Draft Options for 30-year Infrastructure Strategy

INFRASTRUCTURE VICTORIA

Stormwater Harvesting and the Potential for New Dams in Victoria

UoMC Ref 2016-161

29 August 2016

THE UNIVERSITY OF MELBOURNE

Contents

1. Introduction

1.1 Background

Infrastructure Victoria is developing a draft 30 year infrastructure strategy covering a number of sectors including water. This strategy is intended to assist governments make informed decisions about the best ways to address challenges and make the most of opportunities associated with our changing population. The foundations paper *From the ground up*[1] provides an overview of the scope of this strategy. Infrastructure Victoria have also published an options paper *All things Considered*[2]*,* which outlines a broad range of options that have been considered to date. Another publication *Draft Options Book*[3] provides further information on each of the options.

1.2 Scope

The options identified for the water sector in the *All things Considered* relate to the needs of managing threats to water security, particularly in regional and rural areas. This includes options for the better management of stormwater as well as considering the capacity for new dams. In the *Draft Options Book* the two relevant options are "Stormwater harvesting and re-use for non-potable purposes (Option SRH)" and "Water supply augmentation through building new dams (Option WSA2)".

The Department of Infrastructure Engineering at the University of Melbourne was contracted to provide a view on the ability of these options to manage threats to water security, particularly in rural and regional areas. Given the restricted time period to prepare a draft, this assessment was to be developed at a high level relying mainly on information available in the public domain. It is expected that additional reports relevant to this scope may well have been prepared by water industry agencies, but without public release such information was not accessible to the authors of this document.

1.3 Report outline

The report is divided into two main sections which separately cover:

- Section 2: *Stormwater harvesting to augment water supply*
  (prepared by Andrew W Western[4], Tim Fletcher[5], Meenakshi Arora[4], Jing Zhang[4])
- Section 3: *Water supply augmentation through building new dams*
  (prepared by Rory Nathan[4], Tom McMahon[4], Avril Horne[4], Andrew W Western[4])

These sections have been prepared as self-contained papers, and as such no overall conclusions are drawn.

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[1] *From the Ground Up: Developing a 30-year infrastructure strategy for Victoria*, Infrastructure Victoria, 2015. www.infrastucturevictoria.com.au
[2] *All things considered: exploring options for Victoria's 30-year infrastructure strategy*. Infrastructure Victoria, 2015. www.infrastucturevictoria.com.au
[3] *Draft Options Book: Version 1.1 – release for consultation*, May 2016. www.infrastucturevictoria.com.au
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2. Stormwater harvesting to augment urban water supply

2.1 Introduction

Stormwater is a potential water resource in urban systems that could be used to supplement traditional reservoir and groundwater based water sources, thus increasing the reliability of the overall supply system. The viability of harvesting stormwater has a variety of aspects that need to be considered including:

- the volume of the resource that can be harvested and/or used;
- the combined reliability of the resource, when considered within the framework of the overall suite of supply sources;
- the cost of stormwater supply systems;
- associated water quality and public health considerations; and
- environmental and landscape amenity ('liveability') considerations.

This document first provides a brief overview of the important pertinent characteristics of stormwater and then concentrates on characterising the cost and reliability of supply.

2.2 General considerations

As with many water resource decisions, stormwater resource characteristics and infrastructure costs are strongly dependent on the local situation and hence it is challenging to draw general conclusions without in-depth study. In particular the amount of resource, the infrastructure required to develop that resource and the available demand (its amount and seasonality) for the resource are key factors influencing the cost of water from stormwater harvesting.

A further consideration is that stormwater harvesting may be implemented as part of a broader water sensitive urban design framework that aims to realise significant environmental and amenity benefits and in those situations it would be appropriate to consider allocating costs across the range of benefits rather than purely to the water supply. These additional benefits typically include:

- mitigation of the degradation of receiving waters (see for example: Wong et al., 2011; Wong et al., 2012)
- significant reductions in flooding (see for example M.J. Burns, Schubert, Fletcher, & Sanders, 2015)
- mitigation of the urban microclimate (see for example Endreny, 2008)
- urban amenity and enhancement of passive recreational opportunities.

Analysis of the benefits of a particular proposal for stormwater harvesting should therefore preferably be undertaken as part of a comprehensive business case. Industry guidelines for preparation of such integrated business case are available at http://waterbydesign.com.au/businesscase/.

It is also true that the costs of the alternative water supplies to stormwater harvesting will be strongly geographically dependent due to the spatial variability in the water cycle and the relatively large costs of moving water (by pumping) over significant distances. This implies the economic viability of stormwater harvesting needs to be considered in the local context. Furthermore, the multiple benefits – particularly those relating to protection of receiving waters, reductions in flooding and the urban heat island effect, and provision of landscape amenity, are greatest when stormwater harvesting is *undertaken as close to source as possible* (Wong et al., 2011; Wong et al., 2012). Indeed, it is self-evident that harvesting can only protect receiving waters *downstream* (by definition, harvesting cannot affect the flow and water quality upstream). Similarly, a large centralised harvesting system will not provide the urban amenity benefits ('urban greening') that are provided by smaller, more decentralised systems located at streetscape or precinct scale. Conversely decentralised systems are difficult to manage properly and pose a greater risk of system failure and public health risk. They therefore present a complex challenge in achieving a balance between benefits received and best practice management by selecting the best scale and ownership/operation models on a case by case basis.

The cost of stormwater harvesting and re-use also depends on the infrastructure requirements for the storage and treatment of collected stormwater. The level of treatment required varies considerably, depending on the end uses.

2.3 Success Factors

The success factors involved in the successful use of stormwater include:

- *Matching infrastructure to demand*: Stormwater harvesting for seasonal irrigation alone is the least efficient use for stormwater harvesting. Therefore, it is important to ensure more regular demand for efficient stormwater harvesting by utilising stormwater for indoor uses such as toilet flushing, laundry and hot water system (V. Grace Mitchell, Deletic, Fletcher, Hatt, & McCarthy, 2007; V. Grace Mitchell, McCarthy, Deletic, & Fletcher, 2008).
- *Implementation at scales that optimise the benefits in addition to water supply*: As discussed above, these benefits fall to virtually zero for large downstream, centralised systems, reinforcing the benefits of considering stormwater harvesting as a complementary approach to the existing centralised potable supply system.
- *Effective construction and maintenance*: While the decentralised approach to stormwater harvesting will give the greatest combined benefits to water supply, waterway protection, flood mitigation and landscape amenity, it also necessitates a different approach to long-term maintenance and thus performance. Rainwater tanks applied at the household scale should, for example, be undertaken within a "service delivery" model, whereby a Water Authority (or similar) undertakes the installation and ongoing maintenance (facilitated by telemetry systems (e.g. http://www.iota.net.au/) which can be used to notify of failures, or can be used to control the tank to, for example, release water prior to heavy rain, to prevent flooding), and thus charges a service fee.

2.4 Cost of stormwater harvesting

We have reviewed a selection of publically available case studies for cost estimates of stormwater harvesting schemes in addition to the cases listed in Adelaide Options Analysis study (Marchi, Dandy, & Maier, 2014). Typically only partial information is available in public documents and hence here we present an incomplete picture (Table 2.1) that serves to illustrate the wide variation in cost of harvested water. We note also that these costs are influenced by generally being "pilot" or "pioneering" projects (because these are the projects most commonly documented) where the costs are thus higher. There is also a variety of additional environmental, downstream infrastructure saving and amenity benefits beyond water supply that are not included here but should be considered in any business case. Finally it should be noted that most of the case studies are for retrofit situations and costs of stormwater harvesting for new developments are significantly lower than for retrofit.

- *Costs can be competitive but are highly variable*. Documented capital plus operating costs of water from case study stormwater harvesting systems considered here vary from around $500/ML to as much as $50,000/ML of water supplied (Table 2.1). In estimating a cost per megalitre, an assumed life of 20 years was applied to lifecycle costs. The actual life span of the various system components will vary significantly around this figure. (Marchi et al., 2014) (their Table 14) provided separate capital and recurrent costs for a range of systems. They estimated capital costs vary between $670/ML (Aquifer Storage and Recovery case) to well over $100,000/ML (for some small scale retrofit system). Recurrent costs vary between $220/ML and $43,000/ML. These cost ranges illustrate that stormwater harvesting schemes can be a relatively cheap source of water but also reinforce the need for case-by-case evaluation.
- *Storage options are important*. The cheapest water from stormwater harvesting systems uses Aquifer Storage and Reuse as the storage option (Table 2.1). ASR is dependent on the availability of suitable aquifers and makes most sense purely from a water supply perspective where the aquifer is either stressed (e.g. Perth) or where it has water quality issues such as water salinity (e.g. Adelaide). In other cases the groundwater could be used directly as a water source, although of course such an extraction would need to be evaluated in terms of sustainability outcomes.
- *Potable use of stormwater may be the most cost-effective*. Costs of stormwater harvesting are dependent on the infrastructure required to use the water, which includes a variety of treatment and distribution costs. Adelaide ASR based systems, (Marchi et al., 2014) considered irrigation uses, non-potable domestic use and potable domestic use. The cheapest options were potable use, especially where water could be directed through an existing treatment plant. This presumably reflects both the year-round demand and use of existing distribution infrastructure. Non-potable domestic use is the most expensive due to the distribution infrastructure required.
- *Towards potable use – a Melbourne example*. The Kalkallo stormwater harvesting and reuse project is a new and innovative project to help deliver sustainable water supply to Melbourne's growth areas. The scheme will capture stormwater from the 160 hectare industrial development through a new wetland system and 65ML storage basin with a view to mitigate excessive storm flows from reaching the environmentally sensitive Kalkallo and Merri Creeks,

and providing water supply to the complex after treatment. The treated water will be initially used within the existing Yarra Valley Water (YVW) recycled water network until regulation allows stormwater to potable use, however the treatment plant will treat the stormwater to a standard suitable for drinking purposes by utilising a treatment train consisting of wetlands, carbon dosed DAFF (Dissolved Air Floatation Filtration) followed by disinfection and ability to retrofit Reverses Osmosis membranes if needed in future. YVW will undertake extensive monitoring and testing over time to provide evidence to the Victorian Department of Health that the quality of water produced by the Project is suitable for drinking. Key leanings from the project to date include:

1. The economic viability of stormwater harvesting is heavily influenced by the model used to justify the business case. Improving methods of analysing business cases including indirect factors such as environmental and social impacts may assist in making more stormwater schemes viable. The operating cost of potable water is estimated to be $2.71/kl without considering the indirect benefits and $1.79/kl with indirect benefits.
2. Stormwater projects for Class A equivalent or better quality treated water will generally be more expensive than recycled water produced from sewage. This is due to the need to construct a large storage basin/tank, with a capacity suitable to maintain an agreed level of reliability.
3. Existing treatment technology has the ability to successfully remove pathogens and viruses. The challenge has been to provide treatment capable of managing the potential chemicals that may exist in the catchment, since YVW has little control over the types of industries that may set up in the new industrial development. This can be a significant cost factor in these projects. The capital cost of Kalkallo project is 20.1 million AUD including 6 million for the storage infrastructure and 13 million for treatment.
4. Regulations in Australia are not ready for potable use of stormwater. The existing guidelines for Recycled Water Quality Management Plan (RWQMP) only provide guidance for non-potable uses with no reference values for the chemical contaminants. The Australian Drinking Water Guidelines (ADWG) provide reference values for contaminants of concern with little guidance on pathogenic risks. Community acceptance of recycled water for potable purposes poses another complex challenge for YVW.

- *Private rainwater tanks are another option for stormwater harvesting*. Rainwater tanks have particularly high variation in the proportion of roof runoff captured. In recent studies relatively high roof runoff capture has been achieved (Matthew J Burns, Ladson, & Fletcher, 2015; M.J. Burns et al., 2015) where demands have been well matched to supply through close guidance in the Little Stringybark Creek trial (see www.urbanstreams.unimelb.edu.au). In such cases the cost of water supply is competitive with alternate sources. This has not been generally true of cases where such guidance has not been available, showing the importance of managing any large scale household tank installation with a disciplined oversight of design and installation (as described above). Broadly across the community typical percentage capture of roof runoff has been low due to limited demand on the tanks (Moglia et al., 2014). Recent experience in Melbourne, through the Little Stringybark Creek Project (http://urbanstreams.net/lsc/) has also showed that household-scale systems are no more expensive (and often considerably less expensive) than large-scale stormwater harvesting systems, due to the simplicity of design and construction at the household system (Fletcher, pers. comm, 2016).

- *Rainwater tanks are complicated by being highly decentralised and in private control*. Under traditional arrangements this implies there are as many operators of systems as there are properties, which adds a significant quality control challenge. In addition to the issues around matching demand to supply discussed in the previous point, adequate maintenance is also important. Maintenance of private rainwater tank system has been problematic in the general community with issues around non-operational systems and poor water quality (CSIRO report) and there are OHS risks associated with system maintenance. Again this can be addressed by close guidance.
- *A new model for rain water tank management is needed for this technology to be optimally applied across a wide area*. Widespread success would require a change in how tank systems are designed, used and maintained. Rainwater tanks applied at the household scale should be undertaken within a "service delivery" model, whereby a Water Authority (or similar) undertakes the installation and ongoing maintenance (facilitated by telemetry systems (e.g. http://www.iota.net.au/) which can be used to notify of failures, or can be used to control the tank to, for example, release water prior to heavy rain, to prevent flooding), and thus charges a service fee. Implementation of such a strategy may require regulatory support and would require involvement of Water Authorities.
- *Lead in rainwater tanks*. Lead levels in excess of drinking water standards have been found in around 22% of urban rainwater tanks (Magyar & Ladson, 2015). This can be partly attributed to lead on rooves (lead flashing), which should not be a problem in new developments, and lead in the environment, which depends on local lead sources. If rainwater tanks are plumbed into hot water systems this could increase exposure to lead, which is a risk that needs to be more thoroughly investigated. This is a risk that would need more formal evaluation if rainwater tanks were to be plumbed to hot water.

2.5 System reliability impacts

A number of factors influence the reliability of stormwater:

- *The total stormwater volume is dependent primarily on rainfall and (connected) impervious area* – as a first approximation it is approximately 90% of rainfall depth multiplied by connected impervious area.
- *Stormwater systems are highly variable in the proportion of stormwater harvested*. Based on the case studies where information is available, the proportion of the stormwater volume captured by supply systems varies from less than 10% and around 90% (Table 2.1). This is highly dependent on the demand patterns and volumes relative to the resource and the storage options available, both of which are case specific.
- *Significant stormwater resource exists but is challenging to capture*. In Melbourne the stormwater runoff volume is similar to the annual potable water demand but harvesting this is challenging in practice. Capturing a significant component of this economically would require

a concerted effort over a long period and would involve a large number of decentralised but coordinated individual projects. The easiest and thus perhaps most important opportunities exist in greenfield developments due to the opportunity to implement schemes at substantially lower costs.

- *In an urban context stormwater harvesting often substitutes for use of potable water and as such reduces demand on the water supply system*. The impact of the stormwater harvesting on reliability of supply thus needs to be assessed for the entire water supply system, which is similar in concept to approaches used to assess the impacts of other supply supplements or demand reduction measures (such as efficient water appliances). The benefits to reliability increase as the level of system stress increases. Explained another way, water supplied from stormwater/rainwater when available reduces demand from the potable water supply reservoirs. This has the effect of creating "virtual supply" into the storages during the wetter part of the year, which can then be drawn on during times where stormwater/rainwater are not available.
- *Stormwater harvesting tends to be inherently decentralised and some is purely in the private domain (e.g. rainwater tanks)*. Nevertheless there is an interaction with potable water supply security where stormwater substitutes for potable water use. Perhaps counter to intuition, significant contributions to overall storage can be achieved by quite small storages installed on each allotment (V.G. Mitchell, McCarthy, Fletcher, & Deletic, 2005).
- *Demand patterns for stormwater use relative to rainfall are critical* in determining infrastructure capacity requirements and the efficiency of stormwater capture and this is a critical design issue for achieving system benefits. Thus indoor uses such as toilet flushing, laundry use and hot water use are preferable because they provide a constant level of demand. Irrigation uses generally result in poorly matched supply and demand and larger more costly storage requirements or low rates of resource utilisation. Non-potable indoor uses (toilet and laundry) represent 32% of domestic use (Roberts, 2005). Supplying hot water from well-maintained rainwater tank systems is also possible and this significantly increases demand to around 60% (given shower use is 29%) but also increases the importance of good system operation and maintenance (see previous discussion on this).
- *Irrigation uses (the most common use of stormwater in Victoria to date) are suboptimal as they have demand patterns that necessitate the largest storage of stormwater*. In general there is a seasonal mismatch between rainfall patterns and irrigation demand patterns (determined by both rainfall and evaporative demand) which has a significant impact on the proportion of the stormwater resource that can be practically captured in situations where storage costs are higher (i.e. all except groundwater/Aquifer Storage and Recoivery (ASR)).
- *Comparison of alternative water supply options should take into account* both (i) their multiple benefits (and the value of these) and (ii) their marginal contribution to the system-wide security of supply as discussed above.

2.6 Other considerations

There are a number of other considerations that influence the utility of stormwater:

- *Water quality is important*. There are a variety of water quality and public health considerations that impact stormwater uses, but there has been significant development, both in terms of treatment capacity, and in terms of the level of guidelines governing stormwater harvesting for non-potable use (e.g. Australian Guidelines for Water Recyling, (NRMMC/EPHC/NHMRC, 2009)). Indeed, stormwater harvesting is widely applied around Australia, at a very wide range of scales. At the lowest levels of treatment, stormwater can be readily used for irrigation (subject to appropriate risk controls), while indoor uses require appropriate treatment such as small-scale UV-disinfection, following treatment using wetlands or biofiltration systems. The risk management framework for stormwater harvesting, developed by the National Health and Medical Research Council, is consistent with that developed for 'standard' potable water supply options.
- *Stormwater leads to receiving water degradation and harvesting it can reduce these*. Stormwater is the dominant source of degradation of Melbourne's creeks and streams, and also impacts major downstream waterways such as Port Phillip Bay, in particular through its delivery of nitrogen and other pollutants. There is now significant research showing the environmental benefits of "best-practice" stormwater management. Burns et al (2012) and Walsh et al. (2012) recently published frameworks for protecting waterways from stormwater. In both these papers, there is a strong focus on the need to return the flow and water quality regime as close as possible to their natural levels, using a combination of rainwater and stormwater harvesting (to reduce the volume, frequency and rate of stormwater runoff) with techniques such as biofiltration and infiltration (to restore the baseflows that are lost due to creation of impervious areas). While the benefits of this mitigation are difficult to quantify, two figures are perhaps useful:
  - Melbourne Water alone spends some $110 million per year on waterway management, much of which is in response to degradation of waterways caused by urban stormwater.
  - Given the impact of excessive nitrogen (N) loads on Port Phillip Bay, there are major investments in nitrogen reduction technologies (such as stormwater wetlands). The cost to remove nitrogen averages $6645/kg, and this price is applied as an "offset" cost where developers are not able to meet their obligations under Clause 56.06 of the Sustainable Neighbourhoods Code to reduce loads of nitrogen (as well as phosphorus and sediments). Given an average nitrogen concentration of 2.2 mg/L in stormwater (Duncan, 1999), each ML of stormwater harvested represents a value of $14619, for the nitrogen reduction benefit alone. As an example of scale, a stormwater harvesting system in Mount Evelyn supplying a carwash with around 1.6 ML per year.
- *Harvesting high in the catchment has most benefit for receiving waters*. Further stormwater can be harvested at a range of scales from the lot scale to substantial urban catchments (Table 2.1). As the catchment scale at which harvesting occurs increases, the environmental benefit decreases (because there is more untreated upstream waterway). This implies that more environmental benefits are gained from more decentralised approaches.
- *Technical aspects of rainwater harvesting infrastructure have matured significantly*. There have been major advances in the design and implementation of stormwater harvesting systems within the last 10 years. Much of the research underpinning this evolution has been

undertaken in Melbourne, which is seen as one of the world's leading cities in stormwater management. Unfortunately, many of the case-studies from which costings have been obtained represent the retrofit context, whereby existing infrastructure is modified. Recent work conducted by the University of Melbourne and Melbourne Water demonstrated that costs of household, streetscape and precinct-scale systems can be reduced by around 50% when installation is taken as part of urban development. This unsurprising result demonstrates that the best-value investment in stormwater harvesting would likely be in greenfield catchments, as part of current/proposed development.

- *There are opportunities to address energy efficiency*. Energy consumption associated with rainwater tanks is ~1.5kWh/kL (c.f. desalination ~5kWh/kL for Melbourne's desalination plant (www.aquasure.com.au/energy-efficiency)). 1.5kWh/kL represents around 10% efficiency for water delivery at 50m head (maximum standard indoor pressure). There is significant scope for energy efficiency improvement in small pump systems.
- *Regulations in Australia are not ready for potable use of stormwater*. The existing guidelines for Recycled water Quality Management Plan (RWQMP) only provide guidance for non-potable uses with no reference values for the chemical contaminants. The Australian Drinking Water Guidelines (ADWG) provide reference values for contaminants of concern with little guidance on pathogenic risks.

2.7 Conclusions

Overall we find that stormwater harvesting has matured over recent decades from a technical perspective and has the potential to supplement traditional urban water sources and can improve system reliability. The potential scale of this improvement could be significant but challenges in economically scaling up harvesting and in developing viable models to ensure decentralised systems are well designed and operated remain. Key priorities for further research and investigation should be:

- developing a clear picture of the economic issues, especially the issue of appropriately accounting for downstream benefits (there are guidelines for this);
- developing service models for the design, operation, and maintenance of systems on private properties, typically rainwater tanks, to ensure practical benefits are obtained; and
- to further assess the impacts of distributed systems on overall system reliability.

The volume of stormwater runoff in Melbourne is approximately equivalent to current water usage, which represents a notional upper limit of its utility. The attraction of this resource is that it is distributed in nature and can be used locally for potable substitution without developing large scale storage and distribution systems. We have identified the challenges that would need to be considered to develop this resource further. A state-wide assessment would provide information on the potential for this resource to be used in regional areas, though it would be expected that this would be most feasible in towns located in the higher rainfall areas of the state.

2.8 References

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Table 2.1: Costs and Volumes

Project	Location	Year	Catch-ment area (ha)	Estimated savings (ML/year)	Treatment	Storage type	Capital cost ($/ML/y)	Recurrent cost ($/Ml)	Type of use	References
Aquifer Storage and Recovery (ASR) of Stormwater	SA (Kingswood Golf Club)	2008		na		700kL tank, aquifer	na	na	Irrigation	62m_-_2047_kingswood_golf_club_asr_final_report-_non-confidential.pdf
South Australian Water Corporation Barker Inlet Stormwater Reuse Scheme	SA	2012	4500	na			na	na	Industrial, commercial and irrigation	AdelaideWaterSupplyOptions_EnergyCostsReport_Marchietal_Final_web.pdf; https://www.sawater.com.au/__data/assets/pdf_file/0018/6642/AnnualReport201112.pdf
South Australian Water Corporation	SA (Adelaide Airport)	June 2013		na			na	na	Irrigation, toilet flushing, industrial	http://www.adelaideairport.com.au/corporate/wp-content/uploads/2015/03/EMGDLAALPALWaterConservation.pdf
BARNWELL PARK GOLF COURSE, FIVE DOCK	City of Canada Bay Council	2004	7 ha	1.5	GPT and 1ML sand filter basin	Above ground tanks	$225,020	$18,000.00	Irrigation – golf course	http://www.urbanwateralliance.org.au/publications/UWSRA-tr9.pdf; http://www.environment.nsw.gov.au/resources/stormwater/managestormwaterb06137.pdf
Hawkesbury water reuse project	Hawkesbury City Council	2000	285 ha	na	Constructed wetlands and settling pond	Dam	na	na	Irrigation of university and TAFE grounds	
PRINCE HENRY DEVELOPMENT, LITTLE BAY	Landcom	2006		70	Sediment arrestors, GPTs, bioretention, filtering	open storage ponds	na	na	irrigation – public open space, golf course	
FOOTSCRAY PARK	Maribyrnong City Council	2006	400ha	na	wetland	underground tank		irrigation – public open	http://www.urbanwateralliance.org.au/publications/UWSRA-tr9.pdf;	

								space	https://maribyrnong.vic.gov.au/Files/Sustainable_Water_Management_Plan.pdf	
Royal Park Stormwater Harvesting Project (Trin Warren Tam-boore wetlands)	City of Melbourne	2006	187ha	95	sediment trap, Wetland,UV	12ML storage basin; 5ML underground tank,		na	irrigation of the neighbouring golf course, sports ovals and parkland.	
Darling Street Stormwater Harvesting Project	City of Melbourne	2011	37 ha	21	GPT, a sedimentation chamber, biofiltration systems, Ultraviolet	underground tank		na	irrigation	http://urbanwater.melbourne.vic.gov.au/tours-videos/take-a-self-guided-tour/east-melbourne-walking-tour/
Fitzroy Gardens Stormwater Harvesting System	City of Melbourne	2013	67 ha	69	GPT, a sedimentation chamber, biofiltration systems, Ultraviolet	Underground tanks	na	na	Irrigation	
Birrarung Marr stormwater harvesting system	City of Melbourne	2014	37 ha	35	GPT, a sedimentation chamber, biofiltration systems, Ultraviolet	underground dual tank system	na	na	irrigation	
Stormwater harvesting in Queen Victoria and Alexandra Gardens	City of Melbourne	2013	34 ha	20	GPT, a sedimentation chamber, biofiltration systems, Ultraviolet	Ponds 1.1ML, above ground tank 230KL,	na	na	irrigation	
Moonee Valley Stormwater diversion	Moonee Valley Racing Club			60	GPT	dam	na	na	Irrigation	
Monash University Stormwater	Monash University	2002	3 ha	4.4	Sendimentation, biofilter	pond	na	na	Irrigation	http://www.eng.warwick.ac.uk/ircsa/pdf/13th/Burns.pdf

Harvesting System										
Homebush Bay	Sydney Olympic Park Authority	2000	760 ha	200	GPT, swales, wetlands, ponds,	350 ML brick pit, 140 ML wetlands	na	na	Irrigation, water features and other outdoor uses, toilet flushing, fire fighting,	
Oaklands Park	HNJ Holdings Pty Ltd	Begun in 1997	174 ha	0.69	swale	Dam	na	na	toilet flushing, fire fighting	
Figtree Place	Newcastle City Council	1988	1.1 ha	1.66	Infiltration	ASR	na	na	irrigation	
EDINBURGH GARDENS	City of Yarra		27ha	15	wetland and UV disinfection	undergro und storage	na	na	irrigation – public open space	
COTTESLOE PENINSULA GROUNDWATER RESTORATION PROJECT	Town of Cottesloe	2010		180	Infiltration, geotextile filter	aquifer	na	na		https://www.environment.gov.au/system/files/resources/97e840af-6406-49f2-8b43-af94ca0e7699/files/water-smart-review-appendix-f.pdf
DOCKLANDS	VicUrban		2.7 ha	0.8	wetlands, gross pollutants, street trees	Wetland, undergro und storage 500kL	na	na	irrigation	
REGENT GARDENS	Department of Environment and Natural	1995	72ha	na	GPT, wetland	ASR	na	na	irrigation	

	Resources									
NEW BROMPTON ESTATE	City of Charles Sturt	1991	2250m2	na	gravel trench, geotextile filter	ASR	na	na	irrigation	
PARFITT SQUARE	City of Charles Sturt	1997	0.6 ha	na	sediment trap, reed bed, underground gravel filled trench and geotextile filter	ASR	na	na	irrigation	
BARRY BROTHERS WATER USE	City of Port Phillip / Barry Brothers	2003		12		Above ground tanks	na	na	Irrigation, street sweeping	

3. Water supply augmentation through building new dams

3.1 Introduction

The basic purpose of a dam is to capture runoff when it is available and store it for later use. Dams are a very attractive resource in that they are able to balance out the natural fluctuations in streamflows to provide a reliable source of water. Victoria has more perennial, good quality surface water resources than most other areas in Australia (State of the Environment Committee, 2011), and thus it is not surprising that dams have played a leading role in providing Victoria with secure water supplies over the past 160 years.

But, Australia is indeed a country of droughts and flooding rains. The variability of Australian streamflows are amongst the highest in the world (McMahon et al, 1987), and consequently dams need to be larger here than elsewhere to provide the same reliability of supply. Building larger dams will tend to provide more reliable water supplies, but the marginal benefits of doing this varies markedly with location due to differences in average streamflow yields and their variability. Early development of water resources in Victoria naturally focussed on those sites which offered the largest benefits for least cost, and it has been over twenty years since attention has shifted from the further development of water sources to the better management of both the natural resource base and existing infrastructure assets (Department of Water Resources, 1989).

The Millennium Drought (1997-2009) was the worst drought on record for south-eastern Australia (van Dijk et al, 2013). The reduced rainfalls severely impacted on inflows to our major water supplies. As shown in Figure 3.1, inflows to Melbourne's major dams over this period were around 60% of the long term average; the impacts in many parts of regional Victoria were worse, for example streamflows in western Victoria were between 5% and 30% of their long-term average conditions (Department of Environment, Land, Water and Planning, 2015[a]). The drought also impacted on our patterns of water consumption and water management practices (Low et al, 2015), and helped prompt the construction of the desalination plant at Wonthaggi.

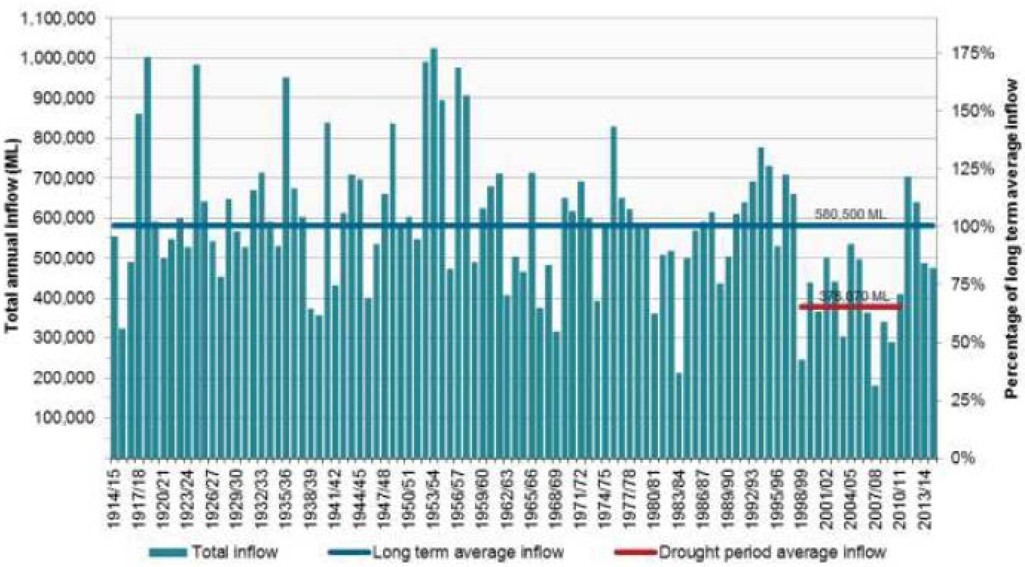

Figure 3.1: Annual streamflows into Melbourne's major dams (Melbourne Water, 2016).

Such events highlight our vulnerability to natural variations in our climate. These stresses will only increase with future population growth, and with the reduction in rainfalls that are expected to occur over Victoria due to a warming climate (CSIRO, 2015). There are many ways that we can increase our resilience to such stresses, and it is appropriate that we consider the potential for additional dams to increase our water supply security.

This paper presents a brief assessment of the potential for new dams to increase our security of supply across Victoria. The focus of this paper is on the construction of new large dams to supply communities with water for domestic, industry and agriculture purposes; it does not consider the potential for further development of small private "farm dams" used to capture and store water for stock, domestic or irrigation purposes (Fowler et al, 2015). A brief history of dam development in Victoria is provided in Section 3.2, and this is followed by the challenges facing further development. Section 3.4 reviews the potential for further dam development based on historical engineering criteria, and Section 3.5 presents the additional factors now required to be considered in sustainable water management. Section 3.6 provides a summary of the yields and costs relevant to new dam sites, and this is followed by brief sections on other considerations (Section 3.7) and conclusions (Section 3.8).

3.2 Dam Development in Victoria

The trend in the development of storage capacity across Victoria is shown in Figure 3.2. This figure only shows the increase in capacity associated with the construction of "large" [6] dams, which by international agreement refers to all dams 15 metres or more in height, though a dam is also classified as "large" if its crest length is at least 500m or if its storage capacity is at least 1 GL (Cole, 2003).

Dam construction across Victoria has spanned a period of 140 years, largely ceasing about 30 years ago. There have been three periods of rapid increase in constructed storage, each of which commenced about ten years after the occurrence of major droughts. The first metropolitan dam (Yan Yean) was built in 1855, and this was soon followed by construction of the Coliban scheme to serve the mining fields around Bendigo. The last dam built to serve Melbourne's water supply was Thomson Dam; it was completed in 1983 and impounds 1068 GL. Dartmouth Dam (3785 GL) was the last storage built to supply Victorian irrigators and it was completed in 1979. The last dam built to serve rural water supplies in Victoria was at Foster in 1997; this was in fact the last "large" dam to be built in Victoria for any purpose, and has a capacity of only 0.26 GL.

In terms of dam numbers, Cole (2003) records a total of 86 storages which meet the definition of "large dam", though the (then) Department of Environment and Primary Industries[6] consider that there are 237 dams in Victoria which are large enough to warrant formal monitoring for dam safety management purposes. The total number of dams constructed in Victoria is estimated to be 450000[6], though over 99% of these are small "farm dams" which impound less than 100 ML (Lowe et al, 2005).

The total storage capacity of major dams in Victoria is variously estimated to be 15740 GL (Cole, 2003), 12860 GL (Bureau of Meteorology[7]), and 13400 GL (Department of Environment and Primary Industries[8]). This range of figures reflects differences in the way accessible storage capacity is estimated, and in the number of dams included in the assessments. Of this total capacity, 12% is used to supply Melbourne, 3% is used to supply rural townships, and the balance (84%) provides water for irrigation purposes (Cole, 2003).

Dam upgrade works have continued since construction of the last new dam in 1997. These works have been primarily aimed at improving dam safety management. Of the 128 improvement projects that have been

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[6] By international agreement, all dams 15 metres or more in height qualify as "large dams", a dam is also classified as "large" if its crest length is at least 500m, or if its storage capacity is at least 1 GL.
[7] http://water.bom.gov.au/waterstorage/awris/#urn:bom.gov.au:awris:common:codelist:region.state:victoria
[8] http://www.depi.vic.gov.au/water/governing-water-resources/dams

undertaken over the past 20 years[9], only a few have increased the volume of storage for temporary flood retention purposes; there has been only one dam known to these authors that has been augmented for water supply purposes, and this was for 2GL increase to Candowie Dam in 2013.

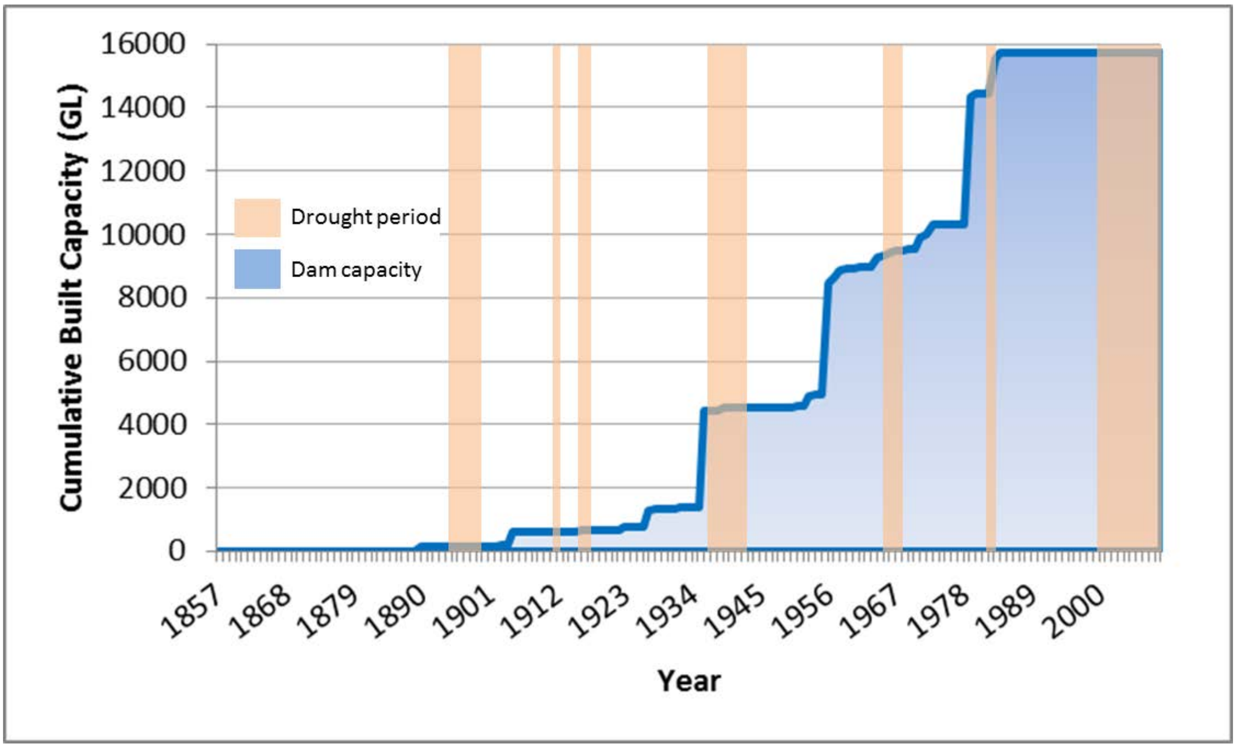


Figure 3.2: Cumulative built storage capacity of large dams in Victoria.

3.3 Development Challenges

Dams, despite their benefits, do present many challenges. The construction of the very first dam in Victoria (Yan Yean) attracted intense levels of political debate, and such controversy has characterised the development of dams throughout Victoria's history. Political factors at local and State levels have historically played a greater role in water management decisions than scientific or economic influences. DCE (1991) describe three examples of "water wars" associated with the development of Yan Yean, the Coliban supply system, and Dartmouth Dam, and note that the themes associated with these sagas are likely to recur when developing major water infrastructure in the future. Such difficulties are not specific to Victoria, but reflect the reality of water resources development globally (eg WCD, 2000; Nakayama, M. and Fujikura, R. 2006).

A fundamental challenge when considering construction of a new dam is the impact on downstream users. Traditionally downstream users are most concerned about the likely reduction in the reliability of supply to meet their own consumptive needs. But over the past 30 years there has been an increasing recognition that the environment is also a downstream "user", and that the alteration to the flow regime caused by dams pose a threat to the health of the river and its associated floodplain and estuary (Poff et al, 1997).

[9] http://www.depi.vic.gov.au/water/governing-water-resources/dams/dam-safety-management/victorian-dam-safety-improvement-program/past-upgrades

The nature of the impact of dams on downstream flows is illustrated in Figure 3.3. It is seen that major dams have the potential to reverse the seasonality of the flow regime. Their ability to capture water in high flow months reduces the magnitude and frequency of high flow events in winter and spring, which disrupt many of the ecological triggers that in-stream and riparian biota rely upon and break links to floodplains and riparian zones (Bunn and Arthington, 2002) . The difference in the magnitude and timing between pre-dam and post-dam streamflows depends on the magnitude and location of water extractions: in some dams water is diverted directly from storage into a piped network, and in others the natural stream channel is used to meet downstream demands. Depending on their design and operation, dams can also impact on downstream water quality and temperature and geomorphological form (Vietz et al, 2007). Overall, dams can have a material impact on the magnitude, variability, and seasonality of flows, and this can have adverse impacts on the environment (Gippel and Blackham, 2002; Cottingham et al, 2003).

The Victorian government has over the past 30 years progressively developed a number of institutional, policy, and legislative water management reforms (Victorian Water Act, 1989; Department of Conservation and Environment, 1992; Department of Natural Resources and Environment, 2002; Department of Sustainability and Environment, 2004, 2007, 2009, 2011[a,b,c], Department of Environment Land and Water Planning, 2016[a]). These reforms are aimed at the sustainable management of water resources, recognising that water is a finite resource that needs to be shared amongst regional and metropolitan users, as well as the environment. These policy reforms support the concepts of the National Water Initiative.

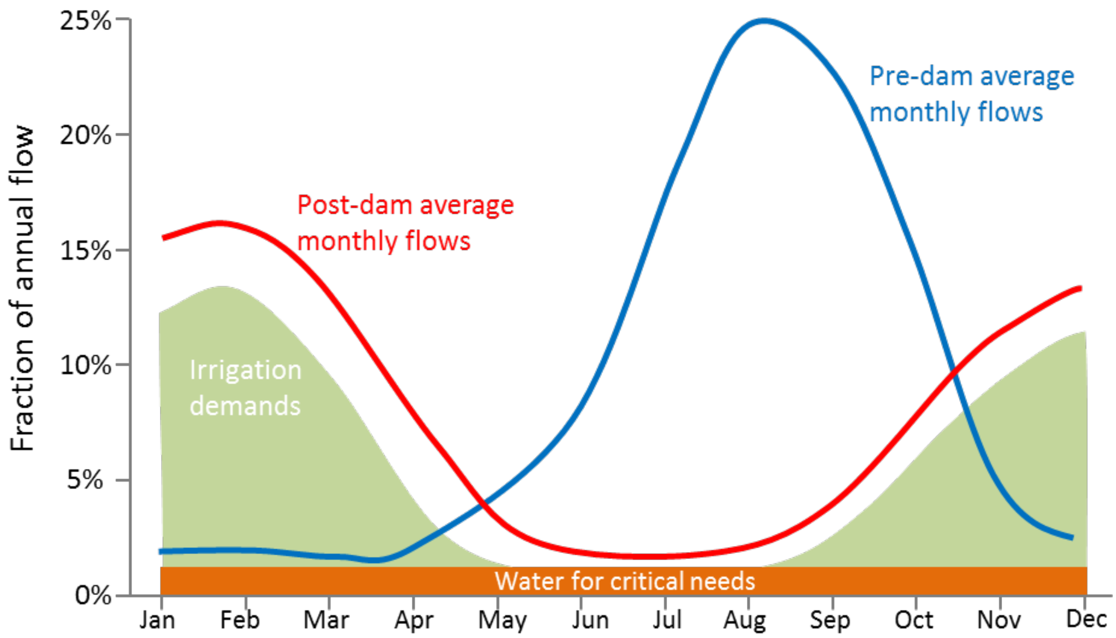


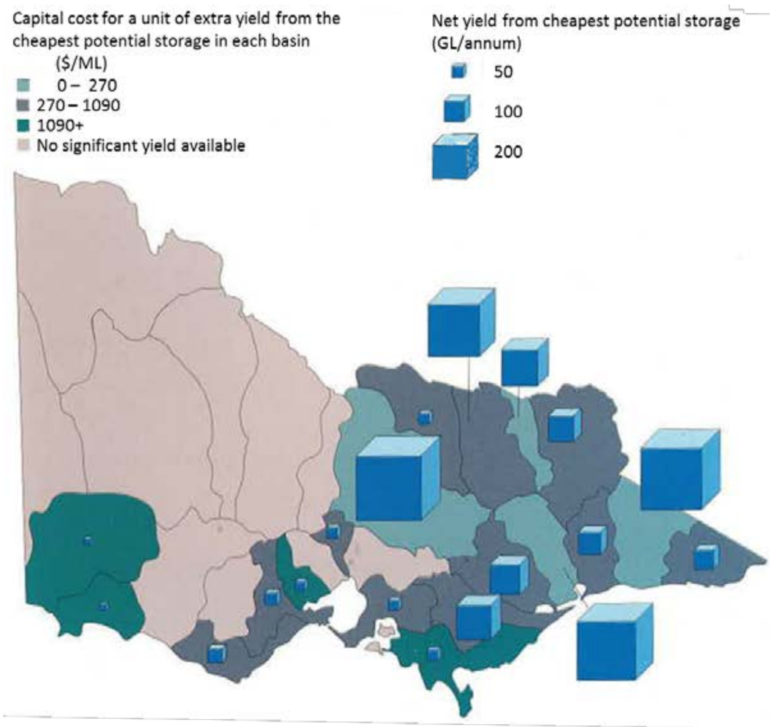
Figure 3.3: Nature of the impact of major dams on average downstream flow conditions.

3.4 Potential dam sites

Systematic planning of water resources at a state-wide level commenced in 1945 with the publication of a report by the State Rivers and Water Supply Commission that identified 350 sites for dams of various sizes. This plan was revised in 1948, 1951, 1955, and culminated in a thorough review prepared by the Department of Conservation and Environment in 1991 (DCE, 1991). This last review included a careful analysis of 143 potential dam sites which satisfied two criteria related to storage size and water quality, namely: 1) only sites suitable for large dams with capacities greater than 10 GL were considered, and 2) the salinity of the river water needed to be less than 1000 mg/l. This list was further culled on the basis of engineering considerations and the likely impact on existing communities, and a final set of 73 sites were subjected to more detailed investigation.

The short-list of potential sites were ranked according to site-specific construction costs and the potential annual supply volumes. The hydrological analyses took into consideration the variability of streamflow yields and the reductions associated with interception by upstream dams. The potential sites were ranked on the basis of the capital cost required to the supply each incremental ML of water.

A summary of the priority sites identified by the Department of Conservation and Environment (1991) is shown in Figure 3.4. This figure suggests that the basins with the lowest marginal cost of development, with high yields, are in the Goulburn, Snowy and Mitchell. In total these developments would add a total of 1260 GL yield at a cost of around $82/ML. This increment represents an increase of 10% to 15% over the total available yields from existing dams. The costs shown in this figure have been adjusted to reflect 2016 prices using the Consumer Price Index as calculated by the Australian Bureau of Statistics (Table 6401.0)[10]. While it might be expected that infrastructure costs vary at a different rate to consumer prices, there is evidence that these two cost indices track each other closely over the majority of this period (GHD, 2011).



No.	Name	Location	Yield (GL/annum)	Capital Cost ($/ML)
1	Upper Murray	Snowy Creek	106	501
2	Kiewa	Kiewa River	181	253
3	Ovens	Buffalo River	388	588
4	Broken	Broken River	43	760
5	Goulburn	Camp Hill	424	80
6	Campaspe	Dalys Hill	2	17901
7	Loddon	McCullum	1	28598
8	Avoca	(Too saline)		-
9	Mallee	(No streamflow)		-
10	Wimmera	(Too saline)		-
11	East Gippsland	Bemm River	81	552
12	Snowy	Snowy River	420	85
13	Tambo	Moonlight	97	521
14	Mithcell	Mitchell River	416	80
15	Thomson	Lower Thomosn	121	382
16	Latrobe	Site L6	145	487
17	South Gippsland	Wilkur Creek	28	1097
18	Bunyip	Heath Hill	40	820
19	Yarra	Watsons Creek	2	15023
20	Maribyrnong	Deep Creek	43	729
21	Werribee	Hogans Springs	0.2	222630
22	Moorabool	Morrisons	27	1571
23	Barwon	Leigh River	45	874
24	Corangamite	(Too saline)		-
25	Otway	Hall Ridge	64	643
26	Hopkins	(Too saline)		-
27	Portland	Surrey River	10	2787
28	Glenelg	Mirranatwa	12	2353
29	Millicent Coast	(No sites)		-

Figure 3.4: Summary of development potential in each basin (adapted from Department of Conservation and Environment, 1991) where costs have been adjusted to 2016 prices.

The analysis of potential dam sites undertaken by the Department of Conservation and Environment (1991) was based solely on engineering and economic criteria. At that time there was little precedence or scientific

[10] http://www.abs.gov.au/ausstats/abs@.nsf/mf/6401.0

understanding to justify an assessment of environmental needs. Nor were there any inter-state agreements in place to limit further resource development in catchments north of the Great Dividing Range to satisfy sustainability criteria relevant to the whole of the Murray Darling Basin. Thus, by today's standards, this analysis of potential dam sites must be regarded as an "unconstrained upper estimate" of yields. The following section provides a "back of the envelope" assessment of the practical limits that are likely to apply to these estimates.

3.5 Sustainable Limit Constraints

3.5.1 Water Management Reforms

As noted in the preceding two sections, over the past 30 years the Victorian government has progressively developed a number of institutional, policy, and legislative reforms to help ensure that water resources are managed in a sustainable manner. In many cases these reforms have been developed in agreement with other State governments (NSW, Queensland, and South Australia), and with other relevant agencies (the Murray Darling Basin Authority). The following reforms are of particular relevance to the development of new dam sites in Victoria:

- Victorian Water Act (1989): the environment is recognised as a legitimate water user (part 4)

- Commonwealth Water Act (2007): establishes the Murray Darling Basin Authority with the enforcement powers needed to ensure that Basin water resources are managed in an integrated and sustainable way, and also establishes the Commonwealth Environmental Water Holder to manage the Commonwealth's environmental water to protect and restore the environmental assets of the Murray-Darling Basin.

- Victorian Government long-term water plan (2004-2007): includes provision for expansion of the "water grid", which is a network of rivers, channels and pipes linking major water systems (Department of Sustainability and Environment, 2007)

- The specification of Permissible Consumptive Volume limits by the State Minister for Water (in 2010)[11].

- Sustainable Water Strategies: covering the development, integration and implementation of management plans across all regions (Department of Sustainability and Environment, 2006, 2009, 2012[a,b])

- Murray Darling Basin Plan (2012): specifies "Sustainable Diversion Limits" that limit the combined volume of surface water and groundwater that can be extracted from northern Victoria (this was preceded by the Murray Darling Basin Cap (1995), which limited the volume of water that can be diverted from catchments north of the Great Dividing Range to 1993/94 levels of development).

The practical limits on the availability of Victoria's natural water supplies were severely tested during the recent "Millennium Drought" (1997 – 2009). Victoria experienced unprecedented dry conditions over this period and resulted in conditions that stretched water supply systems and water sharing rules up to (and beyond) their envisaged limits. The Government responded in a flexible manner and implemented a number of measures that provided: improved water sharing arrangements, clearer entitlements for the environment and more efficient use

[11] http://waterregister.vic.gov.au/images/documents/PCV%20surface%20water%20order%202010.pdf

of environmental water, reserve rules that reduce the likelihood of years with zero irrigation allocation, greater flexibility for water trade and the carryover of entitlements (Department of Environment, Land, Water and Planning, 2016[b]).

These conditions put water management arrangements in Victoria under a sustained period of heightened scrutiny. It is thus worth noting that the current view of the Victorian government as published in a recent discussion paper is that: "*The state's regulated surface water resources are largely already being used at their sustainable limits. This means there is little opportunity for 'new' water to be made available in these systems. Groundwater and unregulated surface water systems are also significant sources of water. In some parts of the state they are already being used at their sustainable limits. In other parts of the state some water remains available within the sustainable limits of some unregulated surface water systems and groundwater systems. It is important that any future increase in the consumptive use of water in those systems does not negatively affect the environment or other water users.*" (Department of Environment, Land, Water and Planning, 2016[a]). While it needs to be stressed that this is a discussion paper that has been prepared to encourage public discussion and feedback, this statement is notable given that the Millennium Drought has only recently ended; it could be imagined that if there was ever a time in the last 30 years to consider building new dams to augment water supplies, then this is perhaps the most opportune time to do so. The absence of discussions to actively pursue this option since the Millennium Drought is indicative of the perceived technical, economic, environmental and/or social challenges involved.

3.5.2 Working Assumptions

The foregoing developments perhaps explain why the strategic review of potential large dam sites has not been updated since the report prepared by Department of Conservation and Environment (1991). As discussed in the preceding section, the estimate of potential yields prepared in 1991 was based on engineering and economic criteria. It is of interest to determine how these estimates might be altered by the subsequent reforms, as discussed above. Given the scope of this paper, a "back of the envelope" approach is taken assuming that:

i) With the Basin Plan and SDL in place, it is not feasible to augment (or build) new large storages north of the Great Dividing Range;

ii) No extractions can occur in southern Victoria in summer months unless there is a transfer, cancellation, surrender or sale of another licence; and,

iii) Any water extracted in the winter months should be kept within a catchment-wide limit defined by the Winterfill Sustainable Diversion Limit[12], or lower limits where these have been determined.

The above assumptions are intended to represent a reasonable "best guess" of the upper limit of extractions that are likely to be considered sustainable; they are intended to represent a pragmatic set of constraints that are intended to balance the interests of the environment and the consumptive users. The rationale for these assumptions can be briefly argued as follows:

i) *Nil potential for new large dams in northern Victoria*: there is a strong acceptance on the need to cap further extractions in northern Victoria. This is primarily driven by the requirements of the Murray Darling Basin Plan (2012), and is entirely consistent with the analyses documented in the Northern Regional Sustainable Water Strategy (Department of Sustainability and Environment, 2009). By way of example,

[12] https://www.data.vic.gov.au/data/dataset/sustainable-diversion-limits

these analyses include an assessment (by detailed hydrological modelling) of the benefits of enlarging Lake Buffalo dam. This dam is located in the Ovens catchment, which is one of the last largely unregulated rivers in the Murray Darling Basin[13]. The analysis demonstrates that augmenting the capacity of Lake Buffalo does not create new water, but rather changes the reliability to other water users. It seems reasonable to argue that if the case can't be made for enlarging the capacity of an existing dam in one the most unregulated catchments in the Murray Darling Basin, then it is very unlikely that any proposal for augmenting or building a new dam could meet the requirements of the Basin Plan.

ii) *No extractions over summer in southern Victoria:* Water management strategies developed for southern Victoria (Department of Sustainability and Environment, 2011[a,b]) have been developed on the premise that the impacts of existing developments are felt most keenly during summer months, and that the available water over this period is already fully committed. It may be possible to develop a resource that includes summer extractions, but any such application would need to demonstrate that the net impact of any new arrangements is minimal. For the present assessment it seems reasonable to assume that any such allowance, if possible, will be negligible compared to the required yields of interest.

iii) *Limit extractions to the Winterfill Sustainable Diversion Limit*[14] *or lower limits where applicable*. One of the tools used to limit diversions in southern Victoria is the winterfill Sustainable Diversion Limit (Department of Sustainability and Environment, 2011[a,b]). Winterfill SDLs have been estimated for 1583 sub-catchments across Victoria, and they represent the upper limit of extractions over the winterfill months (July to October, inclusive) beyond which there is an unacceptable risk to the environment. Winterfill SDLs represent a limit determined on the basis of in-stream needs and do not take into account other environmental requirements which need to be considered. Permissible Consumptive Volumes[15] have been in place since 2010 and cap the total volume of licensed entitlement in a river basin; in general these will limit the potential for diversions below that specified by winterfill SDLs.

The above assumptions have been adopted to estimate the sustainable yields at potential large dam sites, as discussed in the following section.

3.6 Estimates of Sustainable Yields at Potential Dam Sites

Estimates of sustainable yields at potential large dam sites are made using the information presented in Figure 3.4, in combination with the assumption listed in the previous section. That is, the potential "unconstrained" yields that were determined in the original study by Department of Conservation and Environment (1991) are reduced to reflect the sustainable water management provisions that have been introduced over the intervening 30 years.

Adoption of the assumption that there is nil potential for new large dams in northern Victoria means that the effective yield of potential dams sites in the Upper Murray, Kiewa, Ovens, Broken, Goulburn, Campaspe and Loddon basins is zero.

[13] http://www.mdba.gov.au/discover-basin/catchments/ovens
[14] https://www.data.vic.gov.au/data/dataset/sustainable-diversion-limits
[15] http://waterregister.vic.gov.au/images/documents/PCV%20surface%20water%20order%202010.pdf

In southern Victoria, one estimate of sustainable dam yields may be obtained by comparing sustainable diversion limit volumes with the “unconstrained” yields determined by the Department of Conservation and Environment (1991). A plot of this relationship is shown in Figure 3.5, from which it is seen that, on average, the sustainable yields are about 14% of the “unconstrained” estimates. It is worth noting that the slope of this relationship reduces to 8.5% if only the smaller storages (less than 100 GL) are considered. This analysis also assumes that the winterfill licences taken from the SDL allocation are minor compared to the volume available.

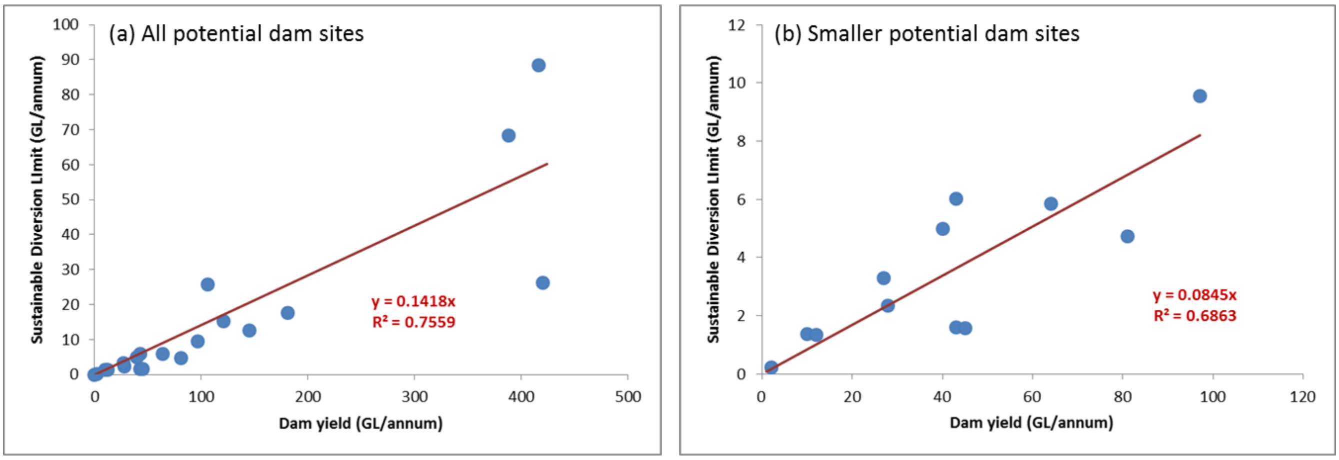


Figure 3.5: Estimate of sustainable dam yields from “unconstrained” estimates for (a) all potential dam sites and (b) smaller dams.

Some further indication of the practicality of developing of potential large dam sites in southern Victoria can be found in the sustainable water strategies developed by Department of Sustainability and Environment (2006, 2011[a,b]), in the associated background report on water availability undertaken by SKM (2011), and in the inquiry into Melbourne’s future water supply (Environment and Natural Resources Committee (2009). The only basins which are assessed to have some level of development potential in regional Victoria are in the East Gippsland, Tambo, Mitchell, South Gippsland, Otway and Portland basins. In terms of the potential for augmenting Melbourne’s water supply in the Central region, it is noted that no government strategy prepared in the past ten years has identified building a new dam as a feasible option compared to other sources of water and demand reduction measures (eg Lovering, 2006; Department of Sustainability and Environment, 2006; Environment and Natural Resources Committee, 2009; Melbourne Water, post-2013), though there are still some who argue on narrow economic grounds (eg Institute of Public Affairs, 2008) that there is the potential for new large dams to be built.

Removing the Northern and Central region basins, the remaining speculative list of potential dam sites is provided in Table 3.1, below. If the winterfill SDL limits are used to define sustainable dam yields (3rd column of Table 3.1) it is seen that there is a total of around 30 GL of additional potential across Victoria. However, this figure does not take into account the dependency of limits on groundwater extractions, nor does it is take into account the environmental water requirements of stressed dependent aquatic systems, such as the Gippsland Lakes. The figures also ignore the special environmental value of the few remaining pristine rivers. Importantly, they ignore climate change which is expected to further reduce streamflows by 20-30% below current levels

(CSIRO, 2015). The 4th column of Table 3.1 show the current best constraints based on such additional constraints identified through regional water strategies. While these figures are regarded as precautionary and are to be re-assessed within ten years, it would be optimistic to assume that these caps will be appreciably raised. The notional total of the additional potential yields across Victoria from these more precautionary constraints is about one third of the estimate based on the winterfill SDLs. In essence, it might be assumed that the estimates based on the winterfill SDLs represent a “reasonable upper limit” of the potential dam yields (3rd column, Table 3.1), and those based on the precautionary limits specified in the regional water strategies (4th column, Table 3.1) represent a “current best estimate” based on current information.

The point also needs to be made that many of the caps on extractions are usually based on limiting patterns of existing water use. The rivers listed in Table 1 are unregulated, and thus the impacts due to additional extractions or distributed interception systems (such as farm dams) tend to reduce seasonal streamflows in a manner that varies with availability. However, as shown in Figure 3.3, the construction of large dams also have the potential to reverse the seasonality of flows, and this has additional adverse impacts on in-stream and riparian biota that unregulated interception schemes do not have. More sophisticated outlet works can be constructed to help mitigate these factors (and those associated with cold-water pollution), but such works will add to the capital cost of the structures above historic benchmarks, and they will further reduce the reliability of supply as some high flows will be released rather than harvested.

Table 3.1: Speculative upper limit of yields from potential dam sites

Basin	Location	Yield (GL/annum) based on		Capital Cost ($/ML)
		SDL adjustment[1] (“reasonable upper limit”)	Other known constraints (“current best estimate”)	
East Gippsland	Bemm River	4.7	0.5 [2]	300 [5]
Tambo	Moonlight	9.5	1.5 [2]	290 [5]
Mitchell	Mitchell River	8.8	6.0 [2]	800-1600 [6]
South Gippsland	Wilkur Ck	2.3	2.5 [2]	600 [5]
Otway	Hall Ridge	5.8	0.3 [4]	360 [5]
Portland	Surrey R	1.3	0.5 [4]	1540 [5]

1. Factor based on the lower value of the SDL specified for the catchment and the regional estimate derived from relationship in Figure 3.5.
2. Department of Sustainability and Environment (DSE) (2011[b])
3. The Aire River is protected under the Heritage Rivers Act 1992
4. Department of Sustainability and Environment (DSE) (2011[a])
5. As per CPI adjusted figures summarised in Figure 3.4
6. Australian Government Department of Agriculture (2014)

The upper estimate of water that could be supplied from these dams is less than 0.5% of the yields provided by existing dams. The cost of the water to consumers will be greater than that indicated by the capital cost shown in the last column of Table 3.1 for several reasons. Firstly, recurring annual operational costs represent, approximately, an additional 5% of the capital costs (Environment and Natural Resources Committee, 2009), and then additional costs are involved in supplying the water to the consumer (particularly if for potable use). Also, the estimates are largely based on historic benchmarks, and it is likely that the unit cost will increase due to the increased need to provide environmental releases. The cost estimate of water supplied from the Mitchell River dam is based on current methodologies, and the upper range of this estimate represents a similar cost per ML as provided by bulk water providers.

Overall, it can be stated that the potential for new large dams to provide a material increase in yields is limited, but that the costs of doing so are perhaps comparable to the existing costs of supply.

3.7 Other Considerations

Although the focus of this paper is restricted to the potential for new large dams, it difficult to do this without making some reference to the broader infrastructure that such developments would sit within. Once built, additional infrastructure is needed to distribute the harvested water to consumptive users, and if the users are not located downstream of the storage then this can add considerable costs to the development.

Victoria has been long served by a "water grid" of pipes and channels that distribute water from high-yielding catchments to where it is needed. The network of irrigation channels in northern Victoria has existed for over a hundred years, and it has long been used to move water across catchment divides in response to community needs. The advent of the Millennium drought has resulted in significant further expansion of the grid, including construction of the Sugarloaf (North-South) pipeline, Melbourne-Geelong Pipeline, Tarago-Warragul-Moe Pipeline, Wimmera Mallee Interconnector, Goldfields Superpipe (connecting Ballarat and Bendigo to the northern water system), the Hamilton Grampians Interconnector. The grid allows water savings to be made in one location, and then used to augment supplies in another. For example, reductions in demand for potable water from natural supplies in Melbourne can be used to increase the reliability of supplies to communities in Geelong and along the Surf Coast. Improvements in irrigation efficiencies "create" more water that allow buyers and sellers to better manage their risks and take advantage of changing water markets over wide geographical areas.

Dams do not create water, they just harvest naturally occurring streamflows. Building bigger dams will not increase the security of supply to downstream users in a drying climate. Shifting rainfall patterns associated with climate change will increase the need to move water across catchment divides, and it is likely that they will alter the historical balance between local supply and demand.

Increased reliance on the water grid will allow a more diverse mix of supplies, including the conjunctive use of groundwater and distributed surface water storages and diversions. It will also facilitate the harvesting and re-distribution of water sourced from stormwater and other "non-traditional' sources. Further expansion and exploitation of our water grid will increase the degree of complexity required to manage the harvesting and distribution of our water supplies. While it is clear that the investments made over the last decade have improved our resilience to drought, it is not clear to what extent further expansion will satisfy the future changes associated with population growth, climate change, and the needs of the environment.

3.8 Conclusions

Any defensible analysis of potential large dam sites must take into consideration economic, environmental, and social factors; a high level review, particularly one undertaken within a limited period of time, is necessarily speculative in nature and heavily dependent on the distillation of analyses undertaken by others.

An attempt has been made in this paper to estimate the sustainable yields for the most promising potential large dam sites in Victoria. The estimates are based on a comprehensive investigation that was undertaken over 30 years ago to identify the best large dam sites remaining in Victoria. The sites were selected on the basis of their potential to provide high yields at low cost, and since only one dam (of only 0.2 GL) has been built since that time, the outcomes of that study are still considered to represent the best opportunities for development based on purely engineering and financial criteria.

However, our understanding of the cumulative impacts of resource development on the environment has undergone a paradigm shift in the past 30 years, and this has had a large impact on policy and legislative changes relevant to sustainable water management. Accordingly, an attempt has been made in this paper to adjust the yield estimates derived using 30-year old engineering criteria with those more relevant to today's practices.

On the basis of the present review, it is concluded that there is:

- *Nil opportunity* for new large dams to be built in northern Victoria; and,
- *Limited opportunity* to build new large dams in undeveloped areas in southern Victoria.

The total additional yields likely from these dams would add less than 0.5% to the supplies provided by existing dams. The financial costs of this water are expected to be comparable to existing bulk supply costs. In considering the benefits of such developments, it needs to be recognised that the few remaining dam sites are located in natural catchments with largely undisturbed flow regimes. Any consideration of development will thus need to weigh up the loss of some of Victoria's most pristine riverine environments with the small incremental gains to supply volumes.

Based on the information available to date, it is concluded that there is only a small potential for new large dams to augment supplies (in southern Victoria only), and that the associated environmental challenges would be considerable. In view of this, it is speculated that there would be greater benefits to be gained in the further expansion and exploitation of Victoria's "water grid"; this has the potential to take advantage of multiple diverse sources of supply and ongoing demand reduction measures, which should lead to a greater level of water security for consumptive users and improved environmental outcomes.

3.9 References

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