Australian Building Code Board

Fixture Unit Rating Systems

Discussion Paper

July 2015

Executive Summary

The current methods for calculating pipe sizing of water supply and sanitary drainage pipework in buildings in Australia are primarily based on methods developed by Roy B Hunter in the USA in the mid 1940s. This fixture unit method is facilitated by assigning number values to fixtures and taps based on:-

- The relative demands on a plumbing system, by comparing their water flow demands, elapsed time of operation and an estimated time interval between successive operation; and
- The application of the probability theory and random usage for a large sample (large numbers of fixtures).

The above method remains valid to date, with the base fixture unit measurement in Australia is based on the discharge from a hand basin, where one fixture unit is equal to the discharge from one hand basin. AS/NZS 3500.1, which provides Deemed-to-Satisfy Solutions for the Plumbing Code of Australia (PCA), also states that all plumbing fixtures have a fixture unit rating which shows their hydraulic load when compared with a hand basin.

In 2014 the Australian Building Code Board (ABCB) commissioned GHD to conduct a literature search on the relevancy and suitability of the current fixture unit rating, given the fact that this method was developed more than 50 years ago. The literature search is to also identify any further research that may be necessary to address any deficiencies in the current method.

Literature search conducted during this study found that there has been significant research conducted around the world to improve methods of estimating water demands and minimising water consumption, primarily due to growing awareness of environmental sustainability and the need to conserve water and energy. This is soon responded to by designers and manufacturers of sanitary fixtures with new fixture and tapware designs, all featuring improved water supply efficiency.

To verify the findings of the literature search, GHD also consulted with a number of current and past representatives of the plumbing industry in Australia. The consultation process identified a number of issues raised by the plumbing industry, including the following.

- Presence of less water in drainage system has generated increased incidences of drainage blockages and foul smells.
- The Hunter method did not sufficiently take into considerations new pipe materials, gradients and stack design, which have significantly changed over the past 70 years.
- The current fixture unit rating, as stipulated in AS/NZS 3500, remains applicable only to domestic installations, with no modifications to commercial or large scale building installations.

The literature search also found that limited study has been conducted to date on:

- the impacts of having less water in the drainage system;
- the relevancy of the current fixture unit rating method in the current water conservation environment and human behaviour patterns of water usage; and
- the accuracy of Hunter's probability method when much more sophisticated computer modelling and simulations are now readily accessible.

In the general community, more public awareness of the implications of low water usage effects on plumbing systems has emerged as an important factor in plumbing system maintenance. In the regulatory field in Australia, limited attempts have been undertaken to:

- assess the consequences of having less water in the systems to the pipework and drainage systems;
- identify the optimum volume of water demand to support the operation of each fixture and effectively drain solid through the system; and
- review the existing method of calculating the size for both water supply and sanitary drainage pipes.

Opinions are divided, however, amongst the plumbing industry, on whether a review of the current fixture unit rating will address any of the dry drain problems, as there are other factors which also need to be taken into consideration when designing plumbing systems and pipework. This research also found that, while the basic principles of Hunter's method remains valid, the original data supporting the principle are now old and may be irrelevant.

Hence, this discussion paper by GHD recommends that further research should be undertaken on the relevancy and suitability of each of the various parameters determining the fixture unit rating and how these parameter should be followed in calculating pipe sizing and designing water efficient sanitary fixtures, so that collectively these may address current dry drain problems.

Table of contents

Table index

Figure index

Appendices

List of abbreviations

Acronyms	Description
ABCB	Australian Building Codes Board
ACT	Australian Capital Territory
ARMCANZ	Agricultural and Resources Management Council of Australia and New Zealand
AS/NZS	Australian Standards/New Zealand Standards
ASA	American Standards Association
AWWA	American Water Works Association
BCA	Building Code of Australia
BH13	Building House 13
BMS	Building Materials and Structures – publication of the US National Bureau of Standards
BOCA	Building Officials and Code Administrators
CAB	Conformity Assessment Body
CABO	Council of American Building Officials
CIBSE	Chartered Institute of Building Services Engineering
CIPHE	Chartered Institute of Plumbing and Heating Engineers
COAG	Council of Australian Governments
CPAA	Committee for Plumbing Product Authorizations
DFU	Drainage Fixture Unit
GPM	Gallon Per Minute
IAPMO	International Association of Plumbing and Mechanical Officials
IPC	International Plumbing Code
ISH	International Sanitary and Heating
JAS-ANZ	Joint Accreditation System of Australia and New Zealand
LUNA	Loading Unit Normalisation Assessment
MPA	Master Plumbers Association
MWS&DB	Metropolitan Water Sewerage and Drainage Board
NCPDP	National Certification of Plumbing and Drainage Products
NPRF	National Plumbing Regulators Forum
NSW	New South Wales
NT	Northern Territory
PCA	Plumbing Code of Australia
PSD	Probable Simultaneous Demand
Qld	Queensland
SA	South Australia
SPC	Standard Plumbing Code
UPC	Uniform Plumbing Code
WA	Western Australia
WC	Water Closet
WELS	Water Efficiency Labelling and Standards Scheme
WMCS	Watermark Certification Scheme

1. Introduction

The current prescribed and accepted methods for sizing of water supply and sanitary drainage pipework for plumbing systems in buildings in Australia are based on methods of estimation of water flows and probabilities of usage that originate in early 20th century. Pipe sizes were calculated based on a fixture unit (or loading unit) method, which is based in part on the allocation of ‘fixture units or ‘loading units’ that have been borne out of empirical research, plus the application of probability theory.

The fixture unit method is still recognised as an effective approach for assessing pipe sizes, facilitated by assigning number values to fixtures and taps based on:-

- The relative demands on a plumbing system (water supply or drainage) by comparing their water flow demands, elapsed time of operation and an estimated time interval between successive operation; and
- The application of the probability theory and random usage for a large sample (large numbers of fixtures).

The base fixture unit measurement is based on the discharge from a hand basin. One fixture unit is equal to the discharge from one hand basin. All plumbing fixtures have a fixture unit rating which shows their hydraulic load when compared with a hand basin.

However, the applicability of the underlying values allocated to fixture unit ratings for tapware and sanitary fixtures is now being questioned because the parameters are now quite old and no longer relevant for today’s modern plumbing systems. As various researches had found recently, this method did not always result in the current acceptable levels of effectiveness and water efficiency. Consequently, community expectations of economical installations that provide acceptable system performance are not necessarily being met because:-

- These days taps and fixtures generally require lower volume operational water flows; and
- Sanitary drains are now being flushed with the smaller volumes of water flow but are still expected to carry unchanged quantities of associated solid.

Terminology

During the research, inextricable links between fixture units for sanitary drainage, sanitary plumbing, and loading units for water supply were regularly encountered. Hence discussion of both is contained in this paper, if not only in derivation of the basic theory, but also because of the implications for pipe sizing and reflection of concerns raised in the industry.

For the purpose of general discussion in this paper, the definitions used in AS/NZS 3500 Part 0 Definitions will generally be followed wherever it does not contradict intended meaning, context or direct quotation:

- Loading units apply to loads on water supply systems.
- Fixture units apply to loads on sanitary drainage and sanitary plumbing systems.

The terms referred to within the quotation will be retained from the quoted author.

Loading Unit (L.U.)

A loading unit is a factor or number given to an appliance which relates the flow rate at its terminal fitting to the length of time in use and the frequency of use for a particular type and use of building (probable usage).[1] Calculations of loading units also take into account the function or use of the building; the probably maximum; the flow rate to the probable usage; and the design and minimum flow rates.

Fixture unit rating[2]

The sizing of sanitary drainage systems is based on a unit of measurement called the fixture unit. Each plumbing fixture has a unit rating which is calculated by considering the rate of discharge, the frequency of use and the time between each use of a plumbing fixture. The fixture unit rating represents the hydraulic load placed by that fixture on the sanitary drainage system.

Whatever the number value assigned to the theoretical plumbing load from the operation of a fixture in a plumbing system, it is still described as a fixture unit. Loading units, a term used by Hunter in BMS 65, is an alternative term and is used for example in AS/NZS 3500.1 - 2003 in water supply systems.

1.1 Purpose and Scope of the Discussion Paper

In mid 2014, the Australian Building Codes Board (the ABCB) invited GHD to:

- undertake the scoping stage of the research project related to the fixture unit ratings for sanitary drainage and plumbing design that are referenced in AS/NZS3500.2 - 2003; and
- identify the framework for future research should it be established that more research would be beneficial.

The paper is to focus on:

1. The origin, basis and value of the current fixture unit values used in hydraulic design in Australia, i.e. ‘a history’ in outline of what is currently done;
2. An indication of the basis and value of fixture unit ratings used overseas;
3. Similarities and differences of overseas ratings compared to the Australian context; and
4. An overview of the system design methodology, using the current fixture unit ratings, including calculation methods and design principles.

The purpose of this discussion paper is to provide information regarding current plumbing design principles utilising fixture unit ratings, systems used overseas, the history of the fixture unit and identifying areas where improvement could be made. It has been presented in this format to promote discussion within the plumbing industry in this area with a view to identify any areas of improvement and/or modernisation of approach.

[1] HAC_C05.qxd 7/24/08 9:35 Page 176
[2] Licensed to Plumb Website – accessed 3 March 2015

1.2 Research Methodology

Research of the literature was aimed at

- Collating the basic theory and history of usage of the fixture unit and loading unit concept that leads to the sizing of pipes; and
- Identifying issues established by Australian and overseas research.

To meet the above objectives, GHD undertook research of the literature with information gathering through:-

- published literature available both in private and public libraries;
- the GHD intranet knowledge portals and databases; and
- contact with industry professional consultants, tradesmen and suppliers of materials.

The following Australian codes are also relevant to this research:

- AS 3500.1 - 1990 National Plumbing and Drainage Code – Water supply.
- AS/NZS 3500.1 - 2003 Plumbing and drainage - Water services (including Amdts 1 & 2).
- AS 3500.2 - 1990 National Plumbing and Drainage Code - Sanitary plumbing and sanitary drainage.
- AS/NZS 3500.2 - 2003 Plumbing and drainage - Sanitary plumbing and drainage (including Amdts 1 – 3)
- AS 5200 - 2006 Technical specification for plumbing and drainage products - Procedures for certification of plumbing and drainage products.
- National Construction Code Volume Three: Plumbing Code of Australia.
- Plumbing regulations applicable to each separate State and Territory.
- National Construction Code Volumes One & Two: the Building Code of Australia.
- Work Health and Safety Acts as applicable to ACT, NSW, QLD, SA and NT,
- Relevant Occupational Health and Safety Acts in WA and Victoria

Appendix A contains the list of literature included in the research.

1.3 Scope and Limitations

The research undertaken for this paper is essentially a study related to fixture units, their derivation and their history of use in Australia and overseas. The research took place between November 2014 and April 2015 and was conducted by the following members of GHD project team:

- Roger Chance – Principal Hydraulic Engineer
- Don Boynton – Service Line Leader Hydraulic Services, Principal Hydraulic Engineer
- Aamod Koirala – Mechanical Services Engineer
- Adeeb Chowdhury - Undergraduate Mechanical Engineer
- Eunice Sarif – GHD Librarian
- Ami Sudjiman – Principal Asset and Facilities Management Consultant

The research is essentially based on historical published research papers and reference books on Building and Plumbing Codes and design standards, and does not include any empirical research or physical testing. The literature search was complemented by consultations with past and present representatives of the plumbing industry, who's opinions or recollection of past events have assisted in many areas throughout the development of this paper, although it is important to note that there were no formal interviews or minuted meetings held.

GHD relied on the following to support the findings of this paper:

- GHD's internal hydraulic consulting engineers team across Australia and overseas to provide support and input as a consequence of their industry experience.
- GHD corporate knowledge and experience in delivering design and documentation projects in Australia and overseas.
- GHD's long established working relationship across the building, construction and plumbing industry, including:
  - State Branches of the Master Plumbers Association; and
  - the Association of Hydraulic Services Consultants Australia.

Acknowledgement and thanks in particular is extended to the Master Plumbers Association of NSW for their kind permission to review the collection of plumbing publications in their archival library, including access to a copy of the Australian Modern Plumbing Code.

Disclaimer

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The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

1.4 The Stakeholders

The following are stakeholders and drivers for the discussion of this fixture unit rating:

- The public – as water consumers.
- Plumbers, designers and hydraulic professionals who calculate the size of the pipework to serve a building.
- Suppliers and installers of plumbing materials and fixtures.
- State and Territory Regulatory Authorities.
- The Australian Building Codes Board.
- Standards Australia.

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2. Historical background

2.1 Plumbing Research and United States Department of Commerce

2.1.1 Background

In the 1920s there was much activity centred on plumbing design reform, driven in part by the ever increasing construction of taller buildings in major cities In the United States of America (USA).

The key factor in building services engineering design that enabled the construction of high rise buildings was the invention of the elevator, followed by the successful development of ventilation and air conditioning systems. This is soon followed with the development of plumbing systems to supply water to the occupants as well to support the mechanical plant, for fire protection and for drainage of soil and waste from sanitary fixtures.

2.1.2 Plumbing Research and the United States Department of Commerce

Following the end of World War I, the Senate Committee on Reconstruction and Production in the USA saw the need for the simplification and standardization of construction in the building industry. The movement resulted in the appointment of a sub-committee on plumbing by Secretary Hoover, supported by the US Department of Commerce, who introduced the first Plumbing Code in the USA. The first Plumbing Code in the USA, known as the "Hoover Code" Building Housing 13 (BH13), was established in 1928 and later revised in 1932[3].

In 1928, the American Standards Association (ASA) established a Committee that lead to the development of the Plumbing Code A40, which was later published in 1944. This Plumbing Code A40 incorporated much of the research work undertaken by Roy B Hunter and his colleagues, Herbert N Eaton (Chief of the Hydraulics Laboratory), John L French and Robert S Wiley[4], entitled Report BMS 65 'Methods of Estimating Loads in Plumbing Systems', issued December 16, 1940[5].

The Abstract from the paper states:-

> *"This report describes a method of estimating the demand and sewage loads for which provision should be made in designing plumbing systems in order that the service may be satisfactory. The characteristics of flow through a plumbing system and of the operation of supply valves and plumbing fixtures are described, and their influence on the method of estimating the load to be expected is discussed. The relative load-producing values of different kinds of commonly used plumbing fixtures are analysed, and a table is developed giving relative load weights in terms of a load factor called the "fixture unit". An estimate curve developed by means of the probability function is given, and its use in conjunction with the table of fixture units is illustrated".*

Hunter was intent on establishing a simple and standardised approach based on scientific principles that would provide safe and hygienic plumbing systems at a low cost for all buildings, independent of the cost of the building itself.

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[3] The American Standard (ASA) 1957, National Plumbing Code Handbook
[4] ditto
[5] Hunter, RB Building Materials and Structures Reports – Methods of estimating loads in plumbing systems BMS65

As a consequence of the world leading research undertaken by Hunter and his colleagues, formalisation of plumbing regulations followed in the USA through the auspices of the International Association of Plumbing and Mechanical Officials (IAPMO). IAPMO issued its Uniform Plumbing Code in 1945. IAPMO and the Uniform Plumbing Code continue to the present day.

2.1.3 The fixture unit – Hunter's definition

Hunter recognised that the loads a plumbing system needs to deal with are not constant. Formulae and reasoning for constant flow in pipework was already well understood; the challenge was to incorporate the fact that unsteady flow (ie. water flows resulting from intermittent demand) is the norm. Steady flow can only be recognised as happening for only very short time periods.

In BMS 65, the definition of a fixture unit is:-

> *"Fixture unit, or load factor, is a numerical factor which measures on some arbitrary scale the load–producing effect of a single plumbing fixture of a given kind. The use of the fixture unit makes it possible to reduce the load producing characteristics to a common basis".*[6]

In BMS 65, Hunter and his colleagues recognised the relative quantities of water required for safe operation of sanitary fixtures and taps and that, in any given domestic type situation, it was reasonable to expect that all the sanitary fixtures would not operate simultaneously. Hunter's method of estimating load in plumbing systems is based on assigning a fixture unit weight (f/u) to the plumbing fixtures and then converting these to equivalent gallons per minute, based on the theory of probability of usage.

The method established the following criteria.

1. the volume of water used with the normal operation of any given type of fixture;
2. the usual amount of time that the fixture drew water from the water pipework system ;
3. an estimate of the time interval between consequent usage of the fixture; and
4. the subsequent load imposed on the drainage system.

The principles established with this work have been applied to the design of water supply systems and sanitary drainage systems in buildings ever since its first publication. The first two factors were established by methodical research and observation of sanitary fixtures in operation. The third and fourth factors were applied through the use of probability theory to result in a mathematically dimensionless number value.

[6] Hunter, BMS 65

Probability theory

Probability theory is based on the likelihood of situations occurring and outcomes may on occasions not be as predicted. The use of probability theory in assessing simultaneous demand is only fully applicable where large numbers of fixtures are involved, as the larger the sample, the more likely that probability theory will result in more accurate predictions.

Probability theory can be structured with a defined likelihood of variance and with its application to loading units; a 1% variance is the usual statistical qualification of actual occurrence versus prediction. That is, in 1% of times (1 in 100) the simultaneous demand will be exceeded.

The probability of a particular number of water draw offs occurring at any one time is determined by dividing the time it takes for an appliance to be filled by the time between successive usage of the appliances to arrive at the following probability factor.

$$P = \frac{t}{T}$$

Where:

P = probability factor
t = time for an appliance to fill (in seconds)
T = time between successive usages' of the appliances(s)

For example, the probability factor for a group of appliances, each taking 24 seconds to fill and used at 20 minute (1,200 second) intervals is:-

P = (24/1200)

= 0.02

All the above factors together determine the rate of water flow within a plumbing pipe[7]. The fixture unit rating represents the hydraulic load placed by that fixture on the sanitary drainage system. Similarly for the loading unit and the water supply system.

It is unlikely that all the plumbing appliances installed in the building will be in use at the same time, except in the case of particular types of buildings such as sport stadiums and large entertainment centres. Also, as the number of plumbing appliances increases, the probability of all being utilised at the same time decreases. It is therefore more economical to design the system for peak flow rates which are based on the probability theory, using 'loading units' instead of using possible maximum flow rates.[8]

Roy B Hunter reasoned with the concept that at any given moment in a plumbing system, the likelihood of all the fixtures being in operation at the same instant in time was very low and that as the sample size (larger number of fixtures) increased, the likelihood of simultaneous demand required of the system lessened. The method thus coupled the finite volume of water required for proper operation of a plumbing system with the statistically random human behaviour patterns that are experienced with each day of human occupation in a building.

[7]Institute of Plumbing, Plumbing Engineering services design guide
[8] Mike Phoenix, John Thompson: Plumbing NVQ and Technical Certificate Level 3 p. 451

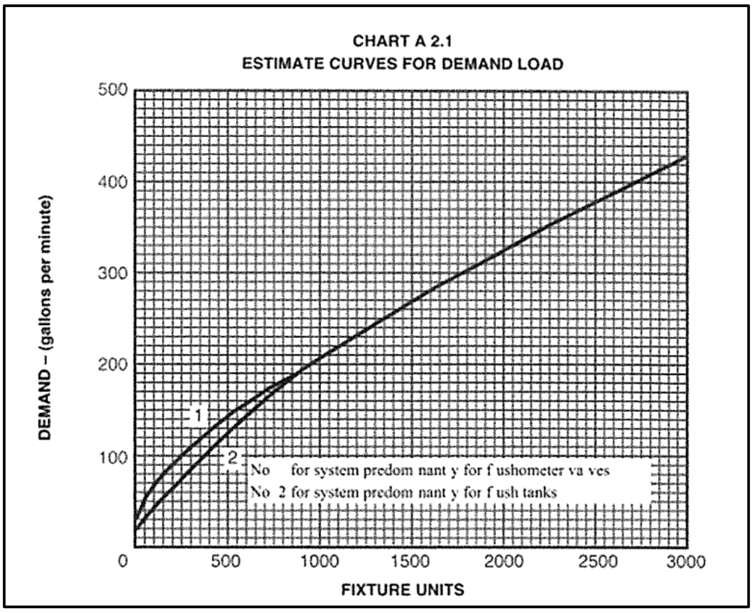

Figure 1 Estimate curve for design purposes [9]

Figure 1 shows the graphic representation of probability of flow as a function of fixture unit count also commonly referred to as 'Hunter's curve'. It shows two separate curves, curve 1 for flush valve and curve 2 for flush tanks. The curves show slight discrepancies from 0 to 1,000 fixture units. The flush tank curve has slightly larger flowrate values within the range. The reason for different flow rate values has to do with sudden instantaneous draw rate of the flush valve. The difference in demand for each system decreases as the fixture unit load increased until 1,000 fixture units are reached. At this loading and beyond, the demand for both types of systems is the same.

By reference to a probability graph like one shown in Figure 1, the predicted likely number of appliances operating simultaneously can be made. In a case like this, it is probable that out of 100 appliances being supplied only six would be in use at the one time. This simple example assumes that all appliances are the same in terms of their load on a plumbing system.

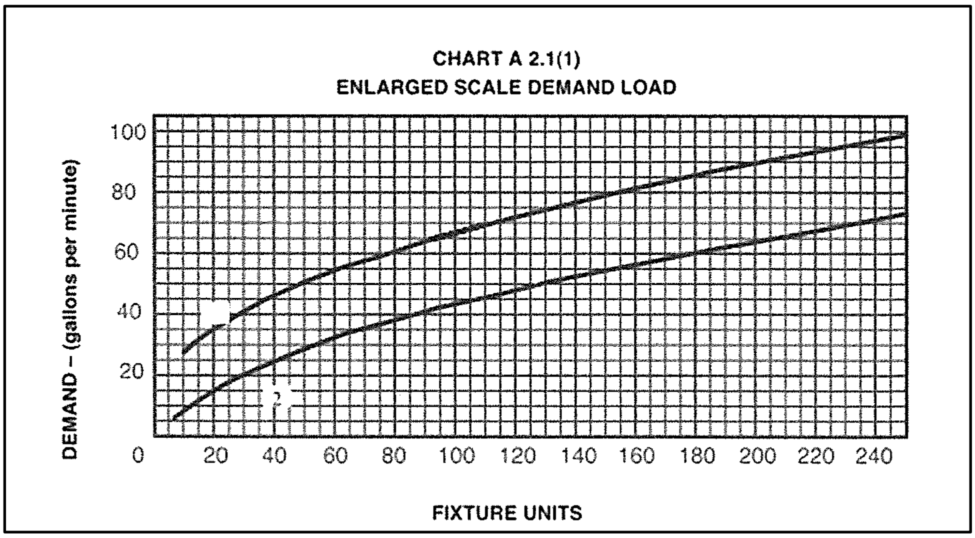

Figure 2 Enlarged scale demand load[10]

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[9] 2012 Uniform Plumbing Code – Appendix A p.264
[10] ditto

The enlarged view of Figure 1 above shows how the graph is applied when only a small number of appliances is involved.

Estimating water load in plumbing system

The following is a summary of a process to estimate water load in gallons per minute (gpm) in a plumbing system, as outlined by Bhatia's PDH online course[11].

$$Water\ load\ estimate\ = \frac{v}{p}\ x\ 60$$

Where:

v = average volume (gallons)

p = period of operation (seconds)

60 – seconds in a minute

Example 1

A flush valve operates over a 9 second period and releases 4 gallons of water on average.

Water load estimate = $\frac{v}{p}\ x\ 60$

Where:

v = 4 gallons

p = 9 seconds

$= \frac{4}{9}\ x\ 60$

= 26.6 gallons per minute

Example 2

For a flush tank (cistern), Hunter found it took approximately 1 minute to release 4 gallons of water.

Water load estimate = $\frac{v}{p}\ x\ 60$

Where:

v = 4 gallons

p = 60 seconds

$= \frac{4}{60}\ x\ 60$

= 4 gallons per minute

[11] A Bhatia PGH On line Course M126 Sizing Plumbing Water System

Table 1 Important Variables in Water Fixture Use during periods of congestion (Hunter, 1940)[12]

Type of fixture	Duration of time water is flowing (t) (seconds)	Duration of time fixture is occupied (T) (seconds)	Probability of busy fixture P=t/T	Flow rate (q) (gpm)	Total volume (gallons)
Flush Valve for WC	9	300	0.030	27	4
Flush Tank for WC	60	300	0.200	4	4
Bath tub	60 to 120	900	0.067 to 0.1333	8	8-16

The particular values shown in the above table reflect empirical observations and characteristics of the water fixtures in use in North America during the early 20th century.

Hunter also found an average time between successive usages (frequency of use) from records collected in hotels and apartment houses during the periods of heaviest usage. This was important to evaluate the number of fixtures that could be operated simultaneously as it is less likely that all the fixtures in the building will be operated simultaneously.

For example: consider a building with 20 flush valves and 20 flush tanks (cisterns). Hunter applied probability theory to determine how many of these 20 fixtures each will be operated at any given instant with the condition that this occurrence won't exceed more than one percent of the time. He calculated that the probability of more than 3 flush valves and 8 flush tanks operating simultaneously is less than 1%. For this example, the peak design flow that is predicted by applying probability theory and will not be exceeded more than one percent of the time, is the flow associated with 3 flush valves and 8 flush tanks (cisterns) operating simultaneously.

Peak design flow = p x q
where p = probability factor (probability of busy fixture)
f = flowrate
gpm = gallons per minute

Number of flush valves = 3

Flow per flush valve = 27 gpm

No. of flush tanks = 8

Flow per flush tank = 4 gpm

Pipe flow capacity must be = (3 x 27) + (8 x 4)

= 113 gpm

Thus 113 gpm is the design flow to use for sizing a pipe system supplying water to 20 flush valves and 20 flush tanks (cisterns).

[12] Buschberger SG, Blokker M & Vreeburg J 2009, Sizes for Self Cleaning Pipes in Municipal Water Supply Systems

Hunter also realized that the probability theory could be greatly simplified if a common fixture loading unit is applied to the plumbing fixtures. Hunter arbitrarily assigned a singular base fixture unit weight of 10 to the flush valve and other fixture types were then given a fixture unit weight in terms of their comparative flow rate and time usage factor in relation to the base fixture (flush valve).

He obtained a weight of 5 for flush tank and 4 for bath tub, which corresponds to demand ratio of 1:2:2.5 between the three common fixture types (flush valves, flush tanks and bathtubs, respectively). All fixtures are thus converted to one fixture type ie each unit of flush valve corresponding to 10 fixture units, each unit of flush tanks have 5 fixture units and each unit of bathtub has 4 fixture units.

The Demand Weights Table

Table 2 lists the demand weights in fixture units as determined by the National Bureau of Standards. This Table is used in conjunction with either Figure 1 or Table 3 in determining the expected normal peak flow for any number or combination of fixtures.

Table 2 Copy of Hunter's Original Table 7 of BMS 65[13]

Fixture or group	Occupancy	Type of Supply	Weight per fixture or group in fixture units
Water Closet	Public	Flush Valve	10
Do[14]	Do	Flush Tank	5
Pedestal urinal	Do	Flush Valve	10
Stall or wall urinal	Do	Do	5
Do	Do	Flush Tank	3
Lavatory	Do	Total	2
Do	Do	Hot or cold	1.5
Bathtubs	Do	Total	4
Do	Do	Hot or Cold	3
Shower Head	Do	Total	4
Do	Do	Hot or Cold	3
Bathroom group	Private	Flush Valve (total)	8
Do	Do	Flush Valve (cold only)	6
Do	Do	Flush Tank (total)	6
Do	Do	Flush Tank (cold only)	4
Do	Do	Hot Water Only	3
Bathroom group with separate shower	Do	Add to corresponding group above for total 2; for cold or hot	1.5

From the above Table, the designer can assign fixture unit weights to the specific fixtures involved in a particular system design. When these are added their total gives a basis for determining the maximum probable flow that may be expected in a water pipe.

[13] Hunter BMS 65 Table 7
[14] Abbreviation for 'Ditto' or 'As above'

Converting fixture Unit Loads to Equivalent Gallons Per Minute (gpm) demand

The conversion of fixture unit loads to equivalent gallons per minute (gpm) demand is partly shown in Table 3 below.

Table 3 Conversion of Fixture Units to Equivalent gpm[15]

Demand (load) fixture units	Demand (load) gpm system with flush tanks	Demand (load) gpm system with flush valves
1	0	-
2	1	-
3	3	-
4	4	-
5	6	-
10	8	27
20	14	35
30	20	41
40	25	47
50	29	52
60	32	55
etc		

Note that the relationship between gallons per minute (gpm) and fixture unit is not constant, but varies with the number of fixture units. As the number of fixture unit is increasing, the flowrate is not increasing linearly. This reflects the proper application of the theory of probability.

2.1.4 The Fixture Unit and Regulations

The concept of assigning fixture unit values to plumbing fixtures as a function of their contributing load on a plumbing system basically became universally accepted. It became fundamental to the theoretical estimation of loads on a plumbing system and is the core value behind a proven principle for efficient and economical pipe sizing of plumbing systems by mathematical calculation.

While Hunter's work centred primarily around residential buildings, the methodology has been successfully applied for other types of buildings, taking into consideration:

- the physical water flow factors required of fixtures and pipes, and
- the unpredictability of when, at any given instant, which fixtures are being used (ie. when the loads are imposed on a plumbing system) being factored into a mathematical calculation.

The method led to standardisation in design approach which assisted the administration tasks required of plumbing regulators. Furthermore, better understanding of water flows and volumes experienced in a plumbing system leads to a more refined design technique which in turn leads to more accurate pipe sizing in both water supply and drainage pipes.

[15] Bhatia, – PDH Centre M126

2.2 Plumbing Standards in the United States of America

The United States is a union of smaller administrative jurisdictions (States and Counties), with each having authority to regulate plumbing through its own administrative procedures related to the standards they adopt. As a result of progressive human encroachment over the large land mass that makes up the United States of America, lack of central government control and less developed means of communication than we experience today meant that many aspects of day to day community health and amenity were developed at a local level.

The drive to pursue the path of a more standardised approach came from government initiatives that were instigated for the economic, health and social value of advancing and standardizing the technical and administrative aspects of plumbing[16]. As mentioned earlier, the technical research behind this drive was facilitated by the Department of Commerce in the 1920s, while the impetus to continue this came from the resource allocations required for the United States involvement in World War Two.

Since the publication of BMS 65 in 1940, there have been some changes to the fixture unit values, which were the results of additional work using Hunter's methods. However, the values assigned to the majority of the fixtures have remained largely unchanged.

Some of the changes are influenced by:

- the introduction of 'new' fixtures in the market, including low consumption water closets;
- the introduction of 3-inch Limitation for Water Closets; and
- changes in trap size.

To accommodate the above changes, various plumbing codes have been progressively modified over the years by adding extensive listings of numerous fixtures. The International Plumbing Code (IPC) maintains the original philosophy by listing the major category of fixtures. The IPC uses the term Drainage Fixture Unit (DFU), which is what is referred to as a fixture unit in Australia. For example, a commercial kitchen sink would have a fixture unit value of 2 DFU's based on the classification of a sink, where the Uniform Plumbing Code uses a DFU to determine the required drainage capacity from the fixtures and their service systems[17]. Similarly, a mop sink in a janitor's closet would also have a fixture unit value of 2 DFU's under the same classification.[18]

Over time however, diversity in approach to local design has meant a common design standard is not universally adopted by all State and County administrations.

[16] The American Standard (ASA) 1957,
[17] The Engineering Toolbox website
[18] The International Plumbing Code: A Guide for Use and Adoption June 1998

2.2.1 The AWWA and the Fixture Value Unit[19]

In 1975 the American Water Works Association (AWWA) introduced the 'Fixture Value Method' for sizing water service lines for non-residential demands, as described in their M22 Manual titled "Sizing Water Service Lines and Water Meters". This method is an empirically derived approach that relies on actual measured data obtained from water meter data loggers, using both the independent variable (fixture value) and the dependent variable (average peak flow rate), for specific building categories.

Using the mechanical data loggers, the AWWA was able to compile peak flow measurements for different customer classes including the small scale buildings, hotels, hospitals, commercial, and public buildings. Peak demand graphs were created by plotting the measured average peak flow rates per customer class versus the cumulated fixture value. The resulting pair of graphs represent 'Probable customer peak water demands vs fixture values'. These curves depict 'low range' (under 1,300 combined fixture values) and 'high range' (up to 13,000 combined fixture values) conditions. Various classes are shown on different curves and allow the fixture value method to account for the diverse water usages characteristic of different customer types.

The M22 Manual also states that these values 'represent the peak flow in gallons per minute of each fixture or appliance when it is operated without the interference of other fixtures at 60 psi'. This approach yields fixture values that are specific to each fixture type and are represented in gallons per minute. For example, the M22 Manual suggests a fixture value of 35 gpm and 4 gpm for water closets with flush valves and flush tanks, respectively. Designers can also modify fixture values based on personal preference. The application of fixture values to peak demand loading is quite different than Hunter's technique.

Procedure for Estimating Non-Residential Demands Using M22 Manual

The M22 Manual lists the following procedure for estimating customer demand:

1. Required system characteristics:
   - pressure at the water meter outlet;
   - type of customer (ie customer class); and
   - number and type of fixtures.
2. Determine combined fixture value:
   - total the number of similar fixtures and multiply by their respective fixture value; and
   - sum all fixture values for each type of fixture in the system.
3. Determine 'Probable customer peak water demand' using the applicable low range or high range graph at the water meter outlet.
4. If the design pressure at the meter is above, or below, the 60 psi design value, a pressure correction factor must be used. Simply multiply the peak water demand by the pressure factor.
5. Add any continuous demands to the domestic loading to find the total customer peak demand. Special considerations, such as outdoor watering needs, process cooling or fire protection requirements, should also be taken into account.

[19] Bhatia A, (2012) PDH Course M126.

How the AWWA's Fixture Value Method Differs from Hunter's Fixture Unit Method

There are four major differences between the two methods as follows:

Table 4 Comparisons Between Hunter's and AWWA's Methods

	Hunter's Method	AWWA's Method
1	Takes into consideration the random usage of plumbing fixtures. It is an integration of empirically derived fixture use data with a theoretical probability model, ie the binomial distribution	Incorporates empirical data obtained at the water meter. It is purely an empirical approach based on water meter data points representing average peak flows.
2	Does not directly provide values for different customer class types, rather, indirectly present a classification scheme	Presents different graphs for varying customer types and includes diverse range of building classes
3	Does not include any pressure adjustment option, as the fixture unit values were derived for constant fixture supply rates.	Includes a provision for adjusting demand based on varying pressure (at the water meter).
4	Provide flow rates for smallest branches and display flowrate values for fixture unit count as small as one.	Developed primarily to size service water lines only.

2.2.2 The Standards and the Fixture Unit Rating Method

A summary of the Plumbing Codes used in the USA is quoted in PDH Online PDH Centre Course for Sizing Plumbing Water Systems, as follows.

1. Uniform Plumbing Code (UPC) adopted mainly in the western USA -
   contains information that considers the earthquake prone western US region. It was developed and introduced through the American Standards Association in 1955 – a culmination of work that was begun by the Department of Commerce in the 1920's.
2. Standard Plumbing Code (SPC) adopted mainly in the southern USA.
3. Building Officials and Code Administrators (BOCA) Plumbing Code adopted mainly in the eastern USA.
4. International Plumbing Code (IPC) -
   a relatively new code originating in 1995 as a joint effort of the three major model code groups (UPC, SPC and BOCA).
5. Council of American Building Officials (CABO) Plumbing Code exclusively for residential construction -
   also derived from these three major codes, is designed exclusively for plumbing of one and two family residential dwellings.

The IPC was developed in the mid 1990's and claims to be adopted State wide or at a local level in thirty five (35) of the states in the USA, plus Puerto Rico.

2.2.3 Other Alternative Design Methods to the Fixture Unit Rating Method

In the last few years there has been a great deal of discussion about how to improve the methodology for estimating peak demands in new buildings. The IPC has allowed the drainage system to be designed by computerised method, which is more accurate than the method originally developed by Hunter. However, some have advocated a return to a modified version of the Hunter curve, while others have advocated continuing research on an empirical approach.

Changes to fixture unit chart(s) are anticipated from data for newer water closets, showers, dishwashers, washing machines, faucets and urinals. Applications of alternate probabilistic techniques have been applied/derived by researchers e.g., Monte Carlo method adopted in recent researches conducted in Brazil[20].

This matter is still open for discussion, and the current revision of M22 seeks to add what new information is available and provide more flexibility for engineers to use current technology to estimate demands. It is anticipated that future M22 revisions will include new research to enhance the empirical demand projections because advances in technology have greatly simplified the acquisition of flow trace data from water meters.

2.3 Development of Method of Estimating Water Demands and Plumbing Standards Globally

Countries around the world typically introduce building and plumbing regulations to their respective building and plumbing industries, taking into consideration the specific requirements of their building industry, community needs, internal governing structure, climate and culture. Government authorities from larger countries usually have sufficient resources and knowledge to conduct extensive research themselves prior to developing and introducing these codes and regulations. Others may elect to simply adopt existing rules and regulations from other authorities, with some modifications to better suit their internal governance structure and community needs.

Within all building regulations there is reference to the design criteria established for plumbing systems. In some instances, like the fundamental aspects of pipe sizing, there are some more universal approaches to basic procedures. Hunter's concept of assessing sanitary fixture loads remains to be the core aspects of plumbing design and has been principally incorporated in plumbing regulations internationally.

Although Hunter's method has also been adopted in many countries all over the world, the actual numerical values assigned to fixtures have been modified since the culmination of Hunter's original research work on this aspect of plumbing was published in 1940. Over time, modifications were introduced in the USA and in other countries who adopted the fixture unit approach.

Such modification includes the 'shift' from using the WC as the unit measurement to using the wash basin. This shift is assumed to have occurred sometime in the mid 1960s, although no reason has been found for why or any particular ramifications of the change. It was noted during literature search that, around the early 1960s, back to back toilets and multi tank flushers were introduced into commercial high rise buildings around the USA. It is likely that the shift was initiated by this introduction of back to back toilets and multi tank flushers. .

The following is a summary on how some different countries have introduced their own plumbing regulations or adopted fixture unit theory plumbing regulations from other jurisdictions to form part of their building regulations, and how some of these plumbing regulations have evolved over the years.

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[20] L.H Oliveira, L.Y Cheng, O.M Goncalves, P.M.C Massolino – Simulation model of design flow rate in water submetering systems using fuzzy logic and Monte Carlo method

2.3.1 Plumbing Standards in Great Britain

The Standards and the Fixture Unit Rating Method

Although no historical records have been established to support this, review of past and current plumbing standards in Great Britain provided indications that Hunter's fixture unit theory was accepted in Great Britain as a valid means of sizing pipework. In turn, most British colonies and associated countries, like Hong Kong, South Africa and Australia, have also adopted British customs and administrative standards in their own Codes and adapted as necessary to the local conditions.

A number of British Standards have been developed under the umbrella concept of public health and sanitation, as part of the establishment of a regulated and well-founded plumbing industry. Around 1966, following trends in the USA, the fixture unit value in Great Britain was shifted from Water Closet to hand (wash) basin. As is the case in the USA, it is likely that the shift is due to the introduction of back to back toilets and multi tank flushers into commercial high rise buildings, offering a much wider range of WC cisterns and drainage basins.

While there are overarching Building Regulations across Great Britain, including the recent establishment of a "Master Framework" of Regions of Councils across Great Britain, there is considerable reliance on the Plumbing Engineering Services Design Guide such as those prepared and published by The Institute of Plumbing (UK) rather than on official published standards. This Guide acknowledges changes in standards and revised editions and reflects these over many years. For example, the Preface to the 2002 Edition of the Plumbing Engineering Services Design Guide clearly states;

> *"The water services section has been greatly expanded to include many additional design considerations and to take account of the statutory requirements of the Water Supply (Water Fittings) Regulations 1999 in England and Wales and the Water Bylaws 200 in Scotland."* [21]

Likewise, in the Forward to the CIBSE (Chartered Institution of Building Services Engineers) CIBSE Guide G, Public Health and Plumbing Engineering in its third and latest (2014) edition, state:

> *"Since the second edition of CIBSE Guide G was published, various amendments to the Building Regulations, British Standards and the introduction of new codes have heavily influenced the content of this new edition. In particular, the emphasis of water conservation and sustainability has had an impact on many chapters, as well as resulted in the Guide being reformatted. The British Standard relating to both building and site drainage and water services has been updated and superseded by a BN EN and this again has affected many chapters."*[22]

[21] Institute of Plumbing
[22][22] CIBSE 2014, Public Health and Plumbing Engineering CIBSE Guide G

Refined Design Methods of Fixture Unit Values

Based on a generalised frequency of usage, the Institute of Plumbing and CIBSE Guide G in Great Britain introduced three basic categories of building that are identified by their differing water demands, namely: Low, Medium or High. The basic principles of this method can be summarised as follows.

- Low use
  deemed to have 1200 seconds between each use
  is considered appropriate for dwellings and in other buildings where appliances are dedicated for use by a single person, a small group of people, as a private facility.
- Medium use
  deemed to have 600 seconds between each use,
  being appliances that are available to be used by a larger group of people, as and when they require on a random basis, typically associated with 'public use' toilets.
- High use
  deemed to have 300 seconds between each use for appliances
  to be used by large numbers of persons over a short period as would be the case within buildings such as theatres, concert halls and fixed period sporting events. [23]

A comparison between fixture unit values assigned in the 2002 Edition of the Plumbing Engineering Services Guide (Institute of Plumbing UK) and the 2012 Edition of the CIBSE Guide G Plumbing and Public Health Engineering reveals that there is little difference between the two eg:

- Frequency of Use criteria are identical (The Institute of Plumbing Guide provides more explanation); the other differences are that a basin with 2 x 8mm mixer taps in the CIBSE Guide G has 4 loading units (only 3 for Institute of Plumbing Guide).
- A sink with a 20mm mixer tap has a loading unit value of 11 in the (newer) CIBSE Guide G compared with 7 in the Institute of Plumbing Guide.

The Plumbing Engineering Services Design Guide demonstrates pipe sizing by worked example by consideration of a pipe layout for a building and applies friction loss allowances and suggests water velocities be the prime consideration.

The CIBSE Guide G pipe sizing description continues with consideration of pipe size selection by factors related to the pipe system being designed. Such factors as water velocity, noise generation, laminar and turbulent flow (Reynolds number consideration) are discussed as factors to consider when selecting pipe sizes[24] . Maximum water velocities are stated for two pipe material types, for different areas installed in a building, (e.g. in bedroom, in a service duct) plus a nominated noise rating. There is no worked example.

[23] Institute of Plumbing - Pp13,14
[24] CIBSE Guide G p2-38 to 2-41

2.3.2 The Application of the Fixture Unit Rating Method in Other Parts of the World

While globally there are differences in its application, there is strong similarity with the definition and allocation of fixture unit values (sanitary drainage and sanitary plumbing). For loading units (water supply) there is also strong similarity with flow rates, although there are a number of countries that do not use the loading unit approach.

Some countries such as Australia/ New Zealand and the USA (as embodied in the Uniform Plumbing Code) have adopted the fixture unit method to both water supply and drainage systems. Other countries such as South Africa and Great Britain adopt the fixture unit method for sanitary drainage only and adopt a minimum rated flow and pressure requirement for given tap outlets.

In some cases, the use of different methods globally is driven by the different sizes and capacities of WC pans.

Table 5 Comparative Table of fixture unit rating methods adopted globally

	USA	Great Britain	Europe	South Africa	Australia
Initially	Fixture unit rating	Fixture unit rating	Fixture unit rating	Fixture unit rating	Fixture unit rating
1960s	Shifted unit value standard from using WC to wash basin	Shifted unit value standard from using WC to wash basin			Shifted unit value standard from using WC to wash basin
1975	AWWA fixture value unit	The use of three levels of water demands	Review use of fixture unit		
Recent years				Fuzzy logic provides opportunity to consider different parameters for different fixtures, and different users, frequency etc	

Table 6 Various Definitions of Fixture Units Globally[25]

Document and country of adoption	Use of fixture units	Definition supplied	Water supply specifications given	Drainage specifications given
AS/NZS 3500 Parts 1 & 2 (adopted in Australia through the Plumbing Code of Australia)	The PCA uses fixture units. AS/NZS 3500 utilises fixture unit rating for sizing drains, stacks and graded discharge pipes.	A unit of measure, based on the rate of discharge, time of operation and frequency of use of a fixture, that expresses the hydraulic load imposed by that fixture on the sanitary plumbing installation. See water supply and drainage specifications.	Loading unit – A weighted factor, applied to a fixture or appliance used for the estimation of simultaneous water usage rates which takes into account the flow rate, length of time in use and frequency of use.	A unit of measure, based on the rate of discharge, time of operation and frequency of use of a fixture that expresses the hydraulic load imposed by that fixture on the sanitary plumbing installation.
UPC (Adopted in parts of the USA, India, Vietnam, Indonesia, Kuwait, Jordan, Abu Dhabi)	The UPC utilises fixture units in the standards' specifications.	A quantity in terms of which the load-producing effects on the plumbing system of different kinds of plumbing fixtures are expressed on some arbitrarily chosen scale.	The quantity of water required to be supplied to every plumbing fixture shall be represented by fixture units as shown in Table 610.3.	Drainage fixture units for intermittent flow into the drainage system shall be computed on the rated discharge capacity in gallons per minute (gpm) (L/s) in accordance with Table 702.2(b). For a continuous flow into a drainage system, such as from a pump, sump ejector, air conditioning equipment, or similar device, 2 fixture units shall be equal to each gallon per minute (gpm) (0.06 L/s) of flow.
IPC (Adopted in certain US States)	The IPC uses fixture units in its specifications regarding drainage systems. For water supply however, they favour a maximum flow rate approach. Despite this, they provide a non-mandatory methodology of water supply pipe sizing using water supply fixture units which is	A definition is only supplied for Drainage Fixture Units: A dfu is a measure of the probable discharge into the drainage system by various types of plumbing fixtures. The drainage fixture-unit value for a	The water distribution system shall be designed, and pipe sizes shall be selected such that under conditions of peak demand, the capacities at the fixture supply pipe outlets shall not be less that shown in Table 604.3[	Drainage fixture unit values as given in Table 709.1 designate the relative load weight of different kinds of fixtures that shall be employed in estimating the total load carried by a soil or waste pipe, and shall be used in connection with Tables 710.1(1)[and 710.1(2) of sizes for soil, waste and vent pipes for which the permissible load is given in terms of fixture units.

[25] Buchberger S, Blokker M and Cole DP, Estimating Peak Water Demands in Hydraulic Systems – I - Current Practice

Document and country of adoption	Use of fixture units	Definition supplied	Water supply specifications given	Drainage specifications given
	to subsequently converted into flow rates.	particular fixture depends on its volume rate of drainage discharge, on the time duration of a single drainage operation and on the average time between successive operations.	The methodology of water supply pipe sizing using water supply fixture units can be found in Appendix E.	Drainage fixture unit values for continuous and semicontinuous flow into a drainage system shall be computed on the basis that 1 gpm (0.06 L/s) of flow is equivalent to two fixture units.
BS 8558:2011, BS EN 806-3 (adopted in the UK, EN 806-3 has many equivalents in Europe)	The British standards for water supply favour the use of flow rates over the use of fixture units (which they term loading units).	Loading units are factors which take into account the flow rate at the appliance, the length of time in use and the frequency of use.	1 loading unit (LU) is equivalent to a draw-off flow rate QA of 0.1 L/s.[	N/A
SANS 10252-1 (Water Supply) and SANS 10252-2 (Drainage) [Adopted in South Africa]	For water supply, the South Africans favour the use of flow rates for water demand, with little reference to fixture/loading units. For drainage however, fixture units are the preferred method for drain sizing.	From SANS 10252-2 An arbitrary unit of measurement for expressing the hydraulic loading on a drainage installation	Specific equations are provided for the different uses of water. Additional tables and guidance are provided.	As per Section 6.3 Discharge pipes and drains, recommendations for Hydraulic Loads, the Sizing of Drains and the sizing of discharge pipes are provided centred around the use of drainage fixture units.

The Plumbing Codes and Standards regulating the above methods also differ only slightly between countries.

Table 7 Comparative Table of the Various Plumbing Standards Adopted Globally

United States Of America	Great Britain	Hong Kong	South Africa	Australia	New Zealand
5 different Codes adopted across the nation – UPC last updated in 1997, SPC last updated in 1997, BOCA, IPC and CABO last updated in 1995	2006 BSEN 806-3 2006 BS 6700 2011 BS 8558 96137249 BS 806-3-2006 Water for Human Consumption BSEN 12506 Gravity drainage systems inside buildings – Part 2: Sanitary pipework, layout and calculation, London BSI 2000	Laws of Hong Kong, chapter 1231 Building (Standards of sanitary fitments, plumbing, drainage works and latrines) regulations 1997	SAN 10252-1 (2012) SAN 10252-2 (1993)	Plumbing Code of Australia adopted nationally, incl AS/NZS 3500 Parts 1 and 2	AS/NZS 3500 Parts 1 and 2

2.3.3 Alternative Design Methods to Fixture Unit Ratings

The flow rate of water used for individual fixtures and tapware is easily measured although it continues to evolve in line with changes in technology, regulatory requirements and consumer demand. These changes for water sizing have been reasonably easy to respond to because the loading unit pipe sizing method can be circumvented and direct water flows and velocities used as design criteria.

However, until very recent times, there was no alternative for basic design criteria for fixture units used to design the size of sanitary drainage.

Fuzzy Logic and the Monte Carlo Method

Besides the traditional random usage assumption or probability theory that is the basis of the statistical side of the fixture and loading unit equation, a 'Fuzzy logic' approach has recently also been explored and reported by researchers in Brazil [26].

Fuzzy logic is an inference mechanism based on fuzzy rules, given actual propositions[27], so that one can conceptualize fuzzy logic as a tool to convert subjective information to a numeric value. It is a form of many valued logic that roughly deals with approximate, rather than fixed and exact reasoning. Compared to traditional binary logic, where variables may take on true or false values, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

As the concept of degree of membership in fuzzy logic is usually confused with the concept of probability, it is relevant to explain the difference between the two concepts. Probability is the chance that an element belongs to a group, while possibility (fuzzy logic) expresses the degree of membership of the element in the set.

The following is an extract from the paper prepared by Oliveira LH, Cheng LY, Goncales OM, Massolino PMC.

> *For instance, suppose a father claims that the chance of his daughter taking a shower in the morning is 0.8. Thus, the probability that the daughter will take a shower in the following morning is 0.8, but it does not tell the quality or the duration of the shower. However, by using the different shower times on a scale (1.0 = very long shower, 0.8= long shower, 0.5= normal shower, 0.3= fast shower, and 0= no shower), the father could say that his daughter's shower would be long.*
>
> *It should be observed that probability does not contribute to inform if the design flow rate is high or low, but to establish the likelihood that a certain flow rate is occurring in an event. The measurement of the shower flow rate, for example, is a fuzzy measure that ranges from minimum flow to maximum flow.*
>
> *……*
>
> *Thus, it may be stated that probability theory uses random variables that are dependent on the occurrence of future and uncertain events, while fuzzy mathematics uses fuzzy but certain variables about the occurrence of events.*

As shown in the above example, fuzzy logic provides the opportunity to factor-in human behaviour response patterns into computer models that relate to particular circumstance such as different usage patterns of the same fixture according to the likely gender and age of different users at different times of the day, different days of the week, at different times of the year (summer or winter/ hot and cold days), and the type of building in which the fixture is installed.

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[26] Oliveira LH, Cheng LY, Goncales OM, Massolino PMC, Modelling of Water Demand in building supply systems using fuzzy logic

[27] Yen J, Langarica R and Zadeh LA – Industrial Applications of fuzzy logic and intelligent systems

The Monte Carlo method is widely used in models to determine water demand in building systems, including the following.

- Murakawa[28] have developed models to simulate hot and cold water demand for different types of buildings in the Czech Republic, using Monte Carlo method. This work examines multifunctional buildings, and accordingly it uses the models designed for other typologies.
- Mui and Wong[29] developed a model to contribute to the planning of water supply in cities with a population density similar to that of Hong Kong. Their model uses hourly frequency distributions of toilet discharges, the number of users in relation to the total in the buildings and the variation in the use of water closets in order to estimate hourly and daily water demand for water closet discharge by using the Monte Carlo method.

Oliveira LH, Cheng LY, Goncales OM, Massolino PMC utilised the Monte Carlo method in combination with the fuzzy logic in the research to take into account random events of the use of sanitary appliances such as wash basin, water closet, sink, laundry sink and washing machine. Different from the shower, the use of these sanitary appliances does not show clear relation with some intervening variables.

The research presented a simulation model for the determination of design flow rate in the water sub-metering system of multi-family building. This model considers Monte Carlo simulation for random variables and fuzzy logic to assess the duration of the shower in a residential apartment, due to it better representing the behaviour of the users. The main conclusions are:

- The simulation results show that most of the time when water flows in the supply branch, the flow rate values are below 0.17 L/s, which indicates overestimation of the flow rates that have been used for designing water meter systems similar to that simulated in this study; and
- The results of the simulation model were about 30% lower than those obtained by the Brazilian standard and similar to those obtained by the probabilistic model, but with the advantage that it shows the behaviour of flow rates in the peak period and not only the maximum value in a given section.

By employing fuzzy logic and the Monte Carlo method, their research found that the model developed can be applied to simulate design flow rates in water sub-metering systems of multi-family buildings. A wider field database, however, is required for the consolidation and expansion of the application to other types of buildings.

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[28] Murakawa S, Koshikawa Y, Takata H, Tanaka A, Calculation for the cold and hot water demands in the guest rooms of city hotel, International Symposium CIB W062, 33rd, p.73-85,

[29] Wong LT, Mui KW – Determination of domestic flushing water consumption in Hong Kong, Facilities, v23, n1/2, p.82-92,

2.4 The Most Relevant Research Happening Overseas Now

The International Council for Research and Innovation in Building and Construction (CIB) Commission for Water Supply and Drainage (W62) is the leading global think tank for water supply issues in buildings. Since 1972 CIB has hosted a symposium series that provides an international forum for refining Hunter's method and for introducing new approaches to estimate peak water demands on plumbing systems. Papers at the CIB Symposium consistently reaffirm the solid theoretical basis of Hunter's binomial method. In addition, they provide a wide variety of examples where Hunter's method has been applied successfully in many counties, though the loading factors and fixture flows must be adjusted to fit local conditions.

The following Table summarises some developments presented at recent CIB Symposiums.

Table 8 Recent International Developments for Determining Design Plumbing Loads on Buildings[30]

Country	Institutions	Probability model
Netherlands	KWR Watercycle Research Institute Technical Assoc for Building Installations	SIMDEUM
Brazil	Escola Politechnica of University of Sao Paulo	Fuzzy Logic, Monte Carlo Simulations
Japan	Hiroshima University	Monte Carlo Simulations
Japan	Tokyo Metropolitan University	Regression of Flow on Population
China	Hong Kong Polytechnic University	Monte Carlo Simulation

As shown in the above Table, there is currently significant interest and research being undertaken in many countries as the issues of water conservation and system efficiencies are driving the need to look at some basic design assumptions like loading and fixture unit ratings, as used for water supply and drainage systems. Reports on recent research have also been found to be have been undertaken in Brazil, India [31], and in Asia[32].and reported in the Journal of Building Services Engineering research and Technology[33].

Loading Unit Normalisation Assessment (LUNA) [34]

The most current research underway that is most relevant to this research study is found in Great Britain, titled LUNA (Loading Unit Normalisation Assessment). The aim of the study is to produce an updated and robust method of assessing the water design flow rates within buildings and their curtilages that will be adopted as a national design standard for the UK. The study will initially focus on multiple residential buildings (including large apartment blocks) and student halls of residence. Once this research phase is complete, the intention is to agree on a plan to extend subsequent research phase/s to other types of building occupancies, such as offices, hotels, public places of assembly etc. The project is currently being administered by CIPHE (Chartered Institute of Plumbing and Heating Engineering) and CIBSE (Chartered Institute of Building Services Engineers).

[30] Buchberger S, Blokker M and Cole DP, Estimating Peak Water Demands in Hydraulic Systems – I - Current Practice,
[31] Chakrabarti, SP (1980) Simultaneous peak load on drainage system in multi storey residential buildings for intermittent system of water supply'. Building and Environment, Vol 15, pp 95-100.
[32] Wong LT & Mui KW, CIBSE 2009 , Drainage Demands of Domestic Washrooms in Hong Kong pp 121-133
[33] Oliveira LH, Cheng LY, Goncales OM, Massolino PMC, Modelling of Water Demand in Building Supply systems using fuzzy logic.
[34] Appendix C

3. Plumbing regulations and plumbing design in Australia

3.1 Growth of Population and Demands for Water Supply and Drainage

Australia is a vast continent with settlements across the country separated by long distances, even though the concentration of population is centred primarily in coastal areas. Settlements tended to concentrate where there was reliable and ample fresh water, usually at the head of large rivers and cities such as Sydney, Brisbane, Melbourne, Adelaide and Perth developed at these types of locations. The rivers also provided means of transport for movement of natural resources from the immediate inland.

In the very early years of settlement there was little regulation of how plumbing systems were installed. Buildings were scattered, typically ‘low rise’ and not particularly large by today’s standards. ‘On-site’ water tanks for water supply and simple in-ground water disposal of soil and waste from basic plumbing systems developed without regulation. As cities grew, the response to the need for healthy urban environments lead to piped municipal water and drainage networks.

In major cities, specific units or departments within specific organisations were developed to administer these regulations in response to local conditions and their area of responsibility. However, in the earlier years, there was no national over-arching governance. As the States developed their administrative governmental roles, each State developed its own ‘set of rules’, usually administered by local Council officers and field staff.

Each of Australia’s populated cities became responsible for the plumbing networks in their respective cities under their own State Legislation. Regional areas with smaller urban areas remained administered by local government areas through local Councils. The broad historical chronology of the main Water Authorities around Australia, based on a research of the World Wide Web on various Water Authorities in Australia, can be summarised as follows:

- The Waterworks and Drainage Commission was established in Adelaide in 1865 to Supply water and improve wastewater systems around the city and its surrounding regions. The Water Authority for this region was held by the Engineering and Water Supply Department for a long while before SA Water took over in the early 2000s.
- The Melbourne and Metropolitan Board of Works (MMBW) were established in 1891 to take responsibility for both water supply and the treatment of sewage in Melbourne and surrounding areas. In 1992 the MMBW merged with a number of smaller urban water authorities and Melbourne Water commenced its operation as a water authority in 1995.
- The Sydney Metropolitan Water Sewage and Drainage Board were established in 1925 to provide for the water supply, sewerage and stormwater drainage of certain districts in and adjacent to the County of Cumberland (Act No. 50, 1924). In 1987 the Board was reconstituted as the Water Board, before the Sydney Water Corporation Limited was established in 1995. As from 1 July 2012, the water authority in Sydney is the Sydney Water Corporation Limited with the Department of NSW Fair Trading as its current regulator.

- Brisbane also had its own water authority to deliver water and wastewater services to customers in Brisbane, Ipswich, Lockyer Valley, Scenic Rim and Somerset. The Queensland Urban Utilities (QUU), a unit within the Brisbane City Council, is currently the water authority for this region, with the Department of Housing and Public Works as the current regulator.
- Perth currently has the Water Corporation WA as its current water authority, having taken over the role of the WA Water Authority in the early 2000s.
- Darwin currently has NT Power and Water as the water authority to provide water and sewerage services in the Territory's five major centres.
- Tasmania had several water authorities over the years. Between 2008-2013 the State had three water authorities namely Ben Lomond Water, Cradle Mountain Water, Southern Water, and their service firm; Onstream. TasWater commenced operating as Tasmania's water authority in 2013, with the Department of Justice, Building Standards and Occupational Licensing as its regulator.

3.2 Application of Hunter's Approach in Australia

As the fixture unit theory was accepted in Great Britain as a valid means of sizing pipework, the theory soon also became established in Australia, including the shift of the basic unit rating from WC to wash basins. The Metropolitan Water Sewerage and Drainage Board (MWS&DB) in Sydney from time to time published Approved Variations and Departures to Bylaw 14 and in August 1966, the House Services Branch issued "Fixture Unit System for Sizing Sewerage Service Pipes"[35]. This is the first authority reference to fixture units in NSW and possibly Australia that was able to be found during the research undertaken by this paper. The issue of this departure by MWS&DB in Sydney enshrined in Law the use of the fixture unit method for pipe sizing of sanitary drainage and sanitary plumbing systems in NSW and much of Australia.

From then the Hunter research became embedded within State based regulations through the adoption of the standard and the concept of a table of fixture unit numbers nominated for the design of sanitary drainage systems. The Australian Model Plumbing Code – Sanitary Drainage (Oct 1977) prepared under the Chairmanship of J.L Taylor by the (NSW) Standing Committee, Plumbing and Drainage, NSW for the NSW Technical and Further Education, defines fixture units and is an early reference to using fixture units in a training publication.

However, reference to fixture (loading) units for water supply systems in buildings, as far as could be found, did not appear as a recognised technical text until the first publication of AS 3500.1 in 1990.

[35] Water Sewerage and Drainage Board Sydney (MWS&DB) 1979, Design of Separate Sewerage Systems

3.3 Chronology of the Plumbing Standards

3.3.1 Past Plumbing Standards

Prior to introduction of a national standard

In early 20th century, training for the plumbing trade in Australia was based heavily on British practice and such publications as 'The Modern Practical Plumber' (Martin A.C & Henwood J.H (undated) Caxton Publishing London, were used by those learning the trade. In The Modern Practical Plumber reference is made to the (GB) Public Health Act 1875 and a London County By Law 1930.

It was after the Second World War that Australia, through State based administrations, started to develop more sophisticated, coherent plumbing regulations. The regulations were quite prescriptive, as they were developed to include specific design criteria published for the plumbing industry.

Each of the above water authority and regulator had initially developed and implemented their own individual plumbing legislations. For example:

1. Sydney had Ordinances 40, 44 and 45 and NSW Legislation ByLaw 14 before later introducing the Plumbing and Drainage Act 2011 and the Plumbing and Drainage Regulation 2012 as the current applicable Code.
2. Melbourne had the 1924 The Metropolitan Drainage and Rivers Act to define the city's drainage requirements, before introducing the Water Act 1989 (Vic) as the legal framework for managing Victoria's water resources. This is soon followed by By-law No. 1: Water Supply Protection, dated 24 January 2008 and By-law No. 2: Waterways, Land and Works Protection and Management, dated 9 April 2009, applicable as the current Code.
3. Brisbane had the Plumbing and Drainage Act 2002 Queensland as the law governing plumbing and drainage, the licensing of plumbers and drainers, on-site sewerage facilities, and other matters. This is soon followed by current Codes consisting of:
   - the Plumbing and Drainage Regulation 2003 detailing the types of plumbing and drainage licences and the type of work a licensed person can do;
   - Standard Plumbing and Drainage Regulation 2003 containing specific laws to ensure plumbing and drainage work is compliant; and
   - Queensland Plumbing and Wastewater Code Published 15 January 2013.
4. Tasmania currently has the Tasmanian Plumbing Code 2013 and the Plumbing Regulations 2014 (Tasmania).

The Building Code of Australia and the introduction of the National Construction Code

In the late 1980s, there was a trend towards introducing a national standard for building regulations for adoption by all States and Territories across Australia, which led to the introduction of the Building Code of Australia (BCA) in 1989.

The ABCB was established by agreement between the Australian Government and each State and Territory Government. It is a cooperative arrangement between the signatories, local government and the building industry. Its mission is to address issues relating to safety, health, amenity and sustainability in the design, construction and performance of buildings. Until 2010 this was achieved through two standalone Volumes of the BCA. In 2011 the National

Construction Code (NCC) was first released, including the Plumbing Code of Australia (PCA) for the first time.[36].

The hierarchy of regulatory controls is illustrated in Figure 3.

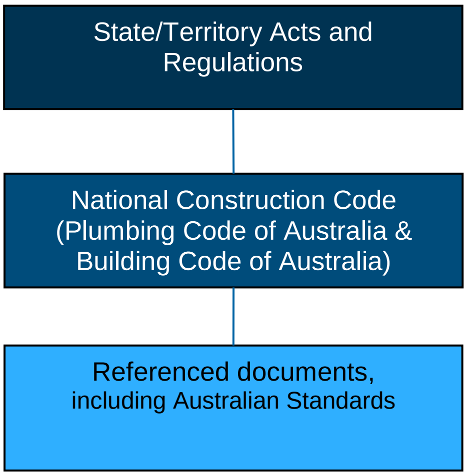

Figure 3 Hierarchy of regulatory controls

While the BCA was not immediately adopted by all States and Territories when first introduced, the benefits of having a national code which called up a series of standards already in place in various States and Territories appealed to various sectors of the building industry, including the plumbing sector.

Standards Australia subsequently introduced the following national standards for water services and sanitary plumbing and drainage to the plumbing industry. These were amended as the need arose, as detailed in the list.

- Water services
  - AS 3500.1 - 1990 National Plumbing and Drainage Code – Water supply.
  - AS 3500.1 - 1992 National Plumbing and Drainage Code - Water supply
  - AS 3500.1.1 - 1998 National plumbing and drainage – Water supply – Performance requirements
  - AS 3500.1.2 - 1998 National plumbing and drainage – Water supply – Acceptable solutions
  - AS/NZS 3500.1 - 2003 Plumbing and drainage - Water services (Including Amdts 1 & 2)
- Sanitary plumbing and drainage
  - AS 3500.2 - 1990 National Plumbing and Drainage Code - Sanitary plumbing and sanitary drainage.
  - AS/NZS 3500.2.1 - 1996 National Plumbing and Drainage – Sanitary plumbing and drainage – Performance requirements
  - AS/NZS 3500.2.2 - 1996 National Plumbing and Drainage – Sanitary plumbing and drainage – Acceptable solutions.
  - AS/NZS 3500.2 - 2003 Plumbing and drainage - Sanitary plumbing and drainage. (Including Amdts 1 – 4)

In addition, in 2004, the National Plumbing Regulators Forum (NPRF) released the first Plumbing Code of Australia (PCA). Although the standards were widely accepted, the PCA had only limited adoption nationally.

[36] National Construction Code Series 2014 Vol 1, p.7-9

3.3.2 Today's Plumbing Regulations

National Construction Code

Following a decision of the Council of Australian Governments (COAG) to examine the possibility of all on-site construction in one national code, the National Construction Code was produced to combine building and plumbing as a first step. Whilst Volumes One and Two are essentially the same BCA produced and regularly updated by the ABCB, Volume Three was a re-badged and refreshed 2004 version of the NPRF PCA.

- Currently, the ABCB, on behalf of the Australian Government and each State and Territory government, produce and maintain the National Construction Code Series. The NCC is published in three volumes: NCC Volume One – Building Code of Australia (Class 2 to 9 Buildings).
- NCC Volume Two – Building Code of Australia (Class 1 and 10 Buildings).
- NCC Volume Three – Plumbing Code of Australia.

All three volumes are drafted in a performance format allowing a choice of *Deemed-to-Satisfy Provisions* or flexibility to develop *Alternative Solutions* based on existing or new innovative building, plumbing and drainage products, systems and designs.

The goal of the NCC is to enable the achievement of nationally consistent, minimum necessary standards or relevant safety health, amenity and sustainability objectives efficiently. This goal is applied so that:

a. There is a rigorously tested rationale for the regulation; and

b. The regulation is effective and proportional to the issues being addressed such that the regulation will generate benefits to society greater than the costs (that is, net benefits); and

c. There is no regulatory or non regulatory alternative (whether under the responsibility of the Board or not) that would generate higher net benefits; and

d. The competitive effects of the regulation have been considered and the regulation is no more restrictive than necessary in the public interest.

Each State and Territory's legislation adopts the NCC subject to the variation or deletion of some of its provisions, or the addition of extra provisions. These variations, deletions and additions are contained where possible in Appendices to the NCC.

The NCC is given legal effect by building and plumbing regulatory legislation in each State and Territory. This legislation consists of Acts of Parliament and sub ordinate legislation which empowers the regulation of certain aspects of buildings structures and plumbing installations and contains the administrative provisions necessary to give effect to the legislation.

Any provision of the NCC may be overridden by, or subject to, State or Territory legislation. The NCC must therefore be read in conjunction with that legislation. Any queries on such matters should be referred to the State or Territory authority responsible for regulatory matters.

The Plumbing Code of Australia (PCA)

The PCA is the technical standard for all plumbing and drainage work in Australia, which sets out performance requirements for the design, construction, installation, replacement, repair, alteration and maintenance of plumbing and drainage installations. Its goal is to enable the achievement of nationally consistent, minimum necessary standards of relevant safety, health, amenity and sustainability objectives efficiently.

The PCA contains the technical provisions for the design, construction, installation, replacement, repair, alteration and maintenance of:

- water services;
- sanitary plumbing and drainage systems;
- stormwater drainage systems;
- heating, ventilation and air conditioning systems;
- on-site wastewater management systems; and
- on-site liquid trade waste management systems.

It also defines the certification and authorisation procedures for plumbing and drainage materials and products so that they may be used or installed in a plumbing or drainage installation.

As part of the NCC, the PCA is given legal effect by enabling legislation in each State and Territory which empowers the regulation of certain aspects of plumbing and drainage installations. Although the PCA was introduced into the NCC in 2011, it was not uniformly adopted Australia-wide at the same time, as each State and Territory had to individually agree to it and agree to adopt it.

The PCA, at 2015, calls up a number of Standards, including the AS/NZS 3500 which consists of the following:

- AS/NZS 3500.0 - 2003 Plumbing and drainage - Glossary of terms.
- AS/NZS 3500.1 - 2003 Plumbing and drainage - Water services (including Amdts 1 & 2).
- AS/NZS 3500.2 - 2003 Plumbing and drainage - Sanitary plumbing and drainage (including Amdts 1 – 4).
- AS/NZS 3500.3 - 2003 Plumbing and drainage - Stormwater drainage (including Amdts 1 – 3).
- AS/NZS 3500.4 - 2003 Plumbing and drainage - Heated water services (including Amdts 1 & 2).

4. Research Discussion and Observations

This section discusses how recent trends towards water conservation has led to the development of new water efficient fixture designs into the plumbing industry; which in turn has led to less volume of waste water being drained through the pipes. As sanitary drainage systems are essential for public health, there has also been increased awareness of health sanitation, treatment and drainage of waste water around the world in recent years, supported by various attempts to improve methods of designing, installing and maintaining drainage systems by the plumbing industry.

Literature reviewed and discussions with industry representatives have indicated that:

- all drainage pipes, initially sized using Hunter's fixture unit rating method, could now be considered to be oversized for the volume of waste water drained from fixtures; and
- a general reduction in volume of waste water being drained can conceivably be the cause of an increase in the occurrence of blocked drainages.

An improved method of estimating water demands should therefore be considered, to support a more accurate method of sizing water pipes which will potentially improve drainage performance and reduce blockages.

4.1 Analysis from the Literature Review

Literature reviewed during this study found that most research to date has focused on accurately estimating water demands and subsequent load into fixture units, primarily driven by the need to conserve water. Very limited research conducted to date has focused on the consequences of having less water in the system and the issues associated with dry drains.

The exception is the research on the dynamic flow models that can predict the depth of flow in a drain at peak flow, being part of the research at Herriott Watt University in Scotland. This research established how solids transport distances related to the volume of flush reduces as flushing volume reduces and how the distances reduce as flushing volumes reduce.

4.1.1 Global trends towards water conservation

All over the world, regulators have been reviewing the requirements for water efficiency and targets to be achieved in terms of total water usage. This has resulted in the design and production of water efficient sanitary fixtures and tapware including:

- dual flush cisterns to domestic and commercial WC systems;
- smaller sized flush tanks;
- water efficient shower heads and tapware;
- flow control valves;
- water plugs, self-closing taps, spray taps, aerators etc;
- high water efficiency appliances, e.g. washing machines and dishwashers; and
- provisions for recycling waste water in domestic and commercial buildings.

As a consequence of the above development of water efficient plumbing appliances, it is now evident that the water flow and quantities that were assigned to each fixture type using the Hunter's method may no longer be relevant.

This trend of consuming less water has also resulted in having less water flow in water supply systems, less water going through fixtures and also less waste water in drainage systems. In recent years, as discussed in the Dry Drains Forum held in Frankfurt, Germany in 2009[37], the plumbing industry has raised concerns associated with dry drains as well as more frequent blockages in drainage systems due to limited volume of water to keep drains clear.

Some specific consequences that result from this include the following:

- lower carrying capacity of drains because of lower water flush volumes;
- self-cleansing velocities in drains not being maintained sufficiently to carry and move solids that have stopped along drains; and
- a build up of sulphide levels in domestic soil drains because of longer residence times

Some concerns that follow from this include:

- a build up of gasses from drains;
- a build up of slime in domestic drains;
- a build up of sulphide generation in domestic drains;
- a build up of general air/ pipe temperature in domestic drains; and
- an increase risk of odour build up, both volume and intensity.

A recent study on non flushing or waterless toilets and urinals systems, conducted by GHD in 2013 revealed a number of issues associated with having less water in the drainage system, from complaints of consistent foul smell, to blockages caused by struvite build up and corrosion of copper piping caused by undiluted discharges in non-flushing urinals. While recommending further research and tests to identify any requirements to amend the existing plumbing Code in Australia, this report identified suggested solutions, such as:

- Increased public awareness of the concepts behind the operations of non-flushing urinals, its methods of operations, cleaning and maintenance as well as hygiene, health, and environmental consequences; and,
- A general education to building cleaners, facility managers, maintenance service providers on the importance of following specific cleaning and maintenance procedures on these fixtures.

4.1.2 Issues Associated with the Hunter Method

The literature reviewed also confirmed that the basic principles of the Hunter method in estimating water demands remain valid, although many of the initial parameters of the assumptions are no longer relevant. Hence, the study identified a number of issues associated with the Hunter method, as follows.

- Hunter's basic assumptions and criteria were promulgated more than 60 years ago.
- The relevance of the pure probability theory, also known as the random theory approach made when fixture units were first created for application to loads in plumbing systems by Hunter in the USA, can now be questioned and alternatives explored. As the probability theory relies on the use of statistically large samples, applying this theory on fixture and loading unit values of smaller plumbing systems leads to less accurate and over conservative results of water pipe sizing. Furthermore, the application lacks relativity of the flushing value of different fixtures because of lower flush volumes of water efficient fixtures.

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[37] Dry Drains Forum, ISH, Frankfurt, Germany, 2009 – various papers

- The use of fixture and loading unit values based on a flush valve for a WC is no longer relevant. Flush valves referred to in Hunter's work are presumably 'manual' type as opposed to electronic flush valves which were not available in the 1940's. Improvements have been made in flush valve design as well as faucets and fixtures.
- Public emphasis on water and energy conservation in recent years has altered many of the basic criteria[38].
- Results utilising Hunter's original curves have been shown to approach twice the flows needed when using modern appliances[39] .
- Pipe materials now used in the installation of plumbing and drainage systems have evolved since the 1940's. Frictional co-efficients and temperature ratings for pipework materials are important factors in determining the performance and efficiency of drainage systems.
- Social customs and living patterns have changed, casting doubts over the relevancy and accuracy of the fixture unit allocations.

All the above points to conclusions that a more accurate method of estimating water demands and calculating drainage pipes sizes is required.

Buchberger S, Blokker M and Cole DP also confirmed the need to improve Hunter's original method due to the fact that the results are restricted to a single point (99th percentile) on the peak flow of Cumulative Distribution Function (CDF), which is accessible only through application of so called Fixture Units. This device is often confusing for blending the effects of different fixture types.

4.1.3 Current Sanitary Fixture Designs

In Australia, environmental sustainability awareness has led to the introduction of energy and water conservation ratings tools such as Greenstar[40] rating and the National Australian Built Environment Rating System(NABERS)[41] for newly constructed buildings, supported by requirements of the AS/NZS 3500 standards. This trend has resulted in the 'standard' WC cistern flush volume being reduced from 13 litres to 11 litres to 9 litres to six litres, with the '6/3' flush now adopted and WC flush 4.5/3 now available. Modern fixture designs have changed from Hunter's time and the usage patterns also. For example, hand basins now are generally smaller in size, typically utilize mixer taps that people use to blend water temperature and wash hands under running water. This typically results in less water usage (from more water efficient taps) and lesser volume and lesser intensity of water flow discharging into a sanitary drain.

In recent years, there has also been a range of designs of wash basins introduced to the market, of varying shapes, sizes and methods of drainage, to suit differing design requirements. In some public buildings, wash basins are now often represented as a single trough with a series of taps and spouts rather than a series of wash basins with their individual taps and spouts, making it difficult to allocate any Fixed Unit Rating to the installation.

[38] Plumbing System and Design 177 Water System Design – May 2011

[39] Das, S, Jaman, H & Mazumdar, A 2013,'Modification of Hunter's curve in the perspective of water conservation',

[40] A one to six stars sustainability rating system for buildings and communities launched by the Green Building Council of Australia in 2003. Green Star Certification is a formal process during which a building, fitout, or precinct is awarded a rating by an independent panel of sustainable development experts through a documentation-based assessment.

[41] A national rating system that measures the energy efficiency, water usage, waste management and indoor environment quality of a building or tenancy and its impact on the environment, by using measured and verified performance information, such as utility bills, and converting them into an easy to understand star rating scale from one to six stars.

There is currently no specific design considerations with regard to drainage configuration attached to the installation of these lower flush volume WC cisterns and no differentiation with fixture unit values. Similarly, the referred standards of design in the PCA have not been extensively reviewed with enough rigour to take the above changes in attitudes to water conservation into consideration.

The currently assigned values of fixture units in the PCA, as embodied in Table 6.1 of Section 6 of AS/NZS 3500 Part 2 are still based on Hunter's philosophy of the 1940s and not based on today's more water efficient taps and sanitary ware. This means that these values are not directly applicable to the loads imposed on plumbing systems currently and recently constructed.

Furthermore, the existing design criteria do not take into consideration:

- the current relevancy of the fixture unit and loading unit systems or their base nominal values;
- the circumstances surrounding events of human behaviour related to the use of plumbing fixtures; or
- the availability of improved and affordable data recording instruments in Australia.

4.1.4 Oversized water supply and drainage pipes

The above mentioned trend of water conservation ensures that there is less water being supplied and drained in our pipework, which had been designed based on the 1940s methodology and water usage patterns. This means that most of the pipework installed is now oversized for the volume of water supplied and drained.

The World Health Organisation "Health Aspects of Plumbing" produced in 2006 (1) states,

" A minimum velocity of 0.6 metres (2 feet) per second will prevent solids building up to block the pipe, and if the maximum velocity is limited to 3 metres (10 feet) per second this will prevent scouring and damage to the pipes."

The above statement is further supported by Table 11.3, 'Gradients to Produce Minimum and Maximum Velocities in Drains' in the same document, showing the gradients at which these velocities are reached in pipes of various diameters and the approximate quantities that will be carried at such velocities. However, this document did not mention the relevancy of the pipe material in preventing blockages.

Research undertaken by GHD in Melbourne (Erakovic E,) [42] on velocity model analysis compares the velocity of flushing WC water from a 4.5 Litre cistern flush to a 6 Litre cistern flush. The initial velocity of the 4.5 Litre flush is 0.2 L/s and the tail off velocity for the 4.5 Litre flush is reduced by approximately 0.5 seconds.

There are further effects discussed such as water flux, or backward movement of water into branch junction pipes, with field advice about the frequent occurrence of back flux into branch junctions that are laid 'flat' in certain circumstances[43]. This implies the importance of keeping drains clear along the geometry of some pipework configurations and the potential need to review the method adopted for designing and sizing pipework.

[42] Don Boynton paper titled 'Leaving A Sustainable future' in Dry Drains Forum at ISH Trade Fair Frankfurt in 2009
[43] Personal communication with Les Barnard, ex Sydney Water Plumbing Inspector

4.2 Issues raised by the Plumbing Industry in Australia

The review included industry consultation with selected members of the plumbing industry as well as the search through published literature. The industry consultation process raised the following issues and concerns about the current fixture unit rating.

4.2.1 Less Volume of Water Travelling Through Drainage Pipework

The major concern expressed by plumbers is blockage in sanitary drainage systems rather than the actual fixture unit methods, with a universal comment that solids tend to build up more readily in drains when there is less flushing water from WCs. Other factors causing blockages include layout of some drainage pipes and branches, with some installations not performing as reliably as others.

The introduction of greywater systems also tend to 'rob' the drainage system of flushing water because waste water, typically from laundry tubs, baths, showers and hand basins, are diverted into a separate system. The effects of this introduction of greywater system are not considered in the standards used in the design process at present.

Problems resulting from lower volumes of flushing water are likely to occur in the following circumstances:

- In low rise buildings (ie. not multiple levels of plumbing fixtures discharging to common drains).
- In low-use branch drains that include a low flush WC.
- In drains from ladies bathroom areas, where ladies tend to use more toilet paper than men, including the use of toilet paper to line the toilet seats and create a 'bird nest'.
- In soil drains that have less flushing water because of greywater collection.
- In older drainage pipework (such as earthenware) that has more joints and potentially more readily misaligned.

4.2.2 Water Pipe Sizing and Materials

The deemed-to-satisfy requirements of the PCA refer to water pipe sizing through a loading unit method for design of a plumbing system. The pipe sizing method then employs an 'index length' to the most hydraulically disadvantaged fixture in order to satisfy minimum flow and pressure to that fixture and pipe branches to other fixtures are based on the index 'length'. The overwhelming view of plumbers and designers consulted indicated the following:

- The sizing of water supply and drainage pipework relies upon loading units based on older fixture flow rates that are not current or compatible with the low flow tapware available and does not support any water conservation measures.
- The newer pipe materials being supplied and installed are frequently made out of PVC and PE, which have inherently lower friction co-efficients.
- The simple application of loading unit equivalents for cold water systems over to heated water systems is not appropriate and, particularly for hot water systems, prone to over-sizing. Because of the energy input required of hot water systems, the economic considerations of hot water loads, piping and heating plant become significant. Furthermore, some plumbing appliances only use cold water, e.g. WC's and drinking fountains.

Concerns resulting from this are:

- A plumbing system that is designed from the current loading unit method will be oversized in its water carrying capacity;
- Even during periods of high water demand, large pipe sizes that result from the prescribed design method do not permit water velocities to reach the speed needed to flush out pipework and keep it free of debris and potential bacteriological contamination; and
- Hot water systems are also prone to build up of potentially dangerous contaminants. Heated water pipework systems require flushing out (or equivalent method) to remove contaminants and if a cleansing water velocity is not reached in the system (at, say peak load), systems can remain stratified and subject to build up of contaminants. This is particularly important in larger buildings.
- An oversized water reticulation pipe in a building will not disrupt, from the users' point of view, the performance of the fixtures and appliances that form part of the system and hence will not create any complaints from users. Similarly, a 'minimum'-sized pipe of a smaller diameter that performs properly would not be subject to complaints.

Most plumbers consulted indicated that water supply pipework problems related to sizing is only an issue due to the additional costs associated with the purchase and installation of larger than required pipework. This in itself does not lead to maintenance call outs in the same way a blocked drain will.

4.2.3 Plumbing Designers and Consultants

Plumbing designers and consultants in Australia are consistently driven by clients and market to deliver sustainable design solutions associated with the design and performance of today's plumbing systems as also required by regulations. Consequently, they are in tune with the effect of water conservation initiatives that are implemented into plumbing installations and are aware of the concerns of the plumbing industry, particularly with the low flows in drains.

As recently mentioned by Don Boynton in his research paper, *"The old decision model is based on a balance between cost (Economic), schedule (Program) and quality*[44]*.*

This is further supported by Mandler and Lazarus in their Guide Book to Sustainable Design, stating that "*designers also need to become equally familiar with the effect their decisions have on the environment and human health, safety and comfort"*[45] *.*

4.2.4 Other Issues

Revisiting the current fixture unit rating method

As outlined above, most issues raised are centred around drainage performance and not on water supply performance, with concerns expressed about the effects of low flow sanitary fixtures and tapware on water supply and drainage systems. However, in Australia and overseas, opinions appear divided on whether revisiting the current fixture unit rating methodology will necessarily solve the problems associated with the performance of sanitary drainage and sanitary plumbing systems currently being experienced by the industry.

The industry has indicated that any improvement to the current fixture unit ratings and loading units has the potential to contribute to the solving of design problems of dry drains in particular, but it is seen only as part of a much broader design and installation issue.

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[44] Boynton, Leaving A Sustainable Future' in Dry Drains Forum
[45] Mandler, S. Odell, W. Lazarus, M.A (2006) The HOK Guide Book to Sustainable Designs,

AS/NZS 3500 Part 2

It is also widely acknowledged that, like the original Hunter method, the fixture and loading unit methods referred to in the AS/NZS 3500 Part 2 are only applied to domestic/residential building types. This is seen as a significant lack of appreciation with the differing demands and loads placed on plumbing systems that serve other types of buildings. Similarly, the industry believes that the introduction of low consumption water closets into the market as a response to water consumption reduction campaigns has not adequately addressed the need to effectively move solids along sanitary drainage pipes.

Furthermore, AS/NZS 3500 Part 2 currently treats fixture units in a graded branch drain having 'the same 'value as those in a vertical stack, when velocity and gradients associated with each are significantly different. This approach should be revisited, as should the relevancy of pipe materials and jointing materials in the market, because pipe materials and pipe jointing materials have changed significantly in the past decades and the co-efficient of friction in water supply pipework have decreased markedly.

Probable Simultaneous Demand

While there is limited theoretical understanding behind the derivation or detail of fixture (and loading) units within the industry, there is general acceptance that fixture unit theory and application result in a Probable Simultaneous Demand (PSD), taking into account the assumption that all connected fixtures will not be operated at once. There is also an acceptance of the concept that the larger the plumbing system, the better the statistical analysis works and there is less likelihood of all fixtures being operated at the same time.

Oversized pipework

Parts of the industry are also of the opinion that the problems are not always directly related to pipe sizing. There is universal appreciation across the industry that an oversized water supply pipe is much less of a concern than a blocked drain. This is not only because a blocked drain poses a more 'in your face' situation, but also because a blocked drain is more easily and directly attributable to potential public health problems. Oversized water supply pipes remain as an acknowledged issue in the plumbing design and installation sectors of the industry because of the fact that oversized recirculated hot water piping can result in low water velocities and sediment build up in the pipe, which in turn can lead to corrosion of the pipe wall and develop some degree of water contamination.

4.3 Hunter's Original Research and its Relevance to the Current Practice

Flush volume and flow rates

As raised by representatives of the plumbing sector in Australia and overseas through this review process, recent trends towards water conservation has led to having significantly less flush volume through fixture units and consequently less volume of water to move solids along drainage systems. With less flush volume of water expected to enter the drainage system, the current method of pipe sizing is considered no longer relevant because it is likely leading to oversizing of pipework.

The reduction of waste water flush volume and flow rates is also being held responsible for the increased number of blockages along drainage systems.

It has been suggested that the change in flush volume through the pipework has also impacted on the flow rates for both water supply and waste water drainage, particularly in larger and longer pipework installations. While flow rate plays a significant role in determining pipe sizes, the flow rate itself is influenced by water pressure as well as pipe design, gradient and materials.

The current methods of designing pipe work and gradient calculations have not been revised to date, and there has been significant changes in pipe materials and jointing methods in recent years, which pose a different co-efficient to the equation. Water pressures can also vary significantly, depending on the sources and the regions. The roles of these contributing factors should be carefully examined if the current method of calculating pipe sizes is reviewed.

The frequency of use of fixtures in fixture unit calculations

The frequency of use of fixtures in fixture unit calculations is critical when designing water supply piping installations, as designers need to combine this with the estimated duration of each use to estimate the total volume of the overall water demands. With recent increased awareness of hygiene requirements, there may have been increased frequency of use in many installations, although each use would have been relatively short due to increased awareness of water conservation; this would not lead to any increase in volume of water consumption or flush volume.

The role of frequency of use of fixtures in fixture unit calculation is only critical when designing drainage systems for buildings with significantly high numbers of fixtures, especially if the fixtures are likely to be operated all at the same time. This primarily applies to sport stadiums, large theatre/entertainment venues, large boarding schools and the like.

The accuracy and suitability of the current ratings

Past research has raised concerns over the accuracy of Hunter's probability method, particularly as some had shown that pipe sizing based on Hunter's method can be as much as 100% oversized. The accuracy and effectiveness of the probability method should be questioned particularly now, with the development and availability of sophisticated computer modelling and simulation programs and water monitoring tools.

The suitability of Hunter's ratings are also now questioned, given the trend of water conservations with less water flowing into the drainage, the now questioned probability theory and the change of overall parameters of the Hunter's method of calculating pipe sizes.

Fixture unit vs loading unit

Hunter's method of calculating pipe sizes for water supply using loading units has been adopted in principal in Australia and is an acceptable deemed-to-satisfy method of compliance with the Performance Requirements of the Plumbing Code of Australia. However, AS/NZS 3500.1, as the deemed-to-satisfy referenced document in the PCA, does not compel the use of loading units.

The advantage of the loading unit allocation is that the differing factors associated with the variety of different fixtures and appliances in a plumbing system can be all rated relative to a common factor or event. Hunter originally did this with comparison to a WC, using different values for a flush valve and a cistern type. As adopted in Australia and referred to in AS/NZS 3500 Part 2 - 2003, most systems now rate fixtures and appliances with a flow rate (typically litres per second or litres per minute).

The mathematical definition of a loading unit has not fundamentally changed since the Hunter research.

In AS/NZS 3500.1 - 2003, a description of a loading unit is found in Section 3 Sizing of Water Services, Clause 3.2 Flow Requirements, Sub-clause 3.2 Loading Units

> *"Loading units are factors that take into account the flow rate, length of time in use, and frequency of use of the fixtures or appliance. When installed in a domestic situation, loading units for fixtures/appliances shall be as given in Table 3.1."*

The above statement is an exact adoption of Hunter's method of estimating water demands. The relevance of loading units in pipe sizing becomes apparent when the flow rate of water required for the functioning of the fixture or appliance is known and the water draw off points in a water distribution system are known. The likelihood of all fixtures being operated at the same time (simultaneously) in a water distribution pipe system is accounted for by application of probability theory.

In the earlier design standard, AS/NZS 3500 Part 1 - 1998, Amendment 2 Table 3.1 lists fixtures and appliances and allocates flow rates and loading units. For example, a WC cistern, a basin and a shower all share the same flow rate value 0.1L/s (6L/min). However a WC has a loading unit of 2, a basin has a loading unit of 1 and a shower has a loading unit of 3. These differences come about because of the effect of the time of operation and time between operations that have been used and applied statistically by probability theory when assessing the function and use of each fixture. Thus a numerical value that represents the relative effect that each fixture has on the system it is part of and so a probable simultaneous demand for the water supply system in a building can be established.

As Hunter's original research was only based on domestic dwellings, the fixture units allocated are stated to apply to residential buildings. Similarly, AS/NZS 3500.1 - 2003 does not distinguish between particular types of buildings and their usage. As noted earlier in this paper, design codes and standards applied in other countries make a distinction between various broad categories of buildings.

The power of analysis and modelling of current computers

Since Hunters time, the computational power of modern computers means a lot of information can be quickly analysed and sensitivities to fixture rate changes can be incorporated to explore options. Statistical theory has significantly advanced and a greater range of factors is able to be studied.

As an example, the Cumulative Distribution Function (CDF) of flows is now able to be studied and applied to refine peak flow estimations. This is explored in Buchberger's paper presented at the 14th Water Distribution Systems Analysis Symposium in Adelaide in September 2012.

5. Conclusion and Recommendations

In recent years, the plumbing industry world-wide has increasingly become more cognisant of the value of fresh water for human consumption, with ultimately led to the design and installation of greater water efficiencies with plumbing products.

In Australia, regulators, building owners and water consumers have also attempted to facilitate this drive to consume less water by adapting to more sensitive water usage behaviour patterns, with manufacturers and suppliers to the plumbing industry responding by developing and introducing water efficient taps, fixtures and appliances into the market.

In the meantime, water services measuring equipment has also progressed significantly and is now readily available in the marketplace at affordable prices. High quality measuring devices have also reduced in cost so that reliable measuring equipment that can detect water flow volumes, velocity and dynamic pressures in a water supply system are now more accessible. Such devices are also readily able to record water demand fluctuations and overall volumes of water used in a water supply system in a building over specified time intervals and sampling time intervals.

The above advances in water services measuring equipment are also complimented with advances in computer modelling and analysis programs. The adoption of the theory of probability of the 1940s can now be improved to obtain better predictions of water demands through the use of these new computer modelling programs.

Whilst it has been suggested that a review be undertaken with possible amendments to the existing fixture unit ratings method, there has also been limited attempts to identify the consequential implications of such amendments should they occur.

5.1 Potential Amendments to the Fixture Unit Rating

The following identifies potential amendments which could be applied to each of the factors contributing to the current fixture unit rating to bring the methodology in line with current trends of water conservation and improved methods of estimating probabilities.

Contributing Factor	Potential Amendment	Potential Implications
Flush Volume	Adjust to reflect contemporary fixtures	More optimum method of pipe sizing, potentially reducing pipe sizes and costs in new installations of water supply (with potentially different methods of calculating hot and cold water systems) and eliminating problems with oversized hot water pipework.
Travel time	Modification of pipe design to reflect contemporary materials	May improve flush volume and capacity to move solid along drainage system in new installations.
Frequency of use of fixtures	Adjust to reflect current usage patterns	Limited impact on drainage systems in general. Different formula may be required for drainage of buildings with large number of fixtures to ensure optimum size and performance of drainage system supporting these kinds of buildings.

Contributing Factor	Potential Amendment	Potential Implications
Probability	Redefine parameters	More optimum pipe sizing for both water supply and drainage pipework.
Pipe gradient	Increase to reflect lower volumes	Greater gradient and stack configurations may result in the need for more space or greater depth of pipework below floor surfaces and underground. This may have an impact on existing drainage systems and network authority drainage networks, including the connection of new installations to existing network.
Loading unit	Change base unit	Will only apply and affect new installations Will require wide industry consultations, with little benefits unless pipe sizes and dry drain issues are addressed.
Ventilation	Increase or decrease if necessary	More ventilation may be required to release and eliminate foul smells and gases produced by dry drains.

5.2 The Need for Further Work

As summarised in the previous Sections, findings and discussions to date question to some extent whether the current method of calculating loading and fixture units in Australia, and most of the rest of the world, is still valid. To reflect current world trends of achieving environmental sustainability, improve public health and reduce energy consumption, more research and development should be considered to ensure plumbing designers estimate design flush volumes and flow rates that are closer to actual user demand.

It is therefore recommended that further research be undertaken on the relevancy and suitability of each of the various parameters that determine the fixture unit rating and how these parameters should be followed in calculating pipe sizing and in designing water efficient sanitary fixtures, so that collectively these may address current dry drain problems and pipe sizing more generally.

The following are some of the potential research topics which could be considered.

Table 9 Summary of Identified Issues and Potential Future Research

Issue	Consequences	Potential Future Research
Water conservation generally, new water efficient fixture and tapware design and promotion of grey water reuse	• Less volume of water to be supplied • Less volume of waste water in drainage pipes	• Assessment of various methods of addressing the issue of lower flows and velocities from flushing WCs, including review of drainage pipework gradient, material and geometry, particularly branch junctions, depth of flow drains and the fixture unit approach, and their impacts to depth of municipal drainage networks. • Seek real time records of residential dwellings and commercial buildings, including analyses' of instantaneous usages, occupant density, living areas and demographic data to assess the impacts of reuse and grey water supply substitutions for potable water pipe sizing demand for selective functionary purposes. • Where appropriate, use simulated modelling programs to test different scenarios.
Reported increase in blockages along drainage systems	Increase in blockages along drainage systems	• Survey and record the frequency of blockages in WC drainage and determine what factors are attributed to the blockages – possibly through a survey amongst members of the Master Plumbers Association, taking into account pipe size, materials, and installation configurations, eg domestic vs commercial vs major venues. • Where appropriate, use simulated modelling programs to test different scenarios.
Peak Water Demand sizing using The Cumulative Distribution Function	Improved estimations for peak flows ,more economical pipe sizes	• Extension of Hunter's Fixture Unit method to apply more broadly to daily flows (including the peak hour) • More precise pipe sizing per individual construction project

Issue	Consequences	Potential Future Research
The Hunter Method is based on domestic installations	Not all domestic installations and water consumption patterns can be readily adopted in commercial, high rise and major event installations. In countries such as the USA and Great Britain, there is at least a distinction between low, medium and high-use plumbing systems for various building types.	An investigation into incorporating the different water demands from different building types and different uses (eg high, medium, low volumes) to loading and fixture units, plus the relevance of the following: • the assumption that cold water pipe sizing theory can be transferred directly across to hot water pipe sizing • the assumption that sanitary drainage fixture units apply equally in value for graded drains and in sanitary stacks • fixture units sizing as the basis for sanitary stack design regardless of how high the stack is
Improved technology, affordability and availability of sophisticated analysis methods and modelling tools, including computer programs	The probability theory is still a valid statistical approach to pipe sizing, but additional parameters, like human behaviour, building types and climate, are not being incorporated and included in pipe sizing methods	Conduct investigations associated with having less volume of water in the drainage systems identified above, using Monte Carlo techniques and Fuzzy Logic for formulating the value and use of fixture units, including the possibility of incorporating human behaviour, gender bias, climate, building types, as well as frictional co-efficients and temperature ratings for pipework materials into loading and fixture unit calculations
The frequent occurrence of water flux, or backward movement of water into branch junction pipes, into branch junctions that are laid ‘flat’ in certain circumstances	Contaminated water potentially being moved back into branch junction pipes etc, causing further contamination of water supply pipework	Investigate the importance of keeping drains clear along the geometry of some pipework configurations and the potential need to review the method adopted for designing and sizing pipework.

5.3 What Should be Excluded from Future Research

Literature research conducted during this study has identified a volume of research on improved methods of estimating water demands on the plumbing systems, although most are focused on the demands on water supply and consumptions, rather than its impacts on the drainage system. Consequently, this study recommends that future research activities on the fixture unit rating exclude the following:

- design and sizing of water supply pipework, as dry drainage is the major issue identified;
- design and sizing of hot water pipework installation, as hot water is not posing a drainage issue; and
- modifications to multi simultaneous events analyses and alternative probability formulations (e.g. Monte Carlo usages) as these are sufficiently addressed.

Appendices

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Appendix B – Definitions

Name	Description
Fixture	A fixture is any device for the distribution and use of water in a building. For example, shower, urinal, fountain, shower, sink, water faucet, tap, hose bibs, hydrant etc
Maximum Flow	Maximum flow or maximum possible flow is the flow that will occur if the outlets on all fixtures are opened simultaneously. Since most plumbing fixtures are used intermittently and the time in operation is relatively small, it is not necessary to design for the maximum possible load. Maximum flow is therefore of no real interest to the designer
The plumbing system of a building	Includes the water-supply distributing pipes, the fixtures and fixture traps, the soil, waste, and vent pipes, the building drain and building sewer, and the storm-water drainage pipes, together with their devices, appurtenances, and connections within or adjacent to the building.
The building main	The pipe from the street water main or other source of supply to the building served
The water-distributing system	The plumbing by which the water is conducted from the building main to its various places of use within and adjacent to the building, consisting of laterals, risers, and branches
The sanitary system of a building	The piping system, including soil, waste, and vent pipes, that conducts waste water and water-borne wastes from the plumbing fixtures to the street sewer or other place of sewage disposal.
A plumbing fixture	Any receptacle through which waste water or water-borne waste is discharged into the sanitary system.
A drain	Any pipe that carries waste water or water-borne waste in either the storm or sanitary system.
A fixture drain	The single drain from a fixture-trap outlet to its junction with another drain
A waste pipe	Any drain that carries the waste water from one or more fixtures other than water closets
A building drain	That part of a sanitary system which receives the sewage from soil and waste stacks and conducts it to the building sewer.
Demand load	The volume rate of demand for water imposed on the water-distributing system or any branch thereof by the use of water, as by plumbing fixtures.

Appendix C – Other topics

Current Research Overseas – CIPHE and CIBSE

L U N A - prospectus

A joint CIPHE/CIBSE research project

Background

The LUNA acronym stands for Loading Unit Normalisation Assessment. The Loading Unit method for assessing the design flow rates in hot and cold water supply systems was developed in the 1960s; since then these systems have evolved dramatically by the use of water efficient appliances, the widespread use of mixer taps, the preference of consumers to shower more frequently than taking a bath, and the move away from gravity distribution to systems fed by pressurised supplies. The ability to estimate design flow rates that are closer to actual user demand has the potential to improve sustainability, reduce health risks and deliver energy savings. The aim of this project is produce an updated and robust method of assessing the water design flow rates within buildings and their curtilages that will be adopted as a national design standard for the UK. Similar investigations and modified assessment methods which reduce design flow rates have already been introduced in several other European countries and in the USA, and the UK should be following this example.

Project status and management

Project administration is provided by the CIPHE, and the LUNA Task Group Chairman reports to the CIPHE's Technical Committee. The Group has several representatives from CIPHE and CIBSE, to ensure there is a fair balance of interest from both organisations. The Chairman, Group members, and technical correspondents act in a voluntary capacity. A research organisation will be appointed to provide the necessary academic and scientific input to the research on behalf of the Group. The Group will be responsible for the overall management and technical suitability of the project. The project will initially focus on multiple residential buildings (including large apartment blocks) and student halls of residence. Once this research phase is complete, the intention is to agree a plan to extend subsequent research phase/s to other types of building occupancies, such as offices, hotels, public places of assembly, etc. An academic research plan is in the process of being prepared which will be used for submission to secure a grant for the research. Any grant that is awarded will not cover the whole cost of the project, and it is inevitable that there will be a significant shortfall that will need to be covered by sponsorship based funding.

Dry Drains Forum ISH Franfurt Germany 2009

→ **Visit the forum website**
www.drydrains.com

2009 Forum Overview
The 2009 Dry Drains Forum was attended by over 80 industry leaders at the Messe Frankfurt Convention Center in Frankfurt, Germany.

2009 Theme
The issue with Drain-Line Carry

2009 Date
March 11, 2009

2009 Venue
Messe Frankfurt Convention Centre
Frankfurt, Germany

2009 Conference Presentations

Dry Drains Opening Statement
(Powerpoint / 5.54mb)
Prof. John Swaffield - **Heriot Watt University**

Down the pipe
(Powerpoint / 17.14mb)
Dr. Lynne Jack - **Heriot Watt University**

Drainline Transport & Scalding Issues Associated with Low Flow Fixtures
(PDF / 1.04mb)
Ron George - **Ron George Design & Consulting Services**

The issue with Dry Urinals
(Powerpoint / 30.31mb)
Prof. Mete Demiriz - **Gelsenkirchen University**

Leaving a sustainable future
(Powerpoint / 1.29mb)
Don Boynton - **GHD Australia**

Performance compatibility of water efficient fixtures with drainage systems and plumbing codes
(Powerpoint / 20.14mb)
Dr. Steve Cummings, Jeff Clark & Les Barnard - **Caroma Dorf, SA Water, Sydney Water**

Dry Drains Closing Statement
(Powerpoint / 1.15mb)
Prof. John Swaffield - **Heriot Watt University**

2009 Sponsors

20Drains_Ron%20George2.pdf

IAPMO caroma

Appendix D – List of people interviewed

The following identifies the names of people across the plumbing industry whose knowledge and opinions were sought during this research:

1. Don Boynton, GHD
2. Paul Naylor, Master Plumbers Association NSW
3. Stephen Mewett, Master Plumbers Association NSW
4. Paul Angus, ERBAS Consultants, Sydney
5. Ross Brown, Hydraulic Consultant Ross

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