Okanagan Valley Water Demand Data
Scenario Modeling
Version 20100322
(revised for presentation 20100421)

This describes the methodology used to model the water use scenarios for the Okanagan Basin Water Board in the fall/winter of 2009. The algorithms used to calculate the irrigation and indoor water demands are documented separately (*Irrigation Water Demand Model – Technical Description*), as are the categorizations of the demands into water use areas, extraction sources and Okanagan Water Database terms (*Okanagan Water Demand Model – OkWaterDb Uploads*). This discussion concentrates on the rules and modifications implemented for each scenario plus some general observations about the scenario results.

Note: In early 2010, modifications were made to the precipitation and temperature files for the cgcm2.a2 model in order to remove biases (primary a dry bias in the precipitation data) from the climate data. Several scenarios were rerun and re-uploaded to the OkWaterDb. Scenarios based on the higher CO2 emissions climate model (cgcm2.b2) were omitted from the second process.

Scenario Differences

The scenarios are combinations of assumptions and rules taken from 4 separate categories:

- Population Growth
- Water use efficiency
- Agricultural land base expansion
- Time period

There is a fifth category (Mountain Pine Beetle levels and effects), but it doesn't play a role in the water demand modeling side of the project. Mountain Pine Beetle effects are accounted for in the Okanagan Basin Hydrology Model.

Population Growth

Standard Growth Rates

Most of the scenarios include an increase in the Valley's population. As part of her thesis work at UBC, Nathalie Maurer created a growth projection scenario for the four main population centres in the Valley through 2026 and produced a spatial representation of that development. Liyang Zhang, a summer student working for MAL, extended Nathalie's growth scenario to the rest of the Valley's population centres and through to 2035. The new residences were mapped by copying a set of templates or "cookie cutter" sets created from existing subdivisions and higher density developments; these were placed on lands deemed probable for residential development through consultation with the various community plans and avoidance of the Agricultural Land Reserve, slopes assumed too steep for building, etc. A total of 20,458 single and multi-family lots were defined to accommodate the population growth projections through 2035 (growth projections and development implementations documented separately by Nathalie Maurer and Liyang Zhang).

Each of the lots in the urban growth map contained a percentage value representing the proportion of the lot considered irrigated for outdoor landscaping purposes. Each lot also contained the property identifier copied from the original templates, which meant that daily indoor water use rates could be assigned by copying the rate values from the current lots upon which the templates were based. Some of the properties used for the urban growth mapping templates did not have any indoor water use associated with them. While this seems reasonable from the point of view of the original properties, some of which may have been vacant lots, it doesn't follow the intent of the urban growth methodology where each new property is intended to represent additional population and therefore water demand. A few other lots in the buildout templates had associated daily uses that were much higher or much lower than normal values for residential use; these were probably taken from shapes corresponding to non-residential uses. For those properties in the growth scenarios that did not contain a daily water use when linked back to the originals in the templates, or that had a daily use of less than 0.3 m^3/day or greater than 12 m^3/day, the most common residential rate of 0.46 m^3/day was substituted.

The urban development lots were brought on line in a random order between 2007 and 2035 (see *Note on Randomness* below), each adding its daily water use factor to the overall demand as it became active. Any water use efficiencies involved in the scenario were also applied to the new lots as they came on stream.

The increase in domestic outdoor irrigated area using this population growth methodology is illustrated in Figure 1 below.

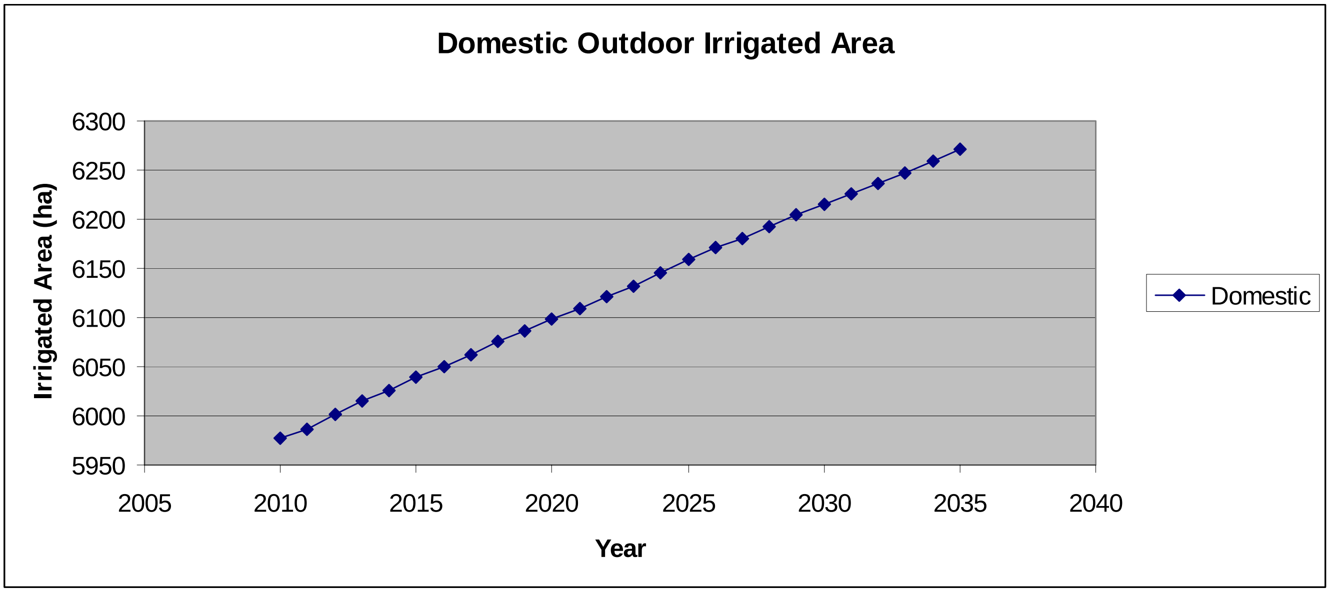


Figure 1 – Domestic outdoor irrigated area 2010 – 2035

Beyond 2035, the urban growth trend was extended statistically, since we don't have any further spatially explicit development shapes to add after that point. The ratio of each year's domestic outdoor irrigated area to the equivalent for 2035 was fitted with a linear trend line to determine an equation of the increase in area as a function of year:

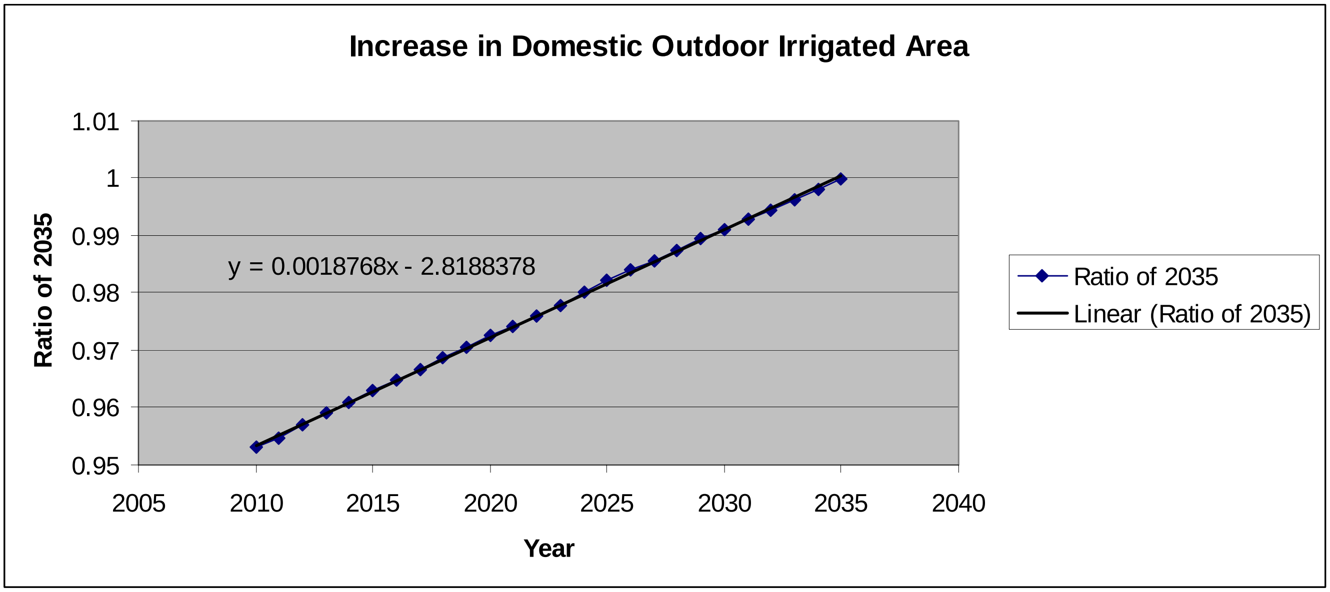


Figure 2 – Domestic outdoor irrigated area as a ratio of 2035's value

This equation was used to extrapolate the increases for 2036 – 2040.

Indoor water use was handled in a similar fashion, using the values calculated for 2010 – 2035 from scenario 1. This includes the competing trends of increases due to urban expansion and decreases due to a 33% improvement in water use efficiency over the 2010 – 2040 period.

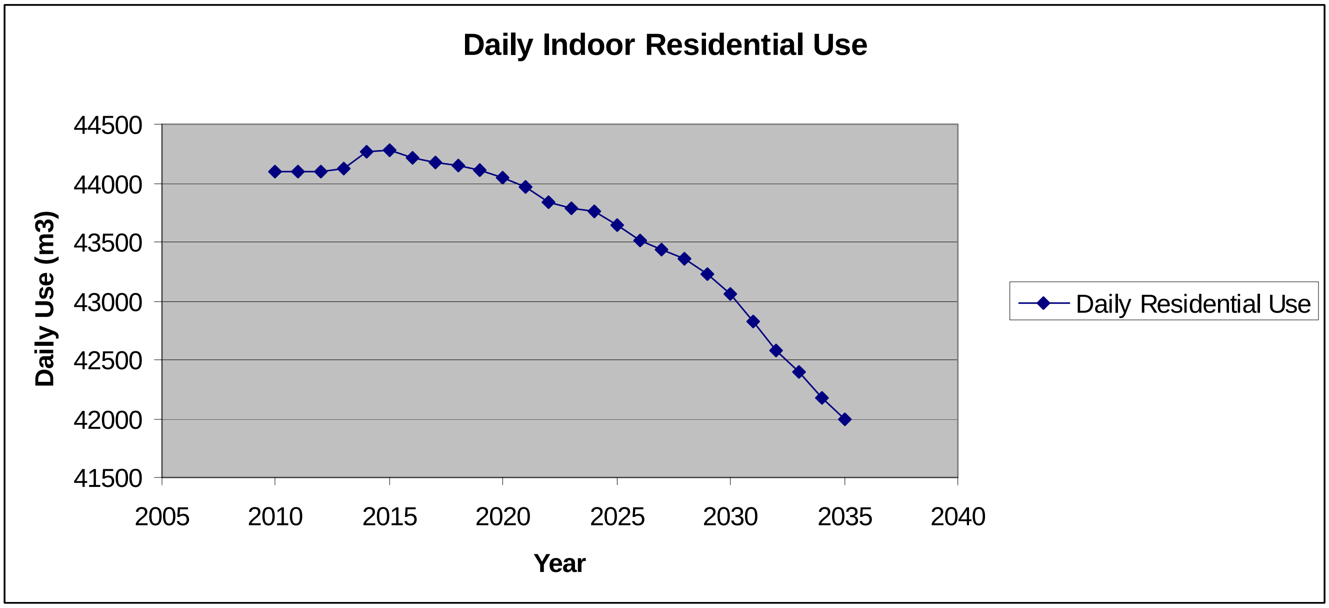


Figure 3 – Daily indoor residential water use for the standard efficiency scenarios

Once again, this was converted to a ratio of each year's daily indoor use to the 2035 value, and a trend line fitted to the points, this time using a second order polynomial.

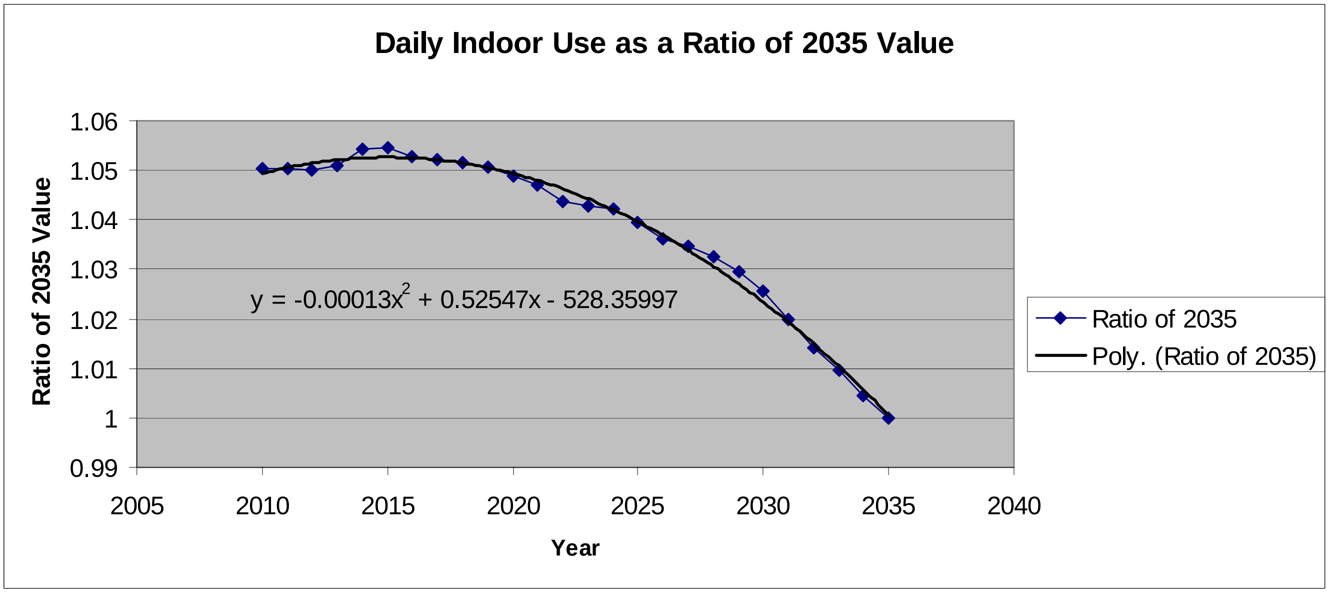


Figure 4 – Daily indoor residential water use as a ratio of the 2035 value

This equation was then used to produce multiplicative factors for each lots daily use rate over the period 2036 – 2040. The resulting indoor use for the complete 2010 – 2040 period is shown in figure 5.

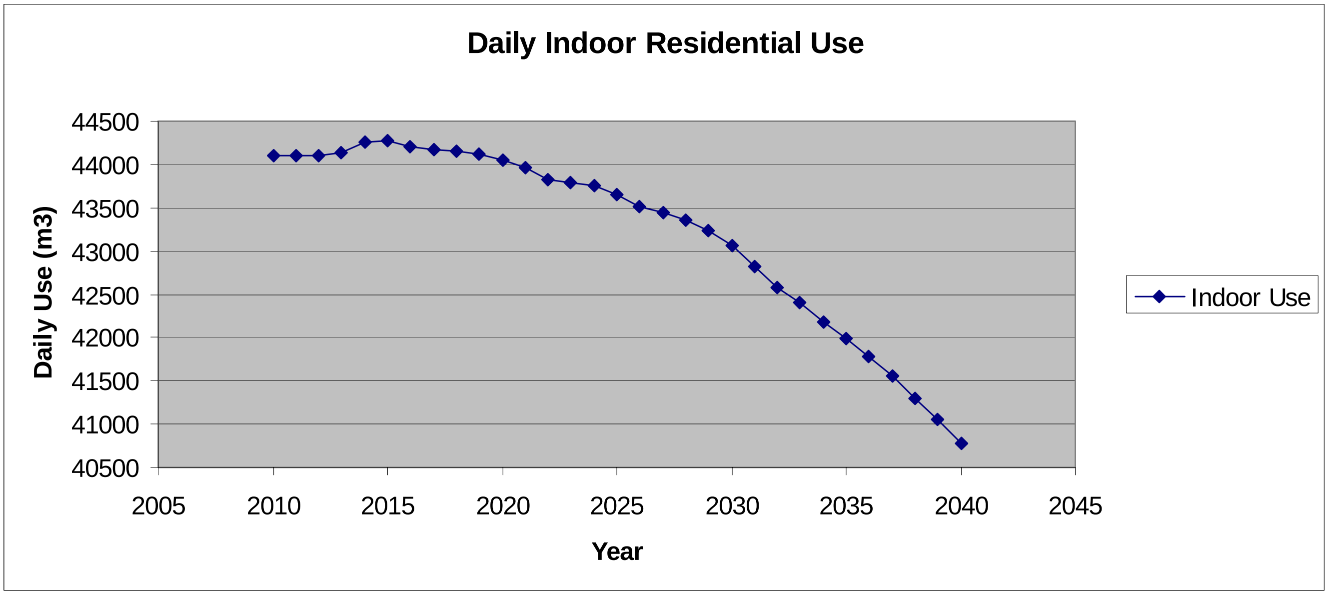


Figure 5 – Daily indoor residential water use 2010 - 2040

A similar process was used for the rapid efficiency implementation scenarios; the modeling process was first used to establish results for the indoor residential water use for 2010 – 2035, bringing the urban lots on stream over the full period, but this time implementing the 33% water use efficiency by 2020. After 2020, there is no further improvement in the efficiency, and the trend line follows a linear pattern between 2021 and 2035.

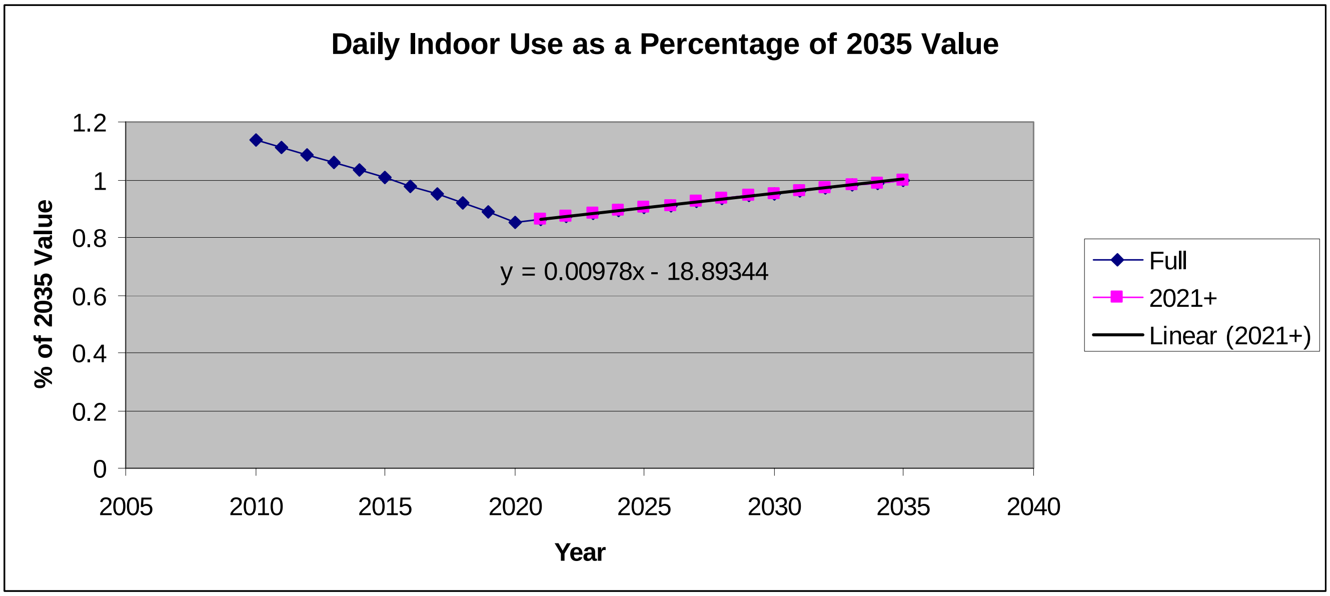


Figure 6 – Daily indoor residential water use as a percentage of the 2035 value for rapid efficiency scenarios

The linear equation was used to increase the indoor residential use for the 2036 – 2040 period.

ICI Water Use

We don't have any representation of growth for Industrial, Commercial or Institutional water use. Instead, for each year of the modeling period, the ratio of the year's total residential indoor water to the 2006 equivalent is used as a multiplier for the ICI rates. This results in an overall increase in the ICI water use to keep pace with the residential buildout, but it doesn't reflect the spatial location of the new services – in effect, it's simply building up on the existing footprints. This lack of spatial location means that the results of the scenario modeling may not be suitable, as far as the ICI demands go, for use at finer resolutions such as an individual water use area.

High Population Growth Rates

For the high population growth scenarios, the same development lots were brought on stream, in the same time frames, as for the standard growth rate scenarios. The standard residential indoor use rates were then increased through additional multiplicative factors developed from higher population estimates. Once again, this type of projection corresponds to increasing the population density within the existing residential lots or *building up* rather than developing additional housing for the increased growth.

Water Use Efficiency

Current Trends

Under current trends, indoor water use is expected to decrease on a per-capita basis by 33% over the 2010 – 2040 modeling horizon, the irrigation management practices for outdoor domestic use are expected to improve, and some of the high water use agricultural crops and irrigation systems will be converted to lower uses and more efficient technology.

Indoor improvements were handled for the 2010 – 2035 period by multiplying the daily indoor per-property values by a factor corresponding to 33% over 30 years (2011 – 2040):

indoorReductionPct = 1 - (33 / 30 * (indoorReductionYear - 2010) / 100)

For 2036 to 2040, the trend line equation representing both population growth and efficiency improvement was used to extrapolate the indoor residential use (described above).

Industrial, commercial and institutional indoor use was adjusted to keep pace with the residential indoor values by comparing the residential indoor yearly total with the equivalent for 2006 (the source date for the indoor use rates), and then applying the same factor to the ICI rates. It was realized late in the process that the implementation of the ICI improvements involves a kind of double-dip whereby the ICI is improved first through the general 33% reduction and then again through application of the trend in indoor residential use changes (illustrated further as part of the discussion on results below). For future scenario runs, a decision will be needed as to whether the modeling of ICI indoor use should be kept the same for consistency or modified. Either way, the ICI indoor use modeling has no spatial component – it increases the use at the current locations regardless of where the population growth would require it.

The water demand model uses an irrigation management practices setting to calculate the amount of water lost to deep percolation from over-watering, and it has values of *poor*, *average* or *good*. For the current trends scenarios, agricultural uses are kept at an *average* setting while domestic outdoor (landscaping) irrigation is expected to improve from *poor* to *average*.

In order to achieve the one setting for agricultural crops and phased-in change for domestic irrigation, the model was first processed using an *average* setting throughout and the results for domestic outdoor irrigation were then modified afterwards. A random conversion year between 2010 and 2040 was assigned to each combination of crop type, climate cell, soil type and irrigation type – these are the factors that are significant in calculating the percolation losses and overall water demand. Domestic properties whose conversion years were greater than the year being modeled were then adjusted to a poor management setting by replacing the percolation and IWD values with recalculated values under a poor setting. Figure 7 below shows the change in domestic outdoor irrigated area under both the poor and average management settings.

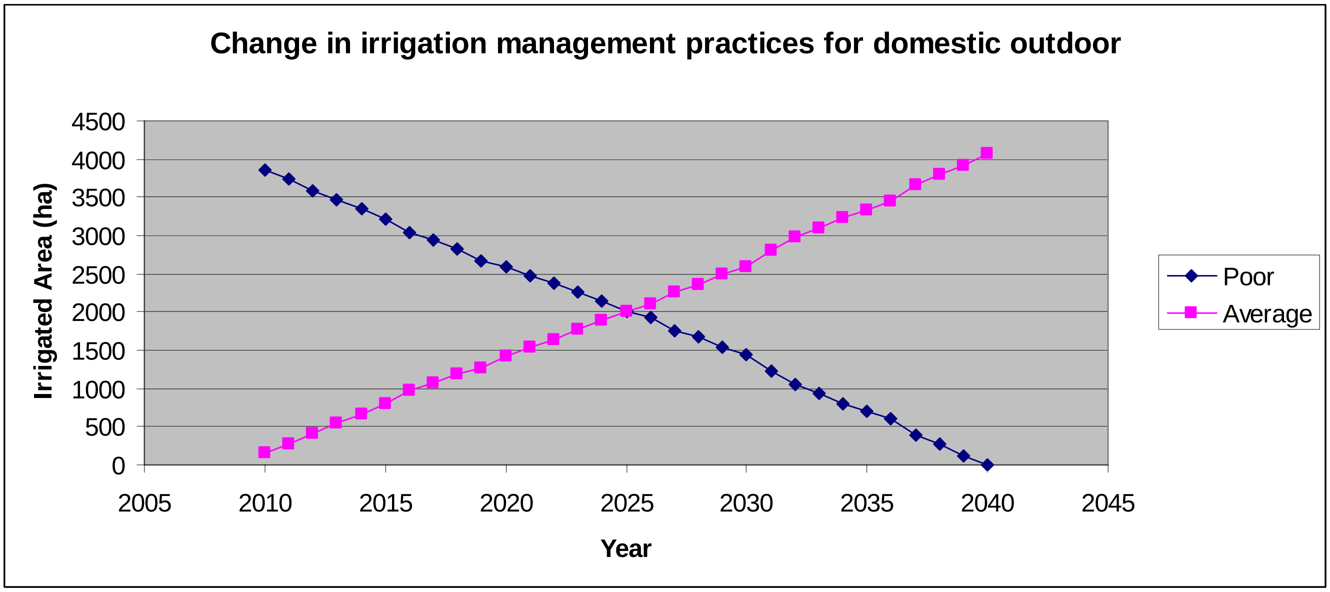


Figure 7 – Change in irrigation management practices for domestic outdoor use

In the *current trends* scenarios, all of the vegetables and grapes that are not currently using drip irrigation get converted to drip over the 2010 – 2040 period, all tree fruits not currently on drip or microsprinkler go to drip or microsprinkler in a 50%-50% split, and all forage crops currently using gun irrigation get converted to sprinkler. The three groups were broken down as:

Vegetables and grapes:	Asparagus Potato Tomato	Berry Pumpkin Vegetable	Blueberry Raspberry	Ginseng Strawberry	Grape Sweetcorn
Treefruits:	Apple Peach	Apricot Pear	Cherry Plum	Nectarine Sourcherry	Nuts
Forage:	Alfalfa	Cereal	Corn	Forage	Grass

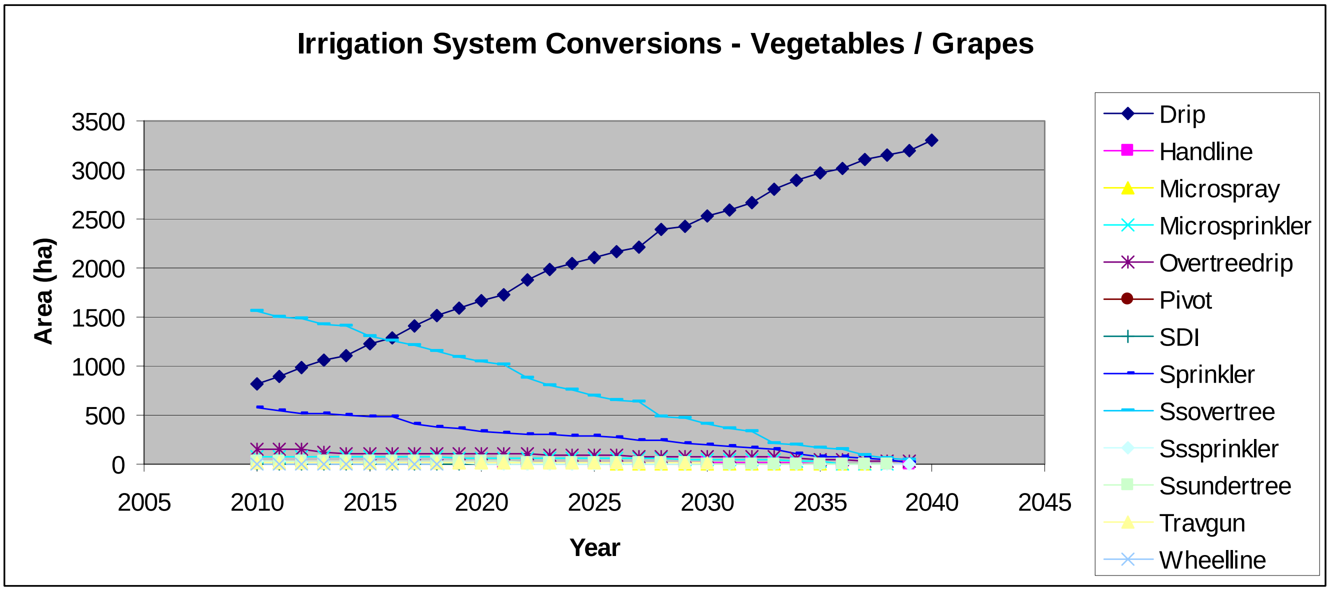


Figure 8 – Change in irrigation systems for vegetables and grapes

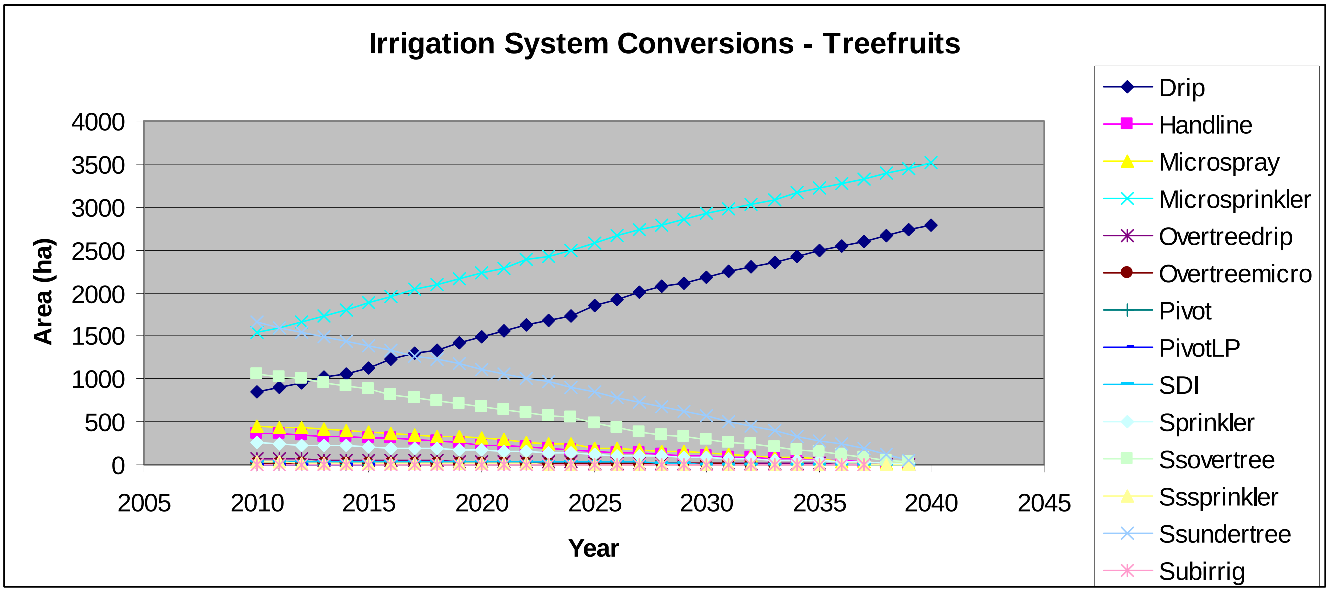


Figure 9 – Change in irrigation systems for treefruits

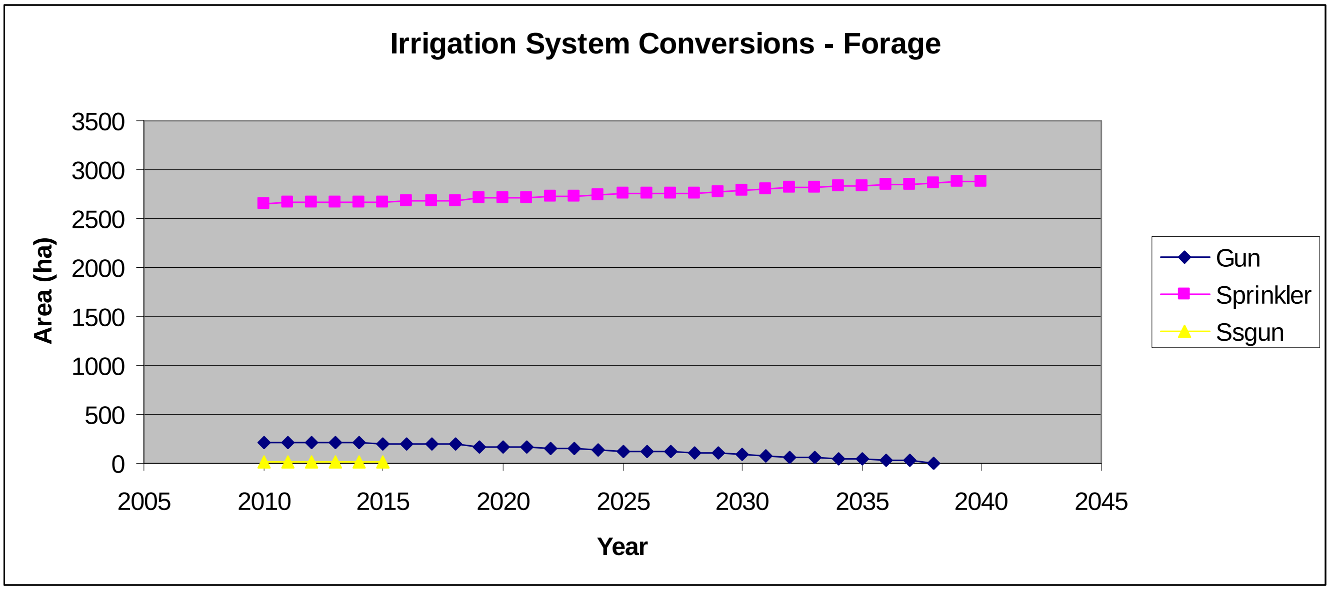


Figure 10 – Change in irrigation systems for forage currently using Gun or Ssgun

Increased Efficiency Improvements
The *33% Efficiency* scenarios include the same improvements as for the current trends, but at a faster pace – all take place over the 2010 – 2020 period instead of 2010 – 2040.

In addition, the irrigation management practices for agricultural crops improves from *average* to *good* over the same 2010 – 2020 period. A similar technique to that used for the phase-in of the improvement from *poor* to *average* management for domestic outdoor irrigation was used for the agricultural improvements; all agricultural crops were converted from *average* to *good* using a random selection process over the 2010 – 2020 period.

Agricultural land base expansion

Areas suitable for agricultural expansion were mapped out by MAL and subsequently overlaid with the source database to produce a list of intersected polygon identifiers. Using a similar process to the urban growth phase-in, the agricultural polygons were assigned random years between 2010 and 2040 and brought on stream accordingly over the modeling period. New agricultural properties in zone 4 (Winfield and north) were designated as growing *alfalfa* under *sprinkler* irrigation; properties south of Wood Lake were treated as *medium density apples* under *microsprinkler*.

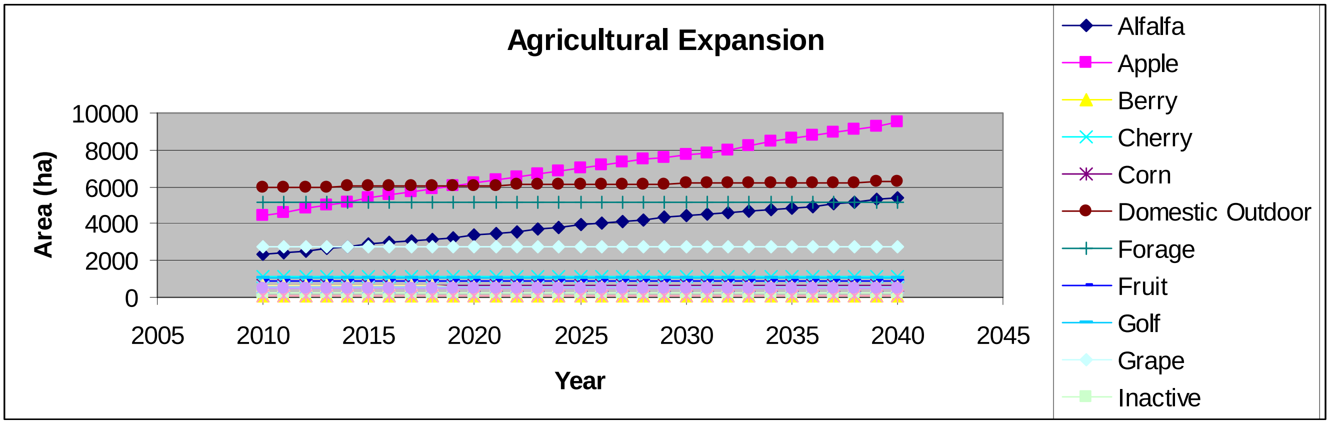


Figure 11 – Increased agricultural area (Apples and Alfalfa)

Time Periods

Most of the scenarios cover the time period 2011 – 2040, although results for 2010 have also been included in those sets. Scenario 26 covers the 2041 – 2070 period. Scenario “99” covers the calibration period (1996 – 2006), but also uses the bias-corrected cgcm2.a2 climate data.

The drought scenarios use 3 separate years selected from the climate data as representing the driest years between now and 2100 (2076, 2033, 2026) modeled under the assumptions for years 2038 – 2040. The climate data files from the cgcm2.a2 model for years 2076, 2033 and 2066 were copied into an alternate climate source structure as years 2038, 2039 and 2040 respectively and modeled as those years using the various combinations of urban growth, efficiency improvements and agricultural expansion assumptions.

Note on Randomness

Several of the scenarios involve modeling some type of trend into the future where the overall effect can be estimated, but not the individual steps towards that general outcome. For example, the population of the Valley is expected to increase, and with it the number of residential lots, but the patterns and timing of the developments can’t be predicted beyond a very few years into the future. A decision of a project sub-committee was to use a random process to introduce these trends, with the intent being a reasonable degree of pattern avoidance rather than a rigorously enforced implementation of true randomness.

The random.org service offers easily generated and freely available sets and sequences of random integers generated through a truly random process based on measurements of atmospheric noise. Sets of numbers downloaded from the web site (http://random.org) were used to introduce randomness into the different trends. In the residential development example, 30,000 randomly selected integers with values between 2007 and 2035 (inclusive) were generated and combined into a lookup table along with a sequential identifier matching the unique keys from the mapped growth polygons. The list was then used to assign a “year of development” to each of the urban growth properties, and each modeling run added the year’s compliment of new lots.

The frequency of selection for each development year for the urban expansion lots is graphed in Figure 12 below.

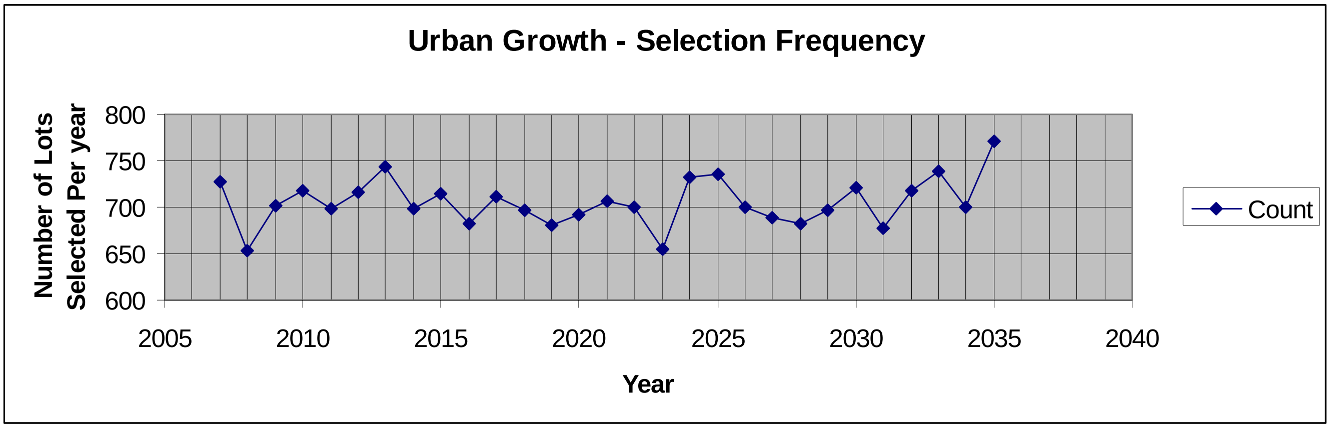
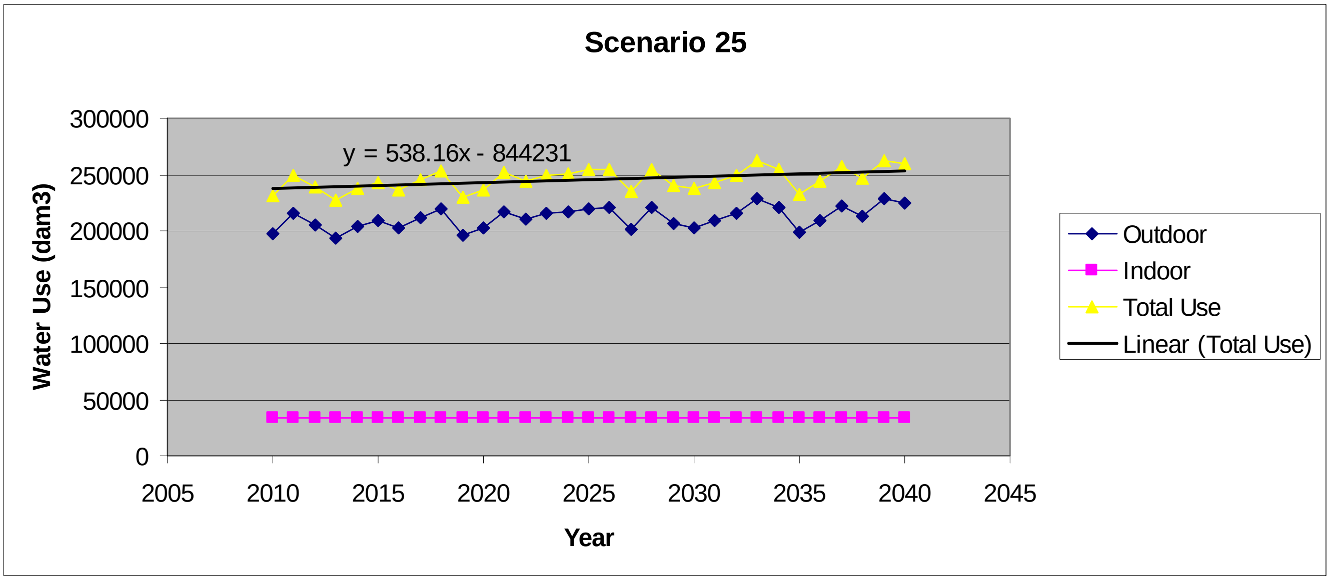


Figure 12 – selection frequency of lots by year of development

Again, the implementation of randomness for this project is not intended to be a rigorous application of the science, but rather to introduce a level of unpredictability that would more closely represent patterns such as conversion of irrigation systems and indoor uses to more efficient or less wasteful practices. In practice, residential development and agricultural expansion would likely occur in both temporal and spatial clusters, rather than at an average yearly rate or as single unconnected properties. For that reason, it could be misleading to try to use the results of the modeling process at spatial resolutions finer than the full valley basin or as other than trends over the complete modeling periods.

Scenario Results

Scenario 25 provides a type of “base case” scenario where only the climate affects the water demands between 2010 and 2040; all of the other factors such as population growth, agricultural areas and water use efficiencies are fixed at 2010 levels.

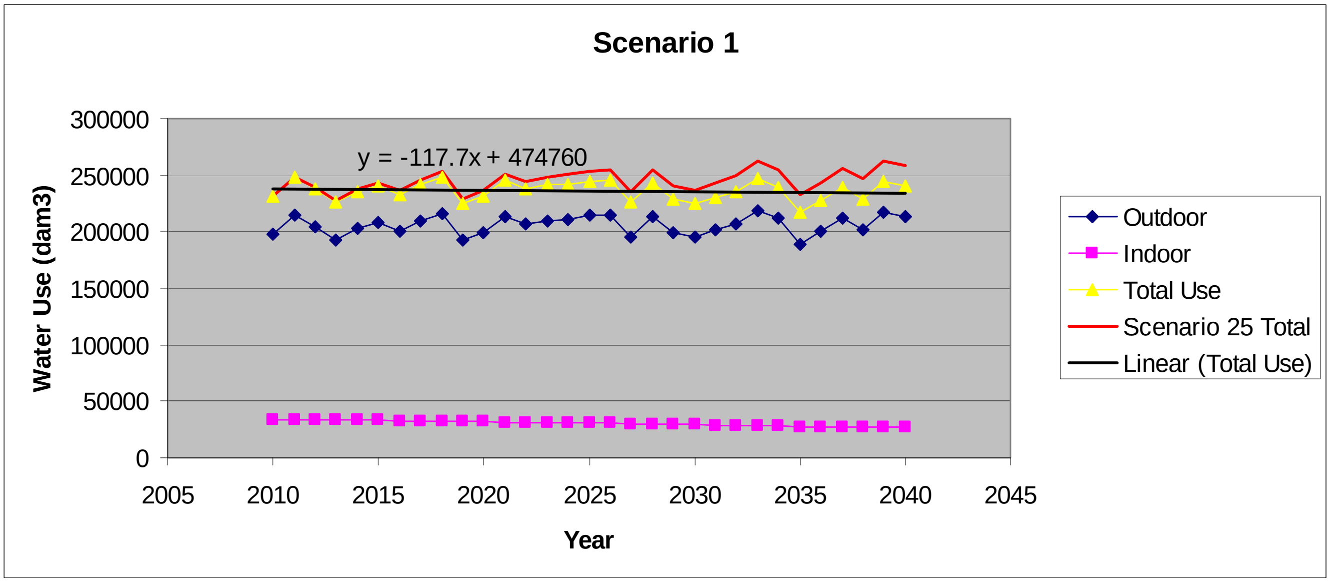


Scenario 25 - Climate change (cgcm2.a2) alone

This indicates that climate change alone (using the expected CO2 emissions of model cgcm2.a2) would account for an overall water demand increase of about 6.8% between 2010 and 2040.

Scenario 1 combines the climatic changes of scenario 25 and current trends in terms of population growth, irrigation system improvements and indoor water use. Over the 31-year period, the following improvements take place:

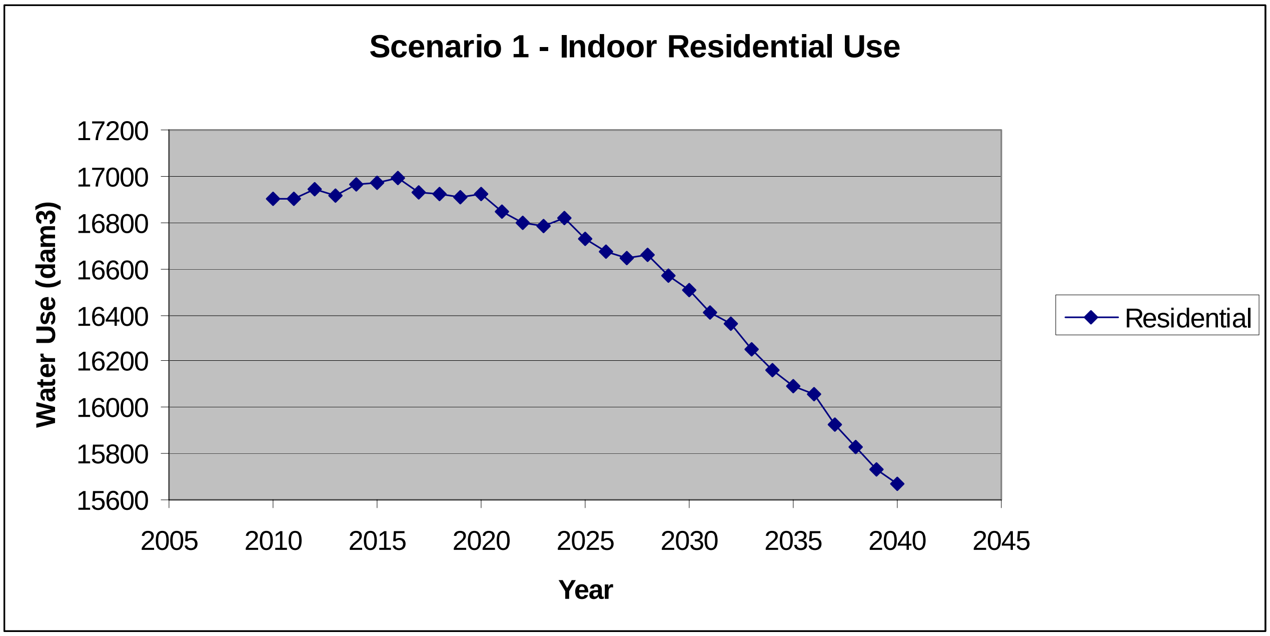
- indoor use improves by 33%
- outdoor domestic irrigation management practices (losses to overwatering) improve from poor to average
- all vegetables and grapes convert to drip irrigation
- 50% of the tree fruits not on drip or microsprinkler irrigation convert to drip or microsprinkler
- Forage crops using gun systems convert to sprinkler



Scenario 1 – Current trends under cgcm2.a2

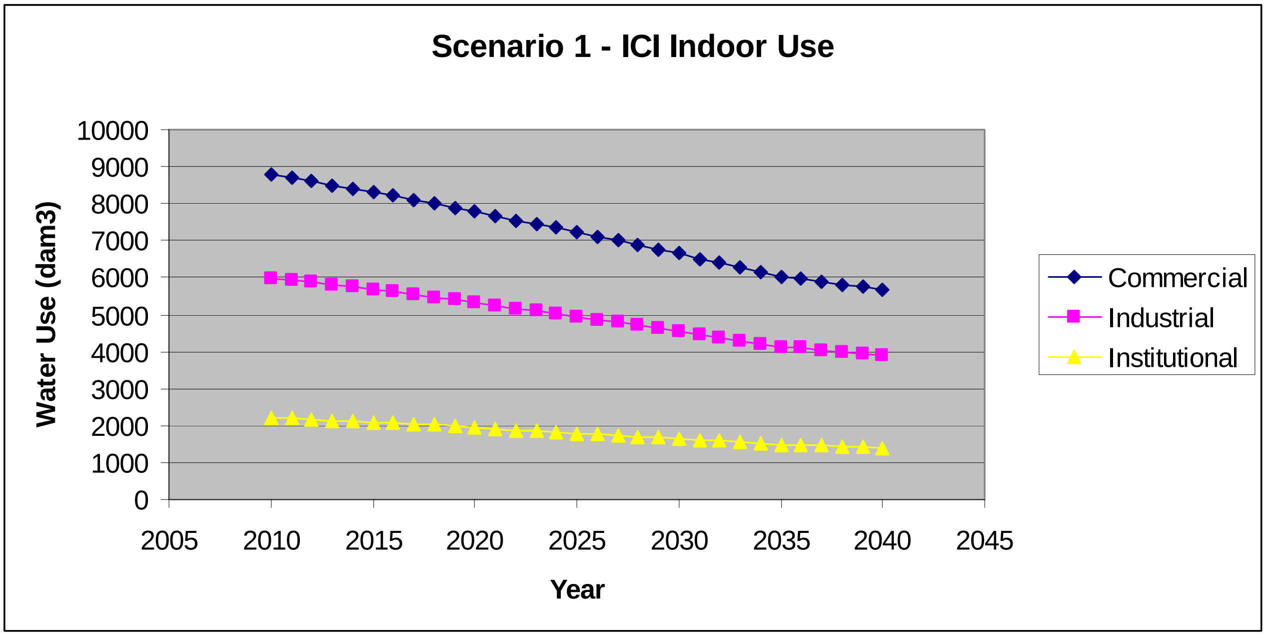
Scenario 1 shows an overall decrease in the total water use by about 1.5% over the 31-year period. The increase in indoor demand due to population growth and outdoor demand for climate change is offset by improvements in use practices and irrigation system types.

Note that in the current set of scenario results, the use levels for indoor uses other than residential (i.e. commercial, industrial and institutional) are probably too low. Since we don't have any projected spatial representations of increasing ICI uses, the basic technique for changing the non-residential indoor use rates over the modeling horizon is to compare the current year's daily use total for residential against the 2006 equivalent and multiply the ICI daily use values by the same ratio. However, in the current modeling process, the adjustment aimed at increasing the overall ICI use to represent an expansion of those services is being performed after other daily use rate adjustments, including the across-the-board implementation of efficiency improvements. The net result is that the ICI use is being given an extra amount of efficiency improvements beyond the levels applied to the indoor residential levels.



Scenario 1 – Residential Indoor use alone

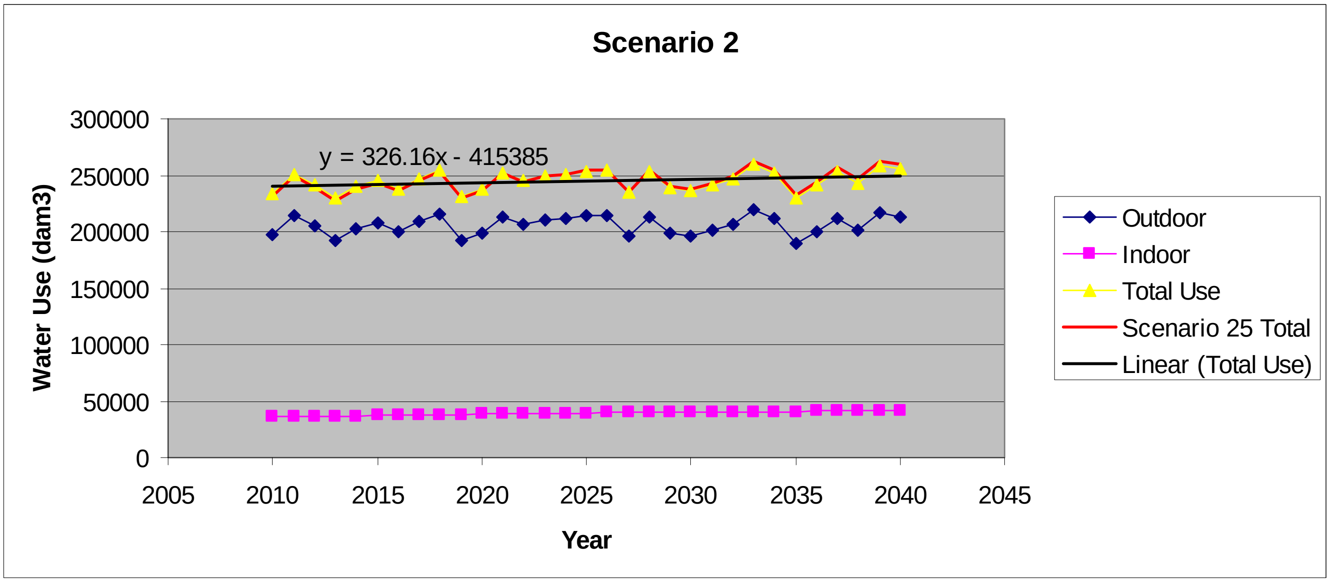
The residential indoor use levels show a slight increase over the first few years of population growth until the improvements in use overcome the increases to produce a general reduction trend.



Scenario 1 – Non-residential Indoor use

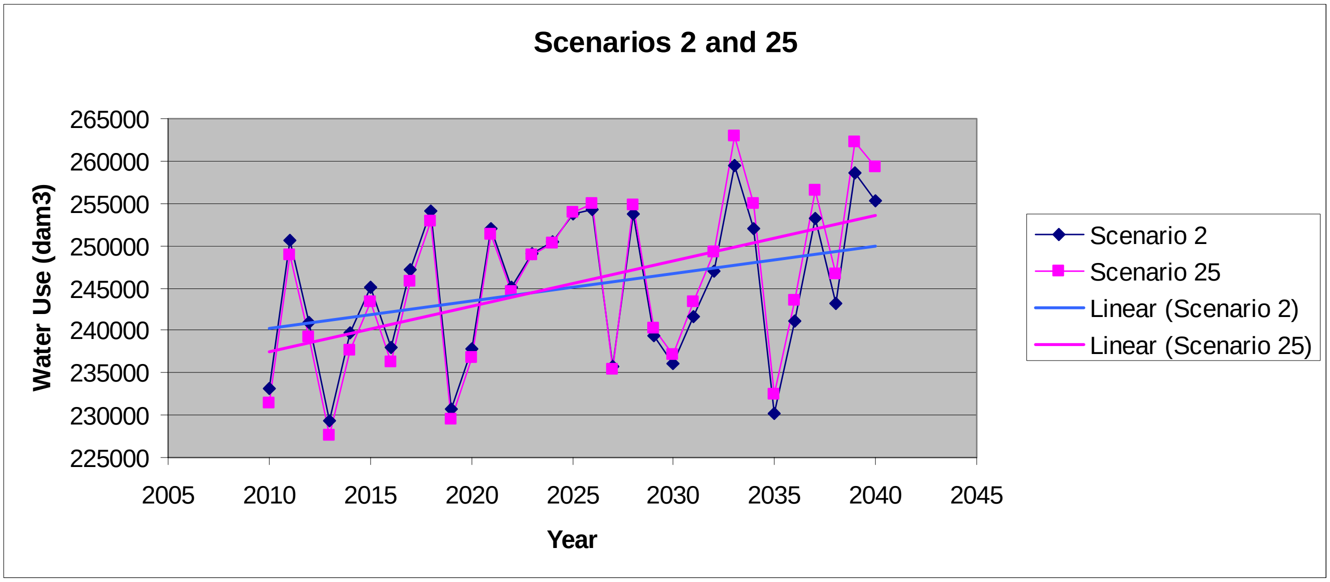
The non-residential (ICI) levels do not show the same initial increase as the residential and instead yield a steady downward trend. Some of this is due to the decrease in ICI areas that are replaced by residential developments, but some may be attributable to a “double-dip” efficiency improvement inherent in the methodology used to model the growth of ICI services.

Scenario 2 uses the same efficiency improvements and irrigation system conversions as scenario 1, but increases the rate of population growth. Since we don't have explicit spatial projections for a high rate of population growth, the modeling methodology for the rapid growth scenarios simply multiplies the daily indoor use values by constants (depending on the expectations for each population centre). The same developments are implemented over the full 2010 – 2035 period, but the multiplication in effect represents a higher population living on the same footprint.



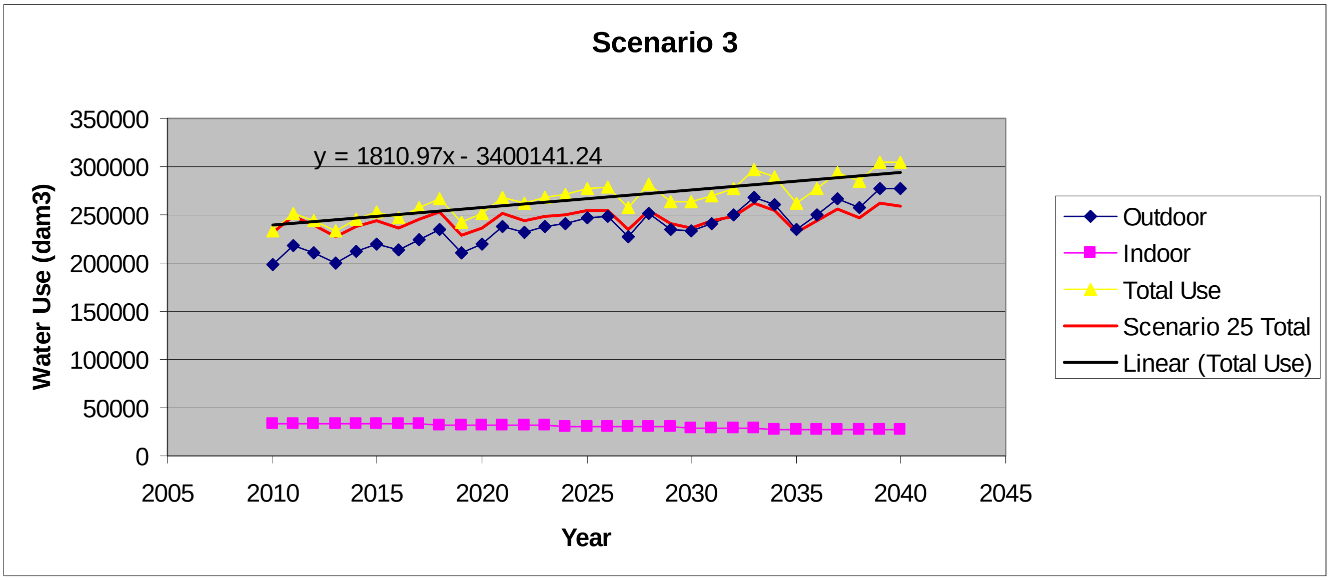
Scenario 2 – Rapid population growth

The increased population growth yields an overall demand increase of about 4.1%, about two thirds of the increases due to climate change alone.



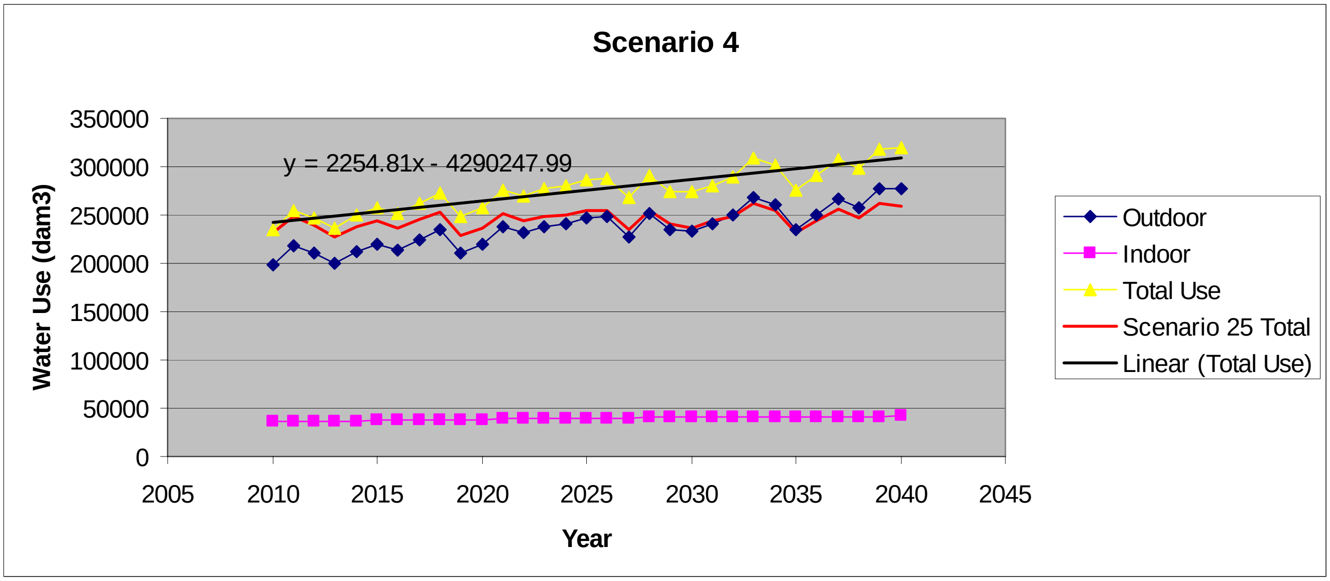
Scenarios 2 and 25 – Rapid population growth and efficiency improvements versus climate change alone

Scenario 3 uses standard population growth but adds to the agricultural landbase (approx 9000 ha. over the 2010 – 2040 period). The increase in agricultural water demand results in an overall increase of about 22.6%, well outstripping the changes due to climate or climate and population growth alone.



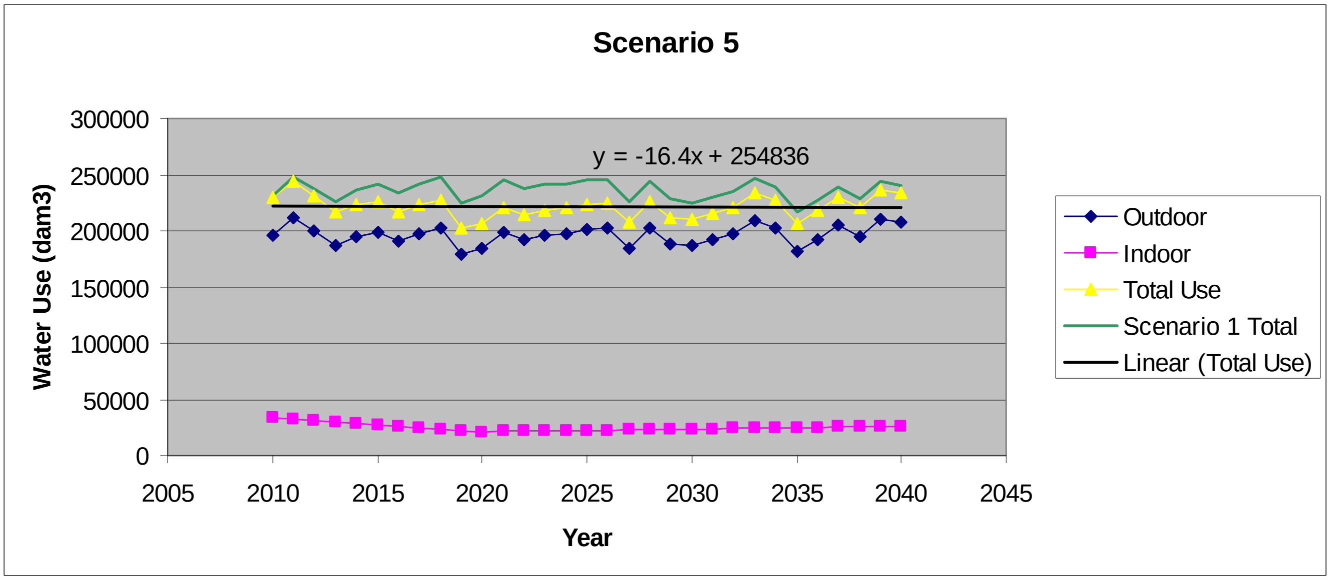
Scenario 3 – Expected population growth, but expanded agriculture

Scenario 4 combines higher than expected population growth with increased agriculture, resulting in an overall water demand increase of about 28%.



Scenario 4 – Rapid population growth and expanded agriculture

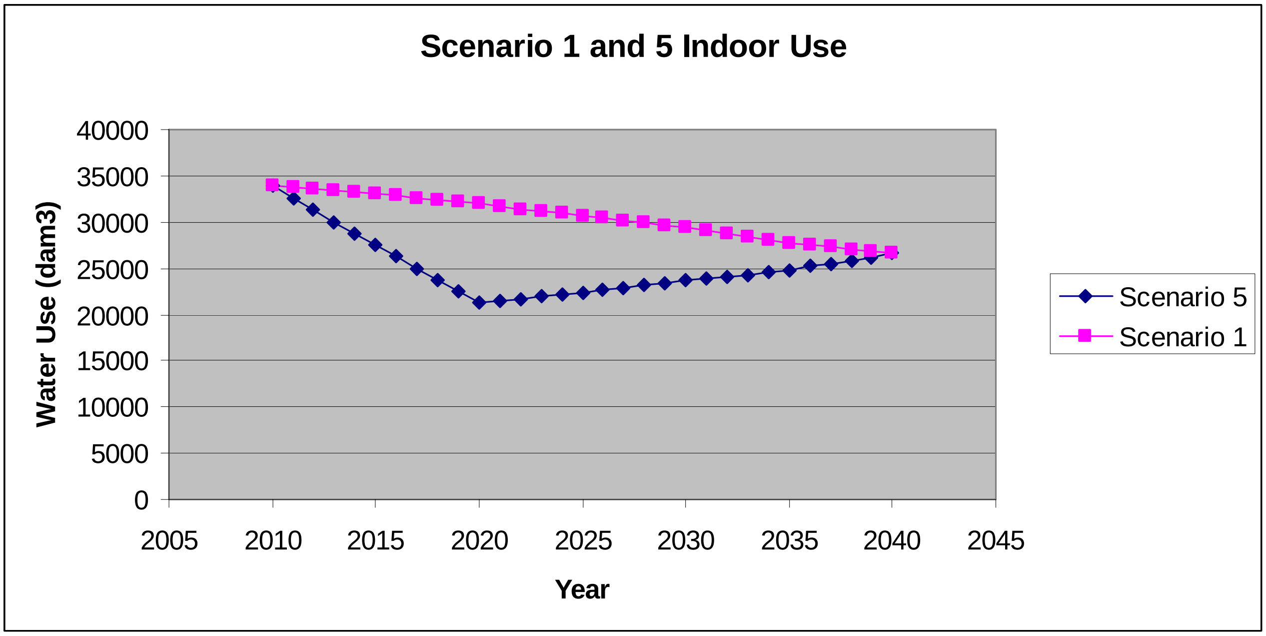
Scenarios 5-8 repeat the changes in population growth and agricultural expansion from scenarios 1-4, but speed up the efficiency improvements so that they complete by 2020 instead of 2040. The irrigation management practices for agricultural lands also improves from average to good over the same 11-year period.



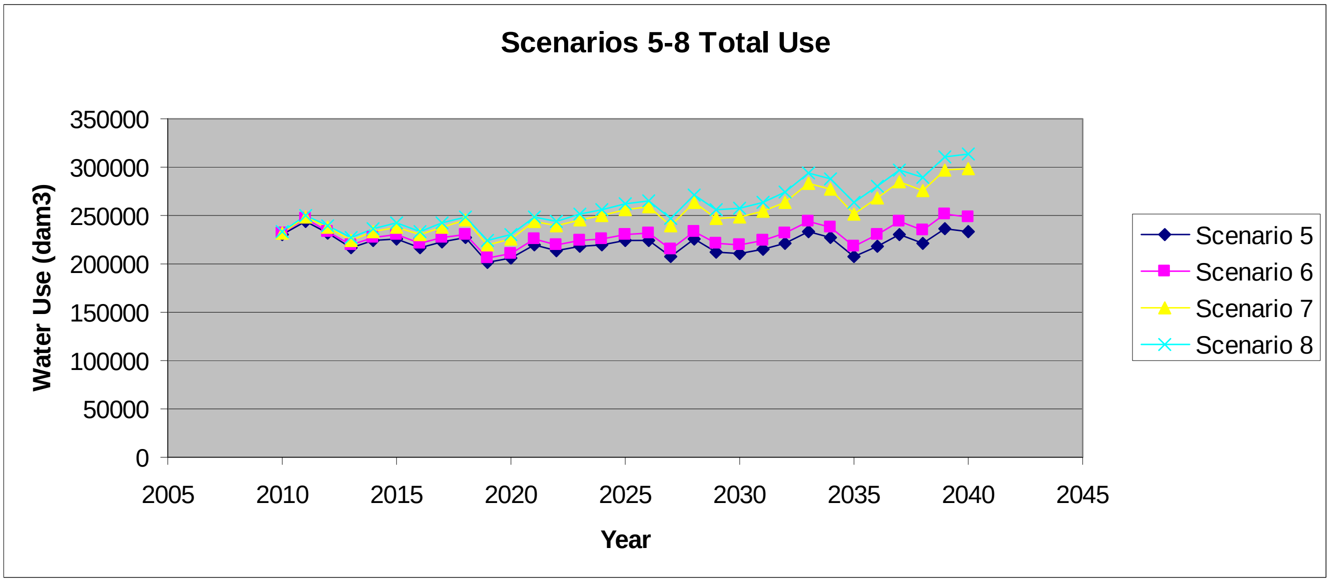
Scenario 5 – Faster efficiency improvements and additional agricultural practices improvements

The result is an almost constant trend over the 2010 – 2040 period (0.2% overall decrease).

Indoor water use for the fast efficiency improvement scenarios drops over the initial 11 years, but then increases over the remaining part of the modeling horizon to meet the standard efficiency scenario use.

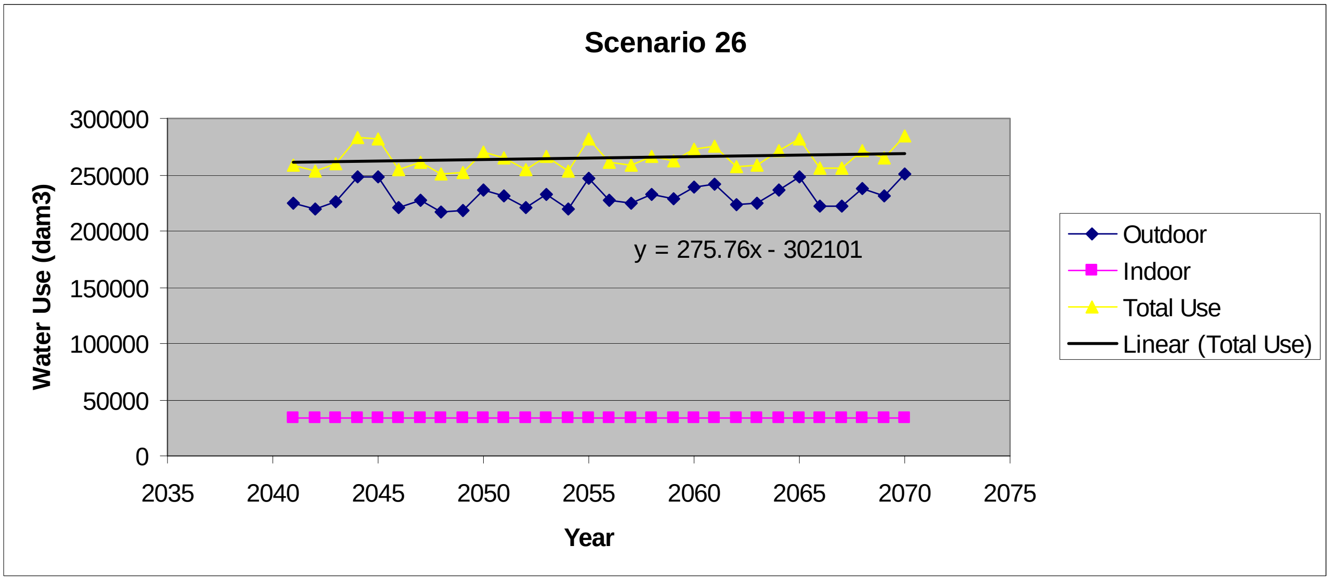


Indoor water use for standard and fast efficiency improvements



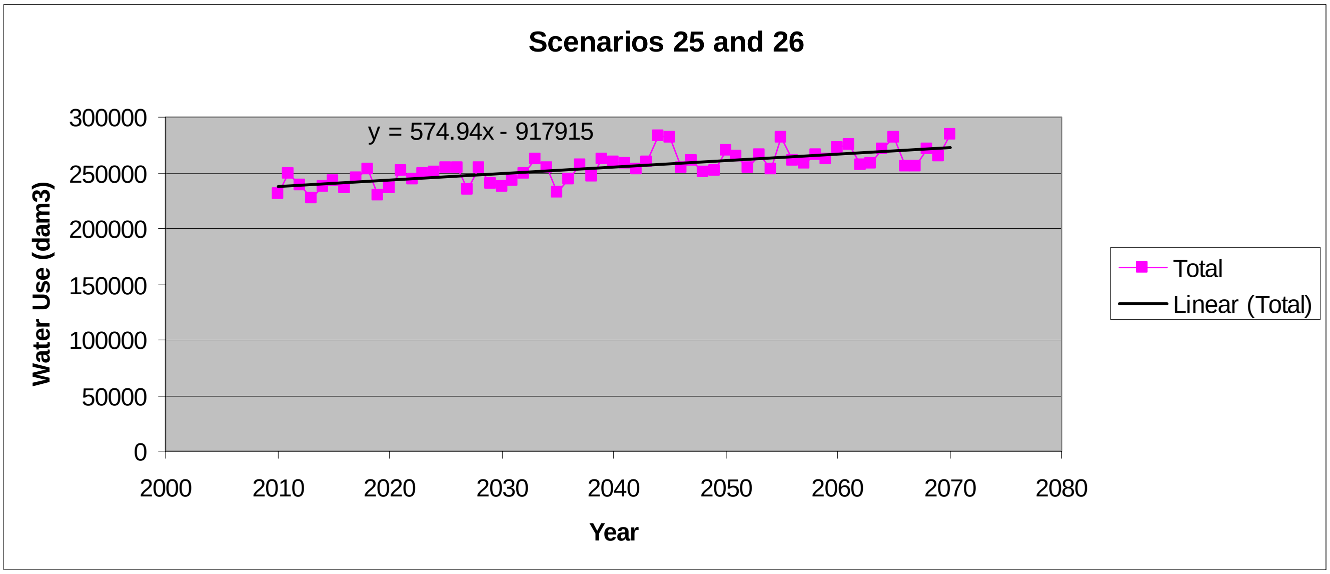
Total water use for fast efficiency improvement scenarios under cgcm2.a2

Scenarios 26 includes the same assumptions as 25 (present conditions except for climate change), but models the 2041-2070 period.



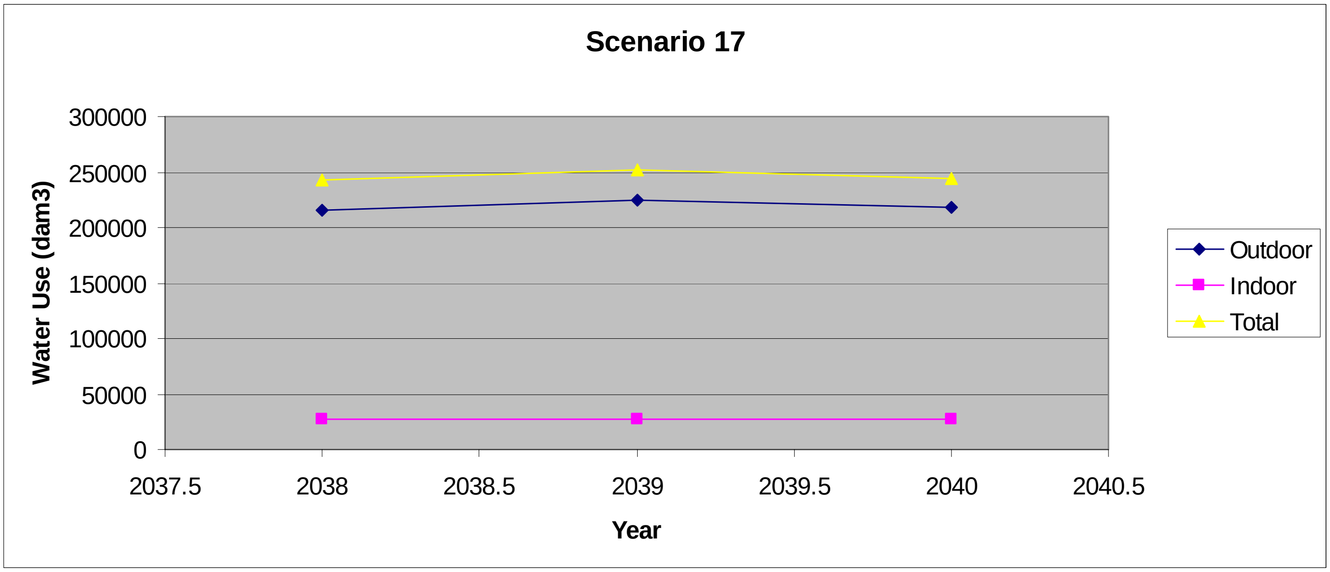
Scenario 26 - Climate change (cgcm2.a2) alone, 2041 - 2070

Combined, the two climate-only scenarios (25 and 26) present a steeper trend line for the full 2010 – 2070 period than those of the individual 30-year periods, giving an overall increase in total use of approximately 14.5%.

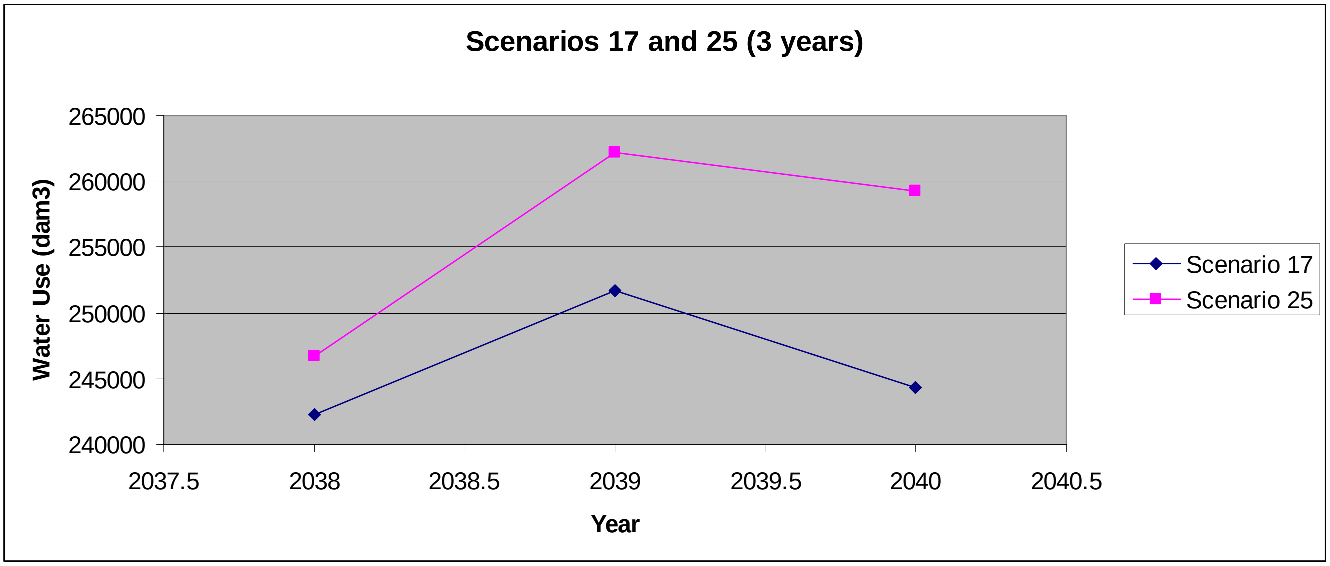


Scenarios 25 and 26 - Climate change (cgcm2.a2) alone, 2010 – 2070

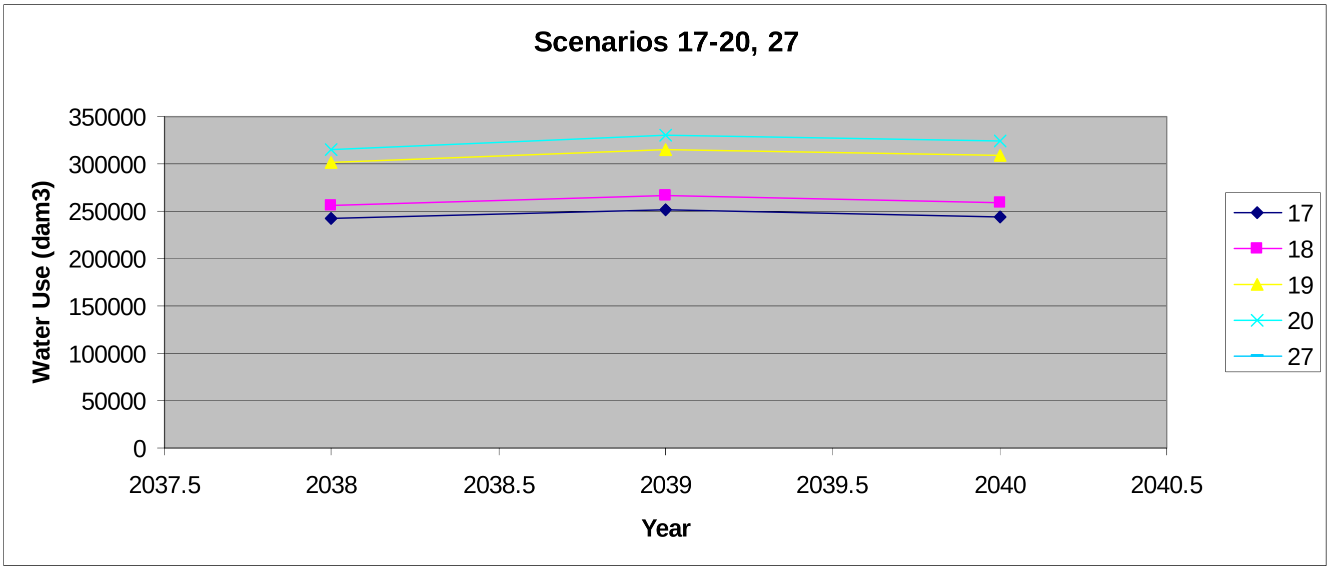
The “drought years” scenarios (17-20 and 27) use the 2038 – 2040 modeling assumptions for population growth, efficiency improvements and agricultural buildout, but the climate data from years 2076, 2033 and 2026 respectively. Those climate years were selected as having the driest hydrologic years (October 1 – September 1), but they do not correspond to the highest crop water demand years. In fact, 2026 is in the bottom third of the 2010 – 2100 period in terms of potential evapotranspiration and crop water demand.



Scenario 17 – Drought years using current trends and cgcm2.a2

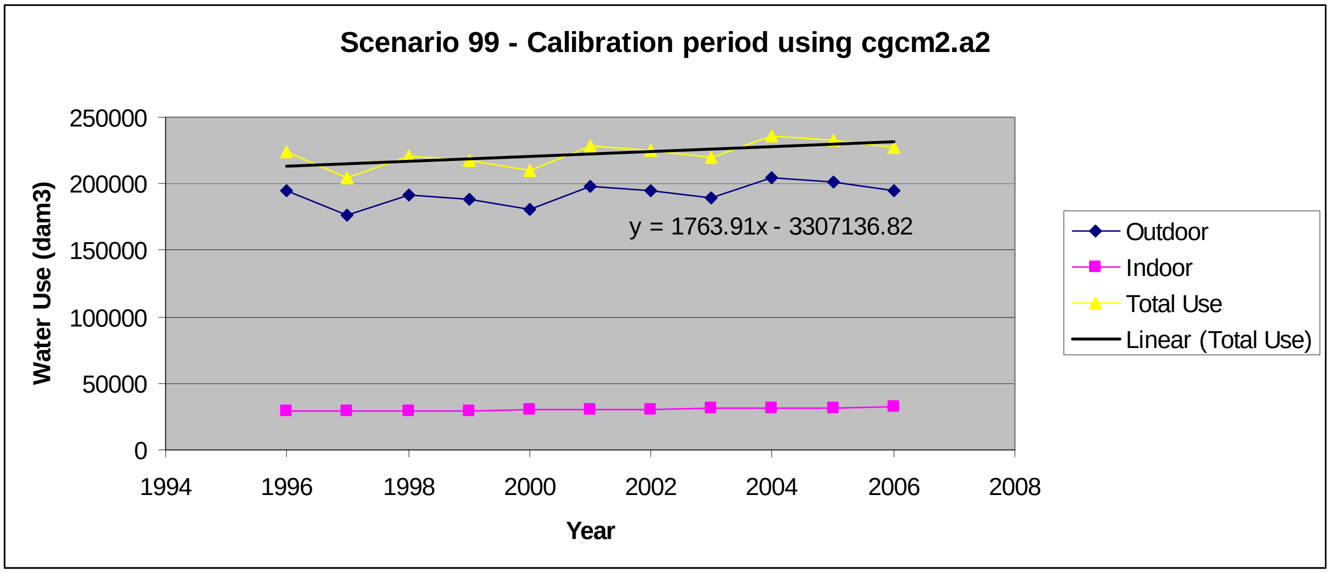


Scenarios 17 and 25 (3 years) – the hydrologic drought years are not the highest water



Scenarios 17-20 and 27

To provide a comparison for the future climate scenarios, the calibration period (1996 – 2006) was processed under the bias-corrected cgcm2.a2 climate data as a scenario “99”.



Scenarios 99 – calibration period under cgcm2.a2

The simple yearly average total use and average yearly increase in total use for the calibration period (scenario 99) and the standard 2010 – 2041 periods are described in Table 1 below.

Scenario	Average Yearly Total Use (dam3)	Average Yearly Change (dam3)
1	236424	-118
2	245097	326
3	267077	1811
4	275750	2255
5	221626	-16
6	228865	409
7	252218	1908
8	259456	2333
25	245536	538
99	224411	1764

Table 1 – Average yearly use and change