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Dear Louise

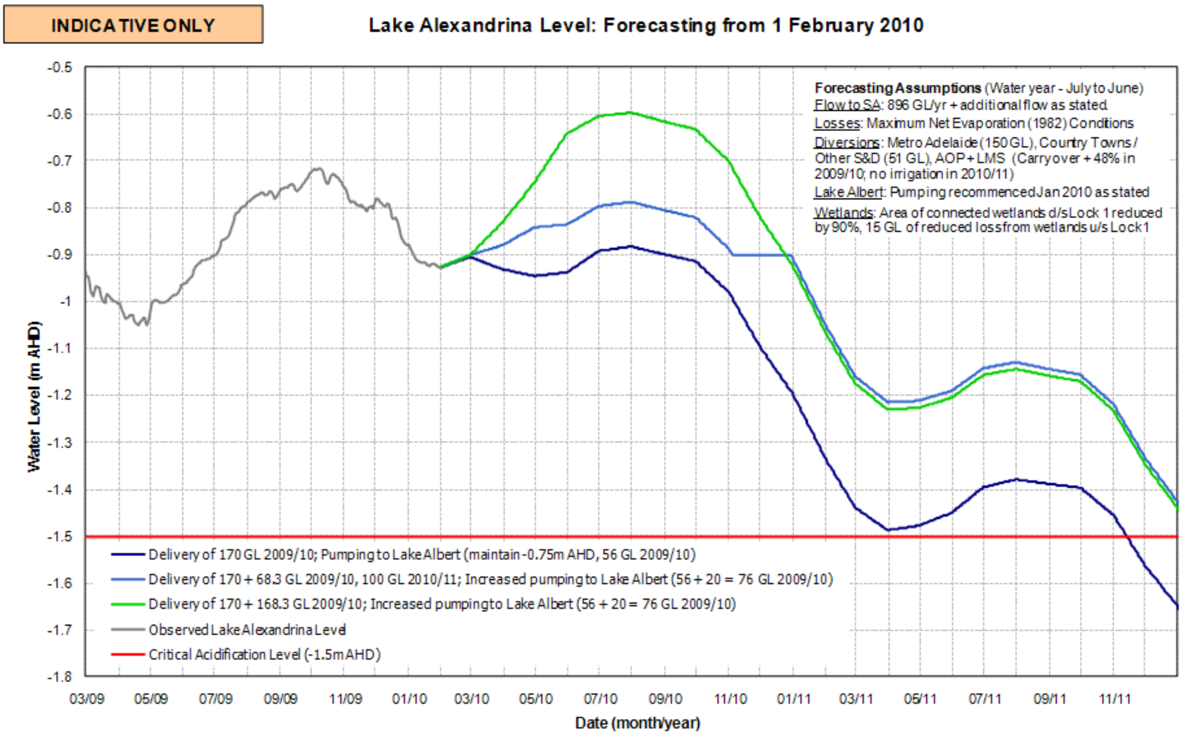
Part A: Lower River Murray - Influence of NSW Floodwaters on the potential for a River Bank collapse to occur

DWLBC commissioned SKM on 28 January 2010 to undertake a desk study on the influence of the arrival of floodwaters from NSW via the Darling River on river bank collapse in the lower River Murray to assist DWLBC in managing potential impacts from the change in water levels in the river between Swan Reach and the lower lakes, as shown in **Figure 1** below.

1. Forecast Water Levels

An initial overview of the likely water levels in the lower pool and Lake Alexandrina was required and provided by letter on 1 February 2010. The findings reported in that letter are consistent with the more accurate hydrology since supplied by DWLBC in the form of **Figure 1**, for SKM use in assessing the influence of the slowly changing water levels on river bank stability in the lower pool.

The increased flows to Lock 1 are expected to result in a rise from March to August 2010 in pool level followed by a fall, from September 2010 onwards, along the Lower Murray as the floodwaters pass downstream. It is expected that the flood will be composed of 100GL of NSW floodwater, 48.3GL of The Living Murray water and 20GL from the Commonwealth Environmental Water holder, totalling about 168.3 GL, that will flow toward Lock 1 as a regulated release from Lake Victoria over four months in early 2010.



- **Figure 1: Forecast of Water Level Change in Lake Alexandrina (provided by DWLBC)**

Flow rates at Lock 1 are likely to vary from about 4,800ML/day initially in February to 3,200ML/day in May according to DWLBC estimates, within the range of 3,000 to 10,000ML/day estimated in our initial letter of 1 February. These flow rates are entirely normal in magnitude in the history of the river and are small when compared with the ~100,000ML/day flows during the 1993 flood, which did not cause extensive erosion problems, so are not expected to result in velocities sufficient to cause scour or erosion of river banks along the lower pool.

Note that the extent of scour by water depends on the bed material and particle size and current speed shearing across the surface. Australian state road authorities in their design manuals typically refer to grassed areas as being capable of resisting erosion from currents of 1.25 to 2.5m/s for short periods of time while typical velocities that can cause stream bed movement are shown in **Table 1** below.

- **Table 1: Velocities that can cause stream bed movement (Vic CRB).**

Material on stream bed	Velocities (m/s) that cause movement
Silt	Less than 0.3
Sand – fine	Less than 0.3
Sand - coarse	0.4 to 0.6
Gravel – 6mm	0.6 to 0.9
Gravel – 25mm	1.0 to 1.25
Gravel - 100mm	2.0 to 3.0
Clay – soft	0.3 to 0.6
Clay – stiff	1.0 to 1.25
Clay - hard	1.5 to 2.0
Stones – 150mm	2.5 to 3.0
Stones – 300mm	4 to 5

DWLBC's observations over the last two years indicate that flows delivered over Lock 1 result in raised water levels immediately downstream of Lock 1, which quickly dissipate within around 20km of Lock 1 (upstream of Swan Reach). Water levels downstream of Swan Reach are generally consistent, nominally 0.05m (5cm) above Lake Alexandrina levels, as advised by DWLBC, with daily, short term variations, primarily due to wind induced wave seiches.

Forecast Lake levels corresponding to the green line from Figure 1 have been used by SKM to re-assess stability of the river banks over the range of forecast water levels at the seven sites investigated, modelled and reported in our Geotechnical Investigation Report of February 2010, copy of which is accessible on the DWLBC website. The results of the re-assessment on river bank stability in the lower pool are reported in this letter.

The maximum water level in the study area along the River will be about 0.05m above the maximum water level in Lake Alexandrina under the given flow conditions, i.e. RL -0.60m + 0.050m = RL -0.55m AHD as a peak , in the period July to August 2010 as shown in **Figure 1.** This peak is still well below normal high water level in the lower pool of +0.75m AHD. Short term (i.e. within about a day) water level changes induced by wind are expected at lower pool sites to be less than +0.65/-0.15m from average water level, as reported on 1 February.

We note the water level rise discussed in our letter of 1 February was in the range 0.2 to 0.6m, to a pool level of about -0.8m AHD while **Figure 1** indicates the likely maximum rise facilitated by regulated release is about 0.3m, from -0.9m AHD in March 2010 to -0.6m AHD pool level in August 2010.

2. Stability Assessments

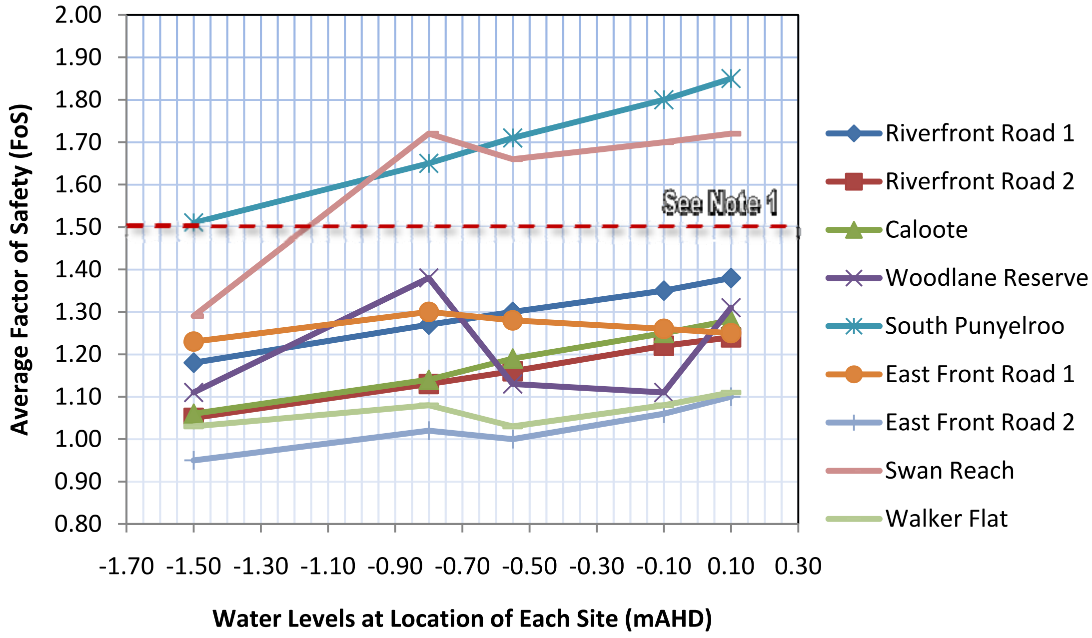
The stability of river banks at the following previously investigated sites has been re-assessed:

- South Punyelroo
- Swan Reach
- Caloote
- East Front Road
- Riverfront Road at Sturt Reserve;
- Walker Flat and
- Woodlane Reserve

The following failure modes have been considered:

- Optimised circular and non-circular failure face with tension crack search;
- Optimised circular and non-circular failure face with the existing tension cracks; and
- Bank stability impacts of drawdown due to river level changes during and after flood flows plus wind effects.

The existing limit equilibrium models for SLOPE/W software (Ver. 7.16), which were developed for the river bank stability investigation, have been used for the assessment at different water levels and the Factor of Safety (FoS) results are summarised in **Figure 2** below. In **Figure 2**, the vertical axis represents FoS and the horizontal axis is Water Level in m AHD, over the range of relevant water levels.



- **Figure 2: Summary of FoS at investigated sites for different water levels at each site**

Note 1: *The Factor of Safety (FoS) of a slope, is the ratio of the net force resisting slope movement to the net force causing movement. When the FoS is one, these forces are exactly balanced; so, as a consequence, any slight overestimation in the net force resisting movement, or underestimation of the net force causing movement, could initiate slope failure. Therefore, for long-term stability assessments, it is industry-standard practice to set the minimum allowable FoS to 1.5 to allow for uncertainties in the estimates of the net force resisting movement and the net force causing movement. Appropriate intervention is needed when FoS is less than 1.5.*

The results of the stability analyses indicate that:

- At Riverfront Road and Caloote, raising water levels increases the FoS, but not to figures above 1.5.
- At Woodlane Reserve, Walker Flat and East Front Road, the Factors of Safety have been reduced by water level rise to -0.55 and -0.1 m AHD and remain below FoS 1.5 to WL +0.10m AHD;
- Only South Punyelroo remains with FoS above 1.5 for the water level range considered.
- At Swan Reach, considering a worst condition for the depth of the existing crack and the slope of the soft layers underlying the site, raising the water level reduces the FoS but not

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to less than 1.5. Lowering the river level to RL-1.50mAHD will result in a FoS less than 1.50 at Swan Reach;

- In Woodlane Reserve, sandy layers provide a significant proportion of the forces resisting slope stability failure. Unfortunately, in this situation, an increase in water level leads to a reduction in the resisting forces. However, the Factor of Safety is already less than 1.5, so the implications are not significant, as the site has already been designated "High Risk". Existing fencing needs to remain in place for the foreseeable future. Long term unrestricted access may require remedial works which would require a separate study.
- The search for possible tension cracks due to the water level rise did not result in new cracks. It should be noted that, after reduction in the water levels, new shrinkage cracks may appear at the sites which potentially have adverse effects on stability;
- The existing cracks do not reduce the Factor of Safety due to water level rise;
- Owing to the very slow rate of river drawdown (650mm in 8 months, a maximum 100mm per month or 3mm per day), the slow rate of fall in water level will not affect stability as "rapid drawdown" conditions do not exist;
- The most rapid conditions of water level rise and fall result from wind seiche, are limited in magnitude to around +0.65/-0.15m in the lower pool and correspond to rates of around 50mm per hour based on interpretation of DWLBC river level records as noted on page 3 of this letter. These wind driven changes in level are not known to cause any major bank stability incidents. Water level changes at rates greater than 50mm per hour are considered unlikely in the current operating regime of the river.
- Wind induced rapid drawdown (up to 650mm over ~12hrs) does not affect global stability significantly; however, it may through wave action increase scouring or erosion locally depending on the friability of and vegetation on the river bank.

It should be noted that this study is limited to:

- the selected sites, because we do not have detailed stability modelling information at other locations, and
- the forecast water level changes.

This study does not cover the effects of possible new shrinkage cracks due to the water level changes because these will be site specific and beyond the scope of a desk study.

3. General Conclusions

In general terms, and based on our observations from river bank inspections and geotechnical investigations at locations where cracking and collapse incidents have been reported, river bank conditions that contribute to higher risk of bank collapse are those where some or all of the following conditions exist under a sustained fall in pool water level that removes the benefit of buoyancy, thereby increasing bank surcharge loading, and allows groundwater movement toward the river via permeable strata underlying river banks in places:

- banks are composed of soft sediments on flat margins adjacent to the river and slope steeply into water level at the bank. Such sediments can only be definitely identified by a “ground proofing” on site;
- there is a distribution of lagoonal environments on the floodplain, as in the lowland irrigation areas and wetlands adjacent to the river. As these have perched water levels, when river water level drops, these areas are slower to respond and there is potential for increased seepage flow towards the river. Sturt Reserve, Woodlane Reserve and Caloote are closely associated with existing or former lagoonal environments;
- there are potholes in the riverbed where water depth is considerably more (up to 2 times or more) than depths upstream and downstream of that location;
- levee banks or road embankments have been constructed close to the bank are already surcharging the bank;
- there are other contributing features like tall (eucalypt) or heavy (willow) trees or structures and buildings that contribute to surcharge loads and/or horizontal wind shears directly on the edge of the bank

The first three of these conditions are the result of the natural formation of the river and therefore such high hazard sites exist along the lower pool at many locations, demonstrating the “metastable” nature of riverbanks that are readily destabilised by falling water levels.

The collapse areas of most interest are those where the high risk of collapse coincides with high consequences of collapse, namely areas where land use is significant or there is a concentrated presence of people or fixed high value assets or services. A systematic study of such areas is recommended.

Please do not hesitate to contact me should you require more information.

Yours sincerely,

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