

## How Much Water Supply Capacity Should a Public Water System Have?

By: Andrew Jacque, Ph.D. PE  
Senior Project Engineer  
Town & Country Engineering, Inc.

Appropriate sizing of public water systems is extremely important for many reasons. An undersized system could result in loss of system pressure, which could be detrimental to the public health, safety and welfare of a community. An oversized system is inefficient, wasting valuable resources on the construction and maintenance of unneeded facilities. In addition, excess capacity could promote wasteful use of the system and could result in water quality concerns due to high water age. Unfortunately, regulations specific to water system sizing are lacking, leaving the sizing of water systems to engineering practice. To further complicate matters, published engineering recommendations regarding water system sizing vary considerably.

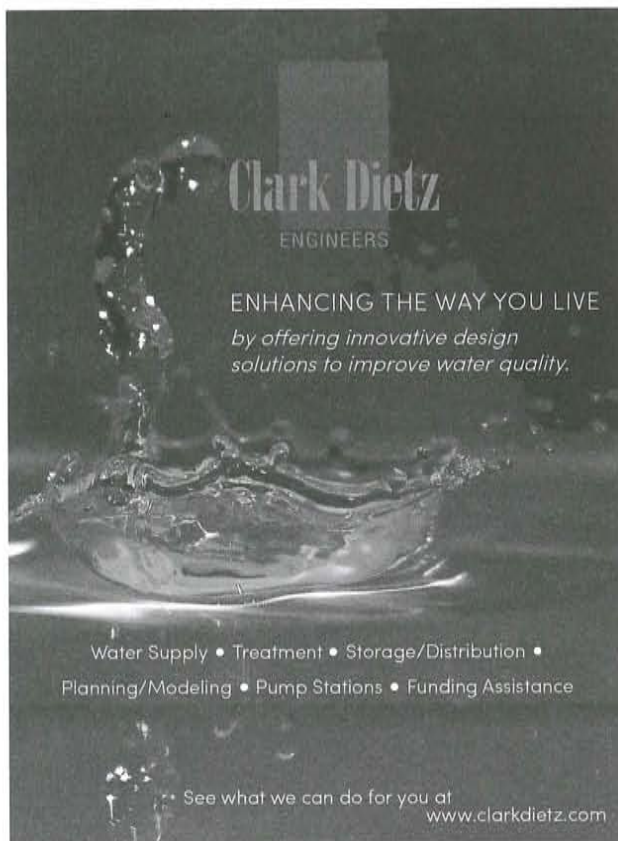
Wisconsin's drinking water regulations indicate a community water system (CWS) should be sized to reliably supply the demands of the water system using available sources of supply. Supply sources constitute water available for use, including water pumped from a well or treatment plant and drawn from storage. Demands can include daily usage for

residential, commercial and industrial purposes, as well as intermittent usages such as fire protection, swimming pool filling, water system flushing, water storage maintenance, and watermain breaks/leakage. Design flows should be based on the maximum hour demand or the maximum day demand plus fire flow requirement, whichever is greater.

A reliable CWS will use a risk assessment approach to quantify anticipated demands and size sources of supply with reserve capacities and/or redundancies to account for unanticipated demands and system failures. Unfortunately, a universally acceptable definition of water system reliability does not exist. Reliability can be as simple as providing redundant system components, or can be determined by complex modeling with system specific parameters. Reliability models can include probability functions such as "time to failure" analysis of components, and severity indices for failure types (Goulter et al, 2000). Advanced reliability modeling methods, which require specific water system information, appear to be best suited for medium to large water systems where multiple components, each with the potential to fail, contribute to the overall reliability of the system.

For small systems, redundant supply appears to be the most appropriate reliability method because of the limited number of vulnerable components present in these systems. For example, small and very small systems in Wisconsin contained an average of 2.1 wells in year 2003, with 23% of these systems only having one well. For these systems, on average, if one well failed the system would be left with one operational well. The redundant supply approach simply indicates that the remaining well(s) must satisfy the peak demand without the need for advanced modeling.

There is general consensus in literature and engineering reference manuals with the redundant supply approach to system reliability. A number of sources indicate that a CWS should be sized to satisfy the maximum day demand plus fire demand with the largest pumping unit out of service (Al-Layla et al, 1977; AWWA, 1998; AWWA, 2002; Wetzel, 1990; Ysusi, 2000). AWWA extends this definition to include maximum hour demands (no fire demand) with the largest pumping unit out of service. For planning and analysis purposes, the maximum day or maximum hour demand is generally deemed to be the largest recorded demand for the preceding three year period (AWWA, 1998; Lindburg, 1992). These sources do not describe the analysis period or demonstrate how to analyze water system capacity.



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There is considerable variation among engineering recommendations, government regulations and approaches for determining fire protection requirements of a CWS. American Insurance Association (AIA) developed a population based approach (**Equation 1** and **Equation 2**) to estimate the minimum recommended fire protection rate for a community. According to the AIA approach, fire protection duration should not exceed 10 hours (Lindburg, 1992). Fredrick County, Maryland established a fire protection rate based on AIA's approach, but recommends longer durations for each fire protection rate. This approach results in a much larger quantity requirement, depending upon the population being served. A comparison of AIA recommendations and Fredrick County's recommended fire protection capacity shows that for smaller populations, Fredrick County's approach would require a significantly larger quantity of water for fire protection. For example, a community of about 3,000 people would have a recommended fire protection capacity of about 100,000 gallons according to AIA, or 735,000 gallons according to Frederick County.

$$Q = 1020\sqrt{P}(1 - 0.01\sqrt{P}) \quad (1)$$

$$T = Q/1000 \quad (2)$$

Q = fire protection rate (gpm)

P = population (1,000's)

T = duration (hours), rounded to nearest hour

Insurance Services Office (ISO), an independent insurance industry advisory agency, calculates recommended fire protection rates for communities based on a physical survey of actual buildings within a community. Physical surveys document items such as building construction materials, square footage, occupancy type, presence of fire suppression systems and distance to fire suppression equipment. Physical surveys are performed throughout a community based on an assessment of at-risk structures, with the information that is gathered maintained and updated by ISO on an as needed basis. Based on these physical surveys, ISO calculates a recommended fire protection rate for each building surveyed, which they term as needed fire flow (NFF). ISO then uses the fifth highest NFF as the recommended fire protection rate for a community. This fire protection rate makes up about 40% of a community's ISO's Public Protection Classification (PPC), which includes other factors such as personnel training, hydrant maintenance, equipment, and historic response time. The PPC is used by insurance companies in setting property insurance rates for communities.

The three fire protection approaches discussed here result in a considerable difference in the recommended amount of fire protection capacity needed by a community, as well as variation in the recommended fire protection rate. The natural question then is which recommendation should be used? All three approaches are minimum recommendations, giving guidance to local governments for use in

setting fire protection capacity. However, ISO's approach uses physical data to support their recommendations. In addition, ISO's calculations and approach are tied to property insurance rates, meaning insufficient capacity could result in higher property insurance rates, not to mention increased risk of loss. Use of a fire protection rate greater than ISO's recommendation would reduce risk but not necessarily insurance rates, and could result in more costly facilities to construct and maintain.

The risk of a large fire is relatively small, with about 95% of all fires in a year extinguished by the use of a single fire hose. In addition, large communities may experience three large fires in a year whereas small communities might only experience one every few years (AWWA, 1998). According to the Wisconsin Department of Commerce (2005), 53% of Wisconsin fire departments reported having a fire incident in 2003 in their community, for a total of 11,100 fire incidents. Of this total, 33% were structure fires. Residential fires accounted for 37% of the incidents, while commercial related activities accounted for 15% of the incidents. Approximately 9% (943 incidents) required mutual aid, indicating a large fire incident had occurred.

Wisconsin, like most states, does not require that fire protection be provided through water system capacity. However, it appears to be common practice in Wisconsin based on the fact that approximately 98% of municipal water systems contain hydrants listed for the purpose of fire protection in annual reports filed by these communities with the Wisconsin Public Service Commission. Alternate sources of fire protection include dry hydrants at water bodies such as streams, rivers, lakes and storm water retention ponds, or could include swimming pools.

A number of literature sources recommend adding reserve storage capacity for use during emergency events, however these recommendations vary considerably. One recommendation uses a blanket approach, indicating reserve storage capacity should be equal to the average day demand (Mandl, 2003). This is consistent with Wisconsin DNR regulations under NR811 and recommendations in Ten State Standards if a groundwater based system has only one well. Reserve storage capacity could also be considered as the amount of water needed to satisfy demands during failures, power outages and/or natural disasters (Ysusi, 2000; Chin, 1999). This reserve recommendation could be satisfied in other ways, such as redundant supply. In addition, power outages could be addressed through the use of alternate power sources, as required by Wisconsin Administrative Code NR811.

Recommendations for reserve storage capacity are another way of looking at system reliability, and can be satisfied through means such as added storage capacity, redundant

**Supply Capacity** *continued on next page*



## Supply Capacity *continued from previous page*

supply, auxiliary power or a combination of these means. A community needs to evaluate which reserve capacity method is most beneficial to their community when deciding how to allocate capacity for unknown situations such as failures, power outages, loss of source, and natural disasters.

A number of "rules of thumb" design guidelines are cited in literature to indicate adequacy of system capacity. On a maximum day basis, the average pump run time using all wells should be less than 22 hours according to Al-Layla (1977), 20 hours according to Ten State Standards (GL-UMRB, 2003), or 18 hours according to recommendations of the Wisconsin DNR. On an average day basis, the average pump run time using all wells should be less than 12 hours according to Ten State Standards (GL-UMRB, 2003) and recommendations of the Wisconsin DNR. If a community has only one source of supply, the storage amount should be at least the average day demand. These rules of thumb do not consider specific operation parameters, and may not be appropriate for determining adequacy of water system capacity.

### Available Water System Capacity

Firm source capacity is a term used to describe the available source capacity of a CWS when the largest pumping unit, treatment process or source pipeline connection is out of service. The term firm well capacity has the same meaning, but is specific to a groundwater based system. Storage facilities, while sized for a certain capacity, are rarely completely filled. Effective storage capacity is the minimum

amount of storage normally available for usage (AWWA, 1998), reflecting the capacity left in storage at the low end of the operational range. The portion of storage which fluctuates under normal usage is defined as operational storage, and may not be present if needed, thus it is excluded from effective capacity. The term dead storage describes the minimum amount of water that should be kept in storage to prevent emptying under demand conditions. Unavailable storage represents the volume above the operating range that needs to be excluded to allow

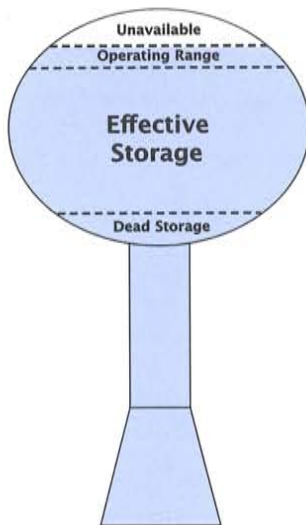


FIGURE 1. Effective storage capacity is the minimum amount of storage that is available after accounting for unavailable storage, operating range and dead storage.

for proper control and alarming functions. Calculation of effective storage capacity is illustrated in Figure 1. Firm capacity then is the combination of firm well or firm source capacity plus effective storage as shown in Figure 2.

The portion of firm capacity that is made up of effective storage is typically based on engineering analysis. Generally though, it makes sense to size firm source capacity to satisfy the maximum day demand, with effective storage used for fire protection and maximum hour demands. This approach allocates normal demands and maximum day demands, which are smaller in magnitude,

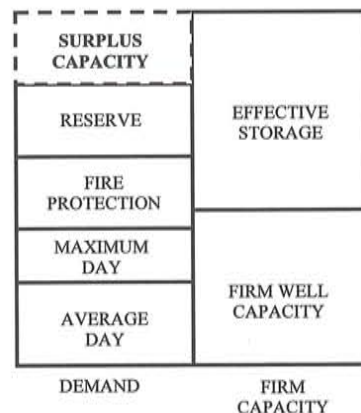


FIGURE 2. Graphic illustration for the calculation of firm capacity for a water system. Relative size of well represents pumping capacity.

to source capacity, and larger demands of short duration to storage capacity, which can be delivered into the water system at faster rates via gravity flow (elevated storage) or large booster pumps (ground reservoir). However, when sizing storage capacity, it is important to consider operation issues such as water quality, aging and thermo clines (Grayman et al, 2000), in addition to satisfying regulatory requirements. For Wisconsin, water quality issues are usually limited to warm weather periods, though not always. If water is in storage for an excessive period during warm weather, loss of disinfectant residual could result which may lead to bacterial growth and/or biofilms. An equally important concern for Wisconsin is freezing or damage of storage facilities by ice sheets, which could occur with excessive storage detention times.

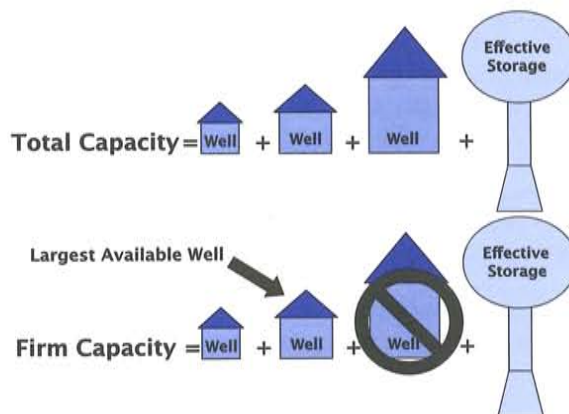


FIGURE 3. Illustration for the calculation of surplus water system capacity for maximum day demand plus fire protection.



### Calculating Spare Capacity

Putting all these engineering recommendations together, determining demands, source capacity and ensuring reliability, spare capacity of a community water system is the lesser of Equation 3 and Equation 4, which represent firm capacity minus system demand for various time periods.

Breaking these equations down, firm capacity is the sum of firm well or firm source capacity plus effective storage divided by analysis basis. Analysis basis is the fire demand duration (system specific) for Equation 3 and 60 minutes for Equation 4. These calculations represent the amount of water which would be considered available for use in a water system if the largest well or source were out of service due to failure or scheduled maintenance. System demand also depends upon which equation is used. For Equation 3 (the fire duration during maximum day demand analysis), system demand is the sum of fire demand plus sum of reserve requirement plus maximum day demand (highest 3-year value) divided by analysis basis. For Equation 4 (the maximum hour demand based analysis), system demand is the sum of reserve requirement plus maximum hour demand (highest 3-year MH value \* 60) divided by analysis basis. For all equations, using firm well capacity and reserve may be overly conservative, so one could use firm well capacity with no reserve, or reserve with total well capacity substituted for firm well capacity. Spare capacity then is the result obtained by subtracting system demand from firm capacity.

$$SC = FWC + \frac{ES}{T * 60} - F - \frac{(R + MD)}{24 * 60} \quad (3)$$

$$SC = FWC + \frac{ES}{60} - \frac{(R + MH * 60)}{60} \quad (4)$$

SC = spare capacity (gpm)

FWC = firm well (or source) capacity (gpm)

ES = effective storage (gallons)

R = reserve (gallons)

F = fire demand rate (gpm)

T = fire demand duration (hours)

MD = maximum day demand (gallons)

MH = maximum hour demand (gpm)

Figure 3 and Figure 4 are illustrations of spare capacity for a theoretical water system. Demands are shown on the left while firm capacity is shown on the right. Figure 3, which represents surplus capacity, shows maximum day demand being supplied by firm well capacity, and storage capacity utilized to satisfy fire demand during a maximum day event. Figure 4 shows deficit firm capacity. This illustration shows that effective storage is needed to satisfy

the maximum day demand and that if reserve storage were needed there would be a deficit in firm capacity. However, Figure 4 also indicates that the system has surplus capacity if reserve capacity is not necessary. These figures hold for each analysis basis (maximum day demand plus fire demand or maximum hour demand) to quantify spare capacity.

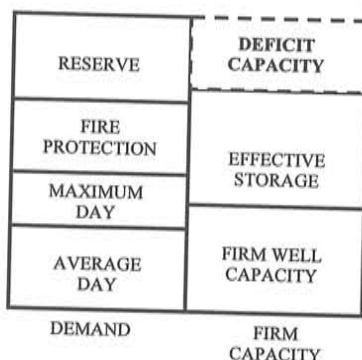


FIGURE 4. Illustration for the calculation of deficit water system capacity for maximum day demand plus fire protection.

### Water System Planning

In addition to assessing current water system capacity, spare capacity equations can be used for planning facility maintenance or for when to construct additional capacity. For planned maintenance activities, such as hydrant flushing, well rehabilitation, pump maintenance, storage facility inspection and/or painting, or critical water main replacement, water system demands could be analyzed for the year on a monthly basis to determine the time of year that these maintenance activities could be performed without impacting overall capacity. Capital improvement planning could be performed five and ten years out by input-

ting predicted maximum day demand, maximum hour demand and current capacities (well and storage) into these equations. If the predicted spare capacity is negative, the absolute value is the minimum amount of additional capacity needed. Further analysis would determine what type of capacity to add, whether it should be source capacity, storage capacity, demand reduction (conservation) or some of each.

To perform a capacity analysis, accurate and system specific data are needed. System specific data includes pumping, treatment and storage capacities, monthly demand data, maximum day and hour demand data, required fire protection rate and duration, and reserve capacity requirements. Much of this data can be obtained from reports required by Wisconsin DNR and Wisconsin Public Service Commission. Maximum hour demand data are difficult to obtain, but can be programmed into a SCADA system.

For water systems that provide fire protection, it is important that water system personnel and fire department officials maintain open lines of communication. This proactive measure will ensure that fire protection capacity requirements of the fire department are incorporated into water system facilities, and that operational and maintenance needs of the water system that may temporarily limit fire protection capabilities are discussed with the fire department. This communication will also allow for determination if fire department needs can be easily provided for by the water system or if there is a need to establish alternate fire protection sources such as dry hydrant connections to surface water bodies and storm water retention ponds. ♦