WATER SUPPLY AND CLIMATE UNCERTAINTY

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WATER SUPPLY PLANNING PRACTICE IN THE U.S.

For more than 100 years, urban water utilities in the U.S. have successfully matched uncertain supply to uncertain demand, providing reliable service under nearly all conditions. Service interruptions have been very rare. Drought, infrastructure problems, and other factors have occasionally required that water be rationed, but even these events have seldom been disruptive or prolonged. Americans have always taken the adequacy of water supply for granted, and they have had good reason to do so.

This performance has been achieved through industry-wide adherence to planning and design practices that can be described as strongly conservative and risk-averse. Long term demand forecasts have generally used simplistic methods which ignore all influences on water use except population. In most cases, these forecasts have overstated future water use. Water supply, while recognized as uncertain in the short term, has been assumed stationary in the long term: future supply is expected to be the same, on average, as present supply. Supply works have been designed for droughts of long recurrence intervals, often 50 years or more. Because of the resulting large amounts of storage (either as groundwater or as surface water impoundments), there is considerable margin for error, especially in the early years of a new facility.

Traditional industry practices can be criticized at several levels. In the past, water utilities have not collected the data or performed the analyses necessary to properly understand the patterns and levels of water use by their customers. The reason for this omission has also been its result: standard industry forecasting practice has usually consisted of a cursory extrapolation of per capita water use. The forecasts obtained in this way were notoriously inaccurate. Demand management was not considered an option.

Supply planning usually avoided tradeoffs between risk and cost, preferring instead to adopt a fixed reliability standard, usually one that defines a very high level of reliability. The end result has typically been large, infrequent, capital intensive water supply projects, interspersed with long periods of excess capacity. Overcapacity, often invisible to the public, has long been preferred to the possibility of undercapacity with its attendant political risks. The rhetoric of least cost planning, so familiar to electric utilities, is hardly heard in the water industry.

But these unflattering generalizations do not describe the entire water industry, especially in the latter half of the twentieth century. Many communities have encountered difficulties in meeting the planned supply targets because of diminishing numbers of untapped sources, competition with other users, or constraints imposed by environmental policy (Baumann *et al*., 1997). Where supply has been expanded as planned in the face of these difficulties, sharp increases in water price have lowered water use levels much below forecasts, sometimes leading to reexamination of forecasting practices.

More often, though, water utilities have reacted by questioning the conventional justification for expanded capacity. In cases where explicit risk-cost tradeoffs have been performed, capacity "requirements" have usually been reduced, sometimes substantially (Ecological Analysts, Inc. 1977). Nearly every utility facing a serious supply constraint, either physical or financial, embarks on some form of demand management. This usually takes the form of long term water conservation measures, but may also include tariff reform and drought management (Baumann *et al*., 1997). Water agencies in the arid Southwest and in Southern California were among the first to attack these problems in a systematic way, and are now among the most proficient in the simultaneous management of supply and demand. The Metropolitan Water District of Southern California, for example, employs advanced water use forecasting models together with an Integrated Resource Planning Model of its supply options. Yet even the most detailed and sophisticated planning methods now in use within the urban water sector treat weather as an uncertain-but-stationary process. Climate, in other words, is assumed to be fixed.

But climate does change. It has always changed and it always will. Most now accept that climate has recently been influenced by human activities such that warming will occur in the future at a rate that is unusually rapid, at least by comparison to recent human experience. This understanding does not include agreement as to exact rates of change, and available model results do not interpolate well to specific locations. In most places, average temperatures are expected to rise. Precipitation may increase or decrease, or simply become more variable. Winters may warm more than summers, or vice versa. Whatever the outcome at a specific location, the characteristics of water resources are likely to change. In considering this prospect from the perspective of urban water supply, two questions may be asked:

- Given that climate has changed - though usually more slowly - in the past, why do even the most advanced water supply planning practices ignore this fact?
- If climate changes more rapidly in the future, will it be necessary for urban water systems to make explicit provision for this fact?

WATER SUPPLY PLANNING IN A STATIONARY CLIMATE

Detailed weather records are available for all parts of the United States for little more than 100 years. Even over such a short period, the data show considerable variation in average annual temperature and in total annual precipitation. Moving averages of these observations can be used to indicate systematic changes in climate, as opposed to the more random fluctuations associated with annual weather averages. Karl (1988), for example, has calculated area-weighted temperatures and precipitation for the U.S., starting in 1895. His data show rapid warming of approximately 1.0ºC between 1918 and 1936, followed by net cooling totaling about 0.8ºC up to 1970. The years after 1970 show, again, steady warming. The moving average record of precipitation does not appear to contain long-term trends, but does include several short periods of unusually low precipitation (1930-35 and 1951-56) as well as two periods of high precipitation (1973-76 and 1981-85). An extension of Karl's data by Trenburth (1991) shows another steep decline in precipitation in the late 1980s.[1]

The recent climatic record, as described by Karl and Trenburth, suggests at least two conclusions. The rate of temperature rise over the 1918-36 period was in excess of 0.5ºC/decade. This is a rate of warming on the same order of magnitude as the global predictions of most general circulation models (GCMs). Near the end of the warming period (after 1931), there was a significant drop in precipitation. Again, this conforms to predictions of "hotter, dryer" climates for some regions of the world.

During the early 1930s, at the apex of the "hotter, dryer" trend, the U.S. did experience widespread hydrologic drought, accompanied by significant loss of farmland in the West and large internal migrations of rural population (the Dust Bowl period). This experience might have persuaded water planners that climate should be treated as an exogenous variable, potentially affecting both the supply of water and urban water demand. But this conclusion does not seem to have been reached or, if it was, it had no impact on planning practice. Instead, climate continued to be viewed as stationary. The effect of brief exposure to rapid climate change was merely to reset the "drought of record," the set of conditions that would thereafter be used to define maximum safe reservoir yields. To this day, many water suppliers still plan on the basis of a "drought of record" taken from local experience in the 1931-36 period.

At the end of the twentieth century, it remains standard practice to project water use on the basis of population and other factors, but not as a function of climate. The capabilities of water sources are judged according to their expected performance during a repetition of some standard design drought – usually a selected "drought of record" expected to have a very long return interval. Supply facilities, therefore, are expected to have excess capacity at nearly all times – only the rare "drought of record" or something worse would cause capacity to be pressed, and then only if it occurs near the end of the design life of the facilities.[2] Over time, planning methods have improved in sophistication and accuracy, and experience with extreme events has influenced the definition of the standard design drought, but the possibility of a long-term change in climate has yet to be incorporated into normal practice.

It is worth noting that had the "hotter, dryer" trend experienced early in this century continued for a longer period, it would have had profound implications for urban water supply. Water demand would have increased nationwide as residents struggled to maintain landscaping under increasingly harsh conditions. Simultaneously, the safe yield of surface water sources, and eventually of ground water sources, would have declined. If anticipated in time, this two-way squeeze on available capacity would have triggered attempts to develop new supply sources, such as new surface water impoundments. Successful and timely implementation of these projects could have maintained reliability at normal levels. But financing problems or other barriers to completion, had they occurred, would have resulted in water shortages. Similarly, failure of planners and decision makers to detect the climate trend and react appropriately could have delayed an effective response, with shortages appearing in the interim.

The fact that climate change is not an issue in conventional water supply planning may be explained by any or all of the following.

- In past years, before there was a widely known anthropogenic explanation for climate change, even lengthy departures from "normal" weather conditions were viewed as random deviations around a stationary mean. These experiences might have suggested reassessment of the magnitude of maximum likely deviations, but they did not call into question the estimate of the mean.

- Conventional planning practice leads to large, infrequent capacity expansions, with long intervening periods of excess capacity. Since supply and demand are continuously observed, any trend resulting from climate change would simply cause a change in the timing of the next capacity expansion, without loss of reliability.

- Because of the long periods of time involved the fact that, e.g., a 50-year supply plan has become insufficient after 30 years would be attributed to the failure of the last generation of planners to properly anticipate future demand conditions. Since present planners likely had no personal connection to the previous plan, they cannot be expected to analyze too closely the reasons for its premature demise.

- Water supply planning methods (incorporating, among other things, the stationary climate assumption) have worked well in the past and there is no convincing evidence that they will not work in the future.

But, in many parts of the U.S., utilities face new challenges. Various restrictions on supply expansion have produced much smaller margins of excess capacity than were common even a few decades ago. Demand management is now practiced in many places, and is used quite aggressively in the Southwest. In many cases, landscape irrigation has already been cut back sharply through a combination of education, regulation, and higher prices. In Southern California, the steady pressure of population growth has forced many suppliers into a posture of almost constant capacity expansion, often through a variety of small, non conventional projects. In this tighter and more volatile situation, some kinds of climate change might be expected to cause serious reliability problems, if not adequately anticipated and planned for. Whether this is a realistic expectation is the subject of the next section.

PLANNING FOR CLIMATE CHANGE: A CASE STUDY

The Washington, D.C. metropolitan area (WMA) is a good example of an urban place that may be vulnerable to climate change-induced water supply problems, for several reasons.

- It is a large, growing area. The standard metropolitan area, consisting of the District of Columbia as well as portions of Maryland and Virginia, had an estimated 1994 population of 4.5 million, an increase of 1.1 million since 1980 (U.S. Bureau of the Census 1996).

- The water supply is uniquely vulnerable to climate change. More than 75 percent of all water used in the WMA is withdrawn from the free-flowing Potomac River. Most of the remainder is taken from impoundments on local tributaries of the Potomac (the Occoquan and the Patuxent Rivers), which are operated at a high rate of utilization. While the average flow of the Potomac is much larger than current withdrawals, single day flow has been as low as 388 MGD (in 1966) while maximum day withdrawal has been as high as 614 MGD (in 1988) (Mullusky *et al.*, 1996). Because of the lack of storage at the point of withdrawal, relatively small reductions in the yield of the upstream watersheds could significantly affect water supply operations.

- Advanced supply management is already in place. As a result of agreements signed in the late 1970s and early 1980s, the three major water utilities serving the WMA cooperate in the integrated management of all available supplies (Holmes and Steiner 1990). This has led to low flow augmentation of the Potomac, using planned releases from Jennings Randolph Reservoir (200 miles upstream) and the local Little Seneca Reservoir. The Occoquan and Patuxent supplies are managed conjunctively with the Potomac. In the event of low flow, all utilities are subject to mandatory allocation and drought management measures. Despite these efforts, existing supplies are not adequate to meet current unrestricted water demands at an acceptable level of reliability.

- Because of supply limitations, demand management is in general use throughout the region. Water conservation measures have been implemented by most utilities. Some, such as the Washington Suburban Sanitary Commission (WSSC) and Fairfax County Water Authority (FCWA), have adopted tariff designs intended to reduce water use. WSSC has been a pioneer in the promotion and adoption of low flow plumbing fixtures.

The general picture, then, is of a large metropolitan area facing substantial growth with a severely constrained water supply capability. But what if climate change were to further increase water use and/or reduce watershed yields? Is it possible to further reduce demand? Is there time to locate and construct additional supply, if needed? The following sections explore these issues, using the results of a prior study (Boland, 1997 and Steiner *et al*., 1997).

Climate Scenarios

Despite steady improvement in the various GCMs used to predict changes in global climate, there are at present no credible predictions of future climate for areas as small as the Potomac River watershed. Depending on the GCM, the WMA corresponds to approximately one cell. Prediction errors that are inconsequential at a global scale may be large for one or a few cells. In the absence of a single plausible prediction of future climate, the results of five different GCM simulations were used, together with a stationary climate assumption, to produce six climate scenarios. In each case, year 2030 predictions, or model results reasonably typical of year 2030 conditions, have been used. The GCMs were selected to produce a range of outcomes, from net cooling to warming, and both wetter and drier future outcomes.

Since the climate results are to be used to forecast water use in year 2030, predicted temperatures and precipitation for the summer months are converted to potential evapotranspiration and effective precipitation, respectively. The excess of potential evapotranspiration over effective precipitation is the moisture deficit. This variable is an estimate of the amount of irrigation water required to maintain maximum growth rate for a crop of turfgrass, given the predicted weather conditions. It has been shown to be a useful explanatory variable for seasonal water use in residential areas (Linaweaver 1965). Moisture deficit is computed for each month, then summed over the summer season. These calculations are performed for each of twelve political jurisdictions within the WMA. The results for the six climate scenarios for the District of Columbia are shown as Table 1. Predicted moisture deficits for 2030 are compared to the 1990 actual data, and to an estimate of the 1990 level given normal (1961-1990 average) weather conditions.

Forecasting Future Water Use

In assessing the impact of alternative climate scenarios on WMA water management, it is necessary to prepare a forecast of water use for year 2030. Ideally, the forecast should be spatially and sectorally disaggregate; it should reproduce the structural differences in water use in the various jurisdictions of the WMA. It must also predict water use as a function of climate. In this case, the forecasting models must include moisture deficit as an explanatory variable. Finally, the forecasting method must incorporate, separately and explicitly, the various demand management measures that might be invoked as a response to climate change. These measures include, at a minimum, long term water conservation measures and tariff changes.

The most detailed and disaggregate forecasting system in general use in the U.S. is the IWR-MAIN model. This is available as an integrated computer-based system containing a range of forecasting models, explanatory variable projection procedures, and data management facilities. At the time the case study was begun, IWR-MAIN was available in version 5.1, which uses moisture deficit, among other variables, to predict residential water use (Davis *et al*., 1988). This version also adjusts forecasts for the effect of water conservation measures and tariff changes as required by this application.[3]

Among the advantages of the IWR-MAIN forecasting system are the following:

- IWR-MAIN is highly disaggregate by user type, providing separate forecasts for as many as 284 water use categories. This detail, while not always needed, can provide increased insight into patterns and trends of water use.

- IWR-MAIN can be used for spatially disaggregate forecasts. In this case, it was helpful to prepare separate forecasts for each political jurisdiction (twelve in all), thus reflecting different tariffs and different water conservation policies. Moisture deficit (and therefore climate change) also differs from one jurisdiction to another, primarily as a consequence of topography.

- IWR-MAIN water use models incorporate many of the likely determinants of water use. These include characteristics of housing units, a detailed structure of employment, tariffs, irrigated residential acreage, and weather. Forecasts, therefore, are responsive to changes in any of these variables.

- IWR-MAIN forecasts are seasonally disaggregate. Separate predictions are provided for summer and winter use. This provides an improved ability to estimate changes in peak period water use, and thus establish the adequacy of water supply.

- IWR-MAIN forecasts take into account the long term impacts of as many as eighteen water conservation measures that have been implemented in the past, or may be implemented in the future.

In applying the IWR-MAIN model to this study, data for a base year (1990) were collected for all of the political jurisdictions. The IWR-MAIN models were then used to estimate base year water use as a function of actual moisture deficit and those demand management measures already implemented. This verification produced results generally within 5.0 percent of reported water use. This error is comparable in magnitude to errors commonly noted in measurements of sectoral water use due to meter misregistration, incorrect classification of customers, etc.

Based on this successful verification, the IWR-MAIN model was used to prepare water use forecasts for each jurisdiction, for each climate scenario, and for each conservation scenario, described below. Review of the resulting forecasts revealed that, in certain jurisdictions, summer water use was forecast as equal to winter use. Further investigation determined that a particular combination of data applied to one of the water use expressions was the source of this anomaly. Appropriate corrections were made to the model, as described in Boland (1997), and the forecasts were repeated without difficulty.

Conservation Scenarios

In order to test the ability of known demand management strategies to deal with climate-induced changes in future water use, three conservation policy scenarios were constructed. These are listed as Table 2, and the terms are defined in Davis *et al*. (1988). Briefly, Conservation Policy 1 consists of all those measures that were actually implemented in 1990, plus 100 percent coverage of the Moderate Plumbing Code (this is complete adoption of 3.5 gallon toilets and 3.0 gpm showerheads, a process that was substantially advanced by 1990). Policy 1 is, then, a status quo policy. Policy 2 adds the ultralow-flow plumbing fixtures already specified by Federal law, as well as expanded public education and increased reuse and recycle by nonresidential users. Finally, Policy 3 adds a 50 percent real increase in all water prices.

Results

The aggregate water use estimates (totaled over all user categories and over all political jurisdictions) for the year 2030 are shown as Tables 3 and 4. Table 3 presents summer season averages, a measure that is related to peak period use, and Table 4 shows annual averages. For comparison, the normal weather estimates for 1990 are 724 MGD as the summer season average and 621 MGD as the annual average. It can be seen that water use is expected to increase substantially, independent of any climate change-related effect.

Under Conservation Policy 1, which implies no further demand management initiatives anywhere in the WMA, there is a possibility of a substantial increase in year 2030 summer water use as a result of climate change. As shown in Table 3, the largest change considered is from 1,448 MGD (Scenario A, the stationary climate assumption) to 1,722 MGD for Scenario F, a 19 percent increase. But the largest forecast summer water use under Policy 2 is only 1,387 MGD, slightly less than the stationary climate scenario without additional demand management. Implementation of Policy 3 would further reduce summer water use, this time to 1,255 MGD in the most extreme case.

Table 4 shows comparable results for average annual water use. In this case, the largest excursion from the stationary climate water use is only 11 percent. As for summer use, both Conservation Policy 2 and Policy 3 are capable of reducing water use for any climate assumption to a level below that implied by a stationary climate.

CONCLUSIONS

These results indicate the following:

- It is possible to analyze the potential impact on urban water use of climate change and of demand management responses to that change, using readily available planning tools such as IWR-MAIN.

- In this case, a diverse set of climate change predictions imply year 2030 water use totals ranging from 8 percent below to 11 percent above the forecast that would have been used in the absence of climate change considerations (the stationary climate forecast).

- A plausible set of relatively aggressive water conservation measures (Policy 2) is capable of reducing year 2030 water use by almost 20 percent. The addition of a 50 percent increase in real tariff levels would produce a further reduction of some 7 percent.

- Even in the WMA, where excess supply capacity is minimal, safety margins are small, and demand management has already been employed to balance supply and demand, there is substantial scope for further demand management.

- The demand management measures needed to reduce water use by 20 percent or more could be implemented in a matter of a few years, possibly up to five years for reuse and recycle regulations. By comparison, the last major impoundment built in the Potomac basin, the Jennings Randolph Reservoir, required more than 25 years from start to finish.

It can be said, then, that if future water planning retains the stationary climate assumption, even the most careful forecasts of annual water use may be exceeded by as much as 11 percent at year 2030. Nevertheless, if supply facilities are constructed to deal with the forecast water use but actual water use is higher because of climate change, managers possess the means to reduce demand effectively and quickly without loss of reliability.

Not considered here, of course, is the effect of climate change on existing supplies or on the design of new supplies. In fact, a parallel analysis of existing supplies showed that the demand management policies described in Table 2 are sufficient to balance supply and demand in year 2030 without construction of new supplies (Steiner, *et al*., 1997). Although water managers should be aware of the possible effects of climate change on both supply and demand, this analysis of the WMA does not suggest a need for new planning paradigms, or for any explicit treatment of climate change at the present time.

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ENDNOTES

1. Note that these observations refer to area-weighted national averages and to moving averages across years. They do not necessarily conform to actual experience with weather at any specific location in the U.S.

2. Despite this characterization, it is well known that many urban water supply systems experience water shortages with greater or lesser frequency. For purposes of this argument, such events can be attributed to either unanticipated external factors (e.g., watershed changes, environmental constraints on withdrawals, groundwater contamination) or unanticipated internal barriers to plan implementation (e.g., financing constraints, environmental review of proposed projects, construction delays). The point of the text is that it is the objective of the planning process to deliver high levels of reliability through project life.

3. After the work reported here was begun, version 6.1 became available (Planning and Management Consultants, Ltd., 1995). This version has many internal differences from 5.1 and generally similar capabilities, but it would have permitted consideration of the impact of climate on nonresidential water use as well as residential use.

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Table 1: Climate Change Scenarios - Summer Moisture Deficit in Inches

	Year 1990 Actual Weather	Year 1990 Normal Weather	Year 2030 Predicted Weather
A: Stationary Climate	8.07	9.57	9.57
B: GISS A	8.07	9.57	10.51
C: GISS B	8.07	9.57	8.27
D: GFDL	8.07	9.57	11.34
E: Max Planck	8.07	9.57	11.50
F: UK Hadley	8.07	9.57	11.81

Table 2: Conservation Policies

Conservation Policy	Water Conservation Measures (as defined in Davis, *et al.*, 1988)
1	Measures existing in 1990 within each political jurisdiction Complete implementation of Moderate Plumbing Code
2	Measures included in Policy 1 Public Education Industrial Reuse/Recycle Commercial Reuse/Recycle Advanced Plumbing Code
3	Measures included in Policy 2 50% real increase in all water/wastewater tariffs

Table 3: Forecast Water Use, Summer Season, Year 2030 (in MGD)

	Conservation Policy		
	1	2	3
A: Stationary Climate	1,448	1,165	1,051
B: GISS A	1,561	1,252	1,136
C: GISS B	1,257	1,012	914
D: GFDL	1,670	1,342	1,213
E: Max Planck	1,688	1,355	1,226
F: UK Hadley	1,722	1,387	1,255

Table 4: Forecast Water Use, Annual Average, Year 2030 (in MGD)

	Conservation Policy		
	1	2	3
A: Stationary Climate	1,244	1,001	903
B: GISS A	1,300	1,043	946
C: GISS B	1,149	922	835
D: GFDL	1,353	1,088	983
E: Max Planck	1,363	1,096	991
F: UK Hadley	1,379	1,112	1,004