**APPENDIX 2**

**SUMMARY OF CONFLUENCE MODELING IN SUPPORT OF THE WSAC**

## Introduction

As the WSAC has done its work over the past months, the Confluence® model has been used to support those efforts by analyzing the performance of many supply/infrastructure alternatives under a variety of different planning scenarios. This modeling has resulted in a series of documents describing the modeling results. The purpose of this document is to summarize, in narrative form and in roughly chronological order, the key modeling milestones over the course of the project.

This document concludes with a numbered list of the key documents that are referenced in the discussion. Such references in the text are followed by a number in parentheses that corresponds to the numbered memo in the list. All of the referenced memos are included as an attachment.

The charts and tables shown in this Appendix represent the modeling results at the point in time being discussed. As the committee refined its supply/infrastructure alternatives and as Water Department and technical staff refined various assumptions, these results evolved. As better information becomes available in the future, the results will continue to evolve. Thus, none of these "snapshots in time" should be considered "final".

## Use of Confluence in Santa Cruz: A Brief History

The Confluence model's first use in Santa Cruz was in support of the Integrated Water Plan (IWP), which was completed in 2003, with a brief addendum in 2005. The model was also used when the IWP modeling results were updated with newer information in 2010-2011. In addition to the IWP, Confluence has been used to assist Santa Cruz Water Department (SCWD) staff in analyzing the impacts of various other water resource issues that have arisen, including those arising from reductions in available flows associated with ongoing HCP negotiations with state and federal resource agencies, water rights, potential water transfers to neighboring districts, and various changes in system operations. The modeling in support of the WSAC has consolidated and updated much of the previous work.

## Review of Underlying Modeling Assumptions

Before the WSAC began its work, SCWD staff initiated a process to carefully examine the assumptions that were embedded in the model, many of which had their roots in the IWP. That process identified a number of modeling assumptions that had to be changed because of better and more recent data becoming available in the intervening years. The final results of that review are shown in Figure 1. These assumptions provided the starting point for the WSAC work.

**Figure 1. Changes in Key Modeling Assumptions**

| Demands | IWP | IWP Update | HCP pre-2013 | Desal EIR | HCP Current |
|---|---|---|---|---|---|
| Service Area Annual Demand (BG) | 4.6-5.3 | 3.5-4.5 | 3.5-4.0 | 3.5-4.0 | 3.5 |
| North Coast Annual Demand (BG) | 31 | 81 | 81 | 81 | 40 |
| Percent occuring in Peak Season | 64% | → | → | → | 59% |
| **Hydrology** | | | | | |
| Hydrologic Record | 59 years | 73 years | → | → | → |
| Available Flows | Linsley- Kraeger | Balance | Multiple Scenarios | Tier 2/3<br>Tier 3 | City Proposal (T3/2) & DFG5 |
| **Diversions** | | | | | |
| Turbidity Constraints | 25 ntu | Updated 25 ntu | Updated 25 ntu; 200 ntu | Updated 25 ntu | Updated 25 ntu |
| Tait Street Buffer (cfs) | 0 | → | → | → | 0.5 |
| North Coast Transmission losses | 15%=>1% | 8%=>3% | → | → | → |
| **Groundwater Availability** | | | | | |
| **Beltz (mgd)** | 1.0-2.0 | 3 scenarios 0.3-1.0 in PS months | 0.8 all years + 0.3 dry years in PS months | 2 scenarios: (1) 0.8 all years + 0.3 dry years in PS months (2) 0.3 dry years in PS months | 0.8 all years + 0.3 dry years in PS months |
| **Tait Street Well Capacity (cfs)** | 1.78 | | | | 1.29 off-pk; 0.78 pk |
| **Loch Lomond** | | | | | |
| Rule curves | Optimize to end of 1977 | Optimize to end of 1977 | Optimize to end of 1990 | Optimize to end of 1977 | Optimize to end of 1990 |
| Max/usable capacity (mg) | 2810/1710 | 2810/1740 | → | → | → |
| Water rights | | | | | |
| *3200 AF withdrawal* | Total Newell & Felton | → | → | → | Newell Only |
| *Allowable diversion months* | Oct-May | Nov-May | | | Sept - Jun |
| **Treatment Plants** | | | | | |
| GHWTP summer/winter capacity (mgd) | 20/20 | 20/20 | 16.5/16.5 | 16.5/16.5 | 16.5/10 |
| Desalination | | Sharing w/ SqCWD | Sharing w/ SqCWD | Sharing w/ SqCWD & 2 operating modes | N/A |

## Baseline System Reliability Assuming Historic Flows (1,3)

In February and March 2015, we used Confluence to do an initial analysis of baseline system reliability. This analysis assumed:

- Current supplies, infrastructure, and system operations
- The interim demand forecast developed by M.Cubed

The analysis looked at the three available-flow alternatives:

- Natural flows, which assume no instream requirements beyond current water rights
- City Proposed (Tier 3/2) flows
- DFG-5 flows

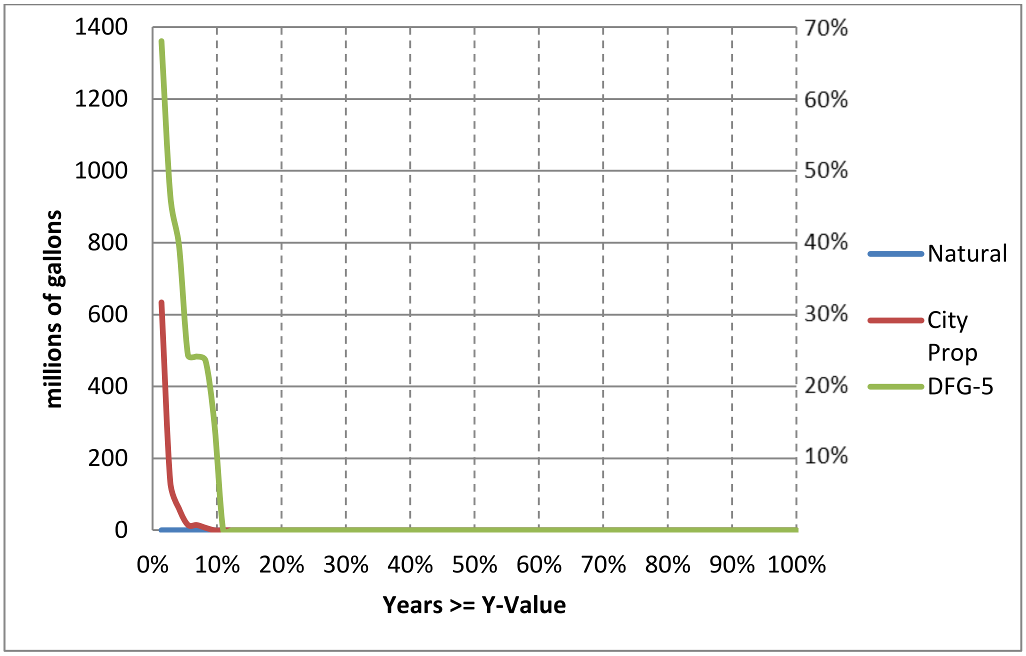
All of these flow sets are based on historic hydrology. The second and third of these are the two HCP flow assumptions which bound the current discussions with the California Department of Fish and Wildlife and the National Marine Fisheries Service.

For the February meeting, Confluence was used to assess the performance of the baseline system against each of these flow regimes, assuming the mid-range interim demand forecast for 2020.[1]

Figure 2 compares the peak-season shortage duration curves under each of these flow sets. Each curve shows the likelihood (horizontal axis) of peak-season shortages exceeding particular levels (vertical axes). For example, the worst-year peak-season shortages, assuming DFG-5 flows, is 1360 mg or 68%. This is reduced by more than half with City-Proposed flows, to 630 mg (32%). With DFG-5 flows, there is about a 5% likelihood of the peak-season shortages exceeding 600 million gallons (a 30% shortage). There is only a 1% likelihood of this occurring with City-Proposed flows. With Natural flows (i.e. without any HCP requirements for enhanced fish flows), the baseline system could serve demands fully even under the driest historic hydrologic conditions.

[1] From this point forward, all results assumed demands for forecast year 2020. Due to the very slow projected demand growth, results are very insensitive to the assumed forecast year.

**Figure 2. Initial Baseline Peak-Season Shortages in 2020 Under 3 Available Flow Assumptions**




**For the March meeting, we assessed the degree to which these results varied with the high and low interim demand forecasts. Figure 3 and**

Figure 4 respectively compare the results for City Proposed and DFG-5 flows. The reliability profiles for the three alternative demand projections are similar. However, there are noticeable differences in the driest years, particularly for the City Proposed flows and particularly for the low interim demand forecast. For the driest year (1977), the low-end forecast results in a peak-season shortage that decreases from just over 30% for the mid-range forecast to close to 20% for the low forecast.

Based on these results, the committee decided to focus subsequent analyses on the mid-range demand forecast.

**Figure 3. Peak-Season Shortage Duration Curves: Forecast Year 2020, City Proposed Flows**

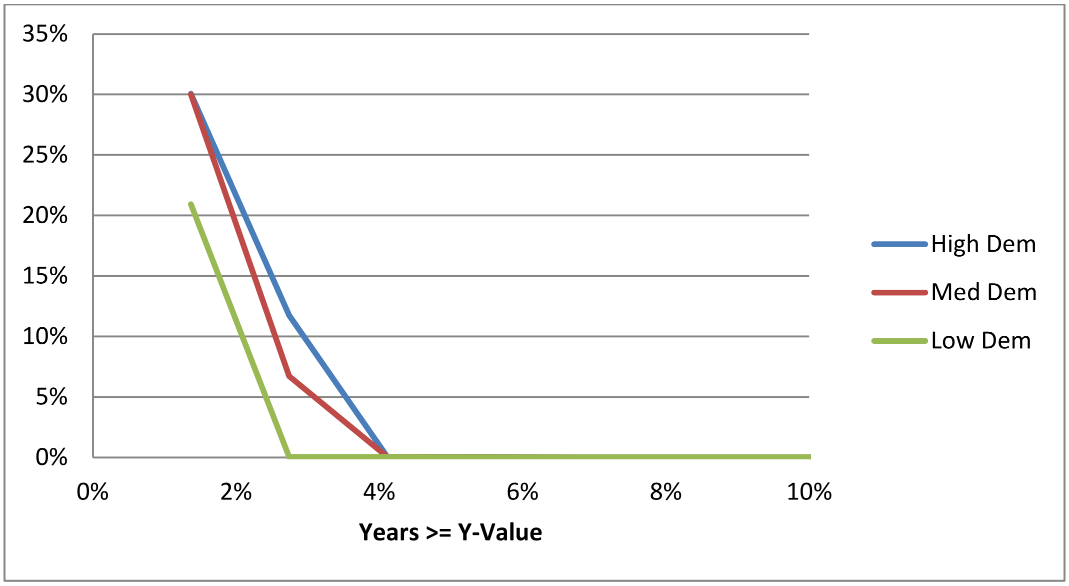
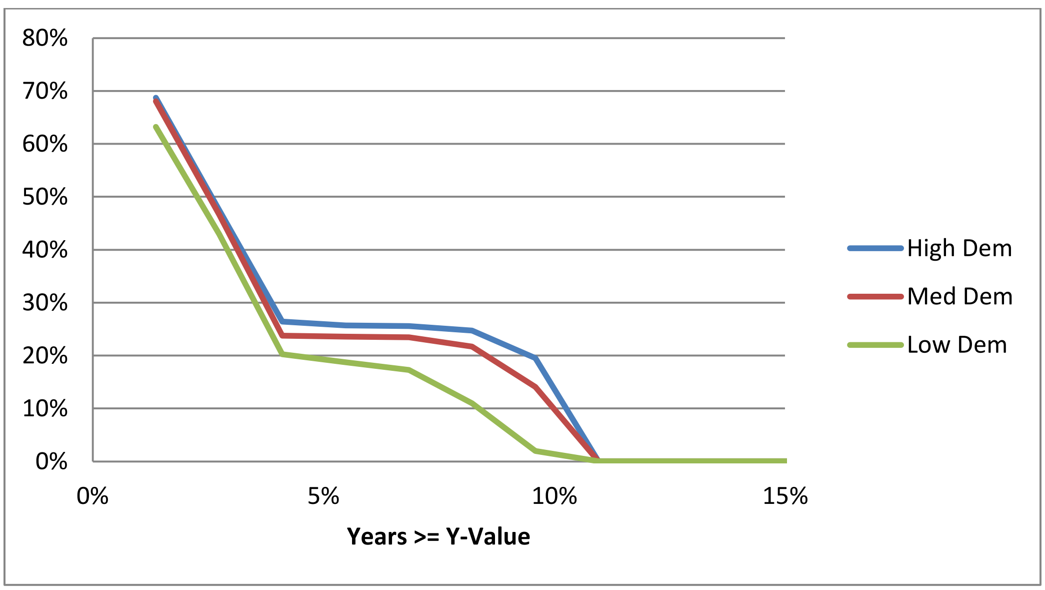



**Figure 4. Peak-Season Shortage Duration Curves: Forecast Year 2020, DFG-5 Flows**




**Baseline System Reliability in an Extended Drought (2,4)**

The historic record contains several drought events, the most notable being 1976-77 and 1987-92. But this 73-year record only extends from 1937-2009. Studies of tree ring and other data that go back millennia make it clear that this record may well overstate long-term water availability in Santa Cruz. In particular, there have been longer and more severe droughts than occurred during our 73-year period. In addition, the consensus of current-day predictions of the future impacts of climate change is that one of these impacts may be longer, harsher, and more frequent droughts. The WSAC therefore thought it important to define an extended-drought scenario against which to evaluate the reliability of the baseline system.

The staff and the technical team examined several possible ways to define a synthesized extended drought, and settled on an 8-year event which is a consecutive sequence of the two worst events in our historic record, namely 1976-77 followed by 1987-92. We analyzed the baseline system response to such an event assuming City Proposed and DFG-5 flows. The results are summarized in Table 1.

**Table 1. Extended Drought Peak-Season Shortage Statistics**

| | City Proposed | DFG-5 |
|---|---|---|
| **Total 8-Year (mg)** | 702 | 5,108 |
| **Average** | 4% | 32% |
| **Maximum** | 32% | 67% |
| **Minimum** | 0% | 6% |
| **Years > 20%** | 1 | 6 |

Assuming City Proposed flows, the only year of the extended drought in which the system experiences significant shortages is the second (1977) year, when the shortage exceeds 30%. The picture is very different with DFG-5 flows. Significant system shortages persist throughout the sequence with more than 5 billion gallons of peak-season demand going unserved over the 8 years. Peak-season shortages average more than 30%, with 6 of the 8 years having shortages that exceed 20% (and one additional year just under that).

In sum, we found that the ability of the current supply system to respond to this extended drought depends critically on the assumed outcome of the HCP negotiations.

**Baseline System Reliability with Climate Change (5,6)**

Confluence modeling of the Santa Cruz system dating back to the IWP has been based on the underlying assumption that the distribution of future weather and streamflows will look like the historic record. Thus, across hundreds of modeling runs, the essential characteristics of the flow record have remained unchanged. The worst drought event corresponded to 1976-77. There was another major drought corresponding to 1987-92. We knew which years in the record were very wet and which were exceptionally dry.

That no longer applies when we analyze how the system will respond to climate change. The essence of analyzing climate change is the assumption that future weather and streamflows will not be the same as the past. While the future is inherently uncertain, that uncertainty is exacerbated when it comes to the impacts of climate change on weather and streamflows, particularly impacts on a local area.

Shawn Chartrand of Balance Hydrologics developed a flow set based on the GFDL General Circulation Model (GCM) and the A2 emission scenario. This GCM/emission scenario is just one of many that could have been chosen to illustrate climate change impacts. It was chosen because it seemed to represent a plausible climate change future against which to assess Santa Cruz system performance. It also represents a GCM/emission scenario approved by the state's CalAdapt program for developing projections of climate change impacts in the state. The flow set resulting from applying this model's suite of precipitation and temperature projections no longer has a 1976-77 worst-case drought benchmark or a 1987-92 sequence. As is illustrated in Figure 5 for City proposed flows at Big Trees, the distribution of flows is completely different than that of the historic record.

**Figure 5. Comparison of Annual Flows at Big Trees: City Proposal**

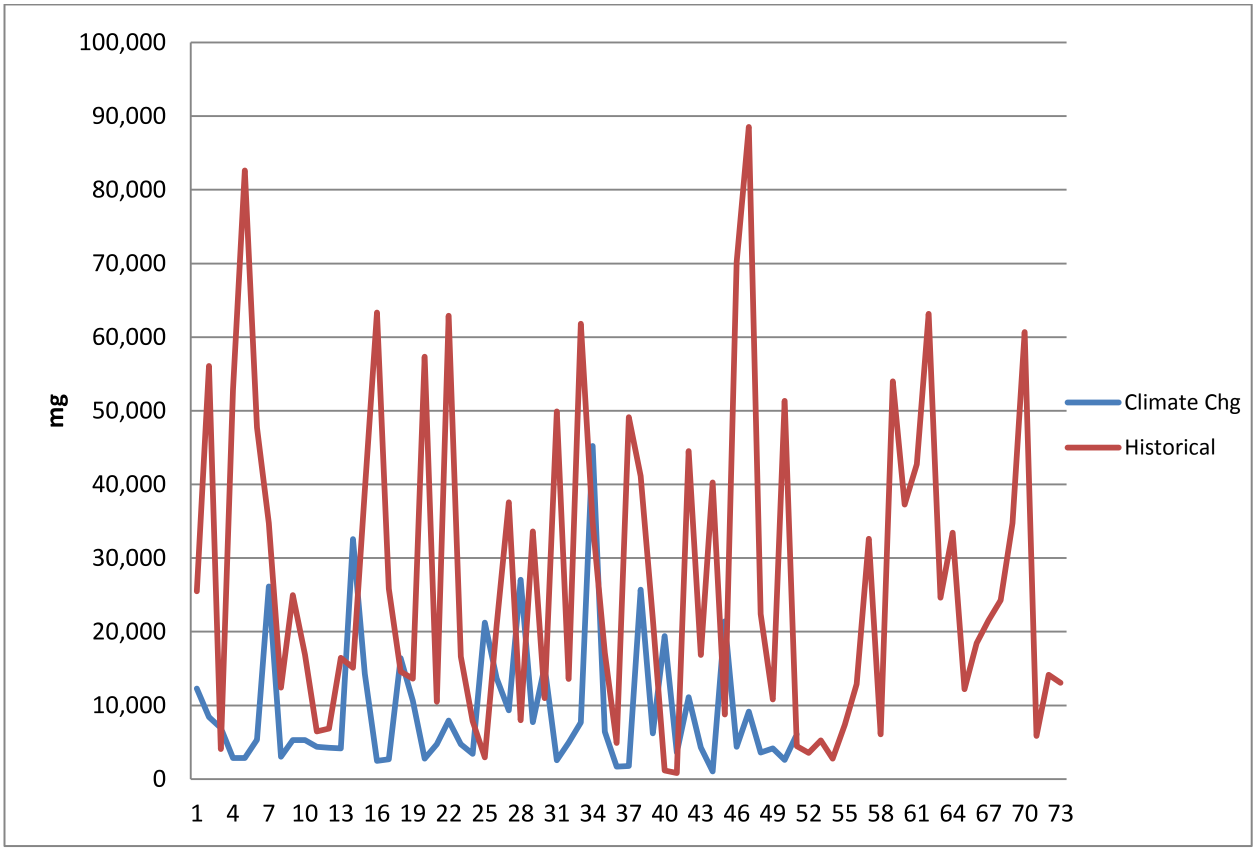



Figure 6 and Figure 7 show respectively the peak-season shortage duration curves assuming City Proposed and DFG-5 flows and interim mid-range 2020 forecasted demand.

**Figure 6. Peak-Season Shortage Duration Curves with and Without Climate Change: City Proposed Flows**

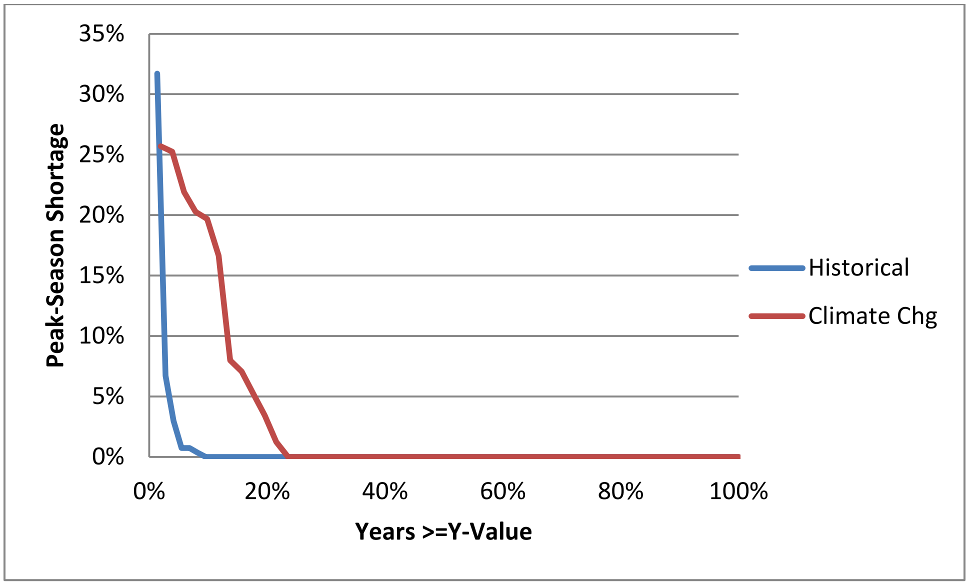
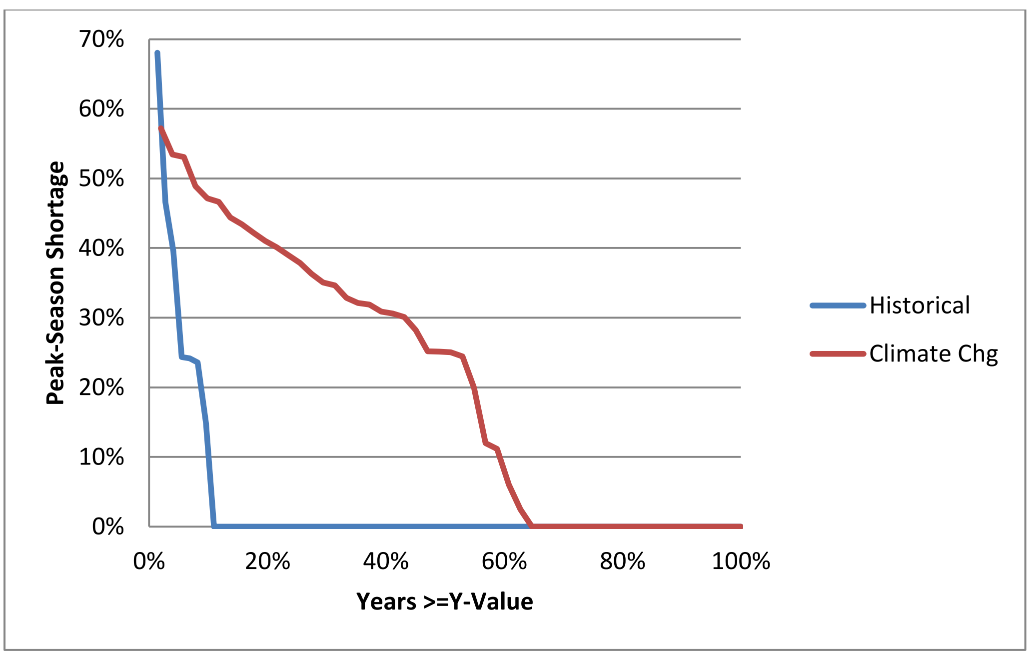



**Figure 7. Peak-Season Shortage Duration Curves with and Without Climate Change: DFG-5 Flows**




While the types of impacts shown in Figures 6 and 7 are similar to those in Figures 3 and 4, their magnitudes with DFG-5 are much increased. For example, with DFG-5 fish flows, a shortage exceeding 25% can be expected in about one of every two years with climate change, compared to approximately 1 of 10 years with historic flows.

**Revised Interim Demand Forecast (7,8)**

In April 2015, M.Cubed slightly revised the interim demand forecast. Figure 8 shows the peak-season shortage duration curves with historic DFG-5 flows. Figure 9 shows the corresponding curves with DFG-5 flows assuming climate change.

**Figure 8. Peak-Season Shortage Duration Curves with Historic DFG-5 Flows**

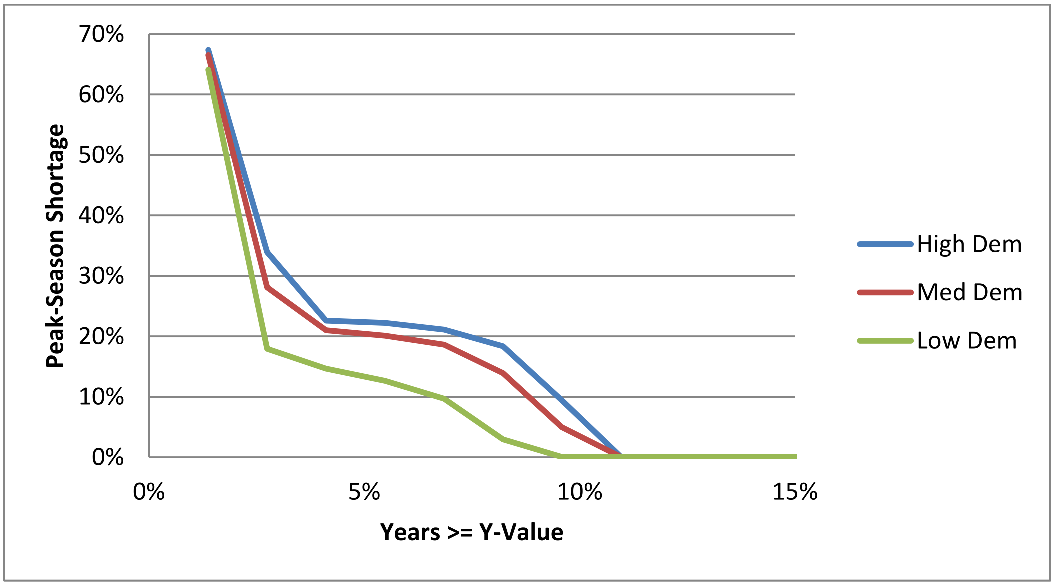
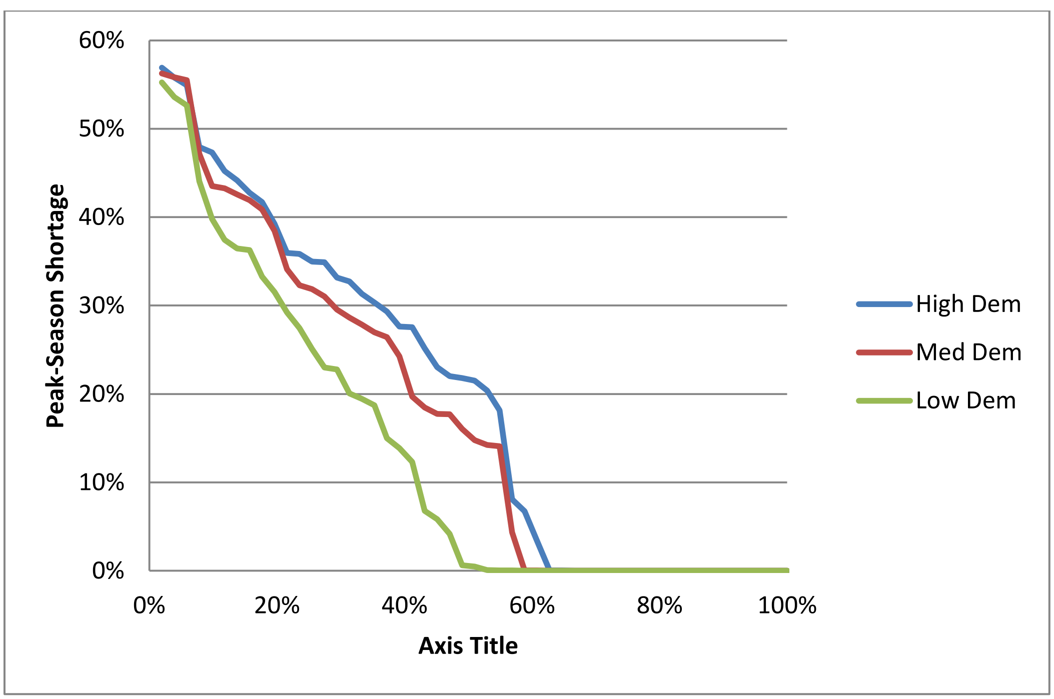



**Figure 9. Peak-Season Shortage Duration Curves with Climate Change DFG-5 Flows**



Comparing Figure 8 to Figure 4 and the mid-range curve of Figure 9 to Figure 7, it is apparent that the revision to the interim demand forecast had little impact on system reliability.

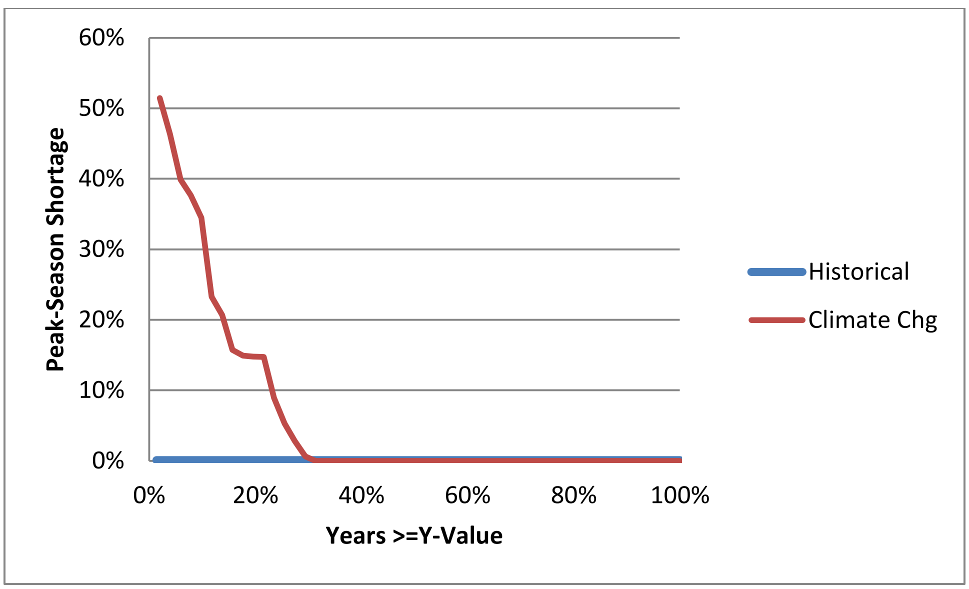
**Analysis of Consolidated Alternatives (9-13)**

The April/May WSAC meeting marked the start of the modeling of the manner in which supply/ infrastructure alternatives address the reliability issues identified to that point. Analyses were performed on the following Consolidated Alternatives (CAs):

- Harvesting Winter Flows (CA-9, CA-16, CA-18)
- Ranney Collectors and Additional Storage (CA-19)
- North Coast Reclaimed Water Exchange (CA-13)
- Indirect Potable Reuse (CA-10)
- Additional Water Conservation (Program CRec) (CA-03)

These initial analyses each compared the reliability profiles of each of these alternatives – as represented by the peak-season shortage duration curves – to that of the base case (no new supply/infrastructure) as shown above in Figure 7. For example, Figure 10 shows the corresponding curves for CA-19 (Ranney Collectors and Additional Storage). Similar curves were developed for the other CAs.

**Figure 10. Peak-Season Shortage Duration Curves with Ranney Collectors & Virtual Storage: DFG-5 Flows**




**Analysis of Portfolios (14)**

By the June WSAC meeting, the Consolidated Alternatives considered above had evolved into several portfolios. All of the portfolios included the CRec conservation programs (CA-3). In addition, each portfolio included a Plan A and a Plan B. The initial supply/infrastructure additions represented by Plan A depended in whole or in part on storing excess winter flows in groundwater aquifers. The Plan B additions consisted of drought-resistant supplies that did not vary with streamflow.

The portfolios were refined in several iterations, and the final set that was discussed at the June meeting was intended to enable the committee to wrestle with different adaptive approaches to dealing with the uncertainties associated with all of the alternatives, particularly the abilities of the regional aquifers to store and allow recovery of significant volumes of water. Resolution of these uncertainties requires a robust program of groundwater modeling, analysis, and testing, and the portfolios recognized the significant risk of simply relying on the Plan A alternatives.

Included in the portfolios were alternatives that had not been modeled previously, including:

- In-Lieu Storage. This alternative uses excess winter flows to directly serve the demands of the Scotts Valley and Soquel Creek Water Districts to enable them to draw less water from the groundwater basins. This "passive recharge" option is distinguished from Aquifer Storage and Recovery (ASR) in that the latter requires "active recharge" via injection of water into the aquifer. The volume of in-lieu storage is limited by the demands of the districts.
- Direct Potable Reuse (DPR). In contrast to Indirect Potable Reuse (IPR) that directs highly-purified recycled water to surface or groundwater storage, the highly-treated DPR supplies are blended with other source waters, treated again at the drinking water treatment facility (Graham Hill Water Treatment Plant), and then directed to the distribution system to meet customer demand.
- Deepwater Desalination. This project, being planned in Moss Landing, could provide water to Santa Cruz.

One of many assumptions on which the analysis of the groundwater storage alternatives was based was the loss rate. It would be unrealistic to assume that every gallon of water that is stored in an aquifer (either through direct injection or through in-lieu storage) is recoverable. For purposes of our modeling, it is assumed that 80% of the ASR injected water is recoverable. This is a function of assumed physical characteristics of the aquifers. For in-lieu, it is assumed that 60% of the water conveyed to neighboring water districts is available to Santa Cruz, a function of both assumed aquifer characteristics and the outcome of discussions with the City's negotiating partners.

It was decided that, from this point forward, all analyses of the system reliability impacts of supply/ infrastructure alternatives would assume DFG-5 flows and climate change. *The measure used to compare the water supply reliability of the portfolios was peak-season yield, which is defined as the reduction in peak-season shortages that are realized when each portfolio component is fully operational, i.e. when all technical and institutional (legal, regulatory, public acceptance) uncertainties have been successfully resolved.* Of course, these modeled yield estimates are based on the infrastructure and operational assumptions associated with each component.

Table 2 shows the yield estimates that were developed for each of the portfolios. Peak-season yields are shown for the worst hydrologic year as well as for the average across all hydrologic conditions. These two measures of yield are limited respectively by the worst-year and average modeled peak-season shortages (1110 mg and 340 mg respectively).

The right-hand column of the table also shows the average annual Scotts Valley and Soquel Creek demand served by the supply options. The estimated combined annual demand of the two districts is 1530 mg. Note that these demands are served in whole or in part not only by in-lieu storage options, but also by excess supply available from the drought-proof options (IPR, DPR, and Deepwater Desal).

**Table 2. Portfolio Yield Estimates**

| | | Santa Cruz Yields (mg) | | | Average Annual Combined SV & SqC Demand Served In-Lieu of Groundwater Draw (mg) |
|---|---|---|---|---|---|
| | | Worst-Year Yield | Average-Year Yield | | |
| **Portfolio 1** | | | | | |
| | **CRec** | 130 | 100 | | |
| | **Plan A-1: CRec+Winter Flow In-Lieu Recharge** | 140 | 110 | | 490 (32%) |
| | **Plan A-2: CRec+Reduced Lake Minimum by 500 mg+In-Lieu Recharge** | 140 | 110 | | 750 (49%) |
| | **Plan B: A-2+IPR to Lake** | 1110 | 340 | | 1530 (100%) |
| | | | | | |
| **Portfolio 2** | | | | | |
| | **CRec** | 130 | 100 | | |
| | **Plan A: CRec+ASR** | 1110 | 340 | | -- |
| | **Plan B: CRec+ DPR** | 1110 | 340 | | 870 (57%) |
| | | | | | |
| **Portfolio 3** | | | | | |
| | **CRec** | 130 | 100 | | |
| | **Plan A: CRec+ASR+Recycled to Seawater Barrier** | 1110 | 340 | | |
| | **Plan B: CRec+DPR** | 1110 | 340 | | 870 (57%) |
| | | | | | |
| **Portfolio 4** | | | | | |
| | **CRec** | 130 | 100 | | |
| | **Plan A: CRec+ASR+DW Desal** | 1110 | 340 | | 1530 (100%) |
| | **Plan B: CRec+DW Desal** | 760 | 330 | | 1070 (70%) |

## Econometric Demand Forecast (15)

Between the June and July meetings, David Mitchell (M.Cubed) transmitted the results of the econometric demand forecast. The results did not differ significantly from the revised interim forecast, so it was determined that, for the sake of consistency, we would continue to base our modeling runs on the revised interim forecast.

## Potential Felton Diversion Enhancements (16)

The WSAC process provided an opportunity to explore in detail ways to more effectively capture excess winter flows. In advance of the July meeting, we used the Confluence model to analyze the impact of several operational and infrastructure changes that affect the timing and volumes of diversions from Felton to Loch Lomond. The results of this analysis were presented immediately prior to the July meeting to a group of committee members and members of the public.

The following changes were examined:

<u>Operational Changes</u>

- Removing current first flush constraint
- Removing current turbidity constraint

<u>Infrastructure Improvements</u>

- Replacing existing pipe between Felton and Loch Lomond
- Adding a second pipe between Felton and Loch Lomond, so that there will be one pipe dedicated to fill and another to draw)
- Improving the pump configuration at the Felton diversion

Table 3 shows the reductions in peak-season shortages associated with various configurations of these changes, assuming climate change and DFG-5 flows. The results lead to the following key conclusions:

- If the Water Department determines it is feasible to relax the first flush constraint or remove it completely in dry years, lake fill and water supply reliability could improve significantly.
- Replacement of the current hydraulically-limited pipe with one that does not suffer from such limitations also provides important benefits, but if the first flush constraint remains, the new pipe would not reduce shortages in the driest year.
- Once the pipe is replaced, improving the current pump configuration at the Felton diversion to enable full utilization of the permitted pumping rate will further improve system reliability, but again as long as the City cannot divert prior to first flush, there are no worst-year benefits.
- Combining these three actions would provide even greater benefits, including significant reductions in worst-year shortages.
- Neither removing the Felton turbidity constraint or adding a second pipe between Felton and the lake provides any additional benefits.

**Analysis of Building Blocks**

Before the July meeting, the portfolios in Table 2 were broken into building blocks. To help the committee in its deliberations, the consulting team created the summary table shown in Table 4. The entries in that table were based on updated runs of the Confluence model as well as preliminary cost and energy savings estimates developed by Brown and Caldwell. This table was updated several times between this version and the final WSAC meeting, as new information and refined configurations were developed. The final version is shown in Table 7.

**Table 3. Comparison of Peak-Season Shortages Under Alternative Felton Infrastructure and Operational Changes**

| Configuration | Worst-Year Peak Season Shortage | | Average-Year Peak Season Shortage | |
|---|---|---|---|---|
| | Volume (mg) | Percent | Volume (mg) | Percent |
| **Current** | 1110 | 57% | 340 | 17% |
| **No First Flush** | 950 | 49% | 230 | 12% |
| **Replacement Pipe** | 1110 | 57% | 250 | 13% |
| **No First Flush & Replacement Pipe** | 780 | 40% | 130 | 7% |
| **Replacement Pipe & Pump Improvements** | 1110 | 57% | 190 | 10% |
| **No First Flush, Replacement Pipe & Pump Improvements** | 650 | 33% | 80 | 4% |

**Table 4. Interim Building Block Summary Table**

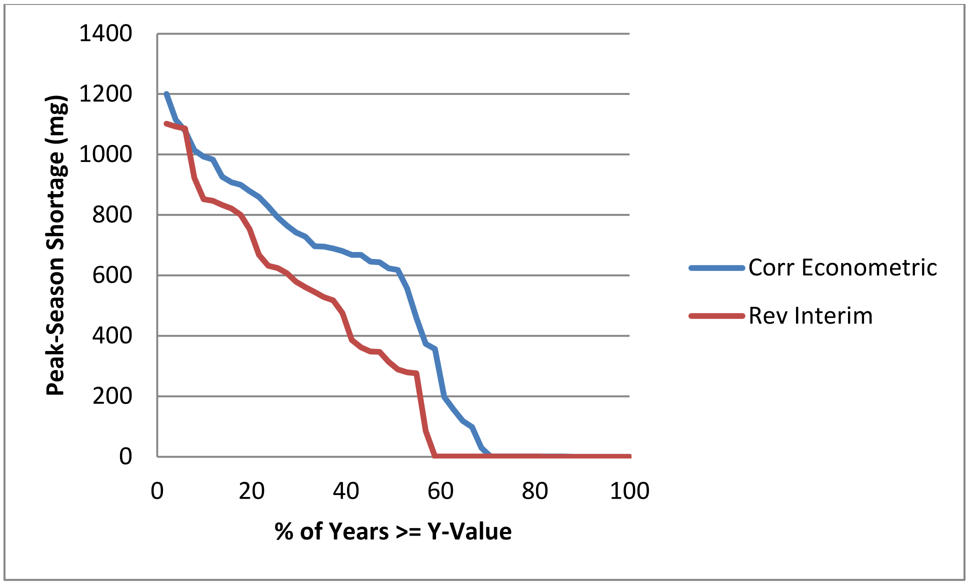
| Building Block # / Building Block Approach | 1 In-Lieu | 2 ASR | 2-small ASR Pase 1* | 3 DPR | 3-small DPR small | 4 IPR-Loch | 5 IPR-SeaBar | 6 IPR=>DPR** | 7 DW Desal | 7-lg DW lg. | 8 Local Desal | 8-lg Local Dsl lg. | 9*** winter flow harvest |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost ($ M) | 121 | 141 | 40 | 116 | 90 | 170 | 153 | 9 | 151 | 173 | 140 | 161 | |
| Annual O&M cost ($ M) | 2.5 | 3.7 | | 4.7 | 3.4 | 7.2 | 5.5 | 4.8 | 6.3 | 7.9 | 3.9 | 4.9 | |
| Total Annualized Cost ($ M) | 12 | 15 | | 14 | 11 | 21 | 18 | 6 | 18 | 22 | 15 | 18 | |
| Present Value Costs ($M) | 276 | 341 | | 300 | | 470 | 400 | 120 | 410 | | 340 | | |
| Energy Use (MWH/MG) | 6.6 | 5.9 | | 6.3 | 4.5 | 9.6 | 7.8 | 6.3 | 12.4 | 15.5 | 11.0 | 13.8 | |
| Annual Production Cost ($/MG) | 133,300 | 42,900 | | 8,200 | 10,000 | 12,200 | na | 3,300 | 16,700 | 16,000 | 13,700 | 13,100 | |
| Average Annual Production (MG/year) | 90 | 350 | 145 | 1715 | 1100 | 1715 | na | 1715 | 1100 | 1375 | 1100 | 1375 | |
| Worst Year Yield (MG) | 780 | 800 | | 1110 | 710 | 1050 | na | 1110 | 710 | | 710 | | 460 |
| Average Year Yield (MG) | 290 | 310 | 130 | 340 | 330 | 330 | na | 340 | 330 | | 330 | | |
| Worst year yield unit cost (Total Ann Cost/Wst Yr Yield) | 15,400 | 18,800 | | 12,600 | 15,500 | 19,900 | | 5,000 | 25,900 | | 21,300 | | |
| Average year yield unit cost (Total Ann Cost/Ave Yr Yield) | 41,400 | 48,400 | | 41,200 | 33,300 | 63,300 | | 16,500 | 55,800 | | 45,800 | | |
| Worst Year Peak Season Shortage (MG) | 330 | 310 | | 0 | 400 | 60 | na | 0 | 400 | | 400 | | 650 |
| Worst Year Peak Season Shortage (%) | 17% | 17% | | 0% | 21% | 3% | na | 0% | 21% | <15%**** | 21% | <15%**** | 33% |
| Average Year Peak Season Shortage (MG) | 50 | 30 | | 0 | 10 | 0 | na | 0 | 10 | | 10 | | 80 |
| Average Year Peak Season Shortage (%) | <3% | <2% | | 0% | <1% | 0% | na | 0% | <1% | | <1% | | 4% |
| Approximate Timeline (Years) | 8 | 15 to 20 | | 9 to 13 | 9 to 13 | 8 | 8 | 2 (plus 8) | 7 | 7 | 6 | 6 | 1-2? |

* Block 2 (ASR-small) starts ASR at the Beltz wells, as described in the Pueblo report, May 2015, Phase 1.
** NOTE: As this is a conversion of Block 5, the unpaid capital costs from Block 5 would still need to be paid. Those are not included in the Block 6 costs.
***Block 9 maximizes harvest of winter flows, and data come from Gary Fiske reports, July 23, 2015.
**** Yields not estimate at this time by *Confluence* runs, but worst year shortages expected to be less than 15%

At the August meeting, these building blocks were recombined by several committee subgroups into different strategies that reflected differing preferences and risk tolerances. Each subgroup presented its ideas to the committee as a whole, which generated questions and discussion. Subsequent to that meeting, various supplemental analyses were done to help the committee better understand the building blocks and strategy alternatives and move toward consensus.

The first issue that had to be addressed was the impact of a correction that M.Cubed made to the econometric demand forecast (17). This correction increased the forecast demand by between 200 and 250 mgy. The impact of this change on the base-case (no added supply or infrastructure) peak-season shortage profiles was analyzed (18). The results are shown in Figure 11, which shows that the worst-year peak-season shortage with 2020 demands goes up about 100 mg, from 1.1 bg to 1.2 bg. The distribution of peak-season shortages across other hydrologic conditions is also affected. The average peak-season shortages over these distributions differ by about 120 mg (~340 mg vs. 460 mg).

**Figure 11. Impact of Corrected Econometric Forecast on Base Case Peak-Season Shortage Profile.**




Using this corrected econometric demand forecast along with a variety of updates to sizing and infrastructure assumptions and minor modeling refinements, the yields and remaining peak-season shortages were re-analyzed (19). The results are shown in Table 5.

**Table 5. Updated Peak-Season Yield Estimates (mg)**

| | Worst Year | | | Average | | |
|---|---|---|---|---|---|---|
| **Element** | **Peak-Season Yield** | **Remaining Peak-Season Shortage** | | **Peak-Season Yield** | **Remaining Peak-Season Shortage** | |
| | **mg** | **mg** | **%** | **mg** | **mg** | **%** |
| ***Base Case*** | *--* | *1230* | *63%* | *--* | *470* | *24%* |
| **In-Lieu** | 750 | 480 | 25% | 350 | 120 | 6% |
| **ASR** | 760 | 470 | 24% | 380 | 90 | 5% |
| **Combined In-Lieu, ASR** | 760 | 470 | 24% | 380 | 90 | 5% |
| **DPR (3 mgd)** | 810 | 420 | 22% | 440 | 30 | 2% |
| **DW Desal (3 mgd)** | 810 | 420 | 22% | 440 | 30 | 2% |
| **Local Desal (3 mgd)** | 810 | 420 | 22% | 440 | 30 | 2% |

These results were supplemented by an analysis of the yields of different IPR configurations (20), with results as shown in Table 6.

**Table 6. Peak-Season Yields of IPR Configurations**

| | Worst Year | | | Average | | |
|---|---|---|---|---|---|---|
| | Yield | Remaining Peak-Season Shortage | | Yield | Remaining Peak-Season Shortage | |
| **IPR @ 3 mgd:** | **mg** | **mg** | **%** | **mg** | **mg** | **%** |
| **To Loch** | 660 | 570 | 29% | 430 | 40 | 2% |
| **To Aquifer (4 mgd withdrawal)** | 740 | 490 | 25% | 380 | 90 | 5% |
| **To Aquifer (8 mgd withdrawal)** | 1190 | 40 | 2% | 465 | 5 | 0% |

All of these results were combined into a final summary table as follows:

**Table 7. Final Elements Summary Table: September 29, 2015**

| | **Element** | **1** | **2** | **3a** | **3b** | **3c** | **3d** |
|---|---|---|---|---|---|---|---|
| | **Building Block Approach** | **In-Lieu** | **ASR and In-Lieu Combined*** | **DPR Small (3 mgd)** | **IPR-Loch (3 mgd)** | **IPR-GW (3 mgd)** | **Local Desal (3mgd)** |
| a | Capital Cost ($ M) | 131 | 159 | 89 | 132 | 119 | 147 |
| b | Annual O&M cost ($ M/yr) | 2.6 | 3.7 | 3.5 | 5.2 | 4.2 | 3.9 |
| c | Total Annualized Cost ($ M/yr) | 11.6 | 14.6 | 9.6 | 14.3 | 12.4 | 14.0 |
| d | Present Value Costs ($M) | 185 | 237 | 162 | 241 | 207 | 229 |
| e | Energy Use (MWH/MG) | 5.8 | 6.5 | 8.3 | 9.3 | 8.8 | 12.5 |
| h | Worst Year Yield (MG) | 750 | 760 | 810 | 660 | 740 | 810 |
| i | Average Year Yield (MG) | 350 | 380 | 440 | 430 | 380 | 440 |
| j | Worst year yield unit cost (Total Ann Cost/Wst Yr Yield) | $15,500 | $19,300 | $11,900 | $21,600 | $16,700 | $17,300 |
| k | Average year yield unit cost (Total Ann Cost/Ave Yr Yield) | $33,200 | $38,500 | $21,900 | $33,200 | $32,600 | $31,800 |
| l | Worst Year Peak Season Shortage (MG) | 480 | 470 | 420 | 570 | 490 | 420 |
| m | Worst Year Peak Season Shortage (%) | 25% | 24% | 22% | 29% | 25% | 22% |
| n | Average Year Peak Season Shortage (MG) | 120 | 90 | 30 | 40 | 90 | 30 |
| o | Average Year Peak Season Shortage (%) | 6% | 5% | 2% | 2% | 5% | 2% |

* Both the costs and yields in this column reflect the combined costs of implementing both in-lieu and ASR.

**Next Modeling Steps**

As the Water Department moves forward with the water supply strategy recommended by the WSAC, it will need to update the Confluence modeling runs to incorporate the results of the studies that will be undertaken and to thoroughly understand the implications of infrastructure sizing and configuration alternatives and operational regimes. Such modeling will address issues that may include:

- Aquifer availability and recovery
- Assumed in-lieu/ASR well and transmission capacities
- Conjunctive operation of Loch Lomond and aquifer storage
- Alternative operations of drought-proof supplies (IPR, DPR) in conjunction with Loch Lomond
- Relaxing first flush and/or turbidity constraints
- Ranney collectors with direct diversion from Felton
- Alternative magnitudes/seasonal patterns of water conservation savings

These are examples of the types of issues that may need to be addressed. It is not an exhaustive list. Other issues will undoubtedly arise.

**Referenced Documents**


1. February 4, 2015, *Baseline System Reliability*
2. February 24, 2015, *2nd UPDATED Analysis of Extended Droughts*
3. March 2, 2015, *Baseline System Reliability with Alternative Interim Demand Forecasts*
4. March 4, 2015, *Baseline System Response to Extended Drought*
5. March 9, 2015, *Baseline System Response to Initial Climate Change Scenario*
6. March 9, 2015 (from Shawn Chartrand), *Development of Streamflow Records Under CC for Water Supply Analysis for the City of Santa Cruz Surface Supply Sources*
7. April 17, 2015 (from David Mitchell), *Low and High Interim Demand Forecasts*
8. April 17, 2015, *Baseline System Reliability with Revised Interim Demand Forecasts*
9. April 23, 2015, *Modeling Results: Ranney Collectors*
10. April 23, 2015, *Modeling Results: Harvesting Winter Flows*
11. April 23, 2015, *Modeling Results: CRec Conservation Programs*
12. April 29, 2015, *Modeling Results: North Coast Reclaimed Water Exchange (CA-13)*
13. April 29, 2015, *Modeling Results: Indirect Potable Reuse (CA-10)*
14. May 21, 2015, *Additional analysis of DPR/winter flow harvest alternative (Portfolio 2)*
15. July 15, 2015 (from David Mitchell), *Summary of Econometric Analysis of Demand and Forecast*
16. July 22, 2015, *Evaluation of Alternative Approaches to Increase Pumping from Felton Diversion to Loch Lomond Reservoir*
17. August 24, 2015 (from David Mitchell), *Corrected Demand Forecast*
18. September 1, 2015, *Impact of Corrected Econometric Demand Forecast*
19. September 8, 2015, *Updated Yields REVISED*
20. September 24, 2015, *Yields of IPR*

# REFERENCED DOCUMENTS

**G A R Y F I S K E A N D A S S O C I A T E S , I N C .**
***W a t e r R e s o u r c e s P l a n n i n g a n d M a n a g e m e n t***

**Date:** February 4, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Baseline System Reliability

This memorandum describes the results of my analysis of baseline system reliability. Because the Santa Cruz water system is primarily dependent on surface water, its performance in any year is a function of that year's and immediately prior years' hydrology. Since rainfall in any year is highly uncertain, the question of "how reliable is the system?" is a complicated one to answer. Several approaches are used in this memo; other suggestions by the committee would be welcome.

## DEFINING THE BASELINE

The baseline is defined by:

- Current supplies and infrastructure
- The interim demand forecast

The Confluence® model was used to assess the performance of the baseline against each of three flow regimes. The second and third of these are the two HCP flow assumptions which bound the current discussions with the California Department of Fish and Wildlife and the National Marine Fisheries Service (collectively the "agencies"):

- Natural flows, which assume no HCP instream requirements
- City Proposed (Tier 3/2) flows
- DFG-5 flows

System performance with each of these three flow assumptions is assessed against forecasted 2020 and 2035 demands.

All of these flow sets are based on historic hydrology. Daily flows at each of the City's points of diversion have been either gauged or estimated over a 73-year historic period (1937-2009). All of the baseline results that follow assess future system performance assuming that the distribution of future hydrology will look like this historical record. This is a very big assumption. Climate change may make future hydrology drier than this 73-year period, with different seasonal patterns of rainfall, and longer and more severe droughts. As we continue to work with the WSAC, we will be modeling various alternative assumptions about how climate change may modify historical flow patterns.

## EXISTING SUPPLY ASSUMPTIONS

As described by Heidi's memo to the committee, the existing system consists of the following supply sources, listed in the order that they are dispatched to meet demand on any day:

- North Coast diversions

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- Tait Street diversion and wells
- Live Oak wells
- Loch Lomond reservoir

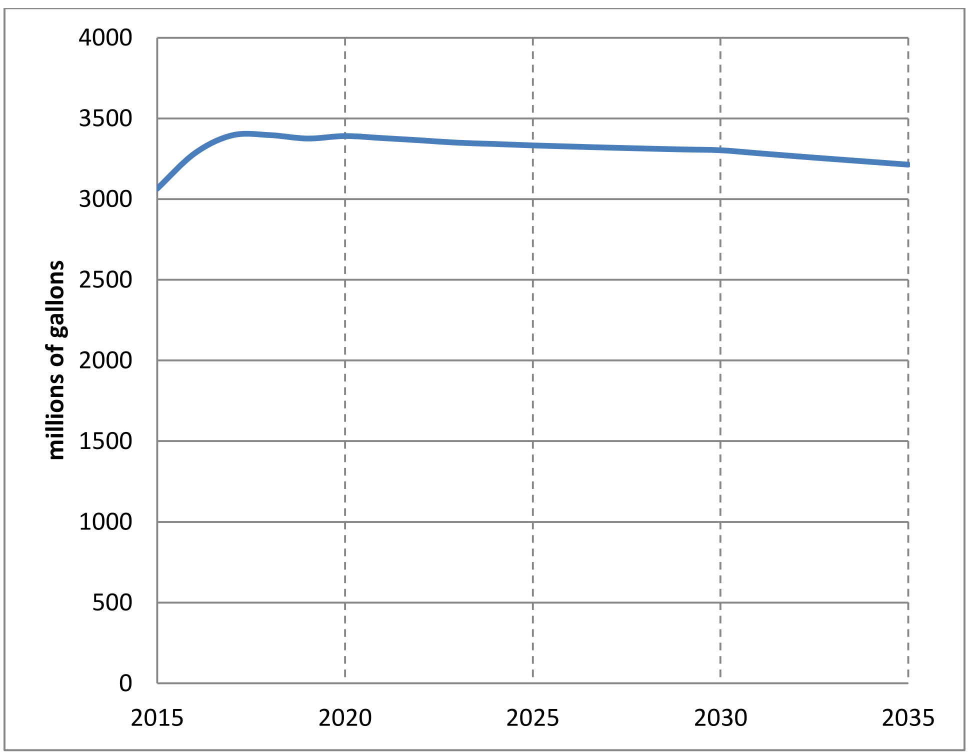
In addition, whenever possible, water is diverted from Felton to Loch Lomond.

**DEMAND FORECAST**

As described in David Mitchell's memorandum to the committee, the 2015-2035 demand forecast is as shown in Figure 12. This is a forecast of unconstrained demand, i.e., the volume of water that Santa Cruz municipal and industrial customers would use without any curtailments or other restrictions imposed by the utility.

After increasing for the next several years, annual demand is forecast to slowly decrease between 2020 and 2035 (by a total of about 175 mg). Thus, we would expect baseline system reliability to slightly improve between these years.

**Figure 12. Interim Annual Demand Forecast**




**BASELINE SYSTEM RELIABILITY**

**Definition of Terms**

To understand what follows, two terms must be defined:

> Shortage: A shortage occurs when the system is unable to provide sufficient water to serve unconstrained customer demand.

System reliability: The projected frequency and magnitude of future system shortages.

**System Reliability Metrics**

In Santa Cruz, since the vast bulk of shortages occur in the peak-season (May-October), all of our reliability measures are for that period.[2] There are many ways to portray system reliability. For purposes of this presentation, we use the following three approaches, which are in increasing order of complexity and completeness:

- Worst-year peak-season shortage. This is a single number that represents the expected peak-season shortage under the worst historical hydrologic conditions. (These worst conditions occurred in the 1977 drought.) While very important and easily understood, such a single number only provides information about shortages under one of the 73 historic hydrologic conditions. It does not tell us about what magnitudes of shortage, if any, might occur under less severe conditions.

- Peak-season shortage profile. This shows the likelihood of peak-season shortages within different ranges.

- Peak-season shortage duration curve. Such a curve provides a complete graphical depiction of how often different size peak-season shortages can be expected to occur.

In what follows, these measures are expressed both as volumes (millions of gallons) and as percentages of unconstrained peak-season demand.

**Worst-Year Peak Season Shortages**

Table 8 compares the worst-year peak-season shortages under the three flow regimes for forecast years 2020 and 2035. With Natural flows (i.e. without any HCP requirements for enhanced fish flows), the baseline system could fully serve future demands even under worst hydrologic conditions. The City Proposed (Tier 3/2) HCP flows result in a worst-year peak season shortage in 2020 of more than 600 mg or 32%; by 2035 this is forecast to decrease to 500 mg. The more stringent DFG-5 flow proposal would result in extremely severe worst-year peak-season shortages, approaching 1.4 billion gallons in 2020.

**Table 8. Expected Worst-Year Peak-Season Shortages**

| FLOWS | 2020 | | 2035 | |
|---|---|---|---|---|
| | Volume (mg) | Percent | Volume (mg) | Percent |
| **Natural** | 0 | 0% | 0 | 0% |
| **City Prop** | 630 | 32% | 500 | 26% |
| **DFG-5** | 1360 | 68% | 1220 | 64% |

[2] In some years, there are small additional shortages immediately following the peak season (i.e., in November) before the fall rains begin in earnest. It is possible that these off-peak shortages may become more significant if future flows are different due to climate change.

**Peak-Season Shortage Profiles**

Table 9 and Table 10 show respectively the forecasted peak-season shortage profiles in 2020 and 2035.[3]

**Table 9. 2020 Shortage Profiles**

| FLOWS | Likelihood of Peak-Season Shortages | | | | |
|---|---|---|---|---|---|
| | 0% | <15% | 15%-25% | 25%-50% | >50% |
| | 0 | <300 mg | 300-500 mg | 500-1000 mg | >1000 mg |
| **Natural** | 100% | 0% | 0% | 0% | 0% |
| **City Prop** | 92% | 7% | 0% | 1% | 0% |
| **DFG-5** | 90% | 1% | 4% | 3% | 1% |

**Table 10. 2035 Shortage Profiles**

| FLOWS | Likelihood of Peak-Season Shortages | | | | |
|---|---|---|---|---|---|
| | 0% | <15% | 15%-25% | 25%-50% | >50% |
| | 0 | <285 mg | 285-475 mg | 475-950 mg | >950 mg |
| **Natural** | 100% | 0% | 0% | 0% | 0% |
| **City Prop** | 97% | 1% | 0% | 1% | 0% |
| **DFG-5** | 90% | 1% | 4% | 3% | 1% |

Several conclusions can be drawn from these profiles:

- With Natural flows, there are no shortages of any magnitude under any hydrologic condition. Since we saw above that there are no expected shortages under worst-year conditions, this is not surprising.

- As expected, the DFG-5 profile is worse (i.e. results in a higher likelihood of larger shortages) than the profile for City Proposed flows. For example, in both forecast years, there is about an 8% likelihood (6 out of 73 years) of a peak-season shortage larger than 15% under DFG-5. This compares to around 1% (1 out of 73 years) under the City Proposal.

- Even under the most stringent flow regime (DFG-5), there are no expected shortages in 90% of historic hydrologic conditions. The City's supply reliability challenges are in the driest years.

- While similar, the 2035 profiles are slightly more favorable than the 2020 profiles due to the somewhat lower forecast demand.

[3] Note that the totals in any row may not add to 100% due to rounding.

**Peak-Season Shortage Duration Curves**

Figure 13 compares the 2020 peak-season shortage duration curves across all 73 historic hydrologic conditions for the three flow sets. Figure 14 shows the same comparison for 2035.

**Figure 13. Peak-Season Shortage Duration Curves: 2020**

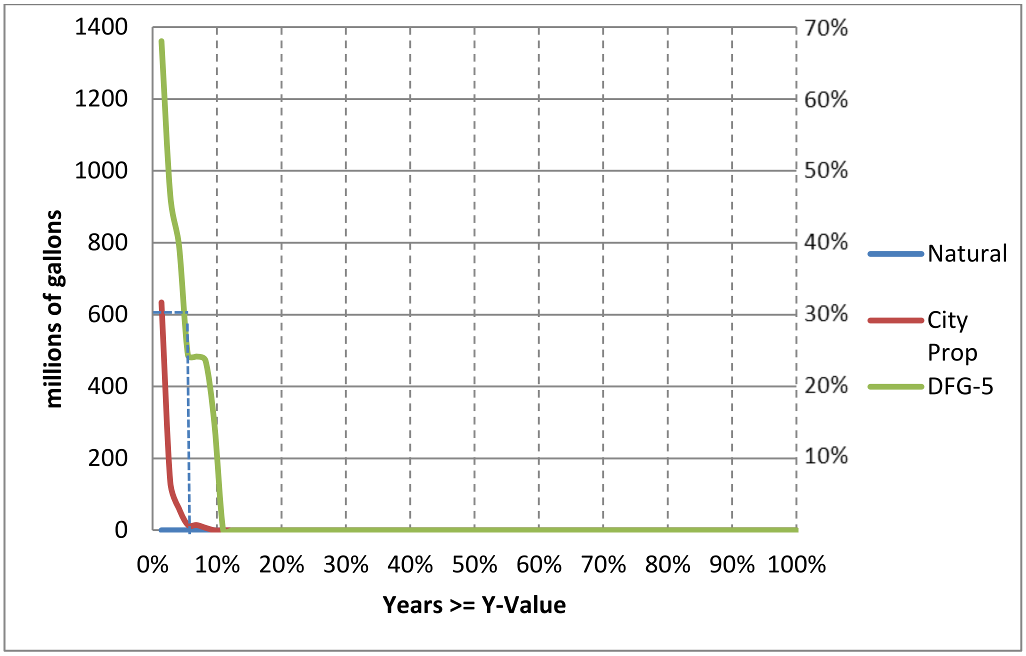
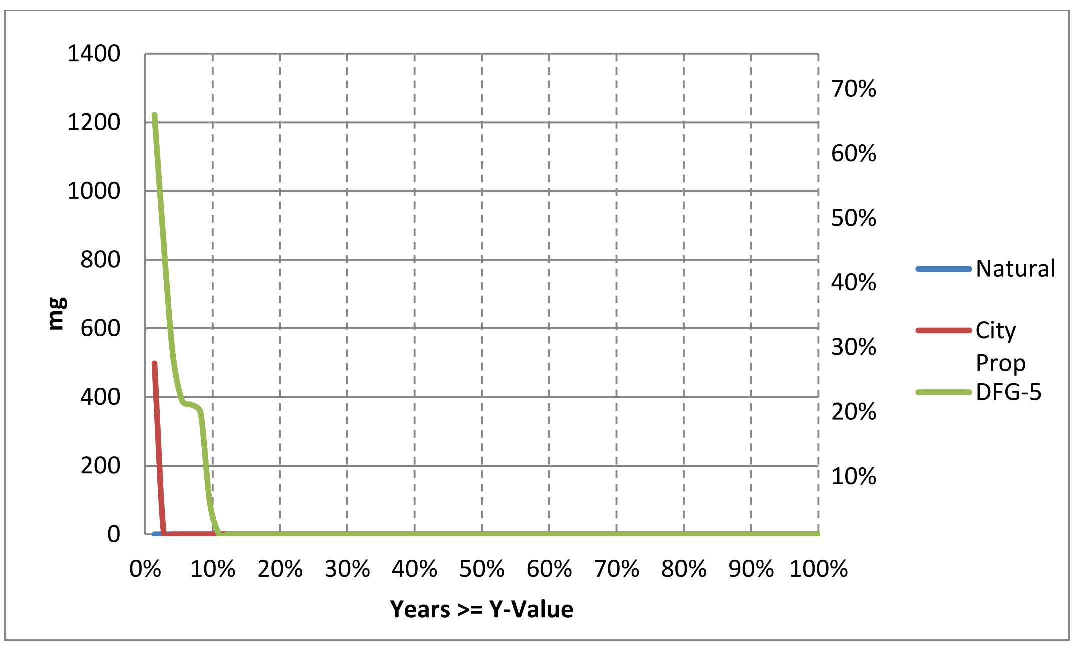



**Figure 14. Peak-Season Shortage Duration Curves: 2035**



Thus, for example, in 2020 under DFG-5 flows, there is about a 5% likelihood of a peak-season shortage of 600 mg or more (see blue-dashed lines in Figure 13). The curves clearly illustrate how much more severe the supply reliability challenges would be under DFG-5 than under the City Proposal. Moreover, when the two charts are compared, the slight improvement between 2020 and 2035 is evident.

Both the worst-year shortages in Table 8 and the shortage profile tables in Tables 2 and 3 are based on the data underlying these charts.

Figures 4 and 5 are duration curves for 2020 (expressed as peak-season shortage percentages) broken down by year type. Figure 15 shows that in 2020, assuming City Proposed flows, there is about a 15% likelihood of a Critically-Dry year having at least a 15% shortage. Figure 16 shows that probability rising to about 55% with DFG-5 flows (plus about a 10% likelihood of such shortages in Dry years). Results in 2035 (not shown) are slightly more favorable.

**Figure 15. 2020 Peak-Season Percent Shortage Duration Curves by Year Type: City Proposed Flows**

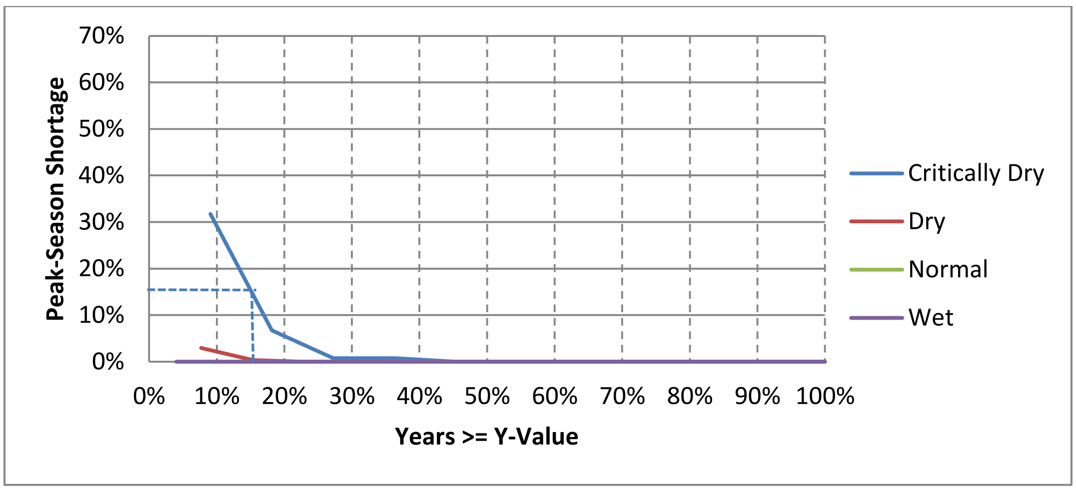
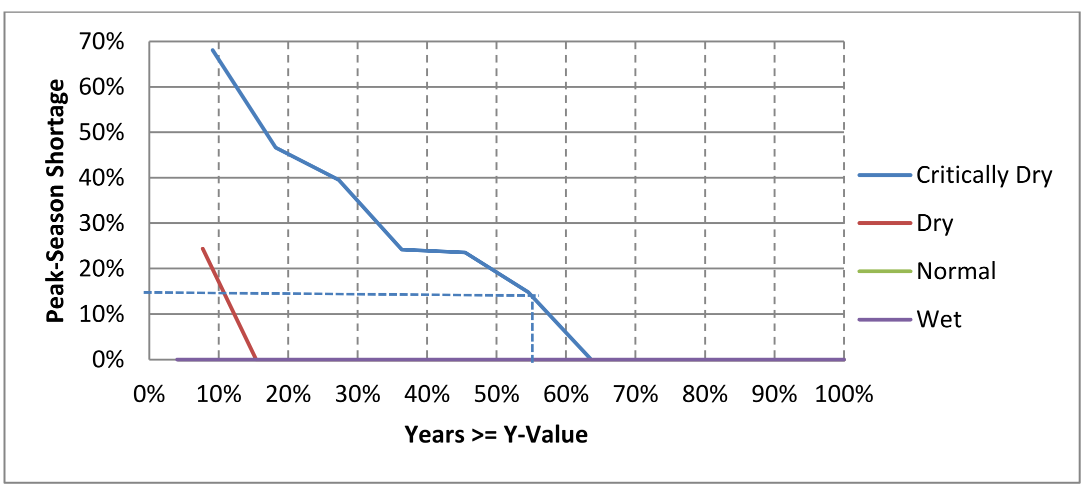



**Figure 16. 2020 Peak-Season Percent Shortage Duration Curves by Year Type: DFG-5 Flows**



**Key Conclusions**

Under baseline conditions, and assuming that future hydrology looks like the historic record, the City would have sufficient supply to serve its demands in the absence of any HCP flow restrictions. While the outcome of the HCP negotiations with the agencies is uncertain, we assume that the two flow proposals currently being discussed bound that outcome. Under either of those proposals, the City faces peak-season shortages in the driest hydrologic conditions. In those driest years, those shortages can be significant, around 600 million gallons under City-Proposed flows and close to 1.4 billion gallons under DFG-5 flows.

GARY FISKE AND ASSOCIATES, INC.
*Water Resources Planning and Management*

**Date:** February 24, 2015
**From:** Gary Fiske
**To:** Rosemary Menard, Bob Raucher, Karen Raucher, Shawn Chartrand, Heidi Luckenbach, Toby Goddard, Kevin Crossley
**Re:** 2nd UPDATED Analysis of Extended Droughts

The following results add a third drought sequence to my February 22 memo on system performance under extended droughts. The three sequences are:

1. An 8-year drought following the San Francisco model, i.e. the 1987-92 historic period followed by a 1976-77 sequence.

2. A shorter (6-year) but much more severe event, i.e., the 1976-77 sequence followed by 4 additional years with 1977 hydrology.

3. An 8-year sequence that reverses # 1, beginning with the 1976-77 historic period followed by the 1987-92 historic sequence.

The approach is identical to that described in the February 22 memo. The results for sequences 1 and 2 are identical to that memo. The results for sequence 3 are added.

**RESULTS**

**Extended Drought Sequence # 1: The San Francisco 8-Year Drought**

Figures 1 and 2 show, respectively, the peak-season volumetric and percentage shortages for each year of the 8-year drought sequence.

**Figure 17. Peak-Season Shortages (mg): San Francisco 8-Year Extended Drought**

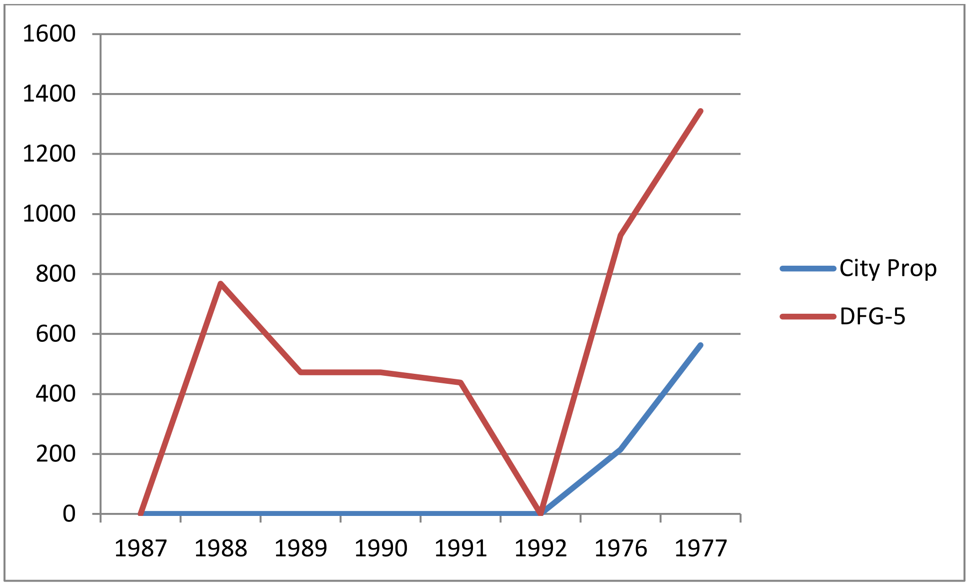



**Figure 18. Peak-Season Percentage Shortages: San Francisco 8-Year Extended Drought**

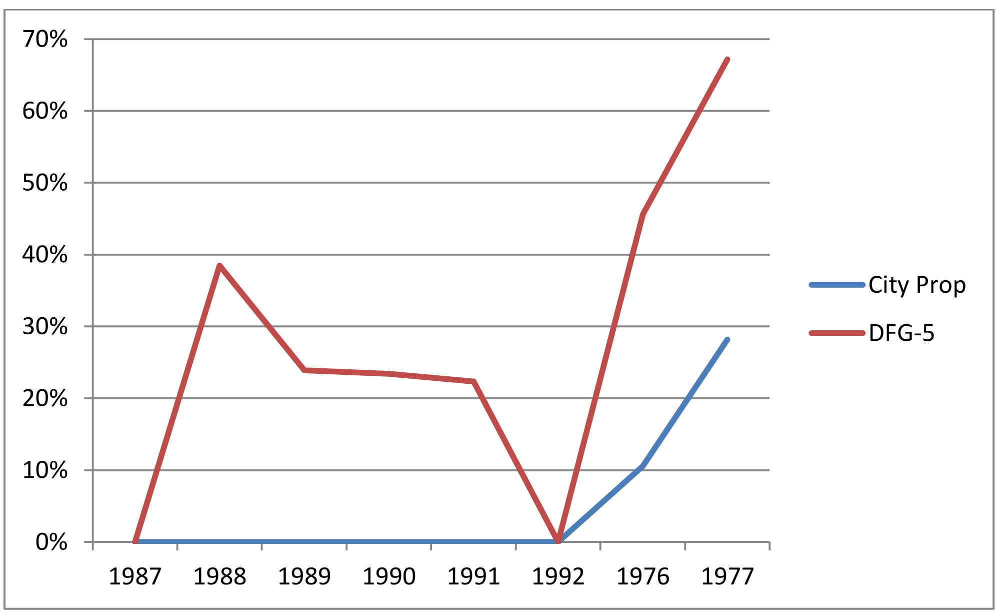
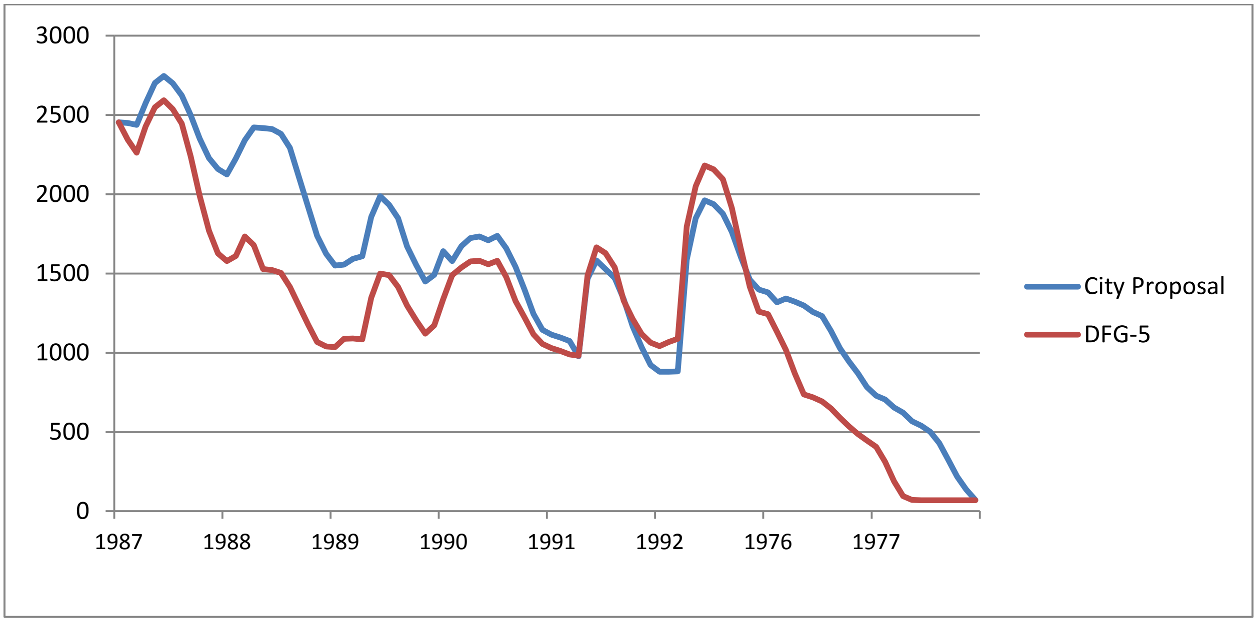



Figure 3 compares the lake levels over the sequence.

**Figure 19. End-of-Month Lake Levels (mg): San Francisco 8-Year Extended Drought**




With City Proposed flows, this extended drought is fairly manageable, with peak-season shortages staying at zero for the first 6 years of the cycle and rising above 10% only in the final of the 8 years. With DFG-5 flows, shortages are in the 20%-40% range in years 2-5 and exceed 65% by the final year.

**Extended Drought Sequence # 2: The 6-Year Deep Drought**

Figures 4-6 show the analogous results for this shorter but more severe extended drought.

**Figure 20. Peak-Season Shortages (mg): Extremely Severe 6-Year Extended Drought**

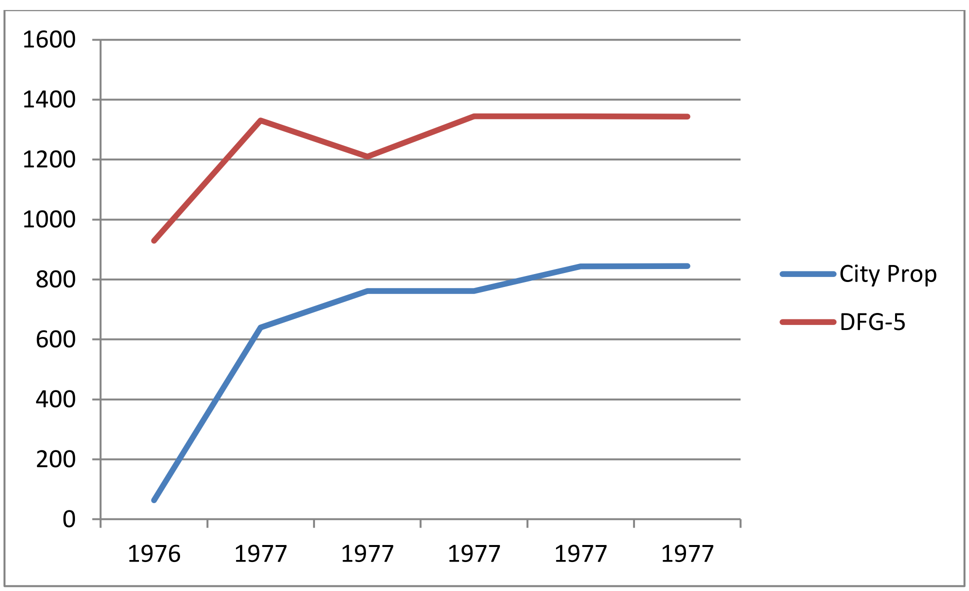


**Figure 21. Peak-Season Percentage Shortages: Extremely Severe 6-Year Extended Drought**

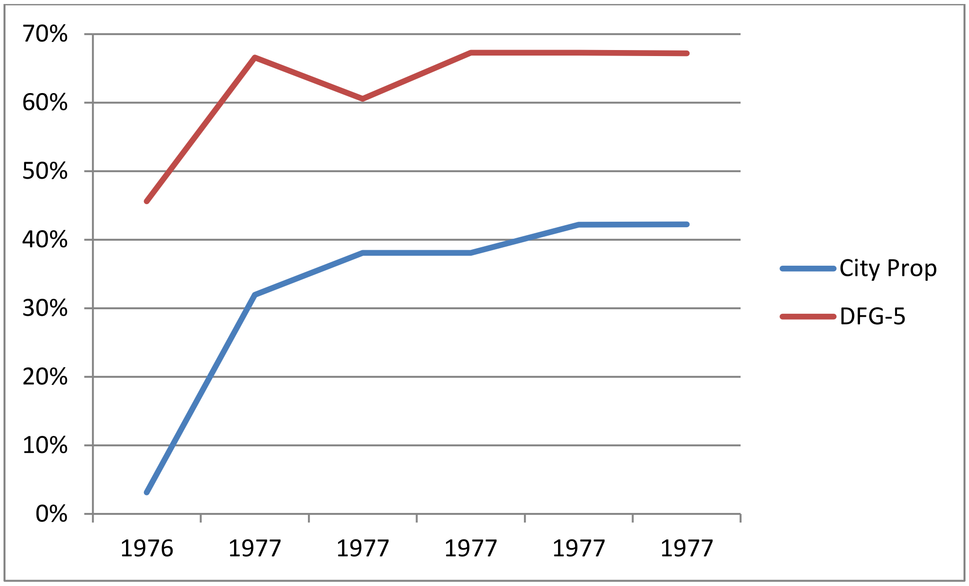
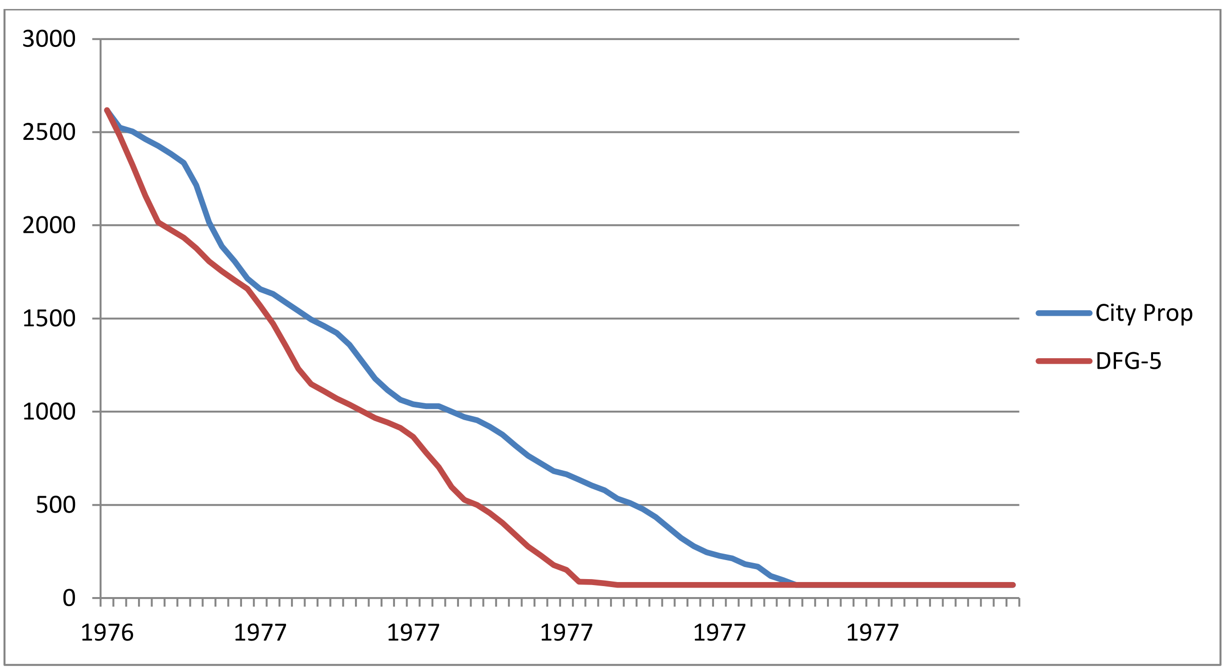



**Figure 22. End-of-Month Lake Levels (mg): Extremely Severe 6-Year Extended Drought**

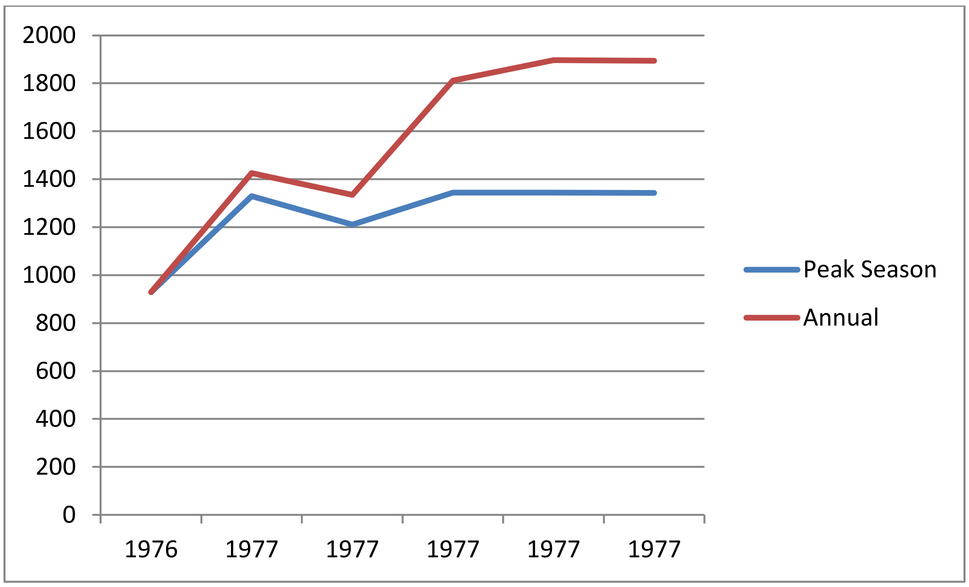



As Figure 6 shows, with both flow assumptions, the lake is steadily drawn down to 70 mg. With City Proposed flows, usable storage is exhausted by the start of the peak season of the next-to-last year of the 6-year sequence. With DFG-5 flows, this occurs about a year and a half earlier. As Figure 5 shows, peak-season shortages climb to just over 40% with City Proposed flows and to near 70% with DFG-5 flows when the lake is exhausted. Put another way, flowing and groundwater sources can serve about

60% of peak-season demand with City Proposed flows and only 30% of peak-season demands with DFG-5 flows.

One other comparison is revealing. Generally, as we've analyzed historic flows, there is very little shortage outside the peak-season months (May-October). As Figure 7 shows, that is not the case for this severe extended drought if available flows are governed by the DFG-5 flow rules. The critical season is expanded well beyond May through October. (This impact is also seen in the 8-year shallower drought, but to a much lesser extent.)

**Figure 23. Peak-Season vs. Annual Shortages (mg):**
**Extremely Severe 6-Year Extended Drought, DFG-5 Flows**




**Extended Drought Sequence # 3: 1976-77 Followed by 1987-92**

Figures 8-10 show the results for this sequence.

**Figure 24.  Peak-Season Shortages (mg): 1976-77 Followed by 1987-92**

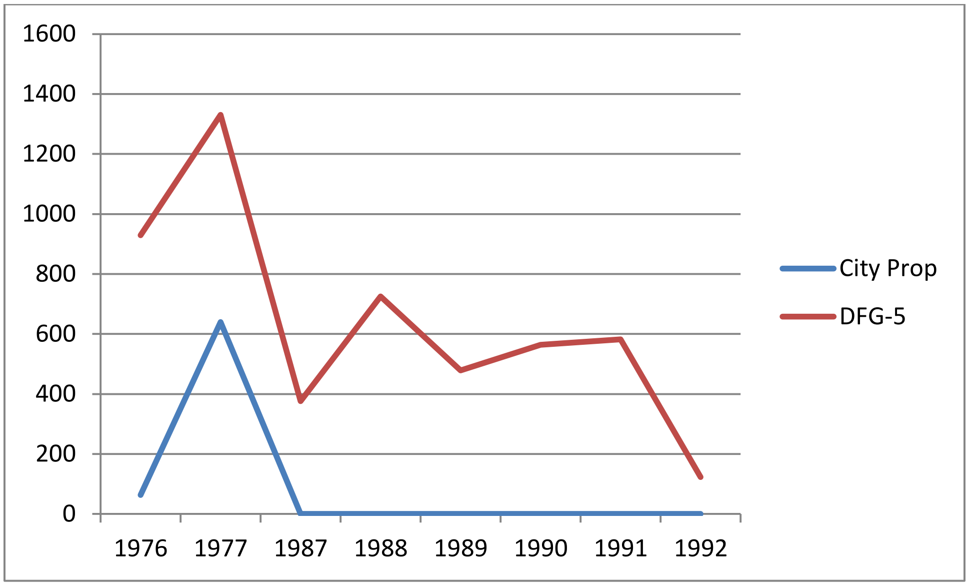



**Figure 25.  Peak-Season Percentage Shortages: 1976-77 Followed by 1987-92**

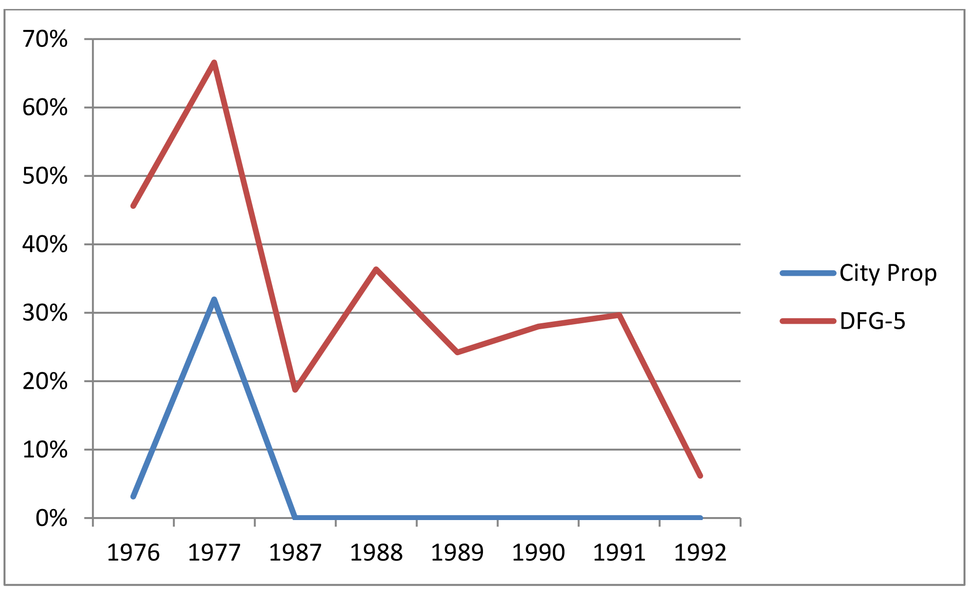
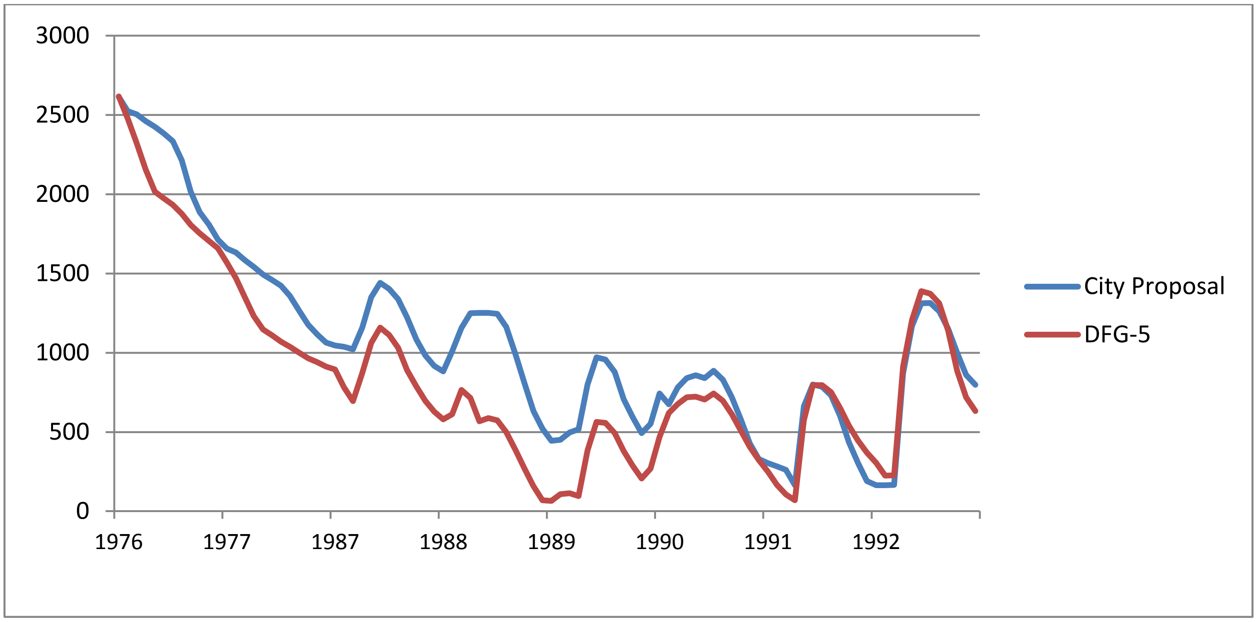


**Figure 26. End of Month Lake Levels (mg): 1976-77 Followed by 1987-92**



**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** March 2, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Baseline System Reliability with Alternative Interim Demand Forecasts

Using the high and low interim demand forecasts that David Mitchell developed, I analyzed baseline system performance and compared those results to those presented at the February meeting. This memorandum reports the results.

In order not to overwhelm the committee with too much redundant information, we decided to denominate the peak-season shortage duration curves as percentages rather than volumes. We felt this was more useful since it gives a feel for how much and how often customers would have to cut back. However, we also realize that there will be times when it is important to think about shortages as volumes. The following conversion table is intended to make it easier to move back and forth between the two. For the three alternative interim demand forecasts, the table shows the approximate peak-season volumes that correspond to different shortage percentages. I intend to include a similar conversion table in all memos and presentations moving forward.

Committee suggestions on how to better present the results are welcome.

**Table 11. Peak-Season Percentage/Volume Shortage Conversions**

| Peak-Season % Shortage | Peak-Season Volume Shortage (mg) | | |
|---|---|---|---|
| | Hi Dem | Mid Dem | Lo Dem |
| 5% | 100 | 100 | 100 |
| 10% | 200 | 200 | 200 |
| 15% | 300 | 300 | 300 |
| 20% | 400 | 400 | 400 |
| 25% | 500 | 500 | 500 |
| 40% | 800 | 800 | 800 |
| 50% | 1000 | 1000 | 900 |
| 60% | 1200 | 1200 | 1100 |

**Results**

Figures 1 and 2 show the peak-season shortage duration curves for forecast year 2020 under the two HCP flow proposals and the three alternative interim demand projections. Figures 3 and 4 show the corresponding results for forecast year 2035. The horizontal axes are all expanded (i.e., they only show the lower range of probabilities) to make the charts easier to read.

**Figure 27. Peak-Season Shortage Duration Curves: Forecast Year 2020, City Proposed Flows**

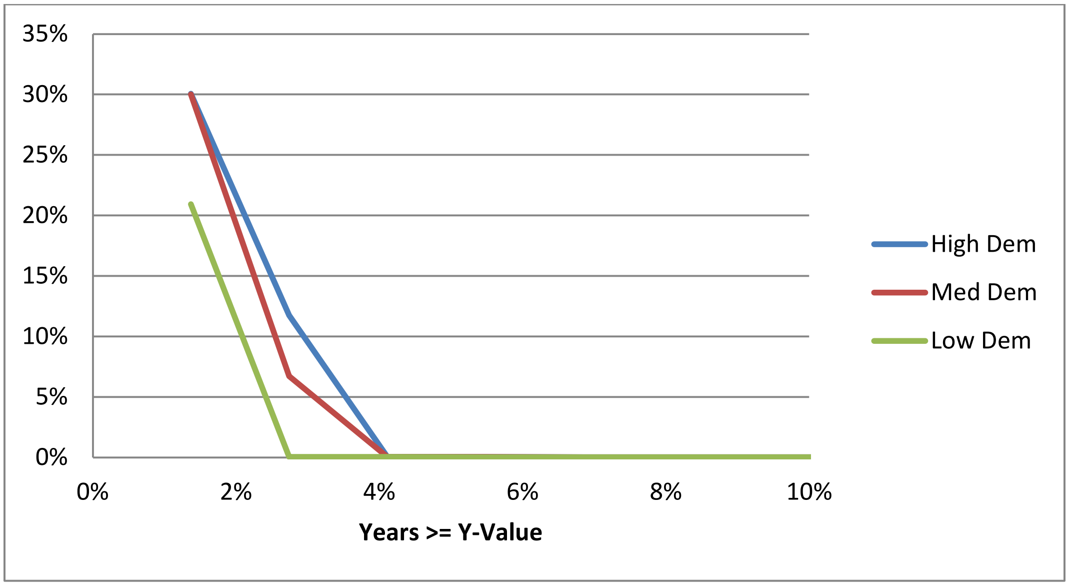



**Figure 28. Peak-Season Shortage Duration Curves: Forecast Year 2020, DFG-5 Flows**

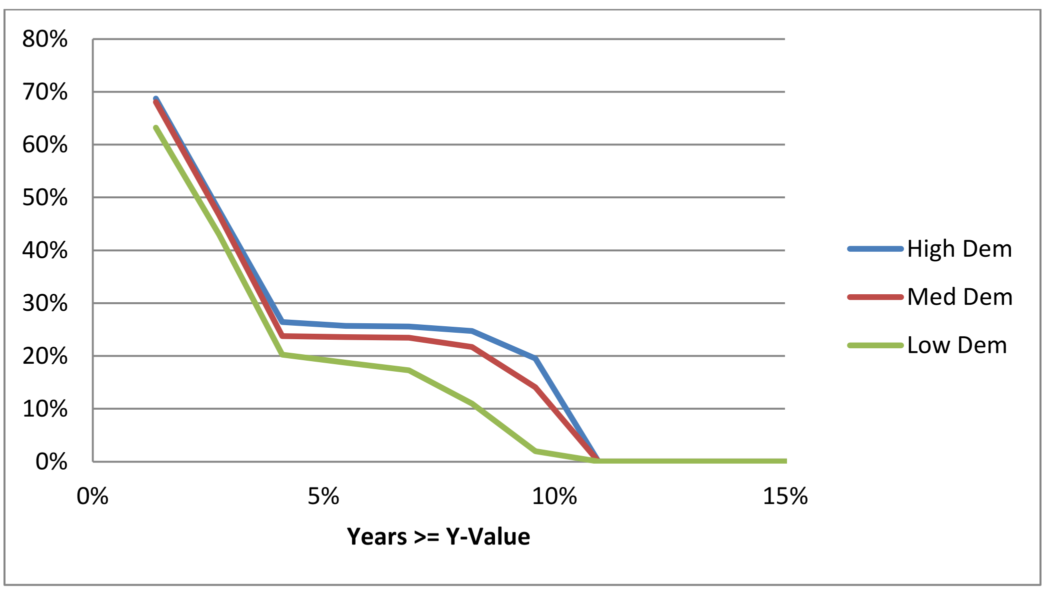


**Figure 29. Peak-Season Shortage Duration Curves: Forecast Year 2035, City Proposed Flows**

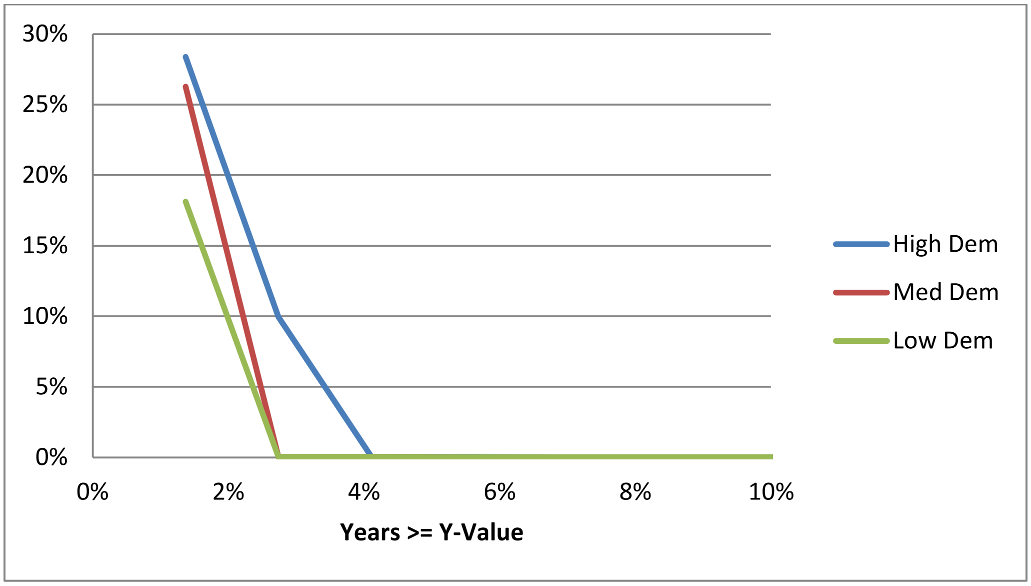
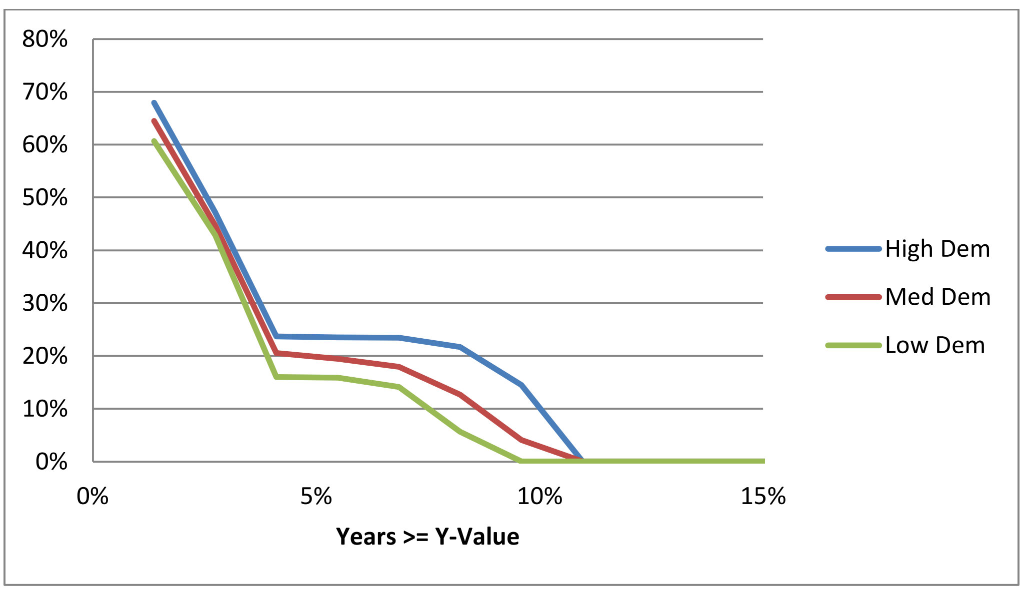



**Figure 30. Peak-Season Shortage Duration Curves: Forecast Year 2035, DFG-5 Flows**



**Key Conclusions**

- The reliability profiles for the three alternative demand projections are similar. However, there are noticeable differences in the driest years, particularly for the City Proposed flows and particularly for the low interim demand forecast. For the driest year (1977), the low-end forecast results in a peak-season shortage that is 8-10% less than the mid-range forecast presented at the February WSAC meeting.

- As before, since the 2020 and 2035 demand forecasts are not very different, the corresponding reliability profiles for those years are also similar.

GARY FISKE AND ASSOCIATES, INC.
*Water Resources Planning and Management*

**Date:** March 4, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Baseline System Response to Extended Drought

Our analysis of the baseline system's expected water supply reliability has to date been based on a 73-year historical flow record stretching from 1937-2009. Those historic flows have been modified to incorporate different HCP fish flow rules that are being negotiated with the California Department of Fish and Wildlife (CDFW). Within that flow record, the worst drought event occurred in 1976-77. Expected peak-season shortages in those drought years have been one of the benchmarks against which we assess system performance.

There are two potential limitations of this approach:

- Seventy three years is a "blink of an eye" in historic time. There are studies that indicate that that record was part of a much longer period characterized by rainfall that was well above long-term averages. The "worst" drought of that 73-year record may therefore underestimate the worst event that Santa Cruz should plan for.

- Human-caused climate change may well result in future weather patterns that differ from the recent past.

Thus, in addition to evaluating different water supply scenarios against our 73-year record, we also need to develop other credible weather and streamflow patterns against which to evaluate them. We've chosen to do that in two ways:

- Define an extended drought planning sequence that represents a discrete plausible future event that should, at least in part, guide water resource planning in Santa Cruz.

- Develop complete new distributions of weather and streamflow based on "downscaling" one or more climate change scenarios.

This memorandum discusses the first of these approaches. Similar approaches have been pursued by other California water suppliers, including the San Francisco Public Utilities Commission, East Bay Municipal Utilities District, and the City of Santa Barbara. While the details have differed, each utility specified an extended drought sequence not reflected in its historical flow record. It then used this extended drought to inform its resource planning and/or system operations.

**What Extended Drought Sequence to Plan For?**

Defining an extended drought planning sequence by necessity requires judgment. While the underlying assumption of such an exercise is that future weather and streamflows will differ from the past, we don't know exactly how they will differ. We know what severe droughts Santa Cruz experienced in the period of record; we don't know how much more severe a future drought might be. While the sequence chosen should exceed past sequences in duration and/or severity, it must also be plausible. That is, there must be a reasonable likelihood of its occurrence.

With this in mind, the extended drought planning sequence that will be analyzed below is an 8-year sequence that begins with two years that assume weather and hydrology that match the historic 1976-1977 period. The last 6 years mimic the 1987-1992 period, which was a longer but less severe historic drought. Note that, although both portions of the drought planning sequence are based on historic weather and hydrologic patterns, the assumption that one immediately follows the other is historically unprecedented.

**Modeling System Operation in Extended Droughts**

Although an extended drought planning sequence is just that, a planning tool, we must model its impacts to mimic as best we can how the City would actually operate the system if faced with such a drought. The first two years of our drought sequence duplicate the 1976-77 historic experience. It therefore stands to reason that in those years, the City would operate the lake as we have been assuming in our modeling to this point, namely with rule curves that result in lake drawdown to 1070 mg by the end of the 1977 water year.

Not only does this ensure consistency with our past modeling, but more importantly it reflects the realization that in the real world, system operators would have no way of knowing in those initial 2 years that a non-historic event is occurring. However, after that, we enter into new territory, where we know that we are in an extended drought and it is here that we must assume that the City starts to redeem its insurance policy by beginning to draw down the lake to zero.[4]

In sum, for modeling purposes, the extended drought sequence is divided into two portions, the first of which does not differ from the historic record and the second of which goes beyond that record and thus merits extraordinary lake drawdown.

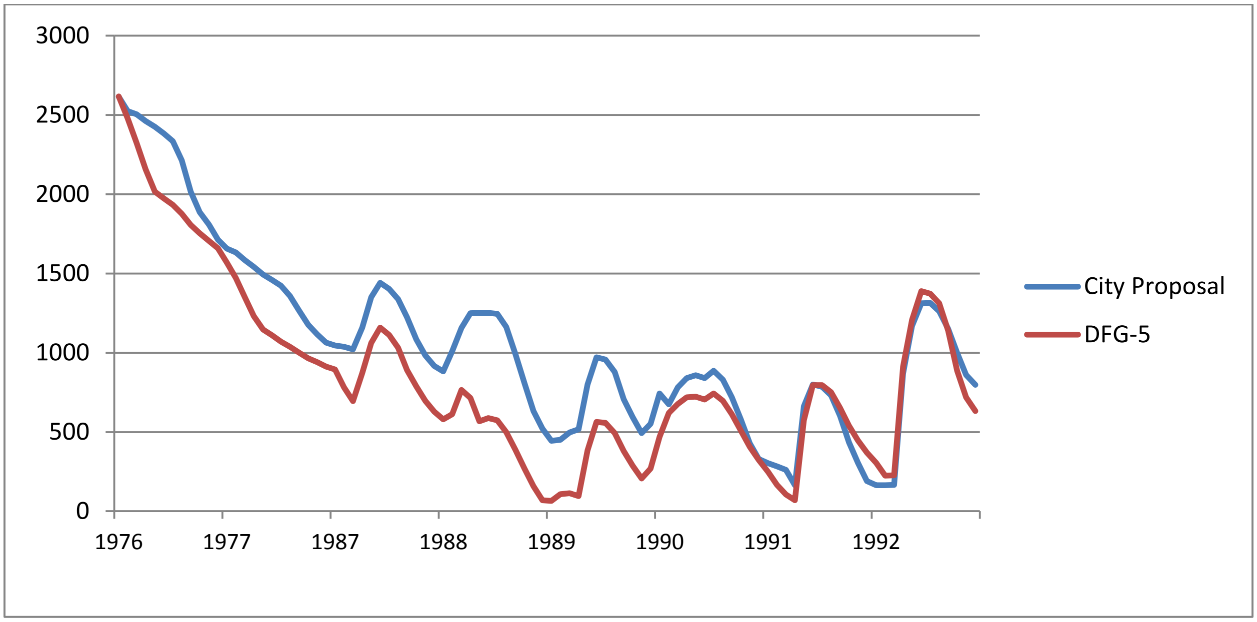
**Modeling Results**

The results that follow assume base interim 2020 projected demands. Results are shown for both City Proposed and DFG-5 flows.

Figure 1 shows the modeled lake drawdown over the extended drought sequence. Assuming City Proposed flows, the lake is drawn down to the billion gallon minimum level at the end of the second (1977) year. The lake then gets drawn down further in each subsequent drought year until it approaches full drawdown in the last two years. With DFG-5 flows, it is impossible to keep the lake above the billion gallon minimum at the end of the second year. After that, the lake stays low and is drawn down to within 150 mg of "empty" in 4 of the next 5 years before recovering to some extent as more abundant rains return in the winter of 1992.

[4] Actually, the lake is drawn down to 70 mg, which is the volume that is assumed to be physically inaccessible

**Figure 31. End of Month Lake Levels (mg)**




Figures 2 and 3 show, respectively, the peak-season volumetric and percentage shortages that result over this extended drought, while Table 1 shows some key summary system reliability statistics.

**Figure 32. Peak-Season Shortages (mg)**

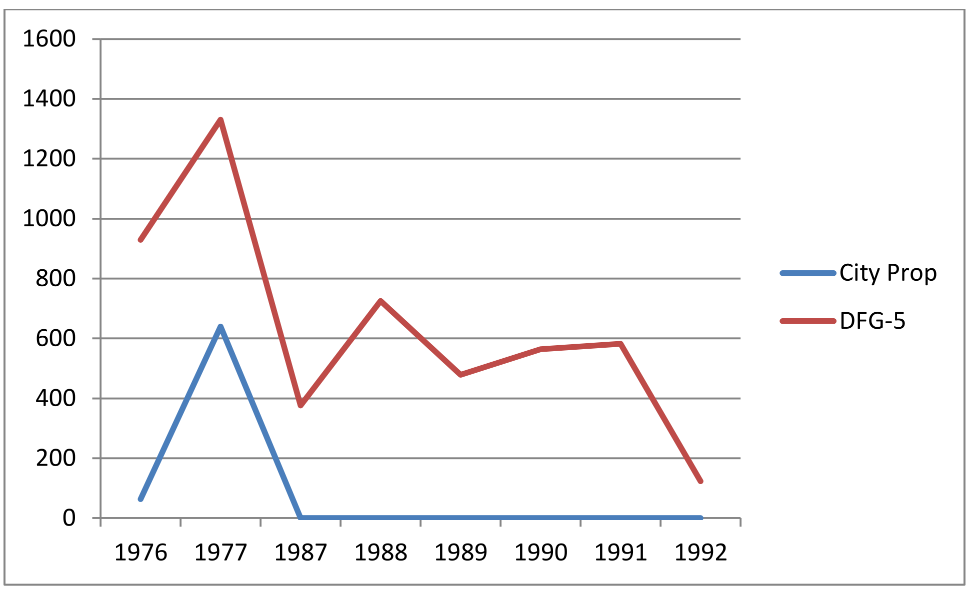


**Figure 33. Peak-Season Percentage Shortages**

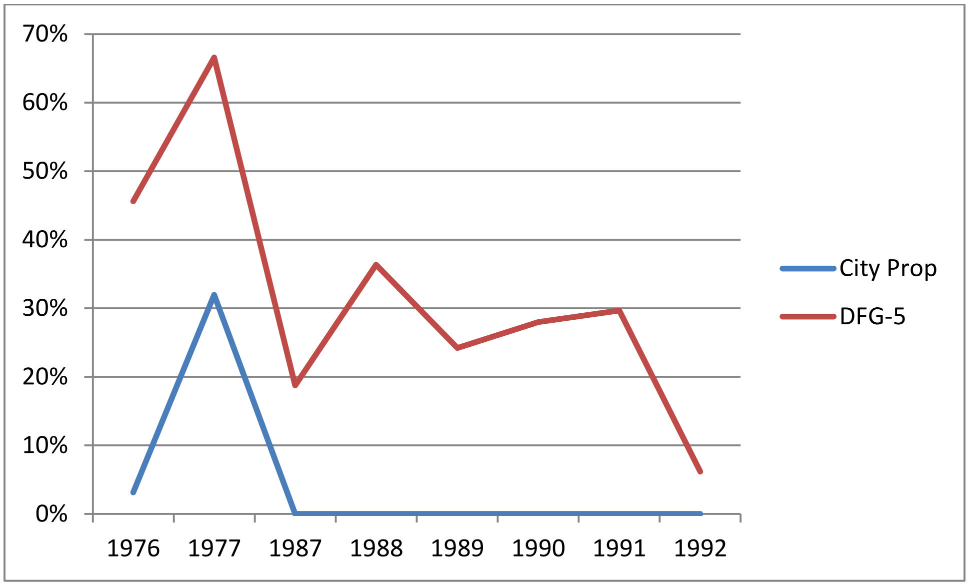



**Table 12. Extended Drought Peak-Season Shortage Statistics**

| | City Proposal | DFG-5 |
|---|---|---|
| **Total 8-Year (mg)** | 702 | 5,108 |
| **Average** | 4% | 32% |
| **Maximum** | 32% | 67% |
| **Minimum** | 0% | 6% |
| **Years > 20%** | 1 | 6 |

Assuming City Proposed flows, the only year of the extended drought in which the system experiences significant shortages is the second (1977) year, when the shortage exceeds 30%. The picture is very different with DFG-5 flows. Significant system shortages persist throughout the sequence with more than 5 billion gallons of peak-season demand going unserved over the 8 years. Peak-season shortages average more than 30%, with 6 of the 8 years having shortages that exceed 20% (and one additional year just under that).

In sum, the ability of the current supply system to respond to this extended drought depends critically on the assumed outcome of the HCP negotiations with CDFW.

**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** March 9, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Baseline System Response to Initial Climate Change Scenario

Previous memos have examined how the baseline system responds to the high and low interim demand forecasts (March 2) and to an extended drought planning sequence (March 4). This memo reports on how the baseline system performs under future climate change. Specifically, the system is modeled against revised flows that Shawn Chartrand developed for the GFDL General Circulation Model (GCM) and the A2 emission scenario, as described by Russell Jones in his March 9 memo. Russ' memo also describes how the weather data was processed to apply to Santa Cruz. Shawn's approach to developing the daily flow records for the City Proposed and DFG-5 flows from that weather data and from the HCP flow rules is described in his [date] memo.

The results reported below should be understood as the baseline system performance that can be anticipated if, at some point in the future, the distributions of Santa Cruz weather and streamflows are as developed in this climate change scenario.

**MODELING SYSTEM PERFORMANCE WITH CLIMATE CHANGE**

In our modeling of the Santa Cruz system to date, we have tested various configurations of supply, infrastructure, operating rules, and demand against an historical flow record.[5] In the IWP, that record included 59 years. More recent work has expanded that record to 73 years. The underlying assumption has been that the distribution of future streamflows will look like the flows in that record.

Thus, across hundreds of modeling runs, the essential characteristics of the flow record have remained constant. The worst drought event was 1976-77. The 1987-92 period represented another major drought. We knew which years in the record were very wet and which were exceptionally dry.

That no longer applies when we analyze how the system will respond to climate change. The essence of analyzing climate change is the assumption that future weather and streamflows will not be the same as the past. Rather, a new flow record has been produced. (It so happens that record includes 51 years.) There is no longer a 1976-77 worst-case drought benchmark or a 1987-92 sequence. As is illustrated in Figure 34 for City proposed flows at Big Trees, the distribution of flows is completely different than that of the historic record.

[5] In the case of the HCP flow sets, those historic records have been modified to model various fish flow rules.

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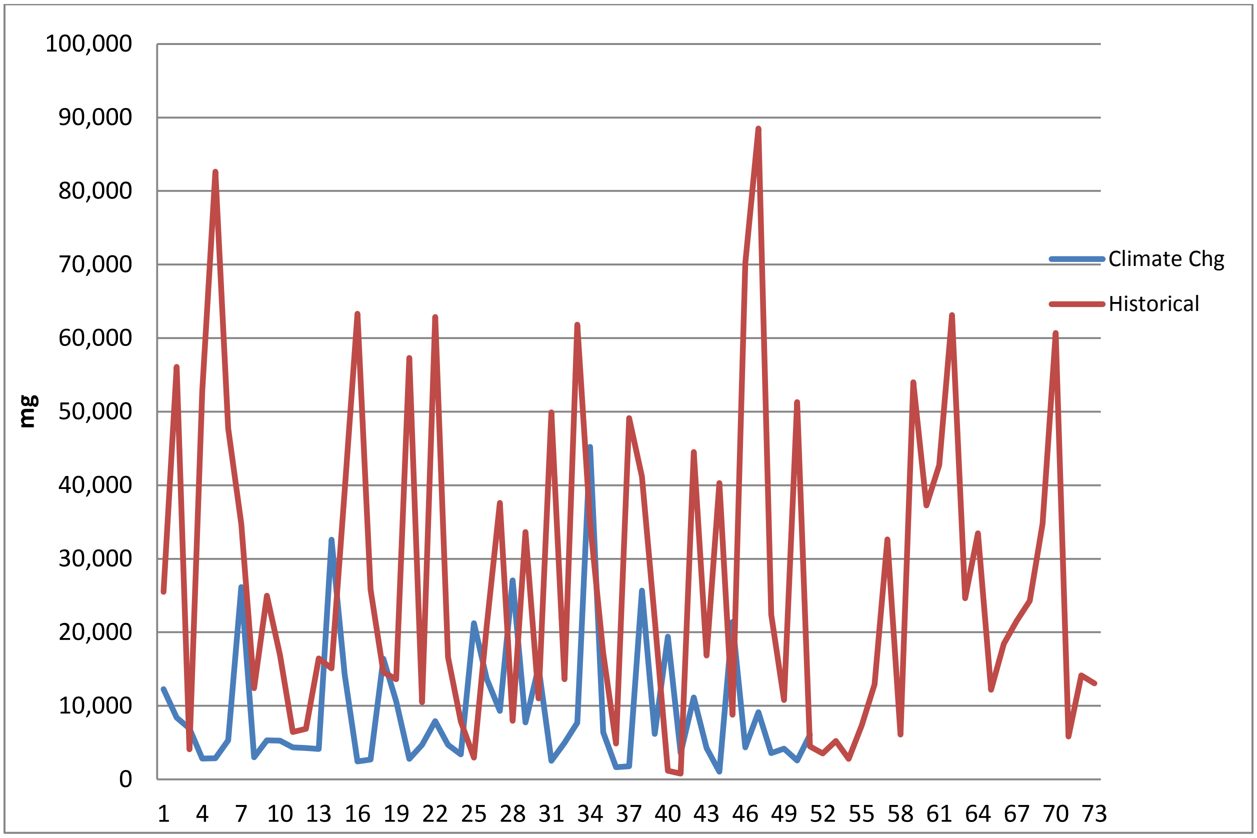
**Figure 34. Comparison of Annual Flows at Big Trees: City Proposal**




Our approach to regulating lake drawdown has been to develop rule curves that constrain the lake so that it draws down to its minimum (1070 mg) level at the end of the driest years. While there are no longer 1976-77 or 1987-92 sequences *per se*, we nonetheless want to use similar principles to operate the lake in this alternative future, so we likewise developed lake rule curves designed to draw the lake down to its minimum by the end of the driest water years.

It should be noted that, while the largest impact of climate change on system reliability results from reduced flows, there is an independent impact of weather. The warmer and drier weather conditions that are expected also result in a small increase in customer demand, and also affect lake evaporation and rain-on-surface. In what follows, we have made an initial attempt to incorporate those impacts. They are small relative to the streamflow impacts.

**MODELING RESULTS**

The following results all assume the mid-range 2025 interim demand forecast developed by David Mitchell. All of the charts and tables are denominated in percentage peak-season shortage. To convert to volumes, use Table 13.

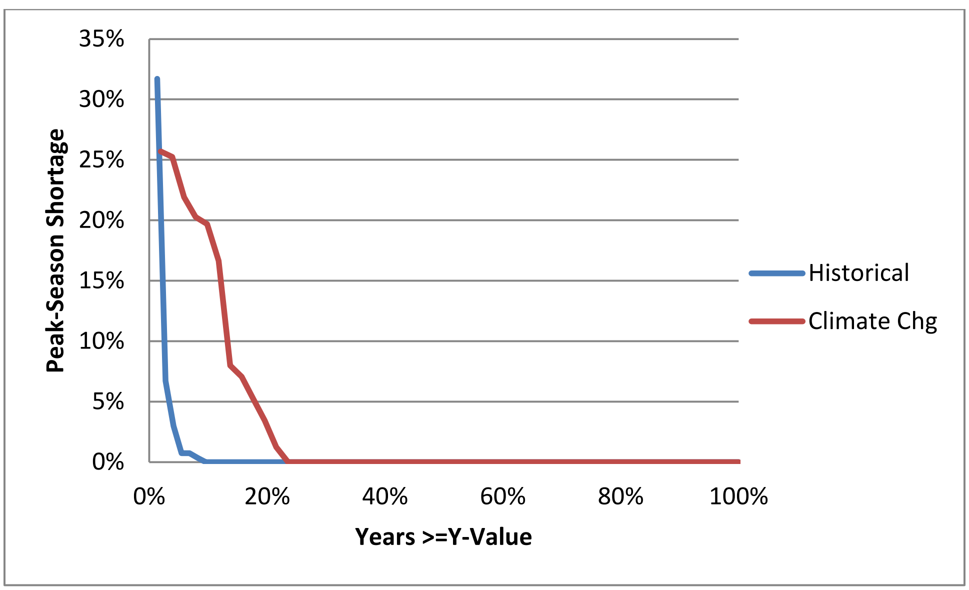
**Table 13. Rough Conversion Between Peak-Season Percentage and Volumetric Shortages: 2025 Interim Demands**

| Peak-Season % Shortage | Peak-Season Volume Shortage (mg) |
|---|---|
| 5% | 100 |
| 10% | 200 |
| 15% | 300 |
| 20% | 400 |
| 25% | 500 |
| 40% | 800 |
| 50% | 1000 |
| 60% | 1200 |

**City Proposed Flows**

Figure 35 compares the peak-season shortage duration curves for City Proposed flows with and without climate change.

**Figure 35. Peak-Season Shortage Duration Curves with and Without Climate Change: City Proposed Flows**




Two differences between the two curves are immediately noticeable:

- Climate change shifts the curve upward and to the right, meaning there is an increased likelihood of larger shortages. Whereas with historic flows, there is a small chance (<10%) of any shortage at all, this rises to more than 20% with climate change. The probability of a shortage greater than 20% increases from about 1% with historic flows to about 8% with climate change. This shift is shown in a different form in Figures 3 and 4.

**Figure 36. Peak-Season Shortage Distribution: City Proposed Flows (Historic)**

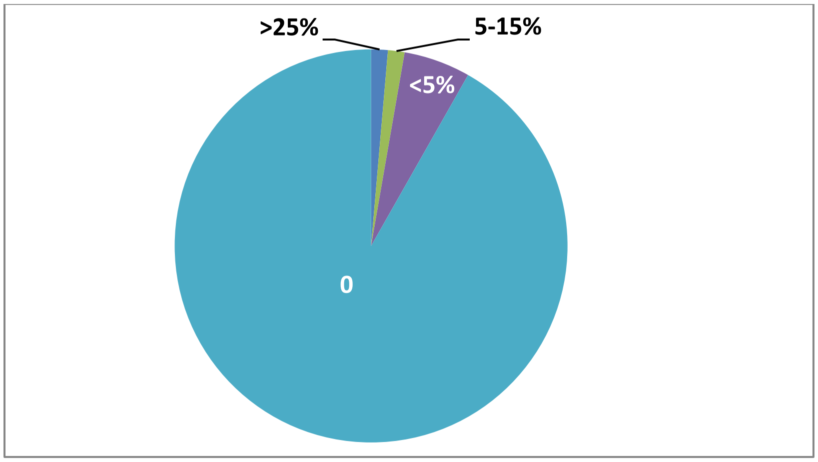
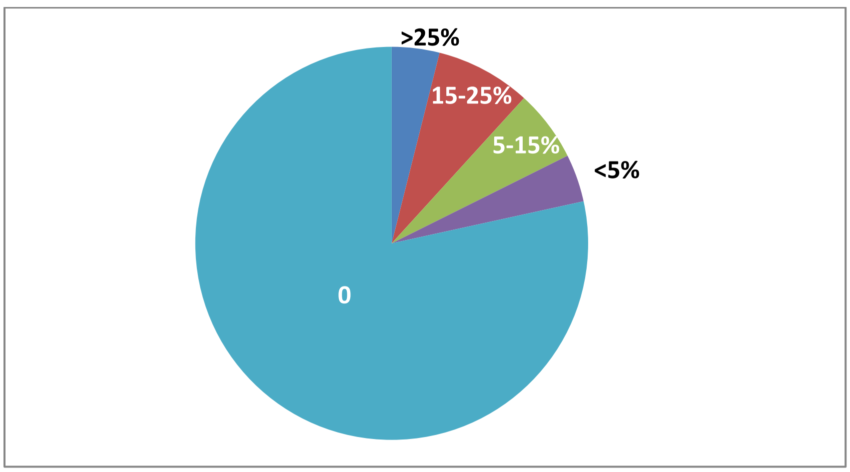


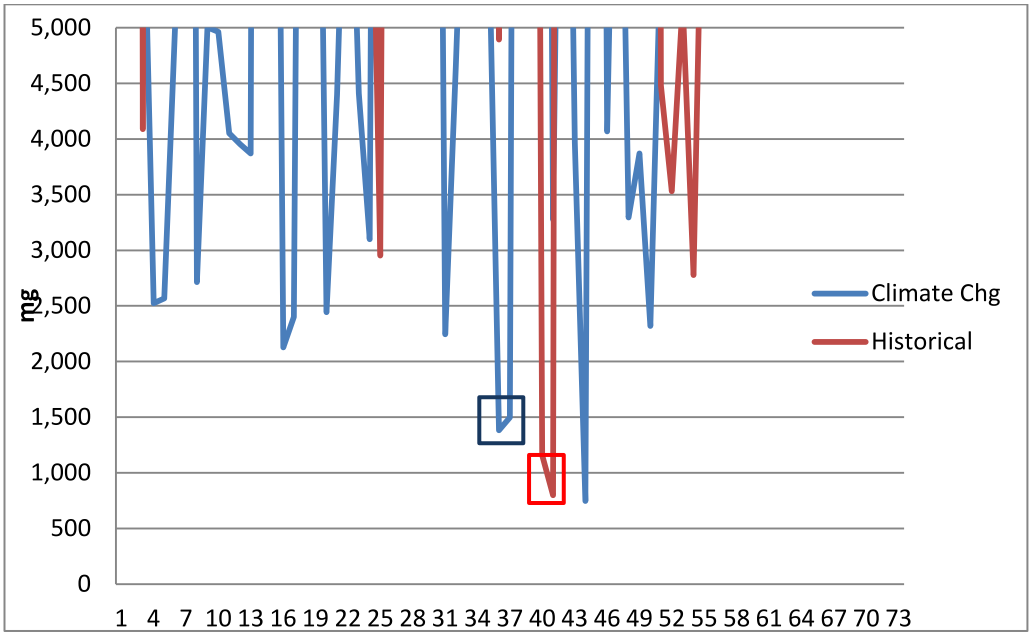

**Figure 37. Peak-Season Shortage Distribution: City Proposed Flows (Climate Change)**




- Despite the overall degradation of system reliability under climate change, we see in Figure 35 that the worst-year shortage is actually somewhat less under climate change. The reason for this is illustrated in Figure 38, which magnifies the lower end of the Figure 34 Big Trees flow distributions. The worst drought events in each case are highlighted and we see that despite the substantial overall reduction in flows under climate change, the worst drought event is not quite as severe as the historical 1976-77 event.[6]

[6] Although system shortages depend on more than just Big Trees flows, those flows are a good predictor of system performance in any year.

**Figure 38.  Magnified Big Trees Dry-Year Flows: City Proposal**




**DFG-5 Flows**

Figures 6-8 show the same system reliability comparisons for DFG-5 flows.

**Figure 39.  Peak-Season Shortage Duration Curves with and Without Climate Change: DFG-5 Flows**

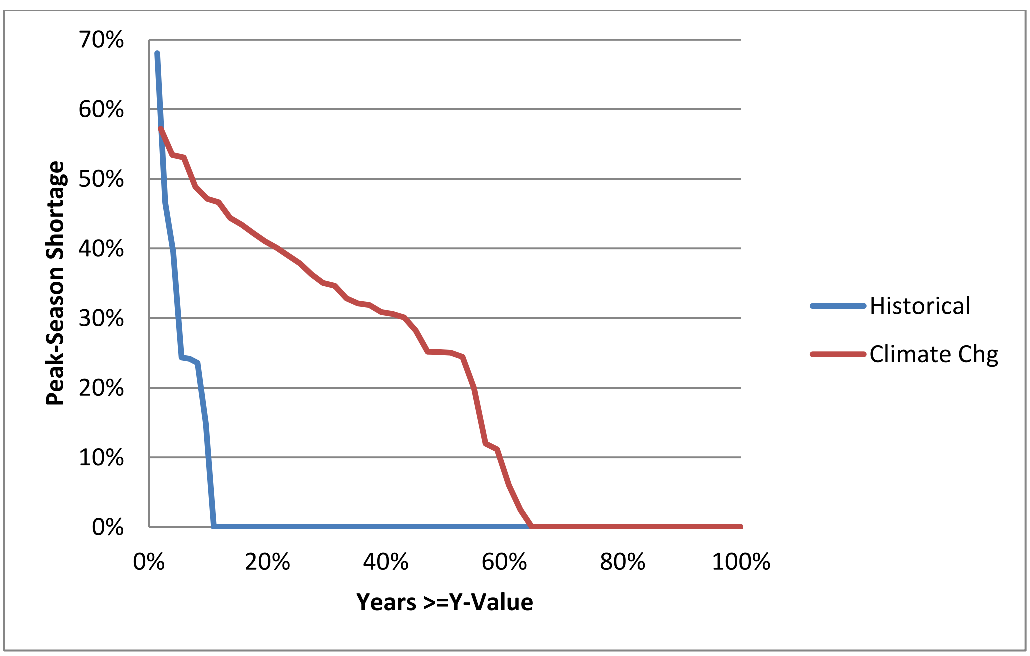


Figure 40. Peak-Season Shortage Distribution: DFG-5 Flows (Historic)

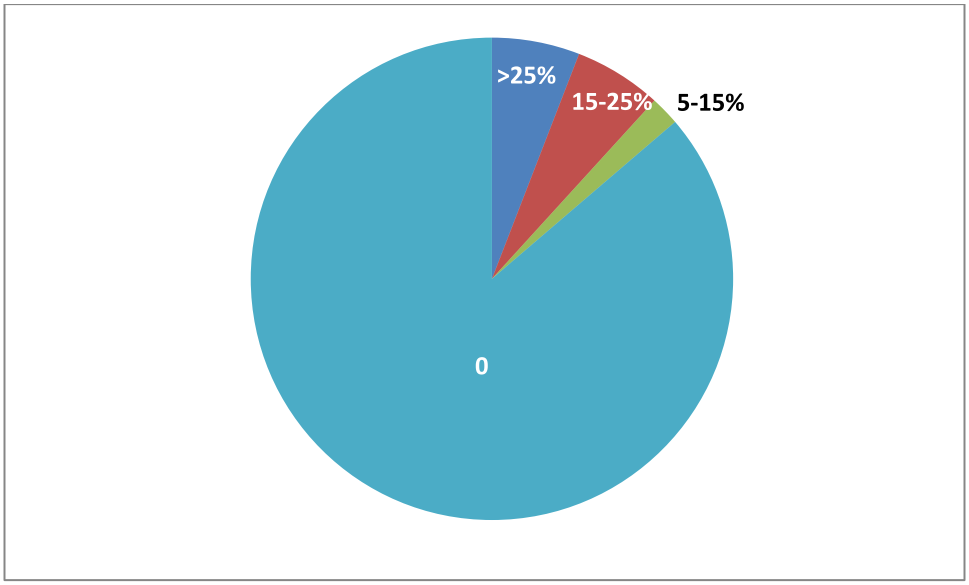
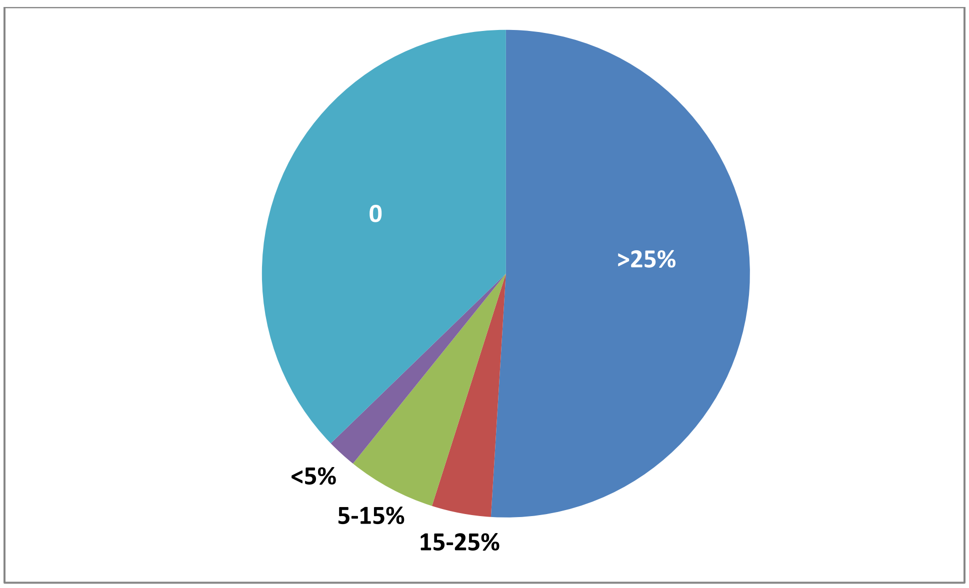



Figure 41. Peak-Season Shortage Distribution: DFG-5 Flows (Climate Change)




While the types of impacts are similar, their magnitudes with DFG-5 are much increased. For example, under more than 60% of hydrologic conditions, there will be a peak-season shortage. In fact, a shortage exceeding 25% can be expected in just over half the years.

**IMPLICATIONS**

The foregoing results highlight the importance of considering climate change as Santa Cruz plans for its water supply future. Even under the City's proposed HCP flows, which represent an upper bound on the streamflows that will likely be available for diversion and storage, water customers would have to contend with frequent shortages under this climate change scenario. If the outcome of the HCP negotiations are closer to CDFW's DFG-5 proposal, the frequency and magnitude of shortages becomes much more onerous.

Thus with climate change, the City's water future will look qualitatively different. With historical flows, while there is a real possibility of large peak-season shortages, these are generally confined to the driest years with the large majority of conditions having no shortages. This is clearly not the case with climate change. Instead, significant shortages can be expected in many years. With DFG-5 flows, large shortages can be expected in the majority of years. The pattern of water availability to customers will be markedly altered.

As the planning process moves forward, the pattern of streamflows that we see under this scenario may also have a significant impact on the effectiveness of various supply/infrastructure alternatives. While the precise impacts remain to be seen as those alternatives are defined and modeled, it is very possible that the supply volumes provided by some alternatives, and therefore their system reliability benefits, will be significantly reduced.

**Memo**

To: Karen Raucher

Cc: Heidi Luckenbach, Chris Berry, Melissa Hetrick, Kevin Crossley, Jeff Hagar, Rosemary Menard, Bob Raucher, Gary Fiske

From: Shawn Chartrand

Date: March 9, 2015

**Subject: Development of streamflow records under CC for water supply analysis for the City of Santa Cruz surface supply sources**

---

We have completed a model-scale analysis of potential impacts to streamflow and water supply using one climate change projection from one downscaled Global Climate Model (GCM) for WY[7] 2015 - 2070. The work is intended to help inform ongoing decisions regarding HCP and water supply planning, albeit for only one possible future scenario at this point. The work was conducted through a few primary steps: (1) decompose downscaled[8] monthly climate projections into monthly projected streamflows; (2) distribute monthly projected streamflows over any given projected month to develop a projected daily record of streamflow; (3) compute hydrologic statistics for the projected months vs. the historic analysis period (WY1936 – 2009); (4) develop regression models of natural flows between points of diversion and reaches of anadromy for all City of Santa Cruz source streams; and (5) use the previous four steps as inputs to the HCP Hydrology Model for the (a) City July 2012 and the (b) DFG5 HCP flow proposals. If not discussed, all other aspects and nature of the HCP Hydrology Model were left as is, and were not changed or altered.

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[7] WY stands for water year, defined as October 1 to September 30 of the following year.

[8] GCM output was downscaled to grid cells measuring 1/8 degree by 1/8 degree (about 12 km on a side in central California). The GCM output is resolved at grid cells measuring 2 degrees by 2 degrees (about 196 km on a side in central California).

The climate change (CC) work for the HCP has been ongoing since 2008. In 2008, we first sought to incorporate CC into the HCP planning process. A first step to doing so involved a substantial literature review to gain an understanding of what the present state of the science was for climate change in California. This review led Balance to contact Prof. Ed Maurer at Santa Clara University to seek expert guidance on how to set-up a simplified analysis using CC information. Our correspondence with Prof. Maurer resulted in the development of a water balance model, which serves as the basis for the CC modeling reported here. At the time, the CalAdapt program and website (www.cal-adapt.org) were just getting up and running, driven by Gov. Schwarzenegger's November 2008 Executive Order S-13-08 that specifically asked the Natural Resources Agency to identify how state agencies can respond to CC. We utilized downscaled GCM data[9] adopted and made available by the CalAdapt program as the basis for our modeling. Thus far we have specifically focused on the worst-case CC data set, which for the CalAdapt data sets is the downscaled GFDL2.1 GCM[10] for the A2[11] emissions scenario.

The original intent of our work was to use the raw CC projection data downloaded from CalAdapt. Upon inspection and completion of a few trial model runs however, it was noted that the projected precipitation record is wet, and quite wet when compared to the historical period record (Figure 1). After much discussion amongst the technical HCP and Water Supply Planning team, it was decided that we would seek to develop a revised precipitation record. The adjusted precipitation record is termed the transient precipitation record (Figure 1), and was developed by Stratus Consulting. In short the transient record preserves the distribution of events present in the raw data set (i.e. the variability of the

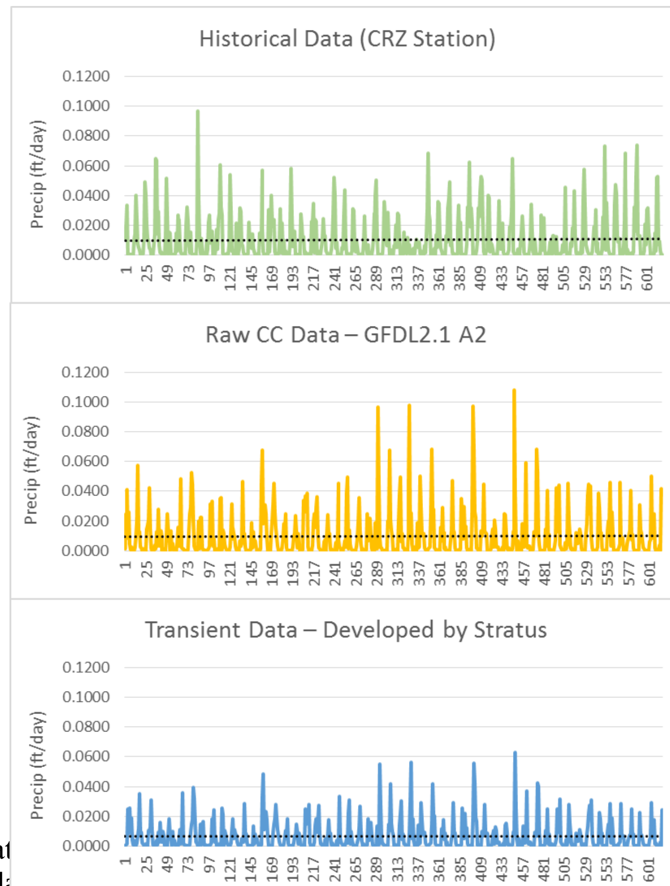



**Figure 42: Comparison of the historical, raw CC projected and transient precipitations records used in the modeling reported herein. Note that the monthly precipitation totals were divided by the number of days in the month to arrive at precipitation in feet per day. The beginning of each data series has been lined to facilitate plotting. Each data series is 50 years in length.**

---

[9] The GCM data originates from the World Climat
Intercomparison Project phase 3 (CMIP3) multi-model da

[10] Geophysical Fluid Dynamics Lab CM 2.1; National Oc

[11] CO2 emissions exhibit a continual rise throughout
concentrations that will be more than triple their pre-indu

raw GFDL2.1 A2 record), but scales it according to the long-term monthly rainfall depths reported for Santa Cruz. The procedure and rationale are discussed in the memo prepared by Russell Jones, Stratus Consulting (March 2015). It is important to note that *no other data* of the GFDL2.1 A2 series used for the modeling reported herein was adjusted – the raw downloaded data was used for all modeling. Each of the five steps presented in the opening paragraph will be reviewed in more detail.

## Monthly Projected Streamflows

Monthly records of total precipitation (mm) and average and maximum air temperature (degrees Celsius) were download from the CalAdapt website for GFDL2.1 A2 using the tabular data option. The geographic location specified for the data query was a point in the San Lorenzo River watershed just south of Ben Lomond, with approximate coordinates of 37.0595 DD by -122.0712 DD. This location and the grid cell it is in is the centroid of the San Lorenzo River watershed. Climate change data for the San Lorenzo River watershed was used because it serves as the basis of modeling for the HCP Hydrology Model, and specifically the San Lorenzo River at Big Trees USGS gage (Big Trees) is the reference gage and streamflow record (USGS # 11160500).

Prior to publication the CC projected precipitation and air temperature data sets were bias corrected and spatially downscaled using spatial statistics reflective of observed, historical conditions. The bias correction and spatial downscaling are two different steps of post-GCM data processing. Bias correction first occurs for GCM output of the historical period 1950 – 1999; correction is based on adjusting GCM cumulative distributions of any one grid cell to that of the historical observed distributions of the specified grid cell. This results in a dampening or amplifying of the GCM continuous data series while preserving the mean and variability of the original GCM output. A similar step is conducted for the projected GCM data set (i.e. the CC projected period) using the same historical observed distributions. The gridded, historical observed data sets were developed by Maurer et al., 2002[12]; these data sets reflect spatially averaged monthly precipitation and surface air temperature conditions computed from point measurements (stations) distributed over any one 2 degree by 2 degree grid cell. Spatial downscaling occurs by developing adjustment factors between observed historical data and the bias adjusted GCM data, where the observed data is the reference value; these adjustment factors are interpolated to the downscaled grid based on an empirical statistical method (Maurer et al., 2002). The

[12] Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen, 2002, A Long-Term Hydrologically-Based Data Set of Land Surface Fluxes and States for the Conterminous United States, J. Climate 15(22), 3237-3251

downscaled adjustment factors are then applied to the coarse-gridded observed data to yield the bias corrected spatial downscaled climate projections.

Development of CC projected monthly streamflow record for Big Tees followed a procedure similar to that used to develop the downscaled climate projections. The first step was to develop a calibration curve (regression model) between the historical observed climatic data for the period 1950 – 1999 (same data used in the bias correction and spatial downscaling steps) and the observed monthly streamflow at Big Trees for the same period. To do this the historical observed climatic data was applied to a simple water balance model to estimate monthly streamflow. The water balance model is stated as:

$$Q = P - ET - R + B(CoS) \tag{1.1}$$

The term *Q* is streamflow discharge ($ft^3$/day), *P* is precipitation (ft/day), *ET* is the evapotranspiration (ft/day), *R* is groundwater recharge (ft/day), and *B* is the baseflow addition, which is a source term dependent upon *CoS* (relative groundwater carry-over storage):

$$B = \sum_{i=-1month}^{-6months} P_{daily} * K * CoS \left[ \frac{ft}{d}, -, - \right]$$

$$CoS = \frac{\left( \sum_{i=0}^{-10months} P_{daily} \right)}{\bar{P}_{daily}} \; [-] \tag{1.2}$$

The term *i* is an index used to specify the period of time used for a calculation, *K* is a simple dimensionless rate-limiting constant which characterizes the release of stored water to the source streams, and *CoS* is a dimensionless precipitation momentum term which scales *B* up or down depending on how wet or dry the present and previous 9 months were relative to the long-term mean. The square brackets indicate units for the associated terms and equation. In more practical terms *B* serves as the primary fitting parameter for the water balance model, and improves model skill for the lowest flows. In particular, *B* helps to better distinguish short-term wet periods (scale of 1 – 3 months) from longer-term wet periods (scale of up to 10 months), when heading into the summer season. A decent example of this is WY1993 vs. WY 1997. It is important to note that Equation 1.1 lacks a change in storage term (ΔS), which would be the more typical source-related term. We are not referring to B as a change in storage term because we have no idea how storage may have or may change in the source watersheds over the time period of interest, nor do we know the initial storage conditions. The calibration curve between monthly streamflow at Big Trees computed with the water balance model vs. that measured at Big Trees is provided in Figure 2, and a comparison between the computed continuous monthly record and that reported by the USGS is provided in Figure 3. Figure 3 indicates that the water balance model does relatively decent job of reflecting historical conditions, and as usual it is most difficult to reflect the extremes within the record, although the baseflow parameter helps to accomplish this to some degree.

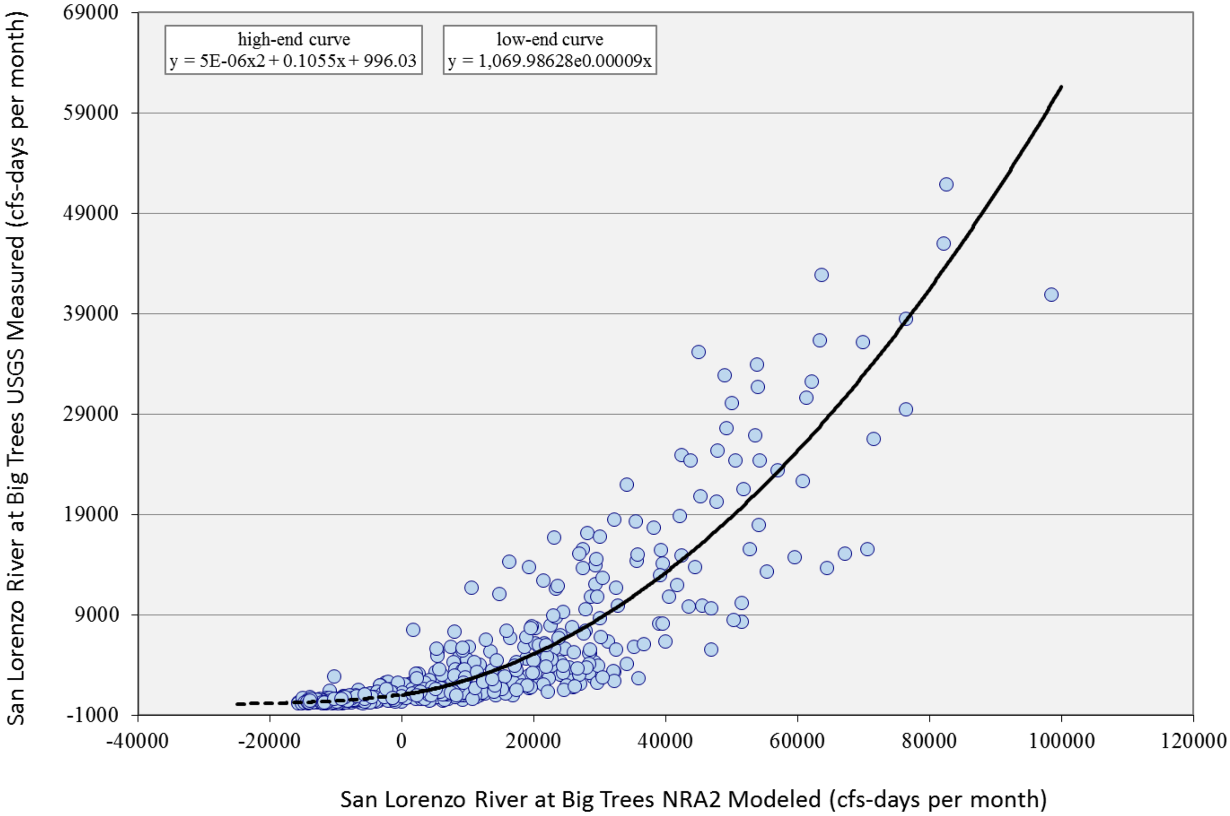



**Figure 2: Calibration curve between monthly streamflow at Big Trees computed with**

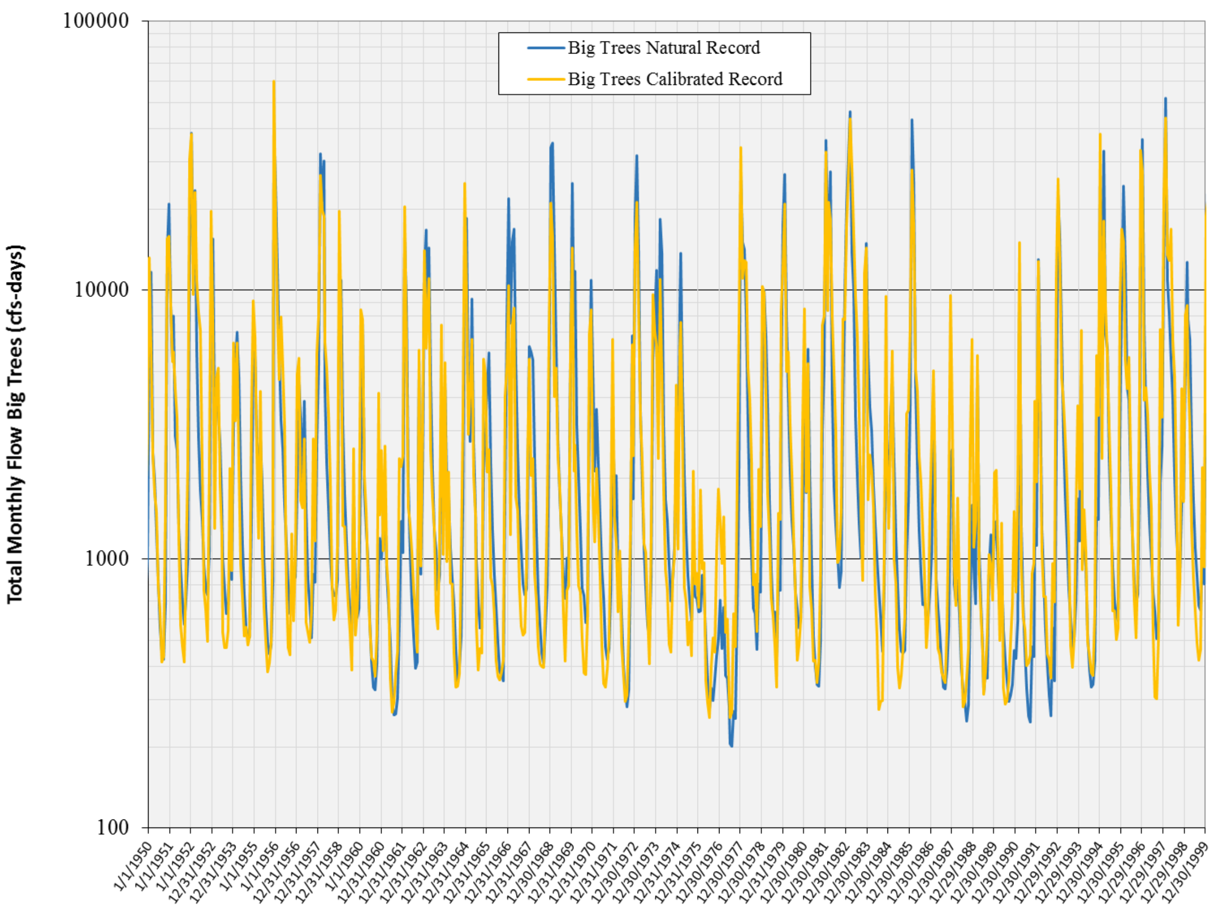





**Figure 3: Continuous monthly records comparison for water balance model computed vs.**

With the calibration between downscaled GCM climatic variables and measured streamflow at the USGS, it is possible to move forward and compute monthly streamflows for the projected CC period. This simply involves applying the CC climatic variables to water balance model and then using the calibration curve to compute monthly streamflow at Big Trees. This was done for the period 2015 -2070.

## Daily Projected Streamflows

Arriving at a daily projected streamflow record could be accomplished many different ways; we tried several to start and ended up utilizing the most simple, which is based on long-term averages. Among other things this method is appealing because CC projections are really about long-term trends. In detail the work involved several different steps. First, daily projected streamflows were apportioned from the projected monthly totals for the period WY2015 – 2070 by distributing the total monthly flow according to the long-term mean daily flow for any particular day. The Big Trees annual record of mean daily flow was computed using the USGS records for the period WY1936 – 2014.

The resultant preliminary daily projected CC record contained two calculation artifacts that were removed. The removal process constitutes the second step in the daily streamflow process. The first artifact was defined by abrupt drops in flow at transitions between some winter months. This drop occurred for projections that go from very wet conditions in one month to average or dry conditions in the next, and the uncorrected drops ranged in magnitude up to roughly a factor of 10. Drops less than a factor 1.25 were not corrected. The drops were removed using exponential smoothing and re-distribution of mass to account for the changing flow conditions (i.e. this means conservation of mass was respected for any given CC projected total monthly flow and that flow was not created or destroyed). The smoothing occurred over the first three days of any particular month, with the smoothing exponent similar to recessional constants which can be computed for the Big Trees record. The smoothing equation for the first day of the month was:

$$Q_{corrected} = Q_{uncorrected}^{previous\ day} - ((1 - e^{-0.5}) * (Q_{uncorrected}^{previous\ day} - Q_{uncorrected}^{3\ days\ ahead})) \qquad (1.3)$$

The equations for days 2 and 3 are identical to Eq. 1.3 except the day referenced by last Q term in the equation would decrease by 1 day, and 2 days respectively. What is important to keep in mind is that Equation 1.3 simply subtracts an exponentially decreasing flow difference from the flow computed for the last day of the previous month. In this way Eqn. 1.3 smooth’s the transition from the end of any given previous month through the first

3 days of the next month, as long as the flow differential across the monthly transition > 1.25. The result of this step in the process is referred to as the corrected, preliminary daily projected record of flow (corrected record).

The second artifact was defined by rapid flow oscillations during many days of the winter months. This is due to the fact that the USGS record is quite long and therefore average daily flows can reflect values that are not necessarily correlated to adjoining values. As a result these oscillations simply reflect the averaging, and were smoothed out in order to avoid imprinting an overly explicit trend in the daily projected CC record. Smoothing of the corrected record was done with a zero-order forward and reverse digital filter. This means that the location of any given peak in time is not effected, but its amplitude is adjusted based on the nature of flows forward and backward in time from any particular position, based on a specified filtering length and

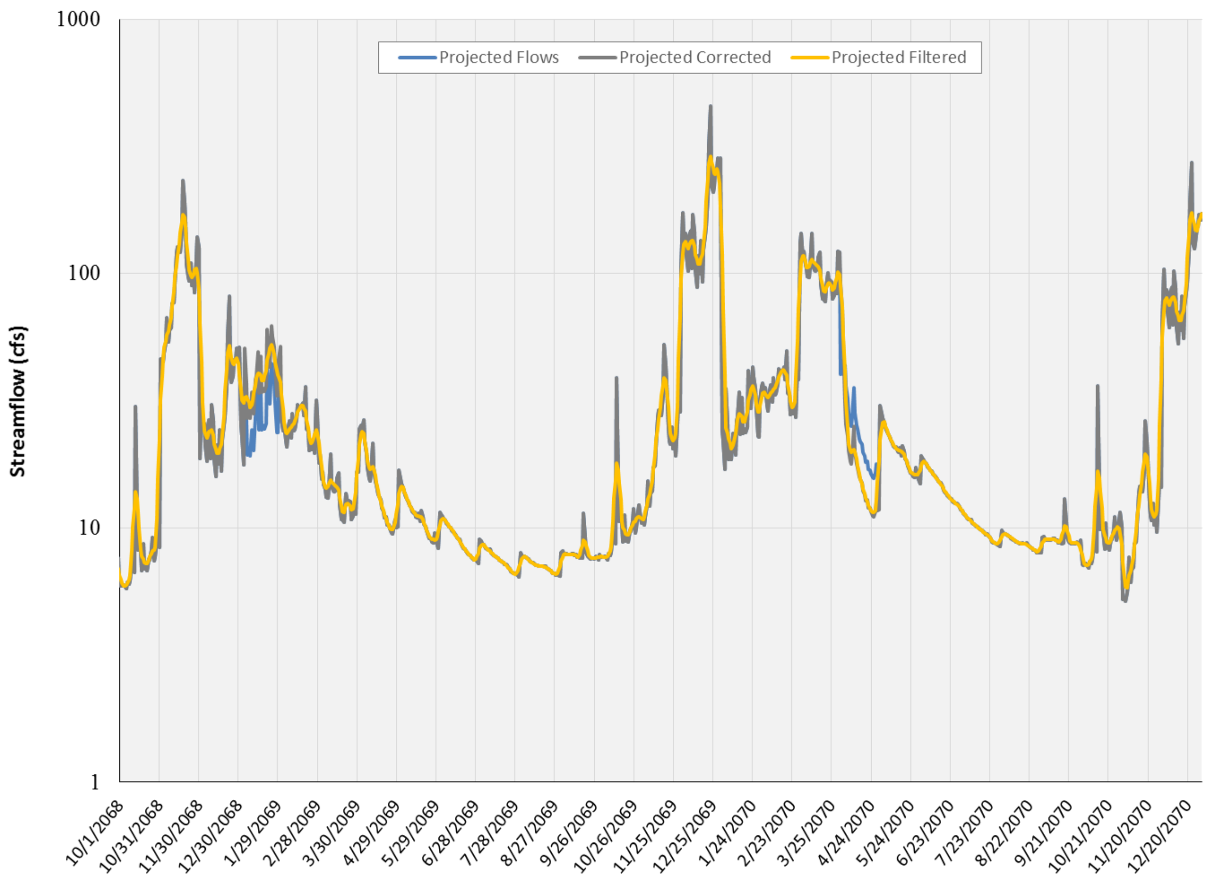



**Figure 4: Comparison of CC daily projected, corrected and smoothed streamflow at Big Trees.**

computed flow differences. This particular filter has the advantage of matching initial conditions well. The smoothing filter length was chosen to minimize the sum of differences between the corrected and the filtered record (< 0.1% difference in total flow). The preliminary daily projected, the corrected and the smoothed records are shown in Figure 4 for WY2068 – 2070.

## Hydrologic Statistics

The HCP Hydrology Model is based on use of flow statistics for the Big Trees USGS gage, which describe how dry or wet conditions are from month to month, based on the historical period as a whole. The hydrologic classification of any given month is based on 5 possible categories (percentile classes) termed critically dry (0 – 20%), dry (20 - 40%), average (40 - 60%), wet (60 - 80%) and very wet (80 -100%). The HCP Hydrology Model uses the hydrologic classification to determine which HCP habitat flow rules are in effect. The flow rules are needed to first set flow aside to meet the stated needs of salmonids, and second to determine how much residual flow remains for potential water supply (results which are fed into Confluence®).

In order to facilitate comparison between the one CC model run and those completed for the historical period, most notably with respect to analyses completed by Jeff Hagar and Gary Fiske, it was determined that monthly hydrologic conditions for the projected CC period were to be computed relative to the historical period percentile class limits, without effecting the numerical value of those limits. This provides for the comparative scenario and implicit assumption that the general distribution of hydrologies is similar between projected and historical, but more importantly is necessary in order to make straightforward comparisons between the model data sets.

## Natural Flow Regression Models

The last step in preparing data for the HCP Hydrology Model is to specify regression models which provide a means to compute natural (i.e. un-impacted by diversion) flows within the reaches of anadromy based on associated daily flows at the points of diversion, or in the case of the San Lorenzo from Big Trees to Tait

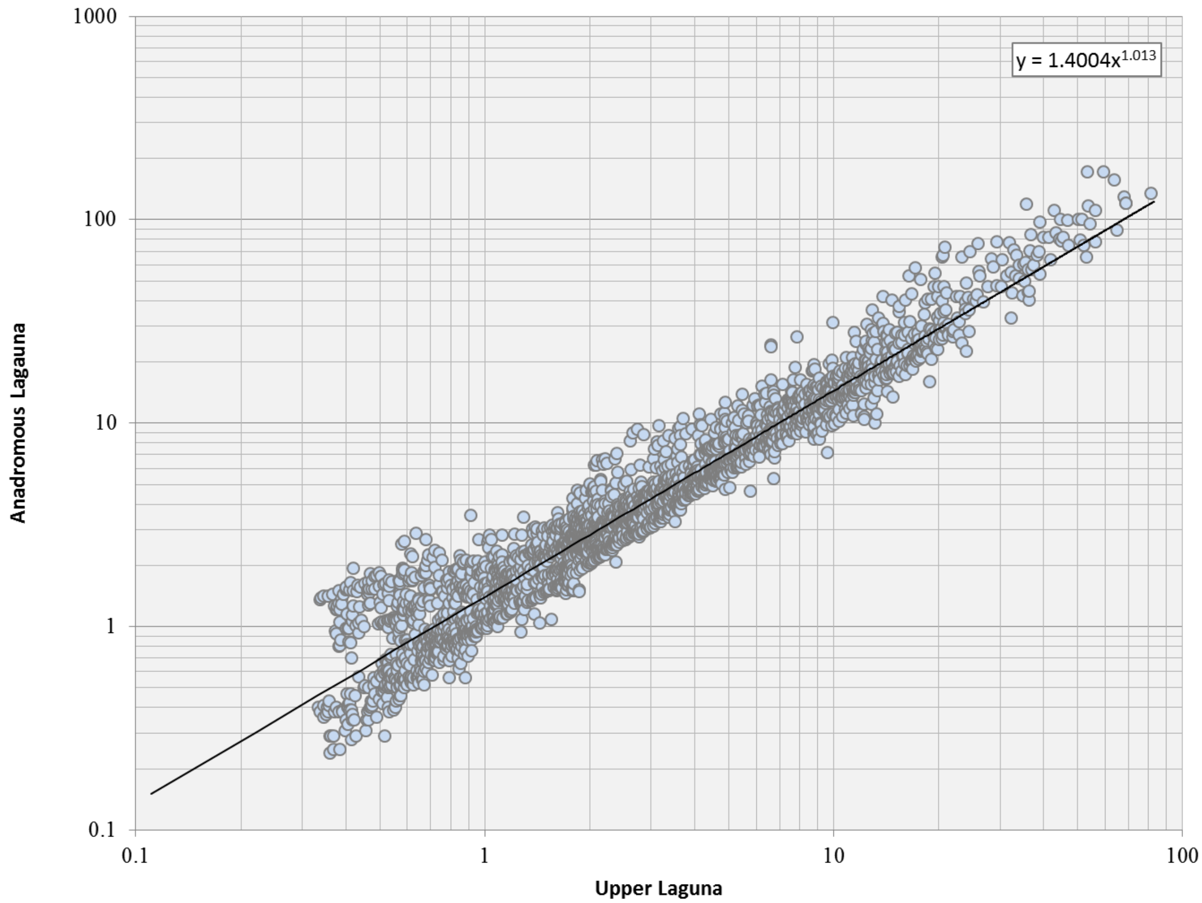



**Figure 5: Natural flow regression model for Upper Laguna to Anadromous Laguna.**

Street. These regression models were constructed from all available historical records of flow and diversion, and there application explicitly assumes that the character of the hydrologic relation from point of diversion to reach of anadromy does not change from the historical period to the projected period. The natural flow regression model for Laguna Creek is provided in Figure 5 as an example. It is worth noting that this is where some of the work completed last year to refine the low-flow regression models for the north coast streams comes to bear, particularly for Laguna Creek, as the projected record contains many more days of very low flow, many instances of which define the lower limit of hydrologic conditions. With this perspective it is better understood that that work was partially done in preparation for the CC model runs.

## Other Assumptions

A few more assumptions were made within the HCP Hydrology Model to best model the CC projected period. These assumptions include:

1. Felton production: Felton production was set to zero for all days in the projected period because no one knows what the Felton production may be in the future. In any event the impact of this assumption is small regardless as production at Felton represents a fraction of total water supply production.
2. Pre-existing legal bypass: a record of annual mean daily bypass was computed for the historical bypass data and used as the model conditions for the future.

No other assumptions were made to complete the HCP modeling component to the projected CC analysis. Model results for the City July 2012 and the DFG5 habitat flow rules proposals were transmitted to Gary Fiske for water supply analysis with Confluence.

DATE: April 17, 2015
TO: City of Santa Cruz WSAC
FR: David Mitchell
RE: Low and high interim demand forecasts

At its February meeting, the WSAC directed the Technical Team to develop low and high interim demands that bound the probable range of future treated water service demand through 2035. This memorandum describes the adjustments made to the interim demand forecast presented at the February WSAC meeting to produce the low and high forecasts.

Price and Income Adjustment Range

The Feb WSAC interim demand forecast used price and income elasticities to adjust the 2010 UWMP demand forecast for future price and income effects on demand. It was noted during the February WSAC meeting that there is uncertainty in the elasticity parameters and that the actual underlying values for the Santa Cruz region could be higher or lower than what was selected. To reflect this uncertainty we looked at the 95% statistical confidence intervals for price and income elasticities from recent studies of urban water demand by Western Policy Research (2014), Chesnutt (forthcoming), Mitchell, et al. (2013), and Mitchell (forthcoming). These intervals have an average range of +/- 20% from the estimated parameter. We used this average percentage range to adjust the price and income elasticities for the low and high demand forecasts as shown in Tables 1 and 2.

**Table 14. Price Elasticity Assumptions for Interim Low and High Demand Forecasts**

| Customer Category | Feb WSAC Value | Interim Low Demand<br>Elasticity is 20% larger in magnitude | Interim High Demand<br>Elasticity is 20% smaller in magnitude |
|---|---|---|---|
| Single Family Summer | -0.30 | -0.36 | -0.24 |
| Single Family Winter | -0.15 | -0.18 | -0.12 |
| | | | |
| Multi Family Summer | -0.15 | -0.18 | -0.12 |
| Multi Family Winter | -0.075 | -0.09 | -0.06 |
| | | | |
| Non Residential Summer | -0.10 | -0.12 | -0.08 |
| Non Residential Winter | -0.10 | -0.12 | -0.08 |

**Table 15. Income Elasticity Assumptions for Interim Low and High Demand Forecasts**

| Customer Category | Feb WSAC Value | Interim Low Demand<br>Elasticity is 20% smaller in magnitude | Interim High Demand<br>Elasticity is 20% larger in magnitude |
|---|---|---|---|
| Single Family | 0.25 | 0.20 | 0.30 |
| Multi Family | 0.05 | 0.04 | 0.06 |

Income adjustments in the Feb WSAC forecast were based on the forecast of per capita income growth prepared by Caltrans for Santa Cruz County. As part of this update, we compared historical rates of median household income growth reflected in decennial census data to the Caltrans forecasted rates of growth and found the Caltrans rates to be significantly higher. Partly this may be due to the coincidence of the 2010 Census with the Great Recession which had a significant impact on median household income. To account for the possibility of lower than forecast income growth, the low forecast assumes income growth of half the rate forecast by Caltrans. Thus the low forecast assumes both a lower income response and slower income growth than the high forecast.

Table 3 shows the combined price-income effect on demand for the Feb WSAC, low, and high interim forecasts.

**Table 16. Combined Price-Income Percentage Adjustment to Demand for Feb WSAC, Low, and High Interim Demand Forecasts**

| | Single Family | | | Multi Family | | | Non Residential | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Feb WSAC | Low | High | Feb WSAC | Low | High | Feb WSAC | Low | High |
| 2015 | -0.9% | -1.6% | -0.4% | -0.6% | -0.9% | -0.5% | -0.7% | -0.8% | -0.5% |
| 2020 | -7.1% | -11.5% | -4.2% | -4.5% | -6.0% | -4.2% | -4.5% | -5.4% | -3.6% |
| 2025 | -7.9% | -14.6% | -3.8% | -5.6% | -7.8% | -4.0% | -6.0% | -7.2% | -4.8% |
| 2030 | -9.4% | -18.3% | -4.0% | -7.0% | -9.8% | -4.9% | -7.6% | -9.1% | -6.1% |
| 2035 | -11.3% | -22.5% | -4.5% | -8.6% | -12.1% | -6.0% | -9.4% | -11.2% | -7.5% |

Personal Income vs. Wage and Salary Income in Forecast

The income adjustments for the low and high interim forecasts, like the Feb WSAC forecast, are based on projected rates of growth in real per capita income for Santa Cruz County, as forecast by Caltrans. At the February WSAC meeting it was suggested we consider using growth in real wage and salary earnings instead. We have not chosen to do this for three reasons. First, and most importantly, the income elasticities we are using are based on empirical studies that used real personal income, not wage and salary earnings, to measure the effect of changes in household income on water use. Given the elasticities we are using, the appropriate income measure is real personal income, not wage and salary earnings. Second, wage and salary earnings, while the dominant source of income for most households, is not the only source of income. Households also receive transfer payments from the government and pensions, and income from assets and property. For lower income and older households in particular, one or more of these latter sources may be the primary source of income. If the various income sources are growing at different rates, which is likely, using just one source – in this case wage and salary earnings – to measure the rate of change in overall household income will produce biased estimates. Third, the Caltrans wage and salary forecast is a forecast of wage and salary income per *worker*, not per *resident*. The distinction is important because not all who work in Santa Cruz County are residents and not all who live in Santa Cruz County also work there. Wage income for those working in Santa Cruz could very well be growing at a different rate than wage income for those who live in Santa Cruz. Since we are trying to forecast changes in resident household income, the wage and salary earnings per worker forecast would seem to be measuring the wrong thing for our purposes.

In-City Commercial Growth Range

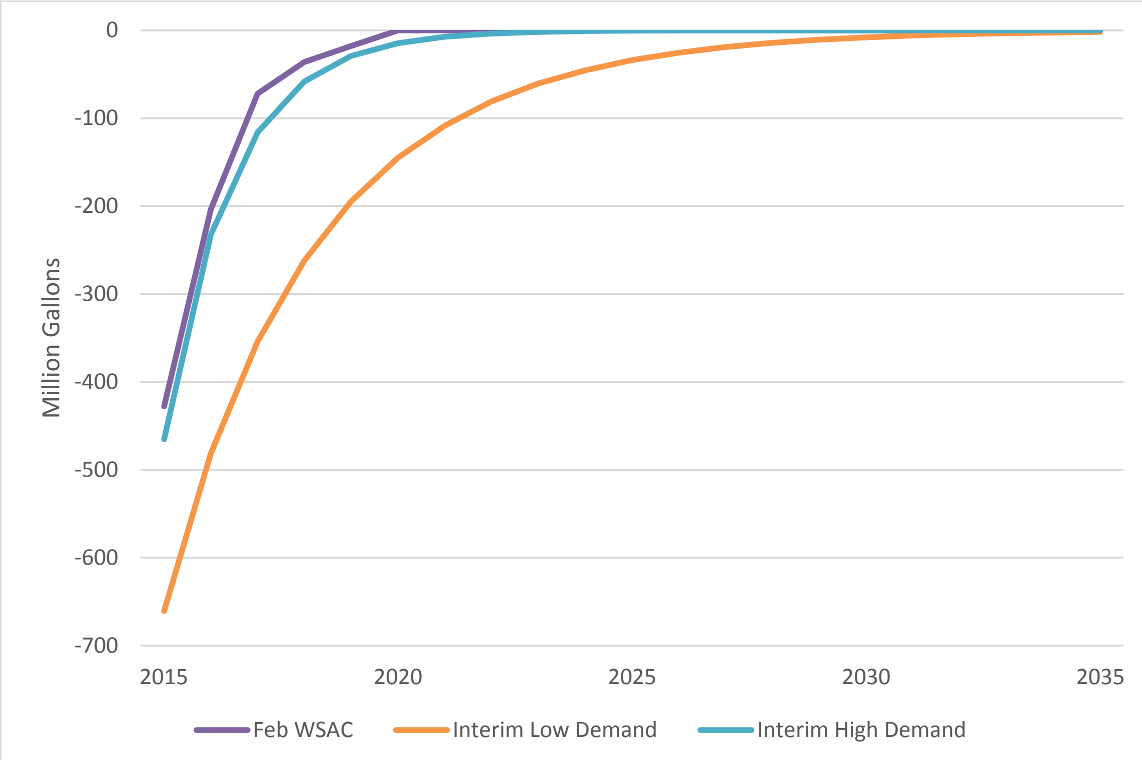
The Feb WSAC interim demand forecast reduced the 2010 UWMP's forecast of new growth in in-city commercial water use from 6 to 3 mg/yr/yr. For the low interim demand forecast we use the adjusted growth rate of 3 mg/yr/yr. For the high demand forecast we use the growth assumption from the UWMP of 6 mg/yr/yr.

Drought Recovery Range

In the Feb WSAC interim demand forecast we assumed demands would rebound from the current drought over a 3 to 5 year period. We assumed that non-residential demands would recover in 3 years while residential demands would recover in 5 years. For the high demand forecast we retain these assumptions. For the low demand forecast we assume recovery of demands other than for municipal irrigation and golf courses is more gradual. While the bulk of the adjustment occurs by 2020, demands don't fully recover until about 2030 in the low demand forecast. The drought adjustments under the Feb WSAC, low, and high interim demand forecasts are illustrated in Figure 1.[13]

[13] Note that there are small differences in the annual adjustments between the Feb WSAC and high interim forecasts because we changed the way the adjustments are modeled. In the Feb WSAC forecast the adjustments were modeled as annual discrete increments. In the low and high forecasts we use a continuous exponential decay process to represent the adjustment.

**Figure 43. Drought Recovery Adjustment to Demand for Feb WSAC, Low, and High Interim Demand Forecasts**




<u>Updated Plumbing Code and Program A Water Savings</u>

The estimated plumbing code and Program A water savings are scaled-down estimates produced by the DSS model seeded with the 2010 UWMP demand forecast. The estimates are scaled down to reflect lower base demands than the DSS model assumed because of the price/income and in-city growth adjustments we make. Because the magnitude of these adjustments in the low and high interim forecasts differ from the Feb WSAC interim forecast, the scaled down plumbing code and Program A savings also differ. The estimates of plumbing code and Program A savings used in the Feb WSAC, low, and high interim forecasts are shown in Table 4. It may seem counterintuitive that the adjustment is smaller in magnitude for the low than the high demand forecasts, but this occurs because under the high demand forecast base demands are higher and potential savings are greater.

**Table 17. Plumbing Code and Program A Savings Adjustments to Feb WSAC, Low, and High Interim**

| Year | Feb WSAC (Mil Gal) | Low Interim (Mil Gal) | High Interim (Mil Gal) |
|---|---|---|---|
| 2015 | -80 | -77 | -80 |
| 2020 | -191 | -185 | -194 |
| 2025 | -287 | -284 | -293 |

| | | | |
|---|---|---|---|
| 2030 | -348 | -346 | -356 |
| 2035 | -380 | -377 | -389 |

UCSC Demands

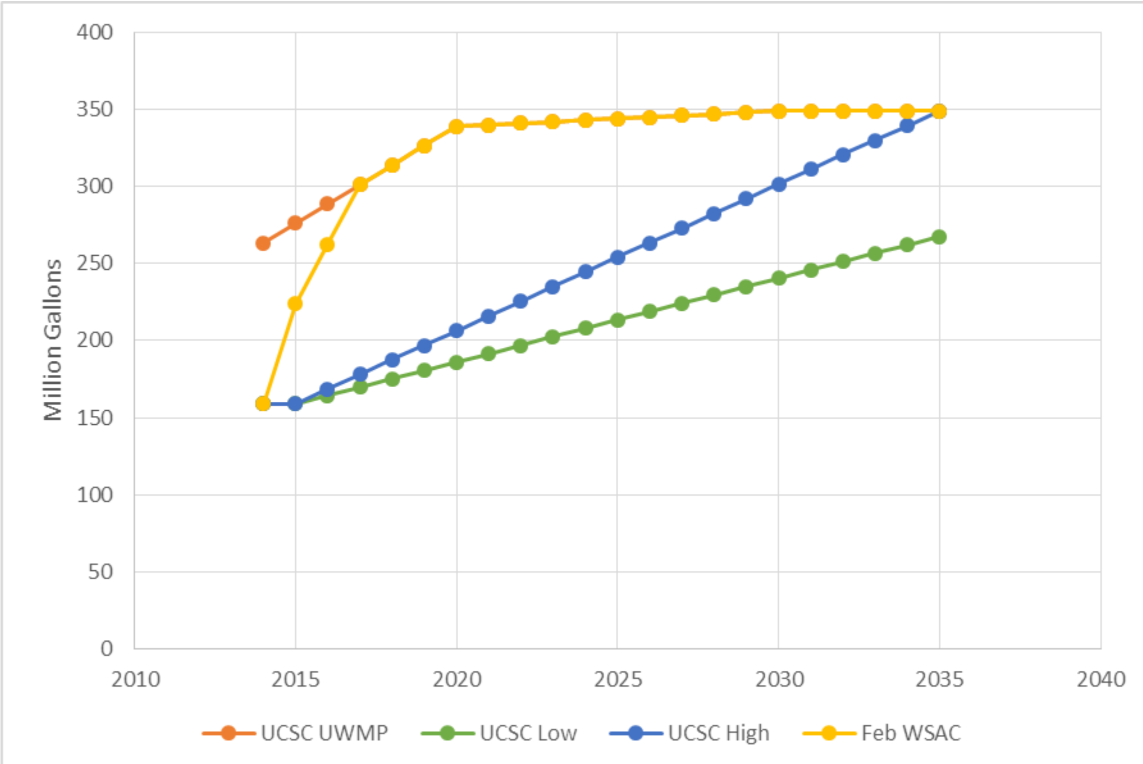
In its response to the City's information request on future demand growth, the University reconfirmed its build out forecast of 349 mgy, but acknowledged the pace of growth would be slower than assumed in the LRDP and in particular that it would not reach projected demand for 2020. The low and high interim demand forecasts each assume a build out demand of 349 mgy. The high demand forecast assumes build out by 2035. The low demand forecast assumes build out by 2050. Both forecasts assume demands in 2015 will be the same as 2014. Demand is linearly interpolated for the intervening years, as shown in Figure 2. Table 5 shows the Feb WSAC and low and high demand forecasts. The baseline interim forecast uses the midpoint between the new low and high UCSC interim forecasts.

The updated baseline interim demand forecast is very close to forecasting future University demand based on projected student enrollment and per capita water use rates. The enrollment-based approach yields a 2035 demand of 304 mgy compared to the updated baseline interim forecast of 308 mgy.

**Table 18. UCSC Feb WSAC, Low, and High Interim Demand Forecasts**

| Year | Feb WSAC Interim Demand (Mil Gal) | Low Interim Demand (Mil Gal) | High Interim Demand (Mil Gal) | Baseline Interim Demand (Mil Gal) |
|---|---|---|---|---|
| 2015 | 224 | 159 | 159 | 159 |
| 2020 | 339 | 186 | 207 | 196 |
| 2025 | 344 | 213 | 254 | 234 |
| 2030 | 349 | 240 | 302 | 271 |
| 2035 | 349 | 268 | 349 | 308 |

**Figure 44. UCSC Low, High, and Feb WSAC Interim Forecasts**



Summary of Feb WSAC, Low, and High Interim Demand Forecasts

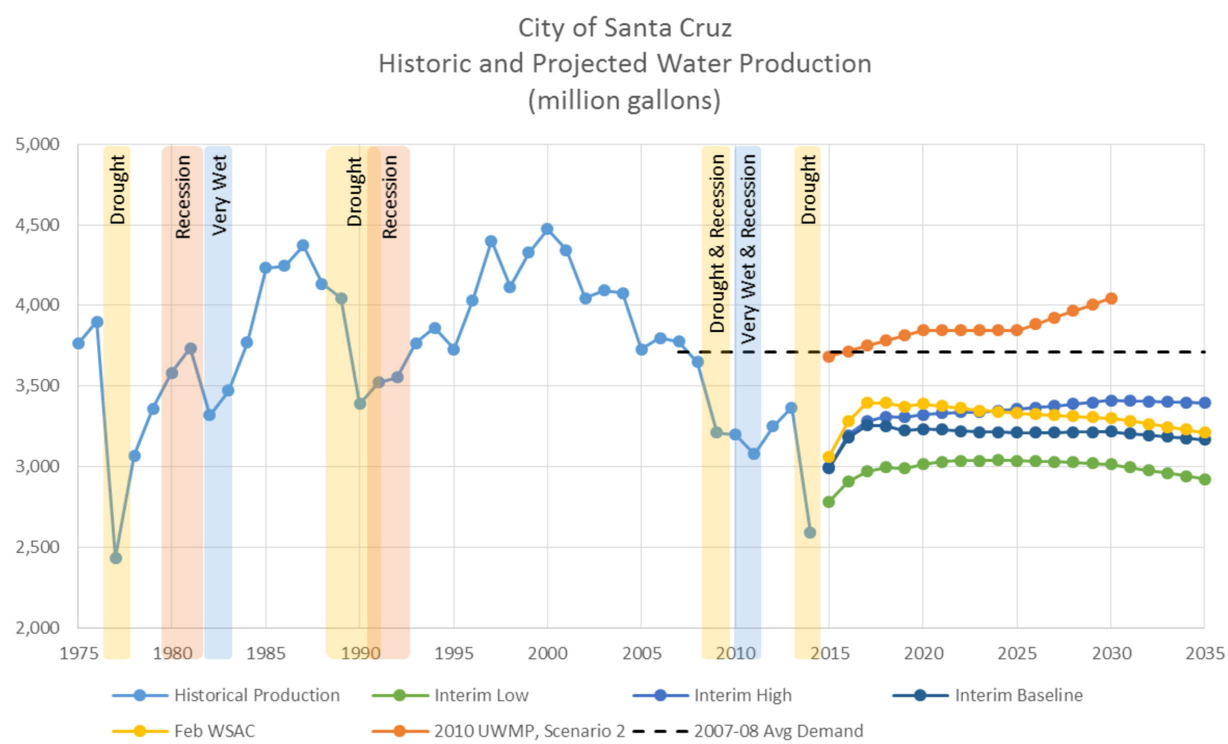
The Feb WSAC, low, high and baseline interim demand forecasts are summarized in Table 6 and Figure 3. In Table 6, demands are rounded to the nearest 100 million gallons.

**Table 19. Feb WSAC, Low, and High Interim Total Treated Water Service Demand Forecasts**

| Year | Feb WSAC Interim Demand (Mil Gal) | Low Interim Demand (Mil Gal) | High Interim Demand (Mil Gal) | Baseline Interim Demand (Mil Gal) |
|---|---|---|---|---|
| 2015 | 3100 | 2800 | 3000 | 3000 |
| 2020 | 3400 | 3000 | 3300 | 3200 |
| 2025 | 3300 | 3000 | 3400 | 3200 |
| 2030 | 3300 | 3000 | 3400 | 3200 |
| 2035 | 3200 | 2900 | 3400 | 3200 |

Rounded to nearest 100 million gallons.

**Figure 45. Interim Demand Forecasts**



Water Use Benchmarks

At the February WSAC meeting a request was made to benchmark the interim demand forecast against historical water use rates. In the figures below we present three water use benchmarks:

1. Gross Per Capita Water Use – total treated water production in gallons per day divided by service area population.

2. Residential Per Capita Water Use – total deliveries to single family and multifamily services in gallons per day divided by service area population less UCSC resident population.

3. Non-residential water use per job – total deliveries to non-residential services in gallons per day divided by the service area's pro-rated share of county employment based on population.

We make the following observations:

- Forecasted gross per capita water use ranges between 79 and 84 gallons for the low forecast and between 85 and 93 gallons for the high forecast. For the period 2004-2008 it averaged 116 gallons. For the period 2009-2013 it averaged 95 gallons.

- Forecasted residential per capita water use ranges between 47 and 54 gallons for the low forecast and between 55 and 60 gallons for the high forecast. For the period 2004-2008 it averaged 75 gallons. For the period 2009-2013 it averaged 62 gallons.

- Forecasted non-residential water use per job ranges between 78 and 85 gallons for the low forecast and between 81 and 95 gallons for the high forecast. For the period 2004-2008 it averaged 105 gallons. For the period 2009-2013 it averaged 91 gallons.

**Figure 46**

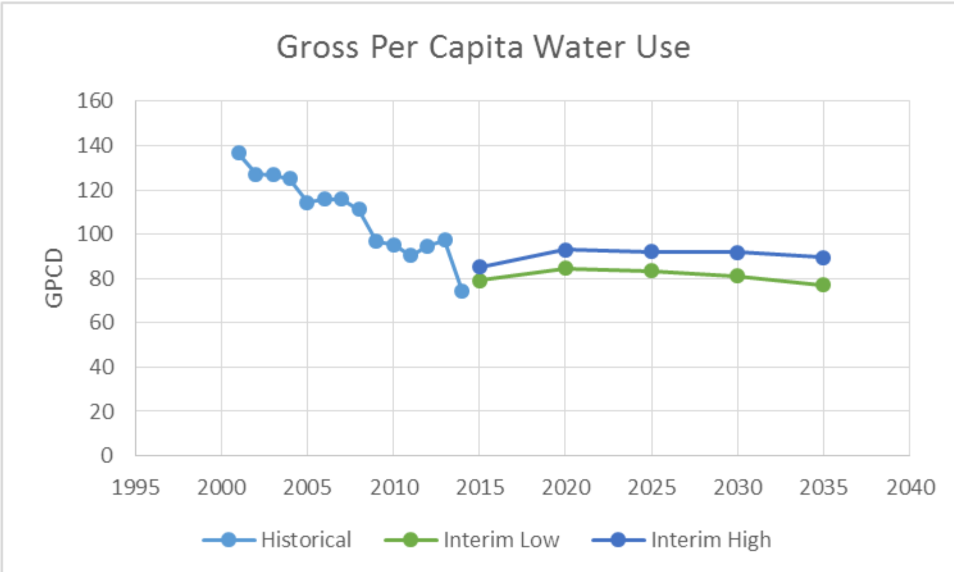



**Figure 47**

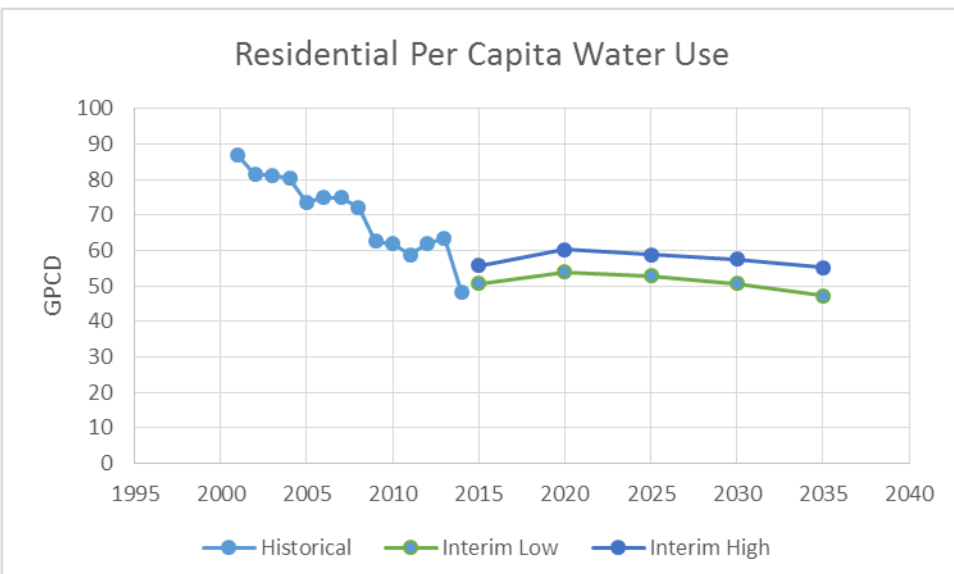
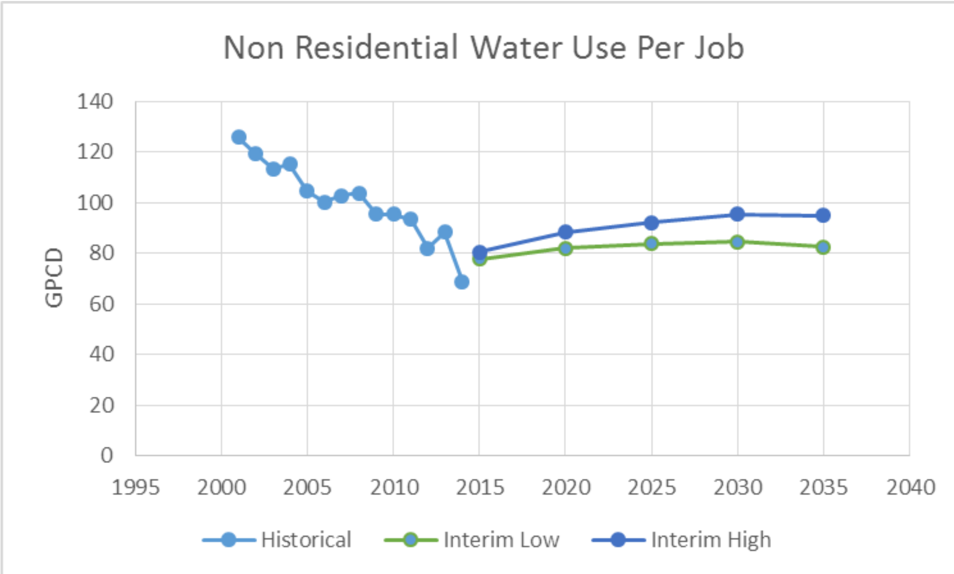


**Figure 48**



Non Residential Water Use Per Job
GPCD
140
120
100
80
60
40
20
0
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
Historical
Interim Low
Interim High

References

Chesnutt, T., Cal Water Long Term Water Demand Forecast Model, A&N Technical Services, (forthcoming).

Mitchell, D., Watson, A., and Cheong, W., Contra Costa Water District Future Water Supply Study Update: Demands Technical Memorandum, M.Cubed and RMC Water and Environment, November 2013.

Mitchell, D., California Water Service Company's 2017 Test Year District Sales Forecasts: 2015 General Rate Case, M.Cubed, (forthcoming).

Western Policy Research and Maddaus Water Management, Bay Area Water Supply & Conservation Agency Regional Water Demand and Conservation Projections, Final Report, September 2014.

GARY FISKE AND ASSOCIATES, INC.
*Water Resources Planning and Management*

**Date:** April 17, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Baseline System Reliability with Revised Interim Demand Forecasts

Using the revised high, medium, and low interim demand forecasts that David Mitchell developed based in part on the updated UCSC demand estimates, I analyzed baseline system performance for the 2020 forecast year assuming DFG-5 flows under historic conditions and climate change. This memorandum reports the results.

In order not to overwhelm the committee with too much redundant information, we decided to denominate the peak-season shortage duration curves as percentages rather than volumes. We felt this was more useful since it gives a feel for how much and how often customers would have to cut back. However, we also realize that there will be times when it is important to think about shortages as volumes. The following conversion table is intended to make it easier to move back and forth between the two. For the three alternative interim demand forecasts, the table shows the approximate peak-season volumes that correspond to different shortage percentages.[14]

Committee suggestions on how to better present the results are welcome.

**Table 20. Approximate Peak-Season Percentage/Volume Shortage Conversions: 2020 Demands**

| Peak-Season % Shortage | Peak-Season Volume Shortage (mg) | | |
|---|---|---|---|
| | Hi Dem | Mid Dem | Lo Dem |
| 5% | 100 | 100 | 90 |
| 10% | 200 | 190 | 180 |
| 15% | 290 | 290 | 270 |
| 20% | 390 | 380 | 360 |
| 25% | 490 | 480 | 440 |
| 40% | 780 | 760 | 710 |
| 50% | 980 | 950 | 890 |
| 60% | 1180 | 1150 | 1070 |

[14] This table would differ slightly with climate change since demands with climate change are slightly higher due to higher temperatures.

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**Historic Results**

We are still experimenting with different ways to express system reliability that will be most useful for committee members. Figure 49 shows the peak-season shortage duration curves for historic flow conditions. Note that the horizontal axis is expanded (i.e., it only shows the lower range of probabilities) to make the chart easier to read. Tables 2 and 3 summarize the information shown in these curves in two different ways. Table 21 shows the probabilities of exceeding designated shortages in any year. Table 22 shows the probabilities of each shortage event occurring at least once over the next 30 years. Thus, for example, under the high demand forecast, there is a 3% likelihood of a peak-season shortage greater than 25% in any year. Over the next 30 years, there is a 57% likelihood of experiencing at least one year with that size peak-season shortage.

***The technical team would be grateful for feedback from the committee on the value of these alternative approaches to presenting information on system reliability.***

**Figure 49. Peak-Season Shortage Duration Curves: Historic DFG-5 Flows, Forecast Year 2020**

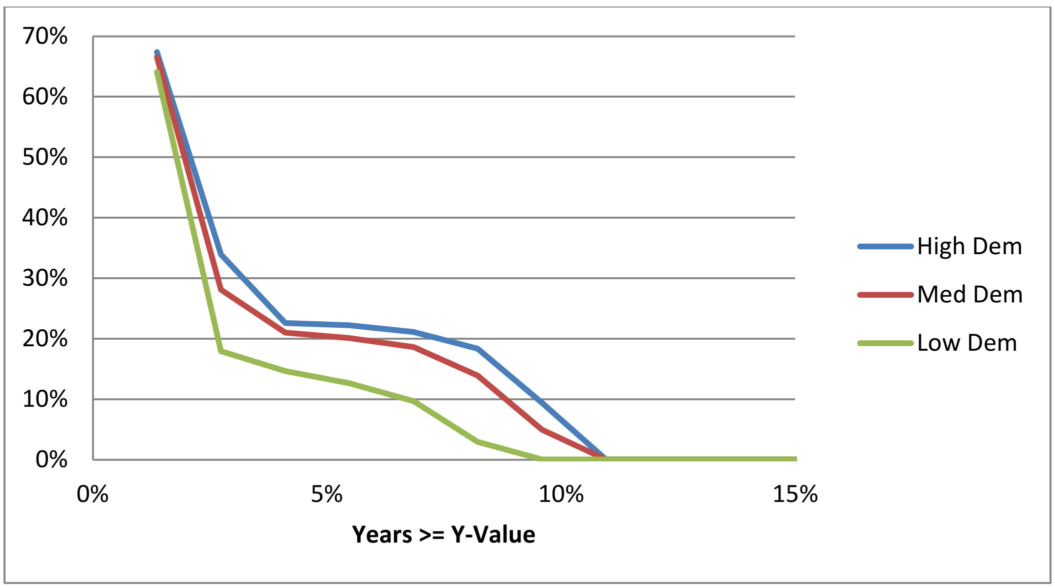


**Table 21. Probabilities of Peak-Season Shortage Events in Any Year: Historic DFG-5 Flows**

| Shortage Event | High Demand | Medium Demand | Low Demand |
|---|---|---|---|
| >50% | 1% | 1% | 1% |
| >25% | 3% | 3% | 1% |
| >15% | 8% | 7% | 3% |
| >5% | 10% | 8% | 7% |

**Table 22. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period: Historic DFG-5 Flows**

| Shortage Event | High Demand | Medium Demand | Low Demand |
|---|---|---|---|
| >50% | 34% | 34% | 34% |
| >25% | 57% | 57% | 34% |
| >15% | 92% | 88% | 57% |
| >5% | 95% | 92% | 88% |

### Climate Change Results

Following are the analogous results under our climate change scenario.

**Figure 50. Peak-Season Shortage Duration Curves: Climate Change DFG-5 Flows, Forecast Year 2020**

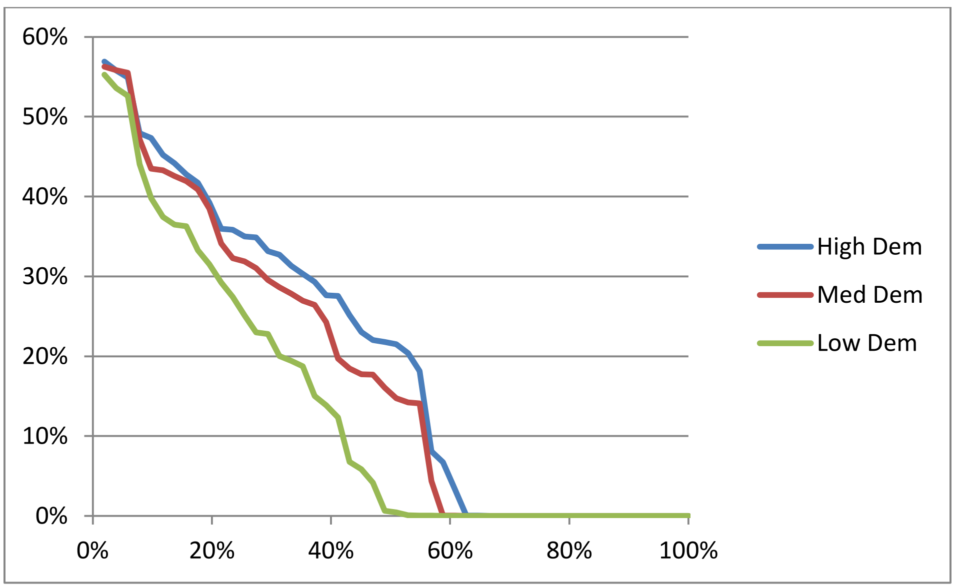


**Table 23. Probabilities of Peak-Season Shortage Events in Any Year: Climate Change DFG-5 Flows**

| Shortage Event | High Demand | Medium Demand | Low Demand |
|---|---|---|---|
| >50% | 6% | 6% | 6% |
| >25% | 43% | 37% | 25% |
| >15% | 55% | 49% | 37% |
| >5% | 59% | 55% | 45% |

**Table 24. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period: Climate Change DFG-5 Flows**

| Shortage Event | High Demand | Medium Demand | Low Demand |
|---|---|---|---|
| >50% | 84% | 84% | 84% |
| >25% | 100% | 100% | 100% |
| >15% | 100% | 100% | 100% |
| >5% | 100% | 100% | 100% |

**Key Conclusions**

- The reliability profiles assuming climate change are considerable worse than under historic flows. For example, with climate change, there is more than an 80% likelihood of experiencing a 50% peak-season shortage over the next 30 years. A 25% shortage sometime over that period is a virtual certainty.

- The reliability profiles for the three alternative demand projections are similar, with the gap between the low and mid-range forecasts larger than the gap between the mid-range and high forecasts. This reflects the relation between the 2020 demands themselves.

- Since the demand forecasts to 2035 are fairly flat, results for a future year other than 2020 would look similar to what is described in this memo.

GARY FISKE AND ASSOCIATES, INC.
*Water Resources Planning and Management*

**Date:** April 23, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Modeling Results: Ranney Collectors

This memo reports the results of the Confluence modeling of CA-19, Ranney Collectors. In CA-19, Ranney Collectors are installed near the Felton diversion. Water diverted from Felton through these collectors is then stored either in Loch Lomond or in another surface or groundwater storage facility (called a Virtual Reservoir or VR in this memo) for use in dry years when current supplies are insufficient to meet customer demands.

The supply impacts of this alternative differ from the winter flow harvesting alternatives in two ways:

- Diversions at Felton are no longer limited by any turbidity constraint.

- The VR is only filled from Felton. Diversions from Felton are limited by the Felton water right. Flows at Tait Street that are in excess of what is needed to serve demand are not available to charge the VR.

**Modeling Approach**

The Confluence system schematic for this alternative is shown in Figure 51. Note that, in contrast to the schematic for the winter flow harvesting alternatives shown in another memo, there is no transmission link between Tait Street and the VR. The only path for filling the VR is from Felton. While the Ranney collectors are not shown in this schematic, their presence is accounted for by removing the turbidity constraint at Felton.[15]

The altered modeling assumptions are the same as in the previous analysis, namely:

- Unlimited infrastructure capacity;
- Current water rights;
- 5 billion-gallon VR storage capacity; and
- 20% storage losses in the VR.

[15] Also note that diversions from Felton are constrained to go either to Loch Lomond or to the VR. There is no direct diversion from Felton to the treatment plant.

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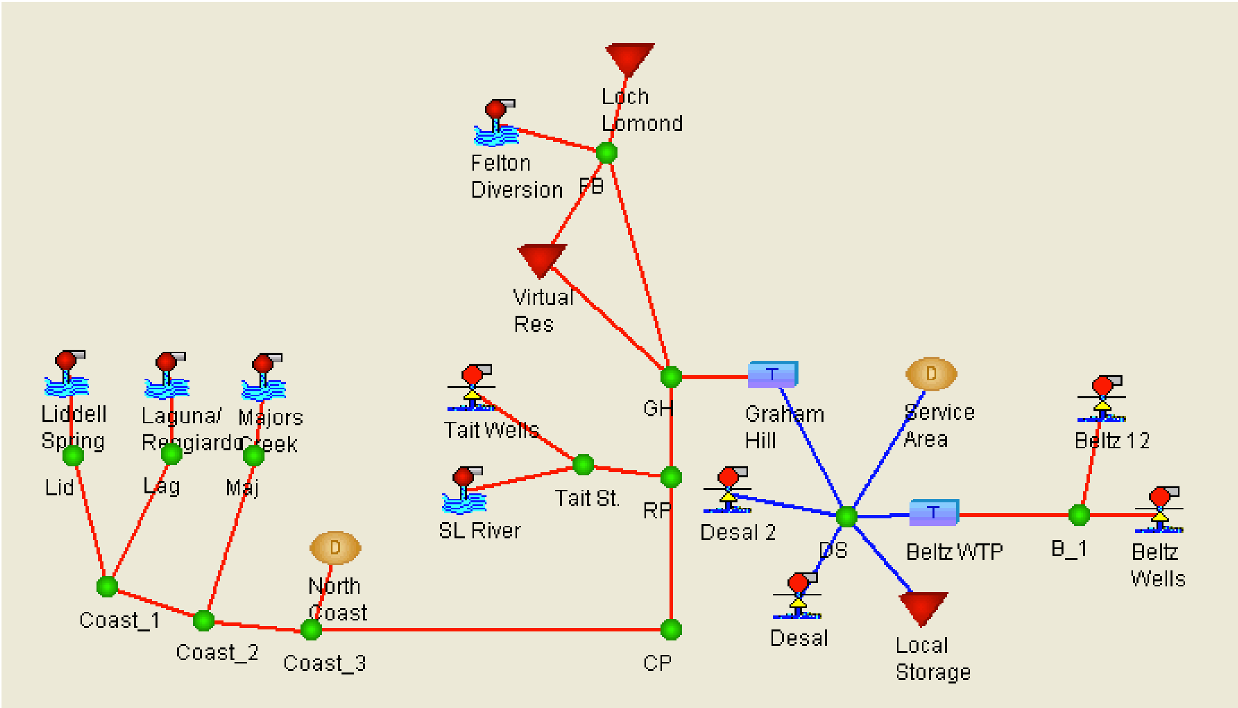
**Figure 51. Confluence System Schematic for CA-19**




**Impacts on System Reliability**

Figure 52 shows the peak-season shortage duration curves assuming DFG-5 flows with current supplies that we have seen before (see my March 9 memo). This is one depiction of the reliability "problem" that we want to solve with our alternatives and ultimately resource portfolios. Tables 1 and 2 summarize the information shown in these curves in two different ways. Table 25 shows the probabilities of exceeding designated shortages in any year. Table 26 shows the probabilities of each shortage exceedence event occurring at least once over the next 30 years. Thus, for example, with historic flows, there is a 10% likelihood of a peak-season shortage greater than 5% in any year. Over the next 30 years, there is a 95% likelihood of experiencing at least one year with that size peak-season shortage.

**Figure 52. Peak-Season Shortage Duration Curves with Current System: DFG-5 Flows**

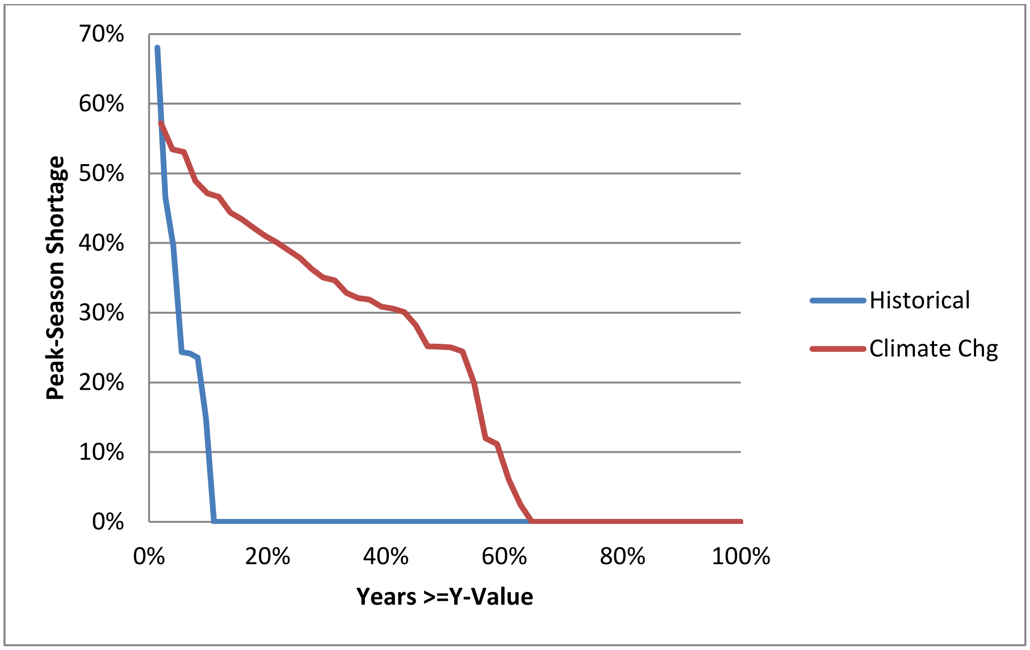



**Table 25. Probabilities of Peak-Season Shortage Events in Any Year**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 1% | 6% |
| >25% | 4% | 51% |
| >15% | 8% | 55% |
| >5% | 10% | 61% |

**Table 26. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 34% | 84% |
| >25% | 72% | 100% |
| >15% | 92% | 100% |
| >5% | 95% | 100% |

Figure 53 shows how these curves are improved through this supply alternative. With historic flows, this alternative's ability to divert and store excess Felton flows is sufficient to eliminate all shortages. However, with climate change, significant shortages remain.

Table 27 shows the probabilities of exceeding designated shortages in any year. Table 28 shows the probabilities of each shortage event occurring at least once over the next 30 years. Thus, for example, with climate change, there is a 2% likelihood of a peak-season shortage greater than 50% in any year.

Over the next 30 years, there is a 45% likelihood of experiencing at least one year with that size peak-season shortage.

**Figure 53. Peak-Season Shortage Duration Curves with Ranney Collectors & Virtual Storage: DFG-5 Flows**

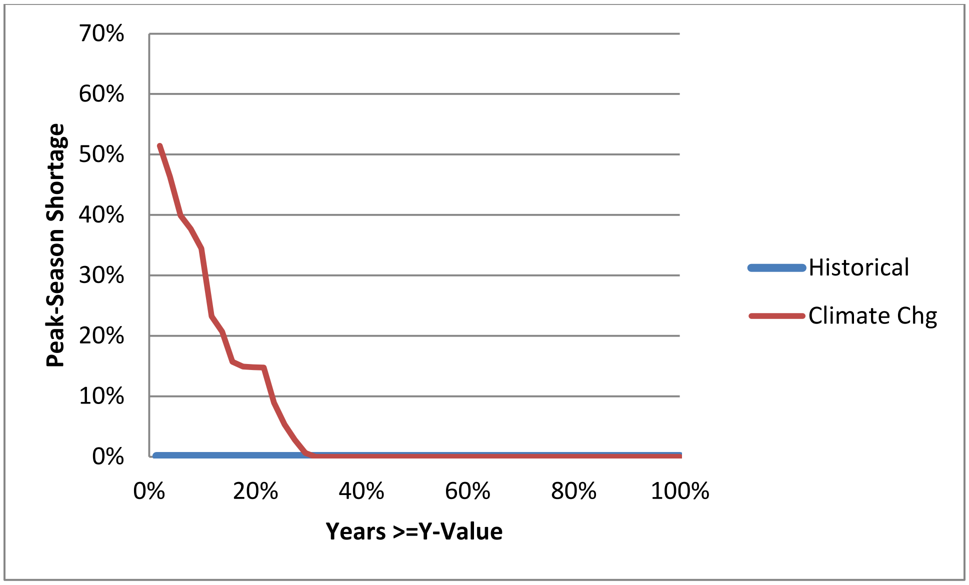



**Table 27. Probabilities of Peak-Season Shortage Events in Any Year: DFG-5 Flows**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 0% | 2% |
| >25% | 0% | 10% |
| >15% | 0% | 16% |
| >5% | 0% | 25% |

**Table 28. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period: DFG-5 Flows**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 0% | 45% |
| >25% | 0% | 95% |
| >15% | 0% | 99% |
| >5% | 0% | 100% |

The remainder of this memo explains these results.

**Source of Reliability Benefits**

This supply alternative includes two potential water supply enhancements to the current system:

- The Ranney collectors remove the turbidity constraint at Felton which is intended to allow diversions on more winter days.

- The VR allows diversions of excess flows at Felton to be banked for later use in dry years.

The reliability improvements in Figure 53 are due almost solely to the ability to divert and store water in the VR. The curves in both Figure 52 and Figure 53 look virtually the same with or without a turbidity constraint. To understand why, we must first understand the nature of the turbidity constraint. The constraints at all the diversion points are based on daily rainfall. On days when the rainfall exceeds a specified threshold the diversion is shut down for a designated number of days. We make the following observations:

- The number of turbidity days differs across hydrologic years. With historic rainfall patterns, the average annual number is around 40; the number ranges from about 10 to 90.

- The winters with more turbidity days tend to be the wetter years, which also tend to be the years when both Loch Lomond and the VR fill. Once these storage facilities are full, there can be no further diversion at Felton.

- Removing the turbidity constraint by installing Ranney Collectors at Felton does allow any added fill of Loch Lomond. This is because the turbidity constraint at Tait Street will still be in effect. Thus, on the days on which the Felton constraint is removed due to the Ranney Collectors, Tait Street will still be turned out, which means that Loch Lomond will have to be drawn down, which in turn means that water cannot be pumped to Loch Lomond because there is a single pipe into and out of Loch Lomond.[16]

- The fill benefit for the VR is also extremely limited due to several factors:
  - For historic flows, the VR fills in 80% of hydrologic years (see Figure 55), with or without a turbidity constraint.
  - With climate change, because of much lower rainfall, there are very few turbidity days. The average number across all hydro years is about 7, with almost 40% of hydrologic years having none. The maximum number of days is around 20. Moreover, the annual water right diversion limit of 3000 AF from Felton is reached in over 50% of hydro years with or without a turbidity constraint, and those few hydro years with a somewhat higher number of turbidity days tend to be among the years in which this maximum is reached.

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[16] Even if the turbidity constraint is also removed at Tait Street, while we do see some noticeable increases in Felton production and marginally-increased lake levels in some years, the benefits to system reliability are still very small.

While one can quibble with the details of the various modeling assumptions, the key point is that improving the city's ability to use turbid water, whether with Ranney Collectors or enhanced treatment, is not an effective approach to dealing with future water shortages in Santa Cruz.

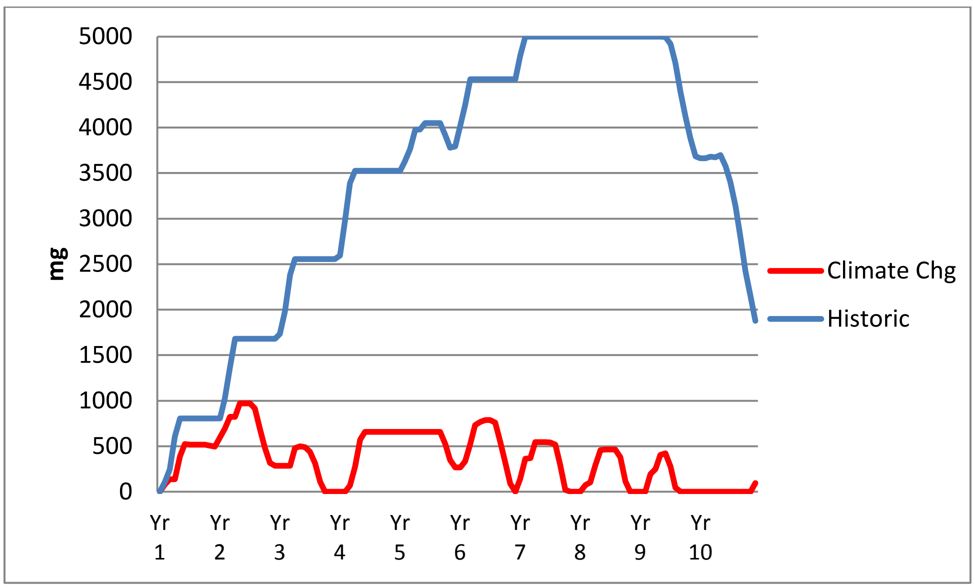
**Virtual Reservoir Fill and Drawdown**

Figure 54 shows the VR fill and drawdown in the 10 years leading up to the worst drought events in the historic and climate change records.[17] In each case, the VR starts at zero.

The differences are large. With historic flows, the VR fills by year 7 of the sequence. With climate change, the excess flows cannot bring the VR level above 1 billion gallons.

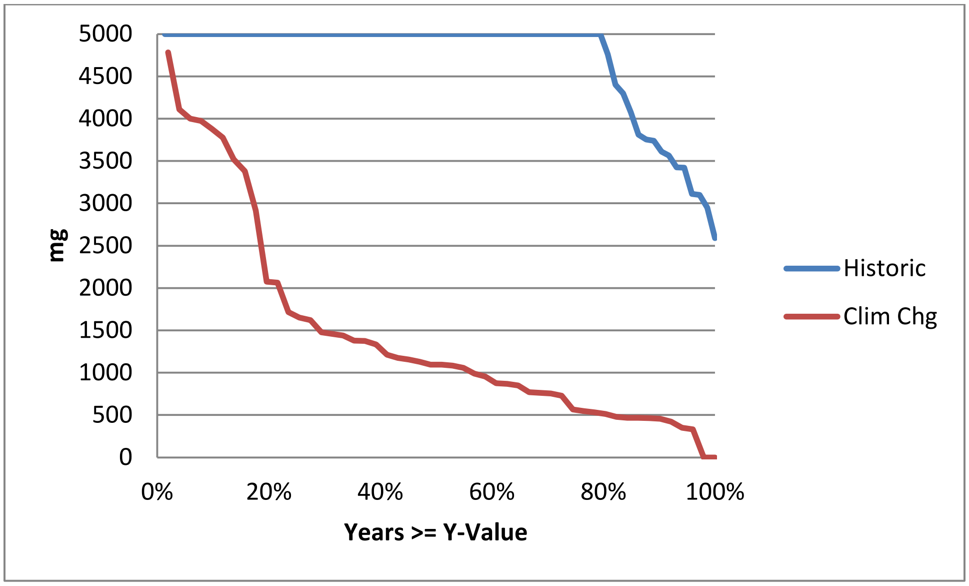
Figure 55 compares duration curves of the end-of-April VR levels. Whereas the VR fills under 80% of hydrologic conditions with historic flows, it never fills with climate change.

**Figure 54. Virtual Reservoir Fill and Drawdown in 10 Years Leading to Worst Drought Year**




[17] Year 10 is the end of the worst drought sequence. For the historic record, the 10-year period shown is 1968-77.

**Figure 55. Duration Curves of End-of-April Virtual Reservoir Contents**




**Increased Diversion from Felton**

Figure 56 compares the average annual incremental production at Felton to charge the VR over a 10 year period beginning with an empty VR. The initial year diversions are high as the VR fills. Then they settle into a steady state of between 150 and 200 mgy with historic flows and 400 mgy with climate change.

Figure 57 shows the duration curves of the steady state incremental Felton annual production with and without climate change. The maximum added diversions are between 800 and 900 mg. But as expected, there are many more hydrologic years with significant added diversions with climate change.[18]

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[18] The few negative results in this chart are years in which both the VR and Loch Lomond are quite full and little VR drawdown is needed, which leads to low diversions from Felton.

**Figure 56. Incremental Felton Diversions in First 10 Years of VR Fill: Historic Flows**

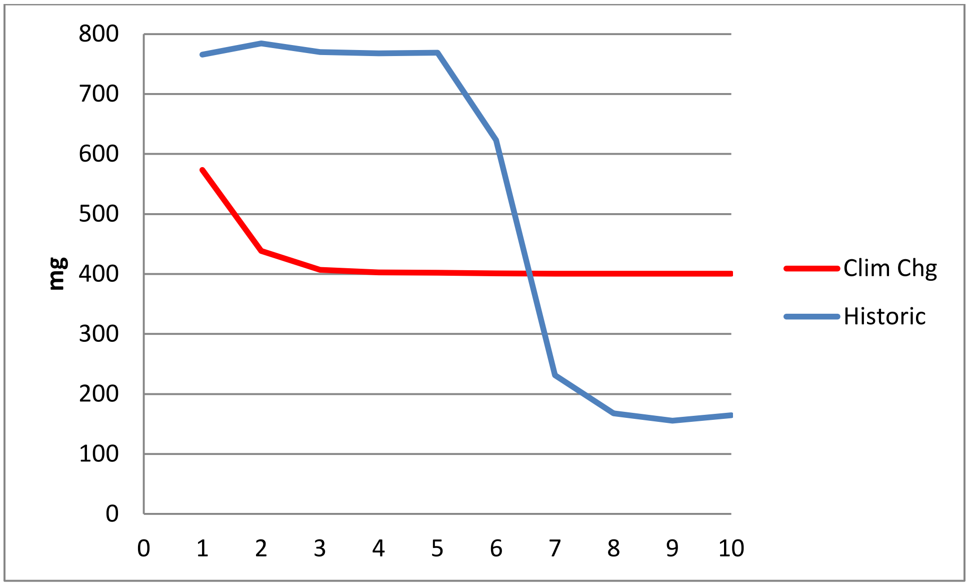
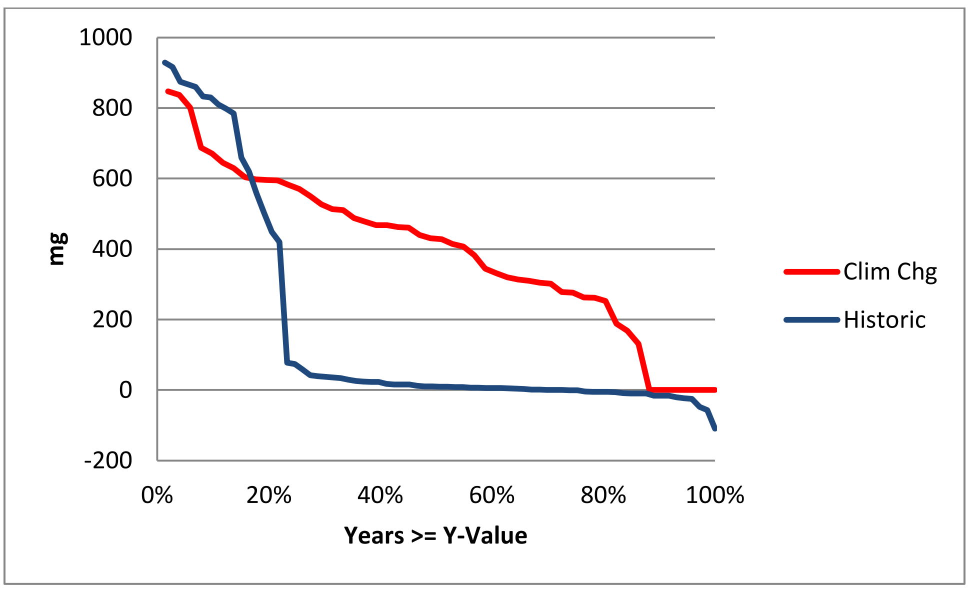



**Figure 57. Felton Annual Incremental Production Duration Curves**




## Project Yield

The difference between the highest points in Figure 52 and Figure 53 tells us the worst-year yield of this alternative, i.e., how well this alternative does in reducing the worst-year peak-season shortage. Expressed volumetrically, this difference is about 1360 mg with historic flows, but only 116 mg with climate change. Since we are relying only on diversions of excess flows at Felton, it is very difficult to keep water in the VR through an extended very dry period. Thus, this alternative does not contribute much to reducing shortages in the final year of such a sequence. The climate change record includes such an event; this accounts for the small worst-year benefit of this alternative with climate change.

Across all hydrologic conditions, the average reduction in peak-season shortage is about 60 mg with historic flows and 290 mg with climate change.

These benefits accrue for two reasons:

- The production (less losses) of the VR itself plus
- The change in production of Loch Lomond (which in many hydrologic years is negative)[19]

The second point is important. In dry years, the benefit of these alternatives derive not only from the VR itself but also from added production from Loch Lomond. In those years, Loch Lomond begins at higher elevations because use of the VR in previous years allowed the lake to "rest".

**Needed Infrastructure Capacities**

One of the pieces of information that we can draw from these runs is a sense of how much capacity is needed for some of the critical required infrastructure. Following are brief discussions of these.

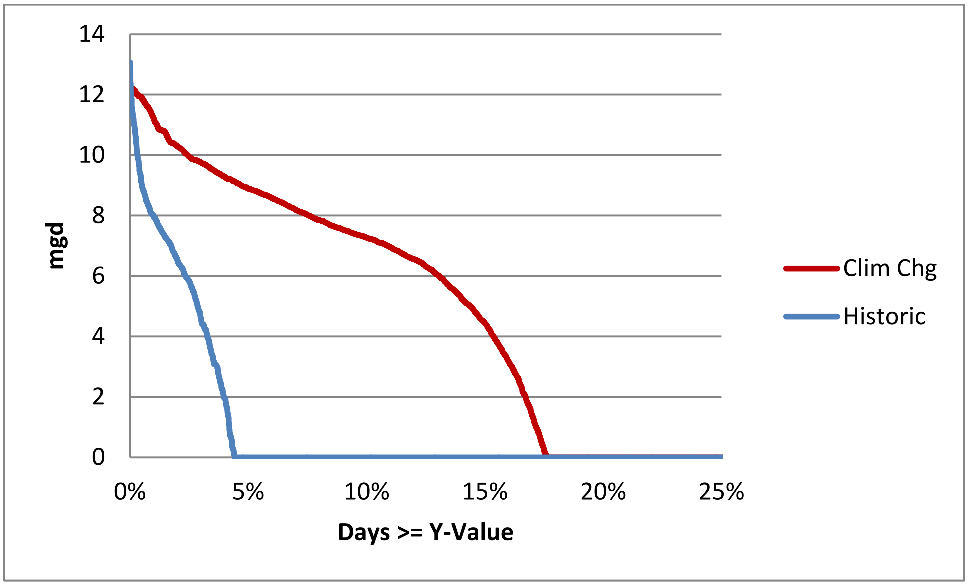
Diversions. The daily diversions at Felton and Tait Street are limited by the maximum water rights, 20 cfs at Felton and 12.2 cfs at Tait. Both of these are larger than the current capacities.

Virtual Reservoir Capacity. For this exercise, we assumed a 5 bg storage capacity. However, as illustrated in Figures 3 and 4, with historic flows the maximum drawdown is just over 3 bg. With climate change, it is only about 1 bg, reflecting the inability to divert sufficient flows at Felton to effectively charge the VR. These figures provide preliminary estimates of the required storage capacity with DFG-5 instream flow requirements.

Virtual Reservoir Production. Figure 58 compares portions of the daily production duration curves for the VR. The maximum daily production is between 12 and 13 mgd. This provides an estimate of the required delivery capacity of the VR itself and the transmission between the VR and the treatment plant.

[19] The total also includes a slight increase in Tait Street production sent to GHWTP because of the assumed unlimited diversion capacity.

**Figure 58. Daily Production Duration Curves of Virtual Reservoir**




**Conclusion**

There are two important conclusions that can be drawn on the supply benefits of this alternative:

- With current water rights and with historic flows modified to conform to DFG-5 flow rules, there are sufficient excess flows at Felton to charge a virtual reservoir so as to eliminate all supply shortages. This is decidedly not the case with climate change, where we still see significant remaining unserved demand.
- Eliminating turbidity constraints at either or both San Lorenzo River diversions does not significantly improve system reliability.

**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** April 23, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Modeling Results: Harvesting Winter Flows

This memo reports the results of the Confluence modeling of the Consolidated Alternatives (CAs) that are based on harvesting and storing excess winter San Lorenzo River flows, specifically:

- CA-9: Winter Flows Capture
- CA-16: Aquifer Restoration/Storage
- CA-18: Off-Stream Water Storage

These three alternatives all divert winter flows that are surplus to fish requirements, current customer demands, and storage in Loch Lomond to another surface or groundwater storage facility (called a Virtual Reservoir or VR in this memo) for use in dry years when current supplies are insufficient to meet customer demands.

**Objectives**

The ultimate objective of this modeling is to estimate how well any of the winter flow harvesting CAs deals with projected system shortages. In order to better understand those reliability impacts, we must also look at these key operating parameters:

1. Fill and drawdown of the VR
2. Increased diversions at Felton and Tait to fill the VR
3. VR production to meet demand

All of these will be discussed below.

**Modeling Approach**

To the current supply sources I added the VR, which can be filled with excess flows either at Felton or Tait Street. On any day, the VR will fill only after available flows have been used either to meet demands (Tait Street) or to fill Loch Lomond (Felton). The VR is drawn on in conjunction with Loch Lomond to meet demands on any day that cannot be met by the North Coast and Tait Street diversions to GHWTP. The revised Confluence system schematic is shown in Figure 51.

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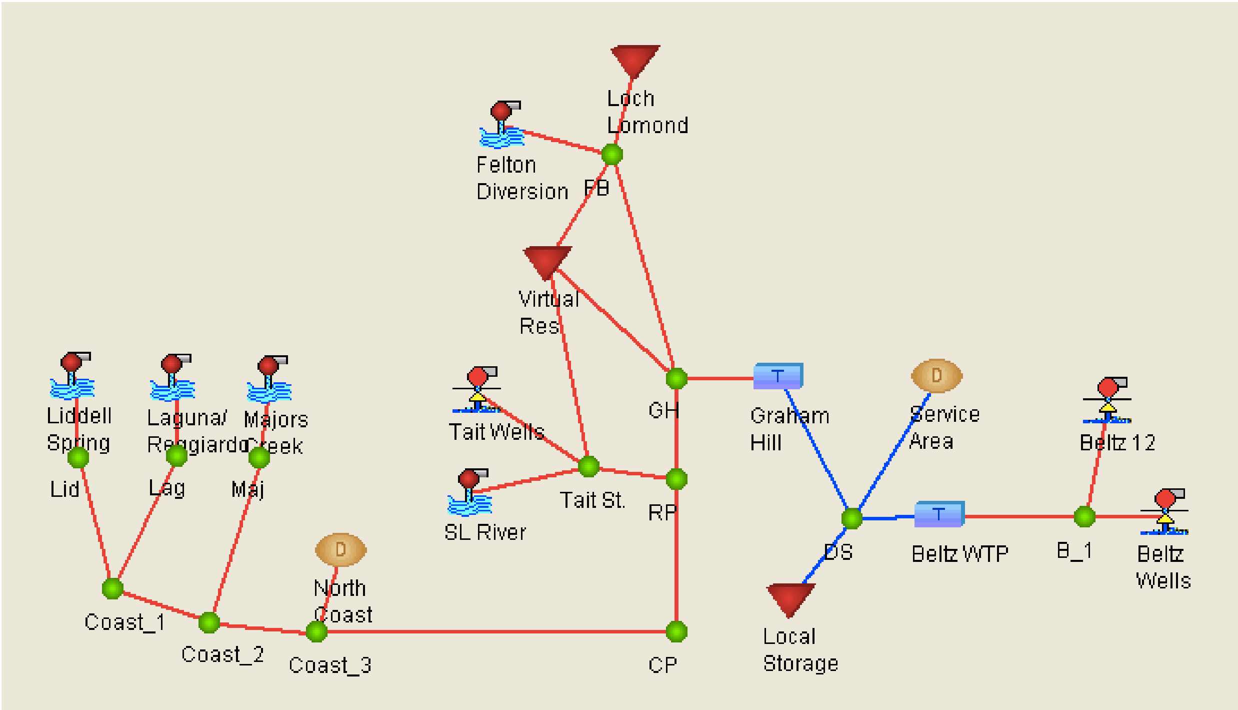
**Figure 59. Confluence System Schematic with Virtual Reservoir**




## Key Assumptions

I analyzed this group of alternatives under two DFG-5 flow scenarios, one based on historic hydrology and one based on the climate change scenario we have so far focused on. For each of these distributions of available flows, I made the following key modeling assumptions:

- Unlimited infrastructure capacity. The objective in this analysis is to assess the potential to harvest winter flows, without regard to current infrastructure capacity limitations. Thus, the modeling assumes unlimited capacity as follows:[20]
  - Diversion capacity at Felton and Tait Street; and
  - Transmission capacity between Felton and the VR, between Tait and the VR, and between the VR and Graham Hill;
- Current water rights. While not limited by infrastructure, diversions at Felton and Tait Street are limited by current water rights. At Felton, this water right limits daily diversions to 20 cfs in all months other than September (in September the right is 7.8 cfs). There is also an annual diversion limitation at Felton of 3,000 AF (978 mg). At Tait, the diversion right is 12.2 cfs year-round with no annual limit.

[20] The modeling enables us to get rough estimates of how much capacity is needed. This will be discussed below.

- Storage capacity. Based on discussions with Bill Faisst, I assumed a maximum virtual reservoir storage capacity of 5 billion gallons. This draws on preliminary work done by Pueblo.

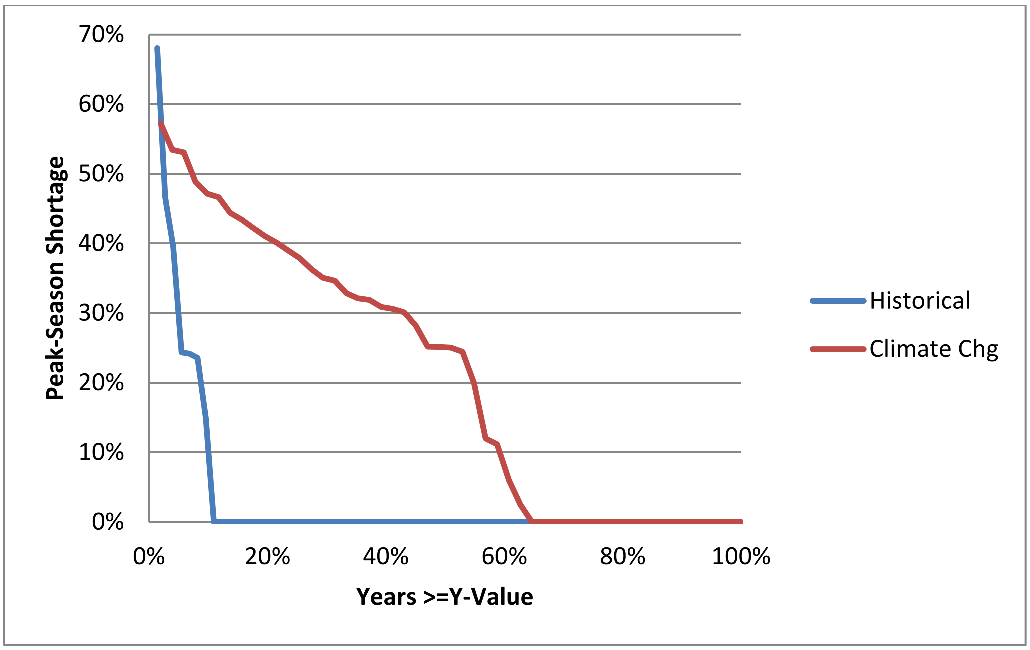
- Storage losses. At Bill's suggestion, I assume that 80% of stored water is recoverable. That is, for each 100 gallons stored, the City can withdraw 80 gallons.

Beyond these, I retained all other current modeling assumptions regarding operation of the current sources (e.g., turbidity constraints, flush flows, etc.)

**The Bottom Line: Impacts on System Reliability**

Figure 52 shows the peak-season shortage duration curves assuming DFG-5 flows with current supplies that we have seen before (see my March 9 memo). This is one depiction of the reliability "problem" that we want to solve with these CAs.

**Figure 60. Peak-Season Shortage Duration Curves with Base Supplies: DFG-5 Flows**




The modeling results lead to the following conclusion:

> ***If the City had a way to store winter flows as described above and developed the necessary infrastructure to store and to withdraw water as needed, these shortages go to zero. That is, all demands can be served, even in the driest years with DFG-5 flows and even assuming climate change.***[21]

The remainder of this memo helps understand why this is the case.

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[21] This conclusion holds after the VR reaches a "steady state", i.e., once a sufficient number of years have passed to fill the empty VR. As will be illustrated below, even with the reduced flows of climate change, this does not require many years.

**Virtual Reservoir Fill and Drawdown**

Figure 54 shows the VR fill and drawdown in the 5 years leading up to the worst drought events in the historic and climate change records.[22] In each case, the VR starts at zero. There is somewhat more fill with historic flows, but in neither case does the VR fill completely before being drawn down. However, there is sufficient fill to ensure that the VR is not completely drawn down before the drought event ends; it is therefore able to meet demands throughout the sequence.

**Figure 61. Virtual Reservoir Fill and Drawdown with 5 Years Fill Before Worst Drought Event**

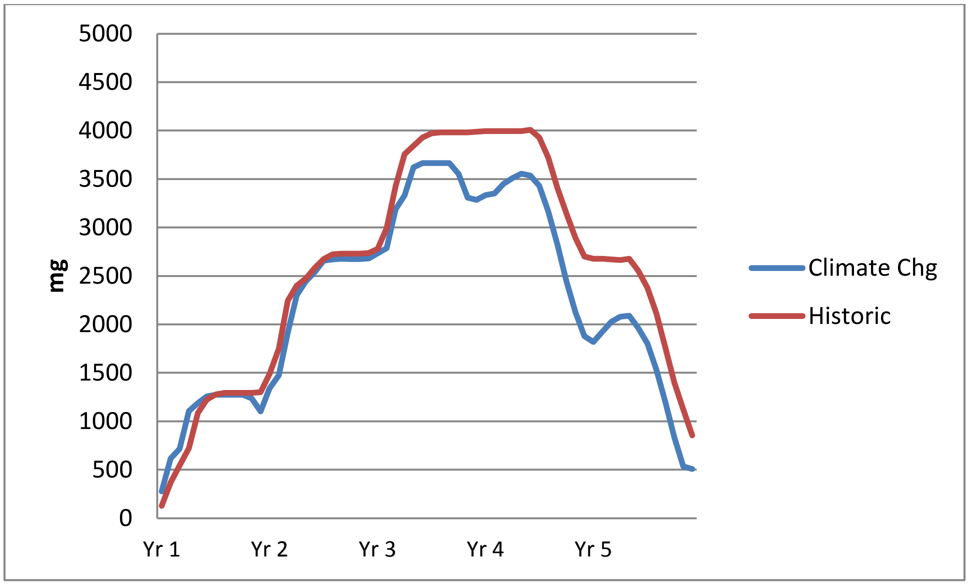


Figure 62 shows the same comparison of VR levels, assuming that there is 10 years before the worst drought year. In both cases, the VR fills.

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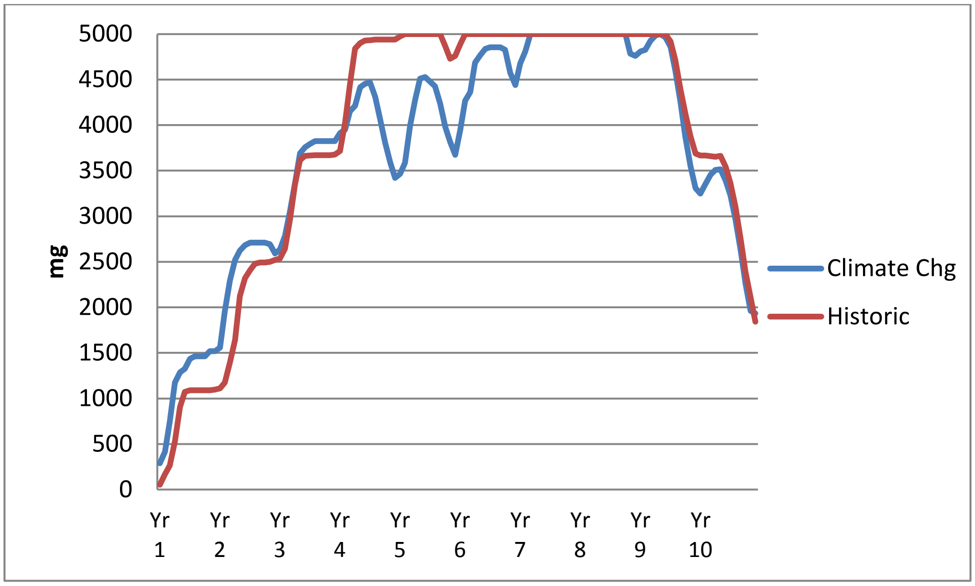
[22] Year 5 is the end of the worst drought sequence. For the historic record, the 5-year period shown is 1973-77.

**Figure 62. Virtual Reservoir Fill and Drawdown with 10 Years Fill Before Worst Drought Event**




**Increased Diversion from San Lorenzo River**

The next question is how much additional water is diverted at the two diversion points to charge the VR and refill it when it is drawn down.

Figure 56 shows, with historic flows, the average annual incremental production at the two diversion points over a 10 year period beginning with an empty VR.[23] The initial year diversions are high as the VR fills. Then they settle into a steady state of about 250 mgy.

shows similar curves assuming climate change. The steady state annual average diversion is around 700 mgy. Despite the fact that river flows are lower with climate change, the average river diversions are considerably higher. This is because the system requires much more frequent VR drawdown which in turn requires more refill.

Figure 57 shows the duration curves of the steady state incremental combined Felton and Tait Street annual production with and without climate change. In each case, the maximum added diversion is about 1500 mg. But as expected, there are many more hydrologic years with significant added diversions with climate change.

[23] Note that the diversions at Tait draw not only on the mainstem flows after diversion at Felton, but also on tributary inflows between the two diversion points.

**Figure 63. Incremental River Diversions in First 10 Years of VR Fill: Historic Flows**

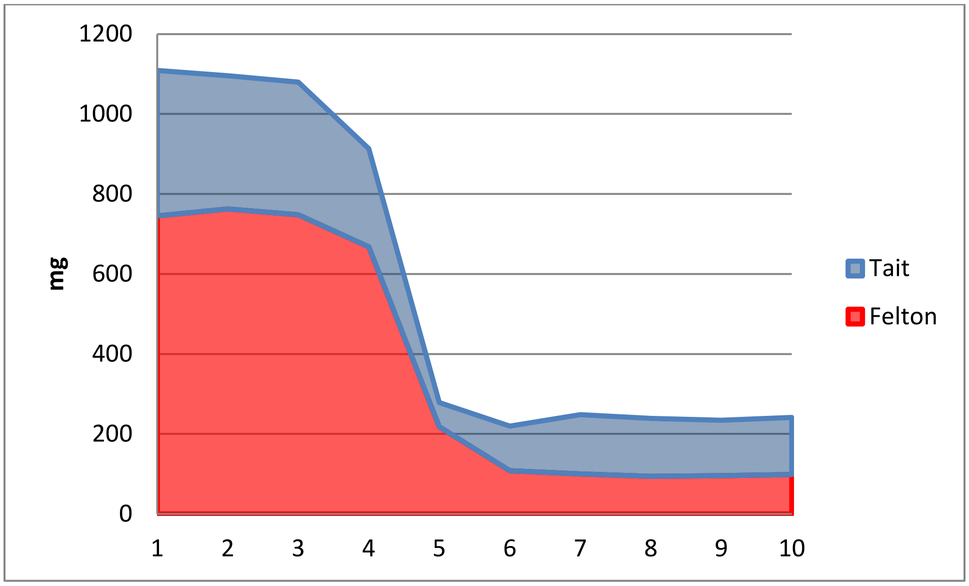



**Figure 64. Incremental River Diversions in First 10 Years of VR Fill: Climate Change**

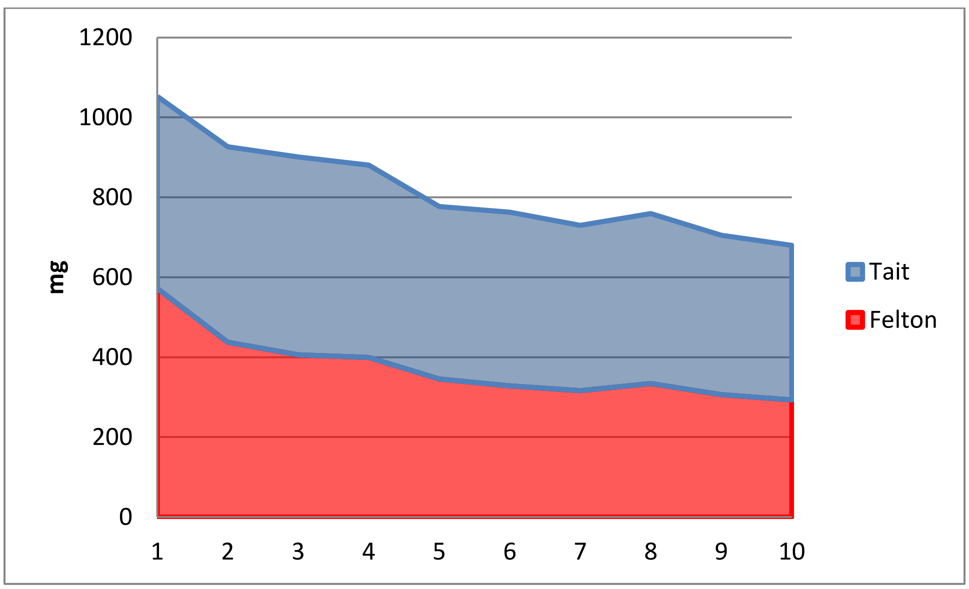
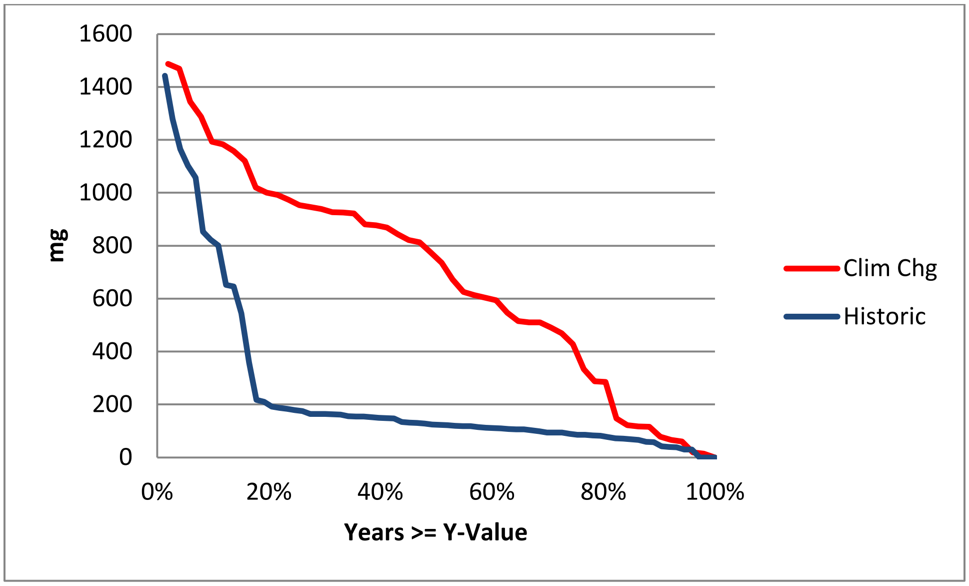


**Figure 65. San Lorenzo River Annual Incremental Production Duration Curves**




**Project Yield**

Since this alternative reduces shortages to zero, the worst-year yields of this alternative, i.e., how good a job this alternative does in reducing the worst-year peak-season shortages, are simply the highest points in the curves of Figure 52. Volumetrically, this is about 1360 mg with historic flows, and 1150 mg with climate change. Across all hydrologic conditions, the average reduction in peak-season shortage is about 60 mg with historic flows and 420 mg with climate change.

These benefits accrue for two reasons:

- The production (less losses) of the VR itself plus
- The change in production of Loch Lomond (which in many hydrologic years is negative)[24]

The second point is important. In dry years, the benefit of these alternatives derive not only from the VR itself but also from added production from Loch Lomond. In those years, Loch Lomond begins at higher elevations because use of the VR in previous years allowed the lake to “rest”.

**Needed Infrastructure Capacities**

One of the pieces of information that we can draw from these runs is a sense of how much capacity is needed for some of the critical required infrastructure. Following are brief discussions of these.

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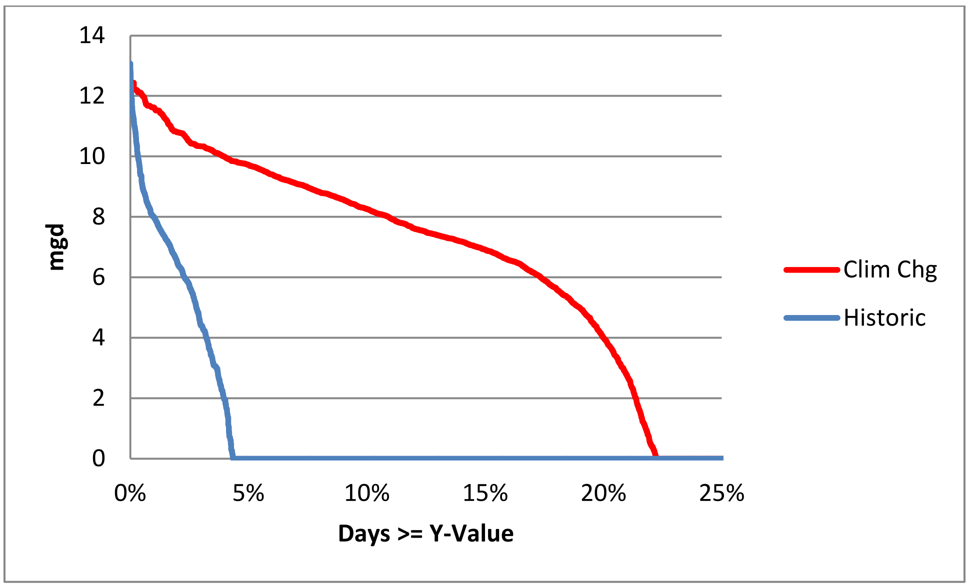
[24] The total also includes a slight increase in Tait Street production sent to GHWTP because of the assumed unlimited diversion capacity.

Diversions. The daily diversions at Felton and Tait Street are limited by the maximum water rights, 20 cfs at Felton and 12.2 cfs at Tait. Both of these are larger than the current capacities.

Virtual Reservoir Capacity. For this exercise, we assumed a 5 bg storage capacity. However, as illustrated in Figures 3 and 4, the drawdown in the worst year is just over 3 bg with both historic flows and climate change. That provides a preliminary estimate of the required storage capacity with DFG-5 instream flow requirements.

Virtual Reservoir Production. Figure 66 compares portions of the daily production duration curves for the VR. The maximum daily production with and without climate change is around 13 mgd. This provides an estimate the required delivery capacity of the VR itself and the transmission between the VR and the treatment plant.

**Figure 66. Daily Production Duration Curves of Virtual Reservoir**




**Conclusion**

The key outcome of this analysis is that the harvesting and storage of winter flows has the potential to completely address the City's water supply challenges and enable the City to meet projected future demands. This is the case even with current water rights, DFG-5 instream flows, and climate change. To achieve these benefits, the "virtual reservoir" used in the analysis would have to become real, i.e. suitable infrastructure improvements and institutional arrangements would have to be made to have a place to reliably store at least 3 billion gallons of water. In addition, the capacities of various current infrastructure would have to be increased.

**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** April 23, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Modeling Results: CRec Conservation Programs

This memo reports the results of the Confluence modeling of CA-03, CRec. CA-03 is a collection of conservation programs that reduce demand. The assumed annual savings of this alternative is assumed to be 188 mg, with 129 mg of that in the peak-season and the remaining 59 mg in the off-peak season.

The January interim demand forecast was modified to reflect the above seasonal savings. All other modeling assumptions were unchanged.[25]

**Impacts on System Reliability**

Figure 52 shows the peak-season shortage duration curves assuming DFG-5 flows with current supplies that we have seen before (see my March 9 memo). This is one depiction of the reliability "problem" that we want to solve with our alternatives and ultimately resource portfolios. Tables 1 and 2 summarize the information shown in these curves in two different ways. Table 25 shows the probabilities of exceeding designated shortages in any year. Table 26 shows the probabilities of each shortage exceedence event occurring at least once over the next 30 years. Thus, for example, with historic flows, there is a 10% likelihood of a peak-season shortage greater than 5% in any year. Over the next 30 years, there is a 95% likelihood of experiencing at least one year with that size peak-season shortage.

[25] For the sake of consistency with the other CA analyses, the most recent interim demand forecast modifications were not used. The conclusions about the impacts of any of the alternatives will not be significantly changed as a result of the new demand forecast.

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**Figure 67. Peak-Season Shortage Duration Curves with Current System: DFG-5 Flows**

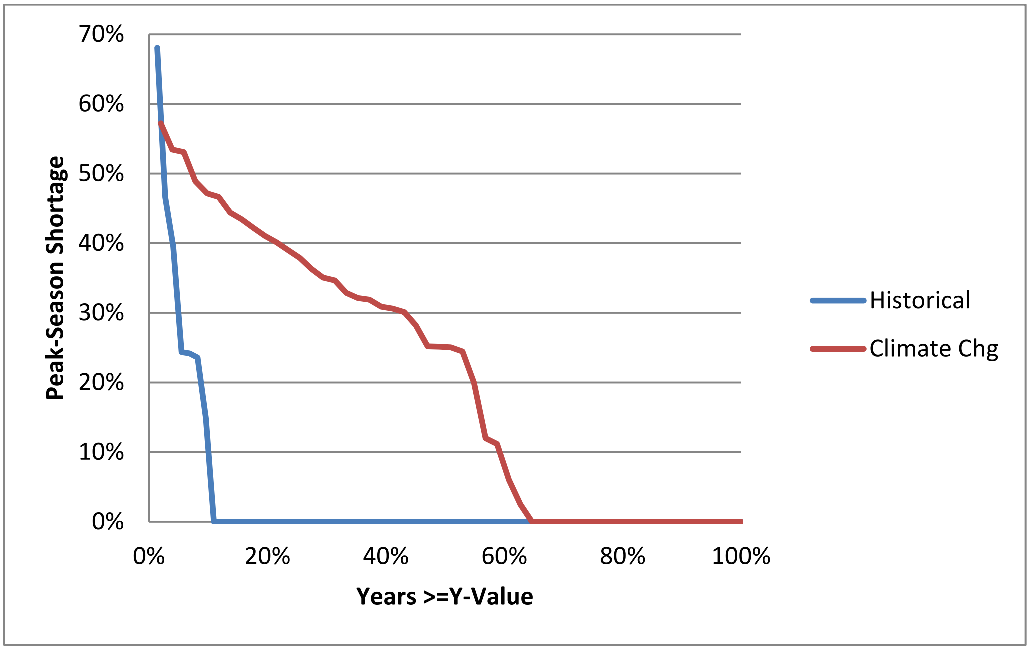



**Table 29. Probabilities of Peak-Season Shortage Events in Any Year**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 1% | 6% |
| >25% | 4% | 51% |
| >15% | 8% | 55% |
| >5% | 10% | 61% |

**Table 30. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 34% | 84% |
| >25% | 72% | 100% |
| >15% | 92% | 100% |
| >5% | 95% | 100% |

Figure 53 shows how these curves are improved through this supply alternative.

Table 27 shows the probabilities of exceeding designated shortages in any year. Table 28 shows the probabilities of each shortage event occurring at least once over the next 30 years. Thus, for example, with historic flows, there is a 3% likelihood of a peak-season shortage greater than 5% in any year. Over the next 30 years, there is a 57% likelihood of experiencing at least one year with that size peak-season shortage.

**Figure 68. Peak-Season Shortage Duration Curves with CRec Conservation: DFG-5 Flows**

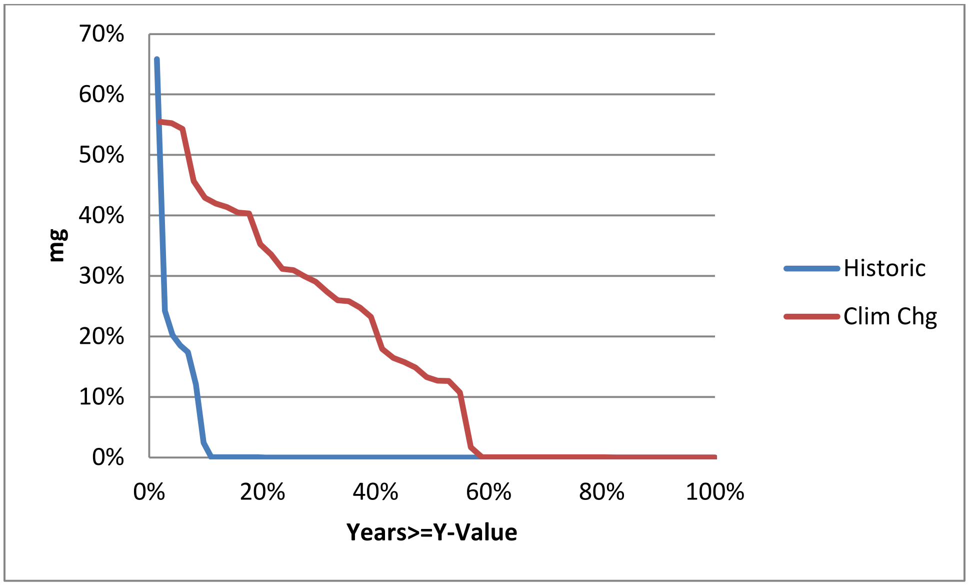



**Table 31. Probabilities of Peak-Season Shortage Events in Any Year**

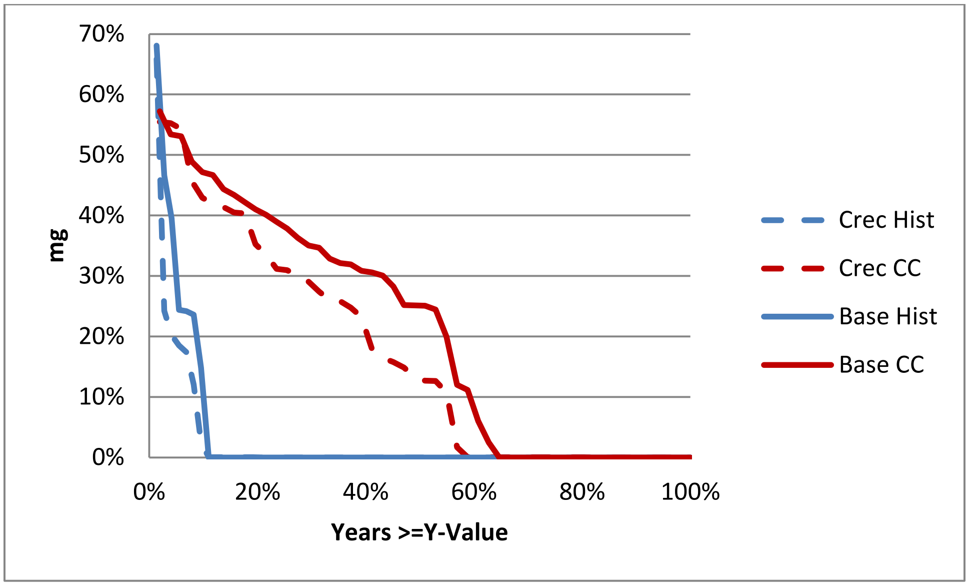
| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 1% | 6% |
| >25% | 1% | 35% |
| >15% | 7% | 45% |
| >5% | 8% | 55% |

**Table 32. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 34% | 84% |
| >25% | 34% | 100% |
| >15% | 88% | 100% |
| >5% | 92% | 100% |

Although the shapes of the curves in Figure 52 and Figure 53 are much the same, the shortage magnitudes are in fact reduced. This is seen more readily in Figure 69 which superimposes the two sets of curves.

**Figure 69. Comparison of Peak-Season Shortage Duration Curves with and without CRec**




**Project Yield**

The difference between the highest points in Figure 52 and Figure 53 tells us the worst-year yield of this alternative, i.e., how well this alternative does in reducing the worst-year peak-season shortage. Expressed volumetrically, this difference is about 130 mg with historic flows, and 90 mg with climate change.

Across all hydrologic conditions, the average reduction in peak-season shortage is about 25 mg with historic flows and 100 mg with climate change. In many hydrologic years the benefit is greater than the actual demand reduction because of the in-lieu storage in Loch Lomond that results from the demand reductions.

**Conclusion**

The worst-year benefits of this demand-side alternative are commensurate with the magnitude of the peak-season demand reduction. However, under other hydrologic conditions, the reliability benefit can exceed the savings because of the ability to retain more water in Loch Lomond which is then available to serve demand when needed.

GARY FISKE AND ASSOCIATES, INC.
*Water Resources Planning and Management*

**Date:** April 29, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Modeling Results: North Coast Reclaimed Water Exchange (CA-13)

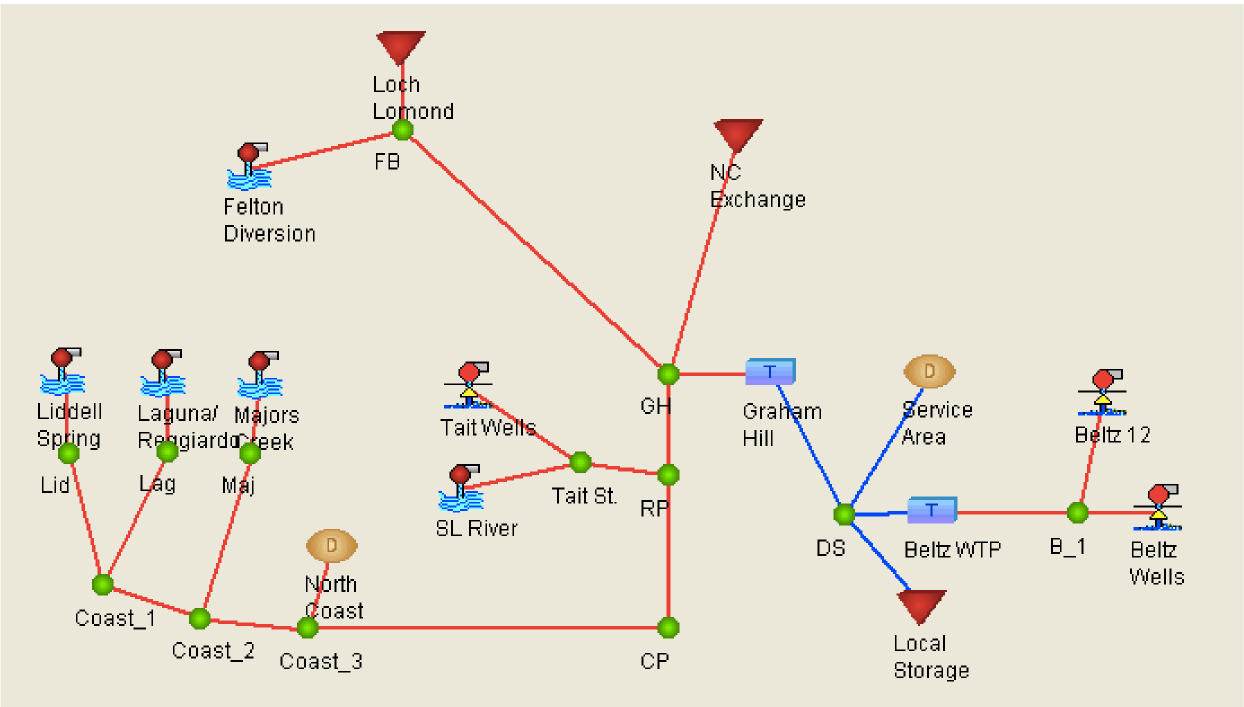
This memo reports the results of the Confluence modeling of CA-13, which sends non-potable reclaimed water to North Coast farmers in exchange for groundwater that can be extracted and treated at Graham Hill or a new treatment plant. Per discussions with Bill Faisst, it is assumed that 4.3 mgd are sent north over a 180-day period for a total 775 million gallons per year. The City can withdraw that water in the current year; it cannot be banked for future years.

Basically 775 mg is available from this source every year if needed to meet demand. There are assumed to be no pumping or transmission capacity limitations on utilizing this new supply.

**Modeling Approach**

The Confluence system schematic for this alternative is shown in Figure 51.

**Figure 70. Confluence System Schematic for CA-13**




Since the nature of this supply is “use it or lose it,” (i.e. it cannot be stored from year to year), the model utilizes this supply on any day prior to drawing on Loch Lomond. This is the most efficient way to use such a supply since it allows for indirect banking by increasing carryover storage in Loch Lomond. As will be shown below, this indirect storage provides substantial reliability benefits.

**Impacts on System Reliability**

Figure 52 shows the peak-season shortage duration curves assuming DFG-5 flows with current supplies that we have seen before (see my March 9 memo). The shortages are expressed as both percentages and volumes. Tables 1 and 2 summarize the information shown in these curves in two different ways. Table 25 shows the probabilities of exceeding designated shortages in any year. Table 26 shows the probabilities of each shortage exceedence event occurring at least once over the next 30 years. Thus, for example, with historic flows, there is a 10% likelihood of a peak-season shortage greater than 5% in any year. Over the next 30 years, there is a 95% likelihood of experiencing at least one year with that size peak-season shortage.

**Figure 71. Peak-Season Shortage Duration Curves <u>with Current System</u>: DFG-5 Flows**

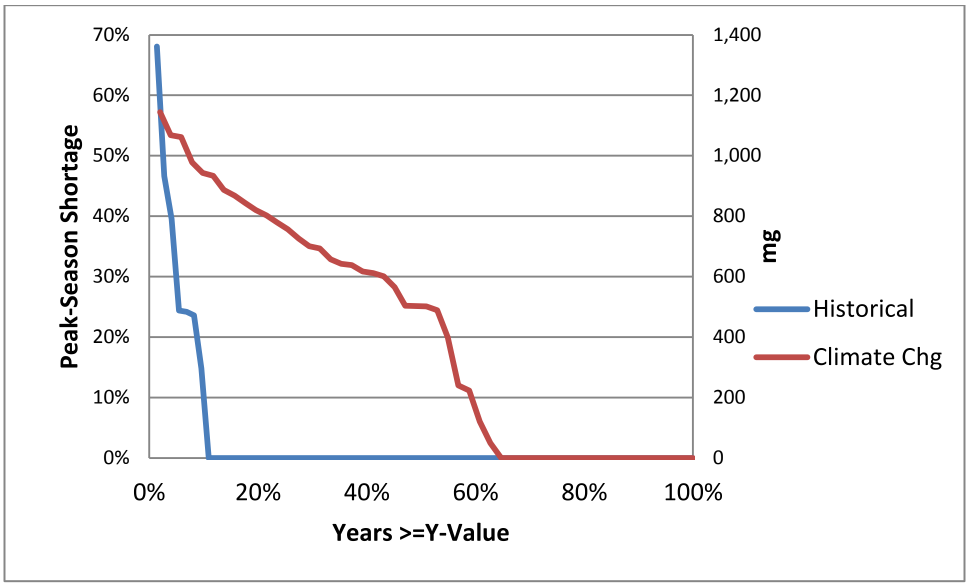



**Table 33. Probabilities of Peak-Season Shortage Events in Any Year**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 1% | 6% |
| >25% | 4% | 51% |
| >15% | 8% | 55% |
| >5% | 10% | 61% |

**Table 34. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 34% | 84% |
| >25% | 72% | 100% |
| >15% | 92% | 100% |
| >5% | 95% | 100% |

Figure 53 shows how these curves are improved through this supply alternative. Note that the horizontal axis is expanded (i.e., it only shows the lower range of probabilities) to make the chart easier to read. Table 35 shows the probabilities of exceeding designated shortages in any year. Table 36 shows the probabilities of each shortage exceedence event occurring at least once over the next 30 years. Thus, for example, with historic flows, there is a 3% likelihood of a peak-season shortage greater than 5% in any year. Over the next 30 years, there is a 57% likelihood of experiencing at least one year with that size peak-season shortage.

**Figure 72. Peak-Season Shortage Duration Curves <u>with North Coast Exchange</u>: DFG-5 Flows**

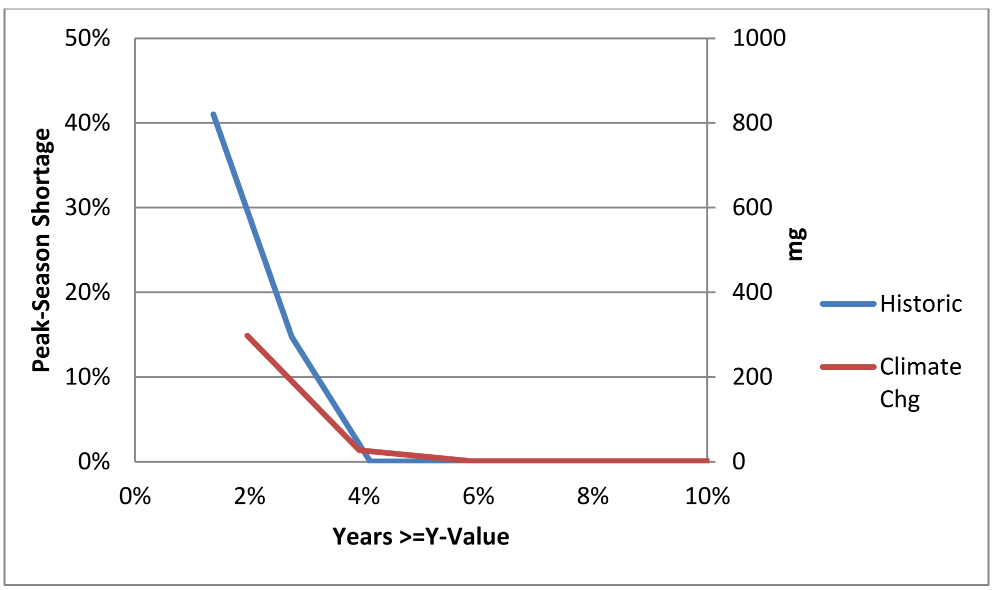


**Table 35. Probabilities of Peak-Season Shortage Events in Any Year: DFG-5 Flows**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 0% | 0% |
| >25% | 1% | 0% |
| >15% | 1% | 0% |
| >5% | 3% | 2% |

**Table 36. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period: DFG-5 Flows**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 0% | 0% |
| >25% | 34% | 0% |
| >15% | 34% | 0% |
| >5% | 57% | 45% |

The shortage profiles with both historic flows and climate change are improved significantly:

- For both historic flows and climate change, this supply option confines shortages to the one or two worst drought years. In all other years, shortages are reduced to zero.
- The reliability improvement from this alternative is greater with climate change than with historic flows. In fact, the reliability profile with this alternative assuming climate change is actually better than with historic flows.
- With climate change, this alternative reduces the worst-year shortage to about 15%.

**Project Yield**

The difference between the highest point in Figure 52 and Figure 53 tell us the worst-year yield of this alternative, i.e., how well this alternative does in reducing the worst-year peak-season shortage. Expressed volumetrically, this difference is about 530 mg with historic flows, and 850 mg with climate change. Across all hydrologic conditions, the average reduction in peak-season shortage is about 45 mg with historic flows and 410 mg with climate change.

These benefits accrue for two reasons:

- The production of the source itself

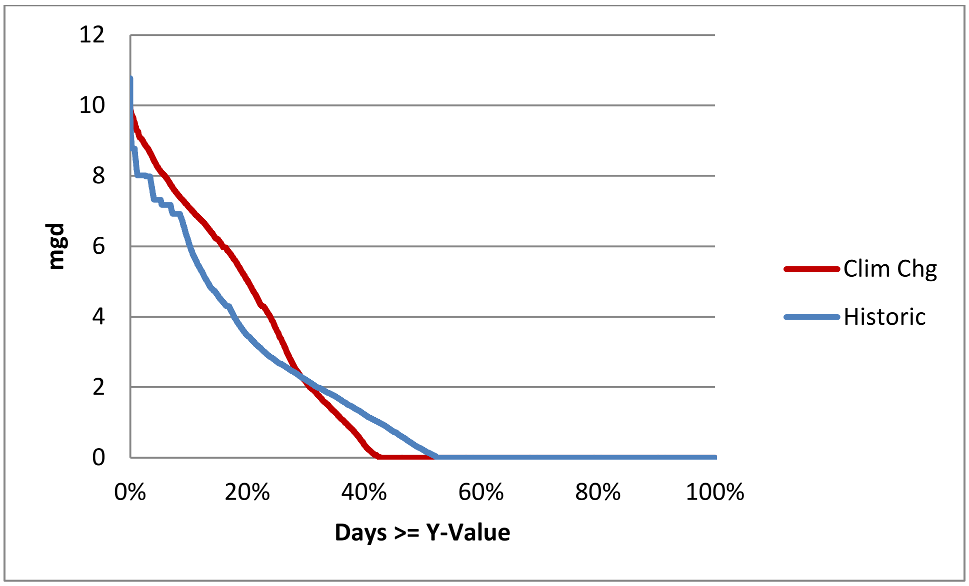
- The change in production of Loch Lomond (which in many hydrologic years is negative)[26]

The second point is important. In dry years, the benefit of these alternatives derive not only from the recycled water produced in that year, but also from added production from Loch Lomond. In those years, Loch Lomond begins at higher elevations because use of the recycled water in previous years allowed the lake to "rest".

**Needed Infrastructure Capacities**

The assumed daily recycled water production in the off-peak months, and thus the needed capacity of the transmission line to move reclaimed water to the North Coast, is 4.3 mgd. Figure 73 shows the duration curves of the daily source production during the peak season, which provide information on the capacity requirements for the extraction wells and the transmission from the North Coast to the treatment plant. The maximum production is between 10 and 11 mgd.

**Figure 73. Duration Curves of Daily North Coast Exchange Production**




**Conclusion**

Fixed (hydrology-independent) sources have very different system impacts than sources that vary with streamflows. CA-13, the exchange of non-potable recycled water for North Coast groundwater, provides 775 mg of additional supply every year. The actual benefit of this source in dry years is significantly greater than this because of the ability to indirectly bank some of this water in Loch Lomond.

---

[26] The total also includes a slight increase in Tait Street production sent to GHWTP because of the assumed unlimited diversion capacity.

The reliability benefit of this alternative is substantial, actually somewhat greater under climate change. The worst-year peak-season shortage with climate change is brought down to 15%. With historic flows, it is 40%, still a substantial improvement but well above our target. Shortages in all hydrologic years other than the worst drought sequence are brought to zero.

Of course, larger fixed sources (e.g. IPR, with annual production of 1330 mg) will produce greater benefits.

GARY FISKE AND ASSOCIATES, INC.
*Water Resources Planning and Management*

**Date:** April 29, 2015
**From:** Gary Fiske
**To:** Water Supply Advisory Committee
**Re:** Modeling Results: Indirect Potable Reuse (CA-10)

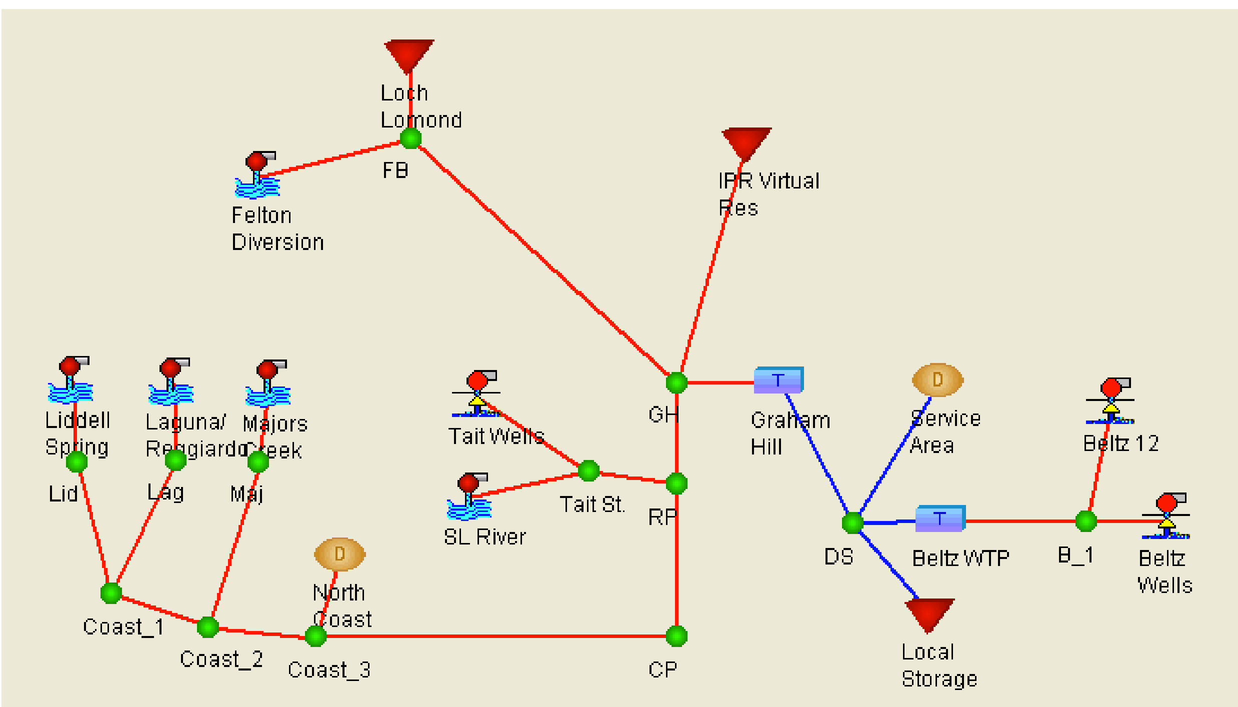
This memo reports the results of the Confluence modeling of CA-10, which produces approximately 3.64 mgd of recycled water 365 days per year for an annual total of 1330 mgy, which is stored in a virtual reservoir (VR) for use to serve demands.

The water supply impacts of this alternative are substantially more than the North Coast exchange (CA-13) analyzed previously. Not only is more water produced each year (1330 mg vs. 775 mg) but unlike CA-13, that water can be stored in an aquifer or surface reservoir for use in subsequent years. There are assumed to be no pumping or transmission capacity limitations on utilizing this new supply.

## Modeling Approach

The Confluence system schematic for this alternative is shown in Figure 51.

**Figure 74. Confluence System Schematic for CA-10**

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**Impacts on System Reliability**

Figure 52 shows the peak-season shortage duration curves assuming DFG-5 flows with current supplies that we have seen before (see my March 9 memo). The shortages are expressed as both percentages and volumes. Tables 1 and 2 summarize the information shown in these curves in two different ways. Table 25 shows the probabilities of exceeding designated shortages in any year. Table 26 shows the probabilities of each shortage exceedence event occurring at least once over the next 30 years. Thus, for example, with historic flows, there is a 10% likelihood of a peak-season shortage greater than 5% in any year. Over the next 30 years, there is a 95% likelihood of experiencing at least one year with that size peak-season shortage.

**Figure 75. Peak-Season Shortage Duration Curves <u>with Current System</u>: DFG-5 Flows**

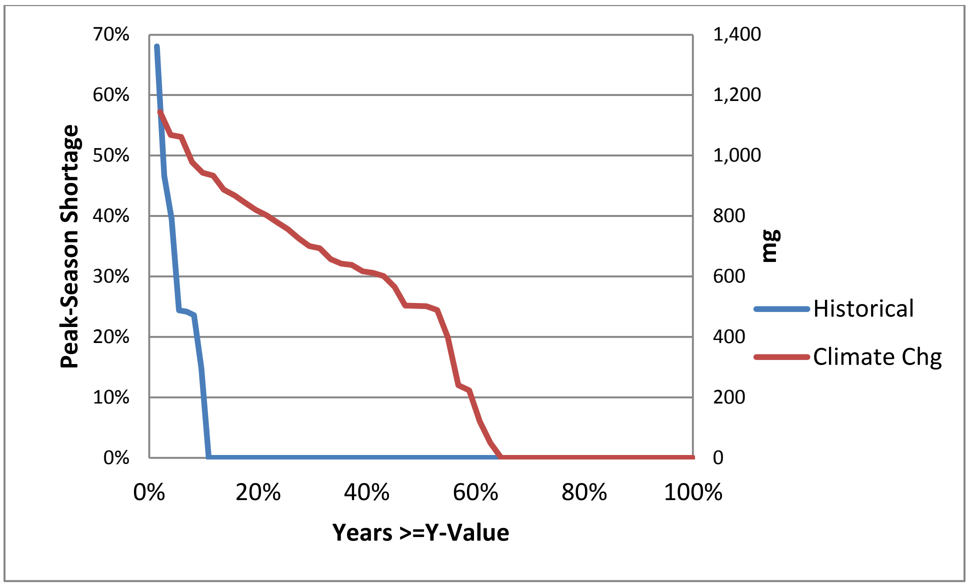



**Table 37. Probabilities of Peak-Season Shortage Events in Any Year**

| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 1% | 6% |
| >25% | 4% | 51% |
| >15% | 8% | 55% |
| >5% | 10% | 61% |

**Table 38. Probabilities of Occurrence of Peak-Season Shortage Events Over 30-Year Period**

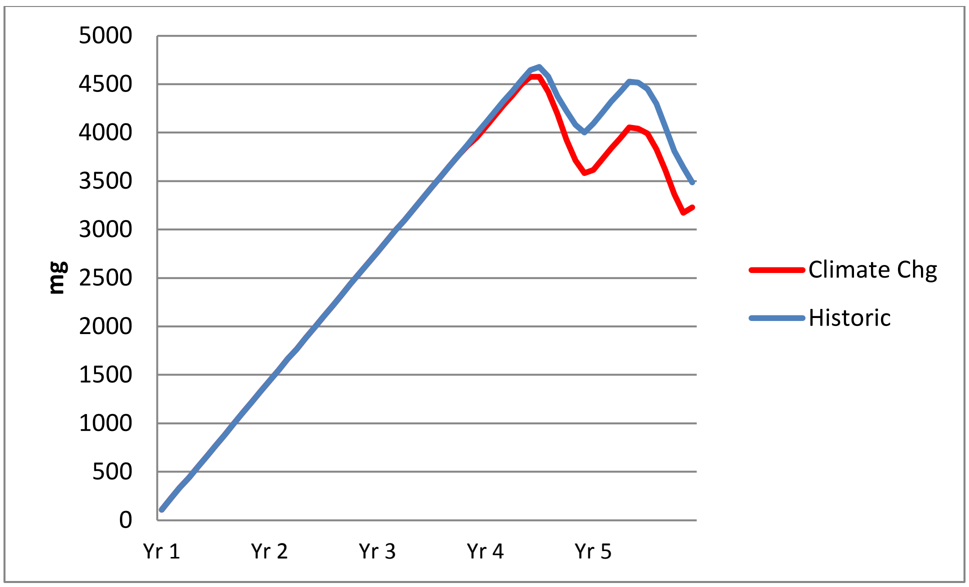
| Shortage Event | Historic | Climate Change |
|---|---|---|
| >50% | 34% | 84% |
| >25% | 72% | 100% |
| >15% | 92% | 100% |
| >5% | 95% | 100% |

As is the case for the winter harvesting alternatives (see April 6 memo), this IPR alternative drives these shortages to zero. That is, all demands can be served, even in the driest years, with DFG-5 flows and with or without climate change.

**Virtual Reservoir Fill and Drawdown**

Figure 76 shows the VR fill and drawdown in the 5 years leading up to the worst drought events in the historic and climate change records.[27] In each case, the VR starts at zero. Since the IPR source is drought-proof, the reservoir fill is the about same with or without climate change. Drawdown in both cases is small because on most days, the 3.6 million gallons added to storage equals or exceeds the drawdown needed to serve that day's demand, so there is much less reliance on storage. This means that much less storage capacity is needed for this alternative. The total drawdown in Figure 76 is between 1200 and 1400 mg. This provides an estimate of the maximum required storage capacity.

**Figure 76. Virtual Reservoir Fill and Drawdown in 5 Years Fill Before Worst Drought Event**




**Project Yield**

Since this alternative reduces shortages to zero, the worst-year yields of this alternative, i.e., how good a job this alternative does in reducing the worst-year peak-season shortages, are simply the highest points Figure 52. In volume, this is about 1360 mg with historic flows, and 1150 mg with climate change. Across all hydrologic conditions, the average reduction in peak-season shortage is about 60 mg with historic flows and 420 mg with climate change.

These benefits accrue for two reasons:

---

[27] Year 5 is the end of the worst drought sequence. For the historic record, the 5-year period shown is 1973-77.

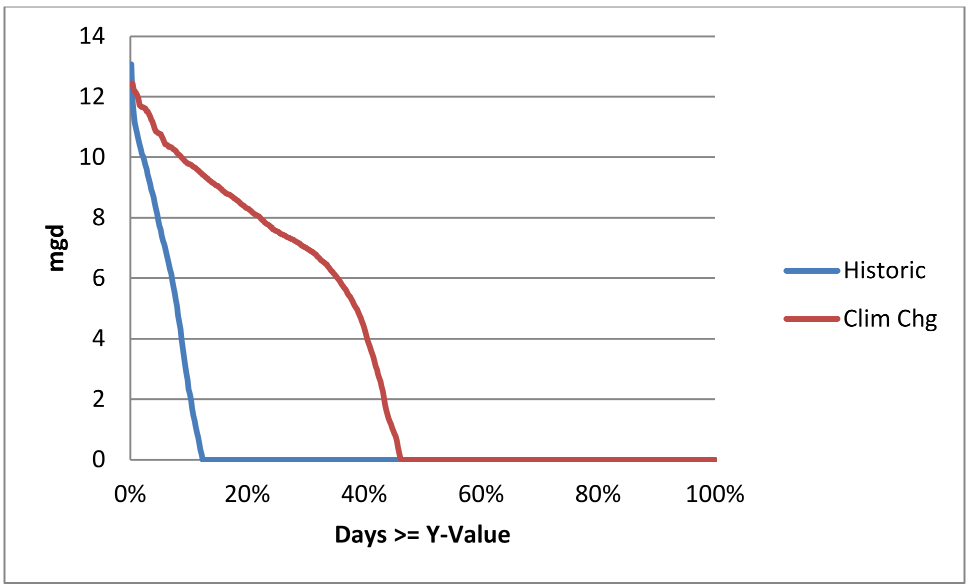
- The production (less losses) of the VR itself plus
- The change in production of Loch Lomond (which in many hydrologic years is negative)[28]

The second point is important. In dry years, the benefit of these alternatives derive not only from the VR itself but also from added production from Loch Lomond. In those years, Loch Lomond begins at higher elevations because use of the VR in previous years allowed the lake to "rest".

**Needed Infrastructure Capacities**

The assumed daily recycled water production capacity is 3.64 mgd. Figure 73 shows the duration curves of the daily VR production during the peak season, which provide information on the capacity requirements for transmission from the VR to the treatment plant. The maximum production is between 12 and 13 mgd.

**Figure 77. Duration Curves of Daily IPR Production**




**Conclusion**

CA-10, Indirect Potable Reuse, assumes daily recycled water production of 3.64 mgd (1330 mg annually). This recycled water is stored either in a surface reservoir or in an aquifer. As is the case with the winter flow harvesting alternatives, the ability to store the source and use it in subsequent years provides substantial system benefits and, in fact, is sufficient to eliminate all projected shortages under historic flows or with climate change. However, because this is source is fixed (i.e. hydrology-independent), it requires considerably less storage capacity to accomplish this than a flow-dependent supply.

[28] The total also includes a slight increase in Tait Street production sent to GHWTP because of the assumed unlimited diversion capacity.

**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** May 21, 2015
**From:** Gary Fiske
**To:** Rosemary Menard, Heidi Luckenbach, Bob Raucher, Karen Raucher, Bill Faisst
**Re:** Additional analysis of DPR/winter flow harvest alternative (Portfolio 2)

Based on our conversation earlier this week, I've thought some more about the DPR/winter flow harvest alternative. Here is some further information to consider as we discuss this option.

First, I re-ran the model assuming 1700 mgy (4.65 mgd) DPR capacity instead of the 1330 mgy (3.64 mgd) I assumed last week. The 2 sets of results are compared in Tables 1 and 2. The added DPR capacity essentially eliminates Santa Cruz peak-season shortages. Somewhat more SV and SqCWD demand is served.

**Table 39. Peak Season Shortages: DPR 3.64 mgd plus Winter Flow Harvest**

| | Historic Flows | Climate Chg |
|---|---|---|
| **Santa Cruz Worst-Yr PS Shortage** | 11.2% | 23.0% |
| **SV Av Ann Dem Served** | 290 mg (73%) | 225 mg (56%) |
| **SqCWD Av Ann Dem Served** | 650 mg (58%) | 540 mg (48%) |

**Table 40. Peak Season Shortages: DPR 4.65 mgd plus Winter Flow Harvest**

| | Historic Flows | Climate Chg |
|---|---|---|
| **Santa Cruz Worst-Yr PS Shortage** | 0.0% | 5.3% |
| **SV Av Ann Dem Served** | 310 mg (78%) | 240 mg (60%) |
| **SqCWD Av Ann Dem Served** | 740 mg (66%) | 590 mg (52%) |

The next question asked by Rosemary was how much recycled water (or other drought-proof supply) would we need (in addition to the excess winter flows) to fully serve SV and SqCWD demands? The answer is a lot. Since we are assuming no ability to store the recycled water, we need enough capacity to directly meet every day's demands, in Santa Cruz as well as the other two agencies. Based on current

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SV and SqCWD demands, we would need ~16 mgd of DPR water with historic flows and ~15 mgd with climate change. Those represent the maximum required daily DPR production.

But I'm not sure this is the right question to be asking. I think a more relevant question may be how often all (or nearly all) of the SV and SqCWD annual demand will be met with different levels of DPR flow. Figures 1 and 2 show duration curves of percent of annual demand served for Scotts Valley and SqCWD respectively with different assumed DPR (or other drought-proof supply) capacity, assuming historic flows. Figures 3 and 4 show analogous distributions with climate change.

**Figure 78. Scotts Valley Annual Demand Served with Different Supplemental Supply Capacities: Historic Flows**

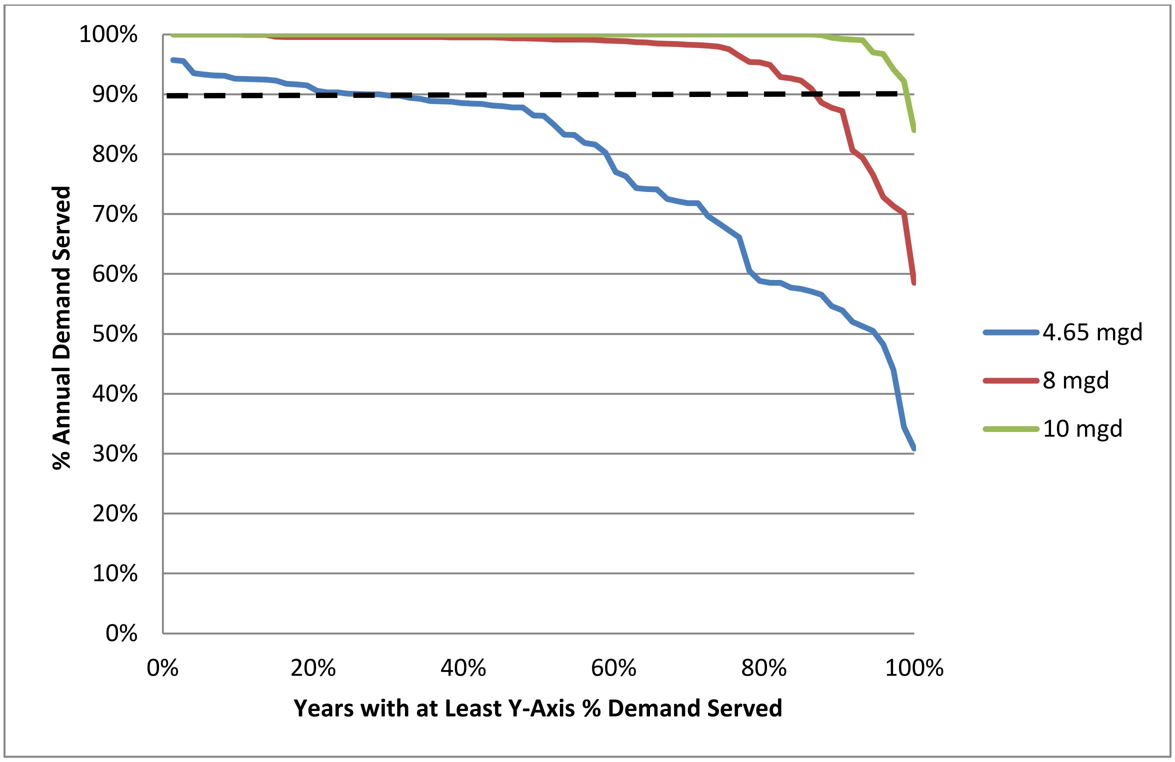


**Figure 79. Soquel Creek Annual Demand Served with Different Supplemental Supply Capacities: Historic Flows**

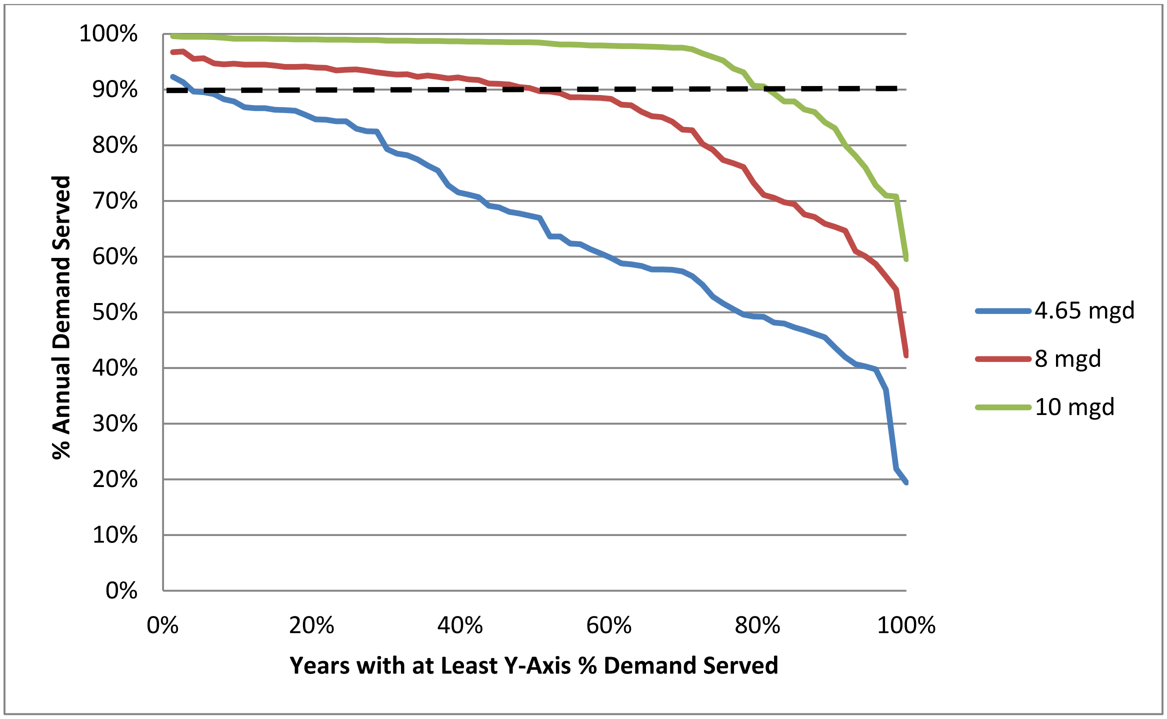



**Figure 80. Scotts Valley Annual Demand Served with Different Supplemental Supply Capacities: Climate Change**

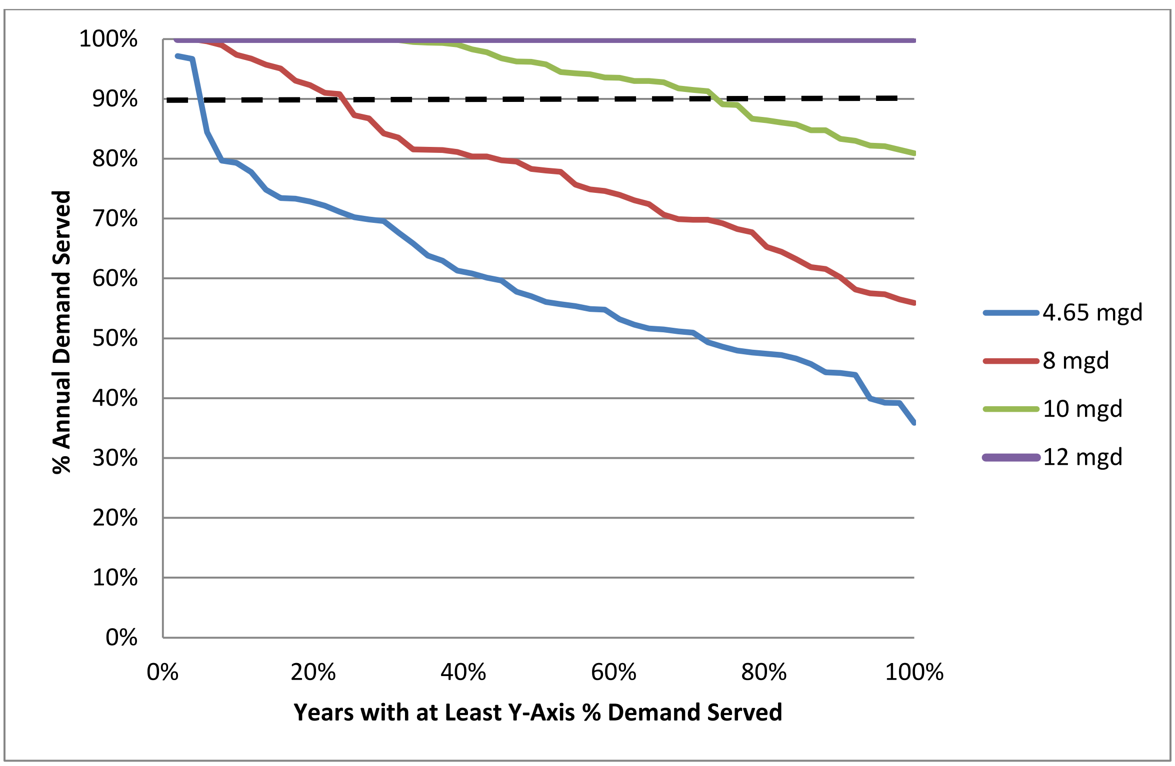
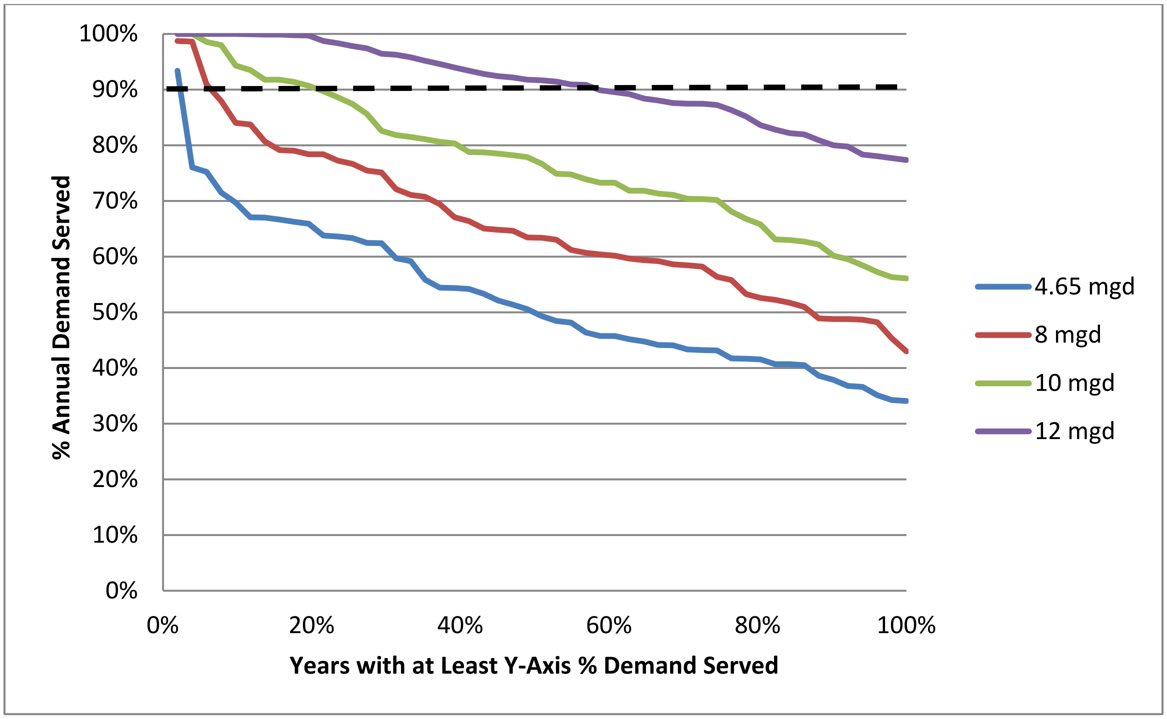


**Figure 81. Soquel Creek Annual Demand Served with Different Supplemental Supply Capacities: Climate Change**




These charts tell us, for example, how often 90% of each district's annual demand is served. With historic flows, 4.65 mgd of supplemental supply will serve at least 90% of Scotts Valley demand about 3 years in 10. With 8 mgd of supplemental supply, that increases to 9 years in 10, and with 10 mgd to nearly all years. The benefits to Soquel Creek are less; it would be extremely rare for 4.65 mgd of capacity to serve 90% of SqCWD annual demand. With 8 mgd, 90% of demand would be served more than half the time; 10 mgd would serve that much demand about 4 years in 5.

With climate change, the ability to serve the demands of either district is much reduced because more of the supplemental supply is needed in Santa Cruz. For example, it would take an additional 2 mgd of supply (12 mgd total) to approach the efficacy of 10 mgd with historic flows.

**The Benefits of (a little bit of) Storage**

As alluded to above, a key reason for needing such large capacity increments is the inability to store any of the drought-proof supply. It turns out that even a small storage volume makes a huge difference by shaving peaks and thereby reducing the required capacity. If we had the ability to store only 500 mg of DPR supply, we could serve considerably more Scotts Valley and SqCWD demand and thereby allow the aquifers to recover more quickly. Figures 5-8 show the multiplier impacts of this small storage volume.

**Figure 82. Scotts Valley Demand Served with Different Supplemental Supply Capacities: Historic Flows + 500 mg Storage**

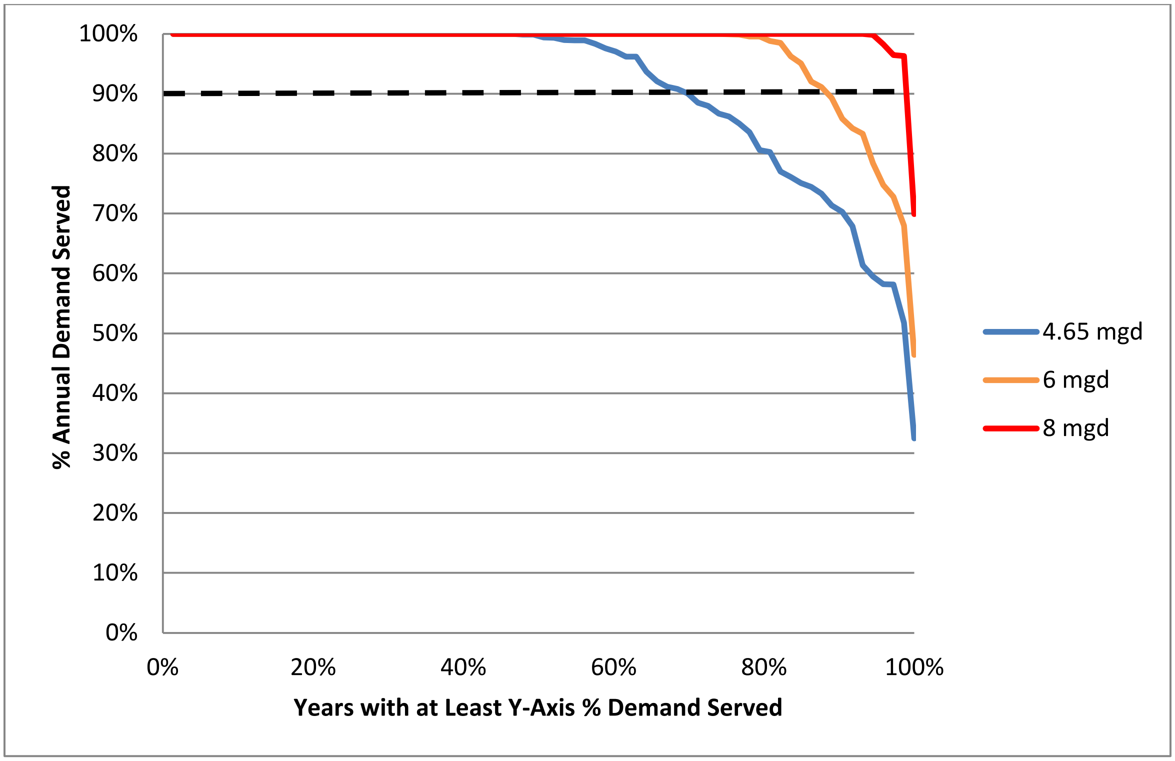



**Figure 83. Soquel Creek Demand Served with Different Supplemental Supply Capacities: Historic Flows + 500 mg Storage**

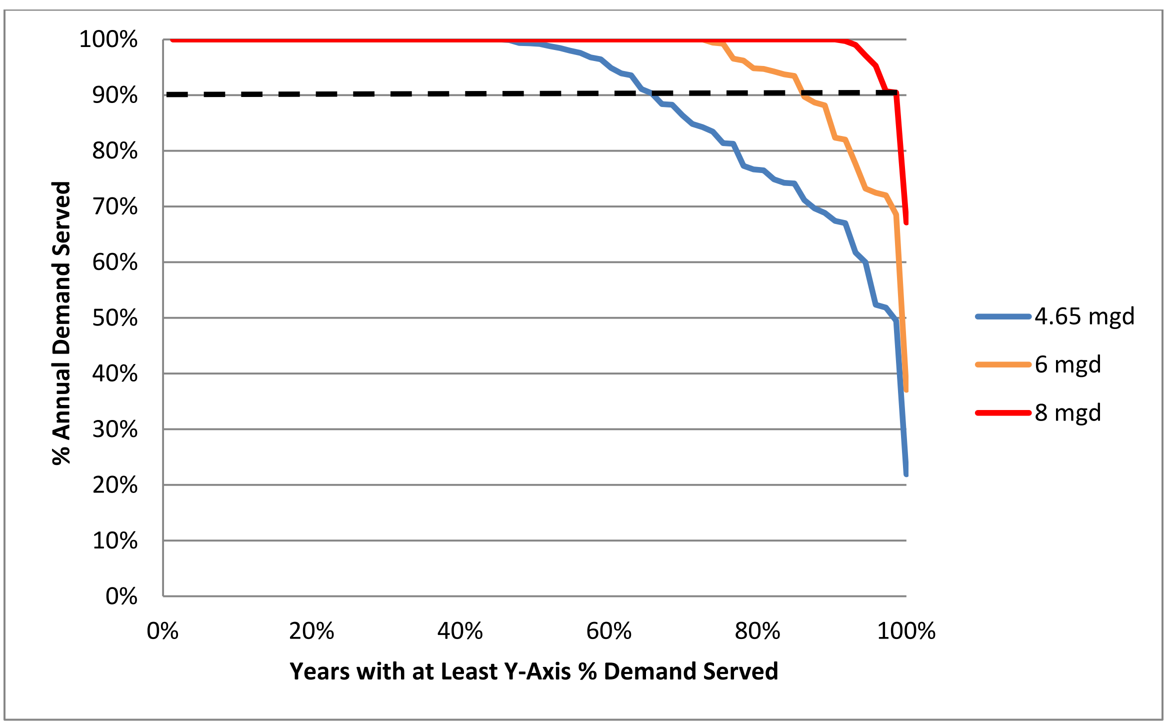


**Figure 84. Scotts Valley Demand Served with Different Supplemental Supply Capacities: Climate Change + 500 mg Storage**

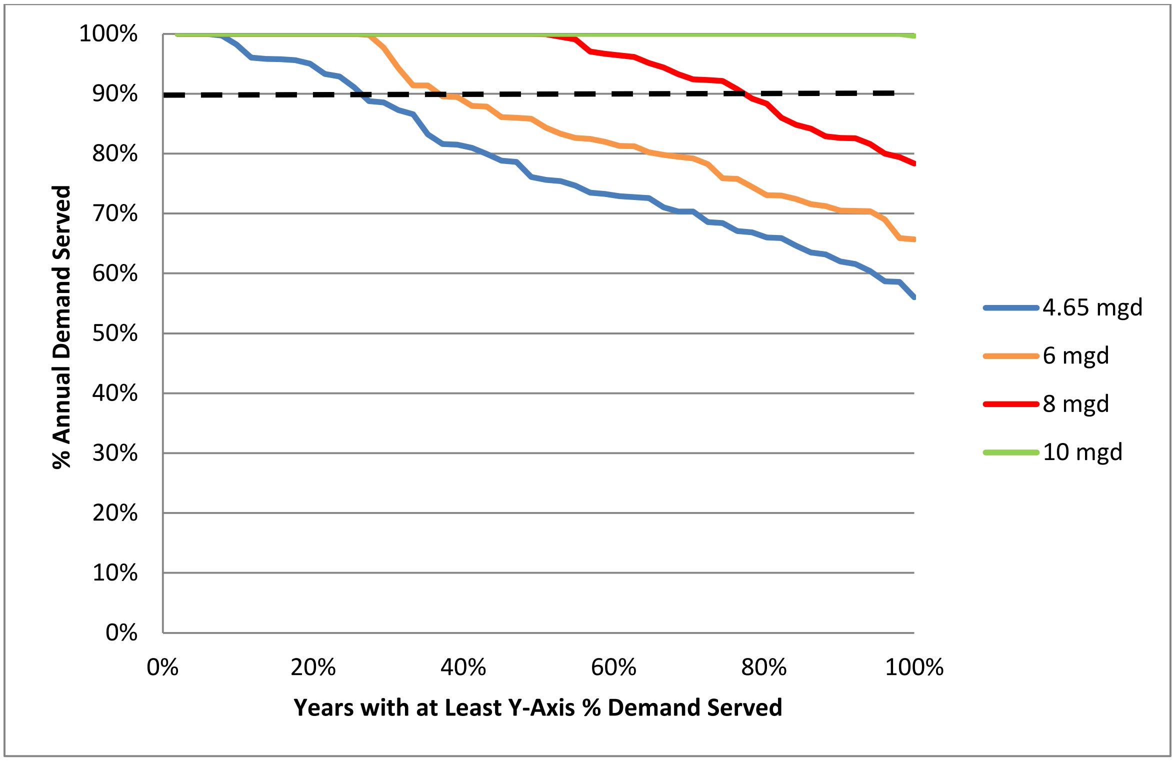
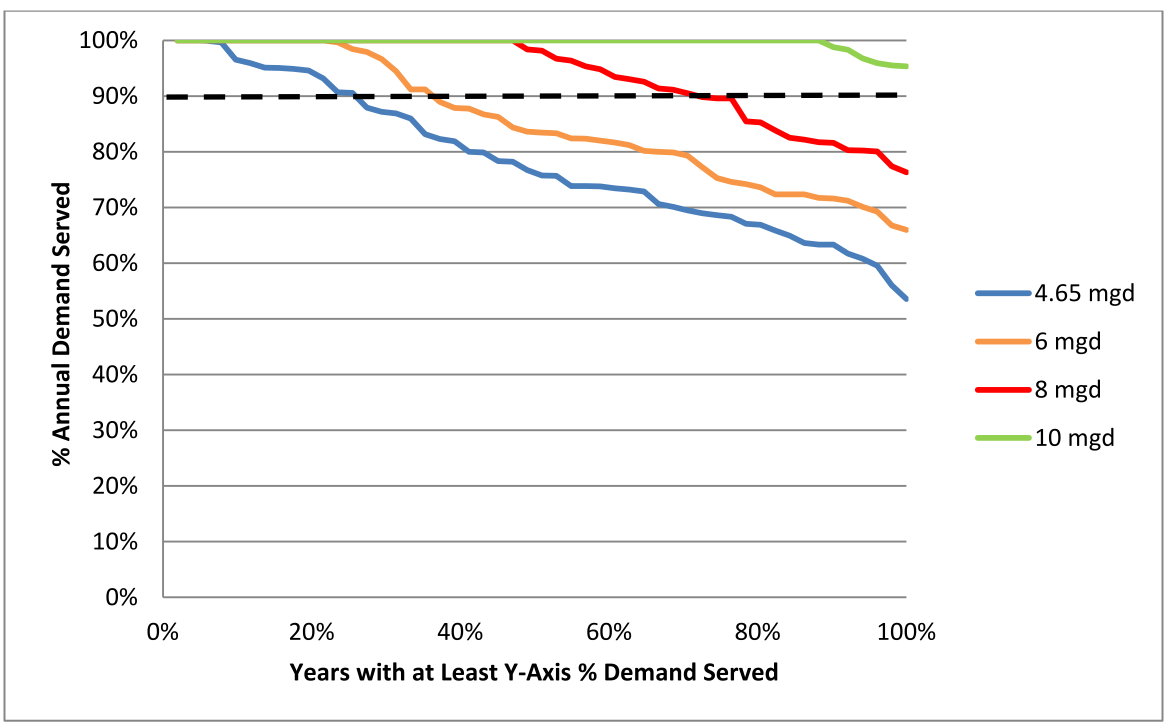



**Figure 85. Soquel Creek Demand Served with Different Supplemental Supply Capacities: Climate Change + 500 mg Storage**



When we compare these charts to Figures 1-4, we see the substantial benefits of storage. For example, Figures 5 and 6 show that with historic flows, the currently available 4.65 mgd DPR capacity can serve 90% of both Scotts Valley and Soquel Creek demands 7 years out of 10. Without storage, the comparable frequencies are 3 years out of 10 for Scotts Valley and near zero for Soquel Creek (Figures 1 and 2). With climate change, storage increases the frequencies from less than 1 year in 20 for both agencies (Figures 3 and 4) to around 3 years in 10 (Figures 7 and 8). The abilities of higher drought-proof source capacities to serve the districts' demands are likewise multiplied.

Perhaps the main reason for considering DPR is the costs and uncertainties associated with developing the 3 billion gallon or greater storage capacity that would be needed to utilize excess winter flows. We see, however, that a lot less storage can greatly increase the supply benefits of a drought-proof source, and it may be less problematic to develop 500 mg rather than 3 bg of storage. Since even without any ability to store DPR its benefits are substantial, DPR can be developed and developing a small storage facility can be looked at as a potential long-term addition to expand the DPR supply benefits. This suggests the following staging of Portfolio 2:

1. Develop the needed DPR infrastructure for the currently-available 4.65 mgd of flow. The benefits of this alternative by itself are substantial.

2. If the ability to store a modest volume of DPR water proves feasible, develop that storage infrastructure and potentially also add more drought-proof supply.

3. If it proves infeasible to develop even this small volume of storage, consider expanding the drought-proof supply capacity even more.

DATE: July 15, 2015
TO: Water Supply Advisory Committee
FR: David Mitchell
RE: Summary of Econometric Analysis of Demand and Forecast

## Introduction

This memorandum provides an overview of the data, methods, and results of an econometric analysis and forecast of Santa Cruz water demand. The resulting forecast from this analysis replaces the interim demand forecast previously developed by M.Cubed (M.Cubed 2015a, M.Cubed 2015b). A full report documenting the work conducted by M.Cubed will be available in August.

## Project Objective and Approach

The project objective is the development of statistically-based models of water demand that will be used to support WSAC deliberations as well as the 2015 UWMP being developed by the Water Department. Demand forecasts based on these models cover the period 2020-2035.

The general approach is to statistically estimate class-level conditional expectation functions of water demand using historical data on class water use, weather, water price, household income, conservation, and other economic variables determining water demand. The result for each customer class is a monthly model of average water use per housing unit (for single- and multi-family residential classes), service (for business, municipal, and irrigation classes), or acre (for golf courses), which can then be combined with forecasts of housing units, services, and acres, to forecast future water demands. The conditional expectation functions are used with forecasts of future conservation, water rates, household income, unemployment, and other economic factors to predict the trajectory of average water use over the forecast period. This represents a key departure from the 2010 UWMP forecast methodology, which relied on static average use estimates to forecast future demands.

## Summary of Demand Forecast

The customer class demand forecasts are shown in Table 1. The production forecast shown at the bottom of the table is the sum of the class demands and miscellaneous uses and system losses. Class demands have been adjusted for the effects of plumbing codes and Program A conservation. Miscellaneous uses and system losses are estimated to average 7.5% of total production, based on historical rates of system losses.

Despite a projected 18% increase in service area population by 2035, total production is forecast to remain below 2013 production and stay within the neighborhood of 3,200 MG (rounded) through 2035. This is primarily due to future effects of plumbing codes, conservation, and rate increases, reduced demand by Pasatiempo golf course, and minimal growth in industrial water use.

A comparison of the new and interim production forecasts is provided in Table 2. Despite being independently derived and based on different data and methods, the two production forecasts are nearly identical, differing by no more than a few percent. As will be shown later, the econometric analysis generally corroborates the assumptions of price and income response used to develop the interim forecast, so perhaps it is not too surprising the forecasts are so similar.

**Table 41. Forecasted Demand by Customer Class (Million Gallons)**

| YEAR | 2013 | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|
| | Actual | Forecast | Forecast | Forecast | Forecast |
| Single Family | 1,233 | 1,180 | 1,175 | 1,172 | 1,177 |
| Multi Family | 705 | 662 | 626 | 625 | 625 |
| Business | 628 | 579 | 566 | 565 | 567 |
| Industrial | 56 | 57 | 59 | 61 | 62 |
| Municipal | 63 | 47 | 46 | 44 | 43 |
| Irrigation | 123 | 119 | 133 | 143 | 153 |
| Golf | 108 | 58 | 50 | 42 | 40 |
| UC | 182 | 196 | 234 | 271 | 308 |
| **TOTAL DEMAND** | **3,100** | **2,897** | **2,889** | **2,923** | **2,974** |
| MISC/LOSS | 251 | 235 | 234 | 237 | 241 |
| **TOTAL PRODUCTION** | **3,352** | **3,132** | **3,123** | **3,160** | **3,215** |
| **ROUNDED** | **3,400** | **3,100** | **3,100** | **3,200** | **3,200** |

**Table 42. Econometric and Interim Production Forecasts (million gallons)**

| YEAR | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|
| | Forecast | Forecast | Forecast | Forecast |
| Unrounded | | | | |
| Econometric | 3,132 | 3,123 | 3,160 | 3,215 |
| Interim | 3,236 | 3,213 | 3,218 | 3,169 |
| Rounded | | | | |
| Econometric | 3,100 | 3,100 | 3,200 | 3,200 |
| Interim | 3,200 | 3,200 | 3,200 | 3,200 |

Econometric Models of Average Demand

The class-level models of average demand build on similar models of water demand developed for the California Urban Water Conservation Council (Western Policy Research, 2011), Bay Area Water Supply and Conservation Agency (Western Policy Research, 2014), California Water Services Company (A&N Technical Services, 2014, M.Cubed 2015), and Contra Costa Water District (M.Cubed 2014).

The models have several useful features. First, climate and weather effects on demand are decomposed into two distinct components. The climate component measures the seasonal load shape of monthly demand under normal weather conditions. The weather component measures the effect on demand when weather departs from normal conditions. The seasonal and weather components are interacted to get season-specific weather effects. This is useful since the response to weather is expected to vary by season. For example, the effect of above normal rainfall on demand in winter, when outdoor water uses are lower, is generally found to be lower than its effect in spring or fall, when outdoor water uses are higher. Second, prior to model estimation, monthly water use is adjusted for historical conservation from plumbing codes. This helps to address the confounding effect of conservation on the estimation of other demand parameters like price, employment, and income. Third, the model includes economic parameters (e.g. price, household income, unemployment) known to influence urban water demand (Renzetti, 2002; Billings and Jones, 1996). Fourth, the model includes drought policy parameters to measure the effect of drought restrictions on demand. Thus, expected demand can be expressed conditional on season, weather, conservation, economic conditions, and drought stage.

The model of expected demand is stated as:

$$ln(\tilde{y}_{it}) = \mu_i + \beta_S Season_t + \beta_W Weather_t + \beta_E Economic_{it} + \beta_D Drought_t + \varepsilon_{it} \quad (1)$$

Where:

| | |
|---|---|
| $\tilde{y}_{it}$ | average use in month t for service region i adjusted to remove the effects of water savings due to plumbing codes and appliance standards |
| $\mu_i$ | model intercept for service region i |
| $\beta_S Season_t$ | seasonal component of average use in month t |
| $\beta_W Weather_t$ | weather component of average use in month t |
| $\beta_E Economic_{it}$ | economic component of average use in month t |
| $\beta_D Drought_t$ | drought component of average use in month t |
| $\varepsilon_{it}$ | stochastic component (error term) |

*Seasonal Component*

The seasonal component is specified using eleven monthly indicator variables. The monthly indicator variables take the value of one if t = j, and zero otherwise.

$$\beta_S Season_t = \sum_{j=2}^{12} \beta_j \, month_{jt} \qquad (2)$$

The eleven monthly parameters plus the model intercept describe the seasonal load shape of average demand. A seasonal index of monthly demand, where January has an index value of one, is easily constructed as shown in Table 3. The eleven seasonal parameters are seen to scale monthly demand relative to January demand.

**Table 43. Seasonal Index of Monthly Average Demand**

| Month | Seasonal Index | Month | Seasonal Index |
|---|---|---|---|
| Jan | 1 | Jul | $e^{\beta_7}$ |
| Feb | $e^{\beta_2}$ | Aug | $e^{\beta_8}$ |
| Mar | $e^{\beta_3}$ | Sep | $e^{\beta_9}$ |
| Apr | $e^{\beta_4}$ | Oct | $e^{\beta_{10}}$ |
| May | $e^{\beta_5}$ | Nov | $e^{\beta_{11}}$ |
| Jun | $e^{\beta_6}$ | Dec | $e^{\beta_{12}}$ |

*Weather Component*

The weather component is comprised of weather measures (monthly rainfall, average daily maximum air temperature, monthly ETo) that are transformed logarithmically with their monthly average subtracted away. In the case of rainfall, both contemporaneous and lagged measures are included in the model.

$$\beta_W Weather_t = \beta_{w1} dlR_t + \beta_{w2} dlR_{t-1} + \beta_{w3} dlR_{t-2} + \beta_{w4} dlT_t \ (or\ dlET_t) \qquad (3)$$

Where[29]

[29] One is added to monthly rain totals to ensure the rainfall measure is defined in months in which total rainfall is zero.

$$dlR_t = ln(Rain_t + 1) - \overline{ln(Rain_t + 1)} \quad (4)$$

$$dlT_t = ln(Temp_t) - \overline{ln(Temp_t)} \quad (5)$$

$$dlET_t = ln(ET_t) - \overline{ln(ET_t)} \quad (6)$$

For the residential and business customer classes, average daily maximum air temperature is used rather than ET. For the golf, irrigation, and municipal categories, which have greater landscape water uses, ET is used.

During model estimation, the weather component is interacted with seasonal indicators to estimate separate seasonal weather effects for fall-winter (Nov-Mar), spring (Apr-Jun), and summer-fall (Jul-Oct).[30]

Weather normalization of historical demands can be done in two ways. The first way is to use the predicted model values assuming average weather. In this case the model's weather component simply falls away and we are left with:

$$Weather\ Normalized\ \tilde{y}_{it} = exp(\mu_i + \beta_S Season_t + \beta_E Economic_{it}) \quad (7)$$

The second approach is to rescale observed water use using the estimated weather effects. The ratio of observed to weather normalized demand is

$$WeatherEffect_t = exp\left(\beta_{w1} dlR_t + \beta_{w2} dlR_{t-1} + \beta_{w3} dlR_{t-2} + \beta_{w4} dlT_t\ (or\ dlET_t)\right) \quad (8)$$

Weather normalized observed demand is then given by

$$Weather\ Normalized\ \tilde{y}_{it} = \frac{\tilde{y}_{it}}{WeatherEffect_t} \quad (9)$$

*Economic Component*

The economic component consists of economic variables that influence average water demand, including water price, household income, vacancy rate, and unemployment rate. The economic variables

[30] The seasonal construct follows the CUWCC's GPCD weather normalization methodology (Western Policy Research, 2011).

are logarithmically transformed prior to model estimation. The vacancy rate and unemployment rate variables are expressed as departures from their long-run average values.

$$\beta_E Economic_{it} = \beta_{E1} lPrice_{it} + \beta_{E2} lInc_{it} + \beta_{E3} dlVac_t + \beta_{E4} dlUnempl_t \quad (10)$$

Where

$$lPrice_{it} = ln(marginal\ price)\ in\ service\ region\ i, period\ t \quad (11)$$

$$lInc_{it} = ln(median\ household\ income)\ in\ service\ region\ i, period\ t \quad (12)$$

$$dlVac_t = ln(housing\ vacancy\ rate) - \overline{ln(housing\ vacancy\ rate)} \quad (13)$$

$$dlUnempl_t = \ln(unemployment\ rate) - \overline{\ln(unemployment\ rate)} \quad (14)$$

Each customer class model uses a restricted form of equation 10, as shown in Table 4. These restrictions are guided both by economic theory and model diagnostics. For the single family model, the primary economic drivers are marginal water price and household income. For the multi-family model, vacancy rate replaces household income. For the business and municipal class models, marginal price and unemployment measures are used. For golf and irrigation, only marginal price is included in the models.

**Table 44. Economic Variable Restrictions in Customer Class Models**

| Customer Class Model | Economic Variable Restrictions |
|---|---|
| Single Family | $\beta_{E3} = \beta_{E4} = 0$ |
| Multi Family | $\beta_{E2} = \beta_{E4} = 0$ |
| Business, Municipal | $\beta_{E2} = \beta_{E3} = 0$ |
| Golf, Irrigation | $\beta_{E2} = \beta_{E3} = \beta_{E4} = 0$ |

*Drought Component*

The model's drought component consists of three indicator variables for stage 1, 2, and 3 drought restrictions. The indicator variable takes the value of one in months that the drought stage was active and zero otherwise.

Data for Model Estimation

Datasets for monthly consumption, weather variables, economic variables, and plumbing code/conservation variables were developed to estimate the models. These datasets were constructed as follows.

*Consumption Data*

The models were estimated with monthly consumption data for the period January 2000 to November 2014. Class-level aggregated meter read data were obtained from the Water Department. The Water Department data were bifurcated between Inside City and Outside City accounts, and contained aggregated data from both bi-monthly and monthly meter read cycles. Before the data could be used for model estimation, it had to be transformed into estimated aggregate monthly consumption. For any read month t, data from bi-monthly meter reads was allocated approximately 25% to month t-2, 50% to month t-1, and 25% to month t. Thus for data from meters read in March, approximately 25% of the consumption was allocated to January, 50% to February, and 25% to March. For data from monthly meter reads, consumption was allocated approximately 50% to month t-1 and 50% to month t. Thus for data from meters read in March, approximately 50% was allocated to February and 50% to March. The allocations are based on the approximate share of total consumption days in each month represented in the aggregated meter read data. The percentages cited above are only approximate values. To do the actual allocations, seasonal weights were applied to each month to account for the seasonal shape of consumption.

Estimated monthly consumption was then divided by the number of housing units (for single-family and multi-family customer classes), services (for business, municipal, and irrigation classes), or acres (for golf courses) to get average monthly water use per housing unit, service, or acre.

Monthly conservation from plumbing codes was then added to estimated average monthly consumption to remove the effects of plumbing code savings from consumption. Monthly plumbing code savings for the estimation period were estimated with the Alliance for Water Efficiency's Water Conservation Tracking Tool.

*Weather Data*

The weather variables were constructed from monthly data on precipitation, ETo, and average maximum air temperature from October 1990 to April 2015 taken from CIMIS Station 104 (De Laveaga), which situated within Santa Cruz city limits.

*Economic Data*

The economic data came from multiple sources. The water rate data set was constructed with Water Department records of water rates for each customer class. Annual unemployment rates in Santa Cruz for the period 1990 to 2014 come from the California Employment Development Department. Median and per capita income estimates for Inside City and Outside City customers come from Decennial Census and American Community Survey data. The income data cover estimation years 2000 and 2005-2013. Values for other years were imputed. Average annual residential vacancy rates for City of Santa Cruz for the years 1991-2014 are taken from the California Department of Finance (DOF E-8).

## Estimation Results

The average demand models were estimated with R version 3.2 statistical software. Robust regression methods were applied to down-weight outlier consumption data. For customer classes that had both Inside City and Outside City customers (e.g. residential, business, irrigation, and golf) fixed effects models were estimated so that the data could be pooled. Estimation results as summarized by adjusted R-squared are shown in Table 5. Across all classes, the models explain 90% to 96% of the observed variation in the data. All statistically significant model coefficients have the expected signs and magnitudes. Estimation results for each customer class are provided in Attachment 1.

**Table 45. Average Demand Model Estimation, Adjusted R-Square**

| Customer Class | Number of Observations | Adjusted R-Square |
|---|---|---|
| Single Family | 358 | 0.917 |
| Multi Family | 351 | 0.900 |
| Business | 353 | 0.942 |
| Municipal | 177 | 0.951 |
| Irrigation | 358 | 0.916 |
| Golf | 352 | 0.957 |

The estimated price elasticities derived from the econometric models are shown in Table 6. Inside and Outside City customers face different rates and so the models were first estimated to detect if price response was statistically different in the two regions. It was for the single family and golf classes, but not for the multi-family, business, and irrigation classes. The municipal class is Inside City only. Single family customers in the Outside City part of the service area were found to be slightly less price responsive than Inside City customers.

The estimated price response for single family is only about half as large as the interim forecast assumed: -0.11 versus -0.24. However, the estimated price responses for multi-family and business are identical to what was assumed in the interim forecast: -0.12 for multi-family and -0.10 for business. The estimated income elasticity for the single family customer class is 0.23, which is also very close to the 0.25 assumption used in the interim forecast.

Irrigation demands are seen to be more price responsive than residential and business demands, which is expected. The Pasatiempo golf course is an exception to this general finding. Its price response was not statistically different from zero. Perhaps this is because it is a top tier course and has a substantially higher willingness to pay for water than other irrigators.

**Table 46. Estimate Price Elasticity by Customer Class**

| **Class** | **Inside City** | **Outside City** |
|---|---|---|
| Single Family [1/] | -0.11 | -0.10 |
| Multi Family | -0.12 | |
| Business | -0.10 | |
| Municipal | -0.24 | NA |
| Irrigation | -0.54 | |
| Golf | -0.34 | 0.00 [2/] |

1/ Weighted average of estimate summer and winter elasticities
2/ Outside city elasticity for golf not statistically different from zero.

Estimated drought responses by customer class and stage are summarized in Table 7.

**Table 47. Average Change in Demand Attributable to Drought Stage**

| **Class** | **Stage 1** | **Stage 2** | **Stage 3** |
|---|---|---|---|
| Single Family | -5% | -7% | -35% |
| Multi Family | 0% | -3% | -17% |

| | | | |
|---|---|---|---|
| Business | 0% | 0% | -12% |
| Municipal | 0% | -10% | -46% |
| Irrigation | 0% | -22% | -60% |
| Golf | 0% | 0% | -31% |

Forecasted Average Demand

Class forecasts of average demand are shown in Table 8. These forecasts are based on the rate and income growth assumptions developed for the interim demand forecast and have been adjusted for plumbing code and Program A water savings. They presume normal weather and economic conditions.

**Table 48. Forecasted Average Demand by Customer Class (CCF/Year)**

| **YEAR** | | **2013** | **2020** | **2025** | **2030** | **2035** |
|---|---|---|---|---|---|---|
| | Per | Actual | Forecast | Forecast | Forecast | Forecast |
| Single Family | Housing Unit | 89 | 81 | 79 | 77 | 76 |
| Multi Family | Housing Unit | 54 | 47 | 43 | 41 | 39 |
| Business | Service | 445 | 405 | 391 | 382 | 372 |
| Municipal | Service | 323 | 289 | 282 | 272 | 263 |
| Irrigation | Service | 339 | 255 | 255 | 233 | 219 |
| Golf | Acre | 740 | 654 | 615 | 565 | 537 |

Population and Housing Unit Forecasts

The population and housing unit forecasts are anchored on the AMBAG 2014 Regional Growth Forecast (AMBAG 2014). Forecasted population and total housing units for Inside City and Outside City are shown in Tables 9 and 10.

**Table 49. Inside City Population and Housing Unit Forecasts**

| | **2010** 1/ | **2020** | **2025** | **2030** | **2035** |
|---|---|---|---|---|---|
| City Total Population 2/ | 59,946 | 66,860 | 70,058 | 73,375 | 76,692 |
| UCSC 3/ | 7,331 | 8,845 | 9,602 | 10,359 | 11,116 |
| City | 52,615 | 58,015 | 60,456 | 63,016 | 65,576 |
| In households 4/ | 50,711 | 55,916 | 58,268 | 60,736 | 63,203 |
| In group qtrs | 1,904 | 2,099 | 2,188 | 2,280 | 2,373 |
| Household size 5/ | 2.34 | 2.38 | 2.41 | 2.42 | 2.44 |
| City Housing Units | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Total [6/] | 22,913 | 24,854 | 25,580 | 26,594 | 27,429 |
| Occupied [7/] | 21,657 | 23,492 | 24,177 | 25,136 | 25,925 |
| Vacancy rate [8/] | 5.5% | 5.5% | 5.5% | 5.5% | 5.5% |

Notes

1/ Actual per 2010 Census.

2/ AMBAG 2014 Regional Growth Forecast (adopted June 11, 2014).

3/ 2020-35 forecast based on projected UCSC enrollment through 2035 and historical and projected share of students living on campus.

4/ 2020-35 forecast based on 2010 ratio of population in households to total population.

5/ 2020-35 forecast assumes household size increases at same rate as forecast for AMBAG region

6/ Occupied housing divided by one minus vacancy rate.

7/ Population in households divided by household size.

8/ 2020-35 vacancy rate assumed to equal 2010 census estimate.

**Table 50. Outside City Population and Housing Unit Forecasts**

| | 2010 [1/] | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|
| Population [2/] | 31,342 | 32,543 | 33,562 | 34,614 | 35,698 |
| In households [3/] | 30,678 | 31,853 | 32,851 | 33,880 | 34,941 |
| In group qtrs. | 665 | 690 | 712 | 734 | 757 |
| Household size [4/] | 2.39 | 2.43 | 2.46 | 2.46 | 2.48 |
| Housing Units | | | | | |
| Total [5/] | 14,323 | 14,630 | 14,902 | 15,329 | 15,669 |
| Occupied [6/] | 12,856 | 13,132 | 13,376 | 13,759 | 14,064 |
| Vacancy rate [7/] | 10.2% | 10.2% | 10.2% | 10.2% | 10.2% |

Notes

1/ Actual per 2010 Census.

2/ 2020 and 2035 Water Dept. forecast. 2025 and 2030 interpolated.

3/ 2020-35 forecast based on 2010 ratio of population in households to total population.

4/ 2020-35 forecast assumes household size increases at same rate as forecast for AMBAG region

5/ Occupied housing divided by one minus vacancy rate.

6/ Population in households divided by household size.

7/ 2020-35 vacancy rate assumed to equal 2010 census estimate.

These forecasts are used to project Inside City and Outside City single- and multi-family housing units with active water services. These forecasts are shown in Tables 11 and 12. The Inside City forecast calibrates exactly to the forecast of total occupied housing units in Table 9. This is not the case for the Outside City forecast. There is a discrepancy between Water Department data on housing units in 2014 with active water service and the forecast of occupied housing units in Table 10. The Water Department's estimate is higher by several hundred housing units. This issue is still under review and has not been resolved. For now, the forecast of Outside City housing units with active services is anchored to the Water Department's estimate of housing units, with growth in total units pegged to the growth in housing units in Table 10.

The disaggregation of total housing units into single- and multi-family housing units starts with the Water Department's 2014 estimates. Single-family housing units are then increased at their historical growth rate. In the case of Inside City single-family housing, growth is capped at 1,000 units based on the General Plan's estimate of potential for new single family housing.[31] No cap is applied to the Outside City forecast. Multi-family units are then the difference between the forecast of total units and single-family units. For the Inside City service area, three-fourths of the gain in housing units is multi-family. For the Outside City service area, multi-family units comprise a little less than half of the gain.

[31] The General Plan, which extends to 2030, identified a potential for 840 new single family units. This was increased to 1000 units since this forecast runs to 2035.

**Table 51. Inside City Forecast of Housing Units with Active Water Services**

| | 2014 [1/] | 2020 | 2025 | 2030 | 2035 | Gain From 2014 | % of Gain |
|---|---|---|---|---|---|---|---|
| Single Family [2/] | 12,246 | 12,534 | 12,780 | 13,030 | 13,246 | 1,000 | 24% |
| Multi Family [3/] | 9,583 | 10,958 | 11,398 | 12,106 | 12,679 | 3,096 | 76% |
| Total | 21,829 | 23,492 | 24,177 | 25,136 | 25,925 | 4,096 | 100% |

Notes

1/ Actual per Water Department billing records.

2/ 2020-35 forecast assumes up to 1,000 new units by 2035

3/ 2020-35 forecast equals the difference between total and single family forecasted units.

**Table 52. Outside City Forecast of Housing Units with Active Water Services**

| | 2014 [1/] | 2020 | 2025 | 2030 | 2035 | Gain From 2014 | % of Gain |
|---|---|---|---|---|---|---|---|
| Single Family [2/] | 6,743 | 6,922 | 7,074 | 7,230 | 7,390 | 647 | 52% |
| Multi Family [3/] | 7,901 | 7,910 | 8,033 | 8,310 | 8,495 | 594 | 48% |
| Total | 14,644 | 14,832 | 15,107 | 15,540 | 15,884 | 1,240 | 100% |

Notes

1/ Actual per Water Department billing records.

2/ 2020-35 forecast assumes single family units added at historical rate.

3/ 2020-35 forecast equals the difference between total and single family forecasted units.

Business, Municipal, and Irrigation Services Forecasts

Historically, the ratio of business demand to residential demand has been very stable at about 0.315. This ratio is used with the forecast of residential demand and average business demand per service to forecast the growth in business services. The number of new business services is added so that the ratio of business demand to residential demand is maintained at 0.315. This results in a gain of 150 new business services between 2013 and 2035. As a check on the forecast, it is noted that over the 18 year period 1996-2013, there was a gain of 120 business services. Extending this rate of growth to 22 years to match the length of our forecast would results in 147 new services, which is very close to the forecast of 150 new services for the 22 year period 2013 to 2035.

Based on discussions with Water Department Staff, no growth in municipal services is anticipated over the forecast horizon.

Growth in irrigation services is related to the growth in multi-family and business services. On average, 0.6 irrigation services have been added for the addition of a new multi-family or business service. This ratio is used with the forecast of multi-family and business services to project new irrigation services over the forecast horizon.

The forecasts of business, municipal, and irrigation services are presented in Table 13.

**Table 53. Business, Municipal, and Irrigation Services Forecasts**

| | 2013 [1/] | 2020 | 2025 | 2030 | 2035 | Gain From 2013 |
|---|---|---|---|---|---|---|
| Business [2/] | 1,889 | 1,910 | 1,935 | 1,980 | 2,039 | 150 |
| Municipal [3/] | 218 | 218 | 218 | 218 | 218 | 0 |
| Irrigation | 452 | 624 | 696 | 820 | 931 | 479 |

Notes

1/ Actual per Water Department billing records.

2/ Based on ratio of business to residential demand.

3/ Based on historical rate of gain in irrigation services per gain in multi-family and business services.

<u>Golf Course Acreage Forecast</u>

No change in irrigated acreage is forecast for the DeLaveaga golf course. This is not the case for Pasatiempo. Interviews with Pasatiempo staff indicate it has plans to reduce its reliance of City water starting this year. It expects to irrigate not more than 40 acres with City water by 2020 and not more than 20 acres by 2030. It currently irrigates about 67.5 acres with City water. The forecast of golf course acreage irrigated with City water is given in Table 14.

**Table 54. Golf Course City Water Irrigated Acreage Forecasts**

| | 2013 [1/] | 2020 | 2025 | 2030 | 2035 | Gain From 2013 |
|---|---|---|---|---|---|---|
| DeLaveaga | 78.9 | 78.9 | 78.9 | 78.9 | 78.9 | 0 |
| Pasatiempo [2/] | 67.5 | 40 | 30 | 20 | 20 | -47.5 |

Notes

1/ Actual per Water Department billing records.

2/ Per communication with Pasatiempo staff.

Industrial Demand Forecast

There is a strong relationship between Santa Cruz County manufacturing employment and industrial water demand. This relationship is illustrated in Figure 1. Prior to the recession, industrial demand averaged approximately 11.9 CCF per job. Immediately after the recession this increased to about 38.3 CCF per job. We use the pre-recession rate with a forecast of manufacturing employment in Santa Cruz County to project future industrial water demand. The pre-recession rather than the post-recession rate of water use per job is used because it is thought to better reflect the long-term rate under normal economic conditions. The Caltrans forecast of manufacturing employment for Santa Cruz County is used to forecast industrial water use. The California Employment Development Department also has a forecast of manufacturing employment, but this forecast extends only to 2022. The two forecasts are consistent, as shown in Table 15.

**Figure 86**

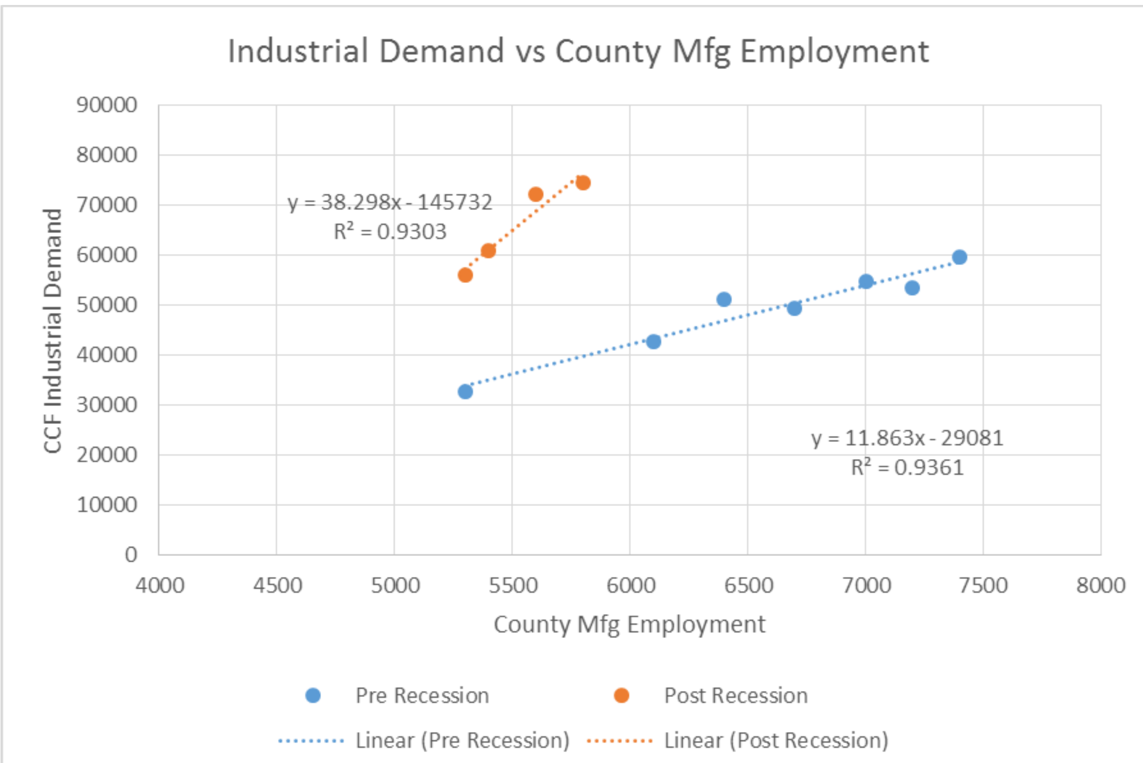


**Table 55. Industrial Water Demand Forecast**

| | 2013 [1/] | 2020 | 2022 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|---|
| Mfg Employment Forecast | | | | | | |
| EDD | 5,800 | | 6,000 | | | |
| Cal Trans | | 5,900 | | 6,200 | 6,400 | 6,500 |
| Industrial Water Demand | | | | | | |
| CCF [2/] | 74,451 | 75,641 | | 79,211 | 81,591 | 82,781 |
| MG | 56 | 57 | | 59 | 61 | 62 |

Notes
1/ Actual per Water Department billing records.
2/ Based on 11.9 CCF per manufacturing job.

UC Demand Forecast
The forecast of UC demand is the same as in the interim demand forecast.

Summary of Demand Forecast
Table 16 provides a summary of the class demand forecasts.

**Table 56. Summary of Demand Forecast**

| YEAR | | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|
| | | Forecast | Forecast | Forecast | Forecast |
| **Service Units** | **Units** | | | | |
| SFR | Housing Units | 19,456 | 19,854 | 20,260 | 20,636 |
| MFR | Housing Units | 18,867 | 19,430 | 20,416 | 21,174 |
| BUS | Services | 1,910 | 1,935 | 1,980 | 2,039 |
| IND | NA | NA | NA | NA | NA |
| MUN | Services | 218 | 218 | 218 | 218 |
| IRR | Services | 624 | 696 | 820 | 931 |
| GOLF | Acres | 119 | 109 | 99 | 99 |
| UC | NA | NA | NA | NA | NA |
| **Avg Demand** | **Units** | | | | |
| SFR | CCF | 81.1 | 79.1 | 77.3 | 76.2 |
| MFR | CCF | 46.9 | 43.1 | 40.9 | 39.5 |
| BUS | CCF | 405.3 | 391.4 | 381.6 | 371.6 |
| IND | NA | NA | NA | NA | NA |
| MUN | CCF | 288.7 | 282.5 | 272.5 | 262.8 |
| IRR | CCF | 254.9 | 255.1 | 232.5 | 219.2 |
| GOLF | CCF | 654.0 | 614.9 | 565.3 | 536.9 |
| UC | NA | NA | NA | NA | NA |
| **Annual Demand** | **Units** | | | | |
| SFR | MG | 1,180 | 1,175 | 1,172 | 1,177 |
| MFR | MG | 662 | 626 | 625 | 625 |
| BUS | MG | 579 | 566 | 565 | 567 |
| IND | MG | 57 | 59 | 61 | 62 |
| MUN | MG | 47 | 46 | 44 | 43 |
| IRR | MG | 119 | 133 | 143 | 153 |
| GOLF | MG | 58 | 50 | 42 | 40 |
| UC | MG | 196 | 234 | 271 | 308 |
| **Total Demand** | **MG** | **2,897** | **2,889** | **2,923** | **2,974** |
| MISC/LOSS | MG | 235 | 234 | 237 | 241 |
| **Total Production** | **MG** | **3,132** | **3,123** | **3,160** | **3,215** |
| **Rounded** | **MG** | **3,100** | **3,100** | **3,200** | **3,200** |

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## Attachment 1: Model Estimation Results

### Single Family Customer Class Model

| | Dependent variable: ln.adj.use |
|---|---|
| geooutside | 0.061 (0.018)*** |
| fmonthFeb | -0.013 (0.010) |
| fmonthMar | 0.014 (0.015) |
| fmonthApr | 0.159 (0.015)*** |
| fmonthMay | 0.451 (0.021)*** |
| fmonthJun | 0.564 (0.021)*** |
| fmonthJul | 0.632 (0.022)*** |
| fmonthAug | 0.615 (0.023)*** |
| fmonthSep | 0.550 (0.018)*** |
| fmonthOct | 0.360 (0.017)*** |
| fmonthNov | 0.143 (0.014)*** |
| fmonthDec | 0.053 (0.009)*** |
| temp.nov.mar | 0.203 (0.091)** |
| temp.apr.jun | 0.422 (0.204)** |
| temp.jul.oct | 0.636 (0.191)*** |
| rain.nov.mar | -0.016 (0.009)* |
| rain.apr.jun | -0.069 (0.014)*** |
| rain.jul.oct | -0.040 (0.020)** |
| ln.rain.dev.lag1 | -0.034 (0.006)*** |
| ln.rain.dev.lag2 | -0.026 (0.007)*** |
| ln.price.winter | -0.075 (0.010)*** |
| ln.price.summer | -0.139 (0.017)*** |
| ln.hh.inc | 0.228 (0.076)*** |
| drght.stage1 | -0.051 (0.019)*** |
| drght.stage2 | -0.071 (0.017)*** |
| drght.stage3 | -0.431 (0.019)*** |
| geooutside:ln.price.summer | 0.020 (0.009)** |
| Constant | -0.605 (0.845) |
| Observations | 358 |
| R2 | 0.923 |
| Adjusted R2 | 0.917 |
| Residual Std. Error | 0.064 (df = 330) |
| F Statistic | 147.089*** (df = 27; 330) |
| Note: | *p<0.1; **p<0.05; ***p<0.01 |

**Multi Family Customer Class Model**

| | Dependent variable: |
|---|---|
| | ln.adj.use |
| geooutside | 0.055 (0.012)*** |
| fmonthFeb | 0.009 (0.014) |
| fmonthMar | -0.006 (0.014) |
| fmonthApr | 0.031 (0.014)** |
| fmonthMay | 0.141 (0.013)*** |
| fmonthJun | 0.185 (0.012)*** |
| fmonthJul | 0.194 (0.015)*** |
| fmonthAug | 0.189 (0.013)*** |
| fmonthSep | 0.150 (0.012)*** |
| fmonthOct | 0.111 (0.011)*** |
| fmonthNov | 0.033 (0.015)** |
| fmonthDec | -0.001 (0.013) |
| temp.nov.mar | 0.100 (0.066) |
| temp.apr.jun | 0.338 (0.099)*** |
| temp.jul.oct | -0.037 (0.089) |
| rain.nov.mar | 0.001 (0.005) |
| rain.apr.jun | -0.020 (0.009)** |
| rain.jul.oct | -0.018 (0.008)** |
| ln.price | -0.124 (0.029)*** |
| ln.vac.cap.dev | -0.164 (0.058)*** |
| drght.stage1 | -0.009 (0.010) |
| drght.stage2 | -0.028 (0.008)*** |
| drght.stage3 | -0.192 (0.010)*** |
| geooutside:fmonthFeb | -0.030 (0.017)* |
| geooutside:fmonthMar | 0.002 (0.021) |
| geooutside:fmonthApr | 0.051 (0.017)*** |
| geooutside:fmonthMay | 0.018 (0.016) |
| geooutside:fmonthJun | 0.022 (0.018) |
| geooutside:fmonthJul | 0.044 (0.017)*** |
| geooutside:fmonthAug | 0.031 (0.016)** |
| geooutside:fmonthSep | 0.057 (0.018)*** |
| geooutside:fmonthOct | 0.017 (0.014) |
| geooutside:fmonthNov | 0.041 (0.016)** |
| geooutside:fmonthDec | 0.033 (0.014)** |
| Constant | 1.726 (0.035)*** |
| Observations | 351 |
| R2 | 0.909 |
| Adjusted R2 | 0.900 |
| Residual Std. Error | 0.035 (df = 316) |
| F Statistic | 93.266*** (df = 34; 316) |
| Note: | *p<0.1; **p<0.05; ***p<0.01 |

**Business Customer Class Model**

```
===================================================
                          Dependent variable:
                       ---------------------------
                               ln.adj.use
---------------------------------------------------
geooutside                  0.486 (0.048)***
fmonthFeb                    0.033 (0.017)*
fmonthMar                   0.048 (0.017)***
fmonthApr                   0.116 (0.015)***
fmonthMay                   0.250 (0.016)***
fmonthJun                   0.330 (0.015)***
fmonthJul                   0.396 (0.017)***
fmonthAug                   0.380 (0.018)***
fmonthSep                   0.273 (0.015)***
fmonthOct                   0.172 (0.014)***
fmonthNov                    0.044 (0.020)**
fmonthDec                    -0.005 (0.020)
temp.nov.mar                 0.243 (0.103)**
temp.apr.jun                 0.400 (0.193)**
temp.jul.oct                 -0.135 (0.121)
rain.nov.mar                  0.001 (0.007)
rain.apr.jun                -0.034 (0.013)***
rain.jul.oct                -0.028 (0.010)***
rain.lag1.apr.jun           -0.017 (0.008)**
ln.price                    -0.099 (0.017)***
ln.unemp.rate.dev.city      -0.160 (0.011)***
drght.stage3                -0.123 (0.008)***
geooutside:fmonthFeb         -0.037 (0.021)*
geooutside:fmonthMar         -0.021 (0.026)
geooutside:fmonthApr          0.010 (0.020)
geooutside:fmonthMay         -0.037 (0.022)*
geooutside:fmonthJun         -0.031 (0.023)
geooutside:fmonthJul        -0.064 (0.022)***
geooutside:fmonthAug        -0.067 (0.024)***
geooutside:fmonthSep          0.007 (0.024)
geooutside:fmonthOct          0.018 (0.020)
geooutside:fmonthNov         0.062 (0.025)**
geooutside:fmonthDec         0.040 (0.022)*
geooutside:ln.price         -0.163 (0.028)***
geooutside:drght.stage3     -0.068 (0.011)***
Constant                    3.488 (0.023)***
---------------------------------------------------
Observations                      353
R2                               0.948
Adjusted R2                      0.942
Residual Std. Error         0.047 (df = 317)
F Statistic             163.460*** (df = 35; 317)
===================================================
```

**Municipal Customer Class Model**

| | Dependent variable: ln.use |
| --- | --- |
| fmonthFeb | -0.025 (0.040) |
| fmonthMar | 0.101 (0.057)* |
| fmonthApr | 0.767 (0.052)*** |
| fmonthMay | 1.214 (0.049)*** |
| fmonthJun | 1.424 (0.046)*** |
| fmonthJul | 1.553 (0.040)*** |
| fmonthAug | 1.579 (0.041)*** |
| fmonthSep | 1.360 (0.045)*** |
| fmonthOct | 1.061 (0.042)*** |
| fmonthNov | 0.521 (0.039)*** |
| fmonthDec | 0.087 (0.034)** |
| eto.nov.mar | 0.516 (0.138)*** |
| eto.apr.jun | 0.804 (0.242)*** |
| eto.jul.oct | 0.357 (0.107)*** |
| rain.nov.mar | 0.037 (0.036) |
| rain.apr.jun | -0.147 (0.050)*** |
| rain.jul.oct | 0.006 (0.038) |
| ln.rain.dev.lag1 | -0.097 (0.019)*** |
| ln.rain.dev.lag2 | -0.063 (0.019)*** |
| ln.price | -0.237 (0.063)*** |
| ln.unemp.rate.dev.city | -0.142 (0.046)*** |
| drght.stage2 | -0.108 (0.034)*** |
| drght.stage3 | -0.621 (0.035)*** |
| Constant | 2.645 (0.076)*** |
| Observations | 177 |
| R2 | 0.957 |
| Adjusted R2 | 0.951 |
| Residual Std. Error | 0.137 (df = 153) |
| F Statistic | 149.772*** (df = 23; 153) |
| Note: | *p<0.1; **p<0.05; ***p<0.01 |

**Irrigation Customer Class Model**

| | Dependent variable: |
|---|---|
| | ln.use |
| geooutside | 0.150 (0.034)*** |
| fmonthFeb | 0.058 (0.039) |
| fmonthMar | 0.380 (0.076)*** |
| fmonthApr | 1.256 (0.069)*** |
| fmonthMay | 1.697 (0.052)*** |
| fmonthJun | 1.938 (0.045)*** |
| fmonthJul | 2.028 (0.046)*** |
| fmonthAug | 1.992 (0.046)*** |
| fmonthSep | 1.920 (0.048)*** |
| fmonthOct | 1.614 (0.049)*** |
| fmonthNov | 1.073 (0.043)*** |
| fmonthDec | 0.479 (0.053)*** |
| eto.nov.mar | 0.509 (0.207)** |
| eto.apr.jun | 0.660 (0.243)*** |
| eto.jul.oct | 0.163 (0.184) |
| rain.nov.mar | -0.044 (0.049) |
| rain.apr.jun | -0.116 (0.065)* |
| rain.jul.oct | -0.085 (0.040)** |
| ln.rain.dev.lag1 | -0.166 (0.025)*** |
| ln.rain.dev.lag2 | -0.090 (0.021)*** |
| ln.price | -0.545 (0.069)*** |
| drght.stage1 | -0.077 (0.048) |
| drght.stage2 | -0.250 (0.044)*** |
| drght.stage3 | -0.930 (0.081)*** |
| Constant | 2.681 (0.080)*** |
| Observations | 358 |
| R2 | 0.922 |
| Adjusted R2 | 0.916 |
| Residual Std. Error | 0.216 (df = 333) |
| F Statistic | 164.036*** (df = 24; 333) |
| Note: | *p<0.1; **p<0.05; ***p<0.01 |

**Golf Customer Class Model**

| | Dependent variable: |
|---|---|
| | ln.use |
| geooutside | 0.783 (0.163)*** |
| fmonthFeb | -0.255 (0.136)* |
| fmonthMar | 0.082 (0.124) |
| fmonthApr | 2.781 (0.227)*** |
| fmonthMay | 4.094 (0.180)*** |
| fmonthJun | 4.765 (0.165)*** |
| fmonthJul | 4.950 (0.167)*** |
| fmonthAug | 5.034 (0.166)*** |
| fmonthSep | 4.814 (0.162)*** |
| fmonthOct | 4.387 (0.162)*** |
| fmonthNov | 3.058 (0.129)*** |
| fmonthDec | 0.696 (0.262)*** |
| eto.nov.mar | 0.626 (0.357)* |
| eto.apr.jun | 0.352 (0.487) |
| eto.jul.oct | 0.767 (0.232)*** |
| rain.nov.mar | -0.155 (0.087)* |
| rain.apr.jun | -0.519 (0.139)*** |
| rain.jul.oct | -0.036 (0.056) |
| ln.rain.dev.lag1 | -0.613 (0.056)*** |
| ln.rain.dev.lag2 | -0.092 (0.037)** |
| ln.price.summer | -0.338 (0.098)*** |
| drght.stage3 | -0.368 (0.071)*** |
| geooutside:fmonthFeb | 0.399 (0.216)* |
| geooutside:fmonthMar | 0.207 (0.240) |
| geooutside:fmonthApr | -0.451 (0.278) |
| geooutside:fmonthMay | -0.880 (0.252)*** |
| geooutside:fmonthJun | -1.080 (0.237)*** |
| geooutside:fmonthJul | -1.102 (0.240)*** |
| geooutside:fmonthAug | -1.109 (0.232)*** |
| geooutside:fmonthSep | -1.098 (0.235)*** |
| geooutside:fmonthOct | -0.986 (0.230)*** |
| geooutside:fmonthNov | -0.443 (0.192)** |
| geooutside:fmonthDec | 0.634 (0.310)** |
| geooutside:ln.price.summer | 0.376 (0.126)*** |
| Constant | 0.344 (0.110)*** |
| Observations | 352 |
| R2 | 0.957 |
| Adjusted R2 | 0.953 |
| Residual Std. Error | 0.368 (df = 317) |
| F Statistic | 209.736*** (df = 34; 317) |
| Note: | *p<0.1; **p<0.05; ***p<0.01 |

G A R Y  F I S K E  A N D  A S S O C I A T E S ,  I N C .
*Water Resources Planning and Management*

# EVALUATION OF ALTERNATIVE APPROACHES TO INCREASE PUMPING FROM FELTON DIVERSION TO LOCH LOMOND RESERVOIR

## EXECUTIVE SUMMARY

The WSAC process has provided an opportunity to explore in detail ways to more effectively capture excess winter flows. As part of that exploration, the Confluence® model was used to evaluate a range of alternatives to determine their effectiveness in increasing pumping from Felton to Loch Lomond and improving water supply reliability. Two operational changes and three infrastructure improvements were analyzed, both separately and in combination, as follows:

<u>Felton Operational Changes</u>

- Removing current first flush constraint
- Removing current turbidity constraint

<u>Infrastructure Improvements</u>

- Replacing existing pipe between Felton and Loch Lomond
- Adding a second pipe between Felton and Loch Lomond
- Improving the pump configuration at the Felton diversion

The evaluation resulted in the following key conclusions:

- If the Water Department determines it is feasible to relax the first flush constraint or remove it completely in dry years, lake fill and water supply reliability could improve significantly.

- Replacement of the current hydraulically-limited pipe with one that does not suffer from such limitations also provides important benefits, but if the first flush constraint remains, the new pipe would not reduce shortages in the worst year.

- Once the pipe is replaced, improving the current pump configuration at the Felton diversion to enable full utilization of the permitted pumping rate will further improve system reliability, but again as long as the City cannot divert prior to first flush, there are no worst-year benefits.

- Combining these three actions would provide even greater benefits, including significant reductions in worst-year shortages.

- Neither removing the Felton turbidity constraint or adding a second pipe between Felton and the lake provides any additional benefits.

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Table ES-1 summarizes the reliability benefits that could be achieved, and also shows the peak-season shortages that remain, which would need to be addressed with other investments in supply or infrastructure.

**Table ES-1. Comparison of Peak-Season Shortages**

| Configuration | Worst-Year Peak Season Shortage | | Average-Year Peak Season Shortage | |
|---|---|---|---|---|
| | Volume (mg) | Percent | Volume (mg) | Percent |
| **Current** | 1110 | 57% | 340 | 17% |
| **No First Flush** | 950 | 49% | 230 | 12% |
| **Replacement Pipe** | 1110 | 57% | 250 | 13% |
| **No First Flush & Replacement Pipe** | 780 | 40% | 130 | 7% |
| **Replacement Pipe & Pump Improvements** | 1110 | 57% | 190 | 10% |
| **No First Flush, Replacement Pipe & Pump Improvements** | 650 | 33% | 80 | 4% |

**INTRODUCTION**

The WSAC process has provided an opportunity to explore in detail ways to more effectively capture excess winter flows. As part of that exploration, the Confluence® model was used to evaluate a range of operational and infrastructure alternatives to determine their effectiveness in increasing pumping from Felton to Loch Lomond and improving water supply reliability. The purpose of this document is to report the results of that analysis.

It is critical to emphasize that increased Felton pumping is not the ultimate goal. Rather, the goal is to improve the reliability of water deliveries to customers. One way to improve this reliability is to maximize the contents of Loch Lomond at the beginning of the dry season, and increasing pumping from Felton to the lake is often considered a good strategy to achieve this. However, depending on hydrologic conditions, increased pumping at Felton may or may not result in commensurate increases in either lake levels or deliveries to customers. This will become clearer in the discussions that follow.

**CURRENT SITUATION**

All of the results shown in this document assume that available flows are limited by DFG-5 fish flow requirements and both flows and weather correspond to our climate change scenario. With these assumptions, the modeled distribution of peak-season shortages with current infrastructure and operations is shown in Figure 87.

**Figure 87. Distribution of Peak Season Shortages: Current Infrastructure and Operations**

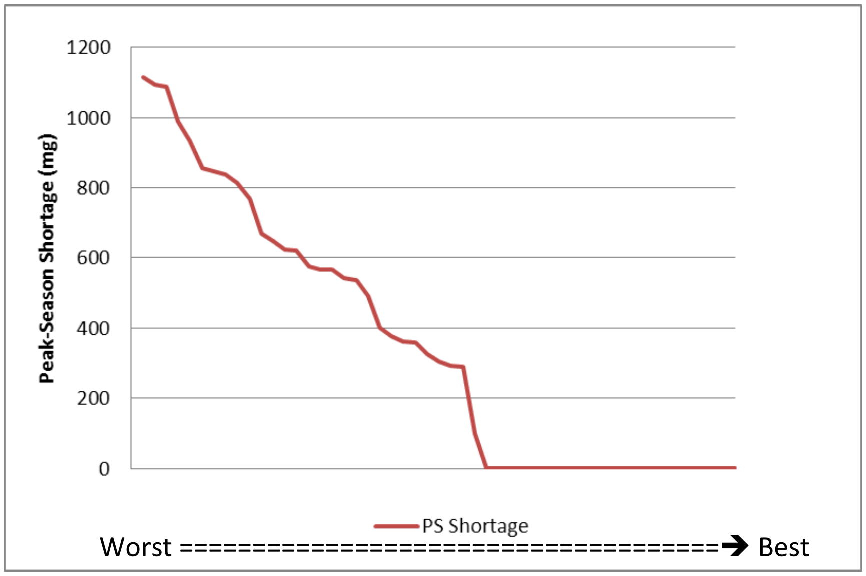
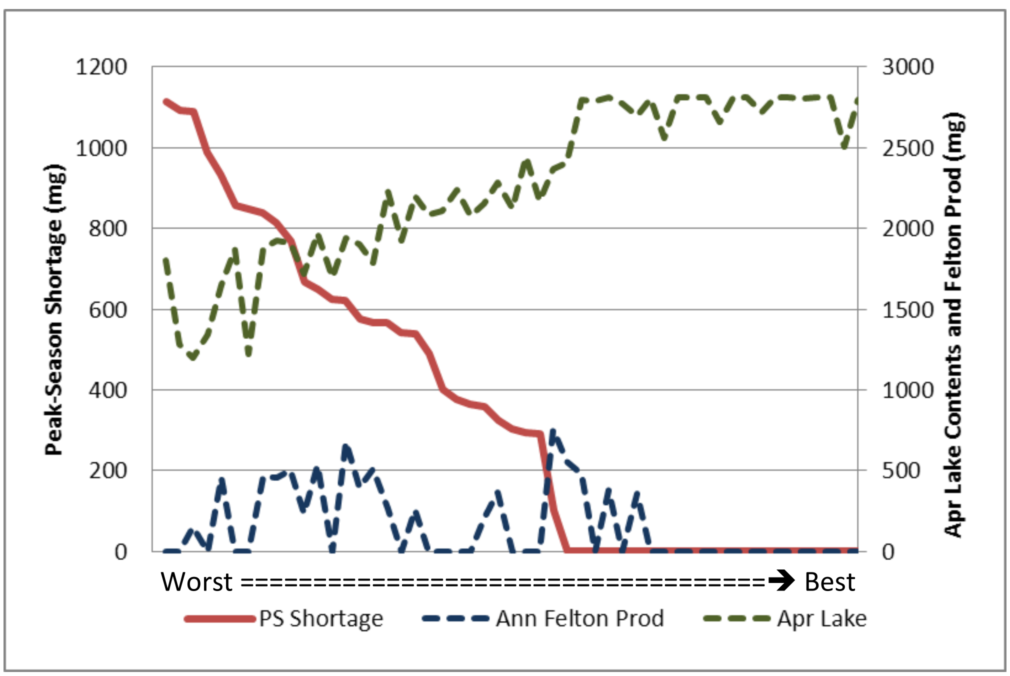



Figure 88 overlays the annual Felton pumping and the end-of-April (start of dry season) lake levels on this shortage distribution.

**Figure 88. Shortage Distribution with Overlay of Annual Felton Pumping and End-of-April Lake Contents**



Three important conclusions can be drawn:

- The years with small shortages tend to be those in which the lake level at the start of the dry season is higher.
- The volumes pumped are near zero in the wetter years. This is due in part to hydraulic constraints in the existing pipeline between Felton and the lake, and in part to there being much less room in the lake in those years. In any event, added pumping in those years would result in little increase in the lake volume available in the dry months and no improvement in reliability to customers (since shortages are already zero).
- The volumes pumped are also near zero in the driest years. This is due largely to the current first-flush operating constraint that will be discussed below.

**POTENTIAL CHANGES IN INFRASTRUCTURE AND OPERATIONS**

This paper evaluates the effectiveness of the following operational changes and infrastructure improvements in increasing Felton diversions and, ultimately, improving reliability of water deliveries to customers:

Operational Changes

- First Flush. The Water Department currently does not divert from Felton in the fall until after there have been sufficient flows to “flush” solids and other contaminants that have accumulated in the river over the dry season. The specific modeled constraint is that diversions cannot start until there have been two days of flow at Big Trees that are at least 100 cfs. With climate change, there are few if any days with flows that high in the driest years. Thus, there are virtually no diversions in those years.

  The Water Department is investigating the possibility of relaxing that constraint, considering such issues as exposing the rubber dam at Felton to major debris flows, water quality issues associated with storing pre-flush water in the lake, and others. For purposes of this evaluation, we assessed the impacts on lake fill and water supply reliability of completely removing the first flush requirement.

- Turbidity. Felton is currently turned out on days when turbidity levels are too high (>25 ntu). We evaluated the extent to which removing that constraint would improve lake fill and reliability.

Infrastructure Improvements

The water right at Felton allows diversion rates of up to 20 cfs in most months.[32] Current infrastructure does not allow the City to take maximum advantage of this water right. We evaluated the effectiveness

[32] Diversions at Felton are also limited to 3000 acre-feet (978 mg) per year.

of several infrastructure investments that have the potential of enabling better use of the right. Two of these improvements focus on the pipe between Felton and Loch Lomond. The third improves the pumps at the diversion.

- Replacement Pipe. The current pipe between Felton and Loch Lomond is old and limited in the pressures it can withstand. This limits the rate at which the lake can be filled, especially when lake levels are higher. We evaluated the impacts of replacing this pipe so as to remove those constraints.

- Second Pipe. The current single-pipe configuration precludes pumping from Felton on any day that the lake is being drawn down to serve demand. There are two situations in which the lake will be drawing down:

    1. The river flows at Tait Street on a particular day are not sufficient to fully meet demand. On this kind of day, Felton will not divert in any event, since all flows are needed at Tait.

    2. River turbidity precludes diversion at Tait Street. Currently, the turbidity constraints at Felton and Tait are assumed to be the same. Thus, on this type of day, we also could not divert at Felton. However, if the turbidity constraint at Felton is relaxed or removed, then a second pipe could allow the lake to fill on days on which high turbidity shuts down Tait Street and the lake is drawn down. We therefore evaluated the benefits of a second pipe assuming removal of the Felton turbidity constraint.

- Pumping upgrades. The current pump configuration at the Felton diversion limits the maximum diversion rate and only allows diversions at certain rates below that maximum. Replacing the pipe creates the possibility of additional benefit from upgrading the pumps.

Following are discussions of how these operating and infrastructure changes affect system reliability. Alternatives are first evaluated separately and then particular operating and infrastructure changes are combined.

**REMOVING FIRST FLUSH CONSTRAINT**

If the Water Department was able to completely remove the first flush constraint, substantially more water could be diverted to the lake, especially in the driest years. Figure 89 shows the improvement in Felton pumping volumes if this constraint were removed. The average annual volume pumped increases by 140 mg. In the driest year, the pumping volume goes from zero to more than 500 mg.

Figure 90 shows the resulting improvement in the distribution of peak-season shortages. The worst-year peak-season shortage is reduced by 160 mg.[33] On average, the peak-season shortage decreases by just over 100 mg.

---

[33] The worst-year peak-season shortage reduction is considerably less than the increased pumping volume for several reasons:

- A small fraction of the pumped volumes is lost to evaporation.
- A portion of the increased diversion is used in the off-peak season.
- The peak-season shortage in the year that was worst prior to removal of the first flush constraint is reduced to a point where another year (which does not benefit as much from the removal of this constraint) becomes the worst year.

**Figure 89. Added Felton Pumping from Removing First Flush Constraint**

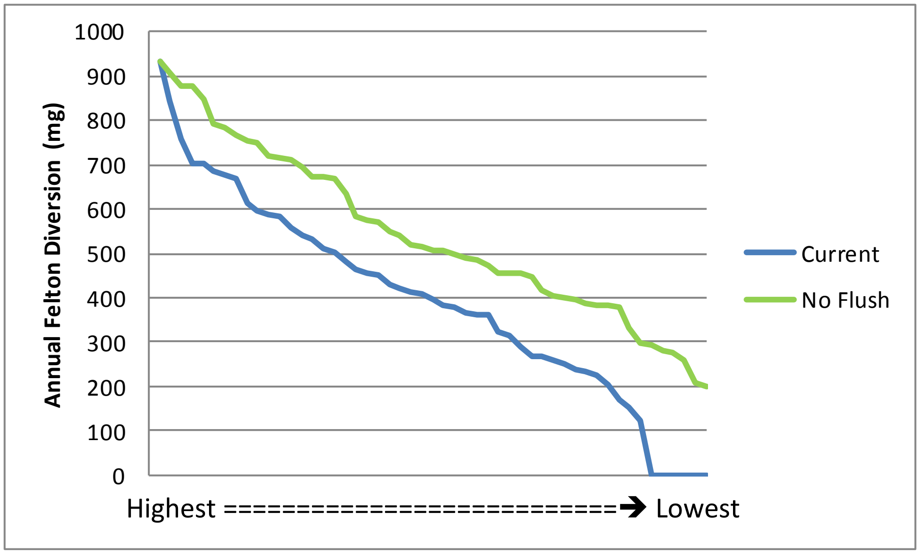
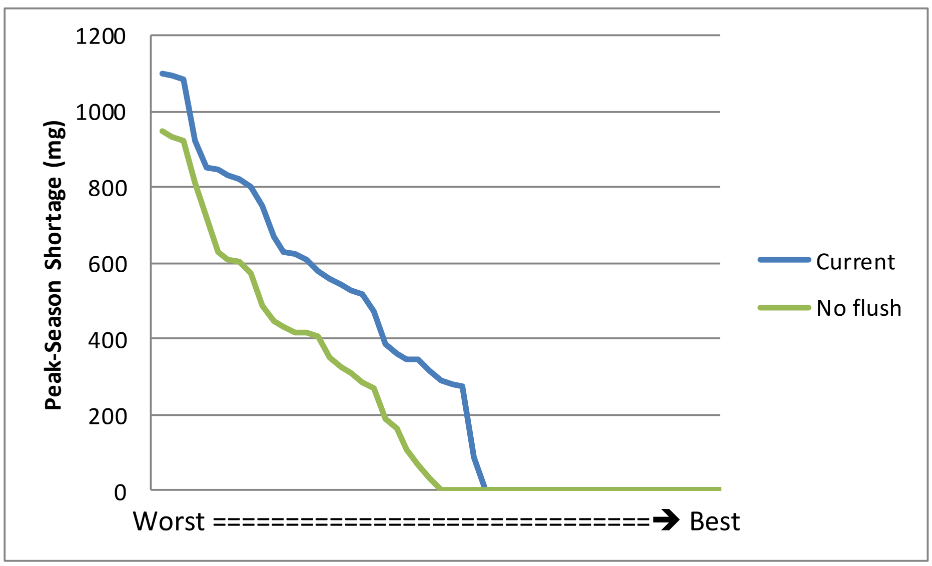



**Figure 90. Improvements in Peak-Season Shortages from Removing First Flush Constraint**




<u>Summary</u>

A determination by the Water Department that water could be diverted from Felton without waiting for a first flush could result in significant increased diversion volumes and improvements in system reliability.

**REMOVING TURBIDITY CONSTRAINT**

As discussed above, simply removing the Felton turbidity constraint without a second pipe that would allow for simultaneous lake fill and drawdown does not provide any benefit. The combination of these two changes will be discussed below.

**REPLACING EXISTING PIPE**

Figure 91 shows the increase in Felton diversions that results from replacing the existing pipe with one that does not have the hydraulic limitations of the current pipe. Figure 92 shows the resulting peak-season shortage reductions.

**Figure 91. Added Felton Pumping from Replacing Felton-Loch Lomond Pipe**

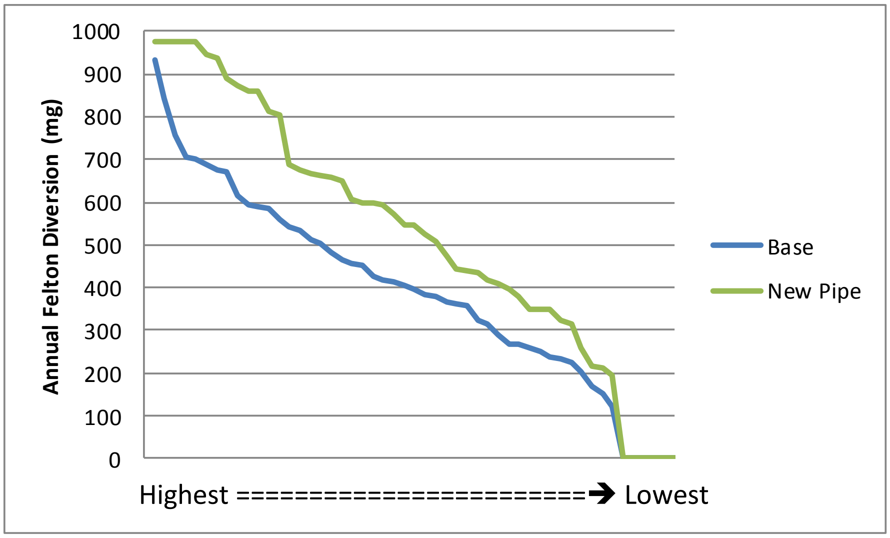
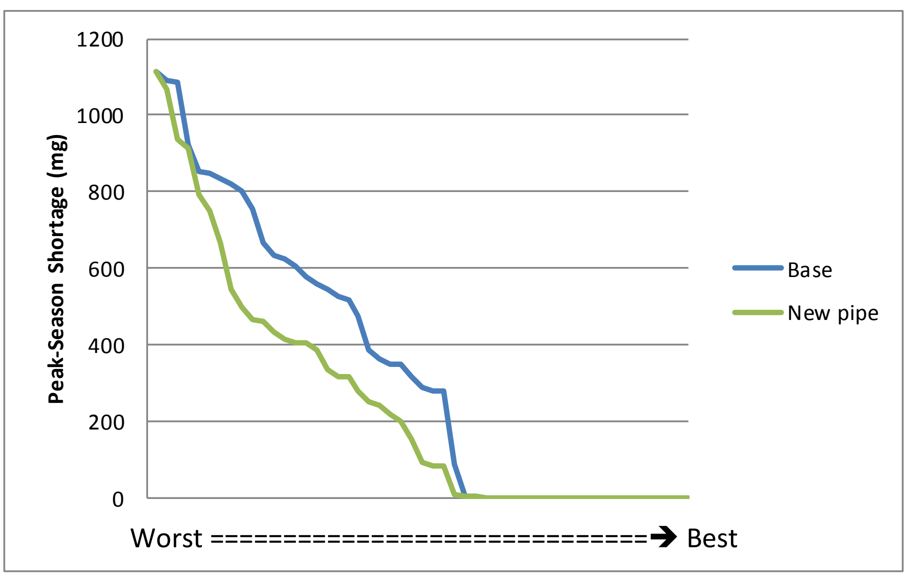



**Figure 92. Peak-Season Shortage Improvements from Replacing Felton-Loch Lomond Pipe**



Summary

Replacing the pipe between Felton and Loch Lomond results in a noticeable improvement in the system reliability profile. It does not provide a benefit in the driest year because the first-flush constraint precludes any diversion in that year.

**ADDING SECOND PIPE and REMOVING TURBIDITY CONSTRAINT**

As discussed above, any benefit of adding a second pipe is only realized if at the same time the constraint on diverting turbid water at Felton is relaxed. It is assumed that the second pipe provides the same hydraulic improvements as the replacement pipe (see above). Figure 93 compares the Felton diversion profiles with a second pipe (and no turbidity constraint) and with a replacement pipe (from Figure 91). Figure 94 shows the corresponding peak-season shortages.

Summary

A second pipe provides virtually no added benefit. This can be understood as follows:

- The days on which there could be a benefit from a second pipe are those on which Loch Lomond could potentially fill and draw down, i.e. days of excessive turbidity.
- In the driest years, there are very few such events, particularly with climate change.
- Most of those events tend to occur in the wetter years, when the lake is close to full and there is little opportunity to divert.
- Even in the years when there is some small additional diversion, there is no system reliability benefit because those are years in which the lake would have filled or nearly filled in any event.

**Figure 93. Annual Felton Diversions with Replacement Pipe and Second Pipe**

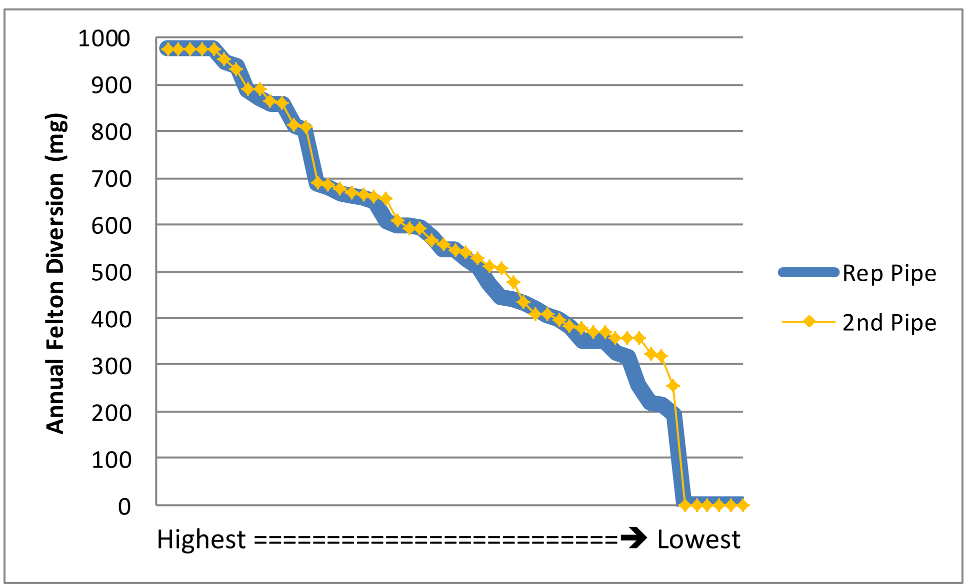
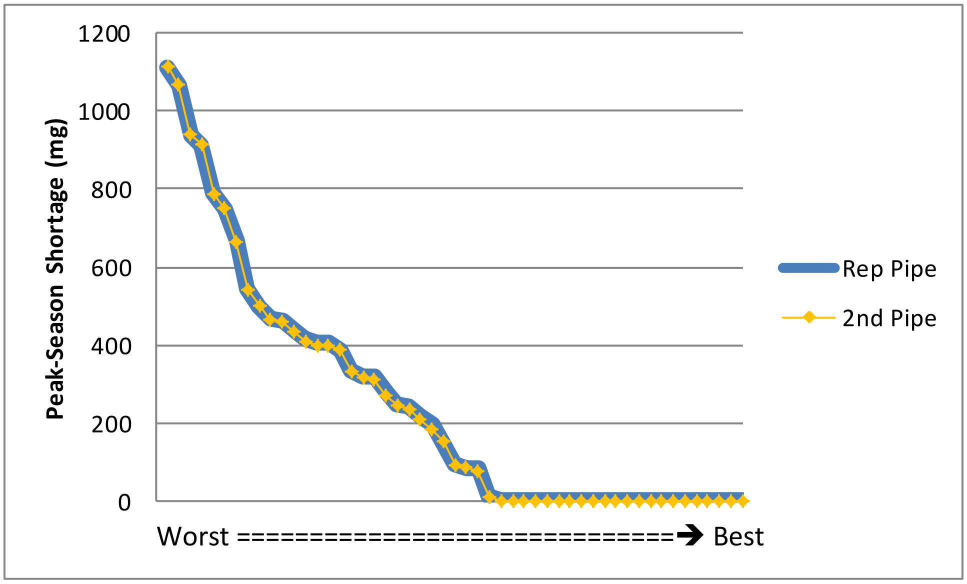


**Figure 94. Peak-Season Shortages with Replacement Pipe and Second Pipe**




**REPLACING EXISTING PIPE and IMPROVING PUMPS**

Once the pipe has been replaced, Figure 95 shows the added Felton pumping volumes that result from improving the pump configuration at the diversion to enable maximum usage of the 20 cfs water right. Figure 96 shows the resulting improvement in system reliability.

**Figure 95. Annual Felton Pumping with Replacement Pipe and Pumping Improvements**

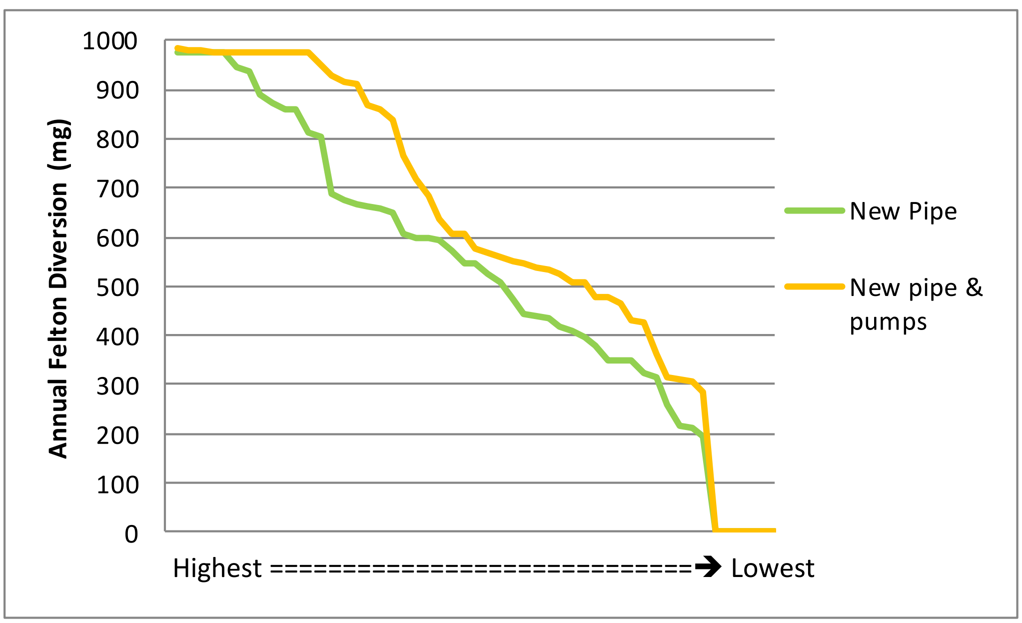
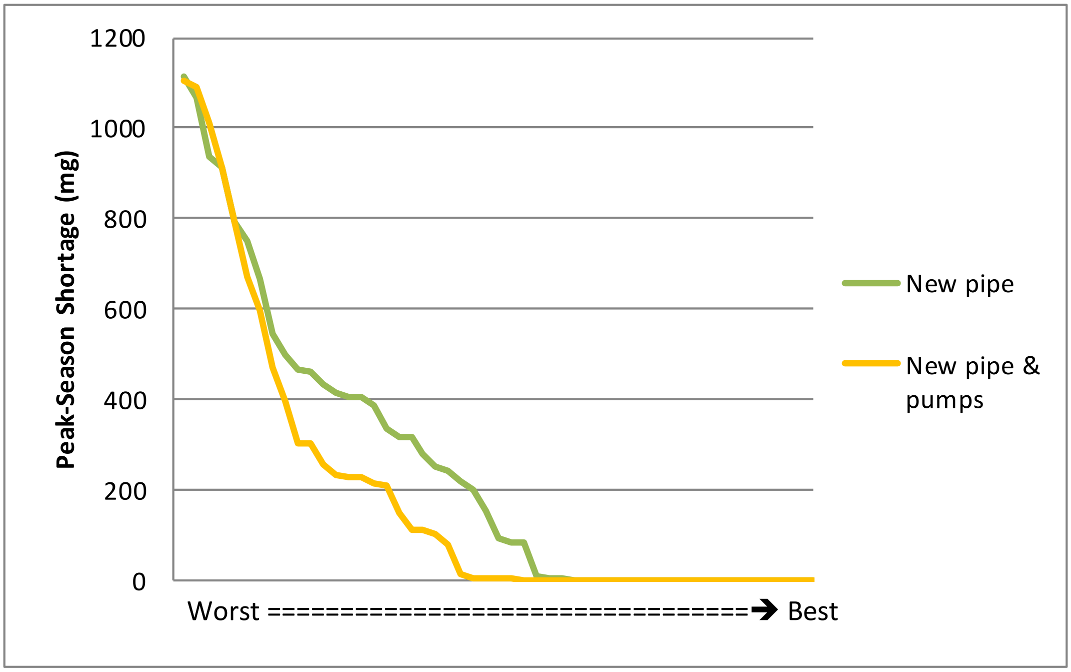


**Figure 96. Peak-Season Shortages with Replacement Pipe and Pumping Improvements**




Summary

Once the current pipe is replaced, upgrading the pumps at the diversion further improves reliability, but once again, there is no benefit in the driest year as long as the first-flush constraint remains.

**REMOVING FIRST FLUSH CONSTRAINT and REPLACING EXISTING PIPE**

Figure 97 shows the increased Felton diversion volumes that result from removing the first flush constraint and replacing the existing pipe. Figure 98 compares the corresponding peak-season shortages.

**Figure 97. Felton Diversion with No First Flush Constraint and New Pipe**

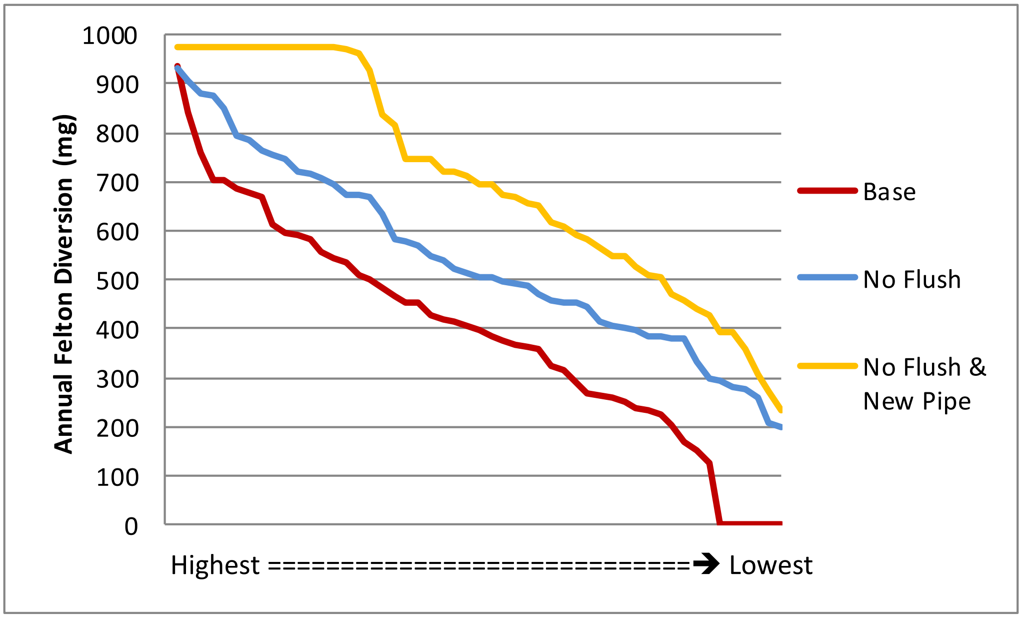
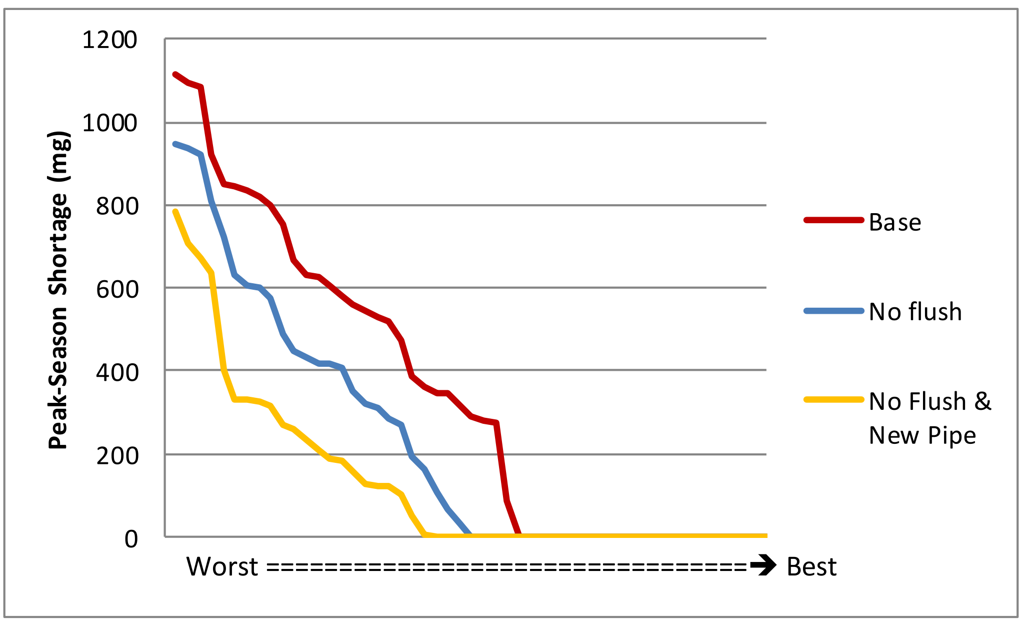



**Figure 98. Peak-Season Shortages with No First Flush Constraint and New Pipe**




<u>Summary</u>

Combining the removal of the first flush constraint at Felton with pipe replacement significantly improves the shortage profile, reducing the worst-year peak-season shortage to less than 800 mg, which is 300 mg less than the current situation.

**REPLACING EXISTING PIPE <u>and</u> IMPROVING PUMPS <u>and</u> REMOVING FIRST FLUSH CONSTRAINT**

Figure 99 compares the annual Felton diversion volumes that result from (1) removing the first flush constraint, (2) combining that with replacing the existing pipe, and (3) combining those actions with pump improvements. Figure 100 compares the resulting distributions of peak-season shortages.

**Figure 99. Felton Diversion with No First Flush Constraint, New Pipe, and New Pumps**

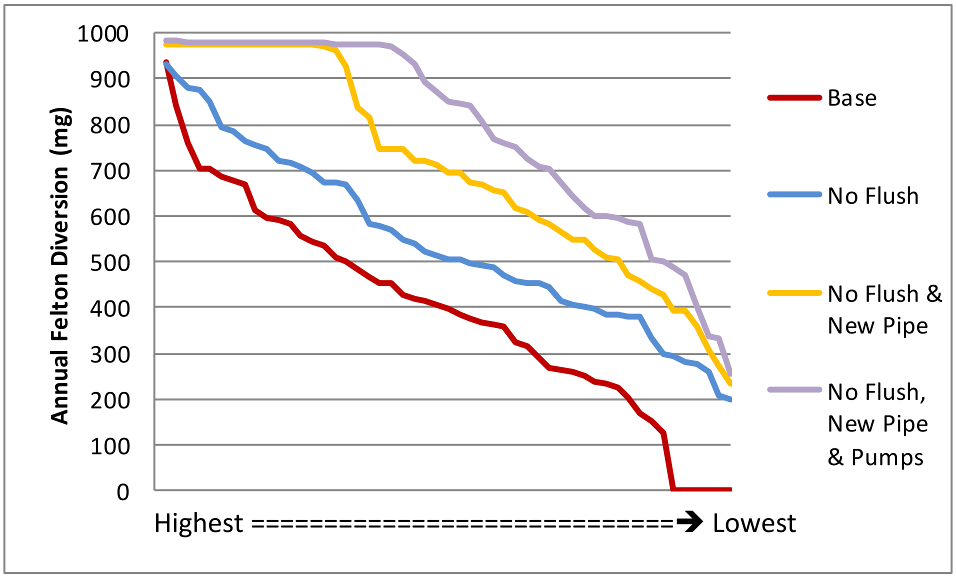
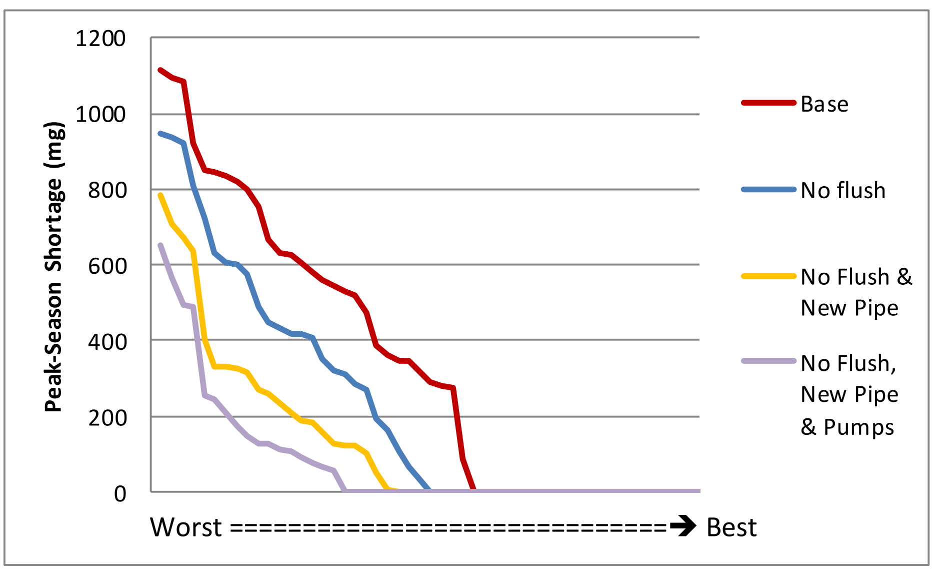



**Figure 100. Peak-Season Shortages with No First Flush Constraint, New Pipe, and New Pumps**




<u>Summary</u>

If each action proves feasible, then removing the first flush constraint, replacing the pipe to the lake, and improving the pumps at the diversion each result in added diversions at Felton and improvements in system reliability. The combination of these three actions reduces the worst year peak-season shortage from about 1100 mg to 650 mg and reduces the average peak-season shortage from 340 mg to 80 mg.

**CONCLUSIONS**

It behooves the Water Department to thoroughly explore any operational or infrastructure alternatives that might result in increased diversions from Felton to Loch Lomond that would improve water supply reliability. The foregoing analysis has shown that there are alternatives that show promise:

- If it proves operationally feasible to relax the current first flush constraint at Felton or completely remove it in dry years, significantly more water could be diverted to the lake with corresponding benefits to system reliability.
- Replacing the existing pipe between Felton and Loch Lomond with one that is not burdened with the same hydraulic constraints also yields notable benefits.
- Pump improvements at the Felton diversion further increase diversions and reduce customer shortages.

Neither removing the current turbidity constraint at Felton or adding a second pipe provides added benefits to Santa Cruz customers.

Table 57 compares the peak-season shortages with the current system configuration to those that the model forecasts with these separate and combined alternatives. The combined alternative significantly improves water supply reliability. However, we are still left with peak-season shortages that must be addressed with other supply or infrastructure investments.

**Table 57. Comparison of Peak-Season Shortages**

| Configuration | Worst-Year Peak Season Shortage | | Average-Year Peak Season Shortage | |
|---|---|---|---|---|
| | Volume (mg) | Percent | Volume (mg) | Percent |
| **Current** | 1110 | 57% | 340 | 17% |
| **No First Flush** | 950 | 49% | 230 | 12% |
| **Replacement Pipe** | 1110 | 57% | 250 | 13% |
| **No First Flush & Replacement Pipe** | 780 | 40% | 130 | 7% |
| **Replacement Pipe & Pump Improvements** | 1110 | 57% | 190 | 10% |
| **No First Flush, Replacement Pipe & Pump Improvements** | 650 | 33% | 80 | 4% |

DATE: August 24, 2015
TO: Rosemary Menard
FR: David Mitchell
RE: Corrected Demand Forecast

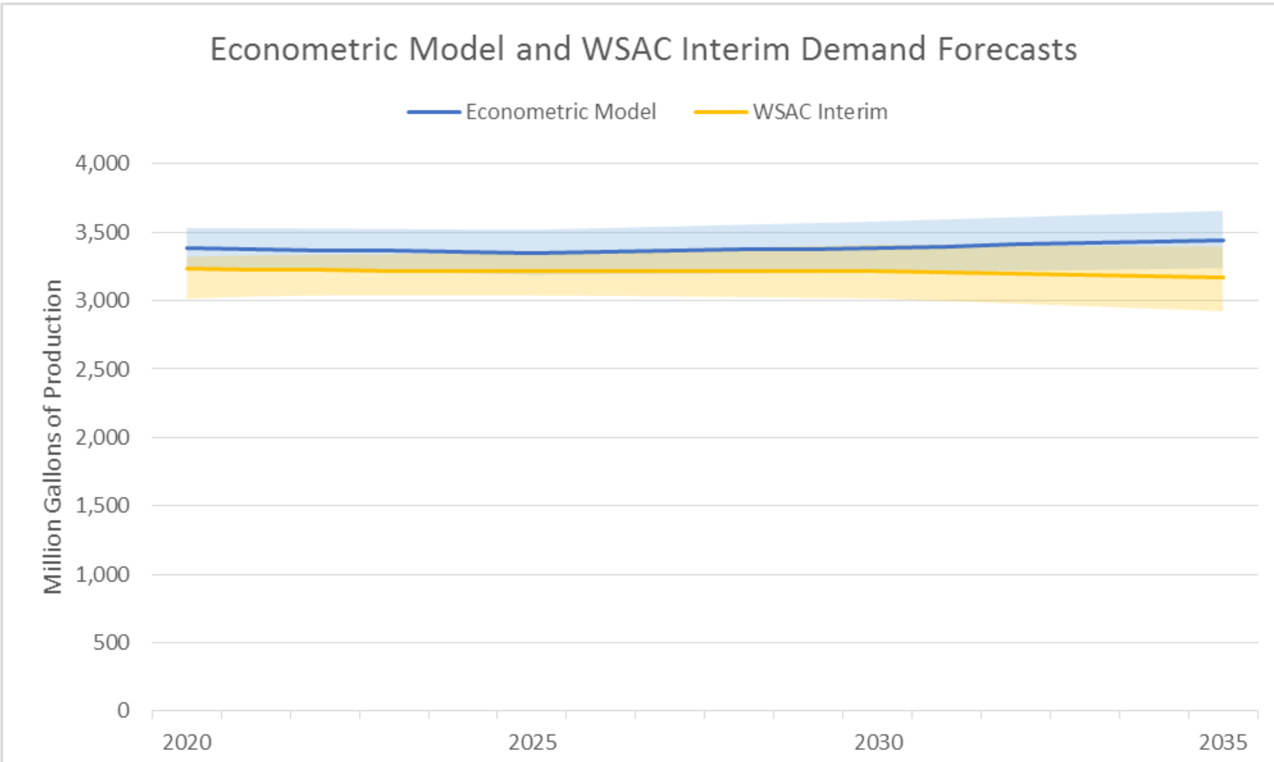
During a review by Maddaus Water Management of the draft econometric demand forecast presented to the WSAC in July, an error in the plumbing code water savings forecast was identified which caused the production forecast to be understated by approximately 200 MGY. The plumbing code forecast from the Maddaus Water Management's DSS model was not in error. Rather, the error occurred when M.Cubed disaggregated the plumbing code savings into customer class water savings and re-expressed these savings in CCF/service so they could be used with the econometric demand model. Unfortunately, we did not catch the coding error until after the draft forecast was presented to the WSAC in July. The forecast presented to the WSAC in July, the corrected forecast, and the WSAC interim forecast are shown in the following table. The corrected forecast is approximately 7 percent greater than what was presented in July.[34]

| **YEAR** | **2020** | **2025** | **2030** | **2035** |
|---|---|---|---|---|
| | Forecast | Forecast | Forecast | Forecast |
| Unrounded | | | | |
| July (with Plumbing Code Savings Error) | 3,132 | 3,123 | 3,160 | 3,215 |
| Corrected | 3,385 | 3,351 | 3,388 | 3,442 |
| WSAC Interim | 3,236 | 3,213 | 3,218 | 3,169 |
| Rounded | | | | |
| July (with Plumbing Code Savings Error) | 3,100 | 3,100 | 3,200 | 3,200 |
| Corrected | 3,400 | 3,400 | 3,400 | 3,400 |
| WSAC Interim | 3,200 | 3,200 | 3,200 | 3,200 |

The chart on the following page compares the WSAC interim forecast to the corrected econometric forecast. It also shows the uncertainty band around each forecast. The uncertainty band on the econometric forecast is based on the 95% confidence intervals for the class-level average use per service forecasts developed with the econometric models. The uncertainty band on the WSAC interim forecast is the range between the low and high interim forecasts presented at the April WSAC meeting. From the chart it is seen that the corrected econometric forecast represented by the dark blue line essentially tracks the upper-bound of the WSAC interim forecast while the WSAC interim forecast represented by the dark yellow line essentially tracks the lower-bound of the corrected econometric forecast. Between these two lines, the forecasts overlap. Future production in the range of 3,200 to 3,400 MGY is consistent with both forecasts.

[34] Both the econometric and interim forecasts are assuming average weather, no restrictions on water use, and normal economic conditions. Neither forecast includes the incremental water savings from Program C REC.

A more conservative uncertainty band obtained by taking the union of the two forecasts suggests future production in the range of 3,000 to 3,500 MGY over most of the forecast period, with a slightly wider band in the last five years of the forecast.




It is important to note that the econometric models were not impacted by the plumbing code savings error. The error occurred during the post-processing of the econometric model results and did not affect in any way the data used to estimate the econometric models or the resulting model parameter and elasticity estimates.

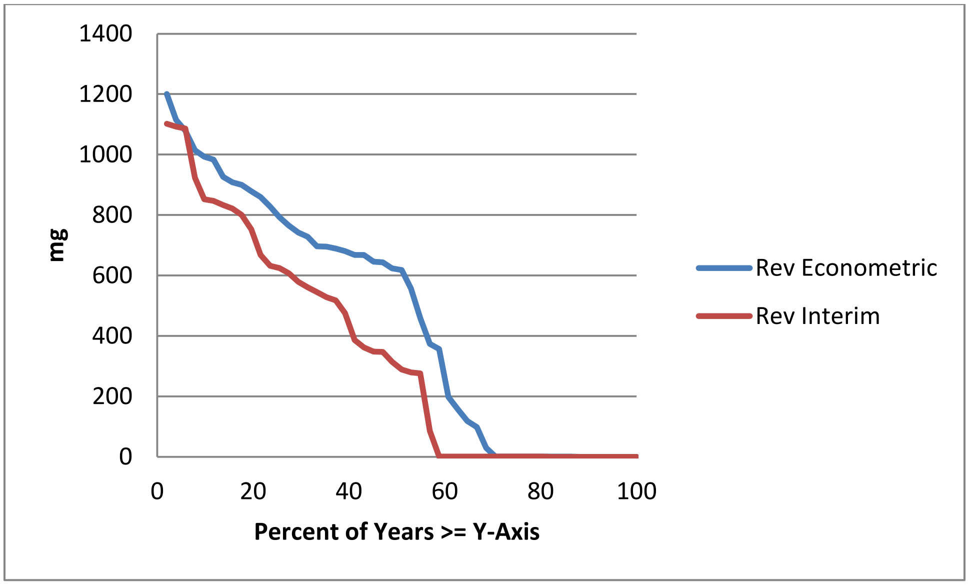
While it is not uncommon to find errors of this type in draft forecast work products, we apologize for not having detected it sooner. We also want to thank Maddaus Water Management for their diligent review of the draft forecast and helping us to identify and resolve the error.

**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** September 1, 2015
**From:** Gary Fiske
**To:** Rosemary Menard
**Cc:** Heidi Luckenbach, Bob Raucher, Bill Faisst, Toby Goddard
**Re:** Impact of Corrected Econometric Demand Forecast

As David Mitchell reported in his August 24 memo, there was an error in the accounting for plumbing code savings that, when corrected, added between 200 and 250 million gallons per year to the July draft econometric forecast. However, the prior analyses that I've done have generally been based on the April revised interim forecast for the 2020 forecast year, which is about 150 mg lower than the corrected econometric forecast.

For the sake of comparison, I've run our DFG-5 climate change base case (no new supply or infrastructure or conservation) with the corrected mid-range demand forecast. As the chart below shows, the worst-year peak-season shortage with 2020 demands goes up about 100 mg, from 1.1 bg to 1.2 bg. The distribution of peak-season shortages across other hydrologic conditions is also affected. The average peak-season shortages over these distributions differ by about 120 mg (~340 mg vs. 460 mg).

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**GARY FISKE AND ASSOCIATES, INC.**
***Water Resources Planning and Management***

**Date:** September 8, 2015
**From:** Gary Fiske
**To:** Rosemary Menard, Heidi Luckenbach, Bob Raucher, Bill Faisst, Erin Mackey
**Cc:** Nicholas Dewar, Carie Fox
**Re:** Updated Yields REVISED

I have updated the yield estimates for the elements shown in the Gantt Chart. These estimates are based on the corrected econometric demand forecast, the sizing and infrastructure assumptions currently being made for each of the elements, and minor modeling refinements. *They assume that all technical and institutional (legal, regulatory, public acceptance) uncertainties have been successfully resolved.*

With that key assumption, the yields and remaining peak-season shortages are shown in Table 1.

Two important observations can be made about the yields of in-lieu and ASR:

- The yields of in-lieu and ASR by themselves are very close. Even when limited by Scotts Valley and Soquel Creek demands and the higher assumed loss rates, an in-lieu program makes enough stored water available to Santa Cruz to provide virtually the same level of reliability.
- The yield of a combination of in-lieu and ASR is identical to that of ASR alone, since each relies on the same winter flows for source water.

The yields for all of the elements, as currently defined, are all in the same range (750-800 mg for the worst year and 350-450 mg on average). Remaining worst-year peak-season shortages are between 22% and 25%.

**Table 58. Updated Peak-Season Yield Estimates (mg)**

| | Worst Year | | | Average | | |
|---|---|---|---|---|---|---|
| **Element** | **Peak-Season Yield** | **Remaining Peak-Season Shortage** | | **Peak-Season Yield** | **Remaining Peak-Season Shortage** | |
| | **mg** | **mg** | **%** | **mg** | **mg** | **%** |
| ***Base Case*** | -- | *1230* | *63%* | -- | *470* | *24%* |
| **In-Lieu** | 750 | 480 | 25% | 350 | 120 | 6% |
| **ASR** | 760 | 470 | 24% | 380 | 90 | 5% |
| **Combined In-Lieu, ASR** | 760 | 470 | 24% | 380 | 90 | 5% |
| **DPR (3 mgd)** | 810 | 420 | 22% | 440 | 30 | 2% |
| **DW Desal (3 mgd)** | 810 | 420 | 22% | 440 | 30 | 2% |
| **Local Desal (3 mgd)** | 810 | 420 | 22% | 440 | 30 | 2% |

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**G A R Y  F I S K E  A N D  A S S O C I A T E S ,  I N C .**
***W a t e r  R e s o u r c e s  P l a n n i n g  a n d  M a n a g e m e n t***

**Date:** September 24, 2015
**From:** Gary Fiske
**To:** Bob Raucher
**Cc:** Rosemary Menard, Heidi Luckenbach, Bill Faisst
**Re:** Yields of IPR

Per your request, I did Confluence runs to estimate the peak-season yields of 3 different standalone IPR configurations:

- IPR to Loch Lomond
- IPR to Aquifer ( current assumption of 4 mgd withdrawal capacity)
- IPR to Aquifer (assumed 8 mgd withdrawal capacity)

The last of these was run to test the sensitivity of the results to our infrastructure assumptions.

The results are shown in the following table. All of these results assume 3 mgd year-round recycled water production capacity. They also assume full implementation of each alternative.

| | **Worst Year** | | | **Average** | | |
|---|---|---|---|---|---|---|
| | **Yield** | **Remaining Peak-Season Shortage** | | **Yield** | **Remaining Peak-Season Shortage** | |
| **IPR @ 3 mgd:** | **mg** | **mg** | **%** | **mg** | **mg** | **%** |
| **To Loch** | 660 | 570 | 29% | 430 | 40 | 2% |
| **To Aquifer (4 mgd withdrawal)** | 740 | 490 | 25% | 380 | 90 | 5% |
| **To Aquifer (8 mgd withdrawal)** | 1190 | 40 | 2% | 465 | 5 | 0% |

In general, since IPR is able to inject a steady 3 mgd into the aquifer, this option requires considerably lower aquifer storage volumes (i.e. much less than our 3 bg target) than do the excess winter flow alternatives. This is particularly the case with our current assumed 4 mgd withdrawal capacity. Intuitively, this can be understood by noting that, during a dry period, we will be injecting 3 mgd and withdrawing 4 mgd, so the net daily drawdown of the aquifer is only 1 mgd. Hence, at the start of the peak season, we only need to have ~180 mg in storage.[35]

The results of the table illustrate that the yield of a standalone IPR-to-aquifer option is extremely sensitive to the rate at which water can be withdrawn from the aquifer. The 4 mgd infrastructure severely constrains yield. If we double the withdrawal capacity to 8 mgd, our yield would increase considerably to the point where we could serve almost all peak-season demands, even in the worst year.

[35] This assumes that there is no minimum residency requirement for the injected recycled water.

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