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Increase in Flow Diversity From Simultaneous Fixture Use: Impact on Peak Flow Estimate

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Foreword and Purpose

An increase in fixture count increases the variety of possible flows from a combination of fixtures. Flow diversity from the simultaneous use of multiple fixtures is important in estimating peak water demand. This paper explains the factors that affect flow diversity and their effect on estimating peak demand using the Water Demand Calculator™.

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IAPMO White Paper

Increase in Flow Diversity From Simultaneous Fixture Use: Impact on Peak Flow Estimate

Executive Summary

In calculating peak water demand, there can be instances where an increase in fixture count results in a decrease in the expected peak demand. This white paper explains why this counterintuitive result can occur, especially when there is some probability of stagnation (i.e., zero demand). Using IAPMO's Water Demand Calculator™ (WDC), we are not designing with zero flow in mind; hence, zero flows are ignored, and the 99th percentile is extracted from actual flows for any combination of busy fixtures. This process is referred to as zero-truncation, and it is used in the Exhaustive Enumeration (EE), Convolution (CONV), and Modified Wistort's Method (MWM) techniques in the WDC. A counterintuitive result occurs when the newly introduced fixture has a different and sometimes significantly lower flow weight due to a combination of its probability of use and flow rate. Introducing a fixture with different probability of use and flow rate increases the flow diversity and creates a new distribution of flowrates from the combinations of busy fixtures. Extracting the 99th percentile demand from this new flow rate distribution might reduce the peak demand. If all the fixtures had the same flow properties, adding one more similar fixture would not reduce the peak demand estimate.

Discussion

The current Water Demand Calculator™ has three methods of estimating peak demand. WDC version 2.1 has Exhaustive Enumeration (EE), Modified Wistort's Method (MWM), and Wistort's Method (WM), while in the WDC version 2.2, Convolution process replaces EE. Each method estimates peak demand transitioning from small buildings with few fixtures to mid-size and very large buildings. Each method requires three key fixture parameters to evaluate the peak water demand: n, the number of fixtures; p, the fixture probability of use (p-value); and q, the fixture flow rate. The combination of these three parameters creates a fixture flow property (mean, variance) that determines how much weight a fixture has when combined with the properties of other fixture types to estimate the expected peak demand.

In any calculation process, it is often expected that when the input increases, there should be some corresponding increase in the output. In this case, when the number of fixtures increases, the predicted demand should also increase or, worst case, be the same as before the newly added fixture. For example, adding the fixtures in a laundry room to a branch servicing a bathroom should increase the demand for that branch. However, this way of thinking is not always true since the output here also depends on the newly added fixture parameters—p-value and flow rate, which determines the probability of simultaneous use.

What happens is an increase in fixture count (with its flow properties) increases the flow diversity; that is, there is an increase in the variety of possible flow rates created from the combinations of busy fixtures. This increase in flow diversity creates a new flow distribution different from the previous one before adding a new fixture. The new fixture adds to the variety of possible demand flows and changes their probability of occurrence and other flow properties (combined flow mean or variance). A decreased demand output is predominantly in examples with some probability of stagnation.

Since we are not designing for zero flow, the instances of zero flows are eliminated in the EE, CONV and MWM process, thus creating a zero-truncated flow distribution with new flow properties. Even if it seems counterintuitive for the estimated peak flow rate to decrease as the number of fixtures increases, this does not indicate a flaw in the EE process, CONV or MWM model. A possible reduction in the output (i.e., 99^{th} percentile demand estimate) is a feature of the truncated distribution for a combination of fixtures with significantly different flow rates and *p*-values. The new fixture flow properties act as weights in the new flow distribution. See some examples below:

> *In the EE and CONV process, an initial fixture configuration consisting of three toilets (q = 3 gpm) has a 99^{th} percentile demand of 6 gpm. After adding one bath sink (q = 1.5 gpm) to the existing three toilets (now four fixtures), the 99^{th} percentile demand decreased to 4.5 gpm. This decrease in the 99^{th} percentile demand was also demonstrated through Monte Carlo simulation, which validated the correctness of the calculations.*
>
> *Likewise, in the MWM model, an initial fixture configuration (base case) consists of 33 fixtures with a 99^{th} percentile demand of 15.9 gpm, as shown in the table below. Cases 1 through 6 have an extra fixture added to the base case. Cases 1 through 4 show a decrease in the 99^{th} percentile demand, while cases 5 and 6 show an increase. Rounded up to zero or one decimal place, there will be no difference in the 99^{th} percentile demand.*
>
> *The CONV process is a simplified EE process. It reduces the possibility of counterintuitive results while transitioning between CONV and MWM techniques in the WDC version 2.2.*

Case	Fixture combination	Total Fixture Count	Probability of Stagnation	99th Percentile from MWM (gpm)
Base	**3 Clothes washer, 3 Dishwashers, 12 Bath sinks; 6 Tub Shower Combo and 9 Toilets**	**33**	**0.4244**	**15.912**
1	Base + 1 Dishwasher (q = 1.3 gpm)	34	0.4223	15.905
2	Base + 1 Bath sink (q = 1.5 gpm)	34	0.4159	15.881
3	Base + 1 Shower (q = 2.0 gpm)	34	0.4053	15.857
4	Base + 1 Kitchen sink (q = 2.2 gpm)	34	0.4159	15.895
5	Base + 1 Toilet (q = 3.0 gpm)	34	0.4202	15.922
6	Base + 1 Clothes washer (q = 3.5 gpm)	34	0.4011	16.042

> *Because the EE and CONV process utilizes the exact result of possible demand flows, the counterintuitive results are easy to observe compared to the MWM—where the decrease in the design demand is usually in the second or third decimal place. Note that this "counterintuitive" phenomenon does not occur when all the fixtures have the same p-value, and flow rate, i.e., the diversity in flow does not change.*

For Wistort's method, there is no probability of stagnation. However, there might be scenarios where an increase in fixture count seems to reduce the expected peak demand. This happens when fixtures with higher weights (q and *p*-values) are replaced with fixtures having lower weights.

> *For example, replacing 10 combination tub/showers with 10 shower heads will reduce the expected peak demand since the combination tub/shower has higher flow rates (5.5 gpm) and p-values compared to the showerhead (2 gpm). Similarly, adding 5 or 10 extra shower heads might not result in an equal or greater peak demand compared to when there were 10 combination tub/shower fixtures because of the increased flow diversity for the new combination of fixtures.*

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