DEVELOPMENT OF DYNAMIC PLANNING TOOLS FOR IMPROVED UNDERSTANDING OF TRENDS IN RESIDENTIAL WATER DEMAND

Detailed Tasks and Deliverables (7 January 2013)

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SUMMARY

Long-term declines in per-household water demand and more recent declines associated with the "great recession" have created uncertainty and major planning challenges for municipal water providers and agencies. This proposed project will investigate the changes in water use that underlie these declines and estimate rates of future changes. The results will be compiled in a dynamic simulation model that supports sensitivity analysis to help identify key unknowns, and scenario testing to address various questions such as, "How low could demand go?" or, "What might be the consequences if some impacts of the recession are permanent? The project will focus on changes within the existing housing stock, but a qualitative examination of future new housing characteristics also will be performed.

BACKGROUND

For over two decades, water providers in Arizona and across the Southwest have observed declining per-household demand. These declines have been attributed to a number of factors. Verifying and measuring the relative contributions of these factors to the overall decline is difficult; modeling and forecasting their impacts on future demand levels is a major challenge.

The housing bubble burst that occurred five years ago precipitated abrupt drops in new residential customers, large increases in vacant homes, conversion of many homes from owner-occupied to rentals, and other impacts that further reduced demand and increased uncertainty. Also uncertain are the water-using characteristics of housing that will be built in the future, further highlighting the need for flexible and dynamic planning tools.

APPROACH AND METHODOLOGY

Single family residential (SFR) water demand will be disaggregated into discrete components,

beginning by separating indoor and outdoor demand. SFR indoor demand is assumed to be primarily determined by the number and type of persons in the household and the home's stock of water-using appliances and fixtures. Outdoor demand is assumed to be relatively independent of the number of persons in the household. Primary determinants are assumed to be the amount and types of landscaping and how it is irrigated; the presence or absence of a swimming pool and how often it is covered, if at all; and whether the home has evaporative cooling, refrigerative AC, or both. Turf is the most important landscape type and will receive special attention.

Observed changes in per-household demand are mostly the result of changes in the existing housing stock and the construction of new, more water-efficient housing. To better understand changes in SFR demand, we therefore must differentiate and measure both how housing stock varies as a function of when it was built, and current rates of change within the housing stock. Changes in water use can be caused by three types of factors. ***Overarching factors*** are those that indirectly affect all or several water use categories. These include: the perceived cost of water, usually determined by the water and sewer bill; socio-demographic changes that affect the number of people per household and the amount of time they spend in the house; microclimate, which can be affected by nearby land use changes, urban heat island effects, and/or regional climate change; and community conservation ethic. These factors, which create the environment within which water use decision are made, have been the subject of numerous studies. They will be considered in one task (see below, "Analyze time series of demand"), but they are not the main focus of the project.

Changes in ***direct factors*** of water demand involve actions such as replacing older fixtures and appliances, altering landscapes, installing or removing a pool, and adding (or subtracting) a person to a household or changing the amount of time they reside there each year. A major focus of this project is measuring both the rates of change in these factors within the existing housing stock, and the impact of these changes on water demand. For example, measuring the rate at which SFR households have been installing swimming pools and the impact of a new pool on water demand allows one to project the number of pools and their impact on overall SFR demand.

For selected factors of demand, we will go beyond simple historical rates and straight-line ***projections*** of these rates into the future and will instead estimate models and use these to ***forecast*** the rates of change. This will require econometric analysis at the household level. In some instances, this will involve analyzing a third type of factor, ***triggers*** of change. Certain events or conditions trigger a household decision-maker to decide that now is time to replace an old fixture, buy a new appliance, install a pool, remove turf, or replace the swamp cooler with AC. Understanding these triggers will result in better models and forecasts, and possibly improve demand management strategies.

To create a useful planning tool for water managers, the results of this analysis on individual factors of demand will be aggregated by developing a dynamic simulation model (DSM). The DSM will forecast changes in SFR demand, support sensitivity analysis to identify key uncertainties, and allow users to address "What if?" questions and explore various scenarios.

TEAM

The project will draw on a team of water professionals at Montgomery & Associates. Key team

members and responsibilities include:

$ Principal Investigator Gary Woodard
$ Project Manager Staffan Schorr
$ Database Programmer Mike Gutierrez
$ Dynamic Simulation Modeler (TBD)
$ Other professional and support staff as needed

TASKS

The project is divided into discrete tasks for the purpose of management and scheduling. Tasks and deliverables are listed below in chronological order; however, as the schedule reveals, multiple tasks will be pursued simultaneously during most of the project's 18-month time frame.

Form and Convene Advisory Panel

Form an advisory panel that includes 1 or 2 representatives from each participating entity. Panels will not meet on a regular schedule, but instead will convene at key points in the project, which include three meetings and a training session:

$ initial "kick-off" meeting, in early 2013;

$ mid-point meeting to discuss results to date and prioritize micro-level analyses, in mid- to late-2013;

$ meeting to discuss micro-level findings and provider-specific models, in early 2014; and

$ training session on using provider-specific dynamic simulation models for forecasting and scenario analysis, in June 2014.

Meetings will last approximately 2 hours and will be convened in both Maricopa County (probably at SRP) and in Pima County (possibly at Montgomery & Associates). The training sessions will also be half day events.

In addition to these meetings, individual panel members will be interviewed as part of the task on gathering background information described below. Panelists also will serve as points of contact for their provider or agency, to facilitate data requests, offer insights, and review provider-specific results.

Deliverables: The meetings are the deliverables.

Explore Causes of Declining Demand

Assemble a list of all plausible causes for the decline in SFR water demand. Also list possible changes over time that could/should have *increased* water demand, as well as factors that have an ambiguous impact, or whose short-term and longer-term impacts on demand may point in opposite directions.

These possible causes of declining demand will be subject to a preliminary screening process to determine if they are in fact occurring, and if their impacts on SFR demand are potentially significant.

Plausible causes include, but are not limited to the following:

- declining household sizes and other demographic shifts
- changing tastes in landscaping, especially with respect to turf
- more efficient water-using fixtures and appliances in newer houses
- replacement of less efficient fixtures and appliances in older houses
- declining popularity of backyard pools

$ increase in frequency and/or use of pool covers

- shrinking lot sizes and landscapable areas
- evaporative coolers replaced by refrigerated AC

- more seasonal and part-time residents
- water and sewer rate increases above the rate of inflation
- more effective water conservation programs

Deliverables: Section of final report.

Gather and Annotate Background Information

Existing information will initially be used to define most water use rate parameters for the conceptual model. Sources of information will include:

$ peer-reviewed journal articles
$ treatises on the subject of urban/municipal water demand
$ articles and reports from agencies such as EPA and professional water organizations such as WRF
$ gray literature from various sources, including unpublished reports, documents, and other analytic efforts from participating water providers
$ discussion with the advisory panel at the kickoff meeting
$ one-on-one conversations with advisory panel members

The studies and reports will be examined to determine how reliable and current the results are, and the geographic areas over which they can be applied. These results will then be used to develop coefficients and parameters for the conceptual model (see next task).

Deliverable: Annotated summary of existing information distributed to project participants for review;
Also becomes section of final report.

Develop Conceptual Model

Construct a dynamic simulation model of changes in SFR water demand using GoldSim software. Dynamic simulation models (DSMs) are able to capture complex relationships and feedback loops, and can integrate the outputs of disparate sources of information. Another advantage of DSMs is their arrow- and icon-based structure that allows non-programmers to see underlying relationships and assumptions. In addition, the dashboard-style user interface lets non-modelers answer "what-if" questions and explore various scenarios.

Note that this is not a comprehensive model of all factors of SFR demand, but rather is a model

of rates of ***change in frequency*** of key water demand factors for SFR customers and ***estimated impacts*** of these changes on per-household water demand. The initial values for these parameters will be set based on results of previous studies, best estimates from project team members, and the professional judgement of the advisory panel. The models will also include preliminary estimated water use/savings for the various changes in water use factors, which will also be based on existing studies and advisory input.

The model will include at least three factors of indoor demand and three factors of outdoor demand. Factors of indoor demand will include:

$ Wholesale fixture/appliance replacement associated with remodeling bathrooms and

kitchens
$ At least one aspect of changing socio-demographics, such as growing rates of seasonal occupancy
$ High-efficiency clothes washers

Factors of outdoor demand will include:
$ Pool installation/removal
$ Turf removal/conversion
$ Evaporative coolers replaced by refrigeration AC.

The model will allow future rates of change in key factors of demand to be simulated; sensitivity analysis will reveal their relative importance. The model will also be designed to serve as a template for development of provider-specific models, as described below.

Deliverables: Conceptual model

Analyze Water Demand Time Series

Each participating water provider will be requested to provide monthly time series of per-household water demand for single family residential (SFR) customers going as far back in time as data are available.

From these monthly time series, the following annual time series will be generated:
$ annual sum of 12 months (total water delivered and proxy for revenue)
$ peak month (proxy for needed system capacity)
$ trough month (proxy for indoor demand)
$ peak - trough (proxy for maximum outdoor demand)
$ annual sum - 12×trough (proxy for total outdoor demand)
$ peak/trough (measure of seasonality)

Each of these time series will be analyzed for correlations with:
$ trends over time
$ impacts of housing bubble/burst and/or great recession (was there a statistically significant change in slope corresponding to this point in time?)
$ cumulative percent of new (additional) service connections since start of time series

$ proxy for total cost of water (e.g., average water + sewer bills)
$ Palmer Drought Severity Index (for series related to outdoor demand)

A qualitative comparative analysis of correlations across all participating providers will seek patterns from which insights can be drawn, such as:
$ are steeper declines in demand found in service areas with older housing stock or with greater percentage increases in new SFR customers?
$ what are the characteristics of service areas where SFR demand was more/less affected by the bubble burst and ensuing recession?
$ is outdoor demand from some providers' SFR customers more strongly correlated

with the PDSI?

Deliverables: Provider-specific descriptions of changes in levels and patterns of demand. Section of final report.

Compile Databases

Databases for each county and each participating water provider will be compiled and merged or linked, as appropriate. Data sources will include participating water providers, county assessors, MAG and PAG, ADWR, multiple listing service, wastewater plants, 2010 census, and various sources of GIS data and satellite coverages. Combining household-level data sources will also allow filtering and quality control of the assessor data.

Assessor databases and other sources of household-level data are particularly important, especially those that are available on an annual basis. These will allow us to identify year-to-year changes in some key demand factors, and also support micro-analyses needed to model and forecast changes in factors.

Some key questions will be addressed by gathering information from diverse, less traditional sources. For example, information on rates at which older water-using appliances and fixtures are being replaced may come from home improvement stores, while understanding what future housing construction might look like will require talking with developers and home builders. Preliminary conversations with pool companies have revealed interesting trends in pool and deck areas, use of pool covers, and reasons why the rate of filling in pools may be increasing.

Other data sets could reveal seasonal occupancy, which in addition to having an obvious and extreme impact on indoor demand (and peaking), may have an impact on outdoor demand. The holders of the data include non-water utilities, home owner associations, and the post office. Preliminary conversations with retirement community HOAs have revealed insights into migratory patterns of snowbirds.

Deliverable: Databases to support the modeling and analysis

Generate Parcel-Level Descriptive Statistics

Relevant characteristics of the current housing stock will be analyzed by year of construction, for

entire county and for each water provider service area These characteristics will included:

- lot size, house area, number of floors
- house value
- swimming pool (existence and “size”)
- type of cooling (AC vs. evaporative cooler)
- percent of SFRs that are rentals

Combinations of some of these descriptors will allow estimates of other demand factors. For example, lot size, house footprint, and number of floors can be used to estimate landscapable area. Also, in addition to determining what percent of SFRs are rented, we will determine how rentals differ from owner-occupied homes.

Many characteristics of SFRs can change over time, but lot size is fairly immutable. We will test the hypothesis that lot sizes have declined over time.

Deliverable: Comprehensive description of the existing housing stock for each provider. Section of the final report.

Determine rates of change in housing stocks

Analyses of factors of demand as a function of the age of the house can be tricky. The current percentage of homes built in the early 1990s that have swimming pools reflects both the popularity of pools at that time, plus the rate at which homeowners have added pools over the ensuing 20 years. We need to separate these effects because future changes in pool-related water use will be the result of decision to add or remove pools to the existing housing stock.

Determining rates of change in water use characteristics therefore requires analyzing databases that are compiled on a regular basis, or which record the date on which characteristics were changed. Annual assessor databases not only allow us to determine the frequency of a water demand factor in the current housing stock and how that factor varies as a function of the age of homes, they also allow us to calculate:

- the recent rate of change in that factor;
- the annual volatility in the rate of change; and
- how houses that have undergone the change compare to the balance of the housing stock.

Annual assessor databases also will allow us to address questions such as:

- What is the overall frequency of turn-over in ownership, and which types of homes are turned over more frequently?
- What is the potential for "home flippers" to affect indoor demand? (E.g., if an older home was bought and then re-sold a few months later, it might have upgrades including new kitchen and bathroom fixtures and appliances.)

Other databases will provide insights into recent rates of change. The census will reveal changes

in socio-demographic factors between 2000 and 2010. Multiple listing databases often record the age of kitchen and bathroom upgrades.

Deliverables: The rates of change that become coefficients in the dynamic simulation models.

Analyze Potential Triggers of Change

What causes a homeowner to decide one day to change some aspect of his/her house that impacts water demand? Why that day and not another? For example, are evaporative coolers replaced with AC units primarily when the existing evaporative cooler fails, or when the home is sold to a new owner? Are lawns more likely to be abandoned during droughts, or recessions? Swimming pools may be installed when the house is sold to new owners, or removed when homeowners become empty nesters. Understanding these triggers is key to forecasting water demand rather than just projecting it. It also will help address the question of what portion in demand reductions were due to the recession, and are these reductions potentially reversible.

Potential triggers to be analyzed include:

$ new owners of existing SFR
$ distressed sale to "flippers" who quickly renovate and re-sell
$ switch from owner-occupied to rental, and vice versa
$ old water-using fixture or appliance breaks
$ targeted conservation programs, such as rebates
$ residents have children, or become empty nesters
$ contagion effect – copying the neighbors
$ prolonged drought
$ abrupt and significant change in water/sewer rates
$ severe economic downturn
$ major regional employer arrives (expands) or departs (contracts)
$ changes in tax policies, tax credits
$ aggressive marketing of new product (e.g., patio misting systems, horizontal axis clothes washers)

Deliverables: Section of report

Mid-Project Review and Planning

The tasks described above will be largely completed by summer of 2013. At this point in the project, the advisory panel will be convened to review what has been learned, and which remaining uncertainties are the most significant. There also will be discussion of whether household-level data exist to address these uncertainties through econometric modeling. Estimates of the resources required for these micro-analyses will be provided to the panel members.

The panel will be asked to help prioritize which rate of change estimates need further refinement, and which water demand impacts drawn from previous studies are least certain and in need of new estimation. This process will be informed by sensitivity analysis using the conceptual

model. Based on this input and subject to resource constraints, new tasks will be defined.

Examples of potential micro-analyses are given in the task description below.

Deliverables: Mid-project meeting
Prioritization and planning for performing selected micro-analyses

Perform Micro-analysis of Key Demand Parameters

Future changes in SFR water demand can be disaggregated and estimated by multiplying projected rates of change in demand factors by estimates of their water use impacts. For example, annual assessor databases might show construction of 350 new pools and removal of 50 existing pools per year in a service area, for a net increase of 300 swimming pools. If previous studies estimate that a typical swimming pool increases demand by 25,000 gallons per year, one can project the impact of future additions to the stock of swimming pools on water demand by multiplying 300 pools x 25,000 gallons/pool.

However, new pools are on average substantially smaller than pools built decades ago, and it might turn out that older, larger, and possibly leakier pools are most likely to be removed. In that case, examining monthly billing records of those SFR customers who have added or removed pools would provide a much better estimate of water use impacts.

In other cases, there might be reason to suspect that rates of change are not constant. For example, households above a certain income level might be likely to replace a failing evaporative cooler with an AC system, while low-income households might be more likely to replace a failing evaporative cooler with a new evaporative cooler. Determining triggers for change events and modeling the rates of change will produce forecasts, rather than simple projections, of rates of change in the housing stock.

In addition to assessor databases, information on rebate programs can be used to support these types of analysis. For example, data on toilet rebates has been used in the past to estimate to a high degree of certainty the water savings associated with replacing older toilets with more water-efficient models.

Deliverables: Refined estimates of selected rates of change in the housing stock and water use impacts.
Improved coefficients for the dynamic simulation models.

Characterize Future Housing Construction
Interviews with builders, developers, home builders association, planners will focus on:
$ pools in new housing (including size, pool covers)
$ neighborhood pools for new housing developments
$ lot sizes and landscapable areas
$ pre-installed landscaping for houses built on spec.
$ possible mandatory and voluntary efficiency standards for water-using fixtures and

appliances (e.g., CalGreen)
$ likely hot water systems (centralized storage tanks vs. centralized on-demand vs. distributed on-demand)

Note that no attempt will be made to predict, model or forecast future housing construction levels or the mix of housing.

Deliverable: Section of final report.

Develop Provider-Specific Models

Information on water use rates from statistical analyses, engineering estimates and other sources will be applied to the conceptual dynamic simulation model. Some of these rates will apply for all water providers (e.g., water use by horizontal axis washing machines), while rates of outdoor water use (e.g., pool evaporation rates, turf irrigation) will vary spatially. Some water use rates may be adjusted for other provider-specific parameters, such as water/sewer bills, and average income levels. Sensitivity analysis will be performed on draft models to determine which parameter uncertainties are most critical. Baseline scenarios will be defined by working with participating water providers and agencies.

Deliverables: Provider-specific dynamic simulation models
Section of report.

Distribute Models and Provide Training
Dynamic simulation models developed with GoldSim can be compiled and freely distributed. Each participating water provider will receive a customized model and training in how to ask "What if?" questions and do basic scenario analysis.
Deliverables: Provider-specific dynamic simulation models
Training session

Prepare and Distribute Final Report
Text, tables, graphics and other types of background information will be incorporated within the GoldSim models, along with instruction on its use and parameters for baseline scenarios. A supplemental written report will document the statistical and econometric analysis and modeling process and contain metadata. It will summarize what was learned about the key factors underlying residential demand declines, their rates of change, and associated triggers. Finally, the results of the model's sensitivity analysis will be described and areas of fruitful additional research noted.

Deliverables: Final report to all participating agencies.

SCHEDULE
The project is scheduled to begin in early 2013 and last up to 18 months. The schedule allows for some unforeseen delays. In addition, parts of the project can be done in parallel, so a delay in one task can be offset by temporarily shifting effort to another task.

SCHEDULE, IMPROVED UNDERSTANDING OF LONG-TERM TRENDS IN RESIDENTIAL WATER DEMAND																		
Task Description	2013											2014						
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Form advisory panel, convene first meeting	■	■																
Explore causes of declining demand	■	■	■															
Gather and annotate background information	■	■	■	■														
Develop conceptual model		■	■	■	■													
Analyze water demand time series				■	■	■												
Compile databases		■	■	■														
Generate parcel-level descriptive statistics			■	■	■	■												
Calculate rates of change in housing stock				■	■	■	■											
Analyze potential triggers of change					■	■	■	■										
Mid-project review and planning							■											
Perform micro-analysis of key demand parameters							■	■	■	■	■	■	■	■				
Characterize future housing construction													■	■	■			
Develop provider-specific models													■	■	■	■	■	
Distribute models and provide training																	■	■
Prepare and distribute final report																	■	■