manager – SE Australia Water and Environment Operations (June 2011 – date)

- Line management of 300 staff
- Commercial management
- Accountable for Profit and Loss
- Business development
- Strategic planning

Manager – NZ Water and Environment Operations (October 2009 – June 2011)

- Line management of 100 staff
- Commercial management (profit and loss)
- Business development/strategic planning

Manager – US Water and Environment Operations (January 2008 – October 2009)

- Business development
- Alliance management
- Commercial management
- Strategic planning

Manager – corporate sustainability strategy (May 2007 – January 2008)

- Responsible for formulation and delivery of the company's global sustainability strategy
- Framed and introduced initiatives to
  - reduce the company's environmental footprint
  - deliver our client's projects in a sustainable way
  - manage cultural change and staff communication

Manager – Catchment Planning (June 2004 – May 2007)

- Line management of 70 staff
- Commercial management
- Strategic planning

Geomorphologist/project manager (November 1999 – date)

- Geomorphology.
  - Investigation to assess potential channel change from proposed irrigation dam, Hurunui River, New Zealand.
  - Investigation to assess extreme sediment discharge (conveyed by the probable maximum flood) through Keepit Reservoir, Namoi River, New South Wales.
  - Assessment of Manilla Weir sedimentation, Namoi River, New South Wales.
  - Sand extraction site closure and rehabilitation plan – stable planform design, revegetation and environmental monitoring – Delatite River, Victoria and Buaraba Creek, Queensland.
  - Investigation of the downstream geomorphological effects of changed powerstation operations, Macquarie River, Tasmania.
  - Investigation of potential avulsion sites on the Goulburn River, Victoria.
  - Hillslope erosion control investigations, Victoria.
  - Investigation of the impact of changed flow on channel morphology in Murray River anabranches due to proposed groundwater interception scheme, Victoria.
  - Glenelg basin geomorphic categorisation, Victoria.
  - Assessing high conservation value in the Murrumbidgee catchment, New South Wales.

- River/estuary restoration.
  - Project manager and project geomorphologist for river restoration plans – Surrey River, Honeysuckle Creek, Moe River, Bruces Creek, Victoria.
  - Development of action plan to manage opening the Surrey River mouth during times of low flow, Victoria.
  - Development of Waituna Lagoon barrier breaching options to manage lagoon health, Southland, New Zealand.
- Catchment sediment budgets.
  Project Manager and project geomorphologist for sediment budget and geomorphological studies – upper Loddon River, Glenelg River, upper Barwon River and upper Hopkins River catchments, Victoria.
- Environmental flow determination.
  Project Manager and project geomorphologist for a variety of projects that determined the of environmental water requirements for the: Onkaparinga River, South Australia; Welcome River, Bluemans Creek, Tommahawk Creek, Tasmania; Wimmera River, Avoca River, Glenelg River, Macalister River, Lindsay River, Mullaroo Creek, Birches Creek, Campaspe River, Yarra River, Woori Yallock Creek, Ovens River, Broken Creek, Tarra River, Avon-Richardson River, Moorabool River, Sevens Creek, Wannon River and Lake Wallawalla, Victoria.
- Nutrient action plans.
  Project manager of nutrient action plans for the Loddon, Campaspe Avoca, Avon-Richardson Rivers, Victoria.
- Strategic sustainability.
  - Project manager of SKM corporate sustainability strategy, global. Responsible for formulation and delivery of the company's global sustainability strategy, including framing and introducing initiatives to: reduce the company's environmental footprint; deliver our client's projects in a sustainable way; and manage cultural change and staff communication.
  - Project director of San Diego International Airport expansion – sustainability analysis, California. Objectively compared two existing expansion proposals with a third, sustainability focused alternative to evaluate major sustainability components.
  - Sustainability consultant for Columbus Solids Treatment and Disposal Master Plan, Ohio, USA. Provided knowledge and technical guidance during, facility tour, expert panel and concept confirmation conferences.
  - Sustainability consultant for Coquina Coast seawater desalinisation project, Florida, USA.
- Regional natural resource management.
  Conceived and managed the development of five-year regional natural resource management plans for the Wimmera and Glenelg Hopkins regions in Victoria; the Eyre Peninsula and Rangelands regions in South Australia; the Western Catchments region in Queensland; and the Cradle Coast, NRM North and NRM South regions in Tasmania.

Cooperative Research Centre for Catchment Hydrology
January, 1999 – November, 1999
Post-Doctoral Research Fellow (University of Melbourne)

Cooperative Research Centre for Catchment Hydrology
March, 1995 – January, 1999
Full-time PhD student (Monash University)

Dames and Moore
November, 1992 – January, 1993
Assistant Environmental Planner

Royal Australian Navy
July, 1980 – July, 1990
Leading Seaman

Papers and presentations

Abernethy, B., 1994. *Predicting the Headward Extent of Gully Erosion using Digital Terrain Analysis*. BSc Honours Thesis. School of Geography, University of New South Wales, Sydney.

Abernethy, B., 1999. *On the Role of Woody Vegetation in Riverbank Stability*. PhD Thesis. Civil Engineering, Monash University, Melbourne.

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