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Course № C-1011

Introduction to Accurate Water Demand Projection

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Introduction

Engineers in local government, working in such places as the municipal public works department, the regional water supply agency, or the county engineer office, are often asked to estimate future demand of water. (One will hear the words projection, prediction, and forecast used interchangeably to describe this process. While all three terms are related, different fields assign different meanings to each; a forecast to a meteorologist is not necessarily the same as a forecast to an economist. For purposes of this course, we will refer to estimating future demand as projection). Engineers have a responsibility to make these projections as accurate and relevant as possible. This course will introduce ways to do so.

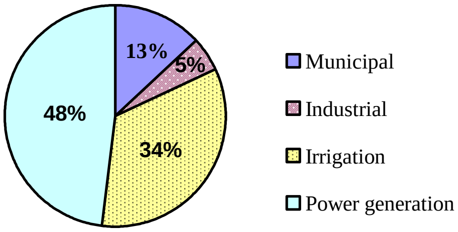
Why do engineers care about accurate projection? First, water is obviously vital to human habitation. Second, the water supply industry is extremely capital-intensive, and water supply capital facilities are particularly long-lived. (Some existing water supply infrastructure has been in use for over one hundred years). For these reasons—the necessity, the high cost, and the longevity—it is important that water supply questions be carefully considered; the answers will have far-reaching economic consequences. Furthermore, in the fastest growing parts of the United States, water resources are being stretched while local government budgets are shrinking. Even though water is cheap to the consumer, it is certainly not free. The value of water includes: (1) the water supply agency's operation and maintenance costs; (2) capital costs to procure and develop additional water supplies to meet growing demands; and (3) social and environmental "opportunity costs" of losing other benefits of the water and natural waterways [1]. Accurate demand projection is important in keeping all of these costs to a minimum.

Water Use

Water use is typically broken into different categories by water planners: public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power cooling. Total water use in the United States during 2000, the most recent year for which statistics were available, is estimated at 408,000 million gallons per day (MGD). For purposes of simplicity, in this course we will focus on a category called municipal that is comprised of public supply, domestic (private wells), and commercial.

On average, municipal consumption accounts for only about 13% of total water consumed. The two largest water users continue to be thermoelectric power generation (one combined-cycle power plant can use five million gallons of water per day for cooling) and agricultural irrigation. Industrial water use makes up the difference. See Chart 1 [2]. These are national figures; clearly every region, state, and locality will have different mixes.

Chart 1: National Average Water Use by Sector



Of municipal consumption, 42% of annual water use is for indoor purposes while 58% is for outdoor purposes like watering the lawn.

Projection Methods

Straight Line

The simplest method to project future demand is to extrapolate current trends into the future. We will call this method the straight line method. One multiplies the projected future population by the current unit rate of water consumption to determine future water demand.

Example 1

Pleasantville, USA, has a current population of 200,000. Average per capita water consumption is 180 gallons/day (according to the EPA, this is the national average). This yields a total municipal water demand of 36 million gallons per day (MGD).

The city planning office has predicted that Pleasantville will grow by 1% each year for the next 20 years. The compound growth equation

$$F = P\ (1+n)^t$$

where F is future population, P is present population, n is growth rate, and t is time horizon, reveals that in 2025, the population will have grown to 245,000, and municipal water demand will reach 44 MGD.

Table 1: Current and Projected Water Use in Pleasantville

Year	Population	Municipal Water Demand (MGD)
2005	200,000	36
2025	245,000	44

If the city engineer were planning future water projects, he would conclude that over the next 20 years, his capital program must contemplate increasing the available water supply by eight million gallons a day.

Population Variation

The straight line projection method makes two important assumptions. First, it assumes that the both current and future populations are monolithic. Or, in other words, it ignores the variation in water use among the different elements of the population. Household income, household composition, and household size are all examples of the differentiating factors that can influence water use. To better understand this, let's go back to Pleasantville.

Example 2

In Pleasantville, water meter and billing data have shown that the water use varies among income groups, as shown in Table 2.

Table 2: Water Use by Household Income

	Household Income ($k)			
	Above 60	40-60	20-40	Below 20
Water use (gal/person/day)	240	190	165	130

Furthermore, census data show that the current population of Pleasantville is stratified as shown in Column A of Table 3. The state planning office has estimated that based on state employment trends, Pleasantville will grow more quickly in the lower income groups than in the upper groups. Column B of Table 3 shows the estimated population composition for the year 2025.

Table 3: Current and Projected Population Composition by Household Income

	A (2005)		B (2025)	
Household Income ($k)	Population	% of total	Population	% of total
Above 60	30,000	15	32,000	13
40-60	70,000	35	76,000	31
20-40	70,000	35	91,000	37
Below 20	30,000	15	46,000	19
Total	200,000	100	245,000	100

Multiplying each segment population by its respective rate of per capita water use, and then summing them, the city engineer calculates the projected water demand as 43 MGD, a difference of 1 MGD from the straight line projection. While this may not seem like a lot, it is a savings of over 10% of the originally projected need, which could be the difference between expanding a water treatment plant or not. More importantly, it illustrates that a straight line projection often overestimates future need.

Demand Side Management

The second assumption in the straight line projection method is that future per capita water demand will remain unchanged as well. This is of course not necessarily true. There are many factors that could change future water use. In fact, water supply agencies themselves can actually reduce this demand through a process called Demand Side Management (DSM). Instead of building new water treatment plants to increase supply to respond to increasing customer demand, water suppliers can try to reduce their customers' demand for water through price incentives, use regulation, and other policies. DSM is well known and successful in the electricity production industry as a way of meeting future demand efficiently and cost-effectively.

DSM has great potential to similarly aid the water supply sector, but unfortunately, many water supply agencies are reluctant to consider it. They often fall victim to what Bollard and Baumann call the “water management myths” [3].

Water Management Myths

Water is a necessity

Many claim that since water is so immediately necessary to life, it is not an economic good like other goods. By this argument, water demand is fixed and can’t be affected by price incentives or policy interventions. However, while it is true that *water* is necessary for life, an *urban water supply* is not. An urban water supply is essential to our quality of life, not to life itself. In this sense, then, water is no different from food, shelter, and warmth, all of which are necessary and all of which are subject to the laws of economics. In other words, water suppliers are not slaves to the inflexible demands of their customers.

Water users are price inelastic

Many say that water users don’t respond to price. The reasons for this are varied: water is a necessity; water use is ingrained habit; water use constitutes such a small part of the domestic budget. However, the fact is that water users *do* respond to price. Studies estimate this elasticity to be between -0.07 and –0.20 [2], which means that for every 1.0 unit increase in the price of water, there will be a 0.07 to 0.20 unit decrease in water consumption.

Water, sewer, and solid waste disposal together account for a relatively small share of the average household budget—less than 0.8% of total expenditures. By comparison, electricity accounts for 2.4% and telecommunications for 2.1%. In fact, on average, a four-person household spends about the same amount each year on cable television and tobacco products as on water services. In many respects, then, water supply is a "bargain" to the average household. At such a low cost, there is no incentive to conserve water. Moreover, for many years, local water agencies used a declining residential rate structure that, by charging a lower unit price the more water is consumed, actually encouraged water consumption. Therefore, it is easy to see that there is much room in the pricing structure to enact DSM measures. In other words, a rate plan could be devised that takes advantage of price elasticities and the relative low cost of water to promote wise water use.

Water conservation will cause water supply agencies to lose money

It seems counterintuitive to say that an enterprise that is in the business of supplying water can actually save money by reducing the demand for its product. Therefore, it is commonly believed that water conservation measures will lead to revenue shortfalls for water supply agencies and subsequent rate hikes for users. That need not be the case, however. Well-designed conservation measures will decrease water use, but will also decrease operating and maintenance costs. Further, they will defer capital costs; if water demand is growing more slowly than originally projected, future facility expansions can be pushed back in time. Over time, then, the conservation benefits (reduced operating and capital costs) should outweigh the conservation costs (reduced revenue). Admittedly, the cost savings do not appear immediately and the costs involved might not even enter into current water charges. But careful financial planning can expose these savings.

DSM Strategies

The range of DSM strategies is wide, and a full discussion of them all is beyond the scope of this course. However, several of them warrant mention here as examples of relatively easy-to-implement, effective measures.

First, let us consider indoor water use. Clothes- and dish-washing, cooking, and personal hygiene are the major indoor water uses. Water is actually consumed by appliances like dishwashers or by fixtures like toilets and showerheads, so reducing the water that these appliances or fixtures use is the key to reducing water use. In 1998, the American Water Works Association (AWWA) found through its Residential End Uses of Water Survey that water-saving fixtures can reduce household water consumption quite significantly [4]. See Table 4.

Table 4: Average Water Use of Selected Household Fixtures

	Water Use (gal/person/day)	
Appliance	Standard fixtures	Water-saving fixtures
Toilet	20.1	9.6
Shower	13.3	10.0
Faucets	14.0	10.9
Total	47.4	30.5

Using water-saving fixtures and appliances is particularly attractive to policy-makers because water is saved in a way that is transparent to the end user. For instance, the results of the AWWA study showed that low-flow, 1.6 gallons-per-flush (gpf) toilets do not require additional flushes to equal the performance of older, less water-efficient models. Those living in households with the low-flow toilets flushed an average of 5.0 times per day, while those living in houses with older 3.5 gpf toilets flushed an average of 4.9 times per day. Put another way, a low-flow toilet saves nine gallons per day with no change in user behavior.

Therefore, a good DSM strategy for local governments is to encourage or require that new construction include water-saving fixtures, or to incentivize the installation of water-saving fixtures in older construction.

Now let us turn to outdoor water use. As we saw earlier, 58% of municipal water is used outdoors, so the biggest gains can be made there to reduce water demand. Lawn irrigation is the major outdoor water use, though swimming pools and vehicle washing are also significant uses. In reducing outdoor water use, there are a number of target areas. For instance, the United States Geological Survey found that:

- Homes with in-ground sprinkler systems use 35% more water outdoors than those who do not have an in-ground system.
- Households that employ an automatic timer to control their irrigation systems used 47% percent more water outdoors than those that do not.
- Households with drip irrigation systems use 16% more water outdoors than those without drip irrigation systems.
- Households who water with a hand-held hose use 33% less water outdoors than other households.
- Households who maintain a garden use 30% more water outdoors than those without a garden.
- Homes with swimming pools use more than twice as much water outdoors than homes without swimming pools, everything else held constant [2].

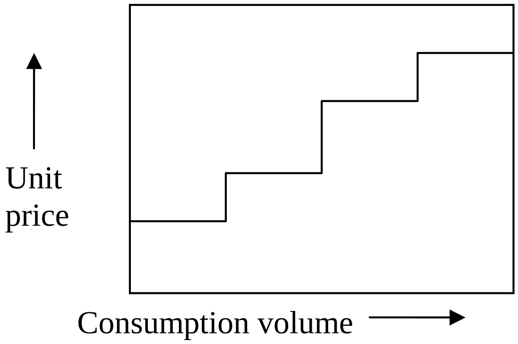
Any one of these areas can be addressed to reduce water demand. For instance, in-ground sprinkler systems can be prohibited in new subdivisions.

The effect of land use on water consumption is often overlooked. Reducing the amount of land that needs to be watered will obviously reduce the amount of water needed. Shrinking a household yard by 25% will reduce the household’s total demand for water by 15%, a nontrivial amount. In general, high density areas use less water per capita than do low density areas because they have less irrigable land, and because multiunit dwellings and larger households achieve economies of scale.

Similarly, the location and use of public open space can play a role in water use. The irrigation of city parks can be better controlled and managed than that of privately owned lawns, so a program of high densities, small or nonexistent private lawns, and thoughtfully applied recreational open space can greatly reduce water use.

Water pricing structures can be a powerful DSM tool. A proper rate structure plays an essential role in communicating the value of water to water customers, thus promoting long-term efficient use. The rate structure known as increasing block rates is the most effective in communicating this value and encouraging efficient use when compared to other types of rate structures. Through an increasing block rate design, the unit price for water increases as the volume consumed increases, with prices being set for each “block” of water use. See Figure 1.

Figure 1: Illustration of Increasing Block Rates



Customers who use low or average volumes of water are charged a modest unit price and rewarded for conservation; those using significantly higher volumes pay higher unit prices. According to the Western Resource Advocates, “If designed appropriately, increasing block rates:

- Provide water at low prices for basic and essential needs, so all customers can afford it;
- Reward conserving customers with lower unit rates for water;
- Encourage efficient use by sending a strong conservation price signal;
- Assign water supply and development costs proportionately to the customers who place the highest burden on the supply system and the natural supply sources; and
- Do all of the above while still maintaining a stable flow of revenue to the utility” [1].

Example 3

The Pleasantville City Council passed a new subdivision regulation that requires all new construction to use water-saving fixtures, a move that the city engineer predicts will reduce household water demand by 20%. Furthermore, the Public Works Department implemented an increasing block rate water pricing scheme. The city accountant estimates that this will reduce household water consumption by 5%. The results of these conservation measures are summarized in Table 5.

Table 5: Water Use by Household Income, Reflecting Conservation Measures

	Household Income ($k)			
	Above 60	40-60	20-40	Below 20
Water use, new houses (gal/person/day)	180	143	124	98
Water use, existing houses (gal/person/day)	228	181	157	124

Using these new usage figures with the demographic data in Table 3, the city engineer calculated that the projected future water demand will be 40 MGD. This is 4 MGD less than the original estimate, a savings of 50%.

Conclusion

Because of the expense, in both natural and fiscal resources, of meeting current and future demand for water, engineers have a responsibility to produce accurate demand projections. Furthermore, engineers are not passive participants in this process, but can and should shape future demand to reduce these expenses. This course was an introduction into methods of ensuring that water demand projections are accurate and appropriate.

Sources:

1. *Water Rate Structures in Utah: How Utah Cities Compare Using This Important Water Use Efficiency Tool*, 2005, Western Resource Advocates: Boulder, CO.

2. *Estimated Water Use in the United States in 2000*. 2005, United States Geological Survey.

3. Boland, Duane D. and John J. Baumann, *The Case for Managing Urban Water*, in *Urban Water Demand Management and Planning*. 1998, McGraw-Hill: New York.

4. *Fact Sheet: Residential End Uses of Water Study*, American Water Works Association. http://www.awwa.org/Advocacy/pressroom/STUDY.cfm

Additional Material Required for the Quiz:

For the questions 9 to 11 on the quiz, use the data in Tables 1 through 4 below for Center City, a city that is experiencing large-scale growth through immigration.

Table 1: Center City demographics

2005 Population	350000
2005 Municipal water demand	63.7 MGD
Projected growth rate for 2025	1.5%

Table 2: Income profile by area of origin

Income ($k)	North (%)	South (%)	East (%)	West (%)
60+	25	15	15	25
40-60	25	35	20	35
20-40	25	35	25	30
0-20	25	15	40	10

Table 3: Population composition by area of origin

	2005 (%)	2025 (%)
Northerners	0.30	0.33
Southerners	0.35	0.31
Easterners	0.15	0.12
Westerners	0.20	0.24

Table 4: Characteristics by income

Income ($k)	Water use (gal/person/day)	Amount of irrigable land (acre/person)
60+	210	.2
40-60	190	.1
20-40	170	.05
0-20	150	.02