Appendix D
Fluvial geomorphic assessment and addenda

Environmental impact statement
Murrumbidgee to Googong Water Transfer
Fluvial Geomorphic Assessment

June 2009
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1 Introduction

1.1 Purpose of this report

ACTEW Corporation Limited (ACTEW) proposes to undertake the Murrumbidgee to Googong Water Transfer Project (referred to in this report as ‘the project’). This report has been prepared to provide an assessment of the geomorphic impacts of the project on waterways as an input to the environmental impact assessment. The environmental impact assessment is being prepared in accordance with the requirements of Part 3A of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) and the ACT Planning and Development Act 2007.

The report addresses the requirements of the Director-General of the NSW Department of Planning (the Director-General’s Requirements) dated 7 October 2008 and the Final Scoping Document prepared by the ACT Planning & Land Authority (the Scoping Document) dated 16 December 2008.

1.2 Project overview

In recent years the Australian Capital Territory (ACT) region has been experiencing severe drought conditions coupled with increased demand for water. Canberra and Queanbeyan have been subject to level three water restrictions since 2006. The current drought, together with predicted climate change and population growth, is driving the search for a more reliable water supply for the ACT. In response to this need, the ACT Government developed the Water Security Program, which identified a range of new water supply projects.

The project is one of the preferred options for delivering improved security to the ACT’s water supply. It involves pumping water from the Murrumbidgee River (within the ACT) and transferring it via a pipeline to the Googong Reservoir via Burra Creek (in NSW). The Googong Reservoir supplies water treated to drinking quality standards to the ACT.

The project involves construction and operation of infrastructure required to transfer approximately 100 ML/day of water a distance of approximately 13 km from the Murrumbidgee River to Burra Creek.

The infrastructure required to transfer the water includes an intake/low lift pump station; a high lift pump station; an underground pipeline; a discharge structure and a power supply.

1.3 The location of the project

The intake/low lift pump station would be located on the east bank of the Murrumbidgee River, in the ACT, approximately 34 km south of Canberra. It would be located in an area known as Angle Crossing, approximately 4 km west of Williamsdale on the Monaro Highway.

The high lift pump station would be located within the ACT, approximately 290 m to the east of the intake/low lift pump station.

The pipeline would cross rural land in an east/north-east direction for approximately 13 km. It is located in the vicinity of Williamsdale and Burra Roads, within the districts of Williamsdale and Burra. The majority (approximately 10.2 km) of the pipeline would be located in NSW, with approximately 2.8 km located in the ACT.

The pipeline would discharge to the discharge structure, located on the banks of Burra Creek, just downstream of an existing flow measuring station approximately 10 km south of Googong Reservoir. The discharge structure is located within land know as the Googong Foreshores, which is Commonwealth land within NSW.
1.4 Purpose and Scope of Report

The purpose of this study is to discuss:

- The existing geomorphic condition of major waterways along the proposed transfer pipeline route at proposed crossing locations;
- The existing geomorphic condition of Burra Creek from the proposed outlet location downstream to Googong Dam;
- The existing geomorphic condition of the Murrumbidgee River near Angle Crossing at the proposed intake location;
- Potential impacts associated with the proposal; and
- Mitigation recommendations.

The study area includes all waterways (as defined by the 25 k GIS layer) in the vicinity of the proposal area. This includes all unnamed waterways along the proposed Transfer Pipeline, Murrumbidgee River (intake point) and Burra Creek (outlet point to Googong dam) (Figure 1).

1.5 Structure of Report

This report has been structured (Table 1) so that the three main facets (Transfer Pipeline, Burra Creek Discharges and the Inlet/Outlet Structures) are independently described and assessed.

Table 1 Report Structure

<table>
<thead>
<tr>
<th>Component Aspect</th>
<th>Relevant Report Section(s)</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Transfer Pipeline</strong></td>
<td>Section 2.1: Existing Condition</td>
<td>Describes the existing condition of waterways along the proposed transfer pipeline alignment.</td>
</tr>
<tr>
<td></td>
<td>Section 2.2: Impact Assessment</td>
<td>Describes the potential impacts associated with the waterway crossing along the proposed transfer pipeline route.</td>
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<td>Section 2.3: Mitigation</td>
<td>Describes the suite of measures recommended to mitigate potential impacts associated with the Transfer Pipeline.</td>
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<td></td>
<td>Appendix A: Transfer Pipeline Waterway Crossing Summary</td>
<td>Provides a summary of the existing condition, impacts and recommended mitigation measures at key waterway crossing points.</td>
</tr>
<tr>
<td><strong>Burra Creek Discharge</strong></td>
<td>Section 3.1: Existing Condition</td>
<td>Describes the existing condition of Burra Creek from the proposed outlet point to the Googong Dam.</td>
</tr>
<tr>
<td></td>
<td>Section 3.2: Impact Assessment</td>
<td>Describes the potential impacts associated with discharge to Burra Creek.</td>
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1 This report only provides discussion on the existing condition, impacts and mitigation measures relevant to a fluvial geomorphic assessment of the proposal.
<table>
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<th>Component Aspect</th>
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<td>Section 3.3: Mitigation</td>
<td>Describes the suite of measures recommended to mitigate potential impacts associated with the discharge to Burra Creek.</td>
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<tr>
<td>Inlet/Outlet Structures</td>
<td>Section 4.1: Existing Condition</td>
<td>Describes the existing condition of Murrumbidgee River and Burra Creek within the vicinity of the proposed intake and outlet structures.</td>
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<td>Section 4.2: Impact Assessment</td>
<td>Describes the potential impacts associated with the proposed intake and outlet structures.</td>
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<td></td>
<td>Section 4.3: Mitigation</td>
<td>Describes the suite of measures recommended to mitigate the potential impacts associated with the inlet and outlet structures.</td>
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1.6 Limitations

This report has been prepared for ACTEW. The purpose of the report is to provide an independent review of the proposal.

It is not the intention of the assessment to assess every waterway in detail, but rather to conduct the assessment with consideration to the prescribed work scope.

The findings of the waterway assessment represent the findings apparent at the date and time of the monitoring and the conditions of the area at that time. It is the nature of environmental monitoring that not all variations in environmental conditions can be accessed and all uncertainty cannot be eliminated. Professional judgement must be exercised in the investigation and interpretation of observations.

In conducting this assessment and preparing the report, current guidelines for waterway management were referred to. This work has been conducted in good faith with GHD’s understanding of the client’s brief and the generally accepted consulting practice.

No other warranty, expressed or implied, is made as to the information and professional advice included in this report. It is not intended for other parties or other uses.

Assessments were undertaken at representative sections of Burra Creek, waterway crossings with large catchments and intake and outlet structures, however there may be some areas of erosion or differences in character and condition which have not been picked up within this assessment.
2 Transfer Pipeline

2.1 Existing Condition

The following sections provide an assessment of the general condition of waterways along the transfer pipeline alignment. Specific details on the location and existing condition of the 6 major waterway crossings are provided in Appendix A.

2.1.1 Transfer Pipeline Route Overview

The intake structure for the proposed project would be located on the banks of the Murrumbidgee River at Angle Crossing. From here the pipeline would proceed to the north-east where it traverses through a predominantly agricultural landscape prior to discharging to Burra Creek.

The proposed transfer pipeline route crosses 17 waterways, as defined by the 1:25,000 GIS layers. Waterways crossed by the proposed route are largely located along the eastern section of the route. Of the waterways crossed, 11 cross through the top 500m – 600m of tributaries, while 6 cross at a more significant distance downstream (see Appendix A for locations).

Europeans first came to the Canberra region in 1820, since this time much of the surrounding land has been cleared and used for agricultural purposes. In addition, many of the local waterways have been dammed to provide water to Canberra and its periphery. There are a number of dams located within the gullies surrounding the Proposed Transfer Pipeline alignment that potentially intercept a large proportion of the flows.

The January 2003 bushfires surrounding Canberra are considered to be the worst fires ever to hit the Australian Capital Territory. These fires had significant impacts on the many of the forest areas surrounding Canberra and over the border in New South Wales. The landscape surrounding much of the proposed transfer pipeline still shows evidence of these impacts today (AON, 2008). Fires result in a loss of vegetative cover leading to slope instabilities. As a result of the fires significant amounts of sediment has been lost from the affected valleys thereby reducing vegetation recolonisation and slope stability.

2.1.2 Site Investigation Scope

Field assessments were undertaken at 6 major waterway crossing points along the proposed pipeline route. Assessments were focused on the waterways with the largest catchment areas where it was considered the project is likely to have the greatest impact. Two geomorphologists completed the site investigations and took note of the following factors:

• Channel Planform;
• Channel Geometry;
• Bank Shape;
• Stability;
• Vegetation Associations; and
• Landuse.

2.1.3 Waterway Existing Condition

European land clearance and the recent fires have resulted in altered hydrological regimes which have had an impact on the morphological character of many of the waterways within the vicinity of the proposed transfer pipeline route.
Land clearance can have impacts on catchment and waterway character and behaviour. Catchment responses to land clearance include increased runoff, increased drainage density, increased erosion and sediment yields within the catchment. In response to altered hydrological regimes channel morphology changes can occur as the result of bank erosion, channel incision and floodplain scour which are generally associated with increasing stream power and sediment transport capacity.

Prior to European land clearance, the majority of the waterways along the proposed route would have been either Chain of Ponds or Valley Fill waterway systems while now they exhibit an incised, channel form. Many of the waterways have significantly altered their form and continue to exhibit signs of channel instabilities. As a result, many of the waterways could be considered to be in moderate to poor geomorphic condition.

**Stability**

**Bed Instability – Headward erosion**

Headward erosion was evident in many proposed waterway crossings (Appendix A). Headward erosion (‘headcut’) is erosion which occurs along a channel in the opposite direction to water flows. This causes down cutting or incision of the bed of a stream and can alter the longitudinal profile of the waterway. Erosion can result in increased rates of sediment to be transported downstream.

Headward erosion was evident at two of the six waterways assessed. This includes major waterway crossings 1 and 5 (Appendix A). Due to the altered landscape and relatively steep topography it is likely that headward erosion is a common occurrence in the nearby waterways.

**Bank Instability**

Bank instabilities were evident in some waterways crossed by the proposed pipeline (Appendix A). Many banks are irregular in shape indicating that erosion has occurred in the past. Banks are generally stable under the current flow regimes, many of which are stabilised by pastural grasses.

**Tunnel Erosion**

Minor tunnel erosion was evident along some sections of the proposed pipeline route (Appendix A). Tunnelling is a subsurface form of erosion, resulting in significant underground damage prior to any surface evidence. Tunnel erosion is caused by the movement of water through a dispersive (usually sodic) soil. As water is transferred through subsurface soils dispersive soils can be transported creating horizontal underground tunnel features. Weaknesses can be created in surface soils leading to collapse and creation of vertical tunnels. These erosion features often occur on steep, cleared land with moderate to high rainfall. As most of the erosion occurs below the surface, these features can pose a risk to surface activities, as they are not clearly evident.

An area of minor tunnel erosion was identified at waterway crossing 2 (Appendix A). However it is possible that this may occur throughout other sections along the proposed alignment. The soil landscapes map indicates that sodic soils occur along the pipeline route, particularly within the middle section.

**2.2 Impact Assessment**

The following sections provide an assessment of the general construction and operational impacts of the transfer pipeline on waterways. Specific details of the potential impacts on the 6 major waterway crossings are provided in Appendix A.

**2.2.1 Construction Methods**

There are a number of available methods for constructing waterway crossings, depending on environmental and engineering constraints. It is likely that all waterways would be crossed by open cut trenching (with or
without flow diversion). This assessment considers the potential impacts associated with this construction method.

**Trenching**

Standard open cut trenching is most often utilised in low flow, shallow or dry conditions. This technique involves setting up a stable work platform on each side of the watercourse and then excavating a trench. The trench is not completed until immediately prior to placement of the pipeline. All welding and coating of the pipeline is conducted in a cleared area away from the waterway embankment before placement. Tie in points are located on high ground away from the banks. Pre-welded pipes are then placed into the trench using slings from the excavators at either side of the waterway. The spoil from the watercourse bed and bank and trench spoil material are stored separately.

This crossing method may be applied in sensitive streams where rapid construction is considered the best means of minimising environmental impacts. The primary risk of impact associated with trenching is the potential for release of high sediment loads during excavation and backfilling. If managed inappropriately, it could increase turbidity, impacting upon downstream water quality. Mitigation measures to reduce the environmental impact of trenching include, flow diversion, sediment capture devices and strict environmental management controls.

Where higher water volumes and flows are present, open trenching using streamflow diversion can be used. This technique typically involves creating a dry construction area within which to work by pumping around the area. Other diversion techniques include diverting the water flow through a flume pipe installed between the dams. Diverted flow is maintained at a flow rate and water quality, which would allow the downstream reaches of the waterway to continue to function.

### 2.2.2 Construction Impacts

**General Construction Impacts**

General construction impacts may include:

- Soil erosion caused by ground disturbance;
- Water quality impacts such as sedimentation and sediment transport associated with inadequate site controls;
- Impacts to water quality from construction vehicle fuels, oils and greases (although it is noted that given the setback from the top of banks of the waterway, these impacts would generally be less for pipe jacking techniques);
- Introduction and spread of weed species from construction vehicles and machinery; and
- Visual impacts of construction equipment.

**Trenching Impacts**

Impacts associated with trenching may include:

- Disturbance to bed and banks;
- Disturbance to floodplains;
- Stream bed degradation;
- Stream bank degradation;
- Scour potential from poor pipeline orientation:
• The impact of erosion from bed and bank disturbance can include water quality impacts on the downstream environment. General construction activities (e.g. stockpiling of material, etc.) may lead to sedimentation issues.

• Impacts to riparian and aquatic flora and fauna; and

• Disturbances or loss of native vegetation (including seedbank, instream and riparian vegetation).

2.2.3 Specific Transfer Pipeline Route Impacts

Alteration of Channel Morphology

Trenching to lay the pipe would disrupt the bed and banks of waterways along the proposed pipeline alignment resulting in altered channel and floodplain morphology if appropriate mitigation is not implemented.

Stability

Site based assessment indicates that headward erosion, bank erosion and tunnel erosion is occurring in some locations throughout the alignment (Appendix A). These bed and bank instabilities (Appendix A) may be further exacerbated by construction associated with laying of the transfer pipeline. This may:

• Increase the risk of headward erosion.

• Where headcuts are evident downstream there is a risk that the pipeline would create bed instabilities leading to further channel incision in an upstream direction. An additional consequence of this may be the risk of exposing the pipeline asset.

• Increase the risk of bank erosion.

• Bank disturbance would occur during trenching activities. If appropriate reinstatement is not implemented this may lead to bank slumping.

• Increase the risk of tunnel erosion.

• An altered hydraulic gradient may occur in some instances where sand is placed around the pipe and enhance the risk of tunnel erosion.

2.3 Mitigation

2.3.1 General Impact Mitigation

A range of measures is commonly used to mitigate potential impacts on the surface water environment. These measures should be incorporated into an Environmental Management Plan (EMP).

Erosion and Sediment Control Measures

• Erosion and sediment control measures should be established prior to construction;

• Erosion and sediment control measures should be regularly inspected, particularly following rainfall events, to ensure their ongoing functionality;

• Vegetation clearance should be avoided where possible to protect soils from erosion. If clearance cannot be avoided, the area of vegetation cleared at any one time should be minimised;

• Reinstatement of vegetation as quickly as practicable after construction;

• All stockpiled material should be stored in bunded areas and kept remote from waterways to avoid sediment entering the waterway;

• Diversion drains and bunds should be established during construction works to manage site runoff and minimise the transport of sediment from the construction site into the waterway; and

• Preferably a waterway should be crossed on a straight portion of the waterway to avoid the risk of erosion. Where this is not possible bank stability works should be implemented.
Other Water Quality Protection Measures

Creation and maintenance of designated construction equipment wash down and refuelling areas outside the riparian zone of the waterway with established bunding and contamination control measures in place.

Timing of Construction

• Waterway crossings should be avoided during periods of heavy rainfall and flooding;
• Contingency plans to address heavy rainfall and flood events during construction should be included in an EMP. The contingency plan should address:
  – Limiting stormwater entering excavation areas;
  – Enhancement of controls when heavy rain is forecast;
  – Siting of facilities;
  – Clean up procedures;
  – A flood warning system; and
  – Procedures for limiting loss of spoil and other hazardous materials.

Minimise Site Disturbance

Actions to be taken to avoid site-based disturbance during the construction period should include:
• Minimise the width and effective footprint of works;
• Control the route used by machinery into and out of the works site;
• Avoid the need for access of heavy machinery to the bed of the waterways as works should be undertaken from the top of the banks where possible;
• Avoid disturbance of surrounding banks by machinery or other construction works; and
• Wash down areas should be placed at key entry and exit points;

Stream Flow Diversion Measures

Implement stream flow diversion measures during construction where high water volumes and flows are present.

2.3.2 Specific Mitigation Measures

In addition to the standard management requirements that would be expected during construction, some waterways may require additional mitigation measures to ensure adequate protection. These measures are outlined within Appendix A for those waterways that have been inspected. Further detailed mitigation measures would need to be established for each waterway crossing prior to construction activities.

Waterway specific mitigation measures would need to address the risk of erosion at each site and may include:

Reinstate Profile
• Replace sediments in order they were removed;
• Reshape according to current profile; and
• Design recommendations informed by the geotechnical investigation to address the potential for differential settlements in areas containing soft or compressible soil types.

Stability
• Reinstate soils over pipeline with a soil-rock mix (~100-300 mm), jute matting and regrassing to reduce risk of headward erosion; and
• Reinstate bed and banks with rock in erosion sensitive areas to protect from bank erosion.
2.3.3 Operational Management Measures

Additional requirements may need to be addressed during the operational phase of the Proposal in order to minimise the impact on the surface water environment: These may include:

- Monitoring of the downstream bed stability of the waterway where erosion has been identified as a key concern to ensure that mitigation is appropriate to protect the asset and prevent waterway degradation;
- The restriction of inspection access in sensitive areas (e.g., waterways) to foot as much as possible; and
- All inspections portals, valves, etc. are not installed in the vicinity of the waterway crossings as they may be inundated during periods of high flow.
3  Burra Creek Discharges

3.1  Existing Condition

3.1.1  Burra Creek Overview

Burra Creek originates in the north-west corner of the Tinderry Nature Reserve and flows in a north-westerly direction through Burra Creek Nature Reserve and intercepts with the Queanbeyan River before discharging to Googong Dam. When Googong Dam is approaching full supply level the lower reaches of Burra Creek are inundated.

Cassidy’s Creek, a main headwater tributary of Burra Creek, originates at an elevation of approximately 800m. Figure 1 shows the confluence of Burra Creek and the Queanbeyan River. By the time the project first crosses Burra Creek the elevation has reduced to approximately 740m where it remains constant until the proposed outlet point and slowly declines to 670m where it meets the confluence with the Queanbeyan River.

The proposal would discharge water at a location downstream of Burra Road where it would flow for approximately 10km down Burra Creek prior to entering Googong Dam. Figure 1 shows the fluvial geomorphic boundaries of this section of Burra Creek. Note, the impact of the proposed flow discharges on London Bridge are dealt with in a separate report.
Figure 1 Burra Creek Study Area
3.1.2 Site Investigation Scope

Site assessments were undertaken at a number of key spots within the study area. Sites were chosen to provide a good overview of the character and condition of the different reach types evident along Burra Creek. Two geomorphologists completed the site investigations and took note of the following factors:

- Reach Classification;
- Channel Planform;
- Channel Geometry;
- Bank Shape;
- Stability;
- Vegetation Associations;
- Landuse; and
- Flow Frequency.

3.1.3 Study Area Overview

This proposal would discharge water into Burra Creek just downstream of Burra Road. Between here and the confluence with the Queanbeyan River, Burra Creek can be divided into three (3) distinct reaches based on valley confinement and channel gradient. Figure 1 outlines the approximate boundaries of the three reaches within the study area. Reach 1 begins at the Burra Road crossing and continues for approximately 3.1 km downstream. At this point the valley widens allowing small, longitudinally discontinuous floodplains to form. A further 3.1 km downstream, the valley widens further and the channel begins to flatten out, such that alluvial floodplain deposits dominate channel banks. Throughout the study area, the channel bed is generally stable and is controlled by natural bedrock bars. Within Reaches 1 and 2, the channel is pinned against the valley margin and therefore has limited capacity for adjustment. Within Reach 3, extending to the confluence with the Queanbeyan River, the wider valley provides greater potential for lateral adjustment.

Reach 1: Confined - Gorge

Reach 1 can be characterised as a gorge. Figure 2 shows that the channel is entirely bounded by bedrock. This bedrock confinement limits lateral and vertical adjustments of the channel. The channel is generally less than 15 m wide and occupies the entire valley floor. This is associated with a relatively steep gradient of 0.015 m/m. As a result, sediment is transported through this reach with sediment deposits limited to small bars largely consisting of gravel to cobble sized sediments and occasional benches in short sections where valley width increases to 20 m. Instream channel features consist dominantly of bedrock controlled pool – step sequences. Recent low flow conditions have resulted in the establishment of stands of macrophytes within the channel.
This reach is characterised by a relatively straight channel planform with an approximate slope of 0.007 m/m. The valley is generally less than 50 m wide and is dominated by bedrock. This wider valley setting has allowed floodplains to develop such that the channel is bounded by bedrock on one bank and alluvial deposits on the other (Figure 3 and 4). As a result the channel has some capacity to adjust laterally via expansion through erosion of the alluvial channel margins.

The pattern of instream geomorphic units is largely influenced by bedrock and valley protrusions and as a result, step-pool-riffle sequences are evident in this reach. The low flow channel within the riffle zones is generally poorly defined. These areas consist of gravel, cobbles and boulders in matrix of silt and sand sediments. These features have been stabilised by terrestrial grasses and macrophytes in low-lying wet areas. This indicates a lack of recent large flow events through this system.

Over recent times, drought conditions and resultant low flows have created suitable conditions for the growth of macrophytes within the channel. In places, the low flow channel becomes discontinuous as a result of the degree of reed growth.
Reach 3: Partly Confined - Planform Controlled

This reach is characterised by a sinuous channel planform with an approximate slope of 0.003 m/m. The channel flows through a valley approximately 50 to 100 m wide. This wider valley setting means floodplains are often present on both sides of the channel. The channel through this reach is approximately 10 – 15 m
wide with steep banks and is characterised by a series of deep pools (~0.5 – 1.5 m deep) separated by vegetated riffle zones with poorly defined low flow channels. The low flow channel width varies between ~1.5 m in pools and 0.25 m in runs. Cobbles and gravels have been deposited within the channels, particularly within the riffle zones.

Fringing vegetation is common surrounding the margins of the pools and have colonised within the sediments of riffle zones. Reeds are choking the channel in many places, limiting the transport of suspended sediments. Recent drought conditions and the lack of high magnitude flow events would have promoted further recent reed growth.

Floodplains clearly indicate the sequences of deposition over time, particularly emphasising the impact of recent post-European land clearance. Exposure of the banks display a layer of light coloured sediments dominated by fine sands 0.3 to 0.5 m thick underlaid by older darker sediments largely consisting of silt. This indicates a change in depositional processes of the floodplains from low energy fine grained accretion to a higher energy environment of mass deposition of sand material. It is thus inferred that the upper deposit is of post-European origin as result of increased sediment loads due to extensive hillslope and gully erosion in the upstream catchment. Such post-European impacts on waterway systems in the region have been well documented previously (eg Prosser et. al., 1994; Wasson et. al., 1998).

Starr (2005) noted two locations of headcut erosion upstream of London Bridge. Both sites were located during the field investigation. As shown in Figure 8 these headcuts are located on a laterally attached bar within the channel which is incised with a high flow channel.

London Bridge, a limestone natural bridge, is located within this reach, approximately 1500 m upstream from the confluence with the Queanbeyan River. Immediately downstream the channel geometry changes slightly due to the hydrological influence of London Bridge. The channel width is similar, however banks are more laid back and the channel is less incised than upstream. An instream sand and gravel bar, immediately downstream from London Bridge, indicates that London Bridge is acting as a hydraulic control as flows spread out and dissipate downstream of London Bridge allowing sands and gravels to deposit as a mid-channel bar.

Anecdotal evidence (Spate, pers.comm) suggests that local adjustments have occurred in the bed form around London Bridge within the last 30 years. During studies undertaken by Jennings et al. (1976) a sand bar was present within the main London Bridge cave. Recent studies undertaken within the scope of this project show that this instream feature is no longer apparent, however the water level still remains similar to that in 1976.
To further document the temporal changes in channel form in Reach 3, a review of historical aerial images was undertaken. The images assessed are displayed in Figure 9 and were dated:

- 30/08/1951;
- 13/11/1961;
- 26/04/1976;
- 23/10/1992; and

From this analysis the following observations have been made:

- Evident in the 1951 and 1961 images, the channel bed of Burra Creek did not exhibit any significant pool features and displayed a continuous low flow channel set within unconsolidated sediments. This suggests that the system had undergone significant disturbance prior to 1951;
- Since 1976, pools have become more established, while the low flow channel in the riffle zones separating pool has become less defined; and
- There has been no significant change in the position and dimensions of the macro-channel since 1951, apart from some localised channel narrowing. In combination with the pools becoming more established, this indicates that channel form is in a state of recovery following the early post-European disturbances.

This temporal study indicates that Burra Creek has undergone significant changes in form over the relatively recent past, from a system with a continuous low flow channel set within mobile sand and gravel deposits to a more discontinuous system exhibiting more developed pools. This adjustment may represent the ongoing recovery of Burra Creek as a result of improved/changed land management practices following the inferred early European impacts on channel form. Alternatively, the adjustment may also reflect a reduction in the frequency of flow events with the capacity to cause morphological adjustment due to the recent drought conditions, allowing the channel bed to become stabilised with vegetation. Nevertheless, the assessment indicates that small-scale bed form alterations are common within this disturbed system.
Figure 5  Upstream of London Bridge

Figure 6  Downstream From London Bridge
Figure 7 View of Upstream Side of London Bridge

Figure 8 Headward Erosion Through High Flow Channel Inset on Riffle Zone (Upstream from London Bridge)
Figure 9 Historical Images – Burra Creek
3.2 Impact Assessment

The Proposal design allows for a capacity to regulate discharge magnitude and duration into Burra Creek. Decisions regarding intake and discharge rates would be dependant upon a combination of the Googong Dam level, water demand and environmental flow requirements within the Murrumbidgee River. Modelling of the hydrological changes has been undertaken using ACTEW’s prudent planning scenario and taking into account these operational variables. The prudent planning assumes high population growth, a step change to the year 2030 climate predicted by CSIRO, 25% demand reduction by 2015, regular bushfire events, and starting from current reservoir storage levels. The results indicate that the transfer discharge would significantly increase the overall flows within Burra Creek with:

- The percentage of days where the Burra Creek flow is less than 1 ML/day is decreased from 47% to 29%; and
- The percentage of days with flows of at least 100 ML/day is increased from 1% to 21%.

The transfer flow does not have a particularly large impact upon peak flows, as reported by ACTEW (2008a):

- The 100 ML/day makes up a less significant portion of the flow in these conditions;
- The need to supply water is probably lower during peak flow conditions; and
- The pump station can be temporarily turned off if necessary during peak flows in Burra Creek.

Hence, the hydrological changes are more a product of an increase in the duration of flows with magnitudes less than 100 ML/day. Modelling results (ACTEW 2008a) of the duration of pumping events indicate:

- 29% of pumping events last for a month or less;
- 54% last for 3 months or less;
- 96% last for a year or less; and
- The average duration of transfer discharges is 4.3 months.

The likely impacts of these hydrological changes on Burra Creek within each reach are discussed in the following sections.

3.2.1 Reach 1: Confined - Gorge

Bedrock confined rivers have limited capacity for both vertical and lateral adjustment, making them particularly resilient to alterations in flow regimes. In the event of altered flow regimes it is unlikely that large scale changes in channel form would occur due to the significant bedrock control. While the larger scale physical template of the creek is unlikely to change, there may be some smaller scale alterations in channel morphology.

The active channel is influenced by flow events with a recurrence interval of about 1 in 2 years (Starr, 2005). These events influence vegetation colonisation within the channel. An increase in smaller flow events may entrain and transport some of the finer sediments from the pool and run areas, thereby reducing conditions appropriate for colonisation of plants such as reeds. In addition, these flows may destabilise such plants, with both scenarios leading to a potential decrease in biomass and biodiversity similar to 1992 levels.

3.2.2 Reach 2: Partly Confined – Bedrock Controlled

Due to the high degree of bedrock control in this reach, there is limited capacity for vertical (bed level) adjustments. Channel bed responses to flow transfer discharges in this reach are expected to be limited to the establishment of a more defined low flow channel within the riffle zones connecting pools.
Localised lateral adjustments may occur through undercutting of banks due to the higher flow operating on banks for longer durations. This would be most pronounced where the developed low flow channel abuts the alluvial banks of the macro-channel. Figure 10 shows the potential locations for this.

In addition, there will be a loss of fringing vegetation with exposure of sediments to erosion by flows. This is expected to result in the establishment of a more defined low flow channel within the riffle zones connecting pools. Once established, fringing vegetation will recolonise the newly formed low flow channel margins and provide long-term stability.

3.2.3 Reach 3: Partly Confined - Planform Controlled

There is greater capacity for both vertical and lateral adjustment in the channel due to the reduced influence of bedrock control in this reach. Geomorphologic adjustments in response to transfer discharges in this reach are expected to result in the establishment of a more defined low flow channel within the riffle zones connecting pools. Further, an increase in smaller flow events may wash some of the finer sediments from the channel reducing the degree of reed colonisation within the channel.

Smaller local adjustments may occur through undercutting of banks due to the higher flow operating on banks for longer durations. This would be most pronounced where the developed low flow channel abuts the alluvial banks of the macro-channel. Figure 10 shows the potential locations for this.

Note, impacts of the flow discharges on London Bridge and other karst features are dealt within a separate report.
Figure 10 Location of banks vulnerable to undercutting.
3.2.4 Hydraulic Modelling – Reaches 2 and 3

HEC-RAS modelling, based upon topographic surveys within Reaches 2 and 3, has been undertaken to compare the hydraulic behaviour of transfer flows with a range of natural flows (ACTEW, 2008b). This indicates that the addition of the maximum 100 ML/d discharge represents about 3% of the once in two year flood event (ACTEW, 2008b). The results of this hydraulic modelling have been used to further assess the potential impacts of the transfer discharge on the morphology of the channel. This is discussed in the following sections.

Riffle Zones

Flow levels associated with the proposed transfer discharge are estimated to increase by 0.4m compared to the ‘typical’ low flow of 5 ML/day (ACTEW, 2008b). Although this discharge would still be contained within the incised macro-channel, the additional flow would increase the flow width over riffle zones resulting in the inundation of fringing vegetation. Given that the transfer flow may operate continuously over extended periods, inundated vegetation may die off, particularly where grasses dominate the ground cover. In such cases this would result in the exposure of riffle zone sediments to flows and potential erosion. Flow velocities over riffle zones are estimated to increase compared to those of the typical low flow discharge of 5 ML/day from between 0.25 m/s and 0.5 m/s to between 0.7 m/s and 0.9 m/s (ACTEW, 2008b). Such velocities exceed the threshold for entrainment of unconsolidated silt to sand sized sediments (see Figure 11). Hence, with the loss of protective vegetation, there is a high potential for a continuous, defined low-flow channel to develop within the riffle zones in response to the proposed discharge of up to 100 ML/day.

Figure 11 Hjulstrom diagram displaying how different sediment sizes behave with various stream velocities.
The formation of a continuous channel will result in the erosion and transport of sediment downstream. It is predicted that due to bedrock influences and the high proportion of gravel to cobble sized material of the riffle zone sediments, that the formation of the low flow channel would be depth limited and is unlikely to incise to depths greater than 0.5 metres.

The development of the low flow channel is likely to occur in the first one to two years of discharging the transfer flows. Hence, the associated impact of increased turbidity will be short-lived and reduce as fringing vegetation re-establishes. Additionally, the quantity of sediment released from development of a low flow channel would be significantly less than transported from the upstream catchment in flood events.

**Pool Zones**

With the formation of a low flow channel through riffle zones, pools would become more connected. In the case that the downstream hydraulic control (upstream extent of a riffle zone) of a pool is composed of unconsolidated sediments, formation of a more defined low flow channel in the downstream riffle zone may result in a lowering of the hydraulic control through exposure of sediments at riffle zone crests and subsequent erosion during natural high flow events. This would lead to a reduction in pool levels during low flow periods when transfer flows are not being discharged. This will vary from pool to pool, depending on the degree of bedrock influence and the proportion of large gravel to cobble size sediment within the riffle zone.

Pools are also likely to be subject to short-term sedimentation impacts through the deposition of sediment released from the formation of a low-flow channel in riffle zones. Deposited sediment is likely to be flushed from pools during natural flow events equivalent to or greater than a 1 in 2 year ARI. As a result, over time, sediment would be transported downstream into the backwater reaches of Googong Dam.

It is important to recognise that macrophytes play an important role in limiting the downstream transfer of suspended sediment during low flow events. As these typically colonise channel marginal areas along Burra Creek, they are likely to capture a proportion of the released sediments, limiting the potential for increased pool sedimentation. After a while the macrophytes will grow back in a different part of the channel. Therefore, the impact of the transfer flows on the growth and distribution of macrophytes, would be a strong determinant in the degree of pool sedimentation experienced.

Flow velocities through pools are estimated to increase from those of the typical low flow discharge of 5 ML/day from less than 0.1 m/s to around 0.2 m/s in Reach 3 and 0.5 m/s in Reach 2 (ACTEW, 2008b). Based on Figure 11, erosion of consolidated silt to clay-sized sediment occurs at velocities greater than approximately 0.8 m/s. This velocity is not exceeded in Reach 3 and only just exceeded in Reach 2. In the case of the latter, pools are often bounded by bedrock on at least one bank and will not experience erosion on this bank. As a result direct changes to pool morphologies in response to the transfer discharges are expected to be minor.

However, the increase in the level and width of flow within pools may impact on fringing vegetation. Prolonged higher discharges will drown fringing macrophyte and result in the exposure of underlying sediments to both transfer discharges and natural flows. This is expected to result in increases in pool widths. The degree of widening will vary from pool to pool but is expected to be more pronounced in Reach 3, where pools have less bedrock influence. It is expected that macrophytes will re-establish themselves along the new margins of the pools providing long-term stability.

### 3.2.5 Impact Summary and Discussion

It is evident that Burra Creek has been subject to significant alterations in morphological form in the recent past and is still in a state of adjustment. The potential morphological impacts identified by this assessment as a result of the transfer discharges are highly likely to be within the bounds of the recent variability in channel form. That is, it is predicted that Burra Creek through Reaches 2 and 3 would adjust in response to the transfer discharges to a form more resembling that seen in the 1992 aerial image as displayed in Figure 10.
This would occur as a result of a variety of morphological adjustments in response to the proposed transfer discharges as a result of longer durations of an increase in the wetted perimeter within the active low flow channel leading to vegetation changes and exposure of sediments. These impacts are summarised as:

- Development of a low flow channel within riffle zones through Reaches 2 and 3 due to the potential loss of vegetative cover and a predicted increase in the duration of flow velocities above the threshold for entrainment of unconsolidated sand to silt sized sediments;
- Potential increase in pool widths with the loss of fringing vegetation under prolonged periods of flow transfer and exposure of underlying sediments to flows;
- Potential for localised undercutting of banks due to the higher flows operating on banks for longer durations;
- Potential lowering of pool levels with the reduction in height of the downstream hydraulic control due to the development of a low flow channel within riffle zones; and
- A potential temporary increase in turbidity and bed smothering sediments as a result of the release of sediments through the predicted channel adjustments.

Of these impacts, the most significant is considered the potential loss of pool habitats as a result of lowering of the downstream hydraulic control with development of a low flow channel within the riffle zones.

While some attempt has been made to quantify the degree of these morphological adjustments associated with the proposed transfer discharge, the exact nature (timing, location, extents) of the impacts is dependant on a range of factors particularly:

- The impact of transfer discharges on the growth and distribution of macrophytes;
- The capacity and timing of macrophytes to recolonise instream features following a large, natural flow event; and
- The timing of large natural flow events in relation to the timing and duration of transfer events.

Most impacts identified above are likely to be unavoidable and will be difficult to mitigate against. However, most of the predicted morphological adjustments are likely to have become established within the first one to two years of operation. Hence, the impact of erosion and the associated water quality issues will be short-lived, reducing as fringing vegetation re-establishes and provides stability along the low flow channel margins.

### 3.3 Mitigation

#### 3.3.1 Construction Impact Mitigation

There would be no construction impacts associated with the transfer discharge along Burra Creek, apart from the outlet structure. This is addressed in Section 4.

#### 3.3.2 Operational Management Measures

The following recommendations are made to mitigate the identified impacts in respect to the proposed transfer discharges:

- Development and implementation of a riparian revegetation plan for waterway banks focusing on those banks in Reaches 2 and 3 identified as having a potential to be undercut due to transfer discharges; and
- As discussed above, the nature of morphological adjustments in response to the proposed discharge cannot be precisely defined, as the potential adjustments are dependant on a range of variables they cannot be readily quantified. Hence, it is recommended that an adaptive management framework be developed based on a monitoring program, including:
– Monitoring of water quality including suspended sediment sampling for both transfer discharge events and during natural flow events at the following locations:

– Upstream of the discharge outlet at the flow gauge;

– Immediately downstream of the discharge outlet; and

– Upstream of London Bridge within Reach 3 with samples taken from both a pool and a riffle zone.

– Monitoring of pool depths within Reaches 2 and 3;

– Monitoring of the bed and bank stability of the waterway primarily focussing on identifying the development of any significant headcuts (greater than 0.3 m) within riffle zones in Reaches 2 and 3. In the event, significant headcuts are identified, structural intervention may be required to limit any further upstream retreat, especially in instances where the hydraulic control of the upstream pool may be compromised; and

– Monitoring of changes in the distribution of macrophytes within the channel in Reaches 2 and 3.

It is important to recognise that the management framework and monitoring program needs to be mindful that Burra Creek has undergone profound morphological change in the past and is currently still in a state of adjustment. As a result, any alterations in channel form identified through monitoring need to be considered in light of whether they are within the bounds of the natural recent variability in channel form. With this in mind, Table 2 provides guidelines for morphological indicators and management actions to assess monitoring observations of morphological changes along Burra Creek.

**Table 2 Guidelines for morphological monitoring and management actions.**

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<td><strong>Undercutting of Main Channel Banks</strong></td>
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<td>Assess options to stabilise affected areas through structural means.</td>
</tr>
<tr>
<td><strong>Pool Sedimentation</strong></td>
<td>Ongoing reduction of pool depths even after other morphological adjustments have completed and affected areas have stabilised.</td>
<td>Reduce recommended turbidity limits of transfer flows.</td>
</tr>
</tbody>
</table>
4 Intake/Outlet Structure

4.1 Existing Conditions

4.1.1 Intake Structure

The proposed intake structure is to be located immediately upstream of the causeway on the true right bank of the Murrumbidgee River at Angle Crossing. The channel alignment at this location is controlled by bedrock valley margins, diverting the channel from a westerly course to a northerly one. A deep pool is located adjacent to the proposed intake site and is controlled by the causeway crossing.

The intake structure would be built into the right bank on top of an existing laterally attached point bar composed dominantly of sand sediments (Figure 12). This bar is largely unvegetated upstream of the proposed intake site, however, at the site the channel marginal section of the bar is well-vegetated with a range of grasses, shrubs and small trees (Figure 13). A high flow channel with gravel deposits crosses the sand bar at its upstream extent.

Figure 12 Bar is Unvegetated Upstream of the Proposed Intake Location
An analysis of historical aerial imagery was undertaken to assess changes in the configuration of the river to assist in assessing the potential impacts associated of the proposed intake structure. The images assessed are displayed in Figure 14 and are dated:

- 03/08/1951;
- 12/11/1961;
- 02/05/1976;
- 14/10/1992; and

From this analysis, a key observation is the lack of deep pools in the 1961 image. Additionally, it can be seen that the upper surfaces of the bars features have become more stabilised with vegetation over time. These observations indicate that the river has undergone a reduction in sediment supply post 1961, allowing features pools to become more defined. However, since 1976 the general configuration of the river has remained constant. Hence, the bar that the proposed intake structure would be located on is considered a stable feature over medium to long time frames.
Figure 14 Historical Aerial Images – Angle Crossing
4.1.2 Outlet Structure
The proposed outlet structure is located downstream of Burra Road near the existing flow gauging weir (Figure 15). The outlet structure would discharge into Reach 1 (Confined Valley – Gorge). Further description of this waterway type is outlined within section 2.1.3.

Figure 15 Burra Creek Downstream of Burra Road

4.2 Impact Assessment
4.2.1 Intake Structure
The proposed intake structure has been designed to merge with the existing bar surface and would not impact significantly on flows within the river. However, as the structure would be a hard structure set within unconsolidated sediments, there would be a propensity for scour of sediments from around the structure when bar sediments are mobilised during moderate to high flow events. Rock protection is to be provided for the margins of the structure. On the upstream side of the structure, rock protection would key into the bedrock hillslope behind the structure to limit any potential for the structure to be outflanked. On the channel edge, the causeway controls the upstream bed levels and the depth of scour within the channel here. Hence, increased scour as a result of the structure would neither be significant nor long-lasting. Figure 16 shows a graphical representation of the structure.

Construction of the intake would involve excavation and disturbance of bank and bar sediments. This may result in an increased potential for sediments to be discharged downstream. Construction of the intake structure will involve installation of a coffer dam (sheet-piling) and placement of a floating silt curtain. This will limit the propensity for sediments to be discharged downstream during low flow conditions. In the event high flow conditions occur during the construction phase, the impact of additional sediment on turbidity as a result of site disturbance would be low as the volume of sediment transported by the Murrumbidgee River in high flow events would be many times greater than the additional sediment sourced from site disturbance.

The flow to be abstracted represents a small proportion of those flows within the Murrumbidgee River at Angle Crossing that have the capacity to transport bedload and generate morphological change. Hence, the
reduction in flow of the Murrumbidgee River will not result in any morphological impacts at Angle Crossing and downstream.

**Figure 16** Graphical Representation of the Intake Structure

### 4.2.2 Outlet Structure

The discharge would enter Burra Creek within a section of the creek that is largely protected by bedrock bed and banks. The outlet structure would be constructed on the right bank of Burra Creek. The outlet structure would consist of a rectangular weir box arrangement. The incoming pipe should be centred on a 2m wide end wall. The water would flow from the pipe and well up to flow over a grated, 10m long weir on the side wall. The structure would be inset within the bank so that the grated outlet weir is flush with the natural surface. Rock protection would be provided to the disturbed banks upstream and downstream of the structure and to the bed and the bank of Burra Creek opposite to the outlet. Figure 17 provides a graphical representation of the completed structure.

**Figure 17** Graphical Representation of Completed Discharge Outlet Structure
As the structure would be flush with the banks and rock protection provided to the bed and banks in the immediate vicinity of the pipe, no long-term morphological impacts have identified with the operation of the structure.

Construction of the structure would require disturbance to the bed and banks of Burra Creek resulting in the short-term exposure of soils to erosion by flows within the creek.

4.3 Mitigation

General mitigation measures proposed to minimise the impact of the intake and outlet structures on Murrumbidgee River and Burra Creek are provided in the following sections.

4.3.1 Intake Structure

Construction

The following recommendations are made to mitigate impacts associated with the construction of the intake structure:

- Develop and implement an Erosion and Sediment Control Plan (ESCP). In regard to the potential geomorphic impacts, this should address:
  - Changes to local run-off flow patterns across the disturbed bar areas with particular attention to those flow paths that lead directly into the Murrumbidgee River;
  - Ensuring any spoil is stockpiled away from the influence of river flows and bunded appropriately; and
  - Limiting vehicular access and movement on the bed and banks of the Murrumbidgee River to minimise disturbance and the potential for scour during a large flood flow event.

- During the construction phase disturbed areas should be closely monitored and progressively rehabilitated as stages are completed;

- Avoid construction activities within the Murrumbidgee River during periods of higher than normal flows;

- Rock protection works should be flush with the existing surfaces; and

- Limit disturbance to existing vegetation on the bar surface as far as practical, especially along the channel marginal area immediately upstream of intake location.

Operation

The following recommendations are made to mitigate impacts associated with the operation of the intake structure:

- Monitor edges of intake structure for evidence of scour;

- As part of a broader rehabilitation program undertake:
  - Implementation of jute matting to retain and stabilise soil in disturbed areas; and
  - Revegetation of disturbed bar areas. Species to be used for revegetation should only consist of local native species.

4.3.2 Outlet Structure

Construction

The following recommendations are made to mitigate impacts associated with the construction of the outlet structure:

- Develop and implement an Erosion and Sediment Control Plan (ESCP). In regard to the potential geomorphic impacts, this should address:
– Changes to local run-off flow patterns across flood plains and down hillslopes with particular attention to those flow paths that lead directly into creek channels; and

– Limiting vehicular access and movement on the bed and banks of Burra Creek to minimise disturbance and the potential for scour during a large flood flow event.

• As part of a broader rehabilitation program undertake:

  – Implementation of jute matting in disturbed areas to retain and stabilise soil in disturbed areas; and

  – Revegetation of disturbed banks. Species to be used for revegetation should only consist of local native species.

• During the construction phase disturbed areas should be closely monitored and progressively rehabilitated as stages are completed;

• Avoid construction activities within Burra Creek during periods of higher than normal creek flows; and

• During the construction phase monitor waterway bed and banks for indications of instability. Particular attention to monitoring channel erosion should be undertaken during and following higher than normal flow conditions. Address any evidence in the increased intensity or extent of erosion with appropriate temporary and/or permanent protection measures as soon as practical.

_Operation_

No long-term morphological impacts have been identified associated with the operation of the outlet structure, hence, no recommendations are provided.
5 Summary

5.1 Transfer Pipeline Impacts

The following provides a summary of the impacts associated with the construction and operation of the transfer pipeline on the morphology of waterways along the proposed pipeline route.

5.1.1 Impact Summary

Most waterways along the proposed pipeline route are generally first to second order, ephemeral streamlines and exhibit a poorly defined channel with grassed bed and banks. Construction of pipeline crossings of waterways will use standard trenching techniques. Most impacts to the morphology of waterways associated with the transfer pipeline are associated with the construction phase of the project and include:

- Soil erosion caused by ground disturbance;
- Disturbance to bed and banks;
- Disturbance to floodplains;
- Stream bed degradation;
- Stream bank degradation;
- Scour potential from poor pipeline orientation:
  - The impact of erosion from bed and bank disturbance can include water quality impacts on the downstream environment. General construction activities (e.g. stockpiling of material, etc.) may lead to sedimentation issues.

Specifically, site based assessment indicates that headward erosion, bank erosion and tunnel erosion is occurring in some locations throughout the alignment (Appendix A). These bed and bank instabilities (Appendix A) may be further exacerbated by construction of the transfer pipeline. This may:

- Increase the risk of headward erosion.
- Where headcuts are evident downstream there is a risk that the pipeline would create bed instabilities leading to further channel incision in an upstream direction. An additional consequence of this may be the risk of exposing the pipeline asset.
- Increase the risk of bank erosion.
- Bank disturbance would occur during trenching activities. If appropriate reinstatement is not implemented this may lead to bank slumping.
- Increase the risk of tunnel erosion.
- An altered hydraulic gradient may occur in some instances where sand is placed around the pipe and enhance the risk of tunnel erosion.

5.1.2 Mitigation Measures Summary

Most of these impacts can be easily mitigated against using standard construction erosion and sediment control measures in conjunction with appropriate reinstatement and rehabilitation of disturbed areas. In addition to the standard management requirements that would be expected during construction, specific waterways require additional mitigation measures to ensure adequate protection. These measures are outlined within Appendix A for those waterways that have been inspected. Further detailed mitigation measures would need to be established for each waterway crossing prior to construction activities. Waterway specific mitigation measures would need to address the risk of erosion at each site and may include:
**Reinstall Profile**
- Replace sediments in order they were removed;
- Reshape according to current profile; and
- Design recommendations informed by the geotechnical investigation to address the potential for differential settlements in areas containing soft or compressible soil types.

**Stability**
- Reinstate soils over pipeline with a soil-rock mix (~100-300 mm), jute matting and regrassing to reduce risk of headward erosion; and
- Reinstate bed and banks with rock in erosion sensitive areas to protect from bank erosion.

**Operational Management Measures**
Additional requirements may need to be addressed during the operational phase of the Proposal in order to minimise the impact on the surface water environment: These may include:
- Monitoring of the downstream bed stability of the waterway where erosion has been identified as a key concern to ensure that mitigation is appropriate to protect the asset and prevent waterway degradation;
- The restriction of inspection access in sensitive areas (eg. waterways) to foot as much as possible; and
- All inspections portals, valves, etc. are not installed in the vicinity of the waterway crossings as they may be inundated during periods of high flow.

5.2 Burra Creek – Transfer Discharge Impacts

The following provides a summary of the impacts associated with discharges of up to 100 ML/day on the morphology of Burra Creek from the proposed discharge outlet location downstream to the backwater reaches of Googong Dam.

5.2.1 Impact Summary

Burra Creek is expected to undergo a variety of morphological adjustments in response to the proposed transfer discharges. These will occur primarily as a result of the longer duration in of a wetted perimeter within the active low flow channel leading to vegetation changes and exposure of sediments. The adjustments are expected to occur largely within Reaches 2 and 3 as alluvial deposits largely bound the channel in these reaches. Hence, they have a greater capacity for morphological change compared to Reach 1, which is almost entirely bound by bedrock. The expected adjustments in Reaches 2 and 3 are summarised as:

- Development of a more continuous low flow channel within riffle zones through Reaches 2 and 3 due to the potential loss of vegetative cover and an increase in the duration of flow velocities above the threshold for entrainment of unconsolidated sand to silt sized sediments;
- Potential increase in pool widths with the loss of fringing vegetation under prolonged periods of flow transfer and exposure of underlying sediments to erosion by flows;
- Potential for localised undercutting of high banks due to the higher flows operating on banks for longer durations;
- Potential lowering of pool levels with the reduction in height of the downstream hydraulic control due to the exposure of sediments to scour during natural high flow events; and
- A potential temporary increase in turbidity and bed smothering sediments as a result of the release of sediments through the predicted channel adjustments.

Of the potential morphological adjustments, the most significant is considered the potential loss of pool habitats as a result of lowering of the downstream hydraulic control with development of a low flow channel.
within the riffle zones. This would lead to a general reduction in the overall diversity of aquatic habitats along Burra Creek.

In regard to the other morphological adjustments, these are likely to have become established within the first one to two years of operation. Following this initial adjustment period, significant ongoing adjustment is not expected due to the re-establishment of vegetation along the low flow channel margins, providing stability. Hence, the associated impacts on water quality and pool sedimentation will be short-lived.

Additionally, while there will be some change in from existing conditions, based on an assessment of historical aerial imagery, it is evident that Burra Creek has been subject to significant alterations in morphological form in the recent past and is still in a state of adjustment. The potential morphological impacts identified by this assessment as a result of the transfer discharges are highly likely to be within the bounds of the recent variability in channel form. Hence, the general form of Burra Creek will remain consistent with that of the recent past, with only minor changes in the diversity of aquatic habitats.

5.2.2 Mitigation Summary

The following recommendations are made to mitigate the identified impacts in respect to the proposed transfer discharges along Burra creek:

- Development and implementation of a riparian revegetation plan for waterway banks focussing on those banks in Reaches 2 and 3 identified as having a potential to be undercut due to transfer discharges; and

- As the exact nature of the morphological adjustments cannot be readily defined, a monitoring program and interpretation guidelines to assess monitoring observations have been recommended to inform management actions to address significant morphological change along Burra Creek. This is summarised in Table 3.

### Table 3 Guidelines for morphological monitoring and management actions.

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### 5.3 Inlet and Outlet Impact Summary

The following provides a summary of the impacts associated with the construction and operation of both the proposed intake structure at Angle Crossing and the outlet structure on Burra Creek.

**5.3.1 Intake Structure Impact Summary**

The proposed intake structure has been designed to merge with the existing bar surface and would not impact significantly on flows within the river. However, as the structure would be a hard structure set within unconsolidated sediments, there would be a propensity for scour of sediments from around the structure when bar sediments are mobilised during moderate to high flow events. Rock protection is to be provided for the margins of the structure. On the upstream side of the structure, rock protection would key into the bedrock hillslope behind the structure to limit any potential for the structure to be outflanked. On the channel edge, the causeway controls the upstream bed levels and the depth of scour within the channel here. Hence, increased scour as a result of the structure would neither be significant nor long-lasting.

Construction of the intake would involve excavation and disturbance of bank and bar sediments. This may result in an increased potential for sediments to be discharged downstream.

The flow to be abstracted represents a small proportion of those flows within the Murrumbidgee River at Angle Crossing that have the capacity to transport bedload and generate morphological change. Hence, the reduction in flow of the Murrumbidgee River will not result in any morphological impacts at Angle Crossing and downstream.

**5.3.2 Intake Structure Mitigation**

**Construction**

The following recommendations are made to mitigate impacts associated with the construction of the intake structure:

- Develop and implement an Erosion and Sediment Control Plan (ESCP). In regard to the potential geomorphic impacts, this should address:
  - Changes to local run-off flow patterns across the disturbed bar areas with particular attention to those flow paths that lead directly into the Murrumbidgee River;
  - Ensuring any spoil is stockpiled away from the influence of river flows and bunded appropriately; and
  - Limiting vehicular access and movement on the bed and banks of the Murrumbidgee River to minimise disturbance and the potential for scour during a large flood flow event.
- During the construction phase disturbed areas should be closely monitored and progressively rehabilitated as stages are completed;
- Avoid construction activities within the Murrumbidgee River during periods of higher than normal flows;
- Rock protection works should be flush with the existing surfaces; and
- Limit disturbance to existing vegetation on the bar surface as far as practical, especially along the channel marginal area immediately upstream of intake location.

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<tr>
<td>Pool Sedimentation</td>
<td>Ongoing reduction of pool depths even after other morphological adjustments have completed and affected areas have stabilised.</td>
<td>Reduce recommended turbidity limits of transfer flows.</td>
</tr>
</tbody>
</table>


**Operation**

The following recommendations are made to mitigate impacts associated with the operation of the intake structure:

- Monitor edges of intake structure for evidence of scour;
- As part of a broader rehabilitation program undertake:
  - Implementation of jute matting to retain and stabilise soil in disturbed areas; and
  - Revegetation of disturbed bar areas. Species to be used for revegetation should only consist of local native species.

5.3.3 **Outlet Structure Impact Summary**

The discharge would enter Burra Creek within a section of the creek that is largely protected by bedrock bed and banks. The outlet structure would be constructed on the right bank of Burra Creek. As the structure would be flush with the banks and rock protection provided to the bed and banks in the immediate vicinity of the pipe, no long-term morphological impacts have been identified with the operation of the structure.

Construction of the structure would require disturbance to the bed and banks of Burra Creek resulting in the short-term exposure of soils to erosion by flows within the creek.

5.3.4 **Outlet Structure Mitigation**

**Construction**

The following recommendations are made to mitigate impacts associated with the construction of the outlet structure:

- Develop and implement an Erosion and Sediment Control Plan (ESCP). In regard to the potential geomorphic impacts, this should address:
  - Changes to local run-off flow patterns across floodplains and down hillslopes with particular attention to those flow paths that lead directly into creek channels; and
  - Limiting vehicular access and movement on the bed and banks of Burra Creek to minimise disturbance and the potential for scour during a large flood flow event.
- As part of a broader rehabilitation program undertake:
  - Implementation of jute matting in disturbed areas to retain and stabilise soil in disturbed areas; and
  - Revegetation of disturbed banks. Species to be used for revegetation should only consist of local native species.
- During the construction phase disturbed areas should be closely monitored and progressively rehabilitated as stages are completed;
- Avoid construction activities within Burra Creek during periods of higher than normal creek flows; and
- During the construction phase monitor waterway bed and banks for indications of instability. Particular attention to monitoring channel erosion should be undertaken during and following higher than normal flow conditions. Address any evidence in the increased intensity or extent of erosion with appropriate temporary and/or permanent protection measures as soon as practical.

**Operation**

No long-term morphological impacts have been identified associated with the operation of the outlet structure, hence, no recommendations are provided.
6 References

ACTEW (2008a). M2G17 – Burra Creek Hydrology and Hydraulics. Discharge Flow Impacts on Burra Creek. ACTEW Corporation Ltd.

ACTEW (2008b) Changes in hydraulic conditions in Burra Creek upstream of and through London Bridge resulting from pumped discharges of 50 and 100 ML/d. M2G Project, Preliminary Report.


Appendix A   Major Waterway Pipeline Crossings
Figure A1 Location of creek crossings in the vicinity of the pipeline
Property: 84/754889
Crossing Number: 1

Existing Condition at Crossing Point

<table>
<thead>
<tr>
<th>Classification</th>
<th>Valley Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>0.75 km²</td>
</tr>
<tr>
<td>Channel Planform</td>
<td>Undefined to slightly sinuous</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>No defined bed and banks</td>
</tr>
<tr>
<td>Bank Shape</td>
<td>Undefined within immediate vicinity of crossing point</td>
</tr>
<tr>
<td>Stability</td>
<td>Stable within immediate vicinity of crossing point</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Grasses</td>
</tr>
<tr>
<td>Landuse</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Flow Frequency</td>
<td>Intermittent</td>
</tr>
</tbody>
</table>

Comments
There is evidence of headward erosion ~ 50 m downstream of the proposed crossing point controlled by bedrock outcrops. Dam immediately upstream of crossing point has altered the hydraulic conditions and caused channel incision downstream. Prior to dam, the flows would have been more dispersed.

Impact Assessment

Proposed works
Trenching to lay the pipe will occur upstream of the incised channel and downstream of the dam.

Potential Impact
Disturbance of bed and banks and potential for downstream sediment transfer during construction. Works in this area have the potential to enhance headward erosion which may threaten the dam.

Mitigation

Construction
Ensure adequate flow and sediment controls are implemented. Avoid construction activities during wet periods.

Reinstate profile
Replace sediments in order they were removed. Reshape according to current profile.

Stabilise
Reinstate upper soil profile over pipeline with a soil-rock mix, jute matting and regrassing to reduce risk of headward erosion up the valley towards proposed pipeline location.
Property: 31/1111074
Crossing Number: 2

Right bank view along alignment

Oblique view of tunnel erosion

<table>
<thead>
<tr>
<th>Existing Condition at Crossing Point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Classification</strong></td>
</tr>
<tr>
<td><strong>Catchment Area</strong></td>
</tr>
<tr>
<td><strong>Channel Planform</strong></td>
</tr>
<tr>
<td><strong>Channel Geometry</strong></td>
</tr>
<tr>
<td><strong>Bank Shape</strong></td>
</tr>
<tr>
<td><strong>Stability</strong></td>
</tr>
<tr>
<td><strong>Vegetation</strong></td>
</tr>
<tr>
<td><strong>Landuse</strong></td>
</tr>
<tr>
<td><strong>Flow Frequency</strong></td>
</tr>
<tr>
<td><strong>Comments</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proposed works</strong></td>
</tr>
<tr>
<td><strong>Potential impact</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction</strong></td>
</tr>
<tr>
<td><strong>Reinstate profile</strong></td>
</tr>
<tr>
<td><strong>Stabilise</strong></td>
</tr>
</tbody>
</table>
Property: 24/754889
Crossing Number: 3

Existing Condition at Crossing Point

<table>
<thead>
<tr>
<th>Classification</th>
<th>Valley Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>0.8 km²</td>
</tr>
<tr>
<td>Channel Planform</td>
<td>Undefined</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>Undefined</td>
</tr>
<tr>
<td>Bank Shape</td>
<td>Undefined</td>
</tr>
<tr>
<td>Stability</td>
<td>Stable</td>
</tr>
<tr>
<td>Riparian Vegetation</td>
<td>Grass</td>
</tr>
<tr>
<td>Landuse</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Flow Frequency</td>
<td>Intermittent</td>
</tr>
<tr>
<td>Comments</td>
<td>There are 3-4 dams upstream. It is likely that these are capturing most of the flows from the valley. As a result this drainage line is generally inactive.</td>
</tr>
</tbody>
</table>

Impact Assessment

<table>
<thead>
<tr>
<th>Proposed works</th>
<th>The crossing point is immediately upstream of the dam.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential impact</td>
<td>Disturbance of bed and banks and potential for downstream sediment transfer during construction.</td>
</tr>
</tbody>
</table>

Mitigation

<table>
<thead>
<tr>
<th>Construction</th>
<th>Ensure adequate flow and sediment controls are implemented. Avoid construction activities during wet periods.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinstall profile</td>
<td>Reshape according to current profile. Replace sediments in order they were removed.</td>
</tr>
<tr>
<td>Stabilise</td>
<td>Jute matting and revegetation of disturbed areas.</td>
</tr>
</tbody>
</table>
### Existing Condition at Crossing Point

<table>
<thead>
<tr>
<th>Classification</th>
<th>Incised Valley Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>1.6 km²</td>
</tr>
<tr>
<td>Channel Planform</td>
<td>Straight</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>~2m wide channel, ~2m high banks</td>
</tr>
<tr>
<td>Bank Shape</td>
<td>Convex Upwards</td>
</tr>
<tr>
<td>Stability</td>
<td>Headcuts</td>
</tr>
<tr>
<td>Riparian Vegetation</td>
<td>Grasses on riparian margin and within channel</td>
</tr>
<tr>
<td>Landuse</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Flow Frequency</td>
<td>Intermittent</td>
</tr>
<tr>
<td>Comments</td>
<td>Headcuts downstream, one controlled by bedrock protrusion. An additional headcut is uncontrolled and has the potential to continue movement up the valley. Three large box culverts (~2000mm) ~30m upstream from the proposed crossing point.</td>
</tr>
</tbody>
</table>

### Impact Assessment

<table>
<thead>
<tr>
<th>Proposed works</th>
<th>Trenching to lay the pipe will occur through the channel ~10-15m below the fenceline and downstream of the culverts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential impact</td>
<td>Disturbance of bed and banks and potential for downstream sediment transfer during construction. Works in this area have the potential to enhance headward erosion. Erosion may undermine the toe of the culverts (depending on their invert level).</td>
</tr>
</tbody>
</table>

### Mitigation

<table>
<thead>
<tr>
<th>Construction</th>
<th>Ensure adequate flow and sediment controls are implemented. Avoid construction activities during wet periods. Consider stabilising downstream headcuts to avoid exposure of pipe in the future.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinstall profile</td>
<td>Reshape according to current profile. Replace sediments in order they were removed.</td>
</tr>
<tr>
<td>Stabilise</td>
<td>Reinstall upper soil profile over pipeline with a soil-rock mix, jute matting and regrassing to reduce risk of headward erosion up the valley towards proposed pipeline location.</td>
</tr>
</tbody>
</table>
## Existing Condition at Crossing Point

<table>
<thead>
<tr>
<th>Classification</th>
<th>Valley Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>3.2 km²</td>
</tr>
<tr>
<td>Channel Planform</td>
<td>Straight</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>Undefined bed and banks</td>
</tr>
<tr>
<td>Bank Shape</td>
<td>Undefined</td>
</tr>
<tr>
<td>Stability</td>
<td>Stable</td>
</tr>
<tr>
<td>Riparian Vegetation</td>
<td>Grasses</td>
</tr>
<tr>
<td>Landuse</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Flow Frequency</td>
<td>Intermittent</td>
</tr>
<tr>
<td>Comments</td>
<td>Dispersed overland flows would occur during and immediately after rain events.</td>
</tr>
</tbody>
</table>

## Impact Assessment

**Proposed works:**
Trenching to lay the pipe will occur to the S-E of Williamsdale Road.

**Potential impact:**
Disturbance of bed and banks and potential for downstream sediment transfer during construction.

## Mitigation

**Construction:**
Ensure adequate flow and sediment controls are implemented. Avoid construction activities during wet periods.

**Reinstate profile:**
Reshape according to current profile. Replace sediments in order they were removed.

**Stabilise:**
Jute matting and revegetation of disturbed areas.
### Existing Condition at Crossing Point

<table>
<thead>
<tr>
<th>Classification</th>
<th>Partly Confined – Planform Controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>70 km²</td>
</tr>
<tr>
<td>Channel Planform</td>
<td>Meander</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>2 to 3 m high banks, ~12m top of bank</td>
</tr>
<tr>
<td>Bank Shape</td>
<td>Convex Upwards</td>
</tr>
<tr>
<td>Stability</td>
<td>Stable</td>
</tr>
<tr>
<td>Riparian Vegetation</td>
<td>Overhanging grasses, small shrubs and trees. Larger trees set back from channel on meander bend. Aquatic macrophytes instream.</td>
</tr>
<tr>
<td>Landuse</td>
<td>Residential/ Grazing</td>
</tr>
<tr>
<td>Flow Frequency</td>
<td>Perennial</td>
</tr>
<tr>
<td>Comments</td>
<td>Bedrock step ~10m downstream of proposed crossing point providing channel stabilisation. Large wood has been cut and placed immediately next to the inside bend of the meander. There is a risk that this will be washed downstream during a large flood.</td>
</tr>
</tbody>
</table>

### Impact Assessment

<table>
<thead>
<tr>
<th>Proposed works</th>
<th>Trenching to lay the pipe will occur through a meander bend in Burra Creek.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential impact</td>
<td>Disturbance of bed and banks and potential for downstream sediment transfer during construction. Removal of aquatic vegetation and instream habitat. Alteration of bank morphology potentially increasing chance for localised erosion. Risk of works resulting in bed instability is low due to downstream bedrock step.</td>
</tr>
</tbody>
</table>

### Mitigation

<table>
<thead>
<tr>
<th>Construction</th>
<th>Pipe to have at least 1 m of cover below creek invert. Ensure adequate flow and sediment controls are implemented. Avoid construction activities during wet periods.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinject profile</td>
<td>Reshape according to current profile. Replace sediments in order they were removed.</td>
</tr>
<tr>
<td>Stabilise</td>
<td>Revegetate banks with grassess, shrubs and trees according to existing vegetation structure. Left bank may require rock protection at the bank toe.</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Monitor water quality pre, post and during construction to ensure increased sediment transport does not occur. Complete visual assessments during construction.</td>
</tr>
</tbody>
</table>