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The Impact of Changes in Inflow and Demand on Folsom Lake

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Internship Project with the Hydrologic Research Center

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Background

Reservoirs store water from various sources and have to be managed for various objectives, such as flood mitigation, water supply, recreational activity and ecological sustainability. My internship project with the Hydrologic Research Center was to analyze various scenarios of input and output to and from Folsom Lake in order to determine which cases and combinations of input and output were most beneficial or detrimental to the water supply of the reservoir. I developed a Matlab script that calculates the storage of the reservoir in cubic meters, using an expression of the mass balance equation. This paper is a review and analysis of the steps that I took to achieve this purpose and the observations I made along the way.

Folsom Lake is a reservoir on the American River in the foothills of the Sierra Nevada Mountain Range. Its surface area is 46.34×10^6 m^2, and has a maximum volume capacity of 1.204×10^9 m^3. The reservoir is controlled by the Folsom Dam, which was built in 1955 as part of the Folsom Project, which included the nearby Nimbus reservoir and dam. The Folsom Project is a part of the Central Valley Project, operated by the United States Bureau of Reclamation. (US Bureau of Reclamation) The objective of the Folsom Project was to form a reservoir in order to manage the risk of downstream flooding, generate hydroelectricity, and supply drinking and irrigation water. From the months of October through May, when inflow is the heaviest in the Sierra Nevada, Folsom Lake is used mainly to store water in order to prevent flooding on the lower American River and protect the city of Sacramento. During the summer months, however, water is released from the reservoir to generate hydroelectricity, provide drinking and irrigation water, maintain water quality and temperature downstream of the dam, as well as prevent salt water intrusion into the Bay Delta.

Matlab Script and Equations

The Matlab code I wrote describes the reservoir's water mass balance based on the conservation of water mass equation. The conservation of water mass equation states that the change in reservoir water storage is the difference between the water mass entering and the water mass exiting the reservoir, and can be written as follows:

$$\Delta x_t = I_t - O_t \qquad (1)$$

where x is the total reservoir storage, I is the inflow, O is the outflow, Δ represents temporal difference, and t indicates intervals of time. While the inflow is mostly controlled by the snow melt and rainfed river flows into the Folsom Lake, the outflow is a function of the water demand downstream and of the water availability in the Folsom Lake.

This equation was written as a Matlab function to calculate the storage and outflow from a set of data that includes the different scenarios of inflow and water demand. The resulting equation shows the storage at the end of the month (i+1) when given an initial condition at the beginning of the month (i) , so that:

$$x_{i+1} = x_i + \Delta t\left(\frac{I_i + I_{i+1}}{2} - \frac{O_i + O_{i+1}}{2}\right), \qquad x_0 \geq x \geq 0 \qquad (2)$$

where Δt in this case is equal to one month, and x_0 denotes the maximum water storage (storage capacity) of the reservoir.

If in a given month the equation above resulted in a value x_{i+1} that is greater than the maximum capacity of the reservoir (x_0), that is 1.2 billion cubic meters, a spillway discharge (*S*) is defined for this month as such:

$$S_{i+1} = x_{i+1} - x_0 \tag{3}$$

The variable *D* represents the actual outflow from the reservoir which is equal to the demand if there is enough water in the reservoir, or less than the demand in cases of insufficient storage.

Study setup

The main challenge in the management of Folsom Lake, and many other reservoirs, is keeping the water level below the reservoir's maximum capacity to allow for flood protection, while having sufficient water supply to meet demand during the drier months of the year. In my project I evaluated various scenarios of the reservoir's inflow and water demand and assessed which scenarios were the most beneficial and which were the most detrimental to Folsom Lake water operations. I tested the difference in impacts between a sudden climate change and a gradual climate change as well as their impact on the amount of water stored in the reservoir. Similarly, I tested sudden and gradual changes in water demand. The purpose of this project was to identify a management strategy that maximizes the amount of water stored in the reservoir at any given time without overflow and ensures to the extent feasible that the downstream water demand is always met.

Table 1 describes the nominal reference case as well as an additional 21 scenarios that were tested. Spillage describes the amount of water lost without benefit to the water resources of the region due to exceedance of Folsom Lake capacity.

Table 1. Scenario description

Scenarios	Change in Input	Change in Demand	Spillage (E9) m^3	Unmet Demand (E9) m^3	Spillage + Unmet Demand (E9) m^3
1-Nominal	0% change	0% change	0.36	1.5	1.86
2	20% decrease during years 2,4,6	0% change	0.06	2.81	2.87
3	20% decrease during years 2-4	0% change	0	2.81	2.81
4	20% decrease during years 2-4, 20% increase during years 5-7	0% change	0.33	1.56	1.89
5	20% decrease during years 2-3, 50% decrease during year 4, 30% increase during year 5	0% change	<0.01	2.19	2.19
6	Every year is decreased by 5% from the previous year	0% change	0	4.99	4.99
7	0% change	10% increase during years 5-10	0.36	2.06	2.42
8	0% change	10% decrease during years 5-10	0.64	0.69	1.33
9	0% change	Every year is increased by 5% from the previous	0.11	5.94	6.05

		year			
10	20% decrease during years 2,4,6	10% increase during years 5-10	0.06	2.99	3.05
11	20% decrease during years 2,4,6	10% decrease during years 5-10	0.06	1.45	1.51
12	20% decrease during years 2-4, 20% increase during years 5-7	10% increase during years 5-10	0	2.13	2.13
13	20% decrease during years 2-4, 20% increase during years 5-7	10% decrease during years 5-10	0.96	1.48	2.44
14	20% decrease during years 2-3, 50% decrease during year 4, 30% increase during year 5	10% increase during years 5-10	0	3.41	3.41
15	20% decrease during years 2-3, 50% decrease during year 4, 30% increase during year 5	10% decrease during years 5-10	0.50	2.14	2.65
16	Every year is decreased by 5% from the previous year	Every year is increased by 5% from the previous year	0	9.23	9.23
17	0% change	Every year is decreased by 5% from the previous year	3.05	0.68	3.72
18	Every year is increased by 5% from the previous year	Every year is decreased by 5% from the previous year	6.53	0.60	7.13
19	Every year is increased by 5% from the previous year	Every year is decreased by 5% from the previous year	1.02	2.71	3.72
20	Every month is increased by .5% from the previous month	0% change	4.13	0.69	4.82

21	Every month is decreased by .5% from the previous month	0% change	0	6.24	6.24
22	0% change	Every month is increased by 0.5% from the previous month	0.07	7.61	7.68

Analysis

The nominal case is the observed inflow of 120 months into Folsom lake and the actual reported demand for these months. Figure 1 shows the results of the nominal case.

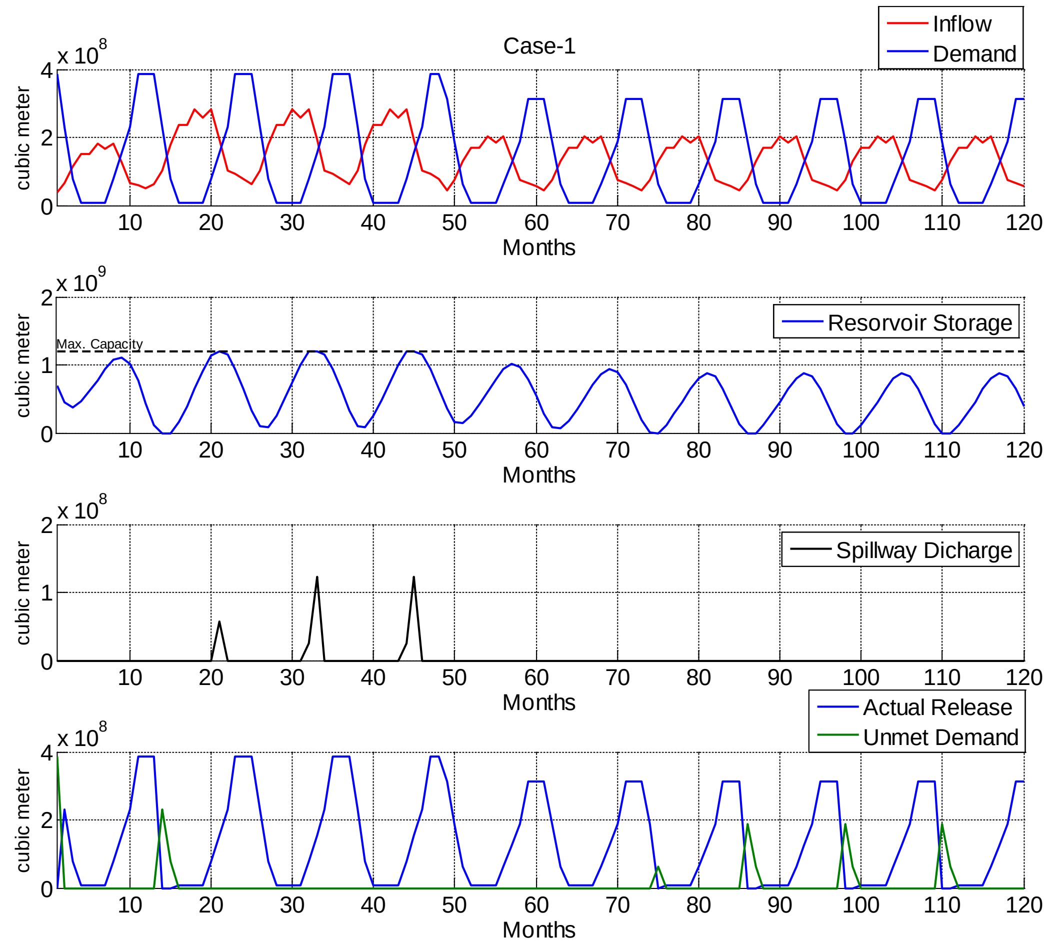

Figure 1. The nominal case. Upper panel shows the inflow into Folsom Lake (red) and the monthly demand (blue). The second panel shows the reservoir's storage (blue) and the maximum storage is indicated by the dashed black line. the third panel is the spillway discharge and the fourth panel shows the actual flow released from the reservoir (blue) and the unmet demand (green).

For the nominal case, the input for the base year, or first twelve months, peaked at less than 200 million cubic meters, and then exhibited a 70% increase in the following 36 months, and followed with a gradual decline until the input for the final year reached a peak a little bit above the base year's peak. The outputs for the first 60 months were nearly 400 million cubic meters at their peaks, and then showed a significant decrease, outputting nearly 300 million cubic meters at their peaks. Through calculations described later in the report, I was able to determine that this scenario resulted in 0.36E9 m^3 of water lost to spillage and 1.5E9 m^3 of water lost to unmet demand, for a total of 1.86E9 m^3 of water lost overall

For each of the 21 remaining test cases, I created similar four-panel charts. The first panel is a plot of the monthly inflows and demands, which may vary from case to case. The second panel depicts the storage (X, or I-O) of Folsom Lake over 120 months, as well as a line marking the maximum capacity of the reservoir which remained constant from case to case. Through this graph, I was able to see when the reservoir either hit 0 or 1.2 billion cubic meters to determine whether the reservoir ran dry or overflowed, respectively. The third panel illustrated cases in which the storage of water in the reservoir was higher than 1.2 billion cubic meters, resulting in spillway discharge (S). This plot varied by case as well, showing no overflow in several cases, mild spills in some cases, and significant amounts of water lost in other cases. The fourth and final panel showed two lines, a green line depicting unmet demand (O-D), which is titled such due to too little storage in the reservoir to meet demand, and a blue line showing actual release (D), or the amount of outflow released after taking into account the times where demand was not met. These four panels were displayed for each case that I then created, showing the differences in storage (X), spillway discharge (S), and unmet demand (O-D) when input and output were varied.

I developed a Matlab script that contained a loop function to simulate all the scenarios. The script can be referred to in Appendix A. I began with cases where only the input was manipulated, first simulating drought years by creating drastic decreases in water entering the reservoir during a small period of time, and then creating a few cases that simulated gradual decreases in inflow by gradually decreasing the multiplier incrementally over time. I then tested cases where only the demand was manipulated. By changing the multiplier for only one year at a time I could show the sudden increases or decreases in outflow due to potentialities such as changes in demand by the population, agriculture and/or industries. I also tested cases where the demand was gradually increasing or decreasing, represented the progressive growth or decline in the region's population or industrial demands. After these tests, I also ran a variety of cases that combined different input and demand multipliers together. Using the information gathered from the plots of the cases, I was able to draw conclusions about the impact of abrupt changes in weather patterns versus the effect of gradual climate change on water storage.

In order to gain a more complete understanding of the impact of each case, I created the variables 'STotal' and 'UTotal' to measure the total spillway discharge and unmet demand, respectively, and then also a 'TTotal' which was a sum of 'STotal' and 'UTotal.' These sums got measured with every loop in cubic meters. For the input only cases, the 'TTotal' proved to be much higher in cases where the inflow of water into the reservoir was decreasing gradually over all ten years, rather than cases where the amount of inflow was dramatically decreased for a period of a couple years. For example, Case 2 had an input that was decreased by 20% in years 2, 4, and 6 (showing drought) had a 'TTotal' of 2.8675E9 m^3, greater than the nominal case of 1.8596E9 m^3 (Figure 2).

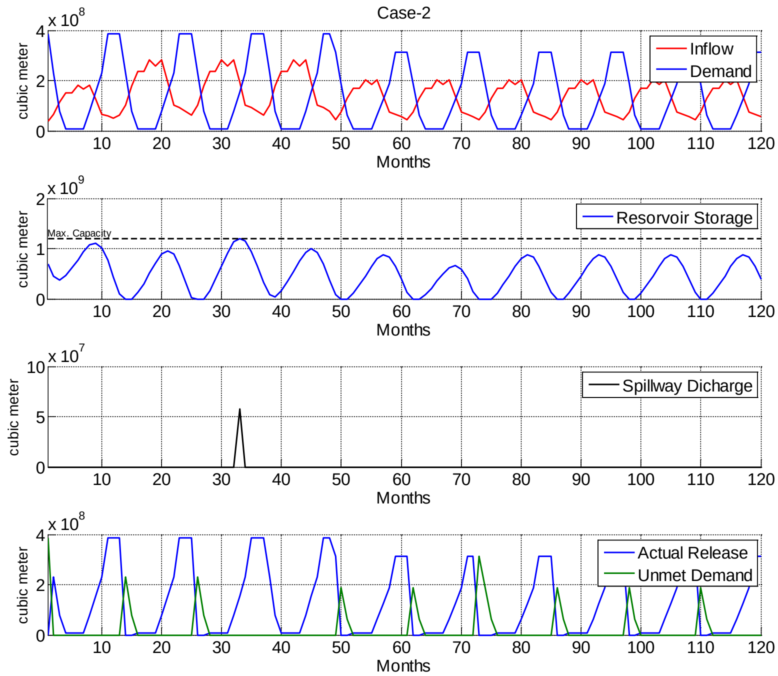

Figure 2: As is Figure 1 for Case 2

However, in Case 6, where the input was decreased by 5% each year, the 'TTotal' was 4.9917E9 m^3, significantly larger than both the nominal case and the drought case (Figure 3). Both of these cases also had little to none spillway discharge, but the differences were great for unmet demand ('UTotal'), with the drought case losing 2.8094E9 m^3 of water in unmet demand (and 0.5801E8 m^3 in spillage), and the progressive decrease case with a UTotal of 4.9917E9 m^3, which is the entirety of the water lost in that case. These cases show the strong effect of long-term climate changes and the effects that they have on the amount of water available for use by consumers and industries. In all cases that looked at input only, the amount of water lost through unmet demand and/or spillway discharge was consistently greater in the cases in which progressive climate change was taking place, rather than abrupt weather phenomena, such as drought or flooding.

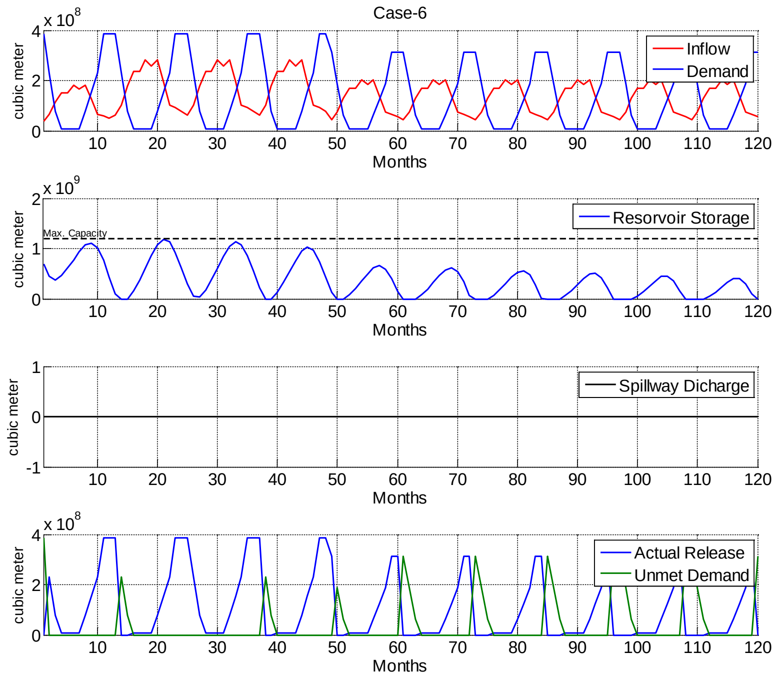

Figure 3: As in Figure 1 for Case 6

The output only cases dealt with population and industry demands and the effects of abrupt changes versus gradual changes in demand. The spillway discharge, or 'STotal', and the unmet demand, or 'UTotal', were both greater than 0 m^3 for every case where only the output was manipulated, meaning that demand was too low during the period of time when the reservoir storage was high, and that demand was too high during the times when the reservoir storage was running low. The storage tended to be higher during the winter months than the summer months, and since demand for water is higher during hotter months, it would make sense that higher demand during times of low storage (and vice versa) was a common pattern. Similar to the input only cases, the 'TTotal' was significantly greater in cases where demand was gradually increased or decreased. For example, in Case 7 the demand was increased by 10% from year 5 until year 10 had a 'TTotal' of 2.4207E9 m^3 (Figure 4).

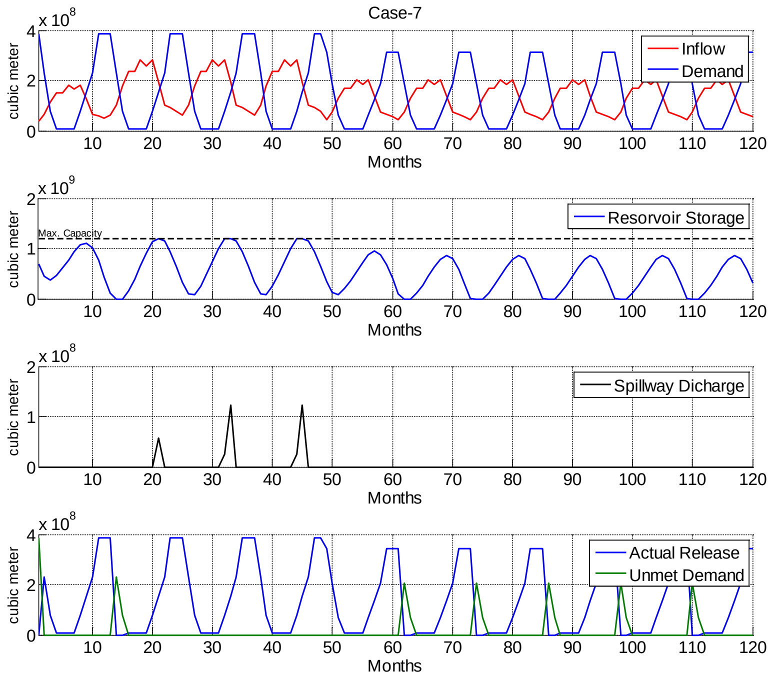

Figure 4: As in Figure 1 for Case 7

On the other hand, in Case 9 the demand was increased by 5% each year for 10 years and had a 'TTotal' of 6.0479E9 m^3. This was because the case in which demand was gradually increased resulted in a high volume of unmet demand, at 5.9409E9 m^3, while the case of abrupt increase in demand had a 'UTotal' volume almost a third the volume of the former case, at 2.0649E9 m^3 (Figure 5).

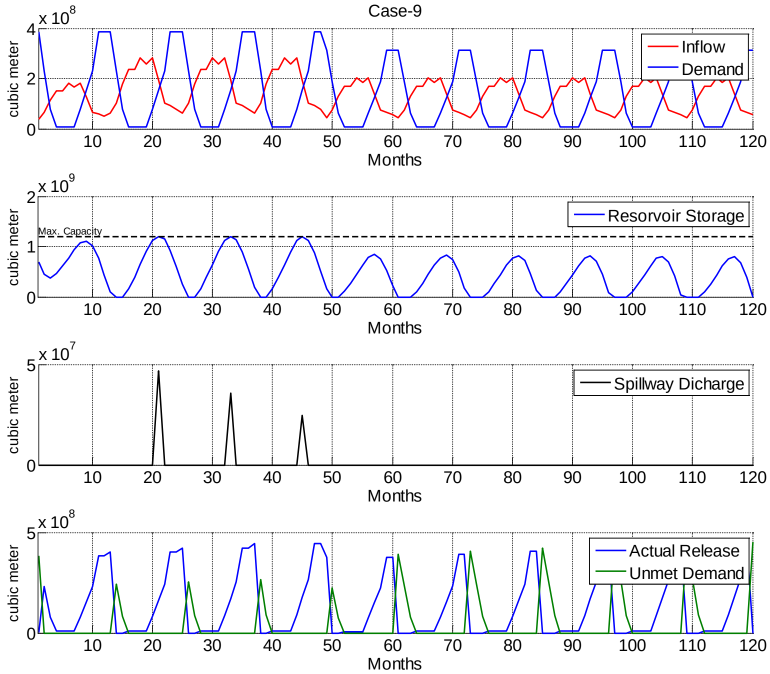

Figure 5: As in Figure 1 for Case 9

This pattern remained consistent when the demand was decreased as well. In Case 8, which demonstrated abrupt decrease, the demand was decreased by 10% from year 5 until year 10, the 'TTotal' was 1.3325E9 m^3 (Figure 6). This was compared to Case 17, which showed progressive decline in demand, where every year was decreased by 5% for 10 consecutive years and the 'TTotal' was 3.7243E9 m^3 (Figure 7).

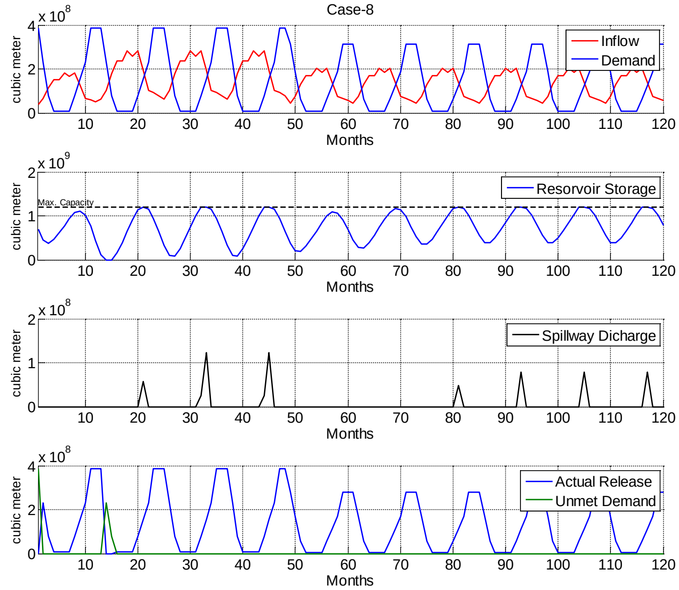

Figure 6: As in Figure 1 for Case 8

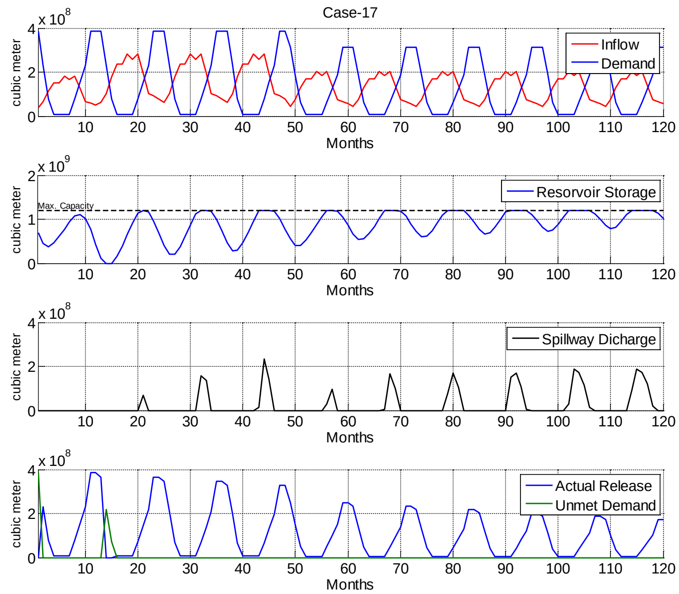

Figure 7: As in Figure 1 for Case 17

In the cases dealing with decrease, however, the volume difference between abrupt decline in demand versus gradual decline in demand was shown mostly in the spillway discharge total, or the ‘STotal’. The case of abrupt decline had an ‘STotal’ of 6.3927E8 m^3, while the gradual decline in output had an ‘STotal’ of 3.0465E9 m^3. This means that almost all of the demand is met, since it becomes low, but there is then too much water stored in Folsom Lake, leading to overflow. The opposite occurs when the output is increased, due to the fact that when the demand is high, there is often too little water stored in the reservoir to meet the high demand. However, regardless of whether the demand is increased or decreased, in both situations gradual incremental changes in output leads to a much higher amount of water lost than sudden changes in demand.

Following the cases that looked solely at input or output, I ran several cases that were combinations of both. This was meant to simulate a more realistic situation, where the demand is based on the climate state. The most detrimental case was Case 16, one that simulated a decrease in input due to progressive climate change alongside a progressive increase in demand due to a lack of resources which occurred as a result of the effects of the climate change. This case resulted in a ‘TTotal’ of 9.2299E9 m^3, by far the highest total out of all the cases that were tested (Figure 8).

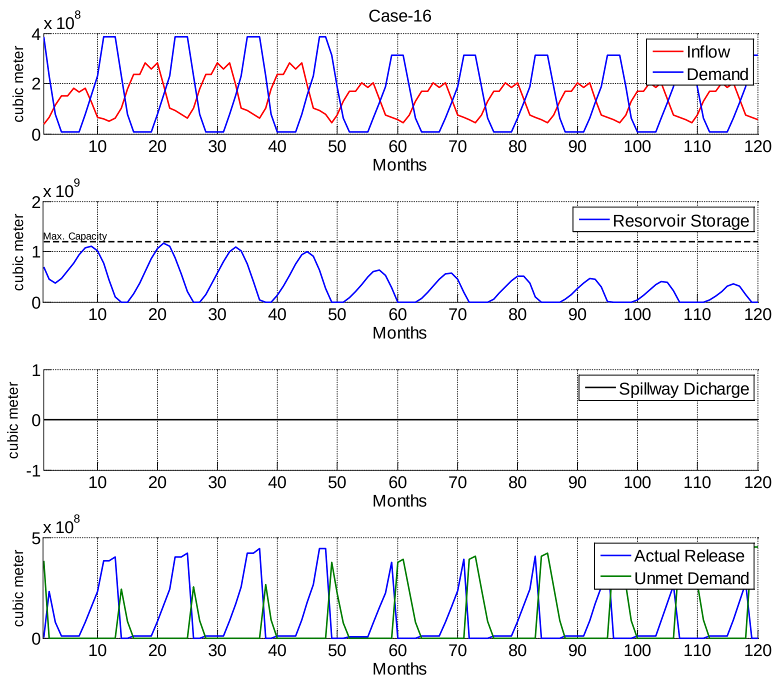

Figure 8: As in Figure 1 for Case 16

The least detrimental case was Case 11, one where the input was decreased by 20% during year 2, year 4, and year 6 and the output was decreased by 10% during year 5 until year 10. This case simulated drought during years 2, 4, and 6, and a decrease in demand due to population and industry decline, which occurred as a result of the dry years. The 'TTotal' in this situation was 1.5082E9 m^3, the lowest of all the combination cases (Figure 9). This case demonstrates a relatively optimal situation for input decline, in which the population and industry of the region are able to base their demand off of what is available to them in the reservoir, rather than raise their demand due to their lack of water.

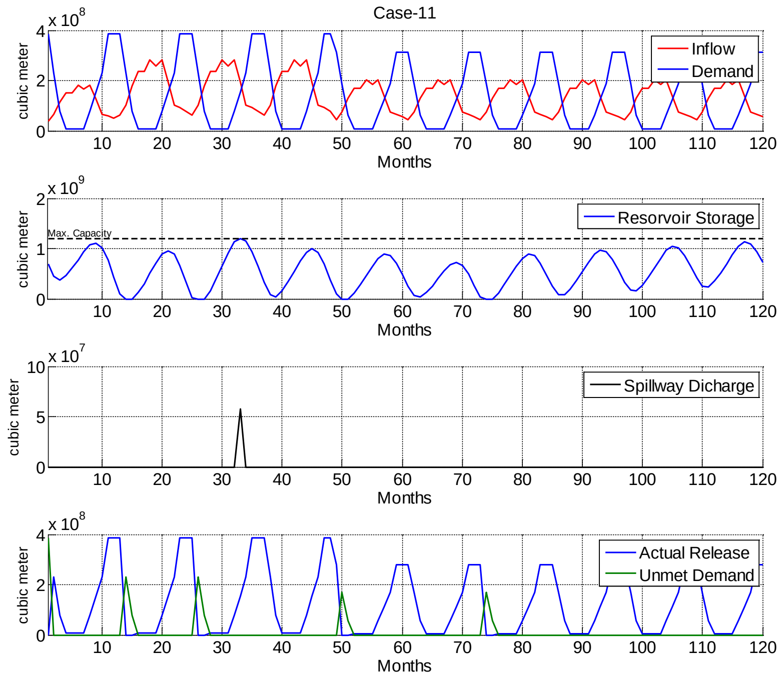

Figure 9: As in Figure 1 for Case 11

Conclusions

From this project, I was able to observe how gradual climate change has a much larger impact on the amount of water lost than sudden weather changes had. The ongoing, long term consequences of climate change, whether increasing or decreasing inflow, have a much greater 'TTotal' in all cases than in any of the cases simulating drought or flood years. While the damages of climate change seem far away, they are, in fact, quite eminent and reservoir managements should consider this when trying to meet the demands of the regional population and industries. Restrictions on demand should be implemented in order to minimize the amount of water lost. The most likely situation to occur during dry years when input declines and storage runs low is for the demand to increase due to need for water. Based on my findings, it can be concluded that progressively increasing the demand in a time when inflow is being gradually decreased is most detrimental to the storage of Folsom Lake because it leads to the reservoir running dry and a lot of unmet demands. The opposite case, when demand is low but inflow is high, is also detrimental to the storage of the reservoir as it leads to a lot of water being lost in the form of spillway discharge. A strong inverse relationship between input and output is most detrimental to the storage of Folsom, while also being the most likely to occur. Minimizing the use of water in everyday life is the most logical solution to optimizing the storage of the Folsom Lake. This way, the inverse relationship between the input and output is weaker, meaning that demand doesn’t run extremely high when the storage is low, or vice versa, and water is being purposefully and properly utilized.

Appendix A: Matlab script, developed by Ariella Shamir

```
% Ariella Example Script  07 25 2016
% recieved

%%
clear
close all
clc

% first file is twelve monthly values
% fols = load('Folsom_inputOuput.txt')

% fols = load('Folsom_Input2.txt');
fols = load('Folsom_Input2017.txt')

m = [ 10 11 12 1 2 3 4 5 6 7 8 9]

for k = 1 :22
    % input
    Y0 = fols(:,2) ; % input (m^3/month)
    O0 = fols(:,3) ; % output  (m^3/month)
    X = zeros(120,1) ; % Storage
    O2 = zeros(120,1); % Actual release
    S = zeros(120,22); %  spill
    X0 = 1200000000;  % max capacity
    X(1,1) = 700000000 ; % (m^3) % initial condition
    Y=Y0;
    O=O0;

    if k ==1
        Y = Y0 ;

    elseif k ==2
        % indx = [ 13 24; 37 48; 61 72] ;
        % mult = .8 ;
        % Y(indx(1,1):indx(1,2),1)  = Y(indx(1,1):indx(1,2),1) .* mult ;
        % Y(indx(2,1):indx(2,2),1)  = Y(indx(2,1):indx(2,2),1) .* mult;
        % Y(indx(3,1):indx(3,2),1)  = Y(indx(3,1):indx(3,2),1) .* mult;
        Y(13:24,1)=Y0(13:24,1).*.8;
        Y(37:48,1)=Y0(37:48,1).*.8;
        Y(61:72,1)=Y0(61:72,1).*.8;
        % variability in inflows from year to year


    elseif k == 3
        Y(13:48,1)=Y0(13:48,1).*.8;
        % three year drought
    elseif k ==4
        Y(13:48,1)=Y0(13:48,1).*.8;
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```
    Y(49:84,1)=Y0(49:84,1).*1.2;
    % three year drought followed by a three year wet period
elseif k ==5
    Y(13:36,1)=Y0(13:36,1).*.8;
    Y(37:48,1)=Y0(37:48,1).*.5;
    Y(49:60,1)=Y0(49:60,1).*1.3;
    % three years of drought that turned severe followed by a flood year
elseif k ==6
    Y(1:12,1)=Y0(1:12,1).*1;
    Y(13:24,1)=Y0(13:24,1).*.95;
    Y(25:36,1)=Y0(25:36,1).*.9;
    Y(37:48,1)=Y0(37:48,1).*.85;
    Y(49:60,1)=Y0(49:60,1).*.8;
    Y(61:72,1)=Y0(61:72,1).*.75;
    Y(73:84,1)=Y0(73:84,1).*.7;
    Y(85:96,1)=Y0(85:96,1).*.65;
    Y(97:108,1)=Y0(97:108,1).*.6;
    Y(109:120,1)=Y0(109:120,1).*.55;
    % progressive climatic impacts
elseif k ==7
    O(49:120,1)=O0(49:120,1).*1.1;
    %somewhat of an abrupt demand increase due to population and industry
    %increase/movement in the region
elseif k ==8
    O(49:120,1)=O0(49:120,1).*.9;
    %somewhat of an abrupt demand decrease due to population and industry
    %decrease/movement out of the region
elseif k ==9
    O(1:12,1)=O0(1:12,1).*1;
    O(13:24,1)=O0(13:24,1).*1.05;
    O(25:36,1)=O0(25:36,1).*1.1;
    O(37:48,1)=O0(37:48,1).*1.15;
    O(49:60,1)=O0(49:60,1).*1.2;
    O(61:72,1)=O0(61:72,1).*1.25;
    O(73:84,1)=O0(73:84,1).*1.3;
    O(85:96,1)=O0(85:96,1).*1.35;
    O(97:108,1)=O0(97:108,1).*1.4;
    O(109:120,1)=O0(109:120,1).*1.45;
    %progressive increase of demand due to growth of population and
    %industry in the region.
elseif k ==10
    Y(13:24,1)=Y0(13:24,1).*.8;
    Y(37:48,1)=Y0(37:48,1).*.8;
    Y(61:72,1)=Y0(61:72,1).*.8;
    O(49:120,1)=O0(49:120,1).*1.1;
    %variability in inflows from year to year and somewhat of an abrupt
    %demand increase due to population and industry increase/movement in
    %the region
elseif k ==11
    Y(13:24,1)=Y0(13:24,1).*.8;
    Y(37:48,1)=Y0(37:48,1).*.8;
    Y(61:72,1)=Y0(61:72,1).*.8;
    O(49:120,1)=O0(49:120,1).*.9;
    %variability in inflows from year to year and somewhat of an abrupt
    %demand decrease due to population and industry decrease/movement in
    %the region
elseif k ==12
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        Y(13:48,1)=Y0(13:48,1).*.8;
        Y(49:84,1)=Y0(49:84,1).*1.2;
        O(49:120,1)=O0(49:120,1).*1.1;
        %three year drought followed by a three year wet period and somewhat
of
        %an abrupt demand increase due to population and industry
        %increase/movement in the region
    elseif k ==13;
        Y(13:48,1)=Y0(13:48,1).*.8;
        Y(49:84,1)=Y0(49:84,1).*1.2;
        O(49:120,1)=O0(49:120,1).*.9;
        %three year drought followed by a three year wet period and somewhat
of
        %an abrupt demand decrease due to population and industry
        %decrease/movement in the region
    elseif k ==14
        Y(13:36,1)=Y0(13:36,1).*.8;
        Y(37:48,1)=Y0(37:48,1).*.5;
        Y(49:60,1)=Y0(49:60,1).*1.3;
        O(49:120,1)=O0(49:120,1).*1.1;
        %three years of drought that turned severe followed by a flood year
        %and somewhat of an abrupt demand increase due to population and
        %industry increase/movement in the region
    elseif k ==15
        Y(13:36,1)=Y0(13:36,1).*.8;
        Y(37:48,1)=Y0(37:48,1).*.5;
        Y(49:60,1)=Y0(49:60,1).*1.3;
        O(49:120,1)=O0(49:120,1).*.9;
        %three years of drought that turned severe followed by a flood year
        %and somewhat of an abrupt demand decrease due to population and
        %industry decrease/movement in the region
    elseif k ==16
        Y(1:12,1)=Y0(1:12,1).*1;
        Y(13:24,1)=Y0(13:24,1).*.95;
        Y(25:36,1)=Y0(25:36,1).*.9;
        Y(37:48,1)=Y0(37:48,1).*.85;
        Y(49:60,1)=Y0(49:60,1).*.8;
        Y(61:72,1)=Y0(61:72,1).*.75;
        Y(73:84,1)=Y0(73:84,1).*.7;
        Y(85:96,1)=Y0(85:96,1).*.65;
        Y(97:108,1)=Y0(97:108,1).*.6;
        Y(109:120,1)=Y0(109:120,1).*.55;
        O(1:12,1)=O0(1:12,1).*1;
        O(13:24,1)=O0(13:24,1).*1.05;
        O(25:36,1)=O0(25:36,1).*1.1;
        O(37:48,1)=O0(37:48,1).*1.15;
        O(49:60,1)=O0(49:60,1).*1.2;
        O(61:72,1)=O0(61:72,1).*1.25;
        O(73:84,1)=O0(73:84,1).*1.3;
        O(85:96,1)=O0(85:96,1).*1.35;
        O(97:108,1)=O0(97:108,1).*1.4;
        O(109:120,1)=O0(109:120,1).*1.45;
        %progressive climatic impacts and progressive increase of demand due
to
        %growth of population and industry in the region
    elseif k ==17
        O(1:12,1)=O0(1:12,1).*1;
```

```
    O(13:24,1)=O0(13:24,1).*.95;
    O(25:36,1)=O0(25:36,1).*.9;
    O(37:48,1)=O0(37:48,1).*.85;
    O(49:60,1)=O0(49:60,1).*.8;
    O(61:72,1)=O0(61:72,1).*.75;
    O(73:84,1)=O0(73:84,1).*.7;
    O(85:96,1)=O0(85:96,1).*.65;
    O(97:108,1)=O0(97:108,1).*.6;
    O(109:120,1)=O0(109:120,1).*.55;
    % progressive decrease in demand
elseif k ==18
    O(1:12,1)=O0(1:12,1).*1;
    O(13:24,1)=O0(13:24,1).*.95;
    O(25:36,1)=O0(25:36,1).*.9;
    O(37:48,1)=O0(37:48,1).*.85;
    O(49:60,1)=O0(49:60,1).*.8;
    O(61:72,1)=O0(61:72,1).*.75;
    O(73:84,1)=O0(73:84,1).*.7;
    O(85:96,1)=O0(85:96,1).*.65;
    O(97:108,1)=O0(97:108,1).*.6;
    O(109:120,1)=O0(109:120,1).*.55;
    Y(1:12,1)=Y0(1:12,1).*1;
    Y(13:24,1)=Y0(13:24,1).*1.05;
    Y(25:36,1)=Y0(25:36,1).*1.1;
    Y(37:48,1)=Y0(37:48,1).*1.15;
    Y(49:60,1)=Y0(49:60,1).*1.2;
    Y(61:72,1)=Y0(61:72,1).*1.25;
    Y(73:84,1)=Y0(73:84,1).*1.3;
    Y(85:96,1)=Y0(85:96,1).*1.35;
    Y(97:108,1)=Y0(97:108,1).*1.4;
    Y(109:120,1)=Y0(109:120,1).*1.45;
    %progressive decrease in demand with a progressive increase in inflow
    %due to climate
elseif k ==19
    Y(1:12,1)=Y0(1:12,1).*1;
    Y(13:24,1)=Y0(13:24,1).*1.05;
    Y(25:36,1)=Y0(25:36,1).*1.1;
    Y(37:48,1)=Y0(37:48,1).*1.15;
    Y(49:60,1)=Y0(49:60,1).*1.2;
    Y(61:72,1)=Y0(61:72,1).*1.25;
    Y(73:84,1)=Y0(73:84,1).*1.3;
    Y(85:96,1)=Y0(85:96,1).*1.35;
    Y(97:108,1)=Y0(97:108,1).*1.4;
    Y(109:120,1)=Y0(109:120,1).*1.45;
    O(1:120,1)=O0(1:120,1).*1.2;
elseif k ==20
    Y(1,1)=Y0(1,1).*1;
    Y(2,1)=Y0(2,1).*1.005;
    Y(3,1)=Y0(3,1).*1.01;
    Y(4,1)=Y0(4,1).*1.015;
    Y(5,1)=Y0(5,1).*1.02;
    Y(6,1)=Y0(6,1).*1.025;
    Y(7,1)=Y0(7,1).*1.03;
    Y(8,1)=Y0(8,1).*1.035;
    Y(9,1)=Y0(9,1).*1.04;
    Y(10,1)=Y0(10,1).*1.045;
    Y(11,1)=Y0(11,1).*1.05;
```

```
Y(12,1)=Y0(12,1).*1.055;
Y(13,1)=Y0(13,1).*1.06;
Y(14,1)=Y0(14,1).*1.065;
Y(15,1)=Y0(15,1).*1.07;
Y(16,1)=Y0(16,1).*1.075;
Y(17,1)=Y0(17,1).*1.08;
Y(18,1)=Y0(18,1).*1.085;
Y(19,1)=Y0(19,1).*1.09;
Y(20,1)=Y0(20,1).*1.095;
Y(21,1)=Y0(21,1).*1.1;
Y(22,1)=Y0(22,1).*1.105;
Y(23,1)=Y0(23,1).*1.11;
Y(24,1)=Y0(24,1).*1.115;
Y(25,1)=Y0(25,1).*1.12;
Y(26,1)=Y0(26,1).*1.125;
Y(27,1)=Y0(27,1).*1.13;
Y(28,1)=Y0(28,1).*1.135;
Y(29,1)=Y0(29,1).*1.14;
Y(30,1)=Y0(30,1).*1.145;
Y(31,1)=Y0(31,1).*1.15;
Y(32,1)=Y0(32,1).*1.155;
Y(33,1)=Y0(33,1).*1.16;
Y(34,1)=Y0(34,1).*1.165;
Y(35,1)=Y0(35,1).*1.17;
Y(36,1)=Y0(36,1).*1.175;
Y(37,1)=Y0(37,1).*1.18;
Y(38,1)=Y0(38,1).*1.185;
Y(39,1)=Y0(39,1).*1.19;
Y(40,1)=Y0(40,1).*1.195;
Y(41,1)=Y0(41,1).*1.2;
Y(42,1)=Y0(42,1).*1.205;
Y(43,1)=Y0(43,1).*1.21;
Y(44,1)=Y0(44,1).*1.215;
Y(45,1)=Y0(45,1).*1.22;
Y(46,1)=Y0(46,1).*1.225;
Y(47,1)=Y0(47,1).*1.23;
Y(48,1)=Y0(48,1).*1.235;
Y(49,1)=Y0(49,1).*1.24;
Y(50,1)=Y0(50,1).*1.245;
Y(51,1)=Y0(51,1).*1.25;
Y(52,1)=Y0(52,1).*1.255;
Y(53,1)=Y0(53,1).*1.26;
Y(54,1)=Y0(54,1).*1.265;
Y(55,1)=Y0(55,1).*1.27;
Y(56,1)=Y0(56,1).*1.275;
Y(57,1)=Y0(57,1).*1.28;
Y(58,1)=Y0(58,1).*1.285;
Y(59,1)=Y0(59,1).*1.29;
Y(60,1)=Y0(60,1).*1.295;
Y(61,1)=Y0(61,1).*1.3;
Y(62,1)=Y0(62,1).*1.305;
Y(63,1)=Y0(63,1).*1.31;
Y(64,1)=Y0(64,1).*1.315;
Y(65,1)=Y0(65,1).*1.32;
Y(66,1)=Y0(66,1).*1.325;
Y(67,1)=Y0(67,1).*1.33;
Y(68,1)=Y0(68,1).*1.335;
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    Y(69,1)=Y0(69,1).*1.34;
    Y(70,1)=Y0(70,1).*1.345;
    Y(71,1)=Y0(71,1).*1.35;
    Y(72,1)=Y0(72,1).*1.355;
    Y(73,1)=Y0(73,1).*1.36;
    Y(74,1)=Y0(74,1).*1.365;
    Y(75,1)=Y0(75,1).*1.37;
    Y(76,1)=Y0(76,1).*1.375;
    Y(77,1)=Y0(77,1).*1.38;
    Y(78,1)=Y0(78,1).*1.385;
    Y(79,1)=Y0(79,1).*1.39;
    Y(80,1)=Y0(70,1).*1.395;
    Y(81,1)=Y0(81,1).*1.4;
    Y(82,1)=Y0(82,1).*1.405;
    Y(83,1)=Y0(83,1).*1.41;
    Y(84,1)=Y0(84,1).*1.415;
    Y(85,1)=Y0(85,1).*1.42;
    Y(86,1)=Y0(86,1).*1.425;
    Y(87,1)=Y0(87,1).*1.43;
    Y(88,1)=Y0(88,1).*1.435;
    Y(89,1)=Y0(89,1).*1.44;
    Y(90,1)=Y0(90,1).*1.445;
    Y(91,1)=Y0(91,1).*1.45;
    Y(92,1)=Y0(92,1).*1.455;
    Y(93,1)=Y0(93,1).*1.46;
    Y(94,1)=Y0(94,1).*1.465;
    Y(95,1)=Y0(95,1).*1.47;
    Y(96,1)=Y0(96,1).*1.475;
    Y(97,1)=Y0(97,1).*1.48;
    Y(98,1)=Y0(98,1).*1.485;
    Y(99,1)=Y0(99,1).*1.49;
    Y(100,1)=Y0(100,1).*1.495;
    Y(101,1)=Y0(101,1).*1.5;
    Y(102,1)=Y0(102,1).*1.505;
    Y(103,1)=Y0(103,1).*1.51;
    Y(104,1)=Y0(104,1).*1.515;
    Y(105,1)=Y0(105,1).*1.52;
    Y(106,1)=Y0(106,1).*1.525;
    Y(107,1)=Y0(107,1).*1.53;
    Y(108,1)=Y0(108,1).*1.535;
    Y(109,1)=Y0(109,1).*1.54;
    Y(110,1)=Y0(110,1).*1.545;
    Y(111,1)=Y0(111,1).*1.55;
    Y(112,1)=Y0(112,1).*1.555;
    Y(113,1)=Y0(113,1).*1.56;
    Y(114,1)=Y0(114,1).*1.565;
    Y(115,1)=Y0(115,1).*1.57;
    Y(116,1)=Y0(116,1).*1.575;
    Y(117,1)=Y0(117,1).*1.58;
    Y(118,1)=Y0(118,1).*1.585;
    Y(119,1)=Y0(119,1).*1.59;
    Y(120,1)=Y0(120,1).*1.595;
    %progressive increase of inflow over a monthly basis due to climatic
    %changes
elseif k ==21
    Y(1,1)=Y0(1,1).*1;
    Y(2,1)=Y0(2,1).*.995;
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Y(3,1)=Y0(3,1).*.99;
Y(4,1)=Y0(4,1).*.985;
Y(5,1)=Y0(5,1).*.98;
Y(6,1)=Y0(6,1).*.975;
Y(7,1)=Y0(7,1).*.97;
Y(8,1)=Y0(8,1).*.965;
Y(9,1)=Y0(9,1).*.96;
Y(10,1)=Y0(10,1).*.955;
Y(11,1)=Y0(11,1).*.95;
Y(12,1)=Y0(12,1).*.945;
Y(13,1)=Y0(13,1).*.94;
Y(14,1)=Y0(14,1).*.935;
Y(15,1)=Y0(15,1).*.93;
Y(16,1)=Y0(16,1).*.925;
Y(17,1)=Y0(17,1).*.92;
Y(18,1)=Y0(18,1).*.915;
Y(19,1)=Y0(19,1).*.91;
Y(20,1)=Y0(20,1).*.905;
Y(21,1)=Y0(21,1).*.9;
Y(22,1)=Y0(22,1).*.895;
Y(23,1)=Y0(23,1).*.89;
Y(24,1)=Y0(24,1).*.885;
Y(25,1)=Y0(25,1).*.88;
Y(26,1)=Y0(26,1).*.875;
Y(27,1)=Y0(27,1).*.87;
Y(28,1)=Y0(28,1).*.865;
Y(29,1)=Y0(29,1).*.86;
Y(30,1)=Y0(30,1).*.855;
Y(31,1)=Y0(31,1).*.85;
Y(32,1)=Y0(32,1).*.845;
Y(33,1)=Y0(33,1).*.84;
Y(34,1)=Y0(34,1).*.835;
Y(35,1)=Y0(35,1).*.83;
Y(36,1)=Y0(36,1).*.825;
Y(37,1)=Y0(37,1).*.82;
Y(38,1)=Y0(38,1).*.815;
Y(39,1)=Y0(39,1).*.81;
Y(40,1)=Y0(40,1).*.805;
Y(41,1)=Y0(41,1).*.8;
Y(42,1)=Y0(42,1).*.795;
Y(43,1)=Y0(43,1).*.79;
Y(44,1)=Y0(44,1).*.785;
Y(45,1)=Y0(45,1).*.78;
Y(46,1)=Y0(46,1).*.775;
Y(47,1)=Y0(47,1).*.77;
Y(48,1)=Y0(48,1).*.765;
Y(49,1)=Y0(49,1).*.76;
Y(50,1)=Y0(50,1).*.755;
Y(51,1)=Y0(51,1).*.75;
Y(52,1)=Y0(52,1).*.745;
Y(53,1)=Y0(53,1).*.74;
Y(54,1)=Y0(54,1).*.735;
Y(55,1)=Y0(55,1).*.73;
Y(56,1)=Y0(56,1).*.725;
Y(57,1)=Y0(57,1).*.72;
Y(58,1)=Y0(58,1).*.715;
Y(59,1)=Y0(59,1).*.71;
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Y(60,1)=Y0(60,1).*.705;
Y(61,1)=Y0(61,1).*.7;
Y(62,1)=Y0(62,1).*.695;
Y(63,1)=Y0(63,1).*.69;
Y(64,1)=Y0(64,1).*.685;
Y(65,1)=Y0(65,1).*.68;
Y(66,1)=Y0(66,1).*.675;
Y(67,1)=Y0(67,1).*.67;
Y(68,1)=Y0(68,1).*.665;
Y(69,1)=Y0(69,1).*.66;
Y(70,1)=Y0(70,1).*.655;
Y(71,1)=Y0(71,1).*.65;
Y(72,1)=Y0(72,1).*.645;
Y(73,1)=Y0(73,1).*.64;
Y(74,1)=Y0(74,1).*.635;
Y(75,1)=Y0(75,1).*.63;
Y(76,1)=Y0(76,1).*.625;
Y(77,1)=Y0(77,1).*.62;
Y(78,1)=Y0(78,1).*.615;
Y(79,1)=Y0(79,1).*.61;
Y(80,1)=Y0(70,1).*.605;
Y(81,1)=Y0(81,1).*.6;
Y(82,1)=Y0(82,1).*.595;
Y(83,1)=Y0(83,1).*.59;
Y(84,1)=Y0(84,1).*.585;
Y(85,1)=Y0(85,1).*.58;
Y(86,1)=Y0(86,1).*.575;
Y(87,1)=Y0(87,1).*.57;
Y(88,1)=Y0(88,1).*.565;
Y(89,1)=Y0(89,1).*.56;
Y(90,1)=Y0(90,1).*.555;
Y(91,1)=Y0(91,1).*.55;
Y(92,1)=Y0(92,1).*.545;
Y(93,1)=Y0(93,1).*.54;
Y(94,1)=Y0(94,1).*.535;
Y(95,1)=Y0(95,1).*.53;
Y(96,1)=Y0(96,1).*.525;
Y(97,1)=Y0(97,1).*.52;
Y(98,1)=Y0(98,1).*.515;
Y(99,1)=Y0(99,1).*.51;
Y(100,1)=Y0(100,1).*.505;
Y(101,1)=Y0(101,1).*.5;
Y(102,1)=Y0(102,1).*.495;
Y(103,1)=Y0(103,1).*.49;
Y(104,1)=Y0(104,1).*.485;
Y(105,1)=Y0(105,1).*.48;
Y(106,1)=Y0(106,1).*.475;
Y(107,1)=Y0(107,1).*.47;
Y(108,1)=Y0(108,1).*.465;
Y(109,1)=Y0(109,1).*.46;
Y(110,1)=Y0(110,1).*.455;
Y(111,1)=Y0(111,1).*.45;
Y(112,1)=Y0(112,1).*.445;
Y(113,1)=Y0(113,1).*.44;
Y(114,1)=Y0(114,1).*.435;
Y(115,1)=Y0(115,1).*.43;
Y(116,1)=Y0(116,1).*.425;
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    Y(117,1)=Y0(117,1).*.42;
    Y(118,1)=Y0(118,1).*.415;
    Y(119,1)=Y0(119,1).*.41;
    Y(120,1)=Y0(120,1).*.405;
    %progressive decrease of inflow over a monthly basis due to climatic
    %changes
elseif k ==22
    O(1,1)=O0(1,1).*1;
    O(2,1)=O0(2,1).*1.005;
    O(3,1)=O0(3,1).*1.01;
    O(4,1)=O0(4,1).*1.015;
    O(5,1)=O0(5,1).*1.02;
    O(6,1)=O0(6,1).*1.025;
    O(7,1)=O0(7,1).*1.03;
    O(8,1)=O0(8,1).*1.035;
    O(9,1)=O0(9,1).*1.04;
    O(10,1)=O0(10,1).*1.045;
    O(11,1)=O0(11,1).*1.05;
    O(12,1)=O0(12,1).*1.055;
    O(13,1)=O0(13,1).*1.06;
    O(14,1)=O0(14,1).*1.065;
    O(15,1)=O0(15,1).*1.07;
    O(16,1)=O0(16,1).*1.075;
    O(17,1)=O0(17,1).*1.08;
    O(18,1)=O0(18,1).*1.085;
    O(19,1)=O0(19,1).*1.09;
    O(20,1)=O0(20,1).*1.095;
    O(21,1)=O0(21,1).*1.1;
    O(22,1)=O0(22,1).*1.105;
    O(23,1)=O0(23,1).*1.11;
    O(24,1)=O0(24,1).*1.115;
    O(25,1)=O0(25,1).*1.12;
    O(26,1)=O0(26,1).*1.125;
    O(27,1)=O0(27,1).*1.13;
    O(28,1)=O0(28,1).*1.135;
    O(29,1)=O0(29,1).*1.14;
    O(30,1)=O0(30,1).*1.145;
    O(31,1)=O0(31,1).*1.15;
    O(32,1)=O0(32,1).*1.155;
    O(33,1)=O0(33,1).*1.16;
    O(34,1)=O0(34,1).*1.165;
    O(35,1)=O0(35,1).*1.17;
    O(36,1)=O0(36,1).*1.175;
    O(37,1)=O0(37,1).*1.18;
    O(38,1)=O0(38,1).*1.185;
    O(39,1)=O0(39,1).*1.19;
    O(40,1)=O0(40,1).*1.195;
    O(41,1)=O0(41,1).*1.2;
    O(42,1)=O0(42,1).*1.205;
    O(43,1)=O0(43,1).*1.21;
    O(44,1)=O0(44,1).*1.215;
    O(45,1)=O0(45,1).*1.22;
    O(46,1)=O0(46,1).*1.225;
    O(47,1)=O0(47,1).*1.23;
    O(48,1)=O0(48,1).*1.235;
    O(49,1)=O0(49,1).*1.24;
    O(50,1)=O0(50,1).*1.245;
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O(51,1)=OO(51,1).*1.25;
O(52,1)=OO(52,1).*1.255;
O(53,1)=OO(53,1).*1.26;
O(54,1)=OO(54,1).*1.265;
O(55,1)=OO(55,1).*1.27;
O(56,1)=OO(56,1).*1.275;
O(57,1)=OO(57,1).*1.28;
O(58,1)=OO(58,1).*1.285;
O(59,1)=OO(59,1).*1.29;
O(60,1)=OO(60,1).*1.295;
O(61,1)=OO(61,1).*1.3;
O(62,1)=OO(62,1).*1.305;
O(63,1)=OO(63,1).*1.31;
O(64,1)=OO(64,1).*1.315;
O(65,1)=OO(65,1).*1.32;
O(66,1)=OO(66,1).*1.325;
O(67,1)=OO(67,1).*1.33;
O(68,1)=OO(68,1).*1.335;
O(69,1)=OO(69,1).*1.34;
O(70,1)=OO(70,1).*1.345;
O(71,1)=OO(71,1).*1.35;
O(72,1)=OO(72,1).*1.355;
O(73,1)=OO(73,1).*1.36;
O(74,1)=OO(74,1).*1.365;
O(75,1)=OO(75,1).*1.37;
O(76,1)=OO(76,1).*1.375;
O(77,1)=OO(77,1).*1.38;
O(78,1)=OO(78,1).*1.385;
O(79,1)=OO(79,1).*1.39;
O(80,1)=OO(70,1).*1.395;
O(81,1)=OO(81,1).*1.4;
O(82,1)=OO(82,1).*1.405;
O(83,1)=OO(83,1).*1.41;
O(84,1)=OO(84,1).*1.415;
O(85,1)=OO(85,1).*1.42;
O(86,1)=OO(86,1).*1.425;
O(87,1)=OO(87,1).*1.43;
O(88,1)=OO(88,1).*1.435;
O(89,1)=OO(89,1).*1.44;
O(90,1)=OO(90,1).*1.445;
O(91,1)=OO(91,1).*1.45;
O(92,1)=OO(92,1).*1.455;
O(93,1)=OO(93,1).*1.46;
O(94,1)=OO(94,1).*1.465;
O(95,1)=OO(95,1).*1.47;
O(96,1)=OO(96,1).*1.475;
O(97,1)=OO(97,1).*1.48;
O(98,1)=OO(98,1).*1.485;
O(99,1)=OO(99,1).*1.49;
O(100,1)=OO(100,1).*1.495;
O(101,1)=OO(101,1).*1.5;
O(102,1)=OO(102,1).*1.505;
O(103,1)=OO(103,1).*1.51;
O(104,1)=OO(104,1).*1.515;
O(105,1)=OO(105,1).*1.52;
O(106,1)=OO(106,1).*1.525;
O(107,1)=OO(107,1).*1.53;
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        O(108,1)=O0(108,1).*1.535;
        O(109,1)=O0(109,1).*1.54;
        O(110,1)=O0(110,1).*1.545;
        O(111,1)=O0(111,1).*1.55;
        O(112,1)=O0(112,1).*1.555;
        O(113,1)=O0(113,1).*1.56;
        O(114,1)=O0(114,1).*1.565;
        O(115,1)=O0(115,1).*1.57;
        O(116,1)=O0(116,1).*1.575;
        O(117,1)=O0(117,1).*1.58;
        O(118,1)=O0(118,1).*1.585;
        O(119,1)=O0(119,1).*1.59;
        O(120,1)=O0(120,1).*1.595

    end
    % Y(13:24,1)=Y0(13:24,1).*.8;
    % Y(37:48,1)=Y0(37:48,1).*.8;
    % Y(61:72,1)=Y0(61:72,1).*.8;



    %change demand
    for i = 1:119
        O2(i+1,1) = O(i+1,1);
        S(i+1,k) = 0;
%         y  = (Y(i,1) + Y(i+1,1) ) ./ 2;
%         o = (O(i,1) + O(i+1,1) ) ./ 2 ;
%
%         X(i+1) = X(i) + y - o ;
         X(i+1) = X(i) + (  ((Y(i,1) + Y(i+1,1) ) ./ 2)  - ((O(i,1) +
O(i+1,1) ) ./ 2));
        if X(i+1) < 0
            X(i+1) = 0;
            O2(i+1,1) = 0;
        end
        if X(i+1) > X0
            S(i+1,k) = X(i+1)-X0;
            X(i+1) = X0;
        end
    end
    t=S(:,k)+(O-O2);
    %sum of the spillway discharge and unmet demand
    % ttot=sum(t)
    TTotal(k,1) = sum(t)  ;
    STotal(k,1) = sum(S(:,k));
    UTotal(k,1) = sum(O-O2);

    %% plot variables
    figure('position',[100 100 1200 1000])
    % fg = figure(k)

    subplot(4,1,1)
    hold on
    plot(fols(:,2),'r','linewidth',2)
    plot(fols(:,3),'b','linewidth',2)
    legend('Inflow','Demand')
    grid on
```

```
    set (gca, 'fontsize',16)
    xlim([1 120])
    xlabel('Months','fontsize',16)
    ylabel('cubic meter','fontsize',14)
    eval(['title(''Case-' num2str(k) ''')']);
    set (gca, 'fontsize', 16)

    xx = zeros(1,120) + X0;
    % figure(2)
    subplot(4,1,2)
    hold on
    plot(X,'linewidth',2)
    legend('Resorvoir Storage')
    plot(1:120,xx,'k--','linewidth',2)
    grid on
    set (gca, 'fontsize', 16)
    xlim([1 120])
    ylim ([0 2000000000 ])
    xlabel('Months','fontsize',16)
    ylabel('cubic meter','fontsize',14)
    text(1,X0.*1.1,'Max. Capacity')
    % set(gca,'YScale','log')
    % at 15 and 110 months, the reservoir went dry/ "below 0"

    % figure(3)
    subplot(4,1,3)
    hold on
    plot(S(:,k),'k','linewidth',2)
    legend('Spillway Dicharge')
    xlim([1 120])
%     ylim([0 200000000])
    grid on
    set(gca, 'fontsize', 16)
    xlabel('Months','fontsize',16)
    ylabel('cubic meter','fontsize',14)




    % hold on
    % plot(Y(1:12,1),'r--')
    % plot(Y(13:24,1),'r')
    % plot(O(1:12,1),'b--')
    % plot(O(13:24,1),'bo')
    % grid on
    % set(gca,'fontsize',16)
    % xlim([1 12])
    % legend('base IN','base+70% IN','base OUT', 'base year 2')
    % the red line shows year 1 input, the blue line shows +70% input in the
    % second year, output of both years stays the same

    % figure (4)
    subplot(4,1,4)
    hold on
    plot([O2 O-O2],'linewidth',2)
    legend('Actual Release','Unmet Demand')
    xlim([1 120])
```

```
    grid on
    set(gca,'fontsize',16)
    xlabel('Months','fontsize',16)
    ylabel('cubic meter','fontsize',14)


    % plot(Y(49:60,1),'r*-')
    % plot(O(49:60,1),'b--')
    % plot(Y(37:48,1),'r')
    % plot(O(37:48,1),'b')
    % grid on
    % set(gca,'fontsize',16)
    % xlim([1 12])
    % legend('year4 IN','year4 OUT','year5 IN','year5 OUT')
    % %shows the final year of a +70% increase in input and the year of
decline
    % %afterwards
    % %the graph shows the years where the output changes


    % saveas(fg,'FIGURES\figx','tif')

     clearvars O O0 X X0 Y0 O2 ;

end % k
```

Sources:

1. http://www.norcalwater.org/water-maps/folsom-reservoir/
2. https://insuremekevin.com/why-is-folsom-dam-releasing-so-much-water-flood-protection/
3. https://www.usbr.gov/projects/index.php?id=74