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A brief overview of the assumptions and outcomes for scientific merit and validation of the report titled "Energy and Carbon Savings Opportunities: Water Demand Calculator"

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Executive Summary:

Due to the depletion of renewable water sources throughout recent decades water security and water savings have become increasingly important. The authors of this paper are actively engaged in international efforts to optimize plumbing system performance in the face of growing water scarcity. Given this work, we have tracked closely research considering whether changes to plumbing pipe sizing can conserve water, in addition to the primary benefits of aligning pipe size with more efficient fixtures. We reviewed a study recently developed by IAPMO, through which ARUP prepared a report. This analysis was completed to determine if the methodology used within this report could be a valid approach to incorporate in future testing and research. The review and criticism of the report developed by IAPMO are based on literature reviews and research conducted by the authors of this paper.

Unfortunately, our review found that the report was fabricated with "particular instructions and requirements of [their] client." Although it is understood that this is not a scientific report and does not implement scientific practices or considerations but rather delivers more of a conceptual report with specific objectives, the authors of this paper analyzed each section of the report for accuracy and conceptual value. This paper's primary response focuses on sections 3-8 as other sections were either summaries or did not provide analysis. It was determined that the analysis performed ignored and/or did not state assumptions surrounding key parameters, such as thermodynamics, mass balance, human interactions with fixtures, water temperature, and water pressure. Additionally, assumptions throughout the report were not stated in a manner such that the outlined concepts could be replicated to confirm

accuracy. Furthermore, conclusions that were drawn from the analysis were overstated given the limited scope of the study. The analysis performed (which was inadequate) was further hindered by the lack of layouts tested, the lack of inclusion of various materials, and the lack of representation of different heating distribution systems that exist in the housing market today. There is also confusion surrounding how sizing methods from IAPMO Appendix A and Appendix C achieved the same results for water savings as the Water Demand Calculator given the vastly different flows.

Introduction:

Water security is a topic of increasing discussion among national and international leaders and decision-makers as natural water sources are depleted due to poor management of water supply, pollution, and changes in hydrologic cycles as a result of shifting weather patterns. A vast array of approaches will be required to address water scarcity in the coming years. It is with this in mind that we reviewed a report, dated On March 17th, 2023, by the International Association of Plumbing and Mechanical Officials (IAPMO) in association with ARUP Group Limited on the "energy, water, and carbon savings" associated with the Water Demand Calculator (WDC compared to traditional methods in the United States. The comparison was specifically focused on comparing Appendix E from the International Plumbing Code (IPC) developed by the International Code Council (ICC), and two iterations of Appendix A and Appendix C from the Uniform Plumbing Code (UPC) developed by IAPMO. This report focused on the savings of two essential resources: energy and water. This report is split into nine sections as noted below:

1. Executive Summary
2. Introduction
3. Multifamily Home Prototypes
4. Plumbing Calculations
5. Water Savings
6. Energy Savings
7. Energy Savings Across the Country

8. Embodied Carbon Analysis
9. Conclusion

The intent of this review is to analyze the assumptions and findings of this report to determine the utility of its methods and results. This review will consider major sections, break down key assumptions, and analyze the validity of assumptions and results achieved throughout. As a general note, this IAPMO/ARUP report (hereafter referred to as the IAPMO report) was not peer reviewed and the document specifically says that "it takes into account the particular instructions and requirements of our client. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party." This report was produced with a specific objective and bias in mind, which led to inaccurate results and skewed data.

As a precursory statement to this review, it is noted that there is a lack of scientific evidence supporting the fundamental claim that reduction in pipe sizing in residential buildings impacts water savings. In fact, only one other study discusses that reduction in pipe sizing in premise plumbing systems contributes to water savings, which was another report commissioned by IAPMO. The report was a conference proceeding written by the person that developed the WDC which stated that there should be less flushing required for fixtures that had hot water, however, it cited that water savings depend on fixture efficiency, and the results of the simulation did not show any significant difference in water consumption [1]. The conclusion of that report operates on the same assumption that pipe sizing inherently leads to water savings. Water-saving parameters that have been accepted by the scientific community include public awareness and engagement, water-efficient fixtures, better policies and regulations, improved engineering and or technological advancements, improved social, cultural, and industrial practices, and using alternative sources of water [2-7]. Based on these discoveries, the basis for the IAPMO study is standing on an unproven assumption, solidifying its lack of validity. Nevertheless, to discuss the results and conclusions created in the IAPMO report all relevant sections were analyzed to determine if any additional flaws exist.

Section 3. Multifamily Home Prototypes

The investigative design intent undertaken in this report is a good approach and, on the surface, appears to imply that a holistic overview is considered which can be systematically scaled up across different types of residential occupancies. The layouts and design decisions of the apartments/homes selected by IAPMO are not representative of the market. For example, according to the US Census Bureau, only 39.3% of housing units in the United States contain 3 bedrooms [8]. Making a generalized claim that the results found from this analysis can apply to all newly constructed residential homes is one that cannot be supported by science and statistics. Analyzing the selected units altered the outcome of the results in a manner that artificially inflates water savings for studio, single-bedroom, and two-bedroom living units which comprise approximately 39.1% of all living units in the United States (assuming that pipe sizing does have an impact on water savings to begin with) [8]. From a scientific perspective, analyzing these units can at most provide a specific outcome for these layouts. Any analysis extending beyond these layouts, particularly claims made about savings for the entire country's market, would be scientifically inaccurate. For claims to be made about savings on water and energy across the entire country, a proper scientific study would prove statistically significant results given many factors such as the nature of water use, its dependency on human interaction, and the various types of water heating technologies and distribution systems that are found in residential occupancies beyond a conventional tank-type water heater and branch-type distribution system (which were the only types reflected in this study) [7]. Additionally, for the single-family unit that was included, IAPMO included two hose bibbs in the design of the house. Although this could happen in some cases, it should not be assumed that all houses have multiple hose bibs. Based on the differences between the way the IPC and UPC deal with hose bibbs, this leads to a higher demand for single-family homes for the IPC. Given the limited layouts in this study, its conclusion regarding water savings is inaccurate. The inclusion of this claim in the executive summary without any discussion throughout the paper including substantive evidence to back such claims, makes this report appear to have a scope that expands beyond its true limitations, yielding results that are unsupported given the analysis performed.

To accurately adjust the water savings, an analysis would have to be done on more than a single unit of each type with varying layouts that are more representative of the housing market, otherwise, results cannot be concluded as statistically accurate. When considering regional climate and temperature variations, this point is further signified and highlighted.

Another unique aspect of the selected layouts was that each of the fixtures included in their "longest run analysis" were fixtures that were dependent on human behavior and had the highest flow rates of those fixtures that utilize hot water. Adjusting layouts so that clothes washers, dishwashers, and/or lavatories are the farthest fixtures and reperforming the analysis described in this paper would achieve lower water savings than those achieved in this report, and in some cases no savings whatsoever. The decision to make the furthest fixtures the ones that use the highest levels of hot water in every layout inaccurately reports higher levels of "water savings." It is also worth noting that water savings are dependent on many factors including human behavior, fixture water consumption rates, length of the pipe run between a fixture and the hot water source (e.g., water heater), and properly sized piping. There has been no evidence to support that altering pipe size alone will lead to increased water savings.

Section 4. Plumbing Calculations

In the Plumbing Calculations section of the report, IAPMO restricts the analysis of water, carbon, and energy savings to the use of type L copper piping with specific velocities of 5 ft/s for hot water service lines and 8 ft/s for cold water lines. Today, velocities and piping materials are much more varied in plumbing systems compared to what was utilized in this section of the report and can lead to different head loss as seen in the Hazen-Williams Equation, and Darcy Weisbach Equation. Developed experiments that would provide a more accurate insight into current plumbing practices would require that other widely used piping materials besides copper (e.g., CPVC, PEX) be accounted for along with water service velocities and pressure losses throughout the water distribution system. The selection of velocities has a crucial role in determining the proper size of potable water distribution pipes. Because pipes are developed in nominal sizes the selection of velocity directly impacts the desired pipe size.

Selecting a velocity that is near a threshold can result in different sizing for very similar applications; pipe sizing selection near a threshold can be the difference between an increase or decrease of ¼” or ½” in diameter. Based on the conclusions in the executive summary it appears that the WDC and IAPMO’s existing methodology resulted in the same size of pipes, which brings into question the need for the WDC as a water-saving tool. Additionally, upon reviewing a separate study commissioned in 2018 by IAPMO the UPC and WDC were compared on a singular unit and achieved different results for pipe sizing [1]. This further contradicts the conclusion that the WDC and the UPC resulted in the same size pipes for the analyzed layouts, which subsequently led to the same “water savings” as shown in the graphs displayed in the executive summary in the IAPMO report.

Beyond the flawed assumptions that the results were built on, it is important to observe the results achieved in the plumbing calculations section. In order for a more transparent visualization of this information a table was constructed to show the peak flow for each development (at building level and not the individual unit level). It is also important to note that when calculating the single-family home for the IPC using Appendix E, two hose bibbs were included in the peak flow resulting in an additional 10 GPM (5 GPM per hose bibb) versus only one hose bibb at 2.5 gpm for the WDC and Appendices A & C of the UPC.

	Single Family Unit (GPM)	6-Unit Multifamily Residential	45-Unit Multifamily Residential	48-Unit Multifamily Residential Highrise
IAPMO WDC	11.5	13.6	30.7	31.9
ICC – Appendix E	28.4	44.1	143.8	151.2
UPC – Appendix A	20.2	56.7	207.2	230
UPC – Appendix C	15	45	150	160

Numerous key parameters such as the minimum incoming daily static service pressure and elevation differences between the source of supply and the highest water supply outlet were not included in this analysis; both of which are needed to properly size piping systems in accordance with Appendix E of the IPC. Based on the discussion provided in the previous sections of the report it is assumed that assumptions were either integrated within the report but not specifically stated, or a lack of understanding of the tools provided within Appendix E led to oversized supply systems. Regardless of the cause, an in-depth approach is provided to show how these units could be sized differently to what was shown in this report using Appendix E. The generalized steps to size pipes following Appendix E can be found below.

Step 1. Supply load in the building water distribution system shall be determined by the total load on the pipe being sized, in terms of water-supply fixture units (WSFU), as shown in Table E103.3(2). For fixtures not listed, choose a WSFU value of a fixture with similar flow characteristics.

Step 2. Obtain the minimum daily static service pressure [psi (kPa)] available (as determined by the local water authority) at the water meter or other source of supply at the installation location. Adjust this minimum daily static pressure [psi (kPa)] for the following conditions:

> 2.1. Determine the difference in elevation between the source of supply and the highest water supply outlet. Where the highest water supply outlet is located above the source of supply, deduct 0.5 psi (3.4 kPa) for each foot (0.3 m) of difference in elevation. Where the highest water supply outlet is located below the source of supply, add 0.5 psi (3.4 kPa) for each foot (0.3 m) of difference in elevation.
>
> 2.2. Where a water pressure-reducing valve is installed in the water distribution system, the minimum daily static water pressure available is 80 percent of the minimum daily static water pressure at the source of supply or the set pressure downstream of the pressure-reducing valve, whichever is smaller.

2.3. Deduct all pressure losses due to special equipment such as a backflow preventer, water filter, and water softener. Pressure loss data for each piece of equipment shall be obtained through the manufacturer of such devices.

2.4. Deduct the pressure in excess of 8 psi (55 kPa) due to the installation of the special plumbing fixture, such as temperature-controlled showers and flushometer tank water closets. Using the resulting minimum available pressure, find the corresponding pressure range in Table E104.1.

Step 3. The maximum developed length for water piping is the actual length of pipe between the source of supply and the most remote fixture, including either hot (through the water heater) or cold-water branches multiplied by a factor of 1.2 to compensate for pressure loss through fittings. Select the appropriate column in Table E104.1 equal to or greater than the calculated maximum developed length.

Step 4. To determine the size of the water service pipe, meter, and main distribution pipe to the building using the appropriate table, follow down the selected "maximum developed length" column to a fixture unit equal to, or greater than the total installation demand calculated by using the "combined" water supply fixture unit column of Table E103.3(2). Read the water service pipe and meter sizes in the first left-hand column and the main distribution pipe to the building in the second left-hand column on the same row.

Step 5. To determine the size of each water distribution pipe, start at the most remote outlet on each branch (either hot or cold branch) and working back toward the main distribution pipe to the building, add up the water supply fixture unit demand passing through each segment of the distribution system using the related hot or cold column of Table E103.3(2). Knowing demand, the size of each segment shall be read from the second left-hand column of the same table and the maximum developed length column selected in Steps 1 and 2, under the same or next smaller size meter row. The size of any branch or main does not need to be larger than the size of the main distribution pipe to the building established in Step 4.

When considering the variables described above, different sizing outcomes can be achieved for the same building layout. Exhibit A shows a scenario in which the same distribution system could be sized differently assuming variables held constant by IAPMO are included, and resulted in pipe sizes using the IPC that mirrored the WDC and were less than the UPC and its Appendix C for single family residences, and that were less than the UPC and matched its Appendix C for 6-unit residences. These calculations were done by an outside consultant who works in the industry to ensure accuracy.

Section 5. Water Savings

The claim that "smaller domestic hot water delivery pipe times in non-circulating hot water systems result in shorter hot water delivery times" is accurate, however, this does not directly lead to water savings. Multiple assumptions are baked into the analysis that do not lead to a strong conclusion. The first assumption the analysis is built on is that the user only uses the fixture for hot water. Again, as described in the previous section, if redone with different fixtures this same analysis could result in smaller water savings. The second assumption included is that the fixture is not used until the hot water reaches the fixture, which is essentially assuming human behavior is constant. It is well-recognized throughout the scientific community that human behavior is far from constant. This is why many new peak water demand methods introduce randomness through Monte Carlo simulation [9, 10]. The final assumption included in this analysis is that the uses of fixtures are mutually exclusive and that every time a fixture is used the occupant has to wait for the water to travel from the water heater again. The use of other surrounding fixtures is not considered. For example, if another fixture is immediately downstream of the "farthest fixture," and is operating at the time of use, the time of delivery could be notably shorter rendering the analysis in this paper inaccurate for water savings.

Water use is typically observed to be diurnal, meaning that there are two notable peaks, one before occupants leave the house, and one typically as the occupants return to the house. Following this pattern, it is likely that the users would use fixtures in succession which would significantly shorten the time it took for hot water to reach the fixture. If diurnal patterns were considered, the introduction of thermodynamics and loss would need to be considered to determine the heat loss between uses. The IAPMO report apparently, and inaccurately, determined diurnal patterns to be essentially indistinguishable, although graphs provided did not show this transparently due to the selection of axis. Otherwise, the assumptions made assume that the water is heated from ambient temperature to use temperature every time. Again, this reality shows the simplicity of the analysis and shows that this report needs significant work to show results that are viable and holistic. In order to validate expected savings, a more representative study incorporating monitoring and data collection from residential households must be conducted. Without a scientific comparative study, the conclusions drawn from the analysis in this report on water savings do not have scientific merit.

The primary analysis was calculating the volume of water stored in between the water heater and the furthest fixture. Aside from the issues with assumptions described in the previous sections, the achieved results need clarification. One of the primary concerns is that the WDC and traditional UPC sizing methodologies have significantly different building demands, however, when it comes to sizing systems for a singular unit, the study assumes that the methods produce the same pipe size resulting in no difference in "Water Savings" between the two methods. Based on the results achieved, it appears as if the WDC does not provide any improvement from the UPC. This bizarre result means either that the WDC provides no benefit over the UPC and does not need to be adopted therein, or that the authors are relying entirely on an edge case where the WDC and UPC produce identical results. In addition, as noted above, the fundamental basis of adopting the WDC does not affect how plumbing fixtures operate, or how they are used. Statements in the report to the contrary, without any documented scientific merit, are highly biased.

Section 6. Energy Savings

In this report, it is mentioned that the heat losses do not differ between different houses, and this is because there is no central heating system. However, the size of the pipes provided in three types of buildings are completely different, especially in the case of the 45-unit building, where there are many variations; this is very much contradictory with the heat loss statement.

It is also mentioned that considering that there is a great similarity between the sizing of the pipes and their insulation is the same, their losses are nearly the same. As noted earlier while WDC and UPC have significantly different water demand estimates, the pipe sizing corresponding is identical and there is no difference in heat losses across the two methods, while larger pipe size and higher heat losses are projected for the IPC outcome.

Table 28: 45-Unit Residence Heat Loss Calculator 45-Unit Residence (BTH/hr)

WDC 349 (single unit) 15,700 (entire building)

UPC 349 (single unit) 15,700 (entire building)

IPC 392 (single unit) 17,652 (entire building)

Considering that the discussion of heat loss is dependent on the flow rate and the size of the pipes, and information about the flow rate is not given, this analysis is not accurate.

High-rise Residence

As summarized in Section 6.1.1 High-rise Residence of the report, the booster pump savings were calculated for the high-rise residential building with the following assumptions:

- Duplex booster pumps, each sized at 100% demand.
- Pump efficiency: 70%
- Height to highest fixture: 80 feet

- Total feet of pipe (3lbs/100 ft): 240 feet
- PSI required at highest fixture: 45 psi.
- Pressure loss through incoming water meter: 7.0 psi
- Pressure loss through backflow preventer: 12.5 psi
- Street water main pressure: 74 psi
- Loss in fittings 15% of total feet of pipe: 0.3 psi
- Pumps operate at 50% power for 80% of annual hours; annual operating hours are 7,008 hours.

Unaddressed variations in the assumptions above (pump efficiency, friction pressure losses and pump duty point operating hours) render this analysis very unreliable and an inaccurate representation of energy consumption. In this report, the method of selecting the pump is not clearly explained, and according to the equation shared, pump energy is directly related to flow rate and system pressure losses; however, this does not imply that if the pipe size is reduced, the pump power will automatically be reduced regardless of other parameters.

The relationship between pipe size and flow rate is more complex than a simple decrease or increase. The flow rate in a pipe is influenced by various factors, including pipe diameter, length, material, fluid properties, and pressure differentials. In general, if all other factors remain constant and the diameter of a pipe decreases, the flow rate is likely to decrease. This is due to the principle of conservation of mass, which states that the mass of fluid entering a section of a pipe must be equal to the mass of fluid leaving that section. Since the cross-sectional area of a smaller pipe is reduced, the fluid velocity must increase to maintain the same flow rate, which can result in a decrease in flow rate.

However, it is important to note that other factors, such as pressure differentials, can affect the flow rate as well.

In summary, as highlighted in the earlier sections above, reduced pipe sizing does not necessarily result in reduced water consumption or reduced flow rates where human behavior and fixture characteristics more directly correlate with flow rate variations. Similarly, without a reduction in flow rate, decreasing pipe size does not necessarily lead to a decrease in pump energy consumption; in fact, a reduced pipe size at the same flow rate may actually result in higher friction losses thus yielding higher energy demand by the pump. In short, the relationship is more nuanced and depends on multiple factors such as system pressure losses, flow velocity, and pump efficiency across a full range of operating conditions.

Given the broad range of design variability with use of booster and circulation pump systems in high rise buildings, the design hypothesis presented in this report appeared to be very elementary, simplistic, and highly generalized without the specificity necessary to validate of potential energy saving implications.

Sections 7 & 8: Energy Savings and Embodied Carbon Analysis Across the Country

These sections of the report represent a highly generalized and simplified approach to demonstrate national-scale energy savings and embodied carbon analysis following the same flawed assumptions made when computing water demand savings in the earlier sections of the report. Geographic parameters such as temperature, topographic gradient variations, piping materials and water distribution network differences in pressure and velocity at utility scale are ignored. A scientific analysis of “high rise residence pumps” should have been at least modeled for thermal and pressure loss variations and normalized using resources readily available from EPANET across regions. However, as highlighted in the above discussions, given that the water savings projected in this study cannot be scientifically validated, the energy and carbon reductions noted cannot be substantiated.

The energy balance calculation for pressurized water networks is a crucial step in assessing the energy efficiency of water distribution systems. However, the calculation generally requires mathematical modelling of the water networks to estimate three important energy components: outgoing energy through water loss, friction energy loss and energy associated with water loss. The approach undertaken in this report did not consider this basic theoretical approach when projecting and comparing energy savings, thus rendering the analysis scientifically unreliable and inaccurate.

Conclusion

From a scientific perspective, the report presented by IAPMO lacks a scientific approach and overall does not achieve accurate results. Based on disclosures given by ARUP stating the intent of this document was created with specific instructions from the funding agency, IAPMO, this study lacks any type of peer review or validation from the scientific community and appears as if the experiment was designed to portray a result that was already fabricated. The fundamental principle upon which this study was based (that pipe sizing can contribute to water savings) has yet to be scientifically proven. If this was overlooked, which it should not be, many other factors found throughout this report make the results achieved inaccurate, including its multiple missing assumptions—such as including ignoring human interactions with fixtures in water savings analysis, ignoring thermodynamics and diurnal patterns in water savings analysis, under representation of the housing market in terms of unit testing, lack of inclusion of new and advanced water distribution technologies, restricted studies to just one type of piping material, lack of discussion on incoming water pressure for referenced layouts, lack of scientific analysis such as mass and energy balances, and improper assumptions on energy savings. To exasperate the issues within this report, it also overstates the conclusions that can be drawn from it by expanding beyond its scope. The study's skew is further illustrated within Appendix A where, utilizing the same distribution system and holding constant the variables IAPMO included, IPC pipe sizes were found to be equivalent to the WDC and less than the UPC. The results achieved in this paper should not be considered as fact and the analysis preformed needs to include many more factors in order to achieve trustworthy results with actual implications for water conservation. Ignoring these factors led to fictional water savings, rather than realistic results.

Exhibit A: Proper Utilization of ICC Appendix E to Size Multiple Scenarios Corresponding to Layouts Provided in the IAPMO Report on Carbon and Energy Savings.

Appropriate Sizing for a Single-Family Residence - IPC Appendix E

The IAPMO report did not include information on available static pressure at the water meter. Assuming a commonly observed average pressure of 50 to 60 psi and maximum developed length (MDL) of 40 to 100 feet for comparison only, while using Table E104.1 in the IPC, we can determine that with an available pressure of 50 to 60 psi and an MDL of 40 to 100 feet the water service line would be ¾ and not the 1 ¼ as proposed in the report.

The flow rate values in the IPC charts below are WSFU and not GPM. The approach in the IAPMO report cites a total WSFU of 17.1. Adding in two hose bibs at 2.5 WSFU each (a measure accepted by the IPC), the total WSFU is 22.1. Utilizing the charts (as found in Appendix E within the IPC 2021 and shown below) 22.1 WSFU would permit a water meter and service line size of ¾ as opposed to the 1 ¼" line determined in the IAPMO report.

TABLE E104.1
MINIMUM SIZE OF WATER METERS, MAINS AND DISTRIBUTION PIPING BASED ON WATER SUPPLY FIXTURE UNIT VALUES (w.s.f.u.)

METER AND SERVICE PIPE (inches)	DISTRIBUTION PIPE (inches)	MAXIMUM DEVELOPMENT LENGTH (feet)									
Pressure Range 50 to 60 psi		40	60	80	100	150	200	250	300	400	500
3/4	1/2[a]	3	3	2.5	2	1.5	1	1	1	0.5	0.5
3/4	3/4	9.5	9.5	9.5	8.5	6.5	5	4.5	4	3	2.5
3/4	1	32	32	32	32	25	18.5	14.5	12	9.5	8
1	1	32	32	32	32	30	22	16.5	13	10	8
3/4	1 1/4	32	32	32	32	32	32	32	32	29	24
1	1 1/4	80	80	80	80	80	68	57	48	35	28
1 1/2	1 1/4	80	80	80	80	80	75	63	53	39	29
1	1 1/2	87	87	87	87	87	87	87	87	82	70
1 1/2	1 1/2	151	151	151	151	151	151	139	120	94	79
2	1 1/2	151	151	151	151	151	151	146	126	97	81
1	2	87	87	87	87	87	87	87	87	87	87
1 1/2	2	275	275	275	275	275	275	275	275	247	213
2	2	365	365	365	365	365	365	365	329	272	232
2	2 1/2	533	533	533	533	533	533	533	533	533	486

Appropriate Sizing for a the Six-Unit Residence – IPC Appendix E

Using the same charts from Appendix E of the IPC and assuming that the MDL is now between 40 to 200' with an available static pressure of 50-60 PSI, and based on 102.6 WSFU as indicated in the IAPMO report, the water meter size/service line size is 1 ½ inches and not the 2 inches that is indicated in the IAPMO report..

TABLE E104.1
MINIMUM SIZE OF WATER METERS, MAINS AND DISTRIBUTION PIPING BASED ON WATER SUPPLY FIXTURE UNIT VALUES (w.s.f.u.)

METER AND SERVICE PIPE (inches)	DISTRIBUTION PIPE (inches)	MAXIMUM DEVELOPMENT LENGTH (feet)									
Pressure Range 50 to 60 psi		40	60	80	100	150	200	250	300	400	500
3/4	1/2[a]	3	3	2.5	2	1.5	1	1	1	0.5	0.5
3/4	3/4	9.5	9.5	9.5	8.5	6.5	5	4.5	4	3	2.5
3/4	1	32	32	32	32	25	18.5	14.5	12	9.5	8
1	1	32	32	32	32	30	22	16.5	13	10	8
3/4	1 1/4	32	32	32	32	32	32	32	32	29	24
1	1 1/4	80	80	80	80	80	68	57	48	35	28
1 1/2	1 1/4	80	80	80	80	80	75	63	53	39	29
1	1 1/2	87	87	87	87	87	87	87	87	82	70
1 1/2	1 1/2	151	151	151	151	151	151	139	120	94	79
2	1 1/2	151	151	151	151	151	151	146	126	97	81
1	2	87	87	87	87	87	87	87	87	87	87
1 1/2	2	275	275	275	275	275	275	275	275	247	213
2	2	365	365	365	365	365	365	365	329	272	232
2	2 1/2	533	533	533	533	533	533	533	533	533	486

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