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Adequacy of environmental assessment of the proposed Macquarie River pipeline to the city of Orange

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Table of Contents

Ford upstream of pump site flowing at 277ML d^{-1}

Executive Summary

The city of Orange in central western New South Wales lies within the Macquarie River catchment of the Murray-Darling Basin. To meet increasing demand for water, a government subsidised pipeline project ($47 million capital cost, $728,000 per year running cost) is proposed to pump an average of 1,616ML yr^{-1} from the Macquarie River, 39km from Orange. This was subject to a legally required Environmental Assessment in August 2012, which modelled impacts of the development and concluded that a significant ecological impact on the Macquarie River was unlikely, and impacts on the downstream Ramsar-listed Macquarie Marshes were negligible. The pipeline was recommended for approval by the Department of Planning and Infrastructure NSW on the 7th May 2013. On the 18th June 2013, the Planning Assessment Commission determined to approve the project, subject to amendments of the river flow model to increase the pumping threshold. The Australian Government is currently considering the development under the EPBC Act 1999.

We independently modelled flows and likely hydrological impacts, including downstream effects on flows to the river and the internationally significant Macquarie Marshes, listed under the Ramsar Convention. The Macquarie Marshes are already considerably affected by upstream development of water resources, causing the Australian Government to notify the Ramsar Bureau of a likelihood of a change in ecological character as a result of human impacts. There were three critical issues we identified as inadequately assessed in the Environmental Assessment, which could potentially exacerbate the poor ecological health of the Macquarie Marshes and adversely impact on the high conservation value section of Macquarie River at and downstream of the pump site.

First, the pumping threshold when water could be pumped using the proposed pipeline was considerably lower in the Environmental Assessment than we estimated with our modelling which was similar to an independent assessment, commissioned by the NSW Department of Planning and Infrastructure. Modelling in the Environmental Assessment was based on dry catchment conditions and

projected climatic scenarios, increasing water currently available to pump in the river. Second, enlargement of capacity to take more water at Orange (e.g. enlarging Suma Park Dam or use of groundwater aquifer for storage) is unclear in the Environmental Assessment, and could considerably increase the potential capacity to take more water from the Macquarie River. Finally, the current approval of the pipeline has adopted a new threshold for pumping but the environmental impact of this threshold has not been assessed. Ultimately, these issues contribute to increasing the impact of the pumping on the river and its dependent ecosystems, including the already degraded Macquarie Marshes. Further, reliability of flows to downstream users including the irrigation industry and towns will be reduced.

We used actual flow data for the three subcatchments, the Macquarie River, the Turon River, and Summer Hill Creek, which provide flows to the pump site, as opposed to using modelled data. We imposed current demand (i.e, population) on the flow and modelled pumping regimes, based on two thresholds: cease to pump, above the 80th percentile (low flow) at the pump site, below which pumping would have to cease, and another threshold trigger to pump, when the receiving storage, Suma Park Dam, was less than 90% capacity for the current and proposed enlarged storage.

Critically, we estimated current flow to be considerably higher than dry conditions modelled in the Environmental Assessment, which affected the cease to pump threshold and opportunity to pump. We estimated the 80th percentile flow to be 102ML d^{-1}, compared to 22ML d^{-1}. If the EA pumping threshold is maintained, this will allow pumping below our 80th percentile and therefore more water will be extracted. The Environmental Assessment adopted a higher threshold of 38 ML d^{-1} but even this was considerably lower than our modelled flows. An independent review of the river flow model used in the Environmental Assessment was commissioned by the Department of Planning and Infrastructure NSW and this modelling was similar to ours, identifying the 80th percentile of 92 MLd^{-1}. We used actual flows while the Environmental Assessment modelled dry and future climate scenarios. We estimated that 13.7%

of low flows, as low as the 96.8th percentile, could have been diverted under the proposed pumping.

There was also additional potential to pump increased volumes by changing the storage threshold, further confounding the conclusion of the Environmental Assessment that there would be no significant environmental impact. It remains unclear in the Environmental Assessment whether increasing dam storage is accounted for. In November 2012, after the Environmental Assessment, Orange Council investigated raising the dam wall by 1 m, increasing storage by 1680 ML. The possible increase in dam capacity, could allow for an average annual increase of 251ML yr^{-1}, when the development is approved. Further, there was opportunity for the pipeline to supply, on average, an additional 1948ML yr^{-1} above the amount allowed under Model A's pumping threshold. This could occur if Orange was able to consume or store the pipeline's capacity, rather than being limited by the dam threshold. Neither of the two thresholds appropriately constrained capacity to divert water.

The pipeline will reduce flows in an already impacted system of the Murray-Darling Basin, negatively affecting downstream ecosystems, including to the Ramsar-listed Macquarie Marshes. The development represents a new source of diversion on an already developed system. The current water sharing planning mechanisms allow for increases in water diversion from the river through the activation of sleeper licences (i.e. water never diverted) and opportunity for towns to grow their water use. It is not clear whether the newly adopted Murray-Darling Basin Plan or the NSW Government's control of growth in use will be able to adequately deal with this increased impact on the river. Ultimately additional water will be diverted from the river, affecting downstream users, including the Macquarie Marshes. The costs will be socialised among downstream users as flows will decrease into the major regulation storage Burrendong Dam. This will reduce the amount of water available for high security and general security licences. This includes recently purchased environmental water purchased by the Australian and NSW Governments to provide environmental flows to the Macquarie Marshes. Such developments directly erode effectiveness of such investments in restoring the environment, undermining the attempts by Australian governments to rehabilitate the internationally Ramsar-listed Macquarie Marshes. Further, there is considerable potential for increased diversions to Orange, exceeding those modelled in the Environmental Assessment.

Water supply challenges will affect many rural urban centres with increasing populations. This is particularly relevant for over allocated rivers in the Murray-Darling Basin. The main solution is similar to that applied to other extractions of water from the river: use of existing extraction and improved efficiency. Potential solutions require retirement of water which is currently used. This could be done by purchasing water within the extractive share of water (i.e. from other water users) and not continuing to divert environmental water for urban use. There are also potential alternative solutions which could reduce demand on water resources, in particular reducing water use from the river. For example, there is about 3,000 ML per year of waste water, about double what the pipeline is currently estimated to divert but which is currently supplied free of charge to the nearby goldmine. This could be treated and cycled back for urban use; such an option will probably be more cost effective in the long-term with improvements in water treatment. Water saving strategies could also be utilised to sustain growing populations in urban centres. Until such mechanisms are adequately implemented, then there will be increasing impacts on river and other downstream water users.

Finally, the current proposed pipeline has had its pumping threshold considerably altered after approval by the Planning Assessment Commission: raised from 38 to 108 ML d^{-1}. The potential impact of this change has not been assessed in terms of its environmental impact. Further, we identified other key issues which will increase water use from the Macquarie River and increase deleterious impacts on downstream users and the environment, including the significantly impacted Macquarie Marshes, a wetland of international importance.

Introduction

There is increasing pressure on Australia's rivers and groundwater resources to meet demand for irrigation and urban water supplies. As a result, wetlands and rivers have degraded, particularly in the Murray-Darling Basin (Kingsford, 2000; Arthington & Pusey, 2003). Orange is one of seven regional centres building its population through the Evocities project but reliant on its water from rivers in the Murray-Darling Basin. To deal with current shortages and future growth, a pipeline from the Macquarie River is proposed to divert up to 3,800 ML per year, costing $47 million, with annual running cost of $728,500. Further reduction in flows in the Macquarie River may affect the Ramsar-listed Macquarie Marshes downstream. The development size and potential effects triggered an Environmental Assessment process.

Wetland health has declined globally, with threats occurring from global to local scales (Dudgeon *et al*., 2006; Kingsford, 2000; Vörösmarty *et al*., 2010; Hermoso and Clavero, 2011). Water resource development, the building of dams and diversion of water, is a major cause for global wetland decline (Lemly *et al*., 2000; Vörösmarty *et al*., 2010). Global threats to biodiversity and human water security of wetland river systems will be exacerbated under predicted climate change (Vörösmarty *et al*., 2010; Hermoso and Clavero, 2011; IPCC, 2007; Kingsford, 2011). The climatic drivers of precipitation, temperature and evaporative demand will synergistically interact with current threats, including invasive species, pollution and overexploitation (Kingsford *et al*., 2009). Reducing water consumption from river abstraction is the most viable conservation strategy for freshwater ecosystem conservation (Xenopoulos *et al*., 2005).

Global wetland conservation is primarily focused on protection through the Convention on Wetlands of International Importance, especially as Waterfowl Habitat (Ramsar Secretariat, 1971), known as the Ramsar Convention. The convention is a key conservation initiative in Australia (Kingsford, 2011), identifying wetlands of importance for biodiversity and ensuring that their ecosystem services are maintained. Ultimately, significant wetlands must be protected through protection of environmental flows to maintain biodiversity and ecological and hydrological functions (Ramsar Secretariat, 1971). This can only be effected through sound water planning that adequately protects and provides sufficient environmental flows. Freshwater management remains a critical global issue, with 2013 identified as the United Nations International Year of Water Cooperation, promoting international cooperation for future economic, social and environmental outcomes (UN Water, 2013).

In Australia, water resource development has significantly degraded wetlands of the Murray-Darling Basin (Kingsford 2000; CSIRO 2008b; Colloff *et al*. 2010; Kingsford *et al*. 2011), becoming one of the more important environmental issues in Australia. This is reflected in the level of political and local debate about the basin, the considerable funding committed to solving the problem (> $10 billion), and significant changes to legislation, policy and management of water with national implications. This culminates in the return of environmental flows to rivers and wetlands under the proposed Murray-Darling Basin Plan through the buyback of water from the irrigation industry (MDBA and Commonwealth Government, 2012). The Murray-Darling Basin Plan will set sustainable diversion limits for all rivers, designed to restore the ecological health of the rivers and wetlands, building on the early policy initiative of the Murray-Darling Basin Cap in 1995 to stem water diversions at the baseline of 1993-1994 levels (Commonwealth Government, 2008). In 2004, the Council of Australian Governments (CoAG) agreed to return stressed river systems to sustainable levels of development under the National Water Initiative (CoAG, 2004). Many stressed rivers include dependent wetlands (e.g. Barmah-Millewa Forest, Coorong and Lower Lakes, Macquarie Marshes), listed as wetlands of international significance under the Ramsar Convention (Pittock and Finlayson, 2011).

River regulation and diversion of water upstream has already significantly impacted on the Macquarie River, with the ecosystem health described as "very poor" following the Sustainable Rivers Audit of all rivers in the Murray-Darling Basin (Davies *et al*., 2008). Reduced flooding to the Macquarie Marshes has affected resilience of biota (Kingsford & Thomas, 1995; Kingsford & Johnson, 1998; Kingsford, 2000; NSW Department of Environment Climate Change and Water, 2010; Thomas, Kingsford, Lu, & Hunter, 2011; NSW Office of Environment and Heritage, 2012). This prompted the Australian Government to inform the Ramsar Bureau under Article 3.2 of the Ramsar Convention that there was a likely change in ecological character resulting from anthropogenic impacts (Department of the Environment Water Heritage and the Arts, 2009, 2000). There will be further reduction of flows in the Macquarie River from the development of the pipeline to augment Orange's water supply, acknowledged in the official Environmental Assessment (GHD, 2012a).

The proposed Macquarie Pipeline was the main component of a drought relief strategy, aiming to meet current water demand and secure allocated supply for projected urban demand (GHD, 2012b). Orange currently has permanent level 2 restrictions, but had level 5.5 restrictions during the Millennium drought (2002-2009). The proposed pipeline aims to extract water from Cobbs Hut Hole at the Macquarie River, supplementing the existing storage capacity for Orange, Suma Park Dam (Fig. 1).

The proponent, Orange City Council submitted an Environmental Assessment for the Macquarie River pipeline in July 2012 (GHD, 2012b), providing an assessment of its environmental impact under the legislative framework provided by the Environmental Planning and Assessment (EP&A) Act 1979, (NSW Government, 2012a). The Environmental Assessment concluded that a significant impact on the Macquarie River was unlikely, and impacts on the downstream Macquarie Marshes were negligible based on hydrological modelling and ecological assessments of the consequences (GHD, 2012a). The NSW Department of Planning and Infrastructure assessed the project, and submissions closed on the 15th October 2012. The pipeline was also identified as a referable action under the Australian Government's Environment Protection and Conservation (EPBC) Act 1999. The pipeline route and site for the pump has changed to a smaller pool, where a greater proportion of water would be drawn, requiring an update to the Environmental Assessment (February 2013), a

Preferred Project Report, which was referred to the Planning and Assessment Commission. On the 1st of February 2013, NSW Department of Planning and Infrastructure commissioned independent hydrological modelling (Bewsher Consulting, 2013) which concluded on the 8th of April 2013 that there was a significant deficiency in the river flow model used, but that environmental impacts raised in the Environmental Assessment would diminish with an updated flow model. The Department of Planning and Infrastructure NSW Director General's report has recommended approval of the development. The development was approved with conditions by the Planning and Assessment Commission on the 18thof June 2013, and is in the closing stages of approval.

Our project aimed to investigate the adequacy of the Environmental Assessment process specifically because of the potential for ongoing cumulative impact to the already stressed downstream river system and particularly the Ramsar-listed Macquarie Marshes. Specifically, we had five objectives: 1) to model flows in the Macquarie River pump site, including the effects of increasing populations in the catchment; 2) to compare these modelled estimates for diversions to those in the models from the Environmental Assessment and examine the potential for increased diversions once the infrastructure for pumping is established; 3) to assess the likely impacts of any disparity, particularly in terms of reduced flows to downstream ecosystems using published literature; 4) to examine the potential options for accessing water, given current supply and demand constraints; and 5) to identify the implications of increased diversions from a stressed river of the Murray-Darling Basin and its internationally important Ramsar-listed wetland, given current water management planning frameworks and the Murray-Darling Basin Plan.

Methods

Study area

The Macquarie River lies within Macquarie-Bogan catchment (74, 800km^2, Department of Primary Industries, 2012) of the Murray-Darling Basin (Fig. 1). Its headwaters originate in the Great Dividing Range where two rivers, the Fish River and Campbell River, join 12km upstream of Bathurst to form the Macquarie River (Fig. 1). The Macquarie River then flows north-west through Bathurst and is joined by Queen Charlottes Creek, Winburndale Rivulet, the Turon River, the Summer Hill Creek system, and Pyramul Creek (Fig. 1). The river continues to flow on to Burrendong Dam and then through the towns of Wellington, Dubbo, Narromine and Warren, before reaching the Macquarie Marshes (Fig. 1), a Ramsar-listed wetland of international importance (NSW Office of Environment and Heritage, 2011; Ramsar Secretariat, 2012).

The sharing of water in the Macquarie River is governed by a water planning framework, defined primarily by two water sharing plans (WSPs): the Water Sharing Plan for the Macquarie and Cudgegong Regulated Rivers Water Source 2003 (NSW Government, 2003), for the regulated river downstream of Burrendong Dam and upstream on the Cudgegong River to Windamere Dam, and the Water Sharing Plan for the Macquarie Bogan Unregulated and Alluvial Water Sources 2012 (NSW Government, 2012b), covering unregulated tributaries of the Macquarie River, including upstream of Burrendong Dam. The entire river and its diversions need to be within the Sustainable Diversion Limits, specified under the Murray-Darling Basin Plan (Commonwealth Government, 2012). There are many other different legislative and policy obligations for managing or conserving aquatic ecosystems at local, State and Commonwealth levels of government (Bino *et al*., 2013).

The Macquarie river supports irrigation in 1.6% of its catchment, with the major irrigation crop of cotton (68%) irrigated on flat alluvial plains of the lower catchment (CSIRO, 2008b; Green *et al*., 2011; Department of Primary Industries, 2012) (Fig. 1). The catchment has a population of 180,000 with more than half living in regional cities (Green *et al*., 2011) dependent on the Macquarie River for water supply. The Macquarie River has 1,530 GL of large dams and weirs (CSIRO, 2008b) that regulate river flows, the largest being Burrendong Dam (Fig. 1; 1,154,000 ML). These dams allow water to be diverted for stock and domestic supply, industry, urban centres and irrigation. Upstream of Burrendong Dam, the

Macquarie River is also regulated by dams, even though it is covered under an unregulated water sharing plan (NSW Government, 2012b). There are six major regulation structures upstream of Burrendong Dam, totalling 93,240 ML storage capacity (Table 1). These structures supply major upstream urban areas of Oberon, Bathurst, and Orange (Fig. 1), as well as the Fish River inter-basin transfer. The proposed Orange pipeline aims to divert water from the Macquarie River to augment urban water supply from the upper catchment of the Macquarie River (Fig. 1).

The upper catchment of the Macquarie consists of three major subcatchments upstream of the pump site (Fig. 1): the Summer Hill Creek system, the Turon River and the Macquarie River (includes the tributaries of the Fish and Campbell Rivers). The Summer Hill Creek system has had significant river development primarily to supply the town of Orange and its associated industries (Figure 1, Tables 1 & 2). On the main branch of the Macquarie River upstream of Burrendong Dam, river development has been primarily to supply the towns of Oberon and Bathurst but also an inter basin transfer of water (Fig. 1, Tables 1 & 2). These developments are in contrast to the Turon River where there is little water resource development (Fig. 1, Tables 1 & 2), with a predominant land use of grazing.

Dams regulate the river to supply total licenced allocations up to 61,930.5ML yr^{-1} upstream of Burrendong Dam, when water is available, (Table 2). Of this, more than half (32,847ML yr^{-1}) can be diverted to supply urban centres with the remaining (29,083.5ML yr^{-1}) available for other uses such as general security (Table 2). Diversions are divided amongst the three catchments above the pump site (Fig. 1). Diversions from the Macquarie catchment upstream of the Turon total 49,351.5 ML yr^{-1} (Table 2). Contrastingly, the Turon catchment has only 328ML yr^{-1} of access licences, reflecting the relatively low level of water use (Table 2).

Orange is in the Summer Hill Creek Catchment (Fig,1), with a town water access licence allowing extraction of 7,800ML yr^{-1} for town water, of which use is about half (3,670ML yr^{-1}) under permanent level 2 restrictions (National Water Commission, 2013). In addition, Orange could increase water access by purchasing a 640ML general security licence to pump from the Macquarie, which is currently not used (i.e. a sleeper licence). Orange has the potential to increase annual water use from the greater Macquarie catchment by 4,770ML yr^{-1} with this licence, and its current allocation. Within the Summer Hill Creek Catchment, there are 4,451ML yr^{-1} of general security licences for other uses, making a total licenced diversion of 12,251ML yr^{-1} (Table 2).

Orange has two dams with a capacity totalling 22,066ML (Table 1). The city also accesses an average of 61ML yr^{-1} (±10 SE) from groundwater sources (2007-2012, National Water Commission, 2013) but can also divert an additional 462ML yr^{-1} (GHD, 2013a): 160ML yr^{-1} from Orange Basalt Groundwater, and the remainder from Lachlan Fold Belt Murray-Darling Basin Groundwater (NSW Government, 2013a). These groundwater sources have yet to be developed.

Table 1 –Capacity (ML), year of building, river location and purpose of regulation structures and diversions, upstream of Burrendong Dam on the Macquarie River, primarily supplying urban water to the towns of Oberon, Bathurst and Orange.

Regulation	Structure	Built	Volume (ML)	River	Purpose
Dam	Fish River (Oberon) Dam[a]	1949	45,420	Fish River	Oberon supply and Fish River transfer
	Duckmaloi Weir[a]	1964	20	Fish River	Additional supply to Fish River scheme
	Chifley Dam	1957	30,800	Campbells River	Bathurst supply
	Winburndale Dam[b]	1936	17,000	Winburndale Rivulet	Bathurst industry, park watering
	Suma Park Dam[C]	1962	17,386	Summer Hill Creek	Orange supply
	Spring Creek[d]	1931	4,680	Spring Creek Dam	Orange supply
	Gosling Creek Dam	1890	650	Gosling Creek	Unused water supply, Recreation
	Lake Canobolas	1918	455	Molong Creek	Recreation
Diversions	Fish River transfer	1949	15,876	Fish River	Lithgow (cooling Mount Piper and Wallerawang power stations[a]) and Sydney Catchment Authority supply.
	Orange pipeline	Proposed		Macquarie River	Orange augmentation supply

[a]NSW Office of Water (2012a)

[b]Australian National Committee on Large Dams (2010), Bathurst City Council (2012)

[c]Australian Bureau of Statistics (2011), Orange City Council (2013), National Water Commission (2013)

[d]Australian National Committee on Large Dams (2010), MWH (2011)

Table 2 – Different types of licensed water use and their total annual volume and priority of access, allowing diversions from the Macquarie River, above the proposed pump site. Purpose is provided in parentheses where relevant to urban water supply.

River	Licence type	Volume (ML) [a]	Priority of access
Fish River	Local water utility access licences	15	High
Macquarie River	(Bathurst)	17,500 [b]	High
Winburndale Rivulet		1,000	High
Summer Hill Creek	(Orange)	7,800	High
Fish River[c]	Major Utility access licence (Oberon, Lithgow, SCA, Delta electricity township)	(6,532 as town supply) 15,876	Major water utility (NSW Office of Water, 2012a)
Fish River	Unregulated River Access licences	2,159.5	Medium (general security)
Campbells River		2,058	Medium (general security)
Macquarie River		8,056[b]	Medium (general security)
Winburndale Rivulet		585	Medium (general security)
Queen Charlottes Vale Evans Plains Creek		1,861	Medium (general security)
Turon Crudine River		316	Medium (general security)
Summer Hill Creek		4,451[d]	Medium (general security)
Fish River	Domestic and stock access	30	Medium (general security)
Campbells River		58	Medium (general security)
Macquarie River		55 [b]	Medium (general security)
Winburndale Rivulet		51	Medium (general security)
Queen Charlottes Vale Evans Plains Creek		47	Medium (general security)
Turon Crudine River		12	Medium (general security)

[a] CSIRO (2008), (1 unit share = 1 ML yr^{-1})

[b]Above Burrendong

[c] Town supply portion of Fish River Transfer Scheme based on water sharing arrangements (Miller, 2012)

[d]Composed of two licences: 4320 ML yr^{-1} and 131 ML yr^{-1}

The proposed pipeline to augment supply to Orange is at Cobbs Hut Hole (Fig. 1), downstream of the flows received from the Summer Hill Creek system and the other two subcatchments: the Macquarie River and the Turon River (Fig. 1) (GHD, 2013b). The development proposes to divert an average of 1,616ML yr^{-1}, modelled to be a maximum of 5.96% of yearly flows from the Macquarie River (GHD, 2013b).

There are six flow gauges immediately upstream of the proposed pump site, on the three focus subcatchments (Fig. 1). These include Lewis Ponds Creek at Ophir, the most downstream gauge on the Summer Creek catchment, the Macquarie River at Yarracoona, Bruinbun, Dixon's Long Point and Downstream Long Point and the Turon River at Sofala (Table 3,Fig. 1). Only some actual flow data existed for Ophir gauge on the Summer Creek catchment. Flows from Summer Hill Creek enter Lewis Ponds Creek at Ophir, where a flow gauge recorded daily data, 1971-1978 (Table 3). Summer Hill Creek is a tributary to the Macquarie River, entering between the Turon River and the proposed pump site (Fig. 1). Flow records existed for the Turon River at Sofala after September 1947 (Fig. 1, Table 3). The Turon River enters the Macquarie River between Winburndale Rivulet and Summer Hill Creek. The Macquarie River has a gauge at Bruinbun, also providing daily flow after September 1947 (Fig. 1, Table 3). Another gauge lies upstream below Winburndale Rivulet at Yarracoona, operating after June 2011. More recently, flows in the Macquarie River were measured upstream of the pump site (Fig. 1), at Dixon's Long Point (6 years and 7 months) and Downstream Long Point (after August 2011).

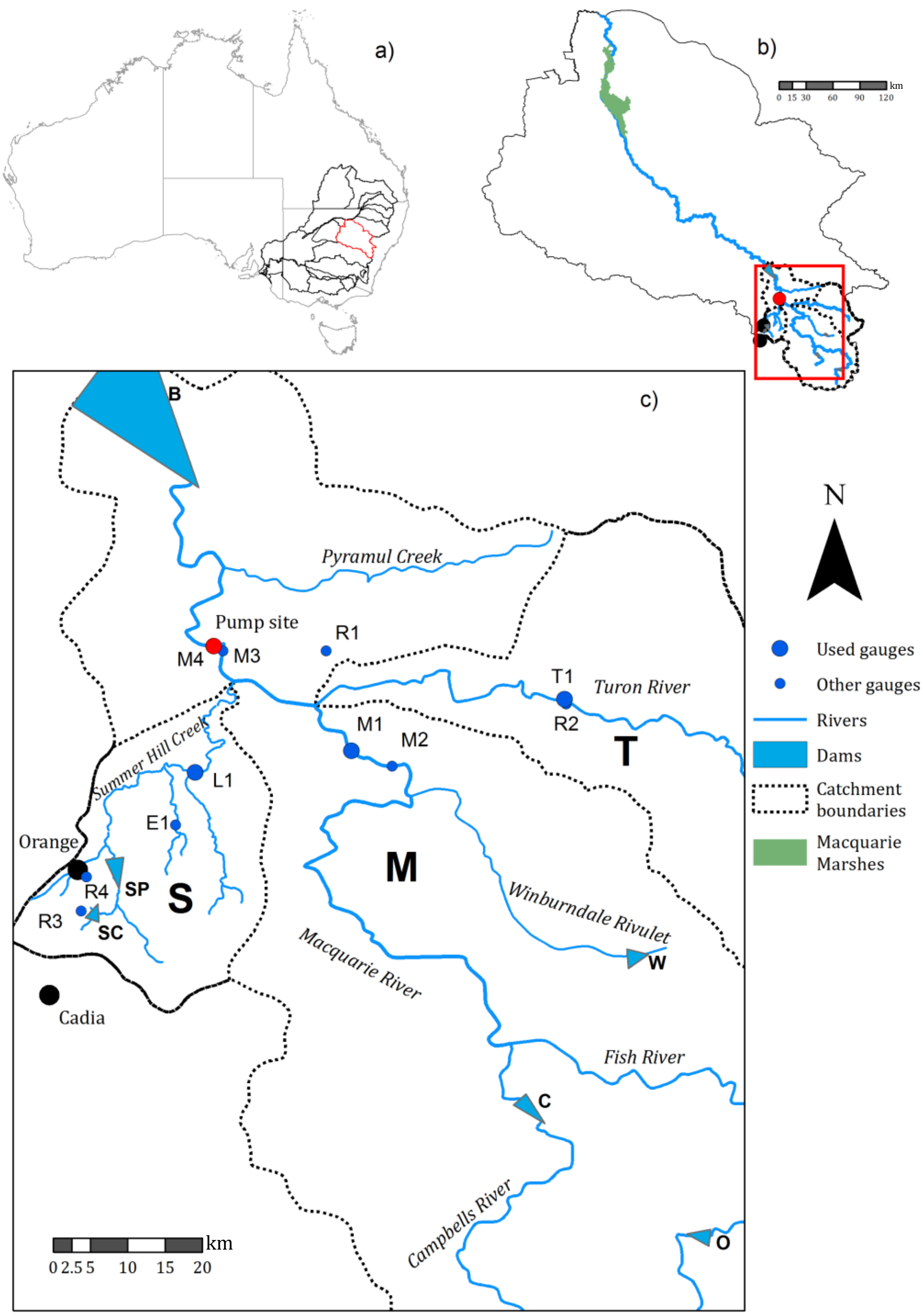

Figure 1 - Location of the study area, showing a) the Macquarie River catchment in the Murray-Darling Basin in southeastern Australia; b) the catchment of the Macquarie showing the major downstream wetland, the Ramsar-listed Macquarie Marshes; and c) the three main tributary catchments and tributaries (identified with dashed lines, Summer Hill Creek system (S); Macquarie River (M); and Turon River (T)), that flow into the Macquarie River just upstream of the proposed pipeline extracts (P). Major dams are identified: B Burrendong Dam, C Chifley Dam, S Suma Park Dam, O Oberon Dam, W Winburndale Dam, major towns, the Cadia Valley mine and the flow gauges and rainfall stations (see Table 3 for symbols).

Table 3 – River flow (NSW Office of Water, 2012b) and rainfall (Bureau of Meteorology, 2013) data availability for the three major river systems in the study area, at different sites (gauges for flow, stations for rainfall, Fig. 1): the Macquarie River, the Turon River and the Summer Hill Creek system (Fig. 1) which contributed to flow, upstream of the proposed pipeline site.

River or stream	Variable	Site[a]	Site No.	Data availability
Macquarie River	Flow	Bruinbun (M1)	421025	02/09/1947 – 22/03/2013
		Yarracoona (M2)	421191	01/06/2011 – 22/03/2013
		Dixon's Long Point (M3)	421080	02/07/1971 – 11/03/1978
		Downstream Long Point (M4)	421192	28/08/2011 – 22/03/2013
	Rainfall	Hill End Post Office (R1)	63035	01/01/1880 – 22/03/2013
Turon River	Flow	Sofala (T1)	421026	12/09/1947 – 22/03/2013
	Rainfall	Old Post Office (Sofala) (R2)	63076	01/01/1892 – 22/03/2013
Summer Hill Creek	Flow	Lewis Ponds Creek at Ophir (L1)	421052	11/02/1971 – 16/03/1978
		Emu Swamp Creek (E1)	421103	08/03/1980 – 28/02/2001
	Rainfall	Agricultural Institute (R3)	63254	01/01/1966 – 22/03/2013
		Post Office (Orange) (R4)	63065	01/01/1870 – 31/07/1968

sSymbols used for flow gauge and rainfall stations used in modelling (see Fig. 1)

Flow modelling

To determine the potential impact of the pipeline on actual flows in the Macquarie River, we used available actual data for each of the three main contributors to flow (Macquarie River, Turon River, Summer Hill Creek system, Fig. 1) to develop a historical model (Historic Model). This was used to develop a current development model, applied to the daily flow data (Model A). We used this model to test the likely effects of full development (Fig. 1, Table 1). Full development required modelling the growing impacts of urban water supply for Oberon, Bathurst and Orange on the three catchments and imposing these requirements on the actual flow regime to allow current effects of the pipeline to be tested.

First, we constructed the Historic Model. There was only one common period for which there were data for the three main flow gauges, measuring input into the Macquarie River above the proposed pump site (1971-1978, Table 3). There were long-term data available for most of the period for the Macquarie River at Bruinbun and the Turon River at Sofala (Table 3, Fig. 2) but most data were missing for flows from the Summer Hill Creek system (Fig. 2). We developed a model which allowed estimation of these daily flows. All flow and rainfall gauge data used in modelling were logarithmic transformed (log x+1) to satisfy the assumption of normality for linear regression, not met by river gauge output data. Flow data were sourced from Pinneena (NSW Office of Water, 2012b) and the NSW Office of Water (www.waterinfo.nsw.gov.au), and rainfall data were sourced the Bureau of Meteorology (www.bom.gov.au).

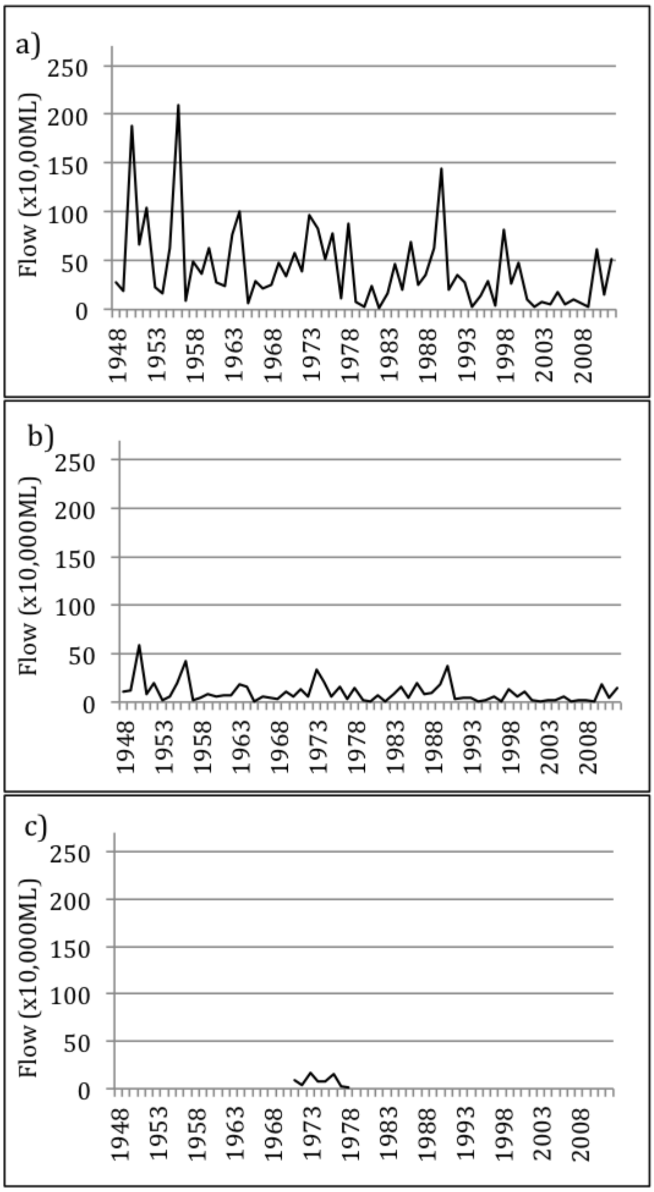

Figure 2 – Actual annual flows for the main tributary rivers (Fig. 1), including a) the Macquarie River, b) the Turon River and c) the Summer Hill Creek, upstream of the pump site.

To estimate flows in the Summer Hill Creek catchment for the full period of data availability (1948-2012), we modelled the relationship of flows in the Summer Hill Creek catchment (Ophir) with flows in the Macquarie River (Bruinbun) and Turon River (Sofala) and local rainfall in the Summer Hill Creek system (Orange). Other gauges in the Summer Hill Creek system had limited data, or did not include the effects of Orange (Emu Swamp Creek, Fig. 1, Table 1). Further, the Ophir gauge was the furthest downstream of the gauges, providing the best measure of the flow contribution from upstream tributaries in the Summer Hill Creek system (Fig. 1).

There was daily data for the two main rivers: Macquarie River (Bruinbun, 2.2%) and Turon River (Sofala, 2.0%). We interpolated data for the Bruinbun gauge using two linear models using the two other gauges on the Macquarie River for two time periods: Dixon's Long Point (1971-78) and Yarracoona (mid 2011-22/03/13). For the remaining missing data (2.0%), we used a model with Turon River flows (Sofala, Table 3). Local rainfall near the Bruinbun gauge (Hill End, BOM, Table 3) was tried but was not a significant explanatory variable in this model ($p=0.60$). Flows in the Macquarie River were reasonably well explained by the linear model which included the Turon River ($R^2=0.748$). For missing data on the Turon River (Sofala), we modelled flows using daily flow in the Macquarie River (Bruinbun gauge) and local rainfall at Sofala (Old Post Office Gauge, Table 3).

For the Summer Hill Creek catchment, we modelled daily flows at Ophir, using daily flow data for the Macquarie River (Bruinbun) and Turon River (Sofala), and local rainfall (Table 3, Fig. 1). We used local rainfall data from Orange Agricultural Institute (Table 3) with missing data (1947-1966) replaced by data from the nearby Orange Post Office (4.43km). Before modelling daily flows in the Summer Hill Creek system, we investigated potential lags in flow at Bruinbun on the Macquarie and Sofala on the Turon, upstream of the Ophir gauge in the Summer Hill Creek system (Fig. 2). Such potential relationships were also important for measuring the potential impact of diversion of flows from the Macquarie River at the pump site (Fig. 1). We modelled lags of negative one (accounting for a potentially faster river), zero, one and two days using ordinary least squares regression. In addition, we also tested for lags between local rainfall at Orange and flows in the Summer Hill Creek catchment at the Ophir gauge. All models incorporating daily lags were significant (Table 4). Lags for the day before on the Macquarie and Turon improved the result of the regression ($R^2 = 0.694$) indicating flows were slower in the Summer Hill Creek system. We also found a one day lag for rainfall improved the regression ($R^2=0.734$, Table 4).

Table 4 – Results of regression analyses testing for lag relationships between different hydrological variables, compared to daily flows in the Summer Hill Creek system (Ophir), including daily flows in the Macquarie River (Bruinbun), Turon River (Sofala), and local rainfall (Orange).

Comparison	Lag tested (days)[a]	R^2 value	p-value
Macquarie River flow	-1	0.694	< 0.001
	0	0.685	< 0.001
	1	0.642	< 0.001
	2	0.628	< 0.001
Turon River flow	-1	0.694	< 0.001
	0	0.685	< 0.001
	1	0.674	< 0.001
	2	0.674	< 0.001
Orange rainfall	-1	0.669	< 0.001
	0	0.685	< 0.001
	1	0.738	< 0.001
	2	0.709	< 0.001
	3	0.677	< 0.001
	4	0.666	< 0.001

[a]We tested four lags for flow, the day before (-1), same day (0) and lagged flows by one or two days and for rainfall, we extended lags to 4 days.

The model that best explained flows linked daily flows in Summer Hill Creek catchment (Ophir, lagged by one day), to the Macquarie River (Bruinbun) and Turon River (Sofala) and rainfall (Orange, lagged one day):

$$Summer\ Hill\ Creek\ catchment\ flows = \beta_0 + Macquarie\ River\ flows + Turon\ River\ flows + Rainfall + error$$

The model was highly significant ($p < 0.001$) with considerable variation explained (Adjusted R^2=73%), where all three variables were significant (Table 5).

Table 5 – Results of regression analysis (coefficients, t-value and probability), relating lagged flow (1 day) at Summer Hill Creek system to flows in the Macquarie and Turon rivers and local rainfall at Orange.

Variable	Coefficient	t-value	Probability
Intercept	-0.523	-5.674	<0.001
Macquarie River flow	0.642	24.739	<0.001
Turon River flow	0.135	6.430	<0.001
Rainfall	0.308	18.513	<0.001

We used this model to estimate daily flows of the Summer Hill Creek system at Ophir and compared modelled to actual daily flows (Figure 3). The model tended to underestimate large flows and overestimate low flows (Figs. 3 & 4).

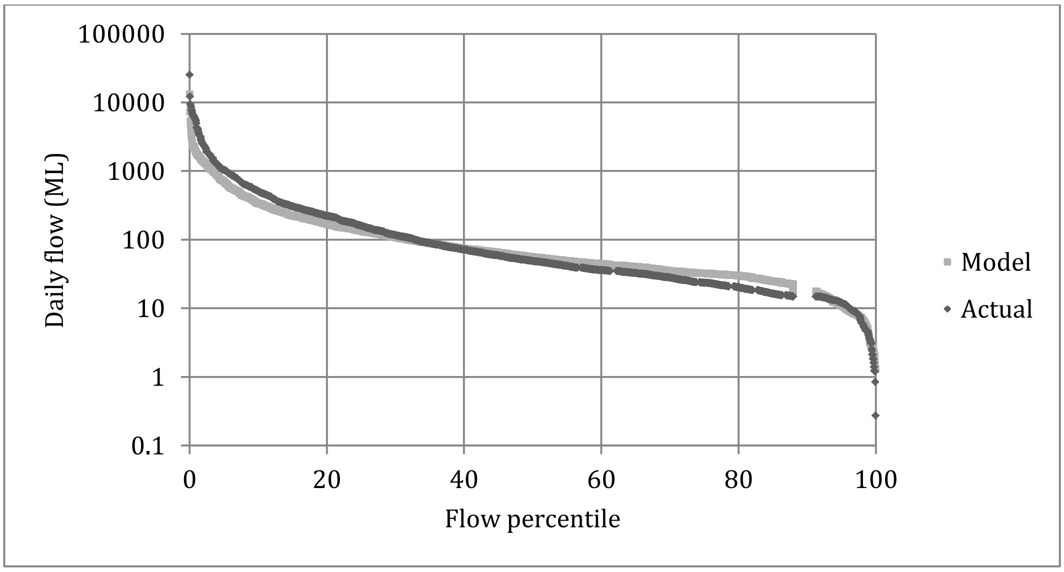

Figure 3 – Daily flow duration curves for modelled and actual flows of the Summer Hill Creek system (Ophir) for the period 1971-1978, based on a linear model using daily flows from the Macquarie (Bruinbun) and Turon Rivers (Sofala) and local rainfall (Orange) as explanatory variables with lags (see Table 4).

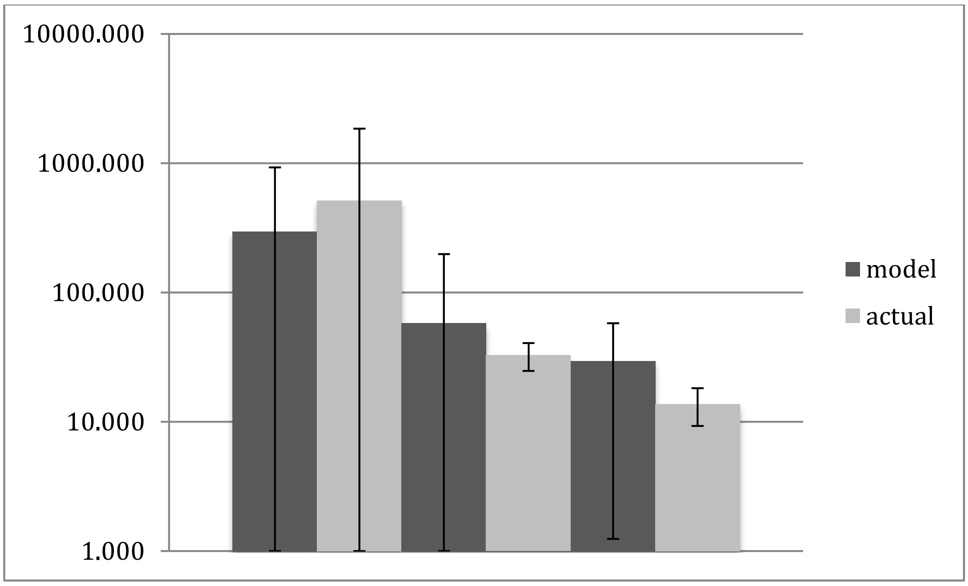

Figure 4 - Comparison of mean (±SD) modelled and actual flows for high, moderate, and low flow of the Summer Hill Creek catchment, measured at Ophir (Fig. 1).

Modelled flows underestimated high flows above the 28th percentile and overestimated low flows between the 46th-88th percentiles (Figs. 3&4). Modelled flows then fluctuated above and below actual data at lower flows than the 88th percentile (Fig. 3). To determine the extent of this difference, data were ranked and differences examined where actual or estimated flows were respectively exceeded by 10%. We then used local linear regression to improve the model, using the relationship between actual and modelled flows at Ophir in the Summer Hill Creek system.

$$Adjusted\ value = \beta_0 + flow\ percentile + error$$

High flows were adjusted with a linear model above the 0.4th percentile (R^2 = 0.86); between the 0.4th – 2.5th (R^2 = 0.93); and the 2.5th – 28th (R^2 = 0.91). Medium to low flows (>10% error) were split into three data sets for further linear modelling: 46th-88th percentile (R^2 = 0.95), 88th - 96th percentiles (R^2 = 0.97), and lower than 96th percentile (R^2 = 0.51). Some of the overestimation of low flows was probably due to errors in actual data, reflected in constant output. For example, 14.878ML d^{-1} occurred for 59 days at Lewis Ponds Creek (15/06/-11/07/71; 21/03/- 02/04/1972; 11/04/- 16/04/72; 23/05/- 31/05/72; 13/06/- 02/07/72). These data were not included in the linear regression modelling. Modelled flows were replaced with actual gauged flow where available, resulting in a dataset that best described flows in Summer Hill Creek for the extent of the modelled period.

This allowed estimation of flows from the Summer Hill Creek catchment but it only reflected the level of development during the period 1971-1978 when the population of Orange was 23,172 (1971). Increased population and related water use further reduced flows in the Macquarie River. We needed to estimate the long-term effect of a growing population in Orange (Fig. 5) on daily flows from the Summer Hill Creek system, post 1971-1978. Similarly, we also needed to adjust flows in the Macquarie River for the effects of increasing diversions upstream for the growing populations of Bathurst and Oberon (Figure 1). Adjustment also included the effects of diversions to the Fish River Scheme. Given low development of the Turon River (no town water allocated)(NSW Government, 2012b), flows in this river did not need to be adjusted.

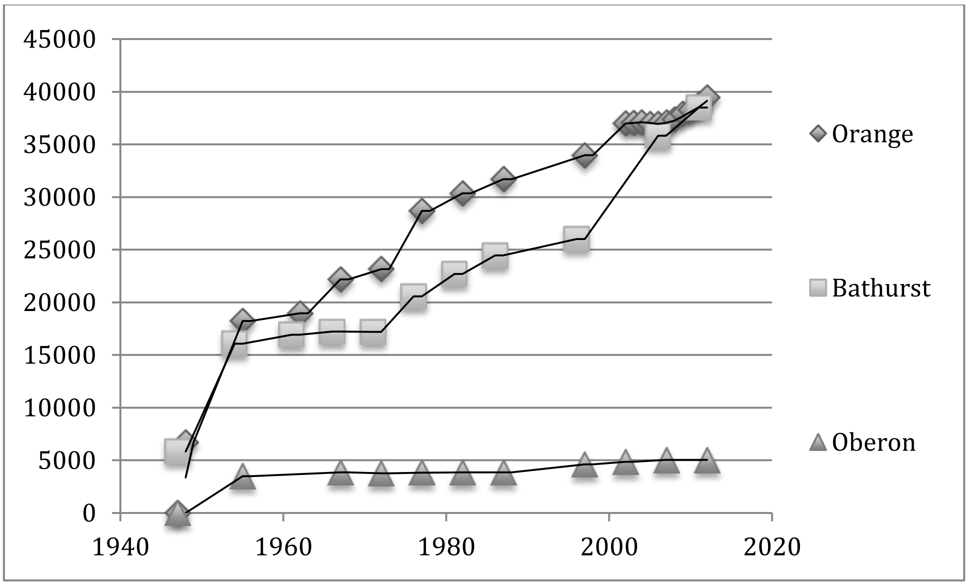

Figure 5 - Population growth in Orange, Bathurst and Oberon on the Macquarie River upstream of the proposed pump site, used to estimate water diversions from the Macquarie River, 1947 – 1996 (Australian Bureau of Statistics, 1947, 1954, 1961, 1966, 1971, 1981, 1986, 1996), 2001-2012 (Australian Bureau of Statistics, 2012; Bathurst City Council, 2012; Central West Catchment Management Authority, 2012; Miller, 2012; Orange City Council, 2004, 2007).

Populations of Orange, Bathurst and Oberon grew by 58%, 44% and 74% respectively between 1971 and 2012 (Fig. 5). Annual water consumption data only existed for major towns (Orange, Bathurst, Oberon) since 2001 (Orange City Council, 2004, 2007; National Water Commission, 2013). We were not able to access any historical urban water use data before 2001 for these urban centres. Long-term data for consumption per capita could only be obtained for Melbourne, from 1940 – 2012 (Victorian Department of Planning and Community Development, 2005; National Water Commission, 2013). We separated the data into two periods because of a clear break in the relationship over time. We then separately estimated slope of the relationship for the two time periods: 1940-1981, when per capita water use increased; and subsequently when it decreased (Victorian Department of Planning and Community Development, 2005). We used this slope to adjust water consumption data for Orange, Bathurst (National Water Commission, 2013), and Oberon (Hunter Developmental Brokerage, 2007). We assumed that the relationship between water use and population would be similar but only used the slope because regional cities consume more water per capita than large water supply utilities (National Water Commission, 2013). For example, in 2012 water consumption was higher in Oberon (353L capita^{-1} d^{-1}), Bathurst (435L capita^{-1} d^{-1}) and Orange (252L capita^{-1} d^{-1}), compared to Melbourne (237L capita^{-1} d^{-1}) (Hunter Developmental Brokerage, 2007; National Water Commission, 2013). We also included the Fish River Supply Scheme inter-basin transfer, using reported diversions since 1998 (State Water Corporation, 2013) and the average of these diversions for the period 1947-1998. These adjustments generated a historical model estimating urban water diversion history for the catchment above the pump site, including inter basin transfers to Lithgow, Sydney Catchment Authority and Wallerawang Power Station through the Fish River (Figure 6).

We then developed Model A for which we estimated current development and applied this across the full period of record. We estimated water use for the three main urban centres, Orange, Bathurst and Oberon. We used recent data (2011-2012) for Bathurst (National Water Commission, 2013) and published data from 2007 for Oberon (Hunter Developmental Brokerage, 2007), and Oberon's maximum licenced allocation (Miller, 2012) as reported water consumption (National Water Commission, 2013) included the Fish River Supply Scheme diversions. Orange's water use was reported separately as a lower value of potable water (L $person^{-1}$ d^{-1}), 2001-2008 (Orange City Council, 2004, 2007; National Water Commission, 2013), compared to the higher total sourced water which includes transfer to Cadia Valley mine (L $person^{-1}$ d^{-1}), 2007-2012 (National Water Commission, 2013). We required estimates for potable water amounts (no diversion to Cadia) before 1998, and total sourced (including diversion to Cadia) from 1998-2013. Total sourced water data was only available from 2007-2012. We used three data points for which potable water and total sourced water were provided (2007, 2011 and 2012) to determine the relationship between potable water and total water. Total sourced water averaged 154% of potable supply, allowing derivation of the equivalent total sourced water for 2001-2006 and projection until 1998.

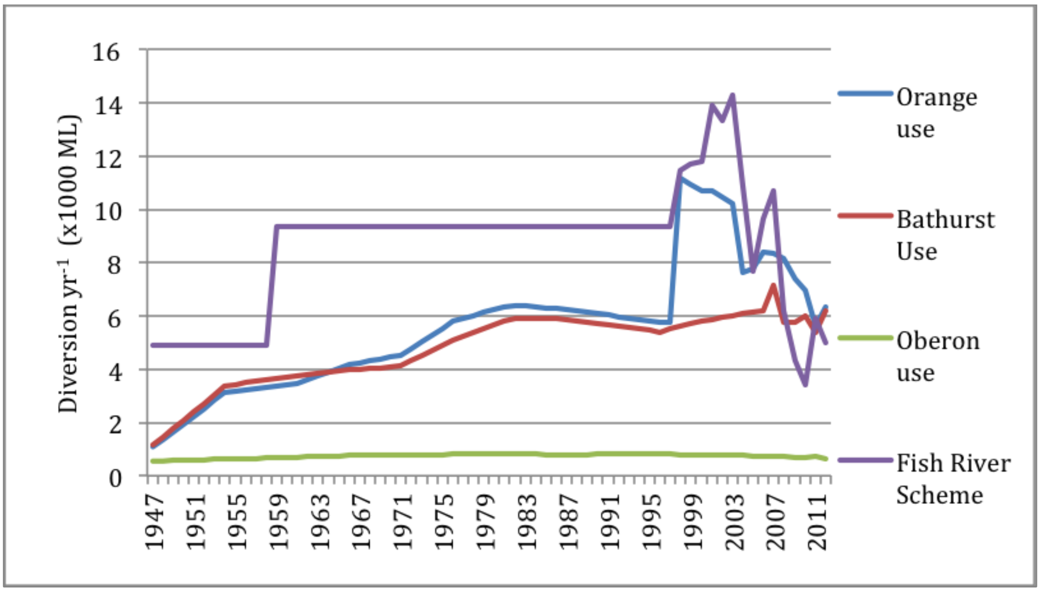

Figure 6 - Diversions upstream of the pump site to the three major urban centres, Orange, Bathurst and Oberon and the Fish River Supply Scheme based on licenced extraction (1998-2012, Miller (2012)) and estimated average diversion based on this actual data for the period 1947-1997)

We calculated flow diversions, upstream of the pump site, based on water use for the three major towns and the Fish River Supply Scheme (Fig. 6). Once we had determined the growing consumption of water of Orange on flows from the Summer Hill Creek system, we reduced daily flow data according to increasing annual consumption per capita from 1978, the model calibration period. We also increased flows before this period (1948–1972), accounting for lower population compared to 1971. This provided us with a historical estimate (Historic Model) of increasing diversions from the three subcatchments (Summer Hill Creek system, Macquarie River and Turon River, Fig. 1), which was used as a model of historical flows (Table 6,Fig. 8).

We also created a current estimated diversion impact on this historical dataset by subtracting the 2012 water consumption from the system as the cumulative impact on the two heavily developed subcatchments, given 2012 water use. We called this Model A, allowing us to test the effects of the proposed development on river flows for the period over which we had data 1948-2012, with the current extraction demand, using available flow, rainfall, consumption and population data.

Potential impact of pumping from proposed pipeline to Orange

We used Model A, total flows for the Macquarie and Turon rivers, and modelled data for Summer Hill Creek to estimate the potential impact of pumping flow to Orange. The proposed pumping regime will fill the dam to 90% capacity at all times that the river is above the Cease to pump (CTP) threshold. This CTP is specified as the 80th percentile which was modelled to be 22 ML d^{-1}, under the Environmental Assessment model (GHD, 2012a).

We obtained data from Orange City Council (Orange City Council, 2013) that described the fill level of Suma Park Dam from January 1992 to March 2013 at monthly intervals. These data were used to generate a pumping regime where the dam was filled according to the specifications in the Environmental Assessment (GHD, 2012b, i.e. when the dam was below 90% full, pumping could begin), reducing Macquarie River flow by 12ML per day as the pump operates. The effects of the pump would impact on a flow rate of 16ML d^{-1}, as it diverts

12 ML over a period of 19 hours, not a full day. Therefore the pump would not turn on unless flow was 16ML above the 80th percentile; equal to, or greater than 38ML d^{-1} (Fig. 7). This pumping regime was imposed on flows past the pumping site at the daily scale, simulating pump operation impact under current population and usage conditions for daily flows since 1992. These flow data simulated the development's impact on the Macquarie River downstream of the pump site, using actual data to model effects of the flow.

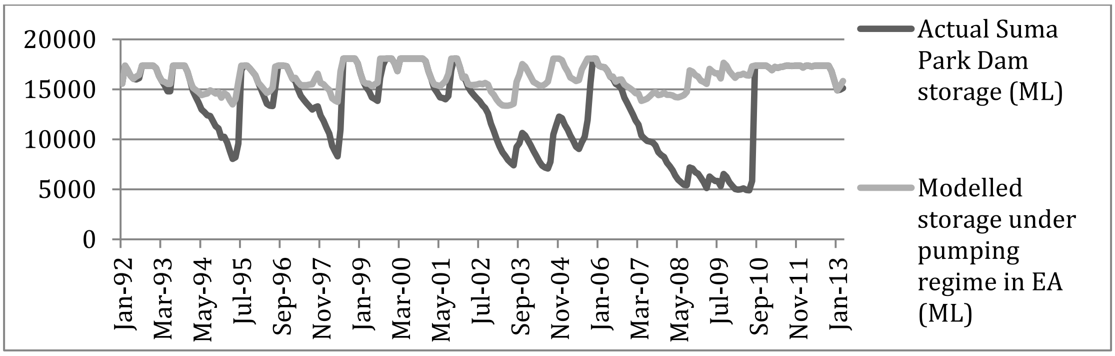

Figure 7 – Suma Park Dam actual levels, and levels under modelled pumping. Modelled dam storage is filled by pumping regime stated in Environmental Assessment.

We compared effects of different pumping regimes using our modelled data (Model A) and the conditions for pumping specified in the Environmental Assessment (GHD, 2012a) to impacts of the pumping from the model in the Environmental Assessment. There were two scenarios compared; one where pumping ceased when the river fell below the 80th percentile from Model A (102 ML d^{-1}) or the 80th percentile specified in the Environmental Assessment (22 ML d-1, Model EA). We also tested the effects of removing the storage threshold, which stops pumping when the dam reaches 90% capacity. This was designed to investigate potential long-term impacts should storage capacity increase.

Council plan to raise Suma Park Dam wall by a metre (Beatty, 2012). It is unclear whether increased dam capacity was accounted for in the Environmental Assessment water modelling (GHD & Geolyse, 2012). Secure yield was modelled with and without dam capacity increase, and the dam wall height was discussed (GHD, 2012a). We developed a model that accounted for the increase in the height of the dam wall, which increased storage capacity at the 90% threshold. We used a low flow 80th percentile estimate provided by an independent review of the flow modelling (92ML d^{-1}, Bewsher Consulting 2013) for this model.

For the period where there were demand data for the dam (1992-2012), we examined the differences between five models. Model A and the EA model were tested under two scenarios, storage threshold from the current Suma Park Dam, and no storage threshold. The fifth model was a probable scenario of an approved development, the peer reviewed model with increased storage capacity in Suma Park Dam (Beatty, 2012).

Results

We used actual flow data for the Macquarie River (Bruinbun) and Turon River (Sofala) and modelled flows for the Summer Hill Creek system to produce a modelled estimate for flows in the Macquarie River at the pump site (Model A), from the cumulative total from these separate water sources (Fig. 8). At the level of annual flows, all water sources showed a similar although declining pattern of flow over time, but clearly the two smaller sources of water (Summer Hill Creek, Turon) had lower flows than the Macquarie (Fig. 8). Total gauged flows were variable, with peaks above 1,500,000ML yr^{-1} in the wet years of 1950, 1956, and 1990. Dry years occurred in 1982, 1982, 1994, 2002 and 2009, with less than 40,000ML yr^{-1} flow (Fig. 8).

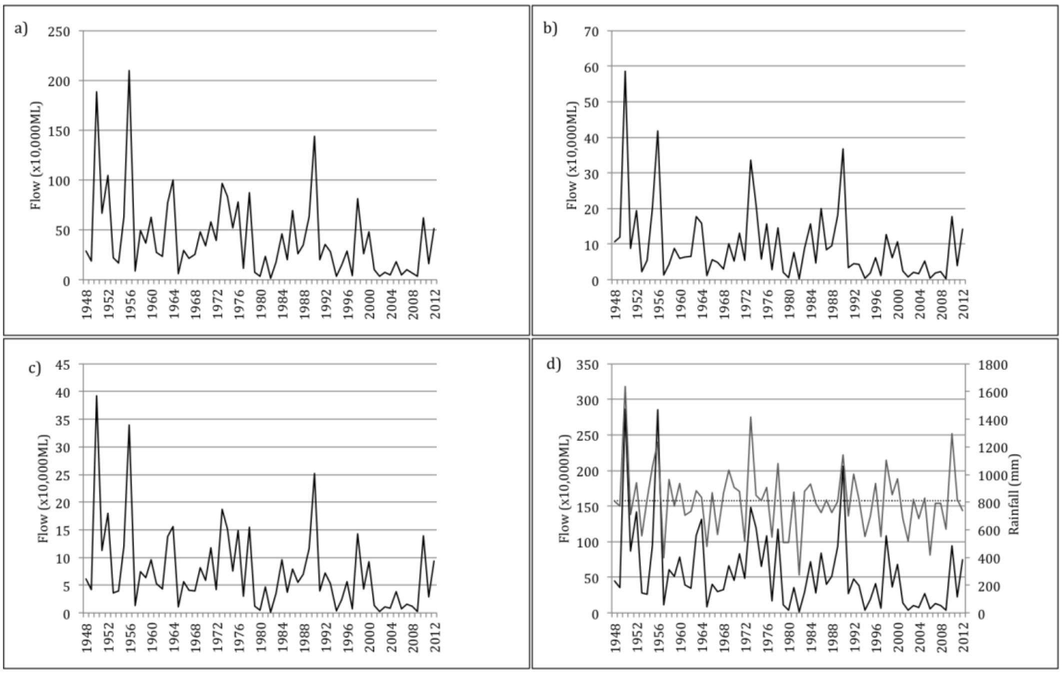

Figure 8 – Annual river flows in three water sources of the Macquarie System upstream of the pump site (Fig. 1), providing an estimate for flows in; a) Macquarie River (Bruinbun), b) Turon River (Sofala), c) modelled flows for Summer Hill Creek, and d) total flows from all three water sources (Model A) with rainfall. Scale differs among panels. Rainfall was the average annual rainfall for three rainfall stations on the three main water sources (Hill End Post Office (Macquarie), Sofala Old Post Office (Turon), Orange Post Office and Orange Agricultural institute (Summer Hill Creek).

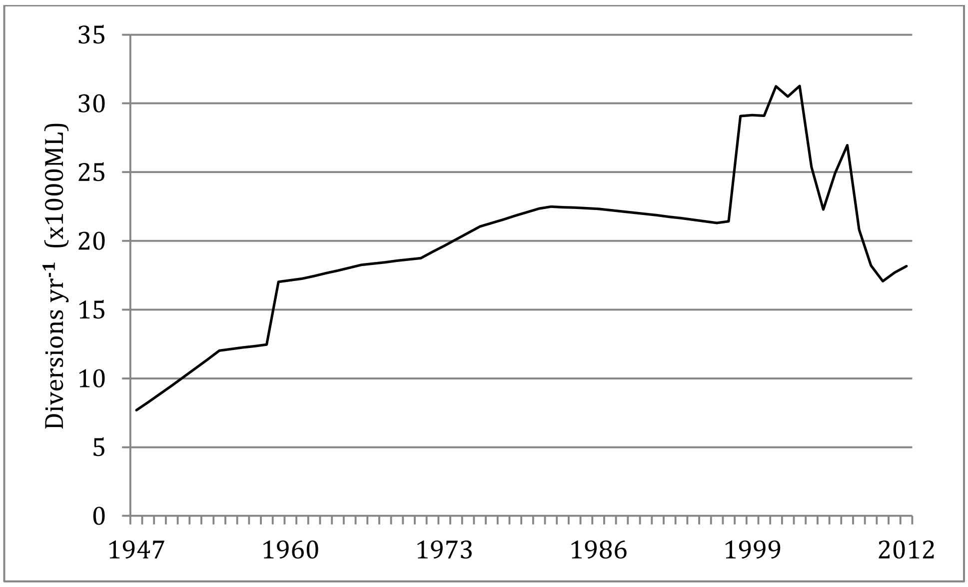

Figure 9 – Estimated diversions from the catchment above the pump site, 1947-2012, using per capita water use with growth for urban populations in the catchment (Orange, Bathurst, Oberon) and the Fish River Supply Scheme.

Diversions from the upstream catchment were estimated to have increased from 7,690ML yr^{-1} in 1947 to 18,156ML yr^{-1} in 2012, an increase of 236% (Fig. 9).

We constructed a historical flow model of flows at the pump site, incorporating estimated reduced flows from Summer Creek Hill system resulting from growth in Orange and actual flows for the Macquarie River and Turon River, which had already incorporated the effects of increasing population (Table 6, Fig. 8). There were considerable differences in the contributions of the different sources of water. Estimated low, moderate and high flows from the Macquarie River were of considerably greater volume (Table 6) than flows from the smaller Turon and Summer Hill Creek catchments, which made an estimated contribution of only 22.67% of total mean annual flows (Table 6, Fig. 8). Respective contributions for the Summer Hill Creek system and Turon River were 11.86% and 10.81% (Table 7).

Table 6 - Descriptive statistics of daily (1948-2012) low, medium and high flows (ML) in the Macquarie River (Bruinbun), Turon River (Sofala) and Summer Hill Creek system (Historical Model, Ophir, Fig. 1) at the proposed pump site. Levels of low, medium and high were set by dividing total flows into percentile ranges, 100th - 80th, 80th - 50th, and 50th to highest flow (0th), following NSW Government (2002).

Flow size (n= 23,928 days)	Total Mean ±SE	Median	Range	Macquarie Mean ±SE	Median	Range	Turon Mean ±SE	Median	Range	Ophir Mean ±SE	Median	Range
Low (0.52 - 107.49)	52.73 ± 30.17	53.19	107.21	40.15 ± 24.40	40.54	84.18	2.33 ± 2.43	1.50	7.58	6.16 ± 2.33	6.36	10.49
Moderate (107.49 -369.13)	221.96 ± 74.25	214.18	261.51	168.79 ± 55.73	163.74	195.10	23.51 ± 10.31	22.51	35.73	21.21 ± 7.13	20.18	25.05
High (369.13 - 263223.62)	3,070.47 ± 7,229.20	1,191.20	262,854.87	2,172.32 ± 4,893.38	880.81	155,538.48	513.14 ± 1,924.94	139.45	96,148.07	400.02 ± 1,018.95	125.26	25,352.80

Table 7 - Mean relative flow contribution (%) to total flows at the pump site from the Macquarie River, Turon River and Summer Hill Creek (Historical Model).

Flow size	Macquarie River	Turon River	Summer Hill Creek
Low (0.52 -107.49ML)	82.54	4.79	12.67
Moderate (107.49 -369.13ML)	79.05	11.01	9.93
High (369.13 - 263223.62ML)	70.40	16.63	12.96
Full range	77.33	10.81	11.86

We then compared modelled outputs of daily flow percentiles from our Model A (imposed current demand on Historical Model) and published estimates from the Environmental Assessment. Estimated daily flows from Model A were considerably greater than those modelled for the Environmental Assessment (Table 8). Flow modelling for the Environmental Assessment was based on a scenario (Scenario B, GHD, 2012b) simulating current catchment conditions and development and future climatic conditions. In particular, compared to our estimated output from Model A, flow analysis in the Environmental Assessment underestimated flows at the pump site by 80ML d^{-1} at the 80th percentile, and by 370ML d^{-1} at the 50th percentile (Table 8). This underestimation occurred consistently at all flow percentiles (Table 8, Fig. 10).

Table 8 – Comparison of flow ranges for different percentile values (0-100) from Model A (this study) and the model used in the Environmental Assessment (GHD & Geolyse, 2012) for daily flows in the Macquarie River at the proposed pump site.

Percentile	Flow (ML, Model A)	Flow (ML, EA model)
0-10	263,219 -3,540	147,344-1,657
10-20	3,540-1,622	1,657-634
20-30	1,622-901	634-325
30-40	901-555	325-185
40-50	555-367	185-110
50-60	367-255	110-66
60-70	255-174	66-39
70-80	174-102	39-22
80-90	102-47	22-11
90-100	47-0	11-0

This difference affected the assessment of different flow percentiles for the river, particularly at low to medium volumes, with relevance for the pumping threshold of the 80th percentile which was specified in the Environmental Assessment at 22 ML d^{-1}.

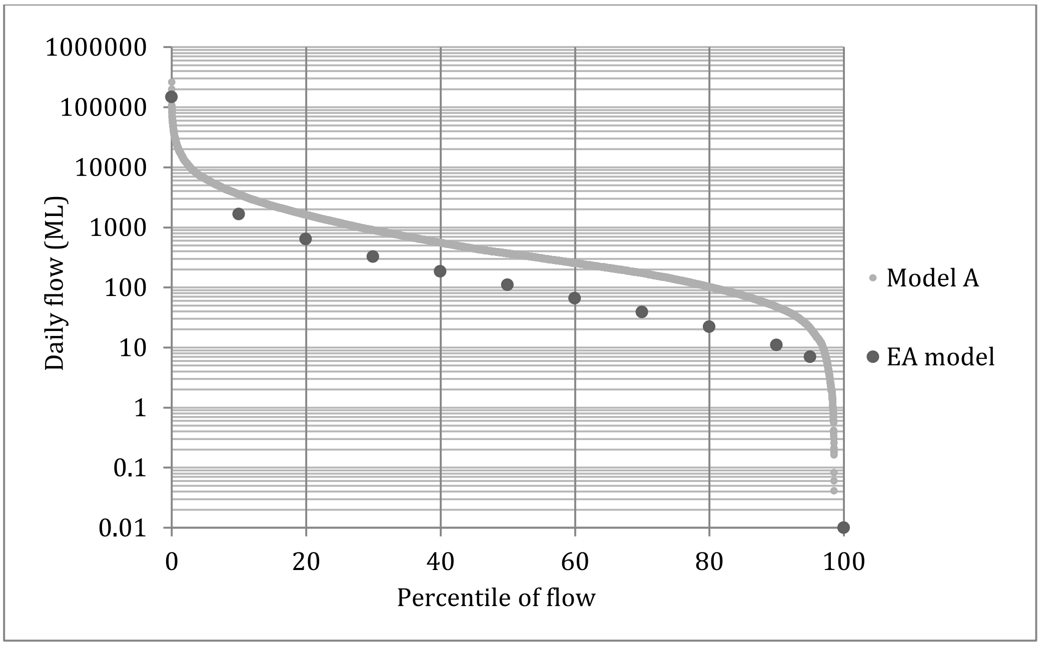

Figure 10 – Daily flow duration curve comparing daily flow outputs from Model A (our study) to the model reported in the Environmental Assessment (points were extracted from (GHD and Geolyse, 2012).

This meant that the proposed extraction rules of only pumping below the 80th percentile of flows (EA model) equated to a significantly lower percentile (96.8th) in our Model A (Fig. 10).

Table 9 – Flows (ML d^{-1}) for three medium to low percentiles calculated for actual flow data (1971-1978), historical model (1948-2012), Model A (1948-2012), EA Model (120 years, GHD 2012a) and Bewsher Consulting peer reviewed model (100+ years, Bewsher Consulting (2013)).

Percentile	Actual flow	Historical model [a]	Model A[b]	EA model	Peer review model
50th	554.219	735.01	367	110	
80th	259.47	247.86	102	22	92
95th	90.73	75.77	21	7	30

[a]Historical flow not adjusted for current population demand.

[b]Model A adjusted to use the full data set with imposed current population water demand.

We compared different percentiles of flows in the Macquarie River at the pump site under five different models (Table 9). We included actual data for the three water sources (1971-1978), which delivered reasonably high flows (Table 9), because the demand was considerably lower given relative size of 1970s populations (Fig. 9). The volumes at different percentiles were the highest from the historical model (Table 9) without current demand (Fig. 9). Our estimates, given current demand (Model A) for the 80th and 95th percentile, were respectively within 8% and 7% of independent modelling (Peer review model) but 80% and 33% higher than outputs from the model in the Environmental Assessment (Table 9). The low 80th percentile threshold (cease to pump) would allow increased pumping from the river.

There were considerable differences among the five modelling scenarios resulting in a range of different impacts on the river flows and consequent reductions. There was a slightly higher diversion from the river between the estimated impacts using the results of the published model in the Environmental Assessment and flows from our Model A with the same thresholds (EA model, Table 10), respectively amounting to a 0.52% and 0.56% reduction in average flows (Table 10). The EA model with its 22 ML d^{-1} CTP threshold diverted flows on more days than Model A with its 102 MLd^{-1} CTP threshold (Table 10), amounting to 772ML yr^{-1} diversion through the pipeline, further reducing average flows by 0.31%. If we used the peer review model with its 92 ML d^{-1} CTP threshold, more water was diverted than using the CTP threshold of Model A, but less than the CTP threshold for the EA model. This was a 251ML yr^{-1} increase over Model A, but 521ML yr^{-1} less than would be diverted by the EA model.

Removal of the dam threshold increased pumped flows for all models, doubling the diversion from the Macquarie River. The EA model had an estimated increase in average diversion of 2,303ML yr^{-1}, more than doubling (2.3) the diversion (Table 10). For Model A CTP without a storage threshold, there was almost a threefold (2.94) increase in diversions, reaching a maximum yearly diversion of 2,951ML yr^{-1}.

Table 10 – Summary of flow reductions for the published EA model (stated in Environmental Assessment, GHD, 2012a) and five modelled pumping regimes which all used flows from Model A: The two pumping thresholds stated in the Environmental Assessment were a cease to pump threshold of 22 ML d^{-1} and trigger to start pumping when the dam capacity of Suma Park Dam fell below 90% (GHD, 2012a). The cease to pump thresholds (80th percentile) for Model A and the Peer Review Model were 102 ML d^{-1} and 92 ML d^{-1} respectively.

	EA published (118 years modelled)	EA Model[a]	Model A[b]	EA Model - no dam threshold[c]	Model A - no dam threshold[d]	Probable Model[e]
Average volume d^{-1} (ML)	4.44	4.82	2.73	11.08	8.02	3.41
Average Volume yr^{-1} (ML)	1,616.00	1,774.73	1,002.97	4,078.01	2,950.62	1,253.94
Number of pumping days	135	147.99	83.67	339.83	245.89	104.51
Maximum yearly extraction (ML)	3,804.00	3,948.00	2,592.00	4,392.00	4,380.00	2,796.00
Annual flow (ML)		318,088.28	318,860.04	315,784.00	316,912.38	318,609.06
Average annual long term extraction (% of flow)	0.52	0.56	0.31	1.29	0.93	0.39

[a]EA Model with stated EA pumping and storage thresholds (GHD, 2012a)
[b]Model A with 80th percentile cease to pump from Model A and the EA storage threshold
[c]EA Model - no dam threshold used the stated EA cease to pump threshold but without the EA storage threshold
[d]Model A – no dam threshold used the 80th percentile from Model A and no storage pumping threshold
[e]Probable Model used the 80th percentile from the peer reviewed model (Bewsher Consulting, 2013) and the pumping threshold for a raised Suma Park Dam (Beatty, 2012).

The pumping regime affected low flows comparatively more than high flows (Figs. 10 & 11) because of the relative difference in volumes compared to daily flow. Reductions in flows were obvious in all below the 70th percentile, with relatively high reductions below the 90th percentile, under the proposed cease to pump threshold of 22ML d^{-1}. Significantly more water was estimated to be diverted from the Macquarie River at low flows with the cease to pump threshold of 22ML d^{-1}.

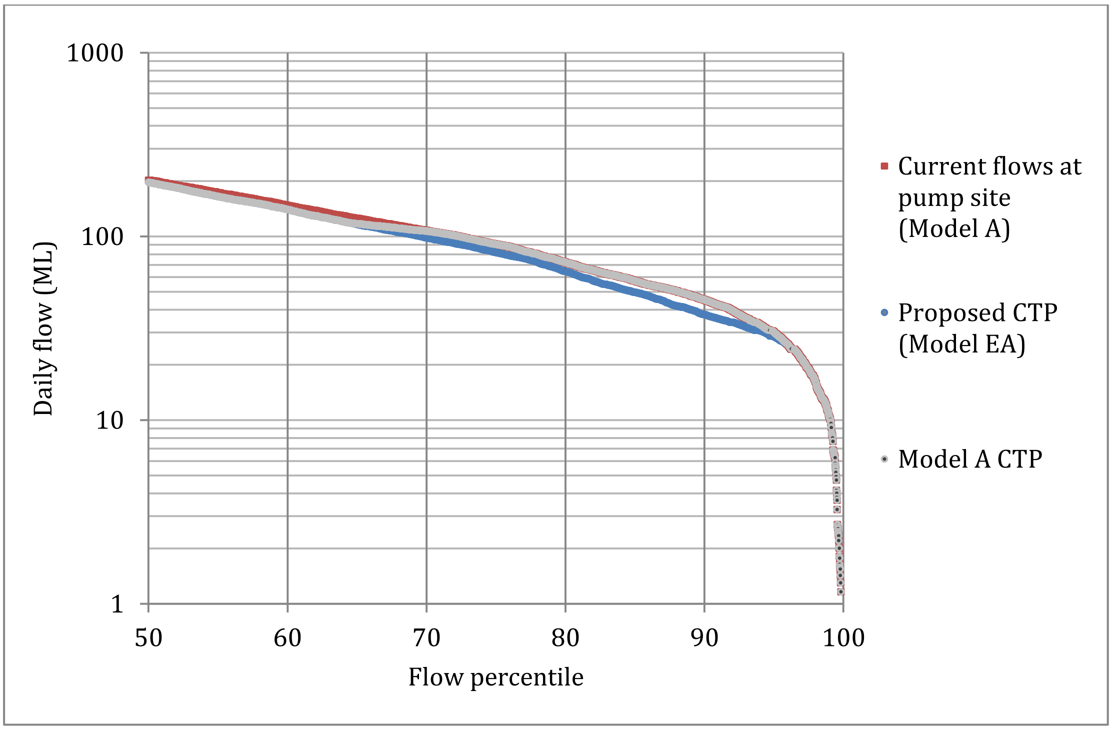

Figure 11 – Flow duration curve (50th-100th percentile) describing flows at the pump site under 2012 demand (red), the pumping regime using model A (grey), and the pumping regime proposed in the development (model EA, blue).

Mean flow at pump site was divided into three flow categories (Table 11). Under pumping from Model EA, the river was subject to lower mean flows than with Model A, which diverted an average of 5.13ML d^{-1} of low flows. With the dam threshold raised, this increased to 7.41ML d^{-1}, which was 21% of low flows. In contrast, this is compared to Model A CTP and the Probable Model, which do not reduce low flows. Moderate flows were affected most by the EA model, taking 6.5% of flows in this category compared to Model A and the Probable Model, diverting 3.5% and 4.1% of flows respectively (Table 11). High flows are not as affected by pumping regimes compared to moderate and low. Overall, both pumping regimes with no threshold had the greatest impact on flows, more than doubling the percentage of flow taken from the river compared to those with the dam threshold. The lowest flows to be impacted by Probable Model were moderate flows (92 - 367ML d^{-1}, Table 10) reduced by 12ML d^{-1}. This impact on flows is less significant than the impact of the EA Model, as low as the 95th percentile of flows.

Table 11 - Summary of current flows (Model A) and flows under five modelled pumping regimes which all used flows from Model A for the period 1992-2013: The two pumping thresholds stated in the Environmental Assessment were a cease to pump threshold of 22 ML d^{-1} and trigger to start pumping when the dam capacity of Suma Park Dam fell below 90% (GHD, 2012a). The cease to pump thresholds (80th percentile) for Model A and the Peer Review Model were 102 ML d^{-1} and 92 ML d^{-1} respectively. Low flows represent those between the 80th and 100th percentile, moderate flows are between the 50th and 80th percentile, high flows are between the largest flow (0th percentile) and the 50th percentile. Flow percentiles differ from Model A, due to shorter model period.

	Current flows Mean ±SE	Median	EA Model Mean ±SE[a]	Median	Model A CTP[b] Mean ±SE	Median	EA Model - no dam threshold[c] Mean ±SE	Median	Model A - no dam threshold[d] Mean ±SE	Median	Probable Model[e] Mean ±SE	Median
Low (0–72ML day^{-1}	42.62± 18.20	45.09	37.49± 15.22	37.51	42.62± 18.20	45.09	35.21± 13.63	35.24	42.62± 18.20	45.09	42.62± 18.20	45.09
Moderate (72– 202ML day^{-1})	129.90± 36.39	125.17	122.00± 37.05	116.48	125.57± 33.78	117.22	117.90± 36.39	113.17	123.16± 31.62	115.74	124.78± 34.29	116.47
High (202 – 154350ML day^{-1})	1,643.86± 5,333.70	546.88	1,641.00± 5,334.23	545.15	1,641.00± 5,334.23	545.15	1,631.86± 5,333.70	534.88	1,631.86± 5,333.70	534.88	1,640.12± 5,334.36	543.29
Total	869.09± 3,849.00	202.05	864.27± 3,850.41	196.82	866.37± 3,849.98	196.82	858.01± 3,849.45	190.05	861.07± 3,848.83	190.05	865.68± 3,850.02	196.11

[a]EA Model with stated EA pumping and storage thresholds (GHD, 2012a)

[b]Model A with 80th percentile cease to pump from Model A and the EA storage threshold

[c]EA Model - no dam threshold used the stated EA cease to pump threshold but without the EA storage threshold

[d]Model A – no dam threshold used the 80th percentile from Model A and no storage pumping threshold

[e]Probable Model used the 80th percentile from the peer reviewed model (Bewsher Consulting, 2013) and the pumping threshold for a raised Suma Park Dam (Beatty, 2012)

Table 12 – Percentage reduction in flows at the pump site for the five pumping regimes modelled; EA model with and without an upper limit, Model A with and without an upper limit; and the probable operating conditions should the EA be approved.

	EA CTP	Model A CTP	EA no dam	Model A no dam	Probable model
Low	13.68	0	21.05	0	0
Moderate	6.48	3.45	10.18	5.19	4.10
High	0.17	0.17	0.74	0.73	0.23
Total	0.55	0.31	1.27	0.92	0.39

Potential ecological impacts at three scales

Table 13 – Predicted impacts on ecosystems, processes and species (including threatened species, Environment Protection Biodiversity Conservation Act 1999 (EPBC), Fisheries Management Act 1994 (FMA), Threatened Species Conservation Act 1995 (TSC)) at the pump site, immediately downstream, and remaining ecosystem scales in the Macquarie River and references to these impacts, resulting from the proposed pumping of flows with the Orange pipeline.

Scale	Habitat	Impact	Conservation implications	Reference
Pump site (Cobbs Hut Hole)	Pool habitats	Pool ecosystem subject to pumping up to 19 hours of the day in Cobbs Hut Hole. Disturbance (noise and vibration) to embankments during construction. Pump operation 19 hours a day reducing quality of habitat. Fish eggs and larvae potentially harmed by the offtake structure, affecting a low proportion of flows in the	Trout Cod *Maccullochella macquariensis* (endangered, EPBC, FMA), Murray Cod *Maccullochella peelii peelii* (vulnerable, EPBC), Silver Perch *Bidyanus bidyanus* (vulnerable, FMA), Flathead galaxias *Galaxias rostratus* (critically endangered, FMA) and Eel tailed catfish *Tandanus tandanus*	GHD and Cardno Ecology Lab, 2012; Cardno Ecology Lab, 2013

		spawning and recruitment season.	(endangered population, FMA) potentially living at the pump site.	
Immediately downstream	Riparian areas	Removal of flows in dry periods affecting connection to riparian and littoral zones. Reduction in habitat potentially increases competition in downstream deep pools.	Trout Cod, Murray Cod, Silver Perch, Flathead galaxias, Purple spotted gudgeon *Mogurnda adspersa* (endangered, FMA) and Eel tailed catfish living downstream in the Macquarie River to Burrendong Dam.	Bunn and Arthington, 2002; Bond *et al*., 2008; Koehn and Lintermans, 2012
	Riffles	Decreased flows will impact riffle structures, reducing available habitat, and increasing barriers to dispersal such as riffles and rock bars. Genetic diversity may decrease with fragmentation, and absence of preferred habitat. Flow modification reduces diversity and breeding success for native species.	Likely to affect species in the Macquarie River, which are currently at threat.	Lloyd *et al*., 2004; Fisheries Scientific Committee, 2008; Faulks *et al*., 2011; Cardno Ecology Lab, 2013; GHD, 2013
	Pool habitats	Reduction in availability and duration of pool habitats	Trout Cod, Murray Cod, Silver Perch, Flathead galaxias, Purple spotted gudgeon and Eel tailed catfish potentially inhabit downstream Macquarie River to Burrendong Dam.	Lloyd *et al*., 2004; Bond *et al*., 2008
Remaining downstream ecosystems	Macquarie Marshes	NSW state Water corporation releases environmental flows, maintaining connectivity, which would be reduced in volume from a decrease in Burrendong Dam inflow. Hydrological change has led to consideration of the Marshes as	Ramsar listed wetland. Silver Perch, Macquarie Marshes Aquatic Ecological Community (endangered ecological community, FMA), Coolibah-Black Box woodland, *Eucalyptus coolabah, Eucalyptus*	Commonwealth of Australia, 1981, 1988; Kingsford and Thomas, 1995; Kingsford, 2000; Convention on Migratory Species

	a threatened ecological community under the EPBC Act. Reduced flows have decreased the size and health of the wetlands, and will amplify the effects of drought. Flooding is linked to health and productivity of multiple indicators of wetland wealth. Waterbird breeding habitat is protected by international bilateral migratory bird agreements with Japan, China, Republic of Korea, and the Bonn convention.	*largiflorens* (endangered ecological community, TSC), Myall woodland *Acacia pendula* (endangered ecological community, TSC). Such ecological communities have recently been suggested as suitable for an IUCN red list.	Secretariat, 2003; NSW Government, 2003; Jenkins *et al*., 2005; Rayner *et al*., 2009; Commonwealth Environmental Water Office, 2012; Department of Sustainability Environment Water Population and Communities, 2013; NSW Government, 2013; Keith *et al*., 2013
Pools and waterholes	Smaller environmental flows give less connectivity of waterholes, and less access to larger areas of river channel. This increases reliance on refugia, where higher competition with alien species is found.	Trout Cod, Murray Cod, River Snail *Notopala* sublineata, Silver perch, Purple spotted gudgeon, Olive Perchlet *Ambassis* agassizii, Darling River Endangered Ecological Community	Rayner *et al*., 2009; Green *et al*., 2011

On site potential impacts during construction included building of the pipeline in the riverbank, using coffer dams to exclude water from the construction. Booms with silt nets will be placed around the construction site to reduce degradation of water quality. Once operational, the pump will affect the ecology of the pool system, reducing water levels (Table 13). These impacts are predicted to affect six species of fish, entraining eggs and larvae in pumped flow (Table 13).

The Macquarie River downstream from the pump site will have reduced flow (Table 11, Fig. 11). Cumulative effects of pump are predicted to affect low flows more than high flows (Table 11). Such flow reduction will decrease connectivity as current natural structures downstream such as riffles impede passage during low flows and these will be more frequently exposed (Table 13). Reductions in flows will also decrease habitat area and affecting the health of riparian vegetation (Table 13).

Ecosystems below Burrendong are currently threatened by overextraction, requiring environmental flow releases to reduce ecosystem degradation (Table 13). Reduction in flow input to Burrendong Dam from the pipeline will reduce water dedicated to environmental flows below the dam (NSW Government, 2003) and other users. A reduction in volume of environmental flow will also reduce its ecosystem benefits (Table 13), which are a State, Commonwealth and International responsibility (Table 13).

Comparative water use

The development proposal is based on unrestricted potable water supply of 404L capita^{-1} d^{-1} at 2010 levels (GHD, 2012c). This is low compared to Bathurst (435L capita^{-1} d^{-1}) and Dubbo (481L capita^{-1} d^{-1}), yet high compared to current water usage by Orange residents, the national average, and global water use (Table 14). The Environmental Assessment suggests that demand management will decrease demand over the 50 year scope, from 404 to 334 L capita^{-1} d^{-1}, lowering consumption to today's national average (Table 14).

Orange has used 252L capita^{-1} d^{-1} under Level 2 water restrictions. Residential water consumption in Orange was either similar or lower than other cities or urban centres across Australia (Fig. 12).

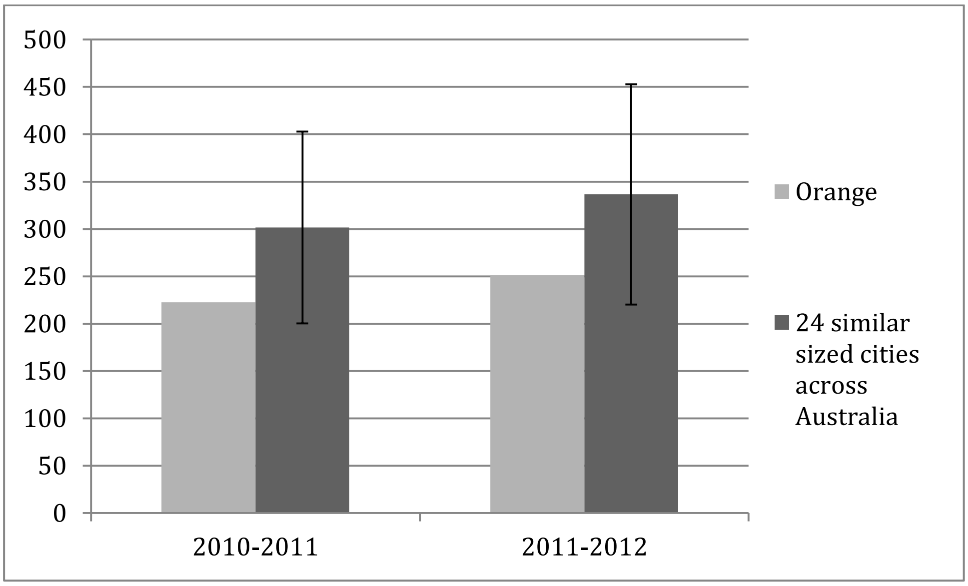

Figure 12 – Urban water use (potable supply) compared to 24 similarly sized utilities (L capita^{-1} d^{-1}). Standard error of compared cities is shown. Cities compared are listed in Appendix 1. (Australian Bureau of Statistics, 2012; National Water Commission, 2013; Orange City Council, 2007).

Orange has low urban demand per capita when compared to Bathurst and Dubbo, other regional centres in the Central West Catchment (Table 14, National Water Commission, 2013). Water restrictions are typically stricter in Orange than these cities, due to lower availability of water (Central West Catchment Management Authority, 2012; Centroc, 2009), with water restrictions at Level 5.5 in place during the Millennium drought. In comparison to the national average of 336L capita^{-1} d^{-1} (Table 14), Orange is currently a low user of water.

Water consumption varies at the international scale (Table 14). Australia has the highest per capita consumption of water globally, and the third highest domestic consumption, behind Lithuania and Estonia. Most countries do not have the freedom of access to water that Australia has. In the global context, Australia is a very high user of water. This consumption pattern is not sustainable amongst an increasing global population (Table 14, Gleick, 2000; Barraque, 2011).

Table 14 - Comparative per capita consumption of water in different parts of the world and within Australia in different urban centres.

Urban Centre /Country	Overall supply [a] /Domestic Use[b] (L $capita^{-1}$ d^{-1})	2012 Potable supply [c] (L $capita^{-1}$ d^{-1})	Reference
Orange	433	252[d]	National Water Commission, 2013
Sydney	293	255	National Water Commission, 2013
Adelaide	333	323	National Water Commission, 2013
Bathurst	513	435	National Water Commission, 2013
Dubbo	493	481	National Water Commission, 2013
Australia	393±178 SE	336±116 SE	National Water Commission, 2013
	1121		The Pacific Institute, 2011
Africa	63		The Pacific Institute, 2011
China	142		The Pacific Institute, 2011
India	126		The Pacific Institute, 2011
Europe	337		The Pacific Institute, 2011
United States	529		The Pacific Institute, 2011

[a] Total sourced water/population receiving water supply in 2012.

[b] Domestic use includes commercial and government water uses, and is more comparable to overall supply for Australian data.

[c] Total urban potable water supplied divided by population receiving water supply.

[d] 2012 population applied growth function to past four years of growth in Orange.

Discussion

Urban water availability conflicts are increasing around the world (Barraque, 2011), given growing demand and decreasing supply. This is currently occurring in the town of Orange in the Murray-Darling Basin, with its population of 40,000. Water use has increased with the population which has grown by 172% since 1971 as provision of water for increased industry development, particularly the Cadia Valley gold mine (Newcrest Mining Limited, 2012). To meet this demand, governments have proposed a $47 million pipeline to pump water from the Macquarie River, 39km from the city. An Environmental Assessment by the proponent, Orange City Council, concluded that the development would have relatively little environmental impact. We independently modelled the impact of the pipeline and found differences in our modelling outcomes compared to the Environmental Assessment. These have important consequences for the environmental impact of the pipeline and water use from the river.

This catchment has already experienced considerable growth in water use, reducing flows (Kingsford and Thomas, 1995; CSIRO, 2008). We estimated that diversions increased by 236% from the upper Macquarie River since 1947, predominantly resulting from urban growth in Bathurst and Orange, and diversion of water to the Fish River Scheme (Fig. 9, Table 1). Increased diversions for urban water supply, combined with water resource development downstream, primarily for irrigation, have caused considerable environmental degradation in the Macquarie River. This has particularly affected the lower end in the Ramsar-listed wetland of the Macquarie Marshes (Kingsford and Thomas, 1995; Thomas *et al*., 2011), where median annual flows are reduced by an estimated 44.8% compared to natural flows (Ren and Kingsford, 2011). The Macquarie Marshes are now one of only three Ramsar-listed wetlands in Australia that the Australian Government has provided confirmation to the international Ramsar Bureau of a likely change in ecological character, as a result of reduced flows (Department of the Environment Water Heritage and the Arts, 2009, 2000).

The Environmental Assessment acknowledged that the pipeline would reduce flows, but concluded this would not significantly impact the Macquarie River and its protected species, and have negligible impact on flows to the Macquarie Marshes (GHD, 2012b). These conclusions were primarily based on the assessment that the pipeline would not extract water when the river was at low flows below the 80th percentile (22 ML d^{-1}, GHD, 2012a). Our modelling estimated that the 80th percentile was 102 ML d^{-1}, more than four times higher (4.63) than the estimate in the Environmental Assessment (Table 9, Fig. 10). Our modelling (Model A) estimated that the cease to pump threshold of 22ML d^{-1} would not be reached until the river was at the 95th percentile (Fig. 10), allowing considerably more water to be pumped. The other threshold that limits the amount of water pumped from the river, apart from the capacity to pump (size of pipe and pumping hours), was when capacity in Suma Park Dam fell below a threshold of 90% (GHD, 2012a).

All models extracted flows from the moderate and high flow ranges (Table 11), which will decrease fill in Burrendong Dam, and reduce water available to downstream ecosystems. Cease to pump thresholds had a strong influence on flows pumped by the models. The EA model would have diverted an average of 1,774.73ML yr^{-1} (Table 11) if approved, more than both Model A and the Probable Model, despite the increase in capacity factored in the Probable Model. The EA Model is estimated to reduce low flows by 13.7%, increasing to 21.0%, without a dam threshold. This is a significant portion of flows, pumped at flows where the ecology of the river is under stress. The purpose of CTP thresholds is to preserve ecology under these conditions (Marsh *et al.*, 2012).

There is future opportunity to increase diversions from the Macquarie River by increasing capacity of receiving storages. While this was an option in early development (GHD, 2012b), it was unclear as to whether this was factored into the pipeline water modelling (GHD & Geolyse, 2012; GHD, 2012a). Also, future increases in storage capacity (e.g. new dams, aquifer storage) always remain possible, allowing for increased diversions from the Macquarie River (i.e.

relaxing the dam threshold). Already, two methods of increasing storage were investigated by Orange City Council: managed aquifer recharge (June 2011, GHD, 2012b); and raising Suma Park Dam Wall (November 2012, Beatty, 2012). Implications of increasing storage capacity and resulting effects on the Macquarie River may not have been considered in the Environmental Assessment, published in July 2012. A 2 metre increase in dam wall height was not considered due to technical difficulties (Orange City Council, 2004; GHD, 2012b). The recommended increase in the wall of Suma Park Dam by 1 metre would increase storage capacity to 110%, providing an additional 191ML before the 90% threshold was reached. There is no discussion of an increase in dam capacity by 2 metres in the Environmental Assessement; only a one metre expansion is discussed. Modelling the pipeline with Peer Review model (CTP level) and increased storage would allow an additional 251ML yr^{-1} to be pumped, above the EA Model average extraction of 1,616ML yr^{-1}, and maximum extraction of 3,804ML yr^{-1} (GHD and Geolyse, 2012). Our modelling estimated that diversions were higher: averaging 1,775ML yr^{-1}, with a maximum modelled pumping of 3,948ML yr^{-1}. This increased impact was not predicted by the EA model.

Orange is currently unable to exploit its full current town water allocation of 7,800 ML yr^{-1} (Table 2) due to a lack of access to water (GHD, 2012c). It currently uses 3,670ML yr^{-1}(National Water Commission, 2013) but has an option to increase use with purchase of an additional 640ML yr^{-1} sleeper licence. Overall diversions from the Macquarie River would increase by 4,770ML yr^{-1}, 2.3 times above 2012 level diversions. If Orange, or even Bathurst, expand with rapid growth, the pressure on water resources will continue, even though Orange City Council do not envision such a change (Geolyse, 2009). The Water Management Act 2000 can allow local water utilities to increase supply under rapid population growth (section 66(4)) (NSW Government, 2012c), which will increase diversions from the Macquarie River, affecting sustainable diversion limits under the Murray-Darling Basin Plan (Commonwealth Government, 2008). This may compromise the success of water sharing plans (Hamstead *et al.*, 2008; NSW Government, 2012b).

Should the development be approved with a revised CTP, matching the current conditions of 102 ML d^{-1} estimated by Model A, the pipeline would transfer an average of of 1,003ML yr^{-1}, increased to 1,947.65ML yr^{-1} without the storage threshold (Table 10). Demand in Orange is projected to rise from 3,670ML yr^{-1} to 6,948ML yr^{-1} in 2060, under medium growth scenarios in the Environmental Assessment (GHD, 2012c). This could be partially serviced by the pipeline, which was able to transfer an average of 2,951ML yr^{-1} under the EA model, with a maximum of 4,380ML yr^{-1} transferred (Table 10). This represents substantial growth in use of the project that has not been assessed in the Environmental Assessment. Purchase of the additional sleeper water allocation for the Macquarie could further increase diversions. Approval conditions of the project from the Planning Assessment Commission include the option for Council to revise the 80th percentile figure from the independently modelled 92ML d^{-1}, if they are in agreement with the Department of Planning and Infrastructure and the NSW Office of Water (Planning Assessment Commission, 2013).

There were considerable differences in modelling outcomes between our modelling and that in the Environmental Assessment. The Environmental Assessment used the Integrated Quantity and Quality Modelling (IQQM) to simulate flow in the Macquarie River, with pumping regimes designed to operate above low flow (NSW Government, 2002; GHD, 2012a). IQQM poorly predicts low flows and high variability (Barma and Varley, 2012), reflected in the flows of the Macquarie River (Fig. 8). The EA Model also modelled projected future catchment conditions, potentially considerably drier than today (Vaze *et al.*, 2011). Selection of this scenario in the Environmental Assessment provided a conservative estimate of flows in the Macquarie, decreasing the cease to flow point to 22 ML d^{-1}, much lower than Model A (102 ML d^{-1}) or independent modelling commissioned by the NSW Department of Planning and Infrastructure (92 ML d^{-1})(Bewsher Consulting, 2013). Our Model A estimate was only 10 ML d^{-1} more than compared to the Environmental Assessment estimate which was 70 ML d^{-1} less. Both our model and the peer review model have estimated that the cease to pump (CTP) threshold in the Environmental Assessment is below the 80^{th} percentile (Fig. 7) for the river, providing some additional confidence for our modelling.

Our EA model was a very close approximation to the model used in the Environmental Assessment (our EA Model overestimated the yearly pumping value by 159ML yr^{-1}). Two weaknesses existed in our modelling. Flow data for the Summer Hill Creek catchment were based on a relatively short time period (7 years), which did not include extended periods of low flow. We also estimated consumption for Orange. Despite this, flows from the Summer Hill Creek catchment only contributed 11.86% of the modelled flow (Model A) at the pump site (Table 7). Population and consumption data were also estimated and generalised for yearly demand.

The proposed development will impact on the river and its downstream ecosystems, depending on the relative size of diversions over time. At the pump site, quality of habitat will be affected during construction and while the pump is extracting flow from Cobbs Hut Hole. Over the operation phase of the pipeline, connectivity and amount of habitat in the Macquarie River will be reduced (Table 13), especially at low flows. As pumping impacts most on low flows (Table 11), there will be long term impacts of the pipeline downstream of the pump site during dry conditions, reducing habitat, connectivity of the river, riparian inundation, and littoral zones (Table 13). This impacts the ecology of the river, which potentially includes six species of protected fish.

End of system flows will be reduced by the development, as environmental flows from Burrendong Dam are calculated on dam inflows, and general security environmental flows are based on dam fill. Environmental flows are critical for the Macquarie Marshes which are currently undergoing long-term degradation (Table 13, DEWHA, 2009). The Australian Government and the NSW Government have invested considerable funding in the buyback of water from the irrigation industry. The Orange pipeline, with its increased diversions, will inevitably effect this investment, eroding its effectiveness and ultimately the ability of governments to deliver on environmental sustainability for internationally listed wetlands, such as the Macquarie Marshes.

The gap between Orange's current use and its water allocation represents unused allocation that will be extracted from what is currently environmental water. Considerable government investment ($73 million) has purchased water allocation in the greater Macquarie catchment (Department of Sustainability Environment Water Population and Communities, 2013b). Orange's consumption increase will erode this investment in restoring environmental water.

There is clearly a challenge for urban centres facing increasing water shortages. In the past, there has generally been opportunity to simply divert water from the closest supply, degrading environmental systems. The proposed Orange pipeline development represents such a strategy. Other options exist to reduce demand or obtain water other than from the environmental share. Demand could be reduced further; managed aquifer recharge could decrease loss to evaporation; active licences could be purchased. The proposed usage is high in a national and global context (Table 14), and the cumulative expectation of this demand over other cities looking to increase their populations through the Evocities Project will further contribute to impacts on the ecosystems of the Murray-Darling Basin water resources (Kingsford, 2000).

Water shortages involve not just a physical shortage but also a social dimension; water use efficiency (Saleth and Dinar, 2004). Orange has implemented demand management schemes including water efficiency promotion and water sensitive urban design, lowering consumption compared to other cities (Table 14). Increased focus on these strategies in future would take advantage of the water saving ethos developed by Orange over the drought period. Another opportunity is to use the water that is already extracted for human use. Trade with irrigation is a cost effective possibility to supply urban areas, yet is rarely exploited (Marsden Jacob Associates, 2006; Quiggin, 2006). Such trade will only occur in a sustainable manner if active water licences are bought.

Demand can also be managed by pricing, which is the cheapest option to increase water efficiency (White and Howe, 1998). Justification for the Orange pipeline was based on the need for an unrestricted supply of water to residential and industrial users. This requires that consumers are willing to purchase the proposed amount at the price that the council needs to charge to make the development economically viable. Water bills are projected to rise by $49 with the development to $65 (quarterly) under a doubling of power costs (GHD, 2012c). Orange's typical annual residential bill was $457 in 2012 (National Water Commission, 2013). Grants by Commonwealth ($20 million) and state ($18.2 million) governments made the pipeline the cheapest option to Council over the 50 year planning scope for the projected demand. While the State grant was transferrable to other water solutions in the region, the Commonwealth Government grant was specific to the pipeline. Fixed Government grants such as this obscure the price signal of the development (National Water Commission, 2012), promoting inefficient solutions (Productivity Commission, 2009), which can lead to perverse outcomes, where an increase in consumption leads to increased revenue for the utility (Reddy, 1991; White and Fane, 2002).

Currently recycled water is diverted free of charge to Cadia Valley gold mine (10ML d^{-1}, Kuter, 2012; Newcrest Mining Limited, 2010, 2005) which could be further treated for potable reuse. This transfer has been factored out of Orange's future supply until after about 2030 (GHD, 2012c). Consumption and transfers out of the catchment have affected low flows in Summer Hill Creek. Effluent from Orange accounts for 32% of Cadia's water source in the 2010 reporting period (Newcrest Mining Limited, 2010), and has been considered for indirect potable reuse (effluent reuse) after 2030, but use of this water by the town would offset the need to pump water from the Macquarie River.

Urban water planning must be better integrated with regional water planning to avoid further overallocation, adapting to a changing understanding of the environment (Kingsford *et al*., 2011a), as the Macquarie River system (NSW Department of Environment Climate Change and Water, 2010) and Murray-

Darling Basin (Commonwealth Government, 2008; Colloff *et al*., 2010; Kingsford *et al*., 2011b) are currently overallocated. The Murray-Darling Basin Plan (Commonwealth Government, 2008) is a step to improve water management, likely to decrease water available to existing licences, yet is unlikely to decrease urban water allocations and the impacts on already severely degraded ecosystems. There is a need to ensure that there are not increasing demands on already highly stressed river systems by utilising all existing supply and demand options that do not mean the environment is automatically accessed for its water.

Conclusions

Orange City Council has proposed the construction of a pipeline to provide secure supply to a projected 404L $capita^{-1}$ d^{-1} demand, significantly higher than the current 252L $capita^{-1}$ d^{-1} achieved under Level 2 water restrictions. Orange is currently a modest water consumer within Australia, which has high consumption in a global context. Options exist for Orange to increase its population and economic development, whilst avoiding a net increase in water diversions from the Macquarie Catchment. The pipeline will fulfill a high water allocation, at the expense of river environmental flows, which have been significantly invested in by government in an effort to restore degraded ecosystems that rely on the Macquarie River (Table 13).

The Environmental Assessment has not realistically modelled flows for current catchment conditions, and consequently underestimated the ecological impact of the development. The modelling of the impact of the pipeline has not accounted for growth in use of the project, and may not have accounted for increasing the capacity of Suma Park Dam, which Orange City Council is already planning. These developments will increase the use of the pipeline, increasing ecological impacts beyond those considered in the Environmental Assessment. Growth in Orange's current use will increase the overallocation of the Macquarie River and the Murray Darling Basin, an issue of national and international concern.

The Environmental Assessment has therefore underestimated the environmental impacts of the development on the Macquarie River at three scales. At the pump site, reduction in low flows will reduce habitat quality. Downstream to Burrendong Dam, ecosystems which are currently threatened by water resource development will have reduced flows in the Macquarie River. Remaining ecosystems downstream of Burrendong Dam, including the Ramsar listed Macquarie Marshes, are already in poor condition as a result of water resource development, and will have flow volumes further reduced by this development.

The proposed Macquarie River extraction development, with its present licencing and configuration, has the potential to significantly impede Australia's ability to meet its local, national and international obligations.

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Appendix 1

Table 15 – Utilities for which water use comparisons were made (Figure 12).

State	City	Population
New South Wales	Ballina Shire Council	37,000
	Bathurst Regional Council	35,000
	Bega Valley Shire Council	30,000
	Byron Shire Council	29,000
	Dubbo City Council	34,000
	Essential Energy	20,000
	Eurobodalla Shire Council	37,000
	Goldenfields Water (Reticulation)	23,000
	Goulburn Mulwaree Council	22,000
	Kempsey Shire Council	25,000
	Lismore City Council	32,000
	Queanbeyan City Council	40,000
	Wingecarribee Shire Council	39,000
Northern Territory	Power and Water - Alice Springs	26,000
South Australia	SA Water - Mount Gambier	26,000
	SA Water - Whyalla	23,000
Victoria	South Gippsland Water	27,000
	Westernport Water	13,000
Western Australia	Aqwest - Bunbury Water Board (water supply)	35,000
	Busselton Water (water supply)	24,000
	Water Corporation - Albany	32,000
	Water Corporation - Australind/Eaton	24,000
	Water Corporation - Geraldton	35,000
	Water Corporation - Kalgoorlie-Boulder (water supply)	30,000