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Urban water security: Assessing the impacts of metering and pricing in Aotearoa New Zealand

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Abstract

With urbanisation and climate change placing increasing pressure on water security around the world, demand-side mechanisms, such as metering and pricing, have emerged as core components of urban water management. Yet the impacts of metering and pricing on water production and consumption in Aotearoa New Zealand are not well understood. This constrains the ability of decision-makers to make targeted wellbeing improvements for the communities they serve. In this paper, we endeavour to estimate the impact of metering and pricing on urban water consumption in Aotearoa. We collect data on residential water production and consumption from 67 local councils and provide comparisons of water use across regions and over time, with particular attention given to Tauranga and Wellington. Our experience reveals the extent of the drinking water data gaps in urban areas in Aotearoa, raising questions about how evidence is being used to inform the design of urban water policy in Aotearoa and issues of public accountability.

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Keywords

Data gaps; demand management; drinking water; metering; policy; pricing.

Summary haiku

Managing water
will be a murky challenge
without the data.

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1 Introduction

Urbanisation and climate change are placing pressure on freshwater in towns and cities globally. Population growth, urbanisation, and socio-economic development are expected to increase water demand by 80% over the next three decades (Flörke et al., 2018). Simultaneously, climate change is expected to affect the spatial and temporal distribution of water availability around the world (He et al., 2021). Identifying more efficient ways to use and conserve water in urban areas is therefore critical for policymakers seeking to achieve the United Nations Sustainable Development Goals (SDGs), particularly SDG11 *Sustainable Cities and Communities* and SDG6 *Clean Water and Sanitation.*

For policymakers, the human component of water management, rather than the technical one, is likely to remain the biggest issue in the efficiency and conservation of urban water use (Cosgrove & Loucks, 2015). Technical, supply-side solutions, such as building new dams and reservoirs, are increasingly viewed as second-best options for addressing water security, unless a robust case can be made for justifying the cost and environmental impacts (Hoekstra et al., 2018). In contrast, encouraging collective action and incentivising behaviour change using demand-side mechanisms, such as metering and pricing, has been shown to deliver improved outcomes for communities and the environment at lower cost (El-Khattabi et al., 2021). For this reason, improving governance outcomes using demand-side mechanisms has become a core component of urban water management (Grafton, 2017).

To ensure that the demand-side mechanisms being proposed and used are the most efficient, effective, and equitable policy options, closing urban water data gaps and improving access to good-quality data is critical (Josset et al., 2019; Marston et al., 2022). Data – that is, any facts, records, or measures – is fundamental to initiate research, validate models, estimate trends, and monitor changes over time (Parliamentary Commissioner for the Environment, 2019). Globally, attention has turned to technologies that enable more accurate collection of data over time. Digital water meters (or smart meters) allow water utilities and consumers to monitor their production and consumption in (near) real time (Goulas et al., 2022). These meters also allow suppliers to rapidly identify leakages and policymakers to introduce targeted and timely tariffs, both of which increase the likelihood of delivering efficient, effective, and equitable outcomes in terms of urban water production and consumption. When coupled with other policy instruments, such as education campaigns, these approaches can be especially effective at curbing demand (Koop et al., 2021).

In Aotearoa New Zealand (Aotearoa), patterns of urban water production and consumption are not well understood (Ministry for the Environment, 2023). Management approaches vary regionally, and little is known about the marginal net benefits of adopting demand-side mechanisms. As demand increases and the impacts of climate change become more pronounced, being able to estimate the efficiency and equity gains of shifting from one regulatory arrangement to another would help deliver improved policy outcomes. As a result, this research endeavoured to understand the impacts of metering and pricing on water consumption in urban areas across Aotearoa. Conducting an interregional comparison was anticipated to help inform ongoing policy reform, such as the Water Services Reform programme[1], and shine new light on the costs and benefits of using price-based mechanisms as an urban water management tool in the context of increased demand, climate change, and ageing infrastructure.

However, our experience and findings end up telling a different story: one that highlights significant gaps in urban water data and entrenched barriers to public accountability. Despite widespread monitoring and reporting against a series of health and aesthetic guidelines, data collation at the national level is incomplete. This limits the ability of national- and regional-level policymakers to make evidence-informed decisions and ensure the delivery of efficient, effective, and equitable freshwater outcomes for the environment and communities.

This paper proceeds as follows. Section 2 addresses how pricing can be used as an urban water management tool, and explores considerations for policymakers in terms of efficiency, equity, and effectiveness. Section 3 outlines the methodology, with particular attention given to how the objectives of the project pivoted as a result of the incomplete data. Section 4 presents our static and dynamic analysis of urban water use in Aotearoa. Section 5 discusses our results and the implications of poor water-data quality for evidence-based policy and public accountability. Section 6 concludes.

[1] The reform programme was originally called the Three Waters Reform in 2022 before being renamed the Water Services Reform programme in early 2023 in conjunction with changes to policy objectives.

2 Background and current literature

Water security in urban areas is of increasing concern to policymakers, and the demand for innovative, evidence-based solutions is growing (He et al., 2021). Technical supply-side solutions have been the traditional response to emerging water scarcity (Brandes, 2011), however, constructing water infrastructure, which can store water during periods of excess rainfall and supply water during dry periods, is costly. Furthermore, technical supply-side solutions often require substantial human, energy, and material resources, are limited by natural conditions such as geographic location and topography, and may have substantial environmental impacts (McDonald et al., 2014).

In contrast, demand-side solutions, such as metering and pricing, can deliver efficient and effective outcomes at lower cost by incentivising changes in consumer behaviour (Reed & Hermens, 2016). The rationale for water pricing is well understood. Volumetric prices, whereby consumers pay per unit of water used, send signals to users regarding the relative scarcity of water. These signals can motivate changes in consumption behaviour in a way that zero prices or fixed charges cannot. In the short term, volumetric prices encourage households to consume less water and use it more efficiently (Olmstead & Stavins, 2009). In the longer term, volumetric prices encourage households to invest in new water conservation technologies to achieve even greater water cost savings (Olmstead & Stavins, 2009). In addition, water pricing promotes equity and efficiency because people pay for what they use and are encouraged to shift their water consumption from low-value to high-value uses.

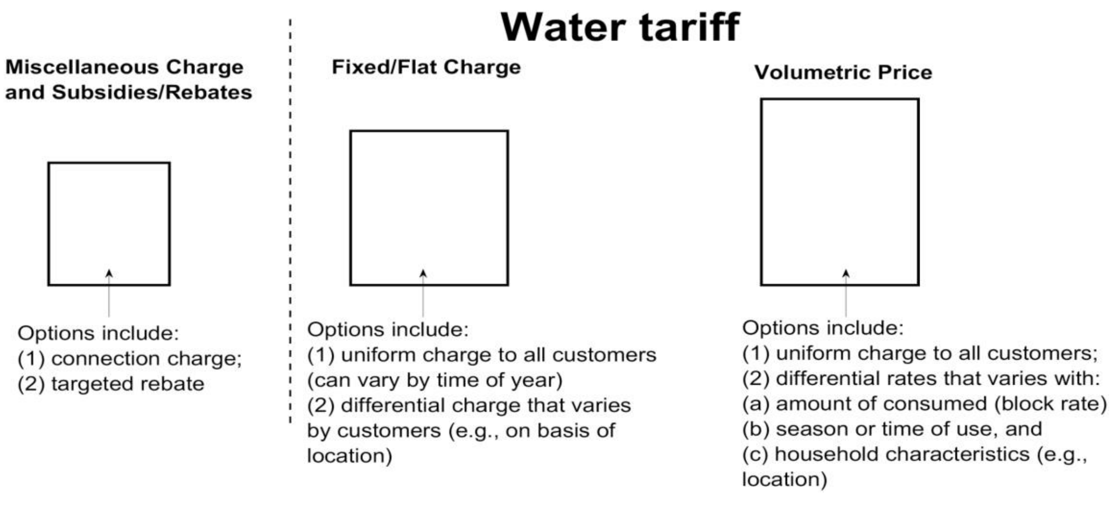


Figure 1: Water pricing options. *Source:* Grafton et al. (2020b).

It is not possible to accurately charge consumers for the amount of water they use if household water meters are not installed. Metering also offers benefits that go beyond the implementation of a socially equitable charging regime. Metering can help water suppliers detect water leakages within the distribution network and can lead to an improvement in long-term water resource planning through a better understanding of consumption data (Reed & Hermens, 2016). This means that metering alone can achieve reductions in water use. Combined with pricing, metering can defer the need for capital expenditure on new water infrastructure by reducing peak demand levels, which consequently elicits significant capital and operational savings (Reed & Hermens, 2016).

Internationally, the benefits of utilising demand-side solutions are well documented (see for example Grafton & Ward, 2008; El-Khattabi et al., 2021; Agarwal et al., 2023). In Aotearoa, despite increasing pressure on available supplies, evidence of the benefits of metering and pricing across regions is less clear (Jenkins, 2015; Ghavidelfar et al., 2017). For policymakers, investigating the potential impacts of metering and pricing (in terms of efficiency, equity, and effectiveness) and drawing on international evidence to inform future outcomes are central to the delivery of desirable outcomes for the environment and communities.

2.1 Efficiency: empirical evidence of the elasticity of demand

Several factors influence the efficacy of water pricing as a tool for demand management. Of interest to water suppliers and policymakers is how consumers respond to a change in the price of water. This responsiveness is captured by the price elasticity of demand. A price elasticity of less than 1 indicates consumers are relatively unresponsive to price changes, while an elasticity greater than 1 indicates they are relatively responsive to price changes. The intuition behind this measure is that the lower the price elasticity, the greater the price increase needs to be to achieve a given fall in consumption. While it is generally accepted that a higher price leads to lower water consumption, it may not achieve the desired reduction in water use if the price elasticity is small.

Ghavidelfar et al. (2017) provide the most in-depth evaluation of the effects of water pricing on household water consumption in Aotearoa. They develop a large dataset by integrating household-level water consumption data from 31,000 individual houses in Auckland with weather data, property data, and household socio-economic data. The level of detail within the dataset allows the authors to evaluate heterogeneous household responses to price changes and the spatial pattern of water consumption in Auckland. Panel data regression models are used to estimate the price elasticity of demand between 2008 and 2014. Annual average daily water consumption is estimated as a function of the volumetric price of water, the fixed charge of water, average air temperature, annual rainfall, and housing characteristics. The estimated price elasticity of demand for all households is 0.02.[2] This shows that the effect of prices on water consumption in Auckland is limited. The authors argue that the low elasticity can be attributed to the fact that the water bill comprises a relatively small share of total household expenditure. They further suggest that the current water pricing scheme with flat volumetric rates may not provide enough incentive to reduce water consumption, especially amongst high-use households.

Matthews (2022) investigates the short-run and long-run dynamics of household responses to water demand management in Tauranga, recognising that urban water supplies are under stress due to population growth and worsening summer droughts. The study aims to understand how households respond to drought and water-demand management, and whether such responses vary between the short and long term. Economic theory suggests that the long-run price elasticity may be higher if households can invest in water conservation technology, or it may be lower because water has no substitutes and water conservation is difficult to maintain. Using billed consumption data from 56,000 single-unit properties in Tauranga between 2011 and 2021, the author employs a dynamic autoregressive distributed lag model to estimate elasticity and found a short-run elasticity of 0.439 and a long-run elasticity of 0.11. A potential reason for the lower long-run elasticity is the length of time water pricing has been used in Tauranga (20 years), which may have allowed any user motivated to install water conservation technology to have already done so. The main implication of this finding is that prices need to continually increase, or be dynamic and adjust to changes in availability, to maintain impact (Matthews, 2022).[3]

Internationally, the empirical literature indicates that residential water demand is relatively inelastic, with price elasticity estimates generally ranging from 0 to 0.5 (Worthington & Hoffman, 2008). This reflects the nature of water as a necessary good, meaning that users are relatively unaffected by price changes, although this can vary over time. For example, Hoffman et al. (2006) use quarterly, suburb-level data from 1998 to 2003 to examine the various factors affecting residential water consumption in Brisbane, Australia. They find that water demand is inelastic (price elasticity of 0.51) in the short run, but elastic in the long run (price elasticity of 1.16), suggesting that there is a possible lag between water price changes and their impact on

[2] In this paper we drop the negative sign in front of all price elasticity values because it is expected that there will always be a negative relationship between price and quantity demanded. Dropping the negative value also avoids confusion by making it clear that a bigger value (in absolute terms) reflects a higher responsiveness of consumers to a price change.
[3] This might make alternative demand management tools, such as outdoor restrictions, appear more attractive for policymakers; however, the author also finds that even outdoor restrictions have a limited total impact on consumption.

consumption. For policy, this type of information is useful because it shows that in some contexts pricing can still be an efficient tool for managing demand in the long run once consumers have had time to respond to price changes.

These results are not conclusive, however. They highlight the importance of using local data to inform local decision-making. For instance, Wichman et al. (2016) argue that raising prices to achieve short-run reductions in consumption is unrealistic and policymakers should use mandatory restrictions to curb demand instead. They argue that policymakers in North Carolina, United States would need to increase the average price of water by more than 50% to reduce consumption by the same amount that would be achieved by mandatory restrictions. They argue that this is an unrealistic choice for policymakers, given it would correspond to a roughly 52% increase in the average consumer's monthly bill. Overall, the international literature shows that the impacts of pricing can be variable across time and across contexts. It suggests that pricing can act as a complementary policy tool for efficiently curbing demand and addressing water security in most contexts, but that local data is critical for ensuring the delivery of welfare-enhancing improvements for targeted communities.

2.2 Equity: heterogeneous household responses to water prices

Heterogeneity also impacts how prices affect water consumption. Households differ in size, income level, and water-use behaviours, which can impact their responsiveness to water price changes. This is particularly important in terms of equity as the incidence of pricing on low-income households can be different than for middle- or high-income households. For example, if water demand is price inelastic, price increases may be inequitable because they will place a larger cost burden on lower-income or larger households (Grafton & Ward, 2008). Furthermore, if high-income households with high use patterns are insensitive to price changes, then price changes may not effectively reduce consumption amongst those who use water the most. Therefore, to design equitable policy measures, it is important to empirically evaluate how different households may respond to changes in water prices within a local context.

Current evidence of heterogeneous household responses to water price increases is mixed. For example, despite both using data from North Carolina, United States, Wichman et al. (2016) find that low-income households are more responsive to price changes than high-income households, while El-Khattabi et al. (2021) find that price elasticity does not vary across household income groups. When estimating responses of high-usage households to price changes, the data is also mixed. Wichman et al. (2016) estimate high-consumption households are less sensitive to price, while El-Khattabi et al. (2021) show that heavy-usage households are significantly more price sensitive than other households. In Aotearoa, Ghavidelfar et al. (2017) find that households with higher incomes and swimming pools in Auckland are slightly more price sensitive than households with low or middle incomes. They attribute this difference to the typically higher outdoor water use among households with higher incomes and swimming pools.

It is unclear whether the mixed findings from the literature arise from methodological or estimation issues, or from differences in local contexts. The latter implies that the findings in one region cannot be assumed to apply to other regions within the same country, and that price elasticities can only be interpreted in the context in which they have been derived. The main implication of this for policymakers is that to achieve a predictable reduction in consumption, water suppliers and policymakers need to estimate price elasticity for their own current customer base, and not infer price responsiveness from other utilities or studies without recognising the potential for variation (Olmstead & Stavins, 2009).

2.3 Effectiveness: the role of information

Since water price changes are found to have a low impact on total consumption over time, some studies focus on assessing whether non-price tools can complement water pricing tools to drive water conservation and increase policy effectiveness. For example, research has revealed that consumers are often unaware of relative water charges and their own consumption behaviour leading to overconsumption (Binet et al. 2014; García-Valiñas & Suárez-Fernández, 2022). Gaudin (2006) finds that including price information in water bills increased the price elasticity of water demand from 0.36 to 0.51. This means that a 10% decrease in water consumption requires a price increase of approximately 29% when price information is not included on a bill, but only a 20% increase when price information is included. This result suggests that combining water prices with information policies can increase household responsiveness to price changes and improve overall water pricing effectiveness.

In a similar vein, Agarwal et al. (2023) investigate how water pricing, utility subsidies, and information on water usage interact to affect water consumption in Singapore. They find that a policy announcement to increase prices by 30% on water consumption leads to a 3.7% decline in water consumption. Although this announcement effect may be due to consumers' anticipation of the future price increase, the authors argue it is more likely due to the increased public attention that was primed by the information provided by the policy announcement. In addition, they find that an increase in utility subsidy reduces the financial burden on low-income households but does not appear to reverse any water conservation achieved by the price increase (possibly due to low attentiveness to the subsidy change). Overall, the results suggest that when combined with attention priming, water prices and subsidies can achieve desired water conservation outcomes with minimal need for technology advancement and institutional innovation.

2.4 What data is needed?

It is clear from the literature that to understand the effects of price on water demand, researchers need access to large, detailed datasets on water consumption. The studies mentioned above all use monthly (or quarterly), household-level water consumption data that have been collected over multiple years (Wichman et al., 2016; El-Khattabi et al., 2021; Agarwal et al., 2023). The Aotearoa studies also benefit from relatively large sample sizes, which helps with the precision and internal validity of their price elasticity estimates. Furthermore, to assess heterogeneous responses to water price changes, water data needs to be integrated with household demographic data. Ghavidelfar et al. (2017) show this can be done in Aotearoa at the aggregated census unit level. Each individual household can be linked with the average household demographics of all households within their census unit area, allowing for comparisons between, for example, low-income census unit areas and high-income census unit areas.

This highlights the level of detail required to allow water suppliers and policymakers to accurately estimate the impact of pricing on water consumption within their jurisdictions. However, detailed household-level consumption data provides benefits beyond allowing water suppliers and policymakers to assess how consumers respond to price changes. Detailed consumption data can be presented to households on water bills, which Gaudin (2006) shows can lead to greater water conservation than if only price increases were implemented. If consumers are shown how much water they consume, and how this compares to average use in their neighbourhood or city, they can be incentivised to change their consumption behaviour over time (Hassell, 2007).[4] For this to be possible, detailed consumption data needs to be collected, analysed, and transformed into a meaningful output that can be easily understood by decision-makers, utility providers, and consumers.

[4] Watercare presents this kind of information on its bills to households in Auckland.

3 Methods

The aim of this research was to investigate how meters and pricing affect water consumption in Aotearoa over time. To do so, primary data was collected from 67 local councils through the Local Government Official Information and Meetings Act 1987 (LGOIMA) process. It was anticipated that consistent daily household level data would be difficult to obtain, but that collecting monthly data over time at an aggregate level was a realistic goal. This data would then be collated in a database that could later be made publicly available for use by researchers and policymakers. With the collected data, the plan was to conduct an interregional analysis that accounted for seasonal variation and a range of other institutional factors affecting consumption and production, such as periods of water restrictions. The results were anticipated to provide useful insights into the impacts of metering and pricing on consumption in Aotearoa over time, as well as the relative benefits of using metering and volumetric pricing over other tariff approaches.

Unfortunately, our data collection process revealed substantive gaps in Aotearoa's urban water database and systemic barriers to public accountability with regards to information about local councils' drinking water production and consumption. The data we were able to compile was of insufficient quality to perform any sort of econometric analysis of the impacts of water pricing on consumption across Aotearoa. We were also unable to gather sufficient data from any council to enable us to estimate demand models and compare consumption behaviour across regions. Instead, the data we received through public channels only allowed us to conduct a surface-level descriptive analysis of metering and pricing effects across Aotearoa and within certain regions. Consequently, the real story that emerges from this research lies in how entrenched and problematic data gaps are for urban water in Aotearoa, and what this means for the development of evidence-based and evidence-informed policy.

3.1 Data collection

Drinking water in Aotearoa is the responsibility of 67 local councils who oversee and monitor drinking water, stormwater, and wastewater within their jurisdiction. Data on production and consumption can be legally obtained by researchers or the public through the LGOIMA process. This involves asking councils for information they may have on file which is not publicly accessible in writing. Councils then have 20 working days to respond to requests and can either provide the information, request an amendment, ask for an extension, or refuse the request if it is perceived as beyond their capacity. Councils can also demand payment for access the information if they have the information but it is poorly organised and difficult to collate, or if the request is too vague or large in scope.

In August 2022 we issued LGOIMA requests to all 67 councils. The LGOIMA requests asked each council to provide data and information on monthly water production and consumption. We asked councils to provide this data over time, and to include records that went as far back as possible. Household-level data was preferred and requested where possible (i.e. where meters are installed). We also asked the councils to provide information on leaks, pricing models (whether fixed or volumetric charges were used), and institutional information regarding the presence of meters and the use of water restrictions over time.

3.2 LGOIMA data quality analysis

After three months of waiting for requests to be fulfilled, only eight councils provided us with comprehensive information that adequately met our request. These councils provided us with (mostly) full records, with some dating back to the 1980s. Most councils provided us with information that was spotty, inconsistent, aggregated at the annual level, and only went back two years. This made it difficult to compare the impacts of meters and pricing across regions over time. In addition, nine councils said they could provide the information at a charge. As some of the requests for charges were several thousand dollars, we were not able to meet these councils' requests for payment. We sent a second, simplified LGOIMA request and were able to obtain some data from these councils. By the end of the data collection process, we obtained data from 53 out of 67 councils. We were unable to obtain data from 14 councils because seven councils refused our information request (citing limited capacity), two councils did not respond, and five councils provided annual reports and website links instead of processed data.

Figure 2 presents the distribution of the data sample periods for the 53 councils. It shows that most councils (53%) provided data for only one year, which means we cannot observe production and consumption trends over time for these councils. Almost a quarter of the councils provided us with over 10 years' worth of data, such as Tauranga City Council and Wellington Water on behalf of Wellington City Council. This enabled us to undertake a case study analysis for councils where the data is consistent and comprehensive; however, most of the data provided over time is inconsistent both *across* and *within* councils. For example, some councils provided consecutive years of production data, but only one year of consumption or population data. This further limited our analysis and made it difficult to conduct a robust interregional comparison.

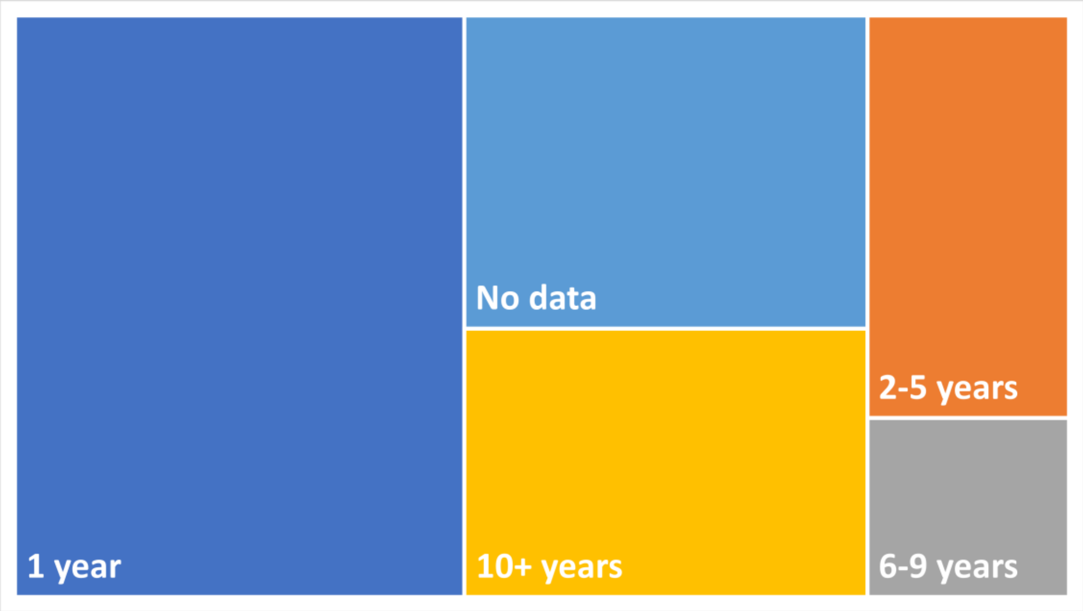


Figure 2: Distribution of the sample periods of production or consumption data provided by the 67 local councils through the LGOIMA process.

Notes: Sample period refers to the number of years of water production and consumption data was available. For councils who provided production and consumption data over different time periods (for example, five years of production data but only two years of consumption data), we report the lower of the two periods in Figure 2.

In terms of the frequency of the data, 72% of councils provided annual data only. This means that for most councils we cannot observe seasonal variations of water consumption and assess how these variations interact with price changes or the implementation of water restrictions (which often only occur during the summer months). A few councils provided monthly data; however, this was often only for some key variables and came as a supplement to annual data. No daily data was provided.

Other limitations with the data included the fact that only two councils provided any household level data, sample sizes are very small for most councils due to the lack of observations over time at daily or monthly frequency, and very little, if any, data on water charges and prices over time was provided.

3.3 Constructing a higher quality dataset

To provide useful analysis on water metering and pricing in Aotearoa, we turned to alternative data sources to build a higher quality dataset. We first contacted the Department of Internal Affairs (DIA), who are currently leading the Water Services Reform programme. As part of the reform, the DIA collected data on water usage from local councils in the form of information workbooks. The workbooks asked the councils to provide a wide range of data and information on their drinking water, wastewater, and stormwater services. Using the Official Information Act process, we obtained the data from the workbooks completed and submitted to the DIA from October 2020 to February 2021. Aggregated annual water production and consumption data was available for 43 councils for the 2018/19 and 2019/20 financial years.

We also contacted Water New Zealand (Water NZ), the largest water industry body in the country. Water NZ runs the New Zealand National Performance Review, which is an annual assessment of drinking water, wastewater, and stormwater service delivery across Aotearoa. The review involves collecting water service data from select local councils each year[5], which is presented online on the National Performance Review Dashboard (Water New Zealand, 2022). Water NZ provided us with a dataset containing drinking water service delivery data from 2013 to 2021. It contains annual data on variables related to water production, water consumption, water charges, and population for the councils which participated in the performance reviews. Although we do not create analytical outputs directly from this dataset, we use it to inform our understanding of the charging mechanisms used in different local councils and how to calculate certain variables.

3.4 Methodological resolution

Due to the limitations of the compiled data, we were unable to perform an in-depth econometric analysis of the impacts of water pricing on consumption across Aotearoa. We were also unable to estimate demand models or compare consumption behaviour across regions. Instead, we present a descriptive analysis of metering and pricing effects across Aotearoa and within certain regions. Our analysis provides an insight into the type of evaluation that can be conducted by policymakers and researchers when accessing urban water data through public channels in Aotearoa.

[5] Participation in the National Performance Review is voluntary.

4 Water use and pricing in Aotearoa New Zealand

Data on urban water use is not easily accessible in Aotearoa. There is no central database or governing authority collecting and collating information about demand and supply. Most councils have direct control over the provision and production of drinking water, while others employ council-controlled organisations to manage them. For example, water services are provided by Watercare on behalf of Auckland Council and Wellington Water on behalf of the councils in the Greater Wellington region. This decentralised system of water provision means that each council can set their own charges to recover the region-specific costs of delivering water and maintaining infrastructure. As a result, there is large variation in the type and level of charges set for water service provision across the country.

Figure 3 shows the charging mechanisms adopted by the 67 local councils for residential users. The charging mechanisms are categorised into five types:

A. Volumetric[6]
B. Volumetric, with some non-metered charging
C. Fixed charge[7]
D. Fixed charge, with some metered charging
E. Fixed charge, with excess volumetric charging.

Councils assigned to Group A have universal metering (i.e. all residential connections are metered) and charge all households a volumetric rate for their water use, with or without an additional fixed charge. Councils assigned to Group B predominantly use volumetric charging; however, some residential connections are unmetered and are charged a fixed amount. Councils assigned to Group C have very few or no residential meters installed and charge a fixed amount that is unrelated to the amount of water consumed. Councils assigned to Group D have some meters installed (below 30% of all residential connections) and are charged volumetrically, although most connections are unmetered and pay a fixed charge. Group E is a special case that only includes Christchurch and South Wairarapa. These councils have near full coverage of residential water meters installed, yet they use a fixed charge and only charge volumetrically when consumption is above a specified threshold amount.

Figure 3 shows that only 14 out of 67 councils (about 20%) have implemented universal water metering and are charging volumetrically as of 2022. Most of these councils are clustered

[6] Volumetric refers to a charge based on the total volume of water consumed.
[7] We use fixed charge as an umbrella term. Fixed charge may refer to a targeted rate, uniform annual charge, flat rate, or capital value rate. It is distinct from a volumetric charge because it does not change when the total amount of water consumed changes.

around the top of the North Island. Three councils have near full coverage and charge most residential connections volumetrically.

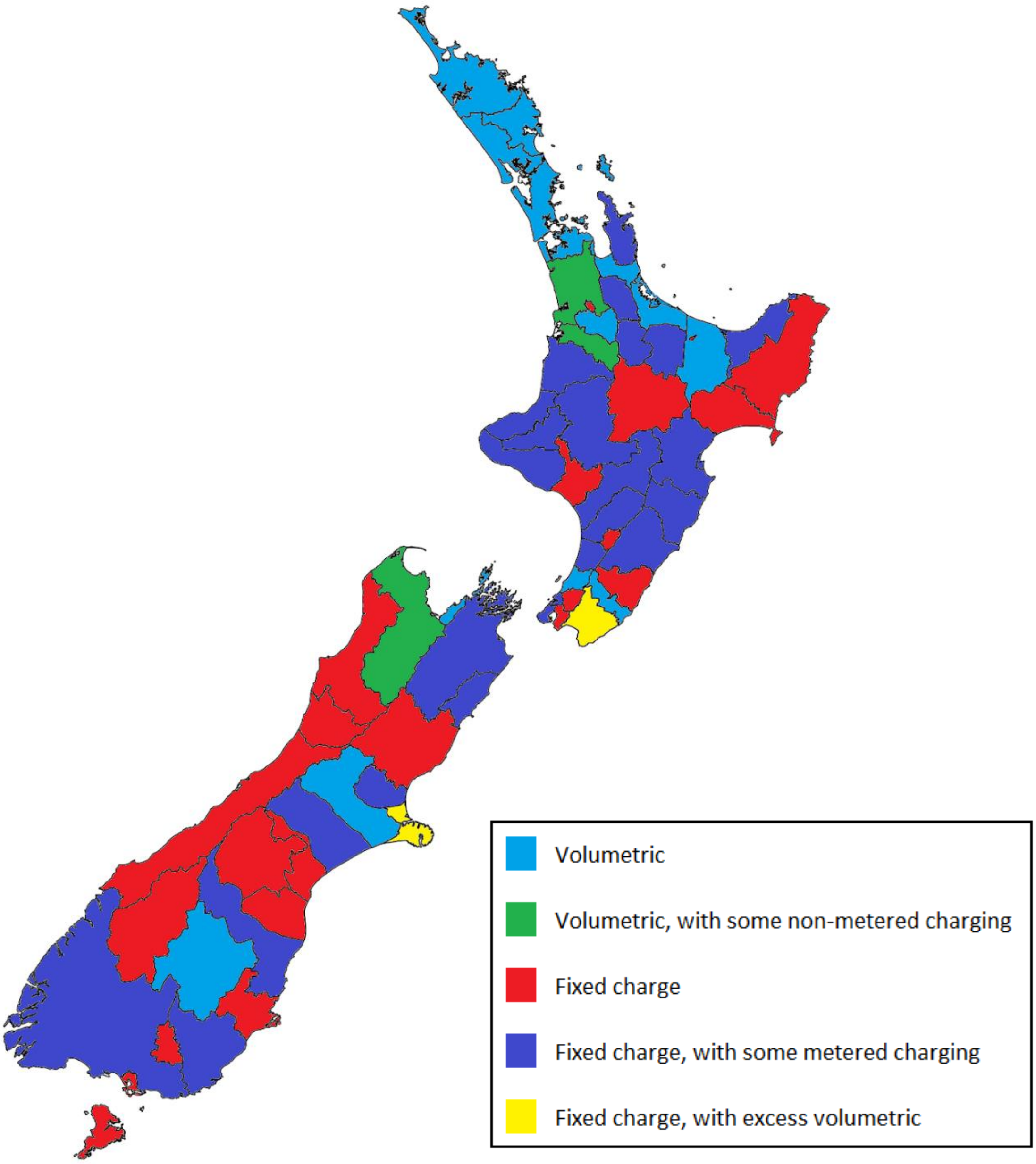


Figure 3: Charging mechanisms adopted by local councils in Aotearoa New Zealand, 2022. Image source (before colour filling): https://creazilla.com/nodes/1668-new-zealand-map-silhouette. Bob Comix License: Creative Commons Attribution 4.0. Free for editorial, educational, commercial, and/or personal projects. Sources: LGOIMA data, Water NZ, BRANZ (2018).

When asked through the LGOIMA process why it uses volumetric pricing, Watercare (Auckland Council) pointed to revenue cycling benefits, particularly in terms of funding the maintenance and improvement of infrastructure in the face of rapid population growth. In addition, it pointed to the benefit of increased customer awareness of water efficiency and wastage mitigation. Nelson City Council commented that volumetric charging helps to encourage water conservation and ensure that residential users pay their fair share of the operating costs.

The most common charging mechanism is fixed charge with some metered charging (38% of councils), followed by fixed charge only (32%). Out of the councils in Group D, the metered charging typically relates to either a volumetric charge for extraordinary users (i.e. properties who have been deemed by the council as large users and made to pay for the water they use) or a volumetric charge that is only applied when consumption exceeds a specified threshold.

Since such councils only have meters installed for less than 30% of the residential connections in their regions, it can be inferred that the majority of households in Aotearoa are not metered and are paying a charge that is unrelated to the volume of water consumed. This also partly explains the absence of detailed water consumption data in Aotearoa: most councils do not have the means to accurately measure the amount of water consumed by all households in their regions.

It is expected that the Water Services Reform programme will streamline metering and pricing across Aotearoa. However, evidence of how best to achieve pricing and metering efficiency in Aotearoa remains unclear.

4.1 Static comparison of urban water consumption

To gauge the potential impact of volumetric pricing on urban water consumption, we conduct a static comparison of water use across 43 councils in 2020. Here we use the data provided by DIA. Following the approach taken by Jenkins (2015), we categorise councils into two groups: those who predominantly use volumetric charges for water supply, and those who predominantly use fixed charges. We then compare water production and consumption across councils of similar sizes and different charging regimes.

Water production is measured as the total amount of water entering the council's distribution system and supplied to customers. Water consumption is measured as total household consumption and excludes water leakage and consumption from non-household/commercial users. For councils who do not have universal metering, reported consumption is an estimate rather than a measured value.

Figure 4 plots per capita production against the population size (on a log scale). As Jenkins (2015) has shown, per capita production falls as population size increases. Furthermore, for councils of a similar size, per capita production tends to be lower for councils whose main method of water charging is volumetric. For example, Tauranga (volumetric charging) and Hamilton (fixed charge) both have a population of 147,000, yet per capita production is 297L/p/d in Tauranga and 400L/p/d in Hamilton.

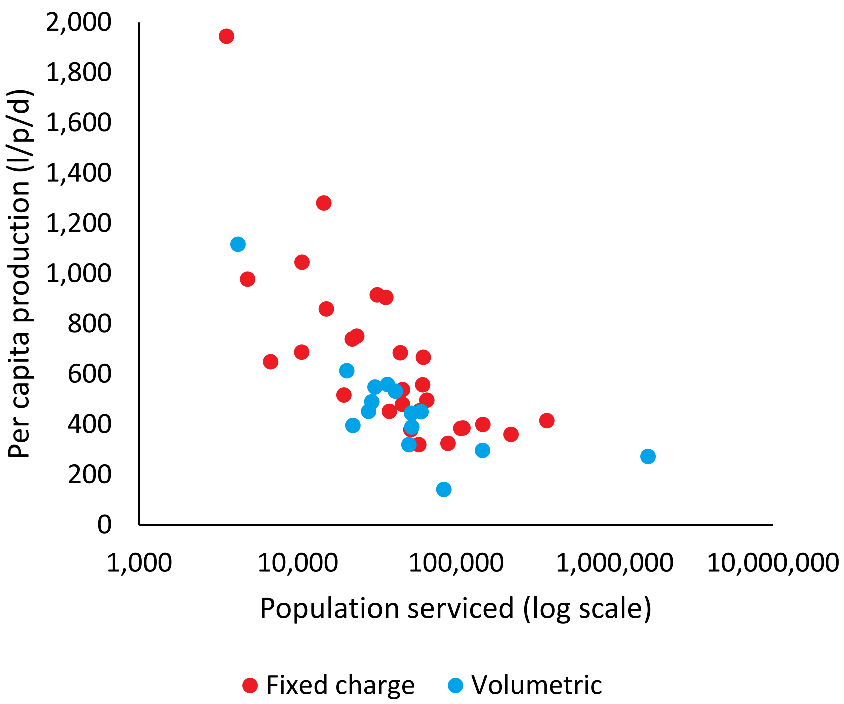


Figure 4: Per capita production versus population serviced in Aotearoa in 2020.

Another example is that Far North (volumetric) and Ashburton (fixed charge) both have populations of approximately 23,000, yet per capita production is 397 L/p/d in Far North and 750 L/p/d in Ashburton. There are some counterexamples to this. Selwyn uses volumetric charging and has per capita production of 445 L/p/d, while Waimakariri uses a fixed charge and has per capita production of 379 L/p/d. Nevertheless, the overall pattern appears to be that councils who use volumetric charging produce less water per person than councils who use fixed charges.[8]

The comparison of water consumption across councils is less straightforward than comparisons of water production because many councils do not have the means to accurately measure residential consumption. Residential water consumption for such councils is typically estimated by subtracting non-residential consumption (which is often metered), water leakage, and other unaccounted water from water production. Such estimates are likely to involve error and should be treated with caution.

[8] Note that there are possibly a range of unobserved factors that we do not control which could be driving this relationship, but it is reassuring that the patterns we observe are comparable with those in Jenkins (2015).

Appendix Table 1 reports the annual water production and consumption for each of the 43 councils using data collected from DIA through the OIA process. Unsurprisingly, Aotearoa's six biggest cities – Auckland, Christchurch, Wellington, Hamilton, Tauranga, and Dunedin – are the biggest water producers. Auckland and Tauranga, which both use volumetric charging, are amongst the lowest producers of water on a per capita basis. They both produce below 300 litres per person per day (L/p/d), compared to Wellington, Christchurch, and Dunedin, who produce between 380 to 420 L/p/d and do not use volumetric charging. Moreover, there is significant variation in per capita production across councils of similar sizes. For example, Whanganui, Invercargill, and Timaru all have a similar population size, yet per capita production varies from 480 to 685 L/p/d between them.

There are a considerable number of small councils who produce relatively large amounts of water, more than or close to 1,000 L/p/d, such as Mackenzie, Ōtorohanga, Clutha, Southland, Queenstown Lakes, and Marlborough. Jenkins (2015) comments that rural residential use is expected to be higher than for urban settings, although closer inspection is needed to understand why these councils produce so much water.

Appendix Table 1 also shows that, as with per capita production, Auckland and Tauranga have lower per capita consumption (146 L/p/d and 174 L/p/d respectively) than Wellington (220 L/p/d), Hamilton (232 L/p/d), and Christchurch (242 L/p/d). This suggests that volumetric charging in urban cities is associated with lower per capita consumption. Dunedin has the lowest per capita consumption (116 L/p/d) out of the six cities, despite not using volumetric charging; however, this value could be affected by data quality issues. Dunedin does not have universal metering, so it cannot accurately measure residential water consumption. Furthermore, the council reports on its website that water consumption is likely between 180 and 250 L/p/d.[9]

4.2 Dynamic comparison of urban water consumption: Tauranga and Wellington

Because monthly or quarterly data over time was not available for all councils, in this section we present two case studies of councils who employ different residential water charging mechanisms: Tauranga (volumetric) and Wellington (fixed charge). While the previous section focused on the spatial variation of water use across Aotearoa over one year, here patterns of water use over time are investigated and compared. For both case studies we use the data collected from the LGOIMA process.

[9] https://www.dunedin.govt.nz/services/water-supply/saving-water-tips

4.2.1 Tauranga case study

Tauranga is a harbourside city in the Bay of Plenty region on Aotearoa's North Island. Due to rapid population growth, it is now Aotearoa's fifth largest city, with a population of almost 160,000 as of 2023. It has a sunny, temperate climate, with climate change pressures anticipated to increase droughts and temperatures in the coming decades.

The decision to install meters in Tauranga in 1999 was made in response to strain on the water treatment system and overall supply network (Jenkins, 2015; Water NZ, n.d.). Universal water metering and billing officially commenced on 1 July 2002, with the impacts of the policy change evident in Figure 5.[10] Figure 5 shows that annual water production in Tauranga sharply increased from 1987 until 1999. It then fell until 2004, after which it began slowly increasing before reaching a peak of 16 billion litres in 2020. Figure 6 shows that although per capita production was rising between 1987 to 1999, it sharply declined from 421 L/p/d in 1999 (when the decision to install meters was announced) to 333 L/p/d in 2003 (when universal billing officially commenced). Per capita production declined modestly after 2003, before plateauing at an average level of 290 L/p/d from 2012 to 2022.

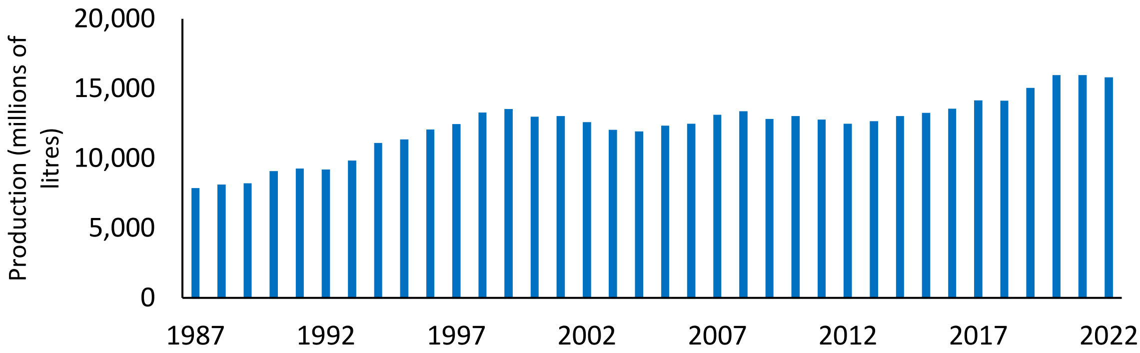


Figure 5: Water production in Tauranga between 1987 and 2022.

[10] The installation and implementation of metering and volumetric charging has been subject to many case studies in Aotearoa (Jenkins, 2015; Reed & Hermens, 2016; Sternberg & Bahrs, 2016; Mayoral Taskforce, 2020). Such studies detail the context behind the decision to install meters and its success in reducing average and peak demand in Tauranga. To avoid repetition, we focus on the recent trends of water use in Tauranga and compare this with water use in Wellington, a city that has not implemented universal metering and volumetric charging.

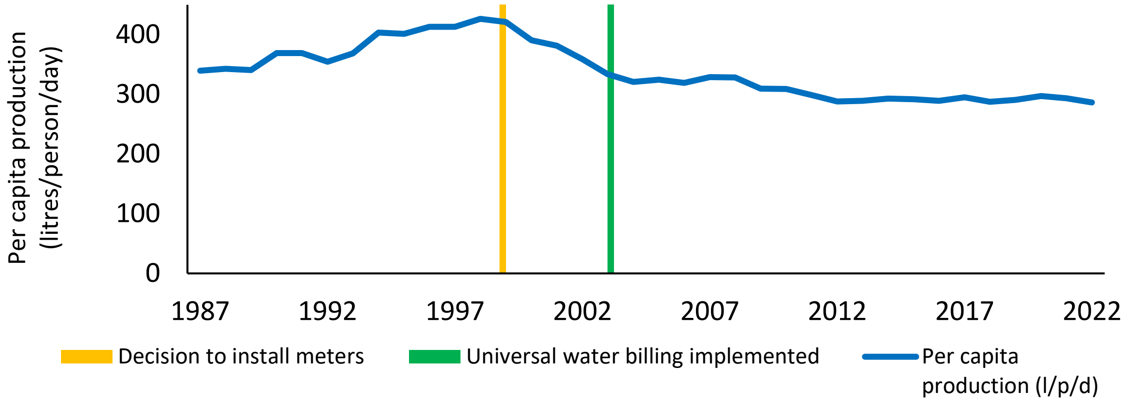


Figure 6: Per capita production in Tauranga between 1987 and 2022.

Figure 7 plots annual residential water consumption from 2012 to 2022. Water consumption was relatively constant at around 7.8 billion litres between 2012 and 2016. It increased to 9.1 billion litres in 2020 (a 17% increase) and remained there until 2022. Figure 8 shows that per capita consumption has been slowly declining since 2012. Starting at 182 L/p/d in 2012, it fell to 168 L/p/d before spiking up to 176 L/p/d in 2017. Between 2018 and 2022, it has remained around 169 L/p/d.

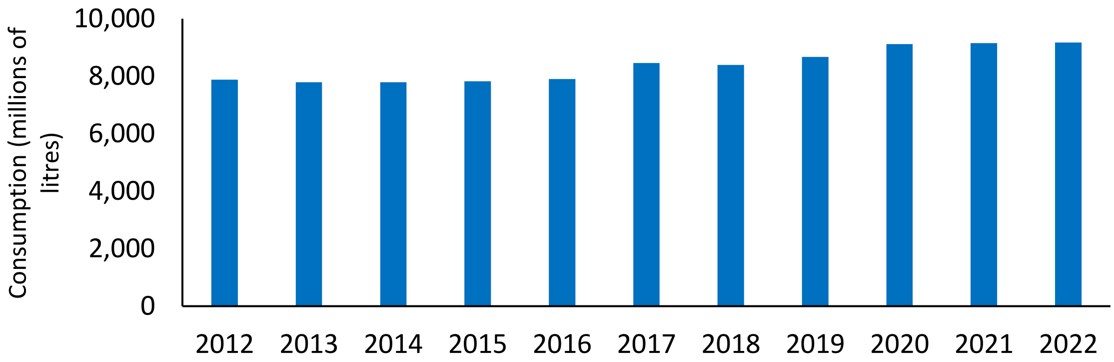


Figure 7: Residential water consumption in Tauranga between 2012 and 2022.

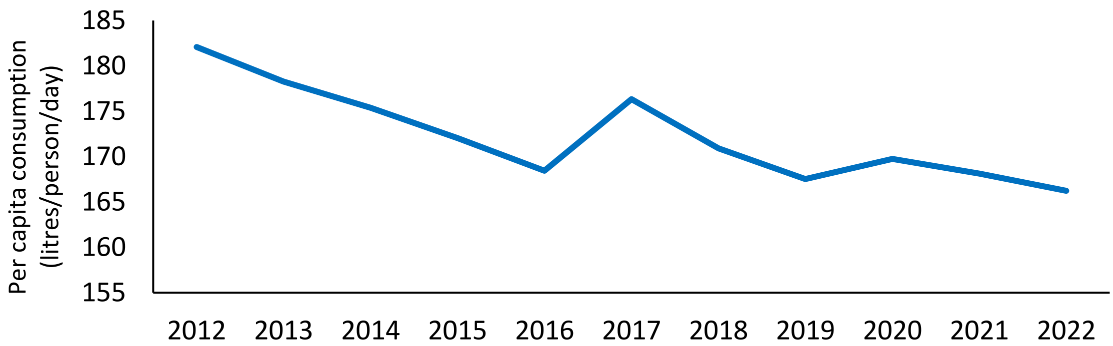


Figure 8: Per capita consumption in Tauranga between 2012 and 2022.

4.2.2 Some reflections

The sharp drop in per capita production after 1999 suggests that switching to metering and volumetric charging significantly reduced per capita water production in Tauranga, and that such reductions can be maintained over time. Important to note is that per capita production declined more in 1999 (when the decision to install meters was made) than in 2003 (when formal billing began). This could be because households were made aware of how the new pricing would affect their bills through the use of dummy invoices which could have lead to some households adjusting their behaviour in anticipation of future water charges.

Before billing began, Tauranga households were sent dummy invoices which showed them how much water they had used in previous months, what the new water prices would be, and how much they would be charged once formal billing began. This means households were able to adjust their consumption based on what they were willing to pay. The dummy invoices were complemented by an educational programme and direct on-site water efficiency services to help raise awareness of water consumption and improve political and community buy-in (Reed & Hermens, 2016). Thus, it can be inferred that the combination of water pricing and non-price tools led Tauranga to significantly reduce its per capita production in the early 2000s.

However, the recent plateau in consumption (between 2018 and 2022) suggests that households in Tauranga may have become relatively unresponsive to volumetric charges. Between 2018 and 2022, the volumetric charge increased from $1.89 to $2.91 (a 54% increase), yet per capita consumption only decreased from 171 L/p/d to 166 L/p/d (a 3% decrease). Although not causal evidence, these values suggest that prices may have reached a level where they can no longer induce households to reduce consumption. Other mechanisms like dynamic pricing, whereby prices move in response to available supply, might be more effect than constant and gradual increases.

4.2.3 Wellington case study

Wellington City is Aotearoa's third largest city with a population of roughly 216,000.[11] Strongly influenced by the Cook Strait and a rugged topography, the climate is temperate and expected to become more variable as a result of climate change, with run-on effects for water supplies and agriculture. For many years Wellington City Council has resisted the adoption of volumetric charging, instead opting to charge a fixed amount based on property capital value.[12] However, the political and social appetite for metering and volumetric charging may change because of

[11] Here Wellington refers to Wellington City, and excludes the surrounding regions of Lower Hutt, Upper Hutt, and Porirua which make up the Greater Wellington region.
[12] https://www.stuff.co.nz/environment/130826662/water-meters-would-help-address-wellingtons-leak-problem--but-will-politicians-act

climate change, growing demand, and increased pressure on ageing infrastructure (Mayoral Taskforce, 2020).

It is estimated that ageing infrastructure is causing Wellington to lose up to 30% of its water through leaks (Mayoral Taskforce, 2020). In addition, average household water consumption exceeds national benchmarks, and rapid population growth means that the water network is nearing capacity in many areas. Overall, the combination of significant water loss and high consumption means that Wellington is forecast to face severe water shortages by 2026 if nothing is done to address demand or supply (Ernst & Young, 2020).

Figure 9 shows that annual urban water production in Wellington has been consistently above 25 billion litres since 1996. Between 2006 and 2015, production fell from a peak of 32 billion litres to its lowest point of 26 billion litres. This was driven by a 22% decrease in per capita production from 464 L/p/d in 2006 to 361 L/p/d in 2015 (Figure 10) that was likely driven by a water conservation education programme and various leak detection measures during 2011–2013 (Jenkins, 2015).

Thus, Wellington City Council has been able to achieve reductions in water use in the absence of water metering and volumetric pricing; however, Figures 9 and 10 show that these reductions have not been maintained over the longer term. In 2022, annual production returned to previous peak levels and per capita production appears to have been slowly trending upwards since 2015. This suggests that the current water management system is not encouraging enough water conservation and may not be able to handle future population and failing infrastructure pressures.

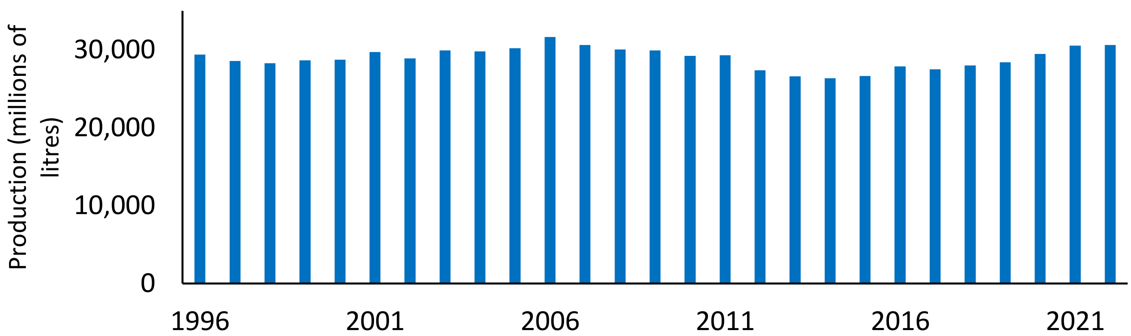


Figure 9: Water production in Wellington between 1996 and 2022.

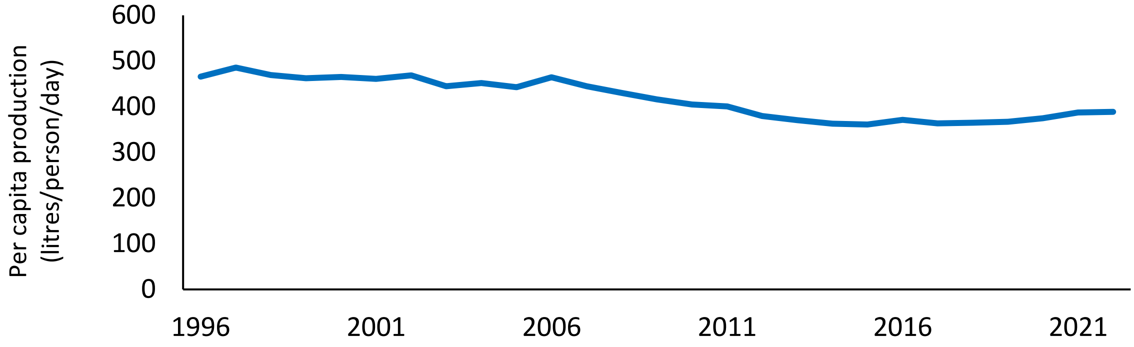


Figure 10: Per capita water production in Wellington between 1996 and 2022.

Figure 11 shows that the estimated annual residential water consumption was relatively constant between 2006 and 2017, averaging 16 billion litres per year. Between 2017 and 2020 it slowly increased, before spiking in 2021 at 19 billion litres. It then dropped back down to 16 billion litres in 2022. Figure 12 shows that estimated per capita residential consumption was constant at 230 L/p/d between 2006 and 2011, and then slowly declined to 215 L/p/d by 2015. The decline in residential consumption coincides with the water conservation education programme carried out by Wellington City Council in 2011 (Jenkins, 2015). After peaking at 241 L/p/d in 2021, per capita consumption reached its lowest point of 203 L/p/d in 2022.

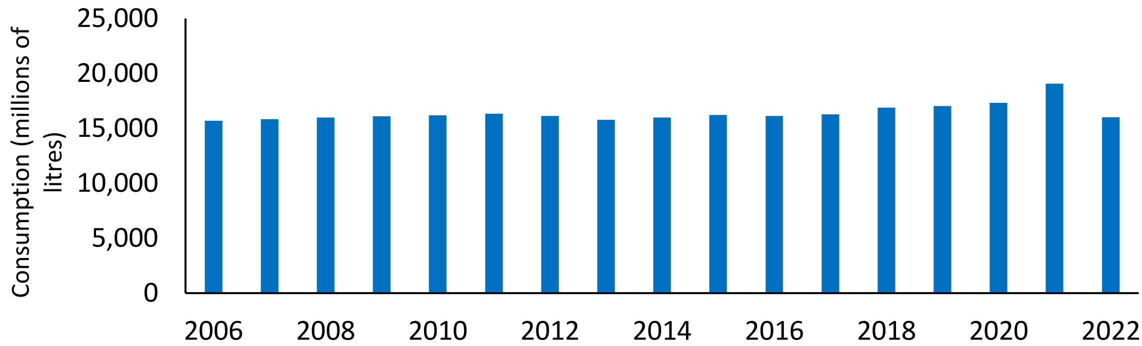


Figure 11: Estimated residential water consumption in Wellington between 2006 and 2022.

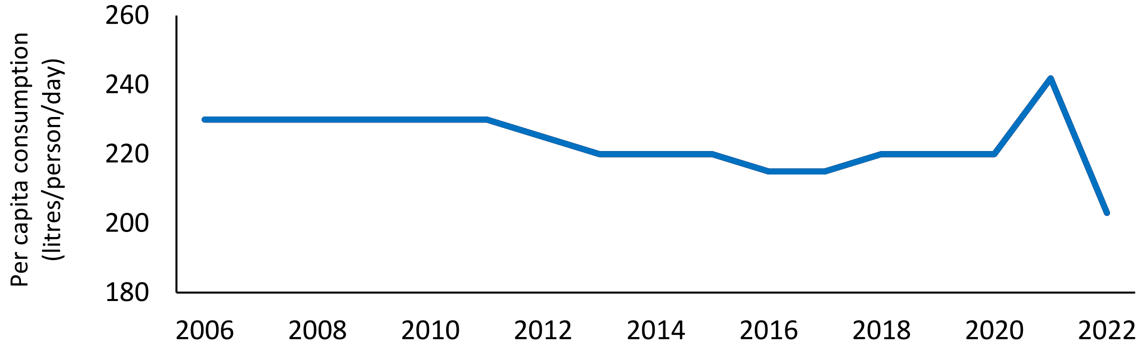


Figure 12: Estimated per capita residential water consumption in Wellington between 2006 and 2022.

Furthermore, although Figure 12 suggests that Wellington City Council has been able to prevent annual residential consumption from rising, it has been consistently higher than per capita consumption in Tauranga, as shown in Figure 13. Thus, if Wellington City Council wants to further reduce consumption, it may have to consider using an alternative demand-side mechanism, such as metering or volumetric pricing, to curb demand.

4.2.4 Some reflections

Analysis of urban water use in Wellington suggests that per capita consumption can decline or remain constant without the need for metering and volumetric pricing. However, caution must be taken when analysing these figures. Due to a lack of meters, the values used in this analysis are only estimates and may not reflect the true levels of residential consumption in Wellington.

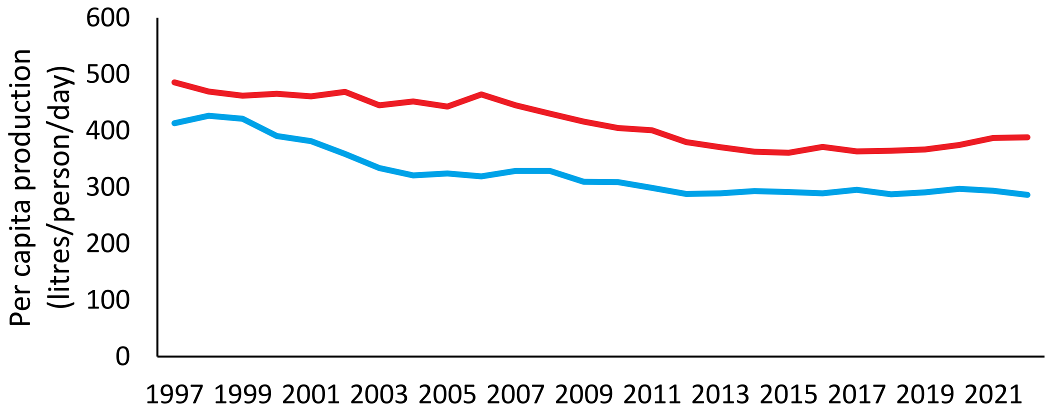
Indeed, in 2020, a Mayoral Taskforce was established to investigate the Wellington water network and to provide recommendations on how water should be managed in Wellington in the future (Mayoral Taskforce, 2020). The taskforce found that water consumption per capita and the level of network leakage were estimated to be high and that leakages were hard to detect. It recommended that water metering should, in time, replace fixed rates charges as the means of funding residential water production. The taskforce argued that this would allow the rapid identification and repair of leaks, encourage water conservation, defer the need for expensive new water sources, and give an accurate picture of the actual levels of leakage and water consumed in Wellington.

Further, in 2020, initiated by Wellington Water, Ernst & Young undertook an economic analysis of the costs and benefits of implementing metering and pricing in Wellington (Ernst & Young, 2020). This analysis was initiated by Wellington Water. Ernst & Young concluded that investing in and implementing water metering would enable Wellington Water to achieve its objectives of reducing water demand and improving network management. Cost-benefit analysis of alternative metering and information provision options suggested that metering would provide net benefits to Wellington customers and be economically viable if it was implemented alongside volumetric pricing. Overall, metering was expected to reduce residential consumption by 2.5% and water leakage by 7.2%, allowing for the need for a new water source to be deferred by between two and 13 years.

4.2.5 Summary

The findings of this comparative analysis support the proposition that volumetric charging can reduce water use more than fixed charges and non-price demand management tools. Between the late 1990s and 2022, Tauranga reduced its per capita production from 420 L/p/d to 286 L/p/d (a 31% decrease), while Wellington reduced its per capita production by a smaller amount, from 485 L/p/d to 388 L/p/d (a 20% decrease). Per capita residential consumption in 2022 is approximately 37 L/p/d higher in Wellington compared to Tauranga.[13]

Finally, Tauranga's reduction in per capita production and consumption exceeded Wellington's over the same time period. This suggests that volumetric charging plays a role in altering household behaviour and inducing greater water consumption in the Aotearoa context. It also hints at the possibility of further reductions in consumption in Wellington if universal metering and volumetric charging were introduced in the future.[14]



[13] Note that both cities implemented educational programmes and other non-price tools during this time. The key difference is that Tauranga used volumetric charging while Wellington used fixed charges unrelated to the amount of water used.

[14] We caveat this by reiterating that our analysis does not provide causal evidence of the impact of water pricing and is merely suggestive.

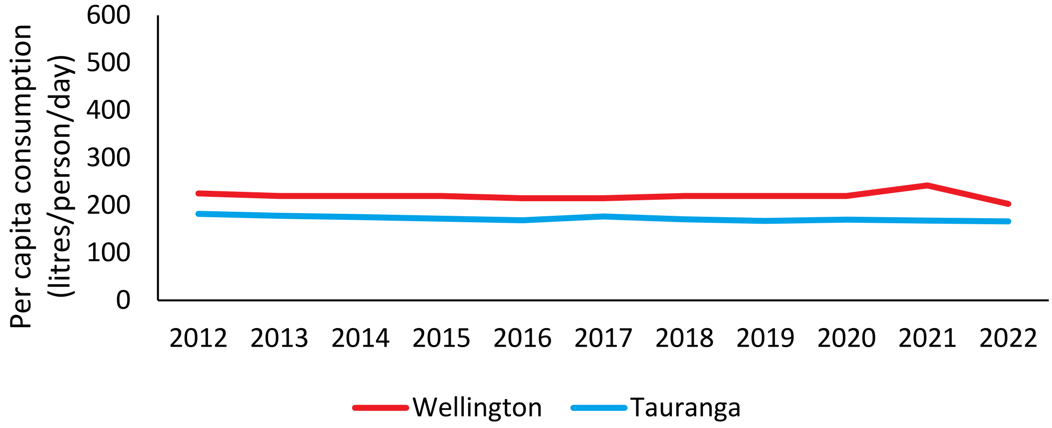


Figure 13: Water use in Wellington and Tauranga over time. The upper panel compares per capita production between 1997 and 2022. The lower panel compares per capita consumption between 2012 and 2022.

5 Discussion

The issues facing urban water management in Aotearoa have spurred the proposed substantive reforms of drinking water, stormwater, and wastewater management. The Water Services Reform programme put forward by central government in 2021 proposes consolidating decision-making responsibility for drinking water, stormwater, and wastewater in three (now 10) centrally controlled entities (Chambers et al., 2022). To ensure that a shift from the status quo results in outcomes that are efficient, effective, and equitable, evidence of current water use patterns is required to forecast the marginal impacts of any future policy change. This paper highlights how difficult it is to obtain data using public channels in Aotearoa and demonstrates some of the limitations this imposes on the creation of evidence-based or evidence-informed policy.

The data that we were able to obtain through public channels made it difficult to test the hypothesis that metering and pricing impact water consumption across Aotearoa. This was for several reasons. First, the aggregation of data by councils constrained our ability to estimate price elasticity and equity impacts. Research shows that estimating water demand models and price elasticities requires monthly household-level data (for example, Ghavidelfar et al., 2017; El-Khattabi et al., 2021; and Agarwal et al., 2023). The data we obtained from councils was mostly aggregated at the annual and regional level, which means we could not observe sufficient variation in water consumption to accurately estimate how households respond to water price changes. This aggregation also restricted our ability to estimate the impact of pricing on low-income or high-use households, limiting the potential for equity analysis.

Second, the absence of consistent data over time constrained our ability to estimate and compare how households respond to the installation of meters and introduction of pricing, or how they react to pricing over the long run. Internationally, the responsiveness of residential users to price changes over time has been shown to be mixed, which means context-specific data is imperative for ensuring policy changes can deliver meaningful improvements in welfare (Espey et al., 1997). Many studies, for example, point to the fact that prices may eventually have an immutable impact on behaviour once households become normalised to the cost of water (Worthington & Hoffman, 2008). However, others find that using pricing methods can remain an impactful tool, particularly when dynamic approaches to pricing are used, whereby prices adjust to reflect scarcity in real time (Grafton et al., 2020a).

Third, a comprehensive interregional comparison of water consumption over time was constrained by gaps within the LGOIMA data. Although this was partially mitigated by shifting the interregional dynamic analysis to a static analysis, the LGOIMA data still had to be supplemented by data collected from DIA (accessed through a separate OIA process) and Water NZ. Although steps were taken to ensure that the process of combining datasets was robust, validity issues can arise through methodological differences in the original data-gathering process.

To ensure that Aotearoa's proposed urban water policy reform will deliver the anticipated results, evidence-based or evidence-informed policy should be the norm across government levels. Data – that is, any facts, records, or measures – is fundamental to initiate any research, validate models, estimate trends, and monitor changes over time (Parliamentary Commissioner for the Environment, 2019). The barriers we experienced collecting and accessing data on urban drinking water production and consumption raises questions about the ability of Aotearoa's policymakers to make robust, evidence-informed policy decisions, and raises issues for public accountability.

To improve the collection and analysis of urban water use over time, institutional change is required to support the development of a more robust data architecture framework. As a starting point, each authority should be provided with a centrally designed Excel template that could help guide the collection of data within their region that will be comparable across regions and over time. If the Water Services Reform goes ahead and management of drinking water, wastewater, and stormwater is centralised, developing consistent data gathering, storage, and disseminating approaches across the 10 government entities should be a priority. Either way, collecting more consistent data will help ensure that any widespread adoption of alternative urban water management mechanisms, such as metering and pricing, will deliver marginal improvements in welfare for the environment and communities affected.

6 Conclusion

To improve management of drinking water in urban areas in Aotearoa New Zealand, policymakers need a better understanding of what water is available and how it is being used. Establishing these linkages requires research but, as this paper has made clear, the data required to undertake any analysis robustly is not always publicly available or easily accessible. Although theoretical and empirical research can inform policy decisions across contexts, local behavioural patterns limit the transfer of findings. Hence, there is a need to have local data available for research and analysis (Espey et al., 1997).

As Aotearoa embarks on a period of substantive reform for drinking water, stormwater, and wastewater, it is unclear what data is being used to justify the policy change, or to ensure that whatever changes being implemented are an improvement on the status quo. The data we gathered from DIA, that is meant to be informing the Water Services Reform programme, was aggregated at the annual level and only consisted of two years of information. Data gathered from councils was spotty, inconsistent, and revealed substantive gaps in the national urban water accounts. In every instance, the data collected was of a lower quality than what is used in the international literature to estimate the impacts of metering and pricing on demand.

To ensure Aotearoa can cope with increased demand and the pressures from climate change, demand-side management tools, such as metering and pricing, need to be at the forefront of decision-makers' considerations. Technical, supply-side mechanisms will be insufficient to deliver efficient, effective, and equitable outcomes for communities and the environment over the longer term. Collecting data on water production and consumption in urban areas and making it publicly available is critical, to ensure that shifting from the status quo will deliver targeted welfare improvements.[15] As pressures on freshwater resources increase, having high-quality data on urban water production and consumption will help Aotearoa meet its SDG commitments and deliver urban water security for all.

[15] Although meters can aid in this process, they are not fundamental, as our experience with Wellington City Council revealed.

References

Agarwal, S., Araral, E., Fan, M., Qin, Y., & Zheng, H. (2023). The effects of policy announcement, prices and subsidies on water consumption. *Nature Water*, *1*(2), 176–186. https://doi.org/10.1038/s44221-023-00028-1

Brandes, L. (2011, May). The water soft path—A new approach to ensuring adequate water supplies. *Environmental Science and Engineering Magazine*, 22–23.

Chambers, T., Wilson, N., Hales, S., Prickett, M., Ellison, E., & Baker, M. G. (2022). Beyond muddy waters: Three Waters reforms required to future-proof water service delivery and protect public health in Aotearoa New Zealand. *New Zealand Medical Journal*, *135*(1566), 87–95.

Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges and research directions. *Water Resources Research*, *51*(6), 4823–4839. https://doi.org/10.1002/2014WR016869

El-Khattabi, A. R., Eskaf, S., Isnard, J. P., Lin, L., McManus, B., & Yates, A. J. (2021). Heterogeneous responses to price: Evidence from residential water consumers. *Journal of Environmental Economics and Management*, *107*, 102430. https://doi.org/10.1016/j.jeem.2021.102430

Ernst & Young. (2020). *Economic Case for Providing Residential Water Consumption Information*. https://www.wellingtonwater.co.nz/assets/Reports-and-Publications/561Wellington-Water-Economic-Case-for-Providing-Residential-Water-Consumption-Information-FINAL-Oct-2020.pdf

Espey, M., Espey, J., & Shaw, W. D. (1997). Price elasticity of residential demand for water: A meta-analysis. *Water Resources Research*, *33*(6), 1369–1374. https://doi.org/10.1029/97WR00571

Flörke, M., Schneider, C., & McDonald, R. I. (2018). Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability*, *1*(1), 51–58. https://doi.org/10.1038/s41893-017-0006-8

García-Valiñas, M. Á., & Suárez-Fernández, S. (2022). Are Economic Tools Useful to Manage Residential Water Demand? A Review of Old Issues and Emerging Topics. *Water*, *14*, 2536. https://doi.org/10.3390/w14162536

Gaudin, S. (2006). Effect of price information on residential water demand. *Applied Economics*, *38*(4), 383–393. https://doi.org/10.1080/00036840500397499

Ghavidelfar, S., Shamseldin, A. Y., & Melville, B. W. (2017). A Multi-Scale Analysis of Single-Unit Housing Water Demand Through Integration of Water Consumption, Land Use and Demographic Data. *Water Resources Management*, *31*(7), 2173–2186. https://doi.org/10.1007/s11269-017-1635-4

Goulas, A., Goodwin, D., Shannon, C., Jeffrey, P., & Smith, H. M. (2022). Public Perceptions of Household IoT Smart Water “Event” Meters in the UK—Implications for Urban Water Governance. *Frontiers in Sustainable Cities*, *4*. https://doi.org/10.3389/frsc.2022.758078

Grafton, R. Q. (2017). Responding to the ‘Wicked Problem’ of Water Insecurity. *Water Resources Management*, *31*(10), 3023–3041. https://doi.org/10.1007/s11269-017-1606-9

Grafton, R. Q., Chu, L., & Wyrwoll, P. (2020a). Dynamic Water Pricing. *Oxford Research Encyclopedia of Global Public Health*. https://doi.org/10.1093/acrefore/9780190632366.013.245

Grafton, R. Q., Chu, L., & Wyrwoll, P. (2020b). The paradox of water pricing: Dichotomies, dilemmas, and decisions. *Oxford Review of Economic Policy*, *36*(1), 86–107. https://doi.org/10.1093/oxrep/grz030
Grafton, R. Q., & Ward, M. B. (2008). Prices versus Rationing: Marshallian Surplus and Mandatory Water Restrictions. *Economic Record*, *84*(s1), S57–S65. https://doi.org/10.1111/j.1475-4932.2008.00483.x
Hassell, T. (2007). *Promoting Behavioural Change in Household Water Consumption: Literature Review*. Waterwise. https://www.waterwise.org.uk/wp-content/uploads/2018/02/Smart-Water-2007_Promoting-Behavioural-Change-in-Household-Water-Consumption.pdf
He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., & Bryan, B. A. (2021). Future global urban water scarcity and potential solutions. *Nature Communications*, *12*(4667). https://doi.org/10.1038/s41467-021-25026-3
Hoekstra, A. Y., Buurman, J., & Ginkel, K. C. H. van. (2018). Urban water security: A review. *Environmental Research Letters*, *13*(5), 053002. https://doi.org/10.1088/1748-9326/aaba52
Hoffmann, M., Worthington, A., & Higgs, H. (2006). Urban water demand with fixed volumetric charging in a large municipality: The case of Brisbane, Australia. *The Australian Journal of Agricultural and Resource Economics*, *50*(3), 347–359. https://doi.org/10.1111/j.1467-8489.2006.00339.x
Jenkins, B. (2015). New Zealand Water Pricing. In *Water Pricing Experiences and Innovations* (pp. 263–288). Springer International Publishing. https://doi.org/10.1007/978-3-319-16465-6_14
Josset, L., Allaire, M., Hayek, C., Rising, J., Thomas, C., & Lall, U. (2019). The U.S. Water Data Gap—A Survey of State-Level Water Data Platforms to Inform the Development of a National Water Portal. *Earth's Future*, *7*(4), 433–449. https://doi.org/10.1029/2018EF001063
Koop, S. H. A., Clevers, S. H. P., Blokker, E. J. M., & Brouwer, S. (2021). Public Attitudes towards Digital Water Meters for Households. *Sustainability*, *13*, 6440. https://doi.org/10.3390/su13116440
Marston, L. T., Abdallah, A. M., Bagstad, K. J., Dickson, K., Glynn, P., Larsen, S. G., Melton, F. S., Onda, K., Painter, J. A., Prairie, J., Ruddell, B. L., Rushforth, R. R., Senay, G. B., & Shaffer, K. (2022). Water-Use Data in the United States: Challenges and Future Directions. *JAWRA Journal of the American Water Resources Association*, *58*(4), 485–495. https://doi.org/10.1111/1752-1688.13004
Matthews, Y. (2022). *The short and long run dynamics of household response to water demand management* [PowerPoint slides]. https://nzares.org.nz/doc/2022/Papers/Matthews2022.pdf
Mayoral Taskforce. (2020). *The Mayoral Taskforce on the Three Waters Report*. Wellington City Council. https://wellington.govt.nz/-/media/your-council/meetings/council/2020/december/report-of-the-mayoral-taskforce-three-waters.pdf
McDonald, R. I., Weber, K., Padowski, J., Flörke, M., Schneider, C., Green, P. A., Gleeson, T., Eckman, S., Lehner, B., Balk, D., Boucher, T., Grill, G., & Montgomery, M. (2014). Water on an urban planet: Urbanization and the reach of urban water infrastructure. *Global Environmental Change*, *27*, 96–105. https://doi.org/10.1016/j.gloenvcha.2014.04.022
Ministry for the Environment. (2023). *Our freshwater 2023*. https://environment.govt.nz/publications/our-freshwater-2023/

Olmstead, S. M., & Stavins, R. N. (2009). Comparing price and nonprice approaches to urban water conservation. *Water Resources Research*, *45*(4). https://doi.org/10.1029/2008WR007227
Parliamentary Commissioner for the Environment. (2019). *Focusing Aotearoa New Zealand's environmental reporting system*. https://pce.parliament.nz/media/vjnfu5kl/focusing-aotearoa-new-zealand-s-environmental-reporting-system.pdf
Reed, J., & Hermens, K. (2016). *A review of water metering practice in New Zealand and overseas*. Water New Zealand. https://www.waternz.org.nz/Attachment?Action=Download&Attachment_id=581
Sternberg, J., & Bahrs, P. (2016). *Water metering—The Tauranga Journey*. Water New Zealand. https://www.waternz.org.nz/documents/other/101029_tauranga_on_metering.pdf
Water New Zealand. (2022). *National Performance Review 2021/2022*. National Performance Review. https://www.waternz.org.nz/NationalPerformanceReview
Wichman, C. J., Taylor, L. O., & von Haefen, R. H. (2016). Conservation policies: Who responds to price and who responds to prescription? *Journal of Environmental Economics and Management*, *79*, 114–134. https://doi.org/10.1016/j.jeem.2016.07.001
Worthington, A. C., & Hoffman, M. (2008). An Empirical Survey of Residential Water Demand Modelling. *Journal of Economic Surveys*, *22*(5), 842–871. https://doi.org/10.1111/j.1467-6419.2008.00551.x

Appendix

Appendix Table 1: Annual water production and consumption in 2020

Council	Estimated population serviced	Production (m^3/year x10^3)	Consumption (m^3/year x10^3)	Per capita production (l/p/day)	Per capita consumption (l/p/day)	Charging mechanism
Auckland	1629000	162204	86978	273	146	Volumetric
Christchurch	375200	56940	33200	416	242	Fixed charge
Wellington	222600	29317	17875	361	220	Fixed charge
Hamilton	147489	21535	12466	400	232	Fixed charge
Tauranga	147200	15951	9327	297	174	Volumetric
Dunedin	110473	15595	4659	387	116	Fixed charge
Hutt City	107400	15111	9251	385	236	Fixed charge
Palmerston North	89100	10567	7285	325	224	Fixed charge
Waikato	83800	4335	2767	142	90	Volumetric
New Plymouth	65499	11870	7528	497	315	Fixed charge
Rotorua Lakes	62128	15154	7628	668	336	Fixed charge
Hastings	61720	12583	2985	559	132	Fixed charge
Whangarei	60049	9884	4054	451	185	Volumetric
Napier	59055	9811	3649	455	169	Fixed charge
Porirua	58300	6800	4681	320	220	Fixed charge
Nelson	52600	7486	3396	390	177	Volumetric
Selwyn	52328	8508	7536	445	395	Volumetric
Waimakariri	51970	7198	5151	379	272	Fixed charge
Kāpiti Coast	50424	5879	3552	319	193	Volumetric
Whanganui	46000	9056	3525	539	210	Fixed charge
Invercargill	45890	8047	3794	480	227	Fixed charge
Timaru	44556	11143	3550	685	218	Fixed charge
Waipā	41508	8063	2244	532	148	Volumetric
Gisborne	38000	6270	3519	452	254	Fixed charge
Western Bay of Plenty	36850	7519	1897	559	141	Volumetric
Queenstown Lakes	36000	11901	7425	906	565	Fixed charge
Marlborough	31840	10648	4526	916	389	Fixed charge
Whakatāne	30854	6186	2465	549	219	Volumetric
Tasman	29351	5262	2138	491	200	Volumetric
Horowhenua	28112	4638	1954	452	190	Volumetric
Ashburton	23658	6492	2610	752	302	Fixed charge
Far North	22360	3240	1780	397	218	Volumetric
Waitaki	22147	5986	4268	741	528	Fixed charge
Central Otago	20435	4582	1258	614	169	Volumetric
Manawatū	19590	3699	1647	517	230	Fixed charge
Hurunui	15194	4771	3179	860	573	Fixed charge
Clutha	14595	6825	655	1281	123	Fixed charge
Southland	10683	4079	3818	1046	979	Fixed charge
Central Hawke’s Bay	10589	2657	2480	688	642	Fixed charge
South Wairarapa	6770	1606	1059	650	428	Fixed charge
Wairoa	4830	1724	421	978	239	Fixed charge
Ōtorohanga	4196	1710	656	1117	428	Volumetric
Mackenzie	3548	2519	879	1945	679	Fixed charge

Source: DIA data