Fire and filtration– addressing Health Based Targets and bushfire risk in water supply catchments

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– addressing Health Based Targets and bushfire risk to water supply catchments

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Abstract

Most of Melbourne's drinking water comes from forested catchments which are largely closed to the public to minimise water quality risks. Potential disruptions to maintaining high quality and low cost drinking water include a growing population and a changing and variable climate. The expected introduction of Health Based Targets (HBTs) in the Australian Drinking Water Guidelines provides an important driver to deliver public health outcomes and provides a consistent framework to show best practice is being used to manage microbial risks at the source. Melbourne's most important and protected water catchments feed into Silvan Reservoir. This study investigated the benefits and costs of integrated catchment management as a treatment process for drinking water supplied by the Silvan system. A facilitated participatory approach combined with benefit cost analysis (BCA) using the Investment Framework for Environmental Resources (INFFER) was used. This included an innovative approach to quantifying the risk of bushfire to Melbourne's water supply within a BCA framework. Benefits and costs were assessed for nine options, two focussing on managing microbial risk to meet HBTs and seven to address bushfire risks. Protecting the Silvan Reservoir had the highest adjusted benefit cost ratio (BCR = 2.14) over 30 years. Protecting the whole system (including Upper Yarra and Thomson catchments) was marginally uneconomic (adjusted BCR = 0.93), but would be economically viable with some minor efforts to reduce project-based risks. Enhanced catchment management to protect against bushfire impacts was also close to being economically viable (BCR = 0.96). Innovative measures to reduce debris flow impacts was also promising (BCR = 1.30) whereas investment in filtration plants was poor (BCRs range 0.06 to 0.45).

Keywords

Health based targets, catchment management, bushfire, benefit cost analysis, INFFER

Introduction

As outlined in the Drinking Water Quality Strategy (Melbourne Water, 2017), Melbourne Water faces a number of challenges in managing Melbourne's water resources over the next 50 years, including providing enough water for an increasing population and changing climate, whilst delivering safe, secure and affordable drinking water. The expected introduction of Health Based Targets (HBTs) in the Australian Drinking Water Guidelines (ADWG) (NHMRC and NRMMC, 2011) (Anon., 2015a) provides an important driver to deliver public health outcomes and provide a consistent framework to show how best practice is being used to manage microbial risks at the source. To achieve best practice in the management of drinking water, MW is exploring the use of HBTs to ensure that water treatment matches catchment risks.

Most of Melbourne's water is supplied from the Silvan water supply system (which includes Silvan Reservoir and the Upper Yarra, Thomson, O'Shannassy and Yarra Tributaries water supply catchments). Given the importance of this system to supply, it is important that risks are identifed and managed in a rigorous, but cost effective way. The approach developed here is helping Melbourne Water to robustly assess different management options to address the dominant threats to the drinking water supply faced in the Silvan system. This includes a benefit cost analysis (BCA) framework that quantifies key risks (such as bushfires) in monetary terms and provides a transparent approach to prioritising management options for the catchment using a participatory approach.

Method

The general steps in the approach to undertaking the BCA of catchment management options was:

- Develop an understanding of the current system, including HBT categories and key threats to the quality of water supplied by the catchment
- Establish a base case scenario and develop an understanding of the trajectory of threats into the future
- Develop potential management actions to address threats
- Quantify the costs of management actions
- Quantify the benefits of management actions
- Using the INFFER process, develop an understanding of the key impediments to delivery of benefits, and adjust benefits accordingly
- Compare discounted benefits and costs and rank options.

Given the complex nature of the issues involved and the need for integration across agencies and divisions within Melbourne Water (e.g. catchment managers, asset managers, integrated planning, drinking water quality scientists, operations management) and across the three land management agencies (Melbourne Water, Parks Victoria and the Department of Environment, Land, Water and Planning (DELWP)), using an iterative participatory approach was crucial. The project worked through a Project Working Group (PWG), with each agency represented and the main discipline expertise was also represented.

Health Based Targets

Melbourne Water aims to achieve best practice in the management of drinking water and has used the recent WSSA HBT manual to ensure that water treatment matches catchment risks. Under this approach, catchments are classified into one of four categories according to their level of risk regarding drinking water quality: from Category 1 (fully protected catchment) to Category 4 (unprotected), as shown in Table 1. Sanitary Surveys along with microbial water quality data are used as a basis of assessing HBT Categories, and water treatment must be matched to HBT Category.

Table 1: Health-Based Target Catchment Categories and current classification of Silvan system components.

HBT Category	Example of protection	Relevant current classification of Silvan system components
1. Protected catchment	No human settlement / recreation Natural bushland Enforcement	Upper Yarra catchment, O'Shannassy catchment, Upper Yarra tributary catchments, Upper Yarra Aqueduct, Upper Yarra supply conduits
2. Moderately protected	Human settlement excluded from inner catchment Recreation in outer catchment Enforcement No farming in inner catchment	Thomson catchment, Silvan Reservoir catchment
3. Poorly protected	Human settlement excluded from inner catchment No water recreation Stock access to feeder streams	
4. Unprotected	No exclusion zone	

Catchments with higher HBT categories have greater risk of pathogens entering the reservoir and require additional water treatment (such as ultra-violet (UV) treatment or filtration) to meet drinking water standards. The PWG agreed that under a 'business as usual' scenario (base case), increased contamination risks from pest animal faeces (primarily deer) and illegal human activities will require ultra-violet treatment to be employed to meet drinking water standards. Catchment management actions that reduce these risks defer the need to implement UV treatment, resulting in cost savings. In this BCA, these savings are the primary benefit of undertaking catchment works that reduce pathogenic risks to the water supply.

Bushfire risk

Bushfire threats to drinking water supply were identified by the PWG as one of the most major threats to the Upper Yarra, Thomson, O'Shannassy and Yarra Tributaries catchments. Whilst this threat is not directly related to achieving HBTs, the PWG agreed that as part of best practice catchment management the threat of bushfire needed to be considered. Water turbidity created by ash and debris flow increases the risk of pathogen outbreaks, while also impacting on water quality more generally, with the potential to shut down water supply from these reservoirs for lengthy periods. Bushfires in the densely forested Upper Yarra catchment have the potential to significantly affect water quality within the Upper Yarra Reservoir, while also preventing access to water stores in the Thomson Reservoir (which supplies Melbourne via the Upper Yarra Reservoir).

The risk that an individual bushfire event poses to Melbourne's water supply is the product of:

- the likelihood that a bushfire event will occur that impacts the water supply (including ignition, fuel, weather, and debris flow factors); and
- the consequence of the bushfire event (which consists of the flow-on impacts of interruptions including the cost of providing alternative supplies and the impact of any water restrictions required).

Assessing the risk of bushfire to the water supply requires an understanding of the relationship between these two components of risk across a range of bushfire events.

Average Annual Damage approach to quantifying bushfire risk

There exists a large variety of possible bushfires of varying scale, location and likelihood that could threaten water supplies. Large fires with flow-on debris flow events have greater consequential impacts, but are less likely than smaller fires with lower consequences. As a result, there is a negative relationship between bushfire consequences and likelihood of occurrence. The approach applied approximates this relationship so that the Average Annual Damage (AAD) of bushfires in the catchment can be estimated.

The AAD caused by bushfire is the (statistically) expected impact of bushfire in any given year, based on a distribution of the consequences of bushfires weighted by their approximate likelihood of occurrence in any given year (the Annual Exceedance probability, or AEP). A bushfire event that is expected to occur once every 100 years is said to have Annual Exceedance Probability (AEP) of 0.01. By mapping the relationship between the consequence of events and their corresponding AEP, a downward sloping curve is developed. The area under the curve represents the AAD (see Figure 1).

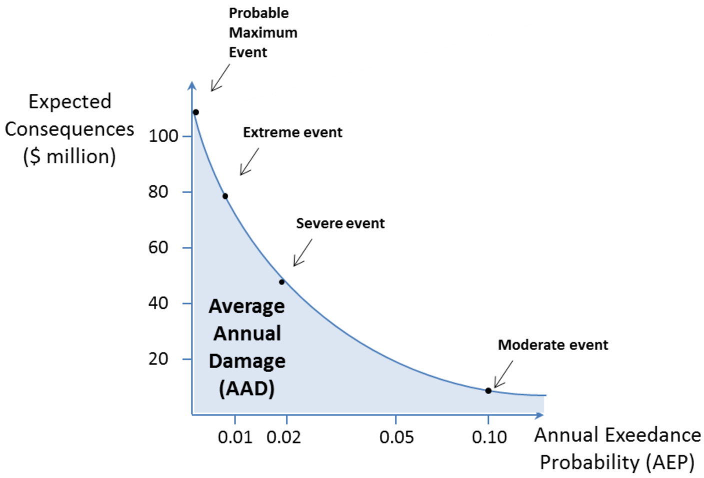

Figure 1. Average Annual Damage curve example.

Bushfire events used to estimate AAD – current and future

Plotting the exact shape of this curve requires the consequences and likelihoods of a large number of events to be estimated, which was impractical for this project. The pragmatic approach taken to approximate this curve uses interpolation between points representing a small number events – moderate, severe, extreme, and an estimated upper limit to consequences (the Probable Maximum Event, or PME) as depicted in Figure 2. The events were defined based on the impact of bushfire on the ability to deliver water from the Upper Yarra Reservoir (which also impacts the ability to deliver water from the Thomson Reservoir). The current likelihood and consequences for these events was developed using inputs in workshops with technical experts and available bushfire and debris flow modelling (not presented here) for the Silvan system, presented in Table 2 (2019 figures).

Table 2: Defined events, consequences, and probabilities of having the Upper Yarra Reservoir offline (2019)

Event	Consequence	Annual probability of bushfire of sufficient size*	Probability of consequential debris flow**	Combined probability of event
Probable Maximum Event	Upper Yarra Reservoir offline for 2 years	0 – 0.001 (<1 in 1000 year ARI)	1	0 – 0.001
Extreme	Upper Yarra Reservoir offline for 1 year	0.025 (1 in 40 year ARI)	0.36	0.009
Severe	Upper Yarra Reservoir offline for 6 months	0.067 (1 in 15 year ARI)	0.33	0.022
Moderate	Upper Yarra Reservoir offline for two months	0.133 (1 in 7.5 year ARI)	0.18	0.024

*Average Return Intervals (ARI) estimated in technical workshop. Annual probability is calculated as 1/ARI.
** Probabilities provided by Gary Sheridan and team at Melbourne University based on debris flow modelling (not shown here).

This was repeated for 2049 to estimate future likelihood (resulting in probabilities that were approximately 20% higher due to climate change impacts, data not shown).

Estimating the volume and costs of water required from alternative sources

The impact of the bushfire events described in Table 2 results in interruptions to the supply of water from the Upper Yarra Reservoir, which also interrupts supply from the Thomson Reservoir. Water must be sourced from alternative supplies when this occurs, and any demand that cannot be met represents a shortfall that will result in cost implications (e.g. water restrictions) to Melbourne Water customers.

Melbourne Water undertook modelling to estimate the impacts of Upper Yarra being offline for the timespans defined under each of the events under consideration for the analysis (results not shown). The cost that this imposes on Melbourne Water and its customers includes the cost of providing water from alternative sources (other catchments and desalination water) and, where alternative sources cannot meet demand, the social cost of water restrictions. These costs were agreed with Melbourne Water and included in the analysis.

Projections of Average Annual Damage over time

Without any change in current management, the risk of bushfire is expected to increase as time progresses. This is due to a combination of factors including: 1) The likelihood of bushfire events being expected to rise with hotter, drier conditions expected under climate change; 2) The likelihood of debris flow events is expected to increase due to an increase in intense rainfall events under climate change. The consequences of interruptions to supply from the Upper Yarra Reservoir are expected to increase as water demand increases and redundancy in the capacity of the overall system diminishes (resulting in greater unmet demand and consequential water restrictions). This results in an outward movement in the AAD curve and associated increase in AAD over time, which was factored into the analysis.

Using Average Annual Damage in the Benefit Cost Analysis

The benefit of managing the risk of bushfire to the water supply is estimated through the expected reduction in AAD over time relative to the base case. Note that benefits may exist even if the total level of AAD does not fall over time relative to current levels – it is the projected change in AAD brought about by the options that is the benefit to be assessed by the benefit cost analysis (see Figure 2). These benefits were then discounted to present value to compare with the discounted costs of management actions over the assessment period.

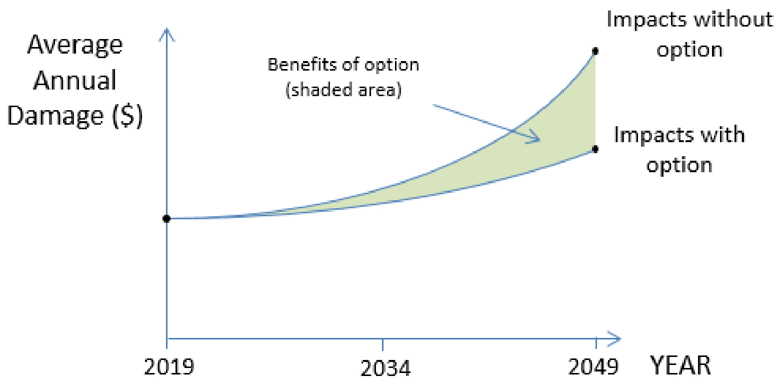

Figure 2. Example of assessment of average annual damage (AAD) reduction benefits.

Results

Overview of base case and options

Options developed to cover HBTs and address the risks of bushfires are shown in Table 3. Two options (Options 1 and 2) were developed for managing the direct risk of pathogens entering the Upper Yarra Reservoir to address HBTs. Seven options (Options 3 to 9) were developed for managing the risk of bushfire impacts on the water supplies from the Upper Yarra Reservoir.

Table 3: Overview of options analysed.

Option name	Brief description
Base Case	The Silvan Reservoir is currently classified as HBT Category 2. An Ultra-Violet (UV) treatment plant will be required in 5 years to manage the growing microbial risks to the water supply posed by pest animals (particularly deer), and illegal human activities (eg hunting, fishing). Current bushfire management will continue, including planned burning and Melbourne Water providing first attack capability within 10km protection zone of

Option name	Brief description
	water supply catchments.
1 - Silvan Reservoir (HBT Cat 1) for 15 years then Cat 2	Protection of Silvan Reservoir by building a more secure fence along with increased patrols and surveillance to prevent illegal entries. Includes removal of the Coranderrk/Silvan inlet channel. Actions undertaken in the Silvan Reservoir catchment can protect the Silvan system as a whole for a time period (assumed to be 15 years) before UV is required.
2 - HBT Cat 1 for all Silvan system except Thomson (HBT Cat 2)	As well as protecting the Silvan Reservoir, this option also protects the Upper Yarra, Thomson, O'Shannassy and Tributary catchments, through catchment actions. The most significant actions are to reduce illegal activities and undertake deer control in all catchments, along with removing cattle from the Thomson catchment. This option protects components of the Silvan system to Category 1 status, except for the Thomson which will remain at Category 2. Actions taken in all catchments are assumed to protect the whole Silvan system and delay the need for the UV plant for the 30 year analysis time-period.
3 - Enhanced bushfire management	Additional effort and resources to avoid and suppress bushfire events can be deployed to reduce the risks to Melbourne's water supply. Actions will be undertaken both within and well beyond the water supply catchments because it is well established that major bushfires come from the north. Three major sets of actions will be undertaken; 1) Actions to reduce the risk of ignitions in catchments; 2) Increased planned burning; 3) Improved first attack response.
4 - Reduce debris-flow risk from bushfires	A range of pre- and post-fire actions are undertaken to reduce the impact of debris flows occurring in the Upper Yarra catchment. Debris flow racks and hillslope barriers will be installed in the 50 highest risk catchment stream beds along with additional road requirements for installation and maintenance. Additional prescribed burning also would be conducted along with post-bushfire mulching.
5 - Build direct filtration plant to reduce bushfire consequences	This option assumes a direct filtration plant is built so that the impacts of bushfire on the water supply can be more effectively managed. The direct filtration plant is capable of treating water to reduce the impacts from bushfire of severity enough to take the Upper Yarra off-line for 6 months in the absence of treatment plant capacity. It is assumed that the plant will be built in year 10.
6 - Build conventional filtration plant to reduce bushfire consequences	The concept is the same as for Option 5, except that a conventional filtration plant would be built which can treat water after an extreme fire in the Upper Yarra which is sufficient to take the water supply off-line for 12 months in the absence of treatment plant capacity.
7 - Build fixed bypass tunnel to reduce bushfire consequences	In this option a tunnel would be built to enable water to be transferred from the Thomson catchment in the event that the Upper Yarra catchment is taken off-line from bushfires. Building a bypass tunnel from the Thomson catchment would allow water to continue to be delivered to the Silvan treatment plant. This option assumes that the Thomson catchment has not been burnt.
8 - Upper Yarra bypass – floating by pass (contingency)	The concept is similar to that of Option 7, in bypassing the Upper Yarra system in the event of a bushfire and enabling water from the Thomson to continue to be used at Silvan. However instead of building a costly fixed pipeline, works would be done at the Upper Yarra Reservoir off-take. A lower cost 'floating' pipe would be installed when needed and stored when not.
9 - Upgrade Winneke	The Winneke treatment plant would be upgraded as a pre-emptive measure to treat turbid water which is anticipated in the event of a major bushfire in the Upper Yarra catchment. Upgrading Winneke would enable an additional 100 ML/day water to be treated in response to bushfires and other emergencies.

Benefit Cost Analysis results

The BCA was undertaken over a 30-year assessment period, using Melbourne Water's discount rate of 4.2 percent. Benefits were then adjusted using the INFFER process based on risk factors that may prevent benefits being realised including technical feasibility, socio-political risks, and security of funding being maintained.

Both the unadjusted and risk-adjusted benefit cost ratios are presented in TABLE 4.

Table 4: Summary of INFFER benefit cost analysis results for the Silvan water supply system.

Option	Option type	Unadjusted benefit cost ratios	Risk-adjusted results benefit cost ratios
1. Silvan Res HBT Cat 1 for 15 yrs then Cat 2	HBT	3.49	2.14
2. Silvan system HBT Cat 1	HBT	1.84	0.93
3. Enhanced bushfire management	Bushfire	1.62	0.96
4. Debris flow management	Bushfire	4.65	1.30
5. Direct Filtration Plant	Bushfire	0.07	0.06
6. Conventional Filtration Plant	Bushfire	0.11	0.10
7. Upper Yarra Fixed bypass	Bushfire	0.16	0.14
8. Upper Yarra Floating bypass	Bushfire	0.90	0.66
9. Upgrade Winneke	Bushfire	0.51	0.45

The preferred HBT option is to provide greater protection to Silvan Reservoir by preventing human access to the reservoir. This will provide sufficient protection to prevent the need for a UV plant until pressures in other parts of the system become greater (at which time the Silvan Reservoir would become a Category 2 catchment). Option 2, which involves greater protection of the whole Silvan system, is also economic before risk-adjustment (BCR=1.84) and only marginally economic (BCR= 0.93) with risk-adjustments. This suggests that addressing some of the risk factors in even relatively minor ways may result in this being an economically viable option.

Of the bushfire management options, the most economically viable option is to manage debris flow risks by taking both pre-emptive and post-fire measures. These actions have the potential to be highly economic (BCR = 4.65), however a number of risks exist (mostly relating to technical feasibility) that significantly reduce the viability of this investment. Enhancing efforts to prevent and suppress bushfire also shows promise, with adjusted BCR of 1.62 and a BCR of 0.96 (Option 3) after accounting for risks in realising benefits.

Conclusions

Health-based targets provide a driver for water authorities to more seriously consider catchment management options to protect the quality of source. Results show that it appears possible to protect most of Melbourne's water supply catchments in the Silvan system to maintain HBT Category 1 status for the Silvan Reservoir, or the Silvan system as a whole, for reasonable costs compared with building water treatment plants in the near-term. Although this result makes intuitive sense, Melbourne Water has not previously had a robust basis for discussion about catchment management compared with engineering options.

Bushfires pose the most significant risk to the Silvan system and Melbourne Water has made substantial investments in improving understanding of bushfire risks and mitigation strategies. However, until now it has been hard for the organisation to know how to incorporate the bushfire science and modelling into decision-making. The AAD approach employed here provides a means of capturing the variability and uncertainty of bushfire impacts in a quantitative way. This approach lends itself to use in benefit cost analysis so that the cost effectiveness of management options can be assessed in a robust manner. The work has provided a basis for discussion and decision-making within the three land management agencies. The outcomes of this work have shown that actions aimed at managing debris flow and additional resources for preventing and suppressing bushfire are more cost effective in managing the risks of bushfire to the water supply than 'hard' engineering approaches such as filtration plants and piped bypasses. The work has generated significant interest and discussion amongst the three agencies and has been seen by Melbourne Water as an important (but initially unintended) benefit of the project.

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