Groundwater and Flood Assessment

Kooyong Park
Lot Consolidation

Moama Street

Moama

NSW

Prepared for
Perpetual Green Developments Pty Ltd
July 2010
(Revised Jan 2012)

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Creating a Sustainable Future

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County	Cadell
Parish	Moama
Title details	Lot 1 DP 1098204 and Lot 2 DP1078090
Development Application No	131/10

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Executive Summary

The proposed Kooyong Park will be a 17 Lot development. 15 lots will have dwelling entitlements ranging in size between 1,775 and 2,774 m^2. Lots 16 (~1.53 ha) and Lot17 (13.29 ha) will not have dwelling entitlements.

It must be recognised from the outset, that from the perspective of land use planning and associated decision making that this is a rural residential development and that construction requirements will be commensurate with environmental risks associated with fire and flood.

This report has been prepared at the request of Murray Shire and addresses concerns and information requirements relating to:

- What impact the development will have on flooding;
- Suitability of the development to the floodplain environment; and
- Actions related to a flood event.

In addition the report covers potential impacts on subsurface hydrology.

Floodplain planning and land use allocation has clearly moved away from the pre 2000 sterilisation approach of flood plains being an untouchable area. The policy outlined in the Floodplain Development Manual and states "The policy recognises the benefits flowing from the use, occupation and development of flood prone land".

Despite the proximity of the proposed development site to the Murray River, it is not readily subject to flooding in low to moderate level floods (<1% Average Exceedance Probability (AEP) or 1:100 Average Recurrence Interval - ARI) due to existing levees.

<u>Low Hazard Flood Storage</u>

The map (Figure 7.2) in the SKM flood study indicates that for a 1:200 ARI event the area is High Hazard Flood Storage, but this is erroneous. The SKM (2001) report specifies (Figure 7.5, P94) it is the area "*east of Old Deniliquin Road that is defined as High Hazard Flood Storage*", as does the Murray Shire Strategic Land Use Plan 2006. The SKM (2001) report tables the water depth at Victoria Street and Old Deniliquin Road and shows that the depth is generally less than 0.8 m and velocity less than 1 m/s (Hydraulic hazard value ~0.14 for a 1:100 ARI event) and is therefore Low Hazard Flood Storage during these very rare events.

The Flood Planning Level (FPL) setting the floor level for new development is the 1% AEP (or 1:100 ARI), that is, 95.34 m AHD at the Echuca Gauge. A 300 mm freeboard above this level is set in the Development Control Plan (2002); requiring a floor level of 95.64 m. A freeboard of +600 mm above

the 1% AEP (95.94) is planned for habitable floor levels on this development because the development is further upstream (~4 km) than the Echuca Gauge,.

The hydrogeology of the area is complex. Watertable depths are currently at 8 to 10 m and falling. Tree planting across the site will assist in reducing recharge.

The conclusions flowing from the investigation and report are:

Flooding

- The Development Control Plan indicates that the site is flood free based on the 1:100 ARI event and is not readily subject to flooding in low to moderate floods including those of 1:100 ARI.
- In a 1:200 ARI event the site would be categorised as a 'low hazard flood storage', which is compatible with the DCP No 7 for the proposed development.
- Any floodworks (e.g. levees) undertaken will have insignificant impacts on flood flows and flood storage.
- There is a long lead time on flooding in the area, allowing for adequate preparation where required. A Flood Management Plan has been prepared for the site as part of the approval process.
- As stated in the SKM report (2001) while large flood events are still possible" the risks to the community from increasingly rare flood events becomes negligible when balanced with the immediate benefits in developing such land".
- Although some of the land (~36 ha) is subject to minor inundation in a 1:200 year event, the greenfield situation makes it possible to engineer the development so that potential costs arising from flood hazards and risks are eliminated.
- The Murray Shire Development Control Plan No 7 and SLUP (2006) indicate that the site is flood free based on the 1:100 ARI.
- The greenfield situation makes it possible to engineer the development so that potential costs arising from flood storage hazards and risks are eliminated.

Groundwater

- With a small area of development and with lower intensity of water application compared to irrigated agriculture there is likely to be less impact on groundwater than there was under agriculture using flood irrigation.
- Additional vegetation will increase interception and deeper soil profile water use.

Groundwater and Flood Assessment
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Introduction

The development site is part of a small farm (~46 ha) and the area (Figure 1 and Figure 2) where development is to be concentrated (footprint area) is the 4.63 ha part of Lot 1 which is 17.92 ha in total area and is located at the corner of Holmes Road and Moama Street, approximately 1.5 km north east of central Moama.

This report provides information on flooding and groundwater and related environmental issues arising from the proposed Kooyong Park rural lot consolidation and development.

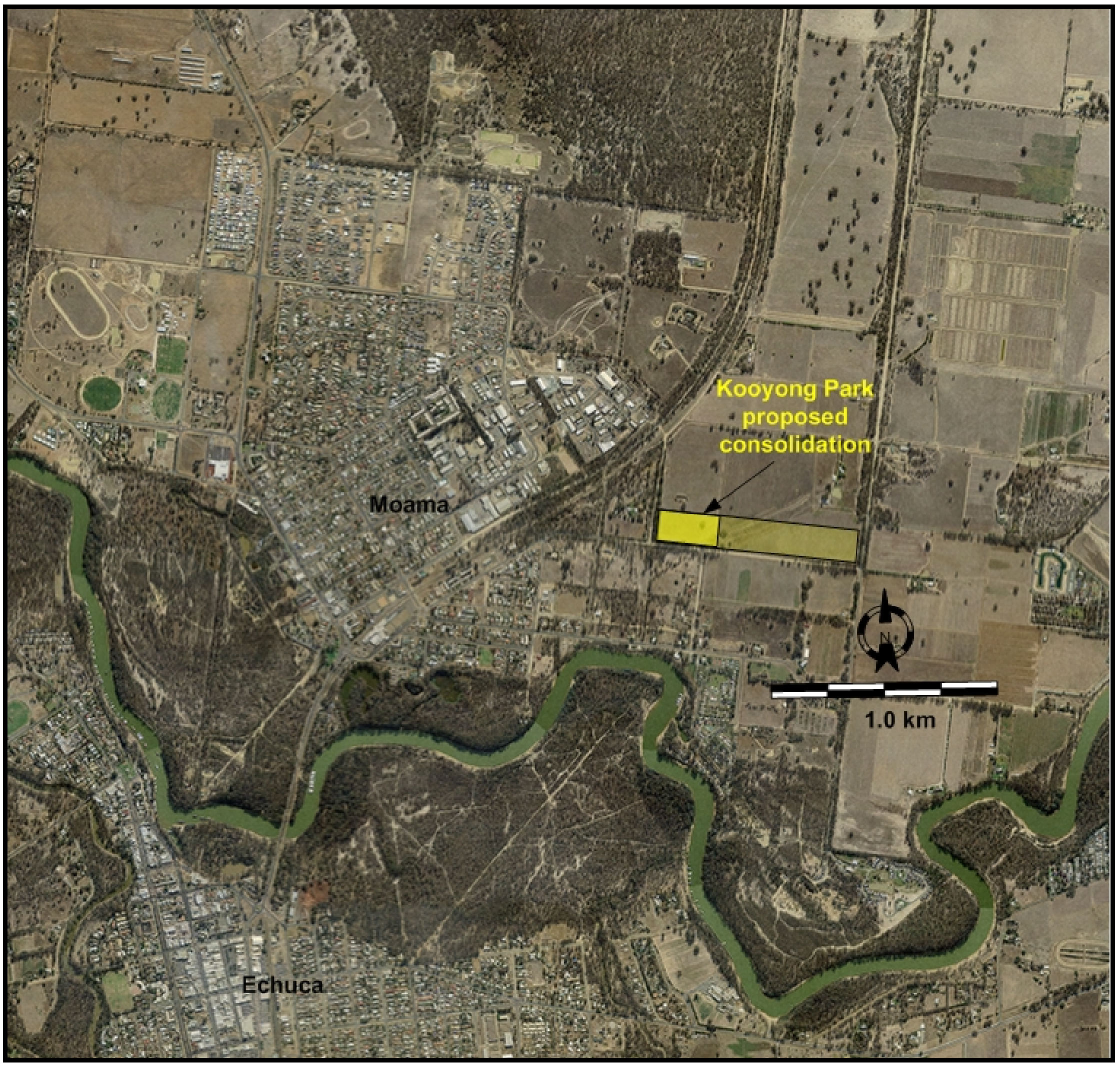


Figure 1. Location of development site

Detailed information is a response to a request from Murray Shire specifically to address matters related to flooding and impacts on groundwater.

In particular:

- The impact of the development on flooding;
- Suitability of the development within the floodplain; and
- Actions and mitigation during a flood event.

The report was prepared following field investigations and database research relating to the site. A major reference source has been the Moama Floodplain Management Study completed for Murray Shire by Sinclair Knight Mertz (SKM) in 2001.

The site topography is flat and since having been cleared in the 1870's the land has been used for dryland cereal cropping and irrigated pasture. The property is surrounded by partly vegetated road reserves. Surrounding land use includes tourist developments, hobby farming with grazing and some cropping on larger holdings.

Previous local studies of cumulative flooding impacts that have been prepared or used in sourcing information for this report include:

- The Flood Atlas (Gutteridge Haskins and Davey *et al*.1986);
- Water Technology 'Kooyong Park' Moama - Rural Levee Realignment study (2007); and
- Murray Shire Council Moama Floodplain Management Study (Sinclair Knight Mertz 2001).

Although the land is subject to inundation in rare events (none in living memory - SKM 2001 P89) mostly greater than a 1:100 Average Recurrence Interval (ARI)[1], the greenfield situation makes it possible to engineer the development so that potential risks and costs arising from the flood hazard are eliminated. Floodplain planning and land use allocation has clearly moved away from the pre 2000 sterilisation approach of flood plains being an untouchable area (DIPNR 2005) and the policy outlined in the Floodplain Development Manual recognises the benefits flowing from the use, occupation and development of flood prone land.

[1] 1% Average Exceedance Probability (AEP) is the equivalent of 1:100 Year Average Recurrence Interval - (ARI). A 0.5% AEP of is equivalent to 1:200 ARI.

1. Proposed Development Overview

The proposed Kooyong Park will involve the development of 15 lots ranging in size between 1,775 and 2,774 m^2. Lots 16 (~1.53 ha) and Lot 17 (13.29 ha) (Figure 3) do not have dwelling entitlements. It must be recognised from the outset, that from the perspective of land use planning and associated decision making that this is a rural residential development and that construction requirements will be commensurate with environmental risks associated with fire and flood around the area. Significant revegetation and landscaping works, including the establishment of substantial numbers of indigenous plants, will accompany the development.

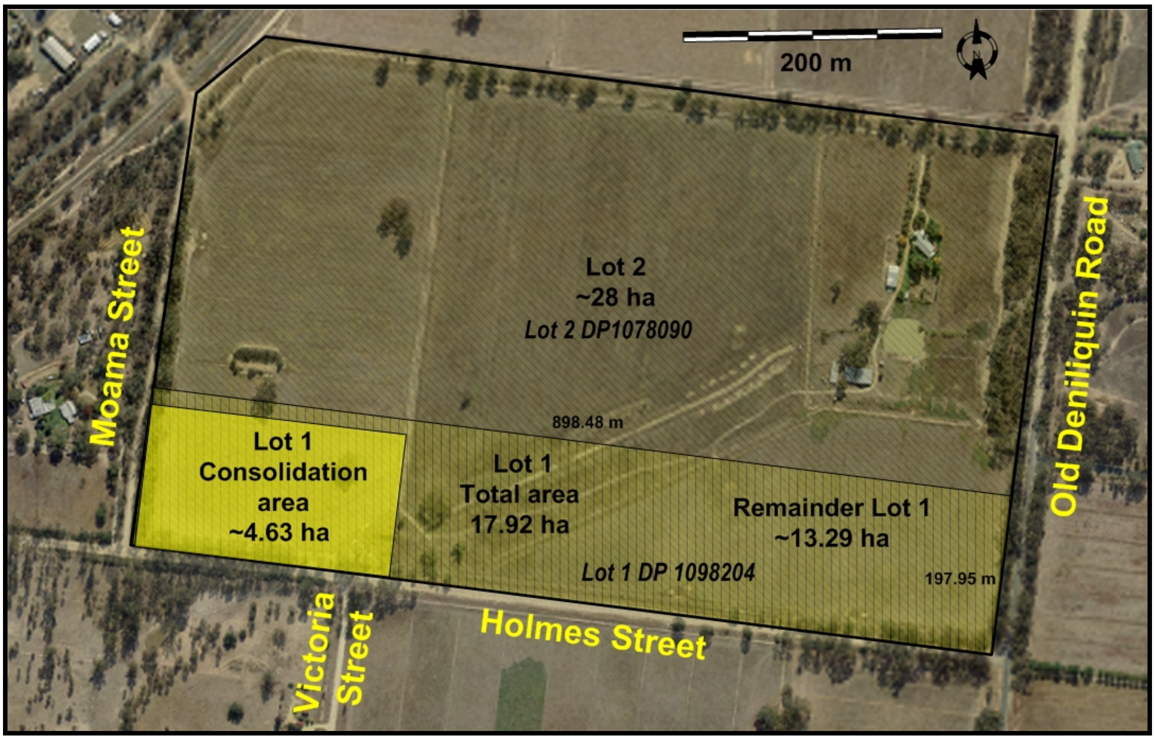


Figure 2. Consolidation overview

2. Planning Considerations

The following information is not intended to cover all aspects of planning in relation to hydrogeology and development of flood prone land, but is an outline of the relevant planning policies that need to be considered at the primary level of decision making.

2.1 Land Zoning

The land (Lot 1, DP 1098204) is in the Murray Shire and is zoned 1(a) (General Rural) under the Murray Local Environmental Plan 1989 as amended.

The development area (footprint) is approximately 4.63 ha and is confined to what is currently agricultural land. A plan of the proposed development area is provided in Figure 3 below.

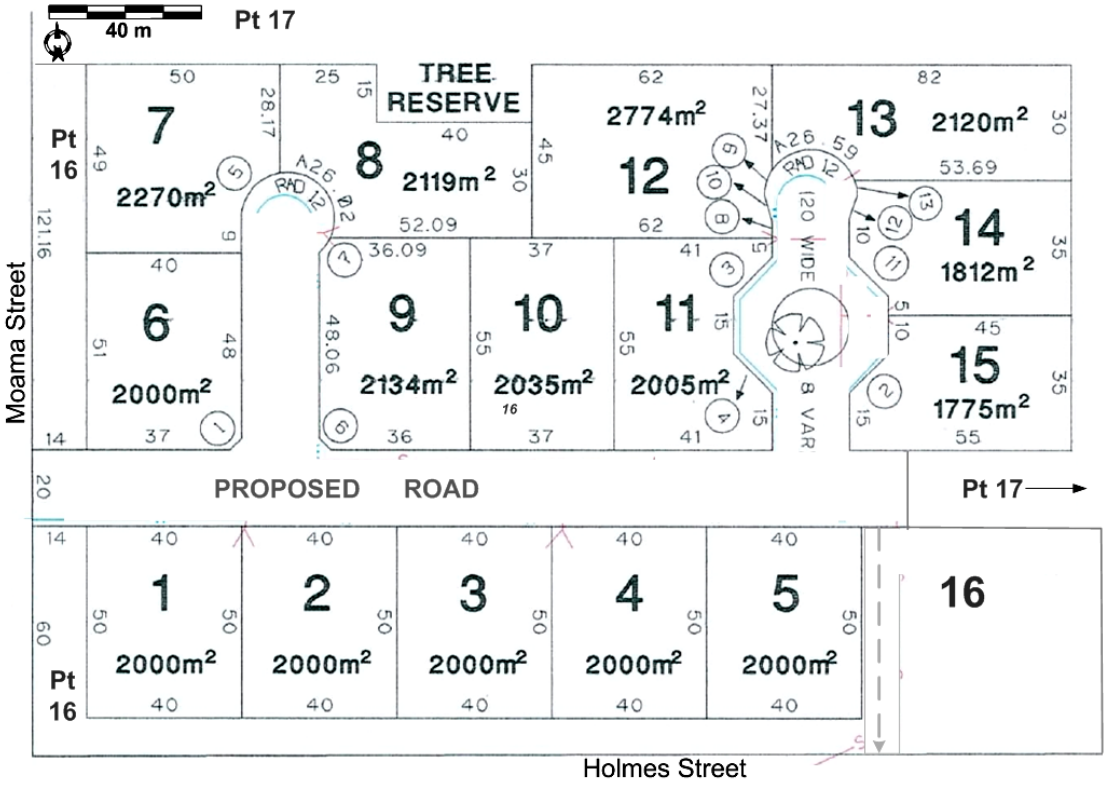


Figure 3. Consolidation lot plan

Moama Development Strategy

Rural residential/low density development was highlighted in the Moama Development Strategy (2004). Lots around 2,000 m^2 have been in demand for a long period of time. In the past all lots, in for example, Perricoota Run, have sold very quickly.

Strategic Land Use Plan

In relation to the development area, the Murray Shire Strategic Land Use Plan (2006, P8) indicates that the area is rural land not subject to flooding or environmental constraints (by nature of a licensed rural levee).

Development Control Plan (DCP)

The Development Control plan also identifies the land as clear of flooding (DCP No 7, Appendix 1, Figure A4) for a 1:100 Average Recurrence Interval (ARI) (or 1% Average Exceedance Probability - AEP) event. In the case of events greater than 1:100 ARI the land could be classed as Low Hazard Flood Storage area (depth <0.8 m and velocity <1 m/s - SKM [2001] Table A1, P A10, A11).

It should be noted that even in high hazard flood storage areas the DCP allows for the consolidation of pre-existing entitlements provided such consolidation does not create any additional lots.

Within the context of floodprone land the Development Control Plan has the following aims:-

(a) Provide detailed controls and criteria for the assessment of development applications on land affected by flooding in the town of Moama and surrounding areas as shown on the map.

(b) Consolidate existing flood planning principles and policies from relevant government agencies into a coherent framework for application at the development control level by Murray Shire Council.

(c) Reduce the impact of flooding and flood liability on individual property owners and occupiers.

(d) Reduce private and public losses resulting from flooding.

(e) Restrict the intensification of development below the FPL.

(f) Limit development below the FPL to those activities and works considered to have an essential relationship with the river and its floodplain.

(g) Provide specific measures for the control of caravan parks and associated development types within flood affected areas.

(h) Provide for the consideration of the cumulative effects of any development on flood affected land, which in or of itself may be considered to be insignificant.

(i) Provide for and protect the natural passage, storage and quality of flood waters.

(j) Recognise and help sustain the natural ecosystems of floodplains and riparian zones including the protection of associated vegetation and wetlands.

(k) Inform the community as to the extent and hazard of flood affected land in the Moama area

(l) Deal consistently with applications for development on flood affected land, generally in accordance with the Floodplain Management Manual: The Management of Flood Liable Land issued by the New South Wales Government 2001.

(m) Encourage the development and use of land which is compatible with the indicated flood hazard.

2.2 Flood Prone Lands Policy (DIPNR 2005)

The Flood Prone Land Policy and associated Floodplain Development Manual sets out to:

> *"promote the use of a merit approach which balances social, economic, environmental and flood risk parameters to determine whether a particular development or use of the flood plain is appropriate and sustainable."*

Policy Objective

> *"The primary objective of the policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods using ecologically positive methods wherever possible. The policy recognises the benefits flowing from the use, occupation and development of flood prone land."*

Moreover, in the context of risks posed by the flooding, the proposed development would fit well within the policy envelope. Furthermore, the policy states:

> *"The potential for flood issues in all areas proposed for development or redevelopment shall be contained by the application of ecologically sensitive planning and development controls."*

The proponent embraces this policy approach and will integrate those ecological sensitivities into the planning and design details of the development.

Floodplain planning and land use allocation has clearly moved away from the pre 2000 sterilisation approach of flood plains being an untouchable area. That is:

> *"The traditional approach to reducing risk and damages is to prevent anyone from undertaking any further development or activity within the floodplain as a means of ensuring that there is no increase in property value or population within the area which could be affected by flooding."* (Bewsher and Grech 2000).

The Floodplain Policy (2005) and processes outlined in the Floodplain Development Manual enable decisions to be made that balance the social, environmental and economic issues and place them in a flood risk management perspective to achieve robust outcomes. There has also been a movement away from engineered solutions to more environmentally sensitive approaches (Romano *et al*. 1997).

The SKM 2001 report (P89-90) states that while extreme flood events (>1% AEP) are still possible:-

> *"while such a severe event has not been recorded in living memory, it is important to recognise that floods greater than 1% AEP can and do occur and that there is no clear separation between flood free and flood liable land delineated by the 1% AEP event. Equally, the risks to the community from increasingly rare flood events becomes negligible when balanced with the immediate benefits in developing such land".*

The site is currently 'Flood Free' during a 1% AEP event, as per the 'Flood Mapping' in Appendix 1 of DCP No 7. This is due to levees surrounding the farm and the development site.

The development will have the capability and inbuilt contingencies to cater for the situations that are likely to arise. An existing approval certificate for a levee surrounding site is in place (Department of Water reference 50CW805701). This is currently a 'rural' levee. However, the license has no height, width and standard restrictions that would prevent it being potentially upgraded to an 'urban' standard of levee if necessary.

The proposed "greenfield" residential development provides opportunities to ensure that the assets can be "flood proofed" and that the economic environmental and social risks can be dealt with appropriately and virtually eliminated. For example:

- Flood notification lead times are considerable (days-weeks), which allows for a high degree of preparedness, inturn allowing for residents to make contingency plans that address issues that might arise from any rare, but large, flood event.
- Habitable floor levels are above the level of the 1:200 ARI event.

A detailed Flood Management Plan for the development has been prepared during the approval process. A survey plan of the site has been prepared and all floor levels can meet the Shires requirement for floor levels to be 300 mm above the 1:200 Average recurrence Interval (ARI) flood levels, these are in fact 600+mm above 1:100 ARI level for the area and 300 mm above the required floor level. Habitable areas of all dwellings will comply with FPL levels.

2.3 Murray Regional Environmental Plan No 2

Murray Regional Environmental Plan No 2 (MREP No 2) - Riverine Land (Environmental Planning and Assessment Act 1979). Regulation 8 of the MREP No 2 applies when:

(a) Council prepares any Local Environmental Plan (LEP), or
(b) A consent authority determines a development application, or
(c) A public authority or person proposes to carry out development which does not require development consent, but which has the potential to adversely affect the riverine environment of the River Murray.

Objectives of the plan

The objectives of the MREP No 2 are:

- To ensure that appropriate consideration is given to development with the potential to adversely affect the riverine environment of the River Murray, and
- To establish a consistent and co-ordinated approach to environmental planning and assessment along the River Murray and to conserve and promote the better management of the natural and cultural heritage values of the riverine environment of the River Murray.

Within the context of the MREP No 2 Objectives rather than adverse effects, favourable outcomes are generated for the riverine and floodplain environment. For example, the development will incorporate flood risk mitigation measures and an extension of habitat for many local fauna species.

Water quality and river flow objectives

The Kooyong Park area comes under the management umbrella of the Murray River, its major anabranches and other streams within its floodplain which are affected by agreements to meet water needs in Victoria, South Australia and NSW. Planning considerations apply to rivers and creeks in the area coloured pink on the map (Figure 4), which includes the Kooyong Park site.

Flows are affected by inflows from the Snowy Scheme, catchment management in Victoria and NSW, reduction of floods by Dartmouth Reservoir (in Victoria) and Hume Reservoir (on the Murray River) and flow regulation to meet water needs in the three States, including increased summer flows and reduced winter and spring flows. While the impacts of the proposal on water quality and flow are negligible, it is important that managers and decision makers are made aware and take account of the relevant objectives in planning and managing development.

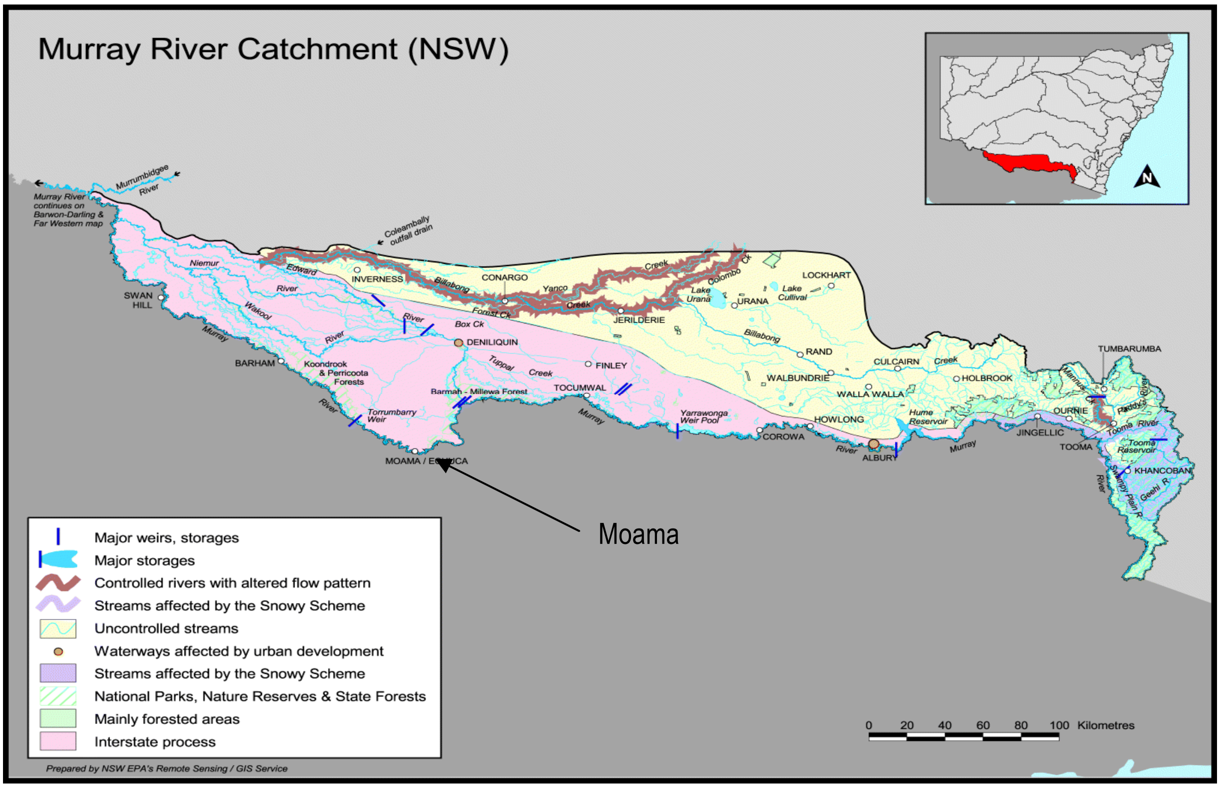


Figure 4 Murray catchment - water management zones

2.4 Floodplain Harvesting Policy (2008)

Floodplain harvesting is the collection, extraction or impoundment of water flowing across floodplains. The floodplain flows can originate from local runoff that has not yet entered the main channel of a river, or from water that has overflowed from the main channel of a stream during a flood. Under the Policy Advice No 3 to Water Management Committees the floodplain is defined as extending to the 1: 100 year flood line. Water harvesting can generally be put into one of three categories:

1. *Diversion or capture of floodplain flows using purpose built structures or extraction works to divert water into storages, supply channels or fields or to retain flows.*

2. *Capture of floodplain flows originating from outside of irrigated areas using works built for purposes other than floodplain harvesting. For example, levees and supply works such as*

off-river, storages constructed in billabongs or depressions that fill from floodplain flows below ground level water channels from which the water is pumped into on farm storages.

3. *Opportunistic diversions from floodplains, depressions or wetlands using temporary pumps, or other means.*

The Licensed Rural Levee will preclude most events less than 1:100 ARI. None of the above activities are planned for the proposed development. If the levee should overtop in larger flood events it will be breached at an appropriate time as flood waters subside.

2.5 Water Sharing Plan for the Lower Murray Groundwater Source

(Water Management Act 2000)

The Kooyong Park property is in Groundwater Management Area 16 (GMA 16) (Figure 6) and is within the sub-surface water basins in New South Wales that were gazetted (1994) under section 117A of the Water Act 1912. The Objectives of the Plan should be taken into account in relation to landuse and irrigation.

The objectives of the Groundwater Management Plan are to:

- *(a) Manage aquifers to support dependent terrestrial and subterranean ecosystems;*
- *(b) Manage the extraction of groundwater for estimated sustainable yield;*
- *(c) Establish and manage groundwater resource security for communities and industries;*
- *(d) Protect groundwater quality from external pollution sources and cross aquifer pollution;*
- *(e) Protect the natural surface environment by managing the extraction of poor quality groundwater from aquifers, and*
- *(f) Acknowledge, respect, and protect the Indigenous culture and cultural heritage of the traditional peoples of the Murray Region.*

3. Regional and Site Biophysiography

3.1 Climate

The climate has Mediterranean characteristics with hot dry summers and cool winters. Rainfall exceeds evaporation only in June, July and August. Average rainfall amounts to 427 mm with a slight peak in October while evaporation totals 1300 mm over the year (Figure 5).

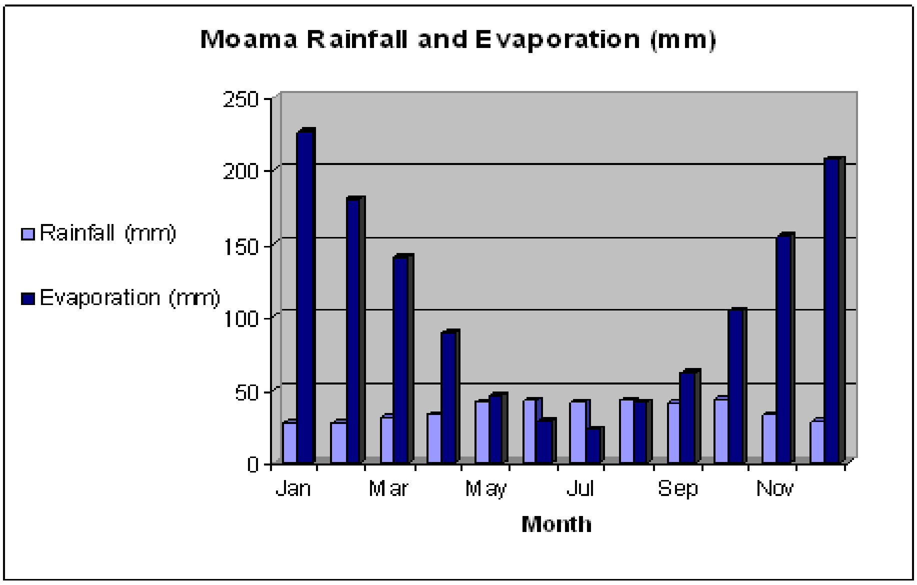


Figure 5. Rainfall and evaporation for Moama

3.2 Topography

The topography of the site is relatively flat with a catchment divide across the property defined by a linear irrigation storage dam (Figure 10). Kooyong Park, being located on a broad floodplain within the catchment to the Murray River, has land slopes that are generally one to two percent, with the exception being prior stream depressions areas. From the linear dam dividing the property there is a slight gradient (1-2%) to the south west towards the Sheepwash Lagoon and the Murray River and in opposite direction to a natural depression draining in a generally north west direction.

3.3 Geology

The riverine zone adjacent the Murray River is Quaternary Holocene (Qc), fluvial, lacustrine, sand clay and sandy clay material as part of the Coonambidgel formation (Bendigo Map Series SJ55-1).

3.4 Geomorphology

Major activity in the Cadell Fault occurred about 25,000 years before present time (BP). Displacement occurred along the Cadell fault, raising the eastern edge of the fault (which runs north-south) 8-12 metres above the floodplain. This created a complex series of events. A section of the original Murray River channel immediately behind the fault was abandoned and exists today as an empty channel known as Green Gully.

The Goulburn River was dammed by the southern end of the fault to create a natural lake. The Murray River flowed to the north around the Cadell Fault, creating the channel of the Edward River which exists today and through which much of the Murray River's waters still flow. Then the natural dam on the Goulburn River failed, the lake drained, and the Murray River avulsed to the south and started to flow through the smaller Goulburn River channel, creating "The Barmah Choke" and "The Narrows" (where the river channel is unusually narrow), before entering into the proper Murray River channel again.

The primary result of the Cadell Fault is that the west-flowing water of the Murray River strikes the north-south running fault and diverts both north and south around the fault in the two main channels (Edward and ancestral Goulburn), as well as a fan of small streams.

3.5 Soils

The land forms part of the Riverina Plains and is within 1 km of the Murray River. Soils are generally clay loam topsoils with mottled brown clay subsoils. In more recent classifications (McKenzie *et. al.* 2004) the soils are considered to be Brown Hypocalcic Sodosols.

Soil physical characteristics

Most of the topsoil (A Horizon) is less than 10 cm deep. The types of minerals present in the clay, influence structure and the proportion of elements such as calcium, magnesium and sodium (as well as organic matter) and can affect structural stability.

While the water storage capacity can be substantial, the amount of water actually available to plants from the medium clay soils is limited by the very small pore size. Similarly, plant nutrients can be locked up in clays, especially phosphorus in the case of clays with high iron content.

Soil capability for water storage

The Brown Sodosol subsoils present on the site, when properly compacted, provide excellent sealing capability and would be suited for use as clay liner in water storage construction. A water storage will be required for drainage detention, garden watering and fire suppression.

In the case of the Kooyong Park site the material to be used will be a clay liner, a well graded clay of medium plasticity compacted to achieve 90–95% maximum dry density, determined in accordance with Method 5.1.1 of Australian Standard 1289. For a water storage depth of up to 2 m, the compacted clay liner should have a minimum thickness of 300 mm and should be constructed to achieve a coefficient permeability of less than 1×10^{-9} ms^{-1}. Further details on engineering specifications will be provided following detailed design.

4. Hydrogeology

The hydrogeology of the area is complex. The northwards thinning of the Tertiary aquifer beneath the northern plains results in discharge to the overlying sands and silts of the Shepparton Formation. The hydraulic connection between the Shepparton and Calivil aquifers is inferred by the similar response times to recharge events (Macumber, 1983). High salinities are observed in the Shepparton Formation away from the highland front, where discharge processes are operative (Heislers 1993). The subsurface aquifer system consists of ancient stream beds that may be either interlinked or discontinuous. Some are linked to the Murray River.

4.1 Groundwater

As stated previously, the Kooyong Park property is within the Lower Murray Groundwater Management Area 16 (Figure 6).

Aquifers

Below the Riverine plains are three aquifer formations. The uppermost layer, the Shepparton formation, extends down to about 70 m. It consists of lenses of fine and course sands, gravel and clay. These lenses can be continuous and connected or discrete confined aquifers.

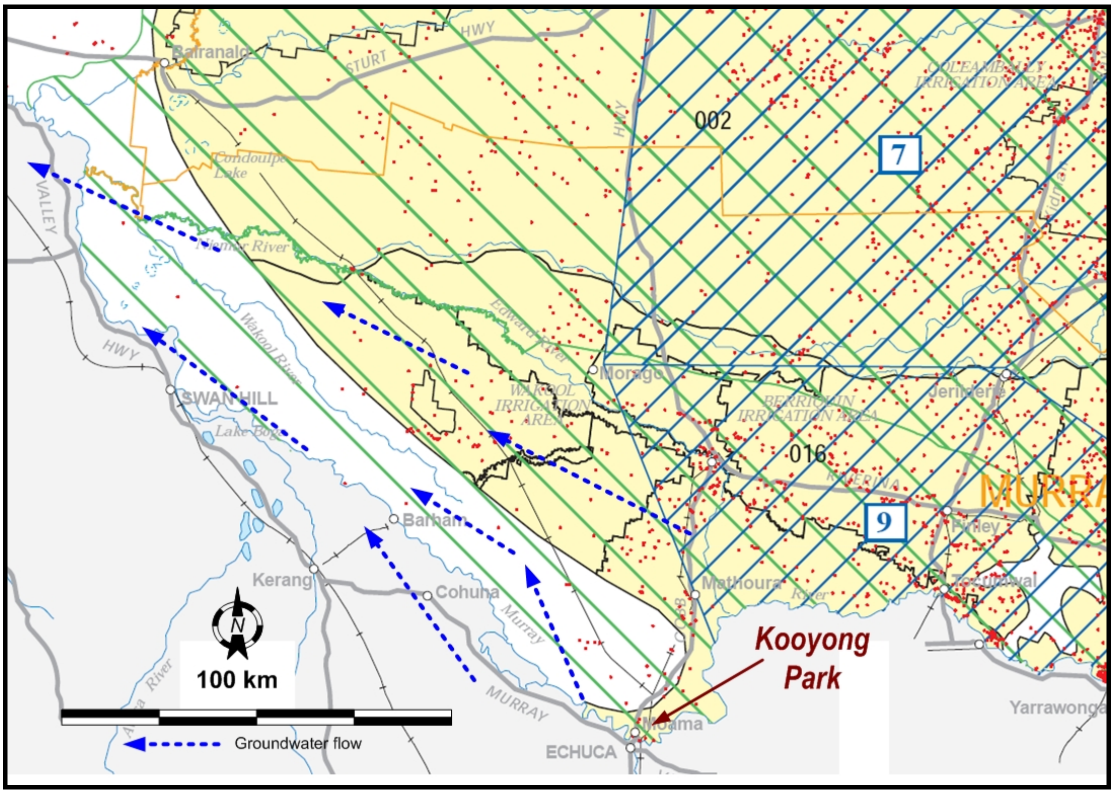


Figure 6. Local groundwater flow and management areas

(With permission LPI - http://waterinfo.nsw.gov.au/historic/doc/dlwc4_gm-2001.pdf)

Differences in the hydraulic characteristics of the upper (top 20 m) and lower parts of the Shepparton aquifer were identified by Enever (1999). Transmissivity ranges from 10-500 m^2 per day. Residing below the Shepparton formation is the Caliville formation which extends from about 70-130 m and consists of sand and gravels layers with interspersed kaolin material. Below this lies the Renmark (or Olney) formation consisting of sands, gravels and lignites from 130 m down to about 200 m below the surface.

Watertable depth and salinity

Recent sampling of the Shepparton formation drilling (2010) in the forest 2 km to the north west indicates that ground water is 8 m below the surrounding ground surface and salinity 9,200 to 17,500 Electrical Conductivity (EC) units.

The indicated aquifer yield is 2.1 - 3.1 L/s. The general trend in groundwater movement is to the north-west (Dimos *et.al*. 19994 - Murray Basin Hydrogeology Map, Bendigo; Evans 1988).

5. Surface Water and Flooding

5.1 Overview

Upstream of Echuca, the "Barmah Choke" and "The Narrows" restrict the amount of water that can travel down this part of the Murray River. In times of flood and high irrigation flows the majority of the water actually travels down the Edward River channel. Channel capacity of the Murray in the Barmah Choke section of the river is restricted to about 8,500 ML per day. These hydrologic control features, as well as the large catchment areas of the river's major tributaries, can result in quite different flood behaviour for different reaches of the river for a specific flood event (MDBC 2002).

The Murray River has not had enough flow power to naturally enlarge the "Barmah Choke" and "The Narrows" to increase the amount of water that can be carried.

The Flood Plain Atlas (GHD *et al.* 1986) indicates that inflow from the Goulburn can reverse Murray River flows upstream of the junction of the two rivers (MDBC 2002). It is when substantial inflows from the Campaspe and Goulburn occur that major flooding results downstream of Echuca. During large floods (e.g. 1956, 1993) water spills from the Murray River mostly across the Victorian part of the floodplain.

Land on the Victorian side of the river, being mostly lower, can convey a greater flow and offers less resistance to most flood flows than rising ground, levees and barriers, such as irrigation channels on the NSW side. This is evidenced in the Flood Atlas (GHD *et al*.1986) which indicates that for the vast majority of floods (e.g. 1956, 1975, 1981) the land on the Kooyong Park property remains above the inundation zone. Importantly, the site has a greater average AHD that the rest of the Moama township west of the Cobb Highway (SKM 1997, Fig 4.2).

Figure 7. Previous flood extent (Note: Low hazard floodway to west was not marked as being active)

Historical flood occurrences

Previous floods have occurred in 1870, 1917, 1931, 1956, 1974, 1975, 1978, 1980, 1981, 1992 and 1993. The Moama Floodplain Study provides the following information:

> *"Major flood level is defined by the Bureau of Meteorology when floods exceed 94.40 m on the Echuca Wharf Gauge. The largest flood since European settlement was in 1870, when the peak was 96.2 m on the gauge.* ***More recently, the largest flood was in 1993 when the peak was 94.80 m (wharf). The 1993 flood was estimated to have an AEP of approximately 5% (1:20 year event)*** *at the Echuca gauge, meaning that in the long term floods of this magnitude or greater could be expected to occur about once in 20 years on average.* ***A flood of 0.5% AEP (1:200 ARI) was estimated to have peak stage at the Echuca Wharf of 95.60 m AHD.*** *Since the present planning level was 95.63 m based on previous study, the flood of 0.5% AEP was accepted as the Flood Planning Level for general planning purposes in Moama. Given the slight difference in the two levels quoted above, the old level of 95.63 m AHD was adopted for convenience"* (SKM 1997).

Such estimates can vary from actual situations depending on the modelling scenario. For example, flooding in the Campaspe and in the Goulburn has substantial influence on the level at Echuca wharf.

What is the height and depth of the 1:100 and 1:200 year flood events?

Information supplied by the North Central Catchment Management Authority indicates that the 1:100 ARI flood level at Echuca Wharf is 95.63 m, the same as the NSW 1:200 ARI (SKM 1997). This was revised by SKM (2001) and determined to be 95.60 m (1:200 ARI) for the purposes of planning on the NSW side of the river. In the case of the Murray River in the vicinity of the proposed development (Victoria Street) the 1:100 ARI level is 95.55 m and the 1:200 ARI level it is 95.78 m at (DCP 2002) 2001 page A10). It should be noted that the height difference between the two events is just 23 cm (Table in Figure 10).

A topographic survey of the development site was conducted by Planright Pty Ltd in 2006 (Figure 10). Land elevation ranges from 94.7 (contour levels in black) in the south west corner of the block up to 95.1 closer to Old Deniliquin Road (Figure 10). The Kooyong Park levee height ranges from 95.50 m in the south west corner up to 95.76 m in the north east corner, near Old Barmah Road and precludes floods of 1:100 ARI and some above that ARI.

Flood Planning Level

There are two flood planning levels (FPL) used in the Murray Shire Development Control Plan (DCP). They are:-

i) Flood planning level to define flood liable land;

ii) Flood planning level setting the floor level for new development.

The flood planning level (FPL) used to define flood liable land for the purpose of the DCP is the flood level represented by the height of 95.63 m AHD at the Echuca Wharf Gauge This FPL represents the approximate level of a 1:200 ARI flood as modelled in the Moama Floodplain Management Study (Actually 95.64 m in the DCP table and 95.61 in the SKM Table for the 200 Year ARI). It should be noted that there is a discrepancy in levels between Table A1 in the SKM (2001) report and the levels in the DCP No 7 Peak Flood Levels Table (Appendix 3p 110), the DCP tabled levels being 3-5 cm higher in most modelled situations.

Council will not permit the intensification of development below this FPL on flood liable land which is likely to cause a significant reduction in flood storage capacity or change in flood behaviour. The findings of the Water Technology Levee Realignment Study (2007) and in particular the findings of the SKM (2001) report state in relation to the licenced existing levee (L3)

> *"Other levees* (including L3)*......have insignificant effects on flood storage."*

The FPL setting the floor level for new development is the 1:100 ARI (1% AEP), as modelled, 95.34 m AHD at the gauge Echuca. Murray Shire has adopted a freeboard of 300 mm (0.3 m) above the 1:100 ARI (95.34 + 0.3) the proposed development has a planned freeboard of 600+ mm (95.94 m). This will act as a general safety and contingency factor and will mean that design floor levels for new structures and planning controls will remain consistent with previous levels.

Moreover, being a "greenfield" site, structures can be engineered to overcome the hazards and risk of property damage and loss, should inundation occur on part of the site. Particularly important for house pads is the use of gentle batters, topsoiling and maintenance of winter cover to ensure protection from rare flood events.

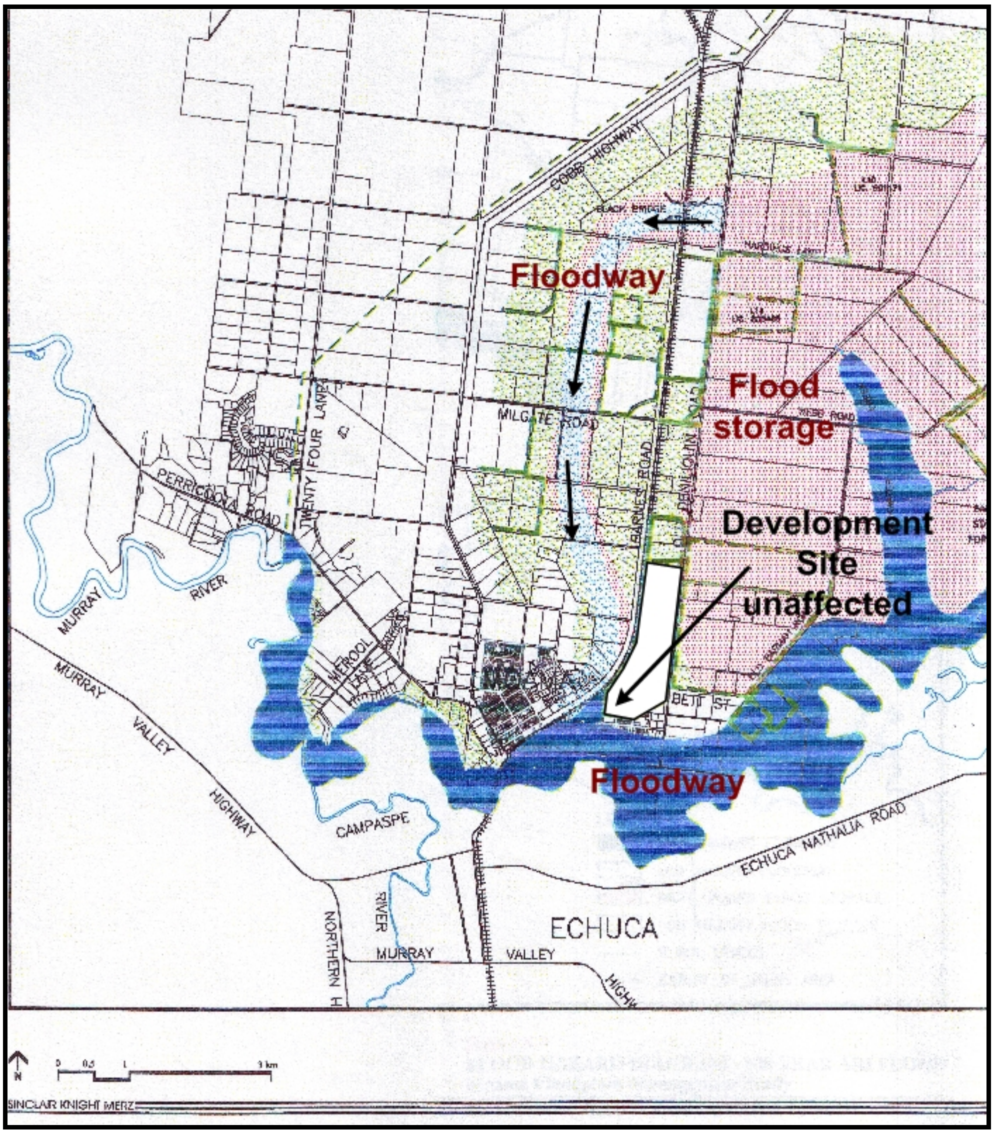


Figure 8. Flood water distribution 1:100 ARI (Source SKM 2001)

Flood flow velocity, depth and risk

Mapping by SKM indicates that the area is High Hazard Flood Storage during a 1:200 ARI event, but this is erroneous. The SKM report itself states (Fig 7.5) it is the area "*east of Old Deniliquin Road that is defined as High Hazard Flood Storage*" (SKM 2001, P94). That is, the water depth at Old Barmah Road, Victoria Street and Old Deniliquin Road may be substantially less than 1 m and velocities less than 1m/s. SKM (2001) describe "*High Hazard Flood Storage will have depths greater than 1 m. The* *depth of flow in Low Hazard Flood Storage may be less than 0.8 m*." Moreover the DCP (2002, p92) defines Low hazard flood storage as those area with depths less than 1 m. In relation to the land in the vicinity of the development 1:200 ARI water depths will be generally less than 0.8 m and from the available data, not more than 1 m.

SKM (2001, Appendix A11) indicates flood velocities at Victoria Street and Old Deniliquin Road to be close to 0.7 m/sec close to the river. Further away from the river (e.g. Old Barmah Road) velocities are much lower ranging from 0.0548 m/s to 0.1070 m/s for the 1:100 and 1:200 ARI flood events respectively. Rare, larger flood events are likely to result in only a very gradual encroachment with restricted velocities in the area surrounded by the levee. The velocity of the flow will, in part, be compromised by flow from the low hazard flood way to the west (Moama Street) and inflow from the south (Victoria Street) tending to reduce the velocity.

SKM (2001) indicates that the site is flood free in a 1:100 ARI event. If a levee were top be overtopped by a 1:200 ARI event the water velocity may be considerably lower, approximately 0.181 m per second (refer chainage 106.35 (Old Barmah Road) on Table A.10 'Peak Levels and Flow Velocities for Design Floods' in the SKM 2001 Moama Floodplain Management Study). The velocity is similar (0.1911 m/s) for an extreme event. According to the NSW Floodplain development Manual (2005, p L3) the site would be classed as Low Hazard Flood Storage, even in an extreme flood. This means property access for trucks (e.g. SES) would be possible.

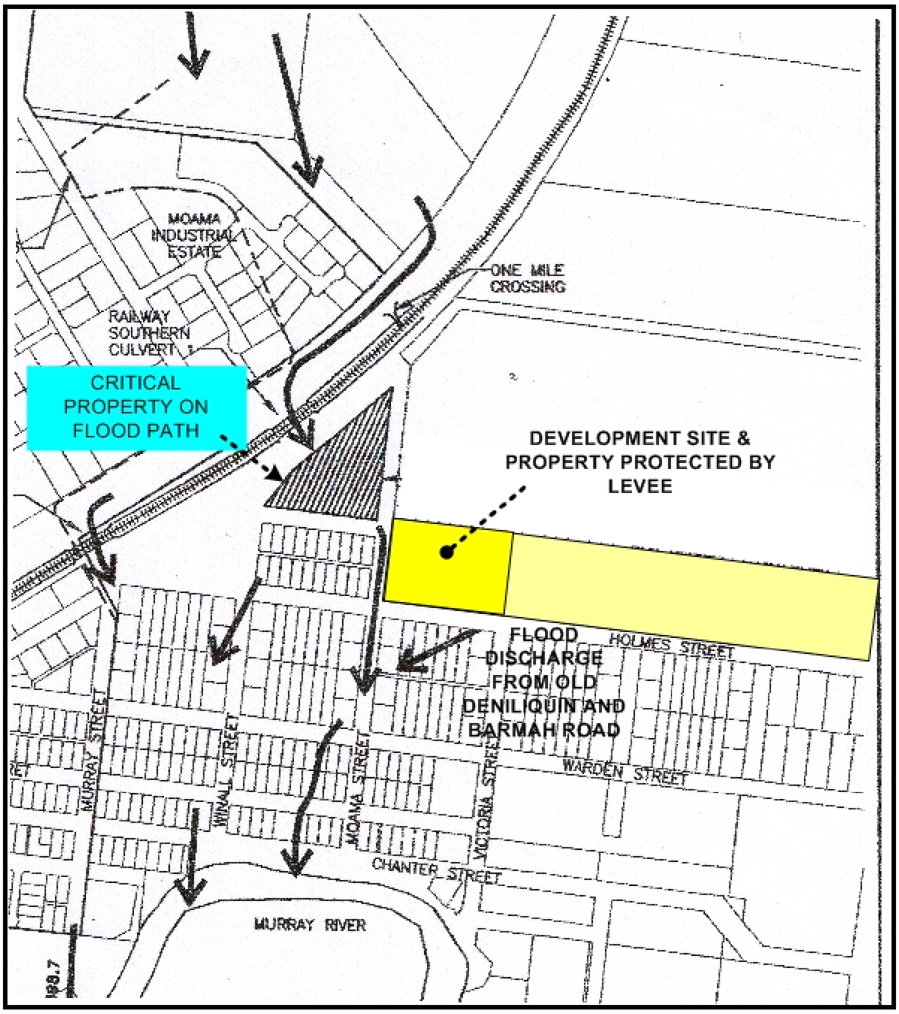


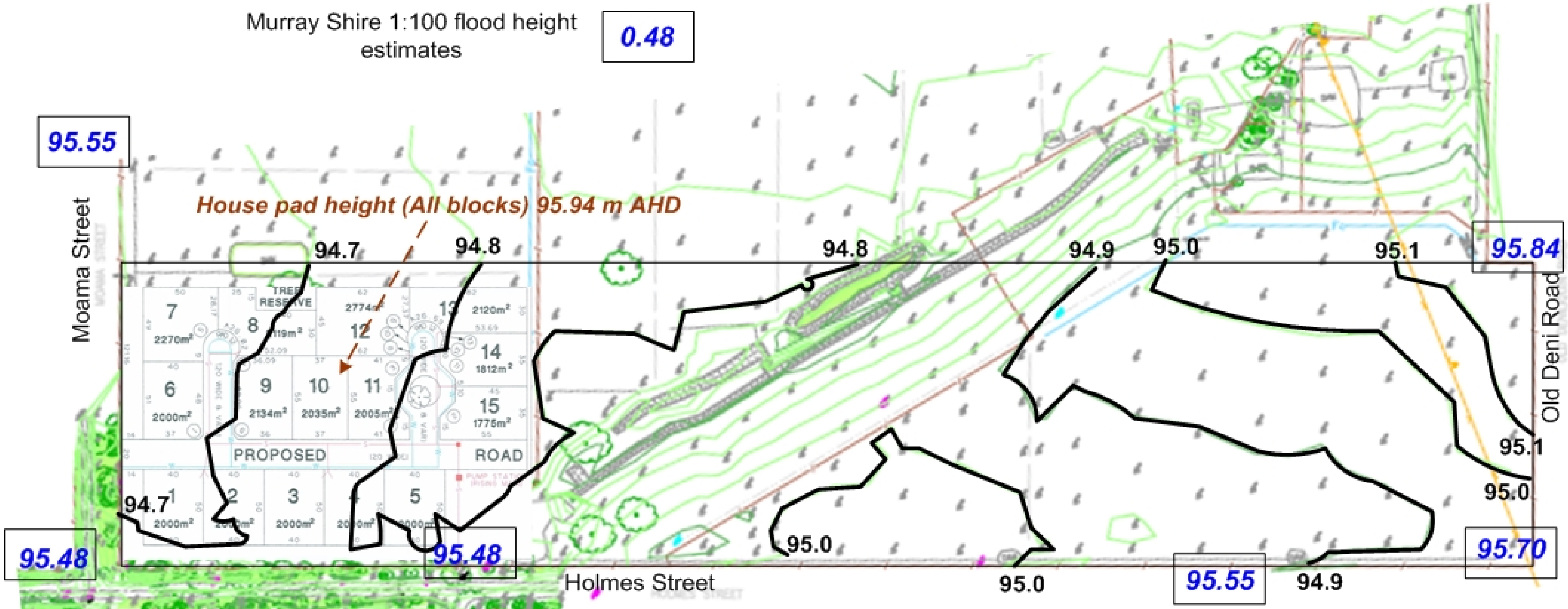
Figure 9. Flood path map (Adapted from SKM 2001)

The depth of water and the velocity on the site are consistent with a '*Low Hazard Flood Storage*'. (See 'Moama Floodplain Management Study' Figure A.5 together with tables on pages A-10 and A-11). The development site has been incorrectly categorised as 'High Hazard Flood Storage' on some flood maps for a 1:200 year event.

This risk factor (velocity x depth) changes over the site for a 1:100 ARI event it is 0.136 to while during a 1:200 ARI event it may reach 0.170. A worst case scenario involving levee failure with velocity of 0.7 m/s and a 1:200 ARI event the risk factor would be 0.58. These 'risk factors' can be considered to be within the 'Low Hazard' categorisation as detailed in Appendix L of the 'Floodplain Development Manual'.

Flow restraining structures

Numerous farm channels and the rail line pose substantial barriers and constraints to flood flows in large floods. Flooding risk on the site is from 'Overland' flows from the north of the site. Not mainstream flooding from the Murray River. (Moama Floodplain Management Study, p21). The railway culvert depicted in Figure 11 will potentially retard local flows and limit the volume of water moving through the depression (Moama Street) located to the west of the property.



Location		Peak flood level (m AHD)			
	Levee Height	1993 flood	50 Yr ARI	100 Yr ARI	200 Yr ARI
Old Deni Rd	95.76	95.18	95.36	95.58	96.80
Victoria St	95.50	95.05	95.28	95.50	96.74
Echuca Gauge		94.76	95.11	95.34	95.58

(Source: SKM, 2001)

Figure 10. Property contours 1:100 & 1:200 ARI flood event estimates table

(Green numbers - levee excludes floodwater, Red numbers - flood may exceed levee height)

5.3 Site situation

The proposed development site has natural surface levels below the 1:20 year flood, but has a protective licensed rural levee surrounding the site which would preclude most floods equivalent to 1:100 ARI and some at higher levels. Flooding in this instance is from overland flows from the north, not direct (and higher velocity) river flow impact from the south.

Is consolidation or subdivision allowed?

In relation to low hazard storage areas the DCP (2002) policy in relation to subdivision states in Section 4.2 that for low hazard flood storage areas:

> *a) Subdivision of land in low hazard flood storage areas will require a Restriction as to user to be placed on the title of the land. Such restriction to advise purchasers that the habitable floor area of dwellings subsequently erected on the new allotments are to be constructed a minimum of 0.3 metres above the 1% AEP (1:100 ARI) flood level.*
>
> *b) Council will not approve subdivision applications in low hazard flood storage land unless it is consistent with the objectives of this DCP, the principles of Murray REP No. 2 and objectives of Murray LEP 1989.*

In this instance the intention is to consolidate the existing entitlements.

Flood threats, past performance and experience.

The flood planning level (FPL) used to define flood liable land for the purpose of the Development Control Plan (DCP) is the flood level represented by the height of 95.63 m AHD at the Echuca Wharf Gauge. This FPL represents the approximate level of a 0.5% AEP or 1 in 200 Year ARI flood as modelled in the Moama Floodplain Management Study (SKM 2001). Council will not permit the intensification of development below this FPL on flood liable land which is likely to cause a significant reduction in flood storage capacity or change in flood behaviour (See explanation below).

The SKM 2001 report (P89-90) states that while extreme flood events (>1% AEP) are still possible:-

> *"such a severe event has not been recorded in living memory, it is important to recognise that floods greater than 1% AEP can and do occur and that there is no clear separation between flood free and flood liable land delineated by the 1% AEP event.*

The Moama Floodplain Management Study (SKM 2001) states that in relation to levees including the relevant L3 levee Section 4.3.2 (Vol 2, P38) east of the railway line to Bama State Forest:

> *"Other levees can remain as they encroach only slightly on the flood paths and have insignificant effects on flood storage."*

Furthermore, the SKM report states:

> *that while 1:100 ARI flood events are still possible " the risks to the community from increasingly rare flood events becomes negligible when balanced with the immediate benefits in developing such land".*

The Murray Shire 1993 flood survey (I. Fisher Pers. Comm.) along Holmes Street indicated a top height flood level of 94.84 m. Records from the 1993 flood (SKM 2001) indicate that this levee held at that time for what was a 1 in 20 year flood (Fig 4.2, SKM 2001). In a 1:100 year flood the levee would be of sufficient height to exclude flood water (refer Table in Figure 10). Maps displaying the impact of floods of 1:100 and 1:200 ARI are depicted in Figure 8 and Appendix 3. In the 1: 200 ARI flood the area could become low hazard flood storage. According to the SKM modelling the difference in water depth between a 1:100 and a 1:200 ARI event is 24 cm at Victoria Street and 22 cm at Old Barmah Road.

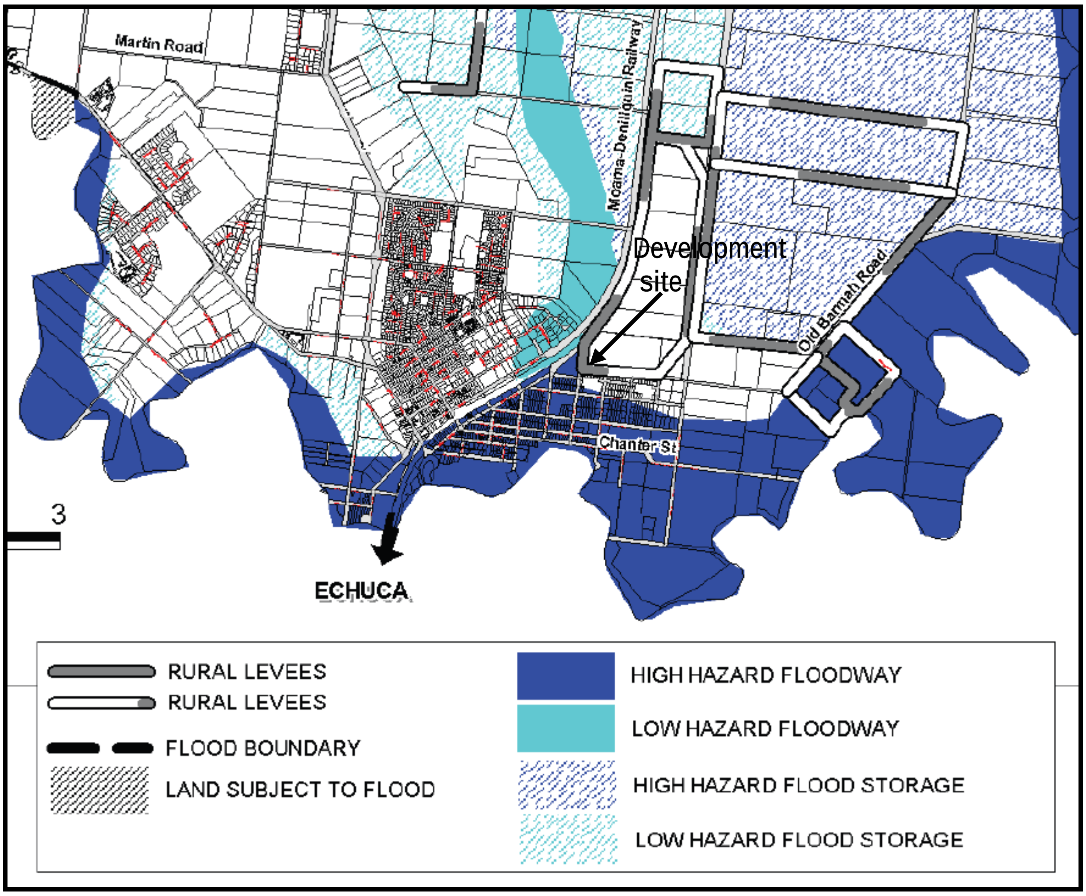


Figure 11. Flood and storage zones -Hazard map (Murray Shire SLUP 2006)

During the 1993 flood (rated a 1 in 20 year ARI flood) the land could still be accessed from the south-east (via Chanter and Edwards Streets) and the south-west (via Holmes Street). In a 1:100 ARI flood the waters would be less than 0.8 m for this locality and for a 1:200 they would be less than 1 m. If deemed necessary, an access point to cope with extreme flood conditions (above 1: 200 year floods) could be configured from the north-west corner of the land.

What is the FPL for the proposed lot consolidation?

Based on the information provided by SKM (2001) and Appendix 3 of the DCP[2] (2002). The FPL setting the floor level for new development is the 1% AEP, as modelled, 95.34 m AHD at the Echuca Gauge. A 300 mm freeboard above this level is set in the DCP; that is a floor level of 95.64 m.

Because the development is further upstream (~4 km) than the Echuca Gauge, a freeboard of +600 mm above the recommended level is planned for habitable area floor levels on this development. The average land level for the development site is 94.75. On the development site, house pads will

[2] Moama and Bama Disrtict Flood Prone Land Development Control Plan No 7 (2002).

be at 95.94 and floor levels at 96.00 m, or 1.25 m above natural surface and above the 1:200 ARI. This is 300+ mm more than the Murray Shire's DCP requirement which would be 95.64 for floor levels and above the 1 in 200 ARI level for Old Deniliquin Road. Moreover, this pad height is the same height as the town levee which has 600 mm free board above the FPL (SKM 2001).

Stormwater detention storage

The detention storage will be located at the eastern end of the development on Lot 16 which will be an unoccupied allotment. The structure will be entirely excavated and will have 1:3 battered banks (no banks above natural surface) with the excavated material used for building house pads and approved flood works.

Table 1. Peak flood levels and Average Recurrence intervals (ARI) at various locations (SKM 2001)

Location	Peak flood level (m AHD) (SKM 2001)				
	Levee Height (m AHD)	1993 flood	50 Yr ARI	100 Yr ARI	200 Yr ARI
Old Deni Road	95.76	95.18	95.36	95.58	95.80
Victoria Street	95.50	95.05	95.28	95.50	95.74
Echuca Gauge		94.76	95.11	95.34	95.58

Shire flood planning level definition of floodprone land 1:200 ARI	Land less than 95.63 m (Section 1.5 DCP 2002)
Town levee height	~95.94 m
Shire Flood Planning Level (New development) 1:100 ARI	95.34 m (Section 1.5 DCP 2002)
Shire floor planning level (+300 mm)	95.64 (Section 1.5 DCP 2002)
Proposed pad levels	95.94 m
Proposed floor levels (Min)	96.00 m

6. Development impacts and site protection measures

6.1 Impacts of the development

Overland flow paths and changes with development

During the development process structures within the development area, such as channel and check banks, would be removed and land levels restored to match the natural topography. In line with the Council's policy of "*no change to existing flow regimes*" the existing levee and internal structures, such as channel banks surrounding the development site will be maintained.

Extreme flood events would still be constrained by the natural rise in topography that conforms to the current alignment of the floodways. The development will not alter flood flows or flood storage capacity.

Will flood behaviour or flood storage be changed by the development?

Flood behaviour will not alter as a result of the development, irrespective of the recurrence interval for the flood event. Floods with an ARI less than 1:100 are not likely to overtop the levee. If some overtopping were to occur in very rare events (>1:100 ARI) there will be no change to storage capacity inside the levee because the material used to construct earthen house pads will be extracted from within the levee area. As previously mentioned, the Moama Floodplain Management Study (SKM 2001) states in relation to levees (excluding L10, 6 km north of the study site), but including the relevant L3 levee Section 4.3.2 (Vol 2, P38) east of the railway line to Bama State Forest:

> *"Other levees can remain as they encroach only slightly on the flood paths and have insignificant effects on flood storage."*

The area (and volume of material) where house pad material is extracted will be additional to any stormwater detention storage or fire fighting storage.

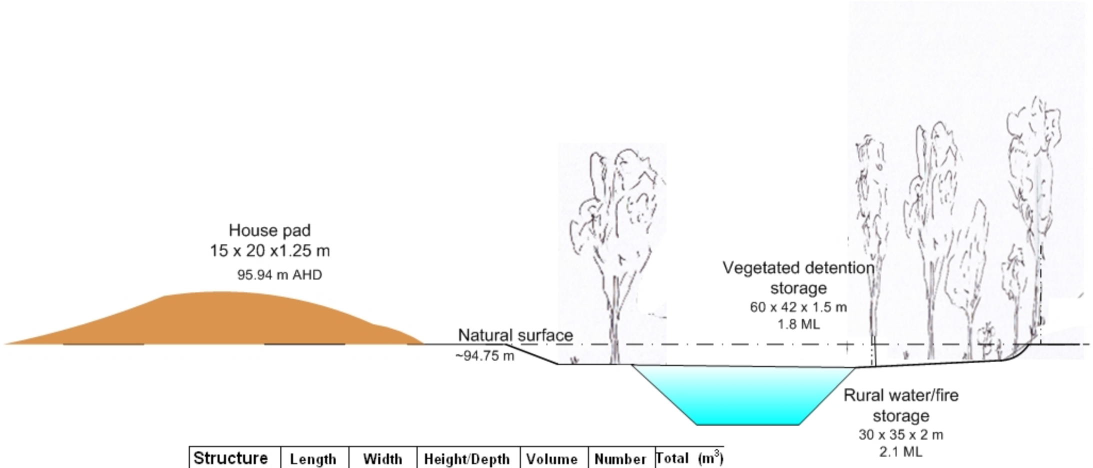
6.2 Site protection measures

Structures

Can house pads be constructed?

In relation to the construction of house pads Section 5.2 of the DCP (2002) states that:

> *a) Filling will be permitted to 0.3 metres above the 1% (AEP) flood level for development pads or foundations.*
>
> *b) Filling must not occupy more than 25% of the block and not affect the flow of floodwaters in the floodplain or have a detrimental impact on other properties.*



Structure	Length	Width	Height/Depth	Volume	Number	Total (m^3)
Pads	20	15	1.25	375	15	**5625**
Detention storage	90	42	1.5	5670	1	**5670**
				0		1.8 ML
Rural water /Fire storage	30	35	2	2100		**2100**
						2.1 ML

Figure 12. Water supply, detention and flood storage.

House pads and infrastructure

Irrespective of the height of flood incursions, all homes will be constructed on pads and associated infrastructure (e.g. sewer pumps) will be set at 600+ mm above the 1:100 PFL (95.94 m). This is 0.16 above the expected 1:200 of 95.78 m at Victoria Street.

Since the pads are constructed from soil borrowed on-site to create a detention storage and the velocity of flow is less than 1 m/s, the impact of pads on the flood flow characteristics for floods >1:100 ARI that may overtop the rural levee will be minimal. The pads (0.45 ha) occupy less than 1% of the area within the levee (~46 ha) and are not in a direct floodway flow path.

By building flood capability into the development there is minimal risk of damage to assets. In its Development Control Plan for Moama the Council specifies development considerations which can include:

i. Floor levels of any permanent structures/amenities will be a minimum of 0.3 metres above the 1% (AEP) flood level;

ii. Access roads will not be built up more than 100 mm above natural topography;

iii. All services to the development will be designed to be disengaged in times of flooding and capped to prevent inundation/contamination/failure;

iv. Existing areas liable to flooding must have the ability to be evacuated at short notice in times of flooding - a flood emergency and evacuation plan will be required to be submitted at the time of application;

All of these requirements can be met during the development of the site. It should be noted that should evacuation be required there is ample (several days) warning due to significant constraints to river flow upstream of the site (SKM 2001).

Detention storage

In order to construct house pads it is proposed to excavate a detention storage of about 1.8 ML. Some material will also be derived from existing channel banks within the levee area.

Blending with the landscape - What will the house pads look like?

House pads will be irregularly shaped and sculpted to resemble a series of interweaving mounds, with a 15 x 20 m building envelope (approx) at a minimum level of 95.94 on each block. Batter slopes will be constructed to appear as gently sloping natural terrain, but allow water to flow between the mounded structures at natural surface level. The rising perspective of the mounds will be offset by a series of lower mounds forming part of the "undulating" rural levee around the perimeter of the development. The sculptured landscape, when vegetated, will resemble the type of natural landforms seen as small lunettes, sandy drifts and rises created by wind and alluvial activities throughout the Murray riverine land system.

In terms of area and levels, no pads will occupy more than 25% (~500 m^2) of the block and only sufficient area to cater for a house footprint (~15 x 20) will be at the 95.94 m level. Batters will be shaped for landscape and aesthetic amelioration below the 1:100 ARI level. Since soil will be extracted from land within Lot 16 and 17 (13.85 ha) there will be no net change in flood storage capacity within the rural levee for larger flood events.

Surface water quality and stormwater management

Low infiltration rates (refer soils section) mean that runoff can occur at times of moderate rainfall intensity. Under drought conditions the soils, due to their sodic nature and fine clay texture will contribute dispersed clay particles to any surface flow. Some fine clay particles may be suspended and transported or caught in detention storage amongst vegetation on the flatter ground. Thus the impact on surface water quality can be substantial. Nonetheless, this is a natural process that occurred prior to settlement. The expected impact post development is for a slight improvement in surface water quality.

Contaminants that can possibly be generated from residential developments include:

- Oil and grease;
- Sediment during construction and from exposed areas;
- Plastic, packaging, and other litter;
- Animal faeces.

- Nutrients from applied fertilisers;
- Herbicides.

Pollution originating from non-point sources is relatively rare and in such instances most pollutants will be assimilated close to their point of origin. Stormwater drainage from roads will discharge to gross pollutant traps and sediment control structures will also be installed where required. The detention storage will be sufficient to hold water from a 1:50 ARI event.

Houses and buildings and individual sheds will have rain water tanks fitted (houses to have 20,000L minimum) and harvested water will be used for toilet flushing and fire fighting purposes.

Although some areas of the blocks will have sprinkler and trickle irrigation the extent and intensity of water application will be substantially reduced from what might have been applied in the "normal" agricultural irrigation seasons. The elimination of grazing and reduction in irrigation application per hectare substantially reduces both the extent of runoff (by detention) and the nutrient load to the drainage system and most importantly the Murray River.

Emergency egress

In the event of major floods occurring, residents will be made aware of the situation by the State Emergency Service. The size of the catchment means that there are long lead times in flood level rise and ample opportunity to address any potential incident. Effective warning time for floods at this site is measured in weeks. The channel capacity of the Barmah Choke is approximately 8,500 ml per day resulting in overland flooding into the Barmah forest. This means that during major floods large volumes of water are temporarily banked up behind the Barmah Choke. This reduces the height of flood peaks downstream and floods the former lake area. In major floods these waters will gradually travel through the largest tracts of red gum forests in the world. This provides a huge storage /detention area for these waters and generates flood characteristics that greatly slow the rise and the velocity of floodwaters. After exiting the forests, it is this ‘overland’ flood water eventually has the capacity to impact the site. Any floodwaters around the site are extremely slow moving as the land in the surrounding district is topographically very flat (MDBC 2008).

Due to its central location, a permanent effective flood access and egress solution for this site could be easily engineered along Holmes Street. This would involve increasing the road height along Holmes Street and incorporating culverts, in order to gain access to the edge of the Kooyong Park site. This would ensure the site cannot become isolated during major flood events.

Evacuation and other emergency response and procedures have been provided in a detailed flood emergency response plan for the site. Vehicle egress would generally be to the west along Holmes Street.

Previous engineering studies (Tomkinson *et al.* 2007) indicate:

- That for a 1:100 ARI event flood waters along Holmes Street are relatively low, posing little problem for access.
- Forecasting is now sufficiently accurate to allow contingencies to be made days, if not weeks, in advance of the arrival of floodwaters.

In consultation with the State Emergency Service Moama (Bruce Smith. Pers. Comm) it was indicated that the only concern the SES would have is in relation to community dwellings or retirement homes where residents are physically disabled. The semi-rural nature of the development precludes this type of use.

Effect of landscaping and habitat areas

Trees and mid storey vegetation intercept and transpire a greater proportion of the total rainfall they receive compared to pasture. This is due to the physical structure (deep rooted) and physiology of trees. Studies on annual rainfall interception have found that it varies from about 10% to 40% depending on the degree of canopy coverage. Technical trials indicated that about 4-8 mm of rainfall from a single precipitation event could be intercepted and prevented from reaching the soil surface by tree canopies. Areas established with trees can provide other environmental benefits. They assist in managing salinity by reducing recharge to groundwater and thereby potentially reducing the salinity of waterways, they provide biodiversity, as well assisting in carbon sequestration.

Conclusions

The conclusions emerging from the investigation and report are:

- With reduced area and intensity of water application there is likely to be less impact on groundwater with the proposed development than there was under agriculture using flood irrigation.
- Additional vegetation will increase interception and deeper soil profile water use.
- The site is not readily subject to flooding in low to moderate floods including those of 1:100 ARI.
- There is a long lead time on flooding in the area, allowing for adequate preparation where required. A Flood Management Plan has been prepared for the site as part of the approval process.
- As stated in the SKM report (2001) while large flood events are still possible" the risks to the community from increasingly rare flood events becomes negligible when balanced with the immediate benefits in developing such land".
- Although some of the land (~36 ha) is subject to minor inundation in a 1:200 year event, the greenfield situation makes it possible to engineer the development so that potential costs arising from flood hazards and risks are eliminated.

- The Development Control Plan indicates that the site is flood free based on the 1:100 ARI event and is not readily subject to flooding in low to moderate floods including those of 1:100 ARI.
- In a 1:200 ARI event the site would be categorised as a 'low hazard flood storage' , which is compatible with the DCP No 7 for the proposed development.
- Any floodworks (e.g. levees) undertaken will have insignificant impacts on flood flows and flood storage.

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Appendix 1 Climate statistics

Climate statistics Echuca 1981- 2007(Source: BOM, Evaporation data- Rochester (Skene and Harford 1964)

Parameter/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temperature (°C)	30.8	30.6	27.2	22.2	17.5	14.2	13.4	15.2	18.3	22.0	26.0	29.0	22.2
Mean minimum temperature (°C)	15.1	15.2	12.9	9.4	6.6	4.7	3.9	4.8	6.4	8.7	11.1	13.4	9.4
Mean rainfall (mm)	26.9	26.5	30.4	32.7	41.3	42.9	41.0	42.3	39.7	43.1	32.0	28.4	427.2
Mean number of days of rain ≥ 1 mm	2.6	2.4	2.9	3.6	5.2	6.2	6.6	6.8	5.8	5.4	3.7	3.3	54.5
Evaporation	226	180	140	89	46	28	23	41	61	104	155	208	1300

Detention storage requirement

Rainfall April to August 240 mm =2.4 ML/ha

Runoff 10% of rainfall = 0.24 ML/ha

Area = 16 ha

Storage required for winter 16 x 0.24 = 3.84 ML

Note: Evaporation April to August (207 mm or 2.1 ML/ha) is not taken into account in calculating storage volume.

Appendix 2 Flood levels SKM 2001 and Murray Shire Development Control Plan 2002

Table A. 1: Peak Levels and Flow Velocities for Design Floods

NOTE: See Figure A.8 for cross-section locations.

	Peak Flood Levels (m AHD)							
	Chainage	10 y ARI	20 y ARI	1993 flood	50 y ARI	100 y ARI	200 y ARI	Extreme Flood
Murray	959.90	95.67	96.08	96.17	96.09	96.21	96.34	97.10
River	960.90	95.62	96.01	96.08	96.02	96.14	96.27	97.10
Gilmour >	962.10	95.50	95.84	95.93	95.85	95.99	96.14	97.09
Rd	964.20	95.36	95.69	95.79	95.77	95.92	96.06	97.08
	965.90	95.29	95.64	95.73	95.74	95.89	96.02	97.08
	968.50	95.23	95.60	95.68	95.70	95.86	96.00	97.03
	970.70	95.21	95.58	95.66	95.69	95.85	95.99	97.00
	975.60	95.19	95.57	95.64	95.68	95.83	95.98	96.98
	978.90	95.18	95.55	95.63	95.67	95.83	95.97	96.96
	980.40	95.17	95.55	95.62	95.66	95.82	95.97	96.95
Goulburn >	982.90	95.14	95.53	95.60	95.65	95.81	95.96	96.94
River	983.40	95.14	95.53	95.60	95.65	95.81	95.96	96.94
	984.20	95.12	95.51	95.58	95.63	95.80	95.95	96.94
	987.90	94.97	95.40	95.46	95.55	95.73	95.90	96.94
	990.40	94.84	95.30	95.36	95.48	95.68	95.86	96.94
	993.70	94.73	95.19	95.23	95.40	95.61	95.83	96.94
	995.50	94.68	95.14	95.18	95.36	95.58	95.80	96.92
	997.10	94.56	95.03	95.05	95.28	95.50	95.74	96.90
	998.70	94.46	94.92	94.91	95.21	95.45	95.69	96.89
	999.20	94.43	94.89	94.88	95.19	95.42	95.67	96.88
bridge >	1000.00	94.38	94.83	94.81	95.14	95.37	95.62	96.83
	1000.40	94.37	94.82	94.79	95.13	95.36	95.61	96.83
Echuca >	1001.15	94.34	94.79	94.76	95.11	95.34	95.58	96.81
gauge	1001.70	94.32	94.77	94.73	95.09	95.33	95.57	96.80
	1004.10	94.22	94.66	94.59	95.01	95.24	95.49	96.75
Campaspe>	1004.50	94.21	94.65	94.58	95.00	95.24	95.48	96.75
River	1005.80	94.13	94.58	94.51	94.94	95.18	95.42	96.69
	1006.80	94.06	94.51	94.44	94.88	95.12	95.37	96.65
	1008.00	93.98	94.44	94.37	94.81	95.06	95.31	96.58
	1009.30	93.93	94.40	94.33	94.78	95.02	95.27	96.56
	1015.10	93.70	94.19	94.11	94.58	94.83	95.08	96.38
	1024.40	93.21	93.71	93.64	94.10	94.34	94.58	95.81
	1030.90	92.72	93.22	93.15	93.59	93.84	94.07	95.27
	1050.90	90.71	91.24	91.17	91.59	91.84	92.16	93.78
Murray-	100.00	95.40	95.68	95.79	95.77	95.92	96.05	97.08
Over	101.80	95.36	95.68	95.79	95.77	95.92	96.05	97.08
Bama Forest	103.10	95.29	95.64	95.73	95.73	95.88	96.02	97.06
	104.65	95.22	95.59	95.67	95.70	95.86	96.00	97.03
Old >	106.35	95.21	95.59	95.67	95.69	95.85	95.99	97.01
Barmah Rd	107.65	95.21	95.58	95.66	95.69	95.85	95.99	97.00
	109.75	95.20	95.57	95.65	95.68	95.84	95.98	96.99
	112.45	95.19	95.57	95.64	95.68	95.84	95.98	96.98
	114.75	95.18	95.56	95.63	95.67	95.83	95.97	96.96
	116.15	95.18	95.56	95.63	95.67	95.82	95.96	96.96
Webb Rd >	117.75	95.18	95.56	95.63	95.67	95.82	95.94	96.95
	119.25	95.18	95.56	95.63	95.67	95.82	95.93	96.95
Bett St >	121.00	95.18	95.56	95.63	95.67	95.81	95.92	96.95
	121.40	95.00	95.19	95.23	95.40	95.61	95.84	96.95
	122.40	94.73	95.19	95.23	95.40	95.61	95.83	96.94
Moama	100.00	95.04	95.25	95.37	95.38	95.57	95.80	96.95
(West of	100.75	95.04	95.25	95.37	95.38	95.57	95.80	96.95
Railway)	101.60	95.04	95.25	95.36	95.37	95.57	95.80	96.95
Milgate >	102.30	94.99	95.24	95.36	95.37	95.57	95.80	96.95
Rd	103.15	94.98	95.24	95.36	95.37	95.56	95.80	96.95
	104.00	94.98	95.23	95.35	95.36	95.56	95.80	96.95
	104.85	94.96	95.23	95.35	95.36	95.56	95.80	96.94
	105.00	94.95	95.23	95.35	95.36	95.56	95.80	96.94
Barnes Rd>	106.30	95.00	95.22	95.34	95.36	95.56	95.80	96.93
	106.70	95.00	95.00	95.00	95.21	95.45	95.69	96.89
	107.30	94.46	94.92	94.91	95.21	95.45	95.69	96.89

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River	Chainage	Mean velocities (m/s)						
		10 y ARI	20 y ARI	1993 flood	50 y ARI	100 y ARI	200 y ARI	Extren[illegible] Floo[illegible]
Murray River	960.90	0.7228	0.8988	0.7245	0.8988	0.8831	0.8966	0.895[illegible]
	962.10	0.6543	0.6755	0.5707	0.6754	0.6616	0.6576	0.655[illegible]
	964.20	0.5520	0.5491	0.5942	0.5491	0.5589	0.5463	0.545[illegible]
	965.90	0.6127	0.6197	0.5820	0.6197	0.6170	0.6179	0.615[illegible]
	968.50	0.4898	0.5774	0.6059	0.5671	0.6039	0.6352	0.615[illegible]
	970.70	0.5128	0.5128	0.5296	0.5128	0.5128	0.5128	0.513[illegible]
	975.60	0.4358	0.4358	0.4912	0.4358	0.4358	0.4358	0.436[illegible]
	978.90	0.3960	0.3984	0.4006	0.3984	0.4023	0.4074	0.396[illegible]
	980.40	0.4579	0.4617	0.4715	0.4616	0.4761	0.4914	0.459[illegible]
	982.90	0.4045	0.4045	0.4494	0.4045	0.4045	0.4045	0.4061
	983.40	0.2343	0.2353	0.2717	0.2353	0.2374	0.2352	0.2351
	984.20	0.7957	0.7957	0.7137	0.7957	0.7957	0.7957	0.8026
	987.90	0.7179	0.7189	0.7060	0.7189	0.7255	0.7286	0.7202
	990.40	0.7309	0.7309	0.6563	0.7309	0.7309	0.7309	0.7391
	993.70	0.3957	0.4220	0.4601	0.3731	0.3768	0.3790	0.3970
	995.50	0.7123	0.7137	0.7659	0.7137	0.7217	0.7234	0.7124
	997.10	0.6851	0.6856	0.6904	0.6856	0.6923	0.6939	0.6943
	998.70	0.7448	0.7482	0.7906	0.7482	0.7590	0.7605	0.7466
	999.20	0.6828	0.6832	0.6626	0.6832	0.6874	0.6874	0.6795
	1000.00	0.7273	0.7278	0.7424	0.7278	0.7335	0.7347	0.7246
	1000.40	0.5753	0.5756	0.5829	0.5756	0.5785	0.5767	0.5713
	1001.15	0.6044	0.6044	0.5411	0.6044	0.6044	0.6044	0.6027
	1001.70	0.6240	0.6193	0.6764	0.6174	0.6255	0.6261	0.6160
	1004.10	0.7320	0.7452	0.8026	0.7290	0.7348	0.7356	0.7256
	1004.50	0.6840	0.6840	0.6685	0.6840	0.6840	0.6840	0.6853
	1005.80	0.8510	0.8639	0.7936	0.8838	0.8897	0.8950	0.9652
	1006.80	0.8573	0.8618	0.7999	0.8679	0.8687	0.8744	0.9535
	1008.00	0.8317	0.8317	0.8196	0.8353	0.8357	0.8376	0.9142
	1009.30	0.7993	0.7993	0.7941	0.7993	0.7993	0.7993	0.8460
	1015.10	1.1776	1.1776	1.1739	1.1776	1.1776	1.1776	1.1740
	1024.40	0.9798	0.9798	0.9853	0.9798	0.9798	0.9798	0.9760
Murray-Over (Bama Forest & East of Railway)	100.00	0.0082	0.0082	0.0094	0.0082	0.0082	0.0349	0.1812
	101.80	0.1012	0.1012	0.1012	0.1012	0.1012	0.1012	0.1728
	103.10	0.4074	0.5697	0.4072	0.6007	0.5870	0.5182	0.4074
	104.65	0.4190	0.4190	0.4286	0.4190	0.4190	0.4190	0.4192
	106.35	0.1522	0.1730	0.1337	0.1722	0.1808	0.1911	0.1995
	107.65	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757
	109.75	0.0966	0.1154	0.0932	0.1110	0.1180	0.1250	0.1326
	112.45	0.1277	0.1620	0.1362	0.1543	0.1659	0.1777	0.1853
	114.75	1.0301	1.1279	1.0731	1.1238	1.1242	1.1507	1.0328
	116.15	0.2658	0.2696	0.2500	0.2716	0.2733	0.2783	0.3285
	117.75	0.0631	0.0697	0.0187	0.0733	0.0782	0.0803	0.1125
	119.25	0.1891	0.1950	0.0555	0.2730	0.2068	0.2759	0.4305
	121.00	0.0373	0.0471	0.0113	0.0498	0.0548	0.1070	0.1128
	121.40	0.2671	0.2671	0.2675	0.2671	0.2671	0.2671	0.2680
	122.40	0.0205	0.0205	0.0206	0.0205	0.0480	0.1036	0.1194
Moama (West of Railway)	100.00	0.0168	0.0277	0.0249	0.0288	0.0305	0.0324	0.0407
	100.75	0.0369	0.0399	0.0298	0.0423	0.0438	0.0472	0.0550
	101.60	0.2265	0.2260	0.2255	0.2200	0.2015	0.2256	0.2035
	102.30	0.0693	0.0819	0.0461	0.0833	0.0861	0.0869	0.0774
	103.15	0.0619	0.0681	0.0354	0.0662	0.0684	0.0657	0.0605
	104.00	0.0853	0.0836	0.0467	0.0668	0.0913	0.0786	0.0566
	104.85	0.1044	0.1012	0.0870	0.0432	0.0444	0.0429	0.1178
	105.00	0.1767	0.2219	0.1312	0.0493	0.0509	0.0496	0.1179
	106.30	0.0236	0.0279	0.0303	0.0303	0.0322	0.0334	0.1218
	106.70	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0399
	107.30	0.0162	0.0162	0.0185	0.0162	0.0162	0.0171	0.0674

Murray Shire DCP (2002)

Peak Flood Levels with the Proposed Town Levee (June 2001)

Peak Flood Level (m AHD)					
River	**Chainage**	**1993 Flood**	**50 y ARI**	**100 y ARI**	**200 y ARI**
Murray River	959.90	96.17	96.10	96.22	96.35
	960.90	96.08	96.03	96.15	96.28
Gilmour Rd	962.10	95.93	95.86	96.02	*96.17*
	964.20	95.79	95.80	95.95	96.08
	965.90	95.73	95.77	95.92	96.05
	968.50	95.68	95.73	95.89	96.03
	970.70	95.66	95.72	95.88	96.02
	975.60	95.64	95.71	95.87	96.00
	978.90	95.63	95.70	95.86	96.00
	980.40	95.62	95.70	95.85	95.99
Goulburn River	982.90	95.60	95.68	95.84	95.99
	983.40	95.60	95.68	95.84	95.99
	984.20	95.58	95.67	95.83	95.98
	987.90	95.46	95.59	95.77	95.93
	990.40	95.36	95.52	95.72	95.90
	993.70	95.23	95.44	95.65	95.87
Old Deni Rd	995.50	95.18	95.40	95.62	95.85
Victoria St	997.10	95.05	95.32	95.55	95.78
Murray St	998.70	94.91	95.24	95.47	95.72
	999.20	94.88	95.22	95.45	95.69
Bridge	1000.00	94.81	95.17	95.40	95.64
	1000.40	94.79	95.16	95.39	95.63
Echuca Gauge	1001.15	94.76	95.14	95.37	95.61
	1001.70	94.73	95.12	95.35	95.59
	1003.05		95.09	95.32	95.56
	1003.65		95.08	95.30	95.54
	1004.10	94.59	95.05	95.28	95.51
Campaspe River	1004.50	94.58	95.04	95.27	95.50
	1005.80	94.51	94.97	95.20	95.44
	1006.80	94.44	94.92	95.16	95.40
	1007.45		94.85	95.09	95.34
	1008.00	94.37	94.83	95.07	95.32
	1009.30	94.33	94.80	95.04	95.29
	1015.10	94.11	94.67	94.91	95.16
	1024.40	93.64	94.18	94.42	94.65
	1030.90	93.15	93.67	93.92	94.14
	1050.90	91.17	91.67	91.94	92.25

Appendix 3. 1:200 ARI Flood distribution (SKM 2001)

Areas shaded red are High hazard flood storage, but the development site has been incorrectly categorised and should be shaded green – Low hazard flood storage. Blue areas are floodway