SINCLAIR KNIGHT MERZ

SKM

Government of South Australia

Department of Water, Land and Biodiversity Conservation

# Study into River Bank Collapsing for Lower River Murray

GEOTECHNICAL INVESTIGATION REPORT

- Rev E – FINAL
- February 2010

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## GEOTECHNICAL INVESTIGATION REPORT

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# Contents

## LIMITATION STATEMENT

This report has been prepared solely for the use of DWBLC and shall not be used or relied on by any other party without SKM's consent. The sole purpose of this report is to present the findings of geotechnical investigations carried out by Sinclair Knight Merz ("SKM") for DWLBC in connection with seven site locations along the Lower River Murray (for the purpose of this limitation statement to be known collectively and individually as the context requires as "the Site"). This report was produced in accordance with and is limited to the scope of services set out in the contract between SKM and DWLBC. That scope of services, as described in this report, was developed with DWLBC.

Undertaking an assessment or study of on-site conditions is a useful tool in identifying risk and may assist in reducing the potential for exposure to the presence of inadequate bearing ground. All reports and conclusions that deal with sub-surface conditions are based on interpretation and judgement and as a result have uncertainty attached to them. You should be aware that this report contains interpretations and conclusions which are uncertain, due to the nature of the investigations. No study can completely eliminate risk, and even a rigorous assessment and/or sampling programme may not detect all problem areas within a site.

This report is based on assumptions that the site conditions as revealed through sampling are indicative of conditions throughout the Site. The findings are the result of standard assessment techniques used in accordance with normal practices and standards, and (to the best of SKM's knowledge) they represent a reasonable interpretation of the current conditions on the Site. However, all sampling techniques, by definition, cannot determine the conditions between the sample points and so the report can only provide an indication of, and cannot be taken to be a full representation of, the sub-surface conditions. It is an indication only of the likely sub surface conditions.

Conditions at Site may change over time and may be different from those SKM infers based on its sampling techniques. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the Site and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

In preparing this report, SKM has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by DWLBC and/or from other sources. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change. SKM derived the data in this report from visual site inspections, detailed geotechnical investigations, information sourced from DWLBC and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

SKM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above and, to the extent permitted by law, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law. This report does not address environmental or geo-environmental issues including the presence of any contaminants or hazardous materials at the Site.

Except as specifically stated in this report, SKM makes no statement or representation of any kind concerning the suitability of the Site for any purpose or the permissibility of any use. Use of the Site for any purpose may require planning and other approvals and, in some cases, Environmental Protection Authority and accredited site auditor approvals. SKM offers no opinion as to the likelihood of obtaining any such approvals, or the conditions and obligations which such approvals may impose, which may include the requirement for additional environmental investigations and/or works. This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by SKM for use of any part of this report in any other context. This report has been prepared on behalf of, and for the exclusive use of, DWLBC, and is subject to, and issued in accordance with, the provisions of the agreement between SKM and DWLBC. SKM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

This Report was prepared solely for DWLBC and the matters covered by our Report and the emphasis placed on them may not necessarily address all or any specific concerns, purposes, requirements or interests of any third party. Our instructions were provided solely by DWLBC and may be different from those a third party would have provided. Third party interests and needs may be different to those of DWLBC. In particular, our Report does not cover all matters that a third party may wish to investigate and that there may be matters of interest to third parties which have not been considered to be material for the Report or investigated to the extent required. Third parties should not rely on this report and should seek their own advice to the matters addressed.

The Report is strictly limited to the matters stated in it and does not extend by implication to any other matter. If DWLBC proposes to release the whole or any part of the Report to any third party DWLBC shall include appropriate limitations and disclaimers releasing SKM from any liability arising from any use or reliance by such third party.

SKM

# Executive Summary

This report contains results, discussions and recommendations, related to Phase 3 of the "*Study into River Bank Collapsing - Lower River Murray*", comprising the results of geotechnical site investigation and slope stability assessment at seven sites along the Lower River Murray which are shown in **Figure 1**. In absence of a quantitative risk assessment for the sites, the critical sites for the further studies have been defined by DWLBC.

Key findings, resulting from the geotechnical assessments at the investigated locations, are summarised below. The recommendations encompass the need for DWLBC's duty of care to minimise consequences of bank collapse due to lowering river's water levels to RL-1.50m AHD for the next three years. The location of recommended fence lines shown on Figures 1-7 represents our assessment of the area where Factor of Safety (FoS) value is 1.5.

### Summary of the Findings

| LOCATION | SECTION | SAFETY FACTOR (Existing Condition) | SAFETY FACTOR (Lowering River) | Probability of Failure* |
|---|---|---|---|---|
| Riverfront Road-Murray Bridge | Boat Ramp | 1.27 | 1.18 | Very High |
| | Riverside Properties | 1.13 | 1.05 | |
| Caloote | Car Park Area - Southern Area | 1.14 | 1.06 | Very High |
| Woodlane Reserve | Car Park Area | 1.38 | 1.20 | Very High |
| South Punyelroo | Residential Area | >1.50 | >1.50 | Low |
| East Front Road | EF1 | 1.30 | 1.23 | Very High |
| | EF2 | 1.02 | 0.95 | |
| Swan Reach | Waste Disposal Facility | >1.50 | >1.50 | Low |
| Walker Flat | Waste Disposal Facility | 1.02 | 0.94 | Very High |

*Note: The average Factor of Safety and Factors of Safety associated with 5% probability of failure have been adopted for the stability classification of the sites:

#### *Riverfront Road-Murray Bridge*

The results of our investigations indicate that this is a VERY HIGH RISK area and it is recommended that the reserve and access road for the riverfront properties within the study area should be fenced off and properly signed to stop all pedestrian and vehicle traffic. The location of recommended fencing is shown in **Figure 2**. The area should be monitored for deformation and any sign of instability. The effects of using the lagoons for surface water collection on the stability of the riverbank should be studied. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

***Caloote***

The results of our investigations indicate that this is a VERY HIGH RISK area. In addition to the risk of bank failure, the riverside properties in the southern area are also at risk of rock-fall from limestone overhangs. As a consequence, we recommend that the residents in the south eastern area should be advised that there is a high risk of bank failure and rock fall. No immediate damage to the structure of the riverside properties in the northern area is expected; however, the road and car park areas are high risk.

We recommend that access to the boat ramp, parking area adjacent to river and residential area in the south eastern areas; and the access road after the residential area in northern area should be fenced off and properly signed to stop public and vehicle traffic. The location of recommended fencing is shown in **Figure 3**. The area should be monitored for deformation and any sign of instability. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

***Woodlane Reserve***

The results of our investigations indicate that this is a VERY HIGH RISK area. We recommend that public and residents of the seven riverside properties be advised that there is a high risk of bank failure at this site, and this risk will be increased after further reduction in the water level (below RL-0.80mAHD). The residents may still use the access road when water level is above RL-0.80m, but it is advised that the cars be parked within the residential properties and away from the river if the water levels fall below RL-0.80mAHD. Road users should be cautioned against parking in proximity to the river. The location of recommended fencing is shown in **Figure 4**. The area should be monitored for deformation and any sign of instability. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

***South Punyelroo***

The results of our investigations indicate that this is a LOW RISK area. Slope stability analyses in the vicinity of the river side properties, based on observed existing static conditions, indicate that the FoS against slope failure, in this area, is well above the FoS that would normally be considered acceptable, for permanent areas used by the public. It is considered likely that further reductions in water level will not affect the stability of the properties; however, it may result in settlement and new cracks.

We recommend that the residents of these riverside properties be advised to monitor the cracks for accelerating ground movements. No fencing is required at this location.

***East Front Road***

Our studies in a limited part of the road indicated that this site is VERY HIGH RISK. Furthermore, quality of the material used for the road construction is poor so on-going cracking in the section is likely. The shape and distribution of the cracks indicate that possible failure zones have already developed and the remedial works undertaken on the asphalt wearing cannot solve the problem or reduce the probability of the failure.

The responsible authority should decide on road closure and urgent remedial studies and works (such as detailed stability assessment) for the road alignment and the development of a new alignment away from the area of possible failure.

We recommend that the road in vicinity of the river should be signed as Very High Risk for road embankment failure in to the river. Furthermore, a reduced speed limit should be applied to the public to avoid car fall into the possible embankment failures. The road should be monitored weekly; however, after water level reduction to below RL-0.80mAHD or heavy rain falls, the road should be monitored more frequently for failure/deformation (at least twice a week). River traffic should be warned of the very high probability of failure and advised not to moor in the area.

***Swan Reach***

The results of our investigations indicate that this is a LOW RISK site. Slope stability analyses in the vicinity of the river side property, based on observed existing static conditions, indicate that the FoS against slope failure, is above the FoS that would normally be considered acceptable, for permanent areas used by the public. It is considered likely that further reductions in water level will not affect the stability of the properties.

We recommend that the owners of these riverside properties be advised to monitor the cracks for accelerating ground movements. No fencing is required at this location.

***Walker Flat***

The results of our investigations indicate that this is a VERY HIGH RISK area and it is considered highly likely that further reductions in water level may trigger a slope (bank) failure in this area. We recommend that public and operators be advised on the high risk of bank failure in the area and the area to be closed to traffic and car parking. Proper measures for closure and removal of important facilities in the area should be considered. It should be noted that the extent of the problem may be beyond the study area. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

### Remediation Works

A series of potential bank remediation options have been considered in this report. Bank remediation options to address issues of bank collapse as assessed at these sites could be difficult and may not be considered economically practical.

### Recommended Development of a Risk Map

The findings of this study, so far, highlight the potential risk of bank failures in some parts of the Lower River Murray, caused by continuing reductions in river level. Further investigations are recommended to determine the distribution of areas where bank collapsing is a high risk and is associated with high consequences. We recommend that a bank failure risk map be prepared for the river's alignment which could be used as a tool for further management decisions, such as requirements for additional studies on potential for bank failures at other locations along the Lower River Murray.

### Risk Avoidance and Separation

Until further work is carried out to determine the extent of the hazard we continue to recommend a strategy of risk avoidance and separation, where measures are taken to avoid the exposure of the public to the hazard, such as limiting access to river banks. Ongoing monitoring in areas deemed to have a high consequence exposure is recommended to support this strategy of risk avoidance and separation.

### Guidance on Use of Report

The Report presents the results of specific investigations at specific sites in accordance with the Scope of Work. The results and recommendations outlined in the Report relate only to those specific sites that have been investigated and are not representative of the conditions at other locations and sites that have not been assessed. The results of investigations should not be used to draw conclusions about the potential for bank failures at locations that have not been assessed. There may be collapses in areas of riverbank that have not been inspected or investigated.

The results and recommendations outlined in the Report are intended to be read in the context of the limitations discussed more fully in the limitations section at the end of the Report. The way in which this report is used to manage the risks associated with river bank collapsing is the responsibility of DWLBC.


**Legend**

● Detailed Geotechnical Investigation Sites


0 — 10,000

A3 1:250,000 Metres

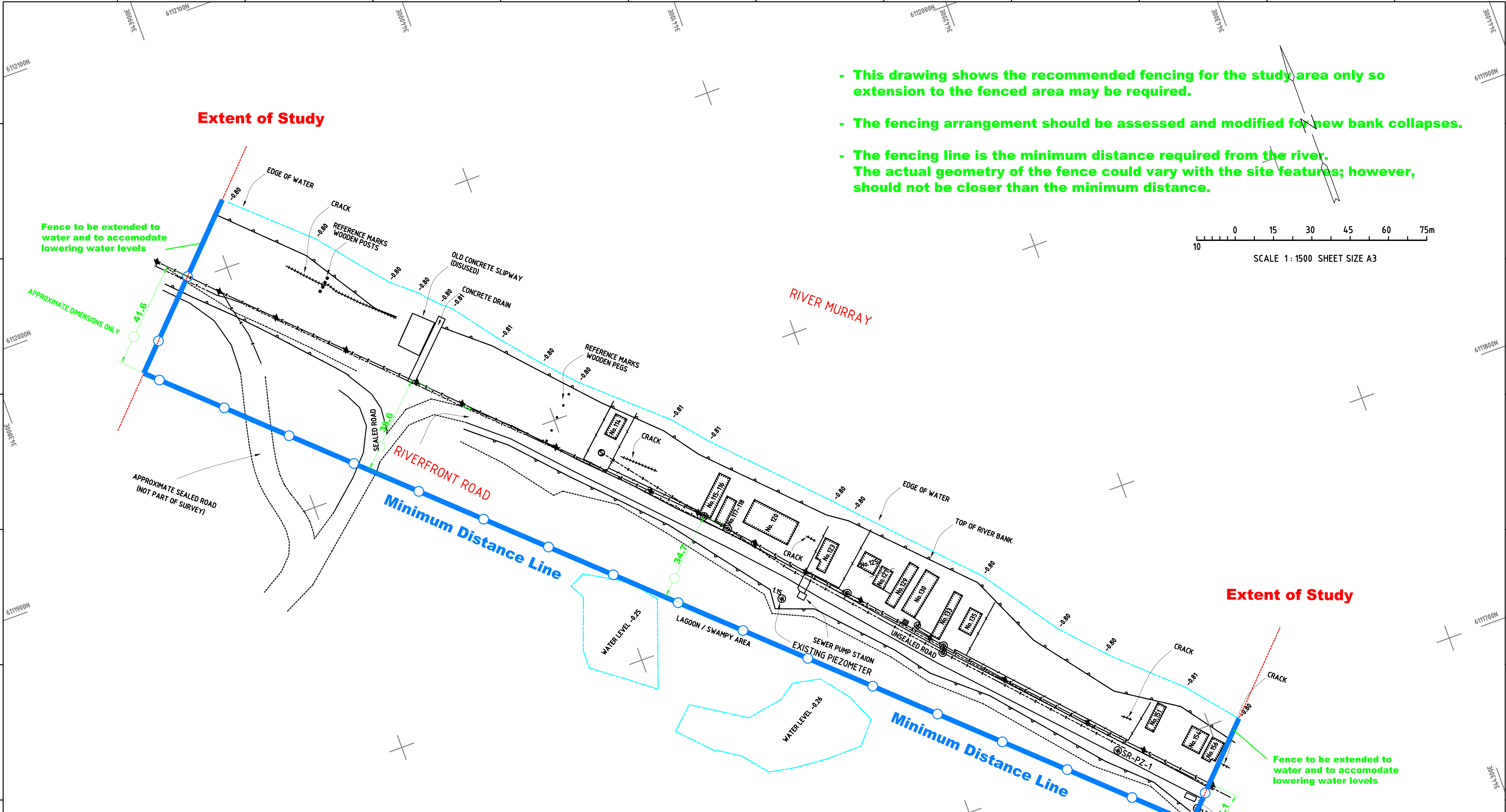
**Detailed Geotechnical Investigation Sites**

River Murray Bank Slumping

GDA 1994 MGA Zone 54

SKM

**Figure 1**




NOTES

1. ELEVATION DATUM AHD. AUTHORITY PSM 6727/3799 E:343489.509 N:6111759.705 RL11.124
2. FIELD SURVEY DATE 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
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LEGEND

| | | | | |
|---|---|---|---|---|
| CABLE JUNCTION PIT | COMMUNICATIONS PIT | DRIANAGE INSPECTION POINT | WATER LEVEL | CRACK |
| FLOOD LIGHT | COMMS CABLE MARKER | DRIANAGE MANHOLE | U/G COMMUNICATIONS LINE | BOTTOM OF BANK |
| EARTH STAKE | COMMS PILLAR | GRATED SUMP & INVERT LEVEL | U/G SEWER PIPELINE | TOP OF BANK |
| CABLE MARKER | MONITORING WELL | SEWER INSPECTION POINT | A/G POWERLINE | BUILDING\SHED |
| STOBIE POLE | BORE HOLE | SEWER MANHOLE | U/G WATER PIPELINE | FENCE |
| SWITCH BOARD | CPT HOLE | WATER MANHOLE | UNSEALED TRACK\ROAD | PHOTO OBSERVATION POINT |

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| A | 2-07-08 | GT | GC | | ISSUED FOR REVIEW & APPROVAL |

| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
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| - | | |
| - | | |
| 1 | A1\4100C-6 | STURT RESERVE, LONGITUDINAL SECTIONS |



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The Department of Water, Land and Biodiversity Conservation

CLIENT DWLBC
PROJECT MURRAY RIVERBANK SLUMPING STUDY

| DRAWN | DRAFTING CHECK | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR |
|---|---|---|---|
| J DOWNES | G TURNER | G COOKE | |
| SURVEYED | SURVEY CHECK | | |
| J DOWNES | G COOKE | | |

TITLE
RURAL CITY OF MURRAY BRIDGE
RIVERFRONT ROAD - MURRAY BRIDGE
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-1 | A |

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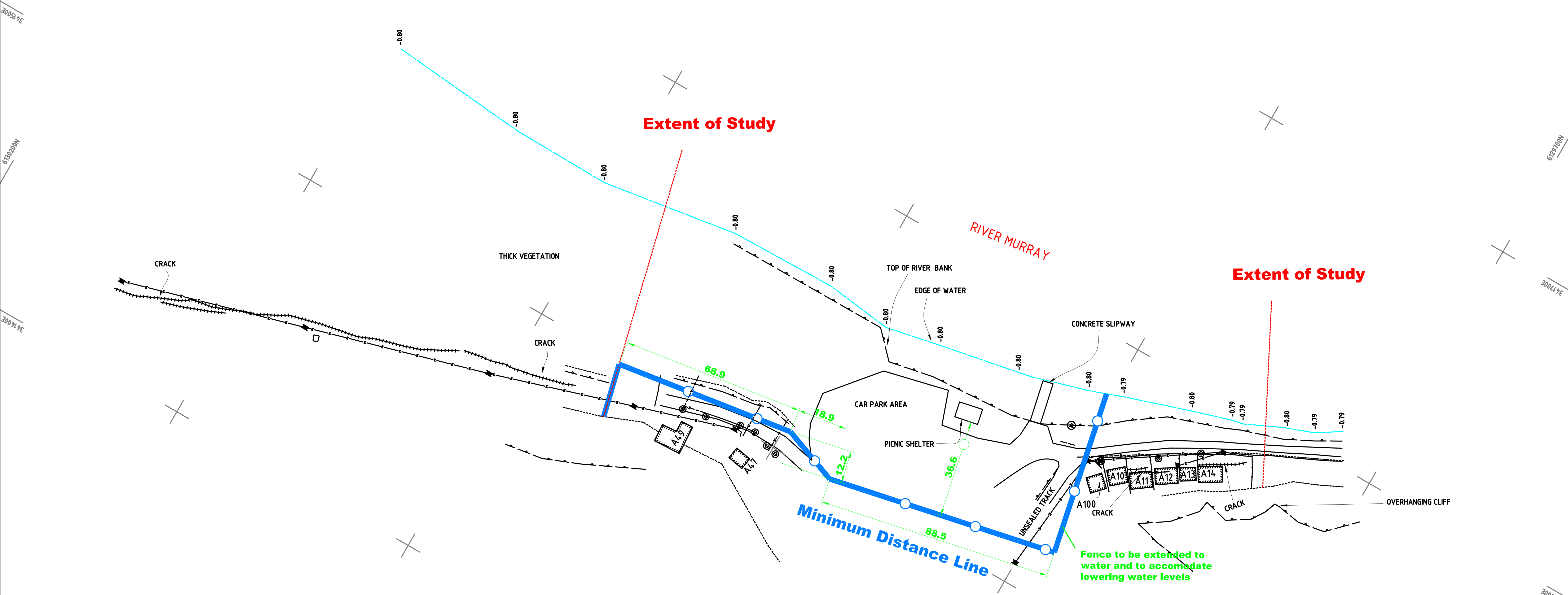
Figure 2

- **This drawing shows the recommended fencing for the study area only so extension to the fenced area may be required.**
- **The fencing arrangement should be assessed and modified for new bank collapses.**
- **The fencing line is the minimum distance required from the river. The actual geometry of the fence could vary with the site features; however, should not be closer than the minimum distance.**

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2. FIELD SURVEY DATE - 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
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LEGEND

CABLE JUNCTION PIT | FLOOD LIGHT | EARTH STAKE | CABLE MARKER | STOBIE POLE | SWITCH BOARD
COMMUNICATIONS PIT | COMMS CABLE MARKER | COMMS PILLAR | MONITORING WELL | BORE HOLE | CPT HOLE
DRIANAGE INSPECTION POINT | DRIANAGE MANHOLE | GRATED SUMP & INVERT LEVEL | SEWER INSPECTION POINT | SEWER MANHOLE | WATER MANHOLE
WATER LEVEL | U/G COMMUNICATIONS LINE | U/G SEWER PIPELINE | A/G POWERLINE | U/G WATER PIPELINE | UNSEALED TRACK\ROAD
CRACK | BOTTOM OF BANK | TOP OF BANK | BUILDING\SHED | FENCE | PHOTO OBSERVATION POINT

0 15 30 45 60 75m

SCALE 1 : 1500 SHEET SIZE A3

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| A | 2-07-08 | GT | GC | | ISSUED FOR REVIEW & APPROVAL |

| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
|---|---|---|
| 1 | A1\4100C-8 | CALOOTE, LONGITUDINAL SECTIONS |




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The Department of Water, Land and Biodiversity Conservation

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|---|---|---|---|
| CLIENT DWLBC | | | |
| PROJECT MURRAY RIVERBANK SLUMPING STUDY | | | |
| DRAWN J DOWNES | DRAFTING CHECK G TURNER | REVIEWED PROJECT MANAGER G COOKE | APPROVED PROJECT DIRECTOR |
| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
MID-MURRAY COUNCIL
CALOOTE
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
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| AS SHOWN | VW04794.1 | A1\4100C-3 | A |

Figure 3

- **This drawing shows the recommended fencing for the study area only so extension to the fenced area may be required.**
- **The fencing arrangement should be assessed and modified for new bank collapses.**
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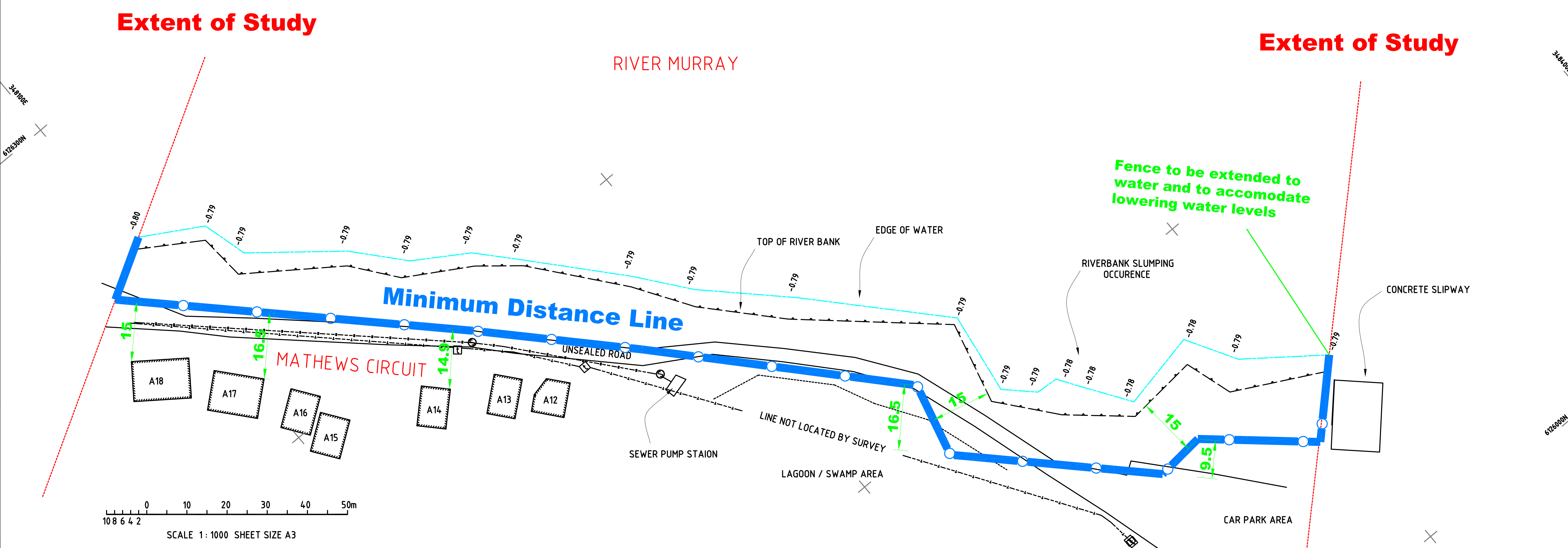


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2. FIELD SURVEY DATE - 24 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
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LEGEND

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FLOOD LIGHT
EARTH STAKE
CABLE MARKER
STOBIE POLE
SWITCH BOARD
COMMUNICATIONS PIT
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COMMS PILLAR
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WATER MANHOLE
WATER LEVEL
U/G COMMUNICATIONS LINE
U/G SEWER PIPELINE
A/G POWERLINE
U/G WATER PIPELINE
UNSEALED TRACK\ROAD
CRACK
BOTTOM OF BANK
TOP OF BANK
BUILDING\SHED
FENCE
PHOTO OBSERVATION POINT

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
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| - | | |
| 1 | A1\4100C-7 | WOODLANE RESERVE, LONGITUDINAL SECTIONS |



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The Department of Water, Land and Biodiversity Conservation

CLIENT: DWLBC
PROJECT: MURRAY RIVERBANK SLUMPING STUDY

| DRAWN | DRAFTING CHECK | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR |
|---|---|---|---|
| J DOWNES | G TURNER | G COOKE | |
| SURVEYED: J DOWNES | SURVEY CHECK: G COOKE | | |

TITLE: RURAL CITY OF MURRAY BRIDGE
WOODLANE RESERVE
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
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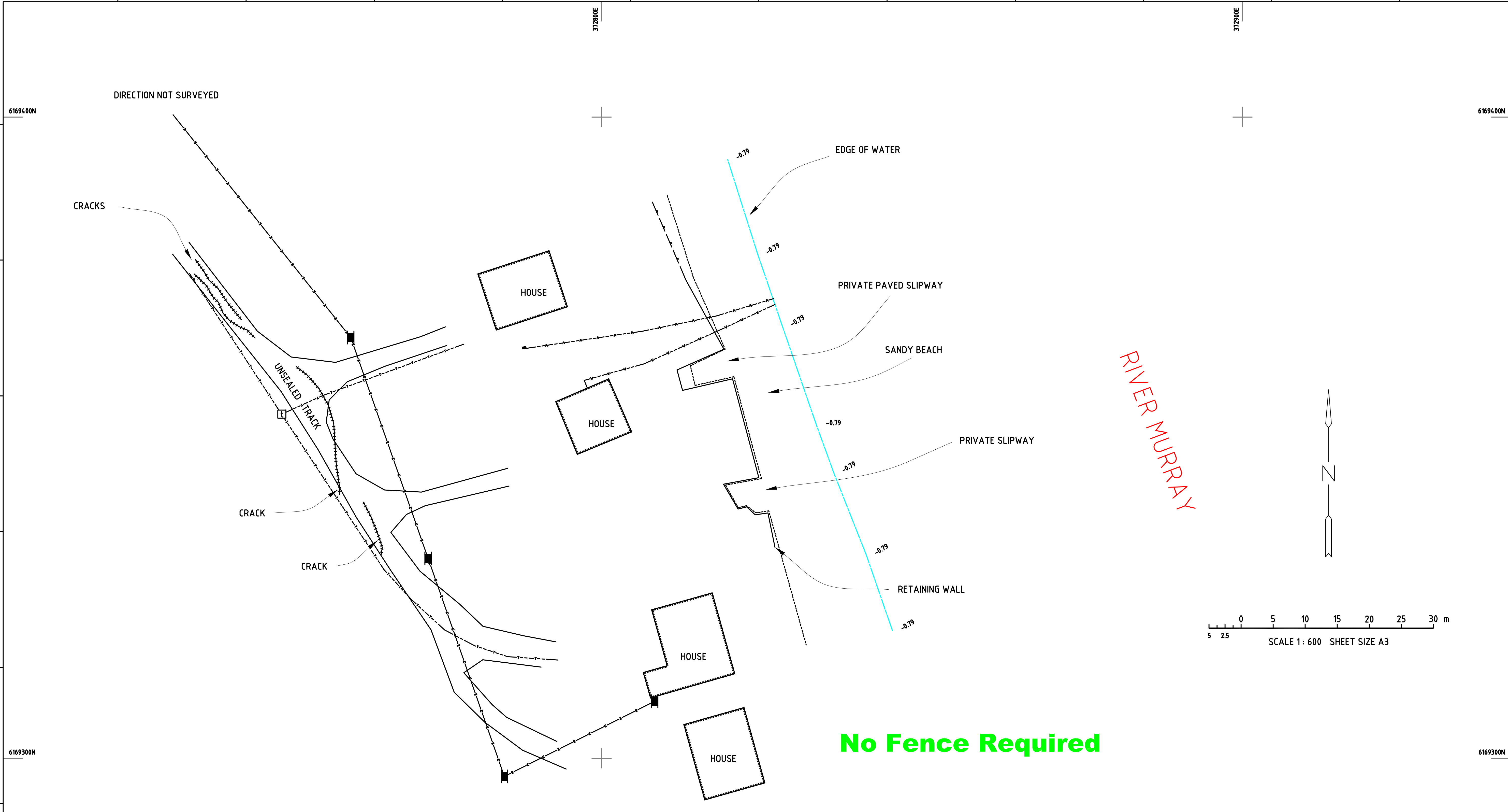
| AS SHOWN | VW04794.1 | A1\4100C-2 | A |

**Figure 4**

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2. FIELD SURVEY DATE - 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
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LEGEND

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CABLE MARKER
STOBIE POLE
SWITCH BOARD
COMMUNICATIONS PIT
COMMS CABLE MARKER
COMMS PILLAR
MONITORING WELL
BORE HOLE
CPT HOLE
DRIANAGE INSPECTION POINT
DRIANAGE MANHOLE
GRATED SUMP & INVERT LEVEL
SEWER INSPECTION POINT
SEWER MANHOLE
WATER MANHOLE
WATER LEVEL
U/G COMMUNICATIONS LINE
U/G SEWER PIPELINE
A/G POWERLINE
U/G WATER PIPELINE
UNSEALED TRACK\ROAD
CRACK
BOTTOM OF BANK
TOP OF BANK
BUILDING\SHED
FENCE
PHOTO OBSERVATION POINT

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
|---|---|---|---|---|---|
| A | 2-07-08 | GT | GC | | ISSUED FOR REVIEW & APPROVAL |

| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
|---|---|---|
| 1 | A1\4100C-10 | SOUTH PUNYELROO, LONGITUDINAL SECTIONS |



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Telephone: 08 8424 3800
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Internet: www.skmconsulting.com.au

The Department of Water, Land and Biodiversity Conservation

CLIENT DWLBC
PROJECT MURRAY RIVERBANK SLUMPING STUDY
DRAWN J DOWNES | DRAFTING CHECK G TURNER | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR
SURVEYED J DOWNES | SURVEY CHECK G COOKE | G COOKE

TITLE
MID-MURRAY COUNCIL
SOUTH PUNYELROO
PROPOSED SAFETY FENCING

SCALE AS SHOWN | PROJECT No VW04794.1 | DRAWING No A1\4100C-5 | AMDT A

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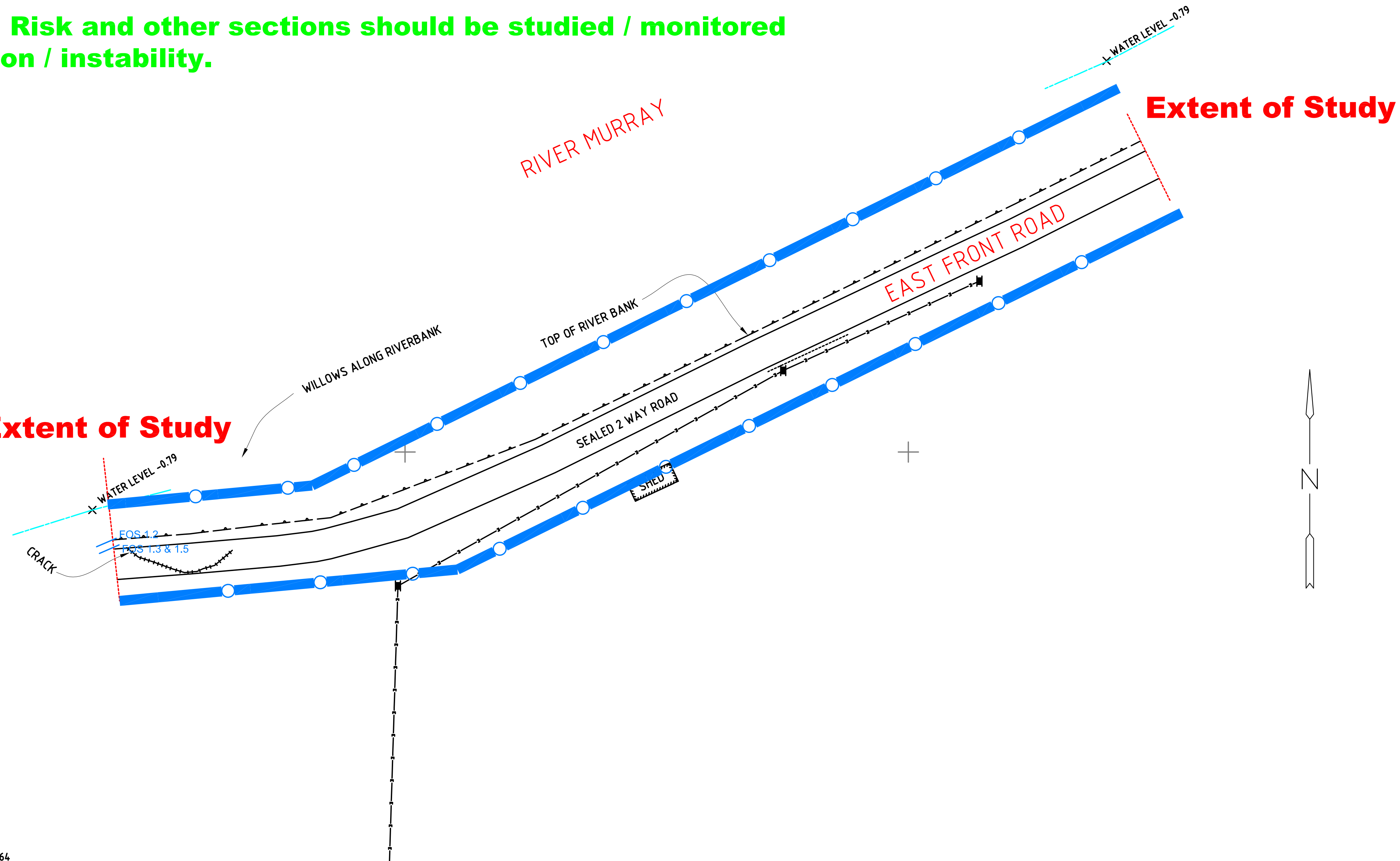
**Figure 5**

- **Due to the instability in the observed cross sections, the public and authorities should be advised on the high risk of failure in the area by proper signage and reducing the speed limit. THIS IS A TEMPORARY MEASURE AND USE OF THE ROAD SHOULD BE DECIDED BY AUTHORITIES.**
- **The area is Very High Risk and other sections should be studied / monitored for signs of deformation / instability.**




0 10 20 30 40 50m
10 8 6 4 2

SCALE 1 : 1000 SHEET SIZE A3

NOTES
1. ELEVATION DATUM AHD. AUTHORITY PSM 6728/2256 E:349342.779 N:6137540.915 RL2.064
2. FIELD SURVEY DATE 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
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LEGEND

| | | | | |
|---|---|---|---|---|
| CABLE JUNCTION PIT | COMMUNICATIONS PIT | DRIANAGE INSPECTION POINT | WATER LEVEL | CRACK |
| FLOOD LIGHT | COMMS CABLE MARKER | DRIANAGE MANHOLE | U/G COMMUNICATIONS LINE | BOTTOM OF BANK |
| EARTH STAKE | COMMS PILLAR | GRATED SUMP & INVERT LEVEL | U/G SEWER PIPELINE | TOP OF BANK |
| CABLE MARKER | MONITORING WELL | SEWER INSPECTION POINT | A/G POWERLINE | BUILDING\SHED |
| STOBIE POLE | BORE HOLE | SEWER MANHOLE | U/G WATER PIPELINE | FENCE |
| SWITCH BOARD | CPT HOLE | WATER MANHOLE | UNSEALED TRACK\ROAD | PHOTO OBSERVATION POINT |

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| A | 2-07-08 | GT | GC | | ISSUED FOR REVIEW & APPROVAL |

| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
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| - | | |
| - | | |
| 1 | A1\4100C-9 | EAST FRONT ROAD, LONGITUDINAL SECTIONS |




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| PROJECT MURRAY RIVERBANK SLUMPING STUDY | | | |
| DRAWN J DOWNES | DRAFTING CHECK G TURNER | REVIEWED PROJECT MANAGER G COOKE | APPROVED PROJECT DIRECTOR |
| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
MID-MURRAY COUNCIL
EAST FRONT ROAD
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-4 | A |

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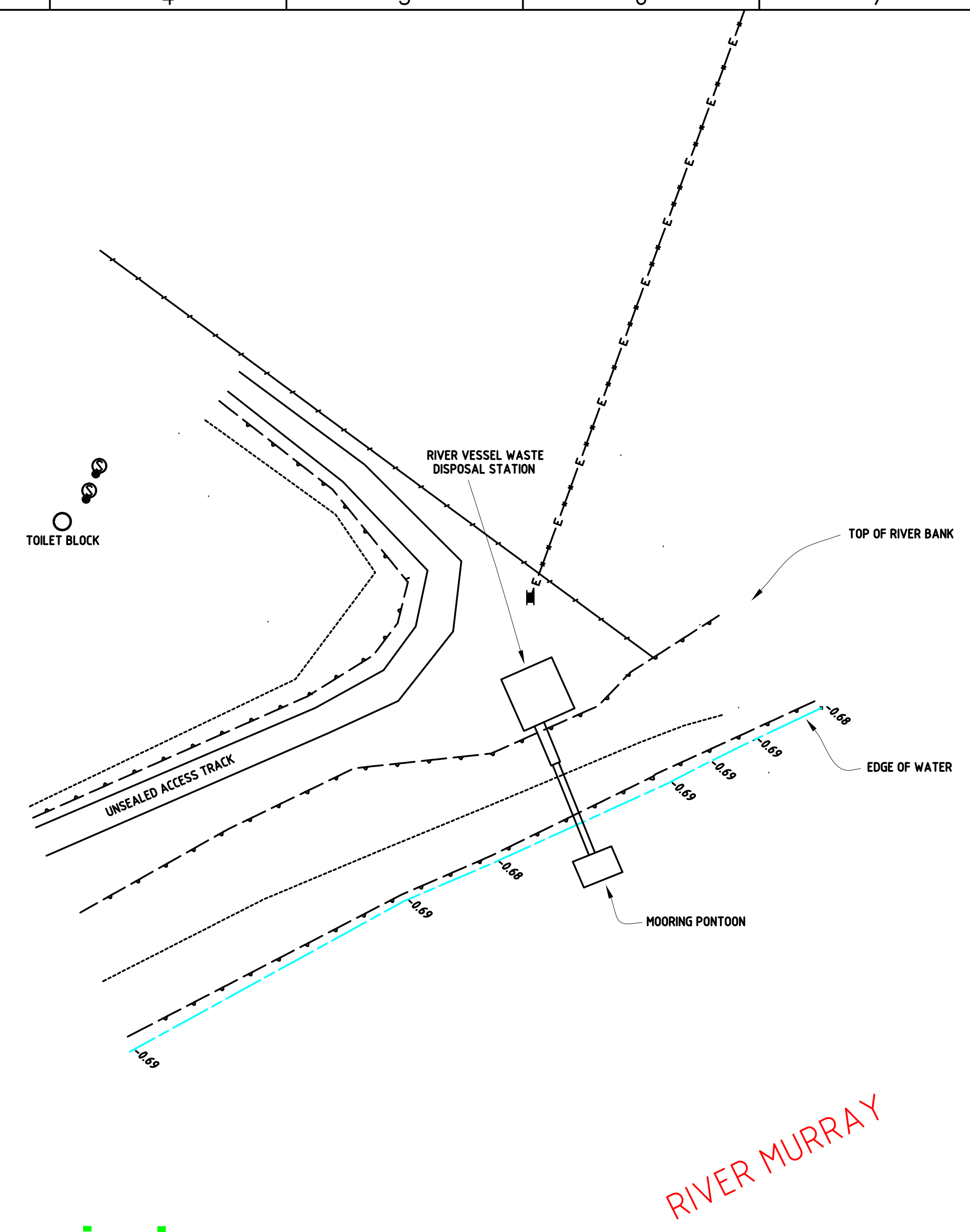
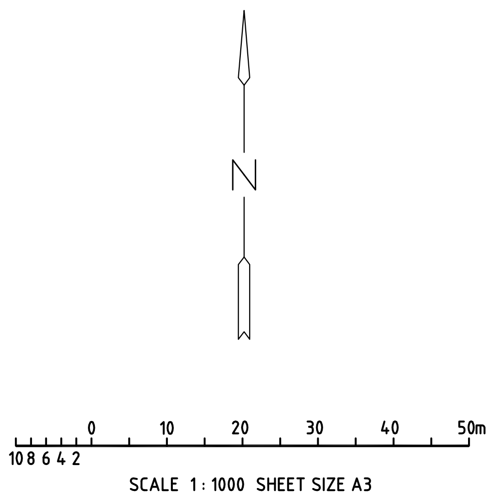
**Figure 6**




**No Fence Required**

NOTES
1. ELEVATION DATUM AHD - AUTHORITY PSM 6828/1204 E:371826.408 N:6174742.830 RL3.258
2. FIELD SURVEY DATE - 16 NOVEMBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GNSS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7.PSM DENOTES PERMANENT SURVEY MARK

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LEGEND

CABLE JUNCTION PIT
FLOOD LIGHT
EARTH STAKE
CABLE MARKER
STOBIE POLE
SWITCH BOARD
COMMUNICATIONS PIT
COMMS CABLE MARKER
COMMS PILLAR
MONITORING WELL
BORE HOLE
CPT HOLE
DRIANAGE INSPECTION POINT
DRIANAGE MANHOLE
GRATED SUMP & INVERT LEVEL
SEWER INSPECTION POINT
SEWER MANHOLE
WATER MANHOLE
WATER LEVEL
U/G COMMUNICATIONS LINE
U/G SEWER PIPELINE
A/G POWERLINE
U/G WATER PIPELINE
UNSEALED TRACK\ROAD
CRACK
BOTTOM OF BANK
TOP OF BANK
BUILDING\SHED
FENCE
PHOTO OBSERVATION POINT

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| A | 28-11-09 | GT | | | ISSUED FOR REVIEW & APPROVAL |

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| 1 | A1\4100E-3 | SWAN REACH, LONGITUDINAL SECTIONS |




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| DRAWN | DRAFTING CHECK | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR |
|---|---|---|---|
| J DOWNES | G TURNER | | |
| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
DWLBC
SWAN REACH
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100E-1 | A |

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Figure 7

A 1

- This drawing shows the recommended fencing for the study area only so extension to the fenced area may be required.
- The fencing arrangement should be assessed and modified for new bank collapses.
- The fencing line is the minimum distance required from the river. The actual geometry of the fence could vary with the site features; however, should not be closer than the minimum distance.

N

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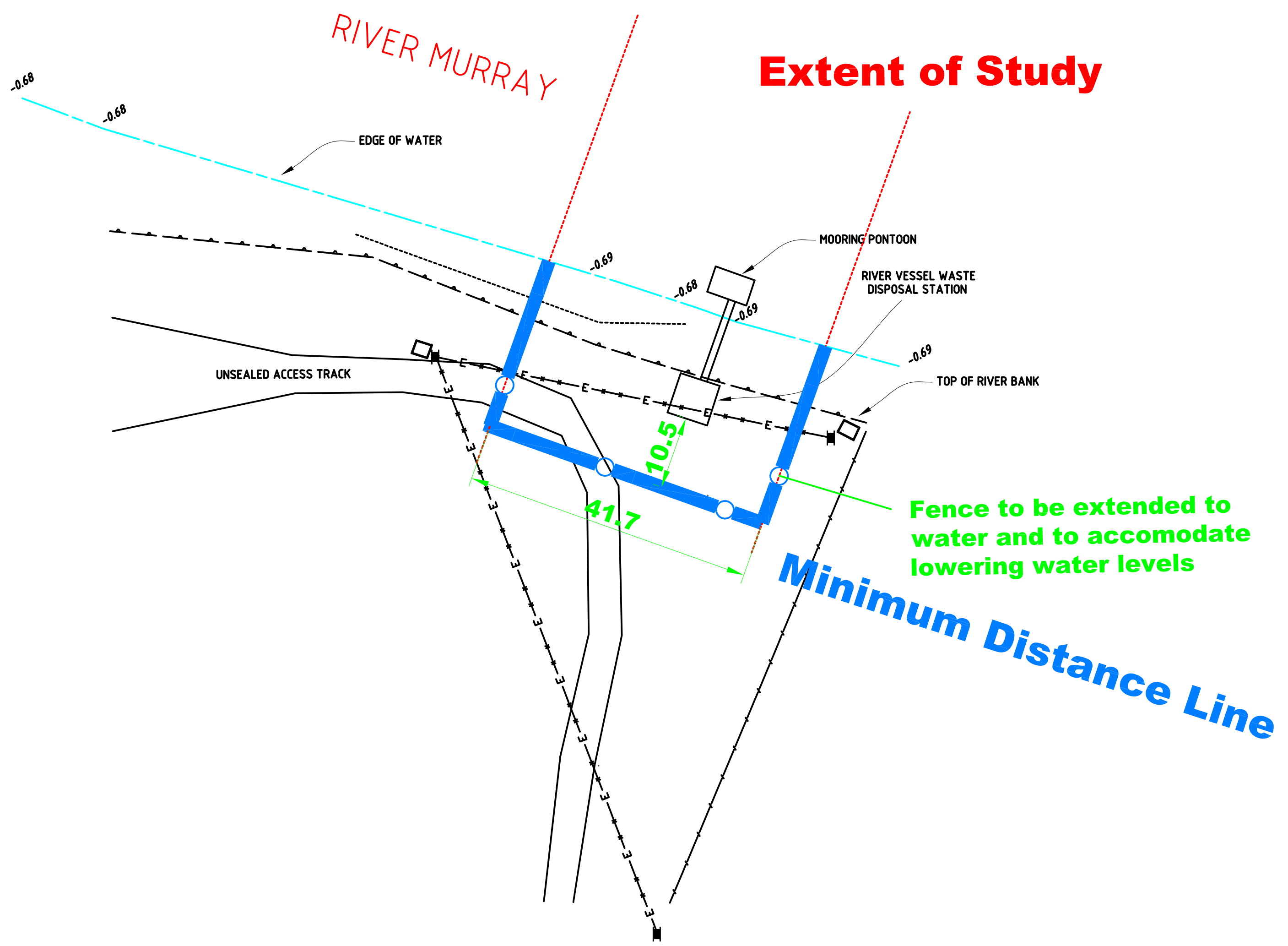
10 8 6 4 2
SCALE 1 : 1000 SHEET SIZE A3




NOTES
1. ELEVATION DATUM AHD. AUTHORITY PSM 6828/1032 E367718.297 N6153088.360 RL35.953
2. FIELD SURVEY DATE 16 NOVEMBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
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LEGEND
CABLE JUNCTION PIT
FLOOD LIGHT
EARTH STAKE
CABLE MARKER
STOBIE POLE
SWITCH BOARD
COMMUNICATIONS PIT
COMMS CABLE MARKER
COMMS PILLAR
MONITORING WELL
BORE HOLE
CPT HOLE
DRIANAGE INSPECTION POINT
DRIANAGE MANHOLE
GRATED SUMP & INVERT LEVEL
SEWER INSPECTION POINT
SEWER MANHOLE
WATER MANHOLE
WATER LEVEL
U/G COMMUNICATIONS LINE
U/G SEWER PIPELINE
A/G POWERLINE
U/G WATER PIPELINE
UNSEALED TRACK\ROAD
CRACK
BOTTOM OF BANK
TOP OF BANK
BUILDING\SHED
FENCE
PHOTO OBSERVATION POINT

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| A | 28-11-09 | GT | | | ISSUED FOR REVIEW & APPROVAL |

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| - | | |
| 1 | A1\4100E-4 | WALKER FLAT, LONGITUDINAL SECTIONS |




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| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
DWLBC
WALKER FLAT
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100E-2 | A |

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Figure 8

A 1

Study into Riverbank Collapsing for Lower Murray River
Riverfront Road - Murray Bridge - Section SR1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.27

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

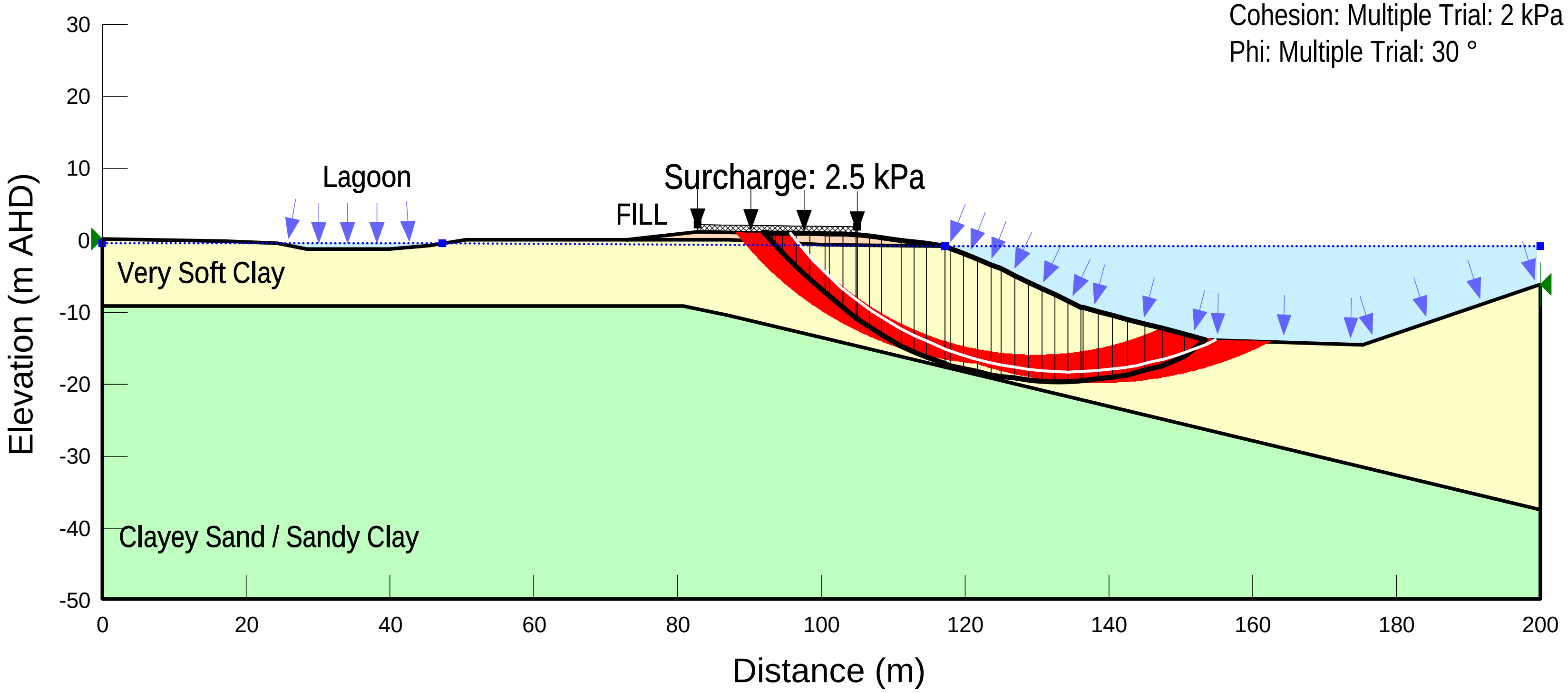



**Figure 9**

Study into Riverbank Collapsing for Lower Murray River
Riverfront Road - Murray Bridge - Section SR1

Assessment of the Future Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.18

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

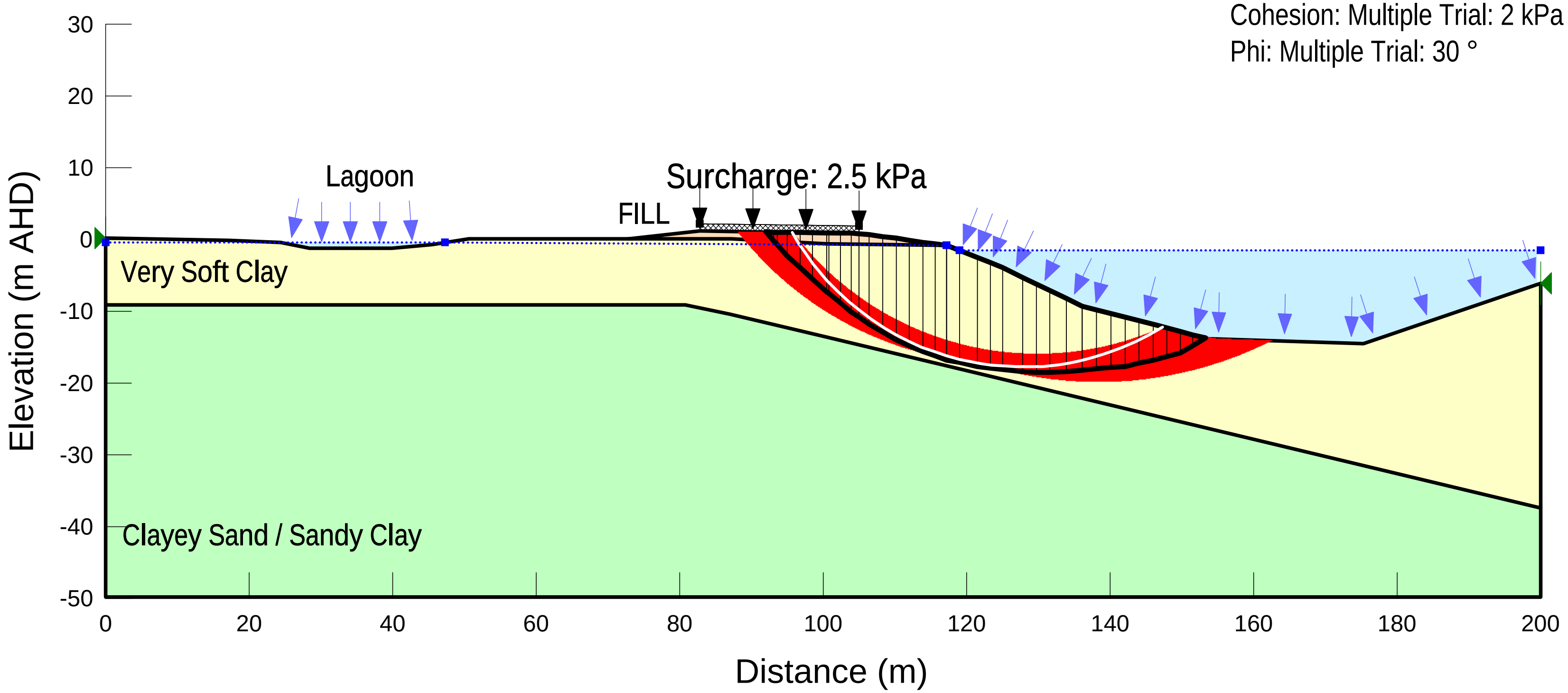



**Figure 10**

# Study into Riverbank Collapsing for Lower Murray River
# Riverfront Road - Murray Bridge - Section SR2

## Assessment of the Existing Condition
## River Water Level at -0.80m AHD

## Factor of Safety = 1.13

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

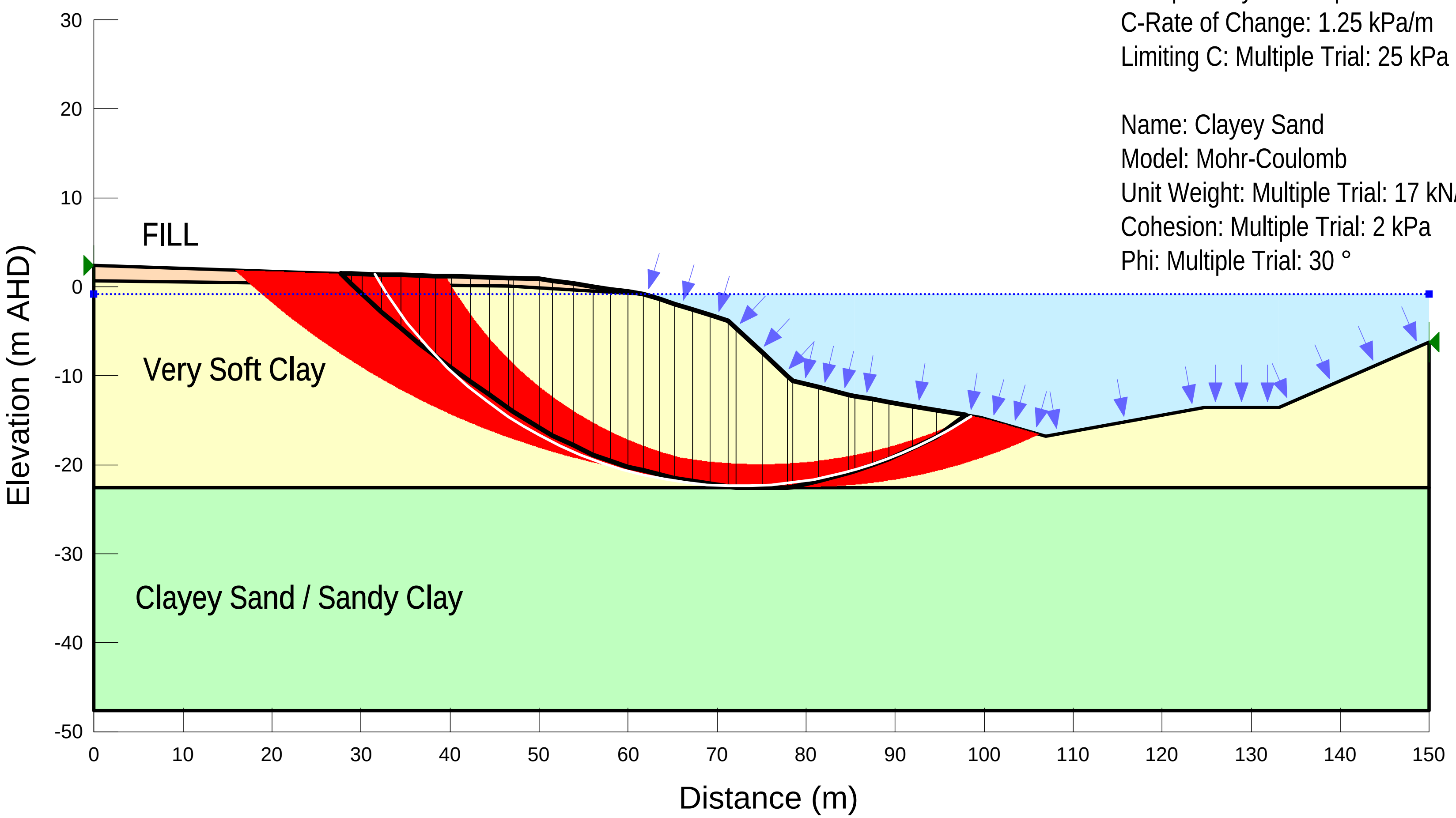



**Figure 11**

## Study into Riverbank Collapsing for Lower Murray River
## Riverfront Road - Murray Bridge - Section SR2

Assessment of the Future Conditions
River Water Level at -1.50m AHD

Factor of Safety = 1.05

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

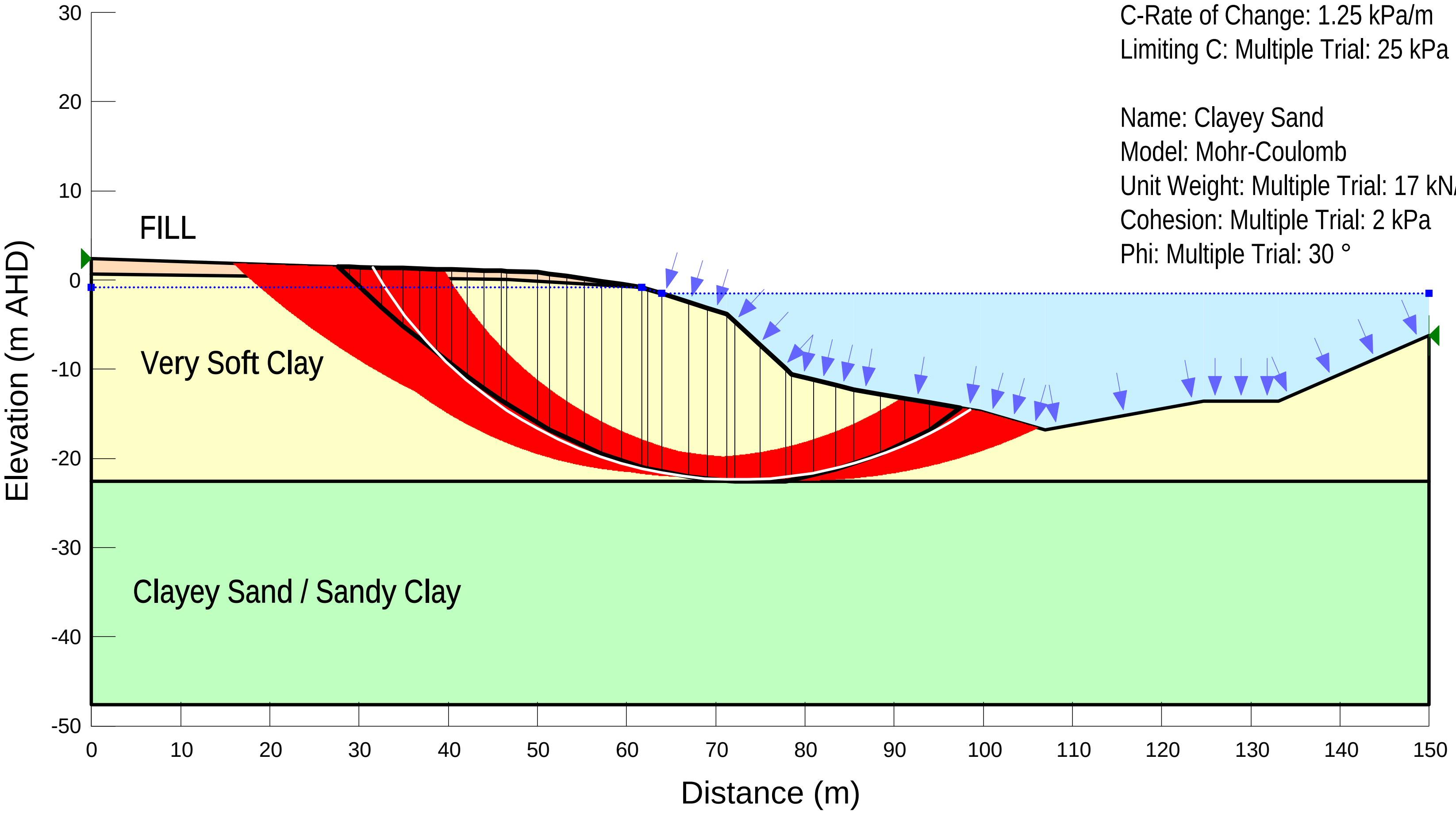



**Figure 12**

Study into Riverbank Collapsing for Lower Murray River
Caloote - Section CA2

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.14

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.07 kPa/m
Limiting C: Multiple Trial: 17.5 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

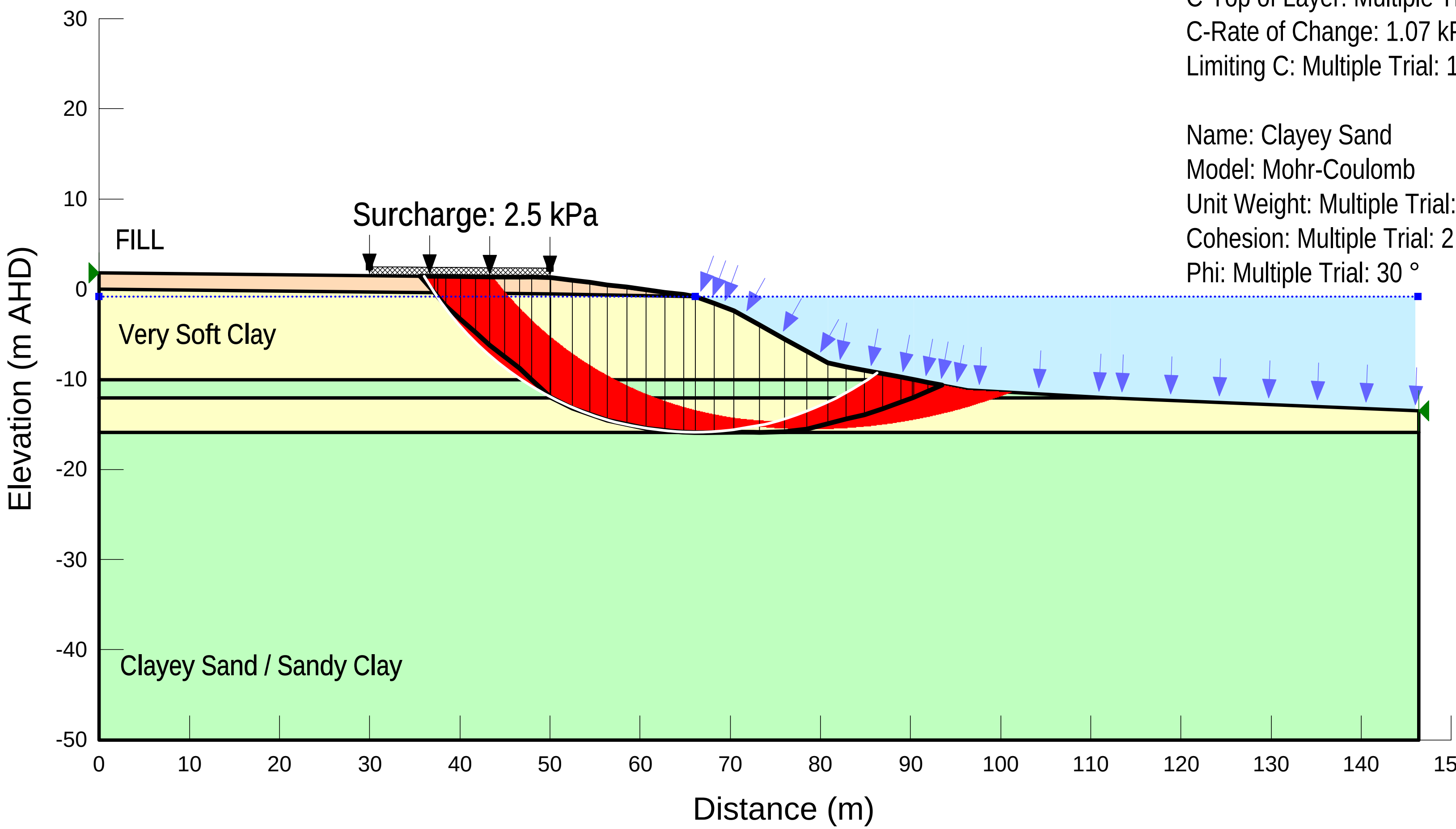



**Figure 13**

Study into Riverbank Collapsing for Lower Murray River
Caloote - Section CA2

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.06

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.07 kPa/m
Limiting C: Multiple Trial: 17.5 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

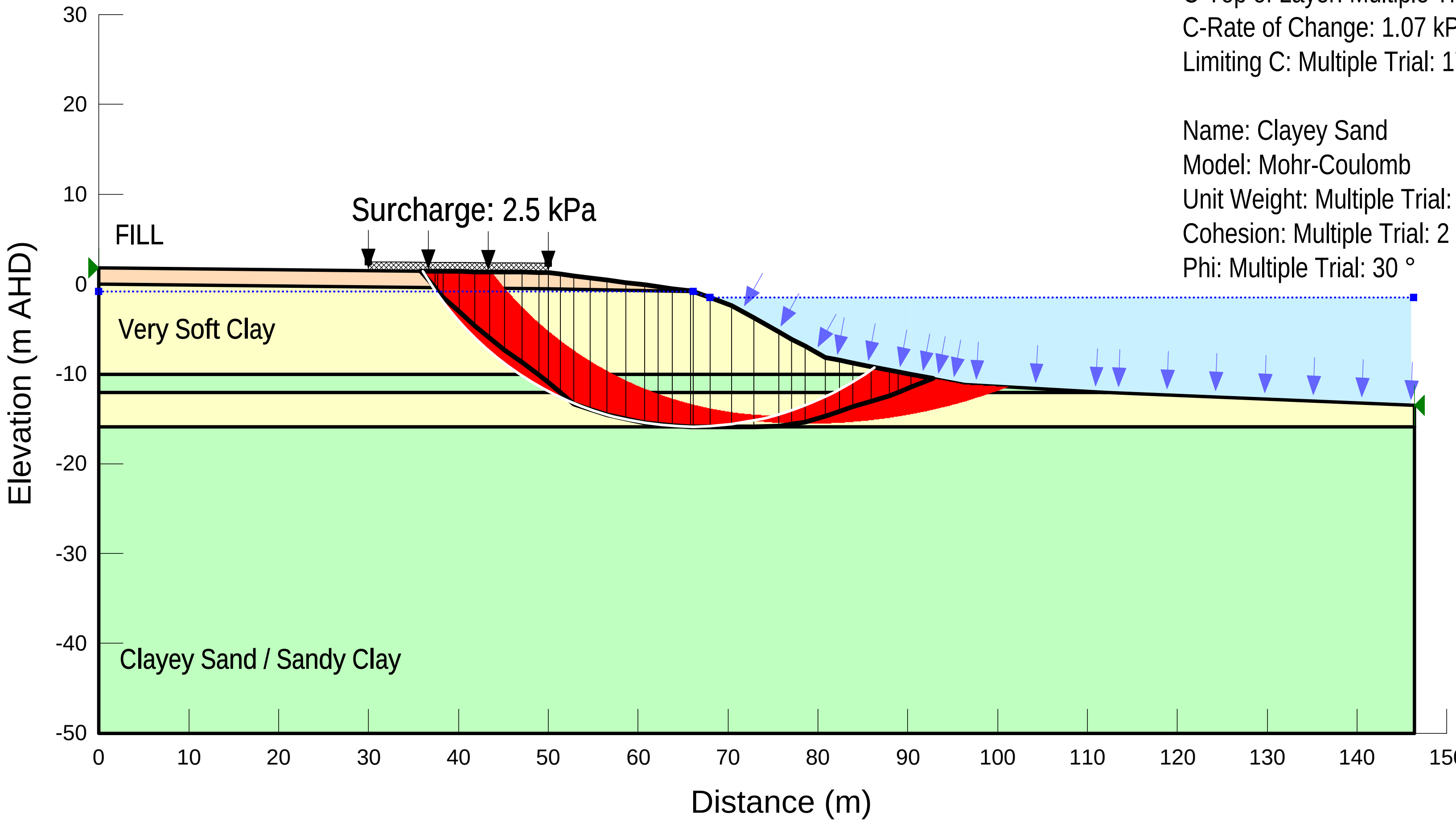
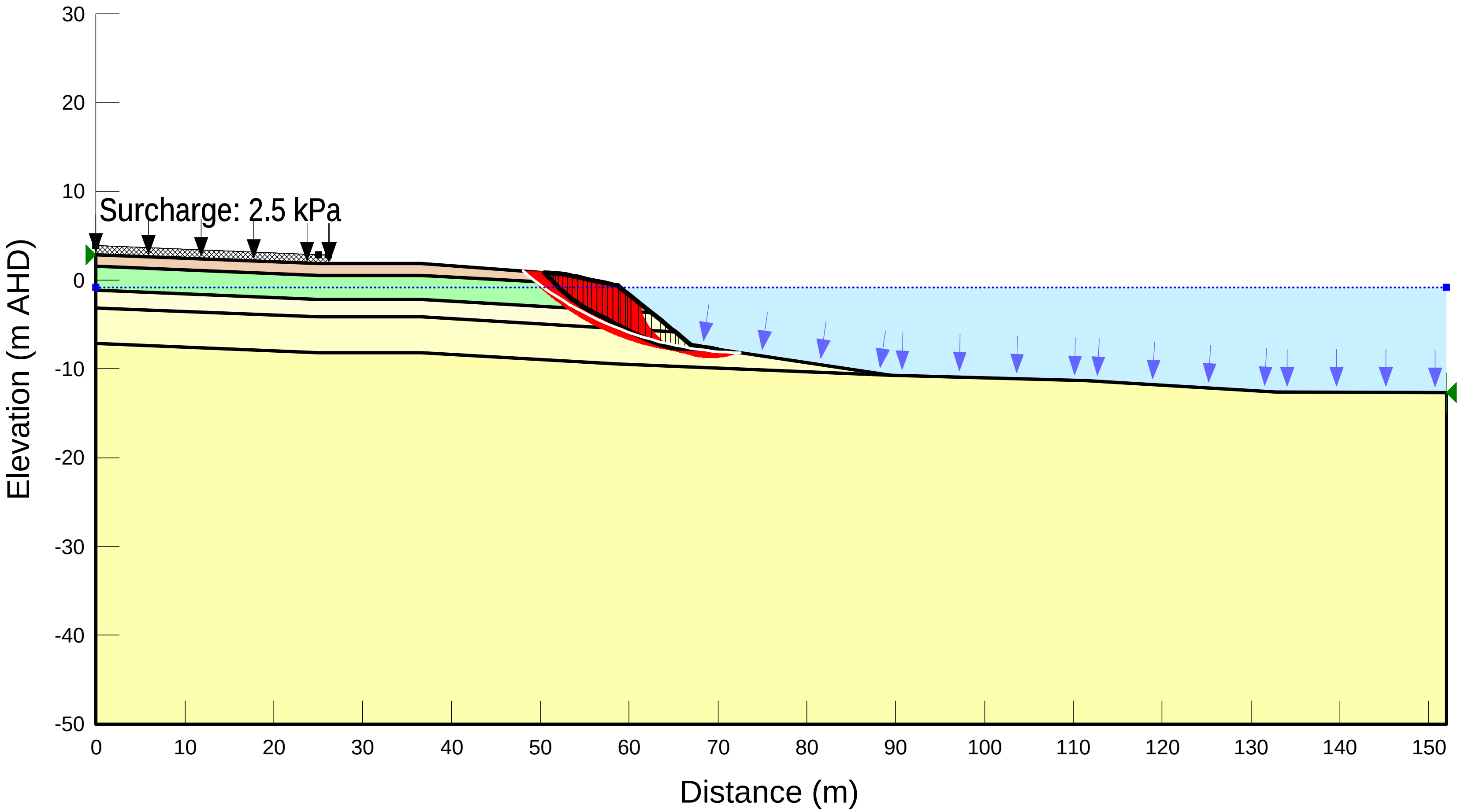



**Figure 14**

Study into Riverbank Collapsing for Lower Murray River
Woodlane Reserve - Section WR1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.38




Name: FILL
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Very Soft Clay (CH)
Model: Undrained (Phi=0)
Unit Weight: 17 kN/m³
Cohesion: Multiple Trial: 20 kPa

Name: Sand / Clay (loose)
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 29 °

Name: Sand / Silt
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

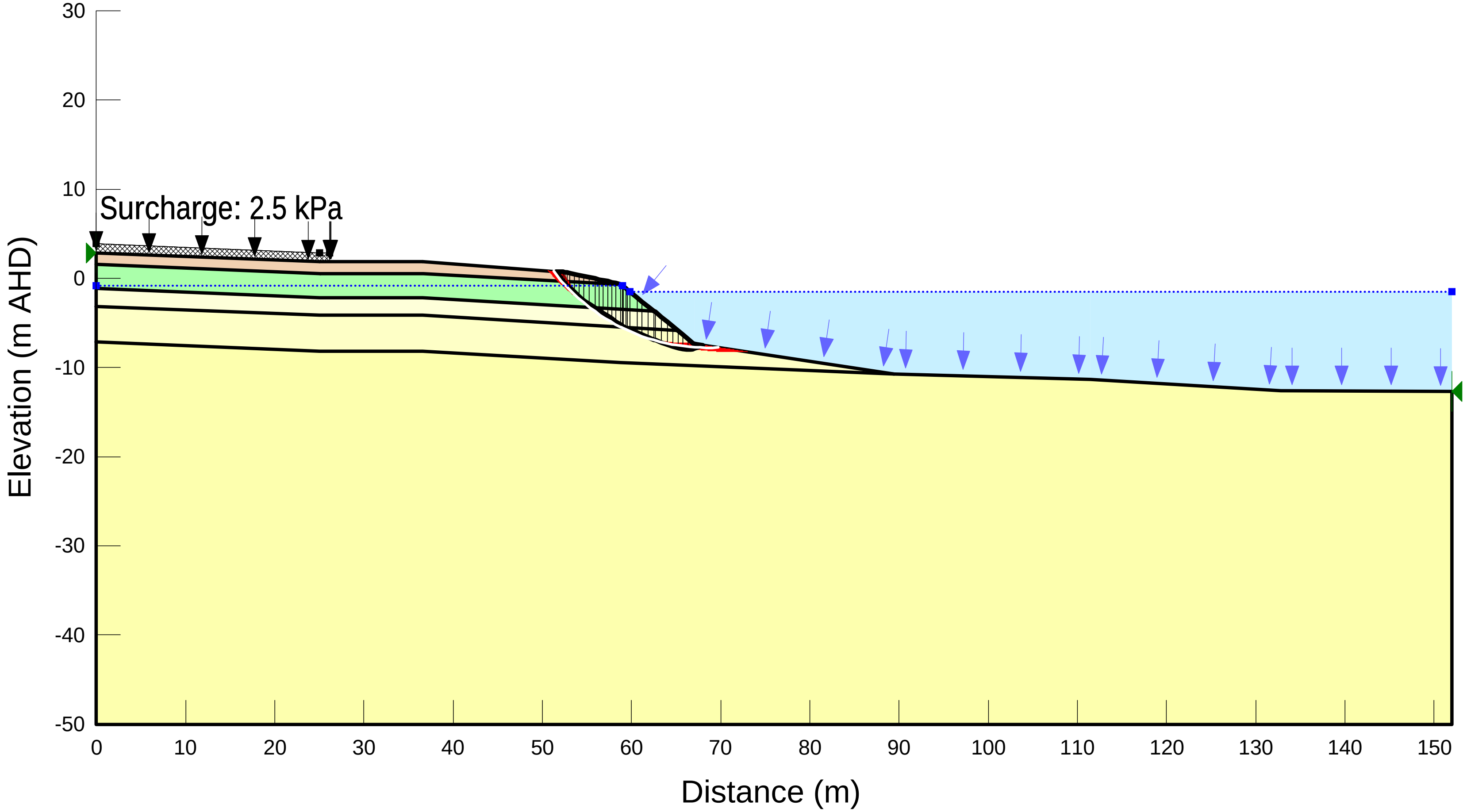
Name: Type 3C
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 15**

Study into Riverbank Collapsing for Lower Murray River
Woodlane Reserve - Section WR1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.20




Name: FILL
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Very Soft Clay (CH)
Model: Undrained (Phi=0)
Unit Weight: 17 kN/m³
Cohesion: Multiple Trial: 20 kPa

Name: Sand / Clay (loose)
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 29 °

Name: Sand / Silt
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

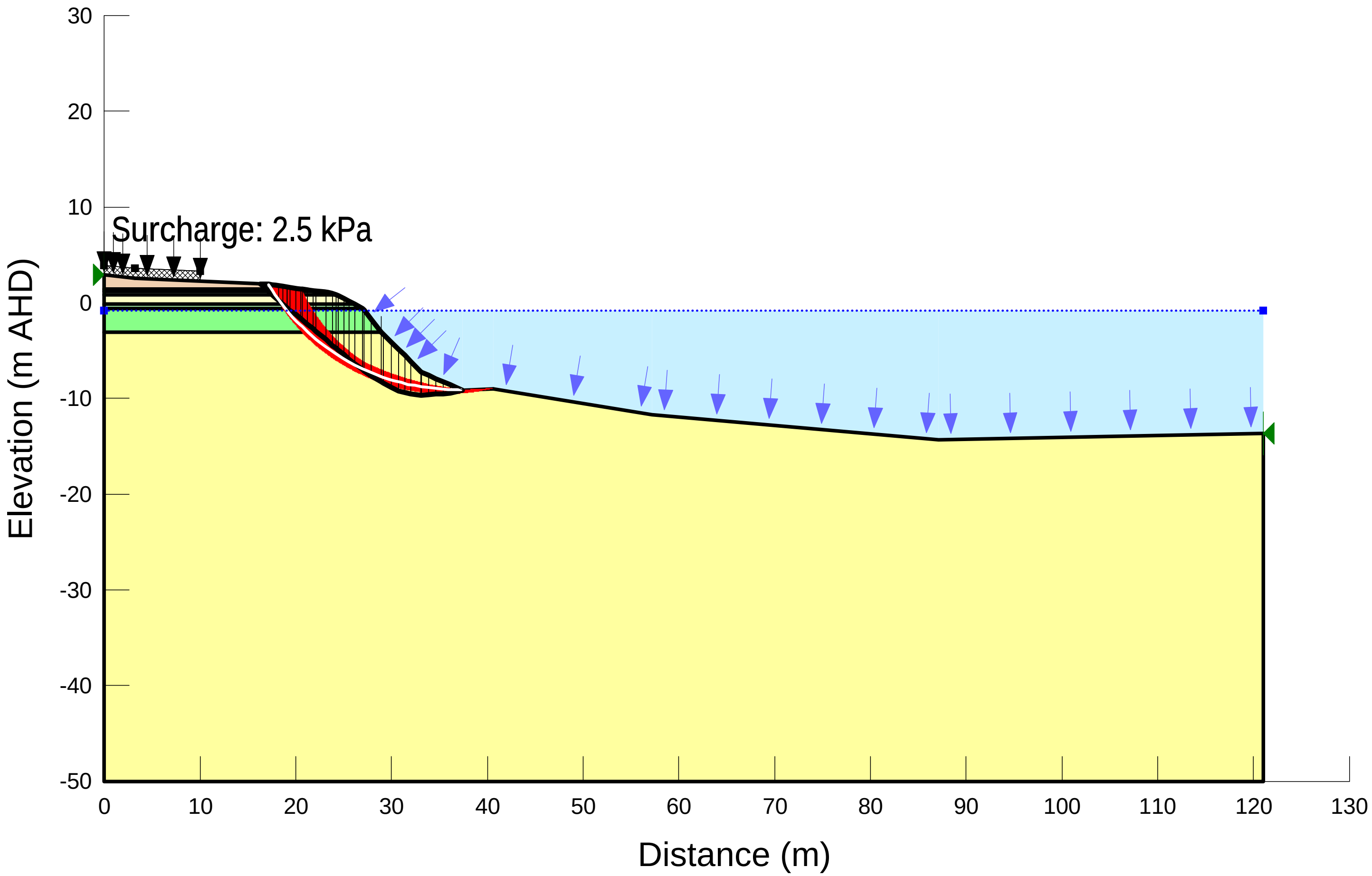
Name: Type 3C
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 16**

Study into Riverbank Collapsing for Lower Murray River
Woodlane Reserve - Section WR2

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.38




Name: FILL
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1 Clay
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B2 Clay
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa

Name: Type C1 Silty Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B3 Clay
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B4 Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 17 kN/m³
C-Top of Layer: Multiple Trial: 28 kPa
C-Rate of Change: Multiple Trial: 7.2 kPa/m
Limiting C: Multiple Trial: 46 kPa

Name: Type C2 Silty Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 1 kPa
Phi: Multiple Trial: 31 °

**Figure 17**

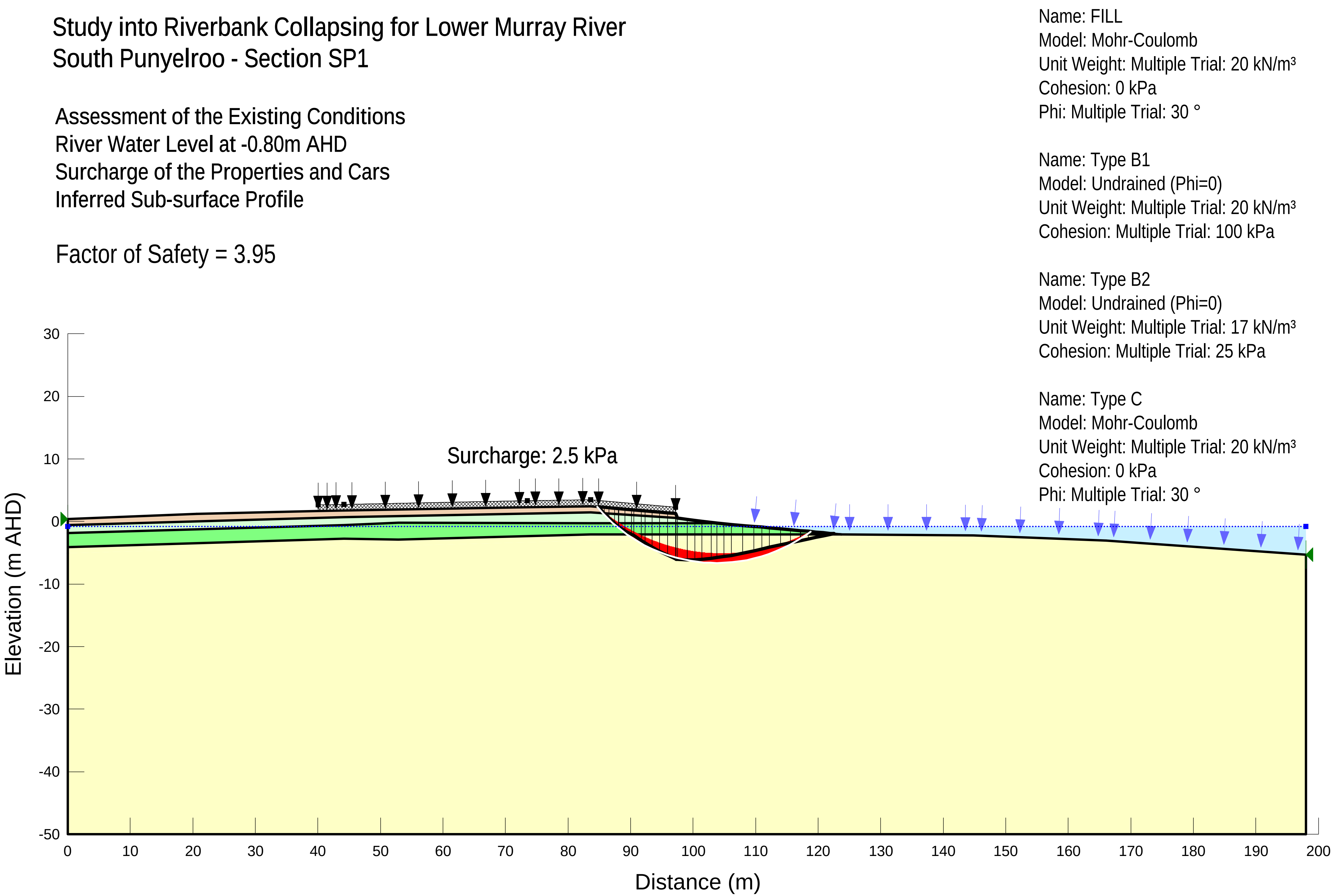
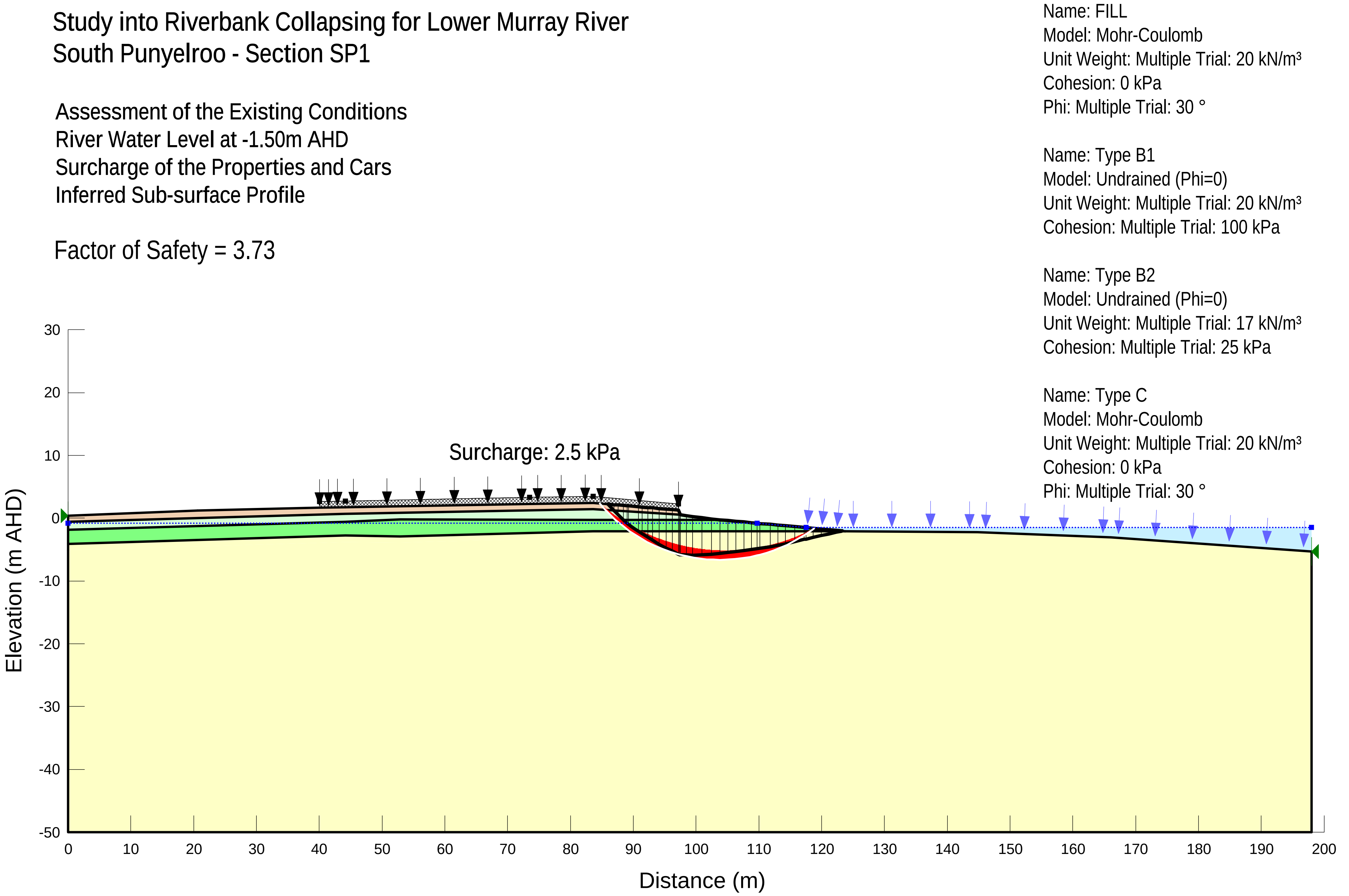

Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1
Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars
Inferred Sub-surface Profile
Factor of Safety = 3.95
Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa
Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Surcharge: 2.5 kPa
Elevation (m AHD)
30
20
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Distance (m)

**Figure 18**



Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1
Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars
Inferred Sub-surface Profile
Factor of Safety = 3.73
Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa
Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Surcharge: 2.5 kPa
Elevation (m AHD)
30
20
10
0
-10
-20
-30
-40
-50
Distance (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200


**Figure 19**

Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars
Worst Case Sub-surface Profile

Factor of Safety = 1.67

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa

Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

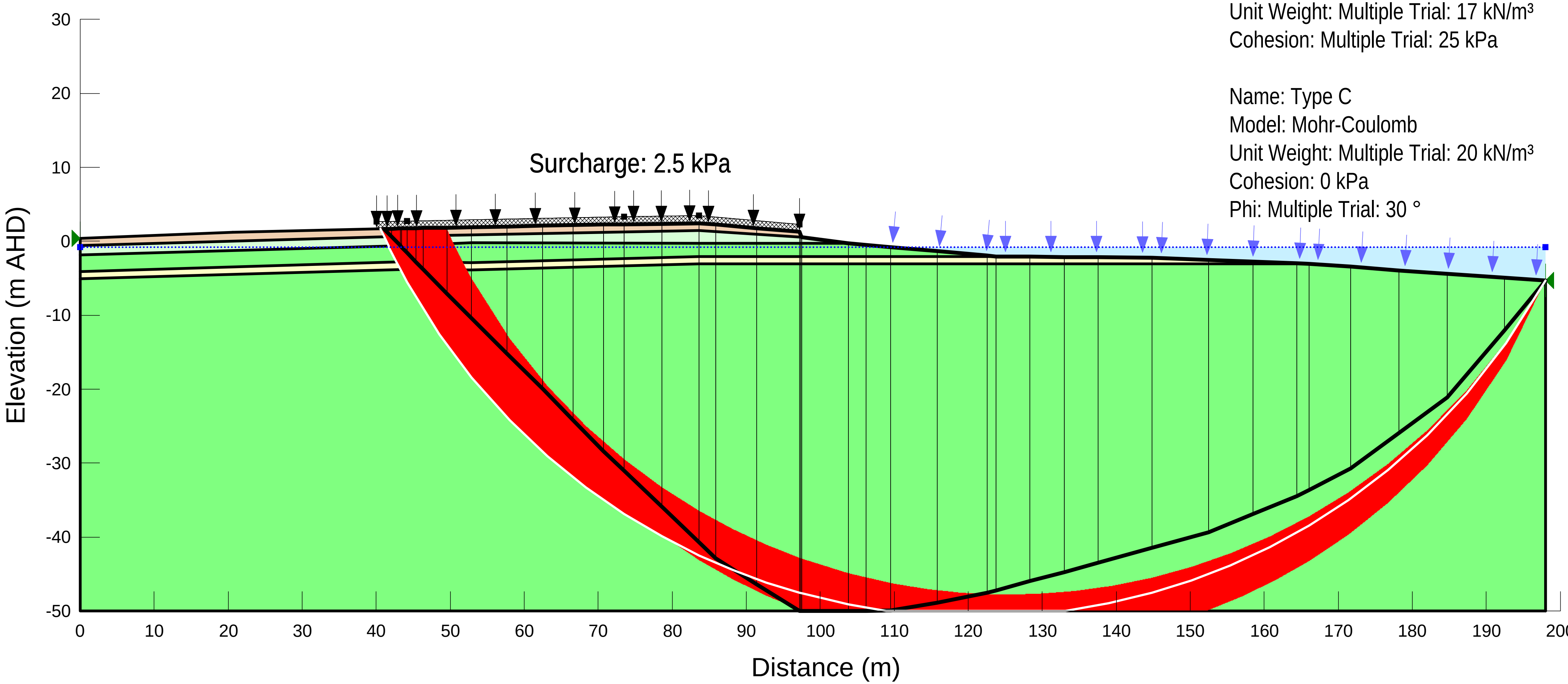



**Figure 20**

Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars
Worst Case Sub-surface Profile

Factor of Safety = 1.54

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa

Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

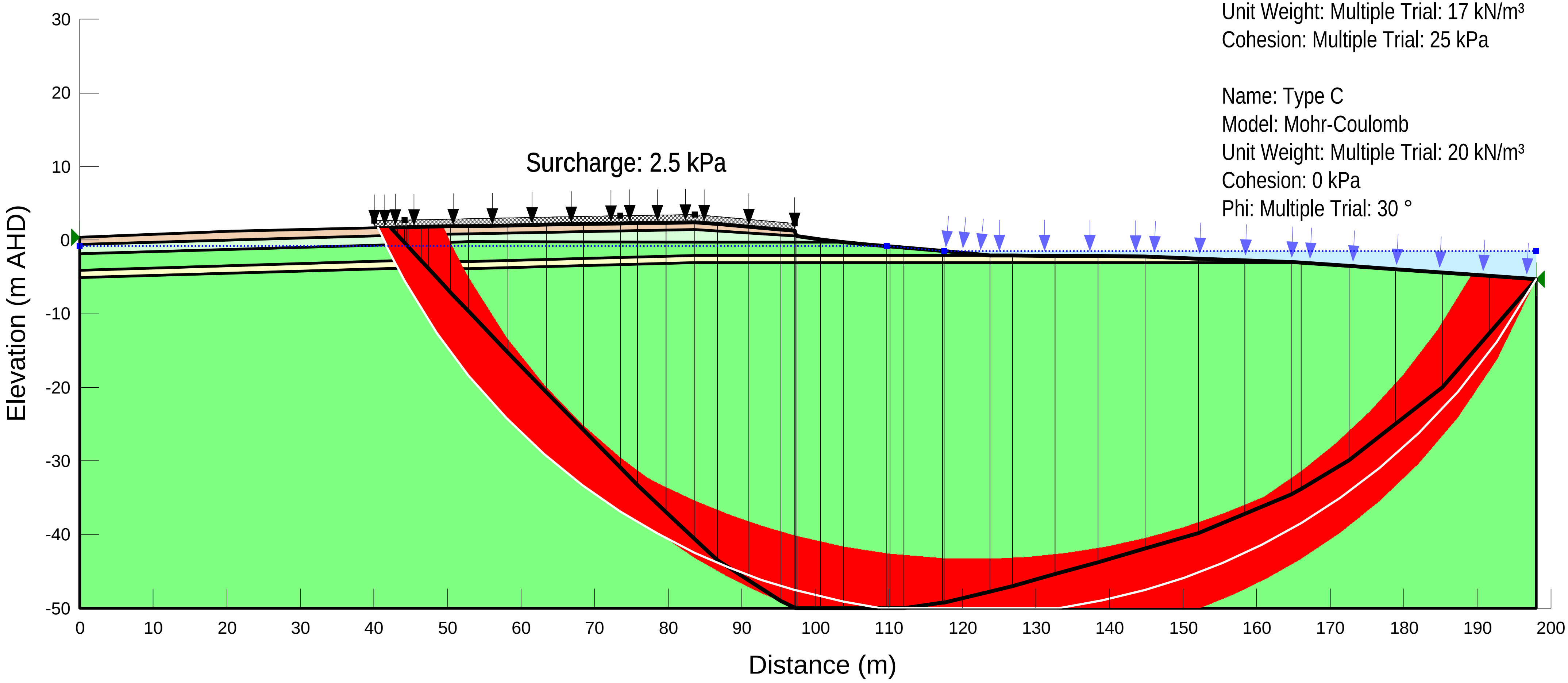



**Figure 21**

Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.30

Name: FILL A1
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 32 °

Name: FILL A2
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 21 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 35 °

Name: Type B
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Rock
Model: Bedrock (Impenetrable)

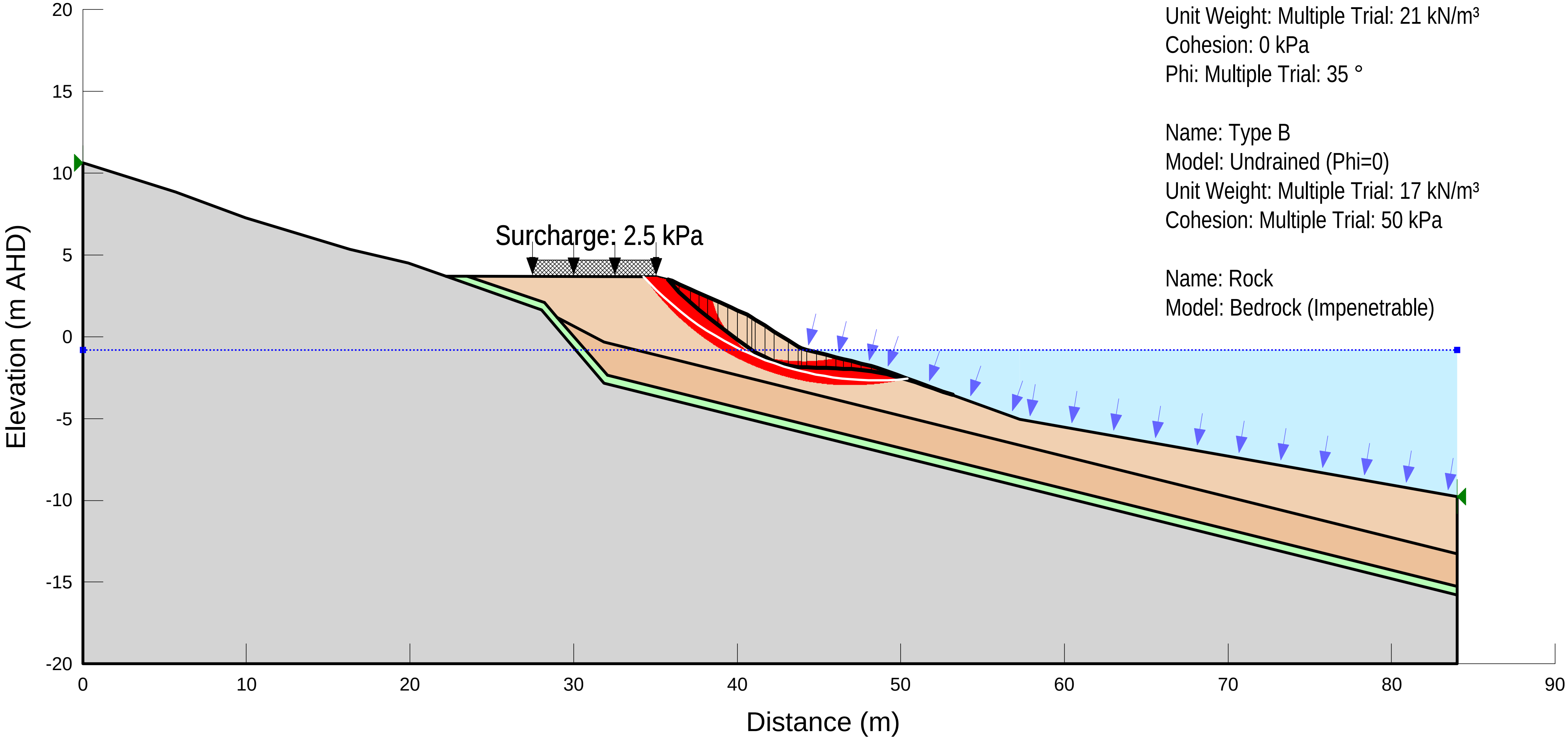
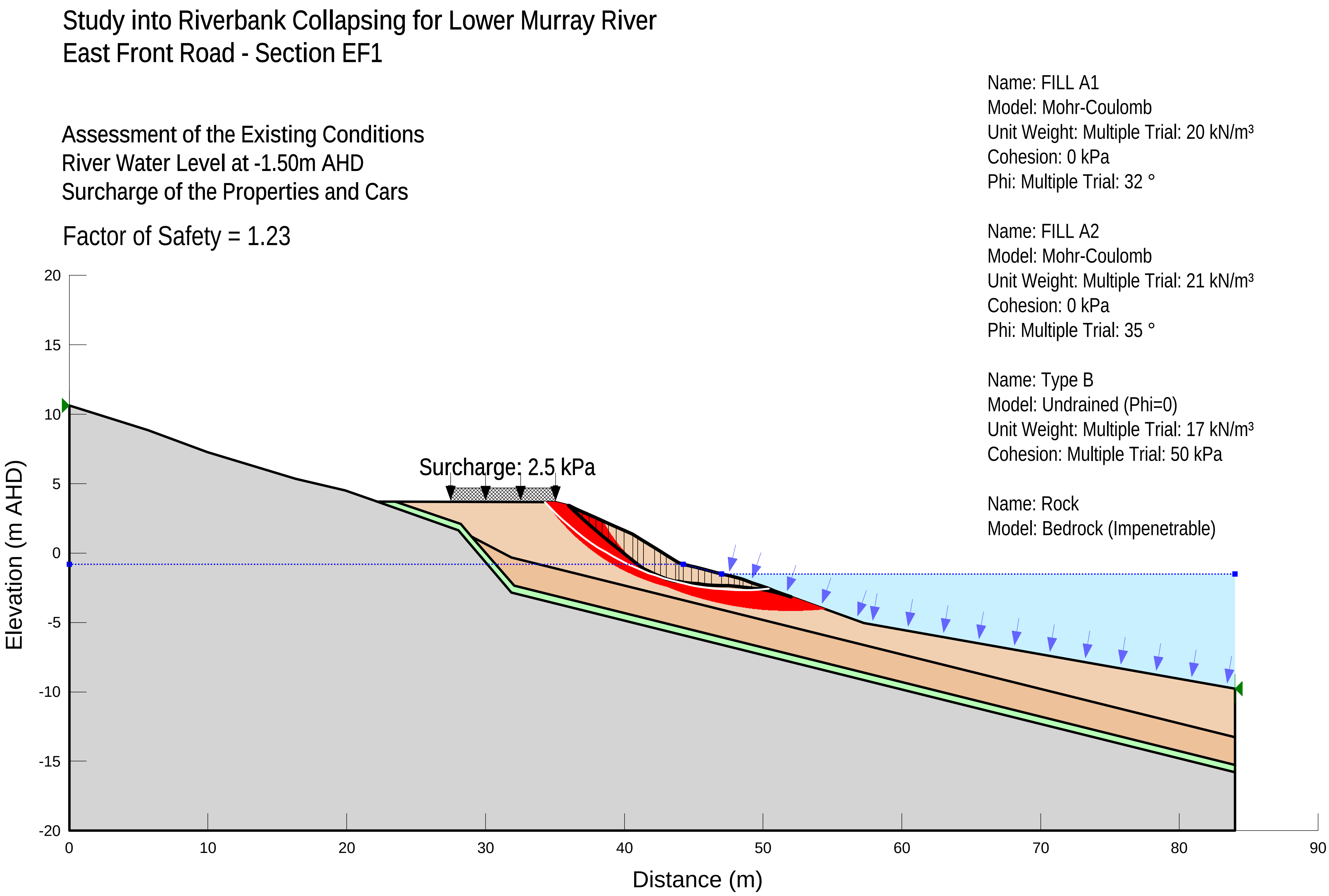



**Figure 22**



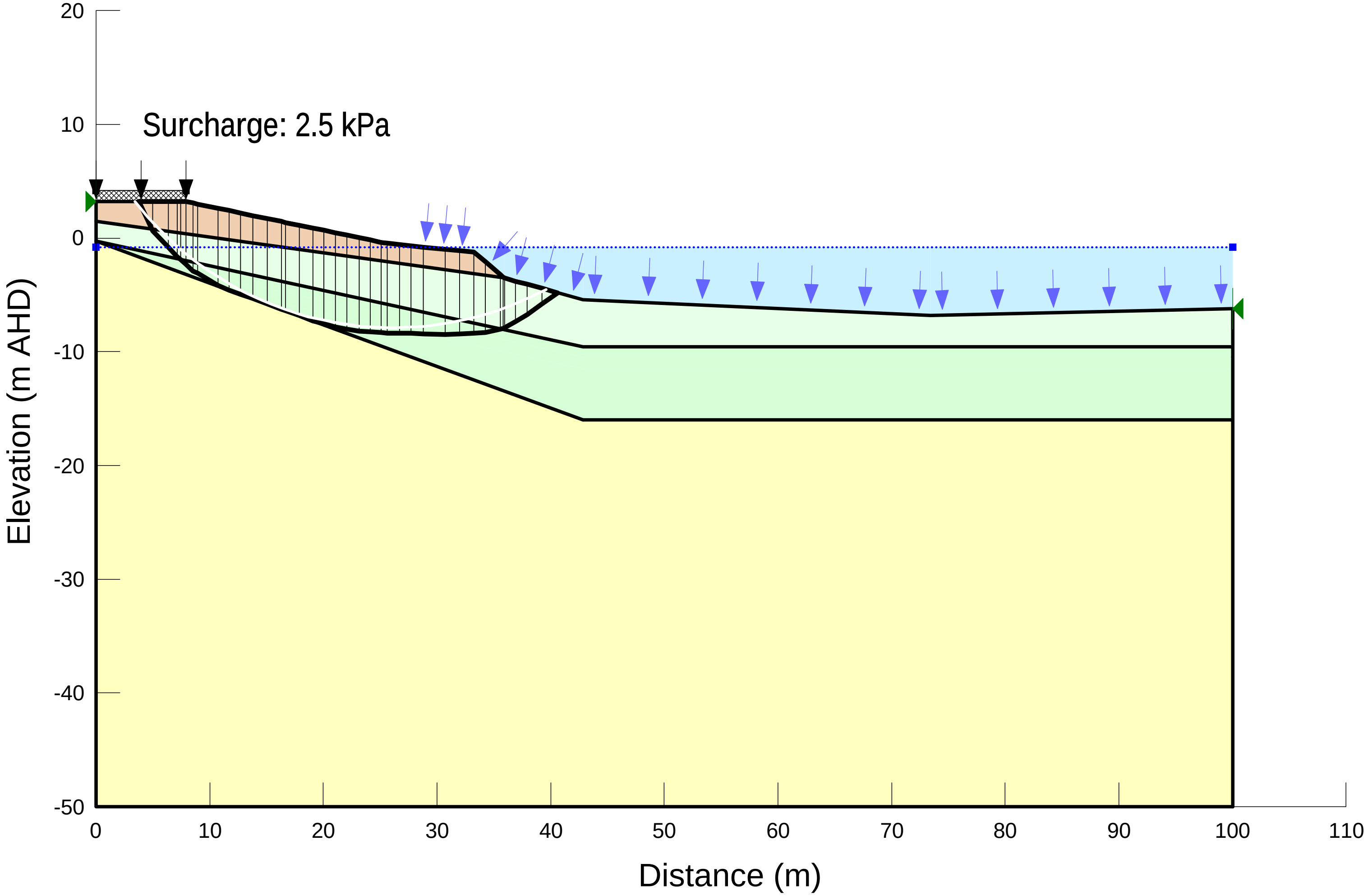
Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF1
Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars
Factor of Safety = 1.23
Name: FILL A1
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 32 °
Name: FILL A2
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 21 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 35 °
Name: Type B
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa
Name: Rock
Model: Bedrock (Impenetrable)
Surcharge: 2.5 kPa
Elevation (m AHD)
20
15
10
5
0
-5
-10
-15
-20
0
10
20
30
40
50
60
70
80
90
Distance (m)


**Figure 23**

Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF2

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.02




Name: Type A FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 17.5 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 14 kPa

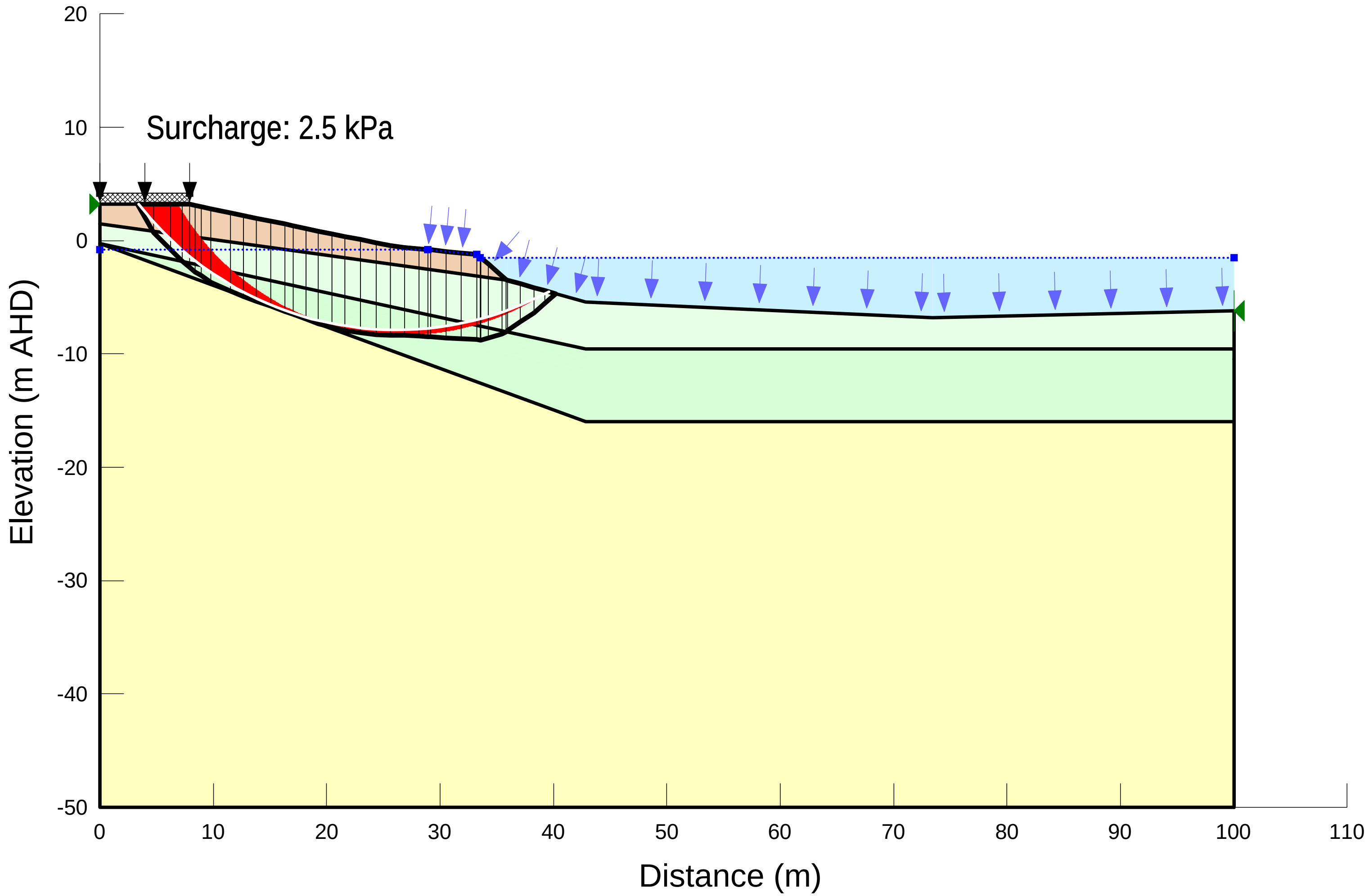
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 24**

Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF2

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 0.95




Name: Type A FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 17.5 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 14 kPa

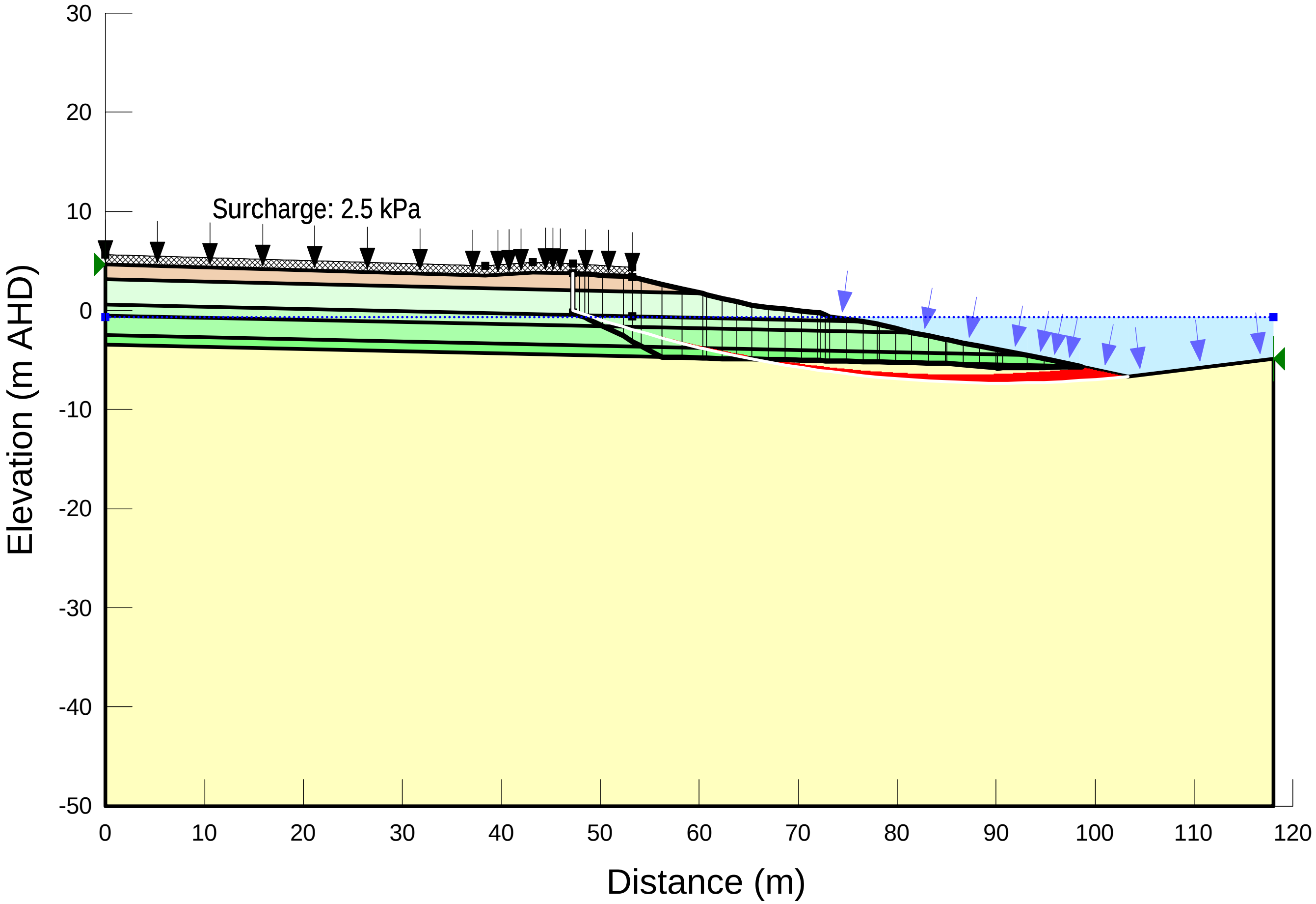
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 25**

Study into Riverbank Collapsing for Lower Murray River
Swan Reach - Section SW1

Assessment of the Existing Conditions
River Water Level at -0.70m AHD
Surcharge of the Structures and Cars
With 4m Deep Tension Crack

Factor of Safety = 1.68




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 250 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 18 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 12.5 kPa

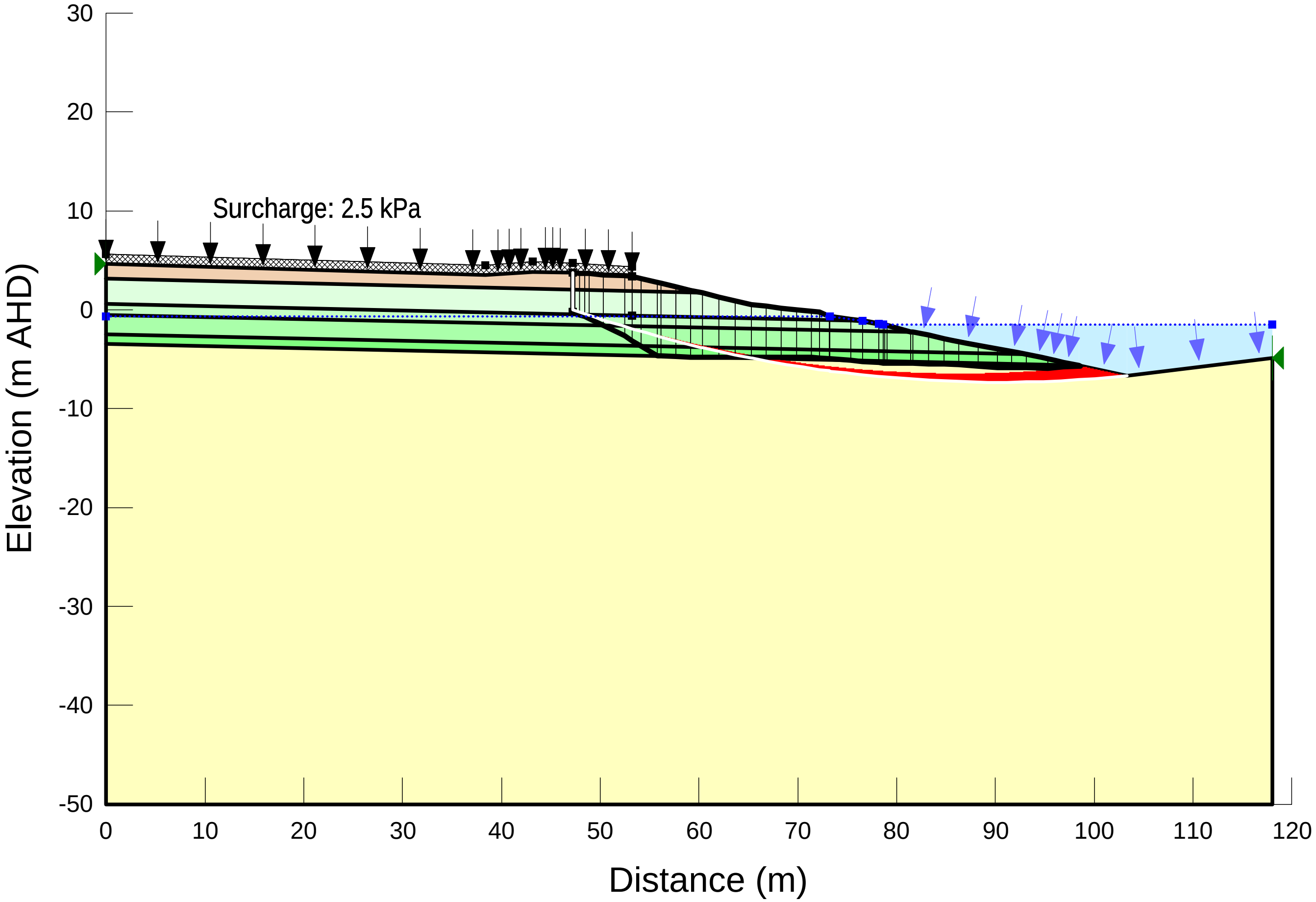
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 26**

Study into Riverbank Collapsing for Lower Murray River
Swan Reach - Section SW1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Structures and Cars
With 4m Deep Tension Crack

Factor of Safety = 1.70




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 250 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 18 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 12.5 kPa

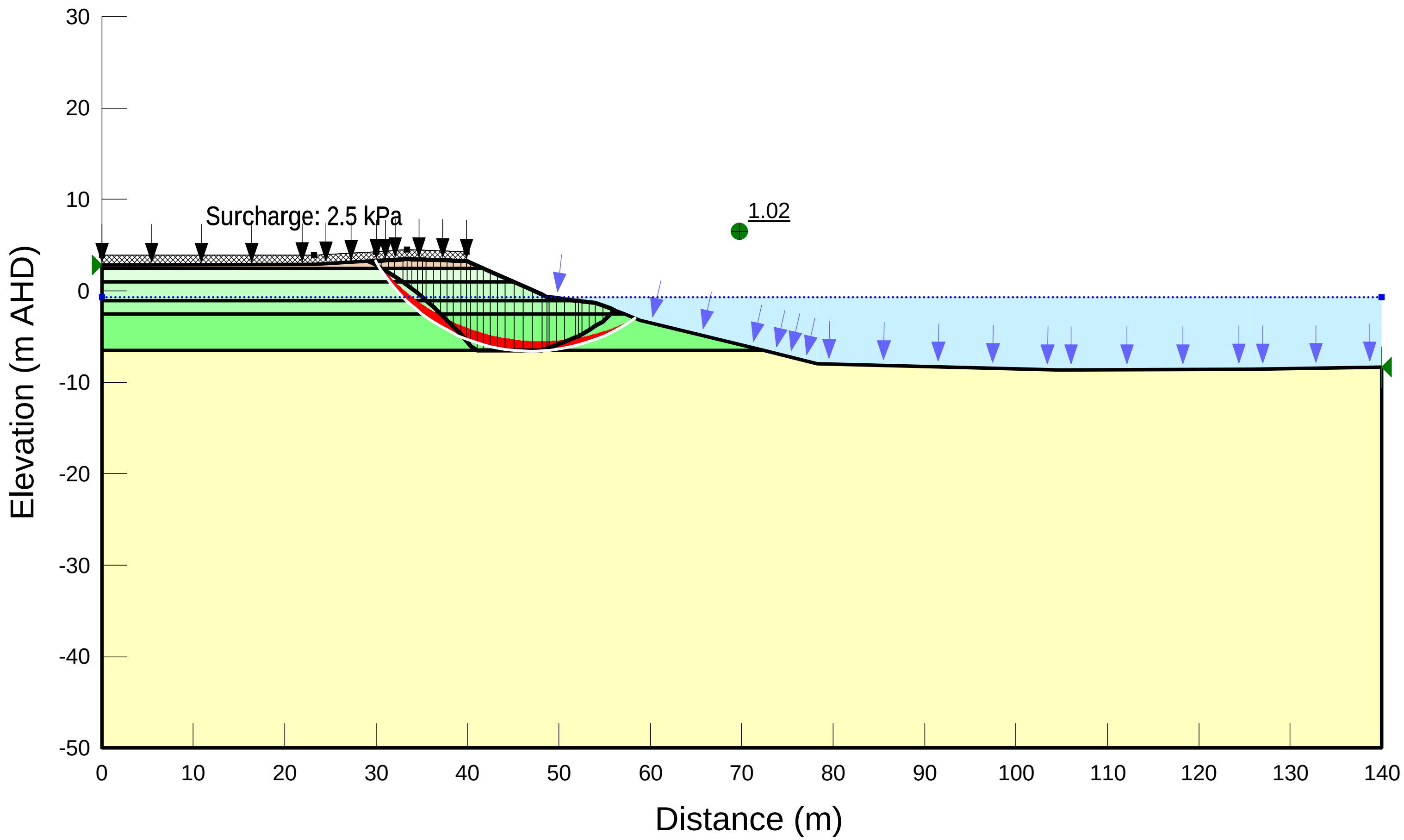
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 27**

Study into Riverbank Collapsing for Lower Murray River
Walker Flat - Section WF1

Assessment of the Existing Conditions
River Water Level at -0.70m AHD
Surcharge of the Structures and Cars

Factor of Safety = 1.02




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 70 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

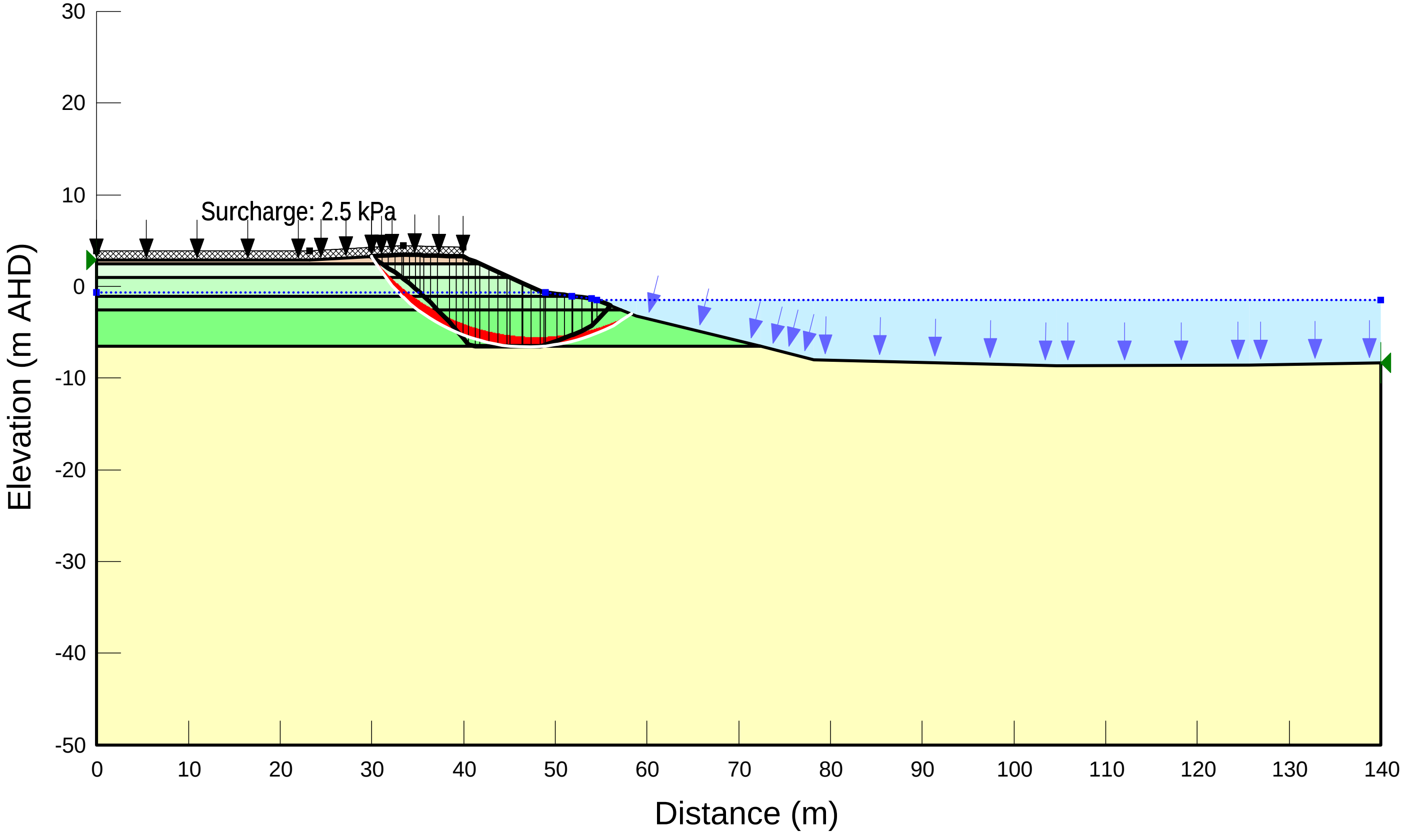
Name: Type B5 / C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Figure 28

Study into Riverbank Collapsing for Lower Murray River
Walker Flat - Section WF1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Structures and Cars

Factor of Safety = 0.94




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 70 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

Name: Type B5 / C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Figure 29

# 1. Introduction

Sinclair Knight Merz (SKM) was commissioned by S.A Department of Water, Land and Biodiversity Conservation (DWLBC) to undertake a Geotechnical Investigation as part of the *Study into River Bank Collapsing - Lower River Murray*. The purpose of the study is to establish an understanding of the river bank collapsing issues arising from current and anticipated ongoing and lowering water levels in the lower pool. DWLBC will use the management and monitoring recommendations from the study to assist it with its response to collapsing.

The Study is being carried out in three phases. Phase 1 related to the development of project objectives and early advice provided from selected consultants. Phase 2 involved specialised observation and review of conditions leading to bank collapse and risk ranking of high consequence areas. A key output from Phase 2 was an *Inspection Report* (SKM, 2009) which provided a series of recommendations for future investigations, management and monitoring.

This work forms a component of Phase 3 of the study and builds upon earlier work documented in SKM (2009). The aim of the geotechnical investigation was to obtain subsurface information for assessment of the cracks and stability problems observed in seven (7) sites along the Lower River Murray. In absence of a quantitative risk assessment for the sites, the critical sites for the further studies have been defined by DWLBC.

Following on from site inspections performed during October 2009 (SKM, 2009) and further discussions with DWLBC, geotechnical investigations were performed between 21 to 28 October, 4 to 5 November and 18 to 19 November 2009, at the following sites:

- Riverfront Road-Murray Bridge (2 Boreholes, 13 CPTu tests, 1 Dilatometer Test and 1 Piezometer)
- Caloote (4 Boreholes, 17 CPTu tests, 1 Dilatometer Test and 1 Piezometer)
- Woodlane Reserve (2 Boreholes and 5 CPTu tests)
- South Punyelroo (3 Boreholes and 7 CPTu tests)
- East Front Road (3 Boreholes and 1 CPTu test)
- Swan Reach (1 Borehole, 3 CPTu tests)
- Walker Flat (1 Borehole, 3 CPTu tests)

Due to presence of very soft clays within the soil profile, additional sensitive CPTu and Dilatometer Tests were carried out adjacent to previous CPTu test locations, performed by Black In-Situ Testing, to supplement the CPTs performed by Engtest (University of Adelaide). The factual results of the investigation, together with the stability assessment results for nominated sites are presented in this report, including the borehole logs, CPTu profiles, in-situ tests from the field, laboratory test results, preliminary stability assessment and advice on possible effects of the further reduction in the river’s level.

# 2. Scope of Work

The objective of the geotechnical investigation was to provide information that would allow greater understanding of the ground conditions at the nominated sites, and, therefore, improve the reliability of associated stability assessments.

The scope of work comprised the following tasks:

- Desktop review of existing geotechnical and geological information;
- Development of a project EHS plan and JSEA for the work planned for each site;
- Provision of field survey including land survey and bathymetrical transects for maximum of two cross sections at each site;
- Provision of underground services locator to identify the existing infrastructures at the proposed test locations;
- Geotechnical sampling and testing, at each site, comprising:
  - Drilling of boreholes at each site. The boreholes were advanced using solid flight augering technique in the soil to a maximum depth of 20m; or at the discretion of the Supervising Geotechnical Engineer;
  - Standard Penetration Tests (SPT) in the boreholes, at nominal intervals at the discretion of the Supervising Geotechnical Engineer;
  - Collecting thin-walled push tube samples from the boreholes at depths nominated by the Supervising Geotechnical Engineer;
  - Identification and visual description of the samples including field classification, colour (referenced to a standard colour chart), odour, structure and consistency;
  - Measurement of the field undrained shear strength of cohesive material by Vane Shear and/or Pocket Penetrometer tests, at depth nominated by the Supervising Geotechnical Engineer;
  - Performance of a Cone Penetration Tests with pore-water pressure measurements (CPTu) at each site. The CPTu was performed to a nominal target depth of 20m, or refusal (as decided by the CPTu Operator);
  - Additional CPTu tests using sensitive cone for more accurate strength assessment of the very soft clays; and
  - Dilatometer Tests in selected sites to assess the in-situ strength of the very soft clays.
- Preparation of a draft factual report summarising the factual data from the field and including the following components:
  - Review of existing geotechnical and geological information;
  - Site plans showing the investigation locations;

- Description of the investigation methodology;
- Borehole logs, including descriptions of the inferred subsurface conditions at each site; and
- CPTu test results;

- Laboratory testing at a registered NATA laboratory, including:
  - Index testing for soil samples including Particle Size Distribution, Atterberg Limits, Moisture Content, Linear Shrinkage, Dry Density, Specific Gravity and Emerson Classification;
  - Strength tests including Unconsolidated Undrained (UU) Triaxial, Consolidated Undrained (CU) Triaxial and Direct Shear test to determine the strength characteristics of the soil profile; and
  - Odometer tests to determine the consolidation characteristics of the soft clays.
- Slope stability assessments for the selected cross sections using soil properties data obtained from the investigation;
- Preparation of a final report, including the following components:
  - Information presented in the draft factual report;
  - Revised borehole logs incorporating laboratory test results;
  - An interpretation of the field data and laboratory test results;
  - Results of slope stability analysis for the selected sites (for existing conditions and allowing for a further reduction in the river's level); and
  - Discussion and recommendations on potential methods to stabilize the slopes (as appropriate).

# 3. Data Sources

The data sources used for this report comprised:

- Geological Survey of South Australia (1962) 1:250,000 Adelaide, Barker and Renmark map-sheets;
- Study into River Bank Collapsing- Lower River Murray Report (SKM, October 2009);
- Ground investigation data (as presented in this report) including:
  - Borehole logs;
  - Cone Penetrometer Tests;
  - Dilatometer tests;
  - In-situ tests including Vane Shear, Pocket Penetrometer and Standard Penetrometer Tests; and
  - Laboratory test results;
- Site Survey and bathymetrical transects; and
- DWLBC GIS Database.

The following subcontractors were engaged during the geotechnical investigation and laboratory testing:

- Drilling Solution Pty Ltd of Lonsdale, South Australia;
- EngTest (via the University of Adelaide) South Australia;
- Black Insitu Testing of Glen Iris, Victoria;
- Australian Soil Testing Pty Ltd of Rockdale, New South Wales; and
- Coffey Information Pty Ltd of Mile End, South Australia.

These data sources are discussed in more detail in the following sections.

# 4. Geotechnical Investigation

## 4.1. Field Investigation

The investigation methodology was generally consistent with Australian Standard *AS1726-1993* (Geotechnical Site Investigations) and SKM's standard work procedures. The investigation was undertaken by experienced geotechnical engineers from SKM in accordance with *AS1726-1993*. The approximate investigation locations are presented on **Figure 1**. Survey plans for each site are presented in the Appendices.

### 4.1.1. Boreholes

The field investigation was performed from 21$^{st}$ to 28$^{th}$ of October, 4$^{th}$ to 5$^{th}$ November, and 18$^{th}$ to 19$^{th}$ of November 2009. The fieldwork comprised 16 boreholes and 49 CPTu tests, to a maximum depth of 20m below existing ground surface level, at seven nominated sites. The boreholes were drilled using a Warman Scout 250. The soil profile encountered in the boreholes was logged (including vane testing and pocket penetrometer strength assessments) and soil samples were collected to confirm visual classification and for additional laboratory testing. The borehole logs are included in the appendices, and a summary of the borehole details is presented in **Table 1.**

- **Table 1 Geotechnical Borehole Details**

| Borehole No. | Location | Easting *[mE]* | Northing *[mN]* | Elevation *[m AHD]* [1] | Final Depth *[m bgl]* [2] |
|---|---|---|---|---|---|
| SR-BH1 | Riverfront Road-Murray Bridge | 343 936 | 6 111 971 | 1.1 | 20.0 |
| SR-BH2 | Riverfront Road-Murray Bridge | 344 163 | 6 111 703 | 1.1 | 17.5 |
| CA-BH1 | Caloote | 341 491 | 6 129 958 | 1.6 | 4.0 |
| CA-BH2 | Caloote | 341 502 | 6 129 911 | 1.7 | 11.2 |
| CA-BH3 | Caloote | 341 526 | 6 129 822 | 1.6 | 18.3 |
| CA-BH4 | Caloote | 341 548 | 6 129 822 | 1.4 | 13.4 |
| WR-BH1 | Woodlane Reserve | 348 154 | 6 126 175 | 2.8 | 19.5 |
| WR-BH2 | Woodlane Reserve | 348 250 | 6 126 063 | 2.6 | 15.2 |
| SP-BH1 | South Punyelroo | 372 786 | 6 169 365 | 2.0 | 4.6 |
| SP-BH2 | South Punyelroo | 372 806 | 6 169 385 | 1.3 | 4.2 |
| SP-BH3 | South Punyelroo | 344 171 | 6 111 718 | 2.4 | 4.6 |
| EF-BH1 | East Front Road | 349 560 | 6 137 674 | 3.6 | 2.0 |
| EF-BH2 | East Front Road | 349 575 | 6 137 684 | 3.7 | 6.2 |
| EF-BH3 | East Front Road | 349 763 | 6 137 768 | 3.1 | 7.4 |
| SW-BH1 | Swan Reach | 371 658 | 6 174 658 | 4.5 | 8.2 |
| WF-BH1 | Walker Flat | 367 898 | 6 153 645 | 3.4 | 11.0 |

*Notes: 1. metres Australian Height Datum and 2. metres below ground level*

SKM

#### 4.1.2. In-situ Testing

In addition to CPTs, "Standard Penetration Tests" (SPTs) were performed at selected depths to assess the consistency and strength parameters of the soil layers. The results of these tests are included on the borehole logs in the relevant Appendix for each site.

#### 4.1.3. CPTu Testing

The CPTu test is a Cone Penetration Test, including pore water pressure measurements, as well as cone resistance and sleeve friction. The addition of pore water pressure measurement allows more reliable assessment of soil type, shear strength, stiffness and consolidation characteristics.

Due to presence of a very soft clayey layer, at some locations, additional CPTu tests using a more sensitive cone were carried out by Black In-Situ Testing. These tests are identified by the suffix 'S' on the CPT number. The CPTu results are included in the appendices, and a summary of the test details is presented in **Table 2**.

- **Table 2 CPTu Test Details (continued overleaf)**

| CPTu No. | Location | Easting *[mE]* | Northing *[mN]* | Elevation *[m AHD]* [1] | Final Depth *[m bgl]* [2] |
|---|---|---|---|---|---|
| SR-CPT1 | Riverfront Road-Murray Bridge | 343 969 | 6 111 932 | 1.0 | 16.2 |
| SR-CPT2 | Riverfront Road-Murray Bridge | 343 928 | 6 111 968 | 1.2 | 19.3 |
| SR-CPT3 | Riverfront Road-Murray Bridge | 343 912 | 6 112 008 | 1.2 | 22.2 |
| SR-CPT4 | Riverfront Road-Murray Bridge | 343 903 | 6 112 002 | 1.2 | 21.7 |
| SR-CPT5 | Riverfront Road-Murray Bridge | 344 171 | 6 111 718 | 1.0 | 16.5 |
| SR-CPT6 | Riverfront Road-Murray Bridge | 344 163 | 6 111 707 | 1.2 | 14.0 |
| SR-CPT7 | Riverfront Road-Murray Bridge | 344 080 | 6 111 828 | 1.1 | 18.7 |
| SR-CPT8 | Riverfront Road-Murray Bridge | 344 068 | 6 111 811 | 1.3 | 16.1 |
| SR-CPT1S | Riverfront Road-Murray Bridge | 343 969 | 6 111 932 | 1.0 | Refusal [3] |
| SR-CPT2S | Riverfront Road-Murray Bridge | 343 928 | 6 111 968 | 1.2 | Refusal [3] |
| SR-CPT6S | Riverfront Road-Murray Bridge | 344 163 | 6 111 707 | 1.2 | 14.7 |
| SR-CPT7S | Riverfront Road-Murray Bridge | 344 081 | 6 111 824 | 1.1 | Refusal [3] |
| CA-CPT1 | Caloote | 341 487 | 6 129 972 | 1.6 | 2.6 |
| CA-CPT2 | Caloote | 341 483 | 6 129 960 | 2.3 | 0.9 |
| CA-CPT3 | Caloote | 341 508 | 6 129 914 | 1.3 | 11.9 |
| CA-CPT4 | Caloote | 341 572 | 6 129 777 | 2.0 | 3.2 |
| CA-CPT5 | Caloote | 341 570 | 6 129 766 | 2.6 | 7.2 |
| CA-CPT6a | Caloote | 341 533 | 6 129 825 | 1.5 | 6.4 |

| CPTu No. | Location | Easting [mE] | Northing [mN] | Elevation [m AHD] 1 | Final Depth [m bgl] 2 |
|---|---|---|---|---|---|
| CA-CPT6b | Caloote | 341 534 | 6 129 823 | 1.5 | 5.2 |
| CA-CPT7 | Caloote | 341 556 | 6 129 801 | 1.7 | 10.9 |
| CA-CPT8 | Caloote | 341 598 | 6 129 725 | 1.6 | 4.4 |
| CA-CPT9 | Caloote | 341 549 | 6 129 813 | 1.2 | 10.1 |
| CA-CPT10 | Caloote | 341 561 | 6 129 806 | 1.2 | 16.5 |
| CA-CPT1S | Caloote | 341 487 | 6 129 823 | 1.6 | Refusal 3 |
| CA-CPT3S | Caloote | 341 487 | 6 129 823 | 1.3 | 11.1 |
| CA-CPT7S | Caloote | 341 555 | 6 129 801 | 1.7 | Refusal |
| CA-CPT9S | Caloote | 341 549 | 6 129 813 | 1.2 | 5.8 |
| CA-CPT9sa | Caloote | 341 549 | 6 129 813 | 1.2 | 6.0 |
| CA-CPT9sb | Caloote | 341 549 | 6 129 813 | 1.2 | 5.7 |
| WR-CPT2 | Woodlane Reserve | 348 102 | 6 126 238 | 2.8 | 6.9 |
| WR-CPT3 | Woodlane Reserve | 348 152 | 6 126 193 | 3.1 | 11.6 |
| WR-CPT4 | Woodlane Reserve | 348 243 | 6 126 056 | 2.9 | 7.3 |
| WR-CPT5 | Woodlane Reserve | 348 302 | 6 126 000 | 3.3 | 12.9 |
| WR-CPT6 | Woodlane Reserve | 348 232 | 6 129 094 | 1.9 | 11.3 |
| SP-CPT1 | South Punyelroo | 372 809 | 6 169 361 | 2.1 | 4.5 |
| SP-CPT2 | South Punyelroo | 372 751 | 6 169 365 | 1.8 | 5.2 |
| SP-CPT3 | South Punyelroo | 372 773 | 6 169 345 | 1.7 | 4.7 |
| SP-CPT4 | South Punyelroo | 372 789 | 6 169 327 | 1.5 | 4.7 |
| SP-CPT5 | South Punyelroo | 372 815 | 6 169 352 | 2.2 | 4.6 |
| SP-CPT6a | South Punyelroo | 372 783 | 6 169 352 | 2.3 | 1.5 |
| SP-CPT6b | South Punyelroo | 372 783 | 6 169 352 | 2.3 | 4.3 |
| SP-CPT7 | South Punyelroo | 372 802 | 616 9385 | 1.4 | 3.9 |
| EF-CPT1 | East Front Road | 349 558 | 6 137 675 | 1.3 | 8.9 |
| SW-CPT1 | Swan Reach | 371 659 | 6 174 658 | 4.5 | 9.2 |
| SW-CPT2 | Swan Reach | 371 646 | 6 174 649 | 4.9 | 8.3 |
| SW-CPT3 | Swan Reach | 371 636 | 6 174 636 | 0.9 | 4.5 |
| WF-CPT1 | Walker Flat | 367 887 | 6 153 650 | 3.2 | 10.1 |
| WF-CPT2 | Walker Flat | 367 899 | 6 153 647 | 3.4 | 11.1 |
| WF-CPT3 | Walker Flat | 367 907 | 6 153 640 | 3.5 | 10.0 |

*Notes:* 
*1. metres Australian Height Datum*
*2. metres below ground level*
*3. Refusal indicates CPT did not penetrate fill material*

### 4.1.4. Dilatometer Tests

The Dilatometer Tests were conducted by Black In-Situ Testing Company in Caloote and Riverfront Road-Murray Bridge sites. The results are presented in **Appendix A** and **Appendix B**.

## 4.2. Laboratory Testing

Geotechnical laboratory testing was undertaken on selected samples from the boreholes by Coffey Information and Australian Soil Testing Pty Ltd, in their NATA registered laboratories. The tests that were undertaken are summarised in **Table 3**. Formal laboratory test certificates are presented in the relevant Appendix for each site.

- **Table 3 Geotechnical Laboratory Testing Program**

| Test Description | Applicable Australian Standard |
|---|---|
| Visual Classification and Moisture Content | AS 1289.2.1.1 |
| Atterberg Limits with Linear Shrinkage | AS 1289.3.1.2, 3.2.1, 3.3.1, 3.4.1 |
| Linear Shrinkage | AS 1289.3.4.1 |
| Percentage Fines (<75μm) | AS 1289.3.6.1 |
| Particle Size Distribution (sieving) | AS 1289.3.6.1 |
| Particle Size Distribution (with hydrometer) | AS 1289.3.6.2 |
| Unconsolidated Undrained (UU)Triaxial | AS 1289.6.4.1 |
| Saturated Consolidated Undrained (CIU) Triaxial | AS 1289.6.4.2 |
| Consolidation | AS 1289.6.6.1 |
| Soil Particle Density | AS 1289.3.5.1 |
| Direct Shear Test | AS1289 6.2.2 |
| Emerson Class Test | AS 1289.3.8.1 |

# 5. Assessment Criteria

## 5.1. Study Area

Seven high risk areas were nominated by DWLBC for this study. The extent of the study, in each area, covers the public accessible areas and residential developments. A vicinity map of the study areas is presented on **Figure 1**.

## 5.2. Failure Modes

Based on the observations in the preliminary site inspections, a number of modes of failure have been identified in the area

- Desiccation and tension cracks;
- Increase in surcharge due to lower river water level;
- Slumping;
- Toe erosion; and
- Slope stability.

The following modes of failure have been adopted for more quantified assessment:

- Slope stability including effects of additional surcharge and shrinkage cracks; and
- Excessive deformation due to settlement and tension cracks.

## 5.3. Geometry

Some cross sections from each area have been selected for the site investigation and stability assessment which are representative of different slopes, developments and soil/rock condition.

Results of the land survey and bathymetrical transects carried out by SKM have been used to generate the cross sections which are presented in the appendices.

## 5.4. Soil Types

Soils in each site have been separated into three distinct soil types, namely Type-A, Type-B and Type-C. A summary of the descriptions and layer thicknesses for each soil type is presented in **Table 4 overleaf**.

**Type-A: Fill Material.**

In Riverfront Road-Murray Bridge, Caloote, Woodlane Reserve and South Punyelroo sites, Soil Type A is generally described as Silty/Clayey SAND with around 1000mm thickness.

In East Front Road, Swan Reach and Walker Flat, Soil Type A is in the form of a fill platform with gravely nature and unknown level of compaction. The thickness of the fill platforms varies from 1.5m to 6.0m.

Fill materials at all sites are located above the river's water table.

**Type-B: Very Soft Silty CLAY (CH)**

Soil Type B generally comprises very soft high plasticity silty CLAY layer with consistent colour, strength and physical properties. Moisture contents of this material under the water table tend to be close to the Liquid Limit. Organic matter, like leaves and roots, has been observed in this layer at different levels.

As the stability and deformation of the cross sections are highly dependent on the properties of this layer, the strength parameters of the very soft clays have been assessed by several different methods, i.e. CPTu, Vane Shear, Dilatometer, UU Triaxial. The undrained shear strength of this material tends to be in the range 10kPa to 25 kPa, with a trend of increasing shear strength with depth.

**Type-C: SANDY Layer**

Soil Type B generally comprises medium dense to very dense sandy material, underlying Soil Type B.

SKM

- **Table 4 Summary of Soil Types Adopted for Stability Assessments**

| Type | Site | Description | Depth (m) |
|---|---|---|---|
| Type-A | Riverfront Road-Murray Bridge | Fill: Silty/Clayey SAND (SM/SC) | 0 to 1 |
| | Caloote | Fill: Silty/Clayey SAND (SM/SC) | 0.to 1 |
| | Woodlane Reserve | Fill: Silty/Clayey SAND (SM/SC) | 0 to 1 |
| | East Front Road | Fill: Silty/Clayey SAND (SC/SM) / Silty/Clayey GRAVEL (GC/GM) | 0 to 2-6 |
| | South Punyelroo | Fill: Silty Sand (SM) | 0 to 0.5-1 |
| | Swan Reach | Fill: Silty SAND/GRAVEL (SM/GM) | 0 to 2 |
| | Walker Flat | Fill: Silty/Clayey GRAVEL (GM/GC) | 0 to 1.5 |
| TYPE-B | Riverfront Road-Murray Bridge | Silty CLAY (CH) | 1 to 10~ >20 |
| | Caloote | Silty CLAY (CH) | 1 to 8.5~15 |
| | Woodlane Reserve | Silty CLAY (CH) | 1 to 4~6 |
| | East Front Road | Silty CLAY (CH) | 3 to 6.5 |
| | South Punyelroo | Silty CLAY (CL) | 0.5~1 to 3.5~4.5 |
| | Swan Reach | Silty CLAY (CH) | 2 to 8 |
| | Walker Flat | Silty CLAY (CH) | 1.5 to 10.5 |
| TYPE-C | Riverfront Road-Murray Bridge | Clayey SAND/Sandy CLAY (SC/CL) | 10~ >20 |
| | Caloote | Silty/Clayey SAND (SC/SM) / Silty/Clayey GRAVEL (GC/GM) | >8.5-15 |
| | Woodlane Reserve | Silty/Clayey SAND (SM/SC), SILT (ML) | >4-6 |
| | East Front Road | Clayey SAND (SC) | >6.5 |
| | South Punyelroo | SAND (SP) | >3.5-4.5 |
| | Swan Reach | SAND (SW) | >8 |
| | Walker Flat | Clayey SAND/Sandy CLAY (SC/CL) | >10.5 |

## 5.5 Stability Criteria

The following criteria were adopted for the stability assessment of the river bank slopes:

- Limit equilibrium methods to estimate minimum Factor of Safety (FoS);
- Morgenstern and Price method of analysis with circular and optimised non-circular slip surfaces;
- Mohr-Coulomb model with drained strength parameters, for the fill and sandy materials;
- The very soft clays have been modelled with undrained shear strength ($s_u$) a function of depth. The results of CPTu, Dilatometer, Vane Shear and Triaxial tests were used to estimate the undrained shear strength, rate of increase and maximum undrained shear strength;
- A minimum of 2.5kPa distributed live loading for car parks, public access and riverside properties;
- Stability assessment for the existing conditions and further reduction in river's water level;
- The minimum acceptable FoS in excess of 1.5 for the existing conditions and after reduction in river's water level to -1.5m AHD over three years (Feb 2010 to Feb 2013);
- Sensitivity analysis to assess the effects of uncertainties in soil parameters on FoS;A probability of failure (Factor of Safety less than 1.5) less than 5% for each section due to variability in the parameters during the existing conditions and after reduction in water levels over three years (Feb 2010 to Feb 2013) using Monte Carlo trials method; and
- In absence of a risk study for the area, the Average Factor of Safety and Factors of Safety associated with 5% probability of failure have been adopted for the stability classification of the sites.
- For the Factors of Safety below the recommended value of 1.5 or above 3, no earthquake loading has been considered.

# 6. Riverfront Road-Murray Bridge

## 6.1. Site Geology

Based on the Geological Survey of South Australia (1962) 1:250,000 Barker map-sheet, the Riverfront Road-Murray Bridge site is located on Quaternary aged Alluvial Flat Deposits, and is in close proximity to the geological boundary with sandy limestone of the Tertiary aged Mannum Formation.

## 6.2. Subsurface Condition

The subsurface profile encountered at Riverfront Road-Murray Bridge generally comprised silty sand overlying Silty CLAY with a transition typically around 1.0m depth. The investigation confirmed the expected Quaternary aged Alluvial Flat Deposits, as seen on the Survey of South Australia (1962) 1:250,000 Barker map sheet.

The layers of dark grey very soft silty CLAY were relatively thick, extending up to 11m deep in SR-BH-2, and up to more than 20m deep in SR-BH-1. SPT results in this layer were typically zero and the sampler tended to sink under its self-weight. The push tube samples also penetrated easily into the soil under the weight of the rod and hand pressure.

Pockets of medium dense Sandy CLAY/Clayey SAND underlay this layer of silty CLAY, extending up to the termination depth of 17.5m at SR-BH-2. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix A**.

## 6.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix A**. Piezometers were installed at Riverfront Road-Murray Bridge for the monitoring of groundwater levels. Groundwater Level in piezometer well was 1.12 m below ground level (measured on 19/11/2009).

## 6.4. Soil Parameter Plots

Results of moisture content and Atterberg limit tests with depth for Riverfront Road-Murray Bridge are presented in **Figure 30**. Results of dry density and bulk density tests are presented in **Figure 31**. A Liquidity Index versus depth plot is presented on **Figure 32**. An activity plot, based on clay fraction and plasticity index, is presented on **Figure 33**.

The variation in sensitivity (calculated as the virgin shear strength divided by the remoulded shear strength from Vane Shear and Triaxial tests) versus depth for Riverfront Road-Murray Bridge is presented on **Figure 34**. Plots of undrained and remoulded shear strength, measured from Vane

Shear, dilatometer, UU triaxial tests and CPTs are presented on **Figure 35** and **Figure 36** respectively. A plot of plasticity index versus depth is presented on **Figure 37**.

Moisture content results in very soft silty clay layer are close to liquidity limits, and dry density of clay material is less than $1t/m^3$. Results of Shear Strength based on in-situ tests (Vane and Dilatometer) and laboratory tests (UU triaxial) are approximately within the range 10kPa to 20kPa.

A summary of the soil parameters used for the stability assessment is presented in **Table 5**.

- **Table 5 Soil Parameter for Stability Assessments – Riverfront Road-Murray Bridge**

| Type | Description | Soil Model | Unit Weight *($kN/m^3$)* | $\phi$' *(°)* | C' / Su *(kPa)* | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type - A | Fill: Silty/Clayey SAND (SM/SC) | Mohr-Coulomb | 18 ± 1 | 28 ± 2 | 2 ± 2 | - |
| Type - B | Silty CLAY (CH) | Undrained Su=f(depth) | 16 ± 1 | - | 10 ± 5 | 1.25 kPa/m (25±5 kPa max) |
| Type - C | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 17 ± 1 | 30 ± 2 | 2 ± 2 | - |

## 6.5. River Bank Issues

This section provides an outline of the river bank issues present at the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

Water level, rainfall and temperature records have been reviewed for the period over which major incidences were recorded along the Lower River Murray earlier this year. It needs to be appreciated that it is very difficult based on existing information to build up an accurate timeline of the history of cracking and slumping at sites. We cannot be certain of the exact timing of events as reports made are of the date in which an incident is reported, and does not necessarily represent the time in which cracking or failure actually occurred.

Riverfront Road-Murray Bridge is located on the southern bank of a straight section of the River Murray, within the urban area of Murray Bridge (**Figure 1**). Riverfront Road-Murray Bridge is an area of reclaimed land, formerly part of a larger wetland, the remnants of which are still present in the area west of Riverfront Road. This area to west of Riverfront Road is indicative of what the floodplain area would have been like prior to development, a series of lagoons/swamps subject to seasonal flooding. The area is believed to have been reclaimed 50-70 years ago, with 1m of fill being placed on top of the banks at this site. A series of riverside properties sitting on shallow stilts were then built on this reserve.

Reports of cracking at this site were first documented in early March 2009 with photographs dating from the 13 March provided in a Report by Robert Frazer on this site. Further development of cracks was noted on the 20 April when water levels were at -1.24 m AHD and on 28 April there was a report that cracking extends from the back of the Barrangul Boat all the way to Long Island Boat Ramp (921 m), taking in 18 riverside properties along Riverfront road. This coincided with the time when water levels were at their lowest. From the 24$^{th}$ to 28$^{th}$ April there was also 30 mm of precipitation, with daily totals ranging from 2-10 mm (**Figure 64** ). At the time in which SKM's detailed geotechnical investigations were carried out, cracking was limited to one area in line with the back of the riverside properties, 9 m from Riverfront Road. This crack is about 100mm wide and 5m in length. This crack and the position of earlier cracks as documented by Glenn Dean (Rural City of Murray Bridge) over the Summer 2008/09 period were surveyed by SKM surveyors.

There is some uncertainty around the nature of historical channel changes along this section of river and the impact that these may be having on bank stability. The splitting of flow around Long Island results in an increase in overall channel width through this reach. It is possible that there may be ongoing processes of channel widening in response to widening and lengthening of Long Island. If this is the case, this may be contributing to problems of bank stability for this section of the River Murray from Riverfront Road-Murray Bridge through to Long Island Marina. Further analysis of historical aerial photography is recommended to determine if channel widening is an ongoing process and the implications this may have for further bank retreat.

### 6.6. Stability Assessment

Two cross sections have been assessed in this study:

- Section SR1: In the vicinity of the riverside properties and the surface water collection lagoons; and
- Section SR2: In vicinity of the boat ramp

Photos for the locations have been presented in **Photo 1** and **Photo 2**. A plan showing the locations of the cross sections are included in **Appendix A**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results are presented in **Figure 9** to **Figure 12**.

### 6.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank; however, the existing surface lagoons away from the river bank may affect the groundwater levels.

The banks of the river contain normally consolidated alluvium overlying over-consolidated weathered calcareous rock. The depth of this alluvium varies and could be deeper than 20m adjacent to the river. Some permeable sand lenses occur in these normally consolidated clays. This means that the lowering of the river level is transmitted quickly back into the banks but vertical flow of perched water tables in the lagoon will take some time to respond to the lowering. A phreatic surface will form between the river and the lagoons with zero drawdown at the lagoons and 2m at the river. At the top of the river bank there is often housing or other assets which are about 1 to 2m above the groundwater table. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Increased seepage flow pressure towards the river;
- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal moisture zone in Murray River area is approximately 4m deep, so as the groundwater table drops so the shrinkage cracks follow.
- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.
- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This can cause additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.
- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Slope stability analyses in the vicinity of the boat ramp, based on observed existing static conditions, indicate that the Factor of Safety (FoS = 1.13) against slope failure, in this area, is well below the FoS (FoS = 1.50) that would normally be considered acceptable, for permanent areas used by the public. It is considered highly likely that further reductions in water level could trigger a slope (bank) failure in this area (FoS = 1.05).

In addition, in the area where riverside properties are present, our analyses indicate an FoS of approximately 1.27 for the existing condition and FoS of 1.18 if the River Murray “pool” level reduces, as predicted, to -1.5m AHD. Again, we consider that both FoS values are below the minimum acceptable level for permanent occupation.

### 6.8. Recommendations

We recommend that residents of these riverside properties be advised that there is a high risk of bank failure and the access road be closed to public traffic. In addition, we recommend that access to Riverfront Road-Murray Bridge should be fenced off to stop all pedestrian and vehicle traffic. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

Furthermore, it is understood that surface water is collected by the existing upstream lagoons which are higher than the river’s water level. The implication of the water seepage from lagoons to the river on the stability should be considered in the future management plan.

# 7. Caloote

## 7.1. Site Geology

The Caloote site is mapped on the Geological Survey of South Australia (1969) 1:250,000 Adelaide map sheet as Quaternary grey fluvial silts, sands and gravels. The site is also mapped close to the boundary of the Quaternary Hindmarsh clays and the Tertiary Mannum Formation. The Hindmarsh clays typically consist of grey and red-brown mottled sandy clay and the Mannum Formation typically consists of yellow-brown calcareous sandstone.

## 7.2. Subsurface Condition

The soil profile encountered at Caloote confirmed the expected Quaternary fluvial silts, sands and gravels as seen in the Geological Survey of South Australia (1969) 1:250,000 Adelaide map sheet.

The subsurface profile comprised of Silty/Gravelly SAND underlain by Silty CLAY. The layer of Silty CLAY was typically encountered at 1m to 1.5m below ground level, generally very soft and wet. The thickness of the very soft Silty CLAY layer varies from 3m in CA-BH-1 to 15m in CA-BH-3. There are some sandy clay/clayey sand layers/lenses in very soft silty clay layer from 6 to 15m depth.

Beneath this layer, the sand content had generally increased up to the depth of termination, transitioning to a Clayey SAND and Gravelly SAND. At CA-BH1, the borehole had terminated at 4m, due to refusal on SANDSTONE, confirming the Mannum Formation. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix B**.

## 7.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix B**. Piezometers were installed at Caloote for the monitoring of groundwater levels. Groundwater Level measured in the installed piezometer was 1.92m below ground level (measured on 19/11/2009).

A high range of pore water pressure has been measured in CPTu tests in very soft Silty CLAY layer in some of the CPTu tests, which is more than the weight of water column at that depth, like an artesian well.

## 7.4. Soil Parameter Plots

Results of moisture content and Atterberg limit tests with depth for Caloote are presented in **Figure 39**. Results of dry density and bulk density tests for this site are presented in **Figure 40**. A liquidity versus depth plot is presented on **Figure 41**. An activity plot, based on clay fraction and plasticity index, is presented on **Figure 42**.

The variation in sensitivity (calculated as the undisturbed shear strength divided by the remoulded shear strength from Vane Shear and Triaxial tests) versus depth for Caloote is presented in **Figure 43**. Plots of virgin and remoulded shear strength, measured from Vane Shear, Dilatometer, UU Triaxial tests and CPTs at Caloote are presented on **Figure 44** and **Figure 45** respectively. A plot of plasticity index versus depth is presented on **Figure 46**.

Moisture content results in very soft silty clay layer are close to liquidity limits, and dry density of clay material is less than 1t/m$^3$. There are some intervals of sandy layers and lenses in very soft silty clay layer which have less parameter in liquid limit tests. There is no clear trend for depth and thickness of sandy layer/lenses but generally they are in depth from 6 to 15m. Results of Shear Strength based on in-situ tests (Vane and Dilatometer) and laboratory tests (TRX UU) are approximately in same range.

A summary of the soil parameters used for the stability assessment is presented in **Table 6**.

- **Table 6 Soil Parameter for Stability Assessments - Caloote**

| Type | Description | Soil Model | Unit Weight *(kN/m$^3$)* | ϕ' *(°)* | C' / Su *(kPa)* | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type - A | Fill: Silty/Clayey SAND (SM/SC) | Mohr-Coulomb | 18 ± 1 | 28 ± 2 | 2 ± 2 | - |
| Type - B | Silty CLAY (CH) | Undrained Su=f(depth) | 16 ± 1 | - | 10 ± 5 | 1.07 kPa/m (17±5 kPa max) |
| Type - C | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 19 ± 1 | 30 ± 2 | 2 ± 2 | - |

## 7.5. River Bank Issues

This section provides an outline of the river bank issues present at the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

Caloote is located on the southern bank of a tight meander bend of the River Murray. A boat ramp and car parking area is located at this site, known as Caloote Landing (**Photo 3**). Similar to Riverfront Road-Murray Bridge, the area around Caloote Landing was formerly a swamp, which was then reclaimed in the 1930's/1940's. Rock for the surrounding cliffs may have been used to provide fill and reclaim the swampy area.

The first reports of cracking and movement in the area are as early as February 2008. Domenic Priolo, who owns one of the residences downstream of the landing area, first noted movement around his doorways and cracking in his building. This early report conflicts with reports from other landowners in the area who state that no incidences of cracking were evident more than 12 months ago and that crack development was not sudden but rather has developed over the duration of the past 12 months.

Tension cracks run through properties downstream of the landing area and there is evidence of slumping at the front of the houses (**Photo 4** to **Photo 10**). Furthermore, long tension cracks are evident in the northern area of the site which resulted in change in the alignment of an overhead.

## 7.6. Stability Assessment

A critical cross section has been assessed in this study:

- Section CA2: In the vicinity of the riverside properties in the southern area and the car park area.

Plan and location of the cross section have been presented in **Appendix B**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results are presented in **Figure 13** and **Figure 14**.

## 7.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank.

The banks of the river contain fill material overlying normally consolidated clay followed by rock with different degrees of weathering. The depth of this alluvium varies from zero to up to around 20m adjacent to the river. Some permeable sand lenses occur in these normally consolidated clays. This means that the lowering of the river level may be transmitted quickly back into the banks but will take some time to respond to the lowering; however, the permeability and continuity of the sand lenses have not been confirmed. At the top of the river bank there is often housing or other assets which are about 1 to 2m above the groundwater table. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal

moisture zone in Murray River area is approximately 4m deep so as the groundwater table drops so the shrinkage cracks follow.

- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.
- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This causes additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.
- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Results of geotechnical investigations at the Caloote site indicate that the factor of safety for the existing condition against slope (bank) failure (FoS = 1.14), in the parking/landing area around the boat ramp and the residential area immediately to the south, are below the FoS that would normally be considered acceptable, for permanent areas used by the public (FoS = 1.5).

Furthermore, stability analysis results indicate that the reduction in the river’s level could trigger the failure (FoS = 1.06).

The houses downstream of the landing area lie beneath a cliff overhang. Tension cracks developed in the cliffs and nature of the overhangs, mean that toppling/cantilever failure will result in blocks landing on the houses (**Photo 11**).

The existing condition of the rock over hang in the south eastern area indicates that cracks have been progressed in the section (**Photo 11** and **Photo 12**). Furthermore, from the general condition of the cliffs in the area (**Photo 13**) it is evident that there is a high risk of rock fall in southern site which could be catastrophic for the coastal home. A recent rock fall has been reported in November 2009 which is presented in **Photo 14**.

Due to the presence of possible large size rocks, determination of the geometry and continuity of the bed rock was not possible; however, it is expected that depth of the rock, thickness of the soft clay and alteration of the sandy lenses are highly variable in the area which may result in differential settlements and cracks.

### 7.8. Recommendations

We recommend that the residents in the south eastern area should be advised that there is a high risk of bank failure and rock fall.

No immediate damage to the structure of the riverside properties in the north western area is expected; however, the road and car park areas are high risk.

We recommend that access to the boat ramp, parking area adjacent to river and residential area in the south eastern areas and the access road after the residential area in the north western side should be fenced off to stop public and vehicle traffic. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

# 8. Woodlane Reserve

## 8.1. Site Geology

The Woodlane Reserve site is mapped on the Geological Survey of South Australia (1969) 1:250,000 Adelaide map sheet as Quaternary grey fluvial silts, sands and gravels.

## 8.2. Subsurface Condition

The soil profile encountered at Woodlane Reserve also confirmed the expected Quaternary aged grey fluvial silts, sands and gravels, as seen in the Geological Survey of South Australia (1969) 1:250,000 Adelaide map sheet. The subsurface profile comprised clayey SAND and SAND overlying silty CLAY, with a transition also occurring around 1.0m in depth. The dark grey very soft silty CLAY extended to about 3.0m to 4.0m depth in both Boreholes WR-BH1 and WR-BH2. From this depth, the sand content with trace of gravel increases with depth up to about 7.5m below the ground level, transitioning from a very soft sandy CLAY to a medium dense SAND or gravelly SAND. From 7.5m below ground level, the silt content increased with depth, transitioning from a soft sandy SILT or clayey SILT to firm SILT. Thereafter, alternating SILTS and SANDS were observed up to the depth of termination of the boreholes. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix C**.

## 8.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix C**.

## 8.4. Soil Parameter Plots

Results of moisture content and Atterberg limit tests with depth for Woodlane Reserve are presented in **Figure 48**. Results of dry density and bulk density tests for this site are presented in **Figure 49**. A liquidity versus depth plot is presented on **Figure 50**. A plot of plasticity index versus depth is presented on **Figure 51**.

A summary of the soil parameters used for the stability assessment is presented in **Table 7**.

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- **Table 7 Soil Parameter for Stability Assessments – Woodlane Resrve**

| Type | Description | Soil Model | Unit Weight *(kN/m$^3$)* | ϕ' *(°)* | C' / Su *(kPa)* | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type - A | Fill: Silty/Clayey SAND (SM/SC) | Mohr-Coulomb | 17 ± 1 | 30 ± 2 | - | - |
| Type - B | Silty CLAY (CH) | Undrained Su=f(depth) | 17 ± 1 | - | 20 ± 5 | - |
| Type–C1 | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 20 ± 1 | 29 ± 2 | - | - |
| Type-C2 | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 20 ± 1 | 30 ± 2 | - | - |
| Type–C3 | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 20 ± 1 | 31 ± 2 | - | - |

## 8.5. River Bank Issues

This section provides an outline of the river bank issues present the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

Water level, rainfall and temperature records have been reviewed for the period over which major incidences were recorded along the Lower River Murray earlier this year. It needs to be appreciated that it is very difficult based on existing information to build up an accurate timeline of the history of cracking and slumping at sites. We cannot be certain of the exact timing of events as reports made are of the date in which an incident is reported, and does not necessarily represent the time in which cracking or failure actually occurred.

Woodlane Reserve is located on the southern bank of a straight section of the River Murray. A large section of river bank slumped at this location in late February 2009, damaging a pump station. The slump occurred at a location where a road runs close to river bank but also borders a lagoon/swamp area. Further collapses were documented on the 7 March, enlarging the slumped area of the first collapse and leading to the loss of the pump station. This slumping continued with a loss of Stobbie Pole documented on the 10 March. The construction of road at this site has added c.1-1.5m of fill on top of the banks. Variation in water level over the March period and temperature and rainfall in the region are shown in **Figure 63** .

## 8.6. Stability Assessment

Two critical cross sections have been assessed in this study:

- Section WR1: In the vicinity of the failed pump station and the car park area; and
- Section WR2: In the vicinity of the last residential home.

Plan and location of the cross section have been presented in **Appendix C**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results were presented in **Figure 15** and **Figure 16**.

### 8.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank; however, the existing surface lagoons away from the river bank may affect the groundwater levels.

The banks of the river contain fill material overlying normally consolidated alluvium followed by over-consolidated clays and sand. The depth of this alluvium varies and could be deeper than 20m adjacent to the river. Some permeable sand lenses occur in these normally consolidated clays. This means that the lowering of the river level is transmitted back into the banks but will take some time to respond to the lowering. At the top of the river bank there is often housing or other assets which are about 1 to 2m above the groundwater table. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal moisture zone in Murray River area is approximately 4m deep so as the groundwater table drops so the shrinkage cracks follow.
- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.
- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This can cause additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of

tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.

- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Slope stability analyses in the vicinity of the failed pump station, based on observed existing static conditions, indicate that the Factor of Safety (FoS = 1.38) against slope failure, in this area, is below the FoS (FoS = 1.50) that would normally be considered acceptable, for permanent areas used by the public. It is considered highly likely that further reductions in water level may trigger a slope (bank) failure in this area (FoS = 1.20).

## 8.8. Recommendations

We recommend that public and residents of these riverside properties be advised that after further reduction in the water level (below RL-0.80m), there is a high risk of bank failure and the access road and car park area be closed to public traffic and car parking (residents may still use the access road when water level is above RL-0.80m, but it is advised that the cars to be parked away from the river). River traffic should be warned of the very high probability of failure and advised not to moor in the area.

# 9. South Punyelroo

## 9.1. Site Geology

South Punyelroo is mapped on the Geological Survey of South Australia (1971) Renmark map-sheet as Quaternary Coonambidgal Formation, comprising fluvial clays, silts and sands; light grey alluvium of the Murray River system.

## 9.2. Subsurface Condition

The soil profile encountered at South Punyelroo confirmed the expected Quaternary Coonambidgal Formation, as seen on the Geological Survey of South Australia (1971) Renmark map-sheet. The subsurface profile consisted of an upper layer of SAND and Silty SAND, with a thickness about 0.4 to 1.2m, usually underlain by firm to very soft silty CLAY. A layer of light green to grey SAND typically underlay this layer around 3.8m to 4.5m below ground level. The three boreholes conducted at this site were terminated just before 5m below ground level in medium dense SAND. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix D**.

## 9.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix D**.

## 9.4. Soil Parameter Plots

Results of moisture content and Atterberg limit tests with depth for South Punyelroo are presented in **Figure 53**. Results of dry density and bulk density tests for this site are presented in **Figure 54**. Results of dry density and liquidity in clay layer indicate that there is a major different between parameters of this layer above and under water table. Consistency of this layer varies from firm to very stiff with increases in depth from above water table to under water table. A liquidity versus depth plot is presented on **Figure 55**. A plot of plasticity index versus depth is presented on **Figure 56**.

A summary of the soil parameters used for the stability assessment is presented in **Table 8**.

- **Table 8 Soil Parameter for Stability Assessments – South Punyelroo**

| Type | Description | Soil Model | Unit Weight ($kN/m^3$) | ϕ' (°) | C' / Su (kPa) | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type - A | Fill: Silty/Clayey SAND (SM/SC) | Mohr-Coulomb | 20 ± 1 | 30 ± 1 | - | - |
| Type–B1 | Silty CLAY (CL) | Undrained Su=f(depth) | 20 ± 1 | - | 100 ± 20 | - |
| Type–B2 | Silty CLAY (CL) | Undrained Su=f(depth) | 17 ± 1 | - | 25 ± 5 | - |
| Type - C | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 20 ± 1 | 30 ± 1 | - | - |

## 9.5. River Bank Issues

This section provides an outline of the river bank issues present the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

South Punyelroo is located on the west bank on an inside meander bend of the River Murray. At this site tension cracks were noted in the shoreline and also along road which is positioned at back of houses, 80m from the shoreline. There has also been lateral movement of earth around house foundations with movement in the direction of the river (c.2cm). Houses were developed in this area in the 1960's/1970's. The cracking in the road first appeared over the 2008-2009 Summer Period, the exact timing is unknown.

## 9.6. Stability Assessment

A critical cross section has been assessed in this study:

- Section SP1: In the vicinity of the failed pump station and the car park area.

Plan and location of the cross section have been presented in **Appendix D**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results were presented in **Figure 18** to **Figure 21**.

## 9.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank; however, the existing surface lagoons away from the river bank may affect the groundwater levels.

The banks of the river contain over-consolidated clays followed by sand. The depth of this alluvium varies adjacent to the river. Some permeable sand lenses were observed within the clayey layers. This means that the lowering of the river level is transmitted back into the banks but will take some time to respond to the lowering. At the top of the river bank there is often housing or other assets which are about 1 to 2m above the groundwater table. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal moisture zone in Murray River area is approximately 4m deep, so as the groundwater table drops so the shrinkage cracks follow.
- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.
- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This cause additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.
- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Slope stability analyses in the vicinity of the river side properties, based on observed existing static conditions, indicate that the Factor of Safety (FoS = 3.95) against slope failure, in this area, is well above the FoS (FoS = 1.50) that would normally be considered acceptable, for permanent areas used by the public. As the boreholes in this area are 4m to 5m deep, a worst case scenario of presence of deep very soft clay (similar to other sites) has been assessed which resulted in

FoS=1.67. It is considered likely that further reductions in water level will not affect the stability of the properties.

Furthermore, the shape and distribution of the cracks (**Photo 16**) indicates that the cracks are likely to be as a result of shrinkage of the top layers due to the reduction in the moisture content.

### 9.8. Recommendations

We recommend that the residents of these riverside properties be advised to monitor the cracks for accelerating ground movements.

# 10. East Front Road

## 10.1. Site Geology

The East Front Road site is mapped on the Adelaide map-sheet as an Upper Cambrian to Lower Ordovician Pegmatite dyke, which is likely to be a medium to coarse grained granitic intrusion. Adjacent to this Pegmatite dyke consists the Mannum Formation as well as Quaternary grey fluvial silts, sands and gravels from the Murray River system.

## 10.2. Subsurface Condition

The soil profile encountered at East Front Road confirmed the expected geology, as seen in the Geological Survey of South Australia (1969) 1:250,000 Adelaide map sheet. The subsurface profile typically consisted of a medium dense clayey or sandy GRAVEL (a base/sub-base material for road construction, with thickness about 0.7 to 1.6m) underlain by a medium dense silty/gravelly sand. Below this layer of gravelly SAND and silty SAND, dark brown silty CLAY was usually encountered. Borehole EF-BH1, which was located adjacent to an outcrop of rock material, refused at a relatively shallow depth of 2.0m below ground level. At Borehole EF-BH2, layers of medium dense to very dense clayey GRAVEL, clayey SAND and gravelly SAND, of varying thickness were encountered. At borehole EF-BH-3 a very soft silty CLAY layer, of about 3.5 to 6.5m depth, was encountered, underlain by a dense clayey SAND layer. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix E**.

## 10.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix E**.

## 10.4. Soil Parameter Plots

Results of moisture content and Atterberg limit tests with depth for East Front Road are presented in **Figure 57**. Results of dry density and bulk density tests for this site are presented in **Figure 58**. A liquidity versus depth plot is presented on **Figure 59**. A plot of plasticity index versus depth is presented on **Figure 60**.

A summary of the soil parameters used for the stability assessment is presented in **Table 9**.

## Table 9 Soil Parameter for Stability Assessments – East Front Road

| Type | Description | Soil Model | Unit Weight *(kN/m$^3$)* | $\phi$' *(°)* | C' / Su *(kPa)* | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type-A1 | Fill: Silty/Clayey SAND (SM/SC) and GRAVEL (GM/GC) | Mohr-Coulomb | 20 ± 1 | 32 ± 2 | - | - |
| Type–A2 | Fill: Silty/Clayey SAND (SM/SC) and GRAVEL (GM/GC) | Mohr-Coulomb | 21 ± 1 | 35 ± 3 | - | - |
| Type-B | Silty CLAY (CH) | Undrained | 17 ± 1 | - | 50 ± 10 | - |
| Type–B1 | Silty CLAY (CH) | Undrained | 17 ± 1 | - | 17.5 ± 2.5 | - |
| Type–B2 | Silty CLAY (CH) | Undrained | 17 ± 1 | - | 14 ± 2 | - |
| Type–C | Clayey SAND (SC) | Undrained | 20 ± 1 | 31 ± 1 | - | - |
| ROCK | ROCK | Bedrock (Inpenetrable) | - | - | - | - |

Type B1 and B2 materials are not present in Section EF1, where Type A1 and A2 FILL overlies a thin layer of Type B Silty CLAY on bedrock.

### 10.5. River Bank Issues

This section provides an outline of the river bank issues present at the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

Water level, rainfall and temperature records have been reviewed for the period over which major incidences were recorded along the Lower River Murray earlier this year. It needs to be appreciated that it is very difficult based on existing information to build up an accurate timeline of the history of cracking and slumping at sites. We cannot be certain of the exact timing of events as reports made are of the date in which an incident is reported, and does not necessarily represent the time in which cracking or failure actually occurred.

The original East Front Road is believed to have been constructed in 1970's. The road was rebuilt in the 1980's and lies on top of fill. The fill consists of cliff rock from the nearby quarry. Large stones were put at the base, with gaps filled with fines. A 150mm limestone layer was put on top and compacted, before sealing the road. On the 24 July 2009 the first report was made on the appearance of tension cracks forming an arc across the road at one location. **Figure 64** shows the history of water level, temperature and rainfall records available for this time.

### 10.6. Stability Assessment

Two critical cross sections has been assessed in this study:

- Section EF1: In the vicinity of the cracks in the road, where the road passes below the approximately 3(H):1(V) rock slope; and
- Section EF2: Approximately 200m north-east of Section EF1 along East Front Road.

Plan and location of the cross sections have been presented **Appendix E**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results were presented in **Figure 22** to **Figure 25**.

### 10.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank; however, the existing surface lagoons away from the river bank may affect the groundwater levels.

The banks of the river contain fill embankment constructed on the rock or natural clays followed by rock. The depth of this alluvium varies adjacent to the river. Some permeable sand lenses occur within the clays. This means that the lowering of the river level is transmitted back into the banks but will take some time to respond to the lowering. At the top of the river bank there is often housing or other assets which are about 1 to 2m above the groundwater table. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal moisture zone in Murray River area is approximately 4m deep so as the groundwater table drops the shrinkage cracks follow.
- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.

- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This cause additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.
- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Slope stability analyses in the vicinity Section EF1, based on observed existing static conditions, indicate that the Factor of Safety (FoS = 1.30) against slope failure, in this area, is below the FoS (FoS = 1.50) that would normally be considered acceptable, for permanent areas used by the public. Furthermore, stability analysis results indicate that the reduction in the river's level will decrease the factor of safety to 1.23. Noting the effects of the existing trees bending toward the river and the existing crack in this area, this section is considered to be high risk.

Slope stability analyses in the vicinity Section EF2, indicate that the Factor of Safety (FoS = 1.02) against slope failure, is well below the FoS (FoS = 1.50) and is high risk for permanent areas used by the public. Furthermore, stability analysis results indicate that the reduction in the river's level could trigger the failure (FoS = 0.95).

Furthermore, the shape and distribution of the cracks (**Photo 17** and **Photo 18**) indicate that possible failure zones already developed and the remedial works undertaken on the asphalt wearing cannot solve the problem or reduce the probability of the failure.

### 10.8. Recommendations

We recommend that the responsible authority should decide on road closure and urgent remedial studies and works (such as detailed stability assessment) for the road alignment and the development of a new alignment away from the area of possible failure.

We recommend that the road in vicinity of the river should be signed as Very High Risk for road embankment failure in to the river. Furthermore, a reduced speed limit should be applied to the public to avoid car fall into the possible embankment failures. The road should be monitored weekly; however, after water level reduction to below RL-0.80mAHD or heavy rain falls, the road should be monitored more frequently for failure/deformation (at least twice a week). River traffic should be warned of the very high probability of failure and advised not to moor in the area.

A soft layer was noticed in the soil profile adjacent to the rock layer which could be developed by water seepage through the fill embankment. Installation of a proper drainage system for interception of the water seepage through the embankment is recommended.

# 11. Swan Reach

## 11.1. Site Geology

Swan Reach is mapped on the Renmark (1971) map-sheet as Quaternary Coonambidgal Formation, comprising fluvial clays, silts and sands; light grey alluvium of the Murray River system. This unit overlies coarse grained riverine sand of the Monoman Formation.

## 11.2. Subsurface Condition

The soil profile encountered at Swan Reach confirmed the expected Quaternary Coonambidgal Formation, as seen on the Geological Survey of South Australia (1971) Renmark map sheet. The subsurface profile consisted of a 0.1m thickness topsoil layer of coarse GRAVEL, underlain by sandy GRAVEL/gravelly SAND fill material to around 1.7m below ground level. The fill material overlaid a dry to moist firm black silty CLAY layer. From 5m below ground level, the moisture content increased, the colour changed to a dark grey and the consistency became very soft to 7.5m depth, where the sand content increased gradually, eventually becoming medium dense SAND. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix F**.

## 11.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix F**.

## 11.4. Soil Parameters

A summary of the soil parameters used for the stability assessment is presented in **Table 10**.

- **Table 10 Soil Parameter for Stability Assessments – Swan Reach**

| Type | Description | Soil Model | Unit Weight *(kN/m$^3$)* | ϕ' *(°)* | C' / Su *(kPa)* | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type - A | Fill: Silty/Clayey SAND (SM/SC) | Mohr-Coulomb | 20 ± 1 | 30 ± 2 | - | - |
| Type-B1 | Silty CLAY (CH) | Undrained | 20 ± 1 | - | 250 | - |
| Type-B2 | Silty CLAY (CH) | Undrained | 20 ± 1 | - | 50 ± 10 | - |
| Type-B3 | Silty CLAY (CH) | Undrained | 18 ± 1 | - | 18 ± 2 | - |
| Type-B4 | Silty CLAY (CH) | Undrained | 18 ± 1 | - | 12.5 ± 2.5 | - |
| Type - C | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 20 ± 1 | 31 ± 1 | - | - |

### 11.5. River Bank Issues

This section provides an outline of the river bank issues present the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

Water level, rainfall and temperature records have been reviewed for the period over which major incidences were recorded along the Lower River Murray earlier this year. It needs to be appreciated that it is very difficult based on existing information to build up an accurate timeline of the history of cracking and slumping at sites. We cannot be certain of the exact timing of events as reports made are of the date in which an incident is reported, and does not necessarily represent the time in which cracking or failure actually occurred.

Reports of cracking at this site are first recorded in the database on the 2 April 2009 (large crack in bank) and then again on the 16 July 2009. The report on the 16 July 2009 noted river bank slumping near the Swan Reach pump station. Longitudinal cracks about 50-70 mm wide were observed parallel to the river approximately 5 metres from the river edge.

### 11.6. Stability Assessment

One critical cross section has been assessed in this study:

- Section SW1: In the vicinity of the existing facilities.

Plan and location of the cross sections have been presented **Appendix F**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results were presented in **Figure 26** and **Figure 27**.

### 11.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank; however, the existing surface lagoons away from the river bank may affect the groundwater levels.

The banks of the river contain over-consolidated to normally consolidated clays followed by sand. The depth of this alluvium varies adjacent to the river. Some permeable sand lenses occur the clays. This means that the lowering of the river level is transmitted back into the banks but will take some time to respond to the lowering. At the top of the river bank there is a waste disposal station facility. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal moisture zone in Murray River area is approximately 4m deep so as the groundwater table drops so the shrinkage cracks follow.
- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.
- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This cause additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.
- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Slope stability analyses in the vicinity of the failed pump station, based on observed existing static conditions, indicate that the Factor of Safety (FoS = 1.68) against slope failure, in this area, is above the FoS (FoS = 1.50) that would normally be considered acceptable, for permanent areas used by the public. It is considered that the predicted further reductions in water level would not reduce the FoS against failure at this location (FoS = 1.70). Factors of Safety for the earthquake loading are about 1.20.

### 11.8. Recommendations

We recommend that the operators of this facility be advised to monitor the cracks for accelerating ground movements.

# 12. Walker Flat

## 12.1. Site Geology

The Walker Flat site is mapped on the Renmark (1971) map-sheet as Tertiary Mannum Formation, comprising sandy limestones and calcarenite.

## 12.2. Subsurface Condition

The subsurface profile consisted of a topsoil layer of silty/clayey GRAVEL, underlain by dry-moist firm silty CLAY layer. From 3.5m below ground level, the moisture content increased and the consistency reduced to very soft. From 9.8m depth, the sand content gradually increased, eventually becoming sandy CLAY/clayey SAND at 10.5m depth. Further details of the subsurface profiles encountered during the investigation are presented on the borehole logs in **Appendix G**.

## 12.3. Groundwater

Due to the drilling methods, it was difficult to determine the inflow of groundwater. Moisture conditions of the soils were recorded in the borehole logs presented in **Appendix G**.

## 12.4. Soil Parameters

A summary of the soil parameters used for the stability assessment is presented in **Table 11**.

- **Table 11 Soil Parameter for Stability Assessments – Walker Flat**

| Type | Description | Soil Model | Unit Weight *(kN/m$^3$)* | ϕ' *(°)* | C' / Su *(kPa)* | Increase Rate for Su |
|---|---|---|---|---|---|---|
| Type - A | Fill: Silty/Clayey SAND (SM/SC) | Mohr-Coulomb | 19 ± 1 | 30 ± 2 | - | - |
| Type–B1 | Silty CLAY (CH) | Undrained | 19 ± 1 | - | 70 ± 10 | - |
| Type-B2 | Silty CLAY (CH) | Undrained | 19 ± 1 | - | 50 ± 10 | - |
| Type-B3 | Silty CLAY (CH) | Undrained | 17 ± 1 | - | 15 ± 10 | - |
| Type-B4 | Silty CLAY (CH) | Undrained | 17 ± 1 | - | 15 ± 5 | - |
| Type - C | Clayey SAND/Sandy CLAY (SC/CL) | Mohr-Coulomb | 19 ± 1 | 31 ± 1 | - | - |

## 12.5. River Bank Issues

This section provides an outline of the river bank issues present the site with respect to its history of development and cracking. This has been determined from information provided by DWLBC and discussions with landowners and council employees on site and over the telephone. For a more general discussion of erosion problems along the River Murray refer to earlier Inspection Report prepared by SKM (2009).

This area was only recently noted as an area of concern. On the 10 October 2009, DWLBC reported a hole on the bank that was a concern as it was located in close proximity to landing.

### 12.6. Stability Assessments

A critical cross section has been assessed in this study:

- Section WF1: In the vicinity of the facilities.

Plan and location of the cross section have been presented **Appendix G**.

Both existing condition and further reduction of the river's level to -1.5m AHD have been assessed. The analysis results were presented in **Figure 28** and **Figure 29**.

### 12.7. Discussion

The Murray River levels have dropped approximately 2m since 2005 along the 200km stretch of the river north of Murray Bridge. This has led to groundwater levels lowering adjacent to the river bank; however, the existing surface lagoons away from the river bank may affect the groundwater levels.

The banks of the river contain over-consolidated overlying normally consolidated alluvium clays followed by sand. The depth of this alluvium varies and could be deeper than 10m adjacent to the river. Some permeable sand lenses occur in these normally consolidated clays. This means that the lowering of the river level is transmitted back into the banks but will take some time to respond to the lowering. At the top of the river bank there is a waste disposal facility. The lowering of the groundwater table adjacent to the river has the following adverse affects on the stability of the banks:

- Tilting of the soil blocks towards the river due to differential subsidence;
- Tension at the crest of the slope due to tilting;
- Shrinkage cracks increasing to the depth of the water table due to drying of the reactive clays being exposed to surface temperatures and evaporation to a greater depth. The seasonal moisture zone in Murray River area is approximately 4m deep so as the groundwater table drops the shrinkage cracks follow.
- Shrinkage cracks become tension cracks that fill with surface water and drive failure from the crest when it rains. Tilting increases the width of shrinkage cracks in the direction of the tilting.

- Shrinkage cracks can form in cubic blocks or hexagonal blocks and the cracks will become wider as the level of desiccation increases with climate change. This cause additional settlement of the ground due to the 3D shrinkage of the desiccated blocks.
- Subsidence due to the lowering of the groundwater level would have led to surface settlement over the last 4 years and the next 3 years with some time delay effects due to the rate of dissipation of the pore water pressures after drawdown. Differential subsidence due to changing thicknesses of the normally consolidated clay in the banks and/or the changes in the drawdown levels between points in the bank can lead to tilting and the development of tensile strains in the river bank. These strains are not necessarily evenly spread at the surface and can concentrate in existing shrinkage cracks or at points near the crest of the bank where tensile strains may already be approaching the maximum tensile capacity of the soil.
- Tree roots exaggerate the shrinkage effects in reactive soils and if the root system cannot follow the falling groundwater level then the tree will become brittle and fall. A row of trees may cause instability at the edge of the river if there is a vertical bank along which a row of trees is subject to high winds leading to an over-turning moment. This may also apply to trees already leaning over the bank. A toppling failure would occur immediately behind the row of trees with the minimum volume of soil in the slide mass to resist the failure.

Slope stability analyses in the vicinity of the failed pump station, based on observed existing static conditions, indicate that the Factor of Safety (FoS = 1.02) against slope failure, in this area, is well below the FoS (FoS = 1.50) that would normally be considered acceptable, for permanent areas used by the public. It is considered highly likely that further reductions in water level may trigger a slope (bank) failure in this area (FoS = 0.94).

## 12.8. Recommendations

We recommend that public and operators be advised on the high risk of bank failure in the area and the area to be closed to traffic and car parking. Proper measures for closure and removal of important facilities in the area should be considered. It should be noted that the extent of the problem may be beyond the study area. River traffic should be warned of the very high probability of failure and advised not to moor in the area.

# 13. Remedial Works

Consolidation settlements and initiation and extension of the shrinkage cracks are mostly due to lowering of the Murray River which resulted in increase in surcharge and changes in the moisture content of the soils which may result in excessive settlement or instability.

The potential remedial works should be able to increase the stability of the slope against failure, reduce the settlements or other deformations due to desiccation and cracks.

Remedial works within the sensitive areas to reduce settlement, control moisture content or increase the stability of the bank; may be resource demanding, expensive and time consuming which could make the remedial measures economically impractical.

A few potential options to improve the stability conditions of the slopes along the Lower River Murray are presented in this section.

## 13.1. Modification of the Geometry

In this method, the driving forces within the sliding mass will be reduced by modifications to the geometry of the slope's cross section.

### 13.1.1. Removal of Material from Top of the Slope

*Advantages:*

- Reduction in driving forces from the accessible parts of the slope;
- Permanent solution;
- Soil removal does not need special techniques; and
- Relatively fast procedure.

*Disadvantages:*

- Deep seated failures require large quantities of soil to be removed;
- Excavated materials should be stored in stockpiles;
- In some of the areas where ground levels are 2m above the existing river level, removal of 2m soil will result in possible intrusion of water landward if water levels rise in the future; and
- In most of the areas, existing buildings, access roads and other infrastructures are within the failure mass so removal of the soil is not practical.

### 13.1.2. Removal of Weak Materials

Due to the presence of very soft clay in depth, removal is not possible.

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### 13.1.3. Modification of the Slope

*Advantages:*

- Reduction in driving forces from the accessible parts of the slope;
- Part of excavated materials could be used in the fill areas at the same location;
- Permanent solution; and
- Relatively fast procedure.

*Disadvantages:*

- Deep seated failures require large quantities of soil to be removed / placed;
- Excavation of material in the water may expose the soft materials to erosion;
- In most of the areas, existing buildings, access roads and other infrastructures are within the failure mass so removal of the soil is not practical and the slopes should be flattened toward the river which requires working over water or dredging;
- Quality control of underwater placement is not possible;
- Changing the cross section of the river can change the erosion behaviour of the area; and
- Imported fill may be required.

## 13.2. Buttressing

In this method, the driving forces within the sliding mass will be moved by adding weight of material or shear keys to the cross section to increase the resisting forces by increasing the mass in the resisting zone, increasing shear strength of the toe or forcing the critical failure surface to go deeper.

### 13.2.1. Soil / Rock Fill / Gabions or Geotextile

*Advantages:*

- Local materials could be used for construction;
- Permanent solution; and
- Relatively fast procedure.

*Disadvantages:*

- Deep seated failures require large quantities of soil to be placed;
- Gabions are expensive;
- Remedial works should be toward the river so working over water is required;
- Changing the cross section of the river can change the erosion behaviour of the area;
- Imported fill may be required; and
- Quality control of underwater placement is not possible.

#### 13.2.2. Shear Key

*Advantages:*

- Local materials could be used for construction;
- Permanent solution; and
- Relatively fast procedure.

*Disadvantages:*

- Deep seated failures require long shear keys to be placed;
- The strength of the very soft clayey layer does not increase significantly with depth;
- Underwater excavation and construction is required which could be economically and technically impractical; and
- Excavation of deep shear keys could result in instability of the slopes.

### 13.3. Drainage

A proper drainage system can reduce the possibility of seepage forces toward the river, erosion, piping and softening of the material.

#### 13.3.1. Surface Drainage

*Advantages:*

- Reduction in face erosion;
- Reduction in softening of the materials; and
- Reduction in erosion and water infill in the cracks.

*Disadvantages:*

- Compared to the effect of river's level fluctuation, the effect of surface water drainage on stability is not significant.

#### 13.3.2. Subsurface Drainage

*Advantages:*

- Reduction in softening of the materials; and
- Reduction in erosion and water infill in the cracks.

*Disadvantages:*

- Compared to the effect of river's level fluctuation, the effect of surface water drainage on stability is not significant.

## 13.4. Reinforcement

Reinforcement methods such as soil nails, piles and retaining walls could be used to reinforce the possible failure face or force them to move to the deeper layers.

### 13.4.1. Soil Nailing

*Advantages:*

- Improving stability in suitable soil and groundwater conditions.

*Disadvantages:*

- Needs soil displacement for developing tension in the nails;
- May need to be installed over/under water;
- Requires stronger soil layers;
- Squeezing of soft clays between the nails;
- Long nails are required for deep seated failures;
- Quality control for construction under water;
- Unknown long term performance and durability in the river; and
- Erosion of the soil around the nail's head.

### 13.4.2. Stone Columns / Soil Mixing

*Advantages:*

- Improving stability in suitable soil and groundwater conditions.

*Disadvantages:*

- May result in drainage and accelerate the consolidation process which increases the settlement;
- May need to be installed over/under water;
- Stability of the holes, may need casing;
- Squeezing of soft clays between the columns;
- Long columns are required for deep seated failures;
- Quality control for construction under water;
- Erosion of the soil around the columns' head.

#### 13.4.3. Retaining Wall / Sheetpile / Driven Piles

*Advantages:*

- Improving stability in suitable soil and groundwater conditions;
- Quality control; and
- Could be constructed from the land.

*Disadvantages:*

- Expensive;
- Squeezing of soft clays between the piles;
- Long piles / sheetpiles / retaining walls are required for deep seated failures; and
- Erosion of the soil around the wall.

### 13.5. Strength Improvement

The consistency of the very soft clay could be improved by different methods.

#### 13.5.1. Electro Osmosis

*Advantages:*

- Improving stability in suitable soil and groundwater conditions.

*Disadvantages:*

- High energy requirement;
- Not effective in vicinity of the river;
- Performance in sandy layers and river's water cannot be guaranteed; and
- May accelerate settlement.

#### 13.5.2. Grouting

*Advantages:*

- Improving stability in suitable soil and groundwater conditions.

*Disadvantages:*

- Working over water;
- Constructability and performance cannot be guaranteed in soft clays;
- Poor quality control and uniformity; and
- Deep grouting is required for deep seated failures.

# 14. Conclusion

The following activities were carried out in this study:

- A detailed desktop study, site investigation, laboratory tests and stability assessment was carried out for seven sites, nominated by DWLBC;
- Land survey and bathymetrical transactions for the critical sections of each site were prepared. The shape and location of the existing cracks were surveyed; however, traffic, heavy rain falls and sediment in-fills already obscured some of the cracks;
- Factual geotechnical information for each site were collected comprising:
  - Observed soil profile including materials and layering information;
  - In-situ test results for strength, consistency and pore-pressures; and
  - Laboratory tests results on the index properties, strength and deformation of the soil samples;
- Interpretation of the factual information were carried out to estimate the properties of the soil profiles to be used for stability and deformation assessments;
- Stability assessment of the selected cross sections were carried out to evaluate the Factors of Safety against instability for each site;
- Preliminary assessments of the predicted settlements due to lowering the river's water level for selected cross sections from 2005 to 2013 were undertaken;
- Stability issues after further reduction in river's level, over the next three years, were assessed and discussed;
- Management recommendations for each site, including location of the fencing and access control have been provided; and
- Preliminary recommendations for possible remedial works, together with advantages and disadvantages were presented.

# 15. Recommendations

On the basis of our assessments, we make the following recommendations:

- The authorities, residents and public need to be made aware of areas considered to be “high risk”.
- Fencing and using “High Risk” signs should be put in place in “high risk” areas.
- Constant monitoring of “high risk” areas should be performed, especially shrinkage cracks and slumping during the dry season, deformation and movements during and after heavy rains and throughout the tourism season.
- Workshop training for DWLBC’s monitoring staff (or other stack holders) for monitoring requirements;
- Preparation of a Risk Map for bank failures for the Lower River Murray. This risk map will incorporate the existing geological information, historical aerial photography, major infrastructures, population at risk and other important items along the river’s alignment to create a base map for the risk study. Using this map together with the assessment of the failure consequences will enable the preparation of a River bank Slumping Hazard Risk Map;
- This map can then used to identify the distribution of high risk/high consequence areas and form the basis for prioritising management actions and monitoring. To achieve this, requires a shift in focus, moving away from specific sites where failure have occurred, to assessments of lengths of river and the distribution of conditions influencing risk of collapse. The diagram over the page outlines the process in which this risk map is developed;
- Preparation of a base map indicating areas near the river that should not be developed, i.e. residential, commercial and other infrastructure.
- Detailed geotechnical assessment of the existing buildings and infrastructures for the high risk areas in the Risk Map, especially East Front Road.
- Preparation of Risk Management Tools, such as “Preliminary Stability Assessment Charts” and “Settlement Prediction Charts” for the river bank.

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## Proposed Methodology to Prepare a Risk Map for Bank Failures along the Lower River Murray

| | |
|---|---|
| **Task 1 – Data collection & review of background information.** | **Review of existing information. Much information has already been collected during earlier phases of the project and is available on the GIS Database.** |
| **Task 2 – Project initiation meeting with DWLBC to identify known risks and scope.** | **The scope of the risk mapping would need to be refined in consultation with DWLBC. This would involve discussions with DWLBC staff about the risks that collapses pose to different assets and its stakeholders.** |
| **Task 3 - Develop a Risk Register in conjunction with DWLBC.** | **This task would involve the development of a draft Risk Register from the results of previous investigations and discussions with DWLBC. Possible threats, likelihood and consequence would be documented in the Risk Register.** |
| **Task 4 – Initial Risk Mapping** | **Risk Maps will be developed based on topography, aerial photography, mapped geology and data gained from recent studies. Threats from Task 3 will be identified on long sections of the Lower River Murray and presented as Risk Maps.** |
| **Task 5 - Workshop to test the risk matrix, and identify data gaps.** | **A technical risk workshop or series of interviews would be convened with stakeholders to workshop potential risks. Any data gaps would be identified at this stage.** |
| **Task 6 –Investigate data gaps & undertake site investigations if required.** | **This task will only be carried out if it is deemed necessary to improve the accuracy of the risk mapping developed from Task 4.** |
| **Task 7 - Prepare final Risk Register & Maps on the basis of all inputs.** | **Finalise Risk Register and Maps based on all information, filling in all data gaps.** |
| **Tasks 8 - Identify, classify and cost risk reduction measures.** | **Report on risk assessment, risk reduction strategies and indicative costs of these options. A series of Risk Maps for the area would be produced.** |

# 16. References


- L.W. Abramson, T.S. Lee, S. Sharma, G.M. Boyce (2002), *Slope Stability and Stabilization Methods*, 2nd Ed.
- J.E. Bowles (1995), *Foundation Analysis and Design*, 5th Ed.
- B.M. Das (2006), *Principles of Foundation Engineering*, 6th Ed.
- T. Lunne, P.K. Robertson, J.M.M. Powell (1997), *Cone Penetration Testing in Geotechnical Practice*.
- Geological Survey of South Australia (1969), 1:250,000 Adelaide Map Sheet.
- Geological Survey of South Australia (1971), 1:250,000 Renmark Map Sheet.
- Geological Survey of South Australia (1962), 1:250,000 Barker Map Sheet.
- SKM (2009) Study into River Bank Collapsing – Lower River Murray. Inspection Report. Report to Department of Water, Land and Biodiversity Conservation.
- Standards Australia (2000), AS1289-2000 *Methods of testing soils for engineering purposes*.
- Standards Australia (1993), AS1726-1993 *Geotechnical Site Investigations*.
- Transportation Research Board National Research Council (1996), *Landslide Investigation and Mitigation*, Special Report 247.

# Photographs

- **Photo 1 Riverfront Road-Murray Bridge Boat Ramp**

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- **Photo 2 Riverfront Road-Murray Bridge Riverfront Homes**

- **Photo 3 Caloote Landing**

- **Photo 4 Caloote Tension Crack**

- **Photo 5 Caloote Tension Crack**

- **Photo 6 Caloote Tension Crack**

- **Photo 7 Caloote Tension Crack**

- **Photo 8 Caloote Tension Crack**

- **Photo 9 Caloote Tension Crack**

- **Photo 10 Caloote Tension Crack**

- **Photo 11 Caloote Cliff Overhanging Houses**

- **Photo 12 Caloote Evidence of Crack Progression**

- **Photo 13 Caloote Cliffs**

- **Photo 14 Caloote Rock Fall**

- **Photo 15 Woodlane Reserve**

- **Photo 16 South Punyelroo**


- **Photo 17 East Front Road**

- **Photo 18 East Front Road**

- **Photo 19 Swan Reach**

- **Photo 20 Walker Flat**

# Figures

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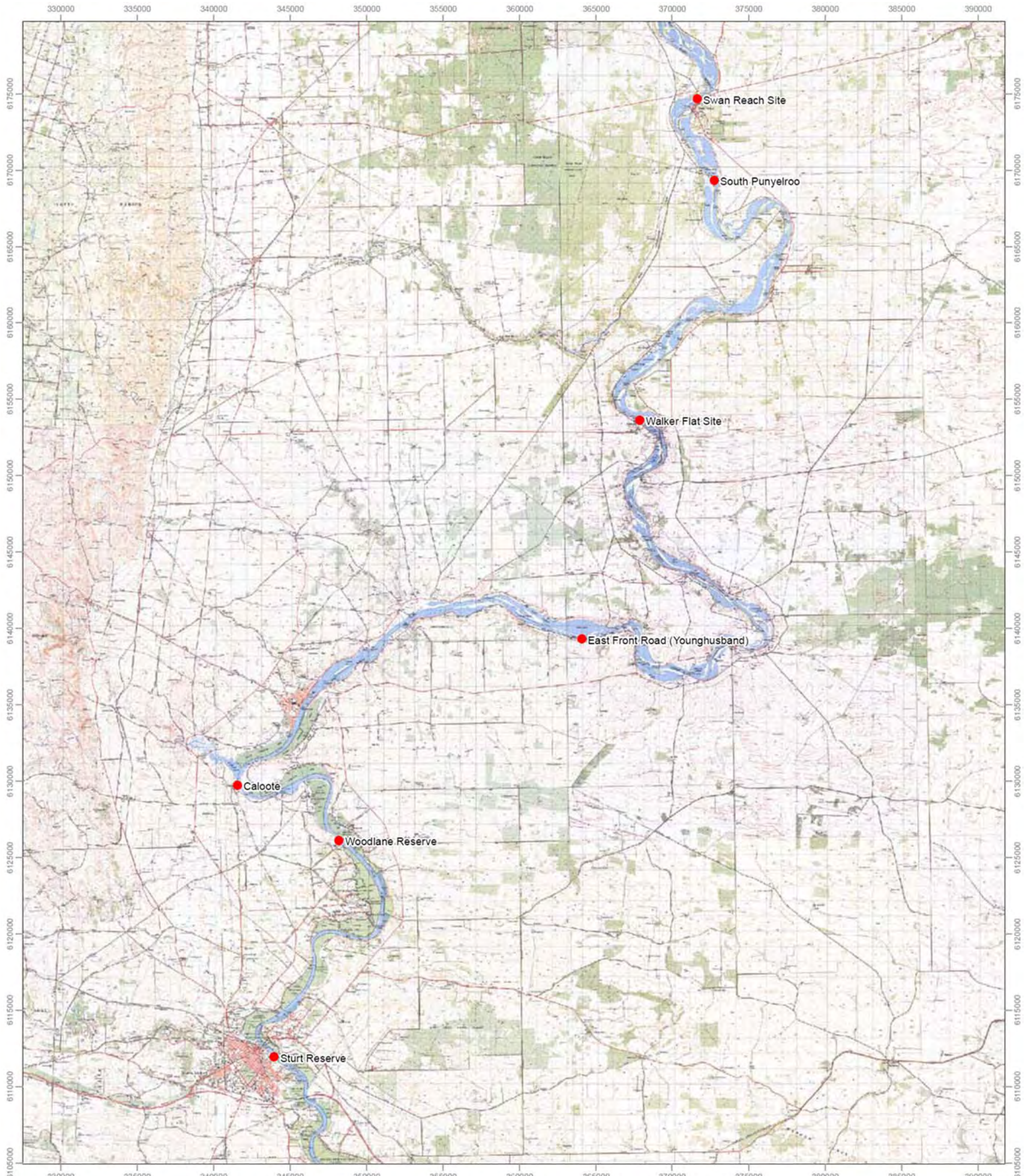
- **Figure 63 River Murray at Mannum (A4261161) – Daily water levels (m AHD) from 1 March to 28 April 2009. Maximum air temperature for region and daily rainfall recorded at Mannum are also shown.**
- **Figure 64 River Murray at Murray Bridge (A4261162) – Daily water levels (m AHD) from 7 January to 30 March 2009. Maximum air temperature for region and daily rainfall recorded at Murray Bridge are also shown.**




Legend

● Detailed Geotechnical Investigation Sites


0 10,000

A3 1:250,000 Metres

**Detailed Geotechnical Investigation Sites**

GDA 1994 MGA Zone 54

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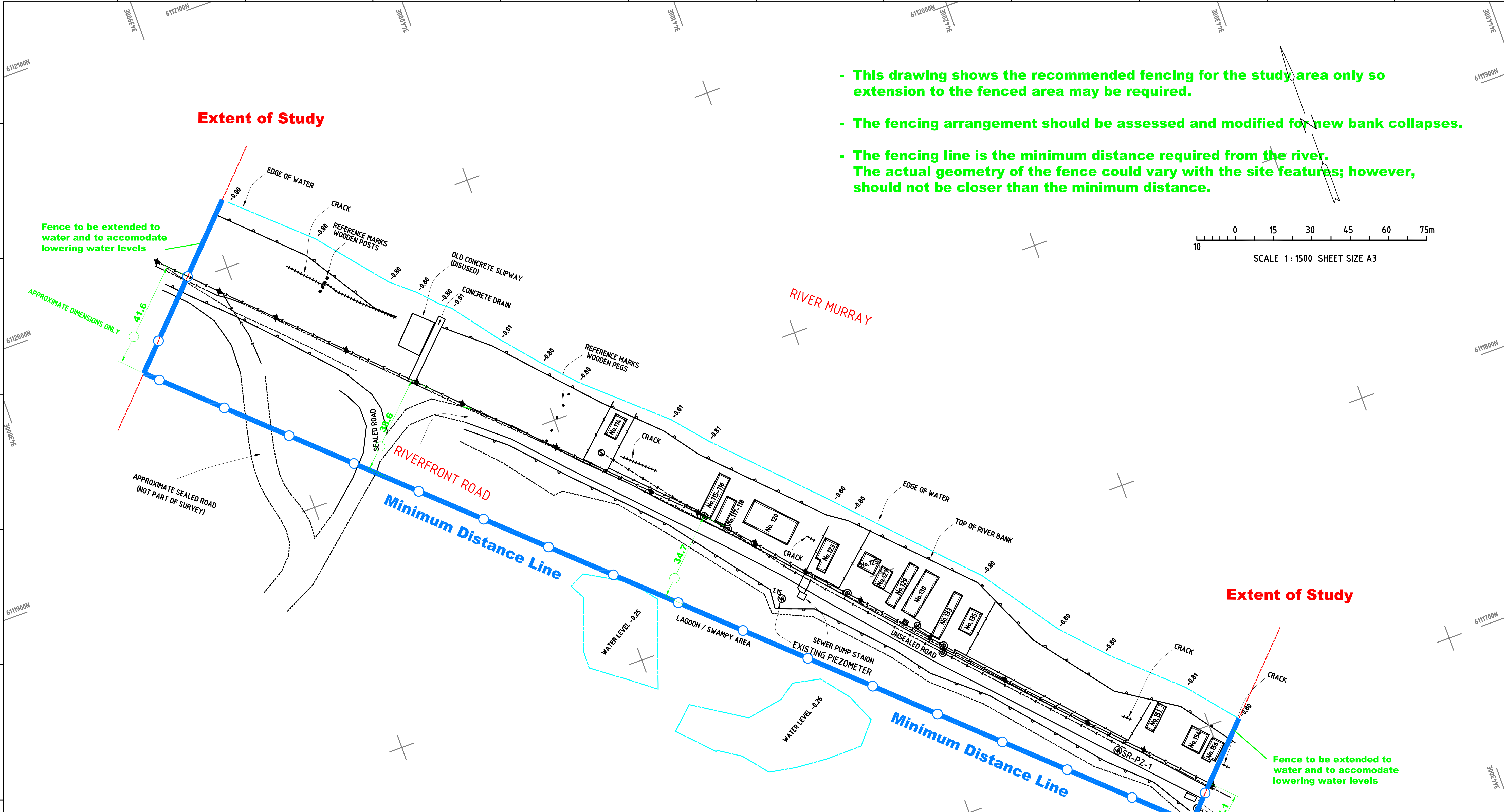
River Murray Bank Slumping

**Figure 1**




NOTES
1. ELEVATION DATUM AHD. AUTHORITY PSM 6727/3799 E:343489.509 N:6111759.705 RL11.124
2. FIELD SURVEY DATE 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7. PSM DENOTES PERMANENT SURVEY MARK

DISCLAIMER

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LEGEND

| | | | | |
|---|---|---|---|---|
| CABLE JUNCTION PIT | COMMUNICATIONS PIT | DRIANAGE INSPECTION POINT | WATER LEVEL | CRACK |
| FLOOD LIGHT | COMMS CABLE MARKER | DRIANAGE MANHOLE | U/G COMMUNICATIONS LINE | BOTTOM OF BANK |
| EARTH STAKE | COMMS PILLAR | GRATED SUMP & INVERT LEVEL | U/G SEWER PIPELINE | TOP OF BANK |
| CABLE MARKER | MONITORING WELL | SEWER INSPECTION POINT | A/G POWERLINE | BUILDING\SHED |
| STOBIE POLE | BORE HOLE | SEWER MANHOLE | U/G WATER PIPELINE | FENCE |
| SWITCH BOARD | CPT HOLE | WATER MANHOLE | UNSEALED TRACK\ROAD | PHOTO OBSERVATION POINT |

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
|---|---|---|---|---|---|
| - | | | | | |
| - | | | | | |
| - | | | | | |
| - | | | | | |
| A | 2-07-08 | GT | GC | | ISSUED FOR REVIEW & APPROVAL |

| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
|---|---|---|
| - | | |
| - | | |
| - | | |
| - | | |
| - | | |
| 1 | A1\4100C-6 | STURT RESERVE, LONGITUDINAL SECTIONS |



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The Department of Water, Land and Biodiversity Conservation

CLIENT DWLBC
PROJECT MURRAY RIVERBANK SLUMPING STUDY

| DRAWN | DRAFTING CHECK | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR |
|---|---|---|---|
| J DOWNES | G TURNER | G COOKE | |
| SURVEYED: J DOWNES | SURVEY CHECK: G COOKE | | |

TITLE
RURAL CITY OF MURRAY BRIDGE
RIVERFRONT ROAD - MURRAY BRIDGE
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-1 | A |

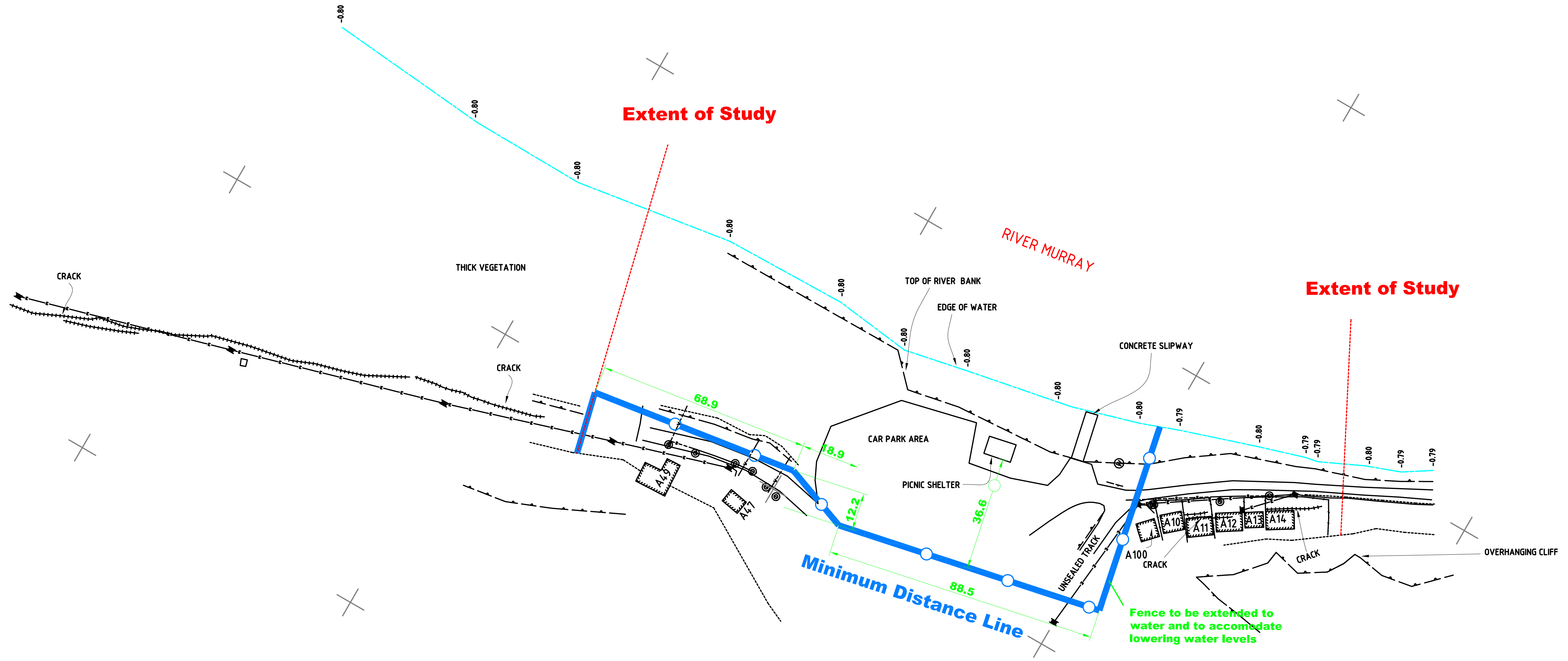
i:\vwes\projects\vw04794\technical\geotechnical\report\figures\murray_river_mga54_fence_rt_r1_20091224.dwg Thursday, 24 December 2009 12:35:10 PM

Figure 2

- **This drawing shows the recommended fencing for the study area only so extension to the fenced area may be required.**

- **The fencing arrangement should be assessed and modified for new bank collapses.**

- **The fencing line is the minimum distance required from the river. The actual geometry of the fence could vary with the site features; however, should not be closer than the minimum distance.**




NOTES
1. ELEVATION DATUM AHD - AUTHORITY PSM 6728/2160 E:341412.917 N:6129922.380 RL19.455
2. FIELD SURVEY DATE - 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
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LEGEND

CABLE JUNCTION PIT
FLOOD LIGHT
EARTH STAKE
CABLE MARKER
STOBIE POLE
SWITCH BOARD
COMMUNICATIONS PIT
COMMS CABLE MARKER
COMMS PILLAR
MONITORING WELL
BORE HOLE
CPT HOLE
DRAINAGE INSPECTION POINT
DRAINAGE MANHOLE
GRATED SUMP & INVERT LEVEL
SEWER INSPECTION POINT
SEWER MANHOLE
WATER MANHOLE
WATER LEVEL
U/G COMMUNICATIONS LINE
U/G SEWER PIPELINE
A/G POWERLINE
U/G WATER PIPELINE
UNSEALED TRACK\ROAD
CRACK
BOTTOM OF BANK
TOP OF BANK
BUILDING\SHED
FENCE
PHOTO OBSERVATION POINT

10 0 15 30 45 60 75m

SCALE 1 : 1500 SHEET SIZE A3

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
|---|---|---|---|---|---|
| - | | | | | |
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| A | 2-07-08 | GT | GC | | ISSUED FOR REVIEW & APPROVAL |

| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
|---|---|---|
| - | | |
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| - | | |
| 1 | A1\4100C-8 | CALOOTE, LONGITUDINAL SECTIONS |




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CLIENT DWLBC
PROJECT MURRAY RIVERBANK SLUMPING STUDY

| DRAWN | DRAFTING CHECK | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR |
|---|---|---|---|
| J DOWNES | G TURNER | G COOKE | |
| SURVEYED: J DOWNES | SURVEY CHECK: G COOKE | | |

TITLE
MID-MURRAY COUNCIL
CALOOTE
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-3 | A |

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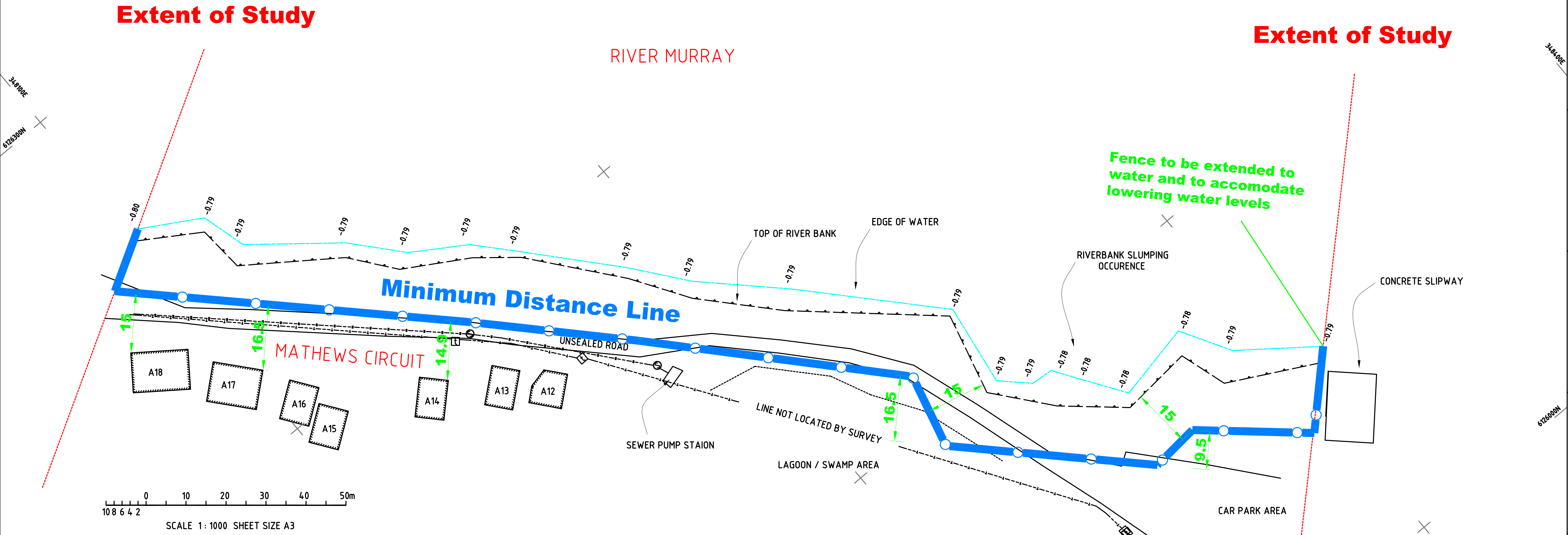
**Figure 3**

- **This drawing shows the recommended fencing for the study area only so extension to the fenced area may be required.**

- **The fencing arrangement should be assessed and modified for new bank collapses.**

- **The fencing line is the minimum distance required from the river. The actual geometry of the fence could vary with the site features; however, should not be closer than the minimum distance.**




NOTES
1. ELEVATION DATUM AHD - AUTHORITY PSM 6727/3549 E:348297.799 N:6125864.949 RL7.016
2. FIELD SURVEY DATE - 24 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7. PSM DENOTES PERMANENT SURVEY MARK

DISCLAIMER

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LEGEND

CABLE JUNCTION PIT, FLOOD LIGHT, EARTH STAKE, CABLE MARKER, STOBIE POLE, SWITCH BOARD, COMMUNICATIONS PIT, COMMS CABLE MARKER, COMMS PILLAR, MONITORING WELL, BORE HOLE, CPT HOLE, DRIANAGE INSPECTION POINT, DRIANAGE MANHOLE, GRATED SUMP & INVERT LEVEL, SEWER INSPECTION POINT, SEWER MANHOLE, WATER MANHOLE, WATER LEVEL, U/G COMMUNICATIONS LINE, U/G SEWER PIPELINE, A/G POWERLINE, U/G WATER PIPELINE, UNSEALED TRACK\ROAD, CRACK, BOTTOM OF BANK, TOP OF BANK, BUILDING\SHED, FENCE, PHOTO OBSERVATION POINT

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
|---|---|---|
| 1 | A1\4100C-7 | WOODLANE RESERVE, LONGITUDINAL SECTIONS |



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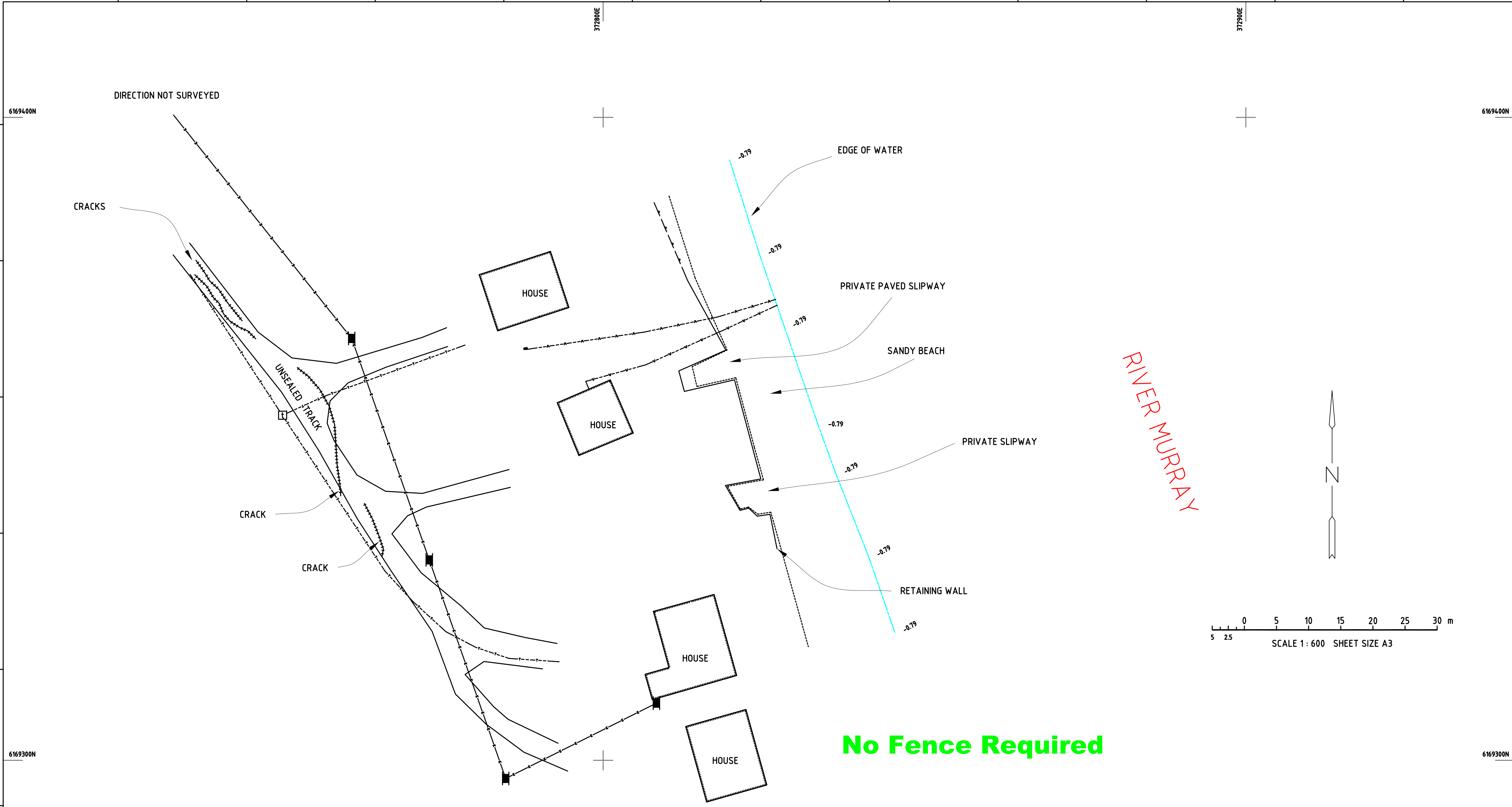
|---|---|---|---|
| J DOWNES | G TURNER | G COOKE | |
| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
RURAL CITY OF MURRAY BRIDGE
WOODLANE RESERVE
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-2 | A |

Figure 4




NOTES
1. ELEVATION DATUM AHD - AUTHORITY PSM 6828/1219 E:372126.805 N:6169675.291 RL4.406
2. FIELD SURVEY DATE - 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7. PSM DENOTES PERMANENT SURVEY MARK

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LEGEND

| | | | | |
|---|---|---|---|---|
| CABLE JUNCTION PIT | COMMUNICATIONS PIT | DRIANAGE INSPECTION POINT | WATER LEVEL | CRACK |
| FLOOD LIGHT | COMMS CABLE MARKER | DRIANAGE MANHOLE | U/G COMMUNICATIONS LINE | BOTTOM OF BANK |
| EARTH STAKE | COMMS PILLAR | GRATED SUMP & INVERT LEVEL | U/G SEWER PIPELINE | TOP OF BANK |
| CABLE MARKER | MONITORING WELL | SEWER INSPECTION POINT | A/G POWERLINE | BUILDING\SHED |
| STOBIE POLE | BORE HOLE | SEWER MANHOLE | U/G WATER PIPELINE | FENCE |
| SWITCH BOARD | CPT HOLE | WATER MANHOLE | UNSEALED TRACK\ROAD | PHOTO OBSERVATION POINT |

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| 1 | A1\4100C-10 | SOUTH PUNYELROO, LONGITUDINAL SECTIONS |




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| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
MID-MURRAY COUNCIL
SOUTH PUNYELROO
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-5 | A |

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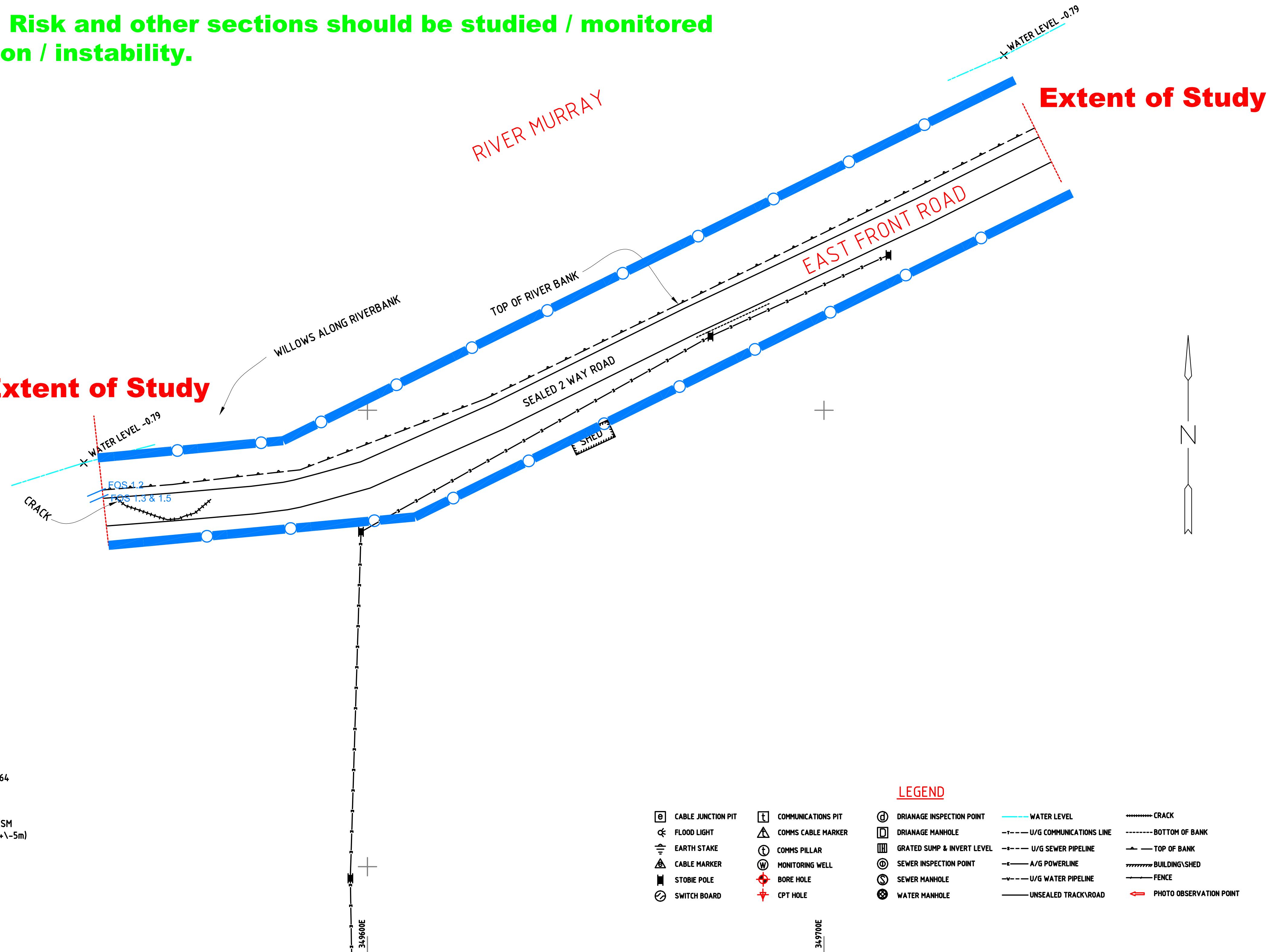
Figure 5

- **Due to the instability in the observed cross sections, the public and authorities should be advised on the high risk of failure in the area by proper signage and reducing the speed limit. THIS IS A TEMPORARY MEASURE AND USE OF THE ROAD SHOULD BE DECIDED BY AUTHORITIES.**

- **The area is Very High Risk and other sections should be studied / monitored for signs of deformation / instability.**




0 10 20 30 40 50m
10 8 6 4 2

SCALE 1 : 1000 SHEET SIZE A3

NOTES
1. ELEVATION DATUM AHD. AUTHORITY PSM 6728/2256 E:349342.779 N:6137540.915 RL2.064
2. FIELD SURVEY DATE 23 OCTOBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7. PSM DENOTES PERMANENT SURVEY MARK

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LEGEND

| | | | |
|---|---|---|---|
| CABLE JUNCTION PIT | COMMUNICATIONS PIT | DRIANAGE INSPECTION POINT | WATER LEVEL | CRACK |
| FLOOD LIGHT | COMMS CABLE MARKER | DRIANAGE MANHOLE | U/G COMMUNICATIONS LINE | BOTTOM OF BANK |
| EARTH STAKE | COMMS PILLAR | GRATED SUMP & INVERT LEVEL | U/G SEWER PIPELINE | TOP OF BANK |
| CABLE MARKER | MONITORING WELL | SEWER INSPECTION POINT | A/G POWERLINE | BUILDING\SHED |
| STOBIE POLE | BORE HOLE | SEWER MANHOLE | U/G WATER PIPELINE | FENCE |
| SWITCH BOARD | CPT HOLE | WATER MANHOLE | UNSEALED TRACK\ROAD | PHOTO OBSERVATION POINT |

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| REF. | DRAWING NUMBER | REFERENCE DRAWING TITLE |
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| - | | |
| 1 | A1\4100C-9 | EAST FRONT ROAD, LONGITUDINAL SECTIONS |



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| SURVEYED J DOWNES | SURVEY CHECK G COOKE | | |

TITLE
MID-MURRAY COUNCIL
EAST FRONT ROAD
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100C-4 | A |

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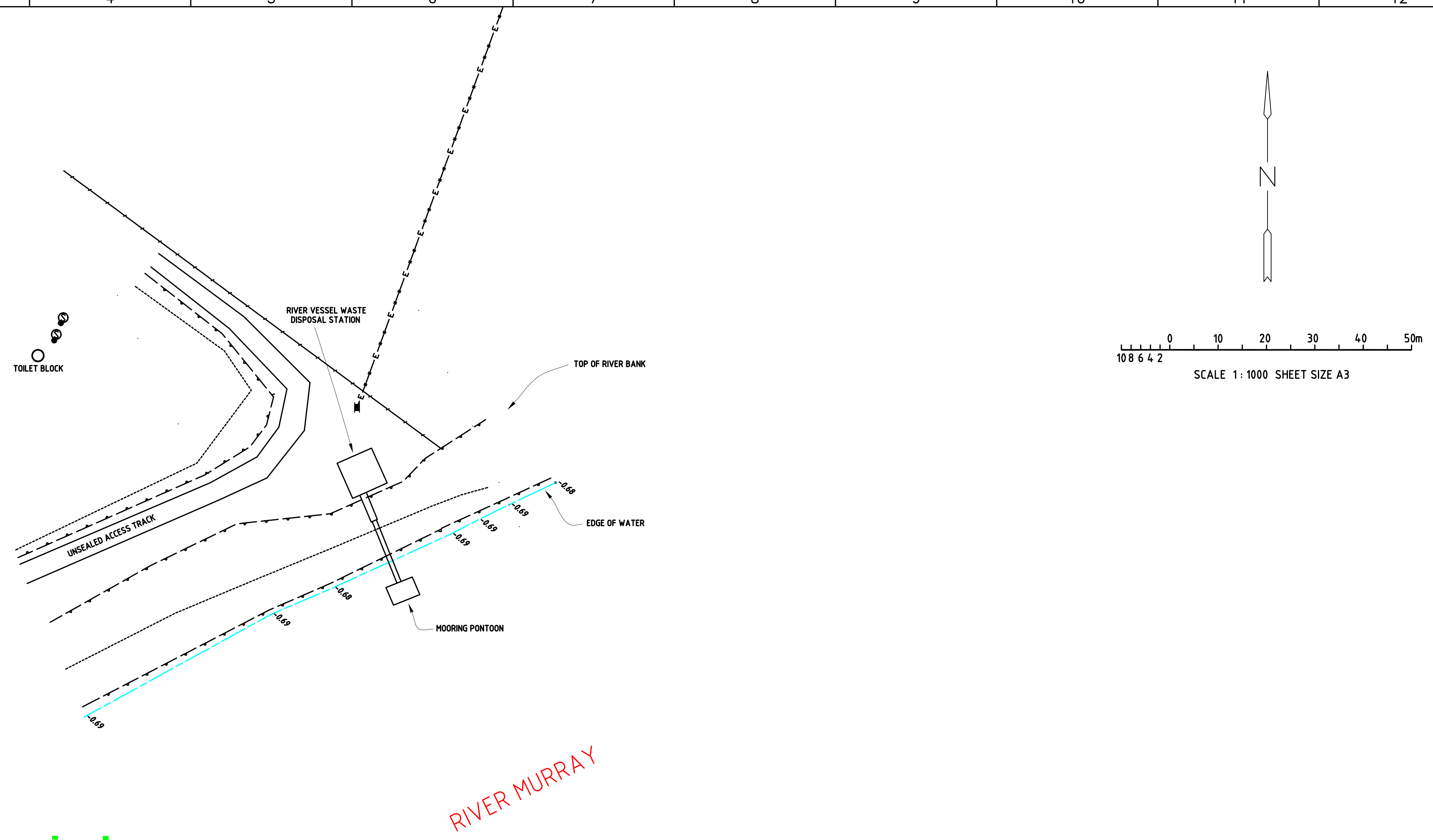
**Figure 6**




**No Fence Required**

NOTES
1. ELEVATION DATUM AHD - AUTHORITY PSM 6828/1204 E:371826.408 N:6174742.830 RL3.258
2. FIELD SURVEY DATE - 16 NOVEMBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GNSS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7.PSM DENOTES PERMANENT SURVEY MARK

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LEGEND

CABLE JUNCTION PIT
FLOOD LIGHT
EARTH STAKE
CABLE MARKER
STOBIE POLE
SWITCH BOARD
COMMUNICATIONS PIT
COMMS CABLE MARKER
COMMS PILLAR
MONITORING WELL
BORE HOLE
CPT HOLE
DRIANAGE INSPECTION POINT
DRIANAGE MANHOLE
GRATED SUMP & INVERT LEVEL
SEWER INSPECTION POINT
SEWER MANHOLE
WATER MANHOLE
WATER LEVEL
U/G COMMUNICATIONS LINE
U/G SEWER PIPELINE
A/G POWERLINE
U/G WATER PIPELINE
UNSEALED TRACK\ROAD
CRACK
BOTTOM OF BANK
TOP OF BANK
BUILDING\SHED
FENCE
PHOTO OBSERVATION POINT

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| 1 | A1\4100E-3 | SWAN REACH, LONGITUDINAL SECTIONS |




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| SURVEYED | SURVEY CHECK | | |
| J DOWNES | G COOKE | | |

TITLE
DWLBC
SWAN REACH
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
|---|---|---|---|
| AS SHOWN | VW04794.1 | A1\4100E-1 | A |

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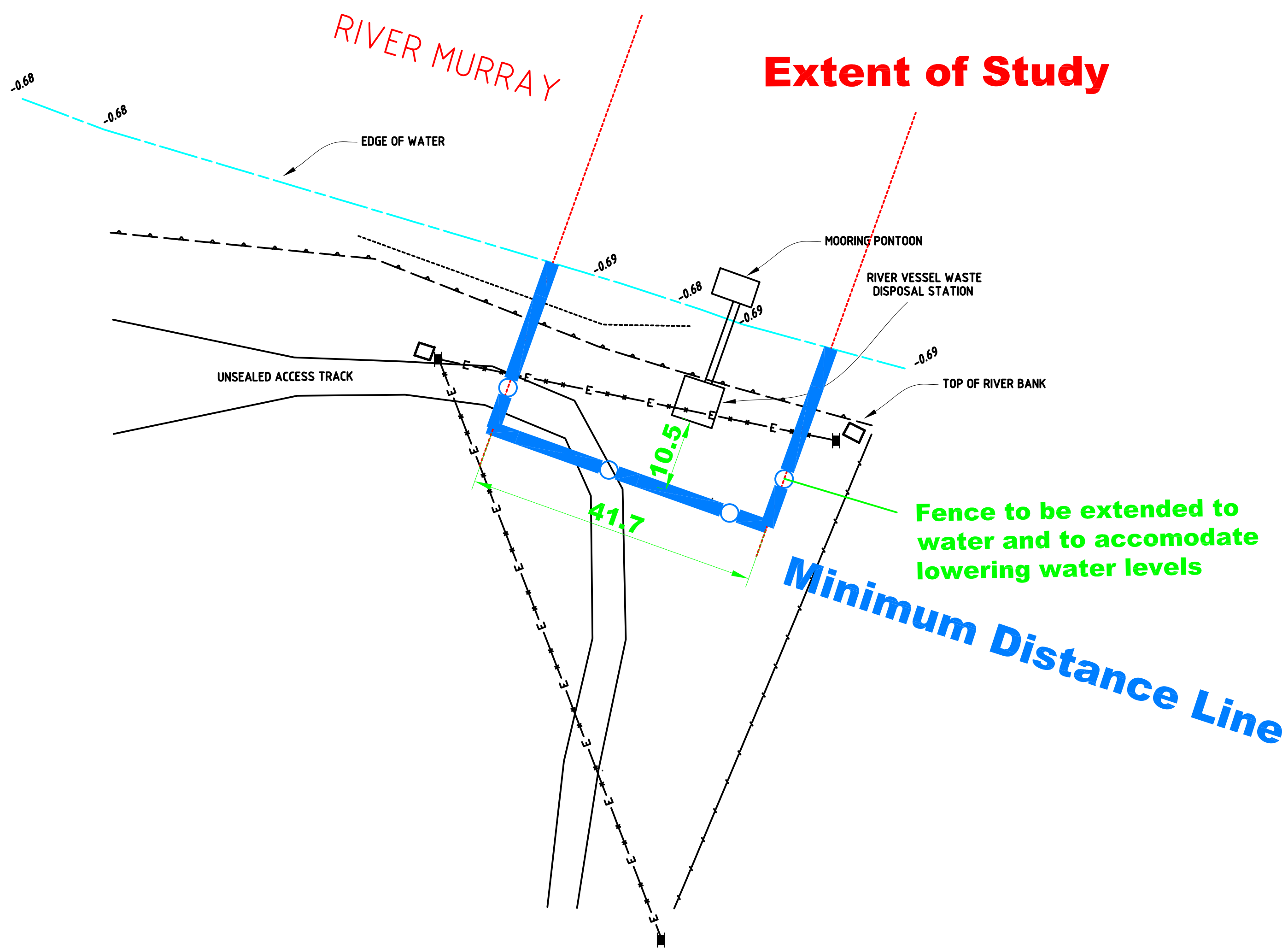
**Figure 7**

- **This drawing shows the recommended fencing for the study area only so extension to the fenced area may be required.**
- **The fencing arrangement should be assessed and modified for new bank collapses.**
- **The fencing line is the minimum distance required from the river. The actual geometry of the fence could vary with the site features; however, should not be closer than the minimum distance.**

N

10 8 6 4 2 0 10 20 30 40 50m

SCALE 1 : 1000 SHEET SIZE A3




NOTES
1. ELEVATION DATUM AHD. AUTHORITY PSM 6828/1032 E367718.297 N6153088.360 RL35.953
2. FIELD SURVEY DATE 16 NOVEMBER 2009
3. DATUME AND PROJECTION - GDA\MGA ZONE 54
4. CONTROL AND DETAIL SURVEYED USING TOTAL STATION AND RTK GPS
5. ESTIMATED HORIZONTAL AND VERTICAL ACCURACY +/- 0.15m RELATIVE TO AUTHORITY PSM
6. CPT TEST AND BORE HOLES ARE LOCATED BY AUTONOMOUS GPS MEASUREMENTS ONLY (+\-5m)
7. PSM DENOTES PERMANENT SURVEY MARK



LEGEND

| | | | | |
|---|---|---|---|---|
| CABLE JUNCTION PIT | COMMUNICATIONS PIT | DRIANAGE INSPECTION POINT | WATER LEVEL | CRACK |
| FLOOD LIGHT | COMMS CABLE MARKER | DRIANAGE MANHOLE | U/G COMMUNICATIONS LINE | BOTTOM OF BANK |
| EARTH STAKE | COMMS PILLAR | GRATED SUMP & INVERT LEVEL | U/G SEWER PIPELINE | TOP OF BANK |
| CABLE MARKER | MONITORING WELL | SEWER INSPECTION POINT | A/G POWERLINE | BUILDING\SHED |
| STOBIE POLE | BORE HOLE | SEWER MANHOLE | U/G WATER PIPELINE | FENCE |
| SWITCH BOARD | CPT HOLE | WATER MANHOLE | UNSEALED TRACK\ROAD | PHOTO OBSERVATION POINT |

| No | DATE | SURVEY REVIEW | REV'D P.MGR | APP'D P.DIR | AMENDMENT |
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| 1 | A1\4100E-4 | WALKER FLAT, LONGITUDINAL SECTIONS |




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| DRAWN | DRAFTING CHECK | REVIEWED PROJECT MANAGER | APPROVED PROJECT DIRECTOR |
|---|---|---|---|
| J DOWNES | G TURNER | | |
| SURVEYED | SURVEY CHECK | | |
| J DOWNES | G COOKE | | |

TITLE
DWLBC
WALKER FLAT
PROPOSED SAFETY FENCING

| SCALE | PROJECT No | DRAWING No | AMDT |
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| AS SHOWN | VW04794.1 | A1\4100E-2 | A |


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Figure 8

A 1

Study into Riverbank Collapsing for Lower Murray River
Riverfront Road - Murray Bridge - Section SR1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.27

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

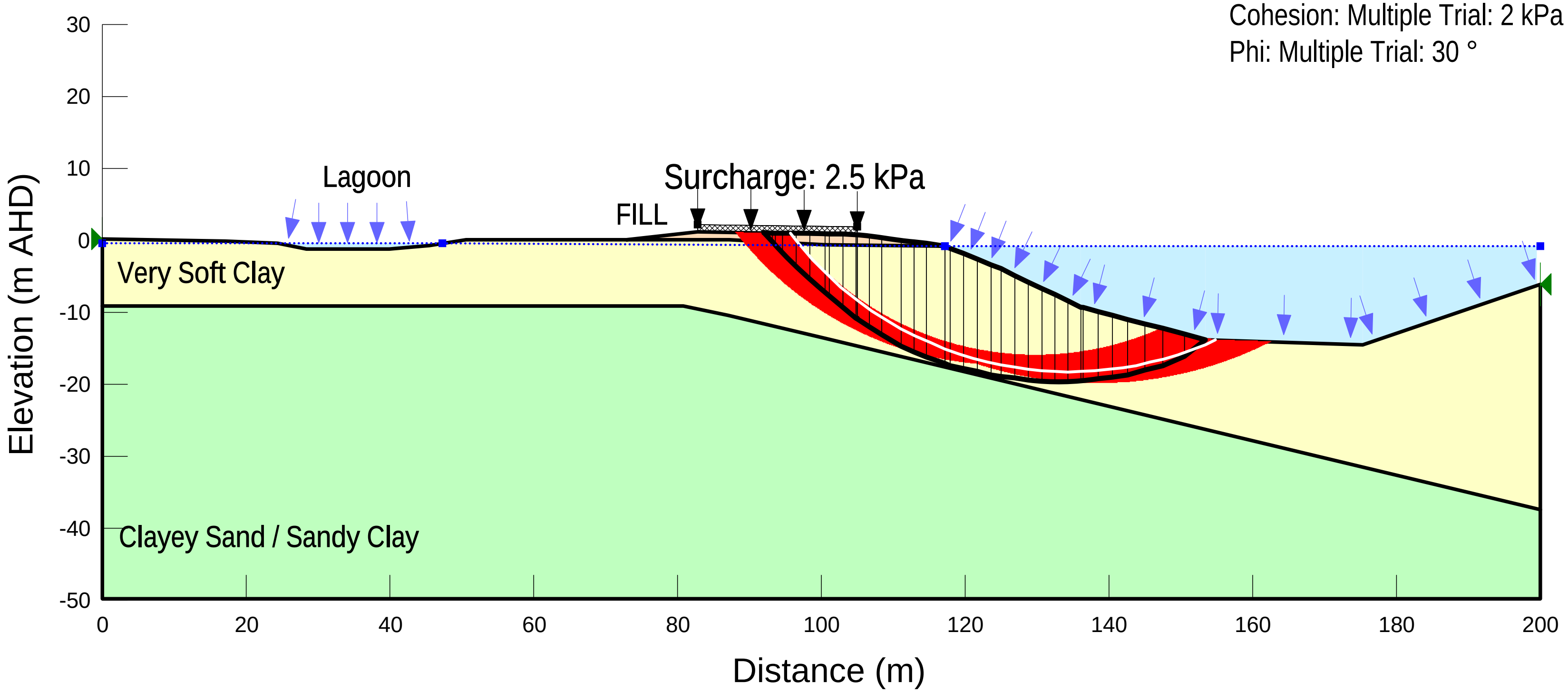



**Figure 9**

Study into Riverbank Collapsing for Lower Murray River
Riverfront Road - Murray Bridge - Section SR1

Assessment of the Future Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.18

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

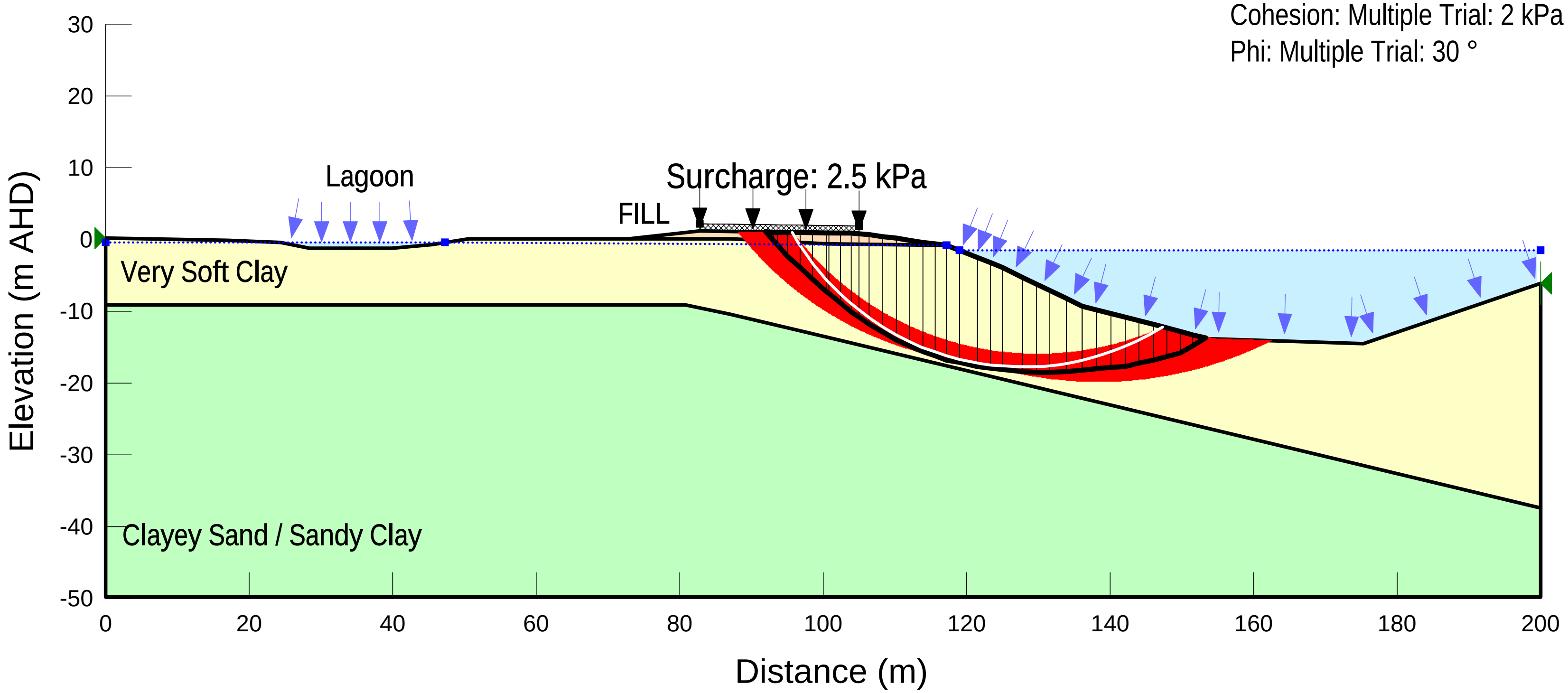



**Figure 10**

Study into Riverbank Collapsing for Lower Murray River
Riverfront Road - Murray Bridge - Section SR2

Assessment of the Existing Condition
River Water Level at -0.80m AHD

Factor of Safety = 1.13

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

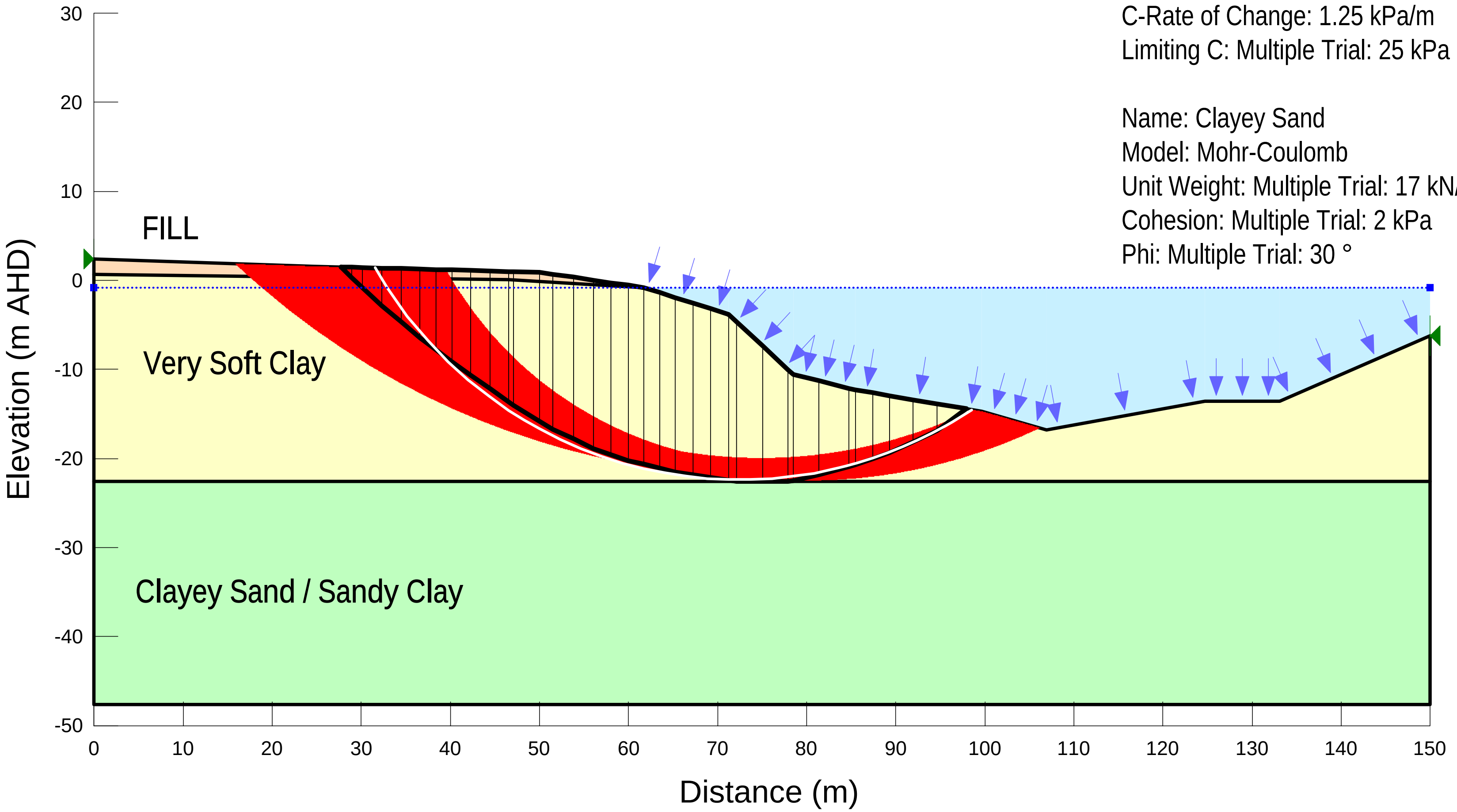



**Figure 11**

## Study into Riverbank Collapsing for Lower Murray River
## Riverfront Road - Murray Bridge - Section SR2

Assessment of the Future Conditions
River Water Level at -1.50m AHD

Factor of Safety = 1.05

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.25 kPa/m
Limiting C: Multiple Trial: 25 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

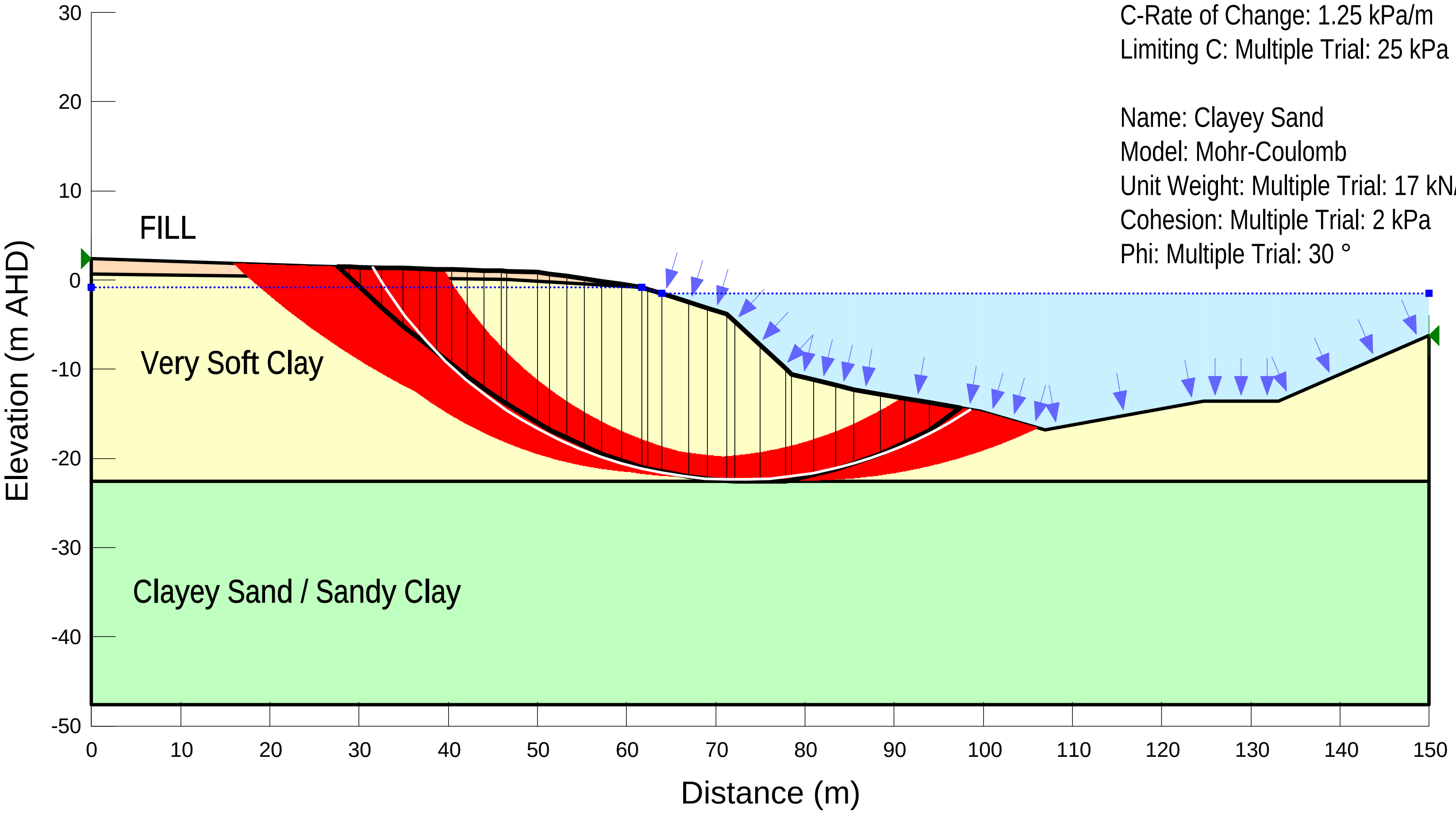



**Figure 12**

Study into Riverbank Collapsing for Lower Murray River
Caloote - Section CA2

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.14

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.07 kPa/m
Limiting C: Multiple Trial: 17.5 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

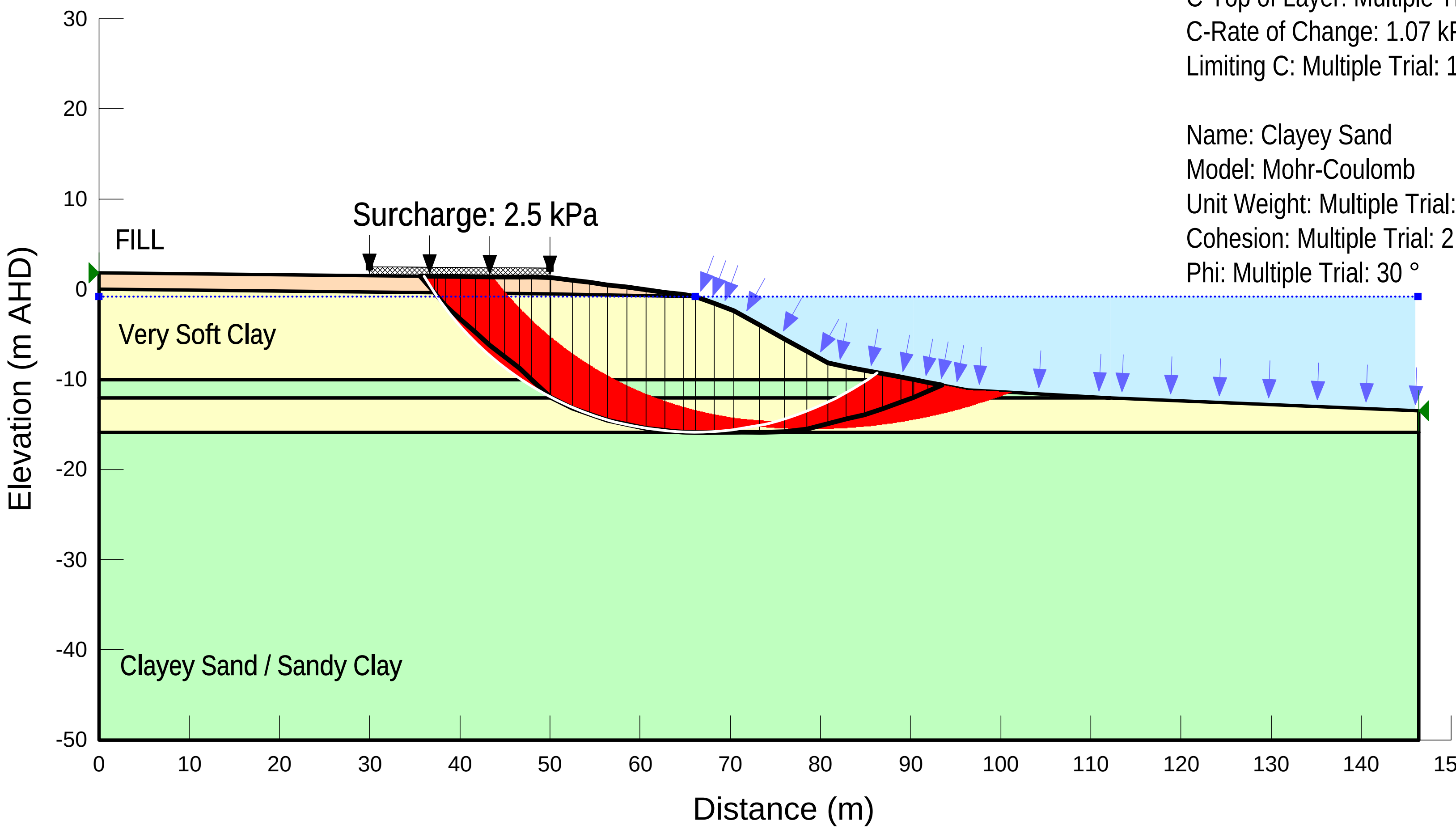



**Figure 13**

Study into Riverbank Collapsing for Lower Murray River
Caloote - Section CA2

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.06

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 28 °

Name: Very Soft Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 16 kN/m³
C-Top of Layer: Multiple Trial: 10 kPa
C-Rate of Change: 1.07 kPa/m
Limiting C: Multiple Trial: 17.5 kPa

Name: Clayey Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 2 kPa
Phi: Multiple Trial: 30 °

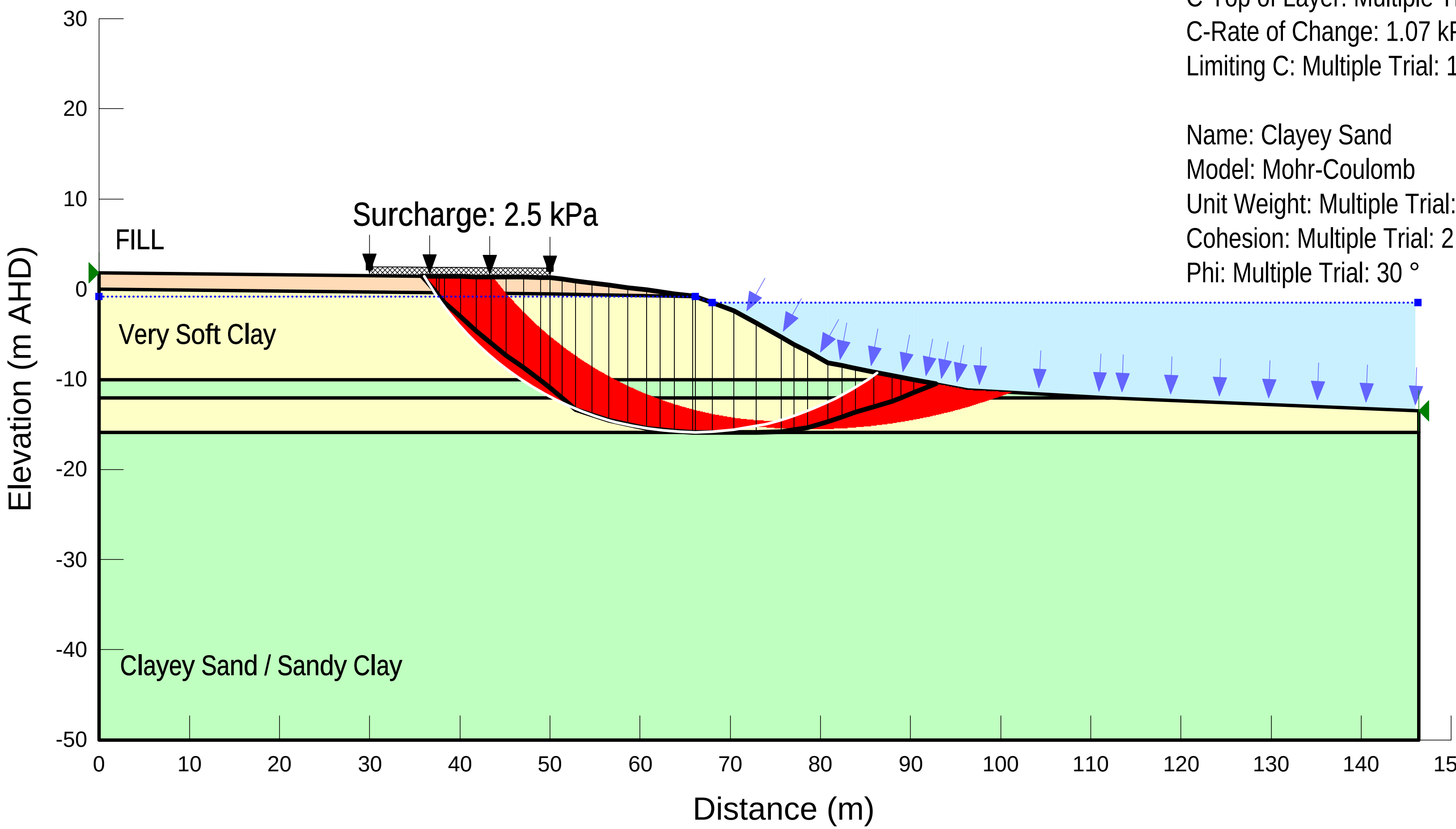
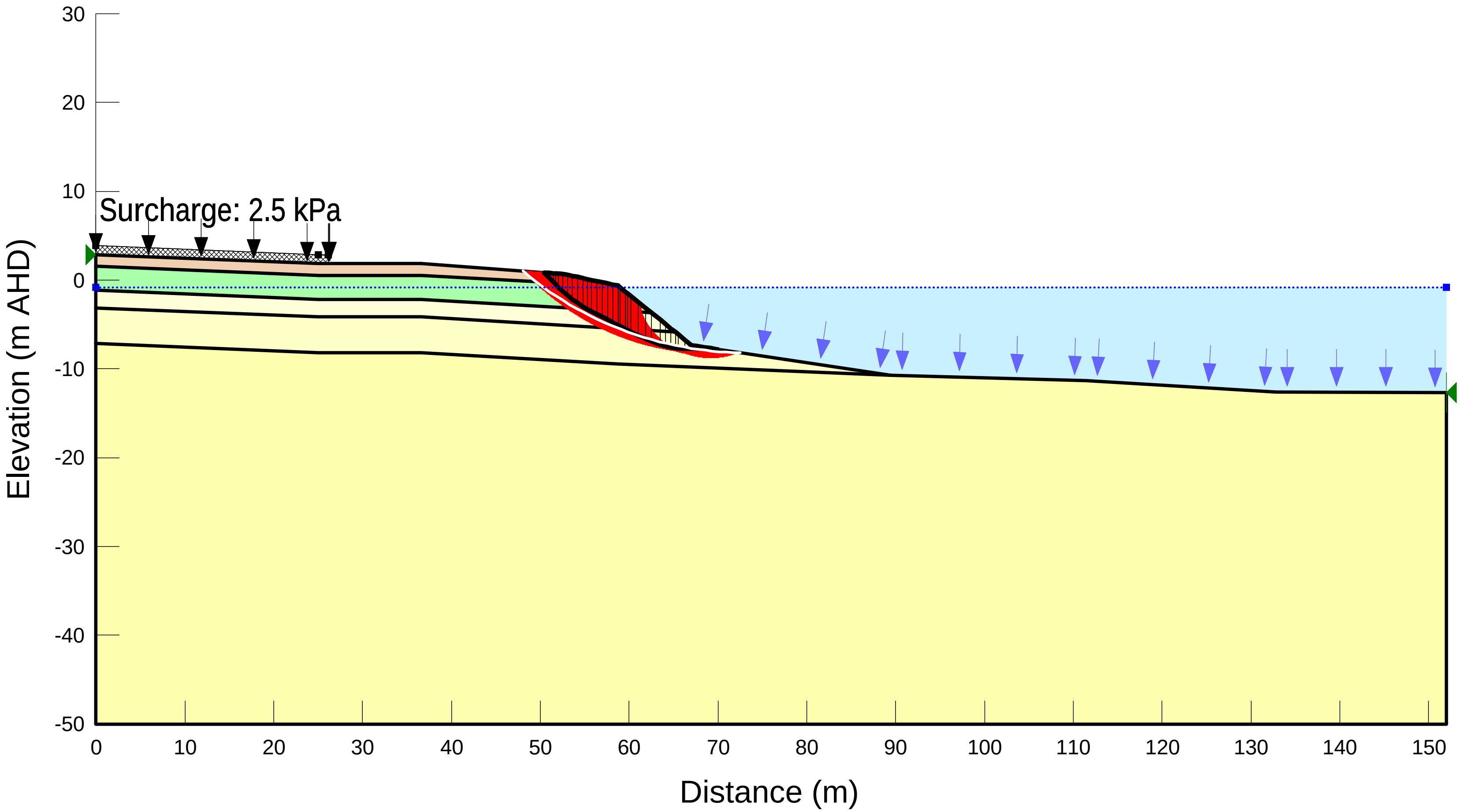



Figure 14

Study into Riverbank Collapsing for Lower Murray River
Woodlane Reserve - Section WR1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.38




Name: FILL
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Very Soft Clay (CH)
Model: Undrained (Phi=0)
Unit Weight: 17 kN/m³
Cohesion: Multiple Trial: 20 kPa

Name: Sand / Clay (loose)
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 29 °

Name: Sand / Silt
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

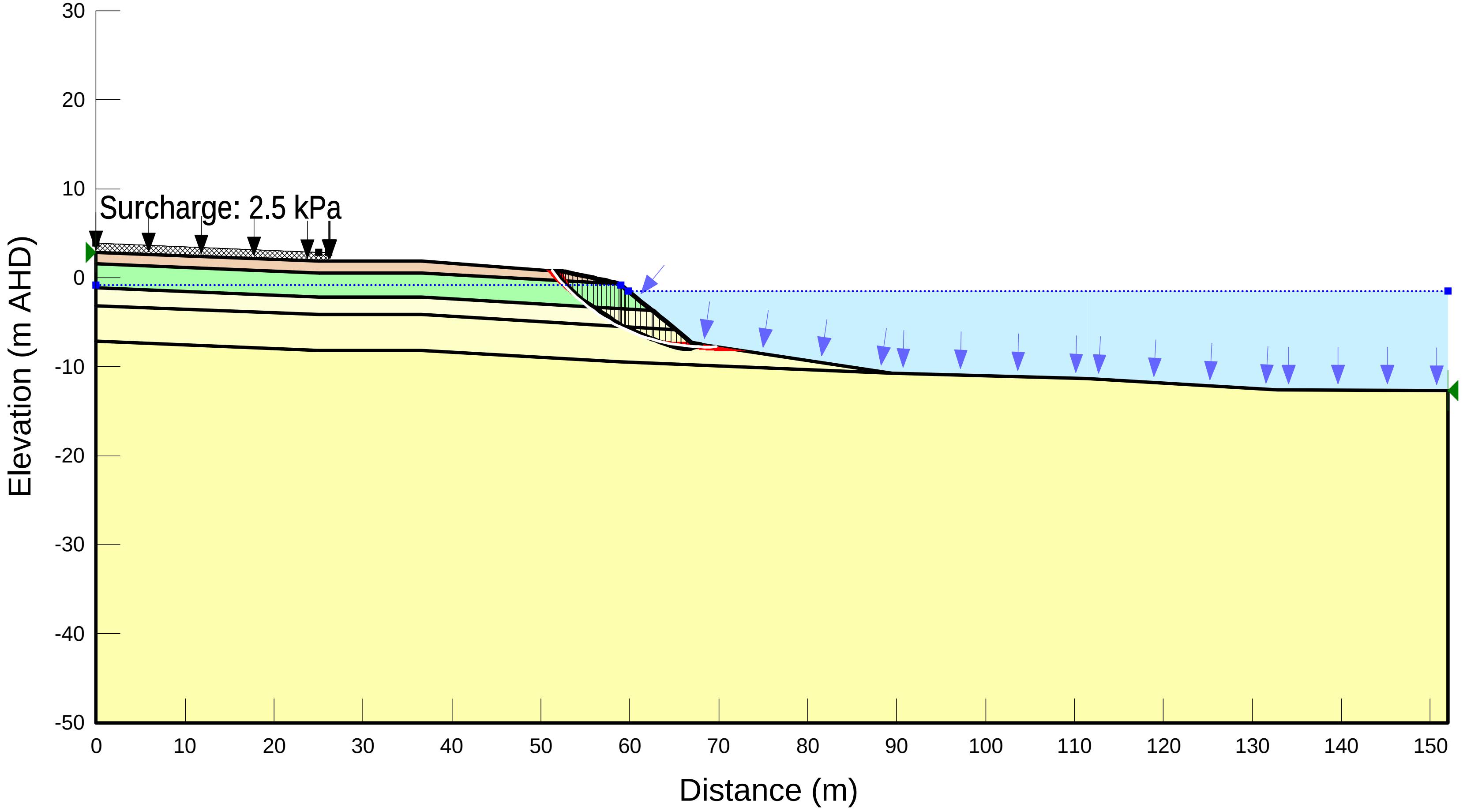
Name: Type 3C
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 15**

Study into Riverbank Collapsing for Lower Murray River
Woodlane Reserve - Section WR1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.20




Name: FILL
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Very Soft Clay (CH)
Model: Undrained (Phi=0)
Unit Weight: 17 kN/m³
Cohesion: Multiple Trial: 20 kPa

Name: Sand / Clay (loose)
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 29 °

Name: Sand / Silt
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

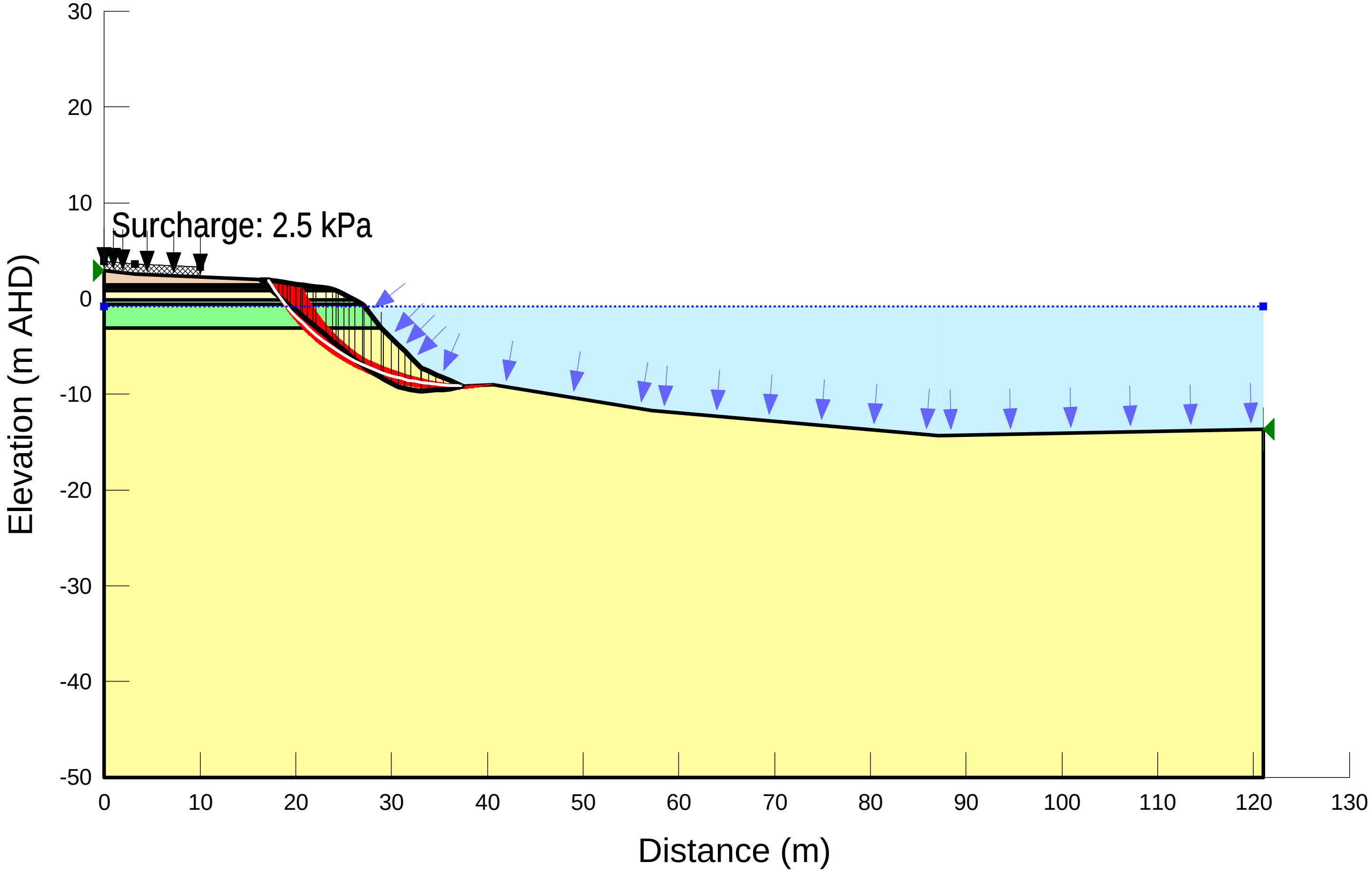
Name: Type 3C
Model: Mohr-Coulomb
Unit Weight: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 16**

Study into Riverbank Collapsing for Lower Murray River
Woodlane Reserve - Section WR2

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.38




Name: FILL
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1 Clay
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B2 Clay
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa

Name: Type C1 Silty Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B3 Clay
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B4 Clay
Model: S=f(depth)
Unit Weight: Multiple Trial: 17 kN/m³
C-Top of Layer: Multiple Trial: 28 kPa
C-Rate of Change: Multiple Trial: 7.2 kPa/m
Limiting C: Multiple Trial: 46 kPa

Name: Type C2 Silty Sand
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 1 kPa
Phi: Multiple Trial: 31 °

**Figure 17**

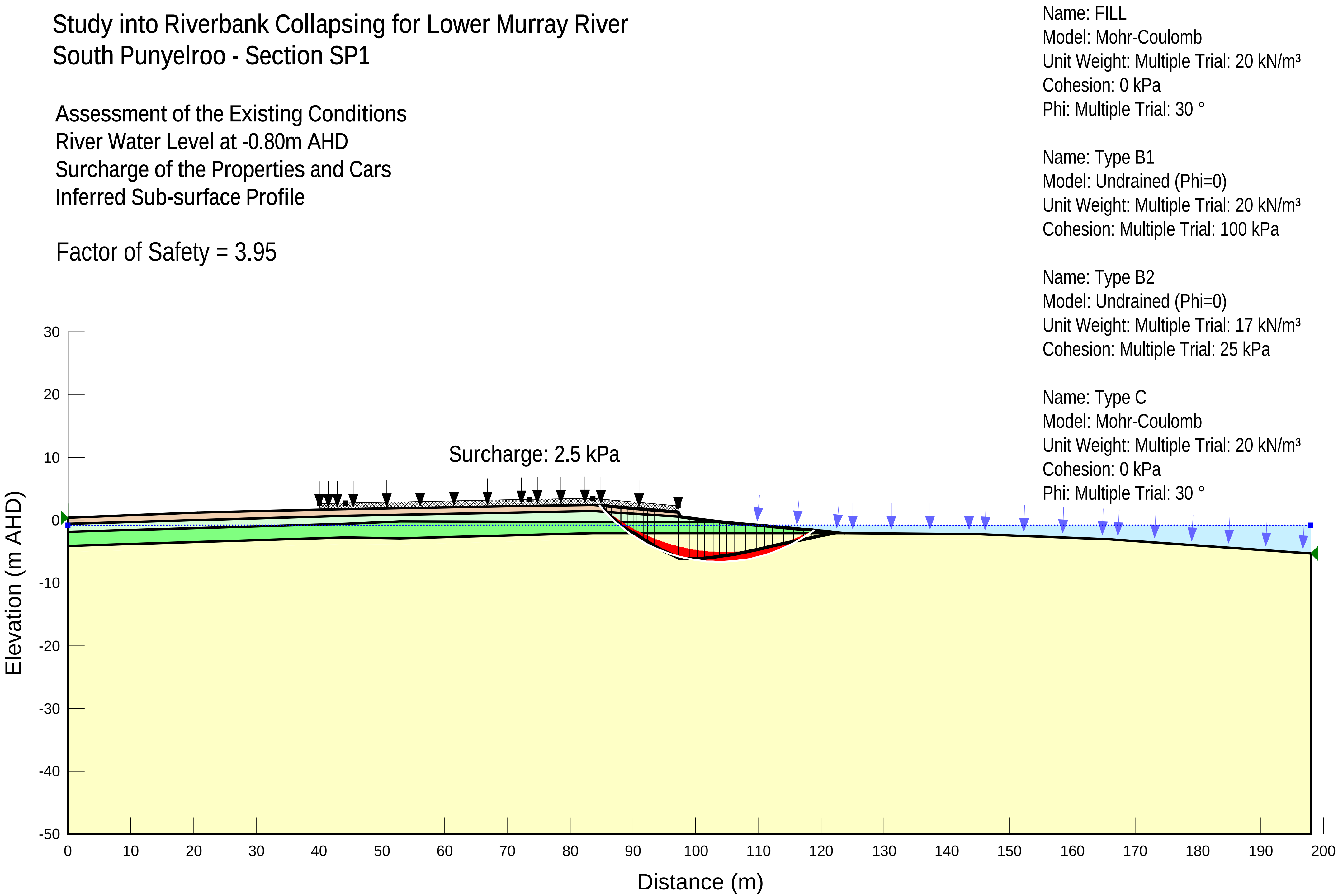

Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1
Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars
Inferred Sub-surface Profile
Factor of Safety = 3.95
Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa
Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Surcharge: 2.5 kPa
Elevation (m AHD)
30
20
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Distance (m)

**Figure 18**

Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars
Inferred Sub-surface Profile

Factor of Safety = 3.73

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa

Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

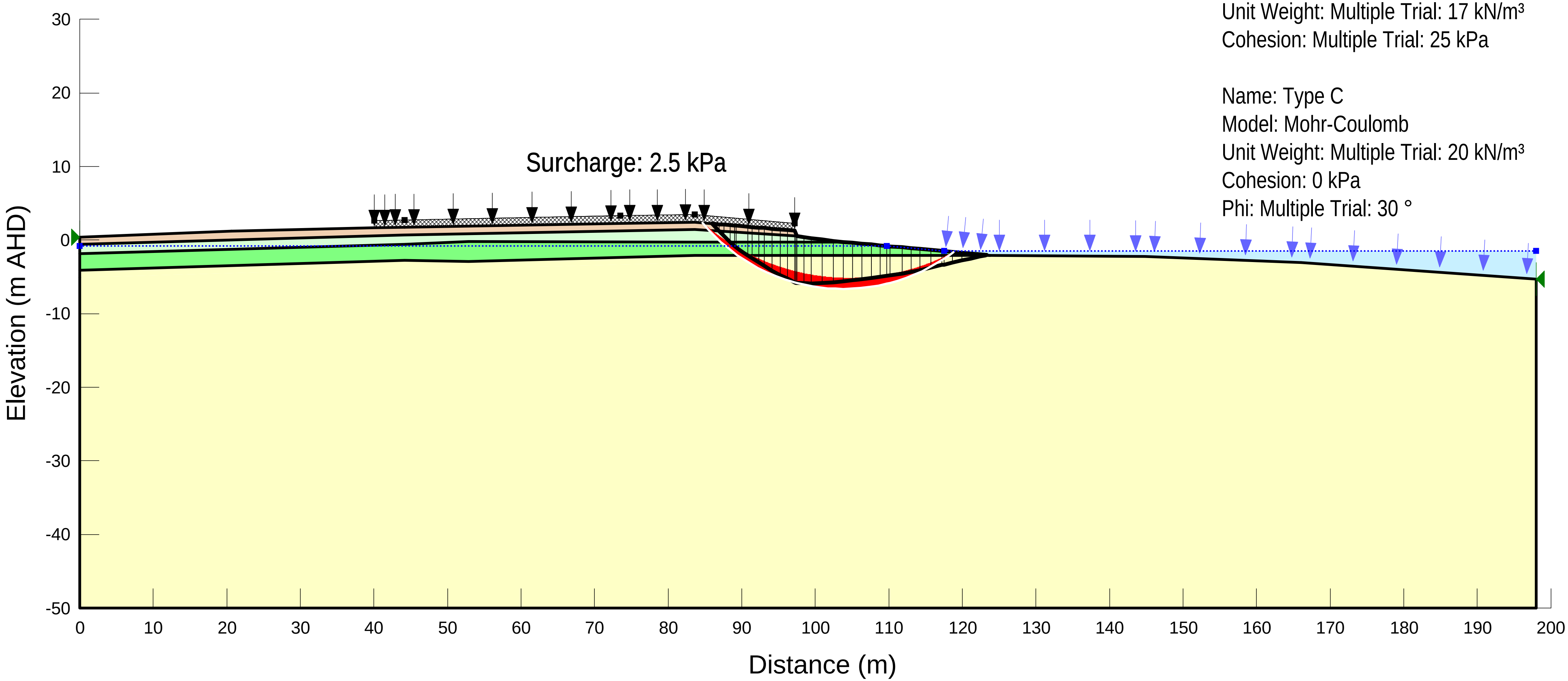



**Figure 19**

# Study into Riverbank Collapsing for Lower Murray River
# South Punyelroo - Section SP1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars
Worst Case Sub-surface Profile

Factor of Safety = 1.67

Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa

Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

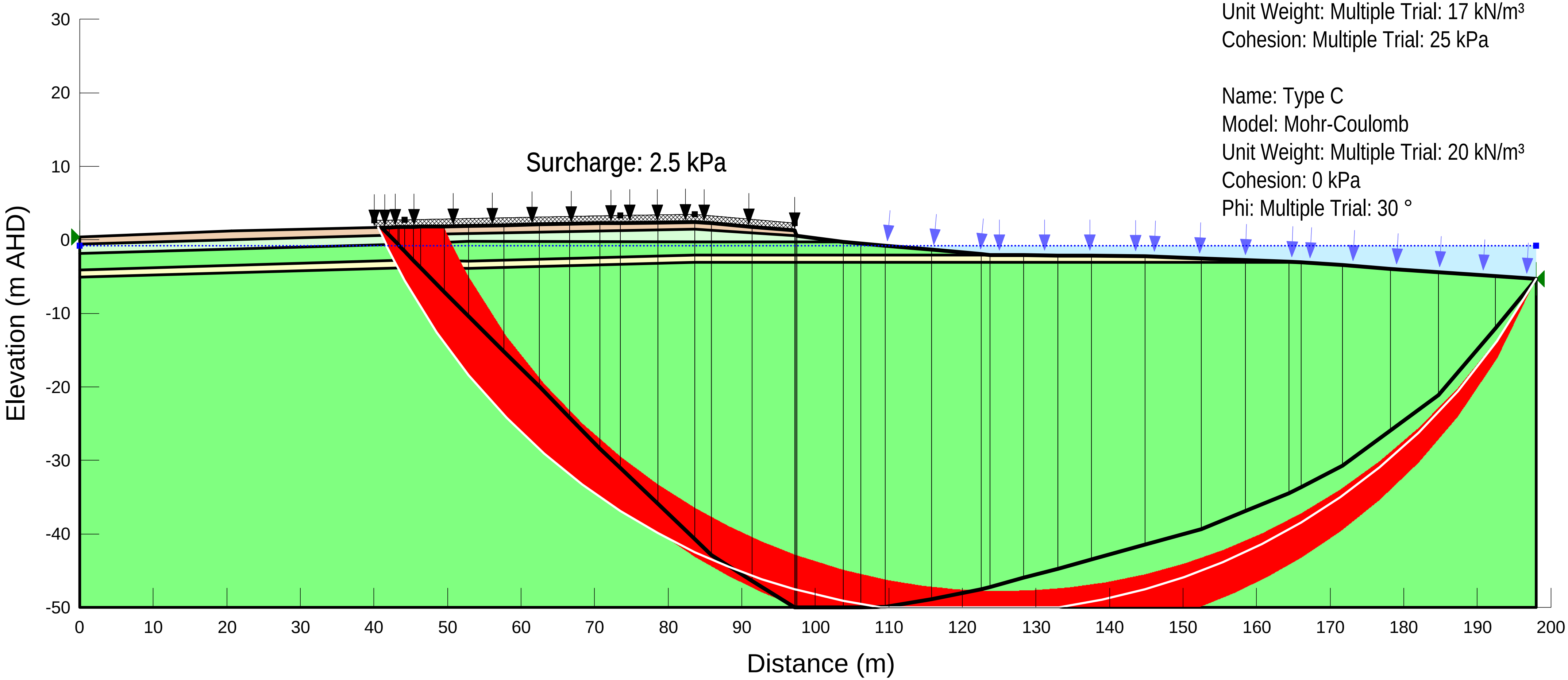



**Figure 20**

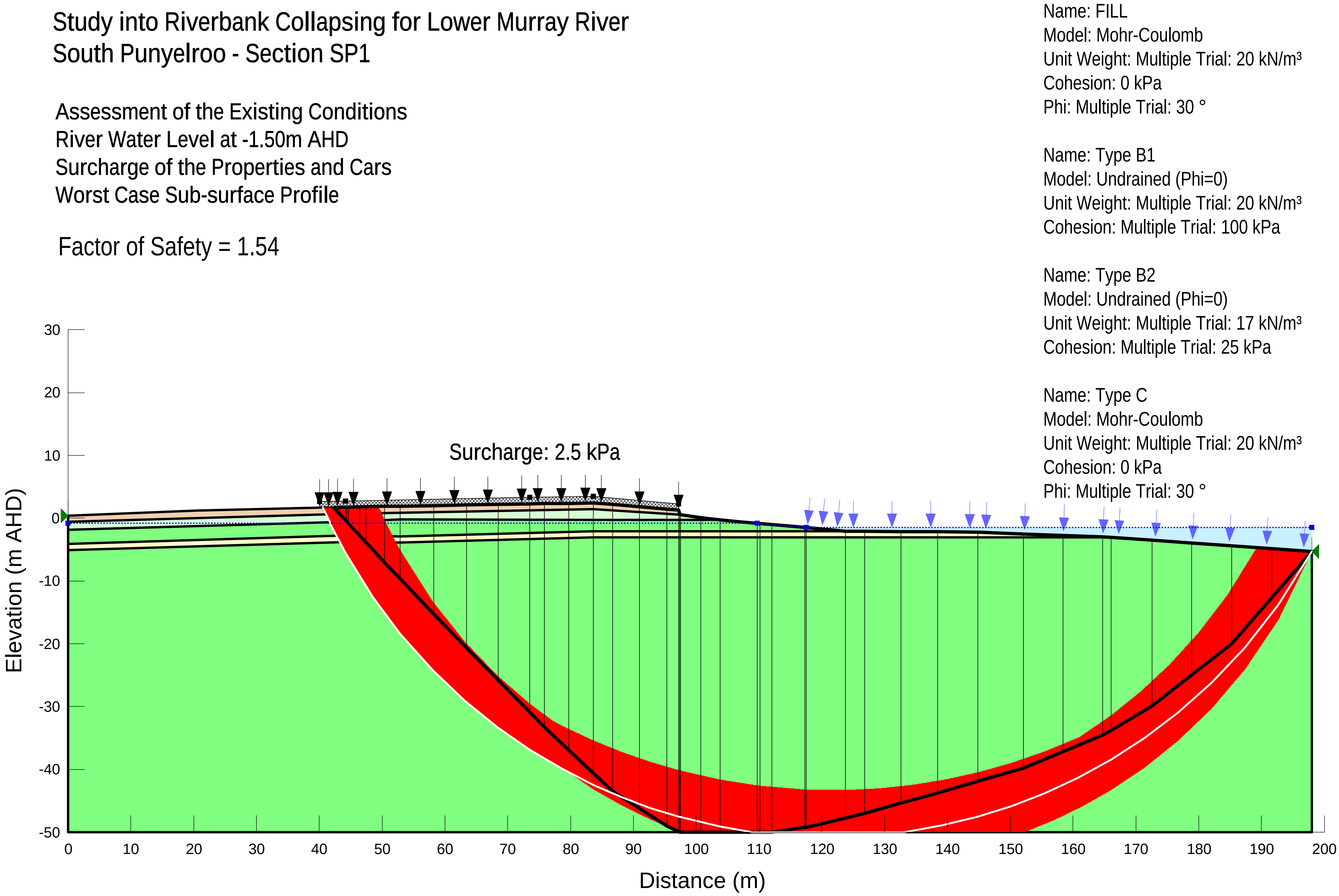

Study into Riverbank Collapsing for Lower Murray River
South Punyelroo - Section SP1
Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars
Worst Case Sub-surface Profile
Factor of Safety = 1.54
Name: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 100 kPa
Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 25 kPa
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °
Surcharge: 2.5 kPa
Elevation (m AHD)
30
20
10
0
-10
-20
-30
-40
-50
Distance (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

**Figure 21**

Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF1

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.30

Name: FILL A1
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 32 °

Name: FILL A2
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 21 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 35 °

Name: Type B
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Rock
Model: Bedrock (Impenetrable)

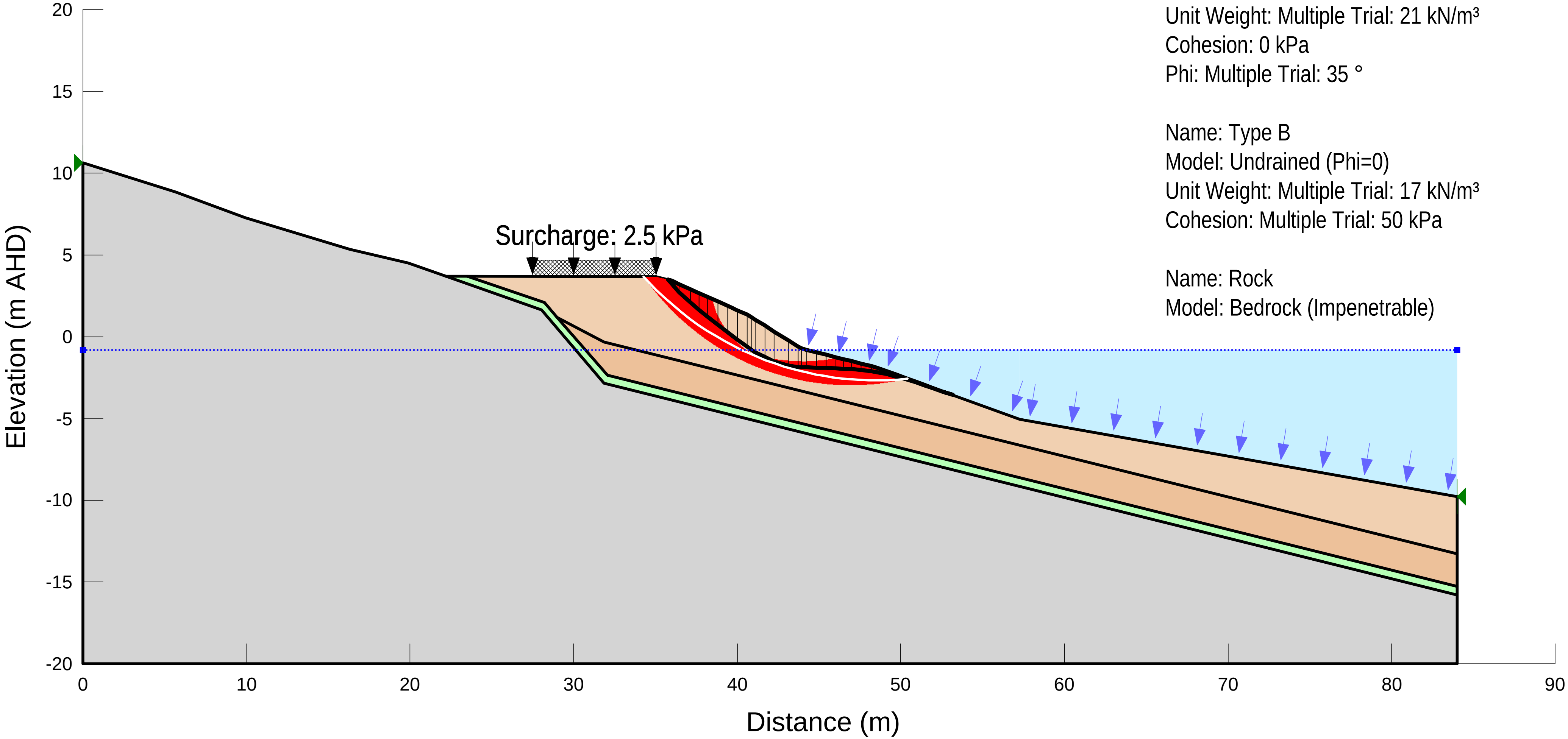
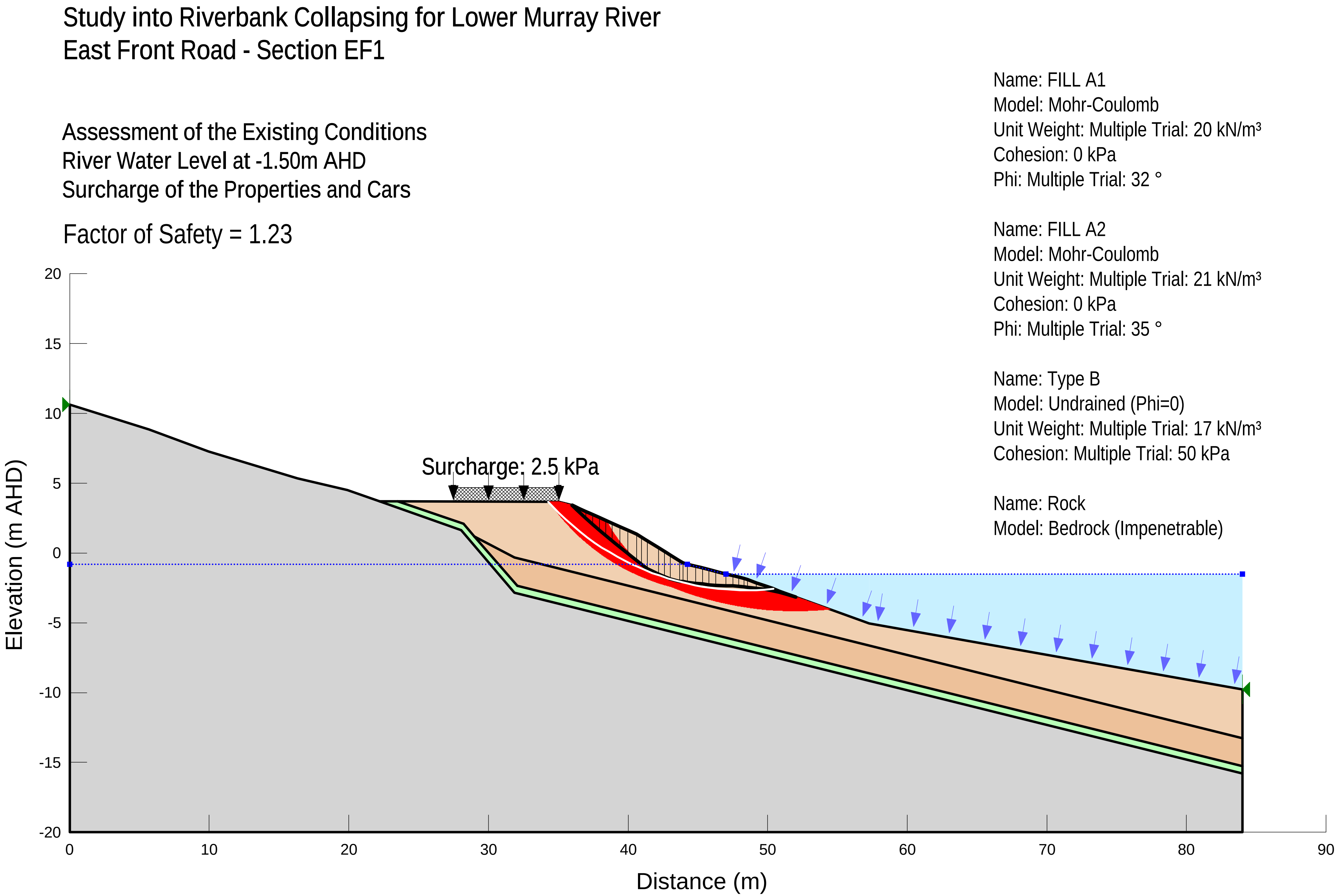



**Figure 22**



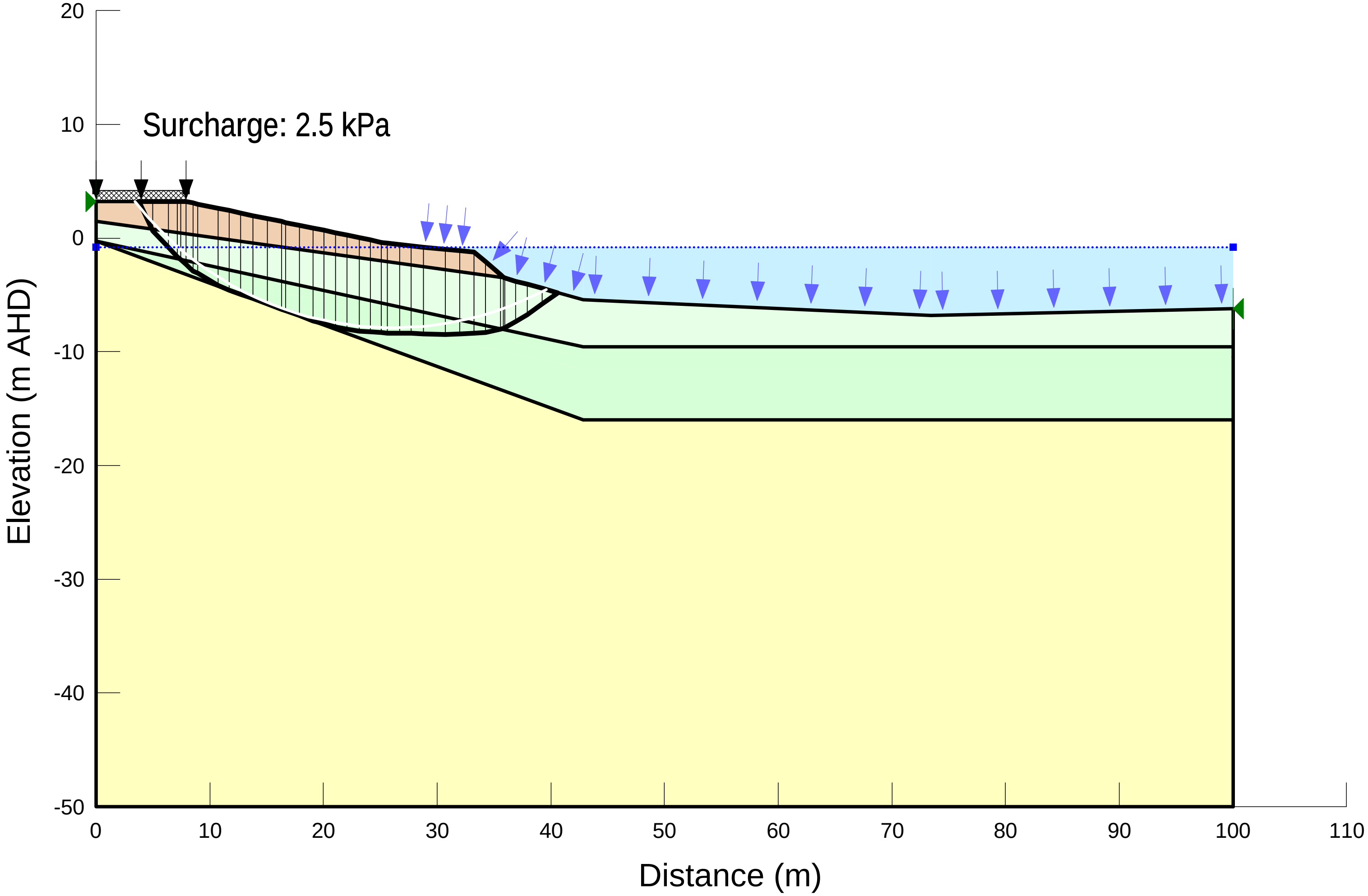
Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF1
Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars
Factor of Safety = 1.23
Name: FILL A1
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 32 °
Name: FILL A2
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 21 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 35 °
Name: Type B
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 50 kPa
Name: Rock
Model: Bedrock (Impenetrable)
Surcharge: 2.5 kPa
Elevation (m AHD)
20
15
10
5
0
-5
-10
-15
-20
0
10
20
30
40
50
60
70
80
90
Distance (m)


**Figure 23**

Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF2

Assessment of the Existing Conditions
River Water Level at -0.80m AHD
Surcharge of the Properties and Cars

Factor of Safety = 1.02




Name: Type A FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 17.5 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 14 kPa

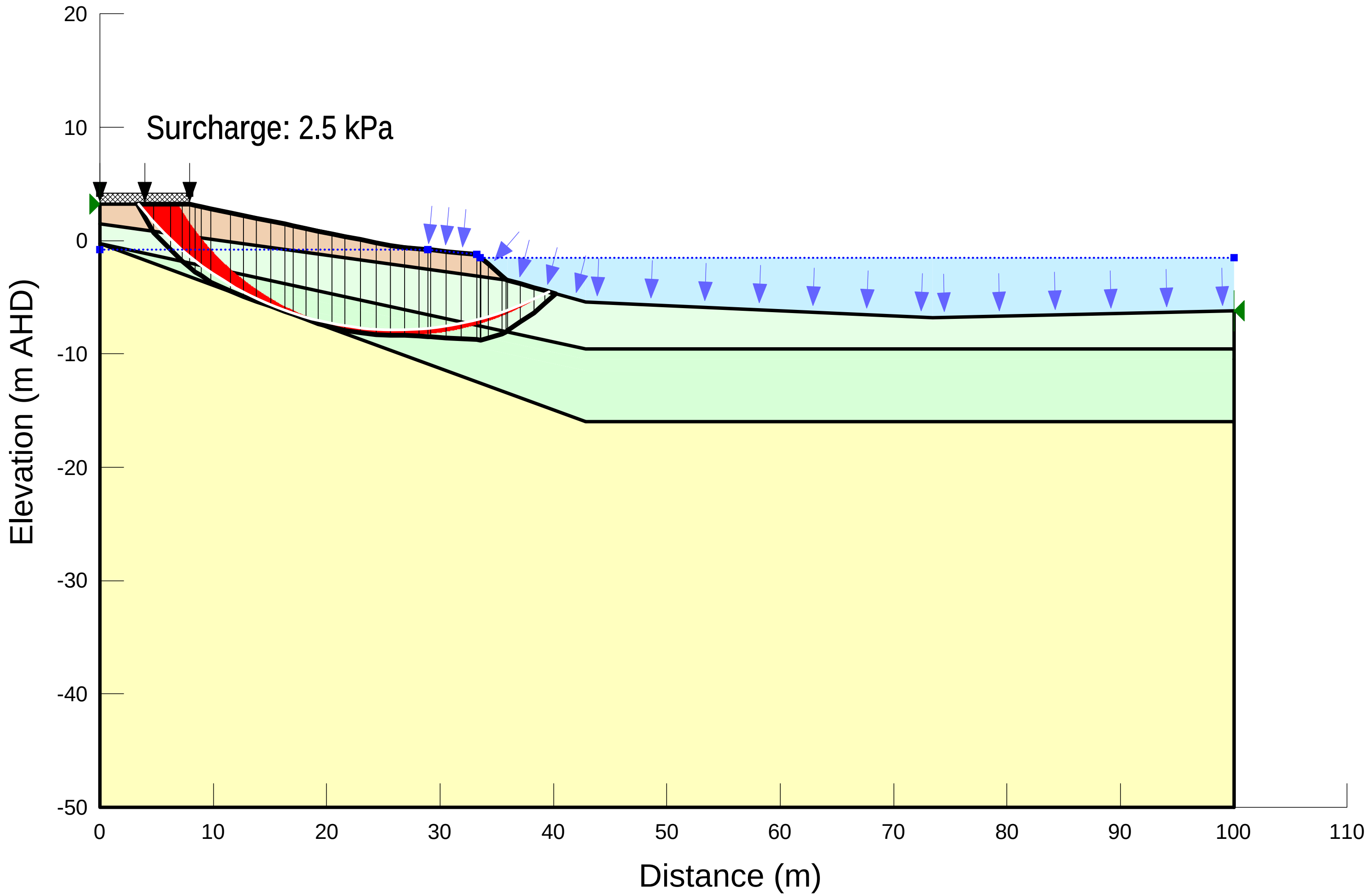
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 24**

Study into Riverbank Collapsing for Lower Murray River
East Front Road - Section EF2

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Properties and Cars

Factor of Safety = 0.95




Name: Type A FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 17.5 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 14 kPa

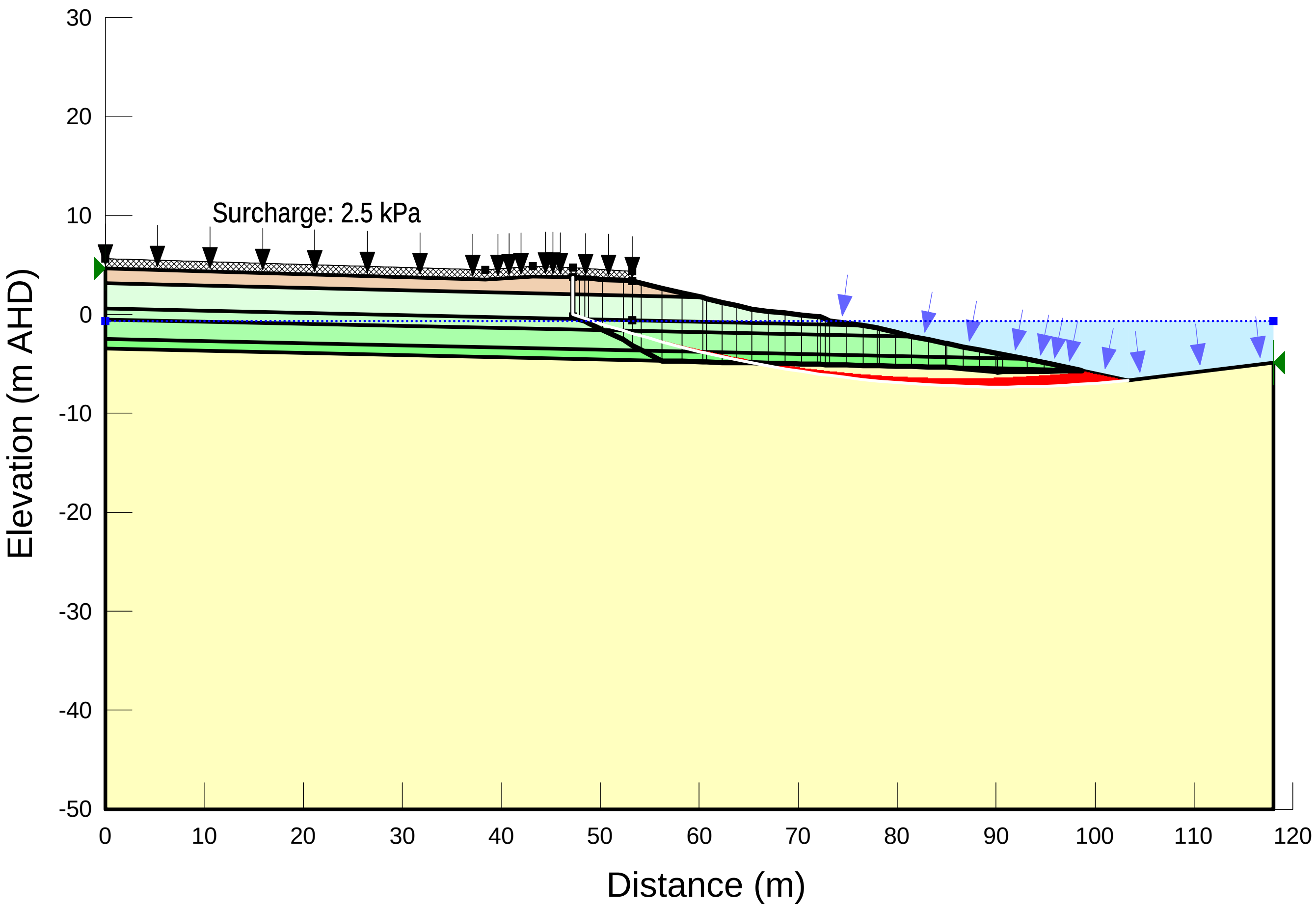
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 25**

Study into Riverbank Collapsing for Lower Murray River
Swan Reach - Section SW1

Assessment of the Existing Conditions
River Water Level at -0.70m AHD
Surcharge of the Structures and Cars
With 4m Deep Tension Crack

Factor of Safety = 1.68




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 250 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 18 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 12.5 kPa

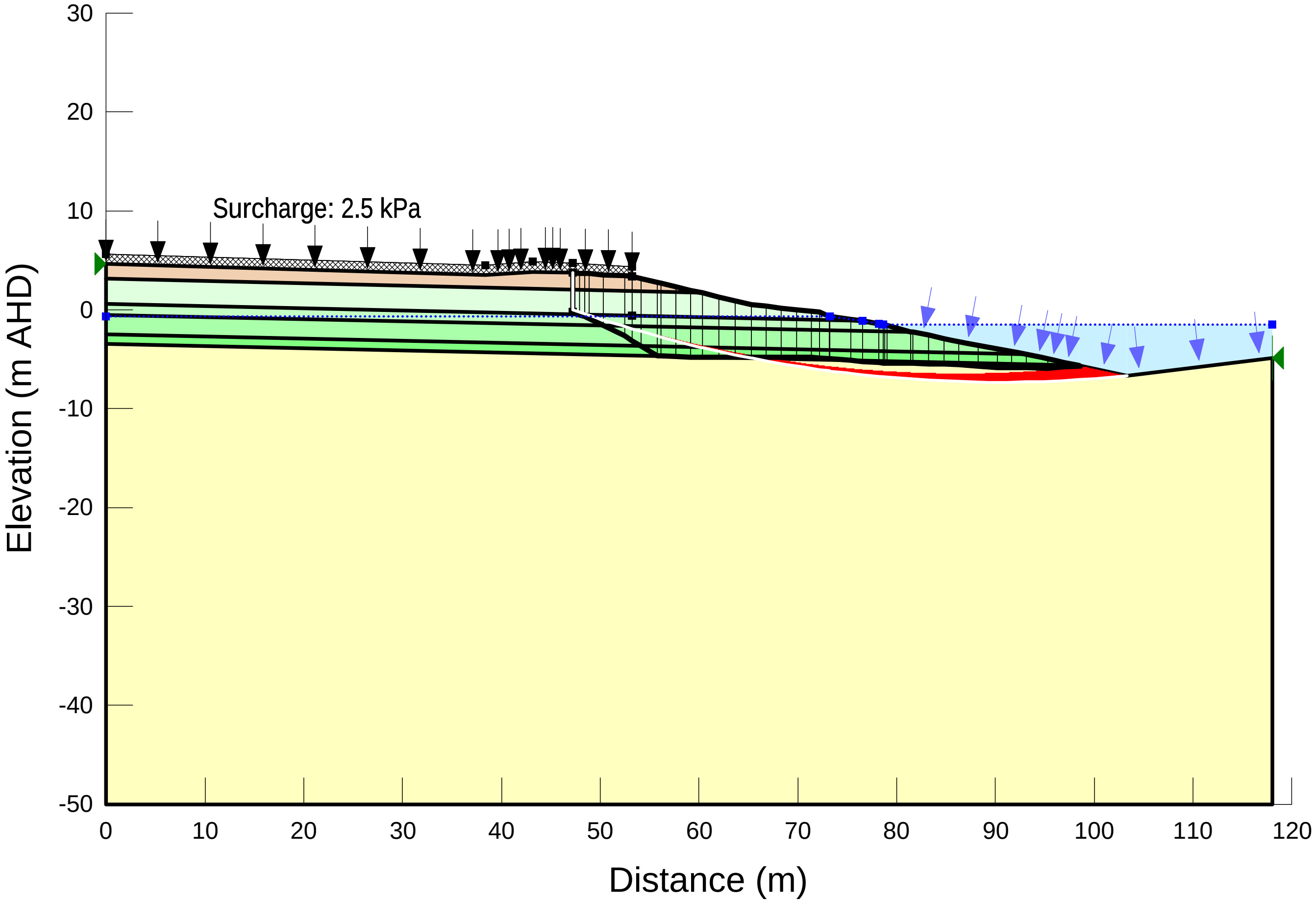
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 26**

# Study into Riverbank Collapsing for Lower Murray River
# Swan Reach - Section SW1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Structures and Cars
With 4m Deep Tension Crack

## Factor of Safety = 1.70




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 250 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 18 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 18 kN/m³
Cohesion: Multiple Trial: 12.5 kPa

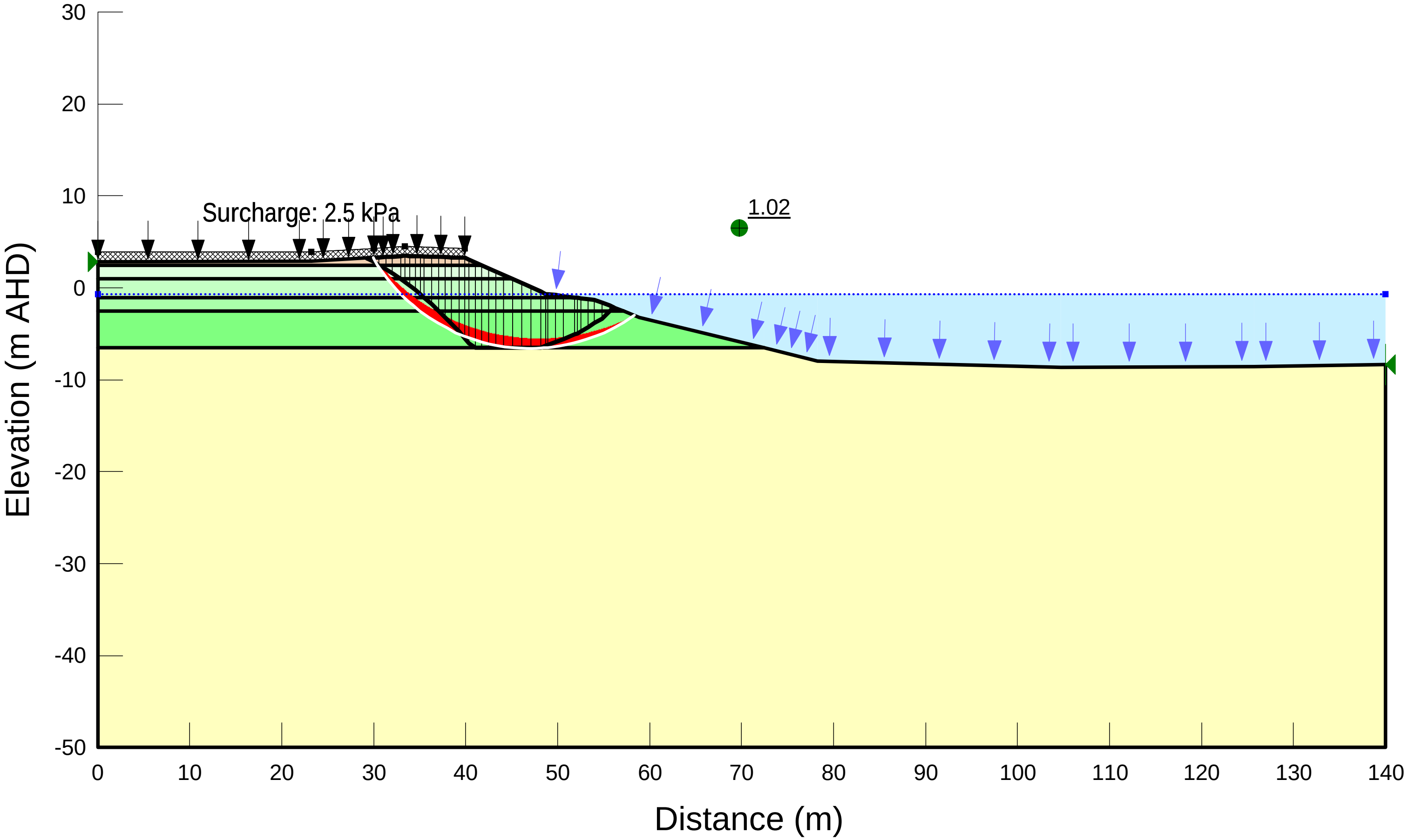
Name: Type C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

**Figure 27**

Study into Riverbank Collapsing for Lower Murray River
Walker Flat - Section WF1

Assessment of the Existing Conditions
River Water Level at -0.70m AHD
Surcharge of the Structures and Cars

Factor of Safety = 1.02




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 70 kPa

Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

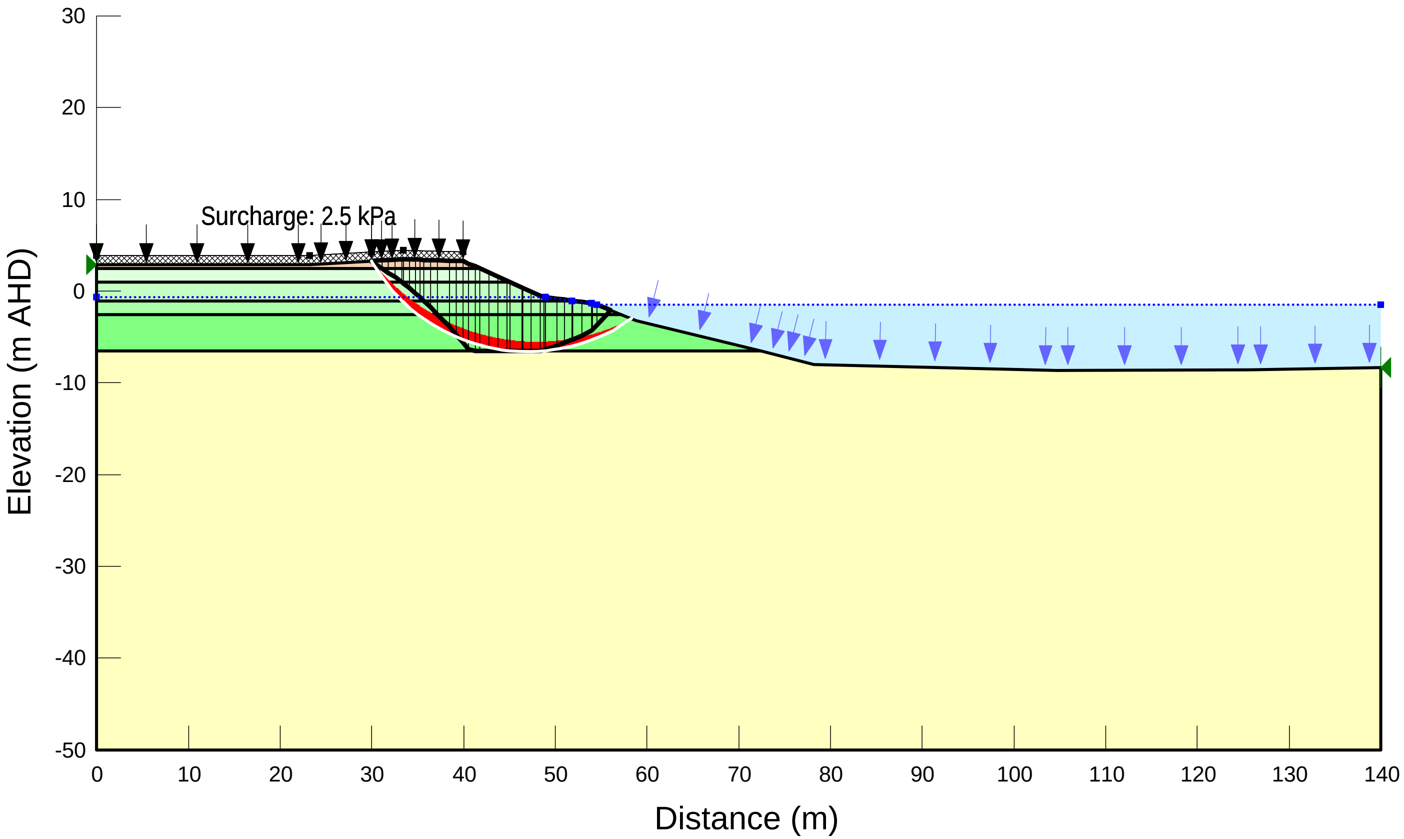
Name: Type B5 / C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Figure 28

Study into Riverbank Collapsing for Lower Murray River
Walker Flat - Section WF1

Assessment of the Existing Conditions
River Water Level at -1.50m AHD
Surcharge of the Structures and Cars

Factor of Safety = 0.94




Name: Type A: FILL
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 30 °

Name: Type B1
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 70 kPa

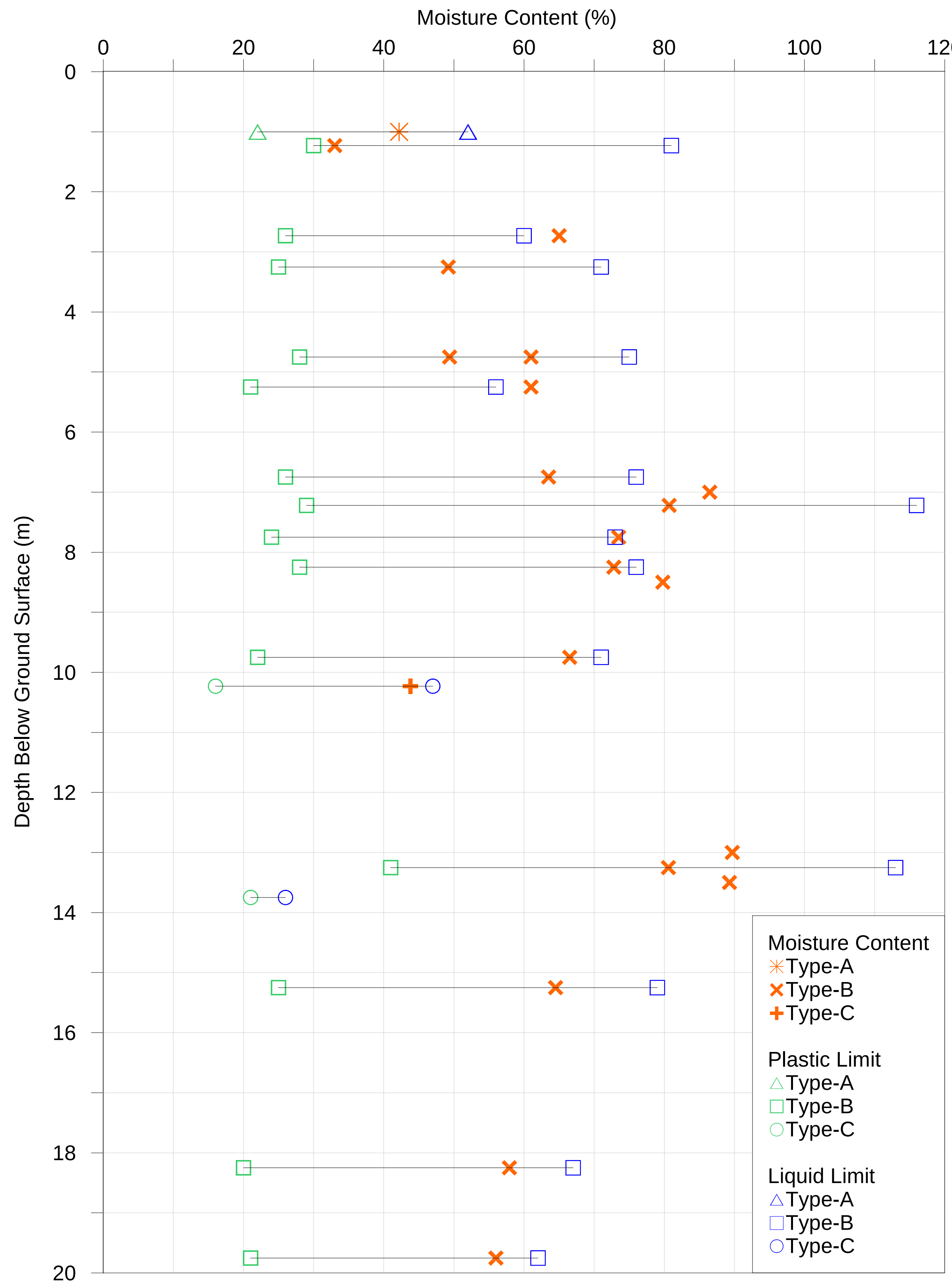
Name: Type B2
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 19 kN/m³
Cohesion: Multiple Trial: 50 kPa

Name: Type B3
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

Name: Type B4
Model: Undrained (Phi=0)
Unit Weight: Multiple Trial: 17 kN/m³
Cohesion: Multiple Trial: 15 kPa

Name: Type B5 / C
Model: Mohr-Coulomb
Unit Weight: Multiple Trial: 20 kN/m³
Cohesion: 0 kPa
Phi: Multiple Trial: 31 °

Figure 29




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE<br>*Murray Riverbank Geotechnical Investigation*<br>**Moisture Content and Atterberg Limits Profile** |
| | Approved: | NR | |
| | Date: | 08/12/09 | |
| JOB No: VW04794 | Revision: | A | |

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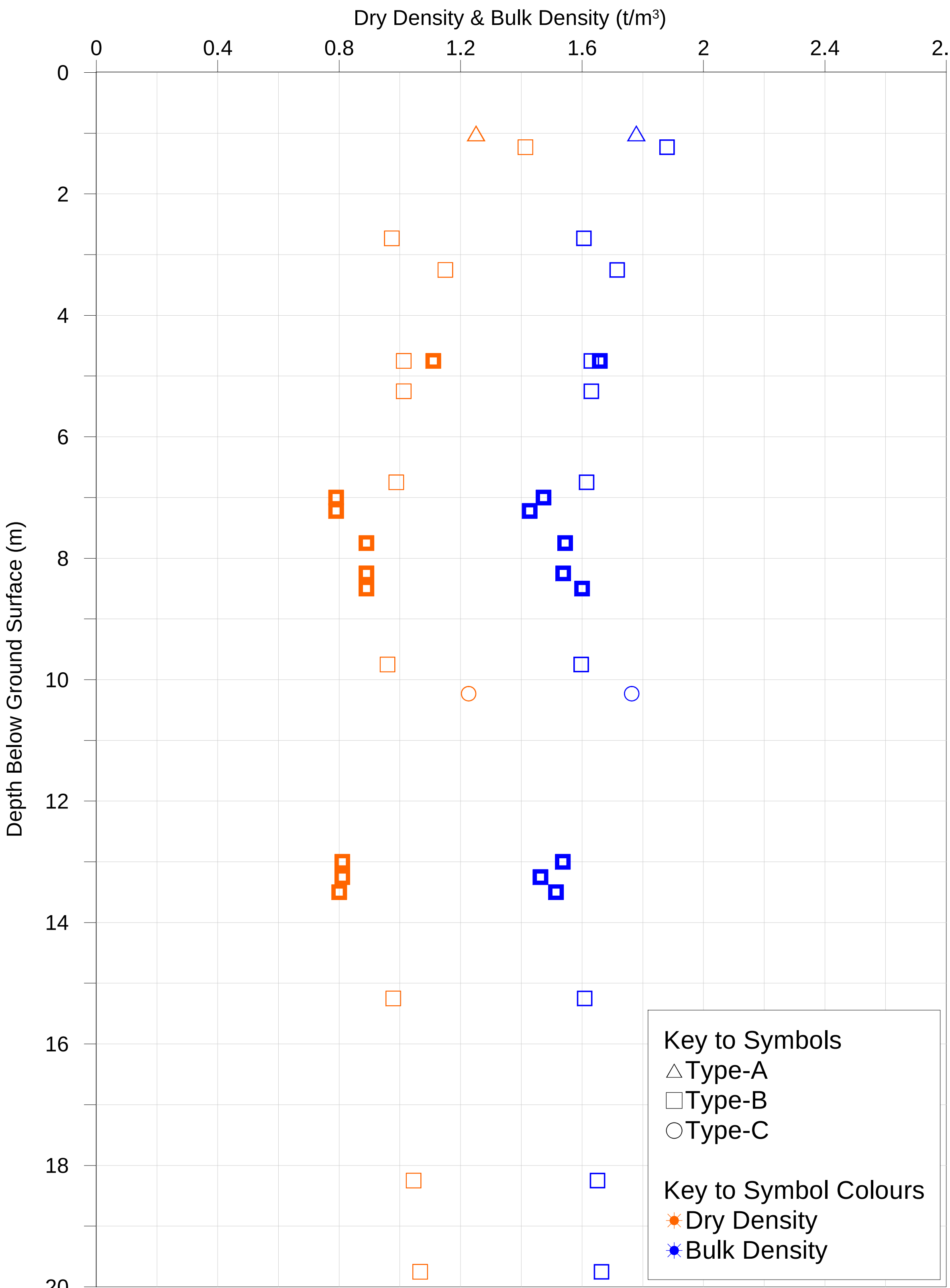
Department of Water, Land and Biodiversity Conservation

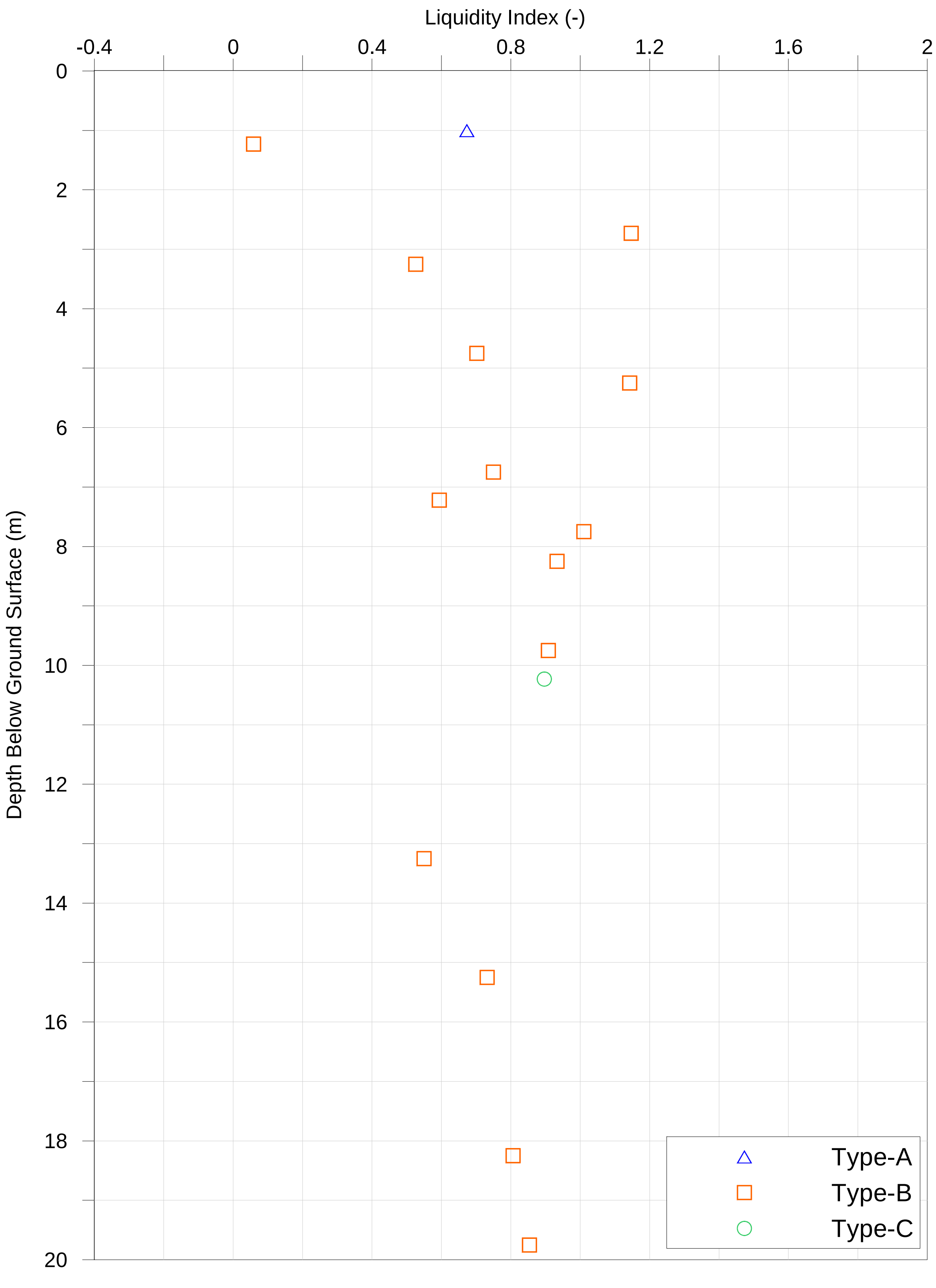
**Figure 30**




Note: Measured values shown in bold type

| SKM | Drawn: | MT | STURT RESERVE<br>*Murray Riverbank Geotechnical Investigation*<br>**Dry Density & Bulk Density Profile** | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |
|---|---|---|---|---|
| | Approved: | NR | | |
| | Date: | 08/12/09 | | |
| JOB No: VW04794 | Revision: | A | | |

**Figure 31**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Liquidity Profile** |
| JOB No: VW04794 | Revision: | A | |

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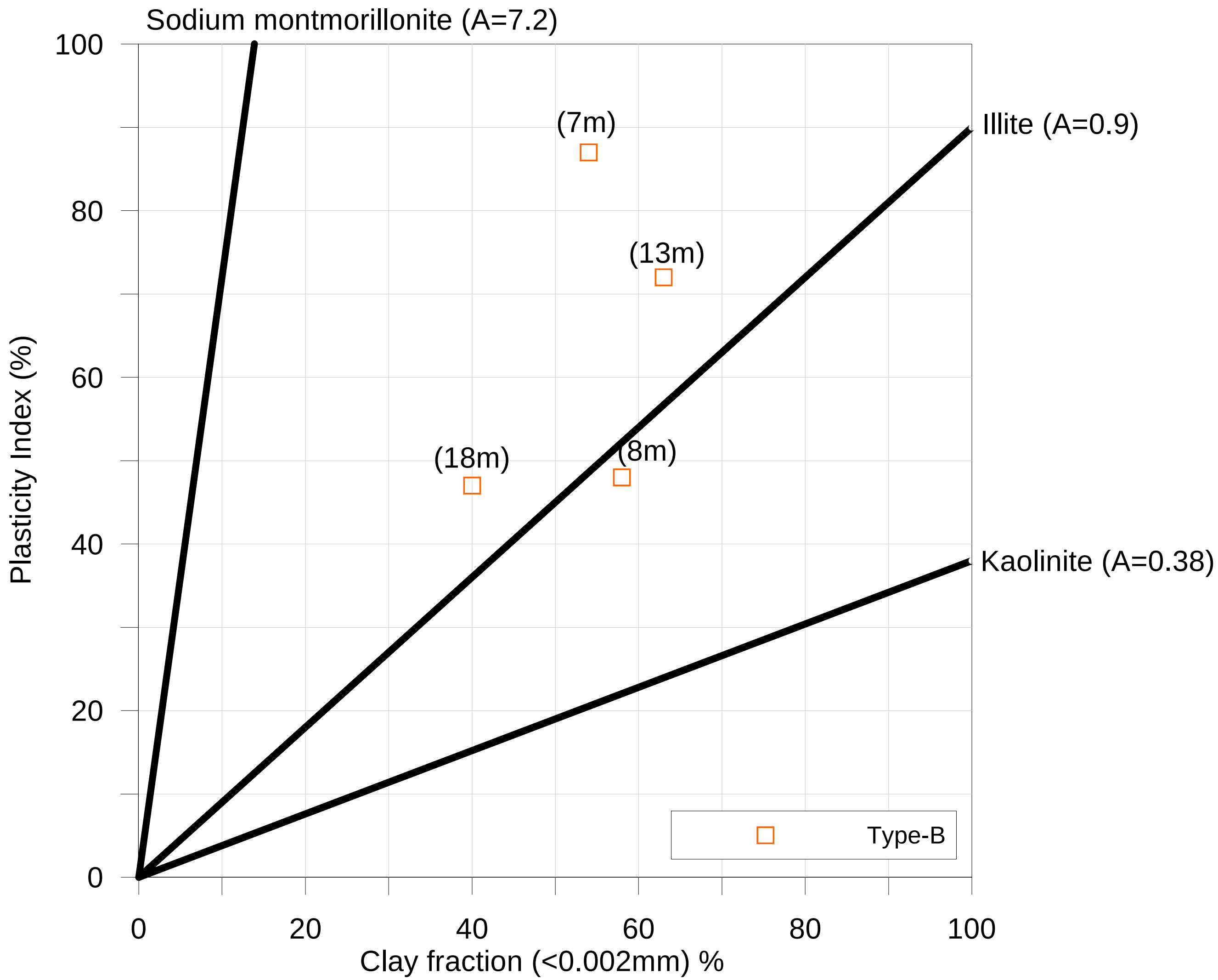
Department of Water, Land and Biodiversity Conservation

**Figure 32**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE<br>*Murray Riverbank Geotechnical Investigation*<br><br>Activity Plot |
| | Approved: | NR | |
| | Date: | 08/12/09 | |
| JOB No: VW04794 | Revision: | A | |

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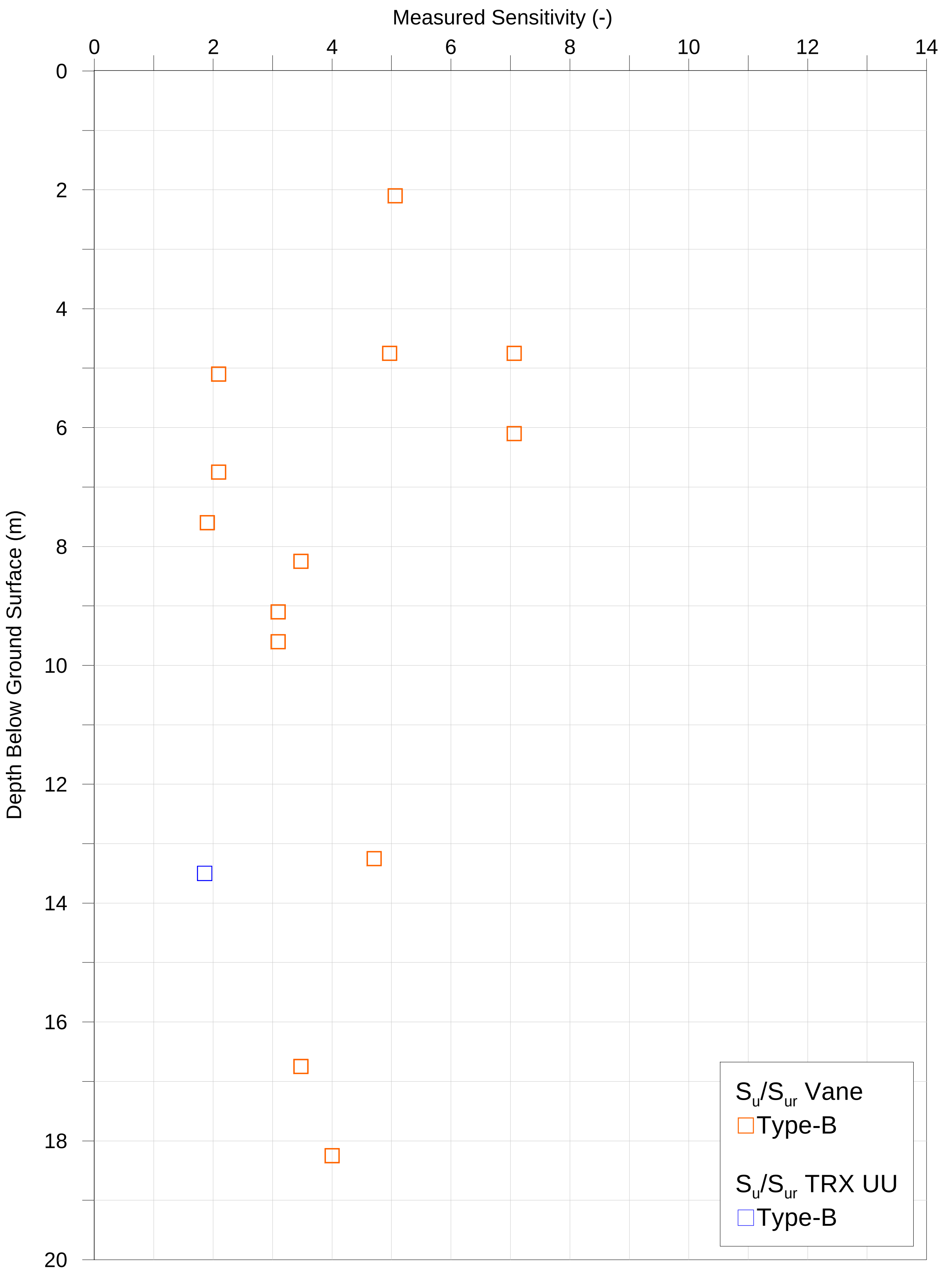
**Figure 33**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Sensitivity Profile** |
| JOB No: VW04794 | Revision: | A | |

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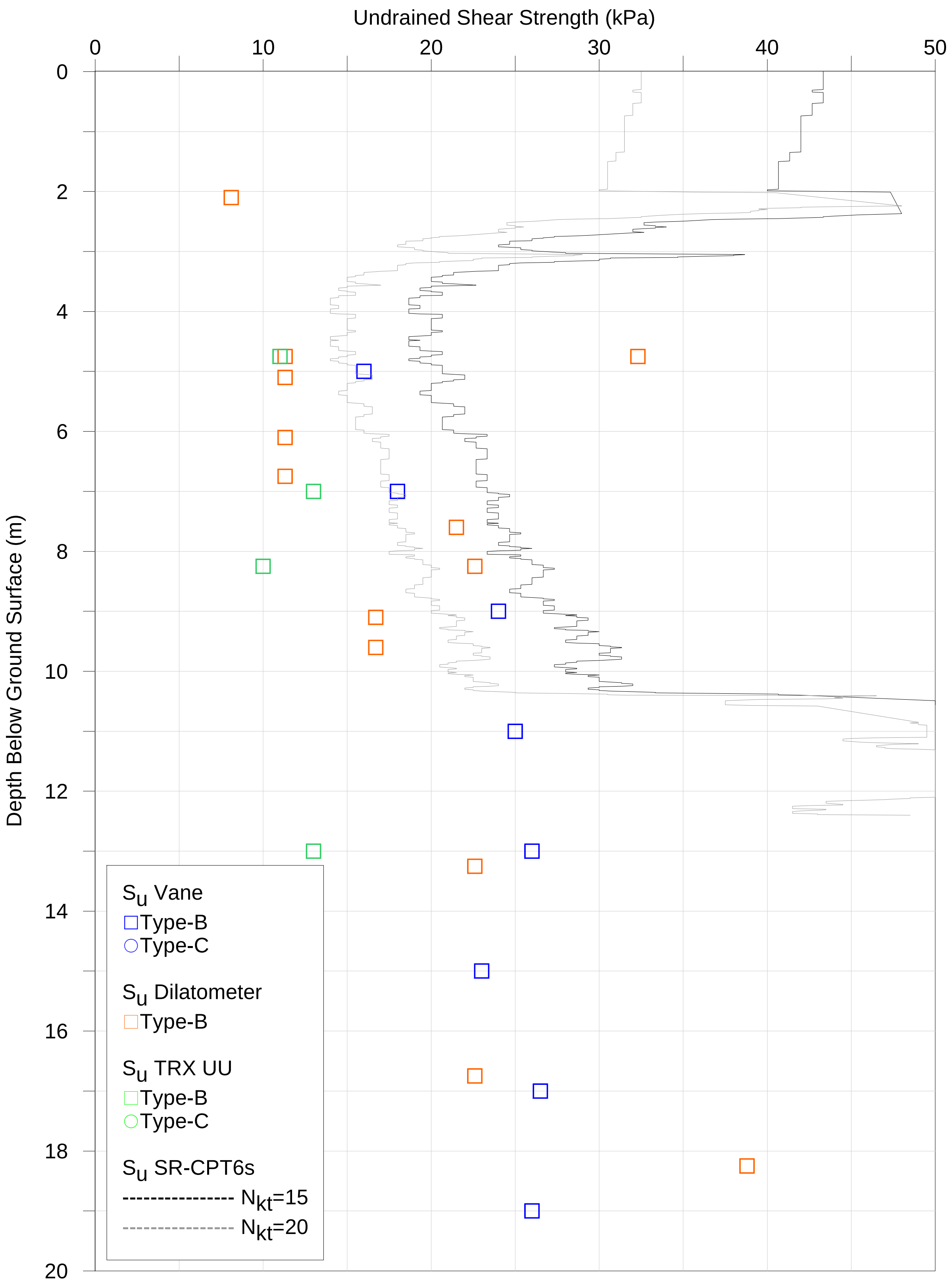
**Figure 34**

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|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Undrained Shear Strength vs Depth** |
| JOB No: VW04794 | Revision: | A | |

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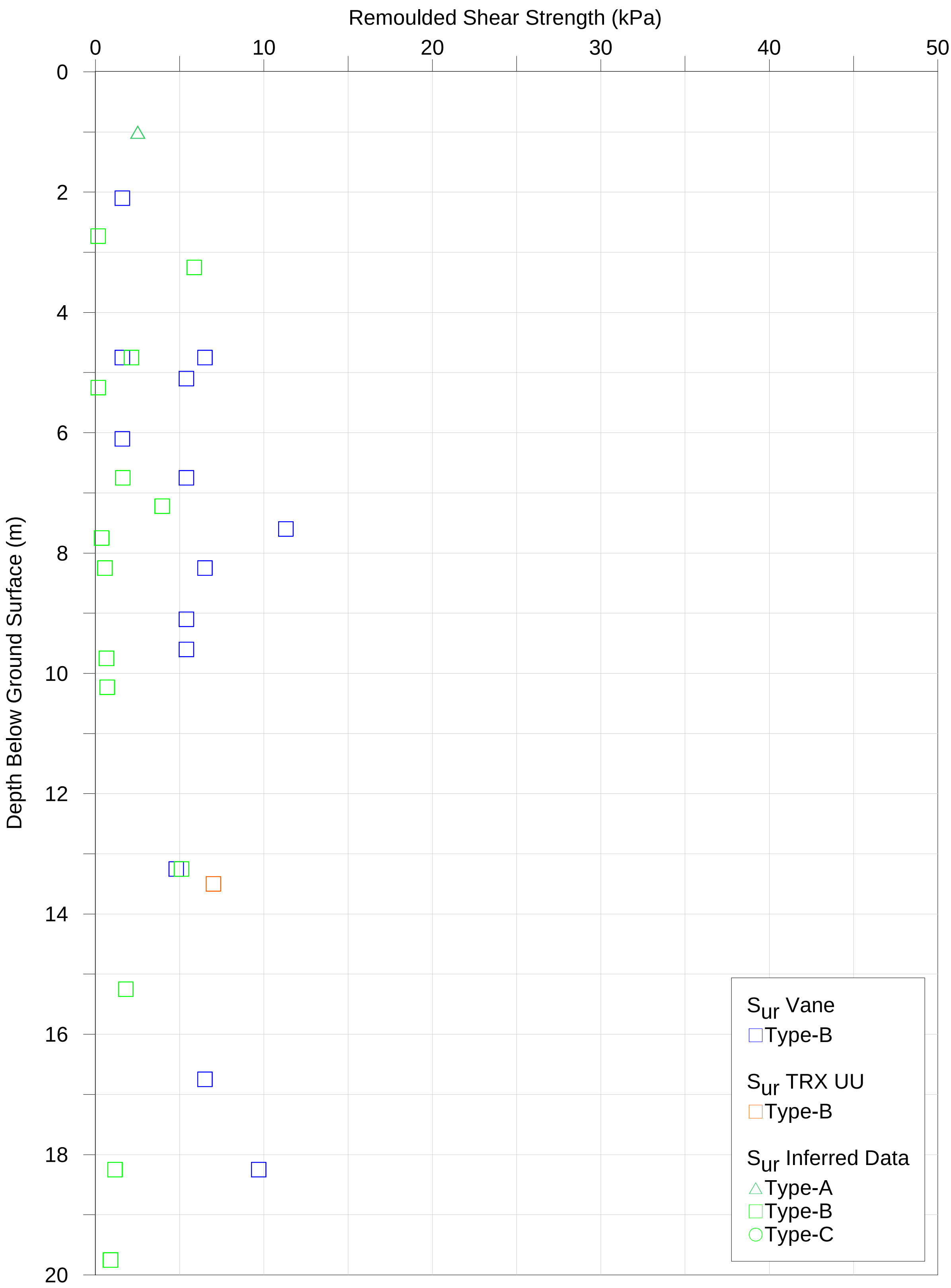
**Figure 35**

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|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE<br>*Murray Riverbank Geotechnical Investigation*<br>**Remoulded Shear Strength vs Depth** |
| | Approved: | NR | |
| | Date: | 08/12/09 | |
| JOB No: VW04794 | Revision: | A | |

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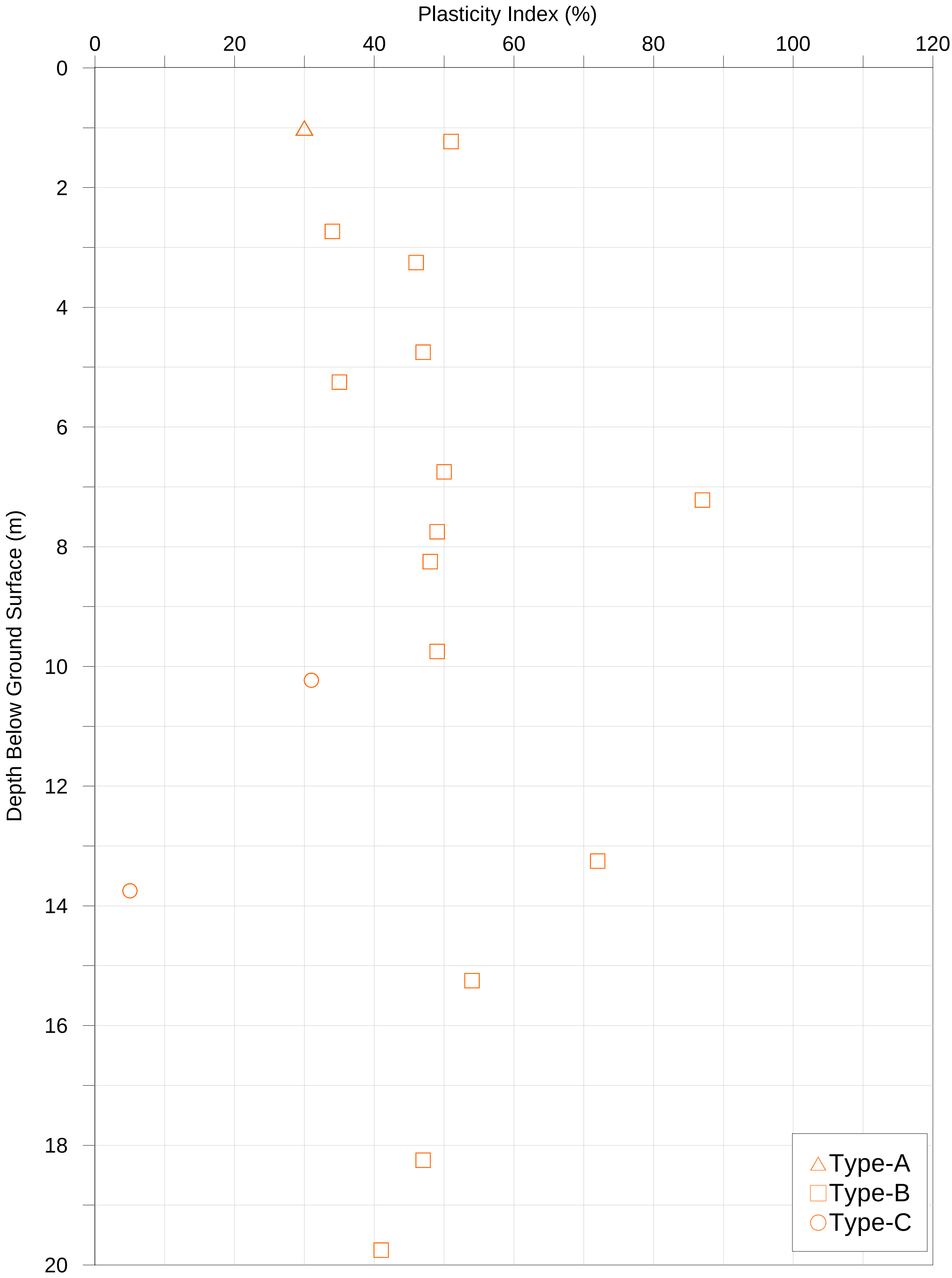
**Figure 36**

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|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Plasticity Index Profile** |
| JOB No: VW04794 | Revision: | A | |

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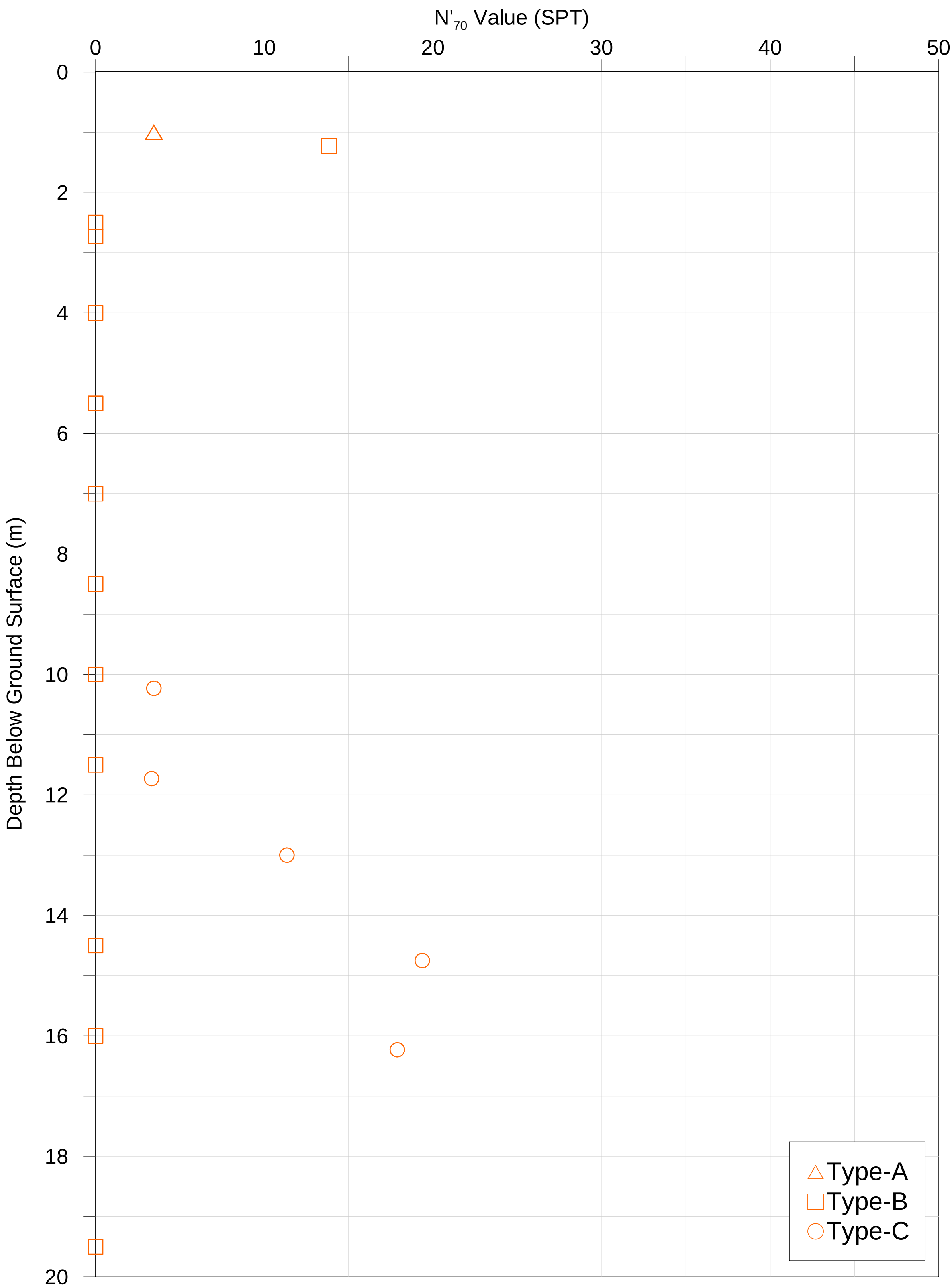
**Figure 37**

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|---|---|---|---|
| SKM | Drawn: | MT | STURT RESERVE<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **N'$_{70}$ Value (SPT) Profile** |
| JOB No: VW04794 | Revision: | A | |

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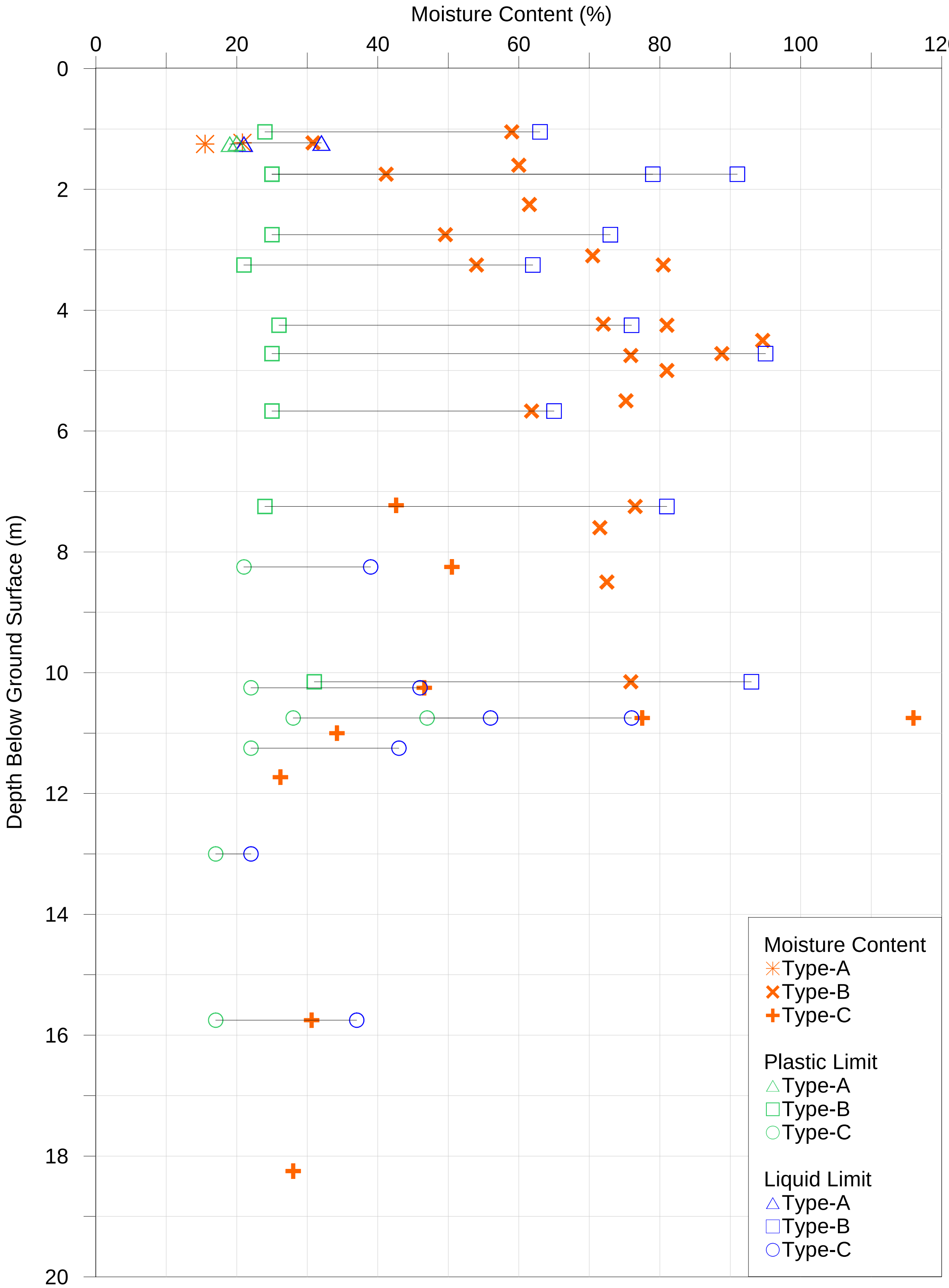
**Figure 38**




SKM

JOB No: VW04794

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|---|---|
| Drawn: | MT |
| Approved: | NR |
| Date: | 08/12/09 |
| Revision: | A |

CALOOTE
*Murray Riverbank Geotechnical Investigation*

**Moisture Content and Atterberg Limits Profile**

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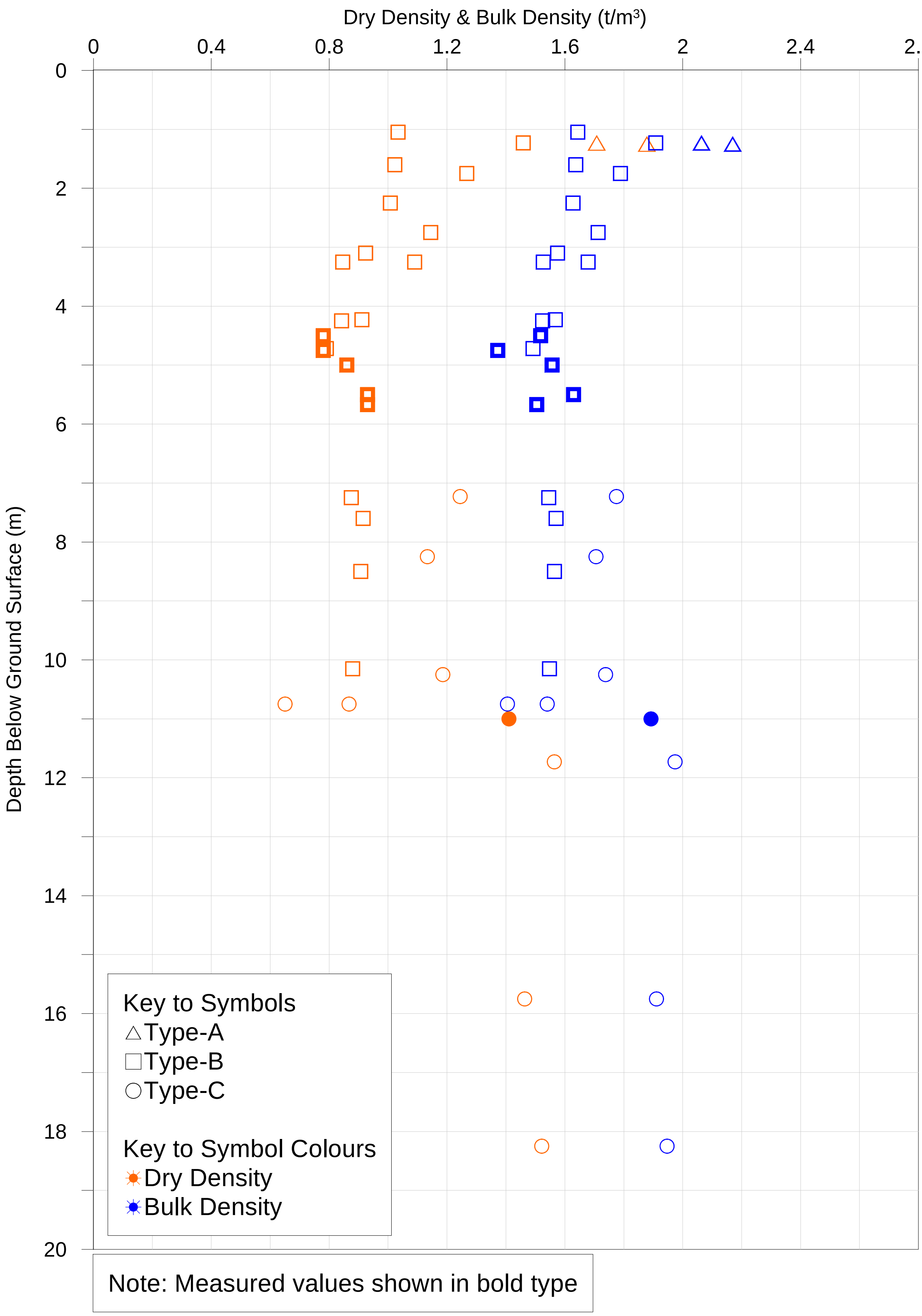
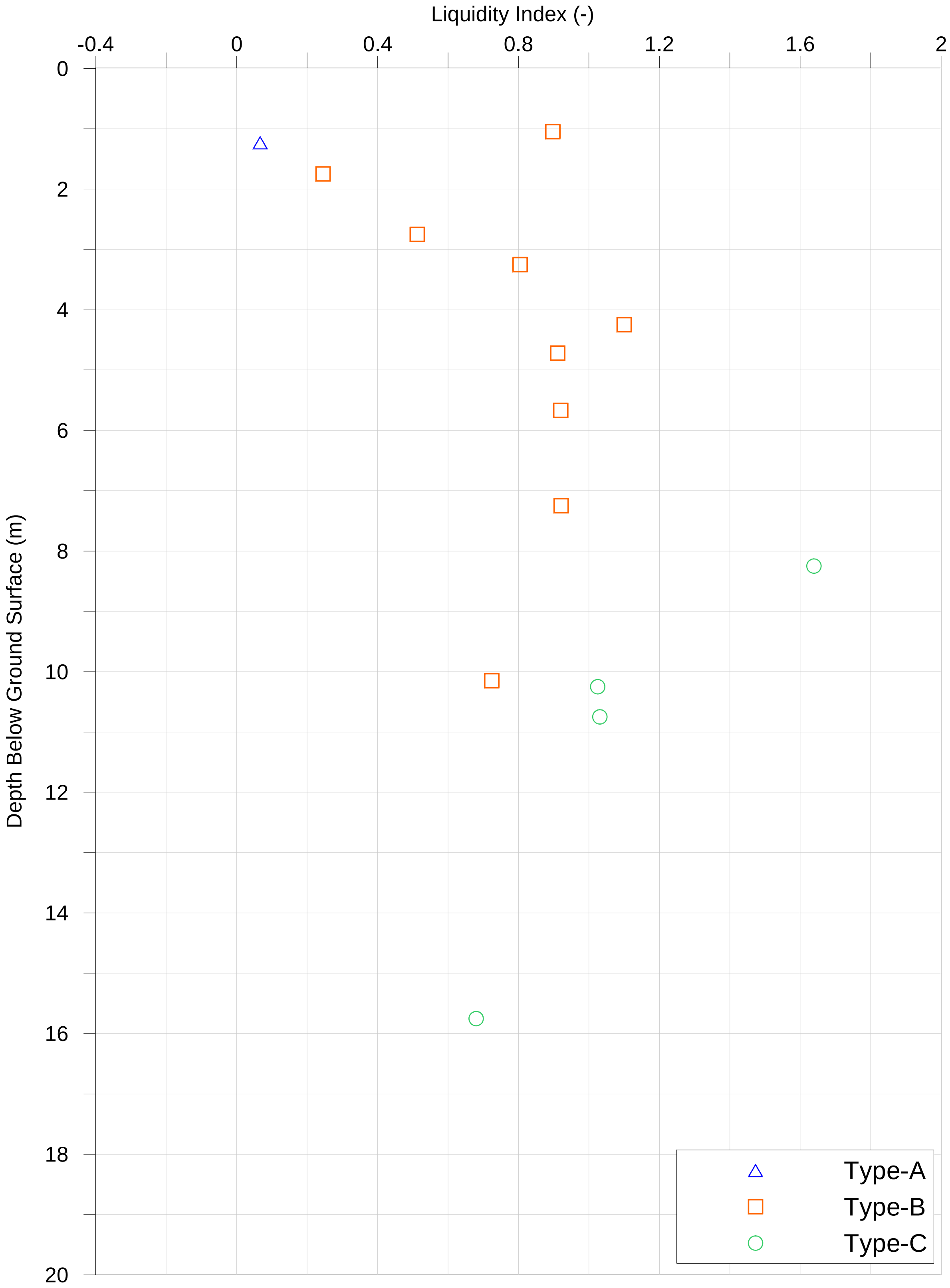
Department of Water, Land and Biodiversity Conservation

**Figure 39**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Dry Density & Bulk Density Profile** |
| JOB No: VW04794 | Revision: | A | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |

**Figure 40**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Liquidity Profile** |
| JOB No: VW04794 | Revision: | A | |

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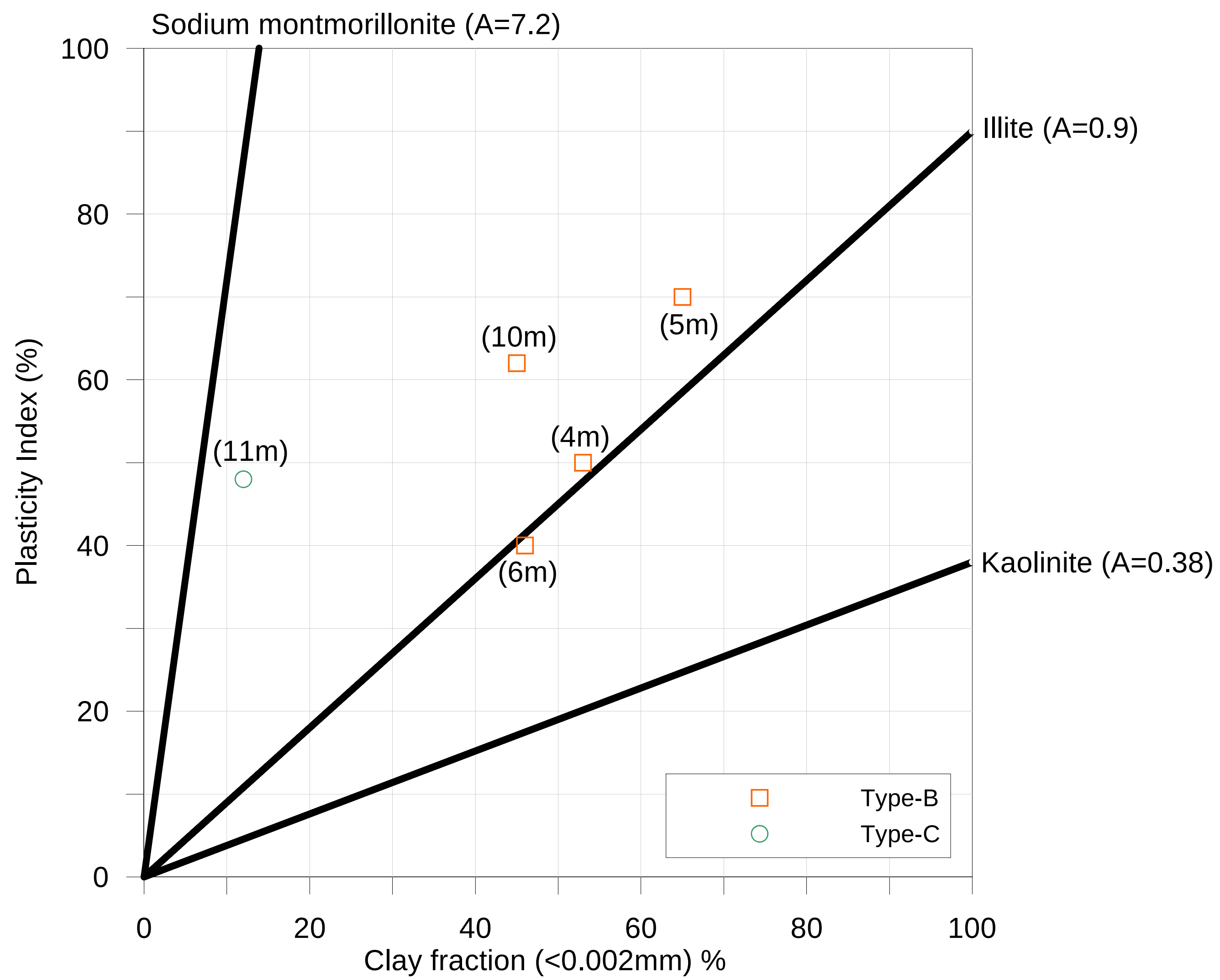
**Figure 41**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE<br>*Murray Riverbank Geotechnical Investigation*<br><br>Activity Plot |
| | Approved: | NR | |
| | Date: | 08/12/09 | |
| JOB No: VW04794 | Revision: | A | |

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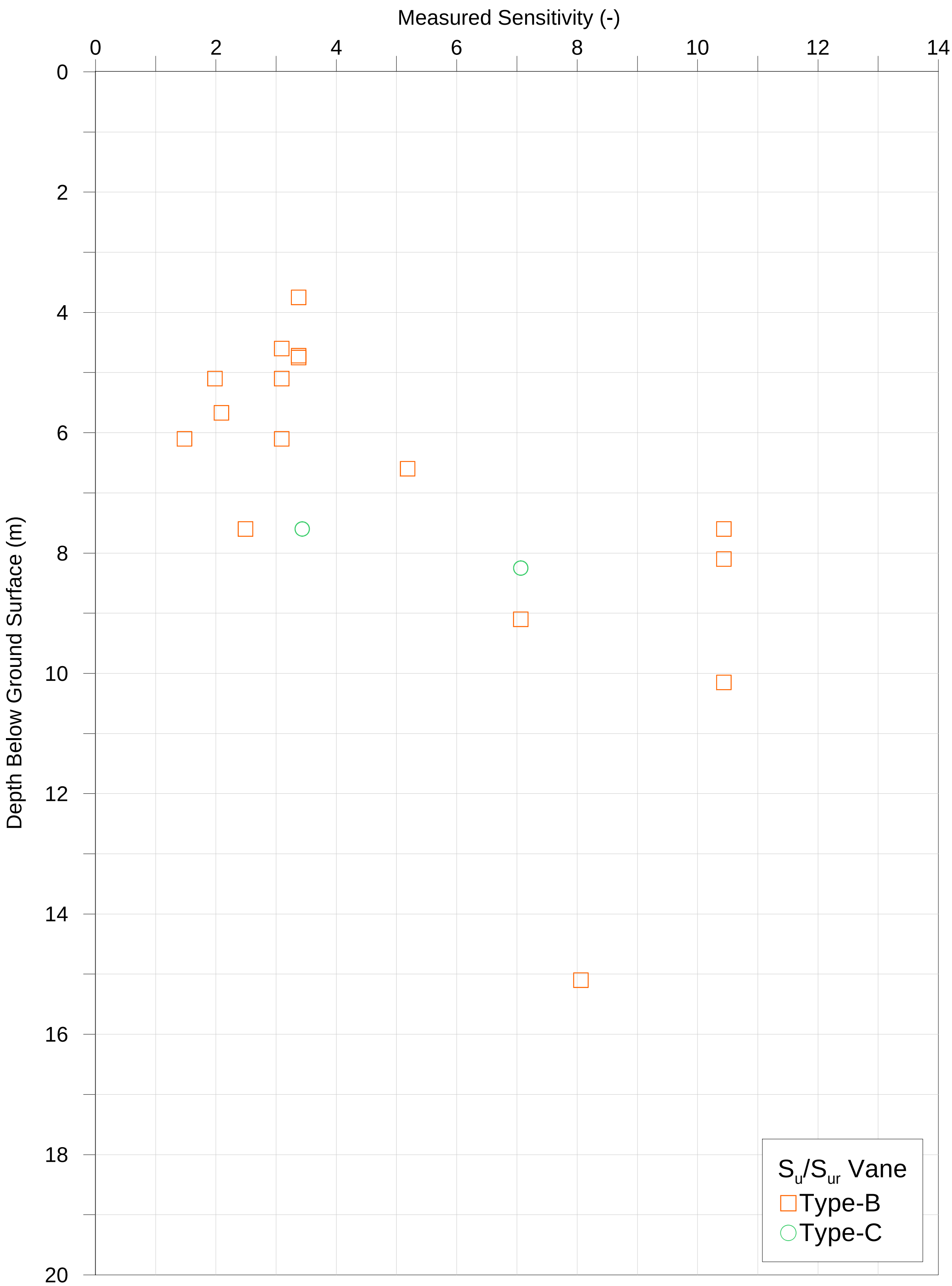
**Figure 42**

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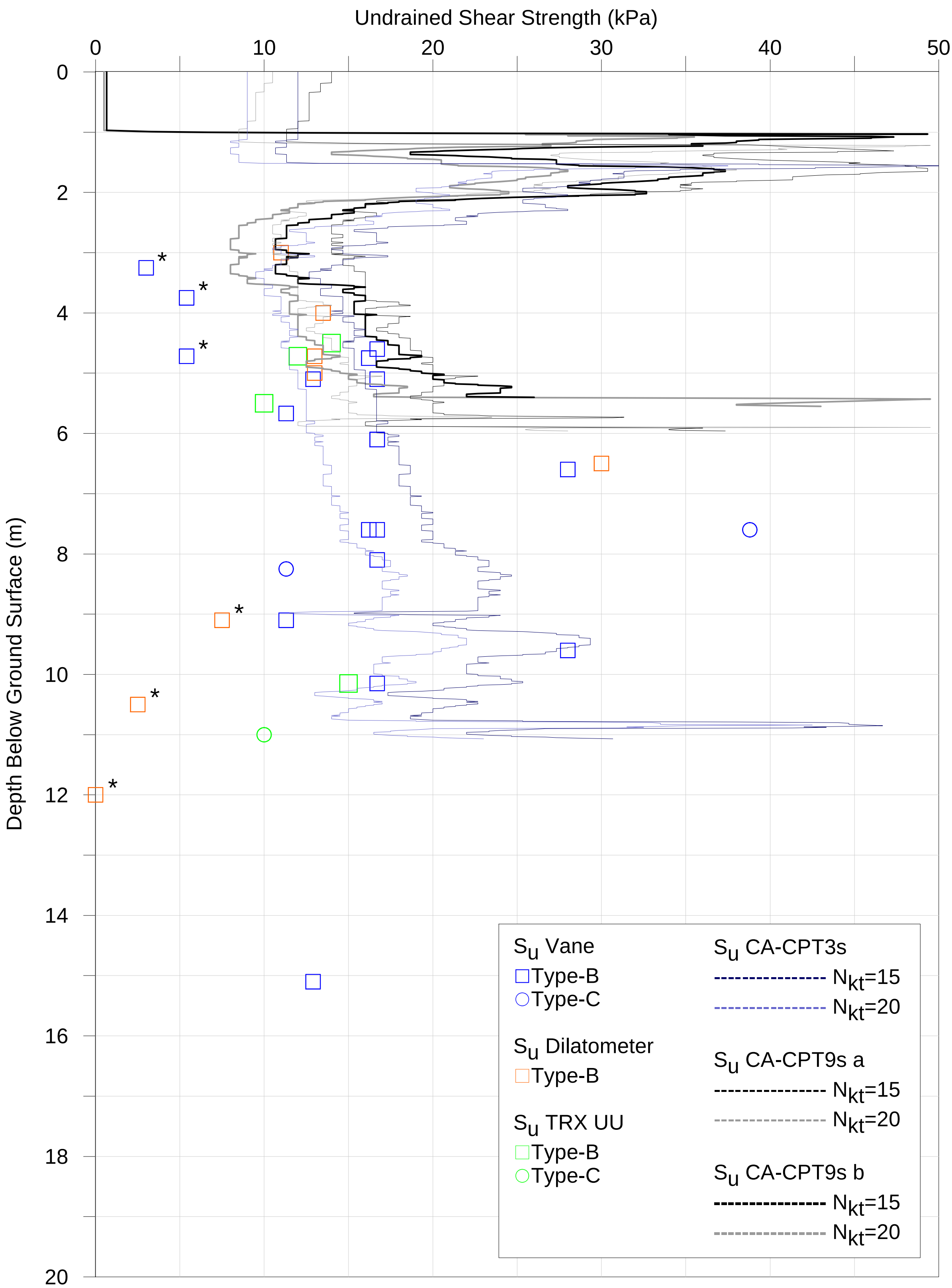
|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Sensitivity Profile** |
| JOB No: VW04794 | Revision: | A | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |

**Figure 43**




* Refer to text for discussion regarding this result

| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE<br>*Murray Riverbank Geotechnical Investigation*<br><br>**Undrained Shear Strength vs Depth** |
| | Approved: | NR | |
| | Date: | 08/12/09 | |
| JOB No: VW04794 | Revision: | A | |

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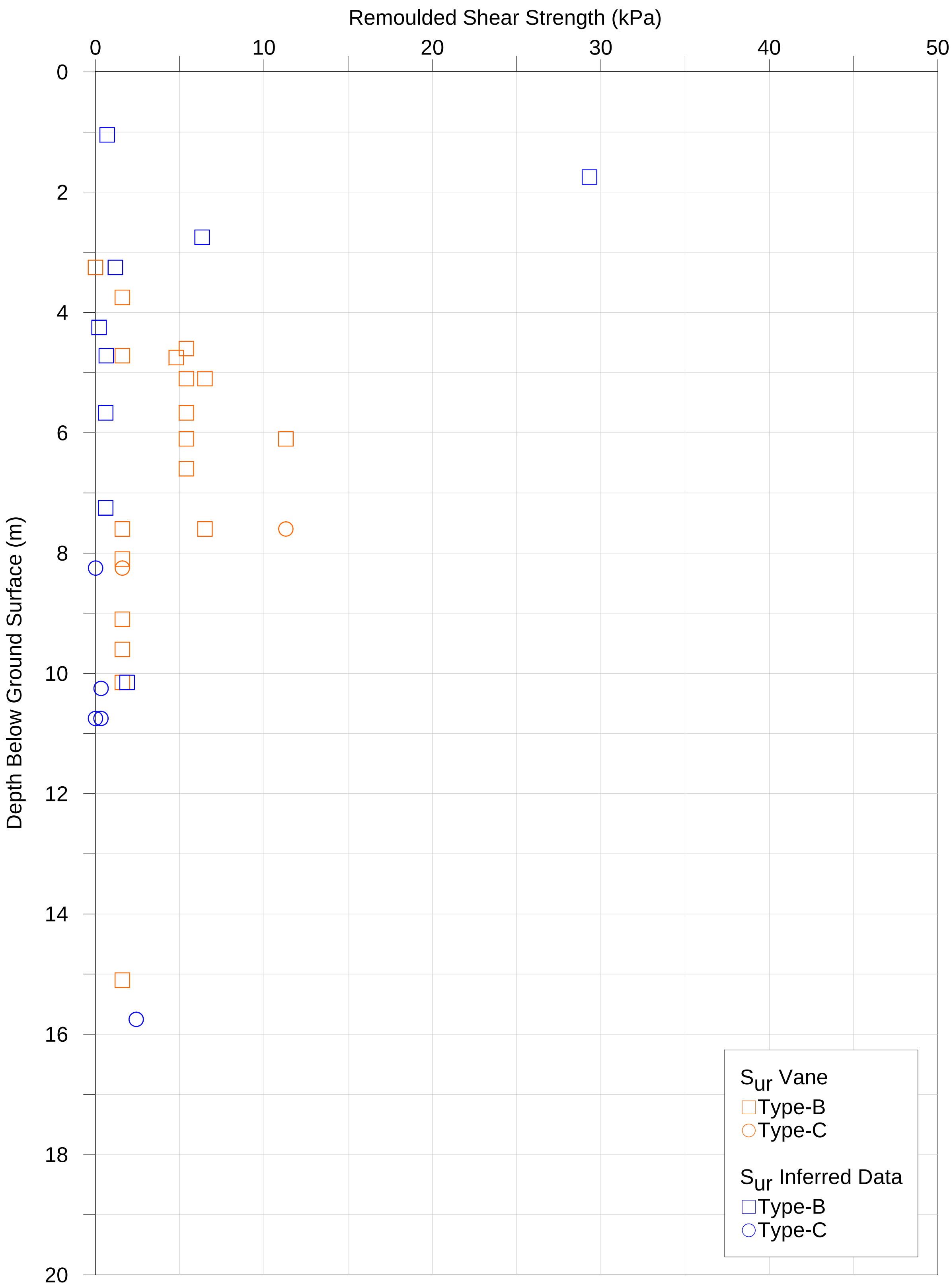
**Figure 44**

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|---|---|---|---|
| SKM | **Drawn:** | **MT** | CALOOTE |
| | **Approved:** | **NR** | *Murray Riverbank Geotechnical Investigation* |
| | **Date:** | **08/12/09** | **Remoulded Shear Strength vs Depth** |
| **JOB No: VW04794** | **Revision:** | **A** | |

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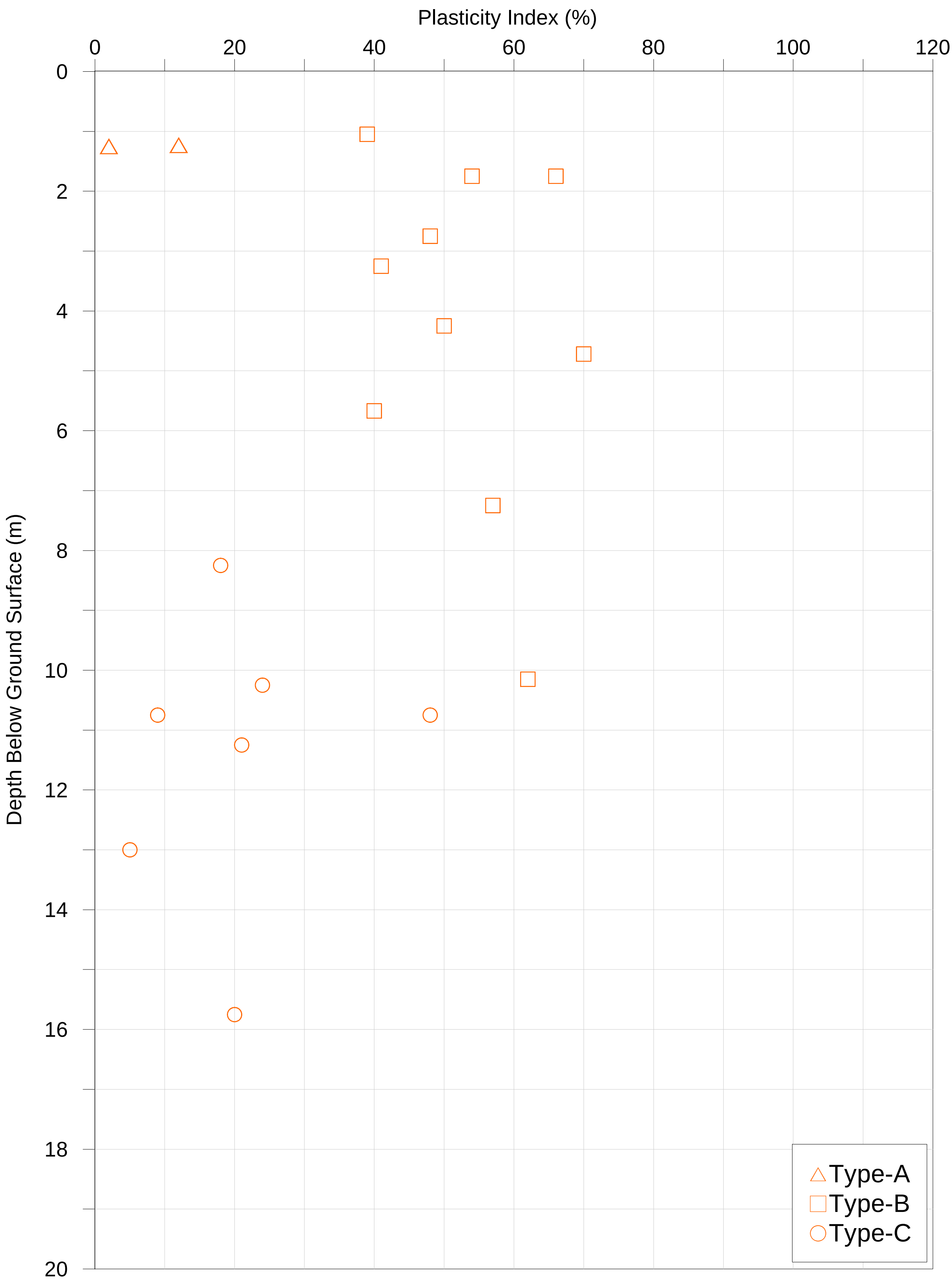
**Figure 45**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Plasticity Index Profile** |
| JOB No: VW04794 | Revision: | A | |

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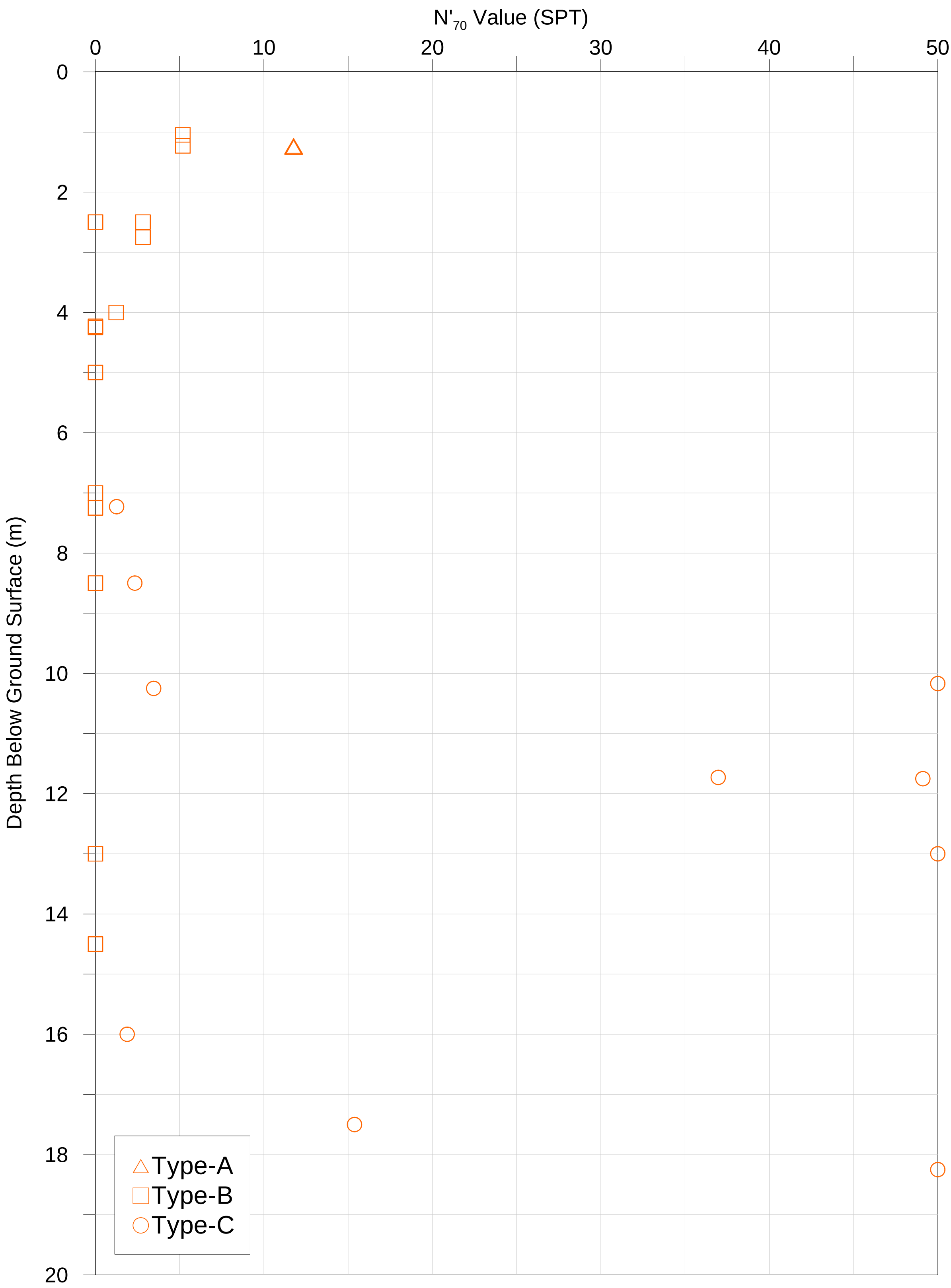
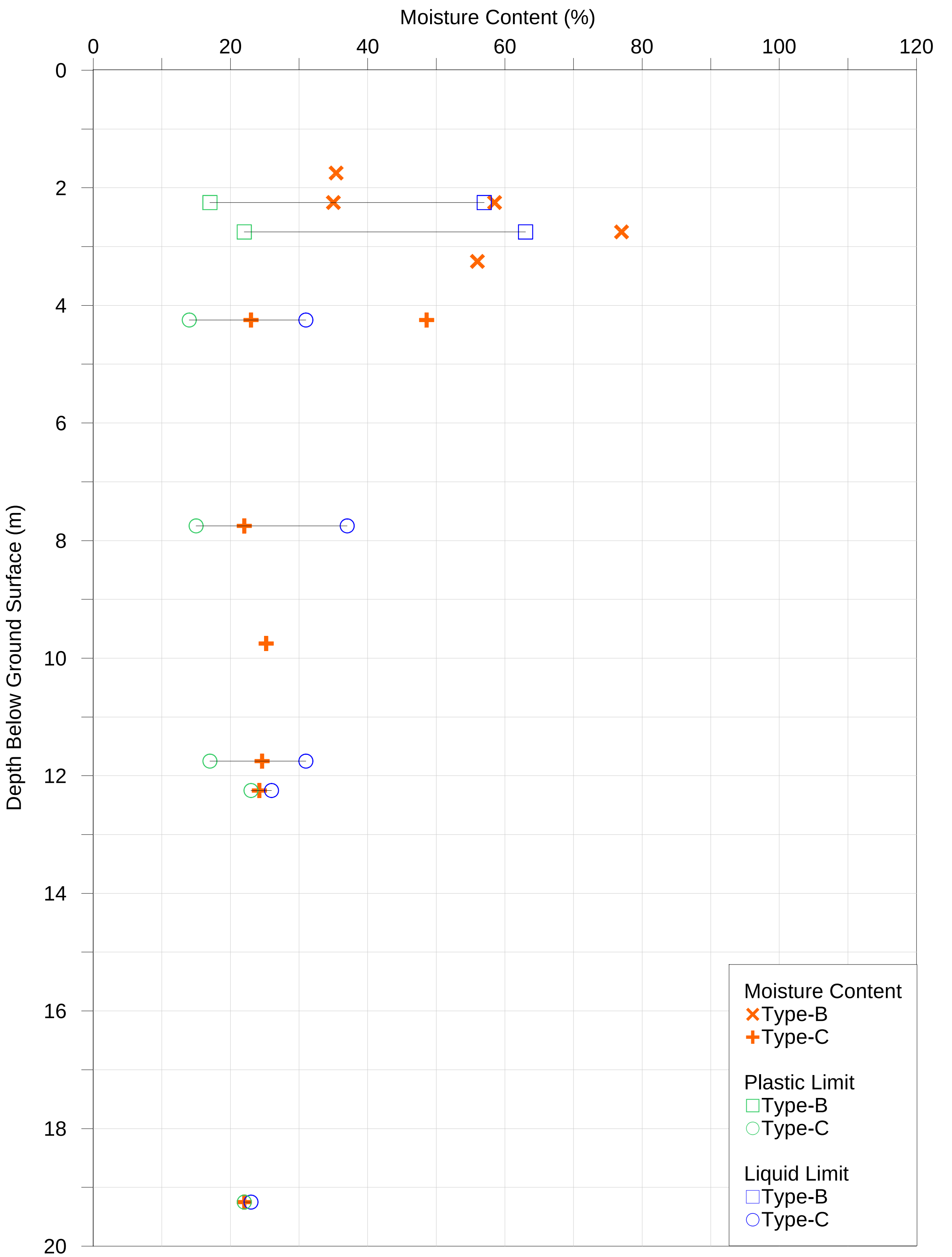
**Figure 46**




| | | | | |
|---|---|---|---|---|
| SKM | Drawn: | MT | CALOOTE<br>*Murray Riverbank Geotechnical Investigation* | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |
| | Approved: | NR | | |
| | Date: | 08/12/09 | **N'$_{70}$ Value (SPT) Profile** | |
| JOB No: VW04794 | Revision: | A | | |

**Figure 47**




SKM

JOB No: VW04794

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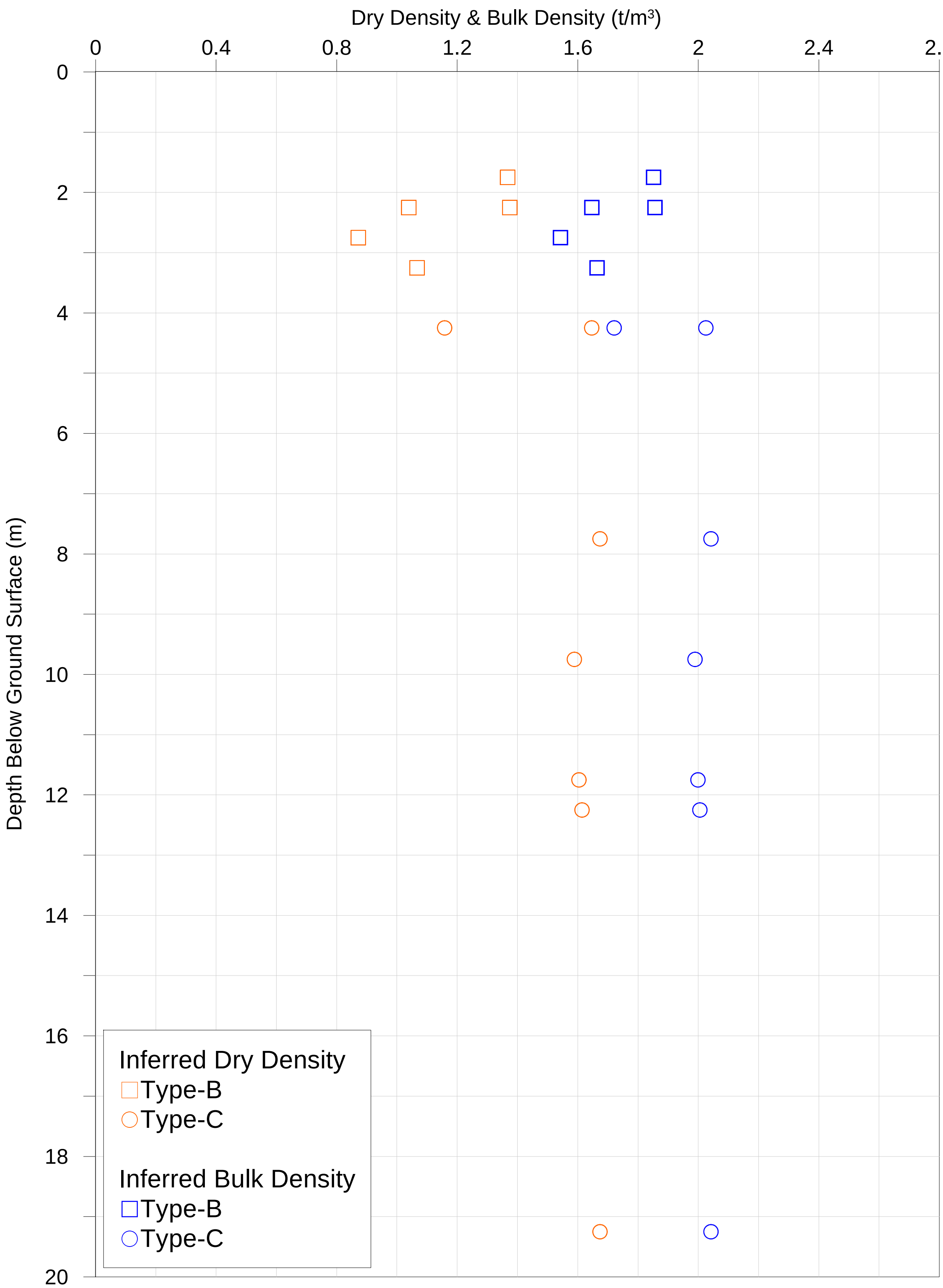
|---|---|
| Drawn: | MT |
| Approved: | NR |
| Date: | 08/12/09 |
| Revision: | A |

WOODLANE RESERVE
*Murray Riverbank Geotechnical Investigation*

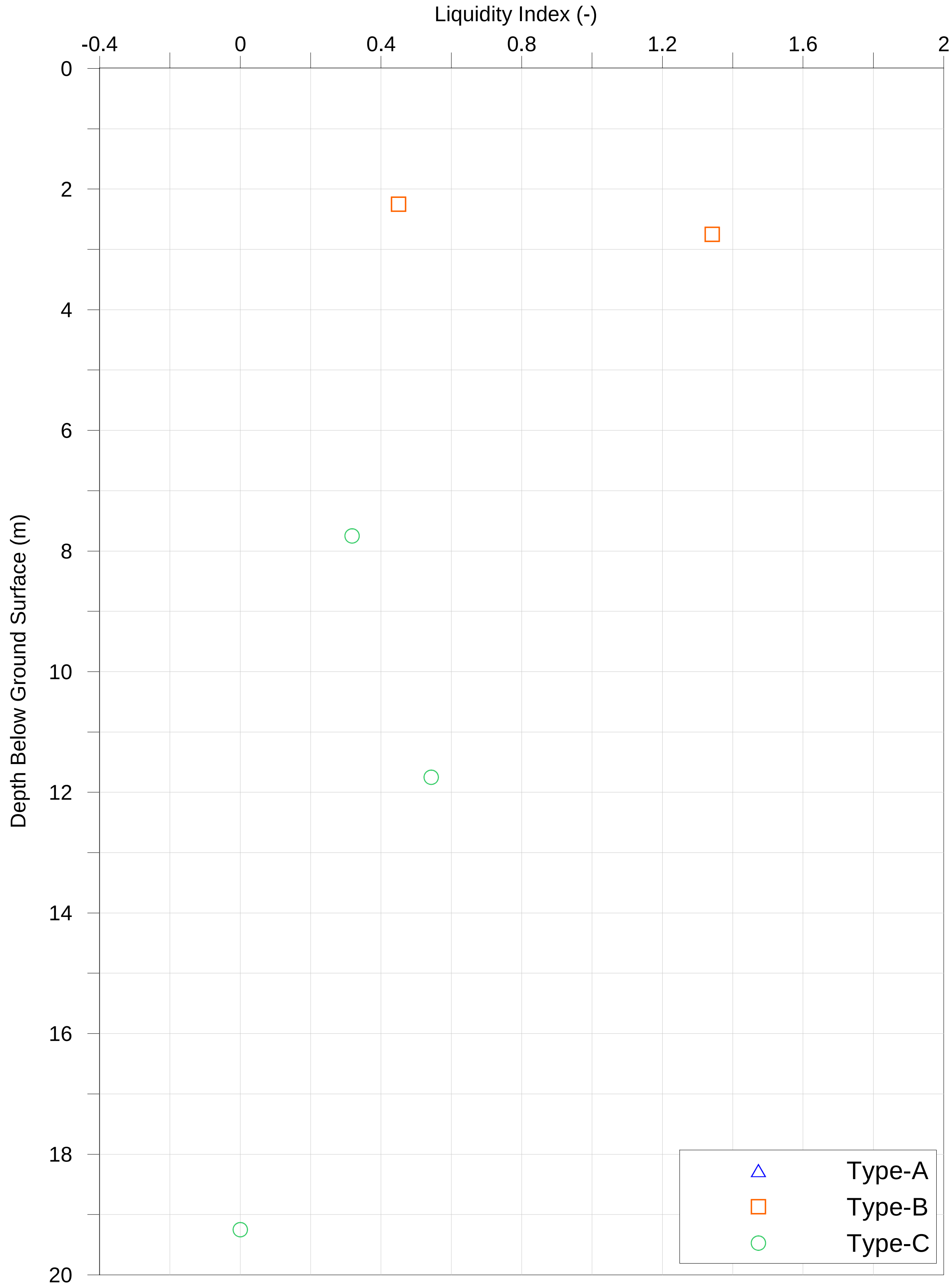
**Moisture Content and Atterberg Limits Profile**

Government of South Australia
Department of Water, Land and Biodiversity Conservation




| SKM | Drawn: | MT | WOODLANE RESERVE<br>*Murray Riverbank Geotechnical Investigation*<br>**Dry Density & Bulk Density Profile** | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |
|---|---|---|---|---|
| | Approved: | NR | | |
| | Date: | 08/12/09 | | |
| JOB No: VW04794 | Revision: | A | | |

**Figure 49**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | WOODLANE RESERVE |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Liquidity Profile** |
| JOB No: VW04794 | Revision: | A | |

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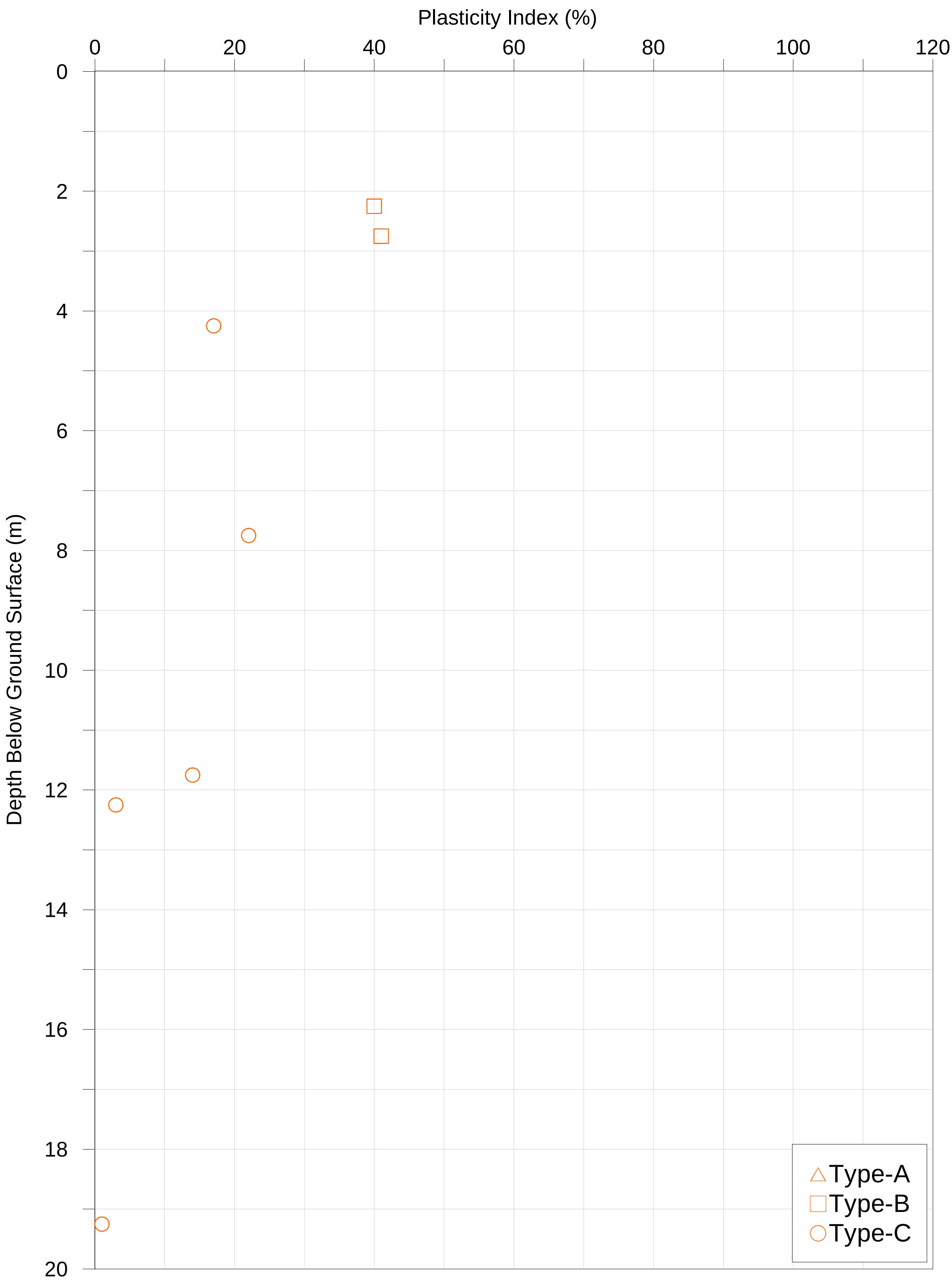
**Figure 50**

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|---|---|---|---|
| SKM | Drawn: | MT | WOODLANE RESERVE<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Plasticity Index Profile** |
| JOB No: VW04794 | Revision: | A | |

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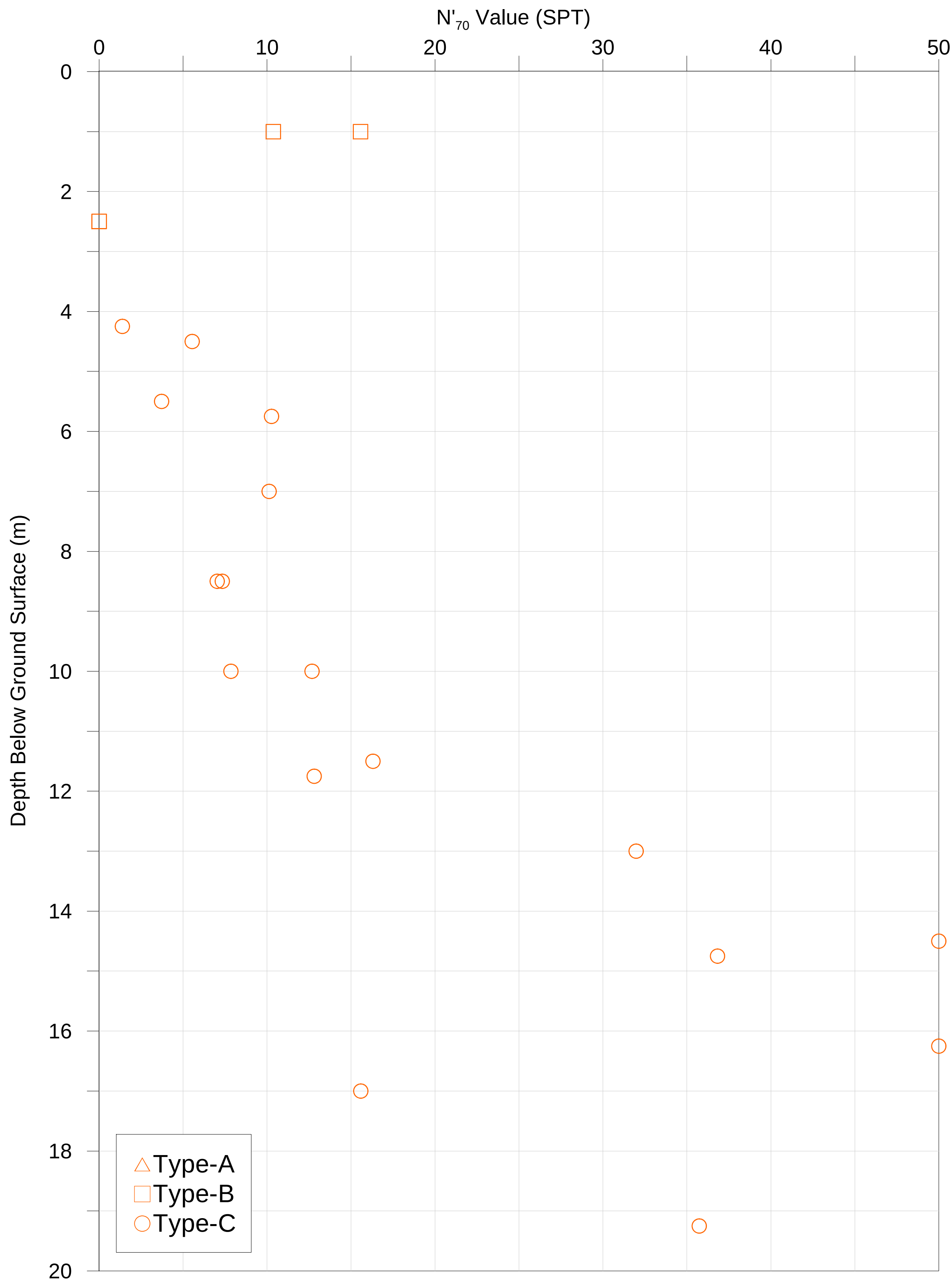
**Figure 51**




SKM

JOB No: VW04794

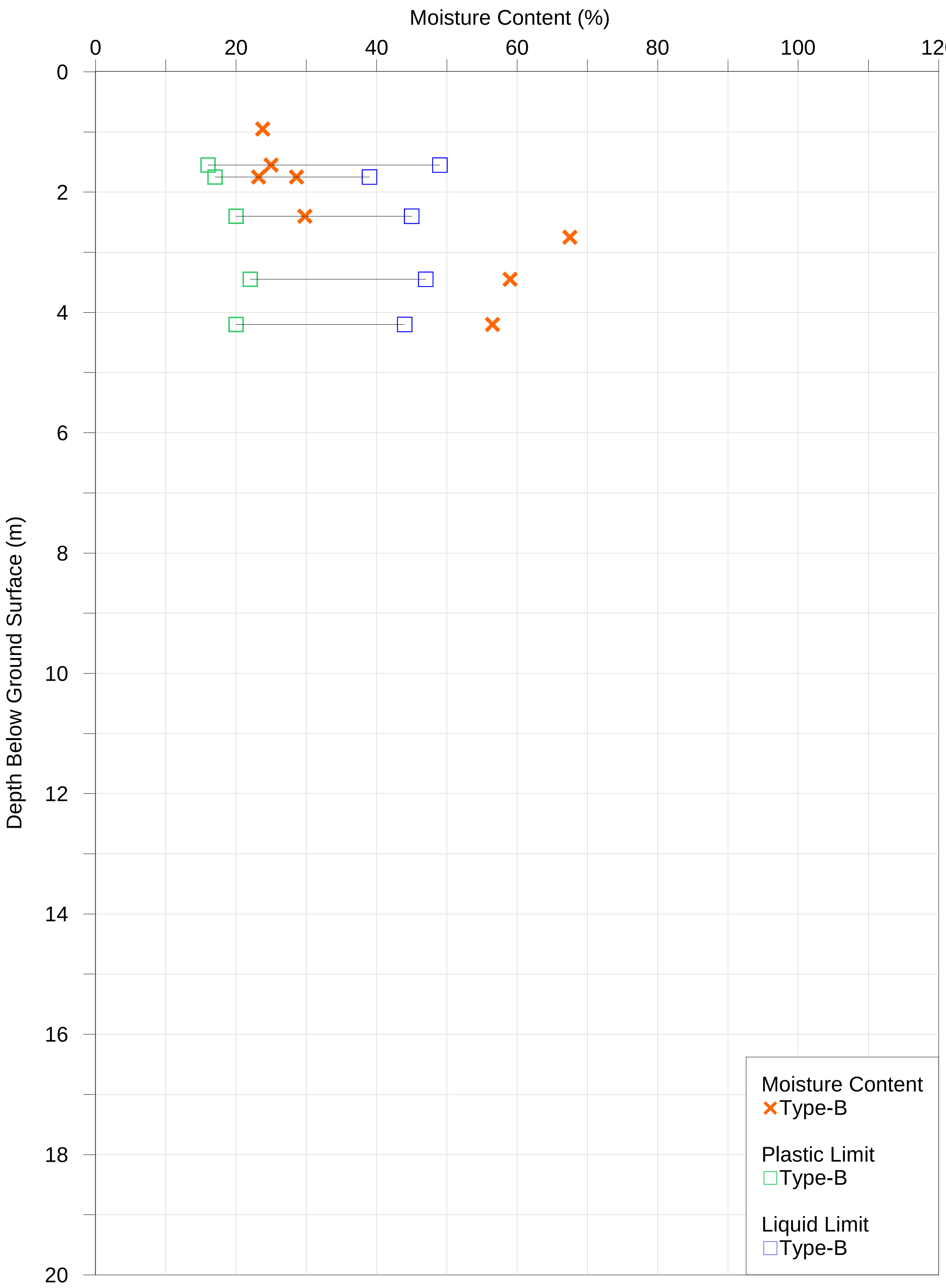
| | |
|---|---|
| **Drawn:** | **MT** |
| **Approved:** | **NR** |
| **Date:** | **08/12/09** |
| **Revision:** | **A** |

WOODLANE RESERVE
*Murray Riverbank Geotechnical Investigation*

**N'$_{70}$ Value (SPT) Profile**

Government of South Australia
Department of Water, Land and Biodiversity Conservation

**Figure 52**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | SOUTH PUNYELROO |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Moisture Content and Atterberg Limits Profile** |
| JOB No: VW04794 | Revision: | A | |

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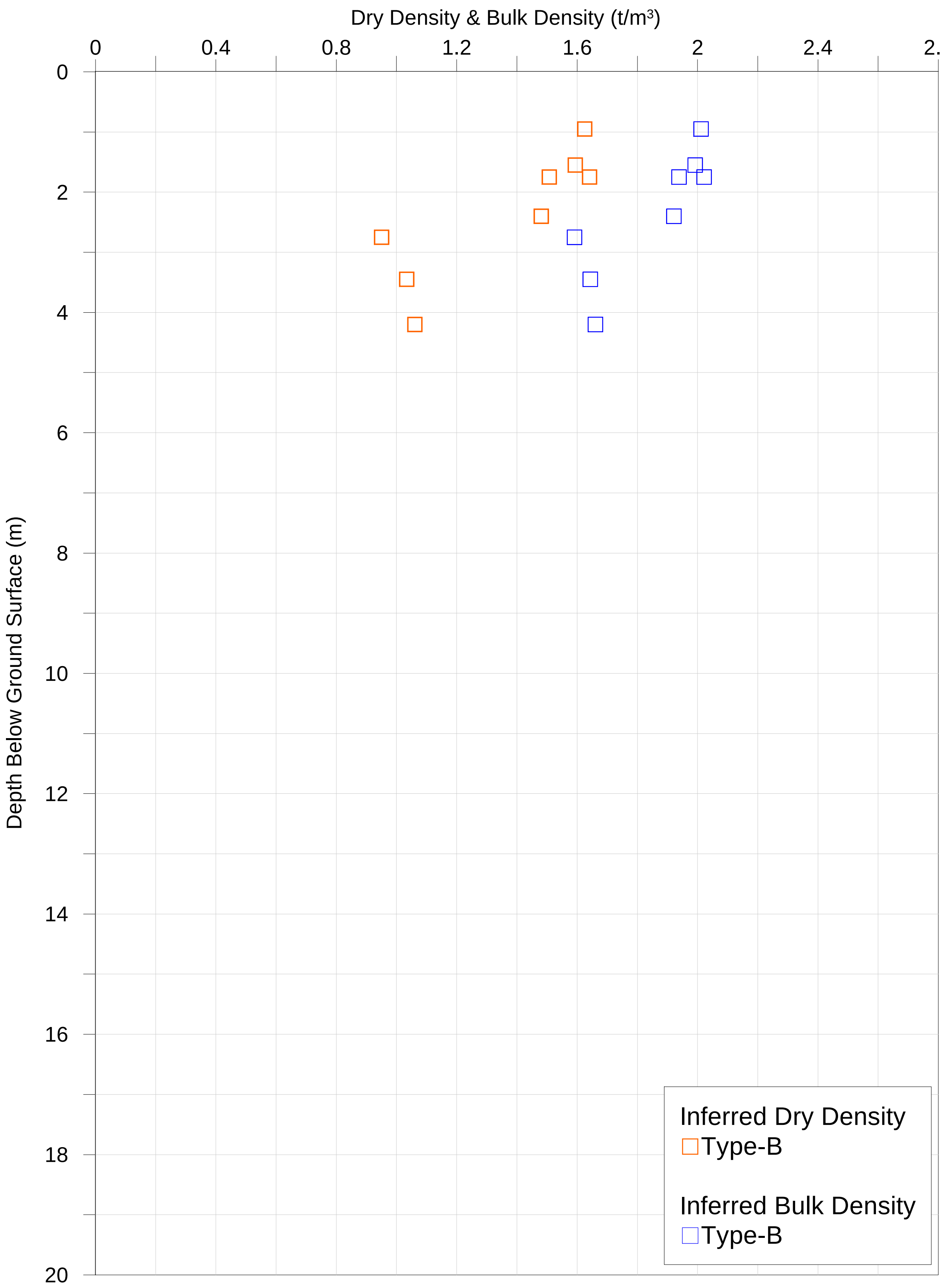


| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | SOUTH PUNYELROO |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Dry Density & Bulk Density Profile** |
| JOB No: VW04794 | Revision: | A | |

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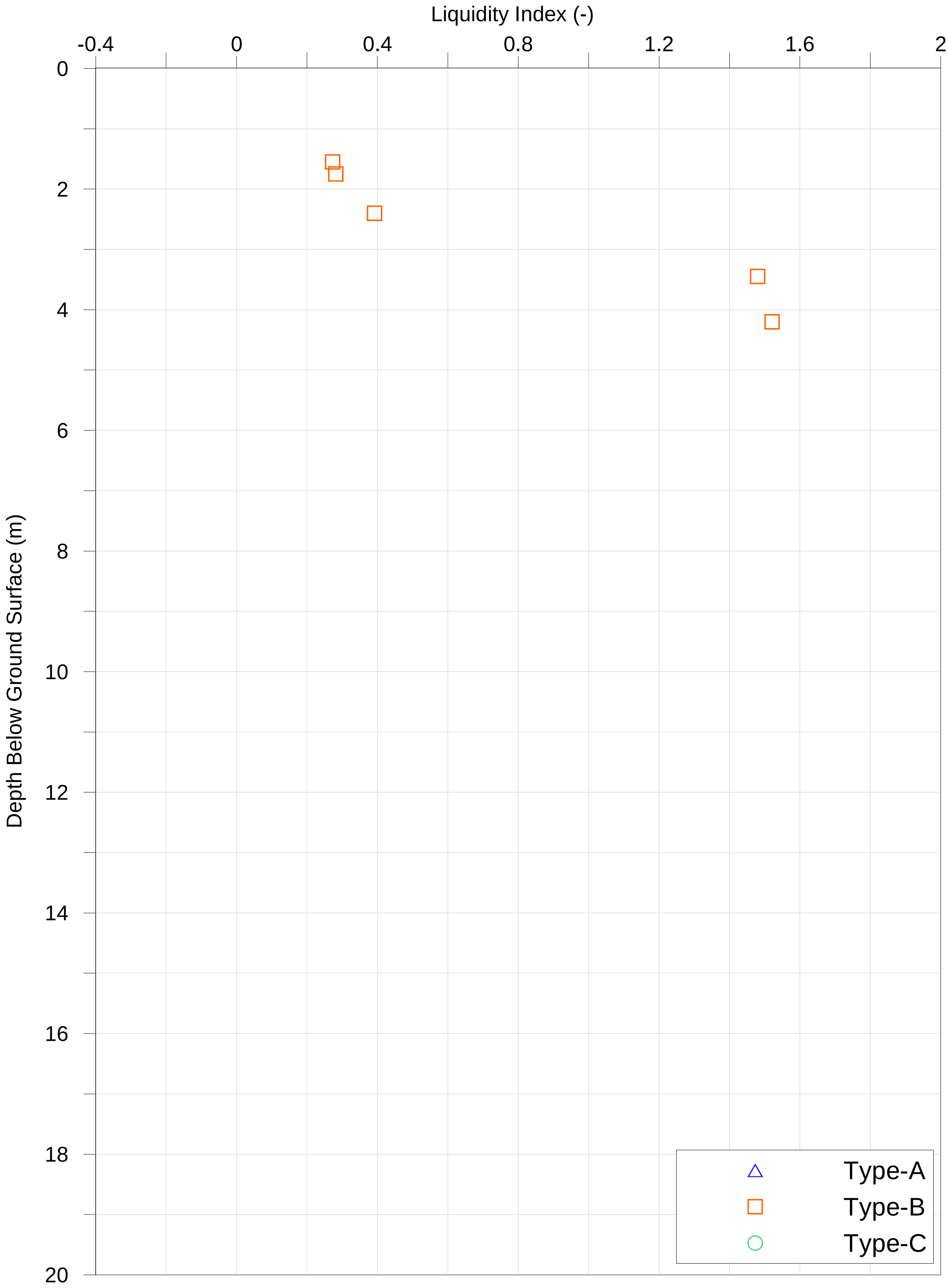
**Figure 54**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | SOUTH PUNYELROO<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Liquidity Profile** |
| JOB No: VW04794 | Revision: | A | |

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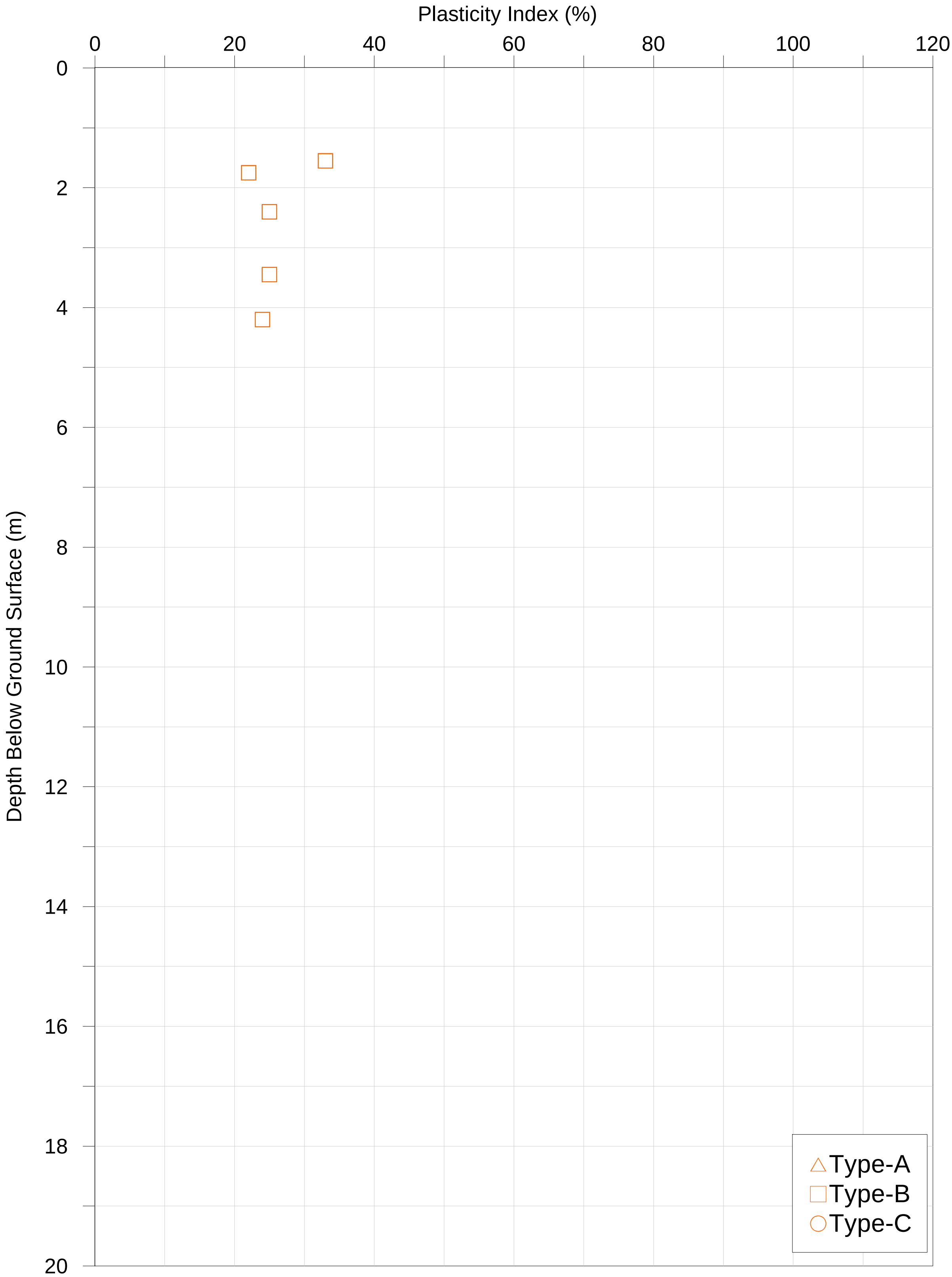
**Figure 55**

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|---|---|---|---|
| SKM | Drawn: | MT | SOUTH PUNYELROO |
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Plasticity Index Profile** |
| JOB No: VW04794 | Revision: | A | |

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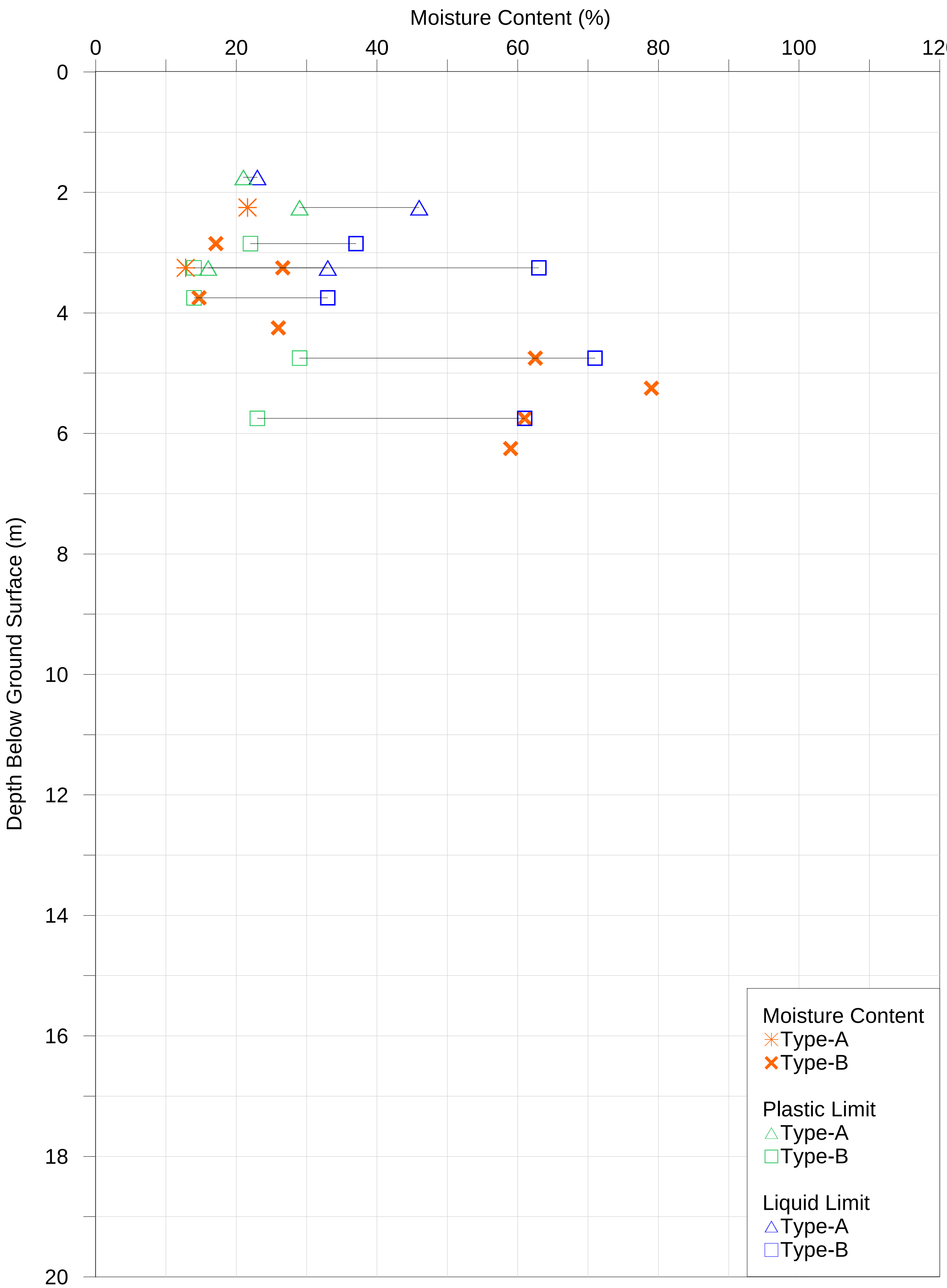
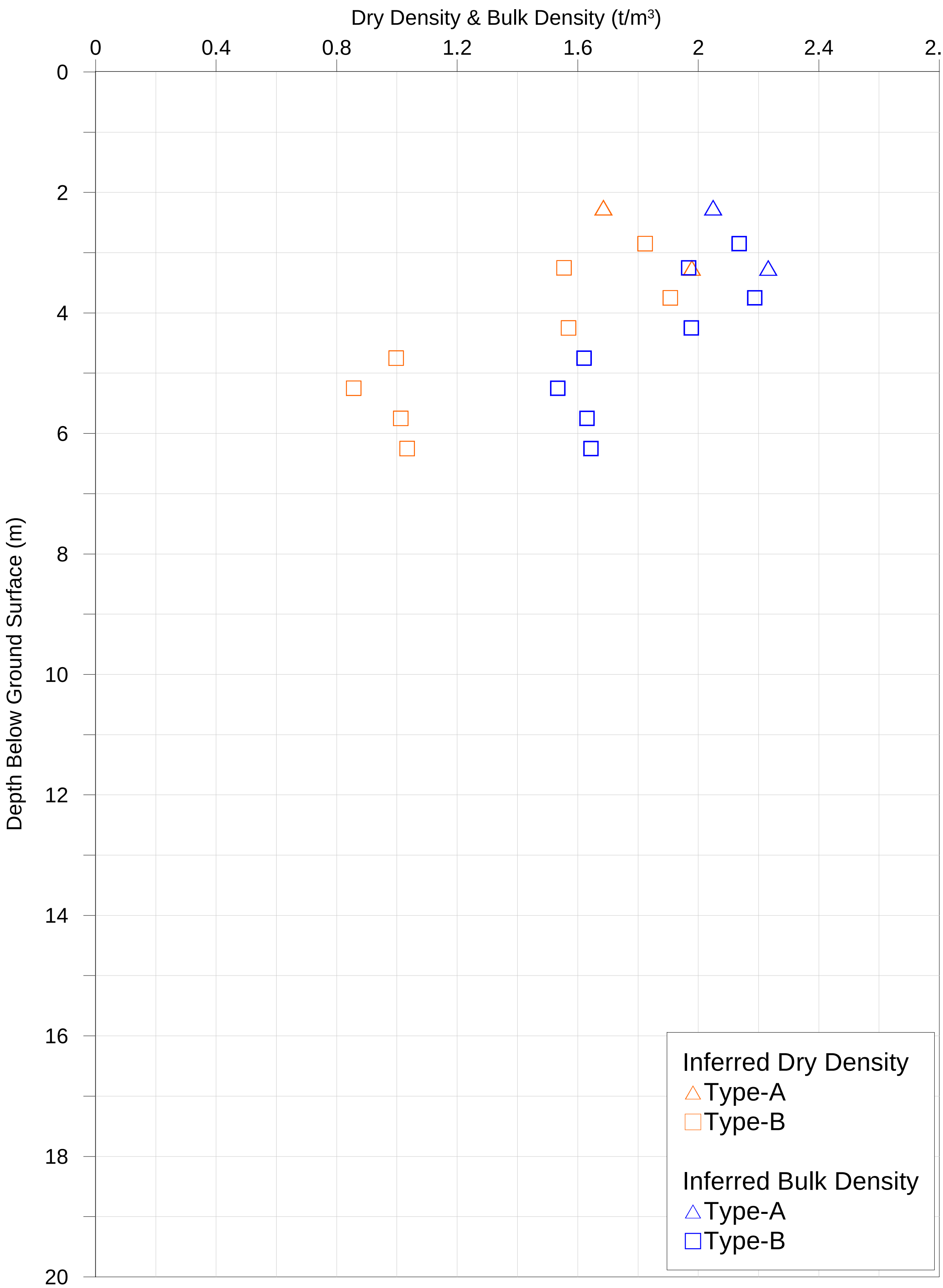
**Figure 56**



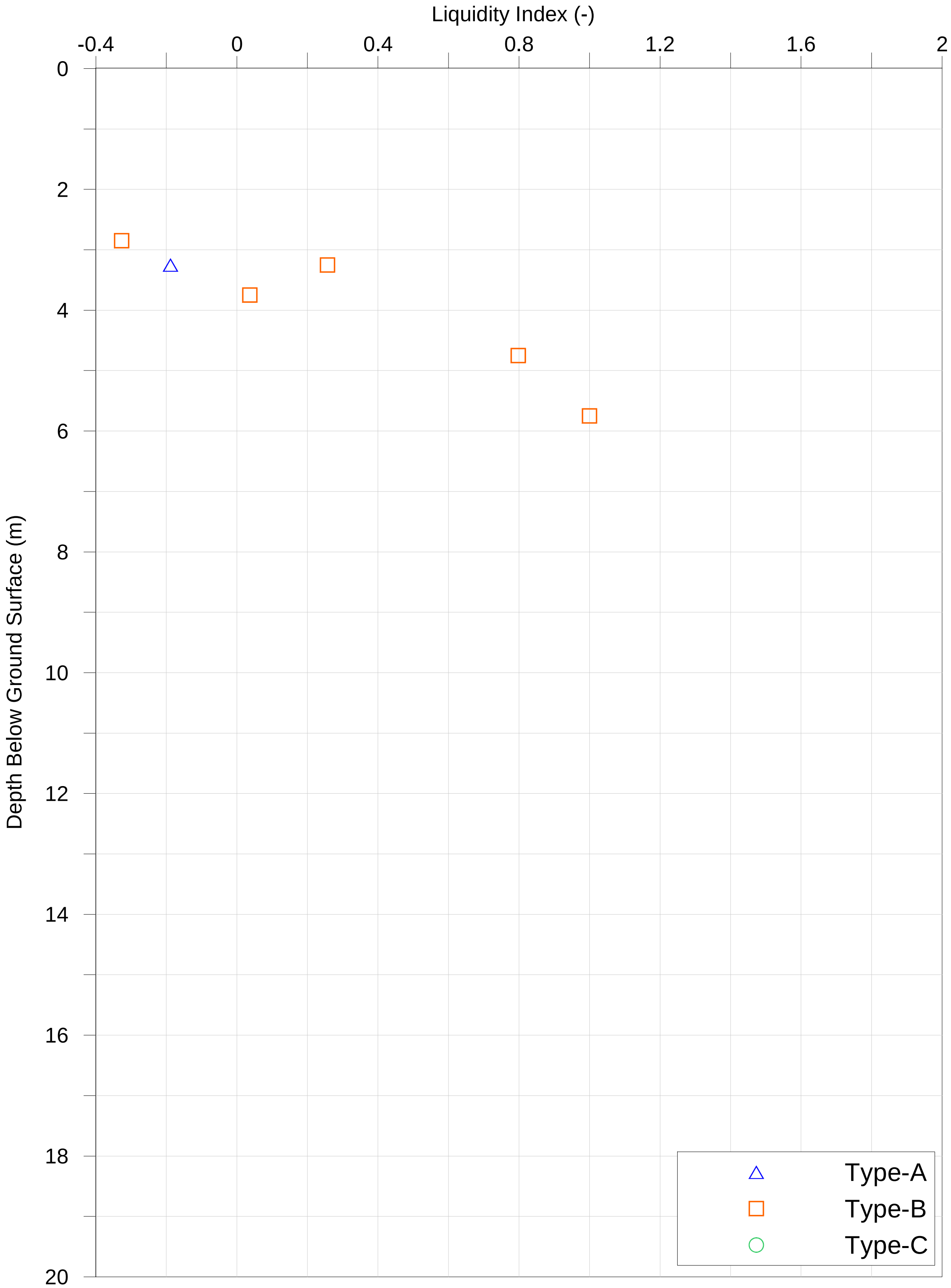

| SKM | Drawn: | MT | EAST FRONT ROAD | Government of South Australia |
|---|---|---|---|---|
| | Approved: | NR | *Murray Riverbank Geotechnical Investigation* | Department of Water, Land and Biodiversity Conservation |
| | Date: | 08/12/09 | **Moisture Content and Atterberg Limits Profile** | |
| JOB No: VW04794 | Revision: | A | | |

**Figure 57**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | EAST FRONT ROAD<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Dry Density & Bulk Density Profile** |
| JOB No: VW04794 | Revision: | A | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |

**Figure 58**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | EAST FRONT ROAD<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **Liquidity Profile** |
| JOB No: VW04794 | Revision: | A | |

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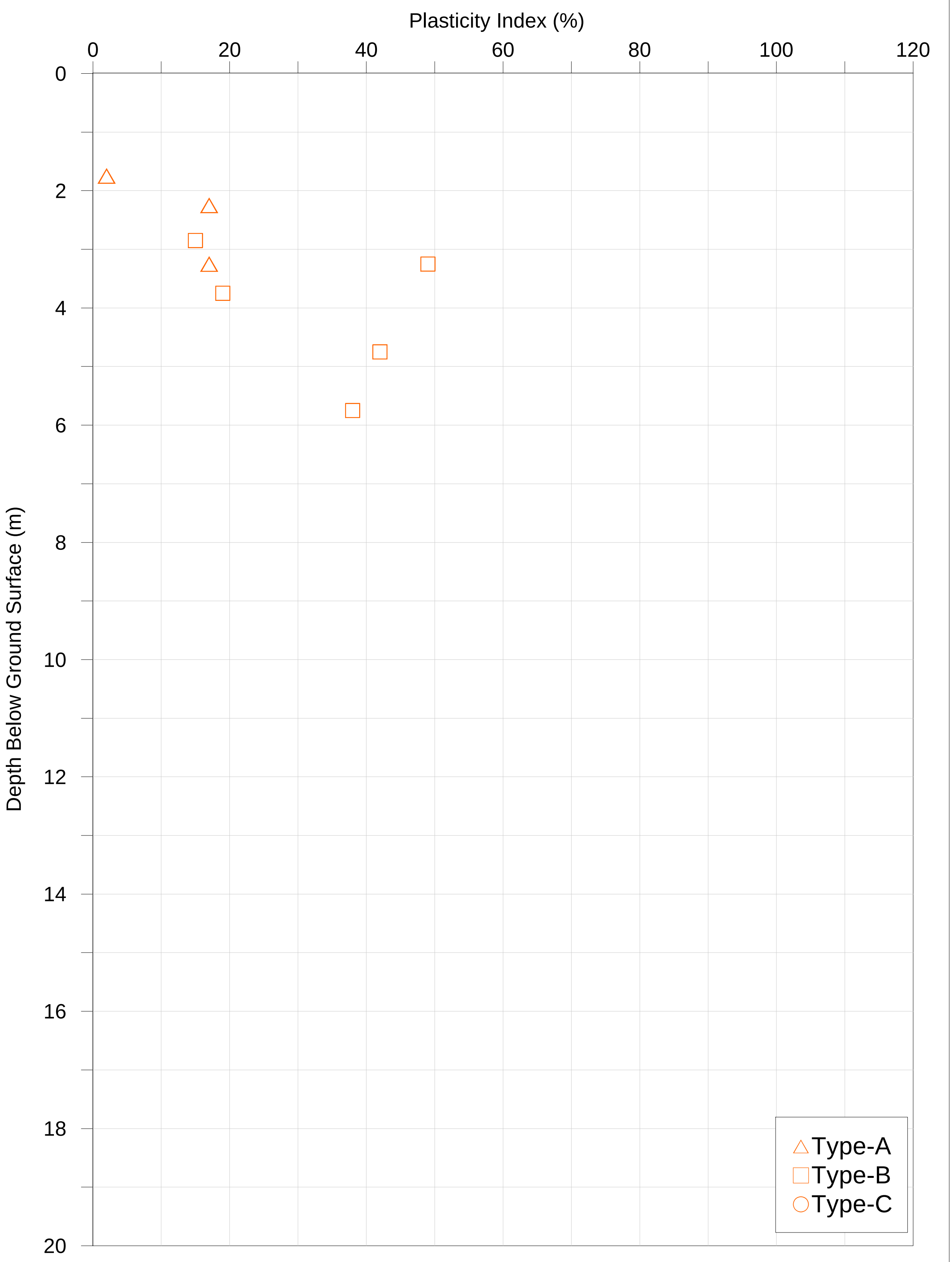
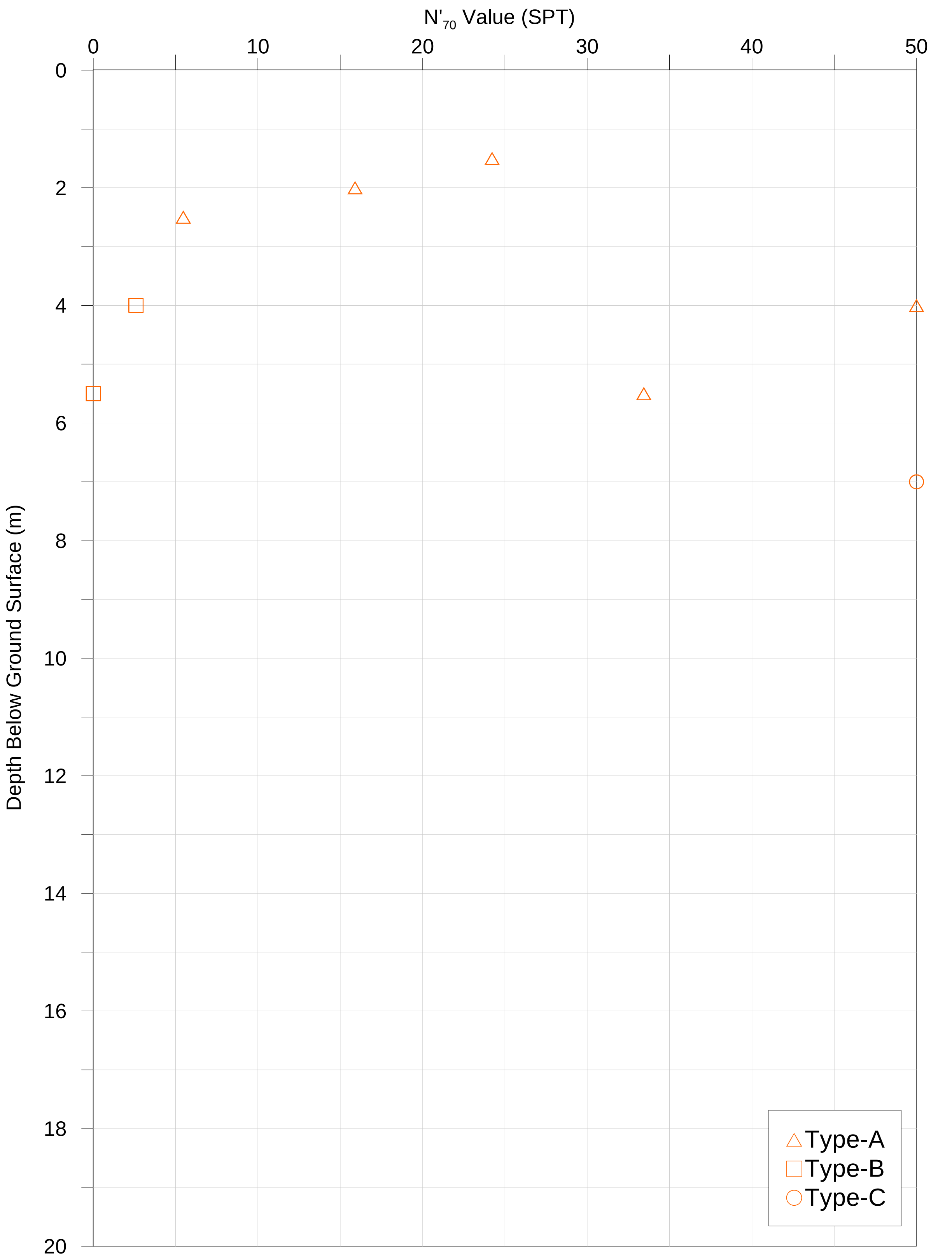
**Figure 59**




| | Drawn: | MT | EAST FRONT ROAD |
|---|---|---|---|
| SKM | Approved: | NR | *Murray Riverbank Geotechnical Investigation* |
| | Date: | 08/12/09 | **Plasticity Index Profile** |
| JOB No: VW04794 | Revision: | A | Government of South Australia<br>Department of Water, Land and Biodiversity Conservation |

**Figure 60**




| | | | |
|---|---|---|---|
| SKM | Drawn: | MT | EAST FRONT ROAD<br>*Murray Riverbank Geotechnical Investigation* |
| | Approved: | NR | |
| | Date: | 08/12/09 | **N'$_{70}$ Value (SPT) Profile** |
| JOB No: VW04794 | Revision: | A | |

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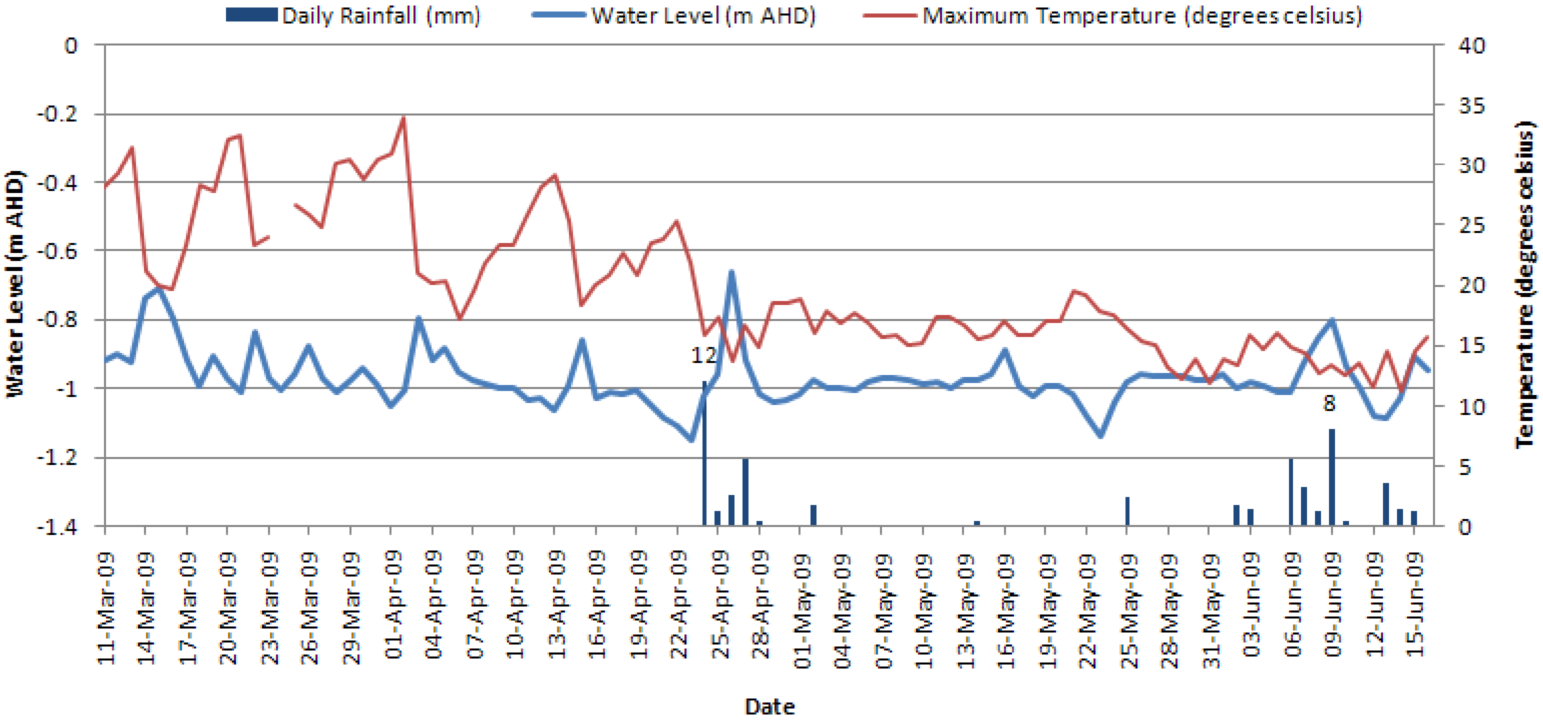
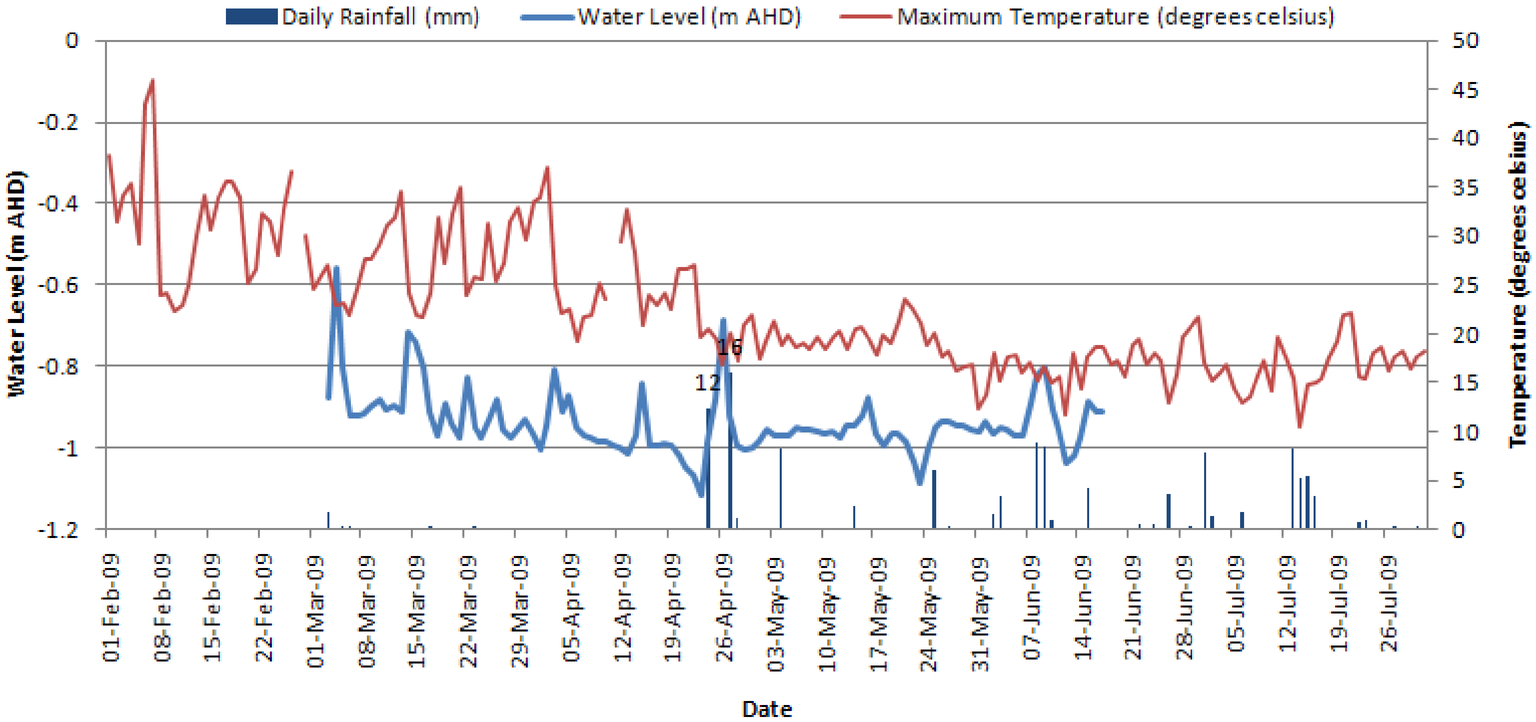
**Figure 61**




- **River Murray at Swan Reach (A4261164) – Daily water levels (m AHD) from 11 March to 16 June 2009. Maximum air temperature for region and daily rainfall recorded at Swan Reach are also shown.**

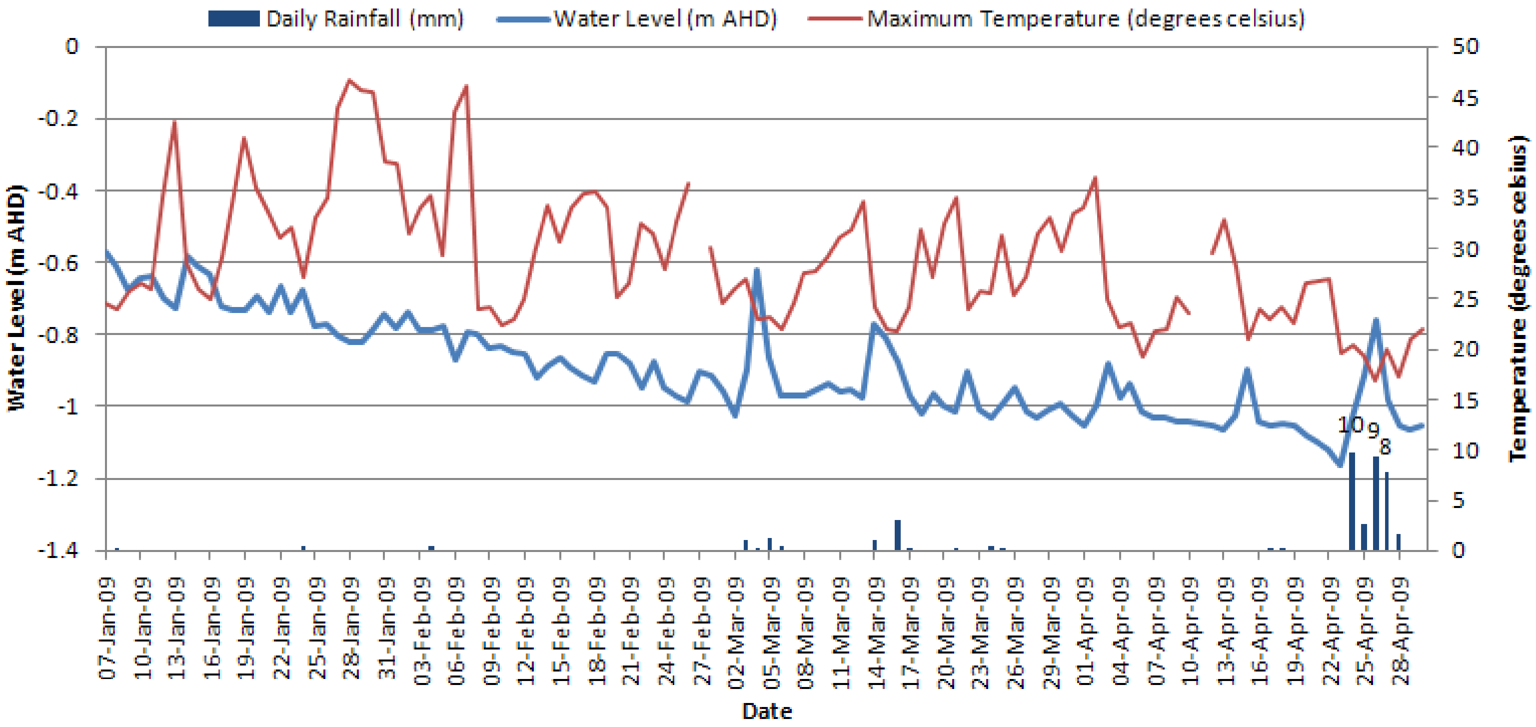



- **River Murray at Mannum (A4261161) – Daily water levels (m AHD) from 1 March to 28 April 2009. Maximum air temperature for region and daily rainfall recorded at Mannum are also shown.**



**Figure 63**

SINCLAIR KNIGHT MERZ SKM




- **River Murray at Murray Bridge (A4261162) – Daily water levels (m AHD) from 7 January to 30 March 2009. Maximum air temperature for region and daily rainfall recorded at Murray Bridge are also shown.**



**Figure 64**