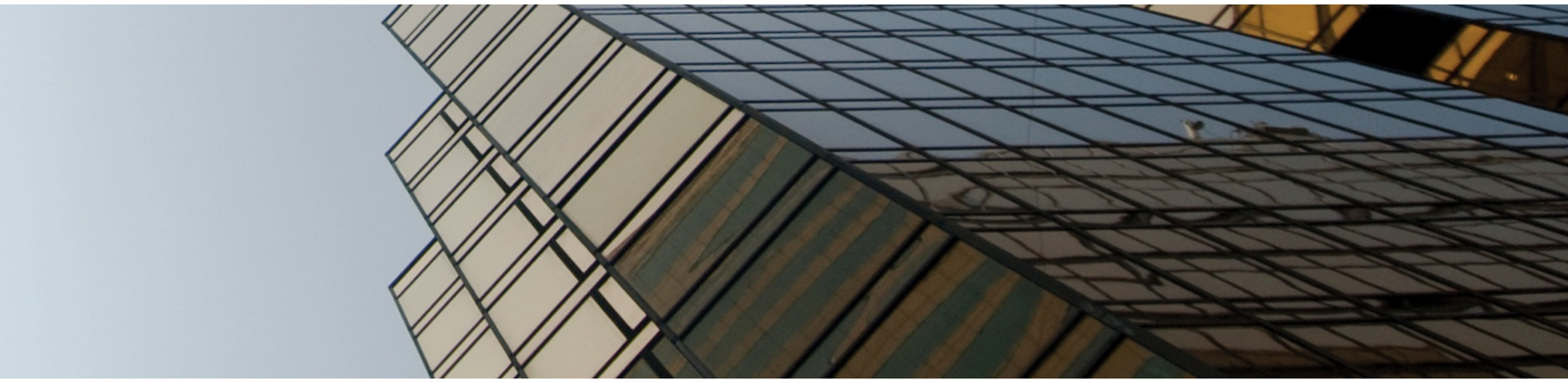

STUDY REPORT SR 277/8 [2014]

BEES INTERIM REPORT

Building Energy End-use Study - Year 5

AUCKLAND'S WATER USE

Hans Roberti

Funded by BRANZ from the Building Research Levy

Ministry of Business, Innovation & Employment

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PREFACE

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. Buildings that are more efficient will help reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) is taking the first step towards this. The aim is to establish where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

The BEES study started in 2007 and ran for 6 years, gathering information on energy and water use through carrying out surveys and monitoring non-residential buildings. By analysing the information gathered, BEES aimed to answer eight key research questions about resource use in buildings:

1. What is the aggregate energy and water use of non-residential buildings in New Zealand?
2. What is the average energy and water use per unit area per year?
3. What characterises the buildings that use the most energy and water?
4. What is the average energy use per unit area for different categories of building use?
5. What are the distributions of energy and water use?
6. What are the determinants of water and energy-use patterns, e.g. structure, form, function, occupancy, building management etc.?
7. Where are the critical intervention points to improve resource use efficiency?
8. What are the likely future changes as building stock type and distribution change?

Understanding the importance and interaction of users, owners and those who service non-residential buildings was also an important component of the study.

For the BEES study, non-residential buildings have been defined using categories in the New Zealand Building Code, but in general terms, the study mainly looks at Commercial Office and Commercial Retail buildings. These vary from small corner dairies to large multi-storey office buildings. For more information on the building types included in the study, see SR224 *Building Energy End-use Study (BEES) Years 1 & 2* (Isaacs et al., 2009).

The study has two main methods of data collection – a high-level survey of buildings and businesses, and intensive detailed monitoring of individual premises.

The high-level survey initially involved collecting data about a large number of buildings. From this large sample, a smaller survey of businesses within buildings was carried out, which included a phone survey and collecting records of energy and water use and data on floor areas. The information enables a picture to be built up of the total and average energy and water use in non-residential buildings. It also identifies the intensity of this use and resources used by different categories of building use, answering research questions 1–4 above.

The detailed monitoring of individual premises involves energy and indoor condition monitoring, occupant questionnaires and a number of audits, including appliances, lighting, building, hot water, water and equipment.

This report presents data and analysis drawn from BEES sample framework. However, it is geographically limited to the Auckland region. This report looks at aggregate water use in BEES properties in the Auckland region. This report is of value as it shows that water use relates to building size and to the way that buildings are utilised. The data and analysis in this report contribute to answering BEES research questions 1–6. Further analysis on this topic that will be done for the final BEES report, including analysis of the detailed monitoring of water use.

SUMMARY

Only a small number of premises that participated in the BEES research were able to provide their water use data. This provided a major opportunity to make use of a non-BEES data source to examine this issue. This report uses the results from an examination of data from Watercare (Auckland's supplier of potable water) to explore drivers of water use in non-residential buildings.

Two measures are commonly used in this analysis:

- Water use – either annual (m^3/yr) or average daily (L/day).
- Water use intensity (WUI) – a measure of water use per square metre ($m^3/yr.m^2$).

The analysis within this water use report found that water-using industrial processes, including food catering and so on, are almost certain in high water-using premises, with a WUI greater than 10 $m^3/yr.m^2$. Building age was not found to have affected water use, with no evidence of an increase or decrease over the last 50 years.

Building use strata were found to be a very important factor. However, the lack of homogeneity within the building use strata suggests that further disaggregation into smaller activity-based groups is desirable.

This report provides an overview of understanding the water demand generated in non-residential buildings. It is focused on the Auckland region. This is a first step to fill this existing knowledge gap on water use in New Zealand non-residential buildings. The baseline data and information provided is constructed by statistical analysis of water performance of a large representative sample of non-residential Auckland buildings.

A representative dataset for the analysis of non-residential water use in Auckland was created by linking BEES building records to records of general water metering. This set has been utilised to create a statistical baseline of non-residential water utilisation for the non-residential building stock in New Zealand.

The result of the data matching has allowed statistical analysis to explore the baseline dataset of more than 5,700 non-residential BEES building records in the Auckland region.

The dataset represents about 10% of the BEES property population in New Zealand, 20% of Auckland non-residential water demand and 14% of properties in the BEES recruitment sample. The breakdown of the matching by building size strata and building use strata is provided in Table A.

Table A: Matching BEES building records with water meter locations

Building use strata	Building size strata					Total
	S1	S2	S3	S4	S5	
Commercial Office (CO)	461	247	142	108	36	994
Commercial Retail (CR)	1,511	244	83	24	15	1,877
Commercial Mixed (CX)	618	242	138	44	10	1,052
Industrial Service (IS)	237	197	64	13	2	513
Industrial Warehouse (IW)	377	428	323	130	31	1,289
Overall	3,204	1,358	750	319	94	5,725

In the dataset, there were a small number of building records that had extremely high water use. The most likely reason for this was they had industrial processes within the building. Therefore, they were removed from the sample for the analysis to determine the water use baselines and intensities. Even with removing these building records, at the other end of the scale, there were a number of building records (approximately 100) that appeared to have no water use at all.

There are several reasons why properties could have zero water use over the 2-year period. For instance, the building could be vacant, nobody is using water or the water meter may be dysfunctional.

Analysis and results – water use in buildings

The BEES water dataset shows that, for non-residential buildings, the range is tremendous. The data ranges from 1.6 L/day to 1,800,000 L/day, although for the majority of buildings, their water use is less than 10,000 L/day. This is shown in Figure A, which compares the total annual water use against the floor area for the building record.

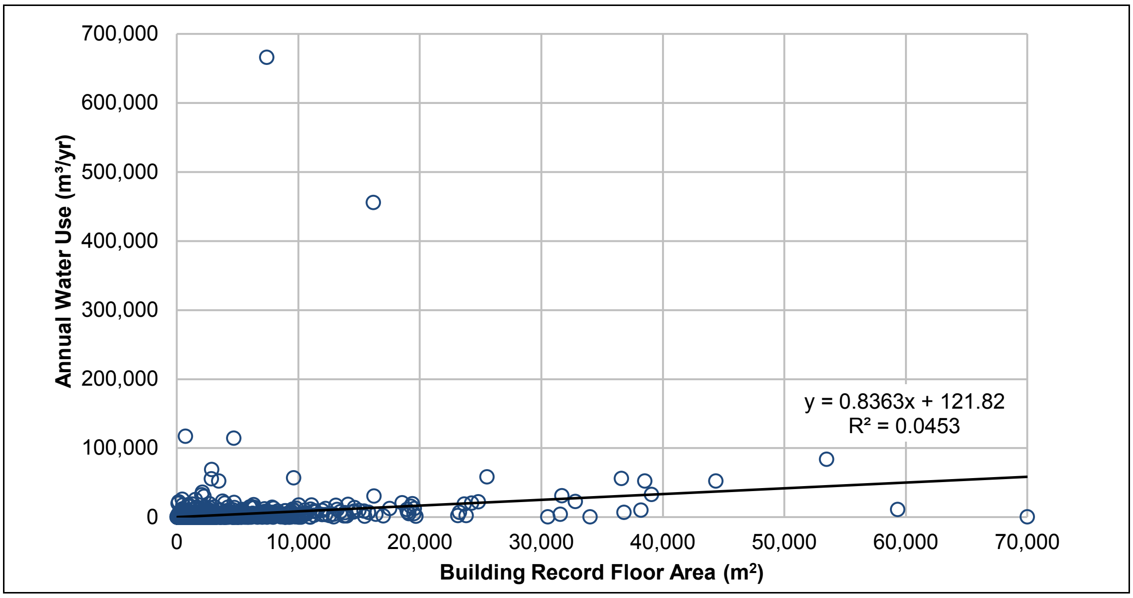

Figure A: Annual water use against building record floor area

It is likely that the high users have industrial processes that use significant amounts of water, along with their office or retail use, so should also be removed from the sample when focusing on Commercial Office and Commercial Retail buildings. Figure B provides an enlargement of Figure A, showing the sample of building records where the annual water use is less than 30,000 m^3/yr and the floor area less than 25,000 m^2. This shows there is a large variation in water use within buildings, even when the outliers are removed.

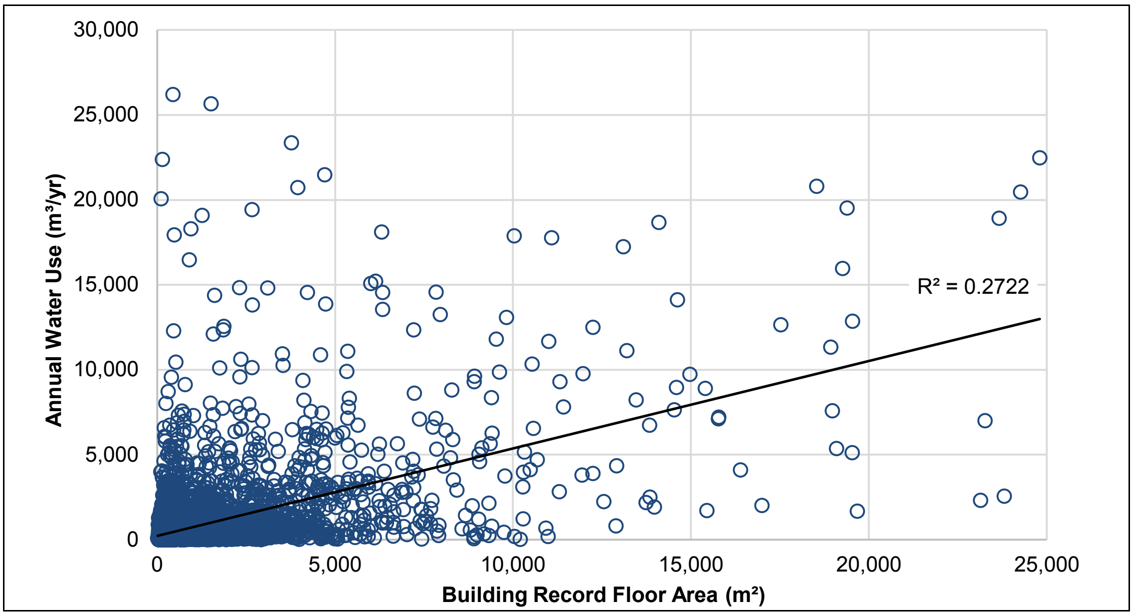

Figure B: Annual water use (zoomed in)

In Table B, the daily rate of water use is given as a function of population percentiles. The median value for the amount of water use per building record is 650 L/day. The first quartile value is 2.6 times lower and the third quartile is 2.8 times higher than the median value.

Table B: Daily and annual water use

Percentile	Water use (L/day)	Water use (m^3/yr)
0% (minimum)	1.6	0.58
25% (first quartile)	250	92
50% (median)	650	240
75% (third quartile)	1,800	640
100% (maximum)	1,800,000	670,000

Figures A and B and Table B show the large variation of water use within building records and also indicate that the data is not normally distributed around an average. Therefore, it is necessary to use logarithmic scales to analyse and graphically represent the data. (A logarithmic scale is a scale of measurement so each 'tick' mark on the scale is the previous tick mark multiplied by a number. For the analysis of Auckland's water use data, the multiplier used is 10.)

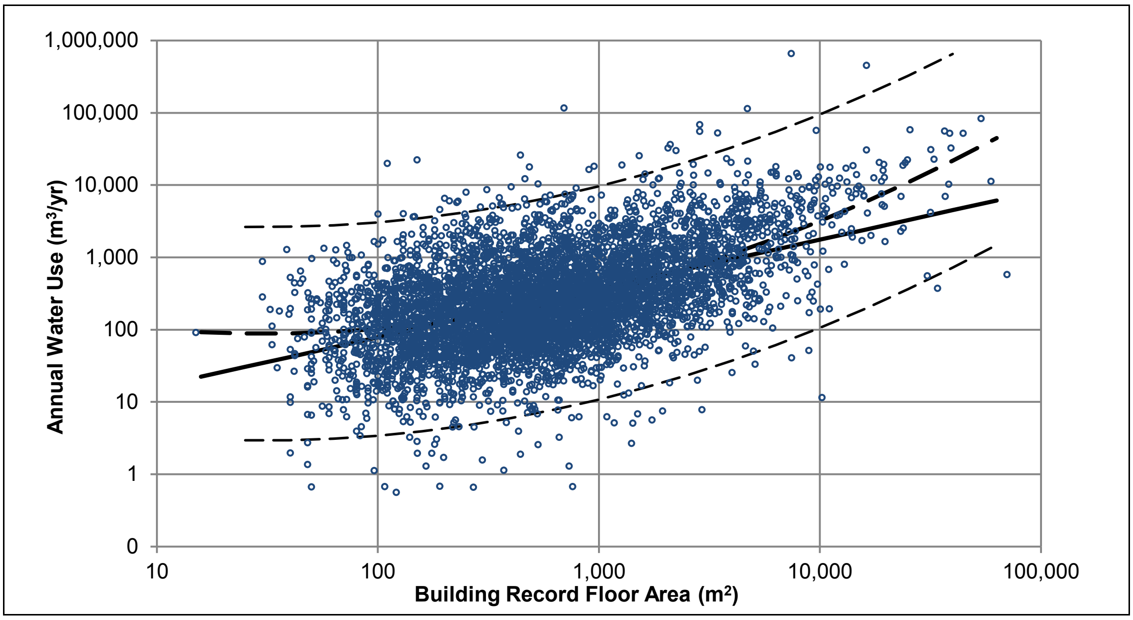

Figure C: Relationship between annual water use and floor area using logarithmic scales

Figure C uses the same data as Figure A but is graphed using the logarithmic scale on both axes. The straight solid line sloping upwards is the first-order trend. This provides a quick indicator that, because it is sloping upwards, shows water use increases as the size of the building increases, as expected. The heavy dashed line is the second-order trend line, which shows a more accurate relationship between annual water use and floor area.

The upper and lower dashed lines represent the 95% prediction interval. Because of using a logarithmic scale, it is important to recognise that the water use at the upper limit is 1,000 times more than the water use at the lower limit.

Water use intensity (WUI)

Water use intensity (WUI) removes the impact of the size of the building by calculating the annual water use per square metre of floor area (m^3/yr.m^2).

In Table C, the WUI is given as a function of population percentiles. The median WUI is 0.41 m^3/yr.m^2. Factors for the first quartile and third quartile boundaries are respectively 2.7 times lower and 2.6 higher than the median value. The minimum water use of 1.6 L/day is a significant 1.1 million times smaller than the maximum water use of 1,800,000 L/day.

Table C: Population percentiles of the WUI for BEES building records

Percentile	WUI (L/day.m^2)	WUI (m^3/yr.m^2)
0% (minimum)	0.0024	0.00089
25% (first quartile)	0.49	0.18
50% (median)	1.1	0.41
75% (third quartile)	2.9	1.0
100% (maximum)	500	182

The skew in distribution of the WUI data that is suggested in Table C can also be seen in Figure D, with the exception of the upper limits. It shows the sample of buildings that have an annual WUI of less than 10 m^3/yr.m^2. It is assumed that buildings that have a higher WUI are likely to also have industrial processes present that require significant amounts of water. Figure D shows that just over 40% of these buildings only use 10% of the water, and at the other end, 20% of the buildings use 50% of the total water. It is likely that 80% of the water use is driven by increased occupancy, but the other 20% has other factors driving the water use. A possibility for this higher use range is that these buildings are linked to food processing and catering.

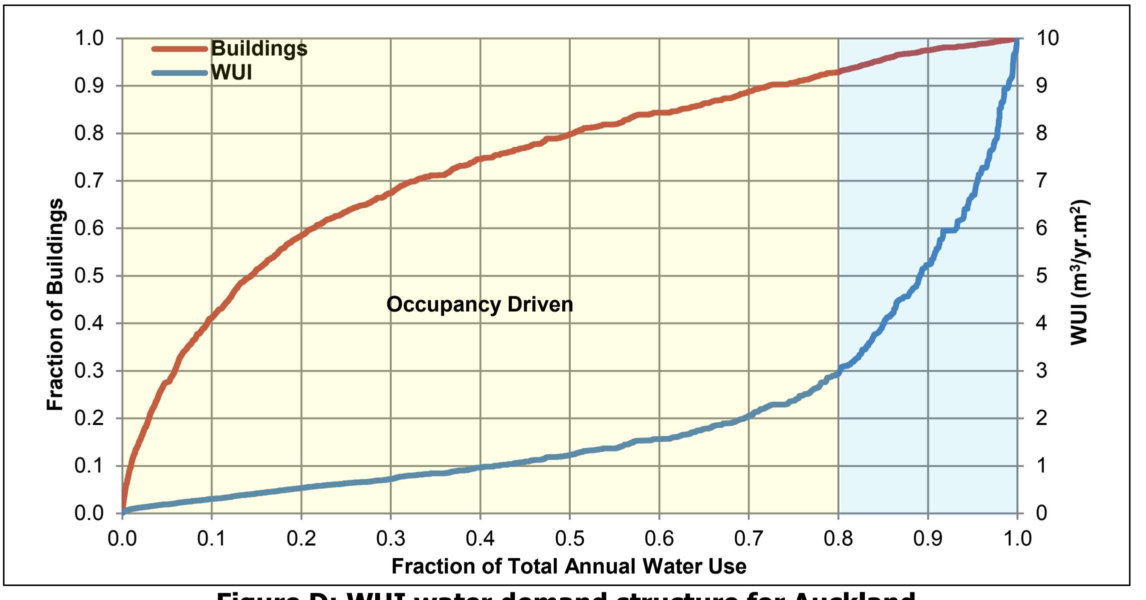

Figure D: WUI water demand structure for Auckland

To understand whether the WUI changes with the building record size for the Auckland sample, once again, a logarithmic scale can be used to observe the first and second-order trends.

Figure E shows that the simpler straight line first-order trend suggests that, as building records increase in size, the WUI decreases. The heavy dashed second trend line indicates that, for the very large buildings, the WUI starts to increase again with a change in slope at just less than 10,000 m^2. However, this should be used with caution because the sample size (as shown by the number of dots) is much smaller once the building size gets beyond 10,000 m^2.

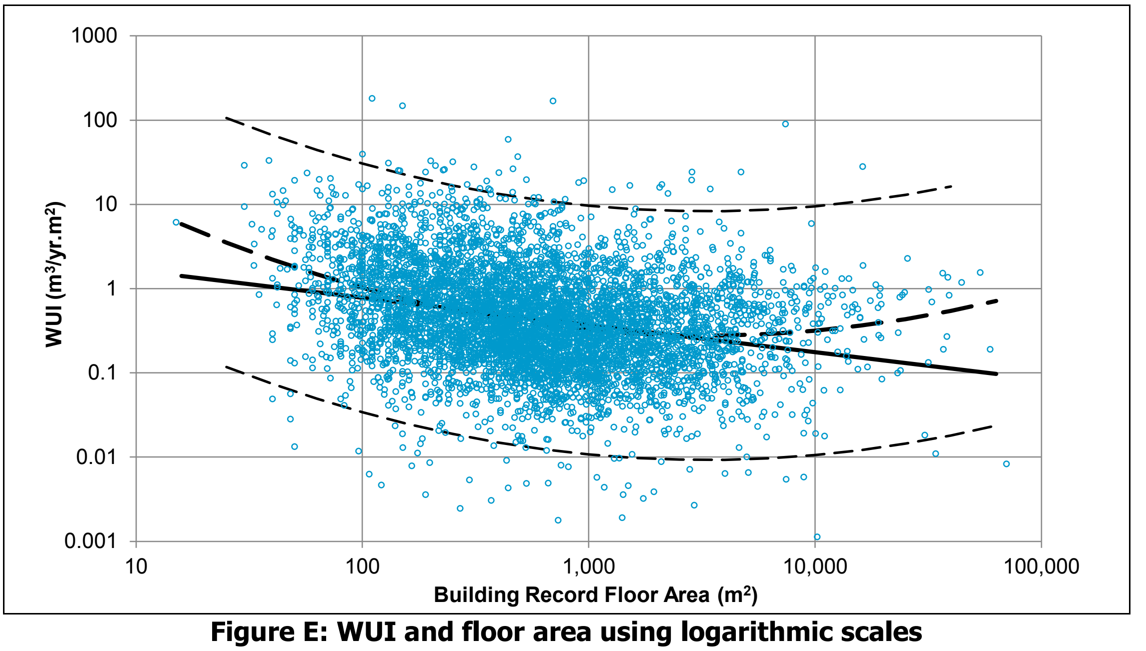

Figure E: WUI and floor area using logarithmic scales

Water use and building type and age

The Auckland BEES water sample has sufficient data points that can be linked back to the building use strata from QV and Auckland City Council building records. This allows an investigation of the differences between office buildings, retail and other buildings (see Figure F).

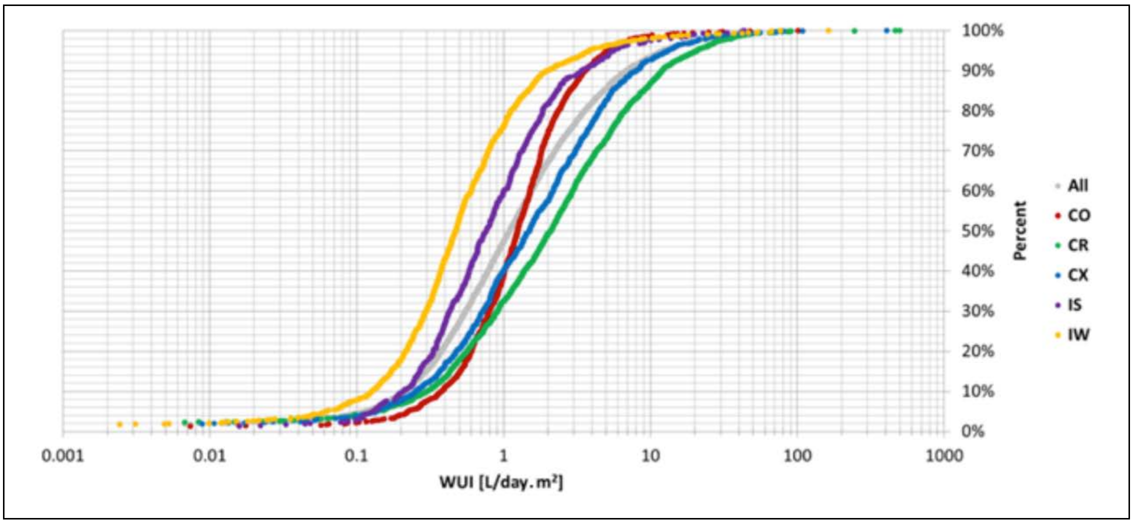

Figure F: Cumulative distribution of WUI by building use strata using full-range logarithmic scale

Figure F shows Commercial Retail (CR) building records (green line) have the broadest distribution and the highest water use. Commercial Office (CO) building records (red line) have the narrowest distribution, as determined by the steepness of the curve. A narrow distribution indicates that water use is very similar (homogeneous) in the population, whereas broad distribution indicates heterogeneity in water use between properties.

It is also interesting to analyse whether newer non-residential buildings are more water efficient than older buildings.

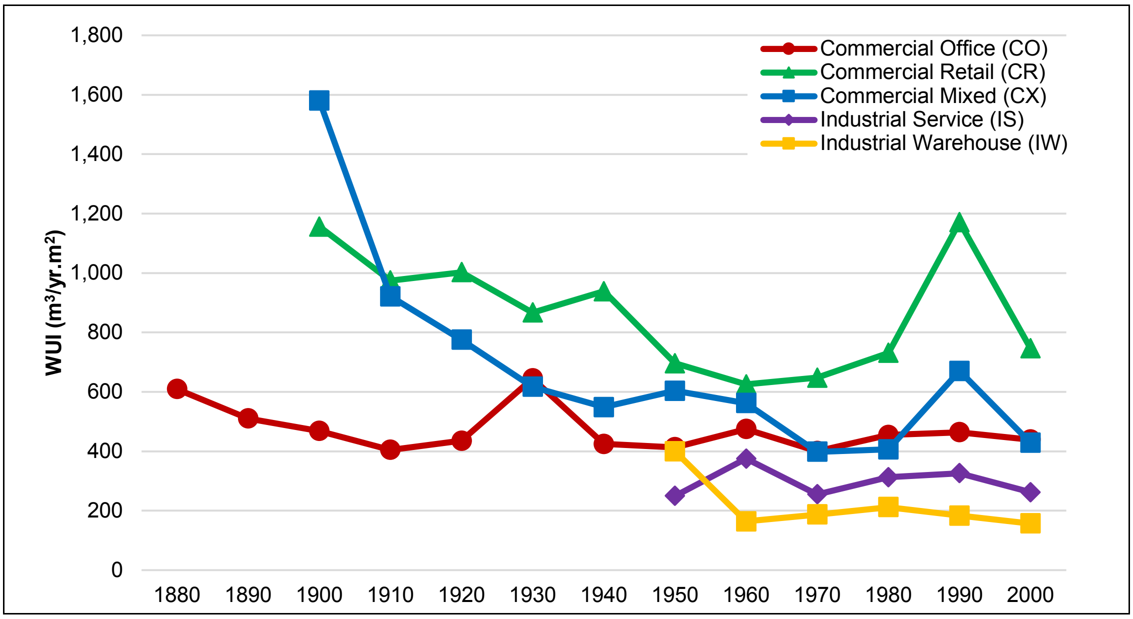

Figure G: Median WUI of building use strata by building age

The total sample, when disaggregated by age, suggests that newer buildings are more efficient than older buildings. However, Figure G, which breaks down the building stock by building use strata, shows a significant factor impacting these use types. The lower use Industrial Service (IS) and Industrial Warehouse (IW) categories only started around the 1950s. It highlights the higher use of Commercial Retail building records with a large spike in the 1990s. Furthermore, when looking at each of the building use strata separately, there is no obvious trend, based on the last 50 years, to suggest any improvement in water use.

Corrected mean values

The skewed nature of this sample, as shown by the necessity to use a logarithmic scale for graphing and analyses, also means it is necessary to consider the outlying values carefully. Basically, this is to take into account the few buildings that have very large water use. One way to reduce the impact of these outliers is to consider a fitted distribution of the points. For this sample, a log-normal distribution was used. Table D shows the total annual water use sample average and the fitted average and the sample median and fitted median. The difference between the sample and fitted average is significant, showing the data is not normally distributed, but it has a significant tail at the higher end creating the skew.

Table D: Mean and median water use for the Auckland sample and building use strata

Water use (m^3/yr)	Mean		Median	
	Simple	Corrected	Actual	Fitted
All	1,170	430	240	260
Commercial Office (CO)	1,400	610	280	340
Commercial Retail (CR)	1,300	410	240	230
Commercial Mixed (CX)	1,000	510	300	310
Industrial Service (IS)	660	300	190	210
Industrial Warehouse (IW)	1,350	350	200	220

The closeness of the fitted estimate of the median and the actual median values is indication of the acceptability of using fitting against a log-normal distribution.

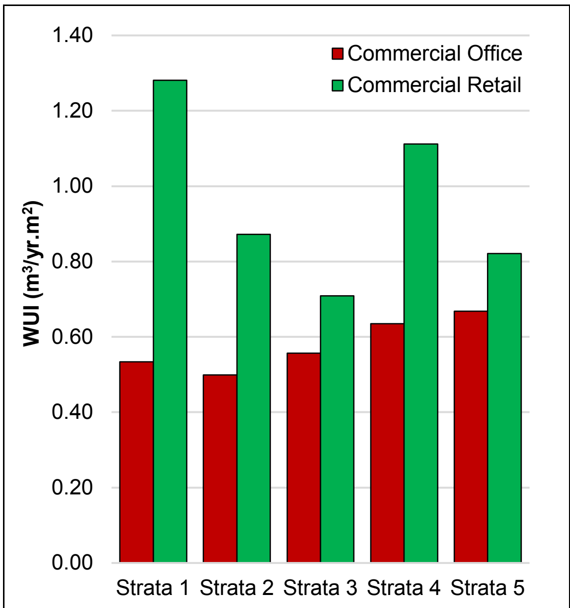

Figure H: Mean WUI for Commercial Retail and Commercial Office categories

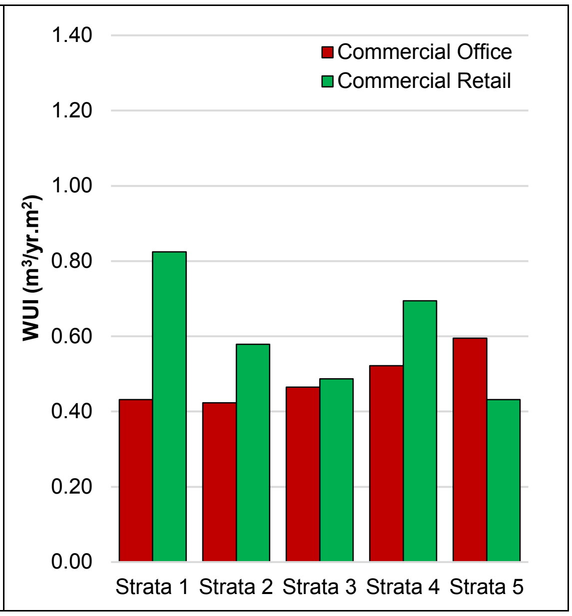

Figure I: Median WUI for Commercial Retail and Commercial Office categories

The WUI average and median for the different building strata and for Commercial Office and Commercial Retail building records were also fitted against a log-normal distribution. These results are shown in Figure H and Figure I and summarised in Table E. These provide good baseline estimates for WUI in Auckland Commercial Office and Commercial Retail building records. For all further use, it is recommended to use the fitted values.

Table E: Mean and median WUI for the whole sample and by building use strata

WUI ($m^3/yr.m^2$)	Mean		Median	
	Simple	Corrected	Actual	Fitted
All	0.93	0.66	0.41	0.44
Commercial Office (CO)	0.72	0.54	0.46	0.45
Commercial Retail (CR)	1.80	1.20	0.79	0.76
Commercial Mixed (CX)	0.97	0.83	0.56	0.56
Industrial Service (IS)	0.66	0.40	0.28	0.30
Industrial Warehouse (IW)	0.68	0.26	0.18	0.19

Conclusion

Water use in non-residential building records was found to vary over a tremendous range. The smallest non-zero water user consumed 100,000 times less than the largest water user.

The analysis has demonstrated that separation of non-residential water users by building use strata is essential as they all have different water-use characteristics. However, none of the groups exhibit very homogeneous behaviour given the variability even within each building use stratum.

This analysis has shown that Commercial Office building records use less water than Commercial Retail building records based on the Auckland sample. Commercial Retail is a heterogeneous group. To better understand the relationship between water use and Commercial Retail building records, it is recommended for future research to divide this group into more homogeneous retail business groups. Linking these subgroups to particular space utilisation would bring more understanding.

The size of a building explained 28% of the variance in water use in the dataset, because larger properties use more water than smaller properties. The WUI was calculated for all properties as a first-order correction for size, going from smaller to larger buildings. The water use per square metre of floor area was found to be first decreasing until a minimum was reached for building records with a floor size of around 3,000 m^2. The WUI then increases for the larger properties (10,000 m^2 or more).

Largest water-using characteristics in non-residential properties

Current water demand for the sample of Auckland non-residential building records is dominated by a relatively small set of building records with very large water consumption. Half of the total demand was generated by only 2% of the building records, which had an annual water use in excess of 7,000 m^3/yr. However, this threshold is not useful for small building records with large water use. Business verification indicated that the high consumption rate in the top 10 of these particular properties is linked to the presence of industrial processes.

Business types such as breweries, meat-processing plants and beverage companies were found to occupy the building records at the high end. It is almost guaranteed that a building record will contain some form of water-using industrial process when the WUI for a building record is found to be in excess of 10 $m^3/yr.m^2$. Looking at the structure of demand corrected for size, 50% of total water demand was found to be generated by 12% of building records. These building records had a WUI that exceeded 2.3 $m^3/yr.m^2$. The likelihood of finding water-using production processes in these building records is significant. However, these processes do not have to be industrial – they can also be food related. In Figure D, a range is indicated where food processing might be the dominant water use. However, this report does not provide further evidence to support this possibility. Cross linkage with data of other parts of the BEES research such as targeted monitoring and the telephone survey is needed to build that evidence.

With regard to water use of the other 88% of building records, the contribution of occupancy-driven water end use becomes a major contributor to overall water use. There are different degrees of service provisions to occupants. An additional factor, for instance, indoor catering, might be important for water use.

The average performance of Commercial Office building records, with a median water use of 0.46 $m^3/yr.m^2$, is indicative for water use driven by occupancy. The low water use in the Industrial Warehouse category indicates storage spaces in buildings do not generate a large demand for water. The likelihood of finding a significant part of a warehouse is dedicated to storage is high. Therefore, in the absence of industrial processes, if the occupant density of a building decreases, the other water-using processes such as cleaning and building climate control become more dominant. Therefore, the largest water use in non-residential building records is governed by the presence of particular functional activities and services in the building.

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GLOSSARY

BEES	Building Energy End-use Study
WELS	Water Efficiency Labelling Scheme
WUI	Water use intensity
CO	Commercial Office building-use category
CR	Commercial Retail building-use category
CX	Commercial Mixed building-use category
IS	Industrial Service building-use category
IW	Industrial Warehouse building-use category
S1	Building size stratum 1, with floor areas 1–649 m^2
S2	Building size stratum 2, with floor areas 650–1,499 m^2
S3	Building size stratum 3, with floor areas 1,500–3,499 m^2
S4	Building size stratum 4, with floor areas 3,500–8,999 m^2
S5	Building size stratum 5, with floor areas ≥9,000 m^2

1 INTRODUCTION

One of the key services in a building is providing potable water. Water is a resource that is central to the way of living. Up to 90% of time can be spent within buildings, both at home and at work. Therefore, it can be expected that the need for water in the urban environment is expressed, to a large extent, by the way people use water in buildings.

1.1 Non-residential water use

This research is focused on increasing the understanding of the distinct character of water use in non-residential buildings in New Zealand. Analysis and understanding of non-residential water use is of key interest to New Zealand's urban water service providers to inform their water demand management programmes and asset planning.

Previous to this study, the character of residential water end use in New Zealand has been scrutinised by BRANZ in a couple of districts, including Auckland. However, residential buildings are only one segment of the overall urban water demand. So far, water use in non-residential buildings has received little research attention in New Zealand.

Non-residential buildings are a heterogeneous group of buildings that are utilised for a wide range of functional uses. Non-residential buildings are built to support our work environments. Therefore, they have a business purpose. However, the separation of buildings into residential or non-residential is not always clear or easy, since there are many buildings in which the distinction can be quite blurred.

The heterogeneity and complexity of non-residential buildings as a group has proved to be a formidable barrier to build a sound and balanced understanding of their current water-use performance. So far, most research on the New Zealand non-residential building stock has had a piecemeal character and is therefore unsuitable as a baseline description for non-residential building water-use performance. For any study that intends to cover the heterogeneity of this particular group of buildings, there is a direct need to collect data from many buildings. This is in order to reach a statistically significant representation in each relevant use category.

The users of non-residential buildings use water for drinking, cooking, sanitation, toileting and personal hygiene. Water is also used for indoor climate control and cleaning and outside the building for irrigation. Other water uses more unique to non-residential buildings are water-using commercial service and production processes.

Water suppliers are interested in moderating the growth of the water demand from the user community. Therefore, they need to understand the water consumption patterns of their users to identify how they can effectively incentivise users to use less water. The context of non-residential water use is different from residential water use and therefore requires an approach that is tailored to it.

The overarching objective behind water-focused research in buildings is improving understanding of the urban water cycle through identifying the most effective aspects of building design by which stakeholders can reduce water demand.

1.2 BEES research programme

In 2007, the BEES research programme was initiated to increase understanding of the energy and water use of non-residential buildings. The programme was funded by BRANZ through the Building Research Levy, the (former) Foundation for Research, Science and Technology (FRST), the (former) Department of Building and Housing (DBH) and the Energy Efficiency and Conservation Authority (EECA).

Although BEES studies the stock of non-residential buildings, the resources of the project are focused in broad terms on buildings that have an office or retail use function. This focus also means that buildings where overall water use (or energy use) is dominated by industrial processes are in principle not targeted by BEES. The study design of the BEES programme is detailed in BRANZ study report SR224 *Building Energy End-use Study (BEES) Years 1 & 2* (Isaacs et al., 2009).

This report is focused on understanding water demand generated in non-residential buildings. It is a first step to fill this existing knowledge gap on water use in New Zealand non-residential buildings.

1.3 BEES water-use study

Developing a suitable baseline for the water use behaviour of New Zealand's non-residential buildings is the prime objective of the research in this report.

An important limitation to the scope of this research is that it is geographically confined to water use in buildings in the Auckland region. The background to this regional focus originated from the particularities of the organisation of water supply and metering practice in New Zealand. Auckland is among the few regions where general water metering has been in place for several years. Auckland also contains a significant part of New Zealand's overall building stock.

This report presents in detail the Auckland baseline study for non-residential water use. This baseline is constructed by statistical analysis of water performance of a large representative sample of non-residential Auckland buildings. Therefore, the baseline describes the performance of the current non-residential building stock in Auckland only.

The baseline provides a starting position from where it can evaluate any water performance data from non-residential buildings against a statistically solid reference for Auckland. This can be regarded as typical to best practice in water management in New Zealand.

1.3.1 Stakeholders

The relevant groups with a professional interest in influencing non-residential water use in buildings are:

- principal clients to construction of new non-residential buildings
- facility managers of existing buildings
- design professionals, services engineers and plumbing specialists
- reticulated water supply and waste water service providers
- Auckland's water service provider Watercare
- other local water service providers in New Zealand
- environmental and water management policy makers
- researchers in building science, environmental science and water management
- architects
- educational institutions.

2 METHODOLOGY

This section discusses the methodology, methods and tools applied. The methodology consists of the:

- study approach
- information needs
- information strategy
- data acquisition
- data validation
- data integration
- data analysis.

2.1 Study approach

The scientific base on which this study is founded is the research structure and methodology formulated in the study design of the BEES programme. This is detailed in BRANZ study report SR224 *Building Energy End-use Study (BEES) Years 1 & 2* (Isaacs et al., 2009).

That report provides this research with a set of key research questions and a base sample framework to identify and select buildings. However, the sample framework does not contain specific eligibility criteria to reject buildings based on their water use. The only provision for rejecting a building is when its water use is dominated by industrial processes. Some potential selection criteria for identifying and rejecting those buildings affected by industrial processes will be formulated as part of this research. Eligible BEES buildings are a subset of all non-residential buildings.

In broad terms, the focus is on buildings that are utilised by businesses as office or retail space.

2.2 Information needs

The primary target is to assist answering the following research questions:

- What is the aggregate water use?
- What is the average water use per unit area per year?
- What is the average water use per unit area for different building-use categories?

Provided the data supports the analysis, the following research questions will be secondary target:

- What characterises the largest water use in non-residential properties?
- What are the distributions of water use?
- What are the determinants of water-use patterns?

2.2.1 Determining aggregate water use patterns

The most important parameter is the water use of a building. This study requires quantitative information on non-residential water use for a large representative set of non-residential buildings that meet the BEES requirements.

The project also needs information to identify non-residential buildings in the building stock. Defining the boundaries of buildings and uses has proven to be a non-trivial point for the BEES research. A significant amount of energy was invested to create the BEES sample framework, which provides traceable clarity in the complex mix of non-residential buildings and property titles. When a potential building is identified, the project needs to have sufficient information and a transparent system to decide if a building meets the BEES selection requirements. One of these selection requirements is that a building should have reliable size and floor area data and an identified functional use.

2.3 Information strategy

For the aggregate survey, BEES relied on access to the records of local water supply network operators that meter the amount of water supplied to properties for billing purposes. However, many districts do not utilise any form of water metering on their water supply. Also, in some places where water meters have been installed, some of the operators can only use the data from the meters for addressing issues of network integrity and excessive use.

It was identified that the original study approach would not deliver enough properties for meaningful statistical analysis. There was also strong bias towards areas that apply general water metering. It was therefore considered necessary for the aggregate water use survey to find an alternative strategy.

The water-use study adapted the study approach to a more regional focus on New Zealand major cities with general water metering, focusing on Auckland. BEES sought and acquired collaboration and support from Auckland's water network service provider Watercare.

2.4 Data acquisition

The dataset of buildings and their water use was gathered by linking data from three distinct sources.

Water usage data was sourced from water meter readings through the Watercare agreement, which are normally utilised for billing purposes. The data provided covers billing accounts for the period from 1 July 2009 to 15 June 2011.

Building and property-specific information with regard to size, age and use was sourced from:

- property records maintained by Quotable Value – the dataset was sourced in 2009 and covers non-residential buildings for the wider Auckland region, with exclusion of the governance area of the former Auckland City district

Table 1: Non-residential account classification

Account use classification name	Description
COM	Commercial
SPREC	Sport and recreation
MUN	Municipal use
INDDRY	Industrial dry (without water-using production processes)
INDWET	Industrial wet (with significant water-using production processes)
BULK	Bulk water users
TRADE	Trade water users

The raw database consisted of 275,775 water meter readings of 18,696 address locations with 31,678 water meters.

To allow analysis using the water meter data available, it was necessary to compare at a property level. BEES property data consists of either one single valuation or an assembled group valuation of related parent-child valuations. In earlier BEES reports, 'BEES property' has also been referred to as 'BEES building record'.

The BEES population consists of a nationwide list of 50,539 properties that qualify as non-residential and have a commercial use function under the BEES criteria. The BEES properties are derived from those valuations that fall into the following Quotable Value (QV) building-use categories listed in Table 2, which are regarded as commercial use.

Table 2: Overview of BEES building-use categories and related QV building-use categories

BEES building-use category	QV building-use categories
Commercial Office (CO)	Commercial Office
Commercial Retail (CR)	Commercial Retail Commercial Liquor Commercial Motor Commercial Service Station Commercial Tourist Commercial Vacant
Commercial Mixed (CX)	Commercial Multiple/Other
Industrial Service (IS)	Industrial Service
Industrial Warehouse (IW)	Industrial Warehouse

The last three categories were incorporated in the sample frame because verification showed many of these buildings contained a significant amount of identifiable space that was allocated to retail and office use. The last two industrial categories in particular could be considered as part of retail, but in this study, we treat them as completely separate use categories. The results show there is good reason to make this distinction.

The 50,539 BEES properties were ranked and sorted according to their size. The sorted list was cut into five size strata such that each size stratum represents about 20% of the total sum of non-residential floor areas of all the listed buildings.

The recruitment approach for this water-use portion is different from other parts of BEES because it is based on the larger BEES sample frame. The chosen approach results in a group of properties that extends beyond boundaries of the BEES matched sample of 955 properties. However, there is analysis of the difference in outcomes between results derived from the two samples.

2.5 Data validation

The raw water-use data consists of water meter readings over period of 2 years for the sample of non-residential properties. In this study, all water meters measure and display total usage in cubic metres (m^3).

The validity of the readings for each water meter was screened using the following rules:

- A water meter reading point consists of a date and time registration and a volume registered on the water meter counter. Data points with missing data were removed.
- Minimum number of readings should be at least two. Water meters with fewer than this number were dismissed from the survey.
- Negative water use over the whole monitoring period is not accepted.
- Consecutive data points in time should register a larger or equal volume on the water meter counter. Failure to meet this requirement was a reason for removal if the anomaly could not be corrected with the following two rules for specific situation:
  - Roll-over of the water meter counter can only be compensated for if there is sufficient evidence to support the correction. All other cases were removed.
  - Outlying water reading points due to digit errors were repaired where possible, and other data points were removed.

From every valid water meter record, the parameters were calculated to describe water use over the monitoring period for:

- daily water use in litres per day (L/day)
- annual water use in cubic metres per year (m^3/yr).

Water use was linked by address where properties had multiple water meters. All water meter records were required to have a credible address description that contained the mandatory elements of suburb name, street name and address number. This address validation was necessary for data integration with the property data from QV and Auckland City Council in the BEES sample framework.

2.6 Data integration

The required link between a BEES property and a water use record could only be established by address matching. In general, address matching data records of different origins is a cumbersome process, especially given that, in New Zealand, there is no uniform standard for address allocation to properties.

Data preparation and matching was performed in a stepwise integration validation process. Each valid address match between sources needed to be accurate before a building was accepted in the final dataset. This implies that inaccuracies, inconsistencies and mutual discrepancies in the address description in each of the sources enhanced the risk of a mismatch. This did inevitably reduce the number of complete datasets available for analysis.

2.7 Data analysis

The typical water use of properties in the baseline sample is presented in terms of:

- rate of water use, which is the volume of water that is used in a building over a defined period
- water use intensity (WUI), which corresponds to a property's rate of water use divided by its gross floor area.

More detail is provided in Appendix B.

2.7.1 Structure of data analysis

In this report, the analysis of Auckland's baseline dataset on non-residential water use is presented using the following structure.

In section 3, the results of the address matching are presented. The representativeness of the collected Auckland baseline sample is discussed. This is followed by a consideration of the basic statistical parameters of the baseline sample for water use and floor area. The influence, impact and risk of the high-end and low-end extremes in water use to the statistical analysis of baseline characteristics are assessed on their relevance. For instance, a small but relevant group of properties have zero water use. These zero users will be put aside as a separate group for further analysis of water use. The main thrust of the analysis of the Auckland baseline sample is focused on the behaviour of properties that actually do use water.

In section 4, the influence of building size on water use of the baseline properties is investigated. The water use and WUI of properties as a function of size is also presented using the BEES size strata.

Section 5 investigates how the significance of information on a building's particular use function is an indicator for its characteristic water use. Water use for the subgroups of the BEES building-use categories is examined by considering the distribution of properties of each use category according to their water use. For these subgroups, cumulative water use and sample average WUI are assessed.

In addition to the general analysis of building size and use, detailed water use profiles were produced for each of the respective five BEES building-use categories specified in Table 2. These profiles can be found in Appendix A.

In section 6, the analysis of the impact of a building's age on its water use is presented. Do older buildings use more water than new ones and, if so, why? To perform this age-based water-use analysis, it is essential to understand the structure change of the non-residential building stock.

How to best estimate the aggregate (total) water use for the Auckland BEES buildings is the focus of section 7. This particular analysis is built on statistical baseline structure developed in the preceding sections. It scouts several analysis pathways and indicates the most appropriate one. Further, it considers the impact of using different sampling techniques on the estimated aggregate water use.

Section 8 provides the required analysis and discussion for the six BEES key research questions. Each question is assessed separately using the information contained in the baseline sample. This is followed by a research summary in section 9.

Statistical analysis has been utilised to explore the baseline dataset of more than 5,700 non-residential BEES properties in the Auckland region. All data processing, graphical presentation and data analysis was performed using standard functionality and statistical functions of MS Excel and MS Access, supplemented with additional dedicated linear regression analysis methods. Further detail on the statistical techniques is provided in Appendix D.

3 THE AUCKLAND SAMPLE

3.1 Count and representativeness

In Table 3, the result of the address-matching process is presented for both the total Auckland building records and the Auckland BEES sample frame. Overall, of the 11,327 BEES properties, the matching process was able to link 51% to a corresponding water use record. This resulted in a total dataset of 5,750 unique relations between BEES properties and water use records.

Further analysis revealed that the relationship was actually between 5,725 unique BEES properties and 5,750 water meters. Some building records possessed more than one single water meter. Therefore, the total number of unique properties was 5,725.

Table 3: Matching building records with water meter location (unique)

Use category	Size stratum										Overall	
	S1		S2		S3		S4		S5			
	Match	Total	Match	Total	Match	Total	Match	Total	Match	Total	Match	Total
CO	461	905	247	402	142	257	108	174	36	58	994	1,796
CR	1,511	2,913	244	545	83	217	24	76	15	39	1,877	3,790
CX	618	1,398	242	505	138	268	44	126	10	31	1,052	2,328
IS	237	520	197	484	64	262	13	104	2	18	513	1,388
IW	377	491	428	644	323	552	130	265	31	73	1,289	2,025
Overall	3,204	6,227	1,358	2,580	750	1,556	319	745	94	219	5,725	11,327
Matched	51%		53%		48%		43%		43%		51%	

The set of 5,750 property water use records was assumed to be a sufficiently representative of non-residential water use in the BEES property considering the size and use categories. In both datasets, the larger properties (S5 size stratum) are slightly less represented compared to the numbers of BEES properties in the region. Only the number of larger Industrial Service (IS) properties are appreciably underrepresented.

In the matching process, no geospatial analysis techniques have been used to narrow the search. However, this line of analysis is definitely an option to increase the score rate. The data analysis of water use has focused on the larger 51% matched part of the Auckland BEES population. Analysis of the difference in the results coming from the Auckland BEES sample in comparison to the Auckland BEES population result will be presented in a separate section.

3.2 Water usage

All water meters in the selection combined used a total volume of 6.7 million m^3/yr of water over the 2-year monitoring period. The corresponding average water use per building is 1,170 m^3/yr. These parameters are summarised in Table 4. The standard deviation is 10 times larger than the average, which is a strong indication that the data is not normally distributed around the average.

Table 4: General statistics on water use in the properties in the dataset

Parameter	Value	
Number of properties	5,725	
Total sum of annual water use	$6.7 .10^6$	m^3/yr
Total sum of floor area	$7.2 .10^6$	m^2
Average annual water use per property	1170 ± 150	m^3/yr
Standard deviation of annual water use	$11 .10^3$	m^3/yr
Maximum annual water use	$670 .10^3$	m^3/yr
Minimum annual water use	0	m^3/yr
Average floor area per property	1,300	m^2
Total WUI (total water use/total floor area)	0.93	m^3/yr.m^2

3.3 Extreme use

In the dataset, there are a number of individual properties with extremely large water use, which is confirmed by the maximum value in Table 4. This shows a single building is responsible for 9.9% of the overall water use of the matched property population. According to the *Auckland Regional Water Demand Management Plan* of June 2011, large industrial water users typically include process industries, manufacturing and food and beverage industries. Verification of the businesses in the top 10 water users in the dataset confirmed that the dataset contained properties with those types of industrial processes.

This presence of industrial processes is a dilemma for analysis of the data in the BEES context. The issue of how to clean the dataset of properties that are dominated by non-BEES activities or at least compensate for their presence is not straightforward. The effect of the issue is investigated later in this report.

3.4 Zero water use

At the other end of the scale, there are a number of properties within the dataset with zero water use. The dataset contains 100 properties that appear to use no water at all, as outlined in Table 5, most of which are small Commercial Retail properties. The water use for these properties is below the detection limit of 0.5 m^3/yr or 1.4 L/day. These 100 properties correspond to 1.7% of the total number of properties within the matched dataset.

Table 5: Numbers of zero-use properties for property size and use categories combinations

Count	S1	S2	S3	S4	S5	Total
CO	7	3		2		12
CR	38	1	1	2		42
CX	14	2	1	1	1	19
IS	4	1	1			6
IW	8	6	7			21
Total	**71**	**13**	**10**	**5**	**1**	**100**

There are several reasons why properties could have zero water use over the 2-year period. For instance the building could be vacant, nobody is using water or the water meter may be dysfunctional. Persistence of zero water use over longer periods in a non-empty building with water appliances should be of some concern to the water manager.

For the quantitative data analysis, these zero-use properties are taken out of the dataset.

4 INFLUENCE OF BUILDING SIZE

4.1 Water use per building

In Figure 1, the annual water use of each building is plotted in a scatter plot against the gross floor area of the 5,625 corresponding buildings. Both axes have a logarithmic scale distribution. The data appears normally distributed on these axes, but this needs to be investigated in more detail. The data was then log-transformation fitted with trend lines of the first order (solid line) and the second-order (dashed line) visible in Figure 1.

The reason for also providing the first-order trend is that the slope is a quick indicator for water use increasing in a straight linear way with size, if its value is equal to one. If not, the relationship is more complex.

The second-order trend line provides a more accurate description of the relationship between size and water use. The upper and lower dashed lines represent the 95% prediction interval assuming a normal distribution. The difference between the upper and lower limits correspond to a multiplication factor, from the standard error for the regression line.

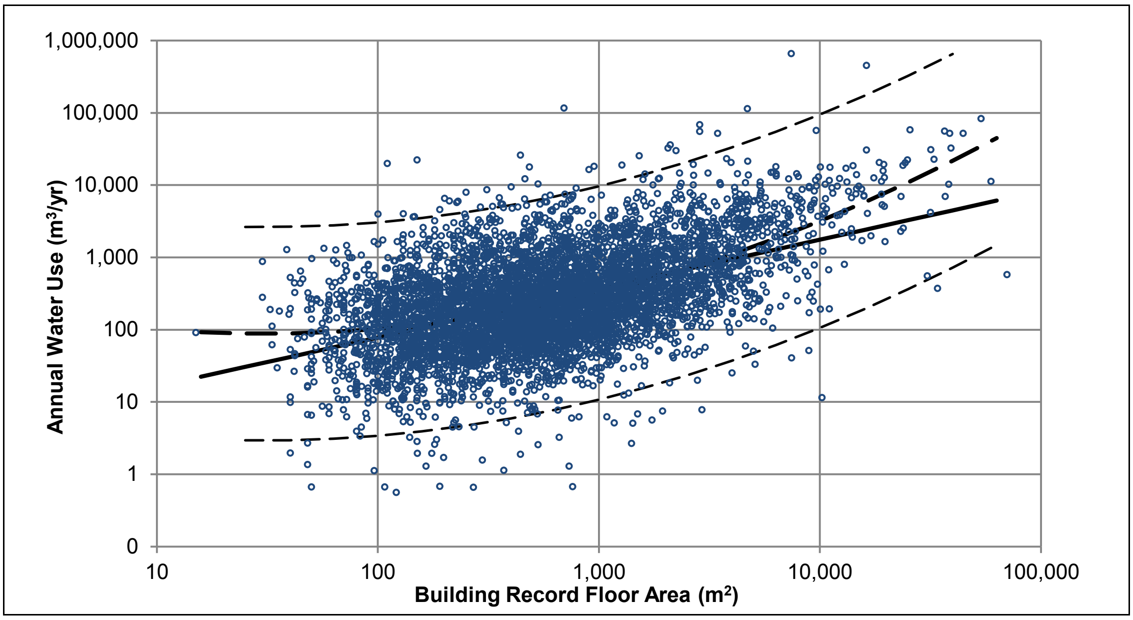

Figure 1: Relationship between annual water use and floor area (*n* = 5,625)

This large difference between the upper and lower line is characteristic of a wide distribution in water use. The regression indicates that 28% of the variance of the data can be explained by differences in floor area between the properties.

The trend confirms that larger properties tend to use more water than smaller properties. However, the curve of the trend indicates that water use tends to increase more slowly than the proportional increase in floor area.

4.2 Water use intensity (WUI)

To compare the water use of small properties to the water use of large properties, it is necessary to compensate for property size. For this, the parameter water use intensity (WUI) will be used, which is the typical water use per unit of building floor area (see Appendix C and Figure 44).

To calculate the WUI, a building's annual water use is divided by its floor area. The WUI of all 5,750 properties in the dataset was calculated to be 0.93 $m^3/yr.m^2$. Table 6 provides additional general statistics of the WUI for the dataset.

Table 6: General statistics on WUI of the properties in the dataset

Parameter	Value	
WUI of total set (see Table 4)	0.93	$m^3/yr.m^2$
	2.6	$L/day.m^2$
Average WUI	1.3	$m^3/yr.m^2$
	3.5	$L/day.m^2$
WUI standard deviation	4.9	$m^3/yr.m^2$
	13	$L/day.m^2$
Maximum WUI	180	$m^3/yr.m^2$
	500	$L/day.m^2$
Minimum WUI (5,625 non-zero properties)	0.00089	$m^3/yr.m^2$
	0.0024	$L/day.m^2$
Minimum WUI (100 properties)	0	$m^3/yr.m^2$
	0	$L/day.m^2$

The cumulative distribution of the WUI is plotted on a linear scale in Figure 2 and logarithmic scale in Figure 3. Clearly, the data is not normally distributed. A log-normal distribution is more appropriate due to the skewed nature of the sample. Figure 3 has an offset of almost 2% because the zero-use properties were incorporated in the presented set. This is less visible in Figure 2.

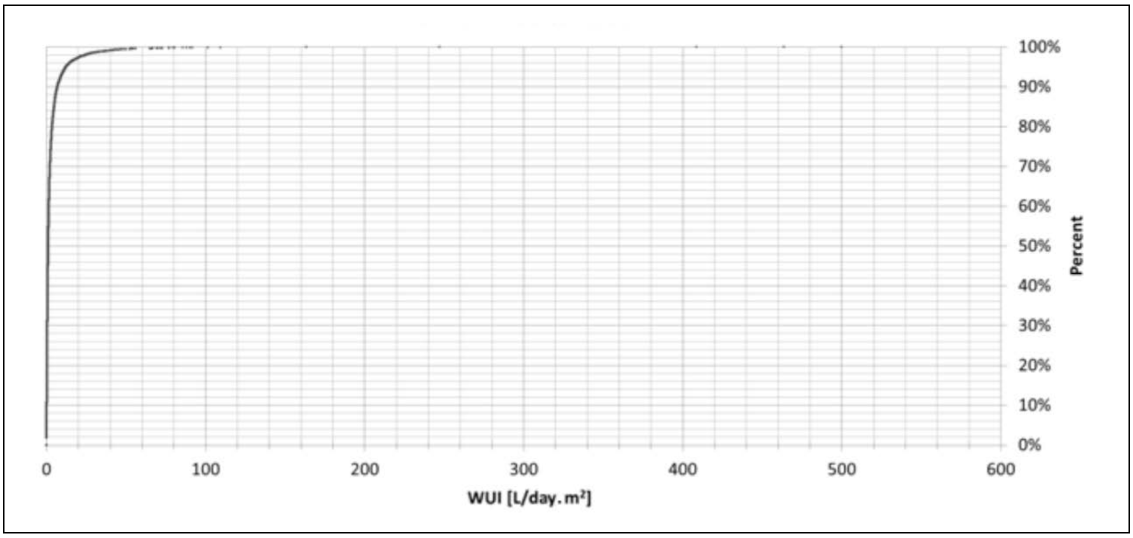

Figure 2: Cumulative distribution of WUI of all 5,725 matched non-residential properties on a linear scale

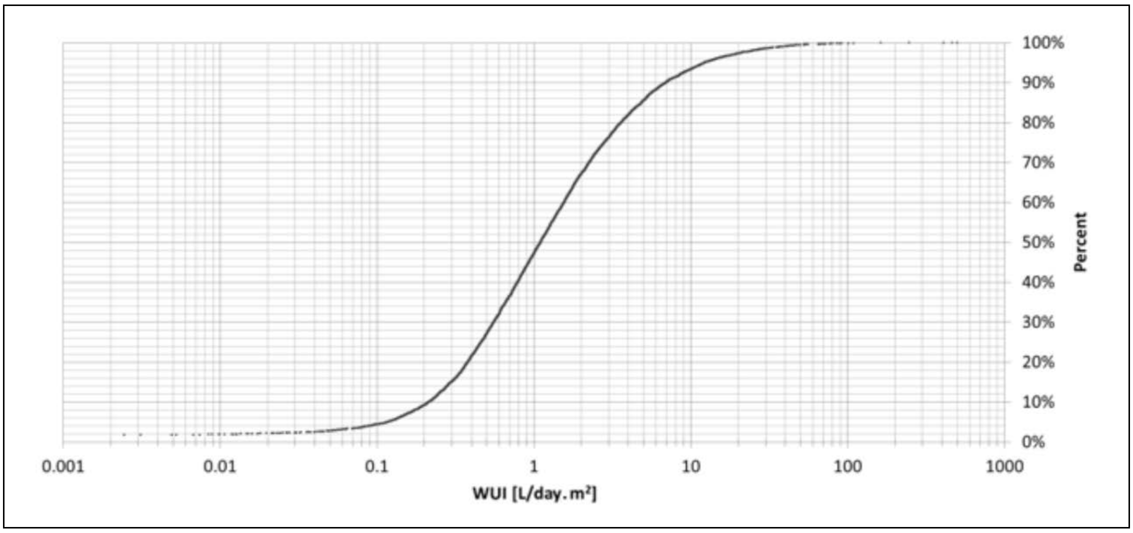

Figure 3: WUI cumulative distribution (*n* = 5,625) using a logarithmic scale

In Table 7, water use and the WUI are given as a function of population percentiles. The median value for daily water use is 650 L/day. The first quartile value is 2.6 times lower and the third quartile is 2.8 times higher than the median value. The median WUI is 1.1 L/day.m^2. Factors for the first quartile and third quartile boundaries are respectively 2.7 times lower and 2.6 higher than the median value. The minimum water use of 1.6 L/day is a significant 1.1 million times smaller than the maximum water use of 1.8 million L/day. For the WUI, the ratio between the maximum and the minimum is a multiplication factor of 210,000.

Table 7: Daily and annual water use

Percentile	Water use		Water Use Intensity	
	(L/day)	(m^3/yr)	(L/day/m^2)	(m^3/yr/m^2)
0% (minimum)	1.6	0.58	0.0024	0.00089
25% (first quartile)	250	92	0.49	0.18
50% (median)	650	240	1.10	0.41
75% (third quartile)	1,800	640	2.90	1.00
100% (maximum)	1,800,000	670,000	500.00	182.00

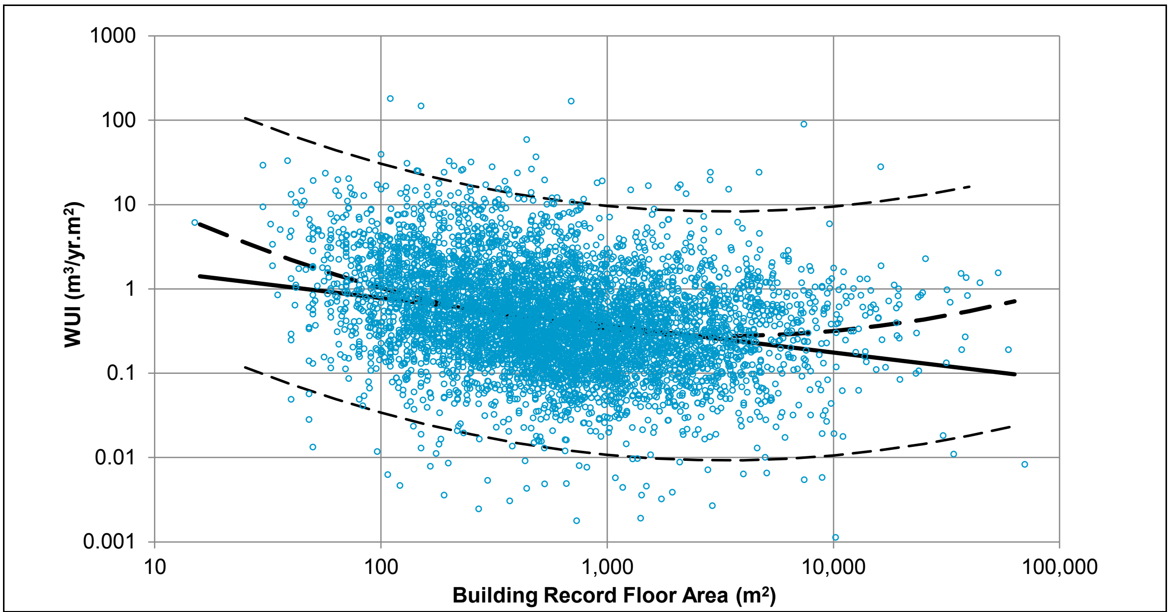

Figure 4: Relationship between WUI and floor area (*n* = 5,625) using a logarithmic scale

In Figure 4, if the heavy dashed line was horizontal, if would infer that a square metre level water use was not the same. The downward trend shows that, the larger the building, the less water per square metre.

The linear regression of the WUI with the first and second-order function of the building floor area presented in Figure 4 confirms that larger properties tend to use less water per square metre than smaller properties. However, for the very large properties, this trend is reversing.

Overall, 72% of the variance still remains unexplained. We need to consider other factors to understand if there is more detail hidden in the wide cloud of data points.

4.3 BEES size strata

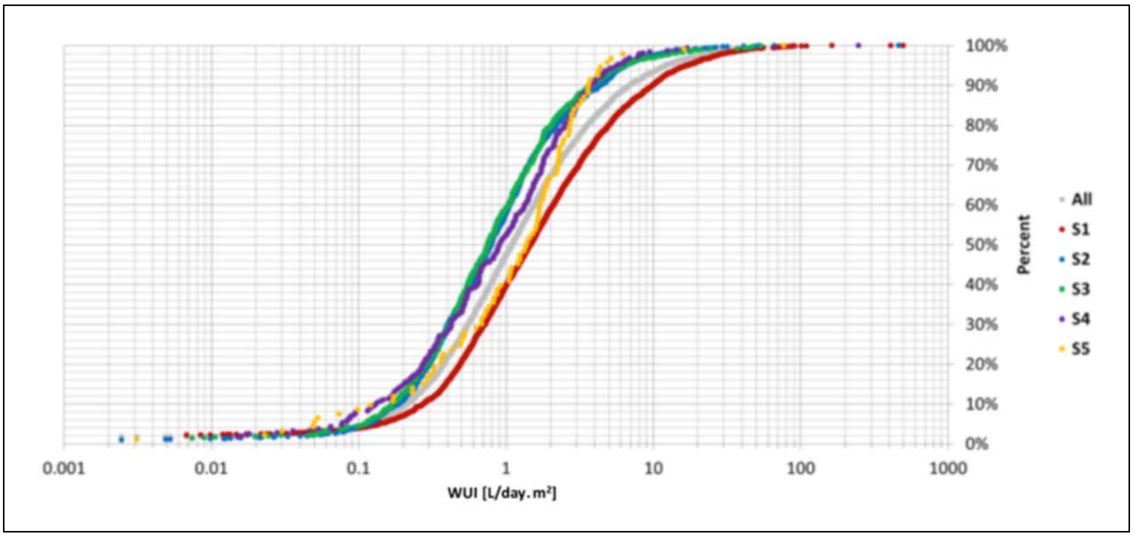

Figure 5: Cumulative distribution of WUI by BEES size strata (*n* = 5,625)

In Figure 5, the sample has been separated along the boundaries of the five BEES size strata. Figure 5, provides a cumulative distribution plot of the WUI for each BEES size stratum, using a logarithmic scale. The zero water use building records were not excluded in this plot.

The median value of the size strata shows a similar trend as observed in the modelled size trend in Figure 4. The smallest and largest strata use more water than the properties in the strata in between these extremes. Both S4 and S5 have heavy tails at the low end of the distribution. S5 has, relative to the other strata, a light tail on the high end.

For the calculation of prediction intervals for the trend line in Figure 4, the assumption of normal distributed data for the prediction of larger properties' water use is probably less accurate. A more complicated model would be needed to compensate for this deviation. However, it would not provide the project with much additional insight.

5 INFLUENCE OF BUILDING USE

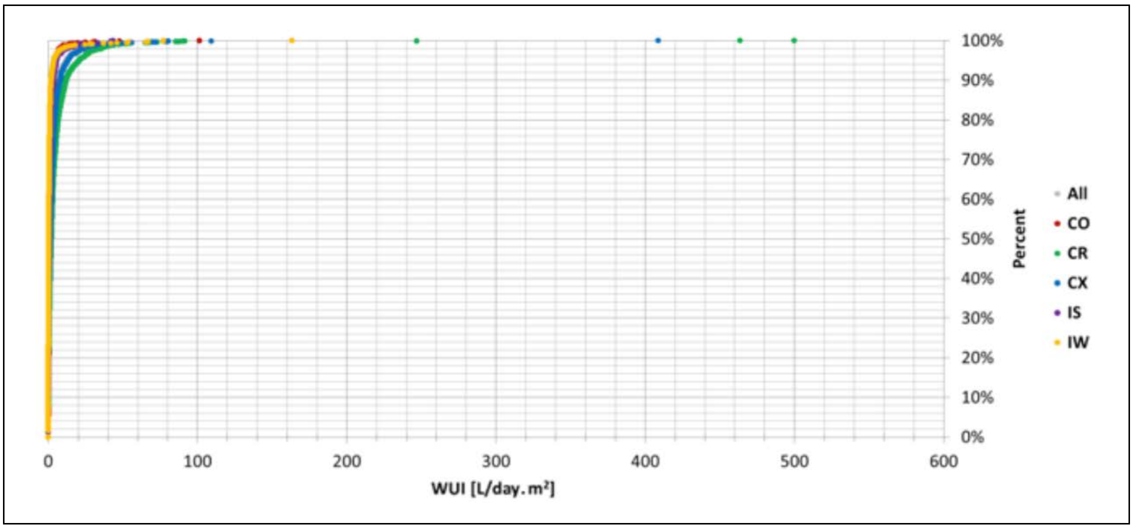

Figure 6: WUI cumulative distribution by building-use category using a linear scale (*n* = 5,725)

The cumulative distribution in Figure 6 is a refinement of Figure 2, with the sample broken down in the five BEES building-use categories. However, on the linear scale, we still cannot see much of detail of the data. Therefore, we zoom in to the lower end of the scale in Figure 7, to look at those using less than 5 L/day.m^2. Here, it is clear that individual use categories have a very different behaviour.

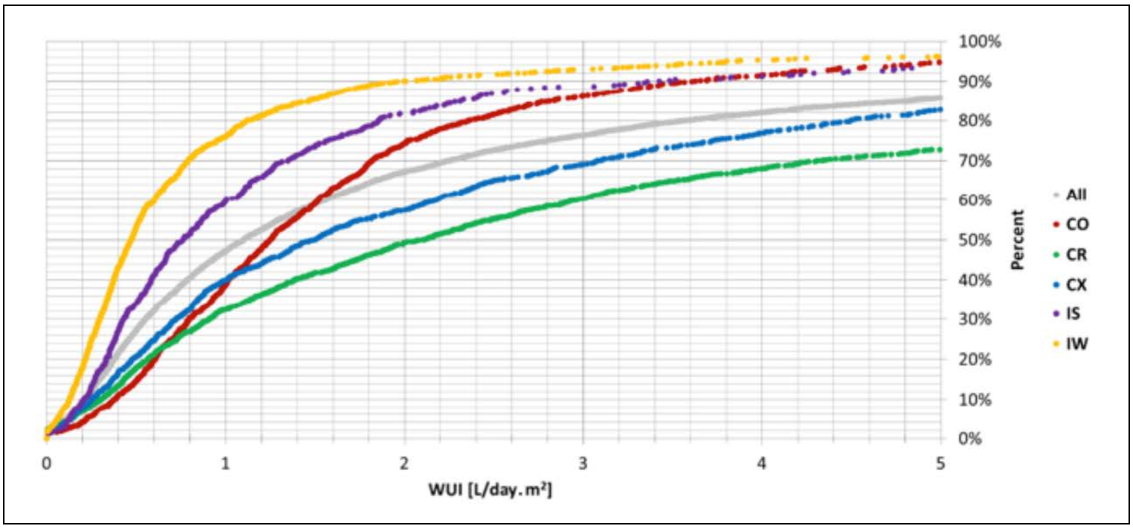

Figure 7: Mid-range part of Figure 6 (*n* = 5,725)

A significant part of the population of the Industrial Warehouse category (IW, yellow line) has a low WUI. It is very likely that this profile can be linked to the dominant presence of storage spaces that do not require much water. In comparison, the water use of the Commercial Retail (CR, green line) population is about four times higher on each percentage level.

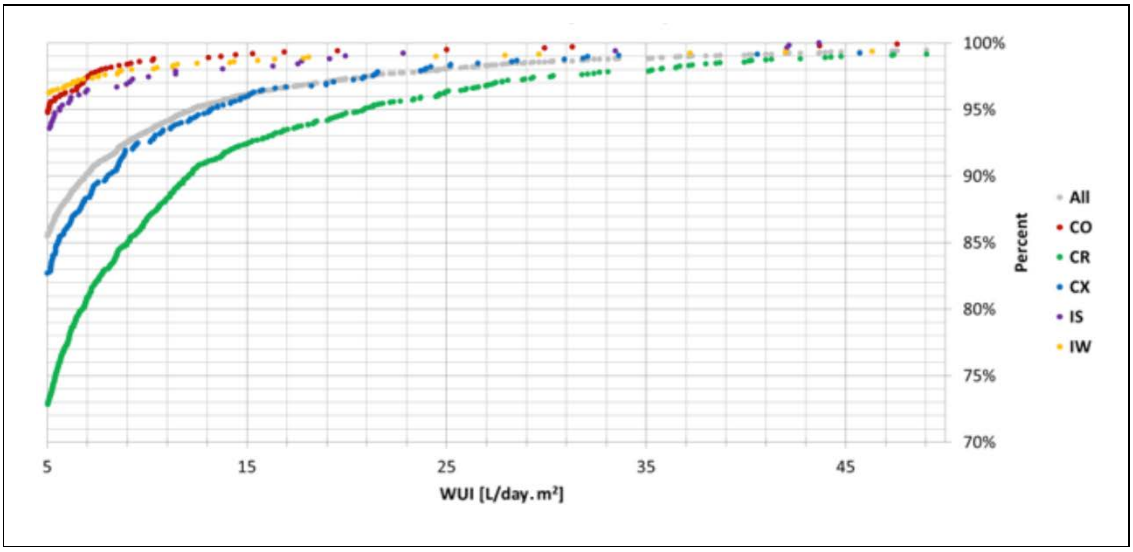

Figure 8: High-end part of Figure 6 (*n* = 5,725)

Figure 8 looks at the part of the building-use categories population with a WUI between 5 and 50 L/day.m^2. More than 25% of the Commercial Retail building records fall in this high-end range.

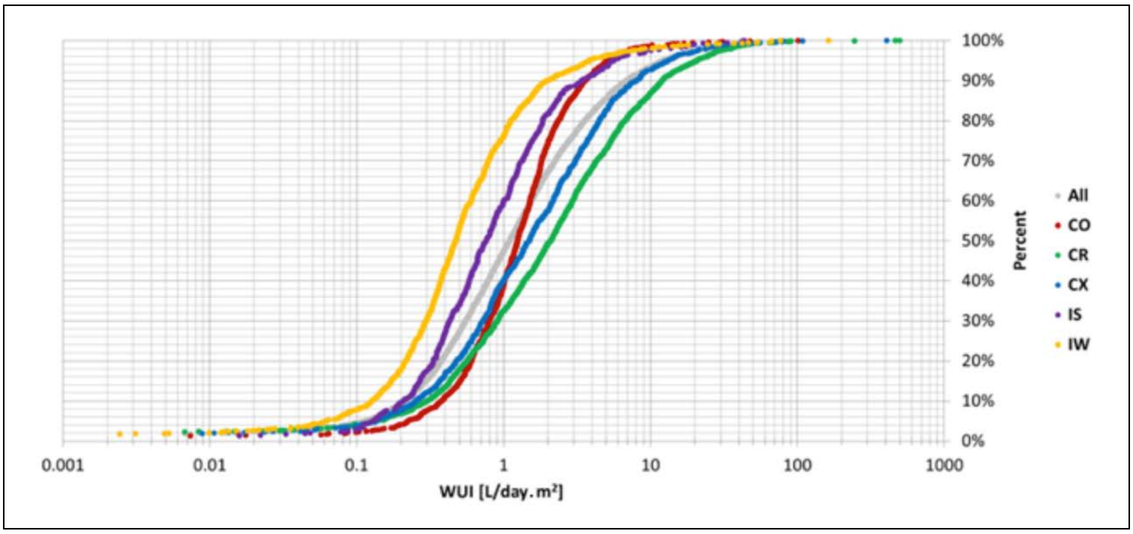

Figure 9: WUI cumulative distribution by building-use category using a logarithmic scale (*n* = 5,625 including 0 water use).

When the building-use categories are plotted on logarithmic scale, we can observe that their distribution can best be estimated with a log-normal distribution, as shown in Figure 9. Commercial Retail properties have the broadest distribution, and Commercial Office (CO, red line) properties have the narrowest distribution, as determined by the steepness of the curve. A narrow distribution indicates that water use is very similar (homogeneous) in the population, whereas broad distribution indicates heterogeneity in water use between properties.

When Figure 9 is compared with Figure 5, building-use categories appear to explain more of the statistical variance in the WUI data than the size strata. In this observation, it is important to realise that the WUI is an indicator for water use that is already scaled by size. Therefore, it is the remaining variance of the water use data after first-order size correction.

5.1 Data summary for building-use categories

In this section, a summary of the key results of the refined data analysis of the whole sample and BEES building-use categories is discussed. They form the basis of the statistical baseline for non-residential water use. More detailed profiles for the building-use categories are presented in Appendix A.

5.2 Corrected mean values of normal distribution

The only new element in this subsection is that a corrected value for the mean of the dataset and the subsets is presented, which is derived from the fit of the data with a log-normal distribution. This corrected mean is almost insensitive to influence of the industrial processes in the sample. In Table 8, the new corrected mean for the volume flow rate is presented next to the mean simple.

Table 8: Mean and median water use by building-use category (*n* = 5,625)

Water use m^3/yr	Mean simple	Mean corrected	Median simple	Median corrected
All	1,170	430	240	260
Commercial Office (CO)	1,400	610	280	340
Commercial Retail (CR)	1,300	410	240	230
Commercial Mixed (CX)	1,000	510	300	310
Industrial Service (IS)	660	300	190	210
Industrial Warehouse (IW)	1,350	350	200	220

The closeness of the fitted estimate of the median and the actual median values is an indication of the quality and confidence we can have in these fits. The summarised results for the WUI are presented in Table 9. For all further use, it is recommended to use the corrected values for the mean.

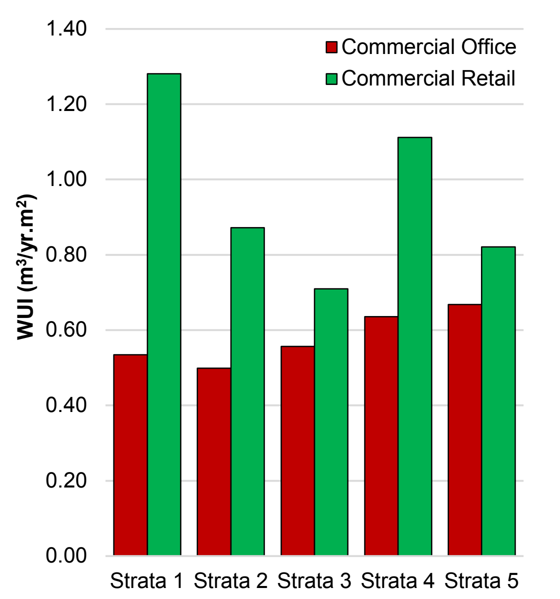

Figure 10: Mean WUI for Commercial Retail and Commercial Office categories

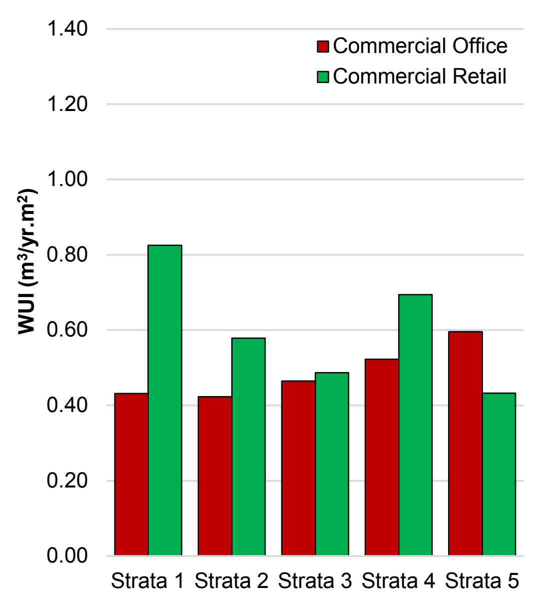

Figure 11: Median WUI for Commercial Retail and Commercial Office categories

Table 9: Mean and median WUI by building-use category (*n* = 5,625)

WUI $m^3/yr.m^2$	Mean simple	Corrected	Median actual	Fitted
All	0.93	0.66	0.41	0.44
Commercial Office (CO)	0.72	0.54	0.46	0.45
Commercial Retail (CR)	1.80	1.20	0.79	0.76
Commercial Mixed (CX)	0.97	0.83	0.56	0.56
Industrial Service (IS)	0.66	0.40	0.28	0.30
Industrial Warehouse (IW)	0.68	0.26	0.18	0.19

5.3 Relationships and implications

The analysis has demonstrated that separation of non-residential water users in coherent building-use categories is essential. Based on the evidence, the main building-use categories are found to have a very different water-use character, although none of the groups exhibit a very homogeneous behaviour.

The following causal relations between water use and building use seem reasonable:

- The Commercial Office (CO) category consists of a reasonably homogeneous group of properties for a well-defined purpose. The steeper (narrow) distribution of the offices in Figure 9 (red line) is a confirmation of that single purpose. We will see later that this water use scales relatively well with size – as water use is occupancy driven and linked to the amount of office space occupied by businesses.
- The Commercial Retail (CR) category is very heterogeneous. Retail water use has a wide distribution. Further subdivision into more homogeneous groups and removal of outliers is required to bring more understanding. Already, the current use subcategories show strong differences in water use. Statistics on space allocation and occupancy in this category is essential for further analysis
- The Commercial Mixed (CX) category has similarities to retail, although its distribution shows some influence of office space behaviour, which can be expected for a mixed category.
- The Industrial Service (IS) category is very similar to the Industrial Warehouse (IW) category. However, they use more water per unit area.
- The Industrial Warehouse (IW) category has low water use, because much of the space will be allocated to storage of goods and machine production not using water. There may also be a low occupancy density.

6 INFLUENCE OF BUILDING AGE

How does water use relate to the age of a non-residential building?

6.1 WUI by building age

The WUI of properties as a function of a property's age is given in Figure 12 with a first-order trend and third-order trend with associated 95% prediction intervals.

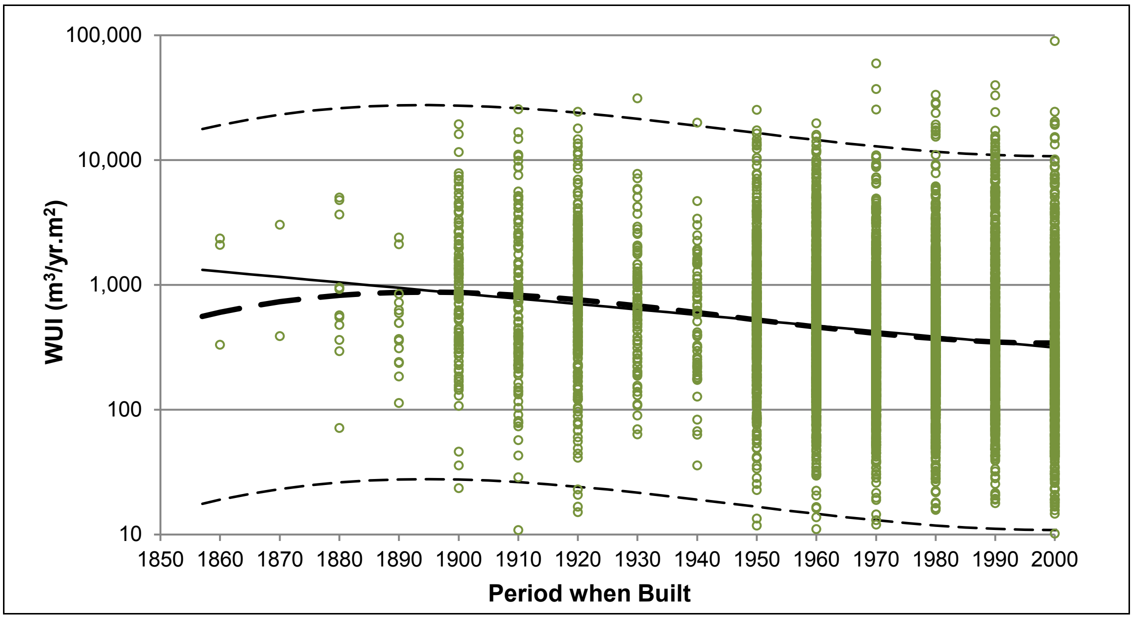

Figure 12: Non-residential properties' WUI in relation to building age

There is a slight downward trend visible, which is currently flattening off for properties of the last decades. Water use per unit area in the last generation of properties is about half of that of pre-Second World War properties.

6.2 Counts by period

To check the validity of the observed trend, additional background understanding of the composition of the ageing building stock is required. Most properties in the sample were built after the Second World War (after 1945). This fact can be seen in Figure 13, which provides the number of properties in the sample that were constructed in each decade. The peak of construction of BEES properties happened in the 1980s. However, the counts for the respective building-use categories (see Table 2), which have been colour coded, have a different occurrence as a function of their age. The peak in the 1980s is a result of the construction of offices and industrial warehouses. For retail, the peak is earlier in the 1960s. Most industrial services were built in the 1970s. Construction in the 1990s and 2000s was dominated by new industrial warehouses.

The introduction of water-efficient appliances has only happened in the last two decades, so older properties are less likely to have them. The question is whether older properties use more water than new properties. If that is the case, would the retail category, which features the oldest stock of properties, have higher water use due to age?

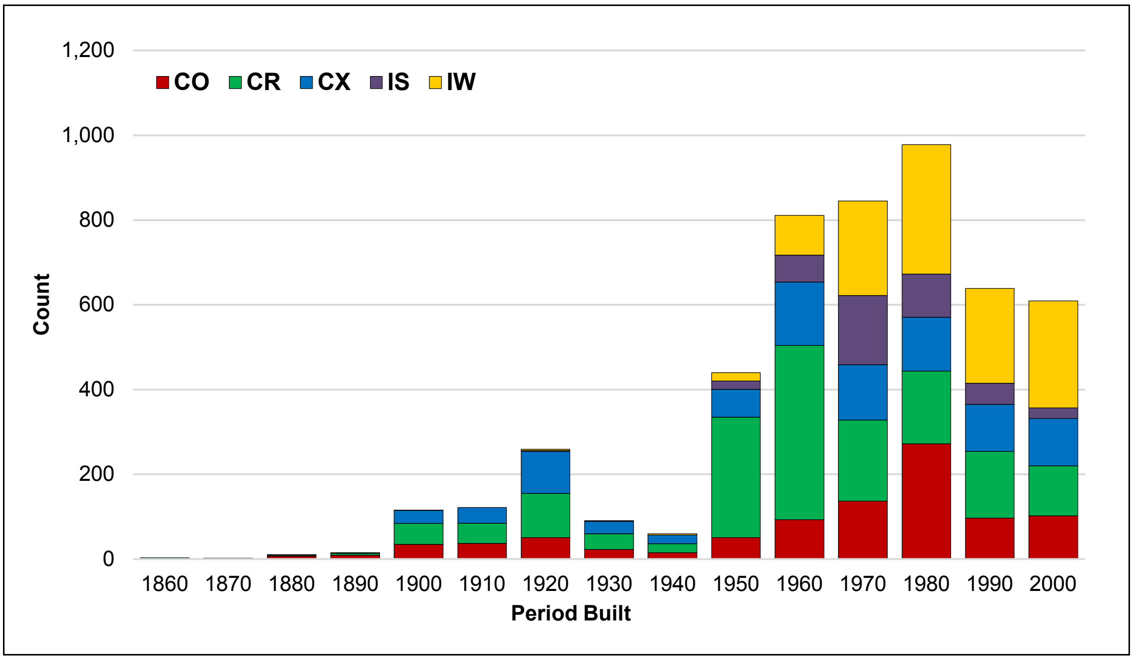

Figure 13: Histogram with number of properties per age group

6.3 Cumulative floor area distribution

In Figure 14, the amount of total available floor area in the BEES properties as a function of age and use is dominated by construction after the 1950s. The maximum average floor area per decade corresponds to the last decade, with Industrial Warehouse being the dominant subcategory. There was a peak in office construction was in the 1980s. The peak in retail construction was in the last decade. Given the high number of retail properties constructed in the 1950s and 1960s (Figure 13), they will be much smaller than newer establishments. Therefore it can be observed that, for most subcategories, there seems to be a trend for the construction of increasingly larger properties. This underlying trend can have an impact on the average age of properties in the BEES size strata.

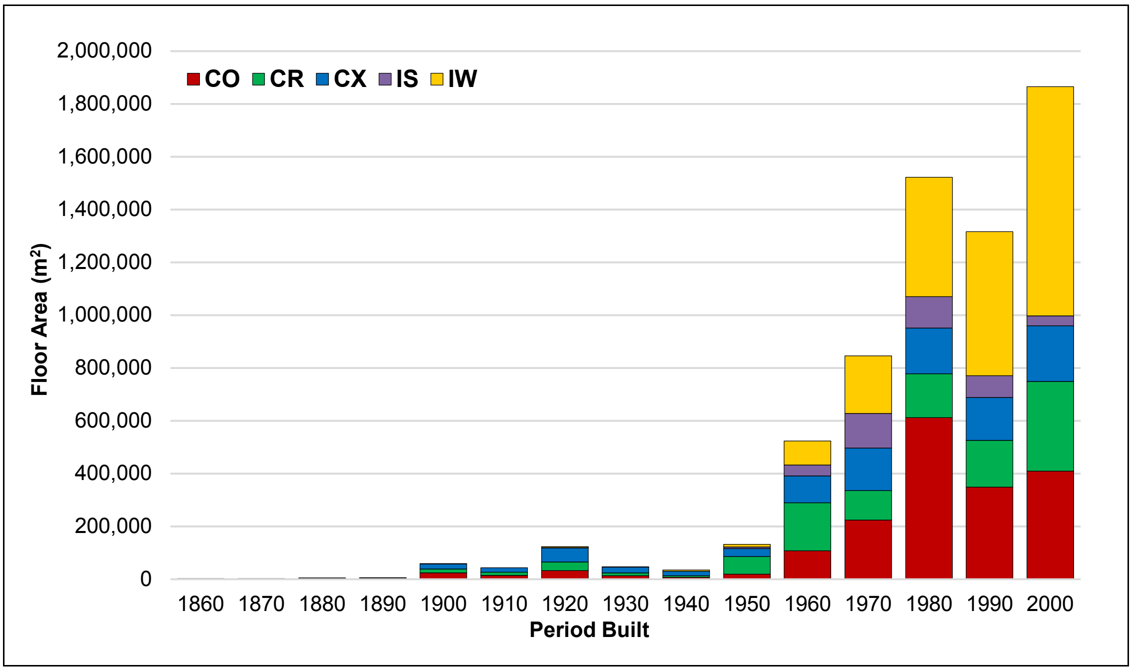

Figure 14: Cumulative floor area for each building age group

6.4 Average floor area distribution

The existence of this trend is confirmed in Figure 15, which gives the average floor area of the BEES properties in the sample for each decade. The average building size per decade before the 1960s did not exceed 600 m^2, but in some decades, it was as low as 300 m^2. Especially in the 1950s, a high number of small properties were erected that are still being used today. From the low of 300 m^2 in the 1950s, average non-residential building size has been rising with tremendous steps. In the last decade, average BEES properties were more than 3,000 m^2 – 10 times larger than the typical 1950s building.

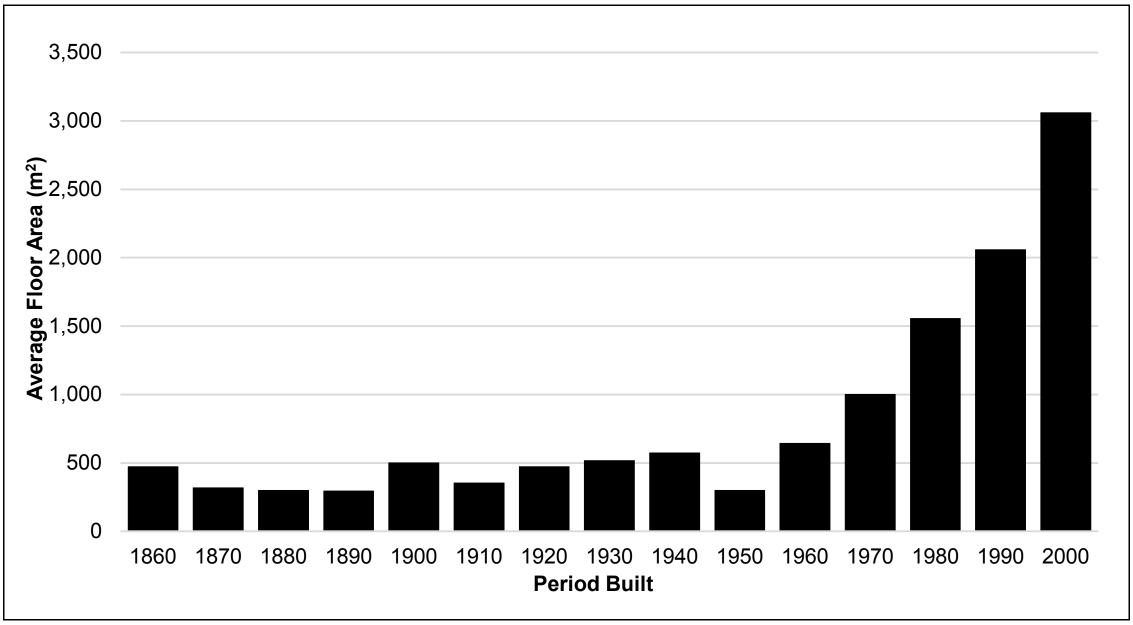

Figure 15: Average floor area in a building by decade

Figure 16 presents the trends in average floor area for the main building-use categories. The increase in size over time is found for all categories. The newest office properties have the largest average size of more than 4,000 m^2, closely followed by the newest generation of industrial warehouses. Both these categories have been growing in size since the 1950s. However, it is in the Commercial Retail category where the biggest relative step change occurs from 1990s to 2000s – size has increased from 1,100 m^2 to 2,900 m^2.

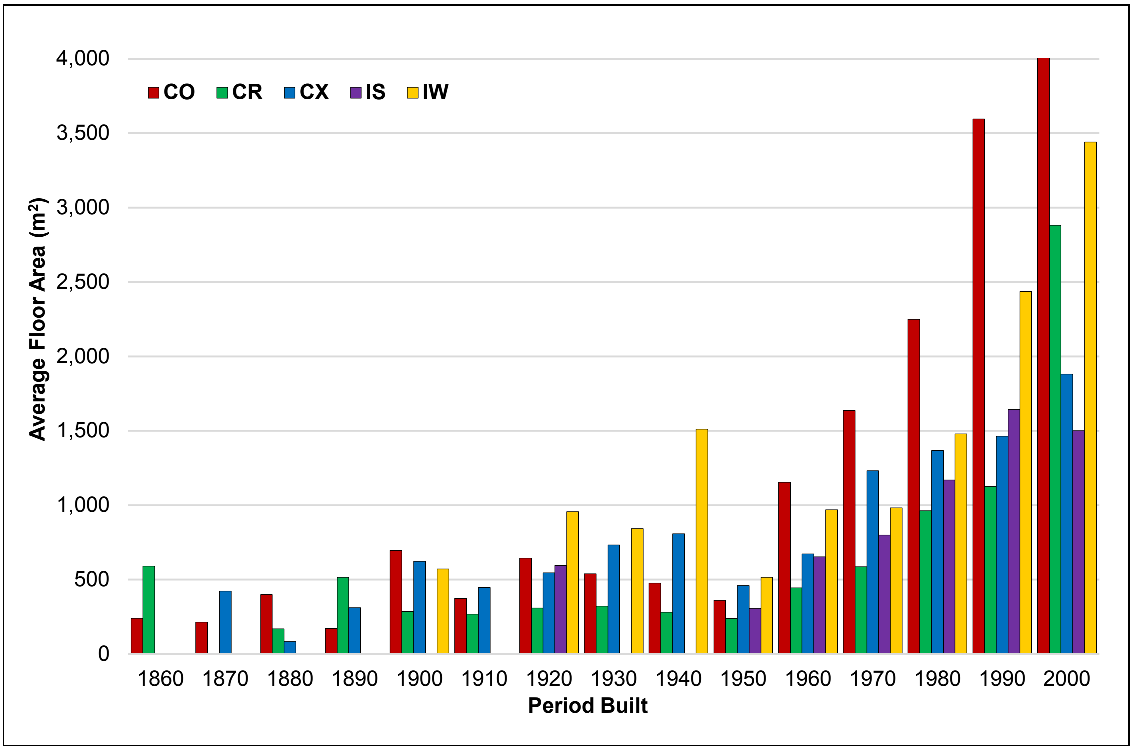

Figure 16: Average floor area in a building by decade by building-use category

6.5 Water use

Most water is used in properties constructed in the last three decades. This can be seen in Figure 17, which expresses the cumulative water use per BEES building-use category as a function of decade of construction. This water consumption pattern has similarities to total floor area in Figure 14.

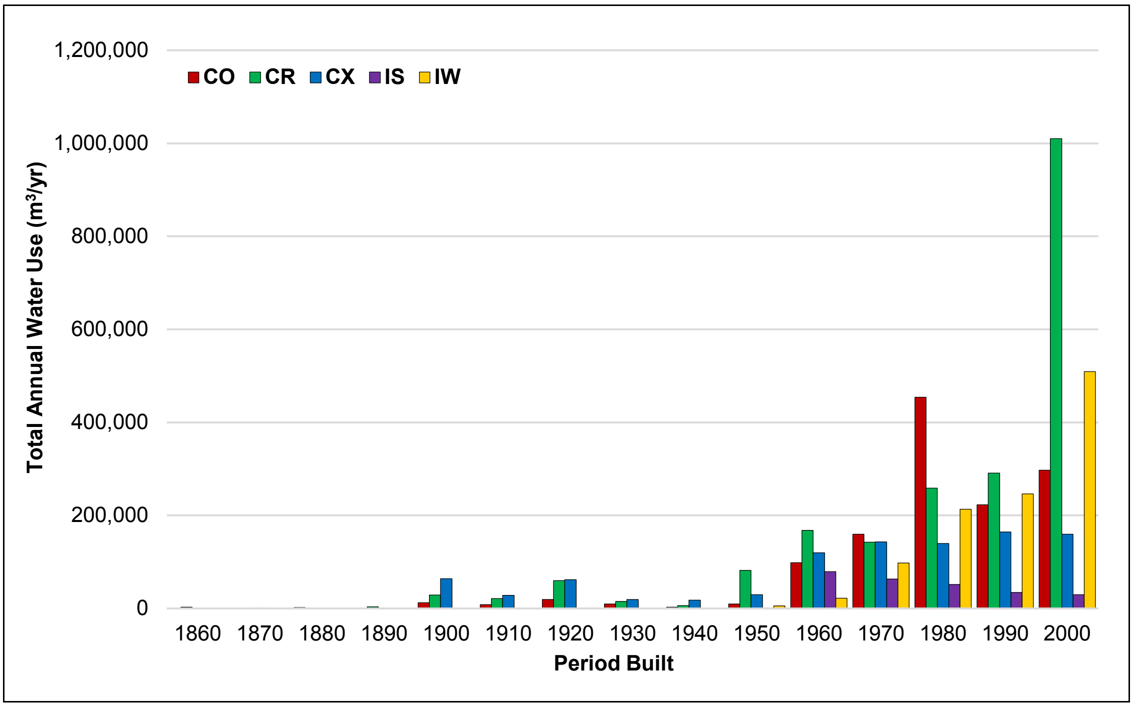

Figure 17: Cumulative water use for the main building use types by decade

6.6 Relations and implications

The trend in the WUI of properties related to age can largely be attributed to changes in the building stock. The tremendous amount of space in low water-using warehouses that has been added in the last decades has an impact (see Figure 16 and Figure 18). There is no clear trend detectable that can be linked to the introduction of water-efficient appliances.

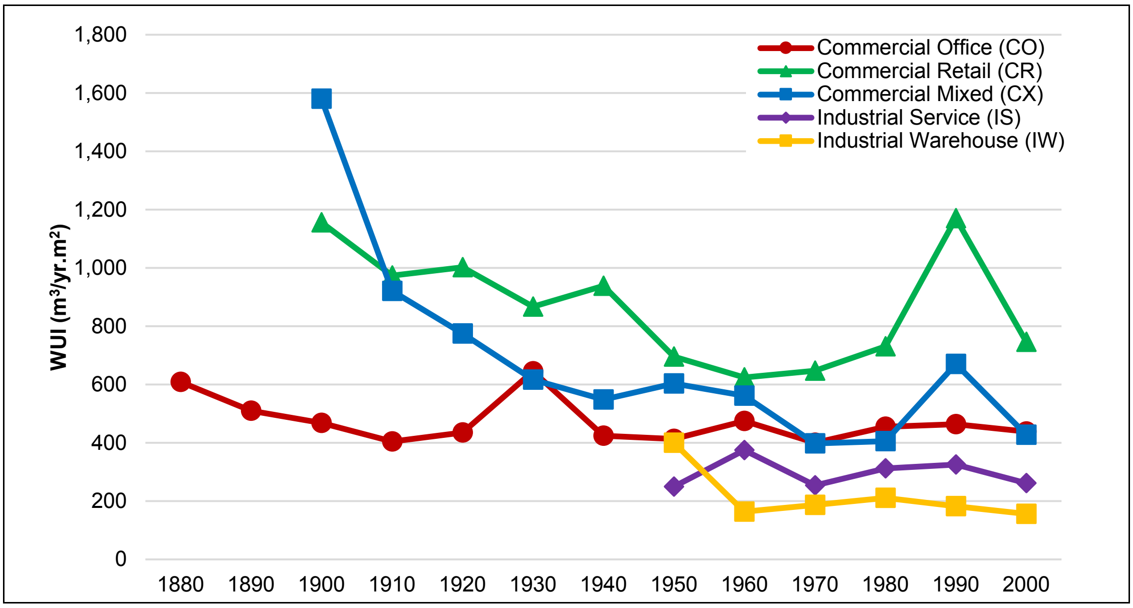

Figure 18: Median WUI by period built

The initial detected effect of the age of building on water use is misleading. Therefore, straightforward ageing analysis of a heterogeneous mix of non-residential buildings should be avoided due to strong differences in use.

Separate analysis of ageing trends within building-use categories might be more suitable for these purposes. The trends in median water use per unit area (Figure 18) show different behaviour for different use classes. The Commercial Retail (CR) and Commercial Mixed (CX) categories feature trends that show older buildings to use more water than newer buildings. Buildings from the 1990s also have a higher water use. The median water use of the Commercial Office (CO), Industrial Service (IS) and Industrial Warehouse (IW) categories is constant as a function of building age. Reading these trends, it is important to keep in mind that only a small percentage of the buildings date back to pre-1950. These older buildings fall in the CO, CR and CX categories –, see Figure 13 in combination with Figure 18. Given the poorer statistics for the older buildings, not too much weight should be given to the trends for buildings of the pre-Second World War period. The source of the peak in median water use for CR and CX use in the 1990s is still unclear. It could be the result of Auckland’s specific business preferences or business development history as well as the potential increase in the population. Additional evidence is needed.

7 STRUCTURE OF WATER DEMAND

To structure the water demand of the non-residential properties, we can sort and rank them according to their particular water use using their WUI. Each building represents a small amount of the total non-residential water demand. The sum of all the contribution is the total annual water demand of the building in the sample. To find the relative contribution, we divide the individual contribution by the total annual water demand.

In Figure 19, Figure 20 and Figure 21, three almost identical graphs are presented. The only difference is the scale on the secondary vertical axis. This split has been done to assist the reader to appreciate the full range and details of the curves. For this set of graphs, the properties were sorted according to their annual water use. On the horizontal axis, the parameter is the fraction of the total demand. For each value on the horizontal axis, which corresponds to the fraction of the total demand, the graph provides two values. The first value comes from the blue curve, which is the threshold value for the water use. Water demand of all individual properties having a water use lower than the indicated threshold value has been added to calculate the fraction of the total demand. The second value is the number of properties that contributed to the sum divided by the total number of buildings to calculate the fraction of properties contributing. It is given by the red curve.

For example looking at Figure 21, we can see that only 40% of total demand (horizontal axis) is generated by around 96% of the properties, which all use less than 4,400 m^3/yr of water. This means the remaining 60% of demand is generated by 4% of building using more than the threshold value.

We can use these curves to predict the demand of any random set of non-residential properties. Since the sample population has a sufficiently high number of properties, it can be regarded as statistically representative for all non-residential properties that meet the selection criteria.

7.1 Impact of extreme users

As noted previously, a single building was responsible for 9.9% of the total demand. This building has had a significant impact on the shape of the blue curve. Therefore, it is important to indicate that the high end is more sensitive to building-to-building variations. Here, we have kept them in the sample to indicate how important it is for water managers to give special attention to extreme water users.

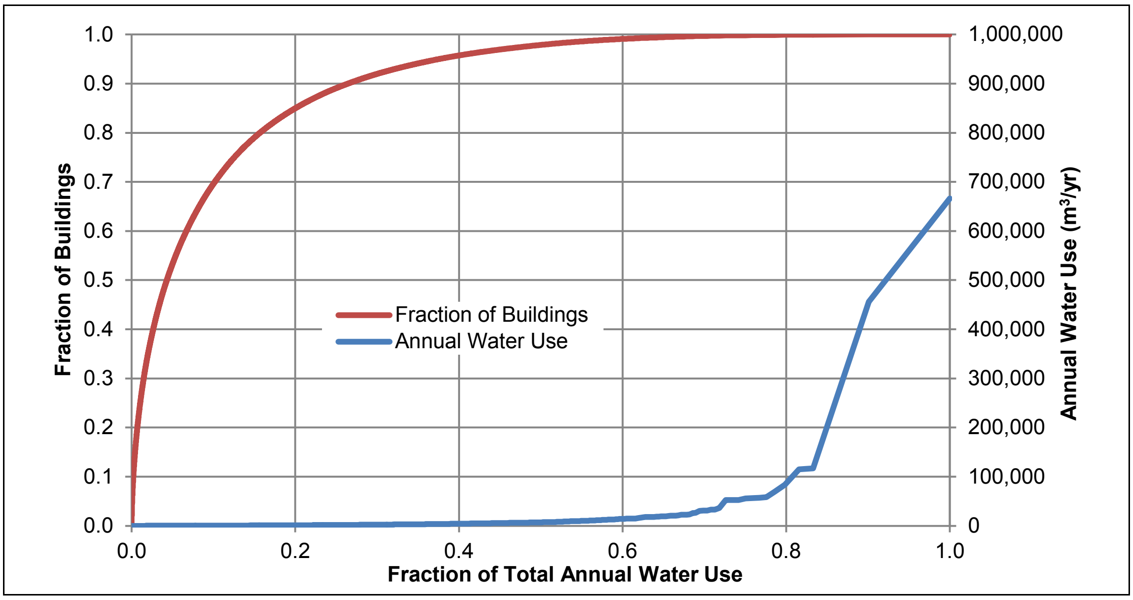

Figure 19: Building population sorted by annual water use

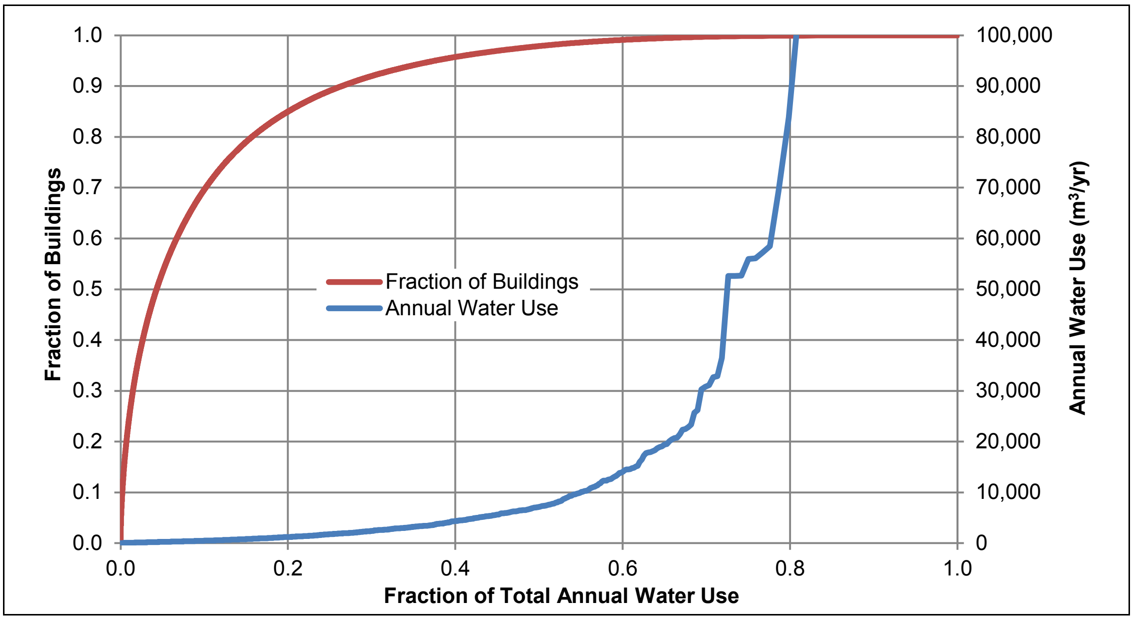

Figure 20: Figure 19 zoomed in to lower end of the secondary scale

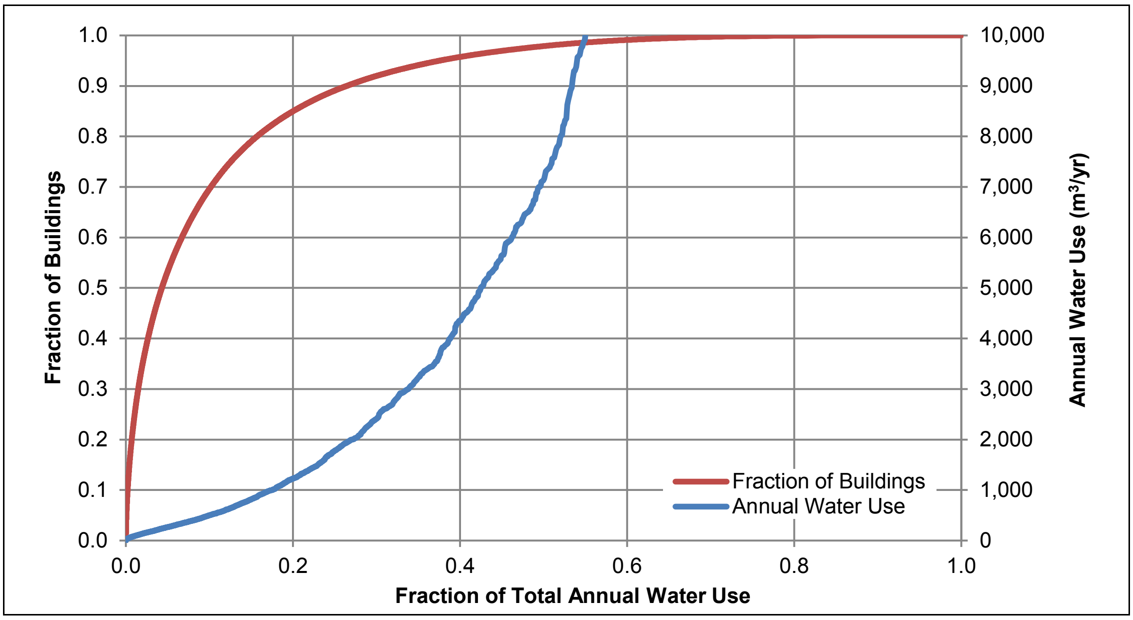

Figure 21: Figure 20 zoomed in to lower end of the secondary scale

7.2 Sorted by WUI

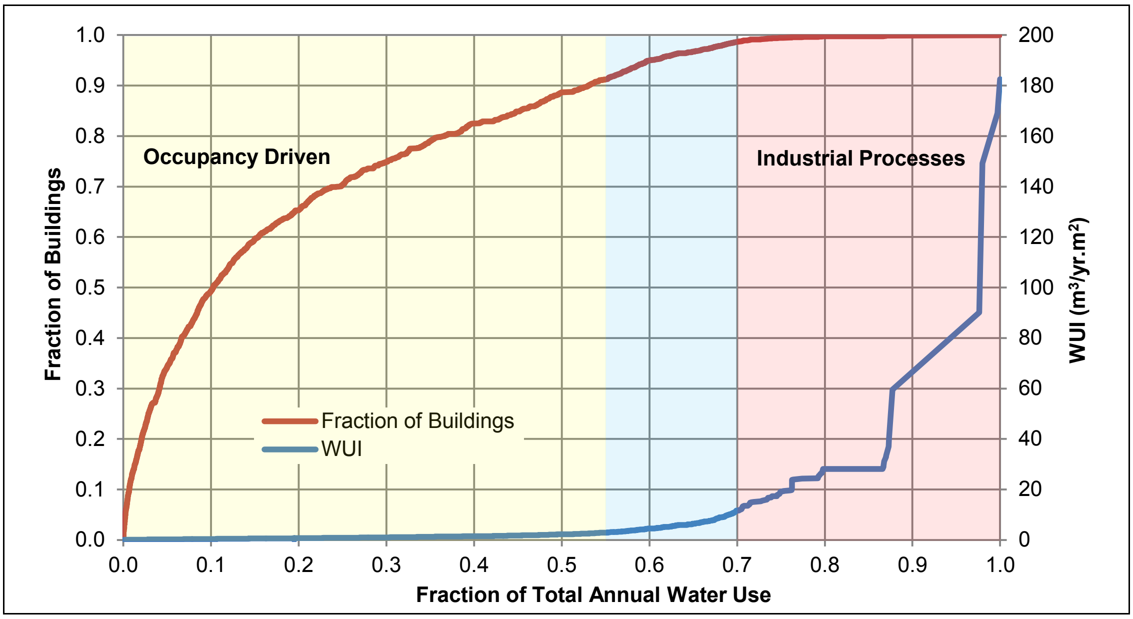

Figure 22: Population sorted by WUI

When the building population is sorted by WUI, which has been done to create a water demand profile in Figure 22, it is found that 50% of the water use can be allocated to 12% of the properties. (The red line gives the fraction of the total non-residential building population as a function of the associated fraction of the total non-residential water use. The blue line provides corresponding threshold value of the WUI.) Therefore, it appears that there are more properties contributing to the high end than when water demand is sorted by rate of water use as seen in Figure 22. Clearly, some of the large water users also have a large floor area. Therefore, their WUI is not exceptional. Around 500 smaller properties with a high water use per unit area have replaced them on the high end. The 50% mark corresponds to a threshold WUI of 2.3 m^3/yr.m^2.

The presence and impact of industrial processes on the high end (Figure 21) is clear. The influence of individual large users is visible. From Table 7, we can read the 98^{th} percentile of the cumulative distribution of the population corresponds to a threshold of 9.1 m^3/yr.m^2 for the WUI. In Figure 22 the threshold for the presence of industrial processes was set slightly higher at 10 m^3/yr.m^2. The fraction of water demand dominated by industrial processes has been marked by a red background colour. The lower end below 3 m^3/yr.m^2 has been marked yellow. Water use in properties in this yellow range is expected to be occupancy driven. However, production processes could still be present in the range between 3 m^3/yr.m^2 and 10 m^3/yr.m^2. A possibility for this range is that these properties are linked to food processing and catering. Verification is needed to confirm this, but this would go outside the scope of this study.

As mentioned previously, BEES is interested in the behaviour of properties without the influence of industrial processes. In demand curves presented in Figure 23, the population has been capped to those properties that have a WUI below 10 m^3/yr.m^2. (The red line gives a fraction of the total non-residential building population as a function of the associated fraction of the total non-residential water use. The blue line provides the corresponding threshold value of the WUI.) This reduced population is good for a demand of 4.6 million m^3/yr of water. The demand curves of the reduced population are far less sensitive to the influence of the extremes and also show more detail on the lower end.

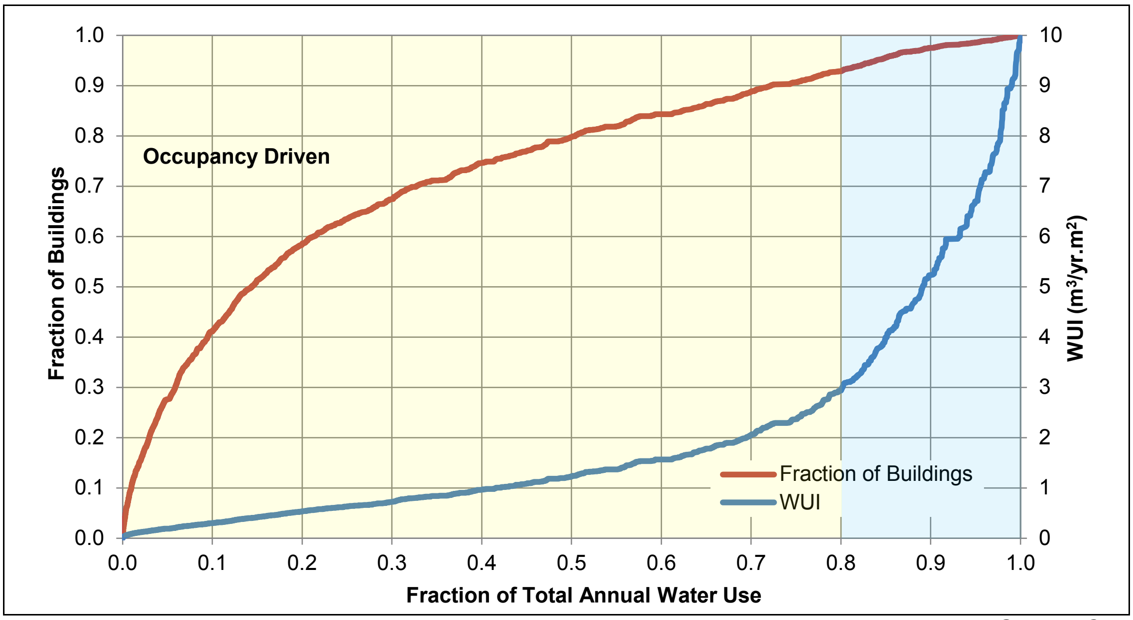

Figure 23: Demand curves of reduced population capped at WUI of 10 m³/yr.m² to remove properties with industrial processes

7.3 Context to water demand in BEES properties

The *Auckland Regional Water Demand Management Plan* provides baseline figures for water use in the water supply network operated by Watercare. This supply network services the whole of Auckland's metropolitan region with water. Over the 2-year period 2009–2010, 135 million m³/yr was supplied by Watercare to a population of around 1.3 million Aucklanders. On a daily basis, each consumer used about 275 L/day, of which about 175 L/day was used in residential properties.

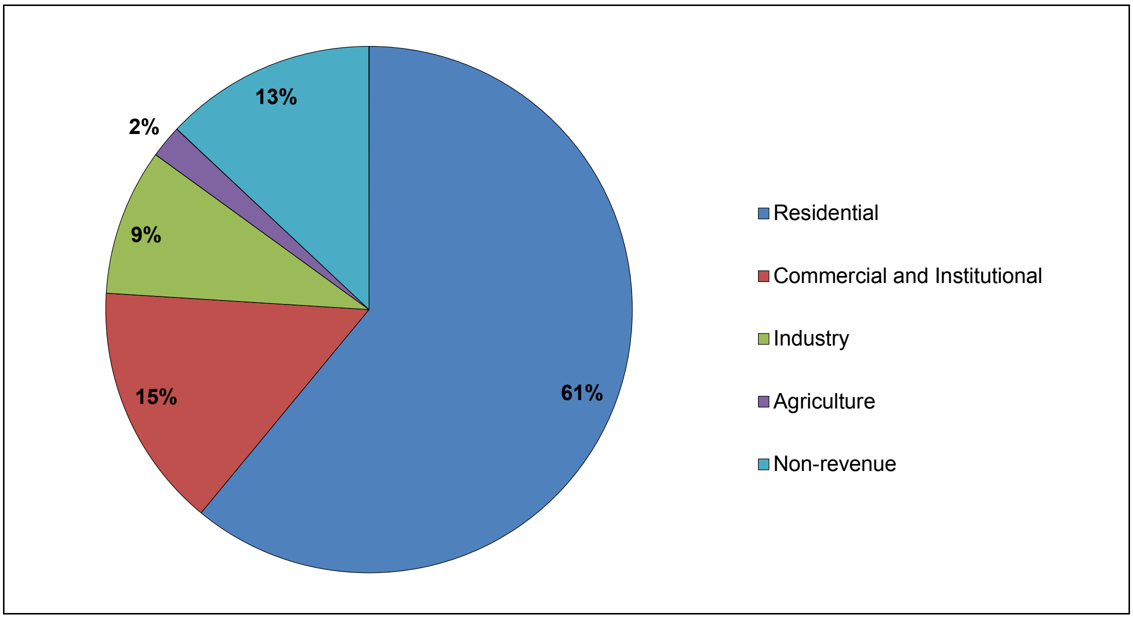

Figure 24: Percentage of total water use consumed in the main use categories (Watercare, 2011a)

In Figure 24, the breakdown of total regional water use in the main use categories is provided. Non-residential urban water use is about 24% of the total use, which is equivalent to a total of 32 million m³/yr. Industrial water use is 12 million m³/yr, and commercial and institutional use is 20 million m³/yr. Commercial and institutional use also includes demand for irrigation of parks and sports fields.

The baseline study best estimate for total water use in non-residential buildings given in Appendix B is 15.1 million m^3/yr, of which 6.5 million m^3/yr is used by industrial processes. On this basis, BEES non-residential buildings account for only 47% of Auckland's non-residential urban water use. This lower figure was expected because BEES is targeting office and retail, with some use categories such as irrigation of parks and sport fields not included in the BEES sample framework.

In the BEES Auckland sample, the percentage of water-using industrial processes is estimated at 44% of total use, based on our best estimate of aggregate water use. This means that at least 56% of non-residential water use in buildings can be influenced by the introduction of water-efficient appliances. Occupancy-driven water use can potentially be reduced to around one-third of current use using WELS-rated appliances with the highest star ratings. Typical WELS performance ratings of several appliances in the scheme are summarised in Table 27.

Based on the non-residential demand figure for Auckland, there is the potential for annual savings of about 6 million m^3 of water. However, replacing all current appliances is a costly and long-term affair.

8 ANALYSIS OF BEES KEY RESEARCH QUESTIONS

A wealth of data has been presented and analysed in the previous sections. In this section, the results are linked to the BEES key research questions including an assessment of the data suitability to answer the questions.

8.1 What is the aggregate water use?

To find out the aggregate building-related non-residential water use in New Zealand, a representative dataset is needed. The Auckland dataset is large but does not have the geographical extent to answer this question appropriately without making a crude assumption. This is that water use in the rest of New Zealand is similar to the Auckland metropolitan area. Compared to current practice in many other districts and regions, water demand and network integrity is well managed in Auckland. Therefore, in general, it can be expected the results are on average at the low end. However, the dataset is definitely representative for the Auckland region.

The detailed analysis of aggregate water use in Appendix B provides a best-estimate total water use of 8.6 million m^3/yr of drinking water for non-residential use in 11,327 BEES properties in the Auckland region. Consequently, our best estimate for the average water use of a non-residential property is 760 m^3/yr.

This number is different from our initial best estimate of the average water use of a BEES building of 460 m^3/yr given in Table 8, which was in comparison 75% too low. This difference indicates that the exclusion of industrial water use is not a simple procedure. This difference can be traced back to appropriate inclusion of weightings for typical water use varying as a function of floor area and building-use categories. Inclusion of industrial water use in the BEES buildings would have resulted in a higher Auckland aggregate water use of 15.1 million m^3/yr of drinking water.

Clearly, this type of estimation is tricky, as it requires the utmost care to remove the influence of industrial processes. Therefore, it is recommended to validate the result of the estimate method in any follow-up research.

8.2 What is the average water use per unit area per year?

Water use intensity (WUI) has been used extensively in this report. It is the parameter that describes the water use per unit area of a building. The simple average WUI from the total water use and the total floor area is 0.93 $m^3/yr.m^2$ (see Table 9). This particular WUI can be used to estimate the change of water use on the base of the change in total floor area of the non-residential building stock. The dataset's median value was 0.41 $m^3/yr.m^2$. Assuming a log-normal distribution a calculated mean of 0.66 $m^3/yr.m^2$ was found. It is recommended to use this last value for the WUI for estimates of the building stock behaviour without influence of industrial processes.

The difference between the mean WUIs results in an estimate of 29% of industrial water use in the BEES properties. This estimate corresponds with a threshold WUI for industrial water use of 10 $m^3/yr.m^2$, which was discussed in the previous section. Using these more refined estimates, the fraction of industrial water use is found to be 44% of demand, which corresponds to a WUI threshold value of 3 $m^3/yr.m^2$. The ranges for industrial water use are marked in water demand curves in Figure 22.

8.3 What is the average water use per unit area for different building-use categories?

The dataset was segmented into five main building-use categories based on existing Quotable Value (QV) categories. For the building stock of each of these categories, a water-use profile has been built up based on the analysis of the particular subset of data in the sample. A data overview is given in Figure 25 and Figure 26. Each building-use category was very different from the others. This is illustrated by the difference in water use between the Commercial Office (CO) and Commercial Retail (CR) in Figure 25.

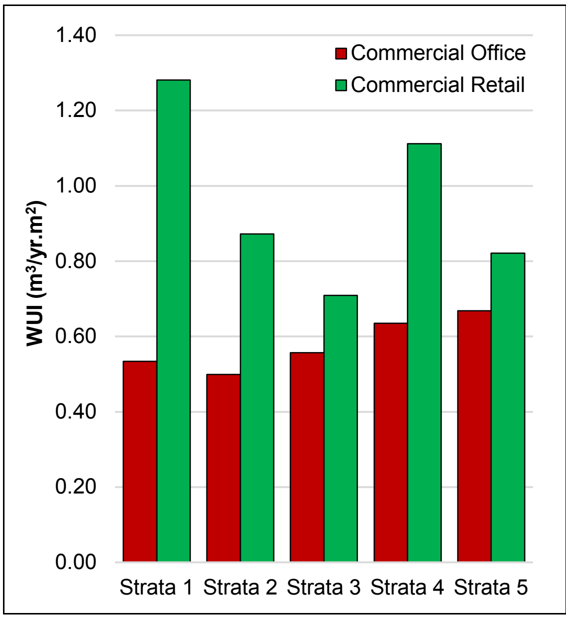

Figure 25: Mean WUI for CR and CO by building size stratum (*n* = 5,625)

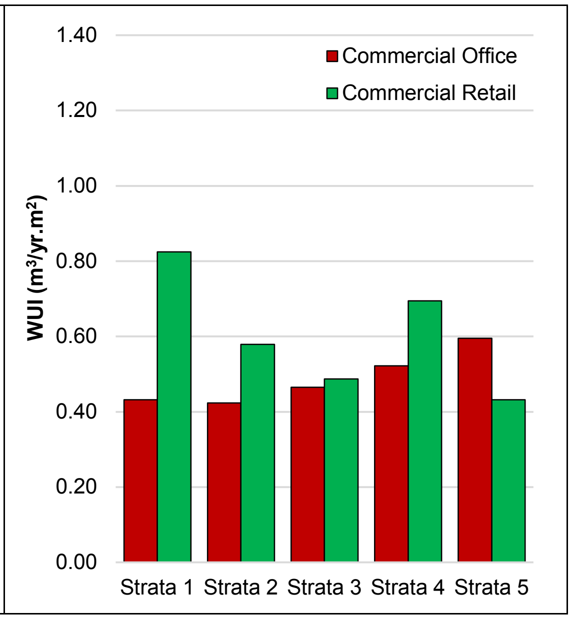

Figure 26: Median WUI for CR and CO by building size stratum (*n* = 5,625)

These figures show that office buildings use less water than retail buildings. For office buildings, there is a trend for larger office buildings to use more water. Retail is far more variable. However, this part of the retail segment excludes retail activity from the Industrial Warehouse (IW) and Industrial Service (IS) categories. Retail is still a very heterogeneous group. It is recommended to isolate more homogeneous retail business groups and link them to particular space utilisation to bring more understanding. The baseline dataset of Auckland is ideal to do this, and there is more information in Auckland city property data on building components to start this process. Cross linking to other BEES research will also provide deeper insights that were out of scope for this baseline study.

8.4 What characterises largest water use in non-residential properties?

Current water demand for the set of non-residential properties is dominated by a relatively small set of properties with very large water consumption. 50% of total demand was generated by only 2% of the properties with a water use in excess of 7,000 m^3/yr. However, this threshold is not useful for small buildings with large water use. Business verification indicated that the high consumption rate in the top 10 of these particular properties is linked to the presence of industrial processes. Business types such as breweries, meat-processing plants and beverage companies were found to occupy the properties at the high end. It is almost guaranteed that a property will contain some form of industrial process that uses water when water usage per unit area is found to be in excess of a threshold value of 10 m^3/yr.m^2.

Looking at the structure of demand corrected for size, 50% of total demand was generated by 12% of properties. These properties had a WUI that exceeded 2.3 m^3/yr.m^2. The likelihood of finding water-using production processes in these buildings is significant. However, these processes do not have to be industrial – they can also be food related. In Figure 22, a range is indicated where food processing might be the dominant water use. However, this study does not provide for further evidence to support this possibility. Cross linkage with data from other parts of the BEES research such as targeted monitoring and phone surveys is needed to build that evidence.

With regard to water use of the other 88% of properties, the contribution of occupancy-driven water end use becomes a major contributor. There are different degrees of service provision to occupants. An additional factor such as indoor catering might be important for water use.

The average performance of offices with a median water use of 0.46 m^3/yr.m^2 is indicative for water use driven by occupancy. The low water use in the Industrial Warehouse category indicates storage spaces in buildings (highly likely in a warehouse) do not generate a large demand for water. In the absence of industrial processes, if the occupancy density of a building decreases, the other water-using processes such as cleaning and building climate control become more dominant. Therefore, the largest water use in non-residential properties is governed by the presence of particular functional activities and services in the building.

8.5 What are the distributions of water use?

On the basis of this study, only indirect evidence with regard to particular end uses is possible. More detailed water use monitoring in relation to functional use of the spaces and the presence and use of water-using appliances in the properties is necessary to provide a further breakdown.

8.6 What are the determinants of water-use patterns?

Water use in non-residential properties was found to vary over a tremendous range. The smallest non-zero water user used a 100,000 times less than the largest water user.

8.6.1 Building size

The size of a building explained 28% of the variance in water use in the dataset, because larger properties use more water than smaller properties. WUIs were calculated for all properties as a first-order correction for size. Going from smaller to larger buildings, the water use per unit of floor area was found to be first decreasing until a minimum was reached around 3,000 m^2. Water use then increased for larger properties.

8.6.2 Building use

Segmentation of the sample into building-use categories explained some of the hidden structures in data. The building-use categories had different probability distributions over the range of possible building sizes. The relationship between water use and size was also unique for each building-use category. However, the remaining unexplained residual variance in each segment is still very large. The comparatively smaller residual variance of the office segment is an indication that these properties are used in a relatively uniform manner. Other segments are likely to feature more plural uses. Further segmentation of the current five building-use categories is still possible and recommended for all retail-related building-use segments.

8.6.3 Building Age

The age of a building was not found to have a significant effect on water use. A major driver of the remainder of the variance is differences in occupancy and type of functional use of the spaces in a building.

9 RESEARCH SUMMARY

A representative dataset for the analysis of non-residential water use in Auckland was created by linking property records for valuation to records of general water metering. This set has been utilised to create a statistical baseline of non-residential water utilisation over the appropriate range of building uses. The dataset represents about 10% of the BEES property population in New Zealand, 20% of Auckland non-residential water demand and 14% of properties in the BEES recruitment sample.

9.1 Key results

Water use in the group of non-residential buildings was found to vary over a tremendous range, with extreme users on both ends of the spectrum. At the high end, a single building was found to be responsible for 10% of total demand of the whole group. At the low end, 2% of the buildings were not using any water at all. A robust analysis was required to handle these extremes in an appropriate way.

The influence of property size using indicator floor area was found to be an important factor in explaining water use in these properties. It explained 28% of the variance in the dataset. However, a significant part of the variance was still unexplained. Using water use intensity (WUI), it was found that, on average, smaller properties tend to use more water than large properties. The details can be found in section 4.

The analysis of the building-use categories revealed that understanding heterogeneity in building use is key to understanding water use in buildings. The group of non-residential buildings was segmented into five BEES building-use categories: Commercial Office (CO), Commercial Retail (CR), Commercial Mixed (CX), Industrial Service (IS) and Industrial Warehouse (IW). Each category displayed a very distinct character different to the other categories. CO properties were the most homogeneous category. They have an average WUI of 0.54 $m^3/yr.m^2$. The CR category had on average the highest WUI of 1.2 $m^3/yr.m^2$ of the five categories. Lowest water use was associated with the IW category with a WUI of 0.26 $m^3/yr.m^2$. CX had a WUI of 0.83 $m^3/yr.m^2$, and IS had a WUI of 0.40 $m^3/yr.m^2$. CR, CX and IS categories showed smaller buildings using more water than larger buildings. For the CO and IW categories, this trend was less pronounced. It was found that further segmentation of the CR category would be beneficial to deepen understanding. There is some additional depth in the dataset that would allow such an assessment. The details can be found section 5 and separate building-use category water use profiles in Appendix A.

A crude assessment indicated that older properties appear to use more water than new buildings. However, a more detailed assessment revealed that the detected trend was the result of changes in the structure of the building stock. In the last decades, numbers of industrial warehouses with low water use have been added to the building stock. The bulk of the building stock has been built after the Second World War. The WUI for the post-Second World War properties of separate building-use categories was nearly constant. The exception was a 50% increase for CR and CX 1990s properties, which requires additional information from other sources to clarify. Therefore, age does seem to be a significant factor in explaining water use. However, it was found that newer buildings are, on average, larger and therefore use more water. This trend for increased building size does not seem to be levelling off at this stage. For more details, see section 6.

Non-residential water demand was found to be dominated by a relatively small group of extreme water users – 45% of water demand was generated by 8% of the properties with a WUI higher than 3 $m^3/yr.m^2$. This was found to be a robust indicator for the presence of water-using industrial processes in buildings. Water use in BEES buildings without the influence of those industrial processes is occupancy driven and can best be understood in terms of the building-use categories. The best estimate of the associated total rate of water use of all these BEES buildings was 8.6 million m^3/yr. More detailed information can be found in section 7.

This study addressed the three following BEES key research questions for non-residential water use to a satisfactory level:

- What is the aggregate water use?
- What is the average water use per unit area per year?
- What is the average water use per unit area for different building-use categories?

For next three questions, an initial analysis been performed that already provides some good leads and drivers that are essential to bring the research towards the final answers.

- What characterises the largest water use in in non-residential properties?
- What are the distributions of water use?
- What are the determinants of water-use patterns?

The answers are representative for a limited geographical area, Auckland, and need to be treated with the necessary care when used in relation to water use in other parts of New Zealand. The details can be found in section 8.

A doorway has been opened to understand the water use of New Zealand's non-residential building stock. More detailed studies can now be performed against the background of a solid Auckland baseline. This water-use performance baseline for buildings has enabled New Zealand to start developing meaningful benchmarks for non-residential properties in collaboration with stakeholders.

9.2 Options for further research and development

This baseline study has opened the door to further research in support of understanding non-residential water use and the development of prediction tools for the water demand of the non-residential building stock:

- Development of a first generation of water use benchmarks for specific identifiable building use groups of non-residential buildings can begin, using this baseline dataset.
- Integration of this water research with the other research components in BEES will strengthen our overall understanding of non-residential building utilisation. In particular, research into relationships between water use per unit area and building occupancy densities might result in a useful indicator that can be utilised to estimate effective occupancy in these buildings.
- Further segmentation to the building-use component level is possible using a deeper layer of information in the sample database.
- The dataset can be used to build a predictive stochastic model of water use by the non-residential building stock.

Acknowledgements

We are grateful for the generous data support that Watercare has given to the BEES project. Without this support, the Auckland baseline study of the BEES project would not have been possible.

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APPENDIX A: RESULTS BY BUILDING-USE CATEGORY

This appendix provides a detailed profile for the water use of three BEES building-use categories:

- Commercial Office (CO)
- Commercial Retail (CR)
- Commercial Mixed (CX)

Each profile contains the following elements

- Tables with the main statistics for water use of the building-use category.
- Statistical analysis of the relationship between water use and size.
- Analysis of water demand.

A.1 Commercial Office (CO)

The dataset contains 952 building records from the CO category. The sample general statistics are presented in Table 10. Average water use is 1,400 m^3/yr, and the WUI of the set is 0.72 m^3/yr.m^2. Maximum use is 37,000 m^3/yr. In the set, there are 16 properties that used no water at all during the 2-year period.

Table 10: General statistics on water use in the CO properties in the dataset

Parameter	Value	
Number of properties (non-zero)	952	
Total water use	1.3×10^6	m^3/yr
Total floor area	1.9×10^6	m^2
Average water use	1400 ± 100	m^3/yr
Standard deviation of water use	3300	m^3/yr
Maximum water use	3.7×10^4	m^3/yr
Minimum water use(non-zero)	3.3	m^3/yr$^-$
Minimum mater use (16 properties)	0	m^3/yr
WUI of total set (non-zero)	0.72 2.0	m^3/yr.m^2 L/day.m^2

In Table 11, the water use and WUI for key population percentiles are presented. The median water use of 280 m^3/yr is considerably lower than the average of the set given in Table 10. The median WUI of 0.56 m^3/yr.m^2 is also lower than the set averaged WUI of Table 10. The set does not appear to have significant outliers with regard to water use. However, there is a smaller building with a very high water use.

Table 11: Population percentiles of rate of water use and WUI for CO properties

Percentile	Water use L/day	m³/yr	WUI L/day.m²	m³/yr.m²
0% (minimum)	8.9	3.3	0.0074	0.0027
1%	26	9.3	0.10	0.037
2%	48	18	0.18	0.064
5%	86	32	0.27	0.099
10%	130	48	0.40	0.15
25% (first quartile)	270	99	0.72	0.26
50% (median)	760	280	1.30	0.46
75% (third quartile)	3,000	1,100	2.10	0.75
90%	8,700	3,200	3.70	1.30
95%	16,000	5,900	5.10	1.90
98%	34,000	12,000	7.80	2.80
99%	49,000	18,000	14.00	5.10
100% (maximum)	100,000	36,000	100.00	37.00

The results of linear regression of CO water use as a function of floor area is presented in Figure 27 and Figure 28 and the associated data of Table 12 and Table 13. All data has been log transformed for the analysis.

Figure 27 and Figure 28 show a first-order trend line (solid) and a second-order trend line (dashed) with associated 95% probability interval (upper and lower dashed lines) – all data of both parameters has been transformed to a logarithmic scale for a normal distribution of the data.

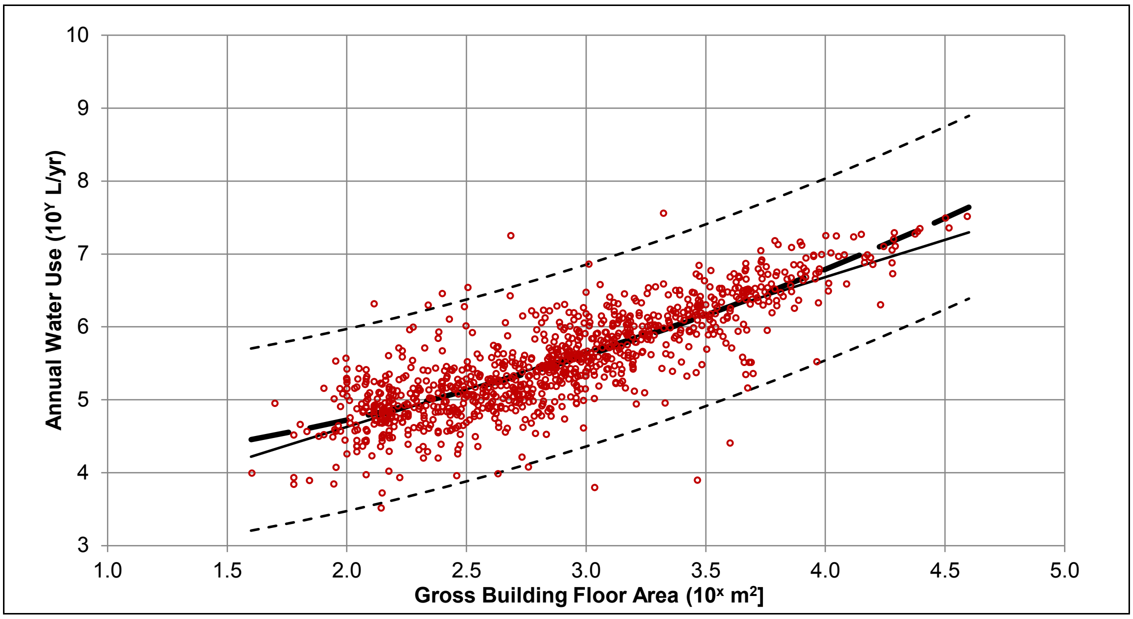

Figure 27: Scatter plot mapping the relationship between 952 CO properties' water flow rate (water use) and floor area

Table 12: Regression parameters for a first and second-order trend line relating water use to floor area using the data plotted in Figure 27

Regression function	$y = ax + b$	$y = ax^2 + bx + c$
parameters	**relations**	**Units**
Water use (Q)	$Q = 10^y, y = \log(Q)$	L/yr
Floor area (A)	$A = 10^x, x = \log(A)$	m^2
	values	**values**
a	1.03 ± 0.02	0.15 ± 0.03
b	2.57 ± 0.07	0.13 ± 0.20
c		3.9 ± 0.3
Number of properties	952	
Standard error in y	0.41	0.40
R^2	0.67	0.68

WUI of CO buildings

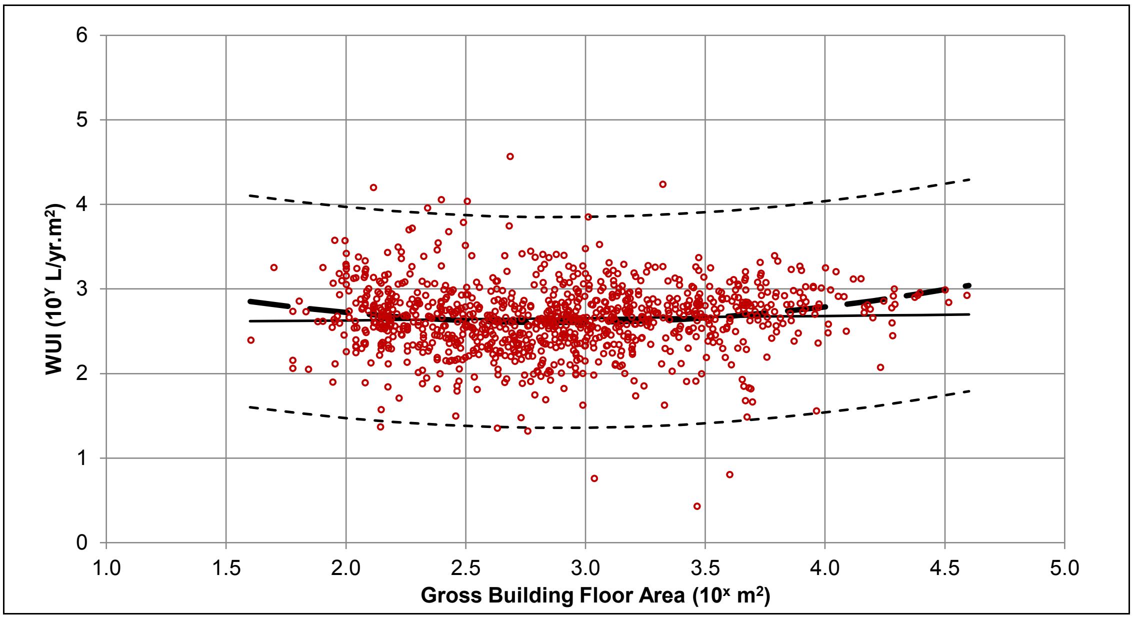

Figure 28: Scatter plot mapping the relationship between 952 CO properties' water volume flux and floor area

Table 13: Regression parameters for a first and second-order trend line relating WUI to floor area

Regression function	$y = ax + b$	$y = ax^2 + bx + c$
parameters	**relations**	
WUI (q)	$q = 10^y, y = \log(q)$	
Floor area (A)	$A = 10^x, x = \log(A)$	
	values	**values**
A	0.03 ± 0.02	0.15 ± 0.03
B	2.57 ± 0.07	-0.87 ± 0.20
C		3.9 ± 0.3
Number of properties	952	
Standard error in y	0.41	0.40
R^2	0.67	0.68

It is found that 68% of the variance in water use can be explained by floor area. This is the strongest relationship or any of the building-use categories. The slope of the first trend in Figure 27 is also nearly equal to 1. There is weak positive second-order term in the trend, which indicates both the smaller and the larger properties use slightly more water per square metre.

Water demand structure of CO buildings

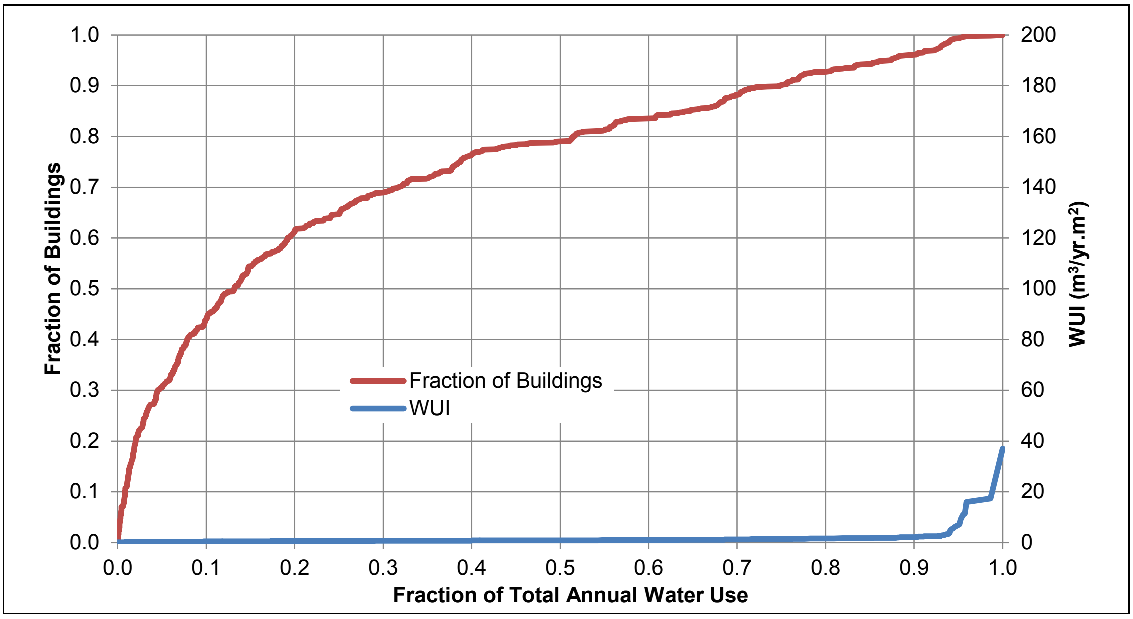

Figure 29: The CO population sorted by WUI

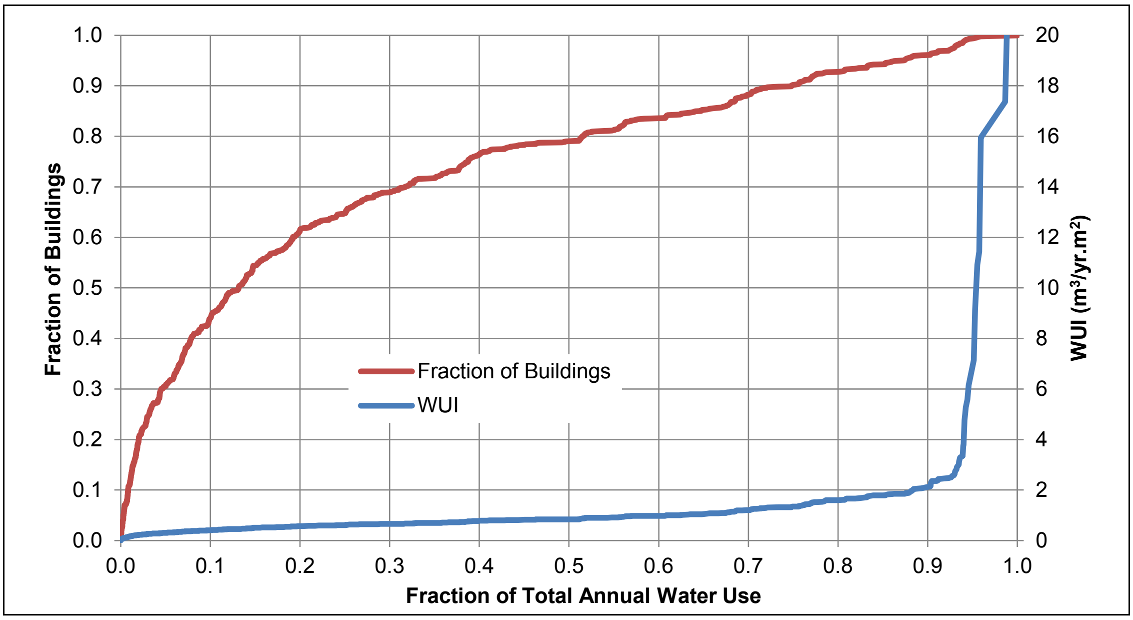

Figure 30: Sub sample, bottom 10% of CO buildings.

From Figure 29 and Figure 30, 90% of water demand is shown to be generated by properties using less than 2 $m^3/yr.m^2$. (The red line gives the fraction of the total non-residential building population as a function of the associated fraction of the total non-residential water use. The blue line provides corresponding limiting annual water use.) Further, there are a few properties with a water use in excess of 10 $m^3/yr.m^2$ responsible for the top 5% of water demand in this group. 80% of the CO properties have demand lower than 1 $m^3/yr.m^2$.

BEES size strata of CO buildings

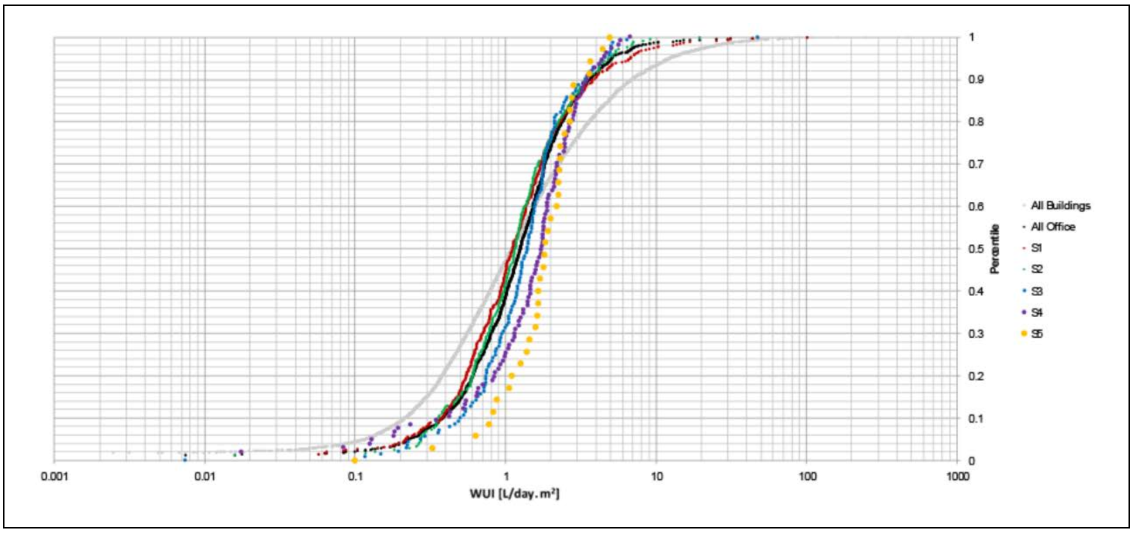

Figure 31: Cumulative distribution of WUI by CO building size stratum

From the cumulative distributions of the five size strata for CO properties in Figure 31, it can be observed that the largest offices have the steepest distribution without a strong tail at the high end. 80% of the S5 population has a WUI between 0.8 and 3 $L/day.m^2$, which is equivalent to 0.3 and 1 $m^3/yr.m^2$. The properties in the smaller building strata tend to use less, but they have wider distribution with longer tails. 80% have a WUI between 0.1 and 1.5 $m^3/yr.m^2$. Medians from the smallest to the largest building strata range from 0.4 to 0.6 $m^3/yr.m^2$.

A.2 Commercial Retail (CR)

The sample of CR building records has been created by combining several QV building-use subcategories (see Table 2). In section 5.1, it has already been identified that the contributing subcategories demonstrate different behaviour. In this section, the water use behaviour of the CR sample will be set out in more detail.

Retail is the sale of goods and services from individuals or businesses to end users or consumers. The word 'retail' comes from the Old French word 'tailer', which means 'to cut off, clip, pare, divide' in terms of tailoring. Under the New Zealand Building Code, retail properties would be classified as commercial properties, which is a use group with a wider definition that includes office properties.

Water use of CR buildings

The CR sample consists of 1,835 properties. Table 14 provides an overview of the general statistics. Average water use per building record is 1,252 m^3/yr, and the sample average WUI is 1.80 m^3/yr.m^2. However, these numbers provide an elevated biased picture because of the presence of the single-largest water user in the whole dataset using 666,000 m^3/yr.

Table 14: General statistics on water use in the CR properties in the dataset

Parameter	Value	
Number of properties (non-zero)	1835	
Total water use	2.30×10^6	m^3/yr
Total floor area	1.28×10^6	m^2
Average water use	1252 ± 374	m^3/yr
Standard deviation of water use	16038	m^3/yr
Maximum water use	6.66×10^5	m^3/yr
Minimum water use (non-zero)	0.57	m^3/yr^-
Minimum water use (52 properties)	0	m^3/yr
WUI of total set (non-zero)	1.80	m^3/yr.m^2
	4.93	L/day.m^2

The median of the CR population given in Table 15 provides a more typical value of 240 m^3/yr. 80% of the sample population has a water use that ranges between 31 and 1,900 m^3/yr, with the high 60 times higher than the low. CR water use has a very wide distribution as indicated by the green line in the graph in Figure 9. The WUI range for 80% of the population goes from 0.13 m^3/yr.m^2 up to 4.5 m^3/yr.m^2 with a multiplication factor of 34, which is also large.

Table 15: Population percentiles of water use and WUI for CR properties

Percentile	Water use		WUI	
	L/day	m³/yr	L/day.m²	m³/yr.m²
0% (minimum)	1.6	0.57	0.0068	0.0025
1%	17	6.1	0.067	0.024
2%	28	10	0.11	0.041
5%	50	18	0.21	0.078
10%	86	31	0.36	0.13
25% (first quartile)	220	79	0.78	0.28
50% (median)	650	240	2.20	0.79
75% (third quartile)	1,800	640	5.5	2.0
90%	5,200	1,900	12	4.5
95%	9,200	3,400	21	7.7
98%	16,000	5,900	36	14
99%	28,000	10,000	46	17
100% (maximum)	18,000,000	670,000	500	180

In Figure 32 and Table 16, the relationship between water use and floor area is analysed using linear regression with both a first-order and a second-order trend line. (Figure 32 and Figure 33 show a first-order trend line (solid) and a second-order trend line (dashed) with associated 95% probability interval (upper and lower dashed lines) – all data of both parameters has been transformed to a logarithmic scale for a normal distribution of the data.)

The slope of the linear trend is 0.75, which indicates that water use increases more slowly than floor area. The second-order term is small and positive. Its relevance is that at the top end of floor area, the curvature increases, indicating water use increasing at a greater rate than the floor area increase.

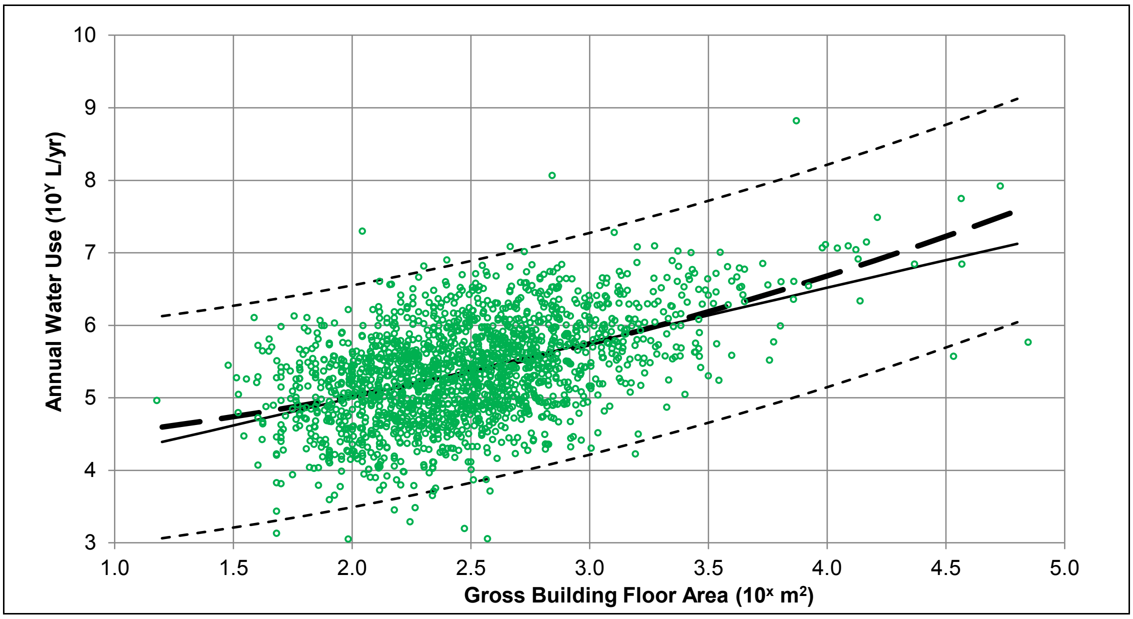

Figure 32: Scatter plot mapping the relationship between 1,835 CR properties' water flow rate (water use) and floor area

Table 16: Regression parameters for a first and second-order trend line relating water use to floor area using the data plotted in Figure 32

Regression function	$y = ax + b$	$y = ax^2 + bx + c$
parameters	**relations**	
Water use (Q)	$Q = 10^y, y = \log(Q)$	
Floor area (A)	$A = 10^x, x = \log(A)$	
	values	**values**
a	0.76 ± 0.03	0.11 ± 0.04
b	3.48 ± 0.08	0.19 ± 0.21
c		4.2 ± 0.3
Number of properties	1835	
Standard error in y	0.61	0.61
R^2	0.24	0.24

WUI of CR buildings

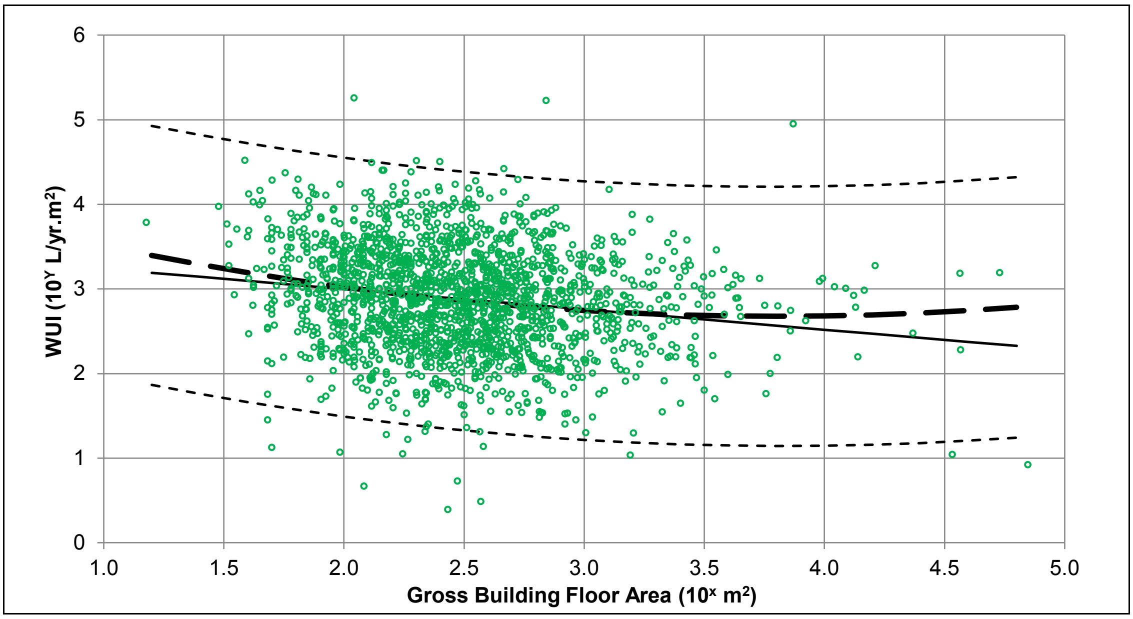

Figure 33: Scatter plot mapping the relationship between 1,835 CR properties' water use intensity and floor area

In Figure 33 and Table 17 show the same sort regression performed on the WUI data. The first-order trend indicates that WUI is decreasing when the floor areas increases. Again, the second-order trend line levels of to a horizontal direction with slope 0 for larger floor areas.

Table 17: Regression parameters for a first and second-order trend line relating WUI to floor area

Regression function	$y = ax + b$	$y = ax^2 + bx + c$
parameters	**relations**	
WUI (q)	$q = 10^y, y = \log(q)$	
Floor area (A)	$A = 10^x, x = \log(A)$	
	values	**values**
a	0.76 ± 0.03	0.11 ± 0.04
b	3.48 ± 0.08	0.19 ± 0.21
c		4.2 ± 0.3
Number of properties	1835	
Standard error in y	0.61	0.61
R^2	0.24	0.24

Water demand structure of CR buildings

Water demand from the sample is heavily influenced by two very large water users – one is using about 6% and the other is using about 30% of the total amount of water. Together, they are responsible for 838,000 m^3/yr of water. This can be seen from the water demand curves presented in Figure 34 and Figure 35. (The red line gives the fraction of the total non-residential building population as a function of the associated fraction of the total non-residential water use. The blue line provides corresponding limiting annual water use.)

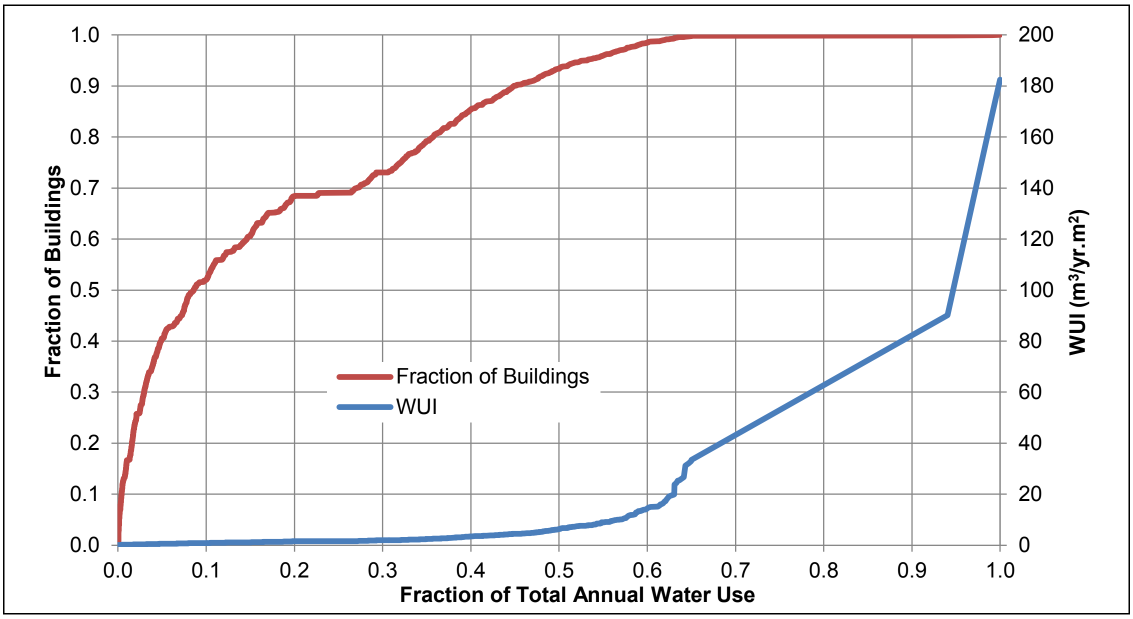

Figure 34: The CR population sorted by WUI

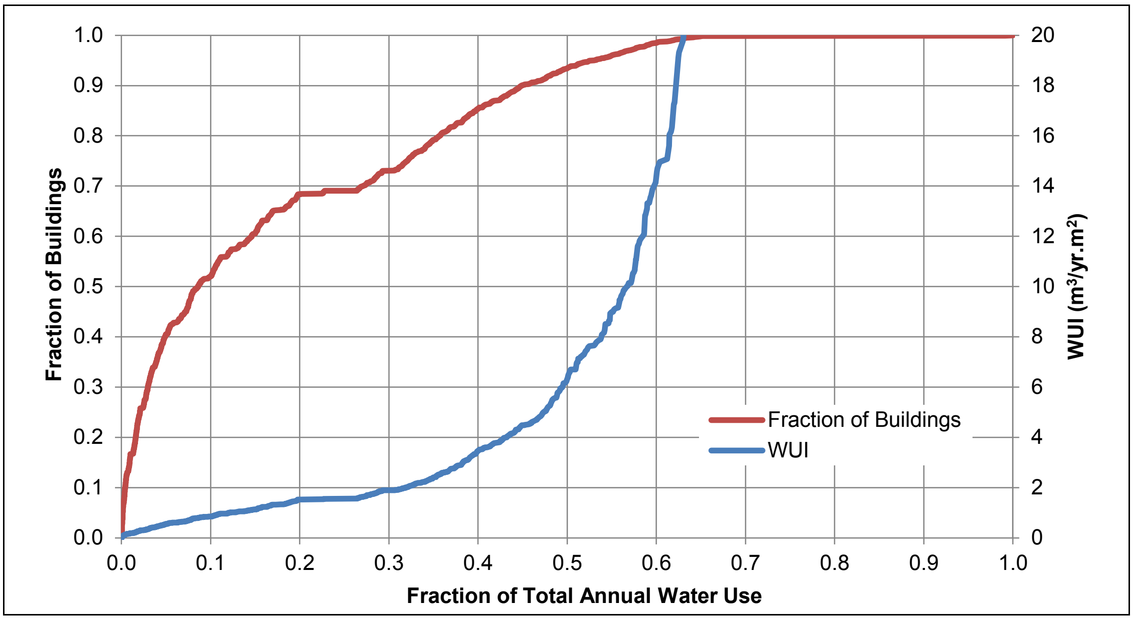

Figure 35: Figure 34 zoomed in to lower end of the secondary scale

Their WUI is respectively 180 $m^3/yr.m^2$ and 85 $m^3/yr.m^2$. 50% of CR water demand is generated by 94% of the properties using less than 6.5 $m^3/yr.m^2$.

The remaining 14% of demand comes from properties with WUIs ranging between 6.5 $m^3/yr.m^2$ and 34 $m^3/yr.m^2$.

Around the horizontal axis 25% demand marker, there are two large properties present in the data that are together responsible for 5% of water demand.

Their WUI is not exceptional – about 1.5 $m^3/yr.m^2$. Still, 70% of the properties have a lower WUI then these two properties.

BEES size strata of CR buildings

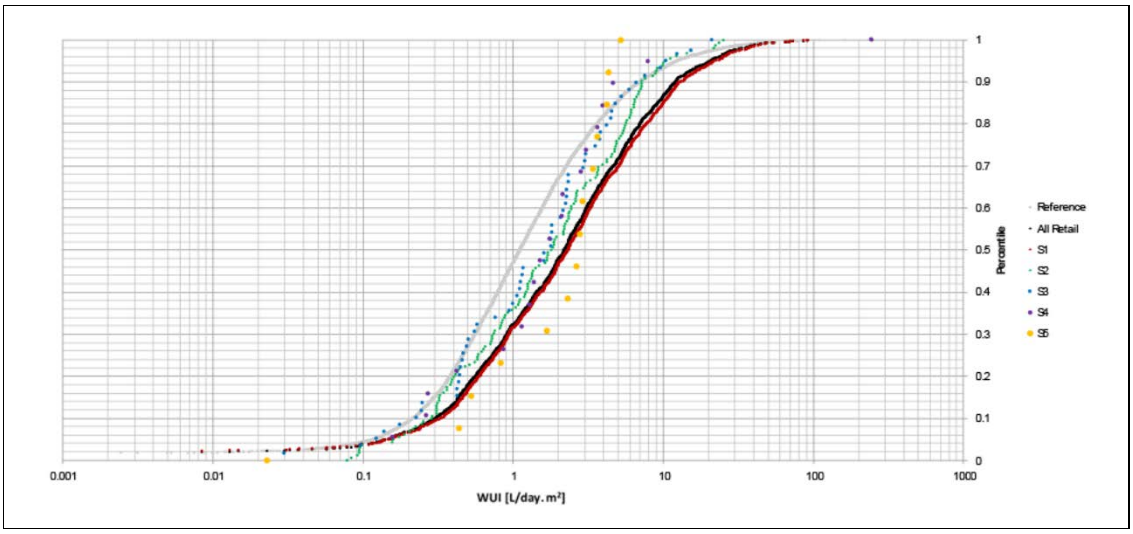

Figure 36: Cumulative distribution of WUI by CR building size stratum

When the sample is split up in subsamples for the BEES size categories, it is evident that properties of strata S2, S3 and S4 consume less water than the small properties of stratum S1.

The large strata also have less pronounced tails. The S5 stratum has a higher median than any of the other strata. However, the statistics are less robust because of the low count number.

Quotable Value retail building use subcategories

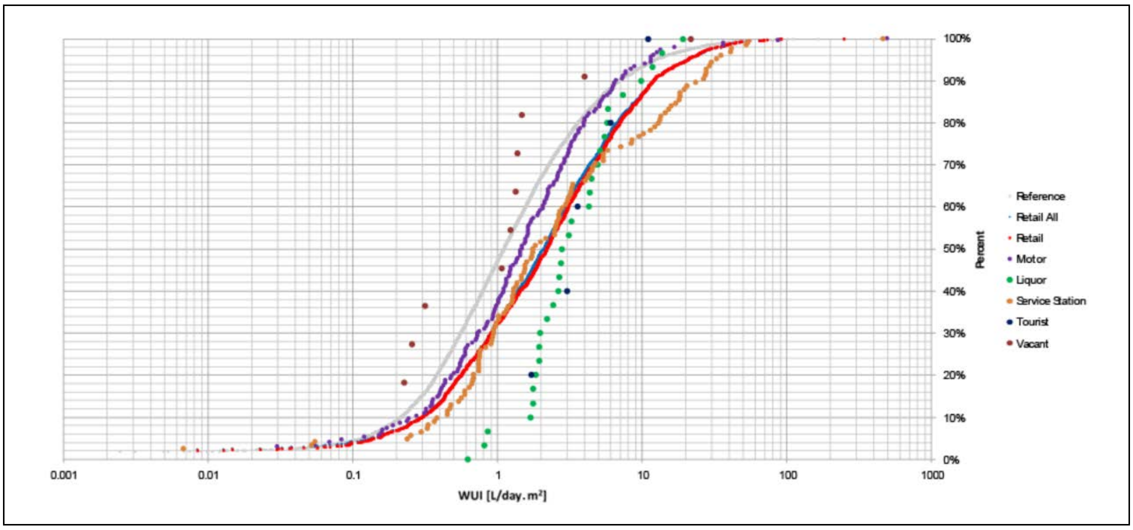

Figure 37: Cumulative distribution of WUI for five subtypes of CR properties

The Quotable Value retail building use subcategories listed in Table 2 in decreasing size order are Commercial Retail, Commercial Motor and Commercial Service Station. The cumulative distributions of all the subcategories are given in Figure 37.

Commercial Retail dominates the behaviour of the overall set. Therefore, we look here how the others differ from this retail group. The percentiles for the retail group are almost identical to the ones presented in Table 15.

The Commercial Motor subcategory uses less water than retail and has more narrow distribution. For 80% of the population between the 10 and 90 percentile lines, the WUI ranges from 0.09 $m^3/yr.m^2$ to 2.5 $m^3/yr.m^2$. The median value of this group is 0.4 $m^3/yr.m^2$.

The distribution of the Commercial Service Station subcategory appears to be bimodal. At the high end, there is fraction of the population with a different water-use profile. The boundary value is near the 74% percentile line. It needs to be verified if this group of high water users is associated with the presence of carwash facilities. Further research is needed. The low end of the group is now very similar to retail.

Commercial Liquor is a small but relative homogeneous group of properties with a higher use profile. The median value is 1.0 $m^3/yr.m^2$. The 80% range between the 10% and 90% percentile lines goes from 0.6 $m^3/yr.m^2$ to 3.5 $m^3/yr.m^2$.

The Commercial Tourist and Commercial Vacant subcategories have too low numbers to be of real value. The most interesting fact is that vacant properties use water.

Therefore, the question is how vacant they actually were during the monitoring period.

A.3 Commercial Mixed (CX)

The CX stratum is a group of commercial properties that can contain retail, offices and possibly even some residential.

It is derived from QV category Commercial Multiple/Other, which was a 'catch-all' category applied when there is more than one commercial use but also non-commercial use of the property.

Water use of CX buildings

There are 1,033 properties in this sample using slightly more than more 1 million m^3/yr of water, which is 15% of the water use of the whole dataset. This numbers result in an average water use of 1,014 m^3/yr. General sample statistics are given in Table 18.

Table 18: General statistics on water use in the CX properties in the dataset

Parameter	Value	
Number of properties (non-zero)	1033	
Total water use	1.05 x 10^6	m^3/yr
Total floor area	1.07 x 10^6	m^2
Average water use	1014 ± 84	m^3/yr
Standard Deviation of Water Use	2713	m^3/yr
Maximum water use	5.26 x 10^4	m^3/yr
Minimum water use (non-zero)	0.68	m^3/yr$^-$
Minimum mater use (22 properties)	0	m^3/yr
WUI of total set (non-zero)	0.97 2.67	m^3/yr.m^2 L/day.m^2

Table 19: Population percentiles of water use and WUI for CX properties

Percentile	Water use L/day	m^3/yr	WUI L/day.m^2	m^3/yr.m^2
0% (minimum)	1.9	0.68	0.0089	0.0032
1%	219	7.7	0.052	0.019
2%	37	13	0.10	0.038
5%	85	31	0.17	0.063
10%	140	51	0.29	0.11
25% (first quartile)	330	120	0.64	0.23
50% (median)	830	300	1.5	0.56
75% (third quartile)	2,100	760	3.8	1.4
90%	6,100	2,200	8.2	3.0
95%	12,000	4,400	13	4.9
98%	21,000	7,,500	24	8.7
99%	33,000	12,000	33	12
100% (maximum)	140,000	53,000	410	150

The distribution for finding a particular water use and WUI is given by the percentiles presented in Table 19. The median water use is 300 m^3/yr. 80% of the building records use water within the range of 51 m^3/yr to 2,200 m^3/yr. The median WUI is 0.56 m^3/yr.m^2 with the WUI ranging between 0.11 m^3/yr.m^2 and 3.0 m^3/yr.m^2 for 80% of the building records.

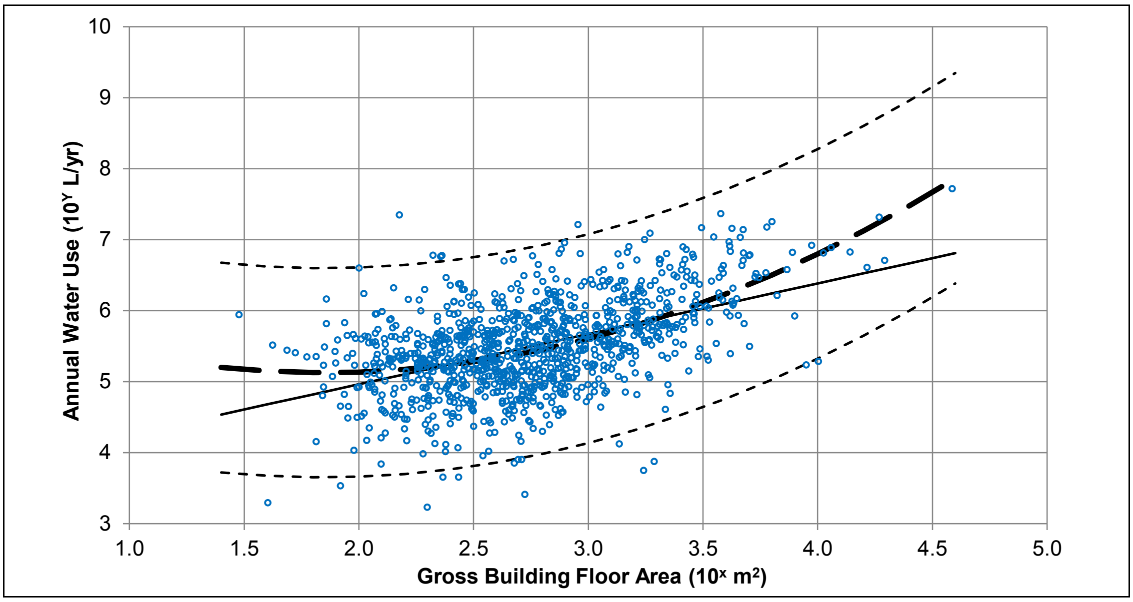

Figure 38: Scatter plot mapping the relationship between 1,033 CX properties' water flow rate (water use) and floor area

Table 20: Regression parameters for a first and second-order trend line relating water use to floor area using the data plotted in Figure 38

Regression function	$y = ax + b$	$y = ax^2 + bx + c$
parameters	**relations**	**units**
Water use (Q)	$Q = 10^y, y = \log(Q)$	*L/yr*
Floor area (A)	$A = 10^x, x = \log(A)$	m^2
	values	**values**
A	0.71 ± 0.03	0.36 ± 0.06
B	3.54 ± 0.11	-1.3 ± 0.3
C		6.4 ± 0.5
Number of properties	1033	
Standard error in y	0.57	0.56
R^2	0.24	0.27

The relationship between water use and floor area is presented in Figure 38. The water use and floor area data in the graph is log transformed. The transformed data has been fitted with respectively a first-order and a second-order trend line. (Figure 38 and Figure 39 show a first-order trend line (solid) and a second-order trend line (dashed) with associated 95% probability interval (upper and lower dashed lines) – all data of both parameters has been transformed to a logarithmic scale for a normal distribution of the data.) The fit parameters are given in Table 20. The slope of 0.71 L/yr.m^2 for the first-order trend line indicates that larger properties use relatively less water per unit floor area than smaller properties, because the slope is smaller than 1. The presence of the second-order term indicates that, for the larger properties, the straight relationship between water use and size is probably restored. There is a detection limit of 0.5 m^3/yr for the dataset, which might have some influence on the distribution for small properties.

WUI of CX buildings

Analysis of the WUI data presented in Figure 39 confirms the observations done for water use. However, the second-order trend is relatively strong, with a minimum for buildings with a floor area of 1,500 m^2. The parameters for the first-order and second-order regression are given Table 21. The values in this table are strongly linked to the parameters in Table 20.

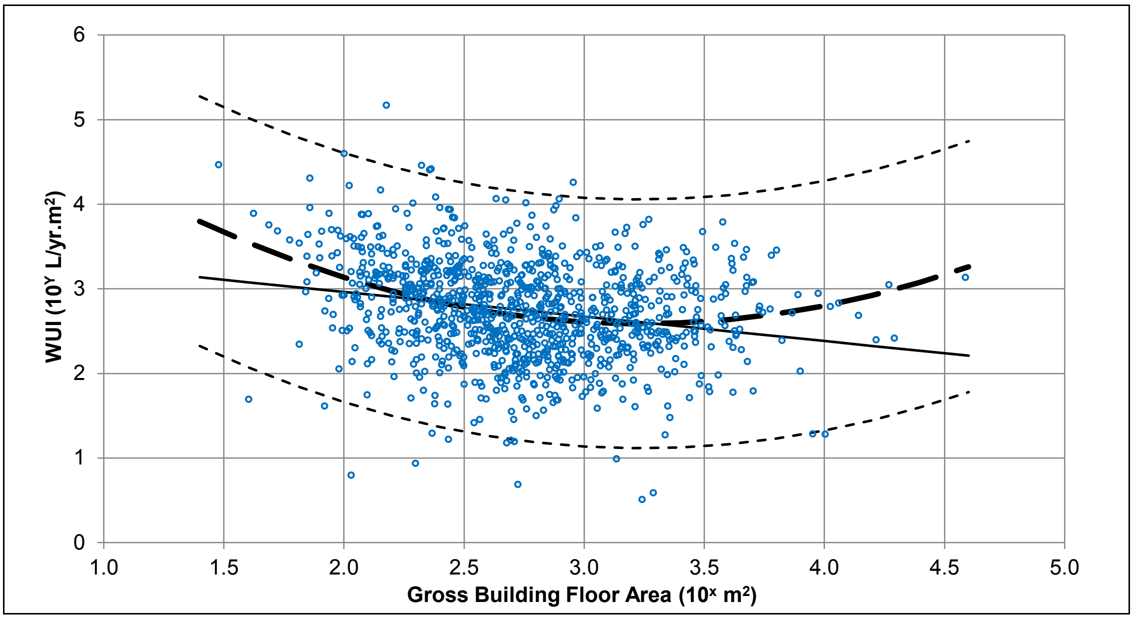

Figure 39: Scatter plot mapping the relationship between 1,033 CX properties' water WUI and floor area

Table 21: Regression parameters for a first and second-order trend line relating WUI to floor area

Regression function	$y = ax + b$	$y = ax^2 + bx + c$
parameters	**relations**	**units**
WUI (q)	$q = 10^y, y = \log(q)$	
Floor area (A)	$A = 10^x, x = \log(A)$	
	values	**values**
A	-0.29 ± 0.03	0.36 ± 0.06
B	3.54 ± 0.11	-2.3 ± 0.3
C		6.4 ± 0.5
Number of properties	1033	
Standard error in y	0.57	0.56
R^2	0.24	0.27

Water demand structure of CX buildings

The water demand structure presented in Figure 40 and Figure 41 indicates that 90% of the water demand is from 98% of the properties all using less than 10 m^3/yr.m^2, and 50% of water demand is from 83% of the buildings that all use less than 2 m^3/yr.m^2. (The red line gives the fraction of the total non-residential building population as a function of the associated fraction of the total non-residential water use. The blue line provides corresponding limiting annual water use.)

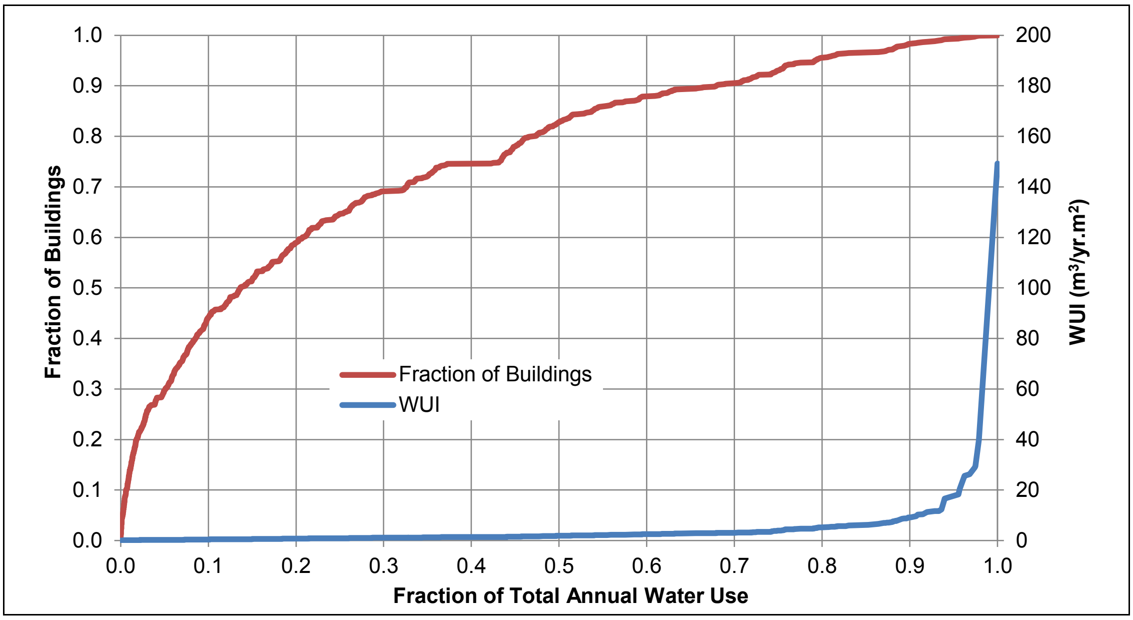

Figure 40: The CX population sorted by WUI

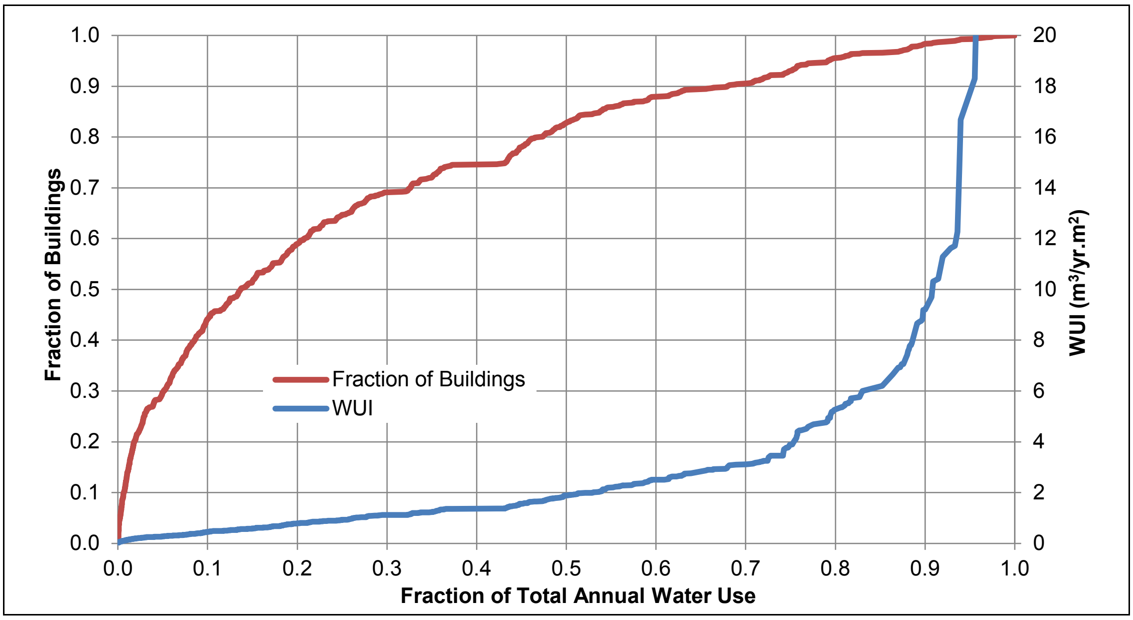

Figure 41: Figure 40 zoomed in to lower end of the secondary scale

The blue demand curve for this category is higher than the curve for CO and lower than the curve for CR in the previous subsections. Using a threshold value 3 $m^3/yr.m^2$, about 32% should be attributed to possible presence of industrial processes in 10% of the CX properties.

BEES size strata of CX buildings

The cumulative distribution plots of the size strata for the CX category are presented in Figure 42. The smallest building stratum S1 is associated with highest water use compared to other strata, with a median value of 0.7 $m^3/yr.m^2$. S2 has the lowest water use, with a median value of 0.4 $m^3/yr.m^2$. S3 shows regime shifts under the 44% percentile line. In this size stratum, there is a group with very similar water use present. S4 and S5 have higher water use than S3, but lower than S1.

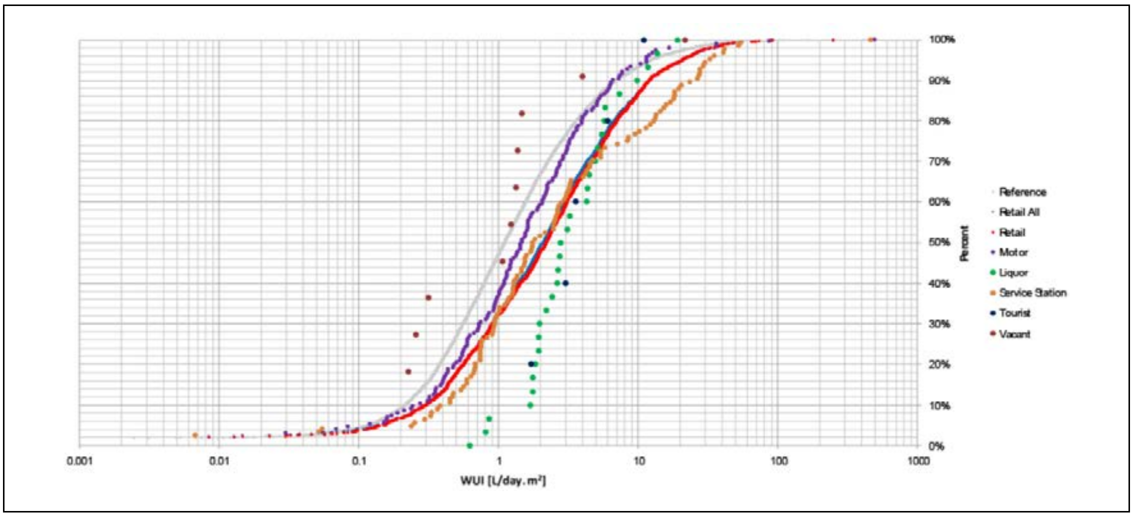

Figure 42: Cumulative distribution of WUI by CX building size stratum

The floor area associated with the minimum in the second-order trend line in Figure 39 falls at the boundary of S2 and S3, which is consistent with the observation of the behaviour of size strata.

APPENDIX B: ESTIMATION OF AGGREGATE WATER USE IN AUCKLAND BEES BUILDINGS

For the construction of the Auckland baseline, a dataset was created with a very different structure than has been used for the wider BEES project. This fundamental difference in sampling will impact on any result that is derived from it. Fortunately, the baseline dataset can also be used for a direct assessment of the sensitivity of results to this difference in sampling strategy. This is because the BEES sample is a subset of the BEES population. In this appendix, we will show that results for aggregate water use derived from the matched BEES sample and the BEES population are equivalent within reasonable margins.

First, a simple estimation of Auckland's aggregate water use is presented. Aggregate water use is the combined water use of all non-residential buildings (or properties). However, in the BEES context, it needs to be the consumed water use without the contribution of industrial processes. In this analysis, we focus on estimating water use of 100% of the BEES Auckland population. There are different pathways to reach such a regional estimate. Some are more appropriate than others. We explore some options starting with a simpler one to set the scene for slightly more sophisticated analysis using sample and population figures.

Simple estimation of aggregate water use

For the justification of the first approach, it is important to recognise that the Auckland BEES population has been sampled in a straightforward way. The water use dataset already represents 51% of the BEES properties in the Auckland region, and the address-matching score rates for the size strata were reasonably equal. Therefore, it is not necessary to apply any weighting for the first estimation. We can simply use an estimate of the average water use per building. Initially, a simple analysis provided an average water use for a non-residential building of 1,170 m^3/yr (see Table 4). Multiplication of this mean value by the 11,327 BEES properties in Auckland gives a total aggregate annual water demand of 13.2 million m^3/yr. However, this figure still includes industrial water use.

The median value of the dataset was 240 m^3/yr, which is lower than the mean. We have seen that the data as a function of size was approximately log-normally distributed. Under this assumption, analysis of the data distribution in the log-transformed domain resulted in a calculated mean water use of 430 m^3/yr and fitted median of 260 m^3/yr. The small difference between the actual median and the fitted median is an indication of quality of fit in the transformed domain and reasonable confirmation of the log-normal distribution of the data. However, this latter estimated value of the mean under assumption of a log-normal distribution has reduced sensitivity to the influence of very high water users. Their presence is balanced by the presence of equal numbers of very low users and therefore gives an estimate number for average water use without industrial water use.

The difference between the two mean values provides us with an estimate of the proportion of the total demand used by retail and office buildings, which is 37%. The other 63% of non-residential water demand is attributed to water-using industrial production and services processes. Using these fractions, aggregate water use for office and retail in Auckland is estimated at 4.8 million m^3/yr of drinking water. These indicated fractions do not correspond to the findings in section 7, which provides a lower estimate for industrial water use. This method might be crude but gives a first indication.

Another method of calculating aggregate water use is the WUI. In Table 9, we had two values for the average WUI of the properties – a high 0.93 $m^3/yr.m^2$ and low 0.66 $m^3/yr.m^2$ were found. The higher value includes industrial water use. These two numbers can be multiplied with total floor area of all the Auckland properties of the BEES population, which is 16.1 million m^2. This results in estimates for aggregate water use in Auckland of

15.0 million m³/yr including industrial water use and 10.7 million m³/yr for retail and office water use. The estimates are more reliable, because the influence of building size has been reduced. Industrial water use is estimated at 29% of total demand, which corresponds better to the findings in section 7.

However further refinement is possible using separate parameter estimates for the size strata. We apply this more sophisticated method for the BEES property sample and the BEES property population and compare the results below.

Aggregate water use from BEES sample and BEES population

In section 3.1, the initial matching score rates for the BEES property sample and the BEES property population in the Auckland region where described. The numbers related to matched water use records. The number of matched properties of the Auckland BEES population was lower – 5,725 to be precise. Most of the properties with multiple water meters were in stratum 1. These numbers are important to get the relationship between properties right.

Table 22: Matching building records with water meter location (unique)

Use category	Size stratum										Overall	
	S1		S2		S3		S4		S5			
	Match	Total	Match	Total	Match	Total	Match	Total	Match	Total	Match	Total
CO	461	905	247	402	142	257	108	174	36	58	994	1,796
CR	1,511	2,913	244	545	83	217	24	76	15	39	1,877	3,790
CX	618	1,398	242	505	138	268	44	126	10	31	1,052	2,328
IS	237	520	197	484	64	262	13	104	2	18	513	1,388
IW	377	491	428	644	323	552	130	265	31	73	1,289	2,025
Overall	3,204	6,227	1,358	2,580	750	1,556	319	745	94	219	5,725	11,327
Matched	51%		53%		48%		43%		43%		51%	

For the assessment of the difference in outcomes between the non-residential datasets, an estimate of water demand in the Auckland region was done using two methods. One method estimates water demand based on estimated floor area and average WUI per size stratum. The other method uses the number of properties and average water use per size stratum. Input data was taken from the matched BEES sample with an overall score rate of 45% and matched BEES population with an overall score rate of 51%.

This leads to four different estimates for Auckland's non-residential water demand. The input data and results are given in Table 23. Water demand estimations using both methods are given for an estimate based on two datasets – the Auckland BEES sample (43%) and 51% Auckland population. The results based on the first method, using floor area and WUI, are 11% higher than those based on the other method for both datasets. Further, the estimates of the BEES sample dataset are 10% higher than the estimates that were derived from the matched BEES population.

The difference between the results of the two samples was expected and is now scaled. The contribution of stratum 1 is the main source of the difference. Stratum 5 is identical, because it is the same properties. However, it gives confidence to see that the results of the BEES sample and BEES population are very similar. More exploration of the uncertainty in the results is possible by reducing the number of properties in the BEES sample.

With regard to understanding the difference in outcomes between the methods, it is important to realise that both methods incorporate a correction for building size, but the correction is more refined for the first method (floor area and WUI). Therefore, 8.6 million m³ is our best estimate of non-residential water use in Auckland's non-residential buildings excluding water use by industrial processes. The difference between the methods is largest for stratum 1 and stratum 5.

Table 23: Water demand estimations

Parameter		S1	S2	S3	S4	S5	Total
Count	Population non-residential properties NZ	33,781	10,081	4,288	1,825	564	50,423
	Population Auckland	6626	2580	1552	740	219	11327
	51% population Auckland	3204	1358	750	319	94	5725
	BEES sample NZ	609	609	611	607	564	3000
	BEES sample Auckland	113	156	221	246	219	955
	45% BEES sample Auckland	58	71	97	106	94	426
Average floor area (m^2)	Population non-residential properties NZ	293	955	2226	5269	17317	959
	Population Auckland	300	985	2276	5259	19639	1425
	51% population Auckland	303	969	2252	5176	17918	1278
	BEES sample NZ	296	945	2232	5252	17317	
	BEES sample Auckland	302	991	2275	5221	19639	
	45% BEES sample Auckland	321	941	2215	5001	17918	
Mean WUI (m^3/yr.m^2)	51% population Auckland	0.898	0.425	0.415	0.460	0.576	0.664
	45% BEES sample Auckland	1.168	0.465	0.453	0.477	0.576	
Mean water use (m^3/yr)	51% population Auckland	224	405	917	2330	9439	430
	45% BEES sample Auckland	321	413	970	2325	9439	
Estimate of total water use (10^6 m^3/yr)	51% population Auckland and WUI	1.785	1.081	1.466	1.789	2.477	8.60
	45% BEES sample Auckland and WUI	2.322	1.182	1.599	1.856	2.477	9.43
	51% population Auckland and water use	1.489	1.044	1.423	1.724	2.067	7.75
	45% BEES sample Auckland and water use	2.128	1.066	1.506	1.721	2.067	8.49

APPENDIX C: PRINCIPLES FOR WATER USE IN BUILDINGS

For the analysis of water end use in non-residential properties, the following conceptual and analytical framework was used to describe the data that was collected.

Reticulated water in buildings

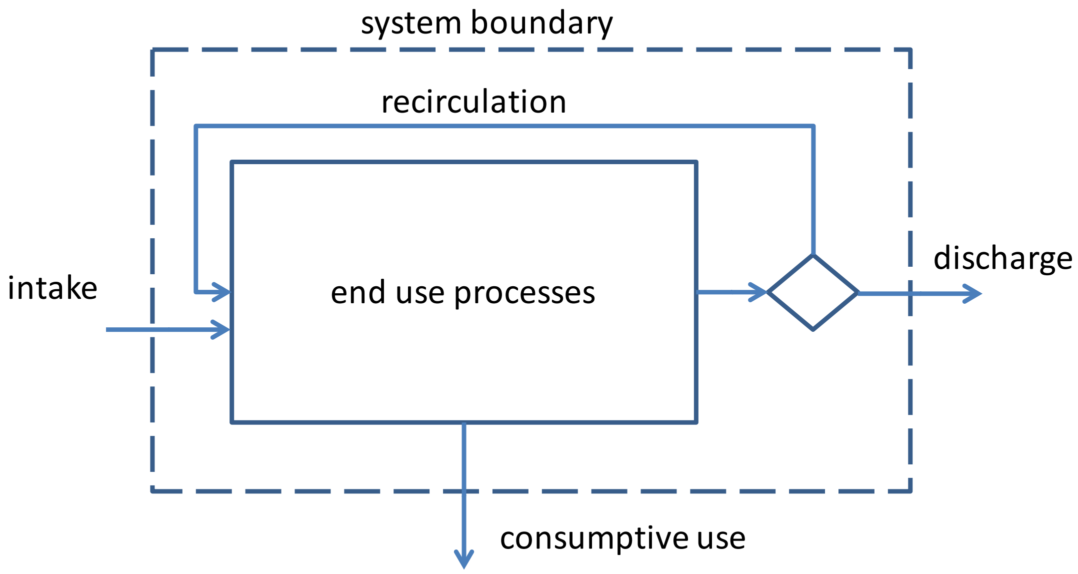

Figure 43: Schematic representation of a reticulated water system

Buildings built for human occupation have reticulated water systems (Figure 43). These contain a set of water-using processes for different end use purposes such as sanitation, toilets or cleaning. The building's water system receives water through a single intake point, and the water is distributed within the system boundaries to the different end-use processes. A building has only limited storage capacity for water, for instance, in a hot water cylinder, a header tank or a swimming pool. Therefore, water will have to be removed from the building.

Water can leave the building in two forms. A building has a water disposal system that aggregates all used water to a single exit point were the water will be discharged. However, not all water received at the intake will leave the building by this means – some will be lost due to evaporation, consumption or leaks. Some properties have special facilities to reuse water that has already been used before such as greywater systems.

Water transport parameters

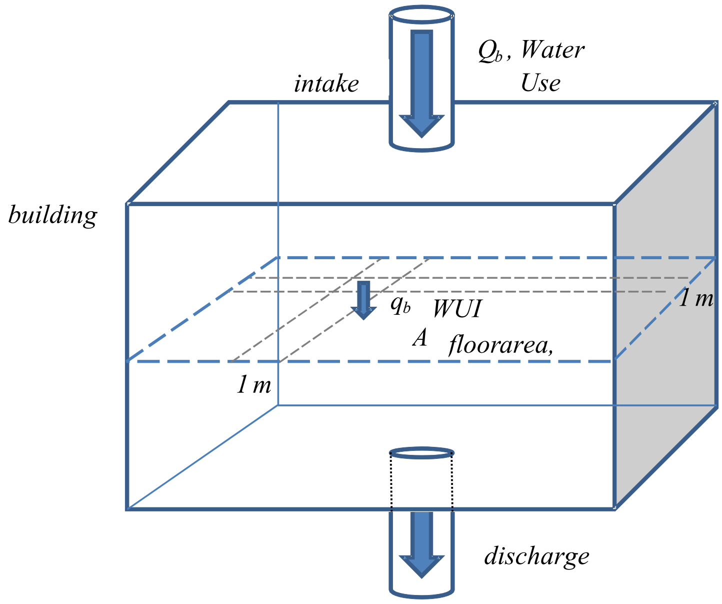

Figure 44: Conceptual diagram of water use in a building

For a description of water use in properties, we will use two parameters – the rate of water use (Q_b) and the water use intensity (WUI) (q_b). Figure 44 represents a building as a pipe with an intake section and a discharge section both of very small diameter. The wide section represents the building. The cross-section of the pipe in the wide section is equal to floor area (A_b) of the building. We assume the flow velocity is uniform on every cross-section that we use for calculations.

Rate of water use

The building's rate of water use (Q_b) at the intake is the volume of water that is pumped into the building per unit of time. We assume that no water is lost, consumed or evaporated. Therefore, the amount of water discharged from the building is equal to the amount entering the building. Under this condition, the rate of water use is equal for every cross-section of the pipe.

$$Q = Q_{in} = Q_b = Q_{out}$$

To meet this requirement, the flow velocity (v_b) will be very much lower in the wider section of the pipe than the flow velocity in the intake pipe (v_{in}). Typically:

$$Q = v_{in}A_{pipe} = v_b A_b$$

Under uniform flow conditions, the flow rate in a pipe is the product between the flow velocity (v) and the cross-sectional floor area (A).

Water use intensity (WUI)

This idealised flow velocity (v_b) at the building cross-section is the water use intensity (WUI), for which we will use the symbol q. In the study of transport phenomena such as fluid dynamics, WUI is defined as water use per unit area. It is used to compensate for the fact bigger buildings will likely consume more water than smaller properties when used in a similar way. To make the water use of properties of different sizes comparable, we divide the water use (Q) by the floor area of building.

$$q_b = v_b = \frac{Q}{A_b}$$

This corresponds to the WUI (m^3/yr.m^2 or L/day.m^2 or m/s).

Segmentation of water end users

In this study, the data collected was limited to non-residential water use in a well-defined geographical region. In this region of interest, all properties are connected to a reticulated water supply network serviced by a single water service provider. Water demand in this regional network can be expressed as a rate of water use (Q). This rate of water use can be understood as the change in the volume (ΔV) of a water supply reservoir required to feed the network area with water over a time interval (Δt).

$$Q = \frac{\Delta V}{\Delta t}$$

in the limit of very small time steps

$$Q(t) = \frac{dV}{dt}$$

corresponding to the time derivative of volume.

From a water supply network perspective, residential water demand (Q_R) and non-residential water demand (Q_R)are specific market segments of the overall demand (Q_{total})for water in the network.

Parameter	Function
Used volume over period	$V_p(t_1, t_2) = \int_{t_1}^{t_2} Q(t)\, dt$
Network water use	$Q_{total}(t) = \sum_{s=1}^{N_S} Q_s(t)$
	$\rightarrow Q_{total}(t) = Q_R(t) + Q_N(t) + \sum_{s=3}^{N_S} Q_s(t)$

The actual number (N_S) of segments with demand (Q_s) in the network is a choice of the network operator. The reason for segmentation of the total demand is that water demand of a segment is expected to demonstrate typical behaviour. The character of both residential and non-residential water demand can be so heterogeneous that a breakdown in further segments is required to get groups of users with a similar type of demand.

Parameter	Function
Residential water use	$Q_R(t) = \sum_{i=1}^{N_R} Q_{r,i}(t)$
Non-residential water use	$Q_N(t) = \sum_{i=1}^{N_N} Q_{n,i}(t)$

This is reflected in the formula above, which allows for further segmentation of each of these demand groups.

Water use patterns of building-use categories

This study's objective is to establish deeper insight into the behaviour associated with non-residential demand (Q_N). Non-residential demand is a result of water utilisation in very heterogeneous group of non-residential properties. As part of the analysis, these non-residential properties are split into building-use categories. For these categories, we can use a formula for a water use segment that consists of a group of particular properties that use water as a function of time. Summation of the respective building water demands ($Q_b(t)$) of the individual properties results in that segment's particular water demand.

$$Q_{n,i}(t) = \sum_{j=1}^{N_{B,s}} Q_{b,ij}(t)$$

Non-residential water use is associated with a business-oriented environment. Where is non-residential water use different from residential water use? It is expected that water use in non-residential buildings is higher during working hours, because in that period, most people are present in the building and most systems will be operational. Mid-week periods will feature higher use than weekends. Holiday periods will result in lower water usage. Since the occupation of non-residential properties can be described as almost counter-cyclic to residential occupation, it will be very hard to translate end-use figures from residential properties to non-residential.

Water end use in properties

From a functional point of view, non-residential properties will feature many water end uses that are very similar to those in residential properties. Water is used in a mixture of different appliances with various end-use signatures such as toilets, basins, taps, showers, washing machines and dishwashers. Therefore, a building's water demand can be expressed as the sum of the water used by the individual appliances (Q_a) in the building.

$$\boldsymbol{Q_b(t)} = \sum_{k=1}^{N_{K,l}} \sum_{j=1}^{N_{J,kl}} \sum_{i=1}^{N_{I,jkl}} \boldsymbol{Q_{a,ijk}(t)}$$

$\boldsymbol{i}$	Appliance model count index
$\boldsymbol{N_{I,jkl}}$	Total number of appliances of appliance model type *j* in end-use category *k* in building *l*
$\boldsymbol{j}$	Appliance model type index
$\boldsymbol{N_{J,kl}}$	Total number of appliance model types in building *l* in end-use category *k*
$\boldsymbol{k}$	Appliance model end-use category index
$\boldsymbol{N_{K,l}}$	Total number of end-use categories in building *l*

Each specific appliance function $Q_{a,ijk}$ will demonstrate a unique distinct pattern on how it uses water as a function of time. Water end use is typically defined on the appliance level.

Water efficiency in properties

Each appliance serves a particular need of a particular end user at a particular time, resulting in a specific demand for water. Water demand management aims to reduce demand from the population of end users. Reduction can be reached by invoking a change in the behaviour of end users and/or by incentivising the use of more water-efficient appliances and/or fixing leaks.

APPENDIX D: STATISTICAL ANALYSIS METHODS

Statistical analysis has been utilised to explore the large assembled dataset of more than 5,700 non-residential BEES properties in the Auckland region. All data processing, graphical presentation and data analysis was performed using standard functionality and statistical functions of MS Excel and MS Access, supplemented with additional dedicated linear regression analysis methods.

Table 24: General and normal probability functions

Function name	Function	Mean	Standard deviation
Probability density function (PDF)	$\int_{-\infty}^{\infty} f(x)dx = 1$		
Cumulative distribution function (CDF)	$F(x) = \int_{-\infty}^{x} f(t)dt$		
Normal PDF	$f(x\|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$	μ	σ
Log-normal PDF	$f(x\|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln x-\mu}{\sigma}\right)^2}$	$e^{\mu+\sigma^2/2}$	$\sqrt{\left(e^{\sigma^2}-1\right)e^{2\mu+\sigma^2}}$

The distribution of water use is described in terms of a normal probability distribution function (Table 24). The cumulative distribution function is also given – a comprehensive associated form to describe the probability distribution of the data. Some data is described in cumulative distribution plots. Most data was log-normal distributed, so this function is also given. When data is log-normally distributed, it will be log transformed for analysis. For analysis of how water use relates to building size, we use linear regression to model the relationship. The fitting of data was performed by a 'least squares' estimation of the parameters using the Excel function LINEST. This provides parameters and error estimation and estimation of the goodness of fit. Table 25 provides an overview the statistical parameters used in the regression analysis.

Table 25: Statistical parameters

Parameter	Function	Estimator for normally distributed data
Sample mean	$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$	μ
Total sum of squares	$SS_{tot} = \sum_{i=1}^{N}(y_i - \bar{y})^2$	
Sample standard deviation	$s = \sqrt{\frac{SS_{tot}}{N-1}}$	σ
Residual sum of squares	$SS_{err} = \sum_{i=1}^{N}(y_i - \hat{y}_i)^2$	
Mean square error	$MS_E = \frac{SS_{err}}{N-n}$	σ^2
Regression sum of squares	$SS_{reg} = SS_{tot} - SS_{err}$	
Square of correlation coefficient	$R^2 = 1 - \frac{SS_{err}}{SS_{tot}}$	
F_0 – test statistic	$F_0 = \frac{SS_{reg}}{MS_E}$	
Variables	y_i = observed values $\bar{y}$ = mean of the observed values $\hat{y}_i$ = modelled values N = number of observations n = number of parameters in the model	

APPENDIX E: AUXILIARY INFORMATION

Aggregation structures of water end uses

Table 26: Aggregation, averaging and levels of details related to water use in properties

Aggregation levels	Hierarchy of categories	Examples
Groups of properties	Geographical and administrative entities	New Zealand, region, district suburb, supply network
	Building-use category	Residential, office, retail, warehouses
	Building size and form	Large, medium, small Single versus multi-storey
	Building construction categories	Timber frame, concrete-steel
Parts of properties	Water-use functions	Sanitation, cleaning, toileting, food, drinking, irrigation, washing, cooling, maintenance
	Water demand-driving spaces	Offices, showrooms, workshops
	Water-using spaces	Bathroom, toilet, kitchen, laundry (garden)
	Water-use appliances categories	Toilets, urinals, taps, showers, washing machines, dishwashers, irrigation

Water Efficiency Labelling Scheme (WELS)

Table 27: WELS performance ratings

Product	Water consumption	0 star	1 star	2 star	3 star	3 star (4 star)	3 star (5 star)	3 star (6 star)
Shower								
	L/min							
	Upper limit		16.0	12.0	9.0	7.5	6.0	4.5
	Lower limit	16.0	12.0	9.0	7.5	6.0	4.5	-
Urinal	Conscious demand		*	*	*			
	Smart demand		*	*	*	*	*	*
	Urine sensing							*
	L/flush							
(single)	Upper limit	-	2.5	2.5	2.0	1.5	1.0	1.0
	Lower limit	2.5						
(N=2+)	Upper limit	-	2.0*N	2.5*N	2.0*N	1.5*N	1.0*N	1.0*N
	Lower limit	2.0*N						
Lavatory								
	L/flush							
	Upper limit		5.5	4.5	4.0	3.5	3.0	2.5
	Lower limit		4.5	4.0	3.5	3.0	2.5	-
Tap								
	L/min							
	Upper limit		16.0	12.0	9.0	7.5	6.0	4.5
	Lower limit	16.0	12.0	9.0	7.5	6.0	4.5	-