Proposed Damming of the Merced River

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Foundation

To solve problems of water scarcity, dams are often constructed to retain large quantities of water for future use, whether agricultural, as drinking water, or otherwise. With these structures in place and filled, a retained supply of water is now maintained for dryer seasons when river and water supplies cannot mean the demand of cities, industry, and agriculture. Dams are already common throughout the Sierra Nevada Mountains of Eastern California, a natural result of a high population and agricultural industry residing in California’s relatively dry climate. The dams help the state deal with annual water fluctuations as well as droughts which recur over larger time periods, but with the combined effects of climate change and urbanization, California’s water supply remains vulnerable. Despite that, California has not built a new dam since 1980. In this report, the plausibility of adding another dam to the ranks of the Sierra Nevada, to help ensure stability to California’s water supply, is explored.

The new dam is proposed on the Merced River, which flows through the central Sierra Nevada Mountains, including Yosemite National Park, until it feeds into the San Joaquin River in the Central Valley. Several locations along the river were evaluated to identify the optimal location for a new dam that would retain the maximum volume of water at the lowest cost. Through GIS analysis, locations were tested to determine the volume of the reservoir that would be created for various dam heights and determine the approximate crest length the dam would need to retain that reservoir. Overall, four locations were evaluated, and the two best are presented here. This would allow engineers and regulators to weight the costs and benefits of each location and determine if a dam should be built along the Merced River, which location would be best (or dams could be built at both), and what size the dam ought to be.

This is a preliminary analysis with many limitations, but it seeks to establish a sanity check for these questions, at the very least. Ultimately, the decision to build a dam and with what specifications is answered by weighing costs and benefits. The benefits of a dam are flood control, hydroelectric power generation, and other smaller factors, but primarily the retention of water, ensuring a more durable supply year-round and through droughts. Thus, reservoir volume will be utilized as an approximate quantification of benefit. This value is obtained through the GIS analysis detailed in this report. The costs are multifaceted, but the two most significant are in the cost of construction and the flooding of the area needed to create the reservoir. The former is very complicated and can only be very roughly approximated in this report, but for now, the area of the dam will be employed as an index for monetary cost of construction. Note that this is only an index, and the marginal cost should be expected to increase with area. The latter, however, is also detailable through GIS analysis, as it will be here. Note that this cost is not proportional to reservoir area but accumulates as important structures and populated areas will need to be replaced or moved.
Data Collection and Preprocessing

The core datafile behind this analysis was a GeoTIFF file obtained from the USGS’s National Map. The file was a raster DTM with 1/3 arc second resolution measured in 2020. This formed the topographic overlay for all the maps included in this report and was foundational to all analysis performed here. The DTM is projected according to the NAD83 datum, and all other files were projected to it as well. The citation is provided here:


A shapefile containing the rivers and creeks of California was obtained from ArcGIS Hub. Most of the features of this file were deleted within ArcMap until only the Merced River, the Merced River’s South Fork, and Tenaya Creek remained. When obtained, this shapefile was projected on WGS 1984, so it was reprojected to NAD 1983 to match the DTM. The shapefile can be found here:

https://hub.arcgis.com/datasets/CDFW::california-streams/about

The information of these two files, the only two GIS files directly imported for this project, is tabulated here:

Table 1: Tabulation of GIS file info

<table>
<thead>
<tr>
<th>File</th>
<th>Source</th>
<th>Data Type</th>
<th>Spatial Reference</th>
<th>Notes</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTM</td>
<td>USGS</td>
<td>Raster</td>
<td>NAD 1983</td>
<td>1/3 second resolution</td>
<td><a href="https://www.sciencebase.gov/catalog/item/60e5e51cd34e2a7685cf4da6">https://www.sciencebase.gov/catalog/item/60e5e51cd34e2a7685cf4da6</a></td>
</tr>
<tr>
<td>CA Rivers</td>
<td>ArcGIS Hub</td>
<td>Shapefile</td>
<td>WGS 1984</td>
<td>Edited down to just Merced River</td>
<td><a href="https://hub.arcgis.com/datasets/CDFW::california-streams/about">https://hub.arcgis.com/datasets/CDFW::california-streams/about</a></td>
</tr>
</tbody>
</table>

Furthermore, Google Earth was used to qualitatively study the landscape, determine the location of various landmarks (notably the town of El Portal), and identify the names of minor waterways (Tenaya Creek and the South Fork of the Merced River). No geodetic data files taken from Google Earth.

Finally, Wikipedia was referenced for general information about various subjects related to this project:

Information on existing California Dams:


Information on the Merced River was sourced here:

https://en.wikipedia.org/wiki/Merced_River

Information on the town of El Portal:


Information on Yosemite Valley:

https://en.wikipedia.org/wiki/Yosemite_Valley,_California
Data Processing

As discussed before, the core questions of this analysis are what area will be flooded and what volume of water can be retained by a dam at each prospective location across multiple design heights. This section describes the process of answering those questions.

First, a line was drawn perpendicular to the river at the prospective location dam location. The elevation of the river at that location was determined on Google Earth, and this value served as the base elevation for that prospective dam. For each dam location, four heights were considered (100, 150, 200, and 250 meters). Single elevation contours were created for each of the reservoir elevations given these heights (sum of the dam height to the base elevation; each contour was a separate shapefile) via the Contour tool. A new polygon shapefile was then created and drawn, including the upstream extent of the greatest of these contours but excluding the downstream extent, featuring the dam as an edge. The four contour shapefiles were clipped to the area within this polygon, and an additional line was added to each of them spanning the length of the dam, connecting the two now-severed ends. This length was also measured and recorded. Thus, the maximum extent of the reservoir for each dam height was determined, and the area of the dam was roughly estimated as half the product of the dam height and dam length.

Next, the Feature to Polygon tool was used to create a polygon of the reservoir for each depth. This would serve as the raster mask in the next step.

To determine the maximum volume of each reservoir, the Raster Calculator tool was used to create a new raster, masked to the extent of the respective reservoir. This raster contained the depth of the reservoir and was determined by subtracting the DTM elevation from the respective maximum reservoir surface elevation. For example, when the reservoir height was expected to be up to 1400 meters, the depth raster for that reservoir was calculated as 1400 – DTM. These rasters were then used to calculate reservoir volume by multiplying the number of value-bearing cells by the cell resolution and the mean value (depth) of the raster (average depth times area), along with appropriate unit conversions.
The two dams determined to be the most viable plans are referred to hereafter as the “El Portal Dam” and the “Wawona Dam.” Figure 1 displays the two optimal proposed locations of the dams and the maximum extent of their reservoirs (at maximum dam height). As one can observe, the El Portal Dam is located farther downstream, in the foothills of the Sierra Nevada, whereas the Wawona Dam is located higher in the mountains and employs Yosemite Valley as its reservoir. These two locations each have unique advantages and disadvantages which will be examined here.

Table 1 tabulates the quantitative aspects of each dam design: length, dam area, and reservoir volume for each of the possible heights (obviously, intermediate heights can be interpolated between these values). The other two dam locations which were considered were located along the Merced River between the El Portal Dam and the Wawona Dam. They were excluded because they were inferior to at least one of the other two in every way (higher cost for a smaller reservoir in all cases).
Table 2: Table of dam lengths, dam areas, and reservoir capacities for each dam location at varying heights

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Reservoir EL (m)</th>
<th>Crest Length (m)</th>
<th>Dam Area (m²)</th>
<th>Water Volume (acre-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Portal Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>525</td>
<td>414</td>
<td>20,700</td>
<td>180,882</td>
</tr>
<tr>
<td>150</td>
<td>575</td>
<td>541</td>
<td>40,575</td>
<td>512,731</td>
</tr>
<tr>
<td>200</td>
<td>625</td>
<td>677</td>
<td>67,700</td>
<td>1,102,871</td>
</tr>
<tr>
<td>250</td>
<td>675</td>
<td>819</td>
<td>102,375</td>
<td>2,026,601</td>
</tr>
<tr>
<td>Wawona Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1250</td>
<td>276</td>
<td>13,800</td>
<td>461,528</td>
</tr>
<tr>
<td>150</td>
<td>1300</td>
<td>335</td>
<td>25,125</td>
<td>1,217,961</td>
</tr>
<tr>
<td>200</td>
<td>1350</td>
<td>464</td>
<td>46,400</td>
<td>2,126,788</td>
</tr>
<tr>
<td>250</td>
<td>1400</td>
<td>598</td>
<td>74,750</td>
<td>3,158,389</td>
</tr>
</tbody>
</table>

Figure 2: "El Portal Dam" Reservoir Extent Options

Figure 2 presents the reservoir contours of the El Portal Dam, the maximum extents of the reservoir surface at different dam heights. This dam spans a wider gap than the Wawona dam, so its area is larger, which will lend itself to greater construction and maintenance costs. Upstream from this...
location is the town of El Portal, a small town of less than 500 people which contains three major hotels marketed for Yosemite visitors. Because this town extends a relatively large area at this map scale, it is not presented as a point on the map. This town will be completely flooded at the two greater heights and partially flooded at the two lesser heights, so the cost of relocating the town’s residents and facilities must be considered in this design. Highway 140 runs along the Merced River here and approximately 15 kilometers of this road would be flooded and need to be reconstructed to restore this route to Yosemite National Park.

By analyzing the map, one can quickly notice that this dam creates a reservoir from not only the Merced River but also the South Fork Merced River. Fortunately, there are no major roads or settlements located immediately upstream of the South Fork beyond a few hiking trails. Therefore, this dam makes use of two river valleys for reservoir space but only one of the two imposes any major extra cost.

Figure 3: "Wawona Dam" Reservoir Extent Options

Figure 3 presents the reservoir contours of the Wawona Dam, named after the Wawona Tunnel adjacent to which it is built and could be converted into a penstock. This dam exploits the narrow, sheer cliffs of the Highway 140 passageway into Yosemite Valley to create a large reservoir from a relatively small dam. Owing to these cliffs, there is very little difference in the surface area extent of the reservoir between different dam heights. This dam would be smaller than the El Portal Dam, requiring less
concrete and would require significantly less excavation costs given the preexisting fresh granite abutments of the valley wall.

The obvious downside to this design is, however, the loss of Yosemite Valley as the crown jewel of Yosemite National Park, which also has a permanent population of just over 1000 people who would be displaced. However, the roads which traverse the valley are not vital for anything besides park access and would not need to be replaced. Overall, this dam would incur a smaller financial cost, a greater reservoir capacity, but a much greater public relations cost.

At 250 meters, either of these dams would become the tallest dam in the United States. The current tallest (in California and the United States) is the Oroville Dam at 235 meters, but dams have been constructed in other countries up to 300 meters. Furthermore, neither would contain the largest reservoir in the United States or even California. Currently, Shasta Dam retains the largest reservoir in California at 4.5 million acre-ft. At maximum height the Wawona Dam would retain the third largest reservoir in the state and the El Portal Dam the seventh. Therefore, these designs are within the precedent ranges of existing California dams, though building either dam to 250 meters of height would be record.
Conclusions

![Figure 4: Reservoir Volume vs Dam Size Comparison](image)

Figure 4: Plot of reservoir volume over dam area for each of the two designs

Remembering that dam area is, in this project, an index for cost of construction, Figure 4 attempts to plot reservoir capacity over cost of construction. Clearly, the Wawona Dam delivers a greater capacity at a lower cost of construction, but there are other costs not reflected in the dam area. To review:

- The Wawona Dam will displace approximately 1000 people, but the El Portal Dam only 500 people
- The El Portal Dam will require the rebuilding of at least 15 km of Highway 140 through steep terrain
- The El Portal Dam will require significantly more excavation cost for its abutment as the Wawona Dam is already located between fresh granite cliffs
- The Wawona Dam involves flooding Yosemite Valley which draws approximately 5 million tourists every year

While the El Portal dam incurs more immediate costs, the Wawona Dam may cost more in the long run due to lost tourism and the ensuing PR nightmare severe enough to get Larry Elder elected governor. Thus, the former can be seen as the “safe” choice while the latter the “ambitious” choice. Which of the two is optimal is again a question of costs versus benefits which would depend on factors beyond the scope of this report such as the availability of capital and the current political environment and water needs of California. It must be again restated, though, that the purpose of the dam, whichever is selected, is to ensure a stable water supply for a state which currently lacks it, and the Wawona Dam is significantly superior at delivering that.