DYNAMIC ADAPTIVE PATHWAY PLANNING – ADDING FLEXIBILITY IN AN UNCERTAIN FUTURE

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ABSTRACT

New Zealand needs a fresh approach to deliver infrastructure planning which better accounts for uncertainty around future growth, climate change impacts, discharge requirements, influent quality, drinking water standards, societal perspectives, economics, new technologies and so on. Our water infrastructure must be able to adapt to these changing conditions in technically effective and economical ways. The traditional 'static' Master Planning approach is increasingly found to be inadequate and constrains water infrastructure planning. This can result in redundant infrastructure being built, leading to suboptimal outcomes for communities.

Dynamic Adaptive Pathway Planning (DAPP) is an innovative and valuable tool which enables asset owners to explore the outcomes of multiple scenarios and therefore develop a flexible but clear roadmap that is responsive to a range of future uncertainties.

This paper provides an overview of what Dynamic Adaptive Pathway Planning (DAPP) is. It outlines the DAPP method, discussing the establishment of drivers (eg capacity increase or new regulations) which lead to trigger points (eg capacity limits) followed by implementation points (eg new plant works), which then define potential pathways which an asset's life may follow.

DAPP is relatively novel in New Zealand's water industry and is mainly used for coastal adaptation and resilience planning, with Watercare beginning to incorporate DAPP into their infrastructure projects. This paper outlines Watercare's approach in applying DAPP to the Helensville water and wastewater treatment plants; these consider the handling of climate impacts on drought resilience and effects of increased flooding and sea level rise. These also consider uncertainty in growth forecasting. This long-term deep uncertainty has resulted in the need for short-term solutions that retain flexibility, such as the recent implementation of a floating cover and PE liner in the WWTP system as an effective low-tech alternative to traditional upgrade solutions. There are other ongoing examples of applying DAPP, including the Whangārei WWTP.

By combining a definition of the DAPP method with relevant case studies, this paper is a starting point for further consideration and adoption of DAPP by asset owners and their advisers. It is essential for the wellbeing of our communities that

we adopt better and more flexible infrastructure planning tools like DAPP in an increasingly uncertain future.

KEYWORDS

Master Planning, Adaptive Pathway Planning, Asset Management, Climate Change, Deep Uncertainty, Water Treatment, Wastewater Treatment

PRESENTER PROFILE

Apra Boyle-Gotla is an Infrastructure Planner at Watercare. She is passionate about the potential of the water industry to lead society's adaptation to a climate impacted future and has led Watercare's adaptive planning through practical implementation of complex strategic planning tools for decision making under deep uncertainty.

Danielle Maynard is a Water and Wastewater Process Engineer at GHD and has been gaining experience in treatment plant planning and design throughout New Zealand and the Pacific Islands. She has a strong interest in developing sustainable and futureproofed solutions and is excited to see the future of increased water reuse in New Zealand.

INTRODUCTION

New Zealand needs a fresh approach to deliver infrastructure planning. Amidst rapidly deepening uncertainty (prominent when considering climate change impacts), asset owners are increasingly finding that the traditional 'static' Master Planning approach is inadequate when planning the life of an asset. Focus is usually only directed towards growth and meeting demand which results in a design that only addresses one scenario. A master plan developed in this way also lacks a clause for regular review; subsequent master plans are then at risk of being completely re-worked with prior knowledge being lost. This outdated approach simply lacks the flexibility to adapt to changing conditions in technically effective and economical ways. This can result in redundant infrastructure being built, leading to suboptimal outcomes for communities. We must change our way of infrastructure planning to account for this uncertainty around future growth, climate change impacts, discharge requirements, influent quality, drinking water standards, societal perspectives, economics, new technologies and so on.

Developed by Deltares, Dynamic Adaptive Pathways Planning (DAPP) is an innovative and valuable tool which enables asset owners to explore the outcomes of multiple scenarios. This allows for the development of a flexible but clear roadmap (adaptive plan) that is responsive to a range of future uncertainties; it defines actions to be taken in the short and long term to address urgent issues while keeping options reasonably open. As a 'living' document, the adaptive plan is subject to periodic review and so evolves with the asset. A structured monitoring programme for the asset is included in the adaptive plan to inform these reviews. This approach may see a shift in the way that asset owners engage consultants for the design and upgrade of water infrastructure; long-term maintenance and review of an adaptive plan requires continuity. This provides both the opportunity for an asset owner to be more deeply involved in the planning and works, and for stakeholders to develop an intimate understanding of an asset and the factors influencing it.

DAPP is relatively novel in New Zealand's water industry and is mainly used for coastal adaptation and resilience planning, ie the Greater Wellington Regional Council's Hutt River Flood Protection strategy (Infometrics & PS Consulting, 2015). Hawke's Bay Regional Council, Napier City Council and Hastings District Council have also applied DAPP for coastal risk management of the Clifton to Tāngōio coastline (Tonkin + Taylor, 2018). Watercare are early adopters of this method and are beginning to incorporate DAPP into their infrastructure projects. This paper outlines the typical asset management challenges faced by Watercare and the deep uncertainty associated with changing weather and environment. Managed by Watercare, the Helensville water and wastewater treatment plants are a key example; these consider the handling of climate impacts on drought resilience and effects of increased flooding and sea level rise. They also consider uncertainty in growth forecasting.

By presenting a simplified definition of the DAPP method grounded in the New Zealand context, this paper is a starting point for further consideration and adoption of DAPP by asset owners and their advisers. It is essential for the wellbeing of our communities that we adopt better and more flexible infrastructure planning tools like DAPP in an increasingly uncertain future.

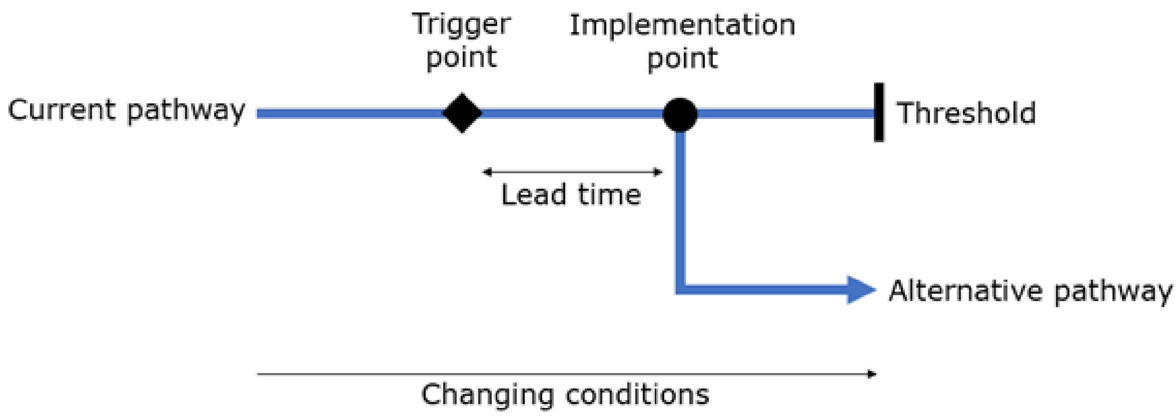
UNDERSTANDING DAPP – KEY CONCEPTS

An adaptive plan will generally include the following:

- Documentation of the drivers, triggers, and actions specific to an asset
- Adaptive pathways map
- Monitoring programme
- Programme for review of adaptive plan

An important component of an asset's adaptive plan is the adaptive pathways map; Figure 1 shows a simplified extract of an adaptive pathways map. A map is a living graphic which provides a way to concisely record the different pathways/options which may be implemented and how these pathways are linked to specific drivers of change and uncertainty. This helps decision makers to be well prepared, with a clear overview of how one decision may affect the overall life of an asset.

Figure 1: Adaptive pathways map, simplified example



This section defines the key concepts represented in an adaptive pathways map.

Pathway

A pathway is a series of option which represents a logical progression of works and initiatives that can be implemented for an asset/system. Decisions must be made to either continue down the current pathway, or to change to an alternate pathway; these decisions are influenced by drivers and trigger points (defined below). The pathways consider the outcomes of the preceding works.

Changing conditions

The X-axis of the adaptive pathways map follows changing conditions. The condition will vary between systems, but this axis commonly represents the progression of time or sea level rise.

Driver

A driver significantly influences the need for an action to be taken. Both the drivers and their urgency can vary between systems and can also evolve over the course of a system's life. For example, population growth is a driver common to most systems. Increasing population can cause strain on a system (ie increased population causing increased flows to a wastewater treatment plant) and drive the need to upgrade the system's capacity. Other drivers may include legislative changes, age of system/asset, industrial growth, emerging contaminants, carbon regulation, etc (Brotchie R., 2020).

Trigger Point

A trigger point is the point at which a decision must be made to either continue progressing down the current pathway, or to divert onto a different pathway. This is the point at which the "lead time" starts, to achieve implementation of the works/other at an appropriate time. A trigger point is determined in relation to a particular driver, eg population reaches a specified level.

Lead time

Lead time is the amount of time that is needed between a trigger point and an implementation point. This is to allow for the completion of the following: final concept preparation, project approval, construction and commissioning work, consideration of uncertainty, etc.

Implementation point

An implementation point is the point at which works/other are predicted to be required in response to a driver. This point may require transferring onto a new pathway, or it may just necessitate the implementation of upgrade works, etc.

Threshold

The threshold is the point at which a pathway/option is no longer viable. This may be due to asset age, capacity, regulatory limits, etc.

UNDERSTANDING DAPP – METHODOLOGY

Figure 2: DAPP methodology circular map (Brotchie R., 2020)

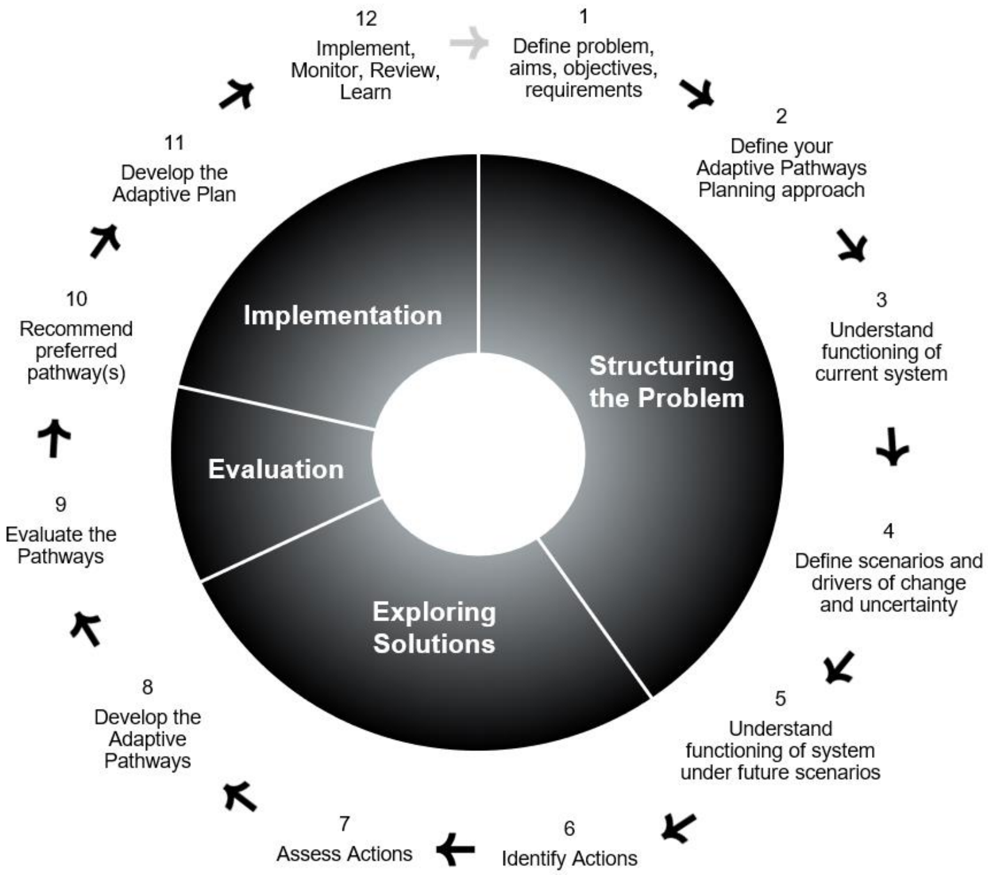


Figure 2 shows a circular map of the methodology to implement an adaptive plan (Brotchie R., 2020). This methodology is broken down into four key steps:

1. Structuring the problem
2. Exploring solutions
3. Evaluation
4. Implementation

Following implementation, it is expected that the adaptive plan will evolve with time as the monitoring and reviews guide its development. Developing the initial adaptive plan can also be an iterative process, eg new information discovered when evaluating the pathways can inform new actions. The benefits of the DAPP approach lie in its lack of rigidity. This section outlines the key steps which may be used when defining an adaptive pathways planning approach.

Structuring the problem

To begin, the problem needs to be defined. This is a phase which should be completed regardless of whether a DAPP approach is applied. This process may be initiated by a current problem, such as the need to upgrade an asset which is aging or which no longer meets capacity requirements for the relevant population. It may also be sparked by the evidence of a future problem, such sea level rise encroaching on an asset. The aims, objectives, requirements, constraints, etc regarding this problem also need to be defined. After defining the problem, it may be determined that an adaptive pathways approach is not applicable for the situation in question; aspects of this methodology may still be used in the master planning even if the full approach is not adopted.

If an adaptive pathways approach is determined to add value, then the particular method needs to be defined. This includes defining the timeframe, people involved, level of detail, etc. While the general structure defined in this paper can be applied to many different types of assets, assessment and planning of a wastewater treatment plant will vary compared to that of a pump station, etc. The nature, size, and criticality of an asset will all affect the level of detail required to develop a suitable adaptive plan.

A thorough understanding of the functioning of the current system is required to evaluate which solutions may be feasible. Depending on the asset, this may involve capacity assessments, evaluation of any sampling data to determine performance, environmental assessments, liaison with operators, analysis of as-built documentation etc.

As mentioned in the section above, drivers of change and uncertainty will also vary between assets. It is important to identify all the relevant drivers, some which may not be readily apparent when considering the identified problem. The ways that these drivers may lead to different scenarios should then be explored. Ie when upgrading the capacity of an asset, an obvious driver is growth of the population services by this asset. However, higher predicted future rainfall can also be a driver; this can cause the scenario of the higher rainfall increasing the expected flow to an asset.

When defining drivers, it is also useful to assess their urgency and to define a parameter which can measure the impact of this driver. This makes it easier to develop a monitoring plan in the following steps. Eg rainfall data collected from relevant weather stations.

The next step is to understand how the asset will function under these different scenarios. In the above example, this asset may not have enough capacity to manage the increased rainfall. It is possible that multiple drivers will interact to have a cumulative effect on the asset; these interactions also need to be considered.

Following this process, the problem should be defined, current system performance evaluated, possible drivers and scenarios considered, and likely impact on the asset estimated. This phase can also be used to invite stakeholder participation and allow them to take ownership of the problem, which also provides feedback in the early stages of planning.

Once these impacts have been identified, the next step is to explore possible solutions to counteract them.

Exploring solutions

Actions must be developed which respond to the identified drivers, scenarios, and impacts. Again, it is very likely that there will be some interaction and crossover of drivers which may lead to requiring the same action to be taken. Ie population growth and increased rainfall are two separate drivers, but they can both add increased flows to an asset which may be unequipped to handle this. An action may be a capacity upgrade of the asset, which addresses both drivers. Even for one action, there may be multiple options; ie there may be several different ways to upgrade the capacity of the asset. These combinations and permutations should be recorded to help build a comprehensive list of possible actions to take.

Once actions are identified, they should be assessed in terms of feasibility, cost, likelihood of one action impacting the ability to implement other actions, etc. Some actions will be eliminated through this process, others identified as preferable, and an idea should be gained as to possible sequencing of actions.

This information will then allow the adaptive pathways to be developed, ie the different logical progressions of works and initiatives that can be implemented for an asset. Using the key concepts above (trigger point, implementation point, lead time, threshold, etc), one can experiment with how the pathways may interact with each other. These may include asking the following questions:

- At what point is it logical to take the asset down a different path?
- What may trigger this decision?
- How long would it take to plan and implement these works?
- Is there a point at which this path is no longer able to be followed? Ie if an asset’s capacity continues to be expanded in a certain way, will there eventually be a lack of available space for upgrades?

Evaluation

Once the pathways are created and a clear roadmap of an asset’s progression has been created from the previous brainstorming steps, these pathways must again be evaluated. This stage may involve stakeholder input to alter or endorse particular pathways.

Following this evaluation and any necessary changes, a preferred pathway can be recommended.

Implementation

The adaptive plan can then be developed, which includes documentation of the above, the adaptive pathways map, a monitoring programme, and programme for review of the adaptive plan.

A key part of the adaptive plan includes outlining the various monitoring schemes and enabling studies (including stakeholder and community involvement) which are required on an ongoing basis. These are to assess and quantify the urgency of the different drivers and inform a decision to change pathways or go ahead with implementing other key decisions/works. Depending on the asset, these can include population growth monitoring, network flow monitoring and modelling, receiving environment water quality monitoring, stakeholder engagement workshops, etc.

The adaptive plan should then be implemented, with plans for regular review to assess the urgency of key drivers and reprioritise where necessary. These reviews are vital to ensure that the adaptive plan is a 'living document' and that the asset can be managed appropriately; these ongoing updates minimise any future need to produce a brand-new master plan for the asset.

UNDERSTANDING DAPP – READING AN ADAPTIVE PATHWAYS MAP

Figure 3: Adaptive pathways map example

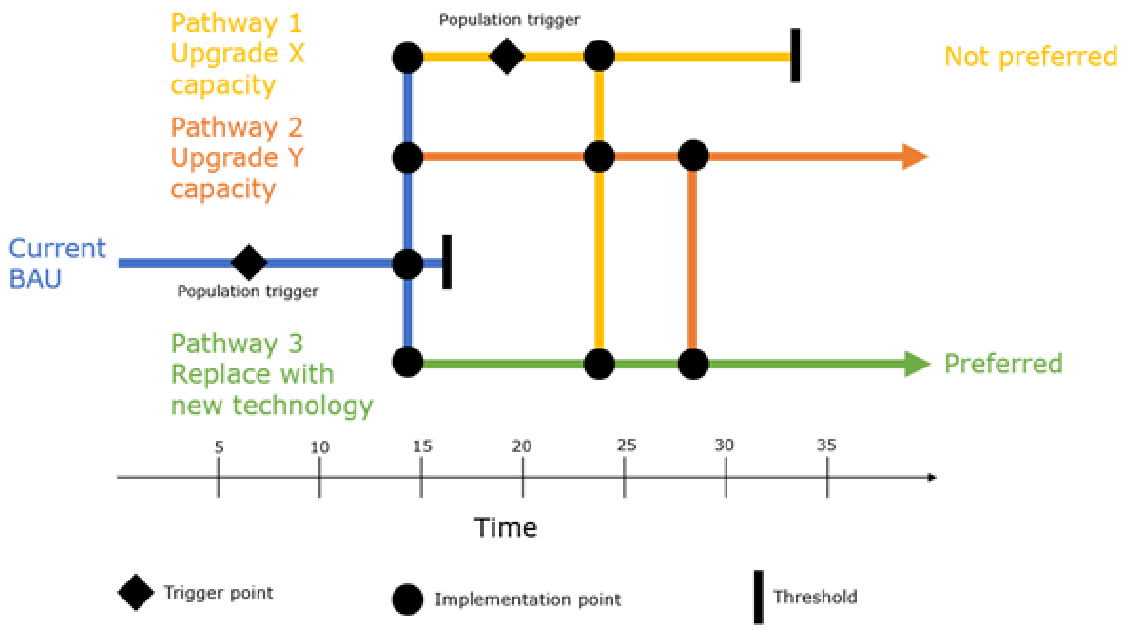


Figure 3 shows a simplified example of an adaptive pathways map, adapted from Deltares (Haasnoot M., n.d.). The asset charted in this map may be a wastewater treatment plant. Pathways are read from left to right, and progression in this example is measured by time.

The current pathway/option is shown in blue and follows a business-as-usual approach, ie no changes made to the plant. There is a trigger point after approximately 7 years when the population reaches a certain size and therefore will not have adequate capacity to accommodate future growth, shown by a threshold at approximately 16 years. A decision must be made to increase the capacity of the asset. Following the blue vertical line shows that there is the ability to switch to Pathway 1 and upgrade the capacity of the X component of the plant. There is also the option to switch to Pathway 2 and upgrade the capacity of the Y component of the plant. Finally, the decision may be made to replace the plant with an entirely new technology, shown by Pathway 3.

If Pathway 1 is selected, the specified capacity upgrades for X component of the plant will still mean that a population trigger is met quite soon after the implementation. Following the yellow vertical line, there is then the option of moving to Pathway 2, or Pathway 3. As seen by the relative brevity of the life of this pathway, it is not a preferred option; however, it may be chosen as it is the first viable option in terms of funding, approvals, etc.

There may be uncertainty with regards to the timing and influence of drivers; in these cases, the trigger and implementation points may be based on other factors, ie population, rainfall, etc. This provides flexibility in when to switch pathways and to which pathway. As mentioned previously, the regular reviews can also reveal a change in key drivers and their urgency which can in turn spur a change in the adaptive pathways map.

UNDERSTANDING DAPP – MANAGEMENT AND REVIEW OF THE ADAPTIVE PLAN

As mentioned, an adaptive plan includes ongoing monitoring schemes and enabling studies to assess and quantify the immediacy of different drivers and inform decision making. These reviews should focus on the following:

- Reflect on the outcomes of previous actions implemented in this adaptive plan
- Assess urgency of key drivers and reprioritise if necessary
- Assess whether additional drivers or pathways should be added
- Assess whether to change or remove pathways
- Identify if the next step of a pathway should be implemented

WATERCARE'S DAPP JOURNEY

Traditional asset management planning at Watercare

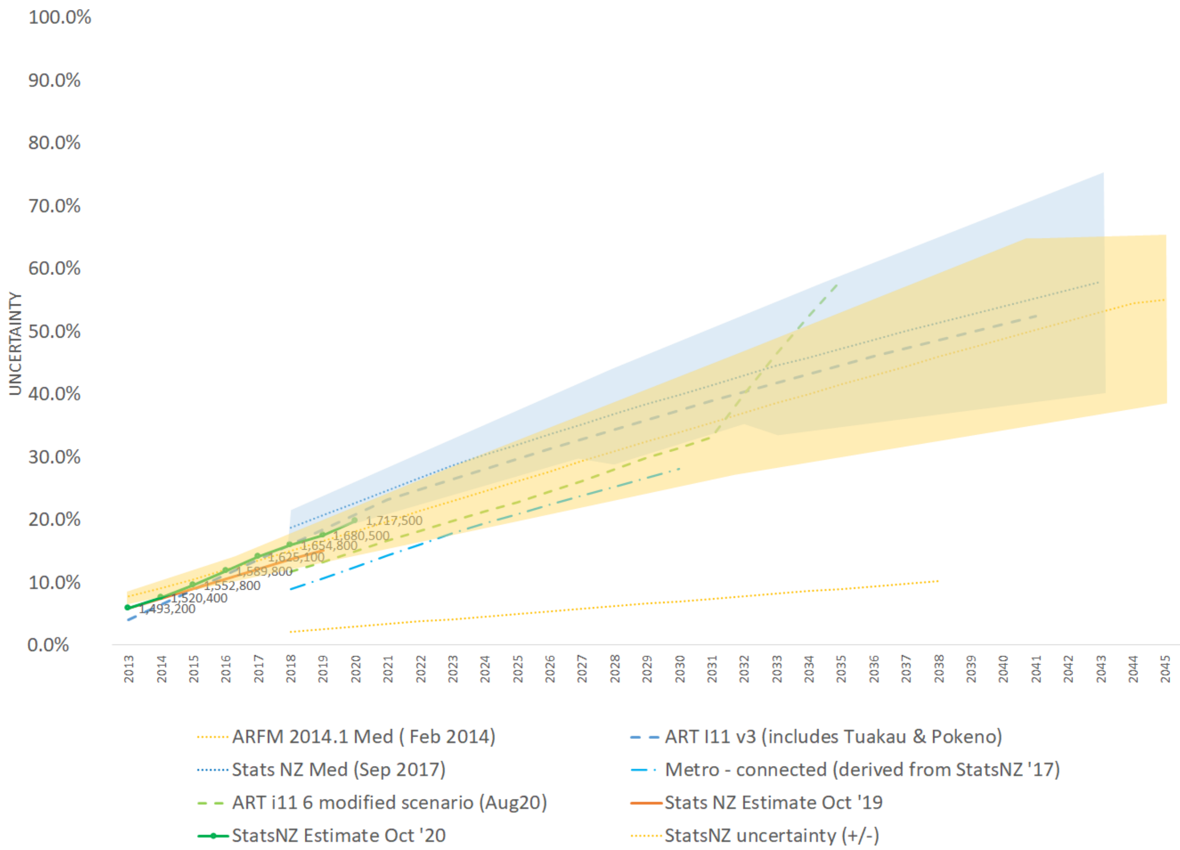
Watercare provides water and wastewater services to the Auckland region spanning Pukekohe in the south to Wellsford in the north; and with a combined $10b worth of assets. These include 12 dams, 15 water treatment plants, 18 wastewater treatment plants, 9000km of water pipes, 8000km of wastewater pipes, numerous pumpstations and smaller wastewater systems.

Like most water utilities, Watercare faces traditional asset management challenges to keep its sizeable network in working order via investment in renewals of ageing assets and capacity increases to address level of service and growth. The scope and hence scale of these interventions are highly sensitive to external stressors, such as population growth, changing demand patterns, public perception, extreme events and the impact of climate change.

Renewals spending for increasingly ageing infrastructure is a challenge. Underinvestment in asset depreciation has been highlighted nationally (Water New Zealand, 2020). A report commissioned by the Department of Internal Affairs from the Water Industry Commission for Scotland states that in New Zealand, "asset condition and performance are likely to be getting worse; or risks to levels of service and quality performance are increasing; or both". This statement perfectly highlights the challenge of simply understanding and maintaining existing water and wastewater systems, even without addressing the complex challenge of a deeply uncertain future.

Over the next 20 years, approximately 45% of Watercare's capital investment is in the expansion of its existing network to cater for growth. Auckland is a high-growth region, with projected population expected to grow 29 percent over the coming 20 years. Uncertainty in growth is typically characterised using high, medium and low growth projections (Figure 4). However, the level of uncertainty begins to grow and propagate at granular scales due to assumptions made in the spatial distribution of overall regional growth. Land-use planning and the sequencing of growth, in general, is a key uncertainty in infrastructure planning.

Figure 4: Uncertainty in Auckland region's population projections



The arrival of deep uncertainty

Climate change increases the unpredictability of weather patterns and extreme events, therefore introducing deep uncertainty in the long-term planning and design of infrastructure. The ability of Watercare's infrastructure to provide an adequate level of service is intricately linked to the impact of weather and the environment. The Tasman Tempest of 2017 and the current drought in the Auckland region are examples of these extremes that have already impacted our existing resilience and levels of service. These impacts will be compounded due to climate change (NIWA, 2018; Watercare, 2020). In Auckland, increase in extreme rainfall events and sea level rise will lead to more flooding and coastal inundation impacts on our low-lying assets. Droughts will also become more common and more severe leading to increased fire risk, reduced water source availability, pipe cracking and sewage septicity.

The shock of Covid-19 has also introduced deep uncertainty in growth projections in the short and medium-term. The sensitivity of infrastructure planning and design decisions to the wider, long-ranging impact of the Covid-19 pandemic on global and local socio-economic trends needs to also be considered (Zechman Berglund et al., 2021).

Therefore, the 21st century challenge has ushered a shift into deeply uncertain realms in which traditional asset planning to address renewals, level-of-service and growth requires an updated strategic approach to maintain effectiveness.

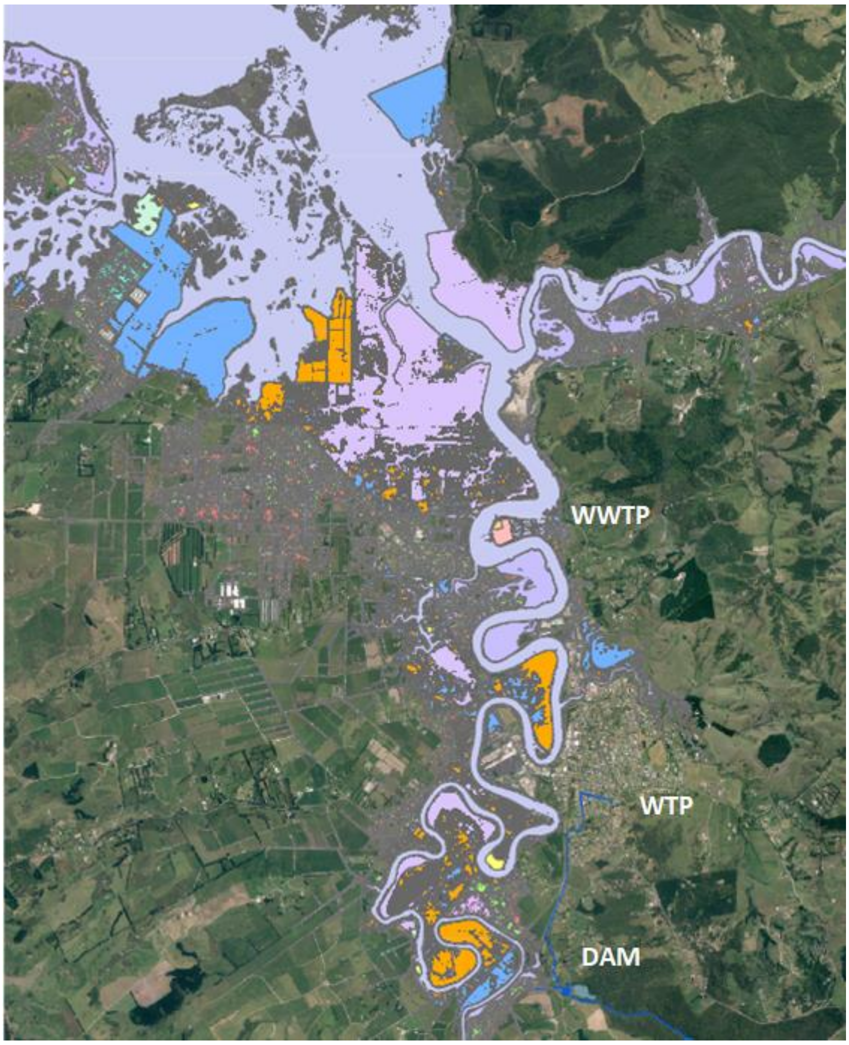
Watercare's planning for deep uncertainty

Approaches to address uncertainty traditionally assume that the future can be predicted, either via historic trends or via probabilistic methods and that robust actions can be taken that can do well in multiple scenarios. However, when uncertainty becomes 'deep', experts and stakeholders are unable to agree on what the future might bring and hence what actions need to be taken. In deeply uncertain situations, the past is no longer an adequate indicator of the future and future trends are difficult to discern.

In deeply uncertain domains, traditional water infrastructure planning that addresses uncertainty using robust actions, i.e. by adding a safety factor to new infrastructure, may incur a high risk of overinvestment especially at times of resource and funding scarcity. Adaptive planning therefore has been a useful strategic tool that has helped Watercare manage deep uncertainty in its long-term infrastructure planning by understanding where flexibility can be introduced, in order to incrementally respond to the future as it emerges.

An example of Watercare's adaptive plan is one that addresses long-term interventions for assets that service the Helensville-Parakai region. Like most of Auckland, the assets in this region require on-going investment over the next 20 years to cater for renewal, growth and level of service. The wastewater treatment plant (WWTP), located at the lowest point of the catchment, is currently vulnerable to hydrological and hydrogeological flooding during extreme wet weather and high-tide events. Site geology (alluvial and colluvial soils) also makes the WWTP susceptible to tidal erosion and slumping of pond embankments. These effects are forecast to worsen with the impact of climate change related sea-level rise (Figure 5). A 0.25m sea level rise, projected in 2040, will inundate the WWTP. Raw water supply quantity and quality in the region is also vulnerable to the impacts of long-term climate change related increase in hot days, droughts and extreme weather events. Other important triggers include the expiry of water take and wastewater discharge consents. Additionally, there is a significant impact of growth assumptions on planned interventions. Several options that largely address capacity increases for a high population growth scenario may not be required in a medium growth scenario. Therefore, the high level of uncertainty in this region highlights the importance of flexibility and a consideration of the risk of overinvesting in capital solutions too early in the planning horizon that may lock-in undesirable pathways if future scenarios differ significantly from those assumed today.

Figure 5: Helensville-Parakai. 0.1 to 0.5m sea level rise (NIWA, 2019)



Given the above context – a number of ***actions*** were brainstormed by Watercare staff through internal strategy sessions. These actions were grouped into ***options*** A to D in the water plan, and 1 to 4 in the WW plan. A sequence of options creates a ***pathway***. Two broad tactical pathways are shown as an example in Figure 6, highlighted in yellow and grey and detailed in Table 1: Example of turning actions into options and adaptive pathways:

- Regional (yellow pathway): A flexible pathway can be taken, that incrementally upgrades the existing WWTP and relocates when inundation tipping points are reached.
- Centralised (grey pathway): A robust pathway that immediately decommissions both plants and connects the region to the metro network, therefore centralising service.

Figure 6: Watercare adaptive plan example

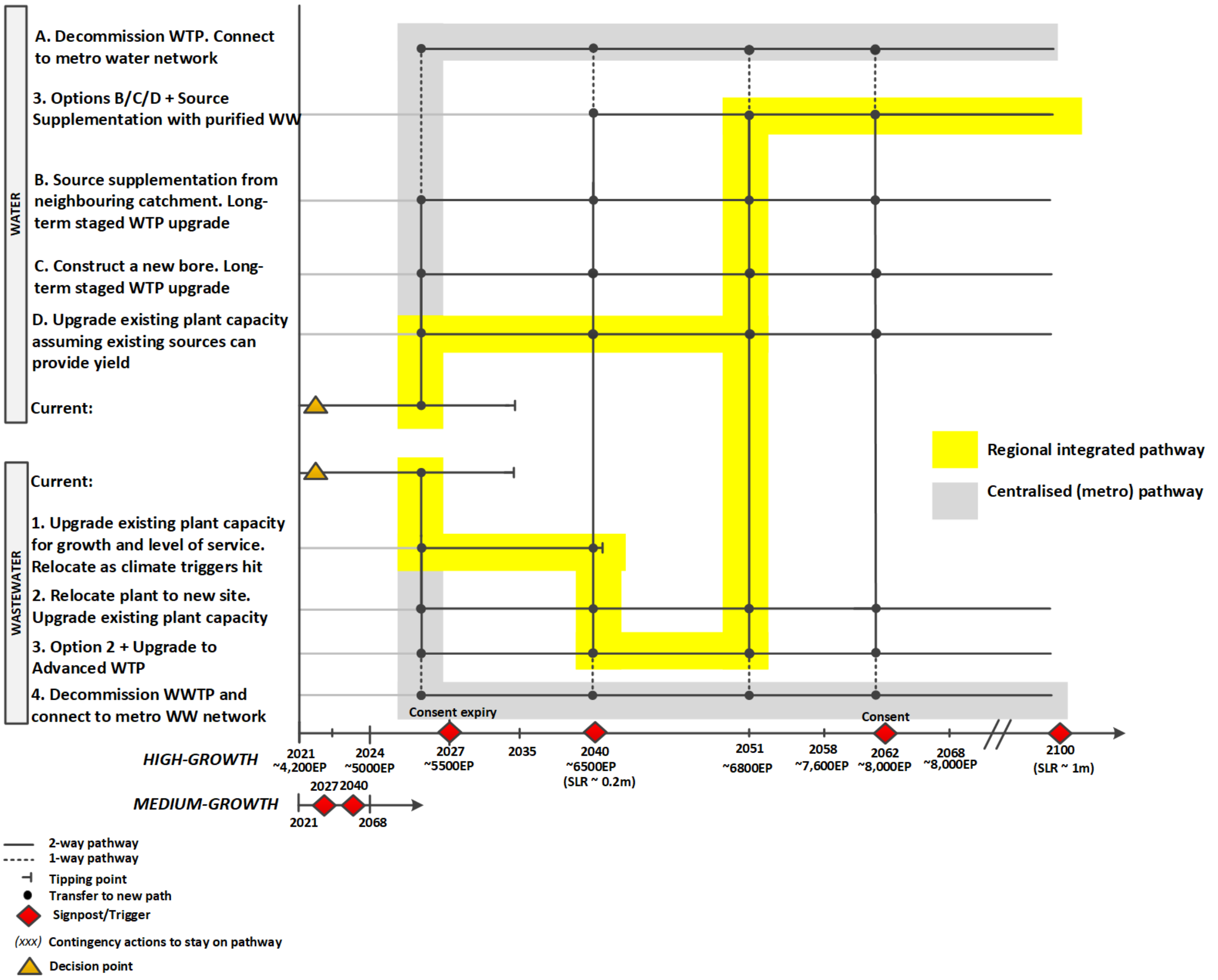


Table 1: Example of turning actions into options and adaptive pathways

Actions	Options	Pathways
Upgrade existing WWTP	1	Regional integrated pathway

Relocate plant	3	
Upgrade to advanced WTP		
Water source supplementation with purified wastewater		
Decommission WTP	A	Centralised (metro) pathway
Connect region to metro water network		
Decommission WWTP	4	
Connect region to metro WW network		

Flexibility versus robustness

A key advantage of the flexible (regional) pathway is that it delays big transitional decisions such as relocation of the WWTP. In this example, choosing the flexible pathway enables the WWTP to be relocated and upgraded for growth that is actually realised in time. This pathway also leaves the option open in future to upgrade the WWTP to a purified recycled water plant as a potential water supply option, thereby providing an integrated water and wastewater solution to the Helensville-Parakai region. However, enabling flexibility requires adequate monitoring of climate triggers so that relocation action can be taken well before the tipping point of an option is reached. Therefore, enabling flexibility requires substantial proactive planning. Flexibility can also be potentially more expensive as it does not consider economies of scale.

On the other hand, the robust pathway, while immediately solving the problem, requires a large capital investment upfront and is not flexible to changes in growth scenarios, therefore potentially overestimating the scale of upgrade required. The robust pathway also locks out the opportunity for future circular water economy solutions such as purified recycled wastewater if local treatment assets are decommissioned.

Therefore, decision-making in an adaptive planning setting requires weighing the risks and benefits of incremental adaptation vs. robust transition.

Adaptive plans are useless without adaptive planning

A key learning in the development of Watercare’s adaptive plans is the need for consistent follow-up and review of the plans with internal stakeholders across the business. A shifting context requires a forum for individuals to be able to report what has changed. The increased acceptance of remote working tools through the

Covid-19 lockdowns has been highly beneficial. A Microsoft Teams page for this regional strategy that is accessible by multiple internal stakeholders across the business enables feedback in real-time.

Another important learning is that complexity requires a shift in the planning approach to risk and uncertainty. Traditional planning approaches seek to reduce and control uncertainty. However, the water industry has entered a complex domain that requires addressing uncertainty by understanding the concept of emergence and collective problem solving.

A desired next step is to be able to co-create Watercare's adaptive strategies and plans with external stakeholders such as Mana Whenua, council and infrastructure providers and communities. We have been sharing our adaptation challenges and approaches at external forums to reach out to organisations facing similar issues. We have also offered our adaptive planning case studies to the scientific community, who are assisting in furthering the practical implementation of adaptive planning concepts in the water industry (Stephens et al., 2020). Through this, we hope to be part of a wider movement in the water industry that seeks to be genuinely adaptive by considering multiple perspectives, scenarios and co-creating solutions that truly serve our communities in a challenging future.

CONCLUSIONS

Current forms of infrastructure master planning simply do not provide stakeholders with the flexibility needed to accommodate uncertain futures and rapidly changing conditions; without rethinking this approach, New Zealand risks restricting communities to inadequate and inappropriate infrastructure. With proper planning and management, the DAPP method is an attractive solution for stakeholders to explore the outcomes of multiple scenarios and therefore develop a flexible but clear roadmap that is responsive to a range of future uncertainties.

Watercare, New Zealand's largest water utility, has used DAPP in addressing the impacts of deep uncertainty due to climate change and growth on long-term infrastructure planning. The use of DAPP has helped visualise the multiple options available for water and wastewater servicing and how these options can be integrated into long-term pathways that are either flexible and adaptive or robust. Complexity over time in scenarios and options are easily visualised in one plan, and hence brings to light trade-offs and consequences of each individual action. A key learning is that adaptive plans require consistent follow up and monitoring to ensure that adaptive actions are taken before trigger values are reached.

ACKNOWLEDGEMENTS

GHD: Ryan Brotchie, Anthony Kirk, Sarah Sunich

Watercare: Chris Thurston, Chris Allen, David Ward, Shane Morgan, Brendon Harkness

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