DRINKING WATER TREATMENT PLANNING IN A CLIMATE OF CHANGE

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ABSTRACT

Drought, bushfires, floods, high temperatures; the unprecedented events that are a result of climate change are becoming more frequent in New Zealand. Regardless of climatic changes and/or instantaneous weather events, there is a critical requirement for the provision of safe and reliable supplies of drinking water during these times of increased risk to public health.

Many drinking water treatment schemes have been in operation for decades, often with minimal operational issues, but in recent times we have started seeing more variable and increasing peak poor water quality events. In many cases the planning and design of water treatment schemes did not have the foresight to consider how such events can affect water quality.

Results from a range of research and investigative projects have confirmed the impact of climate change and extreme weather events on raw drinking water quality, with an emphasis on the compounding of negative impacts when multiple hazardous events occur simultaneously or in quick succession. It is these events that have left some drinking water treatment systems in a position where they cannot produce a safe supply of water: some in the short-term, others for longer periods of time.

Typically, water treatment schemes are designed based on a review of historical data, then a selection of a set of design values is made based on a tolerable level of risk in regard to addressing peak poor water quality operationally. It should be stressed that supply of water that doesn’t meet drinking water quality standard requirements is not and must never be an option.

When reliable supply of safe water is a key driver for a system and there is a non-zero probability that an unprecedented water quality event will occur in the future, simply selecting a design value based on percentiles of historic data is inappropriate. This brings about the question of how to select a set of appropriate design values to ensure future reliability and/or adaptability, to cover raw water quality conditions that may never happen. How to adapt when you don’t know what you need to adapt to?

KEYWORDS

Climate Change, Water Treatment, Unprecedented, Water Quality, Adaptation

PRESENTER PROFILE

Sally Williamson is a lead engineer with Aurecon currently sitting in Sydney Water's treatment planning team. She has worked in a range of areas in the water industry over the past seventeen years, from microbiological analysis through to treatment design and commissioning, but specialising in water quality and risk management for drinking and recycled water schemes.

INTRODUCTION

Historically, drinking water treatment has remained relatively static with respect to technology. Thus, many drinking water treatment and supply schemes have been in operation for decades, often with only minimal operational issues and augmentation driven by growth/capacity. Outcomes of research and investigative projects (Khan et al., 2016) have confirmed the impacts of climate change and extreme weather events on raw drinking water quality. Drought, wildfires/bushfires and extreme wet weather are the key events that have been observed globally, not just in Australia and New Zealand.

Such events have left some drinking water treatment systems, which have historically operated well, in a position where they cannot produce a safe supply of water; some in the short-term, others for longer periods of time. The uncertainty around climate change and the unprecedented events it causes brings challenges in planning for future drinking water treatment needs.

CLIMATE CHANGE IMPACTS

A range of impacts on drinking water treatment and supply caused by climate change have been observed globally, but with varying risk profiles depending on location. Usually quantity is the first aspect that is thought of with respect to the impacts of climate change on drinking water supplies with reports of many communities approaching "day zero" caused by the combination of increased temperatures and reduced rainfall frequency that is commonly associated with severe and long-lasting drought. However, it is the quality of raw drinking water that can have an equally significant impact on communities.

The effects that are linked to climate change that have the potential to impact the quality of raw drinking water sources and/or the ability to treat raw water include:

- Increases in high temperatures and increases in occurrences of heatwave conditions
- Decreasing frequency but increasing intensity of wet weather events
- Increased duration of bushfire/wildfire seasons and increased intensity due to the combination of increased temperatures and dry conditions
- Combinations of the above resulting in the compounding of impacts

The specific impacts on raw water quality that are a direct result of effects of climate change are presented in Table 1.

Table 1: Climate Change Impacts on Raw Water Quality

CLIMATE CHANGE EFFECT	EVENT TYPE	IMPACTS TO RAW WATER QUALITY	TYPICAL TREND
• Increased average and maximum temperature • Reduced rainfall frequency • Reduction in volumes available for environmental flows and groundwater replenishment	Drought	• Settling of turbidity and other particulate contaminants • Concentration of contaminants – Organic carbon, salinity • Drawing Feed from New Depths/Sources • Saltwater intrusion into raw drinking water supplies	• Slow improvement or slow deterioration depending on the contaminant • Unknown water quality risk profiles
• Increased average and maximum temperature • Consecutive days at high temperatures	Heatwave	Increased temperature resulting in a chain of linked events: • Nutrients → Algae/Cyanobacteria → Low dissolved oxygen levels → Leeching of metals (Iron and Manganese) from sediments and/or Blackwater events resulting in fish kills	• Slow deterioration (site specific)
• Increased average and maximum temperature • Reduced rainfall frequency – increased dryness	Bushfire	Increase in: • Solids/turbidity (and potentially pathogens from deceased wildlife) • Organic carbon • Nutrients Magnitude of effect linked to subsequent timing and intensity of wet weather event.	• Slow deterioration (site specific)
• Decreased rainfall frequency, but increased rainfall intensity	Wet Weather and Flooding	Increase in: • Solids/turbidity (and potentially pathogens from deceased wildlife) • Organic carbon • Nutrients Dependent on time since last wet weather event and spatial occurrence of rain.	• Fast peaks followed by gradual decrease. *Note that different contaminants will decrease at different rates.*

Other risks to drinking water quality that are caused by climate change that are more relevant to the distribution network, but which also require risk mitigation, include:

- High temperatures of treated water increasing the likelihood of occurrence of *Naegleria fowleri*, putting pressure on the operation and maintenance of network chlorination systems.
- Increased formation of disinfection by-products observed at higher water temperatures and increasing trends in raw water organic carbon concentrations.

As an example of a poor water quality event that represents a long period without rain followed by an extreme wet weather event, Figure 1 shows the concentrations of dissolved organic carbon (DOC) and total organic carbon (TOC) during drought. This event started with available storage in a surface water reservoir that went as low as 35% followed by an extreme wet weather event that occurred in February 2020 that resulted in the fast filling of the reservoir. The inflows that entered the reservoir were high in DOC and TOC and caused the entire water column to be mixed (Williamson et al., 2021). The figure shows that the pre-2020 maximum TOC/DOC concentrations, that occurred at the last significant wet weather event in 2017 was around 3 mg/L lower and that during the drought that occurred between the two events TOC and DOC gradually decreased.

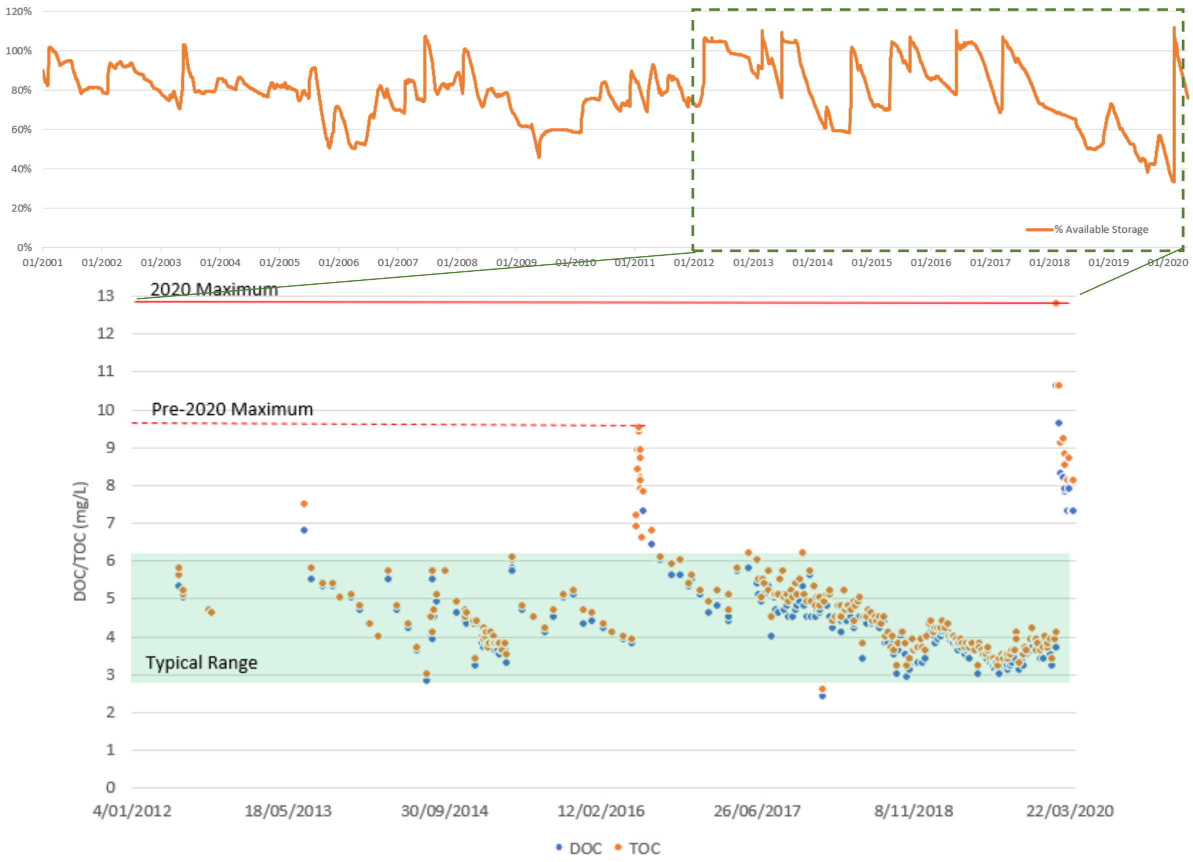

Figure 1: % Available Storage and Raw Water DOC/TOC Concentrations

Figure 2 provides a higher resolution snapshot of the behaviour of three key contaminants in raw water: turbidity, true colour, and DOC after the 2020 extreme wet weather event. The figure shows the difference between the behaviour of turbidity, which reduces to less than 50% of the peak after seven days and to around 10% of the peak in 20 days, whereas the concentration of DOC and true colour decreases at a much slower rate.

It is this behaviour that needs to be well understood when planning for treatment upgrades, as it could be the difference to system demand being met with respect to, on the one hand, being able to treat water of sustained poor quality or, on the other hand, a reduction in plant production capacity and the accompanying reliance on sufficient treated water stored in the network.

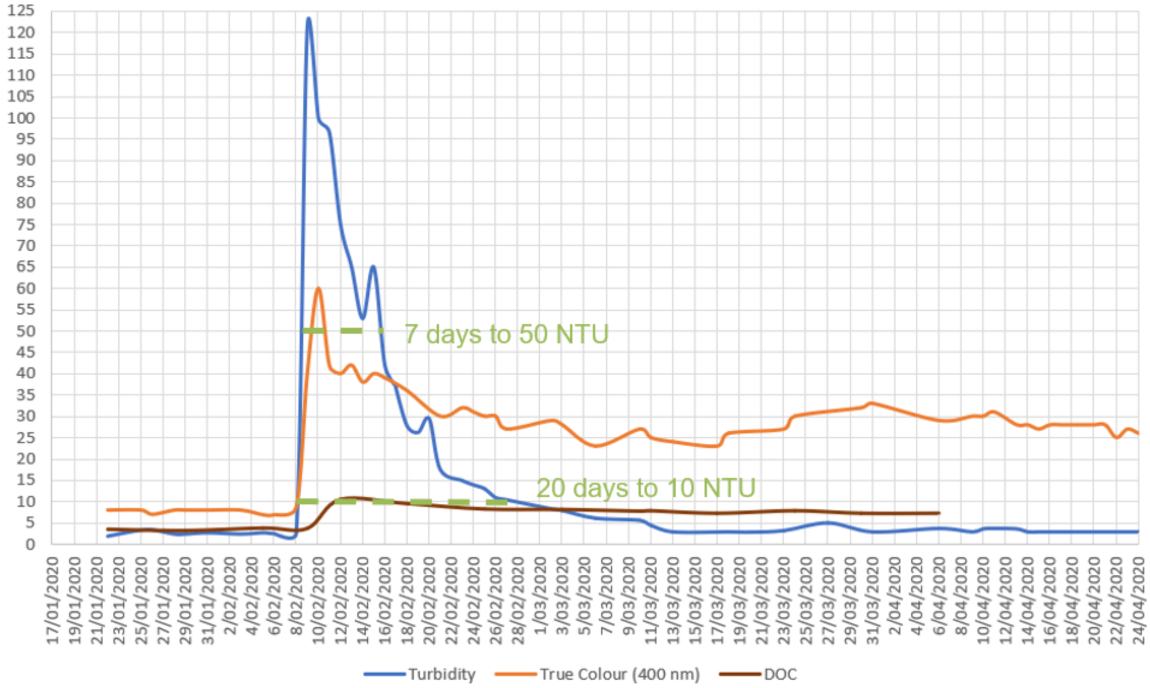

Figure 2: Raw Water Turbidity, Colour and DOC Trends After Wet Weather Event

DRINKING WATER TREATMENT

TYPICAL WATER TREATMENT TECHNOLOGY

Technology selection for drinking water treatment has always been specific to the type and characteristics of the raw water source. In the absence of climate change impacts the most complex drinking water treatment for surface water reservoir sources has typically been conventional treatment of flocculation/coagulation followed by settling (or flotation) and filtration. With many schemes having a direct filtration plant or even less depending on the raw water quality and/or catchment-related risk.

With relatively stable feed water quality, these types of treatment plants can operate with minimal operator intervention. However, with the increased intensity of extreme weather events as well as the compounding of risk when multiple events happen simultaneously or in quick succession, conventional treatment designed without climate change in mind are unlikely to be appropriate.

TREATMENT CRITERIA

There are two main categories of drivers with respect to water quality requirements and the treatment of drinking water:

- Safe drinking water, which is a non-negotiable requirement and comprises both health-based limits and maximum acceptable values (MAVs); and utility/site-specific operating targets/key performance indicators (KPIs).
- Drinking water that is aesthetically drinkable, which is an important requirement that involves meeting aesthetic guidelines values/limits to supply water that has minimal colour and no offensive taste or odour.

These drivers need to be considered in conjunction with the requirement to produce sufficient drinking water to meet demands in the community and the potential impact that water quality has on the production capability of drinking water treatment plants.

PLANNING CONSIDERATIONS

There is no "one size fits all" approach for drinking water treatment planning due to the variability in water supply system configurations as well as the nature of climate change impacts resulting in variable risk profiles for each raw water source. The following sections look at three considerations that should be made in the process of planning for drinking water treatment upgrades when developing an approach to climate change adaptation and risk mitigation.

ACCEPTABLE LEVEL OF SERVICE

The first consideration that needs to be made in the planning process is the acceptable level of service to the community. That is, what is the minimum quality and quantity of supply that the treatment system must meet to be acceptable to the community. As described previously, there are non-negotiable (health) water quality criteria that are regulated and represent the acceptable level of service for production quality. The acceptable level of service for aesthetic water quality criteria/limits is lower than for health criteria, in that the maximum duration they are exceeded is higher than for health limits and thus could potentially be exceeded if there is no alternative, but they are still an important consideration for designing treatment upgrade capability. In other words, water that is entirely healthy to drink may not meet aesthetic water quality criteria/limits.

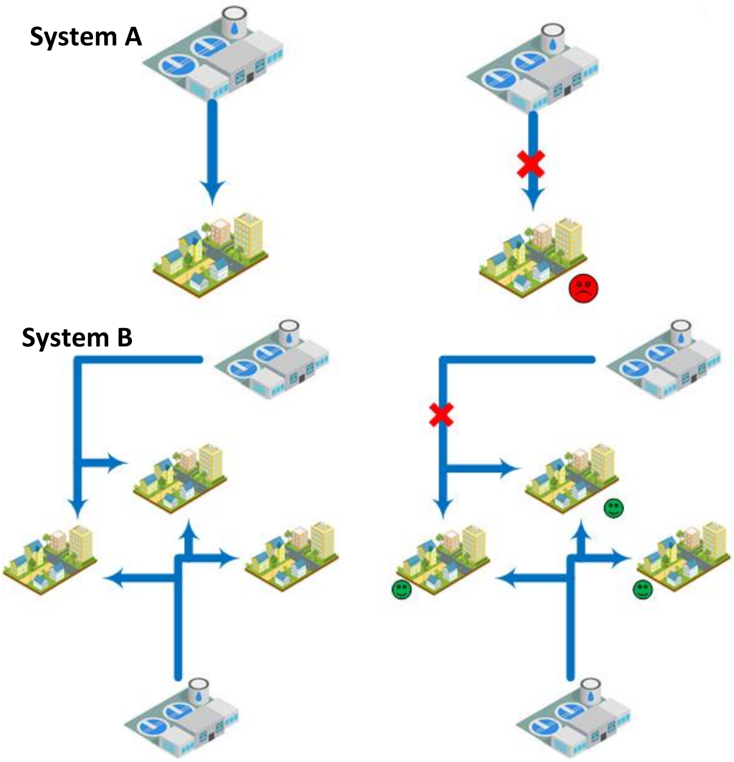

Figure 3: Isolated (System A) and Connected (System B) Systems

A key deciding factor in determining the minimum level of service for production quantity is the level of connectivity between systems. Where a treatment plant has a single source and supplies water to an isolated system the risk (system A in Figure 3) of not meeting demand is higher than for a system that can be supplied by multiple treatment plants and/or sources (System B in Figure 3). Thus, for System A emphasis needs to be placed on planning for a treatment process that can meet the demand under all raw water quality scenarios.

MANAGING VARIABILITY WITH STORAGE

Planning to manage variability can be approached in two ways: management using storage or management using treatment. For the hypothetical raw water quality event represented by a sudden peak followed by gradual decrease of one or more contaminants as described previously, management using storage uses either existing or new storage to store raw (System B in Figure 4) or treated (System C in Figure 4) water before or after treatment, respectively. This is compared to the configuration (System A in Figure 4) where the only option during a poor water quality event is to attempt to treat the available raw water (or turn the plant off) and if demands can't be met, the potential reliance on tankering or community boil water alerts, which incur a cost both in terms of finance and in terms of reputation.

The premise behind the approach to utilise storage is as follows:

- Offline storage of good quality raw water (pre-event) that can be used as the plant feed until the raw water quality event has passed (System B).
- Storage of treated water in network storages to allow the plant to be shut down during raw water quality events (System C).

Both approaches require operating the system (feed or network) above demand when raw water quality is good so that storages are as close to full as possible just prior to the event that can impact water quality in other ways. The key considerations that should be made when utilising system storage for mitigating the impacts of poor feed water quality events include the following:

- The duration of the poor raw feed water quality event during which the treatment plant would be unable to perform to meet the required water quality and/or quantity targets. That the types of events can be managed using this approach are limited by the available storage volumes. For example, if the event results in elevated turbidity only, the duration of the event is likely to be lower than if the event results in elevated colour (refer to Figure 2) or if the event results in elevated salinity caused by ongoing drought conditions with an unknown event end.
- The timing of the poor water quality scenario versus demand trends. That is, the likelihood of a poor water quality event (which are often triggered by an extreme wet weather event) occurring at the same time as a high customer demand and whether demand management needs to be employed.
- The limitations to available footprint to construct new storages that are sufficient in size to be able to buffer against the full duration of water quality events as well as operational issues around water age that could be introduced.

For the same hypothetical raw water quality event, managing using treatment relies solely (System A in Figure 3) on designing and operating a water treatment plant to continuously meet the acceptable levels of service to the community. That is, the treatment plant must be designed for not only the historic worst quality raw water event: due to climate change, we need to consider the potential future worst quality raw water event. To accomplish this, the full suite of process risks in the system, including those introduced by climate change, need to be considered. This is discussed in the following section.

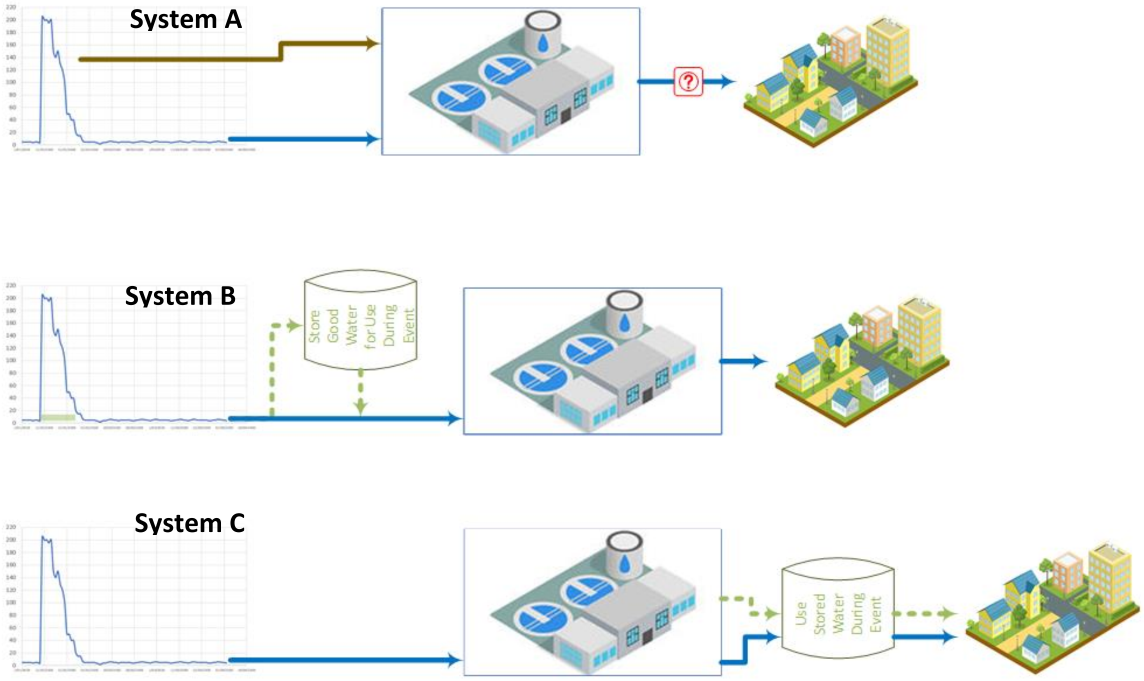

Figure 4: Storage Scenarios: System A – No storage, System B – Raw Water Offline Storage, and System C – Treated Water/Network Storage

PROCESS RISK

Process risk relates directly to the ability of the treatment plant to mitigate the water quality hazards that are caused by the impacts of climate change. As summarised in Table 1, different impacts of climate change increase the risk of different water quality hazards. However, the impacts of climate change on water quality don't present themselves uniformly in different locations let alone from one event to another.

Typically, water treatment schemes are designed based on a review of historical data, then a selection is made of a set of design values based on a tolerable level of risk of having to address peak poor water quality operationally. However, when a reliable supply of safe water is a key driver for a system (e.g. for systems such as System A in Figure 3, but also applicable to all system types and configurations at various magnitudes) and there is a non-zero probability that an unprecedented water quality event will occur in the future, simply selecting a design value based on percentiles of historic data is inappropriate. This brings about the question of how to select a set of appropriate design values to ensure future reliability and/or adaptability to cover raw water quality conditions that may never happen.

The first step in mitigating process risk is developing a broad understanding of the raw water catchment and the behaviour of the raw water source (reservoir, groundwater, or river) under the various climate change related events. Specifically, understanding of the types of events that could occur, the frequency and magnitude of those events (including the occurrence of multiple events types simultaneously or in quick succession), and the resulting water quality impacts that would arise with each event.

Once the process risks are understood, in addition to utilising available storage to mitigate the variability of raw water quality change, there are two approaches that could be taken with respect to mitigation. They are as follows:

- Increased treatment flexibility through the addition of new treatment processes to target specific hazards (System A in Figure 5).
- Increased monitoring at operational and critical control points (OCPs and CCPs) along the treatment train with targeted operational changes to mitigate risks in real time (System B in Figure 5).

The key differences between these two approaches come down to capital versus operational expenditure. The upgrades required for System A would require capital investment in treatment infrastructure to allow flexibility in treatment approaches and could be described as a proactive approach, whereas System B requires a finer resolution of monitoring and development of operational procedures (corrective actions) that could be implemented quickly and could be seen as a reactive approach that puts significant pressure on operations teams. However, the limitation that applies to both systems is the uncertainty around the magnitude of raw water quality degradation and the ability to mitigate this risk through additional treatment or targeted operational changes.

For System A, the uncertainty relates to the raw water quality feed design envelope that is selected, which will be able to cover a future scenario of unknown severity. This uncertainty could result in a treatment process that is not capable of meeting treatment targets, or in a treatment process that sits idle for long periods, or both. Typically, water treatment plants are designed based on a review of historical data, then selection is made of a set of design values based on a tolerable level of risk of having to address peak poor water quality operationally, however with the increased frequency of unprecedented events leading to previously unseen poor water quality this approach is no longer suitable. Thus, to minimise uncertainty when designing new or upgrades for water treatment the following should be employed in addition to the standard historic source water quality assessment:

- A detailed risk assessment looking at the behaviour of key water quality parameters in the catchment.
- An assessment of the existing system (if applicable) and its historical performance under adverse water quality scenarios.
- Application of climate forecasting and water quality modelling to historical peak contaminant levels, to develop future worst-case peak contaminant levels under a range of defined events.

For System B the uncertainty relates to the rate that raw feed water quality changes and the overall limitations on the operations team and the process. That is, even if there is a robust corrective action plan for a poor feed water quality scenario, can it be implemented quickly enough to mitigate risk, and what happens if the magnitude of raw water quality degradation exceeds the treatment capability of the plant. In other words, the plant will have a limit at which poor water quality can’t be treated with the available infrastructure and may eventually require capital expenditure. It should also be noted that whilst this approach can defer the need for capital investment, it puts significant pressure on the operations team, which requires the team to be highly trained and able to make key decisions quickly.

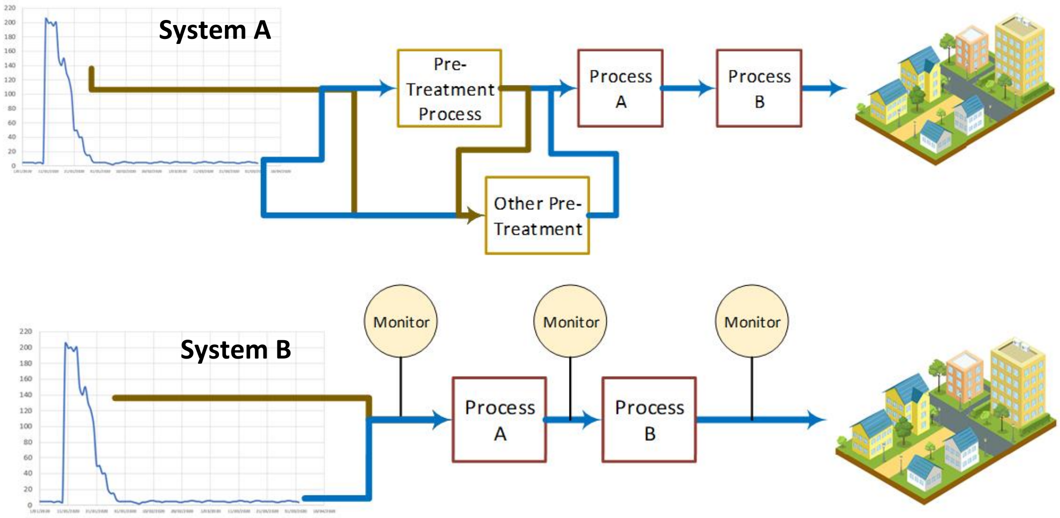

Figure 5: Treatment Configuration and/or Operational Scenarios: System A – Flexible Configuration, and System B – Optimised Monitoring

CONCLUSIONS

When assessing the overall risk of adopting an approach for mitigating process risk caused by climate change, there are multiple aspects that need to be considered. Selecting the approach for the mitigation of impacts of climate change inevitably comes back to the acceptable level of service with respect to quality and quantity of drinking water to the community. In selecting the most appropriate approach for a specific drinking water system, the key considerations are as follows:

- The configuration of the system and the ability to service the community with drinking water that meets the non-negotiable (health-based) water quality criteria.
- The ability to operate the system to avoid poor water quality events through utilisation of available storage and demand management.
- The level of investment (capital and/or operational) that is suitable for that system to mitigate process risks given the system configuration and its treatment limitations.

Whilst there is no “one size fits all” solution, through an increased understanding of the frequency and magnitude of climate change related events, the process risks relating to different events and the limitations of the system, planning to mitigate the risks to water quality caused by climate change impacts is feasible and necessary to maintaining an acceptable level of service to the community.

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