Staff Report

TO: Board of Directors

FROM: Jennifer Hanson, General Manager
Doug Roderick, Director of Engineering

DATE: September 25, 2024

SUBJECT: **Storage Alternatives**

ADMINISTRATION

RECOMMENDATION:

Participate in discussion related to various storage options to address future forecasted unmet demands, and Adopt Resolution No. 2024-36:

A. Authorizing Filing an Amended Petition for Extension of Time on Permit 11626 in support of increasing storage at Rollins Reservoir.
B. Withdrawing Application for Assignment of State-Filed Right 5634; and
C. Discontinuing all Feasibility, Environmental and Other Analyses in Support of the Proposed Centennial Reservoir Project

BACKGROUND:

The District began the Plan for Water (PFW) in November of 2021. The PFW is a public collaboration process to determine the best ways to meet the NID's community demand for water over the coming decades. The PFW process has been a community collaboration effort supporting the District's long-term water resources management. Through this process, the District has developed strategic options that reflect a balanced mix of community perspectives.

The process included a review of available water supply and the long-term impacts on varying water demands. The Plan shows how future supply and demand scenarios may be integrated into the District's water management practices to ensure the community enjoys the same high-quality water and reliable water system it has now and for the past 100 years.

The breadth and variability of the watershed under the District's jurisdiction is amongst the most complex in the nation. Therefore, the stewardship of this system, and the communities it serves, is a responsibility that NID and its board regard with significant honor and duty.

The District has conducted monthly public workshops since November 2021, focusing on how future supply and demand scenarios may be integrated into the District's water management practices. The PFW consisted of the following stages:

- Stage 1: System Overview
- Stage 2: Water Rights
- Stage 3: Watershed
- Stage 4: Risk
- Stage 5: Strategic Planning
- Stage 6: Basis for Plan for Water
- Stages 7, 8, and 9: Hydrology & Hydrography, Demand, and Supply Modelling
- Stages 10 and 11: Strategy Options and Evaluation

The PFW has yielded potential scenarios for analysis and consideration. This process has been a teaching tool to facilitate community understanding of the challenges of managing water resources in the face of a changing climate and increasing customer demands. It also presented an educational opportunity to build an appreciation of District operations. During the past two years, public participation has remained constant, and trust in the District has improved, as evidenced by the number of community collaborations and partnerships. The Plan for Water collaboration among the District and community has yielded positive outcomes to enable NID to develop strategic options to determine the best ways to meet water demands over the coming decades.

The last PFW meeting on March 21, 2024, focused on Reservoir Operations Modelling of strategic alternatives. The PFW modeling (Stages 7, 8, and 9) consisted of the development of three numerical models that collectively represent how NID's water delivery system works. Attachment A includes the technical memorandum that provides the technical assumptions and data used for the modelling effort.

The three models developed are summarized below:

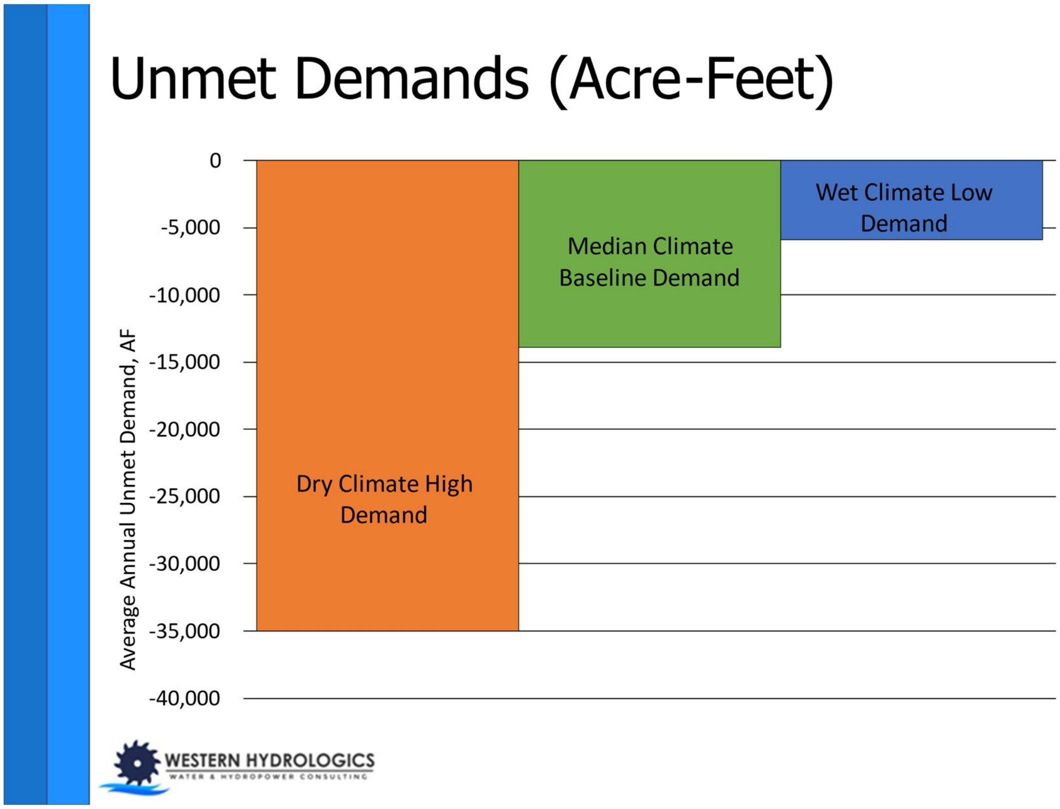
1. **Hydrological Model:** A physically based hydrological model that represents runoff conditions within NID watersheds. Runoff scenarios were developed using hydrological with precipitation and temperature projections as inputs. These projections were generated from three representative global climate models (extreme dry, medium, and wet climate conditions).

2. **Demand Model:** A demand model was configured and applied to estimate projected demands for a 50-year planning horizon. The demand model analyzed projected customer demand under three different demand scenarios (high, baseline, and low demand). The model utilized local data to account for the relative effects of estimated future changes in land use, climate, irrigation practices, soil properties, and other facts that impact demand.

3. **Operations Model Development:** A reservoir operations model was developed to simulate the operation of NIDs current storage, conveyance, and delivery system. The operation model used inflows from the hydrology model, operating rules, and regulations to assess how well customer demands were met. Three main scenarios were simulated through the operations model:

    a. Dry Future Climate with High Demands
    b. Median Future Climate with Baseline Demands
    c. Wet Future Climate with Low Demands

Utilizing the models described above, it is projected that the District will experience an annual average unmet demand under any of the three scenarios.



Strategic Alternatives: On March 21, 2024, results for seven strategic alternatives to address unmet demand that were modeled were presented to the Board (Please see Attachment A for the July 17, 2024, Plan for Water Final Technical Memorandum). The purpose of the modelling was to determine the impact of each alternative on reducing projected unmet demand. Below are the Strategic Alternatives:

- A Rollins Reservoir storage increase of 10,000 acre-feet (AF), equivalent to an increase of 18 percent of existing storage capacity.
- A Rollins Reservoir storage increase of 50,000 AF, equivalent to an increase of 91 percent of existing storage capacity.
- The addition of Centennial Reservoir, a new reservoir on the Bear River downstream of Rollins Reservoir with a usable storage capacity of 96,660 AF
- A reduction in reservoir carryover storage targets in NID reservoirs at the end of the irrigation season totaling 50,000 ac-ft, equivalent to 38% of the current carryover storage target. Please note that historically the District does implement reduced carry-over targets when experiencing a water supply decrease. This scenario mimics typical operational considerations.
- Additional water purchases from PG&E based on the existing 2018 Coordinated Operating Agreement (COA) between NID and PG&E.
- A combination of revised carryover storage targets plus additional water purchases from Pacific Gas & Electric based on the existing 2018 COA.

- An extended irrigation season, assuming two additional weeks in October. *Please note – this strategic alternative was requested by the Board and would not reduce unmet demand, therefore, it is not further discussed in this staff report*.

FINDINGS AND ANALYSIS:

Rollins Reservoir Storage Increase of up to 10,000 AF

This alternative was briefly studied in 1986 (Attachment B, June 30, 1986, Rollins Labyrinth Weir Feasibility Review). It would increase the storage between 4,250 to 9,740 AF by raising the elevation of the spillway crest and the dam. There were three options studied in 1986, including two (2) options replacing the existing ogee spillway crest with a labyrinth weir increasing spillway crest elevations 5 - 6.5 feet, and installation of bascule gates that would are movable to control water levels, increasing spillway crest elevation by 11.2 feet.

- **Cost**: This is the least costly alternative. The estimated cost of construction is approximately $30,000,000. There is a low confidence in the original cost estimate as the project was reviewed was in 1986. New requirements, including increases in the Probable Maximum Flood (PMF) and spillway requirements will increase the amount of study, investigation, design and regulatory approval substantially increasing the costs of this alternative.

Project Cost Estimate	Raw Water Project Cost	Cost Per Miners Inch	Treated Water Project Cost	Cost per Hundred Cubic Feet
$30,000,000	$28,200,000	$2,131.45	$1,800,000	$0.53

  Based on the costs shown above, 1-inch raw water customers would be required to pay an additional $71.05 per year with no debt service. Costs were distributed in this analysis based on percentage of water use. Raw water typically accounts for 94% of water deliveries and treated water customers account for 6% of water deliveries.

- **Water Rights**: The District's existing water rights would be sufficient to supply the additional storage capacity. Please see Attachment C for Rollins water rights analysis. It should also be noted that in 9 out of 10 years Rollins Reservoir spills during the late winter and springs months, therefore it has been determined that the additional storage capacity would be filled in most years. The District's Permit 11626 is one of the primary rights for Rollins Reservoir. In 2009, the District petitioned the State Water Resources Control Board seeking a license for Permit 11626. In light of the PFW analyses, the District is proposing amending its petition to seek additional time to perfect use under Permit 11626 to potentially accommodate future water supply needs of the District.

- **Environmental**: There would be environmental impacts associated with this alternative, but they would be minimized due to the small increase in surface water elevation associated with the project. It is likely that this project would still require the completion of a full Environmental Impact Report (EIR) due to the reported presence of yellow-legged frogs and the potential for impacts to other species. It would also be subject to numerous environmental permits and mitigation.

- **Other Regulatory Concerns:** FERC and DSOD would have to approve the design of the project and specially approve the potential changes to the ability to pass the probable maximum flood and freeboard. Additionally, any modifications to the spillway and/or the dam would require approval.

- **Water Supply:** A modified Rollins Reservoir was built into the PFW model, simulating an additional 10,000 AF of usable storage capacity at Rollins Reservoir. Please see Attachment A for details. All outlet works are assumed to have the same capacities as the current Rollins Reservoir outlet works. Proposed future FERC minimum flow requirements and minimum pool requirements were also assumed.

  This strategic alternative allows for more water to be stored in Rollins Reservoir ahead of the summer storage delivery season, allowing a larger buffer from minimum pool levels. Currently, Rollins Reservoir spills most years, and there is water available to be stored in nearly all years. The table below summarizes the demand, delivery, and unmet demands under all three climate scenarios:

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Rollins 10 TAF increase	181,616	152,544	29,072
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Rollins 10 TAF increase	151,806	142,221	9,585
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Rollins 10 TAF increase	109,705	105,485	4,220

- **Constructability:** It is anticipated that there would be some impact to water supply during construction of this alternative, but it would be minimized because most of the work would be completed above the surface water elevation. There is some question as to whether this concept would be authorized by DSOD/FERC.

- **Benefits Analysis**: This alternative has the following advantages when compared to the other storage alternatives
  - Smaller footprint reduces environmental impacts and would likely have less environmental impacts when compared to the other storage alternatives.
  - Least impact to private property when compared to other storage alternatives. The footprint associated with an increase in surface water elevation would need to be analyzed through additional modelling, although it is anticipated that minimal property impacts would occur.
  - Small increase in power generation due to additional head available at certain times of the year.
  - Small increase in water storage to reduce unmet demands versus current Rollins capacity.
  - Least expensive of the alternatives that construct new storage.
  - Could be combined with operational strategies such as maximizing the purchase of PG&E water and strategically implementing carryover targets during drought events.

Rollins Reservoir Storage Increase of 50,000 AF

This alternative includes raising the Rollins embankment dam to store an additional 50,000 AF. The existing embankment dam is 252.5 feet in height. This proposed alternative would increase the embankment to 306 feet and also increase the length from 1,260 feet to approximately 1,500 feet. The 53.4-foot dam crest raise would include an inclined core zone that would be flanked by inclined filters and by rockfill shell zones. The spillway crest would be raised by 52.4 feet. This alternative was preliminarily studied in the Draft January 2020 AECOM Enlarged Rollins Reservoir Concepts Opinion of Probable Construction Costs (Attachment D).

- **Cost:** This alternative is currently estimated to cost $290,202,500 to construct based on the 2020 AECOM study. Decreased recreation and power revenue would also be experienced during construction due to reservoir elevation and flow variations during construction, which are expected to be between 4 to 5 years. Once completed there may be an increase in hydropower revenue due to increased available head and storage. Below is a table that summarizes the total cost per customer class.

Project Cost Estimate	Raw Water Project Cost	Cost Per Miners Inch	Treated Water Project Cost	Cost per Hundred Cubic Feet
$290,202,500	$272,790,350	$20,618.40	$17,412,150	$5.12
$470,100,000*	$441,894,000	$33,399.82	$28,206,000	$8.30

*Cost shown with debt service, assumed 30-year issuance with 4% interest rate.

Based on the costs shown above, 1-inch raw water customers would be required to pay an additional $687.28 per year with no debt service and $1,113.33 per year with debt service. Costs were distributed in this analysis based on percentage of water use. Raw water typically accounts for 94% of water deliveries and treated water customers account for 6% of water deliveries.

- **Water Rights:** The District's existing water rights may be sufficient to supply the additional storage capacity. Please see Attachment C for the April 25, 2024, Water Rights Assessment to Support a 50 TAF Expansion of Rollins Reservoir. There are 6 water rights that entitle the District to store water at Rollins Reservoir. Five of those rights are for consumptive use, and the 6th is for power generation. In 2009, the District began pursuing the licensing of several of the water rights used for consumptive purposes in Rollins. Historically, the beneficial use of these rights was less than the face value. In order to construct this alternative, the District would need to request withdrawal of licensing the suite of Rollins Reservoir Storage Rights and pursue a petition for extension to allow for additional time to develop the enhanced storage project.

- **Environmental**: Environmental impacts associated with this alternative would likely be greater than Rollins 10,000 AF but likely less than Centennial. This project would still require the completion of a full Environmental Impact Report (EIR) due to the reported presence of yellow-legged frogs and the potential for impacts to other species and would be subject to numerous environmental permits and mitigation.

- **Water Supply:** This strategic alternative allows for more water to be stored in Rollins Reservoir ahead of the summer storage dispatch season, which allows a larger buffer from minimum pool levels. Currently, Rollins Reservoir spills most years, and there is water available to be stored in nearly all years. The modelling completed for the PFW also shows that Rollins reservoir would not fill every year by the additional capacity of 50,000 AF, but storage would remain higher than the current capacity every year. Please see Attachment A for additional details.

  The table below summarizes the demand, delivery, and unmet demands under all three climate scenarios:

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Rollins 50 TAF increase	181,616	167,384	14,232
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Rollins 50 TAF increase	151,806	150,092	1,714
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Rollins 50 TAF increase	109,705	108,892	813

- **Constructability:** The existing spillway would need to remain functional throughout construction of the raised dam. The raise would begin by excavating the top of the dam to establish the inclined core zone and rebuilding the dam back to original crest elevation 2190.1 feet during the dry season to allow use of the spillway during the winter season. Additional engineering and geotechnical analysis would be required to determine if the existing core and support a large dam on top of it. It is estimated that construction would take 4 to 5 years to complete.

- **Benefits Analysis**: This alternative has the following advantages when compared to the other storage alternatives
  - Greater environmental impacts when compared to Rollins 10,000 AF but less impacts when compared to Centennial Reservoir.
  - More private property impacts than Rollins 10,000 AF but far less impacts than Centennial Reservoir. The footprint associated with an increase in surface water elevation would need to be analyzed through additional modelling.
  - Would result in increased power revenue opportunities once completed due to additional head and storage available.
  - Highest decrease in unmet demands. Although this alternative would create less additional storage than Centennial, Rollins 50,000 AF creates a greater benefit to unmet demand because water can be delivered to more customers via the Bear River Canal due to the higher location of Rollins when compared to the lower elevation of Centennial.
  - This option may garner interest in a partnership for construction. Currently Placer County Water Agency relies upon PG&E water stored in Rollins Reservoir and could potentially benefit from additional Rollins Reservoir Storage.
  - Could be combined with operational efficiency such as maximizing the purchase of PG&E water and strategically implementing carryover targets during drought events.

Centennial Reservoir

Centennial Reservoir would be a new reservoir on the Bear River that would provide for 96,660 AF of usable storage. The Centennial Reservoir would extend upriver from just above the existing Combie Reservoir for slightly over six miles to a point west of the Town of Colfax, approximately two miles downstream of the existing Rollins Dam. The anticipated water depth at the dam would be approximately 255 feet, and the height of the dam would be approximately 275 feet. Minimum flow requirements below Centennial Reservoir were assumed to be the same as Lake Combie. Centennial Reservoir would be used to store water in the winter and spring and provide water to Lake Combie for deliveries into the Combie Phase I and Magnolia III canals in the summer and fall.

- **Cost:** The cost for this alternative is based on the August 17, 2017, Centennial Reservoir Project Roller Compacted Concrete Dam Opinion of Probable Construction Cost. Below is a table that summarizes total cost per customer class.

Project Cost Estimate	Raw Water Project Cost	Cost Per Miners Inch	Treated Water Project Cost	Cost per Hundred Cubic Feet
$584,077,620	$549,032,963	$41,497.74	$35,044,657	$10.31
$946,200,000	$889,428,000	$67,225.93	$56,772,000	$16.71

*Cost shown with debt service, assumed 30-year issuance with 4% interest rate.

Based on the costs shown above, 1-inch raw water customers would be required to pay an additional $1,383.26 per year with no debt service and $2,240.86 per year with debt service. Costs were distributed in this analysis based on percentage of water use. Raw water typically accounts for 94% of water deliveries and treated water customers account for 6% of water deliveries.

- **Water Rights:** The Centennial Reservoir would require the district to obtain new water rights. In 2014, the District applied for unappropriated water on the Bear River, including filing a petition for assignment of available State filings. NID made an application to the State Water Board for assignment of state-filed application 5634 (Application), with a priority date of 1927. The District is currently in the State Water Board's Administrative hearing process to address protests filed by third parties against the District's application. The next step in the process, if it proceeds, would be for the District's application to move to formal hearing proceedings.

  It should also be noted that there are other regulatory proceedings that are currently ongoing that may result in the state-filled applications not being available for appropriation.

- **Environmental**: This alternative would likely have the most environmental impacts as it would be a new on river reservoir. This project would still require the completion of a full Environmental Impact Report (EIR) and would be subject to numerous environmental permits and mitigation.

- **Water Supply:** Centennial Reservoir would create the greatest amount of new storage when compared to the other alternatives but does not decrease unmet demand by as much as the Rollins 50,000 AF raise due to its lower elevation location. Please refer to Attachment A for details.

The table below summarizes the demand, delivery, and unmet demands under all three climate scenarios:

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate	Existing Operations	181,616	146,458	35,158
High Demand	Centennial Reservoir	181,616	165,322	16,294
Median Climate	Existing Operations	151,806	137,706	14,099
Baseline Demand	Centennial Reservoir	151,806	144,332	7,473
Wet Climate	Existing Operations	109,705	103,941	5,763
Low Demand	Centennial Reservoir	109,705	108,815	890

- **Constructability:** This alternative would be new construction and would require extensive site development, site clearing, river diversion, dam site preparation and foundation excavation, foundation grouting, rock borrow, and aggregate production, concrete and fly ash production and installation, construction of outlet and intake structures, and other miscellaneous items of construction. It is estimated that it would take 3 to 4 years to construct the project.

- **Benefits Analysis**: This alternative has the following advantages when compared to the other storage alternatives:
    - Highest increase in storage volume.
    - Highest increase in carryover storage capacity. This is because this alternative results in the largest storage increase but does not have the highest level of increased water deliveries due to the smaller area of customer benefit.
    - This alternative would have less impact on existing customers during construction.
    - This alternative would not require FERC approval as there is not currently a powerhouse proposed as part of the project.
    - This alternative would create a new large recreational reservoir.

Revised Carryover Targets

The revised carry-over targets alternative lowers carry-over targets at NID reservoirs. Existing operations carry-over targets use the average historical reservoir carry-over level. In dry years, the District actually draws these reservoirs lower than the average carry-over level. The original modelling relied on hard carry over target levels that did not reflect actual operations in dry years. To evaluate actual operations on projected unmet demands, revised carry-over targets were modelled that represent the carry-over level the reservoir would be set at in a drought. Attachment A includes the technical analysis related to the revised carry-over target strategy. The table below provides the existing and revised carry-over targets used for modelling purposes:

Reservoir	Existing Operations Carryover Target	Revised Carryover Target
Jackson Meadows Reservoir	35,000	21,000
Bowman Reservoir	30,000	14,500
Sawmill Lake	1,500	1,000
French Lake	7,000	5,000
Faucherie Lake	2,100	1,500
Jackson Lake	600	1,000
Rollins Reservoir	40,000	25,000
Scotts Flat Reservoir	23,000	17,000
Lake Combie	2,500	2,500
Total	**141,700**	**88,500**

- **Cost:** There is no cost to implement this operational strategy. This strategy is already relied upon during periods of drought or decreased water supply.

- **Water Rights:** No additional water rights are required to implement this strategy.

- **Environmental:** No additional environmental impacts associated with this strategy.

- **Water Supply:** The revised carryover targets result in further drawdown of the reservoirs by the end of the year, and more storage capture in the winter and spring before the initiation of spill. These revised carryover targets did not significantly affect the ability of these reservoirs to fill in most years.

  The additional delivery and resulting reduction in unmet demand is shown below:

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Revised Carryover Targets	181,616	150,528	27,715
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Revised Carryover Targets	151,806	138,963	9,814
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Revised Carryover Targets	109,705	104,218	3,079

- **Constructability:** Not applicable to operational strategy.

- **Benefits Analysis:** This alternative has the following advantages when compared to the other storage alternatives:
  - No cost alternative.
  - Decreases unmet demand but not as much as Rollins 10,000, Rollins 50,000, or Centennial.
  - Limited environmental impacts.
  - No additional water rights needed.
  - An operational strategy that could be combined with other operational strategies or one of the smaller storage projects.
  - Feasible short-term solution that is consistent with existing operations.

Purchase Additional Supply from PG&E

The District is currently a signatory to the 2018 Coordinated Operating Agreements between Pacific Gas and Electric and Nevada Irrigation District (COA). The COA specifies amounts of water that will be made available for purchase by the District from PG&E. The monthly purchase volumes and maximum flow rates are based on the Sacramento Valley Index, a water year-type index defined and calculated by the Department of Water Resources. During the PFW modelling process, maximizing the purchase of PG&E water supply was incorporated into the model to determine when unmet demands were occurring and identify water that could be purchased to meet or reduce those unmet demands. The results of this effort are included in Attachment A.

- **Costs:** The cost to maximize the purchase of PG&E water would be approximately $1,500,000 per year. The actual cost would be based on the amount of water available and purchased. Below is a table that summarizes total cost per customer class per year and total costs per customer class over a 30-year period.

Project Cost Estimate	Raw Water Project Cost	Cost Per Miners Inch	Treated Water Project Cost	Cost per Hundred Cubic Feet
*$1,500,000	$1,410,000	$106.57	$90,000	$0.03
**$45,000,000	$42,300,00	$3197.18	$2,700,00	$0.79

*Annual Cost
** 30-year Cost

- **Water Rights:** No additional water rights are required to implement this strategy.

- **Environmental:** No additional environmental impacts associated with this strategy.

- **Water Supply:** Maximizing the purchase of PG&E water supply decreases unmet demand

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Purchase of additional supply	181,616	152,344	29,272
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Purchase of additional supply	151,806	141,892	9,914
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Purchase of additional supply	109,705	105,868	3,837

- **Constructability:** Not applicable to operational strategy.

- **Benefits Analysis:** This alternative has the following advantages when compared to the other storage alternatives:
  - Lower cost alternative when compared to the new storage alternatives.
  - No environmental impacts.
  - No impacts to private property.
  - Operational strategy that could be combined with other alternatives.

- o Decreases unmet demand but should be considered with revised carryover storage targets.
- o Feasible short-term solution that is consistent with existing operations.
- o No additional water rights needed.

Combined Reduced Carryover Storage Target and Maximize Purchase of PG&E Water Supply

The PFW also evaluated combining the two proposed operational strategies to determine the combined impact on decreasing unmet demand. These alternatives work together to reduce the unmet demand further than the individual alternatives. The table below

The additional delivery and resulting reduction in unmet demand is shown below:

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Revised Carryover Targets and Purchase of additional supply	181,616	158,277	23,338
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Revised Carryover Targets and Purchase of additional supply	151,806	145,636	6,170
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Revised Carryover Targets and Purchase of additional supply	109,705	107,762	1,943

RECOMMENDATION SUMMARY:

Based on this analysis and the supporting studies, staff recommends the following actions:

A. Move forward with the Rollins 10 AF raise for further consideration. This alternative it is the least costly option for increased storage and could be a viable interim step to address future predicted unmet demands. Further consideration would require the District to initiate a more thorough engineering analysis of Rollins 10,000 AF, specifically focusing on whether the increased height of the weir and a potential small dam raise would impact the ability to pass the PFM and result in an acceptable level of freeboard. This analysis needs to be completed to determine if this alternative is feasible. Approval of this recommendation will be requested from the Board through a separate item that considers adding a potential project to the Capital Improvement Program.

B. Move forward for further consideration Rollins 50,000 AF and conduct a more thorough engineering analysis. This alternative provides the greatest benefit of the new storage alternatives, has less environmental and property impacts than Centennial Reservoir, and is less costly than Centennial Reservoir. Additionally, due its location, the District would have a greater ability to attract partners for the project. Approval of this recommendation will be requested from the Board through a separate item that considers adding a potential project to the Capital Improvement Program.

C. File an amended petition on Permit 11626 for an extension of time to further develop and use water under Permit 11626 to allow for increased storage at Rollins Reservoir under either storage alternative.
D. Remove from further consideration Centennial Reservoir. Centennial Reservoir has reduced benefits due to its location and has the highest financial and environmental impacts. The cost of the project would be a significant burden on ratepayers and it would be difficult to obtain financing for the project. The bond underwriting process would not allow for speculative out-of-district water sales to be utilized to meet revenue requirements for the purpose of paying ongoing debt service. As such, the revenue required for debt service payments would be required to be incorporated into water rates. Additionally, there is great uncertainty regarding the state-filed water right availability due to ongoing regulatory proceedings. Due to the District's own regulatory proceedings with the State Board regarding the application for the state file water right, the District has only two options: proceed with the project or withdraw the pending application. Staff is recommending that the existing application for assignment of state-filed water right 5634 be withdrawn.

- As an interim solution to address unmet demand, staff recommends moving forward with continuing to implement revised carryover storage targets and maximizing the purchase of PG&E water. Approval to purchase PG&E water supply will be requested through the annual budget process.
- Conduct an analysis to determine if there is a project that could be constructed to reduce further sedimentation of Rollins Reservoir. Implementation of this action will be considered as a separate item that will be presented to the Board.

FISCAL IMPACT:
The proposed actions do not require an amendment to the 2025 Annual Budget. Additional engineering studies for increasing storage at Rollins and the purchase of PG&E water supply would be considered during the annual budgeting process if approved.

Attachments:

- Attachment A: July 17, 2024, Plan for Water Final Technical Memorandum
- Attachment B: June 30, 1986, Rollins Labyrinth Weir Feasibility Review
- Attachment C: April 25, 2024, Water Rights Assessment to Support a 50 TAF Expansion of Rollins Reservoir
- Attachment D: Draft January 2020 AECOM Enlarged Rollins Reservoir Concepts Opinion of Probable Construction Costs
- Draft Resolution - Authorizing Filing an Amended Petition for Extension of Time on Permit 11626; Withdrawing Application for Assignment of State-Filed Right 5634; and Discontinuing all Feasibility, Environmental and Other Analyses in Support of the Proposed Centennial Reservoir Project

Nevada Irrigation District

Plan for Water

FINAL TECHNICAL MEMORANDUM

7/17/2024

Prepared For:

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TABLE OF CONTENTS

Abbreviations ix

Executive Summary xii

Chapter 1. Introduction 1-1

1.1. The Nevada Irrigation District 1-1

1.2. NID's Water Supply Network 1-1

1.3. The Plan for Water 1-2

1.4. General Approach 1-3

1.5. Stakeholder Participation 1-4

Chapter 2. Hydrological Model 2-1

2.1. Watershed Description Development 2-1

2.2. Software 2-5

2.3. Data Collection 2-5

2.3.1. Spatial Tools and Reference 2-5

2.3.2. GIS Data 2-5

2.3.3. Digital Elevation Model 2-5

2.3.4. Land Cover 2-6

2.3.5. Soil Data 2-6

2.3.6. Precipitation Data 2-6

2.3.7. Temperature Data 2-6

2.3.8. Evapotranspiration 2-6

2.3.9. Snow Data 2-7

2.3.10. Streamflow and Reservoir Data 2-7

2.4. HEC-HMS Model Development 2-11

2.4.1. Watershed Delineation 2-11

2.4.2. Infiltration 2-15

2.4.3. Canopy Losses 2-18

2.4.4. Unit Hydrograph Transform 2-19

2.4.5. Baseflow 2-19

2.4.6. Streamflow Routing 2-20

2.4.7. Reservoir Routing 2-20

2.4.8. Snowmelt 2-21

2.5. Calibration of Snow Processes 2-22

2.5.1. Approach 2-22

2.5.2. Performance 2-25

2.5.3. Results 2-26

2.6. HEC-HMS Model Calibration 2-30
2.6.1. Calibration Parameters and Approach 2-30
2.6.2. Results for Selected Water Years 2-32
2.6.3. Results for Other Water Years 2-44
Chapter 3. Projected Hydrology 3-1
3.1. Introduction 3-1
3.1.1. Global Climate Model Projections 3-2
3.1.2. Downscaled Global Climate Model Projections 3-2
3.1.3. Reservoir Inflow Projections 3-3
3.2. Climate Scenario Selection 3-3
3.3. Historical Hydrology 3-5
3.4. Projected Hydrology 3-8
3.5. Representative Scenarios 3-12
Chapter 4. Demand Model 4-1
4.1. Introduction 4-1
4.2. Demand Model Development 4-1
4.2.1. Background and Major Drivers of Water Demand 4-1
4.2.2. Overview of the NID Demand Model Structure and Inputs 4-3
4.2.3. IDC Model 4-5
4.2.4. Canal System Balance 4-27
4.2.5. Demands from NID Reservoirs 4-28
4.3. Demand Model Scenarios 4-29
4.3.1. Summary of Scenarios 4-29
4.3.2. Projected Demand Scenario Assumptions 4-33
4.4. Results 4-36
Chapter 5. Operations Model 5-1
5.1. Historical Inflow Hydrology 5-1
5.1.1. Methods 5-1
5.1.2. Validation 5-1
5.2. Recent Historical Deliveries 5-4
5.3. USACE Hydrologic Engineering Center ResSim Model 5-6
5.3.1. Description of the Software Package 5-6
5.3.2. Selection Rationale 5-6
5.4. Model Development 5-6
5.4.1. Rebuild in Current ResSim Software Version 5-6
5.4.2. Model Facilities 5-6
5.4.3. Significant Changes from the Previous NID ResSim Model 5-8

5.4.4. Implementation of the Integrated Red-Blue Model ... *5-10*

5.4.5. Historical Conditions Model ... *5-12*

5.4.6. Model Calibration and Validation ... *5-12*

5.5. Projection Inputs ... **5-15**

5.5.1. Integrated Water Flow Model Demand Calculator (IDC) Demands ... *5-15*

5.5.2. HEC-HMS Climate Change Hydrology ... *5-15*

5.6. Simulation Results Based on Existing Operations ... **5-18**

5.6.1. Assumptions ... *5-18*

5.6.2. Comparison to Historical Conditions ... *5-19*

5.6.3. Results Summary ... *5-30*

Chapter 6. Strategic Alternatives ... **6-1**

6.1. Existing Operations Studies ... **6-1**

6.2. Strategic Alternatives Chosen for Modeling ... **6-3**

6.3. Extended Irrigation Season ... **6-3**

6.4. Rollins Reservoir 10,000 AF Storage Capacity Increase ... **6-4**

6.5. Rollins Reservoir 50,000 AF Storage Capacity Increase ... **6-7**

6.6. Centennial Reservoir ... **6-10**

6.7. Revised Carryover Targets ... **6-13**

6.8. Purchase of Additional Supply from PG&E ... **6-14**

6.9. Revised Carryover Targets and Purchase of Additional Supply from PG&E ... **6-17**

6.10. Summary ... **6-19**

Chapter 7. Summary and Recommendations ... **7-1**

Chapter 8. References ... **8-1**

FIGURES

Figure 1. Relative Increase in Average Annual Water Delivery ... xiv
Figure 2. Relative Change in Average Annual Carryover Storage ... xvi
Figure 1-1. Modeling Schematic Demonstrating How Each Model Informs the Next ... 1-3
Figure 2-1. Nevada Irrigation District Map ... 2-2
Figure 2-2. Major Tributaries and Reservoirs Within NID watersheds ... 2-4
Figure 2-3. Snow Stations Used for Temperature Index Calibration ... 2-8
Figure 2-4. Streamflow Gages Used During Model Calibration ... 2-10
Figure 2-5. NID Watershed Delineation ... 2-13
Figure 2-6. HEC-HMS Subbasins Delineation ... 2-14
Figure 2-7. 2019 NLCD Land Cover Classifications for NID Basin ... 2-17
Figure 2-8. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Blue Canyon Station (BLC) ... 2-27
Figure 2-9. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Huysink Station (HYS) ... 2-27

Figure 2-10. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Robinson Cow Camp Station (RCC) 2-28
Figure 2-11. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Central Sierra Snow Lab Station (CSL) 2-28
Figure 2-12. Calibration Locations for NID HEC-HMS Model (Described in Table 2-20) 2-33
Figure 2-13. WY1997 PBIAS Results 2-35
Figure 2-14. WY2004 PBIAS Results 2-37
Figure 2-15. WY2006 PBIAS Results 2-39
Figure 2-16. WY2015 PBIAS Results 2-41
Figure 2-17. WY2021 PBIAS Results 2-43
Figure 2-18. Scatter Plot of WPLM for July Versus Weighted Average Baseflow Index 2-45
Figure 2-19. Cumulative Daily Inflow (1975–2018) for Yuba at Smartsville (USGS gage 11419000)— After Refinements 2-46
Figure 2-20. Cumulative Daily Inflow (1975–2018) for Yuba at Smartsville (USGS gage 11419000)—After Refinements 2-47
Figure 3-1. Required Datasets for the Generation of Projected Inflow and Their Current Availability for CMIP5 and CMIP6 3-2
Figure 3-2. Comparison of the GCM Rankings by Local Climate Metric Performance and Process-Based Metric Performance (Source: Krantz et al. 2021). 3-4
Figure 3-3. Comparison of Average Annual Inflow (1976–2021) for NID Basin 3-7
Figure 3-4. Comparison of Average Annual Inflow (1976–2021) for NID Basin 3-8
Figure 3-5. 50-Year Average Total Inflow for 1-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios 3-9
Figure 3-6. 50-Year Average Total Inflow for 5-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios 3-9
Figure 3-7. 50-Year Average Total Inflow for 10-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios 3-10
Figure 3-8. Median Annual Inflow for 1-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios 3-10
Figure 3-9. Median Annual Inflow for 5-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios 3-11
Figure 3-10. Median Annual Inflow for 10-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios 3-11
Figure 3-11. Total Annual Inflow Time Series for NID Basin, 2022–2071 3-13
Figure 3-12. 50-Years Cumulative Total Annual Inflow for NID Basin 3-13
Figure 4-1. Conceptual Water Budget as Simulated in the IDC Model, Quantifying Inflows and Outflows of Water Through the Landscape (DWR 2016) 4-6
Figure 4-2. Overview of Structural Differences Between a Spatial IDC Model and a Unitized IDC Model 4-7
Figure 4-3. Average ET (2016–2022) from OpenET and Climate Zones 4-12
Figure 4-4. Sample ET Curve Summarized for all Parcels Categorized as Pasture in Climate Zone 3 (2021), with Comparisons to Other Representative ET Estimates for Pasture from Cal-SIMETAW (DWR 2022b), the Yuba Groundwater Model (YWA, 2019), and the Irrigation Training and Research Center ET Data for Water Budget Applications (ITRC 2023) 4-13
Figure 4-5. Average ETo (2016–2022) from Spatial CIMIS and Climate Zones 4-14
Figure 4-6. Distribution of ETo (2016–2022) from Spatial CIMIS Across the Climate Zones, Where Frequency Represents the Number of Pixels Within Each Zone 4-15
Figure 4-7. Average Precipitation from PRISM (30-Year Normal, 1991–2020) and IDC Climate Zones 4-17
Figure 4-8. Land Uses Simulated in the IDC model, Summarized by Parcel (2022) 4-20
Figure 4-9. Predominant Soil Textures Simulated in the IDC Model 4-22
Figure 4-10. Demand Zones and Demand Nodes Simulated in the Demand Model 4-28
Figure 4-11. Annual Results of the Low, Baseline, and High Demand Scenarios, for Dry Hydrologic Conditions (2022–2071) 4-38

Figure 4-12. Annual Results of the Low, Baseline, and High Demand Scenarios, for Median Hydrologic Conditions (2022–2071) 4-38
Figure 4-13. Annual Results of the Low, Baseline, and High Demand Scenarios, for Wet Hydrologic Conditions (2022–2071) 4-39
Figure 4-14. Annual Results of the Current Demand Constant Baseline Scenario (2022–2071) 4-39
Figure 5-1. Accumulated Inflow Calculations, Jackson Meadows Reservoir, WYs 2008–2021 5-2
Figure 5-2. Accumulated Inflow Calculations, Bowman Reservoir, Water Years 2008–2021 5-3
Figure 5-3. Accumulated Inflow Calculations, Lake Spaulding, Water Years 2008–2021 5-3
Figure 5-4. Accumulated Inflow Calculations, Scotts Flat Reservoir, Water Years 2008–2021 5-4
Figure 5-5. Historical Deliveries in Boardman Canal 5-5
Figure 5-6. Historical Deliveries from Lake Combie 5-5
Figure 5-7. Lake Valley Canal Historic Daily Average Flow 5-9
Figure 5-8. Lake Valley Canal Flow Ensemble, 2016–2021 5-9
Figure 5-9. Fordyce Dam Seepage Estimate 5-10
Figure 5-10. Jackson Meadows Reservoir Storage, Water Years 2012–2021 5-13
Figure 5-11. Culbertson Lake Storage, Water Years 2012–2021 5-13
Figure 5-12. Bowman Reservoir Storage, Water Years 2012–2021 5-14
Figure 5-13. Lake Spaulding Storage, Water Years 2012–2021 5-14
Figure 5-14. Average Annual Unimpaired Inflow to NID Reservoirs in Climate Change Hydrology 5-16
Figure 5-15. Daily Average Unimpaired Inflow to NID Reservoirs in Dry Climate Change Hydrology 5-17
Figure 5-16. Daily Average Unimpaired Inflow to NID Reservoirs in Median Climate Change Hydrology 5-17
Figure 5-17. Daily Average Unimpaired Inflow to NID Reservoirs in Wet Climate Change Hydrology 5-18
Figure 5-18. Jackson Meadows Reservoir Average Daily Storage, Existing Operations Simulation Results 5-20
Figure 5-19. Bowman Reservoir Average Daily Storage, Existing Operations Simulation Results 5-20
Figure 5-20. Rollins Reservoir Average Daily Storage, Existing Operations Simulation Results 5-21
Figure 5-21. Scotts Flat Reservoir Average Daily Storage, Existing Operations Simulation Results 5-21
Figure 5-22. Average Daily Flow in Milton-Bowman Conduit, Existing Operations Simulation Results 5-23
Figure 5-23. Average Daily Flow in Bowman-Spaulding Conduit at Bowman Reservoir, Existing Operations Simulation Results 5-23
Figure 5-24. Average Daily Flow in Deer Creek Powerhouse, Existing Operations Simulation Results 5-24
Figure 5-25. Average Daily Flow in Drum Canal below Spaulding Powerhouse No. 1, Existing Operations Simulation Results 5-24
Figure 5-26. Average Daily Flow in Bear River Canal, Existing Operations Simulation Results 5-25
Figure 5-27. Average Daily Diversion from Deer Creek, Existing Operations Simulation Results 5-25
Figure 5-28. Average Daily Diversion from Lake Combie, Existing Operations Simulation Results 5-26
Figure 5-29. Annual Delivery Exceedance, Low Demand Existing Operations Studies 5-27
Figure 5-30. Annual Delivery Exceedance, Baseline Demand Existing Operations Studies 5-27
Figure 5-31. Annual Delivery Exceedance, High Demand Existing Operations Studies 5-28
Figure 5-32. Unmet Demands Exceedance, Low Demand Existing Operations Studies 5-29
Figure 5-33. Unmet Demands Exceedance, Baseline Demand Existing Operations Studies 5-29
Figure 5-34. Unmet Demands Exceedance, High Demand Existing Operations Studies 5-30
Figure 6-1. Annual Unmet Demands Exceedance, Selected Existing Operations Scenarios 6-1
Figure 6-2. November 1 Carryover Storage Exceedance, Selected Existing Operations Scenarios 6-2
Figure 6-3. Annual NID Generation Exceedance, Selected Existing Operations Scenarios 6-2
Figure 6-4. Annual Unmet Demand Exceedance, Extended Irrigation Season Alternative 6-4
Figure 6-5. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Dry Climate High Demands Scenario 6-5
Figure 6-6. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Median Climate Baseline Demands Scenario 6-5
Figure 6-7. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Wet Climate Low Demands Scenario 6-6
Figure 6-8. Annual Unmet Demand Exceedance, Rollins 10 TAF Raise Alternative 6-7
Figure 6-9. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, Dry Climate High Demands Scenario 6-8
Figure 6-10. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, Median Climate Baseline Demands Scenario 6-8

Figure 6-11. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, High Climate Low Demands Scenario 6-9
Figure 6-12. Unmet Demands Exceedance, Rollins 50 TAF Raise Alternative 6-10
Figure 6-13. Centennial Reservoir Project Schematic 6-11
Figure 6-14. Centennial Reservoir Storage 6-12
Figure 6-15. Unmet Demands Exceedance, Centennial Reservoir Alternative 6-13
Figure 6-16. Unmet Demands Exceedance, Revised Carryover Targets Alternative 6-14
Figure 6-17. Available Monthly Purchase Volumes at the Deer Creek Powerhouse 6-15
Figure 6-18. Available Monthly Purchase Volumes on the Bear River Canal 6-15
Figure 6-19. Annual Purchase Volumes Exceedance; Purchase of Additional Supply from PG&E Alternative 6-16
Figure 6-20. Annual Unmet Demands Exceedance, Purchase of Additional Supply from PG&E Scenario 6-17
Figure 6-21. Annual purchase volumes exceedance, Revised Carryover Targets and Purchase of additional supply from PG&E alternative 6-18
Figure 6-22. Annual Unmet Demands Exceedance, Revised Carryover Targets and Purchase of Additional Supply from PG&E Scenario 6-19
Figure 6-23. Deliveries in Strategic Alternatives, Wet Climate Low Demand Scenarios 6-21
Figure 6-24. Deliveries in Strategic Alternatives, Median Climate Baseline Demand Scenarios 6-21
Figure 6-25. Deliveries in Strategic Alternatives, Dry Climate High Demand Scenarios 6-22
Figure 6-26. Unmet Demands in Strategic Alternatives, Wet Climate Low Demand Scenarios 6-22
Figure 6-27. Unmet Demands in Strategic Alternatives, Median Climate Baseline Demand Scenarios 6-23
Figure 6-28. Unmet Demands in Strategic Alternatives, Dry Climate High Demand Scenarios 6-23
Figure 6-29. Average November 1 Carryover Storage in Strategic Alternatives, Wet Climate Low Demand Scenarios 6-24
Figure 6-30. Average November 1 Carryover Storage in Strategic Alternatives, Median Climate Baseline Demand Scenarios 6-24
Figure 6-31. Average November 1 Carryover Storage in Strategic Alternatives, Dry Climate High Demand Scenarios 6-25

TABLES

Table 1. Annual Average Unmet Demand, Acre-Feet xv
Table 2-1. Major Dams and/or Reservoirs 2-3
Table 2-2. Computer Programs Used 2-5
Table 2-3. Snow Stations Used for Temperature Index Calibration 2-7
Table 2-4. Streamflow Gages for Model Calibration 2-9
Table 2-5. HUC-8 and HUC-12 subbasins 2-12
Table 2-6. Soil Textures and Effective Porosity, Wetting Front Suction Head, Saturated Hydraulic Conductivity, and Wilting Point (USACE 1994) 2-15
Table 2-7. Impervious Values Defined Per Land Cover Category (USACE 2022) 2-16
Table 2-8. Canopy Storage Depths for NLCD Land Cover Classifications (USACE 2022) 2-18
Table 2-9. Inventory of Reservoirs in the Model and the Corresponding Routing Methods 2-21
Table 2-10. Elevation Band Parameters 2-23
Table 2-11. Initial Temperature Index Method Parameters 2-23
Table 2-12. Initial ATI-Melt Rate Function 2-24
Table 2-13. Initial ATI-Cold Rate Function 2-24
Table 2-14. HEC-HMS Performance Ratings for Summary Statistics 2-26
Table 2-15. Snow Model Calibration Results from January 1, 2017, through December 1, 2021 2-26
Table 2-16. Calibrated Temperature Index Parameters 2-29
Table 2-17. ATI-Meltrate Function 2-29
Table 2-18. ATI-Coldrate Function 2-30
Table 2-19. Calibration Events 2-31
Table 2-20. Calibration Locations in NID Basin 2-32

Table 2-21. Adjusted Calibrated Temperature Index Parameters 2-33
Table 2-22. ATI-Meltrate Function 2-34
Table 2-23. WY1997 Tabular Results for Primary Locations 2-36
Table 2-24. WY2004 Tabular Results for Primary Locations 2-38
Table 2-25. WY2006 Tabular Results for Primary Locations 2-40
Table 2-26. WY2015 Tabular Results for Primary Locations 2-42
Table 2-27. WY2021 Tabular Results for Primary Locations 2-44
Table 3-1. Climate Change Scenarios for HEC-HMS Simulations 3-5
Table 3-2. Climate Change Scenarios for HEC-HMS Simulations 3-12
Table 4-1. Overview of Demand Component Simulation Approach 4-4
Table 4-2. Combinations of Land Use Categories, Soil Textures, and Climate Zones Simulated in the IDC Model 4-8
Table 4-3. Evapotranspiration Data Sources 4-10
Table 4-4. Precipitation Data Sources 4-16
Table 4-5. Land Uses Simulated in the IDC Model 4-19
Table 4-6. Predominant Soil Textures and Soil Parameters Simulated in the IDC Model 4-21
Table 4-7. Curve Number Used to Represent Runoff Conditions in the IDC Model 4-23
Table 4-8. Root Depths Simulated in the IDC Model by Agricultural Land Use Category 4-23
Table 4-9. Urban Regions Simulated in the IDC Model, With Average Per Capita Water Use 4-25
Table 4-10. Summary of Demand Model Scenarios with Information about Underlying Assumptions and Data Sources 4-30
Table 4-11. Average Annual Results of the Current and Projected Demand Scenarios 4-37
Table 5-1. Average Annual Unimpaired Flow Comparisons for Historical Hydrology 5-2
Table 5-2. Gages Used in Calculating Historical Deliveries 5-4
Table 5-3. Reservoirs Modeled in the Reservoir Operations Model 5-6
Table 5-4. Model Consumptive Demand Nodes 5-7
Table 5-5. Conduit Capacities and Loss Rates 5-8
Table 5-6. Annual Demands from IDC Model 5-15
Table 5-7. Annual Demands at Each NID Demand Node 5-15
Table 5-8. Average Annual Unimpaired Flow in NID Watersheds 5-16
Table 5-9. Existing Operations Scenario numbering. 5-18
Table 5-10. Average Carryover Storage, Baseline Demands 5-22
Table 5-11. Average Annual Diversions into Canals, Baseline Demands, AF 5-22
Table 5-12. Average Annual Deliveries in Existing Operations Studies, AF 5-26
Table 5-13. Average Annual Unmet Demands in Existing Operations Studies, AF 5-28
Table 5-14. Average Annual NID Generation, Existing Operations Studies, GWh 5-30
Table 6-1. Average Annual Demands, Regular Irrigation Season and Extended Irrigation Season 6-3
Table 6-2. Increase in Demand and Deliveries in Extended Irrigation Season 6-3
Table 6-3. Deliveries and Unmet Demand, Extended Irrigation Alternative 6-4
Table 6-4. Demand, Delivery, and Unmet Demands, AF, Rollins 10 TAF Raise Alternative 6-6
Table 6-5. Demand, Delivery, and Unmet Demands, AF, Rollins 50 TAF Raise Alternative. 6-9
Table 6-6. Demand, Delivery, and Unmet Demands, AF, Centennial Reservoir Alternative 6-12
Table 6-7. Revised Carryover Targets 6-13
Table 6-8. Demand, Delivery, and Unmet Demands, AF, Revised Carryover Targets Alternative 6-14
Table 6-9. Demand, Delivery, and Unmet Demands, AF, Water Purchases from PG&E Alternative 6-16
Table 6-10. Demand, Delivery, and Unmet Demands, AF, Revised Carryover Targets and Water Purchases from PG&E Alternative 6-18
Table 6-11. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Wet Climate Low Demand Scenarios 6-19
Table 6-12. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Median Climate Baseline Demand Scenarios 6-20
Table 6-13. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Dry Climate High Demand Scenarios 6-20

APPENDICES

Appendix A: Chapter 2 Supplemental Information

Appendix B: Chapter 4 Supplemental Information

Appendix C: Chapter 5 Supplemental Information

Abbreviations

AF	acre-feet
ATI	antecedent temperature index
BOD	Board of Directors
CDEC	California Data Exchange Center
CFS	cubic feet per second
CIMIS	California Irrigation Management Information System
CMIP	Coupled Model Intercomparison Project
COA	Coordinated Operating Agreement
CSL	Central Sierra Snow Lab
CWC	California Water Commission
DEM	Digital Elevation Model
DSS	Data Storage System
DWR	Department of Water Resources
EM	Engineering Manual
FAO	Food and Agriculture Organization
FERC	Federal Energy Regulatory Commission
GCM	Global Climate Model
GIS	Geographic Information System
gSSURGO	Gridded Soil Survey Geographic Database
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
HUC	Hydrologic Unit Code
IPCC	Intergovernmental Panel on Climate Change
ITRC	Irrigation Training and Research Center
IWFM	Integrated Water Flow Model

LOCA	Localized Constructed Analogs
MAD	management allowable depletion
MMC	Modeling, Mapping and Consequences
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NCAR	National Center for Atmospheric Research
NCSS	National Cooperative Soil Survey
NED	National Elevation Dataset
NID	Nevada Irrigation District
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Efficiency
NWIS	National Water Information System
NWS	National Weather Service
PBIAS	Percent Bias
PCWA	Placer County Water Agency
PFW	Plan for Water
PG&E	Pacific Gas & Electric
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
RAS	River Analysis System
ResSim	Reservoir System Simulation
RMSE	Root Mean Square Error
RSR	Ratio of the Root Mean Square Error to the Standard Deviation
RWMP	Raw Water Master Plan
SCS	Soil Conservation Service

SHG	Standard Hydrologic Grid
SNODAS	Snow Data Assimilation System
SNOTEL	Snow Telemetry
SSURGO	Soil Survey Geographic Database
SWE	Snow Water Equivalent
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
UH	unit hydrograph
UNEP	United Nations Environment Programme
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WMO	World Meteorological Organization
WPLM	Weighted Palmer Drought Severity Index
WRCC	Western Regional Climate Center
WRF	Weather Research and Forecasting
WY	water year

Executive Summary

The Nevada Irrigation District (NID) is committed to meeting the community's demand for water over the coming decades. To achieve this goal, NID is currently implementing the Plan for Water (PFW), a collaborative process to review NID's historical and projected available water supply and demands. The PFW will support NID's decisions about future investments and changes in water management practices to ensure the community enjoys the same high-quality water and reliable water system it has now and for the coming years. For more information on PFW follow the link: https://www.nidwater.com/plan-for-water#page-content.

Three numerical models were developed to collectively represent how NID's water delivery system works: a hydrology model to represent watershed performance, a demand model to estimate how much water is required to meet customer and regulatory needs, and an operations model to simulate the functions of NID's system of water storage and conveyance. Together, the models were used to evaluate a range of alternative operating strategies and their ability to meet the future needs of NID customers.

Hydrological Model Development
A physically based hydrological model (Chapter 2) was developed to best represent runoff conditions in NID watershed. Runoff scenarios were developed using the hydrological model with precipitation and temperature projections as input. Projections were generated based on global climate models known to best represent California's climate. (Chapter 3) From these projections, three scenarios were chosen for further analysis: bookend projections that represent the plausible extreme dry and wet climate conditions, plus a median condition.

Demand Model Development
"Demand" refers to the total volume of water required to meet NID's water users' needs. A well-known demand model (Chapter 4) was configured and applied to estimate projected demands for a 50-year horizon. The demand model provides a means of estimating NID customer demand under different potential future scenarios by physically simulating the processes that drive water use. The demand model leverages available local data, standard technical approaches, and best practices to account for the relative effects of estimated future changes in climate, land use, irrigation practices, soil properties, and other factors that impact demand. Results of the demand model were used to estimate the outflows required from NID's reservoirs to meet potential demands over the next 50 years.

Operations Model Development
A reservoir operations model (Chapter 5) was developed that simulates how NID operates its current storage, conveyance, and delivery system. The operations model used inflows from the hydrology model, current operating rules, and regulations to assess how well customer demands are met.

NID operations were simulated using a wide range of conditions, including historical conditions, current baseline operations, demands (low, median, and high), and climate (dry, median, and wet). Three future scenarios were selected for evaluation of potential PFW strategies.

- Dry Future Climate with High Demands
- Median Future Climate with Baseline Demands
- Wet Future Climate with Low Demands

These scenarios provide dry and wet bookends with a median climate scenario to represent a plausible mid-point. Use of these scenarios provides a wide range of hydrologic conditions and consumptive demands; the scenarios are suitable for testing the strategic alternatives.

Strategic Alternatives

Seven strategic alternatives (Chapter 6) were investigated to assess their potential to improve water security under projected climate conditions estimated by the Plan for Water HEC-ResSim model. These alternatives included:

- An extended irrigation season, assuming two additional weeks in October.
- A Rollins Reservoir storage increase of 10,000 acre-feet (AF), equivalent to an increase of 18 percent of existing storage capacity.
- A Rollins Reservoir storage increase of 50,000 AF, equivalent to an increase of 91 percent of existing storage capacity.
- The addition of Centennial Reservoir, a new reservoir on the Bear River downstream of Rollins Reservoir with a storage capacity of 96,660 AF
- A reduction in reservoir carryover storage targets in NID reservoirs at the end of the irrigation season totaling 50,000 ac-ft, equivalent to 38% of the current carryover storage target.
- Additional water purchases from PG&E based on the existing 2018 Coordinated operating Agreement (COA) between NID and PG&E.
- A combination of revised carryover storage targets (50,000 ac-ft) plus additional water purchases from PG&E based on the existing 2018 COA.

These seven alternatives were individually simulated by the HEC-ResSim operations model. Results of each strategic alternative simulation were compared against the baseline climate change scenario. Changes in average annual delivery, average annual unmet demand, and average annual carryover storage were calculated relative to the baseline to assess the relative benefit of each strategic alternative. This analysis was performed for all three climate change baseline scenarios: Dry Climate with High Demands, Median Climate with Baseline Demands, and Wet Climate with Low Demands.

The relative increase in average annual water delivery for each climate scenario is summarized in Figure 1 and annual average unmet demand (ac-ft) is shown in Table 1. Across all three climate scenarios, the Rollins Reservoir 50,000 AF storage increase alternative resulted in the largest relative increase in average annual deliveries, with similar reductions in average annual unmet demand. The Centennial Reservoir scenario and the Revised Carryover Targets + Water Purchase from PG&E scenario also produced relatively high relative increases in average annual deliveries. Despite the larger storage capacity increase for the Centennial Reservoir (96,000 ac-ft) alternative versus Rollins Reservoir (50,000 ac-ft) alternative, the lower elevation location of Centennial Reservoir limits its potential benefit to the NID water delivery system. An increase in storage capacity at Rollins has much greater potential benefit because it can be used to supply water to a much larger percentage of NID customers. Revised Carryover storage targets produced the least beneficial increase in average annual water delivery.

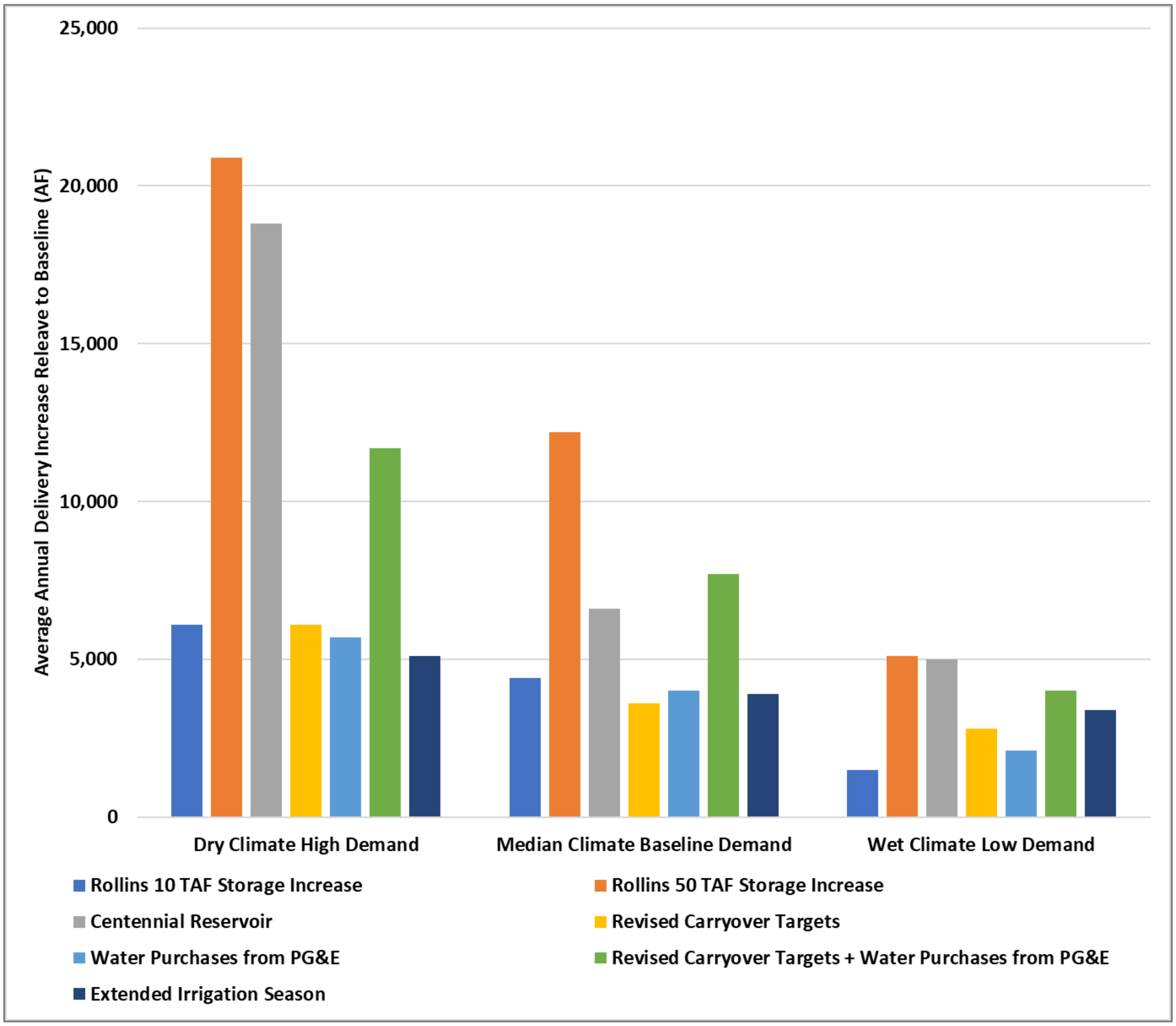

Figure 1. Relative Increase in Average Annual Water Delivery

Table 1. Annual Average Unmet Demand, Acre-Feet

Scenario	Dry Climate High Demand	Median Climate Baseline Demand	Wet Climate Low Demand
Baseline	35,000	13,900	5,900
Rollins 10 TAF Increase	28,900	9,500	4,400
Rollins 50 TAF Increase	14,100	1,700	800
Centennial Reservoir	16,200	7,300	900
Revised Carryover	28,900	10,300	3,100
Water Purchase	29,300	9,900	3,800
Revised Carryover + Water Purchase	23,300	6,200	1,900
Extended Irrigation Season	36,200	15,400	6,300

The relative change in average annual carryover storage for each climate scenario is summarized in Figure 2. Scenarios that added storage to the system, the two Rollins storage increase scenarios and the Centennial Reservoir scenario, increased the average annual carryover storage. The water purchases from PG&E scenario were relatively neutral, and the other scenarios result in a decrease in average annual carryover storage. Increased carryover storage provides additional protection against multi-year droughts. A decrease in carryover storage indicates a reduction in available NID water supply which increases risk.

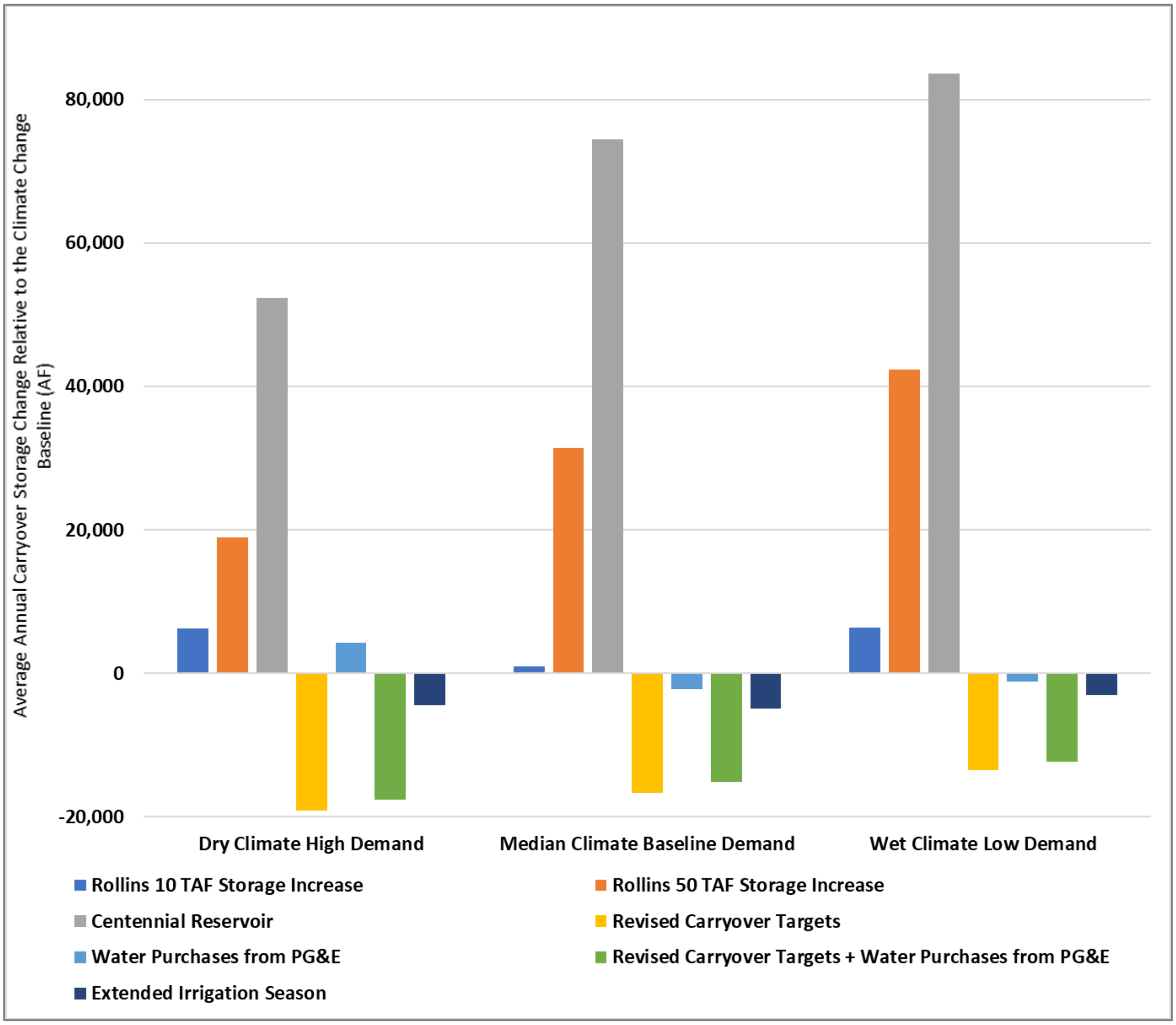

Figure 2. Relative Change in Average Annual Carryover Storage

Each of the strategic alternatives included in this analysis resulted in a net increase in water deliveries to NID customers under various projections of climate change. For some of these alternatives, the increase in deliveries comes with a negative impact on system storage, as measured by average annual carryover storage. Carryover storage is one of NID's four primary sources of water supply, which also includes natural runoff, contract water purchases, and recycled water. Alternatives that increase both water deliveries and carryover storage are much more valuable than those that increase water deliveries alone.

Chapter 1. Introduction

1.1. The Nevada Irrigation District

The Nevada Irrigation District (NID) is an independent public agency governed by a 5-member elected Board of Directors (BOD) and employs about 200 full- and part-time employees. NID supplies water to 25,000 homes, farms, and businesses in portions of Nevada, Placer, and Yuba Counties in the foothills of Northern California's Sierra Nevada Mountains. Water is collected from mountain watersheds and stored in a system of reservoirs. As water flows to NID customers, it generates more than 354 gigawatts of clean, hydroelectric energy per year while supporting environmental flows and serving public recreation. NID supplies both treated drinking water and crop irrigation water. Approximately 90% of NID's annual demand is for raw water/agricultural water during the irrigation season, April 15 to October 15.

In any given year, four primary sources supply NID's water:

1. Reservoir storage carried over from the previous year,
2. Natural runoff (including snowmelt) from the contributing watershed areas,
3. Contract water purchases, and
4. Recycled water.

NID regularly evaluates and updates its water supply availability projections. In the past, this was completed through the Raw Water Master Plan (RWMP), originally developed in 1985. The RWMP assessed the adequacy of the existing water storage and conveyance system to accommodate current and future water demand. Since 1985, the RWMP was updated in two phases: first in 2005 (Kleinschmidt et al. 2005), and then again in 2011 (Kleinschmidt Associates 2011).

Currently, NID's is evaluating and updating its water supply availability projects through the Plan for Water (PFW).

1.2. NID's Water Supply Network

NID's water supply system is a store-and-release system. Reservoirs store snowmelt and seasonal runoff for release during the typically dry summers. Water is delivered to customers via a network of channels, canals, flumes, and pipes. While there is natural runoff during the summer months, this water is generally used to meet regulatory requirements for environmental flows in the rivers. Irrigation demand is met primarily with withdrawals from storage reservoirs. Careful management and operation of storage reservoirs is essential to capture the maximum amount of runoff captured, minimize spillage from reservoirs, and ensure there is sufficient volume available in reservoirs to accommodate runoff during the spring snowmelt and storm events.

Water is stored and released from the high-elevation reservoirs based on NID's consumptive needs and reservoir carryover storage targets. Discretionary releases for water supply are made from Jackson Meadows Reservoir and Jackson, French, Faucherie, and Sawmill reservoirs during the spring runoff season through late fall. Releases from Jackson Meadows Reservoir are conveyed to Bowman Lake via the Milton-Bowman Tunnel. Releases from Jackson, French, Faucherie, and Sawmill lakes are stored and released by Bowman Dam through Bowman Powerhouse into the Bowman-Spaulding Conduit Diversion

Impoundment. Five small diversions along creeks that run perpendicular to the Bowman-Spaulding Conduit augment flows in the conduit up to its capacity and spill the remainder into their respective natural drainages downstream of the conduit.

Flows from the Bowman-Spaulding Conduit pass through PG&E's Lake Spaulding into PG&E's Drum Canal and the South Yuba Canal. Water transported into the South Yuba Canal is diverted into South Fork Deer Creek to supply NID customers in the Nevada City-Grass Valley area. This water is largely diverted at the Cascade Canal Diversion Dam located immediately downstream but is also used to manage Scotts Flat Reservoir storage. Releases from Scotts Flat Reservoir provide water to four other downstream diversions downstream along Deer Creek.

Water transported into the Drum Canal is passed through PG&E's Drum Forebay into the Bear River at PG&E's Drum Afterbay. Water is diverted and returned several times along the Bear River reach upstream of Rollins Reservoir by NID and PG&E for power generation. Daily volumes are scheduled by NID and PG&E for downstream consumptive demand.

Rollins Reservoir is NID's major low-elevation storage reservoir on the Bear River. Rollins Reservoir is a multipurpose facility that meets municipal, irrigation, domestic water supply, recreation, and power generation needs. From Rollins, water supplies NID customers in southern Nevada County and Placer County.

1.3. The Plan for Water

The PFW is a long-range decision tool to guide NID's future water management. The PFW process is an open and comprehensive look at available water resources affected by new regulations, changes in land use, varying climate, and community aspirations. The PFW offers a range of potential scenarios for NID's BOD to consider when assessing ways to best meet customer demands for water over the next 50 years. While 50 years is a sufficient time horizon for major water infrastructure planning, shorter term changes in water supply, water demand, regulation, and technology dictate the need for PFW updates every five years. The NID board members approved a resolution to update the plan every 5 years (NID 2023).

NID's PFW contains 11 stages, the first 6 stages are predominantly planning stages while the last 5 stages are the active modeling and evaluating stages, the latter of which will be discussed further in the next section.

1. System Overview
2. Water Rights Overview
3. Watersheds
4. Risk
5. Strategic Planning
6. Basis for Plan Water
7. Hydrology and Hydrography
8. Demand

9. Supply Needs
10. Strategy Options
11. Evaluate Strategies

More information regarding these specific stages can be found on NID's website at: https://www.nidwater.com/the-11-stages-of-plan-for-water.

1.4. General Approach

As briefly discussed above, watershed, supply and demand, and operation modeling was conducted during Stages 7 through 10 of the PFW. The various models are heavily informed by each other, as shown in Figure 1-1.

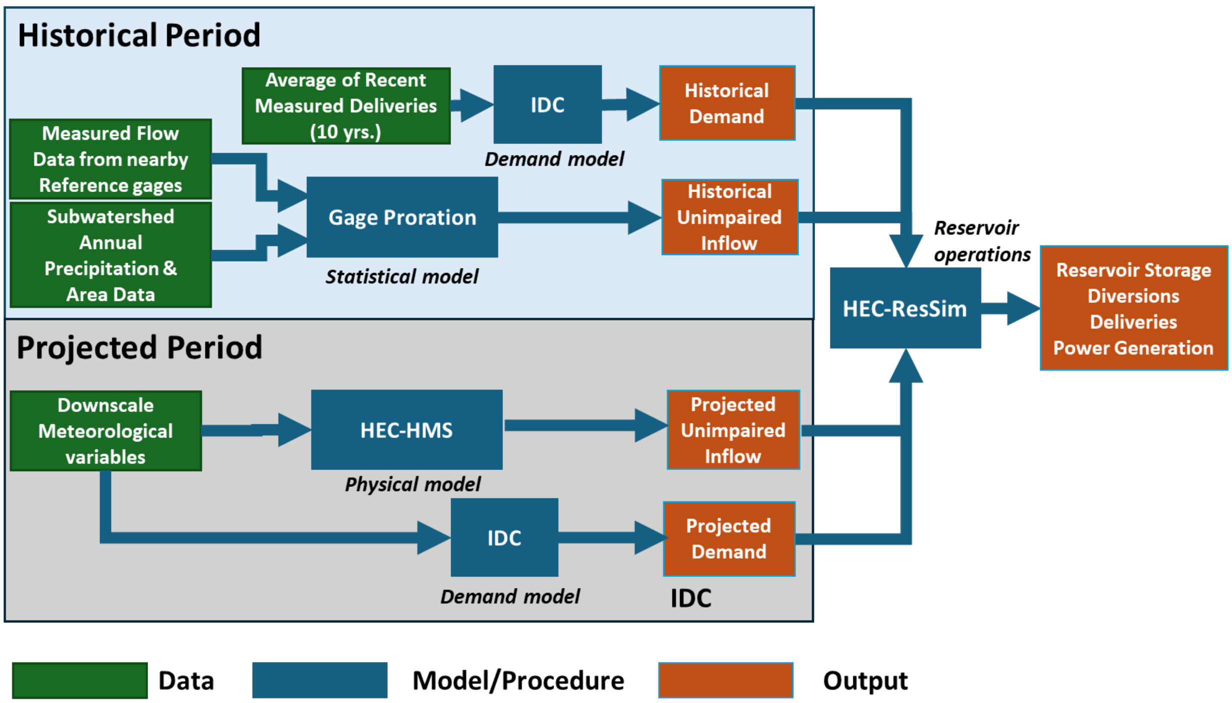

Figure 1-1. Modeling Schematic Demonstrating How Each Model Informs the Next

In the schematic in Figure 1-1, two modeling periods are highlighted: (1) historical and (2) projected. NID's snowpack-based supply and delivery strategy is affected by changing temperatures and precipitation associated with a warming climate. The PFW investigated potential impacts on supplies as temperature and precipitation patterns change. The analysis included projecting future temperatures and precipitation and their potential effect on watershed runoff and demand.

Historical and projected demands were estimated based on the California Department of Water Resources' Integrated Water Flow Model Demand Calculator (IDC model) built for NID's service area. Later chapters will describe the IDC model used for the PFW.

Unimpaired inflows were estimated based on two different methodologies for historical and projected data. For the historical period, the gage proration statistical method was used to estimate historical unimpaired inflow based on measured flow data from nearby reference gages, annual precipitation, and watershed drainage area.

For the projected period, the PFW incorporates hydrologic data representative of projected climate conditions for the next 50 years. Projected climate data cover a range of plausible outcomes based on different scenarios of greenhouse gas emissions. Since observed data are not available for the projected period, a physically based hydrological is required to estimate projected unimpaired flows based on projected precipitation and temperature. The U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) – Hydrologic Modeling System (HMS) was used to simulate projected unimpaired flows. Historical flow data were used to calibrate HEC-HMS. Recent studies have shown that HMS is technically and scientifically defensible as it can adequately simulate streamflow from precipitation, temperature and other hydrometeorological data (Li et al. 2022, Mahato et al. 2022, Moothedan et al. 2022). Later chapters will describe the HMS model development, calibration, and validation for the PFW.

Unimpaired inflows need to be converted into impaired flows based in the influence of reservoirs and other manmade hydraulic structures. The flow impairments that are modeled for the PFW include how the various reservoirs in the watershed hold or divert the unimpaired flows and consumptive, hydroelectric, environmental, and other state-mandated demands. The effects of flow impairments are added using the HEC – Reservoir System Simulation (ResSim) model.

HEC-ResSim is widely used for water supply and flood management in planning studies. The model features rule-based operations that attempts to reproduce the decision-making process that reservoir operators use in reservoir management. The software is Java-based and has the ability for the user to write scripts in Jython, an implementation of the python programming language in Java, which augments the model's flexible rule structures. The HEC-ResSim modeling software is widely used throughout California to model hydropower and water supply projects. The software has all the features needed to model NID's system and previous models of NID's system have been built on HEC-ResSim making it easier to incorporate previous work done to refine the modeling of NID's system. Later chapters will describe the HEC-ResSim model development, calibration, and validation for the PFW.

The combinations of models and methods implemented for the PFW allow for large flexibility on updating the results of this project as situations change (e.g., additional storage or modified regulations) and more information (e.g., updated climate projections) becomes available.

1.5. Stakeholder Participation

Community stakeholders and the public have been involved in numerous workshops covering the 11 stages mentioned earlier in this chapter. NID asserts that the PFW benefits greatly from public outreach that increases the organization and the public's understanding of water resource challenges. It is integral that NID and the community's long-term plans and priorities align with each other.

From the onset of the PFW, NID has promised the community to: assess our water situation together; develop a deeper understanding of subsequent impacts to community interests and the community's future; provide a forum for community members to offer their input, as opposed to a closed process consisting only of technical experts; focus on overarching strategic policies and not on specific projects; understand what is really important to the community; and pursue community solutions within NID's legal responsibilities to its process customers and landowners within its service area.

Examples of stakeholder organizations that were prioritized and engaged throughout this process include: California Department of Fish & Wildlife, South Yuba River Citizens League, Nevada County Contractors' Association, Foothills Water Network, California Sporting Protection Alliance, and community members.

Chapter 2. Hydrological Model

2.1. Watershed Description Development

The NID watersheds, draining 448 sq. mi., are located on the western slope of the Sierra Nevada Mountains and cover portions of three counties: Nevada, Placer, and Yuba (Figure 2-1). The NID watersheds include the upper reaches of the Yuba River, Bear River, and Deer Creek. The highest peak in the NID watershed is the 8,373-ft English Mountain. NID transports water from high elevation mountain reservoirs to the lower elevation foothills and into portions of the northern Sacramento Valley near the City of Lincoln. Summers are dry with mild to hot temperatures. Winters are wet, especially in the upper elevations around Nevada City and Grass Valley. Snow levels are usually around 3,500 ft, but occasionally drop as low as 1,000 ft. Based on the historical data obtained from the California Irrigation Management Information System (CIMIS) and the Western Regional Climate Center (WRCC), the NID service area experiences average monthly temperatures ranging from 26 to 92 ˚F.

Throughout the NID watershed, several water management projects have been built to serve multiple purposes including flood control, water supply, irrigation, and recreation. These projects include dams/reservoirs, local flood reduction systems, and diversions, among others. The major dams and reservoirs located in the NID watershed are listed within Table 2-1. Figure 2-2 shows the locations of the various major water management projects throughout the NID watershed.

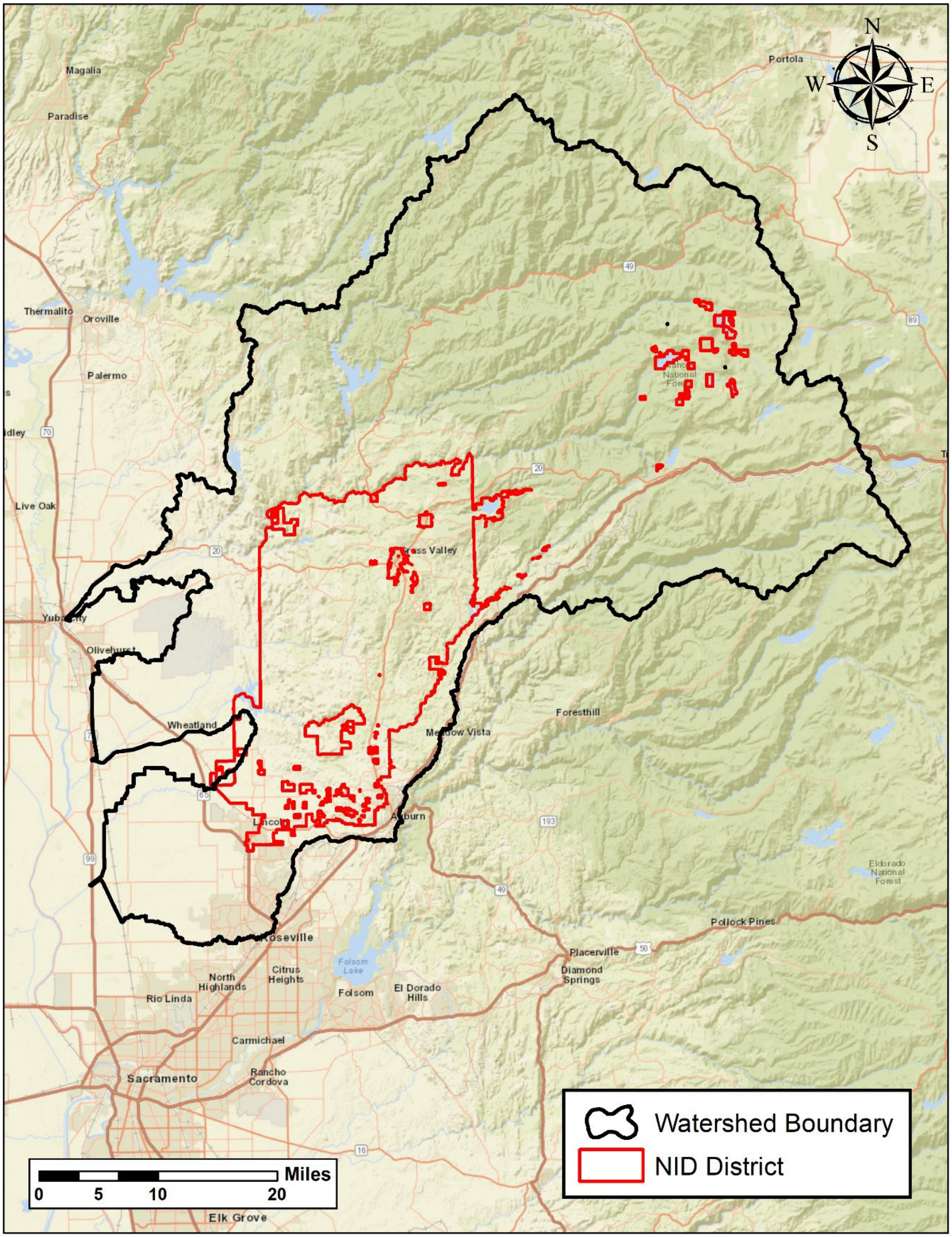

Figure 2-1. Nevada Irrigation District Map

Table 2-1. Major Dams and/or Reservoirs

Owner/Operating Agency	Dams and/or Reservoirs	Owner/Operating Agency	Dams and/or Reservoirs
Pacific Gas and Electric (PG&E)	Blue Lake Carr Lake Drum Afterbay Feeley Lake Fordyce Lake Fuller Lake Halsey Afterbay Kidd Lake Kelly Lake Lake Spaulding Lower Cascade Lake Lindsey Lakes Lake Valley Reservoir Lake Sterling Meadow Lake Rucker Lake Rock Creek Lake Upper Cascade Lake Upper Rock Lake White Rock Lake	NID	Bowman Lake French Lake Faucherie Lake Jackson Meadow Reservoir Jackson Lake Milton Reservoir Lake Combie Sawmill Lake Scotts Flat Reservoir Rollins Reservoir
USACE	Englebright Lake	Placer County Water Agency	Lake Arthur Lake Theodore
PG&E and NID	Dutch Flat Afterbay	Browns Valley Irrigation District	Collins Lake
Camp Far West Irrigation District	Camp Far West Lake	Yuba Water Agency	New Bullards Bar Reservoir
South Feather Water and Power Agency	Slate Creek Reservoir		

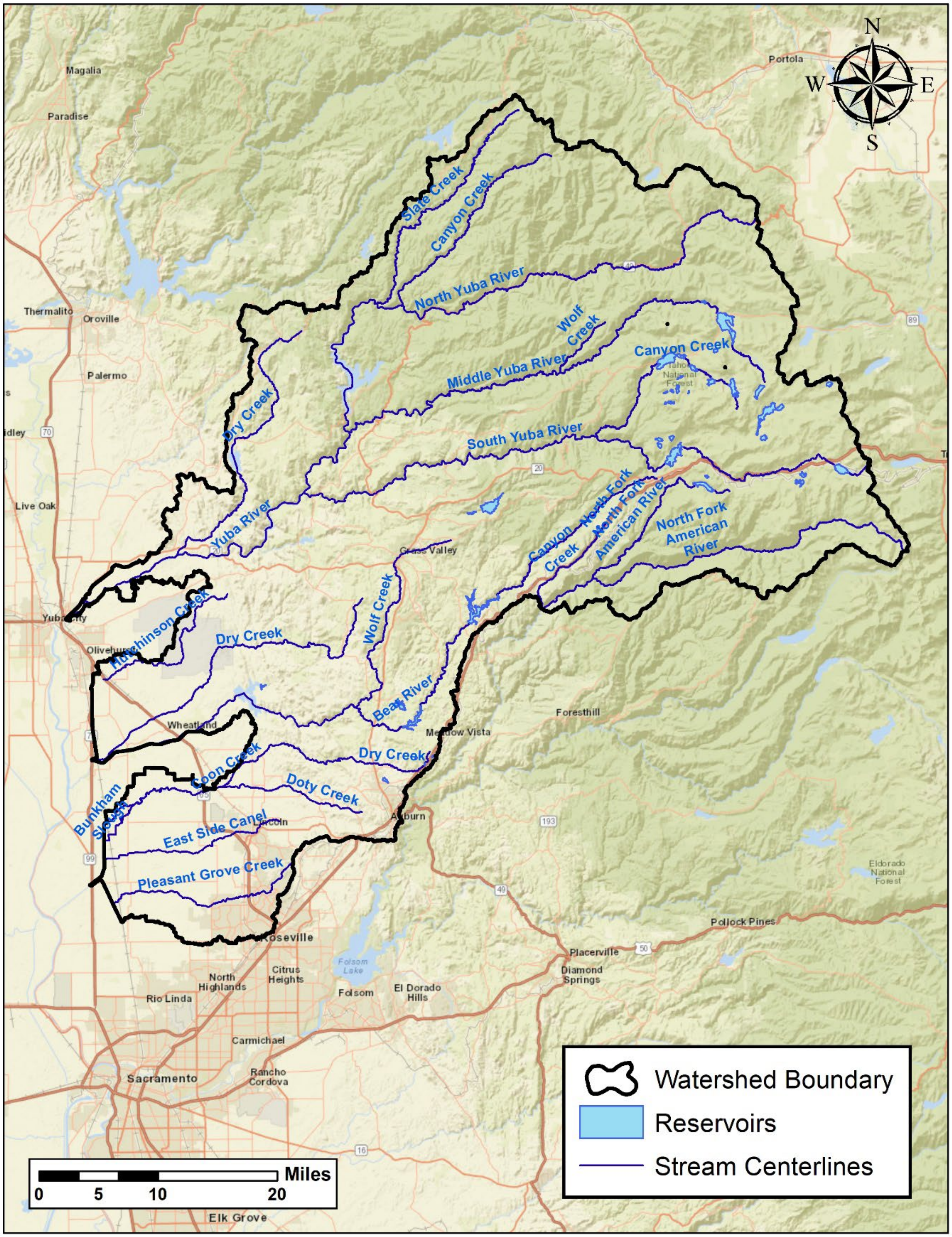

Figure 2-2. Major Tributaries and Reservoirs Within NID watersheds

2.2. Software

Table 2-2 provides a summary of the computer programs and their respective versions employed in development of the HEC-HMS model.

Table 2-2. Computer Programs Used

Program	Version	Capability	Developer
ArcGIS	10.7	Geographical Information System	ESRI
HEC-DSSVue	3.2.3	Plot, tabulate, edit, and manipulate data in HEC-DSS files	HEC
HEC-HMS	4.10	Catchment delineation and rainfall-runoff simulation	HEC
Vortex	0.10.20	Data Processing Utilities	HEC

2.3. Data Collection

The following sections discuss the data and tools used in the development of the HEC-HMS hydrologic model, which simulates NID's unimpaired hydrology.

2.3.1. Spatial Tools and Reference

To process and analyze the data necessary for hydrologic modeling and to generate the subbasin boundaries, ArcGIS and the HEC-HMS Geographic Information System (GIS) delineation tool were used.

The standard USGS map and projection parameters used for this study were:

- Horizontal Datum: North American Datum 1983 (NAD 83)- California State Plane Zone 2
- Projection: United States Contiguous Albers Equal Area Conic U.S. Geological Survey (USGS) version
- Vertical Datum: North American Vertical Datum, 1988 (NAVD 88)
- Linear units: U.S. ft.

2.3.2. GIS Data

The team used USGS web mapping services (USGS 2023) to download the Hydrologic Unit Code (HUC, a system used by USGS and other agencies to divide watersheds into smaller, more manageable units for hydrologic analysis and water resource management), soils, land cover, Federal agency gages, National Inventory of Dams locations, as well as the general base map layers. Additional GIS data were obtained from the ESRI database and used in figures prepared in this report.

2.3.3. Digital Elevation Model

The 10-m USGS National Elevation Dataset (NED, Gesch et al. 2002) was downloaded and merged to create a continuous Digital Elevation Model (DEM) that covers NID area of interest. That DEM was then used to delineate individual subbasins. (See Section 2.4.1).

2.3.4. Land Cover

Land cover data were obtained from the National Land Cover Database (NLCD 2019). The NLCD provides nationwide data on land cover and land cover change at a 30-m resolution with a 16-class legend based on a modified Anderson Level II classification system (Anderson 1976). NLCD 2019 is the latest evolution of NLCD land cover products focused on providing land cover and land cover change data for the United States. These datasets were used to estimate the subbasin-average percent impervious cover within the NID drainage basin. More discussion of land cover data and processing is provided in Section 2.4.2.

2.3.5. Soil Data

The USGS Gridded Soil Survey Geographic (gSSURGO, Soil Survey Staff 2022) for the NID basin were obtained from the Natural Resources Conservation Service (NRCS) for the State of California . The soil data were formatted and processed following instructions available in HEC-HMS Tutorials and Guides (USACE 2022a) to assign surface soil textures throughout the modeling domain and estimate initial soil loss parameters. The gSSURGO soils database includes information related to the available water storage depth as well as the hydrologic soil group classification. These datasets help estimate the initial values for the maximum soil moisture deficit and the initial values for the infiltration rates. More discussion about soils data is provided in Section 2.4.2.

2.3.6. Precipitation Data

Precipitation data used for the modeling effort were generated from Livneh Unsplit (Pierce et al. 2021) and Parameter-elevation Regressions on Independent Slopes Model (PRISM, PRISM Climate Group 2014). The continental-scale 4-km grid dataset was reprojected to the previously mentioned projection. Subsequently, the precipitation grids were delineated to the modeling domain's boundary and transformed into gridded data storage system (DSS) format using HEC-Vortex V0.10.20, accessible at (https://github.com/HydrologicEngineeringCenter/Vortex/releases/tag/v0.10.20). Since HEC-HMS 4.10 is unable to manage gridded DSS V7 produced by HEC-Vortex, the DSS Version 7 was converted to V6 using HEC-DSSVue 3.2.3.

2.3.7. Temperature Data

Temperature data used for the modeling effort were generated from Livneh Unsplit and PRISM dataset. The continental-scale 4-km gridded dataset was reprojected to the previously mentioned projection. Subsequently, the temperature grids were delineated to the modeling domain's boundary and transformed into gridded DSS format using HEC-Vortex V0.10.20. Given that HEC-HMS 4.10 is unable to manage gridded DSS V7 from HEC-Vortex, DSS V7 was converted to V6 using HEC-DSSVue 3.2.3.

2.3.8. Evapotranspiration

The Hamon Method (Hamon 1961) was used to simulate evapotranspiration (ET) losses throughout the modeling domain. Within the Hamon Method, ET losses are directly proportional to the daily average temperature and related to the location of interest and time of year. A modified, gridded version of the Hamon Method estimates potential ET losses using the daily average Livneh temperatures and a coefficient (Harwell 2012). The coefficient for NID watersheds was estimated as 0.0065.

2.3.9. Snow Data

Snow data are required to estimate the model parameters that control snow accumulation and melt. Snow data were obtained from the California Data Exchange Center (CDEC) managed by the Department of Water Resources (https://cdec.water.ca.gov/). The data available in CDEC are from the U.S. Department of Agriculture (USDA)-NRCS Snow Telemetry (SNOTEL) network and the California Cooperator Snow Sensors (https://www.wcc.nrcs.usda.gov/snow/). After analyzing the available data, four snow stations were chosen based on their diverse snowpack characteristics at elevations exceeding 5,000 ft and their data availability in time. The selected stations reflect different conditions present throughout the NID area of interest. The selected stations record key meteorological parameters, including precipitation, temperature, snow depth, and snow water equivalent (SWE). Table 2-3 identifies the snow stations and Figure 2-3 shows their locations within the NID basin.

Table 2-3. Snow Stations Used for Temperature Index Calibration

Source	Identifier	State	Site Name	Elevation (ft)	Latitude	Longitude
Cooperator Snow Sensors	BLC	CA	Blue Canyon	5,280	39.28	-120.71
	HYS	CA	Huysink	6,600	39.28	-120.53
	RCC	CA	Robinson Cow Camp	6,480	39.62	- 120.68
SNOTEL	CSS Lab (428)	CA	Central Sierra Snow Lab	6,894	39.33	-120.37

2.3.10. Streamflow and Reservoir Data

Daily average streamflow and reservoir data were obtained from the USGS National Water Information System (NWIS) (https://waterdata.usgs.gov/nwis) to support HEC-HMS model calibration. The stream flow and reservoir data observation sites are detailed in Table 2-4 and visualized in Figure 2-4.

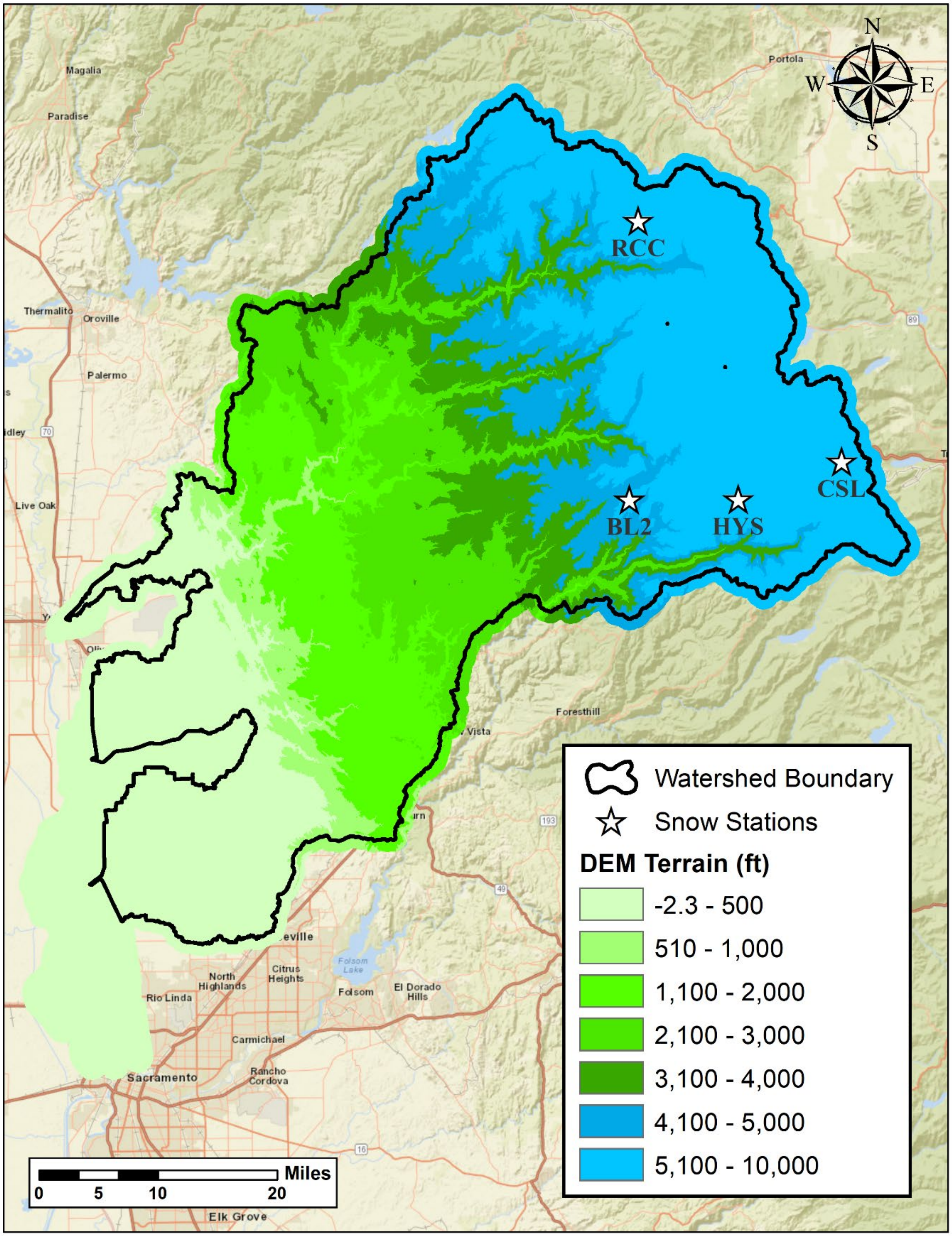

Figure 2-3. Snow Stations Used for Temperature Index Calibration

Table 2-4. Streamflow Gages for Model Calibration

Gage ID	Station Name	Latitude	Longitude
11408000	MILTON-BOWMAN TUNNEL OUTLET NR GRANITEVILLE CA	-120.611	39.46018
11408550	M YUBA R BL MILTON DAM CA	-120.584	39.52185
11408870	LOHMAN RIDGE TU A IT NR CAMPTONVILLE CA	-120.996	39.41239
11408880	M YUBA R BL OUR HOUSE DAM CA	-120.998	39.41156
11409350	CAMPTONVILLE TU A IT NR CAMPTONVILLE CA	-121.059	39.44017
11409400	OREGON C BL LOG CABIN DAM NR CAMPTONVILLE CA	-121.059	39.43934
11413000	N YUBA R BL GOODYEARS BAR CA	-120.938	39.52489
11413510	NEW COLGATE PH NR FRENCH CORRAL CA	-121.191	39.33073
11414100	FORDYCE C BL FORDYCE DAM NR CISCO CA	-120.499	39.3799
11414170	DRUM CN A TUNNEL OUTLET NR EMIGRANT GAP CA	-120.653	39.3174
11414194	DRUM NO 1 PH NR BLUE CYN CA	-120.766	39.25694
11414195	DRUM NO 2 PH NR BLUE CANYON CA	-120.767	39.25712
11414200	S YUBA CN NR EMIGRANT GAP CA	-120.663	39.31351
11414205	DEER C PH NR WASHINGTON CA	-120.844	39.29795
11414250	S YUBA R A LANGS CROSSING NR EMIGRANT GAP CA	-120.658	39.31851
11416000	BOWMAN-SPAULDING CN INTAKE NR GRANITEVILLE CA	-120.659	39.44046
11416100	BOWMAN-SPAULDING CN A JORDAN C SIPHON CA	-120.642	39.34212
11416500	CANYON C BL BOWMAN LK CA	-120.661	39.43962
11417500	S YUBA R A JONES BAR NR GRASS VALLEY CA	-121.105	39.29212
11418000	YUBA R BL ENGLEBRIGHT DAM NR SMARTSVILLE CA	-121.274	39.23517
11418500	DEER C NR SMARTSVILLE CA	-121.269	39.22434
11420750	BROWNS VALLEY IRR DITCH NR BROWNS VALLEY CA	-121.431	39.21711
11420760	BROPHY S YUBA CANAL NR MARYSVILLE CA	-121.45	39.16684
11420770	HALLWOOD-CORDUA ID CN NR MARYSVILLE CA	-121.458	39.20906
11421000	YUBA R NR MARYSVILLE CA	-121.525	39.17573
11421750	DUTCH FLAT NO 1 PH NR DUTCH FLAT CA	-120.835	39.21712
11421760	DUTCH FLAT NO 2 FLUME NR BLUE CANYON CA	-120.775	39.25434
11421770	BEAR R BL DRUM AFTERBAY NR BLUE CANYON CA	-120.775	39.25434
11421780	CHICAGO PARK FLUME NR DUTCH FLAT CA	-120.841	39.21518
11421790	BEAR R BL DUTCH FLAT AFTERBAY NR DUTCH FLAT CA	-120.845	39.21351
11422000	BEAR R CN NR COLFAX CA	-120.954	39.13267
11422500	BEAR R BL ROLLINS DAM NR COLFAX CA	-120.959	39.13129

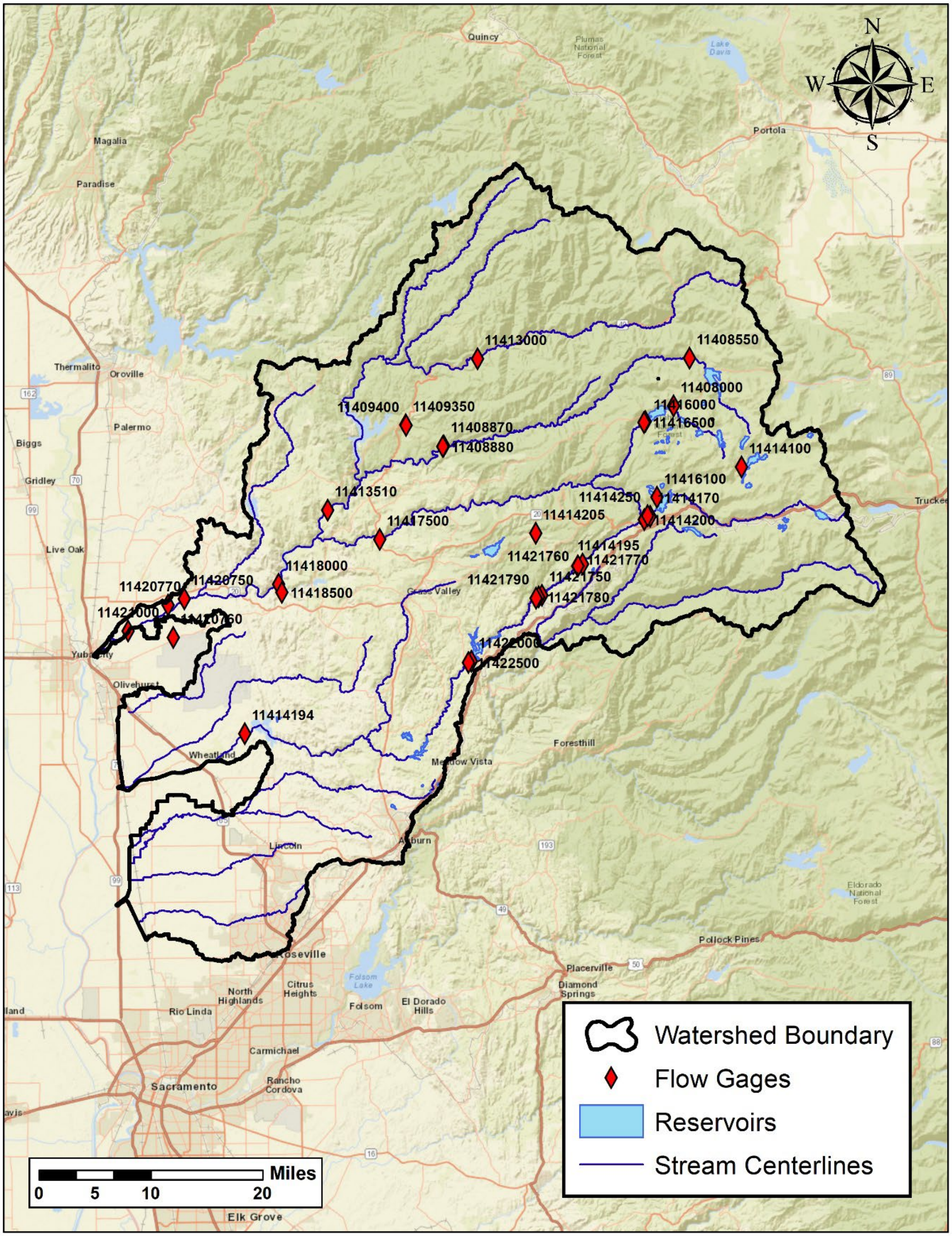

Figure 2-4. Streamflow Gages Used During Model Calibration

2.4. HEC-HMS Model Development

HEC-HMS is a hydrological model that simulates the physical processes that convert precipitation to runoff. An HEC-HMS model has three main components: a basin model, a meteorologic model, and control specifications. The basin model is the physical representation of the watershed. The meteorologic model describes watershed meteorological conditions that "drive" the basin model (i.e., the precipitation, evapotranspiration, and snowmelt data inputs). The control specifications define the length of the simulation period (e.g., years) and the temporal resolution of the simulated streamflow or reservoir storage (e.g., hours, days). HEC-HMS model development followed these steps:

- Collect relevant geographic, climatic, terrain, and time series data.
- Delineate the stream network and subbasins using the ArcGIS and HEC-HMS GIS processor.
- Develop the HEC-HMS basin model using the HEC-HMS GIS tools.
- Develop meteorological models for the calibration events.
- Select the physical models that best represent the dominant processes that control runoff generation in the area of interest. The selected physical models include, but are not limited to, snow, infiltration, baseflow, and routing models.
- Decide on the initial values for the hydrologic parameters required by the physical models chosen.
- Set the computational time step and simulation period in the HEC-HMS control specifications for each calibration event.

The following sections review the model-specific processes used in the NID HEC-HMS model.

2.4.1. Watershed Delineation

ESRI ArcGIS and the HEC-HMS GIS processor managed and analyzed spatial data such as topography and land cover for hydrologic modeling and to define subbasin boundaries. Shapefiles at the HUC-8 and HUC-12 levels were downloaded and reprojected for the delineation of the NID watershed boundary. Three HUC-8 and nine HUC-12 subbasins within the NID watershed are listed in Table 2-5 and shown in Figure 2-5. These selected subbasins were merged, and then buffered by 2 miles to create the watershed boundary. When individual subbasins are merged with the GIS tools, the boundaries might not match exactly, leaving small gaps with no elevation data along interior seams. Buffering mitigates edge effects and helps create a seamless terrain raster with no missing elevation data. The resulting rasters were thoroughly examined to ensure that the GIS tools could correctly process the files.

The resulting terrain raster was imported into a new HEC-HMS project and assigned to a basin model for subbasin delineation. The basin was delineated using the HEC-HMS GIS tool and the methods recommended in HEC-HMS Tutorials and Guides (USACE 2022a). Subbasins were sub-divided based on the inflow points of interest, which correspond to USGS gage and reservoir locations or locations with important hydraulic structures (diversions). The final HEC-HMS model has 146 subbasins encompassing approximately 2,329 sq. mi.

Table 2-5. HUC-8 and HUC-12 subbasins

HUC Level	Subbasin Name
HUC-8	Upper Yuba
	Upper Bear
	Upper Coon-Upper Auburn
HUC-12	Wabena Creek-North Fork American River (NFAR)
	Big Granite Creek
	Big Valley Canyon- NFAR
	East Fork North Fork- NFAR
	North Fork of NFAR
	Humbug Creek- NFAR
	Indian Creek- NFAR
	Upper Shirttail Canyon
	Lower Shirttail Canyon

Each model element—whether a subbasin, reach, or junction—was assigned a unique name. The first two letters of the element name represent an abbreviation for the major river associated with the element, followed by any pertinent secondary river name. The element name concludes with the symbol showing its type, "S" for subbasin, "R" for reach, or "J" for junction, followed by a unique identifying number. The identifying numbers were assigned in increments of 10, systematically increasing in the downstream direction. If an element linked to the main river did not have a secondary river, the secondary river name was designated as the same as the main river. In cases where more than one branch conveys flow into the main river, the element numbers (e.g., S10, S20) along one branch were labeled first. Then, succeeding element numbers (e.g., S30, S40) along the next branch were assigned, with the element numbering continuing after the confluence of the two branches (e.g., S50, S60). The major and secondary river names were determined using the National Hydrography Dataset (USGS 2016) flowlines. The final subbasin delineation is presented in Figure 2-6, and subbasin names, along with their respective drainage areas, are detailed in Appendix A.

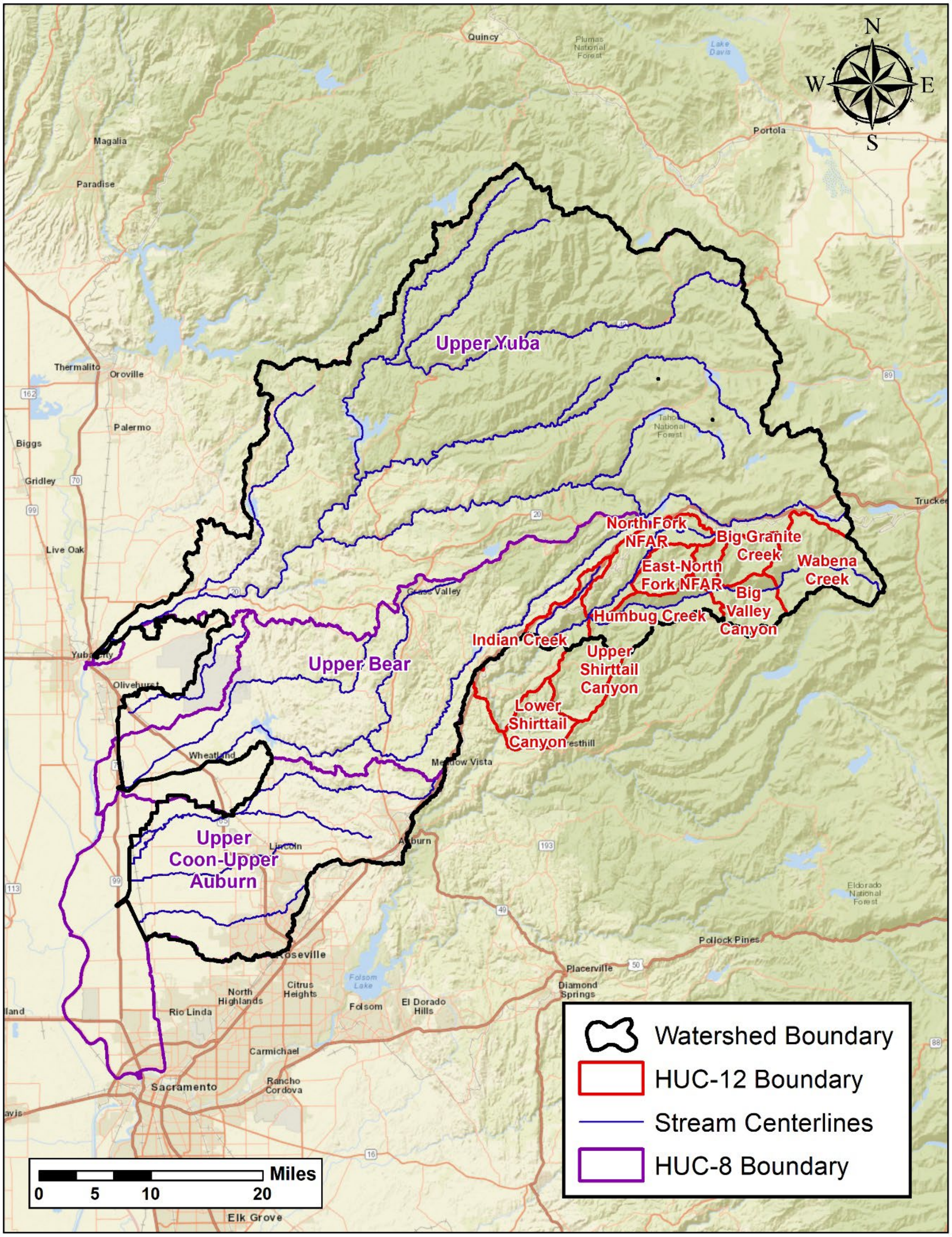

Figure 2-5. NID Watershed Delineation

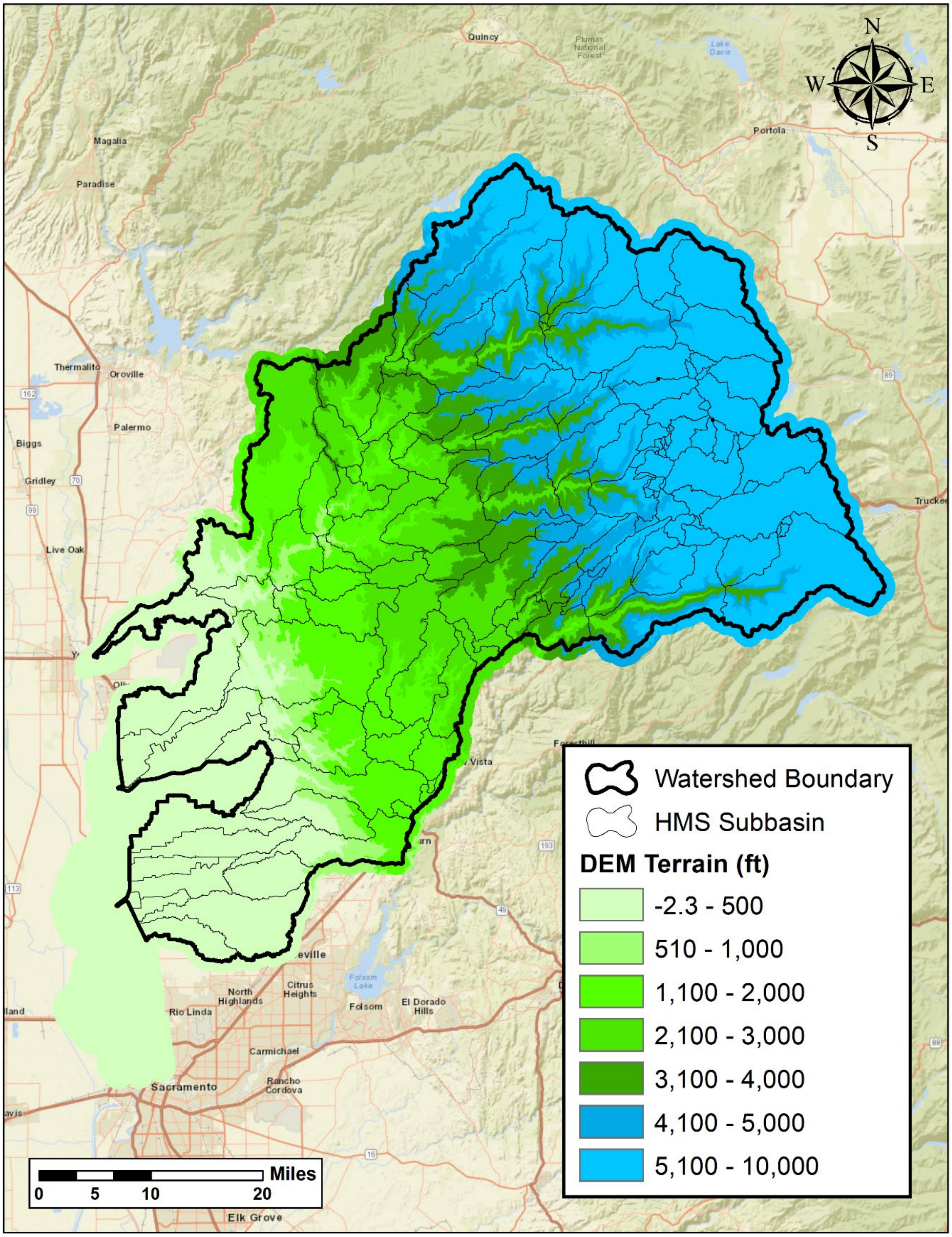

Figure 2-6. HEC-HMS Subbasins Delineation

2.4.2. Infiltration

Infiltration was estimated with the Deficit and Constant Loss Method. Required inputs for this method include initial soil moisture deficit, maximum soil moisture deficit, constant infiltration rate, and percent of directly connected impervious area. The first estimates for initial deficit, maximum deficit, and constant loss rate were based on surficial soil texture estimates. The soil texture was obtained from the NRCS gSSURGO soil coverages. Based on the soil gSSURGO datasets, the five dominant soil textures for the watershed were bedrock, sandy loam, loam, clay loam, and sandy clay loam.

Table 2-6, as listed in the Engineering Manual (EM) 1110-2-1417-Flood-Runoff Analysis (USACE 1994) and the HEC-HMS Technical Reference Manual (USACE 2022b), guided estimates of initial infiltration parameters. These parameters were based on effective porosity, wetting front suction head, saturated hydraulic conductivity, and wilting point. 'Note that the computed values are initial estimates subject to adjustment during model calibration.

The initial deficit parameter represents the initial soil moisture conditions for the soil layer. An initial deficit equal to zero indicates that the layer is fully saturated and that any precipitation falling at a rate exceeding the constant infiltration rate is transformed to runoff. The value used for the initial deficit was set to zero for all subbasins.

Table 2-6. Soil Textures and Effective Porosity, Wetting Front Suction Head, Saturated Hydraulic Conductivity, and Wilting Point (USACE 1994)

Soil Texture	Saturated Hydraulic Conductivity (in./hr)	Wetting Front Suction Head (in.)	Effective Porosity	Wilting Point
Clay	0.01	12.5	0.39	0.27
Clay Loam	0.04	8.2	0.31	0.2
Loam	0.1	3.5	0.43	0.12
Loamy Sand	1.2	2.4	0.4	0.06
Sand	4.6	1.9	0.42	0.03
Sandy Clay	0.02	9.4	0.32	0.2
Sandy Clay Loam	0.06	8.6	0.33	0.15
Sandy Loam	0.4	4.3	0.41	0.1
Silt Loam	0.3	6.6	0.49	0.13
Silty Clay	0.02	11.5	0.42	0.25
Silty Clay Loam	0.04	10.7	0.43	0.21
Bedrock	0	0	0	0

The maximum deficit parameter specifies the maximum depth of water held within the soil layer. This parameter is typically estimated as the difference between the saturation storage of the soil and the wilting point storage over an assumed active soil layer depth. In this study, an active soil layer depth of 24 in. was assumed. Therefore, based on the soil texture, the average (i.e., representative) maximum deficit for the study area was estimated to be 2 in. over the active soil layer depth.

The constant loss rate parameter defines the rate at which water is percolated out of the soil layer. Typically, this parameter is equated with the saturated hydraulic conductivity of the soil, which is defined as the rate at which water moves through a unit area of saturated soil in a unit time under a unit hydraulic gradient. Based on the study area soil texture, the initial value used for constant loss was set to 0.1 in./hr for all subbasins.

Directly connected impervious area estimates for each subbasin were assigned using the NLCD 2019 coverage. Figure 2-7 displays the 2019 NLCD Land Cover Classifications for the study area. The percent impervious parameter denotes the percentage of impervious area within each subbasin that is directly hydraulically connected to the conveyance network. It is assumed that no infiltration occurs within directly connected impervious areas, and all rainfall in such areas becomes direct runoff. Table 2-7 outlines the percent impervious cover defined per land cover type (USACE 2022a) that was used in this study.

Table 2-7. Impervious Values Defined Per Land Cover Category (USACE 2022)

Land Cover Type	Percent Impervious
Open Water	100
Perennial Snow/Ice	100
Developed, Low Intensity	20
Developed, Medium Intensity	40
Developed, High Intensity	60
Woody Wetlands	50
Emergent Herbaceous Wetlands	75
Barren Land	0
Deciduous Forest	0
Evergreen Forest	0
Mixed Forest	0
Shrub/Scrub	0
Herbaceous	0
Hay/Pasture	0
Cultivated Crops	0
Developed, Open Space	0

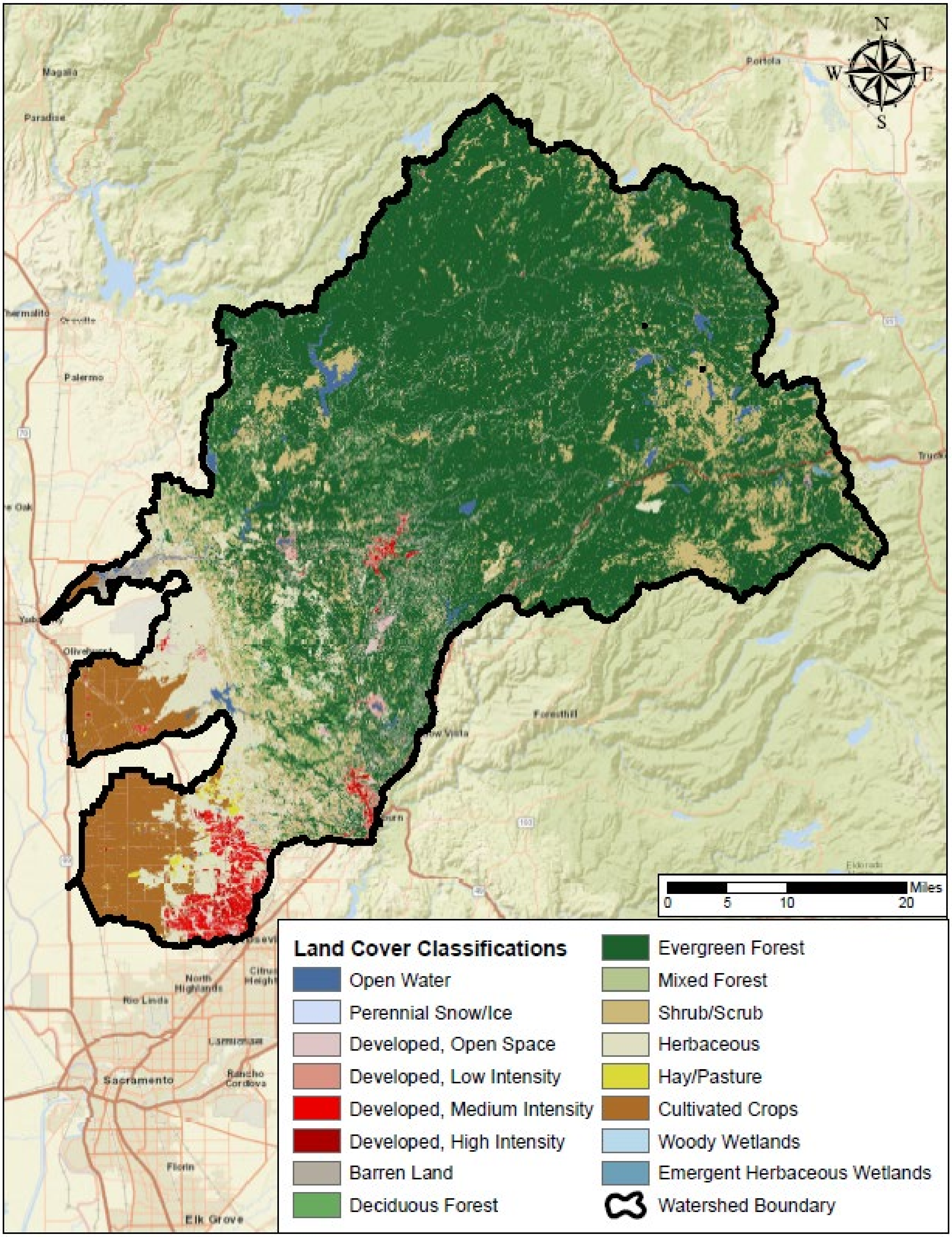

Figure 2-7. 2019 NLCD Land Cover Classifications for NID Basin

2.4.3. Canopy Losses

Canopy losses for this project were computed based on the simple canopy method, which requires five inputs: 1) initial storage percentage, 2) maximum storage, 3) crop coefficient, 4) evapotranspiration timing, and 5) uptake method.

The initial storage percentage was first set equal to 0, indicating a completely empty canopy, subject to adjustment during the calibration. Canopy storage depth depends on vegetation type or land cover. The 2019 NLCD land cover classification, shown in Figure 2-7, was applied to estimate the maximum canopy storage depths.

Canopy storage depths for each of the NLCD classes were recommended based on EM 1110-2-1417 (USACE 1994), HEC training materials, and engineering judgment. Table 2-8 lists the canopy storage values used for each NLCD land cover category.

The crop coefficient, used to adjust potential evapotranspiration, was set to 1.0 for all simulations. In HEC-HMS, evapotranspiration is set to take place either during periods without precipitation or throughout the entire simulation, regardless of whether precipitation is occurring. For this study, evapotranspiration is set to occur only during periods without precipitation ("Dry Periods"). Finally, the soil uptake method is defined as either simple or tension reduction. The tension reduction method only works when the soil moisture accounting method is selected as the soil infiltration loss method; therefore, the simple soil uptake method is used.

Table 2-8. Canopy Storage Depths for NLCD Land Cover Classifications (USACE 2022)

NLCD Code	NLCD Land Cover Classification	Canopy Storage (in)
11	Open Water	0.00
12	Perennial Snow/Ice	0.01
21	Developed, Open Space	0.05
22	Developed, Low Intensity	0.04
23	Developed, Medium Intensity	0.03
24	Developed, High Intensity	0.02
31	Barren Land	0.05
41	Deciduous Forest	0.08
42	Evergreen Forest	0.10
43	Mixed Forest	0.09
52	Shrub/Scrub	0.08
71	Grassland/Herbaceous	0.08
81	Hay/Pasture	0.08
82	Cultivated Crops	0.11
90	Woody Wetlands	0.10
95	Emergent Herbaceous Wetlands	0.09

2.4.4. Unit Hydrograph Transform

HEC-HMS offers a selection of eight transformation methods for modeling hydrologic processes. The ModClark unit hydrograph (UH) transform was used to route excess precipitation to the subbasin outlet within each subbasin. This linear, quasi-distributed transform method uses a grid of cells to depict travel times within a subbasin to the outlet point. It explicitly incorporates variations in travel time from all areas within a subbasin by employing a time travel index for each grid cell. These grid cells were laid out using the Standard Hydrologic Grid (SHG) system with a 2- x 2-km resolution (SHG 2000) and positioned across the modeling domain using tools provided within HEC-HMS.

Two essential parameters are needed for the ModClark method: the time of concentration for the basin, and the basin storage coefficient. USACE (2022a) suggests the following equations to estimate initial values of time of concentration and the basin storage coefficient:

$$T_c = 2.2\,(\frac{L *\ L_c}{\sqrt{S}})^{0.3}$$

$$\frac{R}{T_c + R} = 0.65$$

Where Tc is Time of concentration (hr), R is storage coefficient (hr), L is longest flow path length (miles), L_c is centroidal flow path length in miles, and S is 10-85 slope (ft/mi). The estimated T_c and R values were adjusted, as necessary, during calibration . Those equations were applied in this project to obtain initial parameters for the ModClark method.

2.4.5. Baseflow

The Linear Reservoir method was used to transform infiltrated water into interflow and baseflow. This helps simulate the movement of water within the soil. In this project, the storage and movement of infiltrated water is simulated using two layers. Linear reservoirs are used because, for every time step, the outflow is modeled as a linear function of the average storage within that specific time step. As a result of employing the Deficit and Constant Loss Method, the infiltrated water volume is evenly distributed between the two layers. The resulting outflow from both layers is combined to compute the total baseflow for each subbasin. The conceptualization of the two baseflow layers helps distinguish between short and long baseflow responses. The upper layer is set to respond faster than the lower layer.

Each calibration simulation starts on October 1st, after the summer months, and before the rainy season; therefore, the basin is usually quite dry. Because of that, all initial baseflow was set to originate from the slower draining groundwater storage (the Groundwater (GW) 2 layer).

Since processes that affect storage, attenuation, and timing of surface water also impact the response of interflow and baseflow, a ratio of ModClark storage coefficient was used for the groundwater storage coefficients in both layers. This approach ensures a consistent representation of these hydrological factors across the entire modeling framework. Initially, the GW 1 storage coefficient was set at 1.5 times the subbasin ModClark storage coefficient, while the GW 2 coefficient was set at 50 times the subbasin ModClark storage coefficient. Also, GW fractions in both layers are initially set to 0.5. These values are adjusted during model calibration, as necessary.

2.4.6. Streamflow Routing

Six different options are available in HEC-HMS to route flow through channels. For the routing of reaches across the modeling domain, the Muskingum-Cunge routing method was selected. This choice was made due to its ability to closely mimic more detailed hydraulic routing. The Muskingum-Cunge method uses physically based reach characteristics to compute flow attenuation and timing through the reach. Input parameters for this method are based on measurable physical parameters, which helps to increase the confidence in the routing calculations for ungaged watersheds. These physical parameters are often developed using existing hydraulic models and/or detailed topographic and hydrographic data.

To estimate the necessary depth-discharge, depth-area, and depth-top width relationships for all routing reaches, eight-point cross sections were used. While hydraulic models for rivers within the NID drainage basin were not readily available, cross-sectional data for certain reaches had been obtained during a recent relicensing study (Technical Memorandum 3-2, Instream Flow - October 2011). For the remaining reaches not covered in the study), the 1-m USGS NED was used to generate the cross-sectional data. This approach allowed for a comprehensive representation of the hydraulic characteristics across the modeling domain.

Initial estimates of channel roughness were 0.035 and 0.07 for the main channel and left/right overbank areas, respectively. These estimates were based on channel characteristics and engineering judgment. The length and average slope of each routing reach were determined within HMS GIS tool. For the celerity index method, an index celerity of 5 ft/second, and automatic optimization of space and time steps were used for all routing reaches.

2.4.7. Reservoir Routing

In the HEC-HMS model, dams and reservoirs were incorporated after a thorough screening process. The selection criteria for inclusion involved multiple factors, such as the available storage capacity, the intended purposes of the dam and reservoir, and the upstream drainage area. This approach ensured that major dams and reservoirs were correctly accounted for in the model. Elevation-area-discharge and elevation-storage relationships for the reservoirs were available from previous studies (NID, 2020). All reservoirs with observed discharge data were set to use the specified release method within HEC-HMS. In that method, HEC-HMS uses the observed outflow from a reservoir as input to the next sub-watershed. The observed outflow is a time series that combines all the reservoir’s outflow that are measured by gages, including diversions to other reservoirs, diversions to powerhouses, low flow outlet, spillway outlet, etc. If observed outflow discharge data were not available at a reservoir or for a specific year, the model uses the outflow curve method, which estimates reservoir outflow based on the relationship between storage and reservoir outflow discharge. Table 2-9 presents the list of reservoirs in the HEC-HMS model along with the corresponding routing methods.

Table 2-9. Inventory of Reservoirs in the Model and the Corresponding Routing Methods

Reservoirs	Routing Method		Reservoirs	Routing Method
JACKSON MEADOW RESERVOIR	Outflow Curve		SAWMILL LAKE	Outflow Curve
UPPER CASCADE LAKES	Outflow Curve		JACKSON LAKE	Outflow Curve
LOWER CASCADE LAKES	Outflow Curve		LAKE COMBIE	Outflow Curve
KIDD LAKE	Outflow Curve		ROCK CREEK LAKE	Outflow Curve
MEADOW LAKE	Outflow Curve		LAKE VALLEY RESERVOIR	Outflow Curve
WHITE ROCK LAKE	Outflow Curve		KELLY LAKE	Outflow Curve
LAKE STERLING	Outflow Curve		NEW BULLARDS BAR RESERVOIR	Specified Release
FULLER LAKE	Outflow Curve		MILTON RESERVOIR	Specified Release
BLUE LAKE	Outflow Curve		OUR HOUSE DAM	Specified Release
RUCKER LAKE	Outflow Curve		LOG CABIN DAM	Specified Release
UPPER LINDSEY LAKES	Outflow Curve		LAKE SPAULDING	Specified Release
LOWER LINDSEY LAKES	Outflow Curve		BOWMAN LAKE	Specified Release
CULBERTSON LAKE	Outflow Curve		ENGLEBRIGHT LAKE	Specified Release
UPPER ROCK LAKE	Outflow Curve		SCOTTS FLAT RESERVOIR	Specified Release
LOWER ROCK LAKE	Outflow Curve		DUTCH FLAT AFTERBAY	Specified Release
FEELEY LAKE	Outflow Curve		ROLLINS RESERVOIR	Specified Release
CARR LAKE	Outflow Curve		CAMP FAR WEST LAKE	Specified Release
FRENCH LAKE	Outflow Curve		FORDYCE LAKE	Specified Release (Outflow Curve for 1997)
FAUCHERIE LAKE	Outflow Curve			

2.4.8. Snowmelt

In this study, the gridded temperature index method was used for snowmelt modeling. The gridded temperature index method uses temperature and precipitation data to estimate snowpack melting and accumulation. When computing snowmelt runoff using the gridded temperature index method, multiple factors are considered, including the initial SWE, precipitation, air temperature, the form of precipitation (rain or snow), snowpack temperature, snowpack liquid water content, time of year, and the cumulative thawing degree-days. This comprehensive set of parameters supports a detailed and accurate representation of complex snow processes. The main assumption underlying this method is that the difference between air temperature and base temperature is directly proportional to the snowpack melt rate (USACE 1956). This implies that temperature, along with a melt rate coefficient, serves as the key factor in simulating snowmelt (USACE 1998). The gridded temperature index method requires 12 different parameters as inputs:

- **PX Temperature:** Distinguishes between precipitation falling as rain or snow.
- **Base Temperature:** Specifies the temperature at which snow melts.
- **Wet Melt Rate:** Defines the snow melt rate when rain is falling on the snowpack.
- **Rain Rate Limit:** Determines the difference between wet and dry melt rate.
- **ATI-Melt Rate Coefficient:** Adjusts the melt rate antecedent temperature index (ATI) calculated during the previous time step.
- **ATI-Melt Rate Function:** Allows the melt rate to change as the snowpack ages and the melting season progresses.
- **Cold Limit Rate:** Specifies the amount of snow that is required to accumulate before the snowpack temperature is reset to the base temperature.
- **ATI-Cold Rate Coefficient:** Adjusts the cold content of the snowpack based on the influence of the air temperature on the internal snowpack temperature.
- **ATI-Cold Rate Function:** Selects the cold rate based on the ATI for cold content.
- **Water Capacity:** Defines the maximum amount of melted water that can be held in the snowpack before the liquid water seeps into the soil or exits the snowpack as runoff.
- **Ground Melt Rate:** Specifies the rate at which the ground transfers heat to the snowpack, causing the snowpack to melt.

The parameters of the snowmelt meteorologic model were calibrated independently of the basin model by performing a multiyear daily simulation of SWE values. The calibration used observed SWE data from four stations located within the watershed boundary. A detailed discussion of the multiyear daily simulation calibration effort is presented in Section 2.5

2.5. Calibration of Snow Processes

Snow accumulation and melt depths are sensitive to topographical factors such as elevation and aspect. These factors influence the depth of snowfall and the extent of melting. The calibration efforts were concentrated on snow stations situated in higher elevation mountainous areas. Snow accumulation and melting at elevated locations tend to be more substantial compared to lower elevations. The following sections provide an overview of the calibration process, evaluate model performance, and presents results from multi-year snowmelt model calibration.

2.5.1. Approach

To accurately estimate flow rates when calibrating the HEC-HMS model, it is essential to initially calibrate the temperature index snowmelt and accumulation processes and parameters. The parameters calibrated are then used as the initial input to the HEC-HMS model. Parameters are further refined during calibration of the overall gridded HEC-HMS model. The methodology used to calibrate temperature index method parameters follows guidance in the USACE Modeling, Mapping and Consequences (MMC) Technical Manual for CWMS (USACE, 2016). The calibration steps include:

1. Perform data analysis on four SNOTEL and Cooperator Snow Sensors stations in the NID watershed, as previously illustrated in Figure 2-3 and listed in Table 2-3.
2. Create subbasins for each station, incorporating observed temperature, precipitation, and SWE data. The drainage area for each subbasin was set at 1 sq. mi. All the basin modeling methods are specified as "None" except for snow method. "Temperature Index" snow method was chosen for each subbasin, and a specific elevation band was assigned to each subbasin based on the elevation corresponding snow station. Table 2-10 lists the parameters that were used in the elevation band component for all the subbasin.

Table 2-10. Elevation Band Parameters

Elevation Band Parameter	Units	Value
Percent	%	100
Elevation	ft	Snow Station Elevation
Initial SWE	in.	0
Initial Cold Content	in.	0
Initial Liquid Water	in.	0
Initial Cold Content ATI	˚F	32
Initial Melt ATI	˚F-day	0

3. Set initial values for the parameters of the snow method (temperature index) for all subbasins (Table 2-11)

Table 2-11. Initial Temperature Index Method Parameters

Meteorologic Parameter	Units	Value
PX Temperature	˚F	34.5
Base Temperature	˚F	32
Wet Melt Rate	in./˚F-day	0.12
Rain Rate Limit	in./day	0.2
ATI-Melt Rate Coefficient	-	0.98
Cold Limit	in./day	0.8
ATI-Cold Rate Coefficient	-	0.84
Water Capacity	%	5
Ground Melt	in./day	0

4. Incorporate time series of observed precipitation, temperature, and SWE gages in the model.
5. Link the observed SWE at each snow station to the corresponding subbasins as observed SWE data.
6. Develop a meteorologic model using the specified hyetograph and thermograph methods for the observed precipitation and temperature components, respectively.

7. Assign precipitation and temperature gages to their corresponding subbasins in the meteorologic model.
8. Create paired data for ATI-Melt Rate Functions and ATI-Cold Rate Functions for all subbasins/stations and assign them to their respective subbasins/stations. The initial functions are in Table 2-12 and Table 2-13.

Table 2-12. Initial ATI-Melt Rate Function

ATI (˚F-day)	Melt Rate (in./˚F-day)
0.0	0.000
30.0	0.011
55.0	0.055
120.0	0.077
150.0	0.088
200.0	0.099
1000.0	0.110

Table 2-13. Initial ATI-Cold Rate Function

ATI (˚F-day)	Melt Rate (in./˚F-day)
-100.0	-2.00
-10.0	-0.20
-1.0	-0.02
1.0	0.02
10.0	0.20
100.0	2.00
1000.0	20.00

9. Create control specification using a daily time interval, spanning from January 1, 2017, to December 01, 2021. This 5-year time period was selected due to the availability of snow data for all four snow stations.
10. Create optimization trials and simulation runs to compare simulated and observed SWE at each snow station.
11. Conduct both automatic and manual calibration processes to find parameters that yield the best match to the observed SWE values at each station.

2.5.2. Performance

Model performance is measured using Nash-Sutcliffe Efficiency (NSE), the Ratio of the Root Mean Square Error (RMSE) to the Standard Deviation Ratio (RSR), and Percent Bias (PBIAS). Comparisons are also made for peak SWE, as well as the date of peak SWE.

NSE measures the relative magnitude of the residual variance compared to the measured data variance. NSE ranges between -∞ and 1, where NSE = 1 is optimal. A value of NSE ≤ 0 indicates the mean observed value is a better predictor than the simulated value. NSE is computed using the following equation:

$$NSE = 1 - \left[\frac{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\Sigma_{i=1}^{n}(Y_i^{obs} - \bar{Y}^{obs})^2}\right]$$

where n = number of observed values compared to computed over the duration of the simulation, Y_i^{obs} = observed values, Y_i^{sim} = computed values, $\bar{Y}^{obs}$ = average of observed values.

RSR normalizes the RMSE by using the standard deviation of the observations. By normalizing RMSE, that statistic can be directly compared among different stations. A lower RMSE-to-SDR ratio indicates that the model's predictions are relatively accurate compared to the variability in the observed data, which is desirable. Conversely, a higher RMSE-to-SDR ratio suggests that the model's predictions have lower accuracy relative to the variability in the observed data, which may indicate poor model performance. RSR is computed using the following equation:

$$RSR = \frac{RSME}{STDEV_{obs}} = \frac{\left[\sqrt{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\Sigma_{i=1}^{n}(Y_i^{obs} - \bar{Y}_i^{sim})^2}\right]}$$

where RMSE = root mean square error, STDEVobs = standard deviation of the observations, and $\bar{Y}_i^{sim}$ = average of simulated values.

PBIAS measures the average tendency of the simulated data to be larger or smaller than the observed data. The optimal value for PBIAS is 0.0, with low absolute PBIAS indicating accurate model simulation. A negative PBIAS means the computed volume is low and a positive PBIAS means the computed volume is high, when compared to observed data. PBIAS is computed using the following equation:

$$PBIAS = \left[\frac{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) \times 100}{\Sigma_{i=1}^{n}(Y_i^{obs})}\right]$$

Summary statistic performance ratings are presented in Table 2-14. The ranges shown for each of the performance ratings are based on values found in the literature. An NSE of "Very Good" or "Good" might indicate an adequate fit to the magnitude and timing of the snowmelt; however, the simulated and observed hydrographs should be evaluated along with other metrics for a more complete picture of model performance.

Table 2-14. HEC-HMS Performance Ratings for Summary Statistics

Performance Rating	NSE	RSR	PBIAS
Very Good	$0.65 < NSE \leq 1.00$	$0.00 < RSR \leq 0.60$	$PBIAS < \pm 10$
Good	$0.55 < NSE \leq 0.65$	$0.60 < RSR \leq 0.70$	$\pm 10 \leq PBIAS < \pm 35$
Satisfactory	$0.40 < NSE \leq 0.55$	$0.70 < RSR \leq 0.80$	$\pm 35 \leq PBIAS < \pm 50$
Unsatisfactory	$NSE \leq 0.40$	$RSR > 0.80$	$PBIAS \geq \pm 50$

2.5.3. Results

A sensitivity analysis assessed how variations in the snow parameters influence the model's output. The analysis helped to identify which parameters have a significant impact on the model results. Based on the sensitivity analysis, snow melt and accumulation are extremely sensitive to the PX temperature, base temperature, and ATI-melt rate coefficient. Results were less sensitive to wet melt rate, rain rate limit, ATI-melt and cold rate functions, cold melt rate, ATI-cold rate coefficient, water capacity, and ground melt rate. Therefore, during calibration, attention was focused on the more sensitive parameters.

Figure 2-8 through Figure 2-11 show the precipitation, temperature, and simulated SWE versus observed SWE time series at the selected snow stations. Table 2-15 summarizes the performance statistics. The overall performance rating for all stations varies from Good to Very Good.

Table 2-15. Snow Model Calibration Results from January 1, 2017, through December 1, 2021

Stations	Peak SWE (in.)		NSE	RSR	PBIAS	Overall Performance Rating
	Model	Obs.				
BLC	26.00	31.08	0.91	0.3	-15.29	Good to Very Good
HYS	50.10	53.64	0.87	0.36	0.15	Very Good
RCC	71.06	77.32	0.92	0.28	-19.26	Good to Very Good
CSL	49.97	72.90	0.70	0.55	-29.20	Good to Very Good

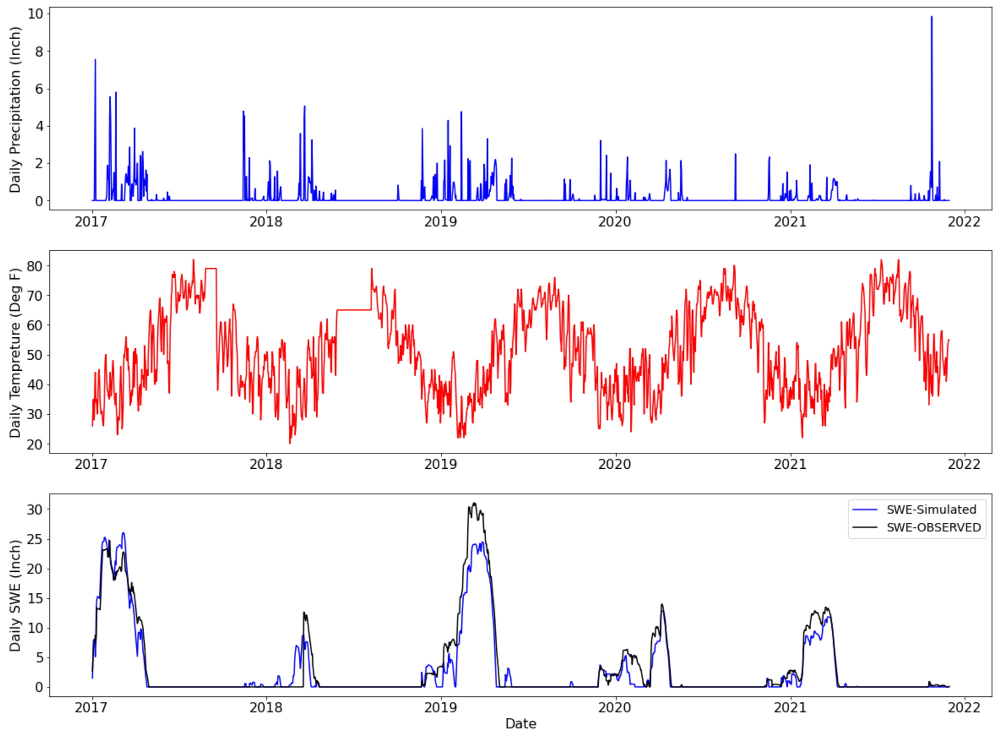

Figure 2-8. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Blue Canyon Station (BLC)

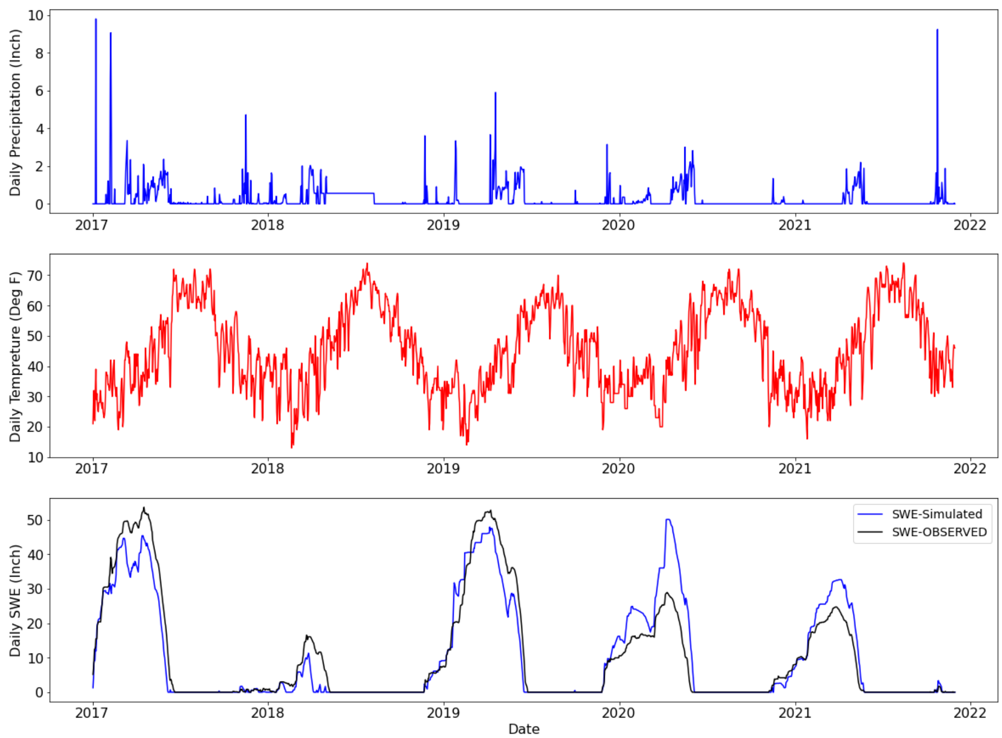

Figure 2-9. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Huysink Station (HYS)

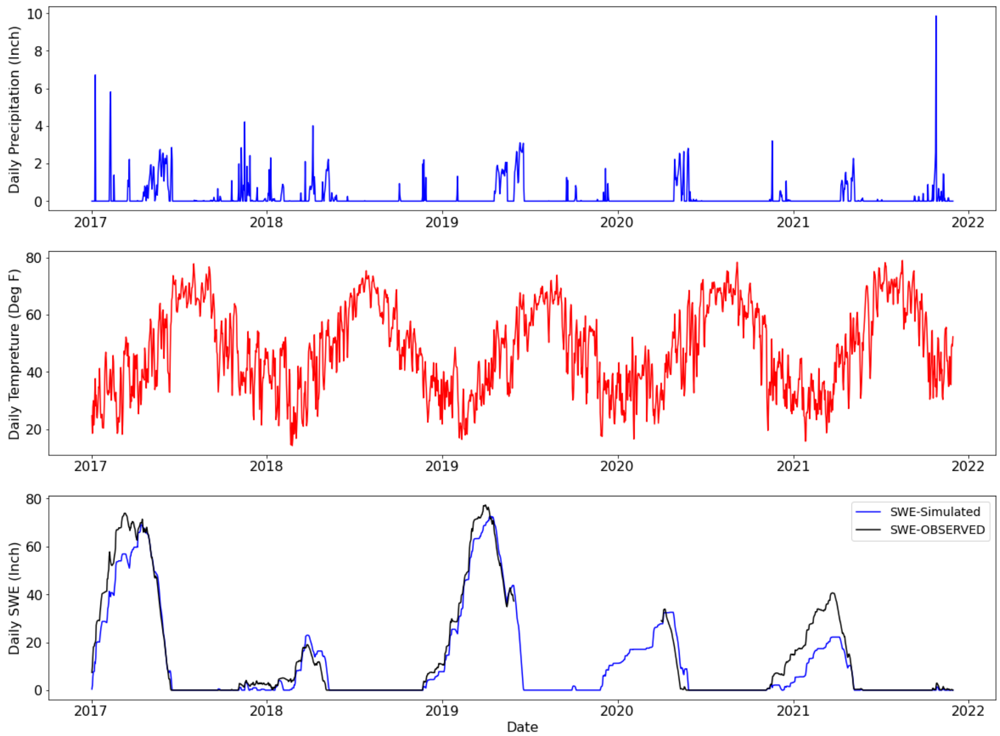

Figure 2-10. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Robinson Cow Camp Station (RCC)

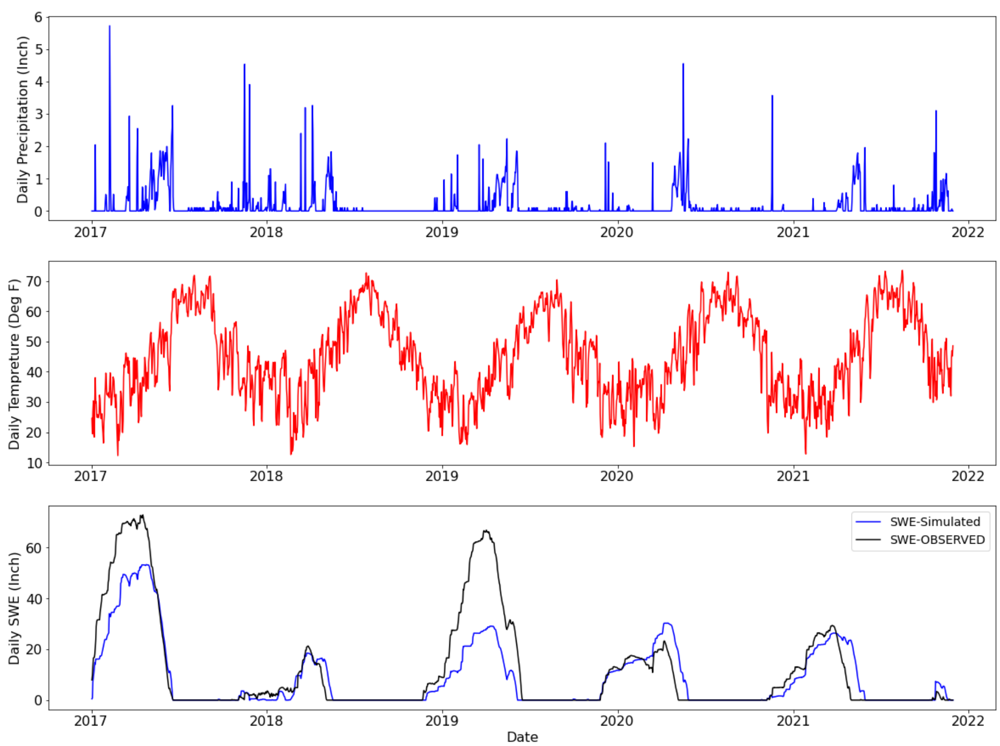

Figure 2-11. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Central Sierra Snow Lab Station (CSL)

The calibrated snow parameters and ATI-melt and cold rate functions for each station are presented in Table 2-16 to Table 2-18. These parameters were used to define the initial parameters in the HEC-HMS model for the whole area of interest. Each subbasin in the model was assigned a specific set of snow parameters. The determination of these parameters for each subbasin was based on the nearest snow station in terms of elevation. Subbasin parameters were fine-tuned during HEC-HMS calibration as discussed in Section 2.6.

Table 2-16. Calibrated Temperature Index Parameters

Parameter	Unit	BLC	HYS	RCC	CSL
PX Temperature	°F	35	33.9	34.5	34.5
Base Temperature	°F	33	32.1	33.6	34.5
ATI - Meltrate Coefficient	-	0.8	0.98	0.94	0.9
Wet Meltrate	in./°F-day	0.13	0.099	0.11	0.17
Rain Rate Limit	in./day	0.1	0.1	0.1	0.5
Cold Limit (in./day)	in./day	0.1	0.1	0.1	0.1
ATI - Coldrate Coefficient	-	0.98	0.99	0.98	0.99
Water Capacity (%)	-	3	3	3	3
Groundmelt	in./day	0	0	0	0

Table 2-17. ATI-Meltrate Function

ATI (˚F-day)	BLC	HYS	RCC	CSL
0	0.000	0.0000	0.000	0.000
30	0.011	0.0075	0.010	0.012
55	0.055	0.0375	0.048	0.060
120	0.077	0.0525	0.067	0.084
150	0.088	0.0600	0.076	0.096
200	0.099	0.0675	0.086	0.108
1000	0.110	0.0750	0.095	0.120
2000	0.132	0.0900	0.105	0.132

Table 2-18. ATI-Coldrate Function

ATI (˚F – Day)	BLC	HYS	RCC	CSL
-100.0	-2.00	-1.800	-2.00	-2.00
-10.0	-0.20	-0.180	-0.20	-0.20
-1.0	-0.02	-0.018	-0.02	-0.02
1.0	0.02	0.018	0.02	0.02
10.0	0.20	0.180	0.20	0.20
100.0	2.00	1.800	2.00	2.00
1000.0	20.00	18.000	20.00	20.00

2.6. HEC-HMS Model Calibration

The previous section described the calibration of the snow model using observed SWE as reference. This section discusses the calibration of other important processes in HEC-HMS, including runoff generation, infiltration, and recharge. The calibration described in this section uses observed streamflow or reservoir inflow as reference.

The calibration procedure consists of adjusting several parameters to guarantee that the model accurately represents hydrological processes and outputs for selected historical events.

The following sections provide an overview of the HEC-HMS model calibration process and results.

2.6.1. Calibration Parameters and Approach

Like the calibration process for snow, the evaluation of model performance involved comparing computed results with observed results across the entire modeling domain. Model parameters were altered to minimize the differences between simulated and observed discharge volume and hydrograph shape at locations where they are available (Table 2-20). Since the focus on the hydrological model for this project is to simulate annual water availability, the calibration process was focused toward ensuring minimal bias in the model. Therefore, model performance evaluation was centered on PBIAS. For detailed explanation of PBIAS, Refer to Section 2.5.2. A second priority was the ability of the model to predict streamflow peak, since a large peak may result in water loss through the reservoir spillways. Differences less than or equal to 15% between computed and observed peak flow rates and flow volumes were desired.

Table 2-14 provides the summary statistic performance ratings for the NID HEC-HMS model calibration. Note that the PBIAS statistics at each location were mostly calculated using the complete water year for each calibration year. The exception was the USGS Station 11418500, between Scotts Flat Reservoir and USGS Station 11418500 on Deer Creek. Since the Deer Creek Diversion Dam is ungaged for flows moving down Deer Creek, the D-S Canal could not be incorporated into the unimpaired hydrology modeling efforts. The diversion predominantly affects the flow in Deer Creek from April through November. To mitigate these effects, the PBIAS statistics for USGS Station 11418500 were computed using the time series from

November through April. Schematics illustrating the complex systems of storage and diversions across the North, Middle, and South Yuba Rivers, along with the Bear River can be accessed on the USGS website and are included in Appendix A.

As described in more detail in the following sections, the calibration approach followed two main steps: (1) calibration based on 5 selected years with varying climatology, and (2) re-calibration based on extrapolation for the period of record.

2.6.1.1 Step 1: Calibration for Selected Years

Based on a first evaluation of the model results with initial model parameters (before calibration), it was concluded that the model captured streamflow peaks and timing reasonably well. For some of the events, disparities in the timing of snow accumulation and melting and in runoff volume were identified. The sensitivity analysis, calibration parameters, and general approach are summarized in Appendix A. To evaluate the model's performance under different hydrological conditions, including dry, normal, and wet conditions, five water years, spanning from October 1 to September 30, were chosen. The details of the calibration water years are provided in Table 2-19.

Table 2-19. Calibration Events

Wet Water-Year	Normal Water-Year	Dry Water-Year
Oct 1996–Sep 1997	Oct 2003–Sep 2004	Oct 2020–Sep 2021
Oct 2005–Sep 2006		Oct 2014–Sep 2015

2.6.1.2 Step 2: Re-Calibration Based on Extrapolation for Period of Record

Following model calibration for the five selected water years using the observed data, the next step was to use the same calibration parameters to simulate streamflow for other historical years (from 1975 to 2022 except WYs 1997, 2004, 2006, 2015, and 2021). A first step in this process was to develop a methodology for defining which of the five sets of calibrated parameters should be applied to simulate each historical year.

While evaluating the five sets of calibrated parameters for various climate conditions (dry, normal, and wet) within the NID basin, it was determined that the baseflow index is strongly correlated with watershed initial condition. Baseflow index in HEC-HMS represents the average percentage of water received as precipitation that is lost to recharge in each water year. In dry years, much of the received precipitation infiltrates in the dry soil and does not end up as runoff. For those years, the baseflow index is high. For years with high precipitation, the soil gets saturated, and a large percentage of the precipitation runs off to the river. Note that the baseflow recharge in HEC-HMS represents a percentage of total volume, not the actual recharge volume. In wet years, both recharge and runoff will present large volumes, with a smaller portion of the volume recharging the aquifer. The relationship between basin moisture condition and baseflow recharge was used to determine the most suitable set of parameters for each year in the historical period.

2.6.2. Results for Selected Water Years

Data for 16 locations for which streamflow data were available (USGS streamflow) or could be computed (reservoir inflow), were used for HEC-HMS model calibration. These locations are listed in Table 2-20 and shown in Figure 2-12. Data for Fordyce Lake were not fully available for the water year (WY) 1997. Therefore, the area delineated above Fordyce Lake for WY2004, WY2006, WY2015, and WY2021 is considered as part of the Lake Spaulding area for WY1997.

Table 2-20. Calibration Locations in NID Basin

River Basins	Number of Locations	Location Name/Stations
North Yuba River	2	USGS Gage 11413000; New Bullards Bar Reservoir
Middle Yuba River	3	Jackson Meadows and Milton Reservoirs jointly (Jackson Meadows-Milton); Our House Dam; Log Cabin Dam
South Yuba River	4	Fordyce Lake; Bowman Lake; Lake Spaulding; USGS Gage 11417500
Bear River	3	Dutch Flat Afterbay; Rollins Reservoir; Camp Far West Lake
Deer Creek	2	Scotts Flat Reservoir; USGS Gage 11418500
Yuba River (outlet)	2	Englebright Lake; USGS Gages 11421000, 11420750, 11420760, 11420770 jointly

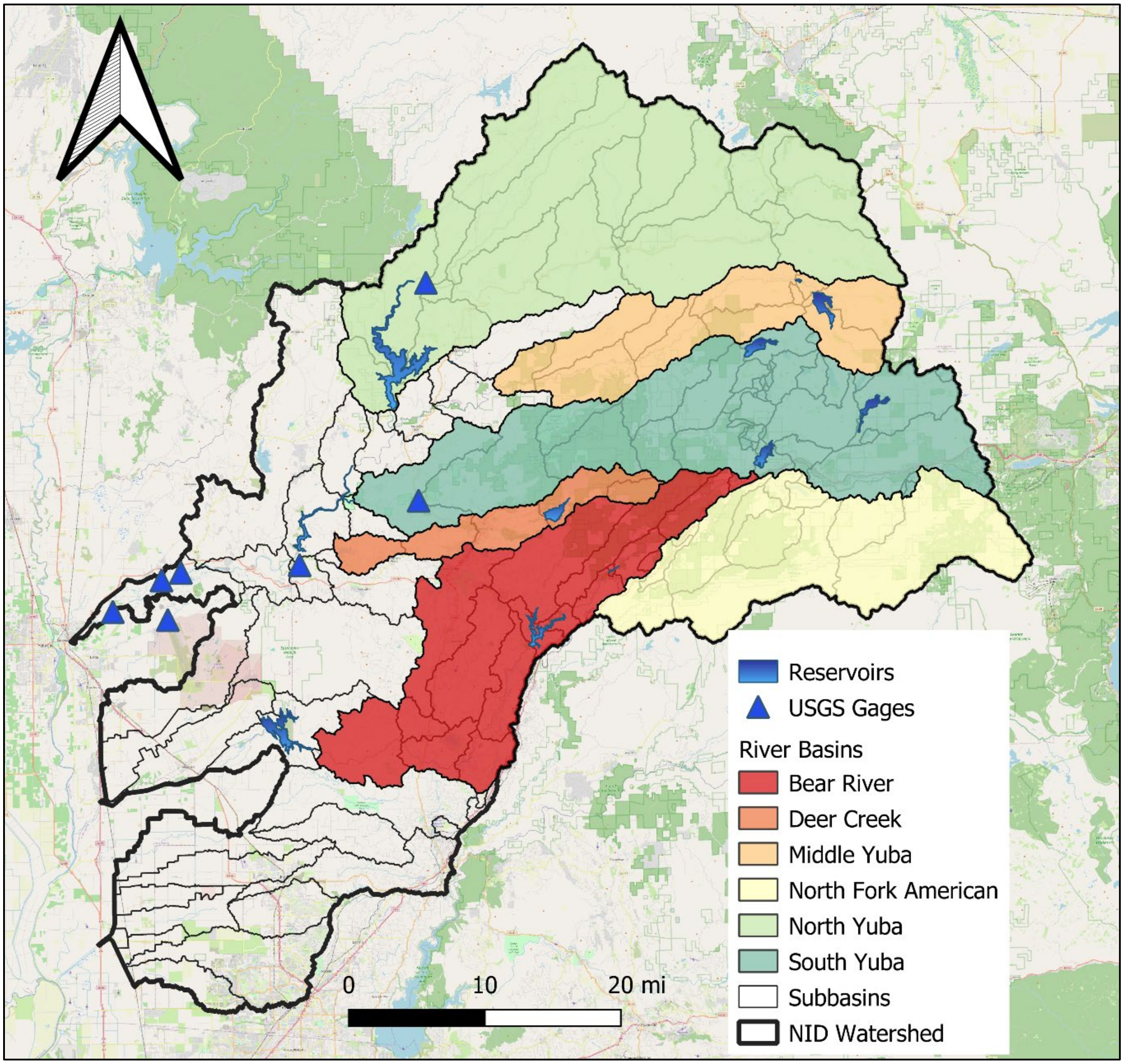

Figure 2-12. Calibration Locations for NID HEC-HMS Model (Described in Table 2-20)

The adjustments to the snowmelt parameters were made in the area upstream of Fordyce Lake, Bowman Lake, and Lake Spaulding. The Wet Meltrate and the ATI - Meltrate Function were adjusted for these subbasins by a factor of 1.1 to minimize differences in observed and simulated snowmelt. The adjusted parameters are listed in Table 2-21 and Table 2-22.

Table 2-21. Adjusted Calibrated Temperature Index Parameters

Parameter	Unit	BLC	HYS	RCC	CSL
Adjusted Wet Meltrate	in./°F-day	0.143	0.1089	0.121	0.187

Table 2-22. ATI-Meltrate Function

ATI (˚F-day)	BLC	HYS	RCC	CSL
0	0.0000	0.00000	0.0000	0.0000
30	0.0121	0.00825	0.0110	0.0132
55	0.0605	0.04125	0.0528	0.0660
120	0.0847	0.05775	0.0737	0.0924
150	0.0968	0.06600	0.0836	0.1056
200	0.1089	0.07425	0.0946	0.1188
1000	0.1210	0.08250	0.1045	0.1320
2000	0.1452	0.09900	0.1155	0.1452

The constant loss rate was first estimated to be 0.1 in./hr. Minor adjustments were made to ensure minimal to no excess precipitation was generated while maximizing runoff using the linear reservoir baseflow routine. The final values ranged between 0.06 and 0.13 in./hr.

Due to the high precipitation magnitudes necessary to generate excess precipitation runoff, most water was infiltrated and routed as baseflow. Therefore, adjustments to the baseflow recharge were implemented during the calibration process that provided the flexibility of varying the amount of water removed through the system based on deep groundwater recharging for different subbasins. To account for high positive/negative PBIAS across the NID watersheds, the fraction of GW 1 or GW 2 baseflow lost to aquifer recharge was adjusted iteratively to achieve Good to Very Good PBIAS.

2.6.2.1 Water Year 1997: Wet Year

This section describes the calibration results and statistics for WY1997. PBIAS statistics were calculated using the complete WY from 01 Oct 1996 through 30 Sep 1997 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 1996 through 01 Apr 1997 was used. PBIAS maps and metrics are shown in Figure 2-13, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 15 previously mentioned calibration locations are shown in Table 2-23. Hydrographs comparing the computed and observed flow at the 15 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Good” to “Very Good.” Unfortunately, the observed data at Fordyce Lake were not available for this WY. For WY1997, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 3,475,200 AF.

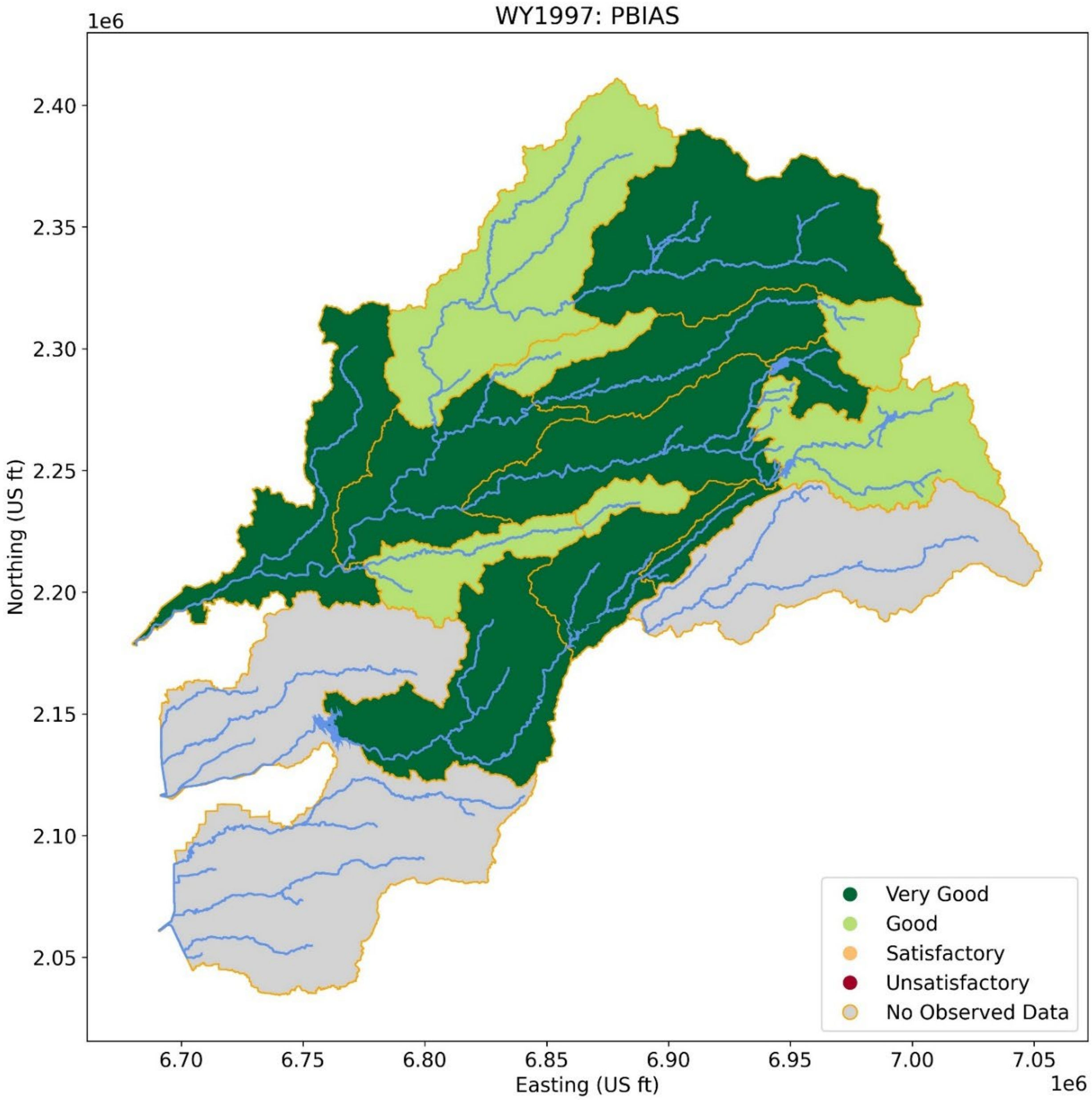

Figure 2-13. WY1997 PBIAS Results

Table 2-23. WY1997 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-4.91	848.9	807.2
New Bullards Bar Reservoir	-19.55	1,834.6	1,476.0
Jackson Meadows – Milton Reservoirs	-19.71	137.5	110.4
Our House Dam	6.46	378.9	403.3
Log Cabin Dam	-21.25	170.2	134.0
Bowman Lake	-1.42	220.0	216.9
Lake Spaulding	11.26	694.0	772.1
USGS 11417500	9.15	676. 4	738.3
Scotts Flat Reservoir	26	108.2	136.3
USGS 11418500[1]	11.43	145.0	161.6
Englebright Lake	6.08	3,088.2	3,275.9
Yuba River Outlet	3.37	3,475.2	3,592.1
Dutch Flat Afterbay	-9.67	377.94	341.3
Rollins Reservoir	-2.85	709.4	689.2
Camp Far West Lake	-1.89	593.7	582.5

[1]Volume is considered only from 11/1/1996 to 4/1/1997.

2.6.2.2 Water Year 2004: Normal Year

This section describes the calibration results and statistics for WY2004. PBIAS statistics were calculated using the complete WY from 01 Oct 2003 through 30 Sep 2004 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2003 through 01 Apr 2004 was used. PBIAS maps and metrics are shown in Figure 2-14, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-24. Plots comparing the computed and observed flow at the 16 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Good” to “Very Good.” For WY2004, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 1,384,900 AF.

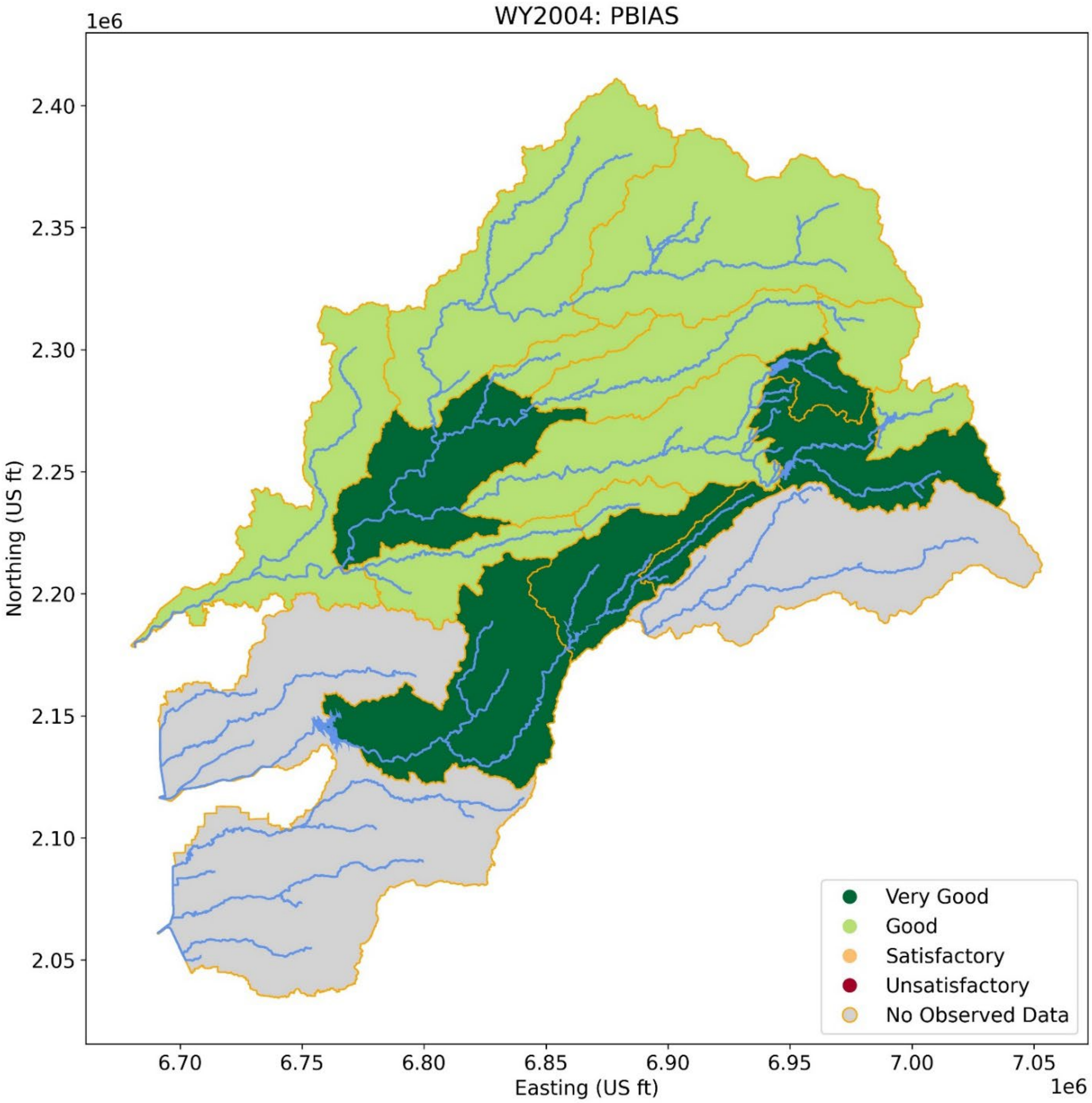

Figure 2-14. WY2004 PBIAS Results

Table 2-24. WY2004 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-27.99	425.3	306.3
New Bullards Bar Reservoir	-28.29	861.8	617.9
Jackson Meadows – Milton Reservoirs	-23.00	66.5	51.2
Our House Dam	-19.87	141.7	113.5
Log Cabin Dam	-18.70	144.8	117.7
Fordyce Lake	-11.88	71.5	63.0
Bowman Lake	-0.40	128.6	128.1
Lake Spaulding	-2.60	425.1	414.0
USGS 11417500	-27.89	161.5	116.4
Scotts Flat Reservoir	11.99	53.9	60.4
USGS 11418500[1]	-26.39	41.5	30.5
Englebright Lake	-4.95	1,294.6	1,230.6
Yuba River Outlet	11.51	1,384.9	1,544.4
Dutch Flat Afterbay	-1.69	409.0	402.1
Rollins Reservoir	-9.64	510.6	461.4
Camp Far West Lake	0.44	273.6	274.8

[1]Volume is considered only from 11/1/2003 to 4/1/2004.

2.6.2.3 Water Year 2006: Wet Year

This section describes the calibration results and statistics for WY2006. PBIAS statistics were calculated using the complete WY from 01 Oct 2005 through 30 Sep 2006 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2005 through 01 Apr 2006 was used. PBIAS maps and metrics are shown in Figure 2-15, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-25. Plots comparing the computed and observed flow at the 16 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Good” to “Very Good.” For WY2006, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 4,161,200 AF.

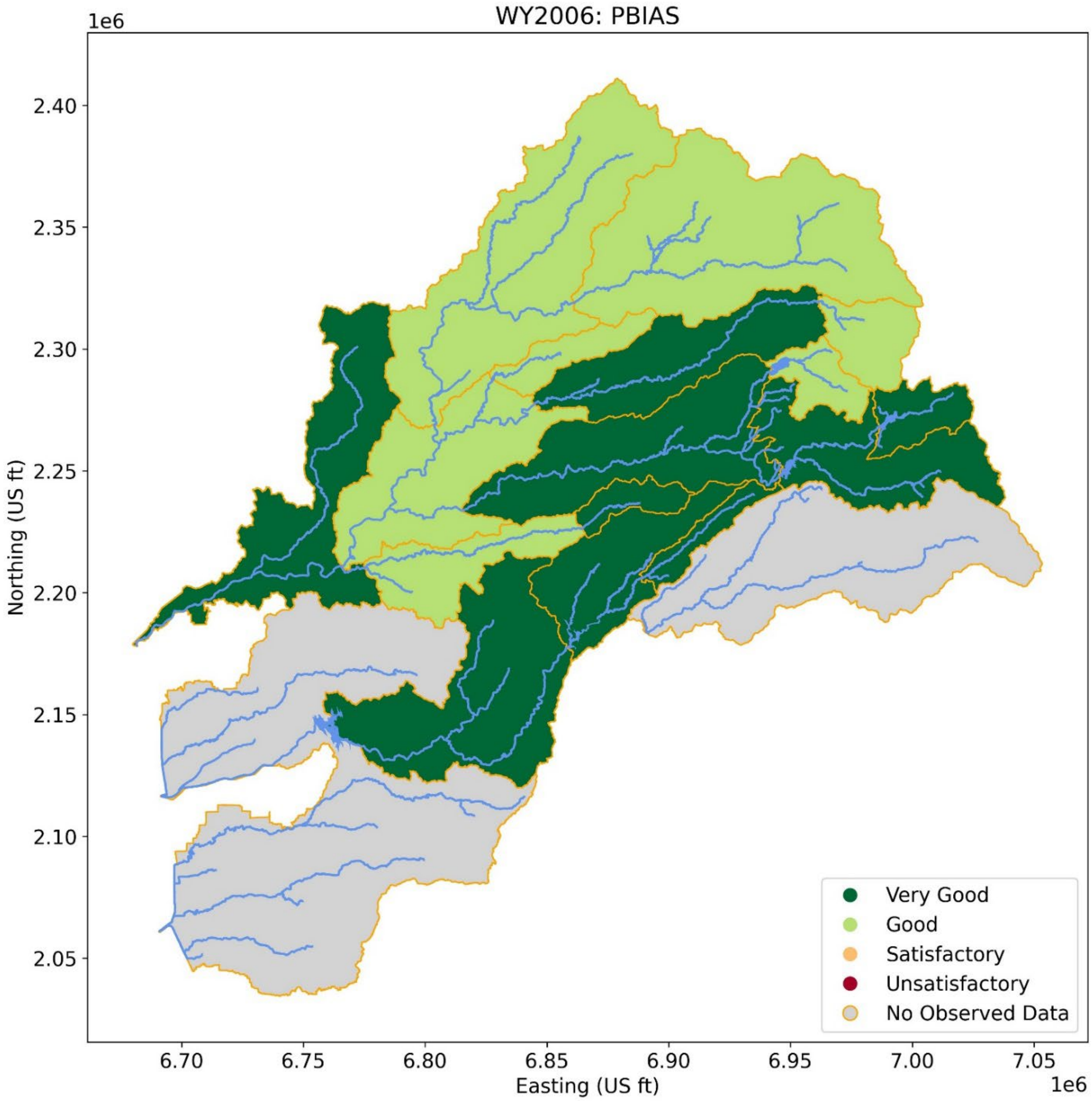

Figure 2-15. WY2006 PBIAS Results

Table 2-25. WY2006 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-20.85	1,005.8	796.1
New Bullards Bar Reservoir	-23.39	2,152.6	1,649.1
Jackson Meadows – Milton Reservoirs	-19.07	149.2	120.8
Our House Dam	-0.92	510.3	505.7
Log Cabin Dam	-23.26	241.0	184.9
Fordyce Lake	-9.99	151.5	136.4
Bowman Lake	-10.3	239.3	214.6
Lake Spaulding	-4.06	780.8	749.1
USGS 11417500	8.83	788.0	857.6
Scotts Flat Reservoir	-8.85	104.5	95.2
USGS 11418500[1]	-14.61	121.4	103.6
Englebright Lake	13.75	3,340.9	3,800.3
Yuba River Outlet	-1.78	4,161.2	4,087.2
Dutch Flat Afterbay	-7.82	523.9	482.9
Rollins Reservoir	-6.28	864.0	809.7
Camp Far West Lake	-1.25	887.0	875.9

[1]Volume is considered only from 11/1/2005 to 4/1/2006.

2.6.2.4 Water Year 2015: Dry Year

This section describes the calibration results and statistics for WY2015. PBIAS statistics were calculated using the complete WY from 01 Oct 2014 through 30 Sep 2015 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2014 through 01 Apr 2015 was used. PBIAS maps and metrics are shown in Figure 2-16, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-26. Plots comparing the computed and observed flow at the 16 calibrations locations are shown in Appendix A.

Overall, calibration for this event was "Satisfactory" to "Very Good." PBIAS statistics for most locations were within the "Good" range that was previously described, with several basins in the "Very Good" range and a few basins in the "Satisfactory" range. It is unsurprising that a couple of basins fell in the "Satisfactory" range for WY2015. WY2015 is the first of two dry year examples, and hydrological processes during dry years are highly non-linear, and those non-linearities are not always captured by the model. However, since volumes are smaller during dry periods, a relatively higher PBIAS in comparison to wet years still represents a small volume of flow. For example, during WY1997, the total volume difference at Jackson Meadows-Milton reservoirs was approximately 27,100 AF and yielded a -19.71% PBIAS. During WY2015, the total volume difference at Jackson Meadows-Milton reservoirs was approximately 13,900 AF, nearly half of the volume difference from WY1997, and yielded a less desirable PBIAS of -39.07%. For WY2015, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 633,800 AF.

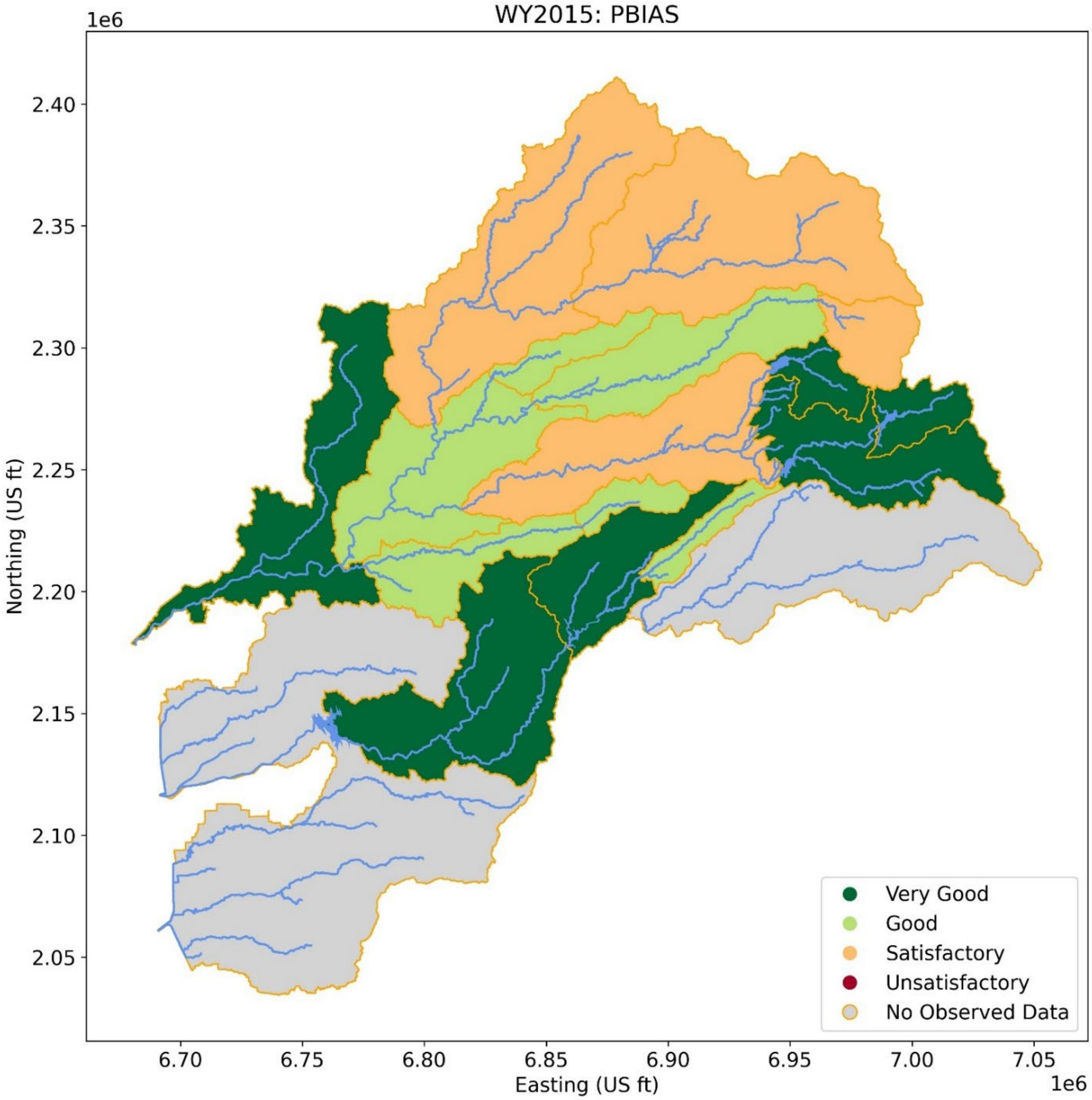

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Figure 2-16. WY2015 PBIAS Results

Table 2-26. WY2015 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-49.63	202.4	102.0
New Bullards Bar Reservoir	-47.18	432.3	228.4
Jackson Meadows – Milton Reservoirs	-39.07	35.5	21.6
Our House Dam	-31.92	72.7	49.5
Log Cabin Dam	-23.14	63.1	48.5
Fordyce Lake	-3.86	44.5	42.7
Bowman Lake	-3.20	75.1	72.7
Lake Spaulding	-0.50	256.6	255.3
USGS 11417500	-43.74	83.3	46.9
Scotts Flat Reservoir	21.46	43.6	53.0
USGS 11418500[1]	-31.00	18.3	12.6
Englebright Lake	-10.26	596.7	535.5
Yuba River Outlet	9.84	633.8	696.2
Dutch Flat Afterbay	10.07	196.6	216.4
Rollins Reservoir	-4.14	236.6	226.8
Camp Far West Lake	-8.71	116.4	106.2

[1]Volume is considered only from 11/1/2014 to 4/1/2015.

2.6.2.5 Water Year 2021: Dry Year

This section describes the calibration results and statistics for WY2021. PBIAS statistics were calculated using the complete WY from 01 Oct 2020 through 30 Sep 2021 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2020 through 01 Apr 2021 was used. PBIAS maps and metrics are shown in Figure 2-17, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-27. Plots comparing the computed and observed flow at the 16 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Satisfactory” to “Very Good.” PBIAS statistics for most of the locations were within the “Very Good” range that was previously described, with several basins in the “Good” range and a few basins in the “Satisfactory” range. As with WY2015, it is unsurprising that a couple of basins fall in the “Satisfactory” range for WY2021, as the water year was a significantly dry year with the same highly non-linear effects mentioned in Section 2.6.2.4. For WY2021, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 630,500 AF.

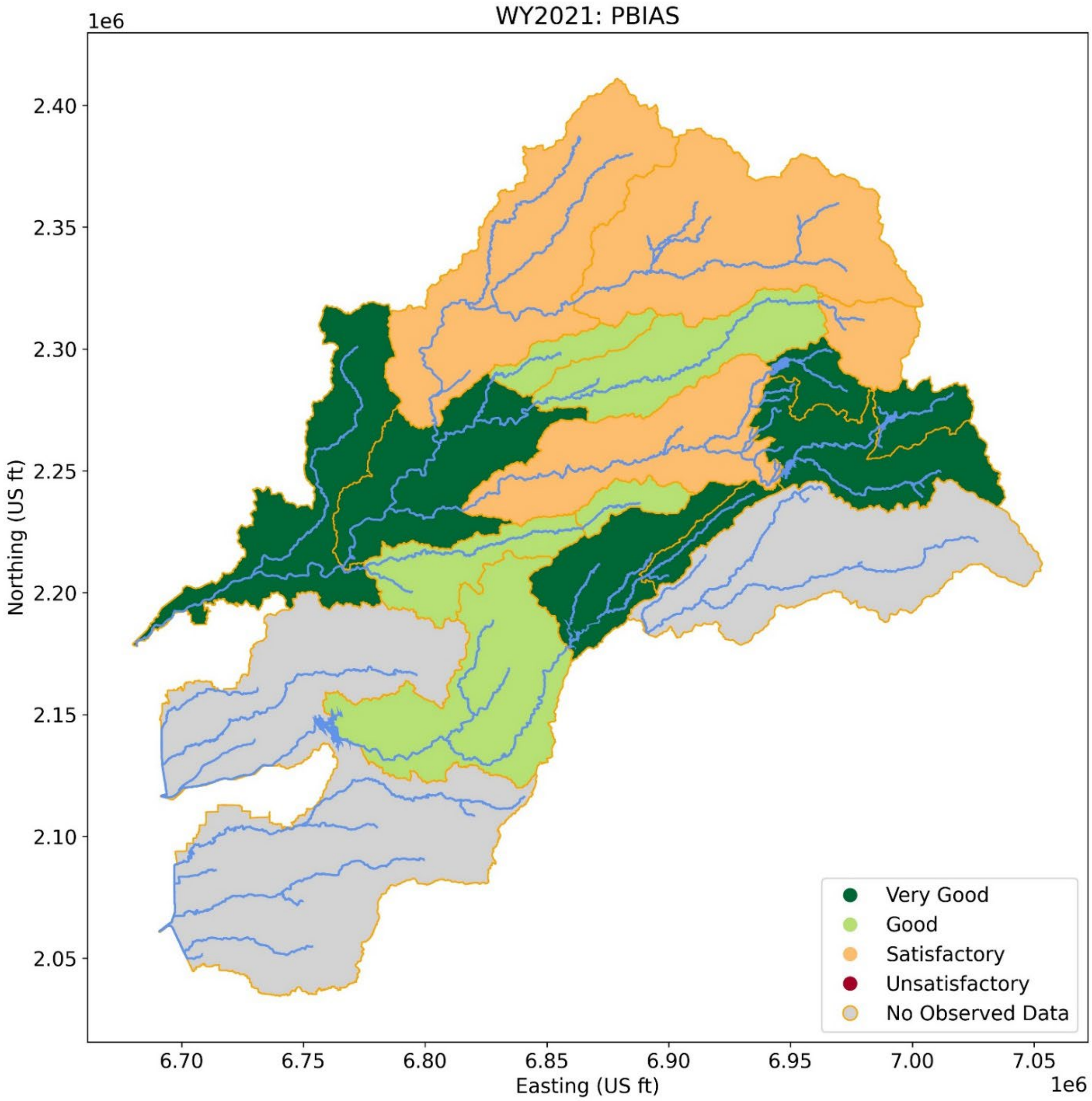


Figure 2-17. WY2021 PBIAS Results

Table 2-27. WY2021 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-48.25	160.4	83.0
New Bullards Bar Reservoir	-42.13	317.0	183.4
Jackson Meadows – Milton Reservoirs	-37.78	25.1	15.6
Our House Dam	-32.81	51.7	34.7
Log Cabin Dam	-30.99	42.0	29.0
Fordyce Lake	-0.91	37.4	37.0
Bowman Lake	-1.31	65.1	64.3
Lake Spaulding	-0.40	275.7	274.6
USGS 11417500	-38.10	57.3	35.5
Scotts Flat Reservoir	21.75	42.8	52.1
USGS 11418500[1]	-13.64	7.4	6.4
Englebright Lake	-3.64	637.8	614.6
Yuba River Outlet	10.00	630.5	693.5
Dutch Flat Afterbay	4.29	182.6	190.4
Rollins Reservoir	-0.45	209.9	208.9
Camp Far West Lake	34.65	62.9	84.8

[1]Volume is considered only from 11/1/2020 to 4/1/2021.

2.6.3. Results for Other Water Years

The first step for simulating other water years was to identify an indicator that describes basin moisture condition. Multiple drought indicators were calculated for each river basin in the NID watershed (North Yuba River, Middle Yuba River, South Yuba River, Bear River, and Deer Creek) using a drought tool (Wells et al. 2004) developed by National Center for Atmospheric Research (NCAR). The input data for the tool include monthly basin-average temperature and precipitation data compiled from the daily Livneh dataset.

The correlation between multiple drought indicators and baseflow index were evaluated, and the indicator that presented the highest correlation was selected as a proxy to select the best parameter set. A different relationship was established for each region (North Yuba River, Middle Yuba River, South Yuba River, Bear River, and Deer Creek). Among all the relationships, it was observed that Weighted Palmer Drought Severity Index (WPLM) for July of each WY has the highest correlation with the weighted recharge for all the regions. The relationships for the multiple areas are shown in Figure 2-18.

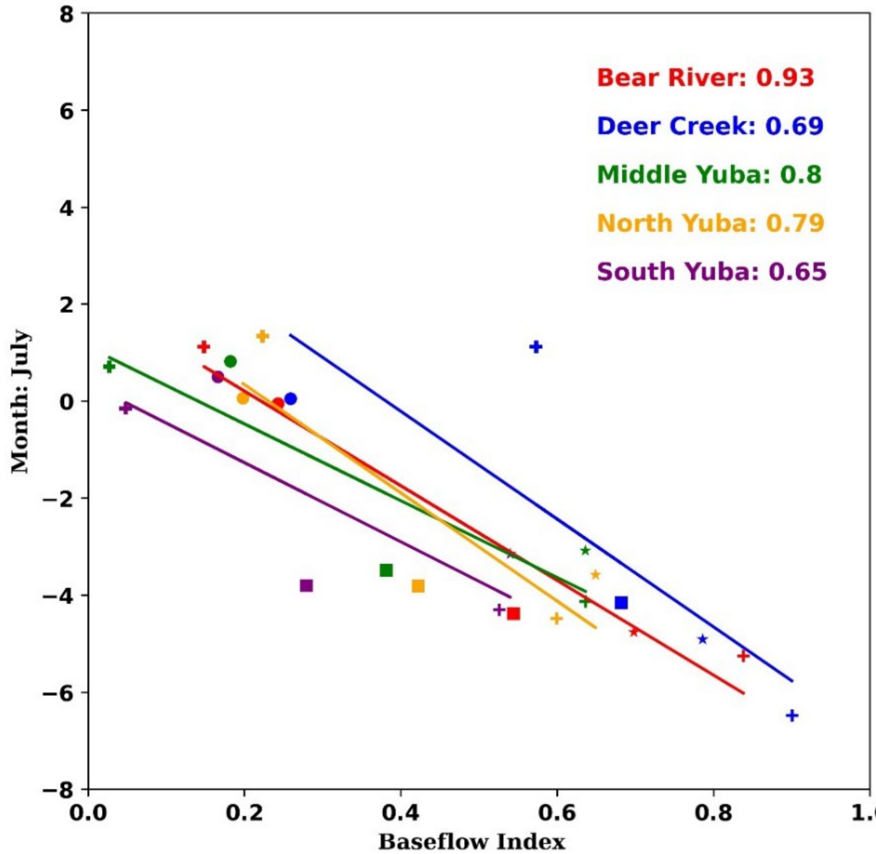


Figure 2-18. Scatter Plot of WPLM for July Versus Weighted Average Baseflow Index

The following procedure was used to define parameters for other water years for each river basin:

1. Identify the minimum monthly WPLM value within a WY.
2. Calculate the baseflow index value using the established relationship and the minimum WPLM value from Step 1.
3. Determine the closest weighted average recharge from the five calibrated parameter sets (WY1997, WY2004, WY2006, WY2015, and WY2021) to the one computed in Step 2. This identifies the calibrated parameter set suitable for that WY.
4. Adjust the GW 1 and GW 2 coefficients in the selected payment set (Step 3) to align with the weighted average recharge computed in Step 2. Other parameters remain unchanged.

The HEC-HMS model was run for the historical period using input daily precipitation and temperature data from the Livneh dataset (available from 1950 to 2018). The approach described above was used to define parameters for each water year. To evaluate the model, the cumulative simulated streamflow from 1975 to 2018 was compared with the one estimated based on the gage proration approach (HDR 2020) at various locations within the NID basin. The validation results revealed bias at six locations. Figure 2-19 presents the cumulative daily inflow (1975–2018) at Yuba at Smartsville (USGS gage 11419000) from the gage proration approach (red line) and HEC-HMS (blue line).

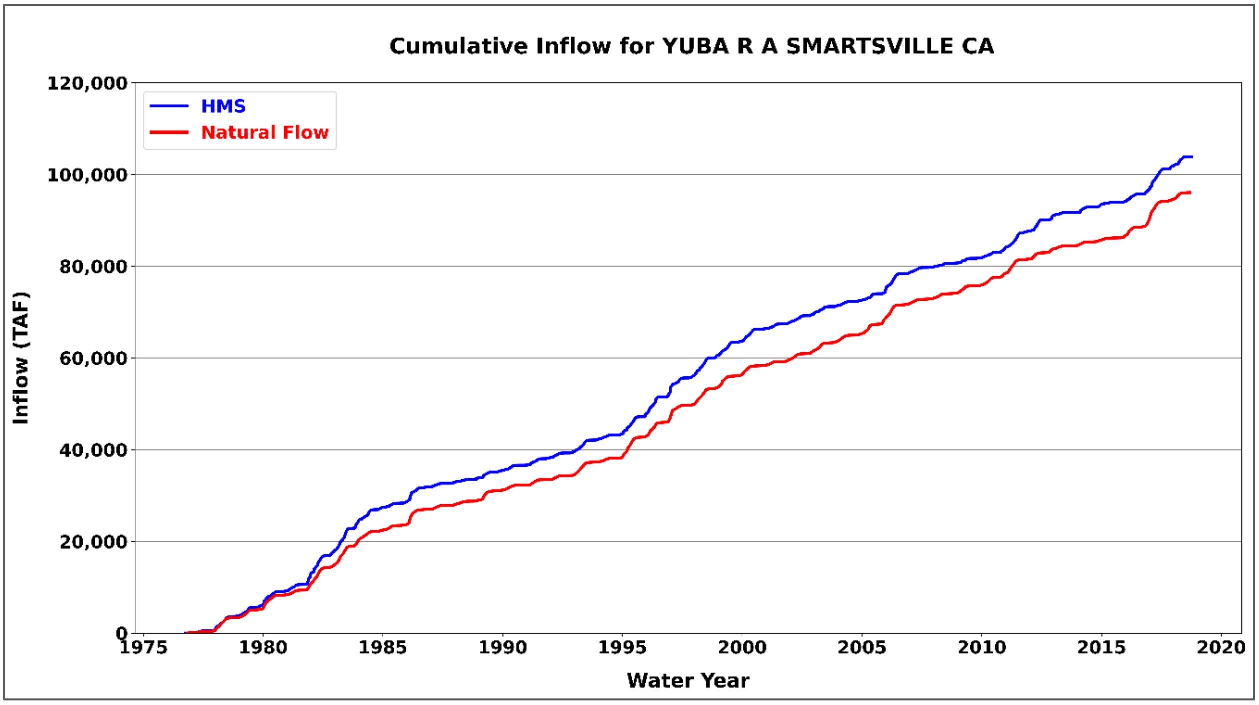


Figure 2-19. Cumulative Daily Inflow (1975–2018) for Yuba at Smartsville (USGS gage 11419000)—After Refinements

To address the bias in the model, calibration refinements were performed using gage proration flows as reference and accounting for all years between 1975 and 2018. In the refinement process, PX, base temperature, and baseflow recharge were adjusted to reduce the bias in the HEC-HMS model.

Figure 2-20 illustrates the cumulative daily inflow (1975–2018) at Yuba at Smartsville (USGS gage 11419000) using the gage proration approach (red line) and HEC-HMS (blue line) obtained after the calibration refinement procedure. Plots comparing the cumulative daily inflow using the gage proration approach and HEC-HMS for other locations are shown in Appendix A. The results for this location and others validate (the HEC-HMS model and demonstrate the mitigation of bias in the HEC-HMS model.

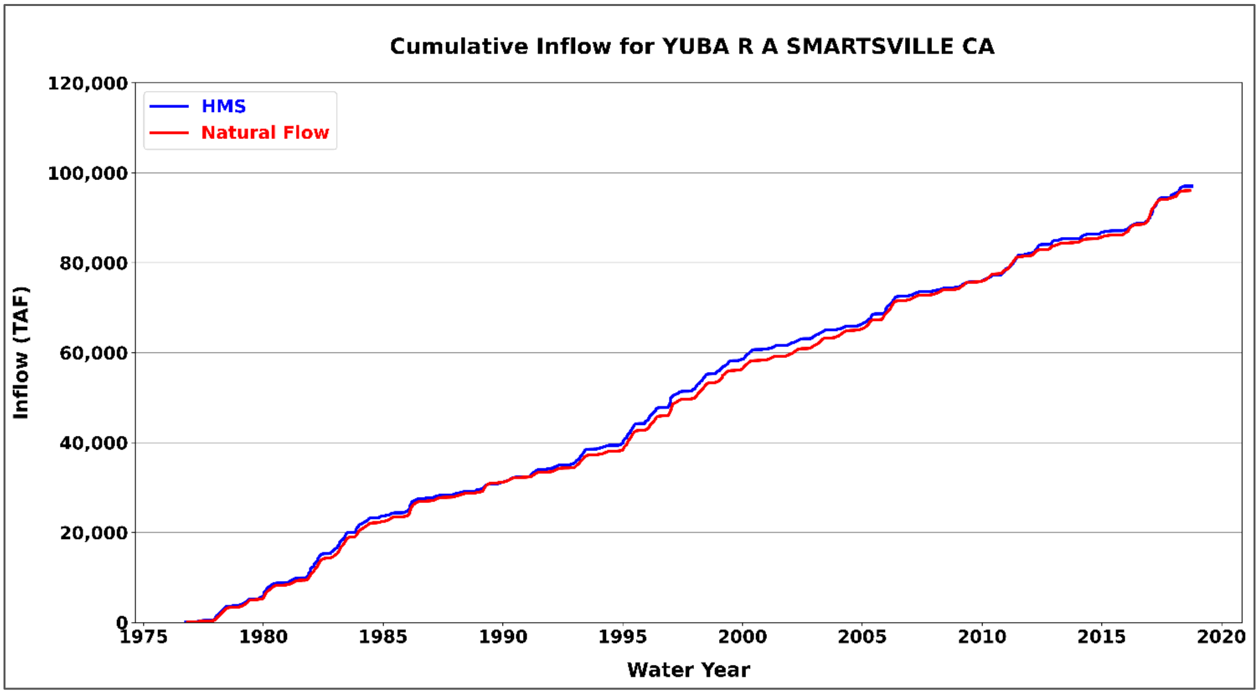


Figure 2-20. Cumulative Daily Inflow (1975–2018) for Yuba at Smartsville (USGS gage 11419000)—After Refinements

Chapter 3. Projected Hydrology

3.1. Introduction

This chapter discusses future unimpaired hydrology for the PFW. The goal of the unimpaired hydrology task is to update historical natural watershed runoff to the most recent available data as discussed in Chapter 2. This chapter discusses unimpaired hydrology anticipated under projected climate conditions. As shown in Figure 3-1, the generation of projected hydrology requires the development of three main datasets:

1. **Global Climate Model (GCM) Projections:** GCMs are mathematical representations of the Earth's climate system. GCMs are important tools for understanding the potential effects of climate variability and changes, providing climate projection data, including precipitation and temperature, at a resolution of 50–250 km for the period of 1950–2100. To understand the strengths and weaknesses of various GCMs, the Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), manages the Coupled Model Intercomparison Project (CMIP). CMIP develops standards for model runs and collects, compares, analyzes, and shares the results of multiple GCMs from around the world. Because GCMs are constantly evolving and computational resources improving, model results and CMIP's protocols, standards, and data distribution mechanism are updated frequently. To reflect this, CMIP has been organized in different numbered phases (e.g., CMIP3, CMIP5, and CMIP6), with CMIP6 being the most recent phase to release its modeling output data.
2. **Downscaled Global Climate Model Projections:** The resolution of temperature and precipitation provided by current GCMs is too course for local and regional planning studies like the PFW. Data downscaling increases the resolution of GCM data to scales more appropriate for analyzing the hydrologic response of the complex terrain of NID watersheds, the variety of water demands across the NID service area, and the details of NID's water infrastructure.
3. **Reservoir Inflow Projections:** To obtain inflow to the reservoirs, hydrological or statistical methods are applied to convert meteorological forcing into projected inflows.

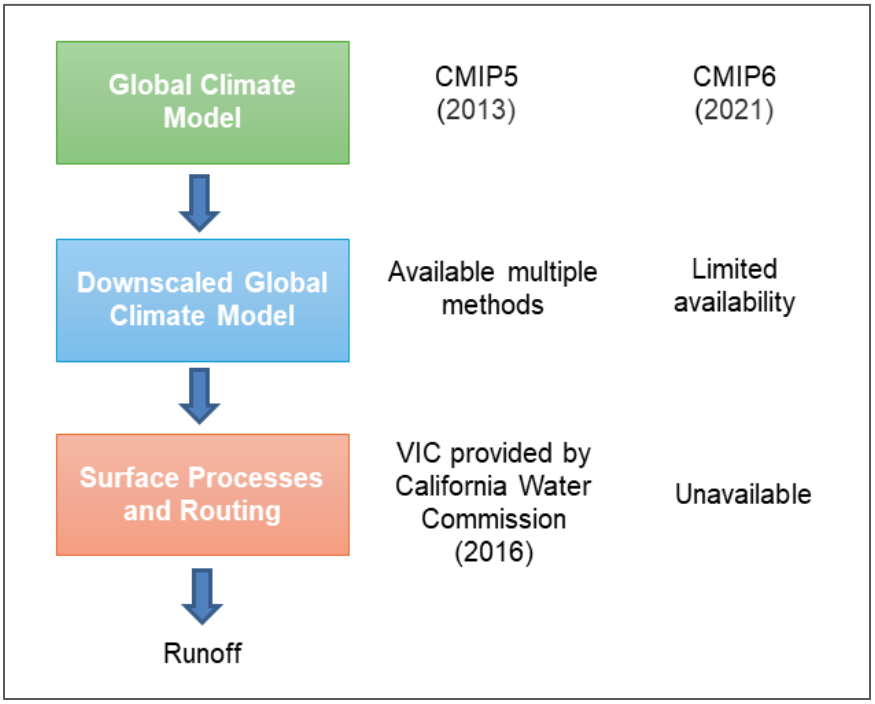


Figure 3-1. Required Datasets for the Generation of Projected Inflow and Their Current Availability for CMIP5 and CMIP6

The NID water plan developed in 2013 applied the projected hydrology the California Water Commission (CWC) developed and provided (2016). The CWC used CMIP5 and the Variable Infiltration Capacity hydrology model to generate projected inflow across multiple California regions. That information was used to generate local inflows to NID's service area. A full description of the hydrologic data and methods used to develop the 2070 projection of unimpaired hydrology are presented in the Hydrologic Analysis Technical Memorandum (HDR 2020).

3.1.1. Global Climate Model Projections

In 2021, a new, updated version of the GCM projections, CMIP6, was released (Li et al. 2021). CMIP6 continues the pattern of evolution and adaptation characteristics of previous CMIP phases, with the CMIP6 models generally having finer resolution with improved dynamical processes and emission scenarios based on the new Shared Socioeconomic Pathways (SSPs) for future climate change projections (Li et al. 2021, O'Neill et al. 2016). Therefore, CMIP6 data were selected for use in the PFW.

3.1.2. Downscaled Global Climate Model Projections

Since CMIP6 was only recently published, precipitation and temperature downscaled datasets were not widely available when the present project was being developed. Multiple groups were working to generate CMIP6 downscaled information using dynamical and statistical methods. In dynamical downscaling, the data from a GCM is used as input and boundary conditions for higher resolution Regional Climate Models. Statistical downscaling uses relationships between the large-scale climate patterns provided by GCMs and observed local climate responses. More details on these two methods are provided at this link.

A research group at the University of California, Los Angeles, is applying dynamical methods to downscale CMIP6 data. The researchers used the Weather Research and Forecasting (WRF) model to generate downscaled information for the period of 1980 through 2100 at a spatial resolution of 3 km and temporal resolution of 1 hr (Rahimi and Lei 2022). While publicly available, because the dataset was still under review, the UCLA researchers suggested not applying this dataset until the review process is complete (Rahimi 2022).

Krantz et al. (2021) is applying a combination of statistical and dynamical methods to downscale CMIP6 precipitation and temperature. The approach is new and combines physics-based simulations with an updated version of the Localized Constructed Analogs (LOCA) statistical downscaling method (Pierce et al. 2014). First, high-resolution physics-based simulations are applied to downscale a selection of GCMs. The simulations are then used to train a new version of LOCA based on statistics of the future climate. Finally, the method is applied to downscale a broader set of GCMs. The downscaled meteorological variables are publicly available and used in the PFW analysis to provide temperature and precipitation time series data at each location in the NID basin grid for 50 years of projected climate.

3.1.3. Reservoir Inflow Projections

The last step includes the application of downscaled temperature and precipitation to estimate runoff and inflow to the reservoirs.

Two types of approaches are commonly used to convert projected temperature and precipitation into inflows: 1) statistical methods (Freni et al. 2009, Xing et al. 2018, Yang and Yang 2011), and 2) hydrological models (Chiew et al. 2018, Islam et al. 2014, Shi et al. 2022). Statistical models are not recommended since they predict the future based on what has happened in the past. However, with climate change, that relationship might not be valid. Moreover, these types of models are usually inaccurate in predicting rare extreme dry or wet events. Hydrological models are preferable since they simulate the important physical processes affecting the rainfall-runoff conversion, including snow accumulation, snow melt, evapotranspiration, and soil dynamics including infiltration (Fowler et al. 2018, Li et al. 2022, Pechlivanidis et al. 2016, Shi et al. 2022). Recent studies (Li et al. 2022, Mahato et al. 2022, Moothedan et al. 2022) show that the HEC- HMS model can accurately simulate the range of inflow scenarios desired for the PFW. Therefore, the HEC-HMS model was selected for the PFW studies.

To obtain the projected inflows to the NID areas of interest, the downscaled precipitation and temperature data were used as inputs to the HEC-HMS hydrological model described in Chapter 2.

3.2. Climate Scenario Selection

To determine which GCMs perform better for the State of California climate, Krantz et al. (2021) evaluated the performance of CMIP5 and CMIP6 models. The results of the analysis are presented in Figure 3-2, reproduced from Krantz et al. (2021). The GCMs that perform best in California are shown in the green box. Additional well performing models are in the blue box. Seven downscaled climate models listed in Table 3-1 were chosen for the analysis from the red box in Figure 3-2.

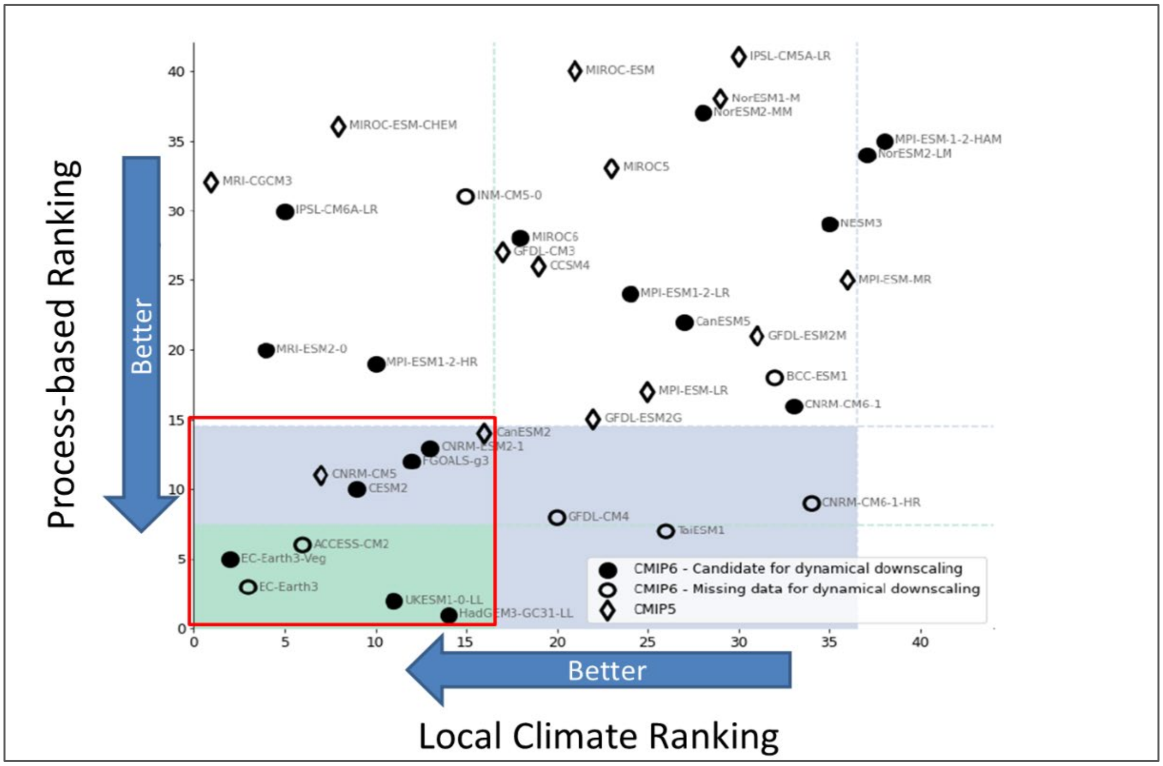


Figure 3-2. Comparison of the GCM Rankings by Local Climate Metric Performance and Process-Based Metric Performance (Source: Krantz et al. 2021).

GCMs use emission scenarios as input data to estimate the amount of CO_2 and other greenhouse gases launched to the atmosphere. Each GCM can use multiple emission scenarios to explore a range of potential future climate outcomes and their associated uncertainties. These scenarios, known as SSPs, outline various trajectories of energy production, land use, and greenhouse gas emissions implications. The SSPs are part of a new scenario framework established by the climate change research community to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The SSPs do not predict the future, but rather provide a range of plausible scenarios that help researchers and policymakers explore the potential consequences of different pathways of human development. In this project, three SSPs were selected to represent endpoints and median scenarios for the analysis:

1. SSP245 (optimistic scenario): This scenario portrays a future characterized by relatively rapid and effective mitigation of environmental and societal challenges. This scenario envisions proactive efforts to address issues such as climate change, resource management, and social equity. Technological innovation, international cooperation, and sustainable development practices feature prominently in this optimistic narrative. Economic growth is balanced with environmental stewardship, leading to a world where human wellbeing is prioritized alongside ecological preservation.
2. SSP370 (median scenario expected to be exceeded): This scenario represents a middle-of-the-road projection in terms of societal and environmental trends. It anticipates moderate efforts to address global challenges, with progress occurring at a pace that may not be sufficient to prevent significant disruptions. While some measures are taken to address issues like climate change and

social inequality, they may fall short of what is necessary to avoid more severe consequences. This scenario reflects a world grappling with both opportunities and challenges, where progress is made but not at a pace that ensures long-term sustainability or resilience.

3. SSP585 (pessimistic scenario): This scenario presents a future marked by escalating environmental degradation, societal conflict, and economic inequality. In this pessimistic narrative, efforts to mitigate climate change and other global challenges are limited or ineffective. Technological progress may exacerbate rather than alleviate societal divisions and environmental pressures. Resource depletion, extreme weather events, and geopolitical tensions are prominent features of this scenario. It paints a picture of a world facing significant crises, with profound implications for human wellbeing, biodiversity, and the stability of global systems.

Table 3-1 shows the 7 selected downscaled GCMs with 3 emission scenarios (SSP245, SSP370, and SSP585) that were selected for this project. Out of the 21 climate scenarios (7 GCMs for each of 3 emissions scenarios), 18 scenarios with available downscaled temperature and precipitation (indicated with "√" in Table 3-1) were used for NID projected hydrology simulations.

Table 3-1. Climate Change Scenarios for HEC-HMS Simulations

GCMs	Emissions		
	SSP245	SSP370	SSP585
ACCESS-CM2	√	√	√
EC-Earth3	√	√	√
EC-Earth3-Veg	√	√	√
CNRM-ESM2-1	√	√	√
FGOALS-g3	√	√	√
HadGEM3-GC31-LL	√	-	√
CESM2-LENS	-	√	-

3.3. Historical Hydrology

Historical hydrology analysis was employed to assess the bias in both the calibrated NID HEC-HMS model (discussed in Chapter 2) and the selected climate models. Model bias refers to the presence of systematic errors in a model resulting in consistent deviations from observed or expected values, leading to inaccurate predictions. It indicates a tendency for the model to consistently overestimate or underestimate certain aspects of the system it is simulating. These errors can arise from many sources, among them, inaccuracies or limitations in the input datasets used for model calibration, the assumptions underlying the model's construction, and the algorithms employed in the modeling process. Climate models can also exhibit some systematic biases due to the limited spatial resolution, simplified physics and thermodynamic processes, numerical schemes, or incomplete knowledge of climate system processes.

To evaluate the bias in the calibrated NID' HEC-HMS model, a comparison was conducted for the average annual local inflow in the NID basin. This assessment focused on the historical period from 1976 to 2021 and involved three independent methods:

1. **Gage Proration:** The local inflows from the gage proration method from the unimpaired hydrology study by HDR (2020).
2. **Water Balance:** The average annual local inflow for the NID basin was estimated from the equation:

   Annual runoff = Streamflow at the basin outlet + Losses + Diversions

   Streamflow at the basin outlet = Sum (USGS gages at outlet)

Where:

USGS streamflow gages downstream at 11418000, 11424000, 11418500, and 11408880 were summed, and the streamflow at location 11413510 was subsequently subtracted.

The estimated annual losses and diversions (Western Hydrologics 2023):

- Evaporation: ~23,300 AF/year
- Diversions to the Bear River Canal: ~132,300 AF/year
- Diversions out of Lake Combie: ~62,000 AF/year
- Diversions: diversions off Deer Creek: ~53,000 AF/year

3. **HEC-HMS:** The calibrated NID HEC-HMS model using the Livneh precipitation and temperature data as input for simulating local inflows within the NID basin.

Figure 3-3 displays the average annual local inflows estimated from the three methods for the historical period (1976–2021), with the y-axis representing the average annual inflow in thousand acre-feet (TAF). Figure 3-3 shows that the three independent methods applied to estimate average annual inflow to the area of interest present very similar results, increasing confidence that the estimates are accurate (negligible bias). The annual average from the HEC-HMS model (1,547 TAF) closely aligns with the estimates from the gage proration method (1,509 TAF) and the water balance method (1,444 TAF).

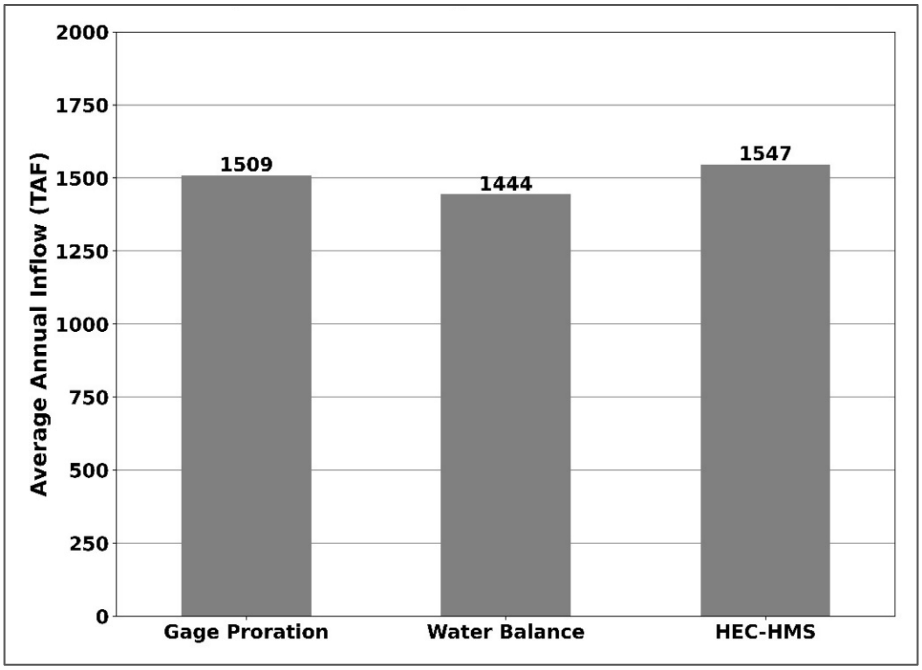


Figure 3-3. Comparison of Average Annual Inflow (1976–2021) for NID Basin

To assess bias in the climate models, the downscaled precipitation and temperature data from the selected climate models and scenarios (refer to Table 3-1) were used as inputs to the calibrated NID HEC-HMS model. This was done to generate local inflow simulations for the entire NID basin during the historical period 1976–2021.

Figure 3-4 visually presents a comparison between the average annual inflow for the NID basin from 1976–2021, as obtained from the HEC-HMS model using the climate model data as input. The average historical inflows derived from the gage proration method (indicated by the green dashed line) is used for validation. This graph contrasts the model's performance against historical inflow estimates, providing insights into any potential biases in the climate models. The x-axis of Figure 3-4 corresponds to a specific combination of a climate model and its associated emission scenario. For instance, the label "HadGEM3-GC31-LL_ssp585" signifies the HadGEM3-GC31-LL climate model paired with the SSP585 emission scenario. Some spread in the results is expected due to natural variability in climate, since the historical simulations represent just one realization of what could have happened in the past, and not exactly the observed historical climate for that period. Since the average annual inflow obtained from the climate models closely aligns with the average historical inflow, it indicates that the climate models are not biased, and are providing simulations that, on average, and considering the whole area of interest, are consistent with the historical data over the historical period.

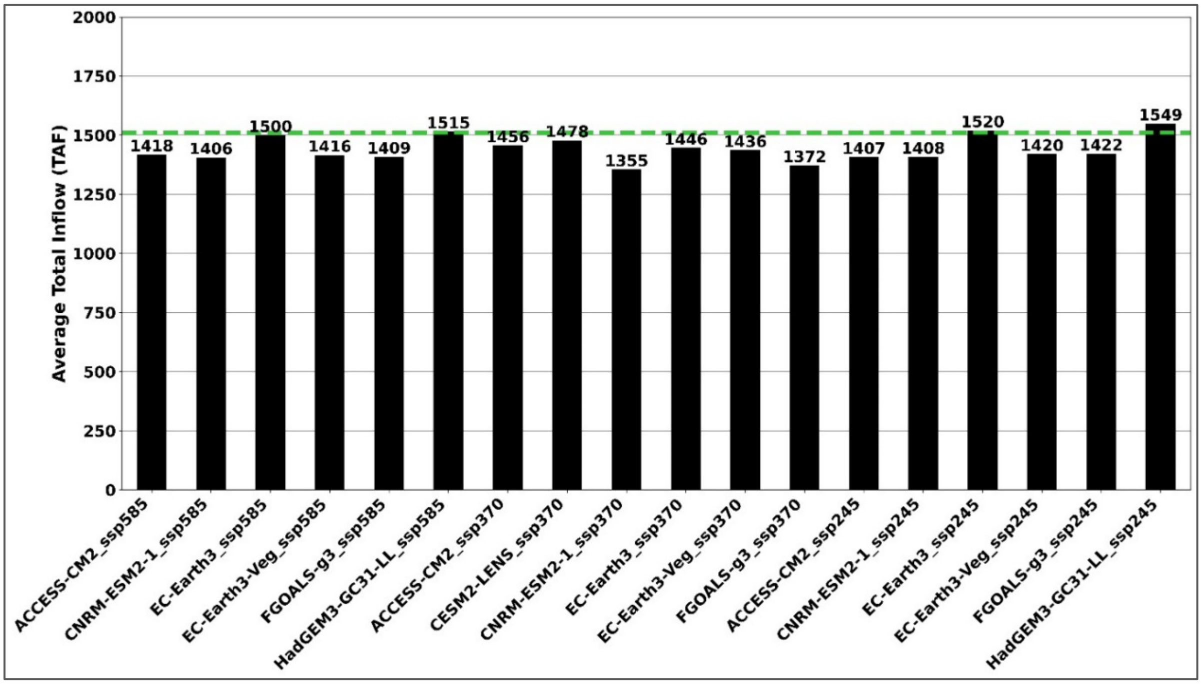


Figure 3-4. Comparison of Average Annual Inflow (1976–2021) for NID Basin

3.4. Projected Hydrology

The downscaled precipitation and temperature dataset from the selected climate models and scenarios (refer to Table 3-1) were used as inputs in the calibrated NID HEC-HMS model to obtain the local inflows for the entire NID basin for the projected period (2022–2071).

Figure 3-5 to Figure 3-7 illustrate the 50-year average total inflow for durations of 1, 5, and 10 years, while Figure 3-8 and Figure 3-9 depict the median of annual total inflow for the same durations using the 18 climate model scenarios. Based on the analysis, three representative hydrology scenarios were selected, and they are outlined as follows:

High Bookend (Wet) Scenario: This scenario implies conditions characterized by higher-than-average precipitation, increased temperature, and/or more frequent and intense rainfall events. The climate model EC-Earth3-Veg_ssp370 has been selected to represent the high bookend (wet) scenario. In this climate scenario, the 50-year average total inflow is highest for all durations along with the highest median annual inflow for 5- and 10-year durations. In Figure 3-5 through Figure 3-10, this scenario is visually presented by the blue bars, indicating a wet 50-year runoff pattern.

Median Scenario: This scenario typically reflects moderate changes or trends, neither excessively optimistic nor pessimistic. The climate model CNRM-ESM2-1_ssp245 has been chosen to represent the median scenario. In Figure 3-5 through Figure 3-10, this scenario is depicted by the green bar , indicating a median 50-year runoff pattern.

Low Bookend (Dry) Scenario: This scenario implies conditions characterized by lower-than-average precipitation, decreased humidity, and/or more prolonged periods of drought. The climate model CESM2-

LENS_ssp370 scenario has been chosen as the representative for low bookend (dry) scenario. In this climate scenario, the 50-year average total inflow is lowest for all durations. accompanied by a consistently low median annual inflow for all durations. This scenario is represented as the red bar in Figure 3-5 through Figure 3-10, indicating a dry 50-year runoff pattern.

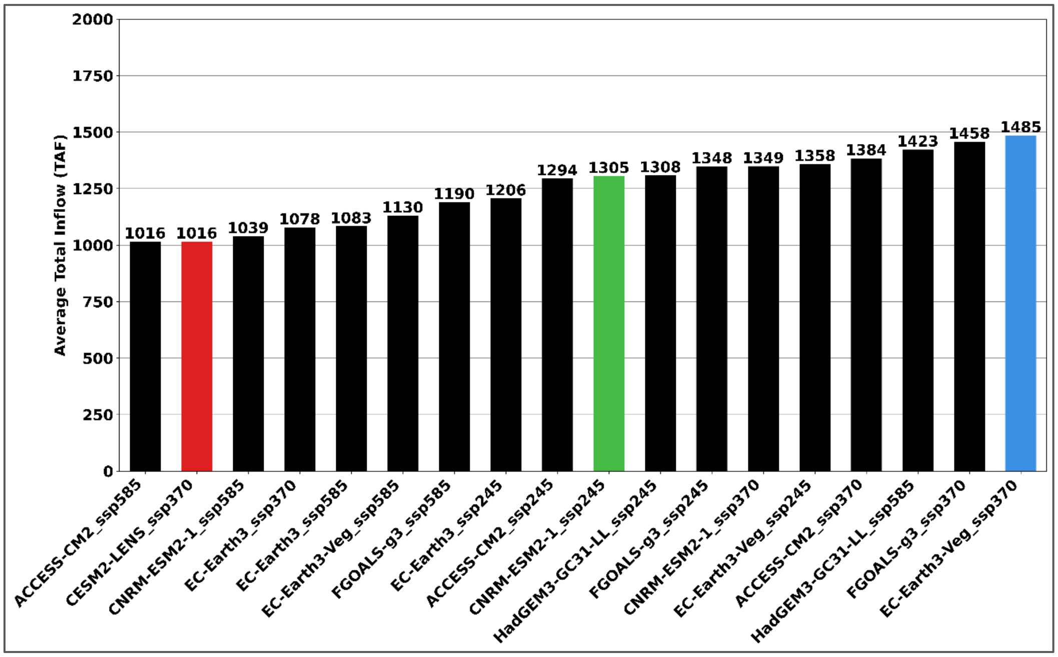


Figure 3-5. 50-Year Average Total Inflow for 1-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

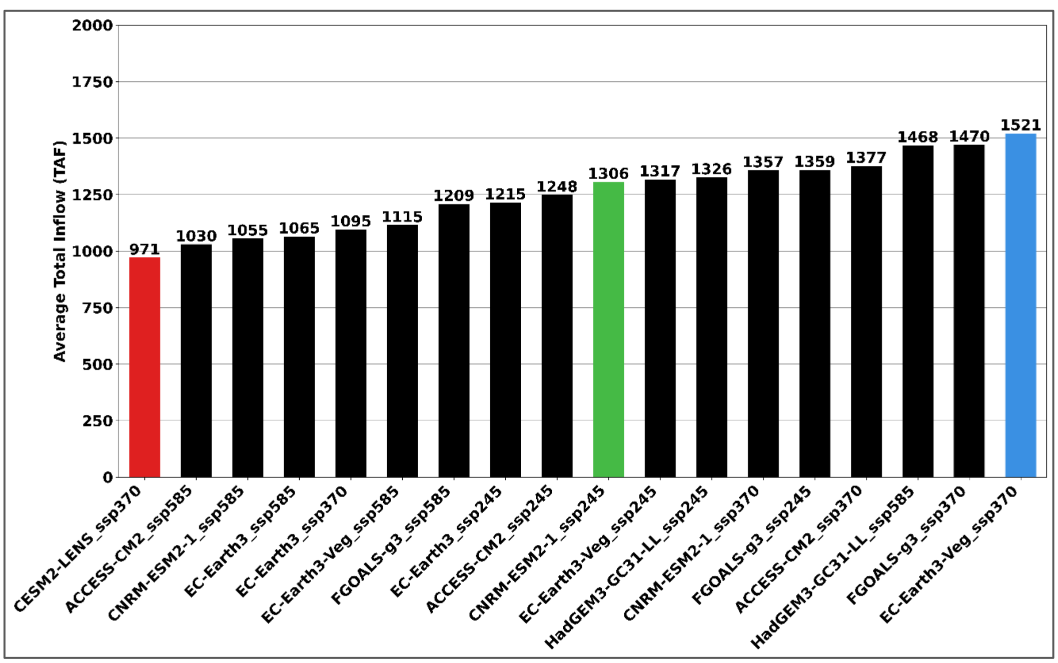


Figure 3-6. 50-Year Average Total Inflow for 5-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

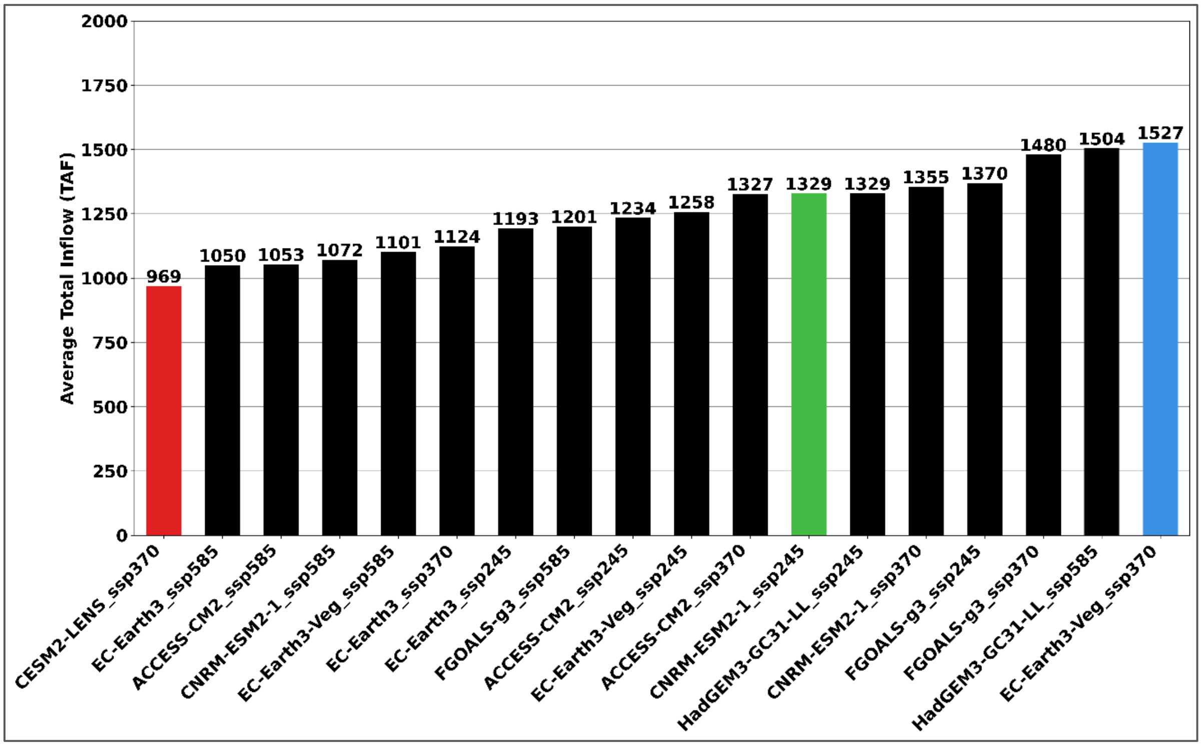


Figure 3-7. 50-Year Average Total Inflow for 10-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

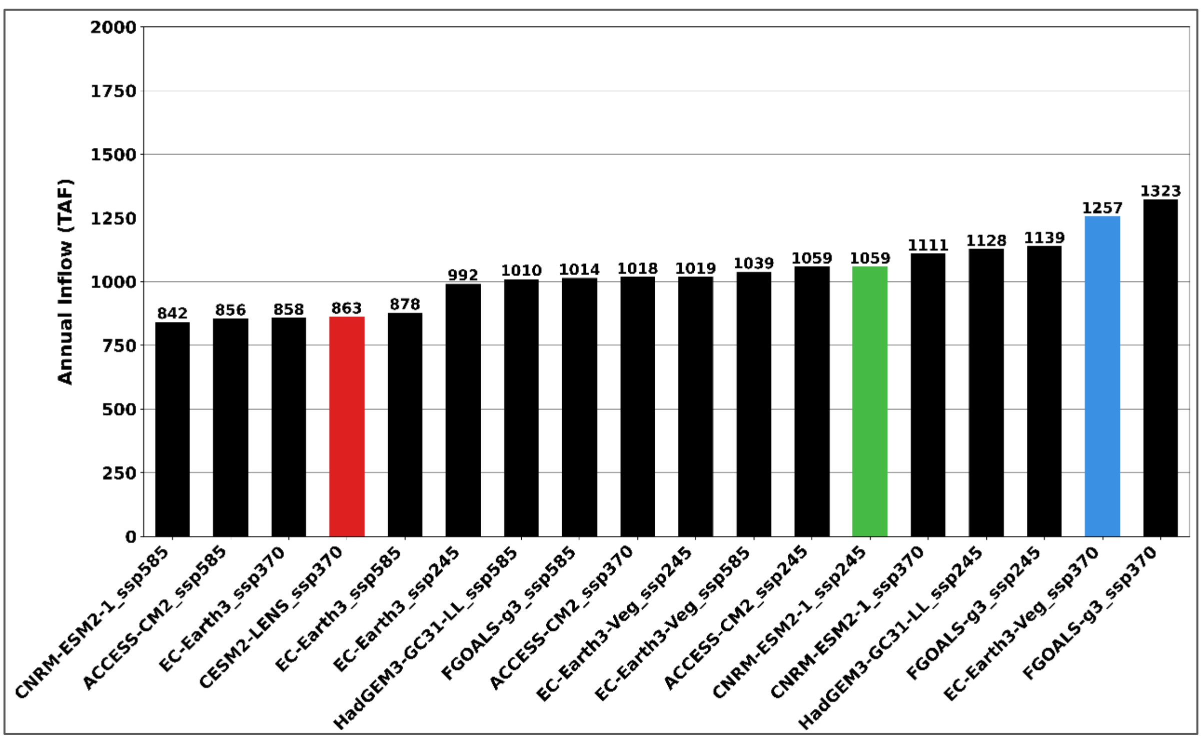


Figure 3-8. Median Annual Inflow for 1-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

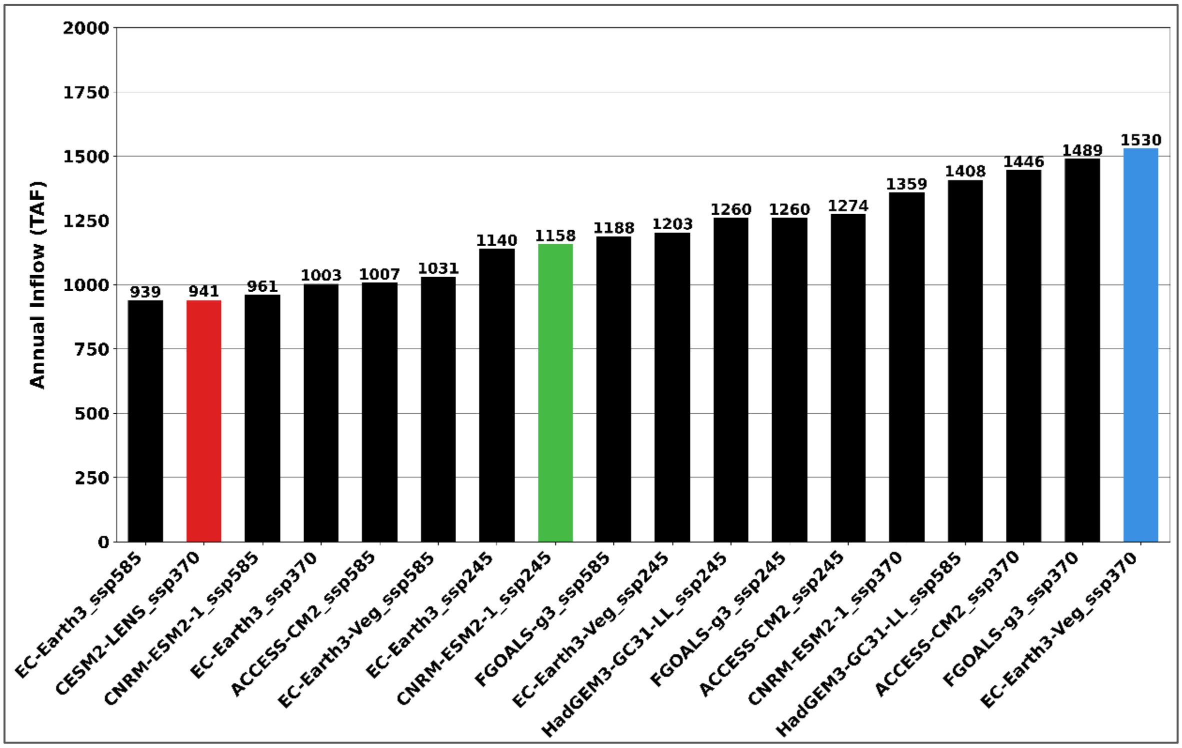


Figure 3-9. Median Annual Inflow for 5-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

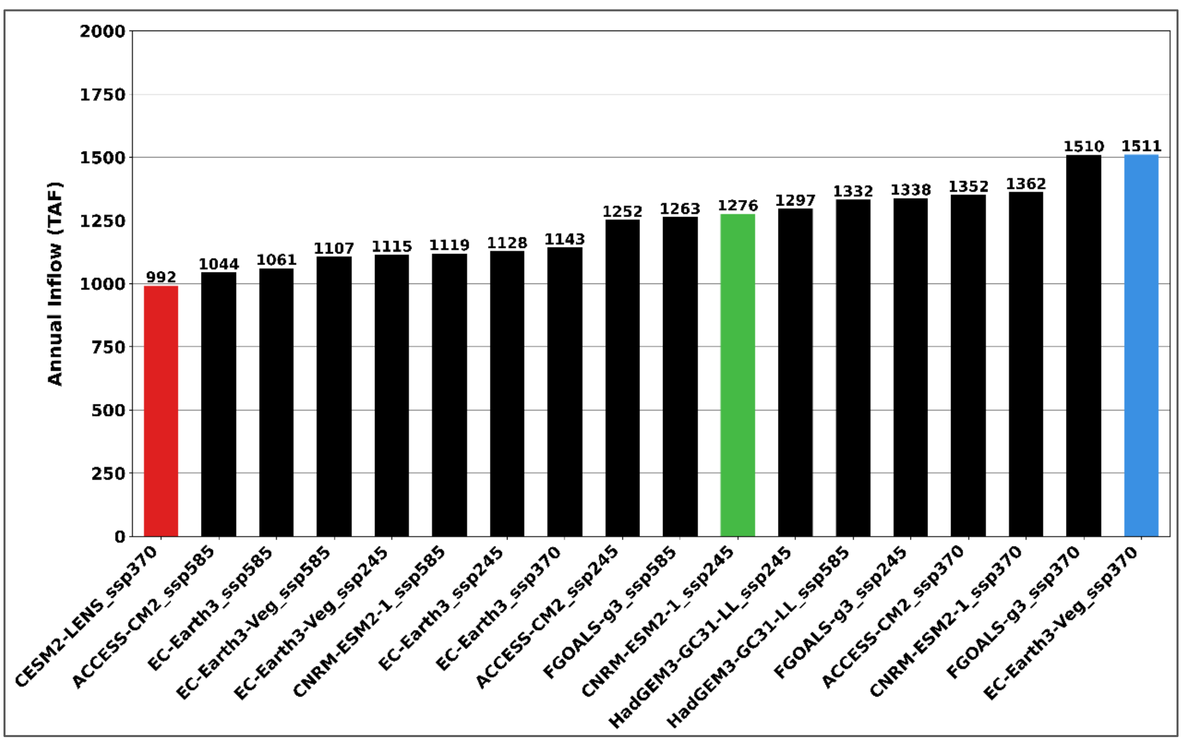


Figure 3-10. Median Annual Inflow for 10-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

3.5. Representative Scenarios

Table 3-2 provides a summary of the three representative hydrologic scenarios. These scenarios encompass two extremes, serving as bookends, and a moderate, middle-of-the-road hydrologic scenario. The range of outcomes covered by these three scenarios reflects both low and high inflow possibilities. It is important to note that while the scenarios may not follow a normal distribution statistically, they are treated as having equal probabilities for analytical purposes. Actual future conditions inflow patterns are expected to be between the low and the high bookends, without preference for any scenario.

Table 3-2. Climate Change Scenarios for HEC-HMS Simulations

Scenarios	Models and Emissions
High Bookend (Wet)	EC-Earth3-Veg_ssp370
Median	CNRM-ESM2 1_ssp245
Low Bookend (Dry)	CESM2-LENS_ssp370

The total annual inflow simulated record from 2022–2071 for the entire NID basin for the three representative scenarios is illustrated in Figure 3-11. The wet bookend (blue line) has the greatest number of high inflow events, but also has occurrences of drought conditions. The dry bookend (red line) has the greatest number of drought conditions, but also has few occurrences of high inflow events. The median scenario (green line) has some high inflow events and some drought events, but not as significant as the bookends.

Figure 3-12 presents the 50 years (2022–2071) cumulative total annual inflow for the entire NID basin for the three representative scenarios. This graph demonstrates that over the 50-year projection of inflows, the cumulative values lie in the proper order. The wet has the highest cumulative total inflow for the 50-year projection, the dry has the lowest, and the median is in the middle. The black dashed line takes the average annual inflow value of 1,509 TAF from the historical dataset of 1976–2021 and creates a cumulative trend line using this average value. This line was included only for comparison. One takeaway is that the wet bookend has a very similar total inflow to historical values over the projected period.

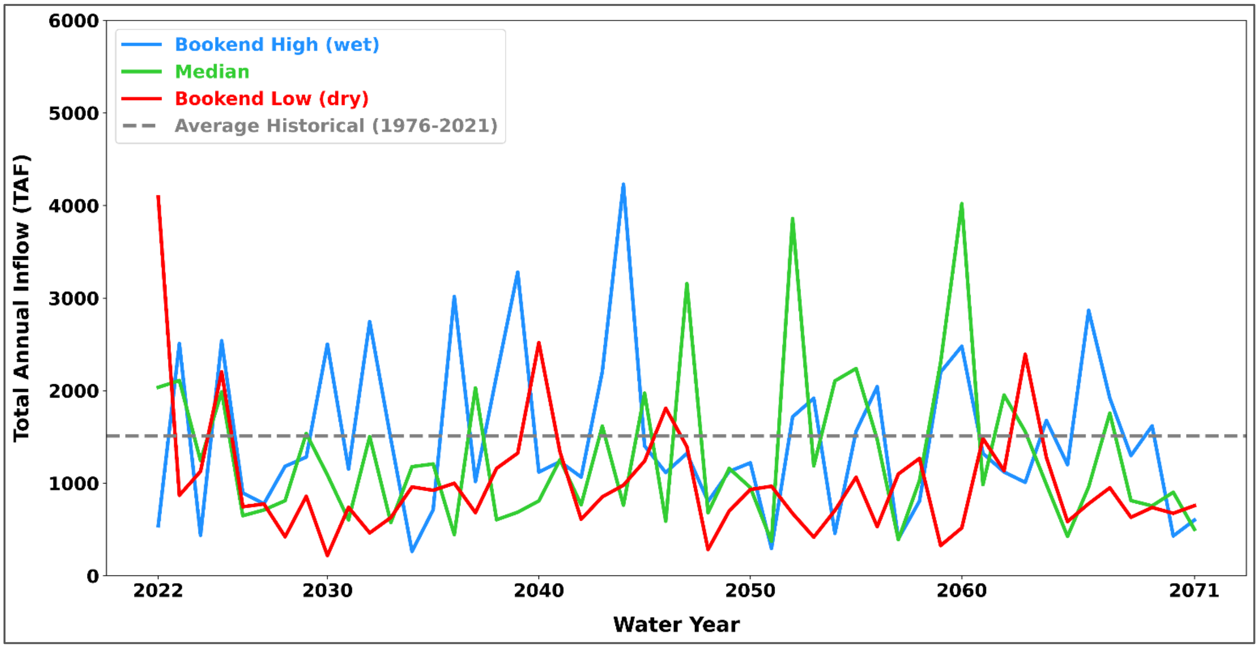


Figure 3-11. Total Annual Inflow Time Series for NID Basin, 2022–2071

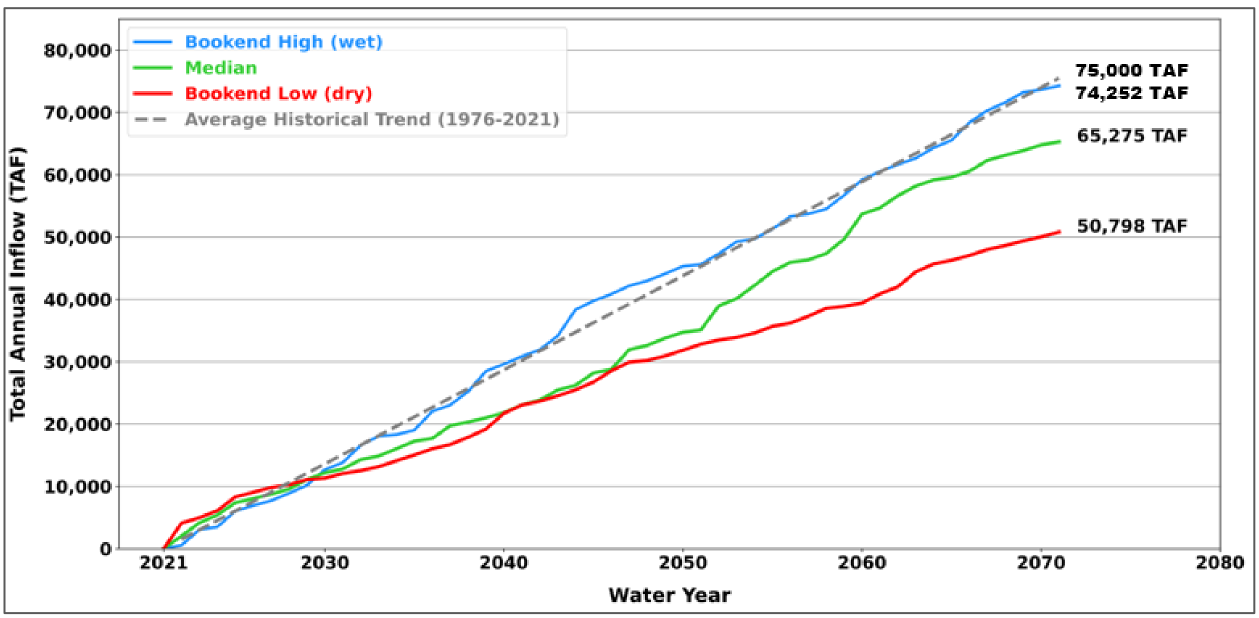


Figure 3-12. 50-Years Cumulative Total Annual Inflow for NID Basin

Chapter 4. Demand Model

4.1. Introduction

This section discusses the development and application of the demand model used to support the NID PFW process. In the context of the NID PFW process, demand generally refers to the total volume of water required to meet water users' needs. This includes water used by raw water customers, treated water customers, and municipal water suppliers that receive water from NID (collectively referred to as NID's customers), together with the system losses that occur delivering water to NID's customers and the regulatory-required environmental flows that NID provides.

The demand model discussed in this section was developed to estimate the demand, or outflows, from NID's reservoirs, required under various scenarios to supply the water needs of NID's customers, inclusive of system losses in NID's canals and distribution system downstream of NID's reservoirs. Regulatory-required environmental flows are included in the reservoir operations model discussed in Chapter 5.

The purpose of this demand model is to provide a means of estimating the demand of NID's customers under different potential projected (i.e., future) scenarios by physically simulating the processes that drive water use on the landscape under the effects of those scenarios. The demand model was thus developed to leverage available local data, standard technical approaches, and best practices to account for the relative effects of estimated future changes in climate, land use, irrigation practices, soil properties, and other factors that impact demand. Results of the demand model were then used to estimate the outflows required from NID's reservoirs to meet those demands, facilitating analyses of water supply versus demand and conditions of unmet demand under potential projected scenarios.

The subsections that follow describe in greater detail the structure and development of the demand model, the projected demand scenarios evaluated in the demand model, and the results of those scenarios.

4.2. Demand Model Development

4.2.1. Background and Major Drivers of Water Demand

Generally, the demand model was developed to create water budgets for the areas within NID where NID's customers receive and use water (e.g., parcels associated with raw and treated water customers). A water budget is a method of accounting for the water that flows into and out of, or is stored within, an area of interest (Healy et al. 2007). A water budget can be calculated for virtually any area of any size, ranging from local (e.g., particular parcels or canal reaches) to regional (e.g., NID service area or canal system) to global. Both the driving forces of water use and uncertainty around water use impact the estimates of water demand at each scale and influence the assumptions and decisions that are made for developing the water budget. The United Nations and other organizations recognize many important environmental, social, economic, and political factors that impact water demand at all scales, including land use change, population change, global climate change, and other technological and economic factors (United Nations 2018, Wada et al. 2016). While the net effects of each individual factor are difficult to quantify and carry significant uncertainty, the importance of considering these factors within the context of local and regional water planning is clear.

4.2.1.1 Major Drivers of Agricultural Water Demand

The majority of NID's raw water customers receive water deliveries from NID to support irrigation of agricultural lands. In general, agricultural water demand includes all water used to irrigate crops or otherwise meet agricultural production-related needs. Agricultural water demand can be divided into consumptive use and non-consumptive use:

- **Consumptive Use:** "That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment" (ASCE-EWRI 2016). The vast majority of consumptive use occurs through evapotranspiration (ET) from plants and water surfaces. Consumptive use is often used interchangeably with ET (Allen et al. 1998).
- **Non-consumptive Use:** "That part of water withdrawn that is not evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment" (ASCE-EWRI 2016). Non-consumptive use encompasses other water uses that do not result in water being removed from the local environment, such as spillage, tailwater, and deep percolation of water into the groundwater system.

At the local level, cropping, soil management practices, land management practices, and irrigation practices all significantly impact both the consumptive and non-consumptive components of agricultural water demand and can also significantly affect water availability in surrounding landscapes (FAO 2011).

Consumptive use (primarily ET) is a major focus of long-term water management planning and irrigation demand projections. In total, projected ET is expected to be significantly impacted by future changes in land use and climate, the major parameters evaluated by the U.S. Bureau of Reclamation (USBR) when developing the irrigation demand projections as part of the "West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections" (USBR 2015). Shifting land use toward or away from higher-demand crops and land uses will likewise shift agricultural water demand (Allen et al. 1998). Increasing temperatures in the future are also expected to increase ET demand across all land uses (USBR 2015). While non-consumptive use also impacts agricultural demand, there are opportunities for improving water use efficiency to reduce or strategically leverage those demands, for example through conservation, reuse, or conjunctive management efforts.

4.2.1.2 Major Drivers of Urban Water Demand

In addition to raw water customers, NID also supplies water to a substantial number of treated water customers and municipal water suppliers to support what may be referred to as urban water demand. In the context of water budget development for demand modeling, urban water demand typically includes water demand from municipal water suppliers, public water systems, and urban, commercial, industrial, or residential water users who either supply or directly use water to meet demands in urban or residential settings. Urban water demand can include water use for indoor uses (drinking, sanitation, etc.) and certain outdoor uses (household landscape irrigation, etc.). Like agricultural water demand, urban water demand can also be divided into consumptive use and non-consumptive use by the same definitions given above (ASCE-EWRI 2016).

Projected urban water demand is expected to be impacted by pressures associated with future changes in land use, climate, and population (USBR 2021). Pressures associated with land use change and climate change are similar to those anticipated for agricultural land use change (described above). In NID, pressures associated with population change are expected to include changes in the total population and changes in per capita water use of NID's treated water customer base and municipal suppliers served by NID. Because the net effect of these changes over the next 50 years is unknowable, a variety of potential projected demand scenarios were developed to evaluate possible future outcomes. However, it is worth noting that a retrospective analysis of total and per capita water use among multiple water suppliers in California between 2000–2015 found that shifts toward increased efficiency (i.e., lower per capita water use) were enough to offset increases in population and decrease the total urban water demand over the same period (Abraham et al. 2000).

4.2.2. Overview of the NID Demand Model Structure and Inputs

As described above, demand in the NID PFW process generally refers to the total volume of water required to meet water users' needs, including water used by NID's customers, the system losses that occur delivering water to customers, and the regulatory-required environmental flows that NID provides.

The demand model developed to support the NID PFW process was used to estimate the components of demand that are directly related to NID's operations to distribute water to NID's customers, including:

- Raw water demand
- Treated water demand
- Municipal water demand
- System losses (in NID's canals and distribution system downstream of NID's reservoirs)

Regulatory-required environmental flows are included in the reservoir operations model discussed in Chapter 5. An overview of the simulation approach for each demand component is shown in Table 4-1.

The demand model was developed to estimate these demands through two integrated model components:

- **Integrated Water Flow Model Demand Calculator (IDC) model**: The IDC model was used to estimate the raw water demand and treated water demand of NID's customers based on information about land use, irrigation practices, soil properties, population, per capita water use, and other factors that impact the water use of NID's customers. Results of the IDC model were linked to parcels within the NID service area to identify the location(s) in NID where demand occurs for raw water and treated water customers and to quantify the volume of demand in those locations (Table 4-1). The IDC model is discussed in detail later in this subsection.
- **Canal system balance model**: The canal system balance model was developed to link the results of the IDC model (by parcel) and the municipal water demand estimates to the conveyance system and canals that NID uses to distribute water to those customers. The canal system balance was then used to estimate the system losses and the inflows to those canal systems from NID's reservoirs that would occur to supply those demands (Table 4-1). The canal system balance model is also discussed in detail later in this subsection.

Table 4-1. Overview of Demand Component Simulation Approach

Demand Component	Model Component Where Demand is Simulated	Associated Section(s) Describing Model Component
Raw water demand	IDC model	Section 4.2.3
Treated water demand	IDC model	Section 4.2.3
Municipal water demand	Quantified outside IDC model, included in canal system balance model	Section 4.2.3
System losses	Canal system balance model	Section 4.2.4
Environmental flows	Reservoir operations model	Chapter 5
Total demand to supply the water needs of NID's customers. (excluding environmental flows)	Demand model	Chapter 5
Total demand (including environmental flows)	Reservoir operations model	Chapter 5

Various data sources and inputs were considered and incorporated into the demand model development, including (but not limited to) the following general information:

- GIS parcel information
- Land use
- Zoning
- Historical water delivery data
- Treatment plant data
- Canal flows
- Cropping and agricultural development
- Typical agricultural practices relating to water use and management
- Soil parameters
- Precipitation data
- Evaporative demand
- Population
- NID's service area, including existing customers
- Changes to NID's service area (e.g., soft service areas, "fill in" areas)
- Population changes stemming from COVID-19 and other factors

The data and assumptions used to develop the demand model and its inputs were documented and discussed through a stakeholder engagement process, leveraging information gained from available local data, technical standards, best practices, and outreach to local agencies, as needed. A comprehensive summary of the data sources, inputs, and assumptions used to develop the demand model is provided in Appendix B.1.

The key data sources, inputs, and methods used to develop the IDC model and the canal system balance are described in the sections below.

4.2.3. IDC Model

The Integrated Water Flow Model Demand Calculator (IDC) model is a modeling tool developed, maintained, and supported by the California Department of Water Resources (DWR). As a tool, IDC is used for applications in estimating demand through simulation of the physical processes that occur on the land surface that drive demand. IDC is the demand-modeling module of DWR's broader Integrated Water Flow Model (IWFM), an integrated surface water-groundwater modeling platform that has been broadly used to support long-term strategic water planning in numerous Groundwater Sustainability Plans (GSPs), Agricultural Water Management Plans (AWMPs), and other long-term, often multi-decade planning documents developed by water managers throughout California. The IDC model used in the NID PFW process was built using DWR's IDC Version 2015.0.0140, the latest available as of early 2023 (DWR 2022a).

The IDC model uses data and information about climate, land use, soil properties, agricultural and irrigation practices, and urban and residential parameters to physically simulate inflows and outflows of water through the landscape over time (Figure 4-1). IDC estimates the amount of water required to meet the demands of water users under different conditions, whether for agricultural, urban, or residential use. The IDC model structure is designed to simulate these inflows and outflows through finite elements, or grids of simple three- or four-sided polygons. Functionally, IDC models (and IWFM models) are typically developed and operated with a relatively coarse grid, in which each element represents tens to hundreds of acres.

The IDC model used in the NID PFW process was developed as a unitized model (as compared to a spatial model) to simulate conditions for unique and representative combinations of land use, soil characteristics, and climate zones that are found throughout the NID service area within each finite element. In the unitized model structure, demand is simulated for each combination (i.e., each element) and represented on a unit basis (e.g., feet of water required per unit area, or AF/acre). Those unitized results are then linked directly to individual parcels matching one of the simulated land use/soil/climate combinations, permitting parcel-level spatial quantification of demand volumes outside the coarse grid and spatial constraints of a typical spatial IDC model (Figure 4-2).

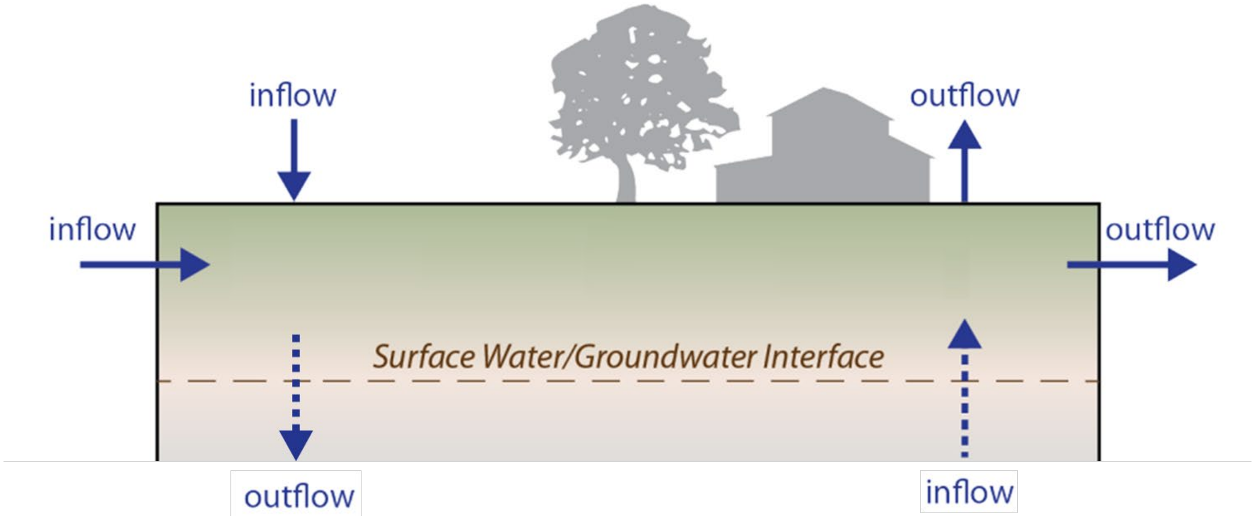
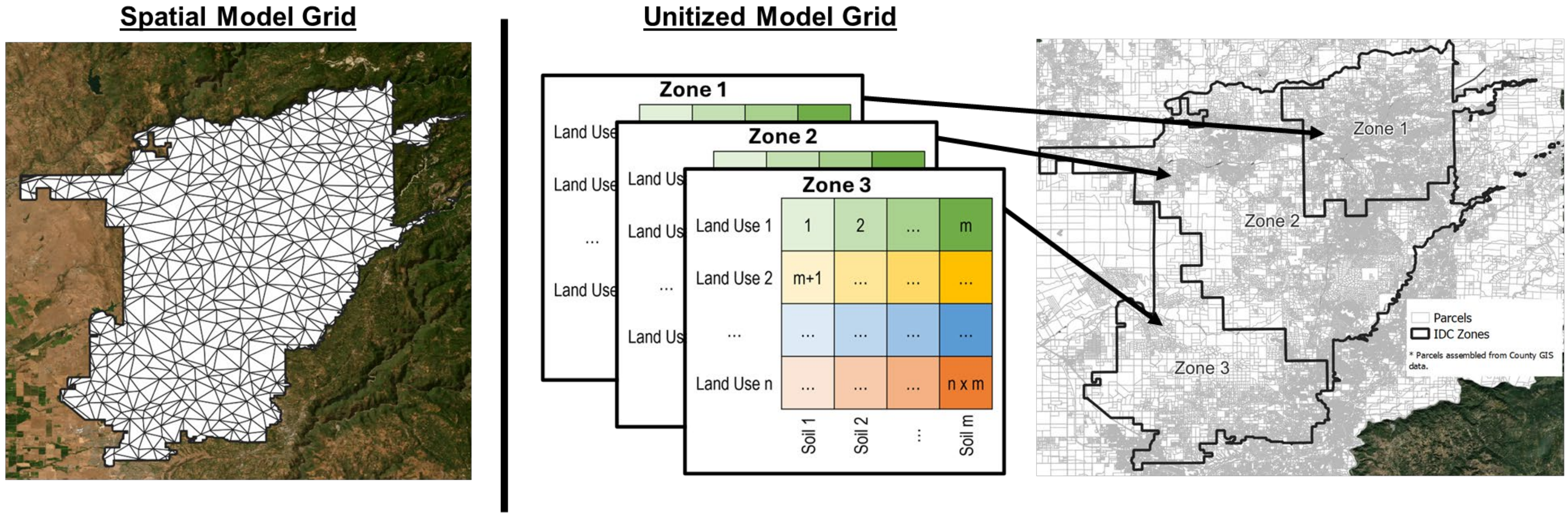


Figure 4-1. Conceptual Water Budget as Simulated in the IDC Model, Quantifying Inflows and Outflows of Water Through the Landscape (DWR 2016)



Model Elements Represent Simplified Areas in NID (Parcel Details Are Simplified)

Model Elements Represent Potential Conditions in NID (land use, soil, climate zones) (Results Are "Unit" Depths, e.g., acre-feet per acre)

Each Parcel Linked to "Unitized" Results for a Model Element (Parcel Details Are Preserved)

Figure 4-2. Overview of Structural Differences Between a Spatial IDC Model and a Unitized IDC Model

In total, 11 land use categories, 5 soil textures, and 3 climate zones were simulated in the IDC model used in the NID PFW process (Table 4-2). Altogether, these represent 165 unique combinations of land use, soil, and climate zones simulated within the NID service area. The land use categories and soil textures were developed through analyses described in Section 4.2.3.2. The representative climate zones were developed by assessing elevation profiles, precipitation, and reference evapotranspiration (ETo) within the NID service area (Section 4.2.3.1) to identify regions with similar climate characteristics.

Table 4-2. Combinations of Land Use Categories, Soil Textures, and Climate Zones Simulated in the IDC Model

Climate Zone	Soil Texture	Land Use Categories[1]
Zone 1 (Higher Elevation)	Clay Loam	Citrus and Subtropical
		Miscellaneous Deciduous
		Miscellaneous Truck and Nursery
		Pasture
		Vineyard
		Young Perennial
		Idle
		Native Vegetation
		Riparian Vegetation
		Water
		Urban and Residential
	Loam	*[All Land Use Categories Repeated]*
	Sandy Loam	*[All Land Use Categories Repeated]*
	Silt Loam	*[All Land Use Categories Repeated]*
	Sandy Clay Loam	*[All Land Use Categories Repeated]*
Zone 2 (Middle Elevation)	Clay Loam	*[All Land Use Categories Repeated]*
	Loam	*[All Land Use Categories Repeated]*
	Sandy Loam	*[All Land Use Categories Repeated]*
	Silt Loam	*[All Land Use Categories Repeated]*
	Sandy Clay Loam	*[All Land Use Categories Repeated]*
Zone 3 (Lower Elevation)	Clay Loam	*[All Land Use Categories Repeated]*
	Loam	*[All Land Use Categories Repeated]*
	Sandy Loam	*[All Land Use Categories Repeated]*
	Silt Loam	*[All Land Use Categories Repeated]*
	Sandy Clay Loam	*[All Land Use Categories Repeated]*

[1]Additional information about the land use categories is provided in Section 4.2.3.2.

In the NID PFW process, the IDC model was developed, refined, and operated to simulate NID customers' demand under different scenarios, in particular:

- Current demand scenario: developed to simulate recent historical demand in 2013–2021, for the purpose of serving as a baseline for comparison and interpretation of the projected demand scenarios.
- Projected demand scenarios: developed to simulate multiple baseline or bookend (low or high) scenarios in 2022–2071 under alternate future conditions with regard to climate, land use, agricultural and irrigation practices, population, and NID system operations.

This section summarizes the general data sources and inputs used to develop the IDC model.

The IDC model was developed using data sources and information that capture the unique, local conditions within the NID service area to the extent available. More details on the assumptions and results of the demand model scenarios—including the projected demand scenario assumptions and rationale—are described in Section 4.3.

4.2.3.1 Climate-Related Inputs

Climate-related inputs to the IDC model included ET and precipitation. Data sources used to develop these inputs are described below.

4.2.3.1.1. Evapotranspiration (ET)

ET, or consumptive water use, is the major driver of agricultural water use. Unlike recoverable water uses, such as surface runoff or infiltration of water into the groundwater system (whether through seepage, deep percolation, recharge, or other means), ET is water that cannot be recovered or directly reused in the NID service area. ET is impacted by: the types of crops or vegetation that are grown (reflecting the inherent differences in water needs of different crops and vegetation); the quality of crops, vegetation, or land use, including water availability, nutrient and pest management, and other factors; and environmental demand for evaporation related to weather and climate parameters, as a function of temperature, solar radiation, wind speed, and humidity. Each of these factors are accounted for in the methods used to quantify ET.

In the IDC model, ET time series information was quantified for different land uses and different climate zones in NID for each of the demand model scenarios using the best available local information and standard technical approaches (ASCE-EWRI 2016).

In the current demand scenario, ET was quantified based on an evaluation of satellite-based remote sensing analyses available from OpenET (described below):

- The ensemble mean ET from OpenET was used to quantify spatial ET on a monthly timestep from 2016 to 2022 for all areas within NID (with a spatial resolution of 30 m by 30 m, or approximately 0.22 acre/pixel).
- Spatial ET results were linked to land uses in NID based on parcel-level land use data (described in Section 4.2.3.2).
- Representative average ET curves (i.e., ET rates over time) were quantified from the spatial ET results for different land uses in the different climate zones within NID, generating monthly ET curves representing hundreds of parcels in NID over the period from 2016–2022. These monthly

ET curves were used to quantify ET for the corresponding land uses within the corresponding climate zones. Before the availability of OpenET data, ET was estimated for each land use based on the monthly ET curves for the same land use and climate zone in a hydrologically similar WY.

In the projected demand scenarios, ET was quantified following the standard crop coefficient approach described in the United Nations Food and Agriculture Organization (FAO) Irrigation and Drainage Paper 56 (Allen et al. 1998). In the crop coefficient approach, ET is calculated by multiplying a reference evapotranspiration (ETo) value by a crop coefficient (Kc) such that: ET = Kc × ETo. Reference evapotranspiration, crop coefficients, and the calculation of ET by this method are described below. Adjustments were made to these parameters, as appropriate, to reflect changes in climate and water needs for particular land uses over time following the assumptions of the projected demand scenarios (described in Section 4.3).

Data sources used to calculate ET, or the parameters comprising ET, are summarized in Table 4-3 and in the sections below.

Table 4-3. Evapotranspiration Data Sources

Parameter	Demand Scenario	Source	Description
ET	Current	OpenET	OpenET data used to generate representative average ET curves for different land uses in the different climate zones in NID
ET	Projected	Calculated	Based on ET = ETo x Kc
ETo	Projected	Calculated based on CMIP-6 results (hydrology scenarios)	Values calculated for the different climate zones in NID based on CMIP-6 results used in the hydrology scenarios (Chapter 3)
Kc	Projected	Calculated	Kc values estimated based on the ratio of recent historical ET (from OpenET) to recent historical ETo (from Spatial CIMIS) for different land uses in the different climate zones in NID

OpenET Data

OpenET is a multi-agency web-based geospatial utility that quantifies ET over time with a spatial resolution of 30 m x 30 m (approximately 0.22 acre). OpenET information is available in raster coverages of the NID service area on both a daily and monthly timestep from 2016 through present. While OpenET is a new utility, the underlying methodologies to quantify ET apply a variety of well-established modeling approaches that are widely used in local, state, and Federal Government and research applications. Additional information about the OpenET team, data sources, and methodologies is available at: https://openetdata.org/. For the NID demand model, OpenET data were used to observe recent historical ET trends and evaluate representative ET rates for land uses in NID (e.g., average ET and percentiles across tens to thousands of pixels in NID) (Figure 4-3). Importantly, OpenET data were not used to directly assign an ET value representing any single point within NID in the demand model.

The OpenET data in Figure 4-3 shows areas with generally higher ET in the upper elevation regions of the NID service area (e.g., climate zone 1) and areas with generally lower ET in the lower elevation regions of NID (e.g., climate zone 3). These differences are mainly attributed to water availability within the landscape and land use within NID. While NID supplies raw water for irrigation to approximately 30,000 acres, most land within the boundaries of NID is “native vegetation” (undeveloped natural vegetation, such as forest, meadows, and non-irrigated open spaces) that relies on precipitation, shallow groundwater, and other water supplies in the landscape. Greater water availability in the higher elevation regions of NID supports generally higher ET for native vegetation in those areas, while generally lower ET occurs in lower elevation regions where less water is available in the landscape. Open water surfaces, such as reservoirs, also show higher ET rates indicating evaporation that occurred.

For the current demand scenario, an analysis of OpenET data spatially across the land uses in NID was used to generate representative average ET curves (i.e., ET rates over time) for land uses in the different climate zones within NID (Figure 4-4). The ET curves from this analysis were compared to representative ET curves reported from other sources—including DWR’s Cal-SIMETAW (DWR 2022b) and the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo (ITRC 2023)—to verify their general consistency with the ET trends for each crop reported in technical literature. In contrast with OpenET, many ET approaches do not account for crop stress, which is caused by a variety of factors, and if present, will reduce ET; thus, many ET approaches overestimate ET. One benefit of the approach used for quantifying ET in the demand model is that the variability of ET is evaluated within NID for each crop group, allowing for identification and use of a representative ET curve that captures local conditions and agronomic practices. The ET curves from other sources (e.g., Cal-SIMETAW, ITRC) tended to be higher than the OpenET results, especially in the mid to late summer period when evaporative demand is highest and when crop stress, if present, will be most noticeable. Differences observed between other sources and OpenET are influenced by these factors.

For the projected demand scenarios, OpenET ET data were used together with ETo information to calculate Kc curves that represent the unique, local water use characteristics of land uses within NID. This was intended to provide a more accurate understanding of local water demands directly in NID, rather than relying on Kc values from technical literature that were developed in other areas of California or the United States. The evaluation of ET data and development of Kc curves are discussed further in Appendix B.2.

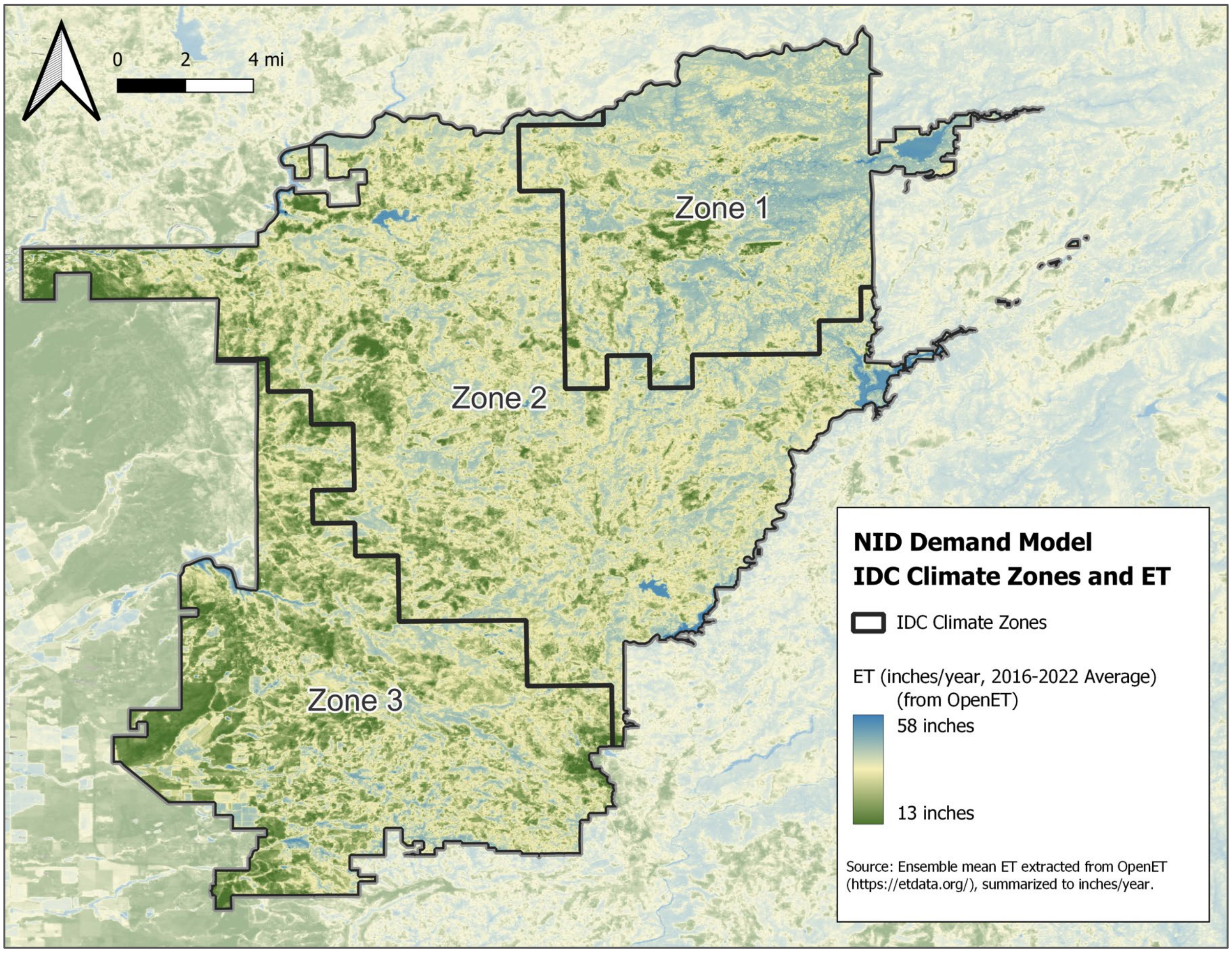


Figure 4-3. Average ET (2016–2022) from OpenET and Climate Zones

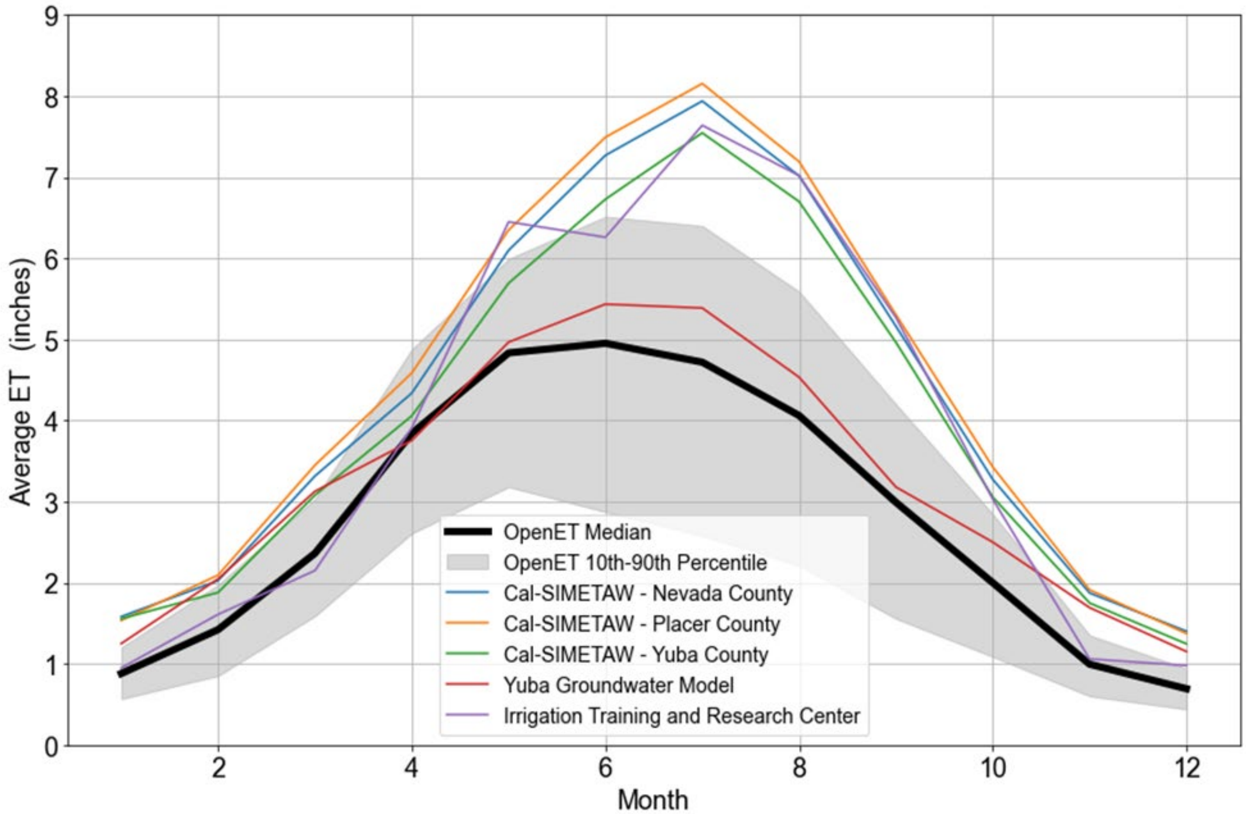


Figure 4-4. Sample ET Curve Summarized for all Parcels Categorized as Pasture in Climate Zone 3 (2021), with Comparisons to Other Representative ET Estimates for Pasture from Cal-SIMETAW (DWR 2022b), the Yuba Groundwater Model (YWA, 2019), and the Irrigation Training and Research Center ET Data for Water Budget Applications (ITRC 2023)

Reference Evapotranspiration (ETo)

Reference evapotranspiration represents the evapotranspiration rate from a reference surface. Throughout California, the standard reference surface used by the CIMIS is a well-watered, full-cover grass surface, commonly referred to as ETo (CIMIS 2023). ETo provides information about climatic parameters that affect ET and essentially quantifies the evaporative demand of the environment. Recent historical ETo estimates are available directly from CIMIS. Projected ETo can be calculated from projected climate parameters or can be scaled to reflect changes in climate parameters.

In the current demand scenario, ET was quantified primarily based on OpenET information (2016–2022), so ETo was not directly necessary for quantifying ET in those years. However, recent historical ETo was quantified to generate local Kc curves for different land uses in different climate zones of the NID service area that were then used to estimate ET in earlier years and projected ET in the future following the standard crop coefficient approach (Allen et al. 1998). The approach used to generate local Kc values is described below. Recent historical ETo used to generate local Kc values was summarized from spatial CIMIS data (Figure 4-5 and Figure 4-6). Spatial CIMIS data extracted for the NID service areas was calculated based on available quality controlled CIMIS station data and interpolation between stations with reference to topography and other factors that impact climate conditions. Additional information about the spatial CIMIS data sources and methodologies is available at: https://cimis.water.ca.gov/SpatialData.aspx.

In the projected demand scenarios, ETo was quantified following the standard Hargreaves-Samani approach (Hargreaves and Samani 1985, Allen et al. 1998). In contrast with other more complex methodologies for quantifying ETo, the Hargreaves-Samani approach simplifies the estimation of ETo based on data and assumptions pertaining to air temperature and extraterrestrial radiation. Average daily ETo for each climate zone within the NID service area was quantified based on spatial projected temperature information derived from the CMIP-6 analyses used in the hydrology scenarios, as described in Chapter 3 and assumptions regarding extraterrestrial radiation based on the geographic location of the NID service area and the day of the year. In this way, projected ETo was calculated and scaled to reflect changes in climate parameters over time and under different projected demand scenarios that will impact ET.

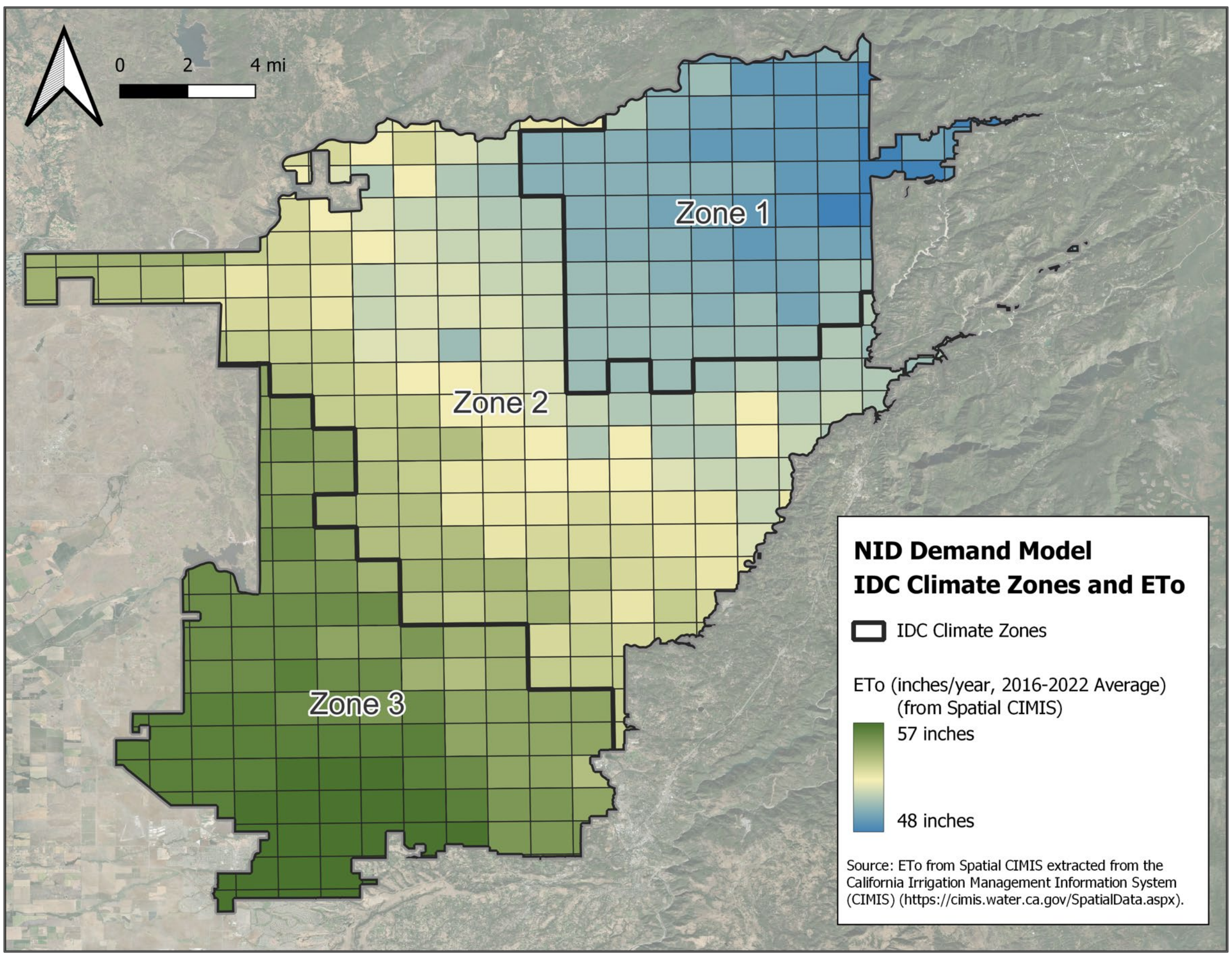


Figure 4-5. Average ETo (2016–2022) from Spatial CIMIS and Climate Zones

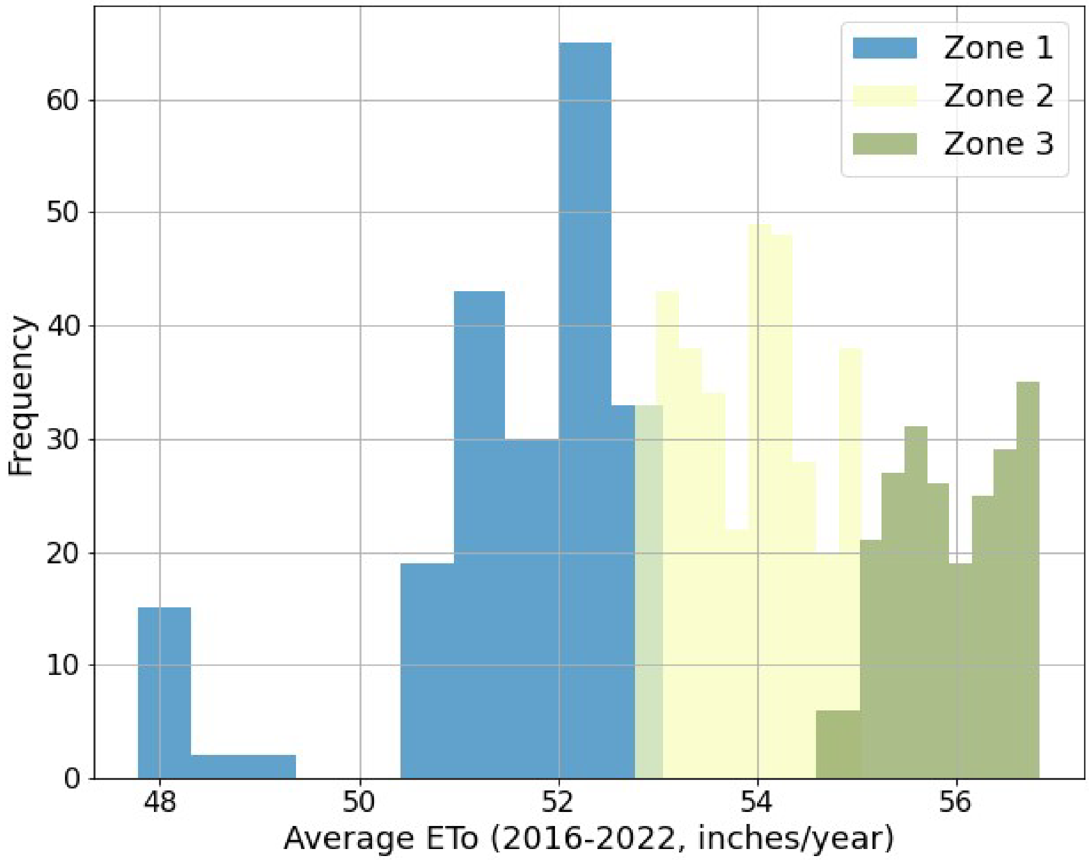


Figure 4-6. Distribution of ETo (2016–2022) from Spatial CIMIS Across the Climate Zones, Where Frequency Represents the Number of Pixels Within Each Zone

Crop Coefficients (Kc)

Kc is calculated based on the ratio of ET to ETo and represents the unique crop characteristics that distinguish a particular land use's water use needs from that of a reference grass surface. Different land uses and crops have different Kc values and curves, depending on their water use needs. In use, Kc is a scaling factor that adjusts the climate-related factors that affect ET (captured in ETo) to reflect the crop-related factors that affect ET as a land use or crop grows and matures.

Local Kc values were developed for land uses in the NID service area over the period from 2016–2022 based on the ratio of:

- ET values from OpenET, which were used to observe trends in consumptive water use and evaluate representative ET rates for specific land uses in NID.
- ETo values from spatial CIMIS, which were used to observe trends in climate and weather conditions that impact ET over the same time period.

Local Kc values were calculated through a geospatial analysis of ET (OpenET data at a 30 m x 30 m resolution) and ETo (spatial CIMIS data averaged over each of the three climate zones in NID, and then downscaled to the ET resolution) over time. From these two data sources, Kc values were calculated on a monthly timestep at a 30 m x 30 m resolution over the full spatial extent of the NID service area and were mapped to specific land uses in NID based on spatial land use information (described below). The end result was a distribution of monthly Kc curves from 2016–2022 that represent the water use needs of particular land uses in particular climate zones within NID calculated across tens to thousands of parcels in NID. Development of the Kc curves is discussed further in Appendix B.2. Evaluation of this range of Kc curves allowed simulation of a range of crop water use conditions across NID. The projected demand scenarios considered the 25th percentile, median, and 75th percentile Kc distribution (described in Section 4.3).

4.2.3.1.2. Precipitation

Precipitation is an important source of water on the landscape that is used to support ET and that results in runoff, percolation, and changes in soil moisture. For the IDC model, precipitation time series information was quantified for the different climate zones in NID for each of the demand model scenarios using the best available information (Table 4-4).

For the current demand scenario, spatial precipitation estimates were extracted from the PRISM developed by the PRISM Climate Group at Oregon State University (Figure 4-7). PRISM quantifies spatial precipitation estimates, among other climate parameters, based on available weather station data and modeled spatial relationships with topography and other factors influencing weather and climate. Additional information about the PRISM data and methodologies is available at: https://prism.oregonstate.edu. Monthly precipitation rasters were evaluated at a spatial resolution of 4 km x 4 km for the demand model.

For the projected demand scenarios, spatial projected precipitation estimates for each climate zone in the NID service area were summarized from the CMIP-6 analyses used in the hydrology scenarios, as described in Chapter 3. In each case, precipitation data were summarized into representative, average precipitation curves (i.e., precipitation rates over time) for the different climate zones within NID.

Table 4-4. Precipitation Data Sources

Scenario	Source	Description
Current	PRISM	PRISM data used to generate representative average precipitation curves for the different climate zones in NID.
Projected	CMIP-6 results (hydrology scenarios)	Values summarized for the different climate zones in NID based on CMIP-6 results used in the hydrology scenarios (Chapter 3)

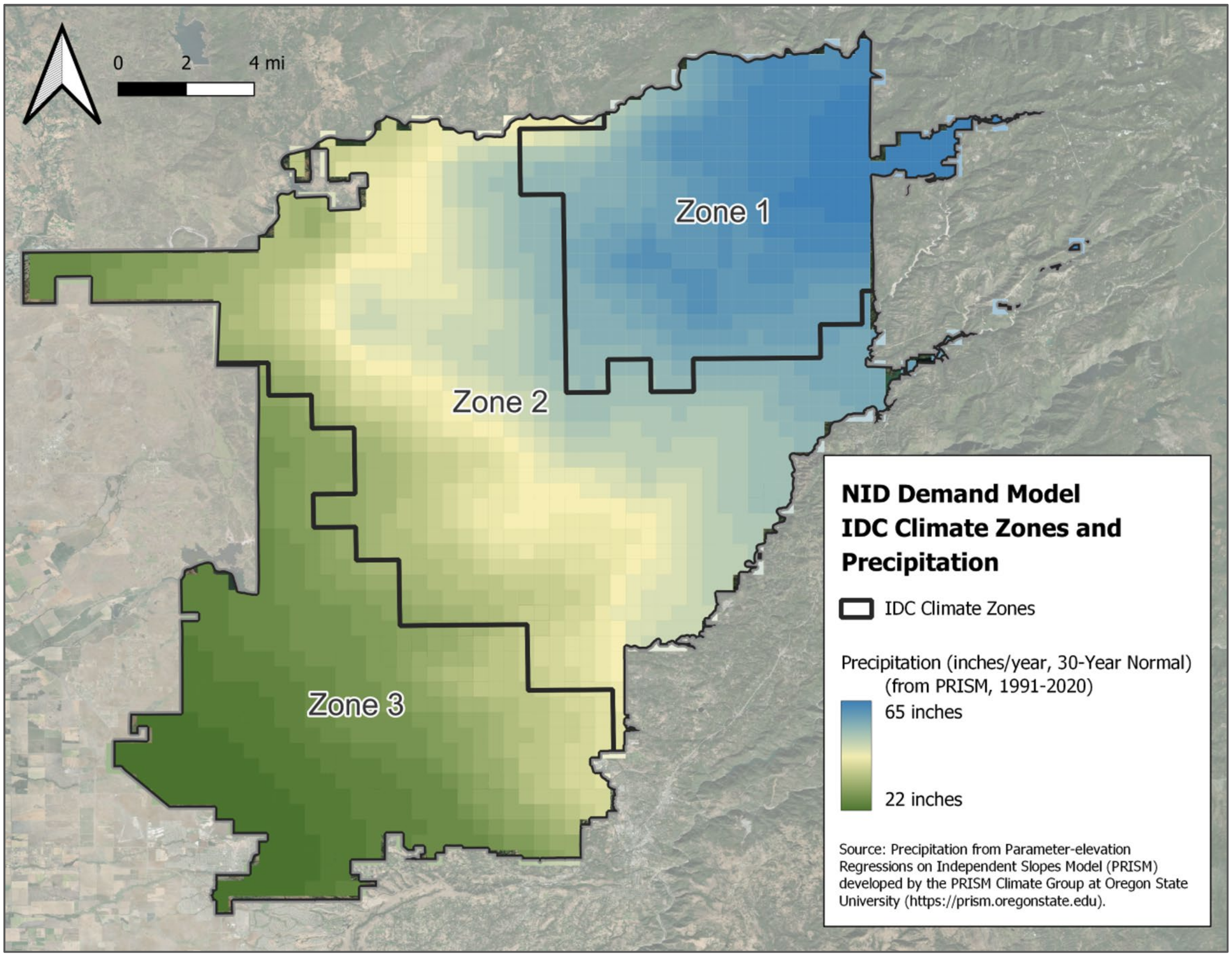


Figure 4-7. Average Precipitation from PRISM (30-Year Normal, 1991–2020) and IDC Climate Zones

4.2.3.2 Land Use and Soil-Related Inputs

Land use and soil-related inputs to the IDC model included parcel-level land use information, runoff characteristics, as well as soil textures and related parameters that influence soil moisture storage. Data sources used to develop these inputs are described below.

4.2.3.2.1. Land Use

Parcel-level land use data across the NID service area were identified using the most recent and reliable geospatial land use data for California, as well as available local information from Nevada, Placer, and Yuba Counties and their General Plans regarding zoning and anticipated land use changes over time. Land use and land cover (simplified to land use in this discussion) refers to both the vegetation and development of the landscape, ranging from developed urban or rural residential areas, to agricultural land, to undeveloped natural vegetation (referred to as native vegetation in the IDC model).

For the current demand scenario, spatial land use information was summarized through a land use analysis process based on:

1. Statewide land use mapping, available from the California DWR (DWR 2023).

2. CropScape Cropland Data Layer coverage, available from the USDA (USDA 2023).

To generate a complete land use map of the NID service area, land use data from these sources were compiled into 30 m x 30 m raster coverages of the NID service area for 2016–2022, according to the following order of preference:

- The statewide land use mapping from DWR was preferentially used to identify agricultural land (including irrigated and non-irrigated lands) and urban areas. These data include extensive ground-truthing and analytical review of results statewide and are considered the most accurate spatial land use data source available within the NID service area in recent years.
- The CropScape Cropland Data Layer coverage from the USDA was subsequently used to back-fill gaps of non-irrigated, idled, and non-developed (i.e., native vegetation) areas within the NID service area that were not captured in the DWR data.

The unique land uses within NID that were identified from these sources were then summarized and aggregated into predominant land use categories for simulation in the IDC model (Table 4-5 and Figure 4-8).

After generating a complete land use map of the NID service area, land use data were then linked to parcels within NID using parcel delineations gathered from Nevada, Placer, and Yuba County and parcel identification numbers from NID's customer and delivery records (described further in Section 4.2.3.5). This linkage allowed identification of the predominant land use that existed within each parcel in each year, and the fraction of the parcel area that was represented by that land use (based on an analysis of the 30 m x 30 m raster coverage within the parcel boundaries). Ultimately, the demand model was developed to estimate raw and treated water demand at the parcel level based on the developed area of each parcel—that is, the area of the parcel in which agricultural, urban, or residential water use occurs, excluding non-developed land (i.e., non-irrigated native vegetation, etc.). Thus, at this stage, the relative fraction of each parcel that was developed was also determined from the land use data based on the relative proportion of developed areas within that parcel. Results of this land use analysis process were then compared with NID crop report information to verify the general acreages and relative proportions of crops grown in NID. Additional discussion of the land use analysis process is available in Appendix B.3.

For the projected demand scenarios, the current demand scenario land use from 2022 was used as a baseline for land use changes over time, layering in information from the counties and their General Plans regarding parcel zoning, land use mapping, and areas where development may occur, as well as information from NID identifying NID's potential growth areas ("soft service areas"). This information was used to modify land use to reflect growth or contraction of customers in the NID service area over time following the assumptions of the projected demand scenarios (described in Section 4.3).

Table 4-5. Land Uses Simulated in the IDC Model

Land Use Sector	Land Use Category	Description
Agricultural	Citrus and Subtropical	Irrigated citrus and subtropical crops (e.g., citrus trees)
	Miscellaneous Deciduous	Irrigated orchard crops (e.g., fruit and nut orchard crops)
	Miscellaneous Truck and Nursery	Other miscellaneous irrigated truck and nursery crops (e.g., berries, tomatoes, cucurbits)
	Pasture	Irrigated pasture, turf, and alfalfa
	Vineyard	Irrigated vineyards and grapes
	Young Perennial	Irrigated young perennial crops (prior to maturation)
	Idle	Non-irrigated, non-cropped agricultural land
Urban	Urban and Residential	Land uses include urban and residential areas
Native and Riparian Vegetation	Native Vegetation	Undeveloped natural vegetation is referred to and simulated as native vegetation in the IDC model. While native vegetation is included in land use analyses and is simulated in the IDC model, demand from native vegetation is not included in the demand results.
	Riparian Vegetation	Undeveloped natural riparian vegetation is referred to and simulated as riparian vegetation in the IDC model. While riparian vegetation is included in land use analyses and is simulated in the IDC model, demand from riparian vegetation is not included in the demand results.
	Water	Reservoirs, ponds, waterways, and other water surfaces are simulated as water in the IDC model. While water is included in land use analyses and is simulated in the IDC model, demand from water is not included in the IDC results but would be included in the system losses.

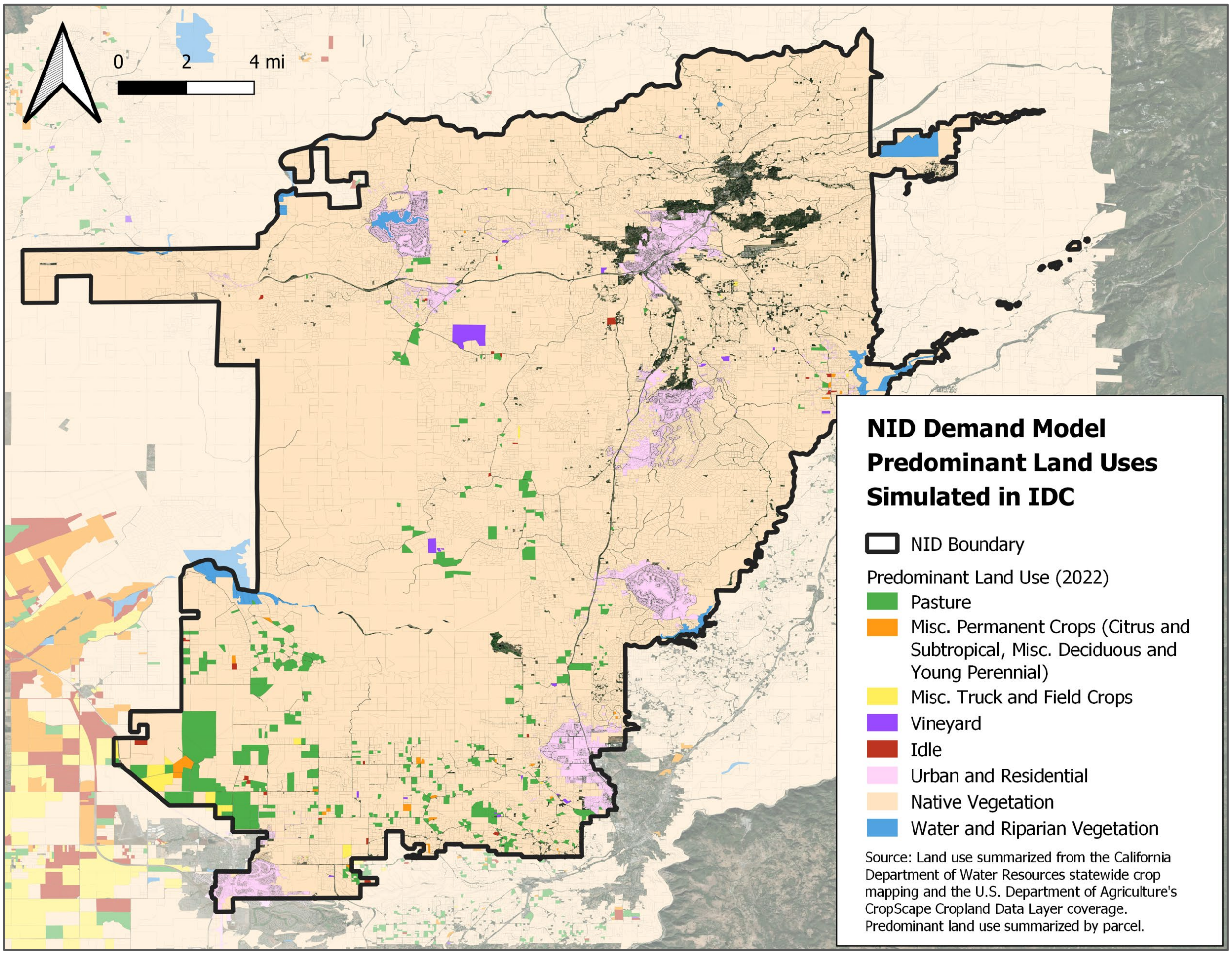


Figure 4-8. Land Uses Simulated in the IDC model, Summarized by Parcel (2022)

4.2.3.2.2. Soil Textures and Parameters

Soil textural classes and associated soil hydraulic parameters used in the IDC model were estimated from a compilation of the Soil Survey Geographic (SSURGO) and State Soil Geographic (STATSGO) datasets available from the California Soil Resource Lab at the University of California, Davis, and University of California – Agriculture and Natural Resources (UC-ANR) (Walkinshaw et al. 2022). The SSURGO and STATSGO datasets contain geospatial soil information collected by the National Cooperative Soil Survey (NCSS) regarding soil textures and soil properties in the United States. The USDA-NRCS organizes the NCSS and publishes soil surveys. The IDC model includes five soil textures representing the predominant soil texture classes found within the NID service area (Table 4-6 and Figure 4-9).

The following five soil parameters were provided as inputs to the IDC model and are summarized for each soil texture class in Table 4-6:

1. Permanent Wilting Point, dimensionless (ratio of volume/volume)
2. Field Capacity, dimensionless (ratio of volume/volume)
3. Total Porosity, dimensionless

4. Pore Size Distribution Index, dimensionless
5. Saturated Hydraulic Conductivity (K_{sat}), (ft/day)

An explanation of these soil parameters and their role in the IDC model is available from DWR in their IDC model documentation (DWR 2022a). Soil parameters were determined through a combination of area-weighted summaries of information in the SSURGO/STATSGO datasets, as well as a calibration process to refine the simulation of these soil parameters within the IDC model. For each soil texture class derived from SSURGO/STATSGO, initial soil parameters were estimated based on pedotransfer functions reported by Saxton and Rawls (2006) and refined to provide drainage from saturation to field capacity within a reasonable amount of time, as determined from the percentage of drainage after three days (generally exceeding 60–80%), and to predict minimal gravitational drainage once field capacity was reached.

Table 4-6. Predominant Soil Textures and Soil Parameters Simulated in the IDC Model

Soil Texture	Area (acres)	Field Capacity (-)	Wilting Point (-)	Total Porosity (-)	Pore Size Distribution Index (-)	Ksat (ft/d)
Clay Loam	100,175	0.31	0.17	0.42	0.150	1.200
Loam	107,757	0.28	0.15	0.40	0.173	1.625
Sandy Loam	45,051	0.19	0.09	0.38	0.322	8.350
Silt Loam	38,941	0.28	0.13	0.40	0.210	0.660
Sandy Clay Loam	11,833	0.24	0.14	0.39	0.195	5.800

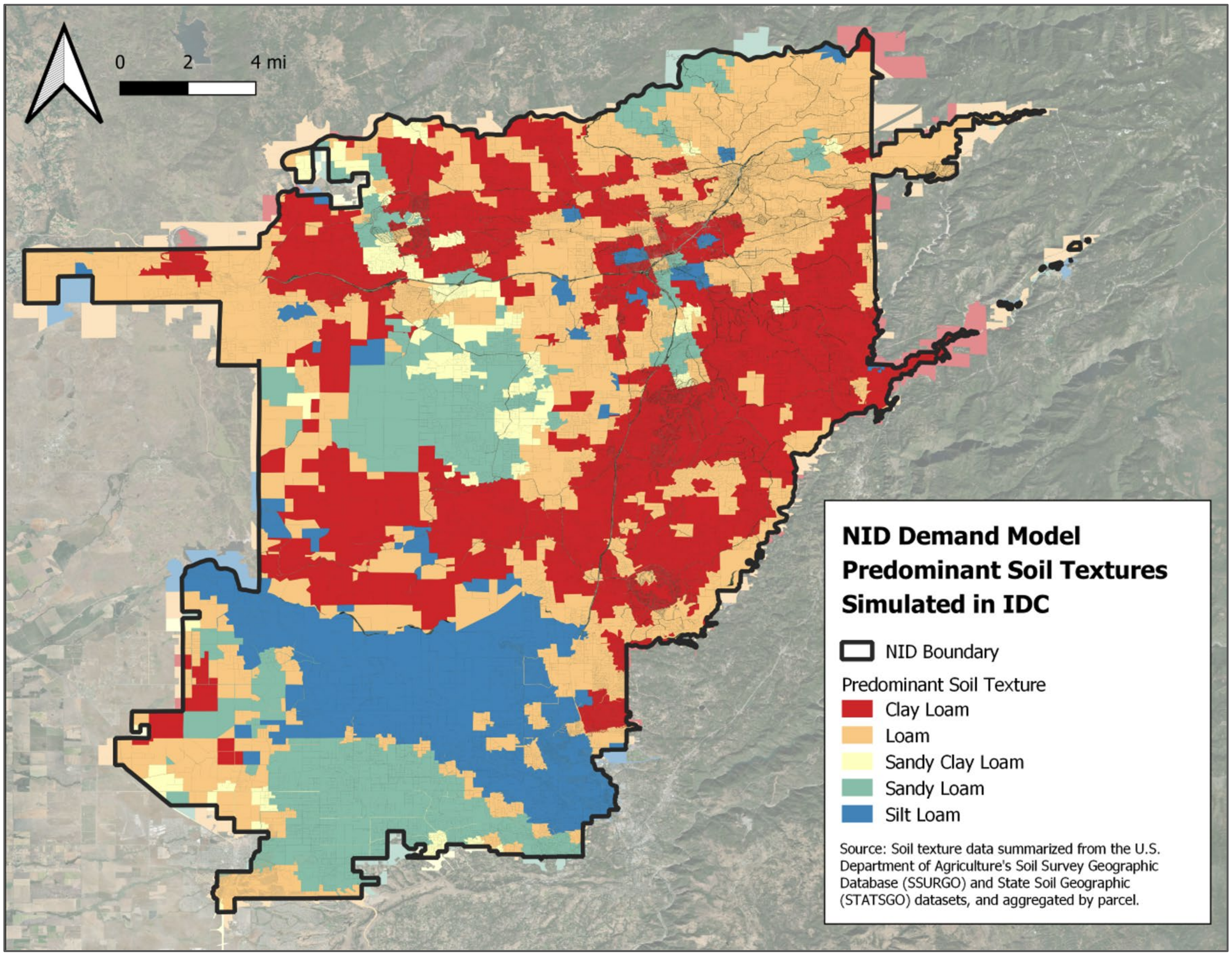


Figure 4-9. Predominant Soil Textures Simulated in the IDC Model

4.2.3.2.3. Runoff Curve Numbers

The IDC model uses a modified version of the SCS curve number (SCS-CN) method to compute runoff of precipitation, which uses curve numbers for each land use class and soil texture to simulate runoff. Curve numbers are used as described in the National Engineering Handbook Part 630 (USDA 2004, 2007) based on the land use or cover type, typical or representative treatment (straight rows, bare soil, etc.), hydrologic condition, and hydrologic soil group. An area-weighted average curve number for each land use-soil texture combination was calculated based on curve number values for each land use (SCS 1986) over the area in each hydrologic soil group, assuming generally good hydrologic conditions (Table 4-7).

Table 4-7. Curve Number Used to Represent Runoff Conditions in the IDC Model

	Soil Texture (Hydrologic Soil Group[1])				
Land Use Category	Clay Loam (D)	Loam (B)	Sandy Loam (A)	Silt Loam (B)	Sandy Clay Loam (C)
Citrus and Subtropical	82	65	44	65	77
Miscellaneous Deciduous	82	65	44	65	77
Miscellaneous Truck and Nursery	89	78	67	78	85
Pasture	78	58	30	58	71
Vineyard	82	65	44	65	77
Young Perennial	82	65	44	65	77
Idle	93	85	76	85	90
Urban and Residential	60	60	60	60	60
Native Vegetation	79	60	36	60	73
Riparian Vegetation	77	56	35	56	70
Water	100	100	100	100	100

[1]Hydrologic soil groups and curve numbers summarized from Appendix B.1 of the SCS Report “Urban Hydrology for Small Watersheds” (TR-55) (SCS 1986).

4.2.3.3 Agriculture and Irrigation Water Use Inputs

Other inputs to the IDC model pertaining to agricultural water use, irrigation, and operational practices are described below.

4.2.3.3.1. Root Depth

Root depths simulated in the IDC model for each of the agricultural land use categories were estimated primarily from ASCE-EWRI (2016) and Keller and Bliesner (1990) (Table 4-8).

Table 4-8. Root Depths Simulated in the IDC Model by Agricultural Land Use Category

Agricultural Land Use Category	Root Depth (ft)
Citrus and Subtropical	4.0
Miscellaneous Deciduous	4.0
Miscellaneous Truck and Nursery	2.5
Pasture	3.0
Vineyard	4.0
Idle	3.0

4.2.3.3.2. Irrigation Period

In the IDC model, the irrigation period determines the periods when each agricultural land use is irrigated. In the IDC model, the irrigation period was enabled, and demand was summarized between March and October for all irrigated agricultural land uses, roughly corresponding with the irrigation season in NID. For idle land uses (and other non-irrigated, non-agricultural land uses), the irrigation period was disabled in all months.

4.2.3.3.3. Tailwater

In the IDC model, tailwater is simulated as a fraction of the total applied irrigation water that results in runoff. In the IDC model, tailwater for all irrigated agricultural land uses was estimated to be approximately 5% of applied water on average, recognizing that a small amount of runoff typically occurs even with high-efficiency irrigation methods. Apart from tailwater, the IDC model assumed that all water supplied to parcels for irrigation of agricultural land uses was available or used for irrigation.

4.2.3.3.4. Soil Moisture Parameters

The minimum soil moisture value for each agricultural land use corresponds to the moisture content at the management allowable depletion (MAD) specified for that land use, which is the desired soil water deficit at the time of irrigation and can vary with growth stage (ASABE 2007). During irrigation, the minimum soil moisture is often restricted to the percent of total available moisture that a crop can withstand without suffering stress or yield loss. Water stress is estimated within the IDC model when the percentage of total available moisture exceeds 50%. Thus, values for the minimum soil moisture were set to 50% for all irrigated land uses to prevent additional stress from occurring in the simulation. However, it is important to note that the ET and Kc values, as described previously, were developed using satellite-based remote sensing analyses of actual ET occurring on the landscape. Thus, in the current demand scenario the ET estimates already included observed ET reductions that may have occurred due to water stress or other factors. In the projected demand scenarios, ET reductions due to water stress were simulated by proxy through other assumptions (described Section 4.3).

The target soil moisture fraction corresponds to the fraction of available soil moisture that irrigation provides. In the IDC model, target soil moisture fractions were estimated between approximately 0.80–1.05 for all land use classes based on common irrigation methods and scheduling practices in which irrigators typically irrigate near field capacity.

4.2.3.4 Urban and Residential Water Use Inputs

In the IDC model, urban and residential water use was simulated based on population data, per capita water use requirements, typical fractions of indoor versus outdoor water use, and parameters used to estimate outdoor water use (ET, curve numbers, etc. described above). Urban and residential water use inputs were simulated for different urban regions within NID to facilitate refinement of IDC inputs to represent population, per capita water use, and other conditions in different areas (Table 4-9). In the IDC model, these urban regions were used primarily to estimate the treated water demand of NID customers located within those regions. The data and information sources used to estimate population and treated water use are described below.

Table 4-9. Urban Regions Simulated in the IDC Model, With Average Per Capita Water Use

Urban Region	Simulated in Climate Zone(s)	Average Per Capita Water Use 2014–2021 (Gallons Per Person Per Day)
City of Grass Valley	Zone 1	150
City of Nevada City	Zone 1	150
City of Lincoln	Zone 3	130
Other Urban Areas (Rural Communities and Residential Areas, Unincorporated Areas, etc.)	Zone 1-3	150–180
Urban Soft Service Areas	Zone 1-3	150

4.2.3.4.1. Population

For the IDC model, annual population information was quantified for the different urban regions within NID for each of the demand model scenarios using the best available information. For the current demand scenario, annual population data were obtained from the California Department of Finance and from the United States Census Bureau American Community Survey for cities, census designated places, and unincorporated areas in Nevada, Placer, and Yuba Counties. Available population data were summarized for simulated urban and residential areas within the NID service area as unitized IDC inputs (i.e., average population per unit area). For the projected demand scenarios, population changes in NID's service area and customer base were evaluated based on analyses of population projections from the California Department of Finance and from Nevada, Placer, and Yuba County General Plan information (summarized in Section 4.3).

4.2.3.4.2. Treated Water Use

Monthly per capita water use and other parameters used to simulate indoor and outdoor water use were also quantified for the different urban regions within NID for each of the demand model scenarios using the best available information.

Per capita water use (as a volume per capita) is used in the IDC model to simulate the amount of treated water that is used within each urban and residential area, on average, across the population. In the current demand scenario, average monthly per capita water use rates were quantified from available historical water production data in 2014–2021 extracted from the California State Water Resources Control Board (SWRCB) and from NID water treatment plant data, with reference to population information available in the SWRCB records and population estimates quantified independently for the IDC model (above). The average daily per capita water use in each urban demand region is summarized in Table 4-9. In the projected demand scenarios, per capita water use in all years was estimated to be similar to the per capita water use in 2022 across all simulations, as changes to treated water demand were simulated through changes to population and other inputs (see Section 4.3). In all scenarios, the fraction of water used indoors versus outdoors was estimated based on the average monthly distribution of per capita water use from available data in 2014–2021, estimating that the water use in February (typically the minimum monthly use) is used primarily for indoor uses. The IDC model simulated all indoor use based on per capita water use requirements, while outdoor use was also simulated with respect to ET demands and available precipitation, similar to irrigated land uses (described above).

4.2.3.4.3. Municipal Water Use (Raw Water)

In addition to serving raw and treated water customers, NID also supplies raw water to municipal water suppliers. NID's municipal water supplies ("municipal water use") are not directly simulated in the IDC model, which simulates direct water use on the landscape for irrigation and urban or residential use. However, municipal water use is quantified outside the IDC model using the best available information. Municipal water use is incorporated into the demand estimates in the canal system balance and is included in the overall results of the demand model.

In the current demand scenario, municipal water use was quantified directly from NID's records of raw water deliveries to municipal water customers in 2013–2022. In the projected demand scenarios, changes to municipal water use were estimated based on five-year projected changes to municipal water use (2020–2040) from NID's Urban Water Management Plan, with interpolation or extrapolation in the intervening and following years through the end of the projected period.

4.2.3.5 Parcel Linkages to IDC and the Canal System Balance

Alongside development of the IDC model, geospatial parcel information was evaluated and summarized for all parcels within the NID service area. Historical parcel maps, parcel areas, and identifying information were gathered from Nevada, Placer, and Yuba Counties. Parcel data were then linked to other geospatial data and summarized to determine the predominant characteristics of each parcel (by area), including:

- Predominant land use within the parcel, based on the land use analysis described in Section 4.2.3.2.1.
- Predominant soil texture within the parcel, based on the soil analysis described in Section 4.2.3.2.2.
- Representative climate zone, based on delineations of climate zones through an assessment of elevation profiles, precipitation (Section 4.2.3.1.2), and ETo (Section 4.2.3.1.1).

The parcel linkages to a predominant land use, soil texture, and climate zone allowed the unitized IDC model results (e.g., AF/acre) to be linked directly to parcels matching the same combination of primary characteristics, with an associated area over which those IDC results are applied (e.g., acre). The IDC-parcel linkages thus permitted spatial representation of demand volumes (AF) across the NID service area over time under the different scenarios.

Parcels were also linked to information about the NID service area and NID customer base, identifying existing NID customers and providing the ability to add or remove NID customers spatially over time in the projected demand scenarios depending on their location within the NID soft service areas and proximity to NID canals. Additionally, parcels were linked to information from the Nevada, Placer, and Yuba County General Plans related to parcel zoning, land use mapping, and planning to identify areas where development may occur over the next 50 years.

In combination, these parcel linkages allowed for:

- Quantification of demand volumes from the IDC model, and connection of those demand volumes spatially within the NID service area and canal system through the canal system balance (Section 4.2.4).
- Verification of the historical demand model results compared to historical NID delivery records (Appendix B.4).
- Simulation of future changes to NID's customers and service area at the parcel-level in the projected demand scenarios (scenarios described in Section 4.3).

4.2.4. Canal System Balance

The canal system balance component of the demand model takes the results of the IDC model that are linked to parcels in NID and connects those results to specific NID reservoirs, incorporating estimates of the canal system losses incurred in the process of delivering water from the reservoirs to NID's customers. The canal system balance thus quantifies the demand, or outflows from NID's reservoirs, which would be required to supply the water needs of NID's customers, inclusive of system losses in NID's canals and distribution system downstream of NID's reservoirs. These demand volumes are incorporated and simulated within the reservoir operations model (Chapter 5. Operations Model), along with regulatory-required environmental flows. This section briefly describes the process and assumptions of the canal system balance.

4.2.4.1 Demand Zones

Parcels and municipal water suppliers within the NID service areas were associated with specific demand zones that identify the specific NID reservoir ("demand node") from which NID's customers receive water deliveries. Through development of the demand zones, linkages were made between:

- Parcels representing raw and treated water customers served by NID, either currently or in projected demand scenarios and the canals that deliver—or would deliver—water to those parcels.
- Municipal water suppliers that receive raw water from NID and the canals that deliver water to those suppliers.
- Canals within the overarching NID canal system and the upstream NID reservoir that supplies water to those canals within the canal system.

A map of NID's service area, the delineation of demand zones, and connection of demand zones to particular NID reservoirs (i.e., demand nodes) is shown in Figure 4-10. Demands within each demand zone are aggregated to the demand node and represent the outflows from the NID reservoir supplying water to that demand zone.

4.2.4.2 System Losses

As water is released from NID's reservoirs into the canal system, some water is lost to seepage, evaporation, and other downstream outflows. In the canal system balance, system losses were estimated to be approximately 15% of the canal inflows, based on findings from NID's RWMP and associated analyses by NID of water that is released into NID canals that is not delivered to NID customers. Opportunities exist for further refinement of these system loss estimates through further data collection and analysis. The system loss estimate is understood to include seepage (i.e., infiltration of water into the groundwater system) from the canal system, evaporation from open water surfaces, and downstream outflows not delivered to NID customers. The system loss estimate does not include losses from NID reservoirs simulated in the reservoir operations model or other upper system losses above those reservoirs. Losses from NID's reservoirs are accounted for in the reservoir operations model.

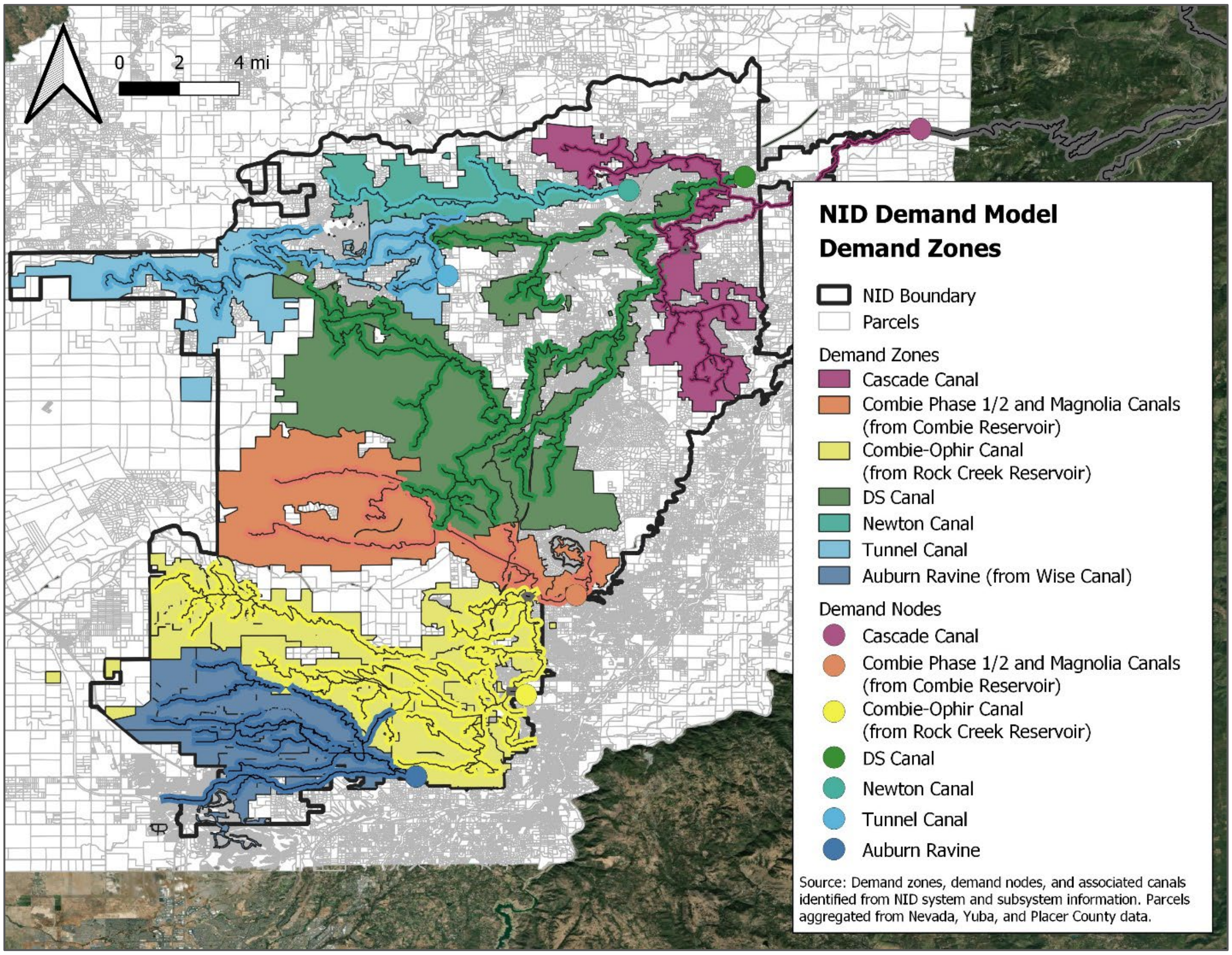


Figure 4-10. Demand Zones and Demand Nodes Simulated in the Demand Model

4.2.5. Demands from NID Reservoirs

As described previously, the demand (or outflows) from each of NID's reservoirs are summarized from the aggregated demands of NID's raw water customers, NID's treated water customers, municipal water customers, and system losses in the demand zones that are supplied from each respective NID reservoir (i.e., demand nodes).

The demand requirements at each demand node include the sum of:

- Demand results from the IDC model, representing the demand of NID's raw and treated water customers. Results are summarized for parcels within the demand zones supplied from the demand node.

- Municipal water use estimates, representing the demand of municipal water suppliers that receive raw water from NID.
- System losses, representing the loss of water from NID's canals downstream of NID's reservoirs that is not supplied to NID customers.

Regulatory-required environmental flows are not included in these demand model results but are included in the reservoir operations model.

The demand requirements from each of NID's reservoir (i.e., from each demand node) serve as an input and the primary point of connection between the reservoir operations model and the demand model. Additional information about how demands are incorporated into the reservoir operations model are described in Chapter 5. Operations Model.

4.3. Demand Model Scenarios

4.3.1. Summary of Scenarios

The demand model was developed and used to estimate demands for a total of 11 scenarios:

- One current demand scenario representing recent historical demand conditions in 2013–2021, as a baseline for comparison and interpretation of the projected demand scenarios.
- Ten projected demand scenarios, representing a range of potential future demand conditions in 2022–2071, including:
  - Nine scenarios representing the combinations of three potential demand scenarios and three potential climate scenarios.
  - One current demand constant baseline scenario, considering current demand (2022) and median hydrologic conditions for 2022–2071.

Assumptions and information used to develop the scenarios are summarized in Table 4-10.

The current demand scenario was developed using recent historical data for the NID service area based on the data sources and methodologies described in Section 4.2. The projected demand scenarios were developed based on the assumptions described in Section 4.3.2. Average results of the current and projected demand scenarios are summarized in Section 4.4.

Table 4-10. Summary of Demand Model Scenarios with Information about Underlying Assumptions and Data Sources

Demand Model Scenario			Climate-Related Conditions		Demand-Related Conditions		
Period	Demand Scenario	Hydrology Scenario (CMIP-6)	Precipitation	Evapotranspiration	Raw Water Demand	Treated Water Demand	System Losses
Current (2013–2021)	Recent historical	N/A	Recent historical data (Section 4.2.3.1)	Recent historical data (Section 4.2.3.1)	Recent historical customers and demand conditions (Sections 4.2.3 and 4.2.4)	Recent historical customers and demand conditions (Sections 4.2.3 and 4.2.4)	Historical canal losses (15%, from NID RWMP, Section 4.2.4)
Projected (2022–2071)	Low	**Dry** (CESM2-LENS_ssp370)	Climate change analysis (Dry hydrology scenario)	Calculated based on temperature-adjusted ETo (Dry hydrology scenario) and 25th percentile Kc curve (by land use, from 2022)	20% demand reduction from baseline	Population decline to lowest since 2000	10%
	Low	**Median** (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 25th percentile Kc curve (by land use, from 2022)	20% demand reduction from baseline	Population decline to lowest since 2000	10%
	Low	**Wet** (EC-Earth3-Veg_ssp370)	Climate change analysis (Wet hydrology scenario)	Calculated based on temperature-adjusted ETo (Wet hydrology scenario) and 25th percentile Kc curve (by land use, from 2022)	20% demand reduction from baseline	Population decline to lowest since 2000	10%

Demand Model Scenario			Climate-Related Conditions		Demand-Related Conditions		
Period	Demand Scenario	Hydrology Scenario (CMIP-6)	Precipitation	Evapotranspiration	Raw Water Demand	Treated Water Demand	System Losses
Projected (2022–2071)	Baseline	**Dry** (CESM2-LENS_ssp370)	Climate change analysis (Dry hydrology scenario)	Calculated based on temperature-adjusted ETo (Dry hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Expansion to soft service areas similar to historical rate (~20 acres/year developed land)	Expansion to soft service areas similar to historical rate (~50 customers/year)	15%
	Baseline	**Median** (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Expansion to soft service areas similar to historical rate (~20 acres/year developed land)	Expansion to soft service areas similar to historical rate (~50 customers/year)	15%
	Baseline	**Wet** (EC-Earth3-Veg_ssp370)	Climate change analysis (Wet hydrology scenario)	Calculated based on temperature-adjusted ETo (Wet hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Expansion to soft service areas similar to historical rate (~20 acres/year developed land)	Expansion to soft service areas similar to historical rate (~50 customers/year)	15%

Demand Model Scenario			Climate-Related Conditions		Demand-Related Conditions		
Period	Demand Scenario	Hydrology Scenario (CMIP-6)	Precipitation	Evapotranspiration	Raw Water Demand	Treated Water Demand	System Losses
Projected (2022–2071)	High	**Dry** (CESM2-LENS_ssp370)	Climate change analysis (Dry hydrology scenario)	Calculated based on temperature-adjusted ETo (Dry hydrology scenario) and 75th percentile Kc curve (by land use, from 2022)	Greater expansion to soft service areas at 150% baseline rate (~30 acres/year developed land)	Greater expansion to soft service areas at 150% baseline rate (~75 customers/year)	20%
	High	**Median** (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 75th percentile Kc curve (by land use, from 2022)	Greater expansion to soft service areas at 150% baseline rate (~30 acres/year developed land)	Greater expansion to soft service areas at 150% baseline rate (~75 customers/year)	20%
	High	**Wet** (EC-Earth3-Veg_ssp370)	Climate change analysis (Wet hydrology scenario)	Calculated based on temperature-adjusted ETo (Wet hydrology scenario) and 75th percentile Kc curve (by land use, from 2022)	Greater expansion to soft service areas at 150% baseline rate (~30 acres/year developed land)	Greater expansion to soft service areas at 150% baseline rate (~75 customers/year)	20%
Current Demand Constant Baseline (2022–2071)	Recent historical (2022)	**Median** (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Recent historical customers and demand conditions (2022)	Recent historical customers and demand conditions (2022)	Historical canal losses (15%, from NID RWMP, Section 4.2.4)

4.3.2. Projected Demand Scenario Assumptions

The 10 projected demand scenarios were developed using available estimates of future climate conditions from the projected hydrology scenarios, as well as assumptions about future changes to NID's raw water and treated water customer base over a range of potential system losses. The purpose of these projected demand scenarios was to develop a range of potential future demand conditions that could occur—as baseline or bookend conditions—from 2022 through 2071.

The primary data sources and assumptions used to develop the 10 projected demand scenarios are summarized in Table 4-10. Nine of the projected demand scenarios were developed as the combinations of:

- Three potential demand scenarios, corresponding to baseline or bookend (low or high) demand-related conditions with respect to raw water customer demand, treated water customer demand, and system losses.
- Three potential climate scenarios, corresponding to the climate change analyses (CMIP-6 results) used in the three projected hydrology scenarios (wet, median, and dry hydrologic conditions). The climate-related conditions were factored into estimates of precipitation and crop water use, as manifested through temperature-related impacts on ET. Precipitation and temperature information from the corresponding projected hydrology scenario were summarized for each of the IDC climate zones before their inclusion in the demand model.

Through these combinations, these nine projected demand scenarios resulted in:

- Three baseline demand scenarios, representing a baseline projection of demand conditions in 2022–2071 that follows the current trajectory and/or best information about expected projected changes to NID's customers and their demands. One scenario each accounted for wet, median, and dry hydrologic conditions.
- Three low demand scenarios, representing a lower bookend of low demand conditions in 2022–2071. These demand scenarios represented the lowest simulated projection of demand conditions, based on assumptions of potential raw water demand reductions, potential population decline, and potential reductions in system loss. One scenario each accounted for wet, median, and dry hydrologic conditions.
- Three high demand scenarios, representing an upper bookend of high demand conditions in 2022–2071. These demand scenarios represented the highest simulated projection of demand conditions, based on assumptions of potential raw water and treated water demand increases, associated with potential expansions of the NID service area, and potential increases in system loss. One scenario each accounted for wet, median, and dry hydrologic conditions.

The 10th projected demand scenario was developed to simulate a current demand constant baseline, considering current demand conditions in 2022 and median hydrologic conditions in 2022–2071. Current demand conditions were summarized from recent historical data for the NID service area based on the data sources and methodologies in Section 4.2. Median hydrologic conditions were summarized using the same data sources and methodologies used for summarizing the climate-related conditions in the other projected demand scenarios, described below.

The parameters and assumptions used to develop the projected demand scenarios are summarized below.

4.3.2.1 Climate-Related Conditions

Climate-related conditions that were considered in the projected demand scenarios include precipitation and evapotranspiration (also described in Section 4.2.3.1).

Precipitation was summarized directly from results of the climate change analyses (CMIP-6 results) used in the three projected hydrology scenarios (wet, median, and dry hydrologic conditions). Average precipitation from the corresponding projected hydrology scenario was summarized across each of the IDC climate zones and was then included in the IDC model component of the demand model. Additional information is provided in Section 4.2.3.1.2.

Evapotranspiration was calculated following the standard crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998), based on:

- Temperature-adjusted ETo, quantified following the standard Hargreaves-Samani approach using temperature information from the climate change analyses (CMIP-6 results) used in the three projected hydrology scenarios (wet, median, and dry hydrologic conditions). Average temperature from the corresponding projected hydrology scenario was summarized across each of the IDC climate zones.
- Kc curves for each land use, representing either the:
  - 25th percentile Kc curve (for the low demand scenario),
  - Median (50th percentile) Kc curve (for the baseline demand scenario), or the
  - 75th percentile Kc curve (for the high demand scenario).

Additional information is provided in Section 4.2.3.1.1 and Appendix B.2. The selection of the 25th percentile and 75th percentile Kc curve for the low and high demand scenarios was informed by comparison of ET differences from the baseline demand scenario to typical differences in ET under reasonable changes in cultivation and irrigation practices where ET is reduced (in the low bookend scenario) or ET is increased (in the high bookend scenario). Typical ranges of ET variability are +/-15% or more, depending on conditions, and are consistent with the ET variability from the baseline scenarios resulting from the 25th and 75th percentile Kc curves (Appendix B.2).

4.3.2.2 Demand-Related Conditions

Demand-related conditions considered in the projected demand scenarios include raw water demand, treated water demand, and system losses (described in Section 4.2.3.1).

Raw water demand was estimated for each of the projected demand scenarios as follows:

- For the low demand scenario: A 20% reduction in raw water demand from baseline conditions. These potential demand reductions are not explicitly tied to any specific future conditions within the NID service area but are considered to be within the range of potential changes due to agronomic practices, future impacts due to regulatory constraints, land use changes, or other constraints.

- For the baseline demand scenario: Expansion of NID's customer base into soft service areas at an average rate similar to the historical average growth of NID's raw water customers (approximately 20 acre/year of developed land). The historical average growth of NID's raw water customers was determined based on an analysis of NID delivery records from 2013–2022, in relation to the total areas (and developed areas) of parcels that received raw water deliveries from NID over time.
- For the high demand scenario: Expansion of NID's customer base into soft service areas at an average rate that is approximately 150% (1.5X) of the historical average growth of NID's raw water customers (approximately 30 acre/year of developed land). This potential growth of NID's raw water customer base was determined to be a high estimate, considering the total area of parcels potentially suitable for raw water customers within the soft service areas (based primarily on land use analyses).

Treated water demand was estimated for each of the projected demand scenarios as follows:

- For the low demand scenario: Estimated based on population decline to the lowest population identified in the NID service area since 2000, based on evaluation of available historical population data (Section 4.2.3.4.1). The potential population decline is not explicitly tied to any specific future conditions within the NID service area but is considered to be within the range of potential changes over the next 50 years.
- For the baseline demand scenario: Expansion of NID's customer base into soft service areas at an average rate similar to the historical average growth of NID's treated water customers (approximately 50 customers/year). The historical average growth of NID's treated water customers was determined based on an analysis of NID delivery records from 2013–2022.
- For the high demand scenario: Expansion of NID's customer base into soft service areas at an average rate that is approximately 150% (1.5X) of the historical average growth of NID's treated water customers (approximately 75 customers/year). This potential growth of NID's treated water customers was determined considering the parcels potentially suitable for treated water customers within the soft service areas (based primarily on land use analyses).

System losses in NID's canals and distribution system downstream of NID's reservoirs were estimated for each projected demand scenario as either:

- 10% of canal inflows (for the low demand scenario),
- 15% of canal inflows (for the baseline demand scenario), or
- 20% of canal inflows (for the high demand scenario).

The baseline demand scenario system losses were estimated as equal to historical canal losses, based on findings from NID's RWMP and associated analyses by NID of water that is released into NID canals that is not delivered to NID customers (Section 4.2.4.2). The low and high demand scenario system losses were estimated as a +/- 5% range around the baseline demand scenario system losses and are considered within the range of typical losses of canal systems in California.

4.4. Results

Average annual results of the current and projected demand scenarios are summarized in Table 4-11. Results of the projected scenarios are also shown in Figure 4-11 through Figure 4-14. The average annual demand estimates in the baseline demand scenarios were approximately 2,500 to 5,300 AF/year greater than the current demand scenario (2–3% greater), with higher demands experienced in the median and wet hydrology scenarios. In contrast, the average annual demand estimates in the low demand scenarios were approximately 39,000 to 41,000 AF/year lower (26–27% lower) than the current demand scenario, while the high demand scenarios were approximately 35,000 to 39,000 AF/year higher (23–25% higher) than the current demand scenario. Some variability was observed between the hydrology scenarios, although that was less than the differences between demand scenarios. The current demand constant baseline scenario resulted in approximately 156,000 AF/year of total demand.

Overall, the demand scenarios resulted in greater changes in total demand estimates versus the hydrology scenarios, pointing toward greater impacts between scenarios due to demand-related conditions rather than climate-related conditions. In total, average annual demand for the high and low demand scenarios ranged approximately +/- 40,000 AF/year around the current demand scenario, and with a similar range around the current demand constant baseline scenario. The wide range of potential demand conditions is reflective of the bookend nature of the high and low demand scenarios; although neither scenario is anticipated to occur with a high degree of certainty, these scenarios do provide useful bounds on the extremes that could strain NID's operations in the future. In reality, changes in demand conditions (either decreases or increases) would be expected to be less pronounced than those presented in the bookend scenarios.

Although climate-related conditions did result in some differences between scenarios—as observed in Table 4-11 and Figure 4-11 through Figure 4-14—the changes between scenarios resulted in less extreme changes. It is noted that the hydrology scenarios (dry, median, and wet) were developed and defined to be reflective of unimpaired inflows to NID's reservoirs, on average, over the projected period. The hydrology scenario naming conventions are not strictly indicative of hydrologic conditions with respect to average precipitation and temperature within the NID service area. For instance, higher average annual ETo is experienced in both the dry and wet hydrology scenarios, as compared to the median scenario, and is tied to higher temperatures in both the dry and wet scenarios. Additionally, while the wet hydrology scenario features the highest average annual precipitation of all scenarios, the timing of that precipitation occurs more during the winter months, whereas the highest precipitation during the irrigation season months occurs in the dry hydrology scenario. Nevertheless, demand estimates for all combinations of climate-related and demand-related conditions are useful for simulating potential future baseline and bookend conditions in the reservoir operations model to analyze water supply versus demand and conditions of unmet demand.

Table 4-11. Average Annual Results of the Current and Projected Demand Scenarios

Scenario			Years in Demand Model	Average Annual Demand (AF/year)	Difference from Current (AF/year)	Difference from Current (%)	Difference from Baseline Median (AF/year)	Difference from Baseline Median (%)
Period	Demand	Hydrology						
Current			2013-2021	153,000	0	0%	-4,000	-3%
Projected	Low	Dry	2022-2071	111,000	-42,000	-27%	-46,000	-29%
	Low	Median	2022-2071	113,000	-40,000	-26%	-44,000	-28%
	Low	Wet	2022-2071	113,000	-40,000	-26%	-44,000	-28%
	Baseline	Dry	2022-2071	155,000	2,000	1%	-2,000	-1%
	Baseline	Median	2022-2071	157,000	4,000	3%	0	0%
	Baseline	Wet	2022-2071	158,000	5,000	3%	1,000	1%
	High	Dry	2022-2071	188,000	35,000	23%	31,000	20%
	High	Median	2022-2071	190,000	37,000	24%	33,000	21%
	High	Wet	2022-2071	191,000	38,000	25%	34,000	22%
Current Demand Constant Baseline	Recent historical (2022)	Median	2022-2071	156,000	3,000	2%	-1,000	-1%

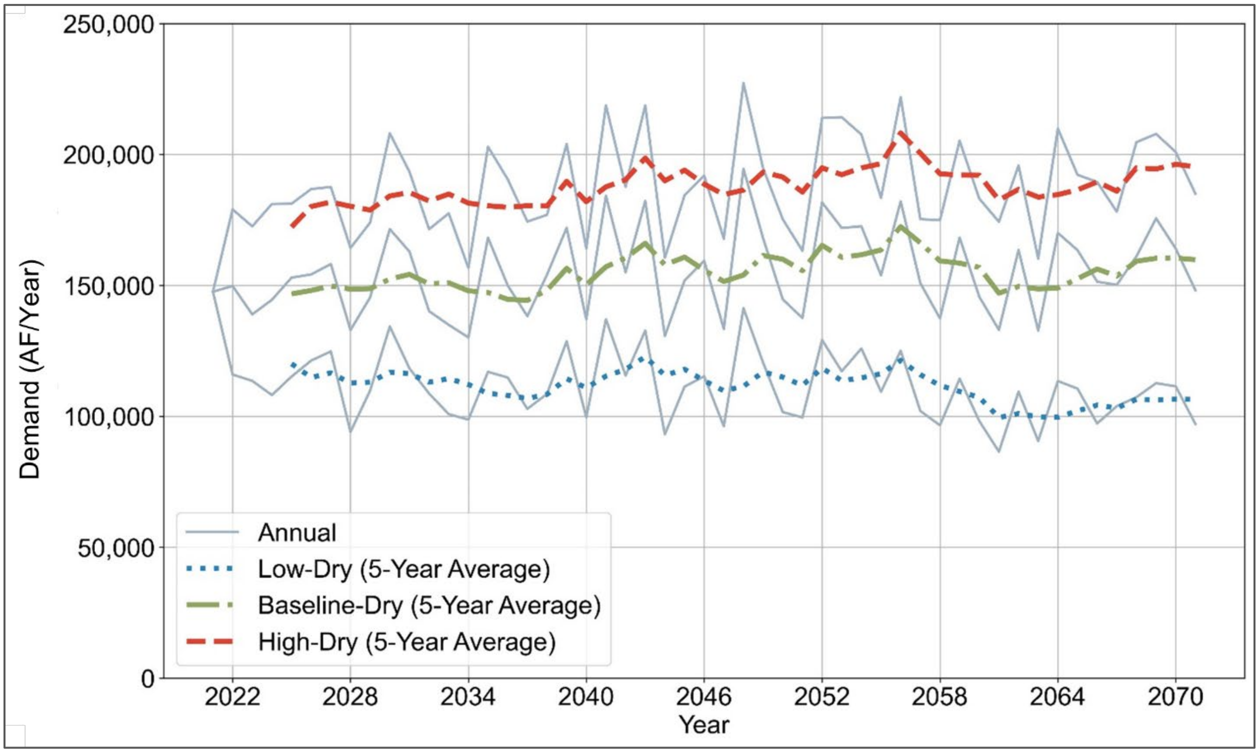


Figure 4-11. Annual Results of the Low, Baseline, and High Demand Scenarios, for Dry Hydrologic Conditions (2022–2071)

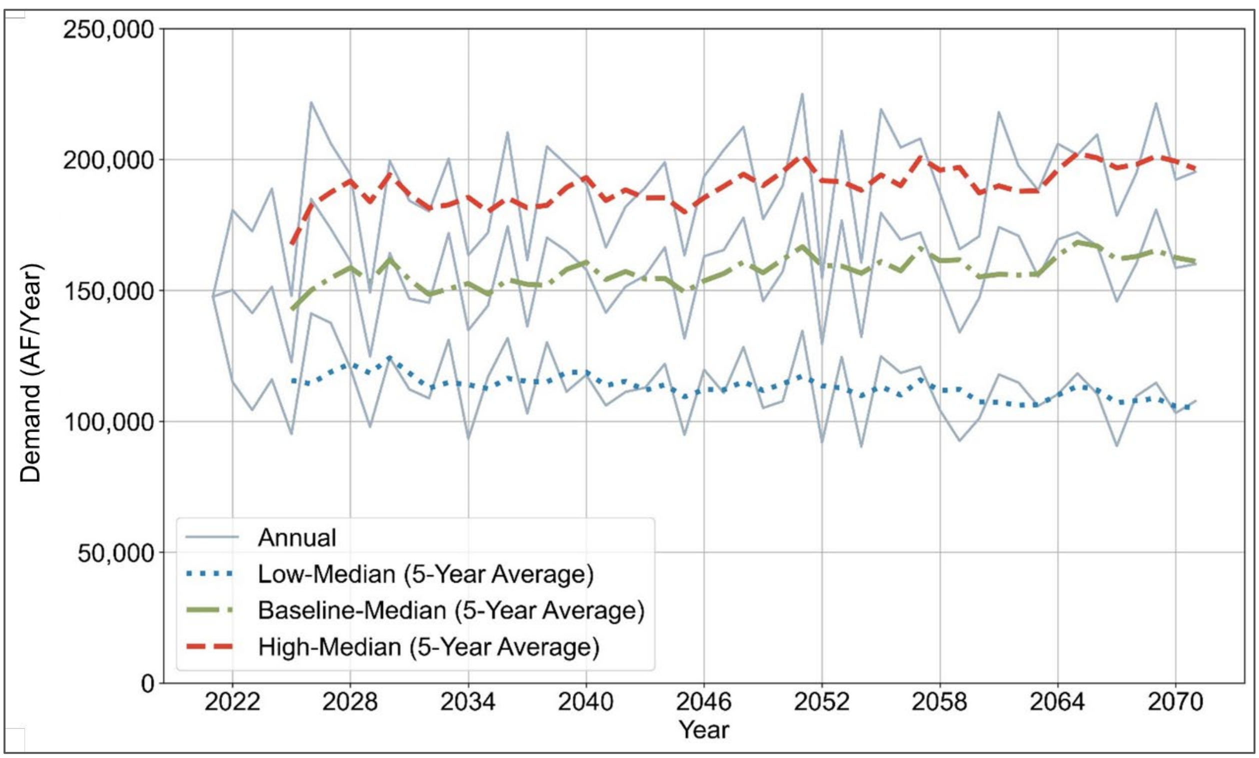


Figure 4-12. Annual Results of the Low, Baseline, and High Demand Scenarios, for Median Hydrologic Conditions (2022–2071)

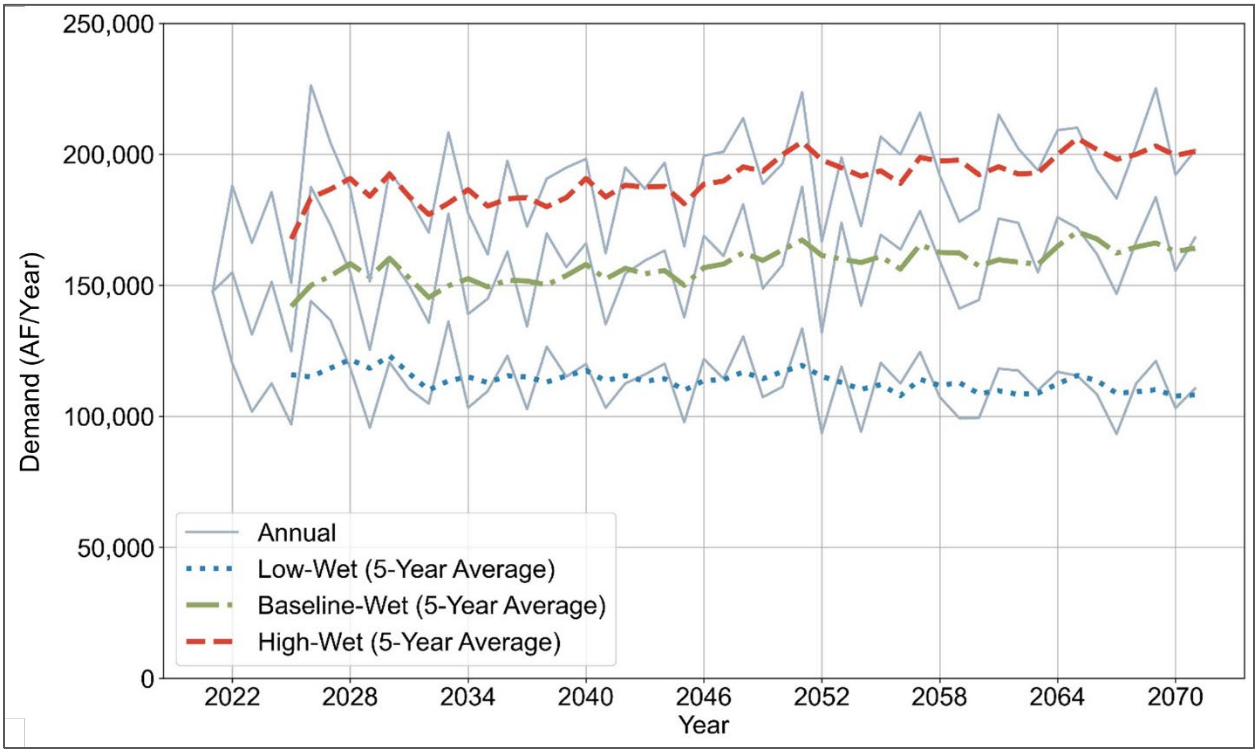


Figure 4-13. Annual Results of the Low, Baseline, and High Demand Scenarios, for Wet Hydrologic Conditions (2022–2071)

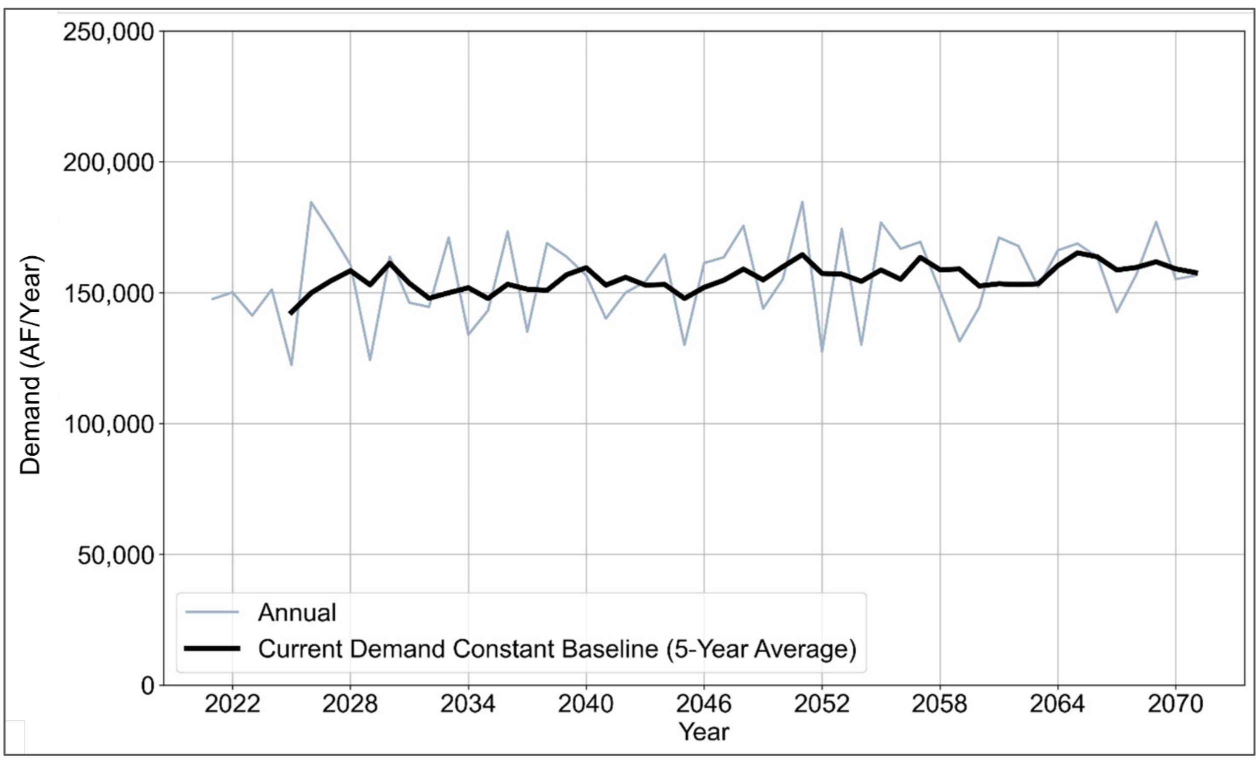


Figure 4-14. Annual Results of the Current Demand Constant Baseline Scenario (2022–2071)

Chapter 5. Operations Model

A reservoir operations model was developed that simulates how NID operates its current storage, conveyance, and delivery system. The operations model uses inflows from the hydrology model, current operating rules, and regulations to assess how well customer demands are met.

NID operations were simulated using a wide range of conditions, including historical conditions, current baseline operations, demands (low, median, and high), and climate (dry, median, and wet). Three future scenarios were selected for evaluation of potential PFW strategies.

- Dry Future Climate with High Demands
- Median Future Climate with Baseline Demands
- Wet Future Climate with Low Demands

These scenarios provide dry and wet bookends with a median climate scenario to represent a plausible mid-point. Use of these scenarios provides a wide range of hydrologic conditions and consumptive demands; the scenarios are suitable for testing the strategic alternatives.

5.1. Historical Inflow Hydrology

Historical inflow hydrology is needed for the calibration of the reservoir operations model and for the development of modeling studies that simulate current facilities and operations over historical inflow hydrology. No facilities in the project area have directly gaged inflows, so inflows need to be calculated or estimated using established hydrologic methods.

5.1.1. Methods

Most reservoirs in the project area do not have sufficient gaging to perform a mass balance calculation to determine inflows. Historical watershed inflows in the project area are estimated using a paired-basin approach, and these estimated inflows are compared to mass balance calculations where available to validate the paired-basin method.

The paired-basin approach used for these historical inflows is the same as that developed for the Yuba-Bear Drum-Spaulding Federal Energy Regulatory Commission (FERC) relicensing process and further refined for additional efforts since the relicensing. The approach is described in detail in NID's 2020 Raw Water Master Plan Hydrological Analysis Technical Memorandum, Appendix B (NID 2020).

5.1.2. Validation

The estimated historical inflow hydrology developed with the paired-basin approach is compared to mass balance calculations for reservoirs where sufficient data exist over a time when gage periods of record overlap. Average annual unimpaired flow is shown in Table 5-1. The comparison for Jackson Meadows Reservoir is shown in Figure 5-1. The comparison for Bowman Reservoir is shown in Figure 5-2. The comparison for Lake Spaulding is shown in Figure 5-3. The comparison for Scotts Flat Reservoir is shown in Figure 5-4.

Table 5-1. Average Annual Unimpaired Flow Comparisons for Historical Hydrology

Watershed	Paired-Basin Estimate (AF)	Mass Balance Calculation (AF)
Jackson Meadows Reservoir	78,477	78,847
Bowman Reservoir	84,705	90,827
Lake Spaulding	340,966	316,177
Scotts Flat Reservoir	19,394	20,537

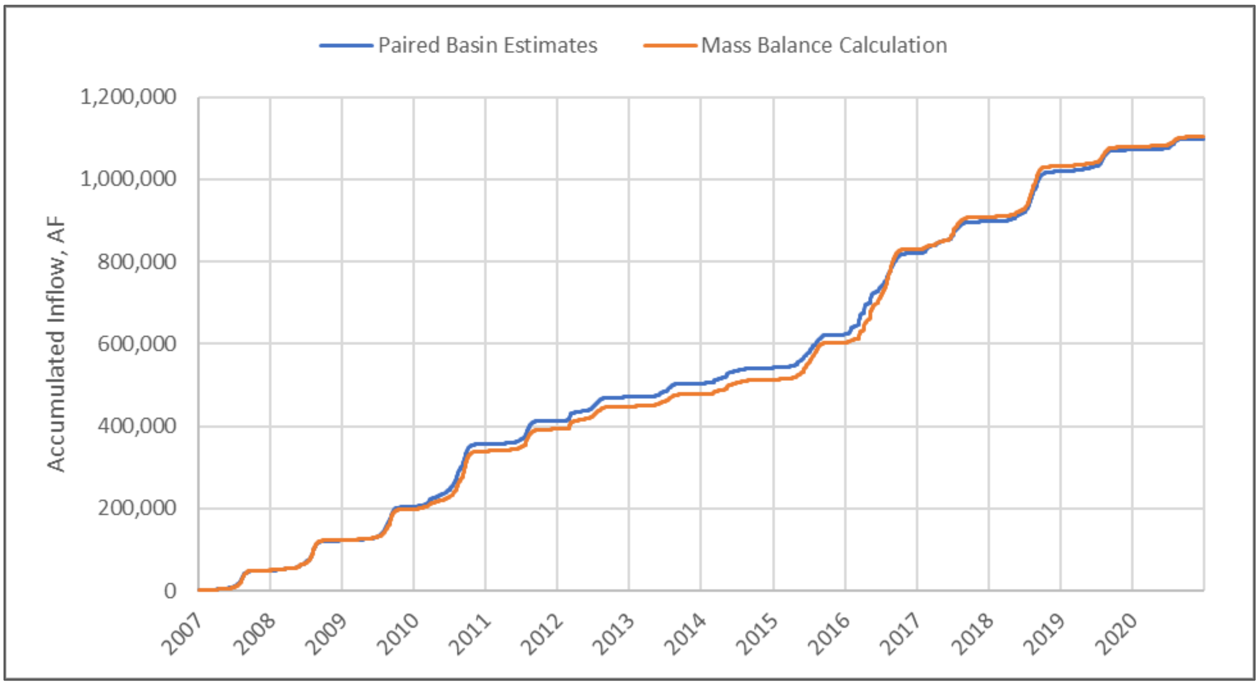


Figure 5-1. Accumulated Inflow Calculations, Jackson Meadows Reservoir, WYs 2008–2021

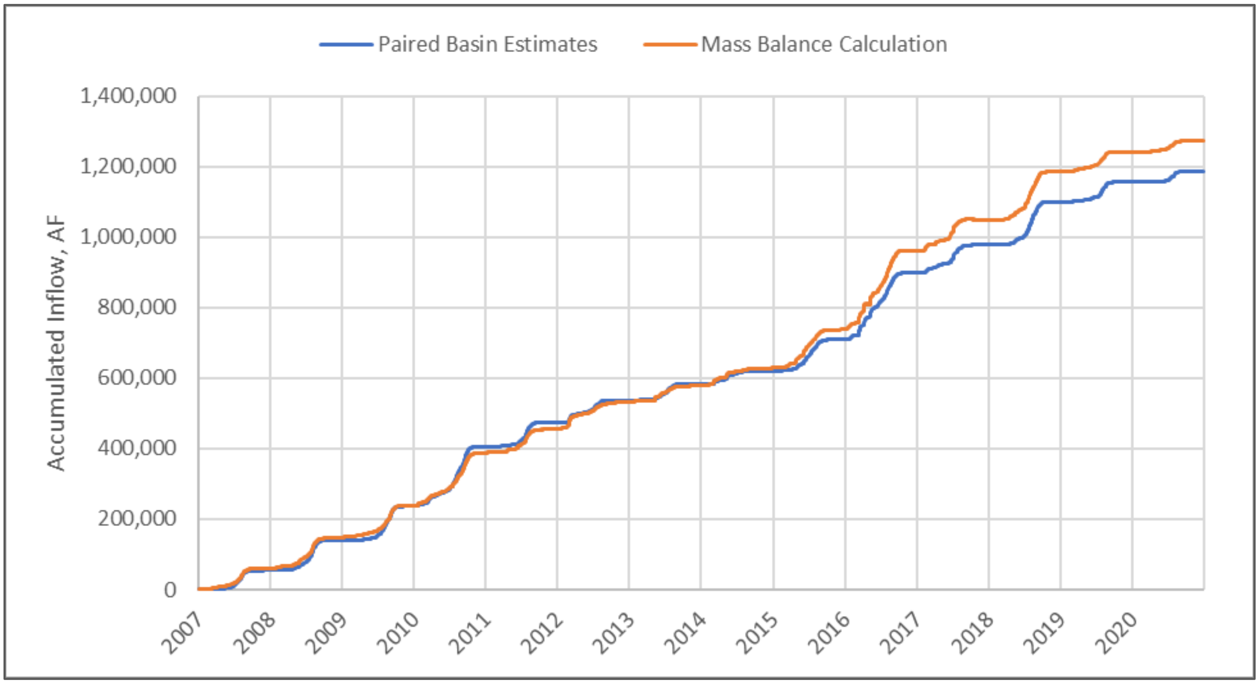


Figure 5-2. Accumulated Inflow Calculations, Bowman Reservoir, Water Years 2008–2021

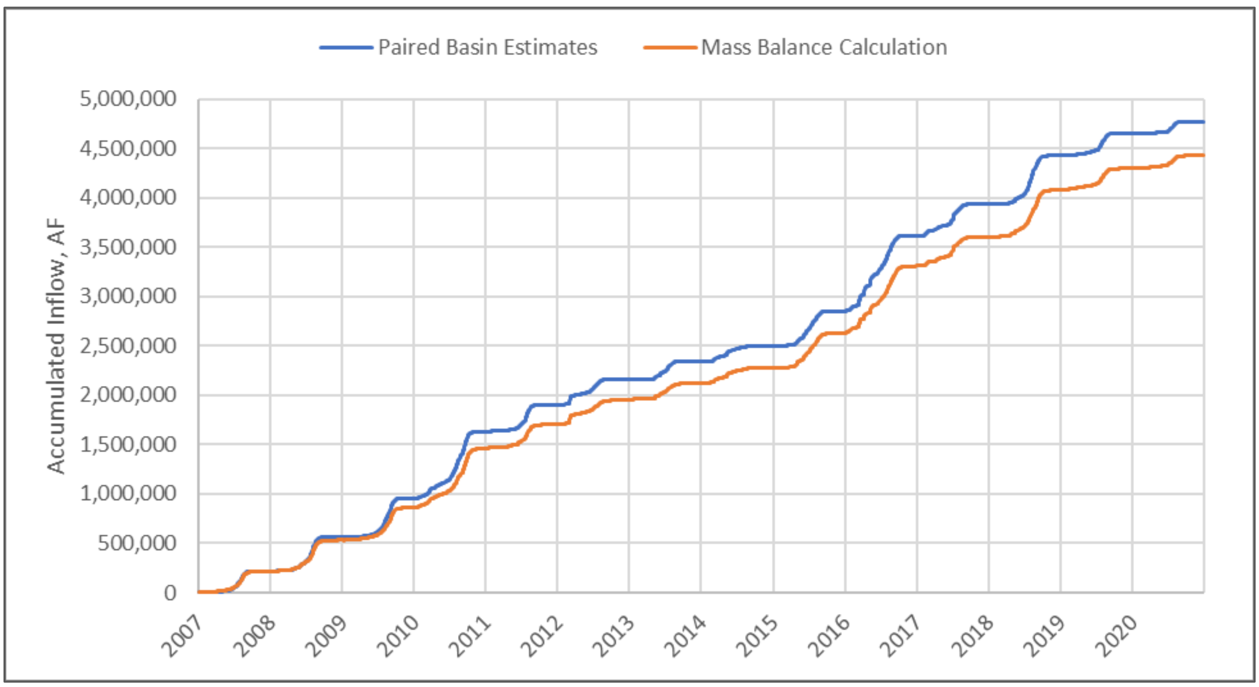


Figure 5-3. Accumulated Inflow Calculations, Lake Spaulding, Water Years 2008–2021

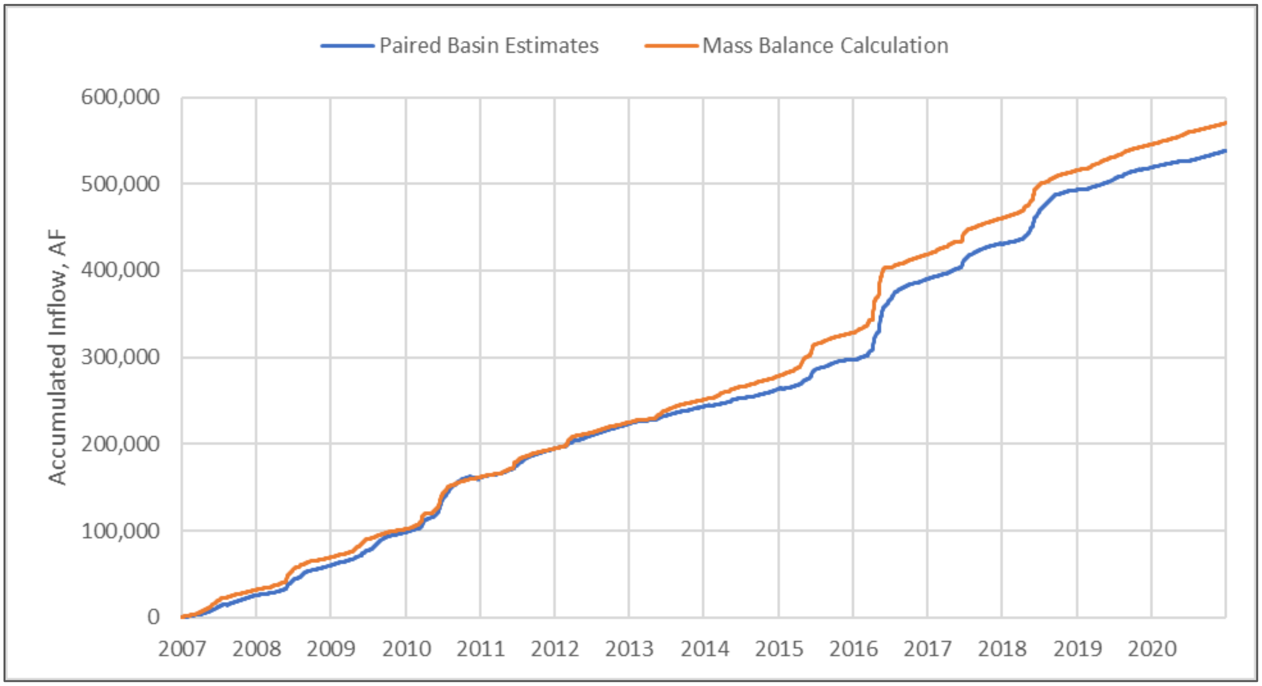


Figure 5-4. Accumulated Inflow Calculations, Scotts Flat Reservoir, Water Years 2008–2021

5.2. Recent Historical Deliveries

Recent historical deliveries were developed for model calibration and for modeling Placer County Water Agency (PCWA) demands[1]. To develop recent historical demand sets, the daily average delivery was calculated at each demand node. The gages used for each demand node are listed in Table 5-2. An example of the average delivery calculation for PCWA's Boardman canal is shown in Figure 5-5, and an example of the average delivery calculation for NID's delivery from Lake Combie is shown in Figure 5-6.

Table 5-2. Gages Used in Calculating Historical Deliveries

Model Demand Node	Diversion Location	Gages Used for Calculation*
NID-1	Rock Creek Reservoir	YB-64 + YB-86 + YB-108 + YB-255
NID-2	Auburn Ravine	YB-132 + YB-136 + YB-259
NID-3	Lake Combie	BR-301 + BR-311
NID-4	Cascade Canal	DC-102
NID-5a	DS Canal	DC-145
NID-5b	Newtown Canal	DC-131
NID-5c	Tunnel Canal	DC-140
PCWA-1	Lake Arthur	YB-184 + YB-95 – YB-288
PCWA-2	Halsey Forebay	YB-56 + YB-87 + YB-288
PCWA-3	Rock Creek Reservoir	YB-69
PCWA-4	Wise Forebay	YB-73

[1] Data received by email correspondence: from Chirs Sanderson, Hydrographer at PG&E, on 9/6/2022 and 9/8/2022.

PCWA-5	Auburn Ravine	YB-75 + YB-76 + YB-78 + YB-91 + YB-278

* Note: gage codes follow NID, PG&E and PCWA gage codes. These agencies group their gages by projects (YB=Yuba Bear System, DC=Deer Creek System, BR = Bear River)

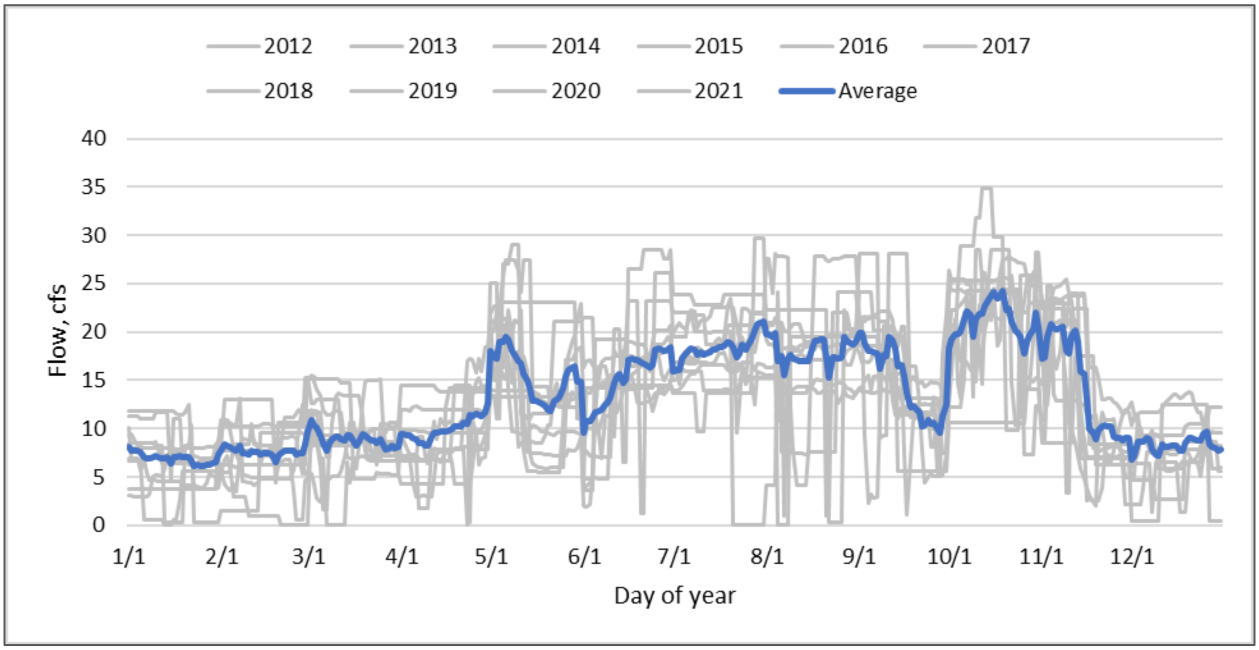


Figure 5-5. Historical Deliveries in Boardman Canal

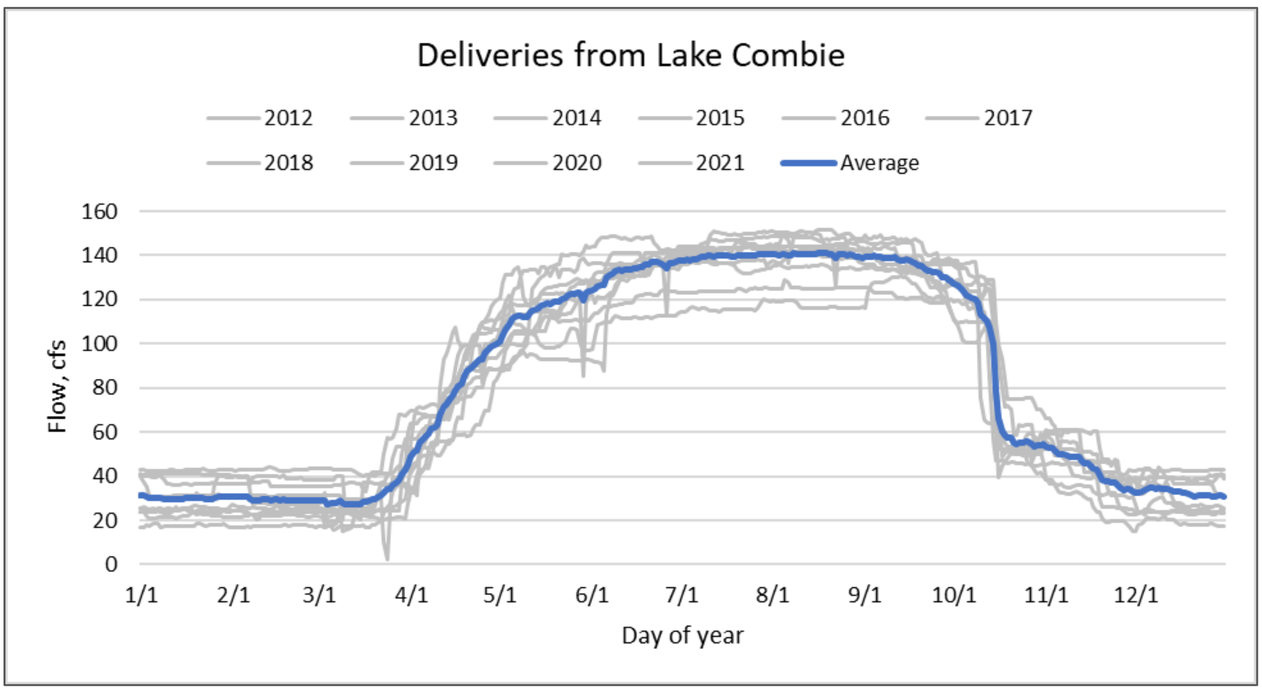


Figure 5-6. Historical Deliveries from Lake Combie

5.3. USACE Hydrologic Engineering Center ResSim Model

5.3.1. Description of the Software Package

The HEC-ResSim software is developed by the USACE HEC and is used to model reservoir operations for reservoir systems. The software is widely used for water supply and flood management in planning studies. The model features rule-based operations that attempts to reproduce the decision-making process that reservoir operators use in reservoir management. The software is Java-based and allows the user to write scripts in Jython, an implementation of the python programming language in Java, which augments the model's flexible rule structures.

5.3.2. Selection Rationale

The HEC-ResSim modeling software is widely used throughout California to model hydropower and water supply projects. The software has all the features needed to model NID's system; previous models of NID's system have been built on HEC-ResSim, making it easier to incorporate previous work done to refine the modeling of NID's system.

5.4. Model Development

5.4.1. Rebuild in Current ResSim Software Version

The latest version of HEC-ResSim is version 3.3, released in 2021, and the NID FERC relicensing model was built in HEC-ResSim version 3.0, released in 2007. Models built in version 3.0 cannot run using the latest ResSim software. Given the software incompatibility issue, the model had to be rebuilt in the current software version. Rules and facility information from the previous model were imported into the new model version, and Jython scripts were written to automate some input and output processing that was previously done in spreadsheets before and after a modeling study was run.

5.4.2. Model Facilities

Reservoirs that are modeled with usable storage are listed in Table 5-3. Additional reservoirs are included in the model that do not have usable storage, such as diversion dams, forebays, and afterbays, which are modeled as nodes or modeled as full at all times.

5.4.2.1 Reservoirs Modeled

Table 5-3. Reservoirs Modeled in the Reservoir Operations Model

Reservoir	Modeled Storage Capacity (AF[1])
Jackson Meadows Reservoir	67,435
French Lake	13,940
Faucherie Lake	3,740
Sawmill Lake	3,030
Jackson Lake	1,330
Bowman Reservoir	66,722
Upper Rock Lake	207

Lower Rock Lake	48
Culbertson Lake	953
Upper Lindsey Lake	17
Middle Lindsey Lake	110
Lower Lindsey Lake	289
Feely Lake	739
Carr Lake	150
Blue Lake	1,186
Rucker Lake	648
Kidd Lake	1,505
Upper Peak Lake	1,697
Lower Peak Lake	484
White Rock Lake	570
Meadow Lake	4,841
Lake Sterling	1,824
Fordyce Lake	49,426
Lake Spaulding	74,890
Kelly Lake	334
Lake Valley Reservoir	7,902
Rollins Reservoir	55,140
Lake Combie	2,790
Rock Creek Reservoir	319
Scotts Flat Reservoir	43,143

[1]Storage Capacity includes normal operating capacity with spill gates closed or flashboards in place and does not include additional reservoir space above spillway in which the reservoir may surcharge during times of high inflow.

5.4.2.2 Demand Nodes

The model has diversions for consumptive demands at seven locations for NID and five locations for PCWA, shown in Table 5-4.

Table 5-4. Model Consumptive Demand Nodes

Model ID	Diversion	Diversion Location
NID-1	North Auburn WTP and Combie-Ophir Canal	Rock Creek Reservoir
NID-2	Auburn Ravine	Auburn Ravine
NID-3	Combie Phase I and Magnolia Canals	Lake Combie
NID-4	Cascade Canal	Deer Creek
NID-5a	DS Canal	Deer Creek
NID-5b	Newtown Canal	Deer Creek
NID-5c	Tunnel Canal	Deer Creek
PCWA-1	Boardman Canal	Lake Arthur
PCWA-2	Ragsdale and Bowman Canals	Halsey Forebay
PCWA-3	Middle Fiddler Green Canal	Rock Creek Reservoir
PCWA-4	Lower Fiddler Green Canal	Wise Forebay
PCWA-5	Auburn Ravine and Dutch Ravine	Auburn Ravine

5.4.2.3 Conduit Capacities

Table 5-5 lists the canals and conduits that are explicitly modeled in the reservoir operations model.

Table 5-5. Conduit Capacities and Loss Rates

Conduit	Capacity (cfs)	Modeled Loss Rate
Milton-Bowman Conduit	425	0
Bowman-Spaulding Conduit		
At Bowman Reservoir	300	0
–Below Texas Creek Div Dam	300	0
–Below Clear Creek Div Dam	310	0
–Below Fall Creek Div Dam	320	0
–Below Trap Creek Div Dam	325	0
–Below Rucker Creek Div Dam	325	0
Spaulding Powerhouse No 1	645	0
Spaulding Powerhouse No 2	200	0
Spaulding Powerhouse No 3	334	0
Drum Canal	840	7.8%
Bear River Canal	470	6.9%
Wise Canal	488	0
South Canal	395	0
South Yuba Canal	90	14.3%
Chalk Bluff Canal	85	0[1]
Deer Creek Powerhouse	110	0
Towle Canal	42	12%
Pulp Mill Canal	25	0
Boardman Canal	58	0
Lake Valley Canal	24	0

[1]14.3% loss rate modeled in the South Yuba Canal is the combined loss for South Yuba Canal and Chalk Bluff Canal.

5.4.3. Significant Changes from the Previous NID ResSim Model

5.4.3.1 Lake Valley Canal Capacity

The Lake Valley Canal was piped in 2014, resulting in less capacity to move water to the Drum Canal. The model was updated to reflect this lowered capacity. The updated model uses a capacity of 26 cfs, while previous models have used a capacity of 36 cfs. Average daily flow in the Lake Valley Canal over three time periods is shown in Figure 5-7. An ensemble of daily flow rates in the Lake Valley Canal for 2016–2021 is shown in Figure 5-8, demonstrating that flow rates rarely exceed 26 cfs.

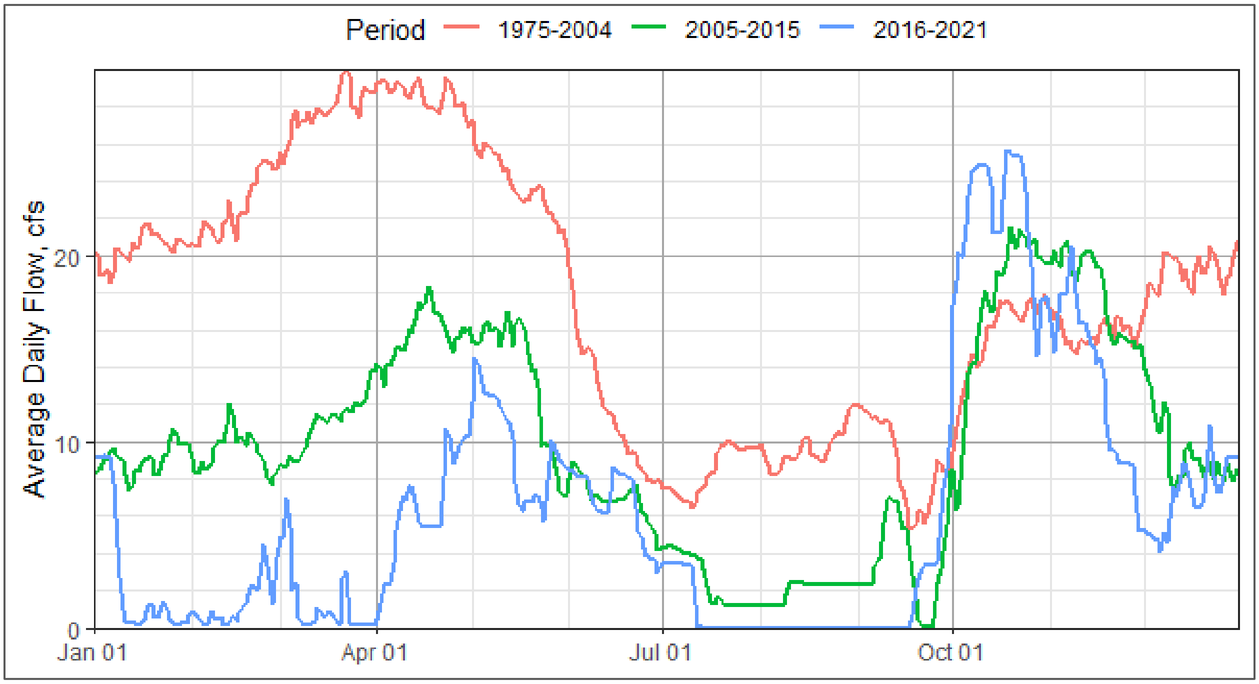


Figure 5-7. Lake Valley Canal Historic Daily Average Flow

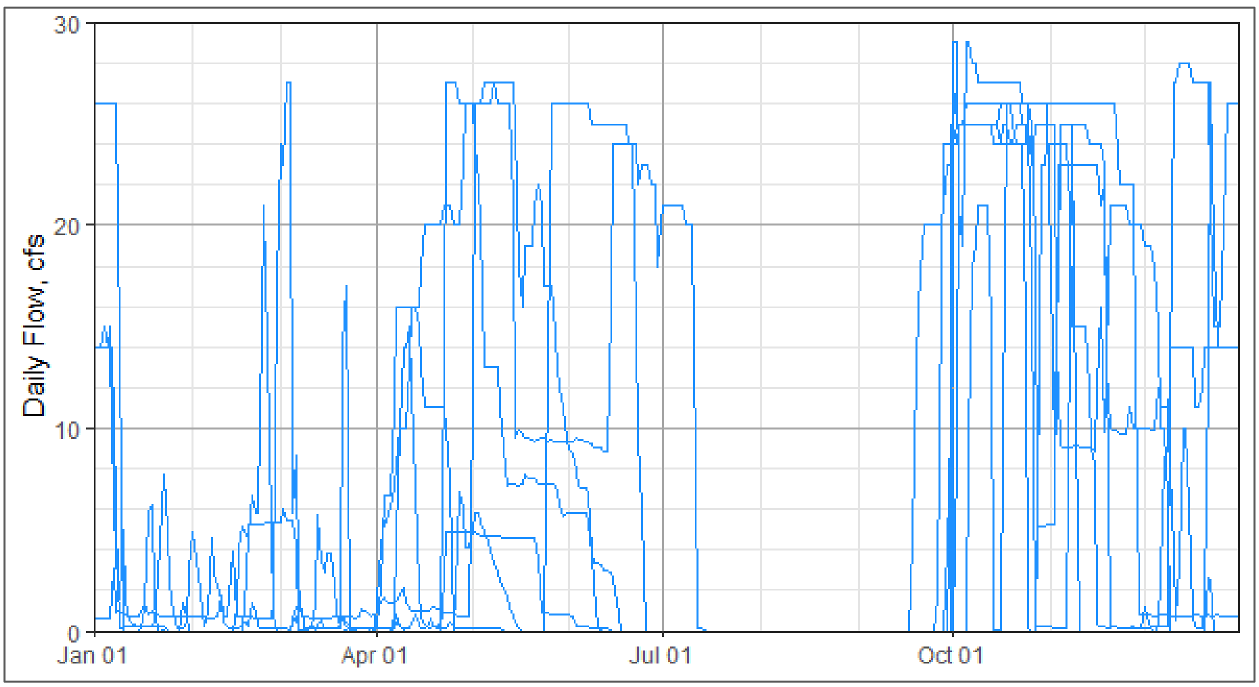


Figure 5-8. Lake Valley Canal Flow Ensemble, 2016–2021

5.4.3.2 Fordyce Lake Seepage (Increase in Seepage Estimate from 2020 SWRCB Document)

Previous modeling had seepage from Fordyce Lake up to a maximum of 24 cfs at full pool. In their Fordyce Lake Seepage Mitigation Project, Pacific Gas & Electric (PG&E) has estimated that Fordyce Lake seepage ranges from 24 to 60 cfs (SWRCB 2020). Historic data were analyzed to estimate the relationship between seepage and reservoir water surface elevation. The resulting relationship is shown in Figure 5-9 which shows that flow below Fordyce Dam increases with increasing water surface elevation above water surface elevations of around 6310 feet. Since minimum flow requirements and discretionary releases are not based on water surface elevations, this near-linear increase in flow below Fordyce Dam is likely due to increased seepage as reservoir head increases.

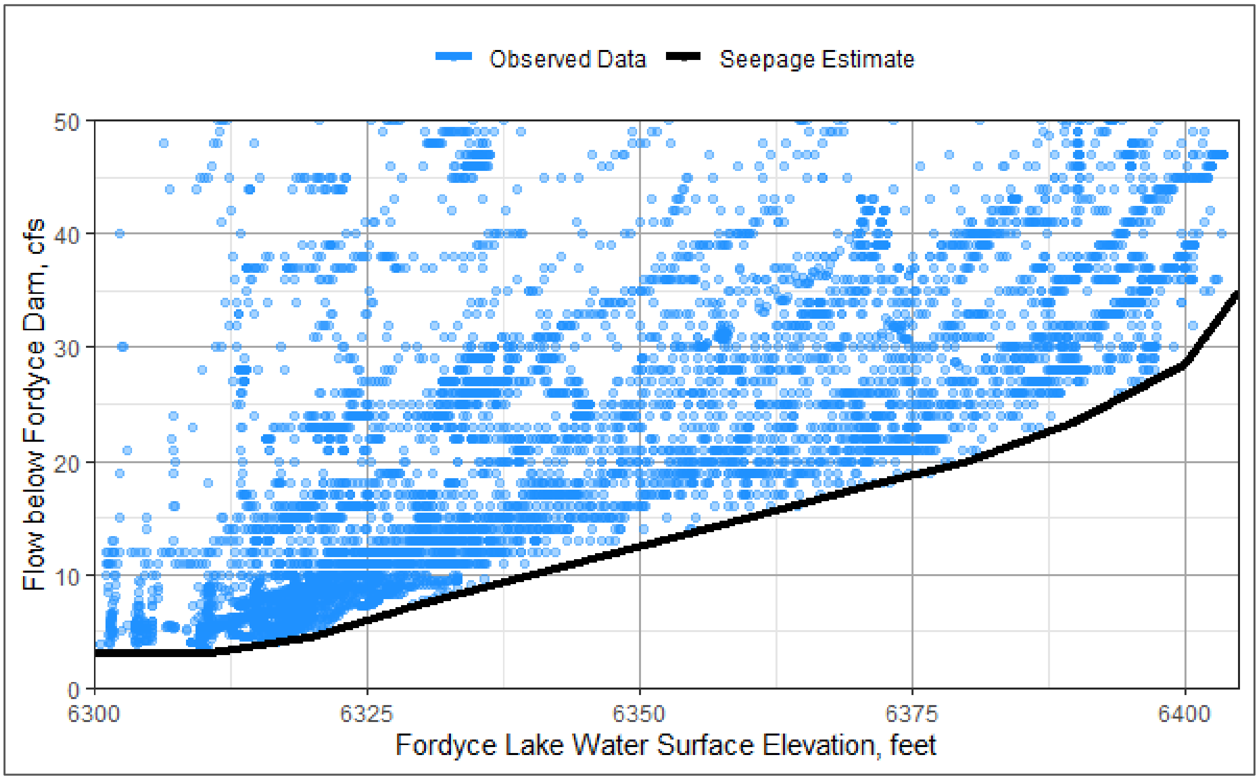


Figure 5-9. Fordyce Dam Seepage Estimate

5.4.4. Implementation of the Integrated Red-Blue Model

The model simulates the integrated operations of NID's Yuba-Bear Project, PG&E's Drum-Spaulding Project, PG&E's Deer Creek Project, and some non-FERC facilities that receive water from FERC projects. A system of tracking the ownership of NID and PG&E water throughout the projects is needed to properly process results. In the FERC relicensing process, this tracking was implemented in a post-processing spreadsheet named the "YB and DS Water Allocation Module" (Red-Blue Spreadsheet), which instituted a "water coloring" scheme where NID water is blue and PG&E water is red. This spreadsheet necessitated a workflow in which the ResSim model results do not correctly track water ownership and the true ownership was calculated in the Red-Blue Spreadsheet. Because the model did not have access to the ownership calculations, it could not implement restrictions on diversions based on ownership.

The updated model integrates ownership calculations into the model code. This allows for the model to make decisions based on ownership during runtime. The model assigns the ownership of water using the definitions contained in the COA between NID and PG&E (NID 2018). The model tracks ownership of water at the following locations:

- **Inflow to Lake Spaulding:** NID owns all water diverted into the Bowman-Spaulding Conduit at the Bowman Diversion Dam. PG&E owns Texas-Fall Creek Water diverted into Lake Spaulding between July 1 and November 30, up to 30 cfs and up to 3,500 AF/year. NID owns the remaining Texas-Fall Creek Water diverted into Lake Spaulding.
- **Head of South Yuba Canal:** All water in the South Yuba Canal that flows past the South Yuba Waste Gate is NID water.
- **Head of Drum Canal:** NID water in the Drum Canal is equal to NID inflows to Lake Spaulding minus NID flow in the South Yuba Canal. The remaining flow in the Drum Canal is PG&E water.
- **Inflow to Rollins Reservoir:** NID imports to Rollins Reservoir are equal to NID water in the Drum Canal minus a 7.8% canal loss. PG&E imports to Rollins Reservoir are equal to PG&E water in the Drum Canal plus diversions into the Lake Valley Canal minus a 7.8% canal loss, minus water diverted from Drum Forebay into Canyon Creek. PG&E diversions through the South Yuba Waste Gate or the Drum Canal Waste Gate are considered additional PG&E imports to Rollins Reservoir. PG&E natural flow into Rollins Reservoir is equal to the first 350 cfs of Bear River runoff into Rollins Reservoir. NID natural flow into Rollins Reservoir is any Bear River runoff into Rollins Reservoir in excess of 350 cfs.
- **Outflow from Rollins Reservoir:** Diversions from Rollins Reservoir into the Bear River Canal are determined from PG&E and NID demands along the canal. Releases from Rollins Reservoir that flow past the Bear River Diversion Dam are considered NID water.
- **Storage in Rollins Reservoir:** Change in storage in Rollins Reservoir for each storage account is calculated as Inflow minus outflow minus a fraction of evaporation equal to the fraction of each account's storage to the total storage volume.
- **Bear River Canal:** NID delivers any NID water diverted into the Bear River Canal minus a 6.9% canal loss. Remaining water in the Bear River Canal is PG&E water. Any minimum flow releases out of the Bear River Canal at Rock Creek or Dry Creek are from PG&E.

The model enforces the following restrictions based on ownership of water:

- NID diversions to the South Yuba Canal must be less than or equal to NID inflows to Lake Spaulding. As outlined in the COA, there is an exception to this restriction during the Bowman-Spaulding Conduit outage period.
- NID diversions to the Bear River Canal must be less than or equal to NID inflow to Rollins Reservoir plus NID storage in Rollins Reservoir minus minimum flow requirements below the Bear River diversion Dam.
- PG&E diversions to the Bear River Canal must be less than or equal to PG&E inflow to Rollins Reservoir plus PG&E storage in Rollins Reservoir.

5.4.5. Historical Conditions Model

The model was used to develop a simulation using historical inflow hydrology, recent historical consumptive demands, and regulatory requirements from the existing FERC licenses over a historical period of record covering water years 1976–2021. These modeling studies were calibrated to the last 10 years of record, water years 2012–2021.

5.4.6. Model Calibration and Validation

A model that is built with existing facility characteristics, historical hydrology, historic deliveries, and historic regulatory requirements should match historic observed data. Errors in historical hydrology estimation, differences between estimated evaporation and historic evaporation, anomalies in historic deliveries that are not modeled (canal collapse, etc.), anomalies in the meeting of regulatory requirements that are not modeled (variances obtained from FERC, accidental non-compliance, etc.), and errors or low precision in observed gage data will all cause the model to deviate from historic observed data. The process of calibrating a reservoir operations model is to find deviations from observed data and identify the cause to verify that the model is working correctly but is not meant to model the errors or anomalies that contribute to the deviation from observed data.

Additionally, at some reservoirs, releases are made to provide discretionary generation, or generation releases that are not required but made strictly for power generation revenue. This can be summer and fall generation in which the discretionary generation is used to generate during times of high prices, or winter and spring generation, in which the discretionary generation is made to make some revenue instead of reservoir spills. Discretionary generation is often scheduled in near real-time using estimates available in the moment that have a degree of uncertainty (weather forecasts, inflow forecasts, power price forecasts) and those decisions are difficult to reconstruct when building a planning model. Calibrating a model to these discretionary generation releases is generally a process of taking an average over a few variables (by month, by water year type, by reservoir elevation) and making a generalized rule that fits some years' observed data better than others.

Most reservoirs in the model match observed data well. An example of one of these reservoirs is shown in Figure 5-10 for Jackson Meadows Reservoir.

A few of the reservoirs on the Texas-Fall Creek system do not match observed data very well. While there are limited observed data at most of these reservoirs, it is likely that the deviations from observed data are due to the difficulty of creating estimated historical hydrology for these very small watersheds. An example of one of the Texas-Fall Creek reservoirs that do not match historical data is shown in Figure 5-11 for Culbertson Lake.

The large reservoirs that do not match observed data very well are Bowman Reservoir and Lake Spaulding. At both reservoirs this is mostly due to a wide variation in the carryover level in the observed data. The model has a simple rule for carryover level at Bowman Reservoir that does not have as wide a range as observed data. Bowman Reservoir storage calibration is shown in Figure 5-12. The carryover level at Lake Spaulding is mostly driven by discretionary generation, which historically varies year to year based on a variety of factors that are not modeled. One example is that in 2015, Lake Spaulding closed the spill gates in early February, which is much earlier than normal, whereas the model closes the spill gates on April 1 every year. This created a deviation in storage through the end of 2015. Lake Spaulding storage validation is shown in Figure 5-13.

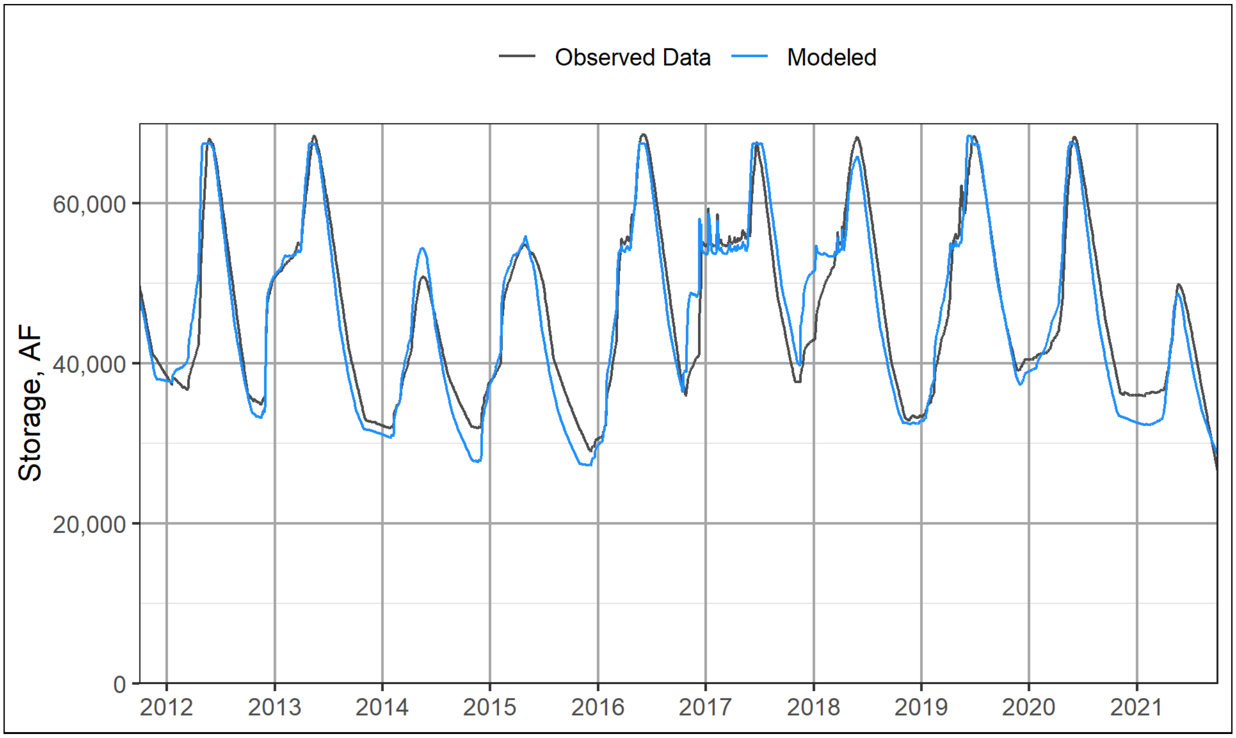


Figure 5-10. Jackson Meadows Reservoir Storage, Water Years 2012–2021

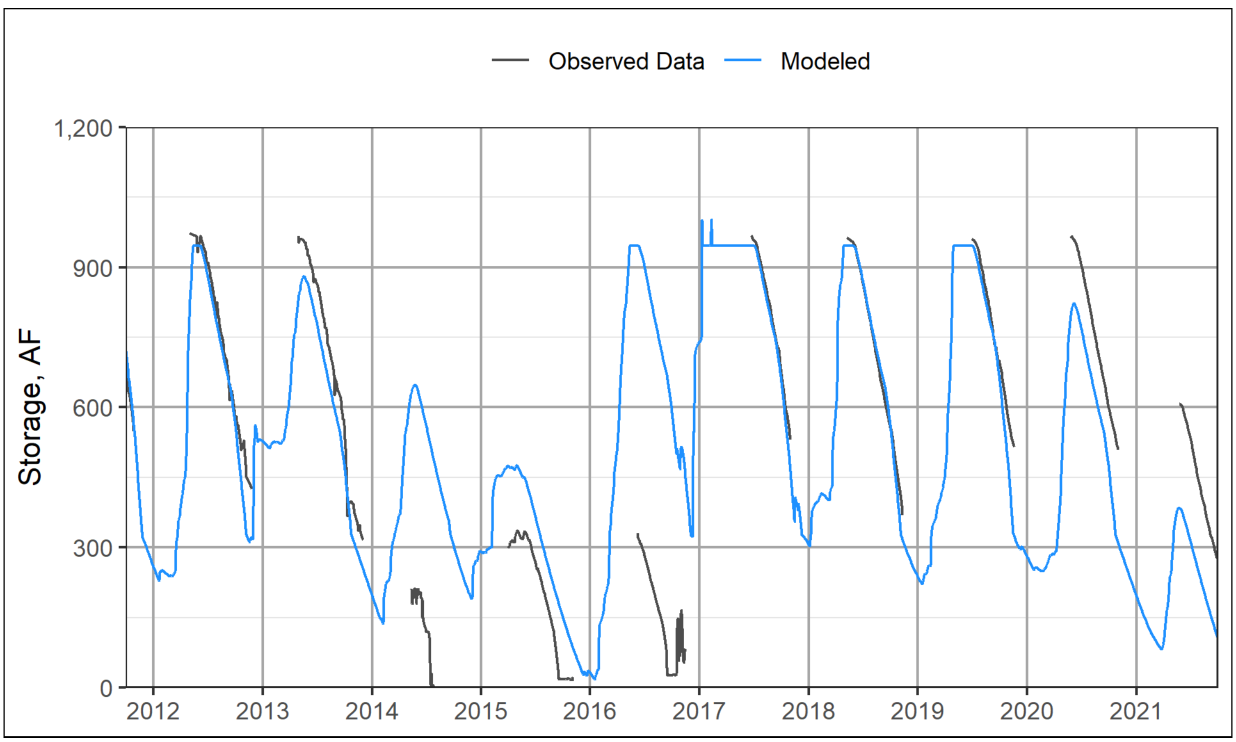


Figure 5-11. Culbertson Lake Storage, Water Years 2012–2021

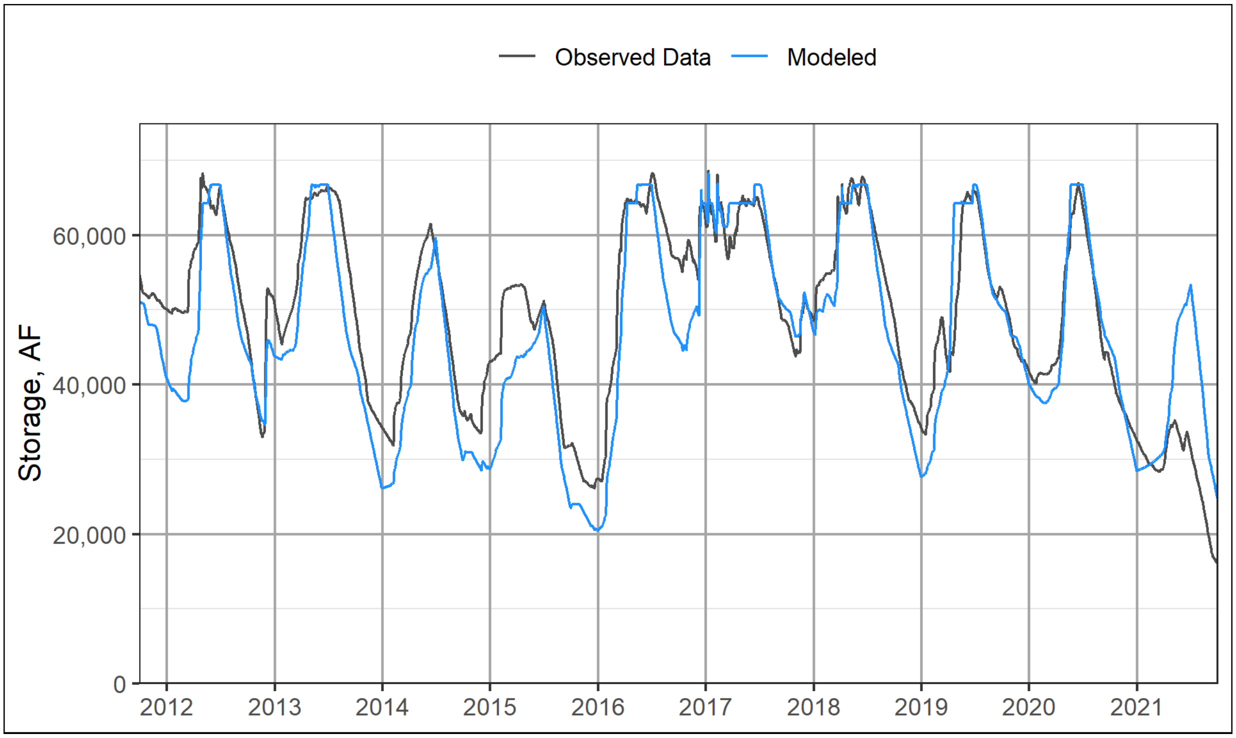


Figure 5-12. Bowman Reservoir Storage, Water Years 2012–2021

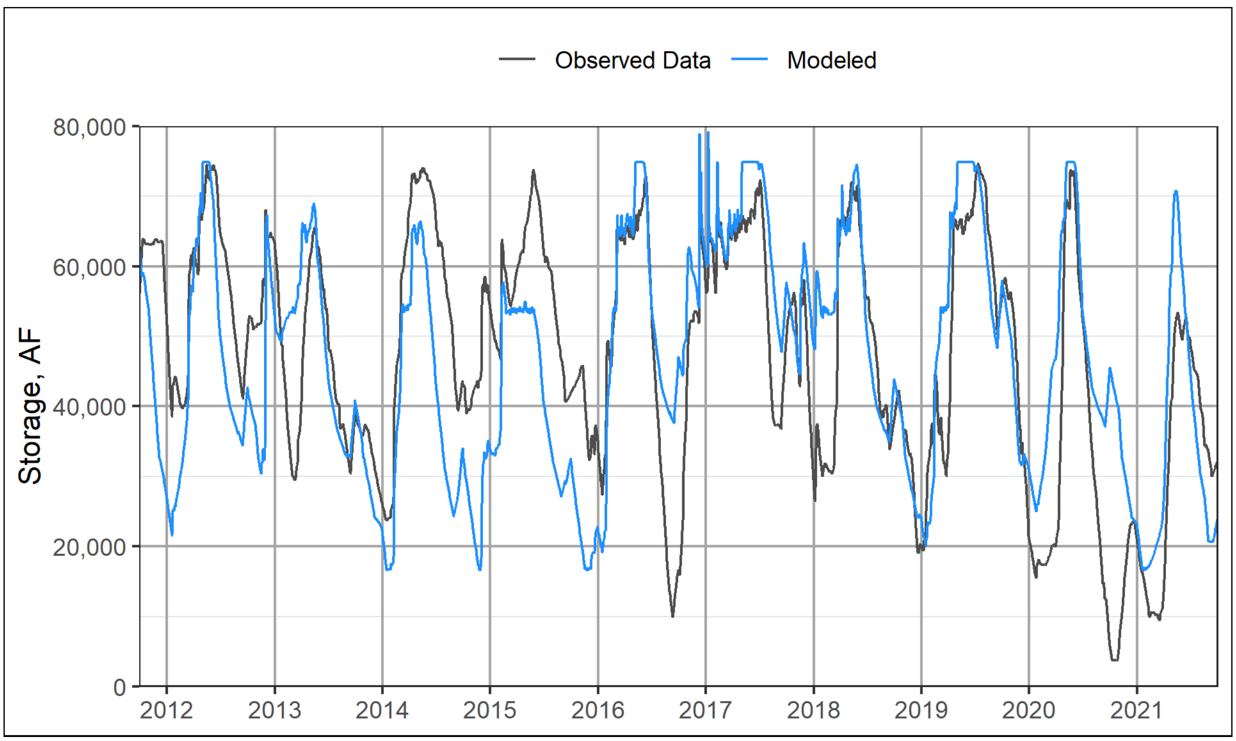


Figure 5-13. Lake Spaulding Storage, Water Years 2012–2021

5.5. Projection Inputs

5.5.1. Integrated Water Flow Model Demand Calculator (IDC) Demands

The model uses demands developed using the DWR's IDC built for NID's service area (NID PFW Demand Model), described in Chapter 4. The NID PFW Demand Model was used to develop 10 demand sets for use in the ResSim model. Annual Demands for these demand sets are summarized in Table 5-6. Annual Demands for each NID demand location in the ResSim model are summarized in Table 5-7.

Table 5-6. Annual Demands from IDC Model

	Dry Climate Bookend	Median Climate Scenario	Wet Climate Bookend
Low Demand	107,657	109,088	109,705
Baseline Demand	149,654	151,806	152,238
High Demand	181,616	183,483	184,638
2022 Demand	N/A	150,100	N/A

Table 5-7. Annual Demands at Each NID Demand Node

Demand Level		Low			Baseline			High		
Climate Bookend		Dry	Med	Wet	Dry	Med	Wet	Dry	Med	Wet
ID	Location	Demands (AF)								
1	Rock Creek Reservoir	3,954	4,018	4,045	6,027	6,135	6,152	7,539	7,664	7,694
2	Auburn Ravine	21,362	21,716	21,900	32,786	33,384	33,526	41,805	42,336	42,653
3	Lake Combie	41,437	42,073	42,379	59,316	60,484	60,567	72,490	73,558	74,033
4	Cascade Canal	15,090	15,120	15,143	17,218	17,210	17,261	18,923	18,887	18,965
5A	DS Canal	14,591	14,910	14,983	21,718	21,981	22,106	27,235	27,424	27,639
5B	Newtown Canal	4,943	4,952	4,951	5,189	5,187	5,194	5,370	5,366	5,377
5C	Tunnel Canal	6,280	6,298	6,303	7,400	7,424	7,433	8,255	8,247	8,277

5.5.2. HEC-HMS Climate Change Hydrology

The HEC-HMS Climate Change Hydrology Model, described in Chapter 2. Hydrological Model, developed three input datasets for the reservoir operations model: (1) a dry bookend scenario, (2) a wet bookend scenario, and (3) a median scenario. These projected hydrology datasets were generated for a 50-year projected period for WYs 2022–2073. The datasets do not predict what will happen, but rather represent what could happen under various climate scenarios. Average annual unimpaired flows in major NID watersheds are summarized for the climate change scenarios in Table 5-8. Average annual unimpaired inflow to all NID reservoirs is shown graphically in Figure 5-14. Daily average unimpaired flow to all NID reservoirs is shown in Figure 5-15 through Figure 5-17.

Table 5-8. Average Annual Unimpaired Flow in NID Watersheds

Unimpaired Flow Location	Average Annual Unimpaired Flow Volume (AF)			
	Historic Hydrology	Dry Climate Scenario	Median Climate Scenario	Wet Climate Scenario
Middle Yuba River at Milton	87,357	67,699	79,470	90,726
Canyon Creek at Bowman	88,811	68,749	82,023	85,097
Deer Creek at Scotts Flat	36,415	14,310	20,822	25,298
Bear River at Lake Combie	171,183	107,410	159,730	193,843
Total Unimpaired Inflow to all NID Reservoirs	383,766	258,168	342,046	394,964

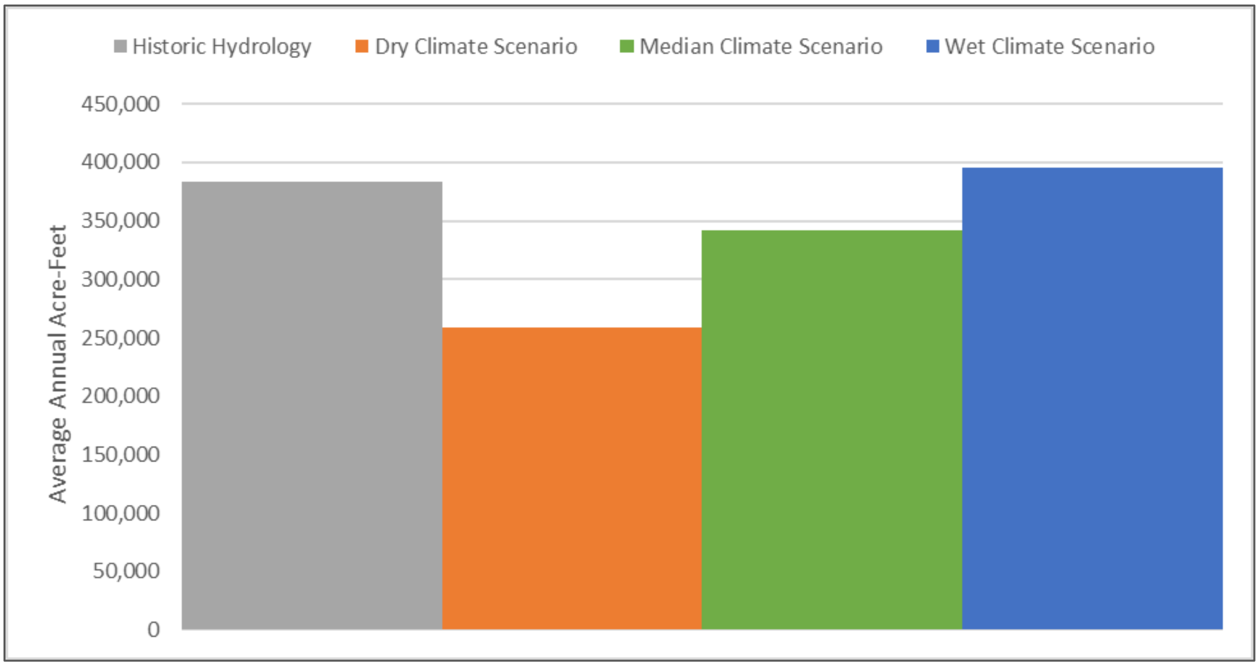


Figure 5-14. Average Annual Unimpaired Inflow to NID Reservoirs in Climate Change Hydrology

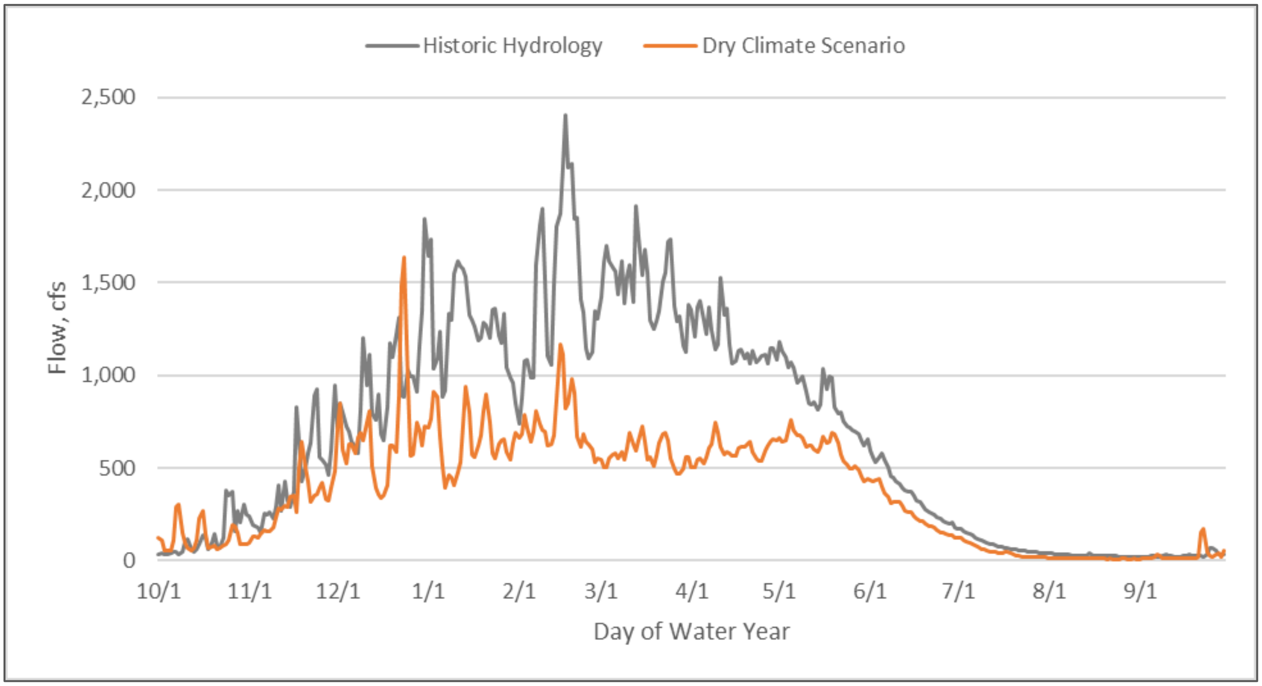


Figure 5-15. Daily Average Unimpaired Inflow to NID Reservoirs in Dry Climate Change Hydrology

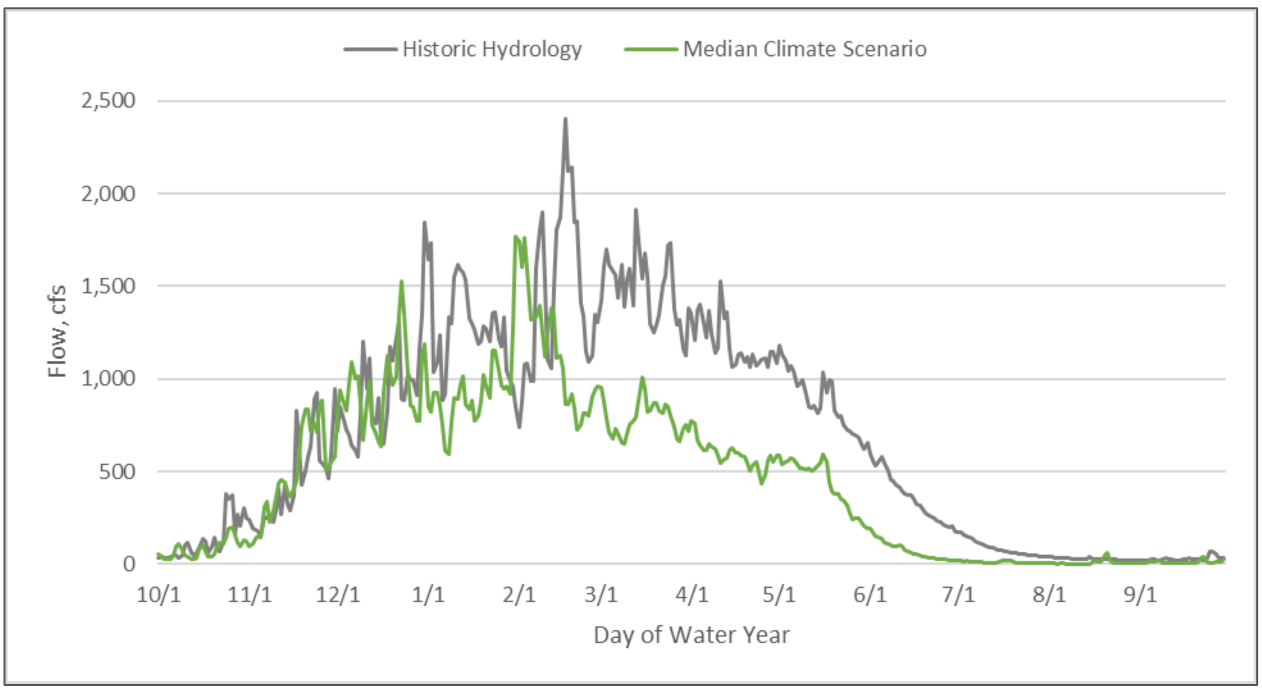


Figure 5-16. Daily Average Unimpaired Inflow to NID Reservoirs in Median Climate Change Hydrology

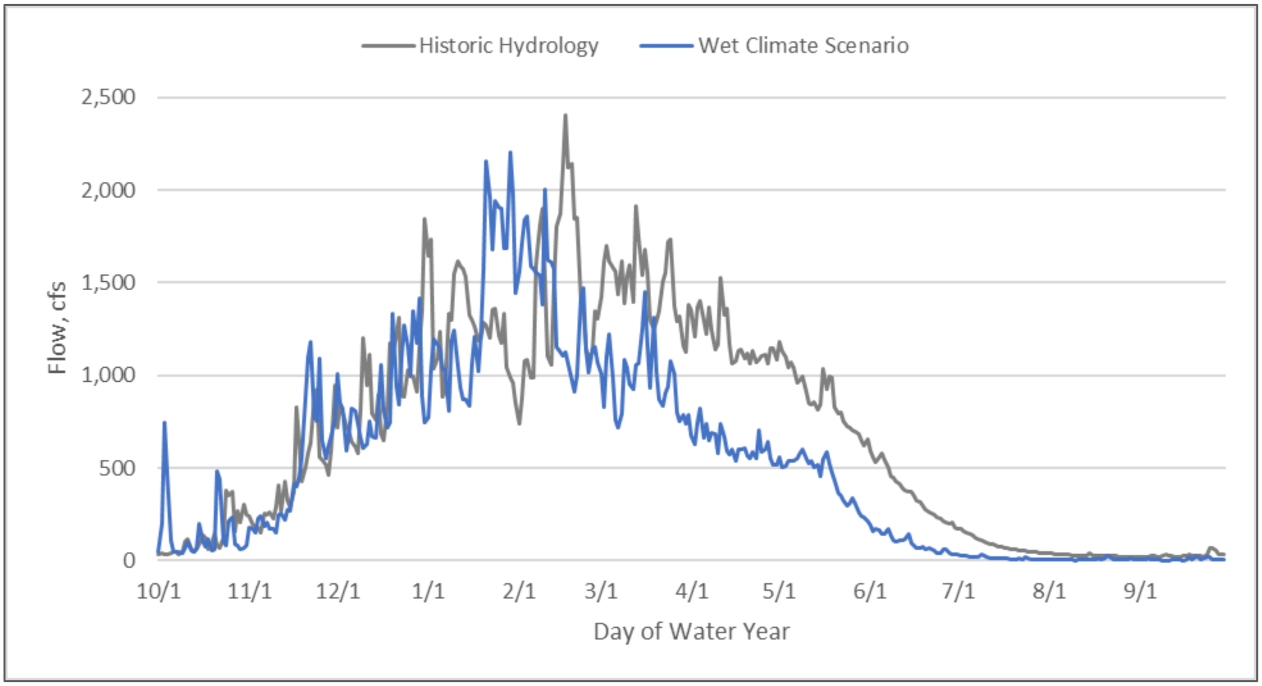


Figure 5-17. Daily Average Unimpaired Inflow to NID Reservoirs in Wet Climate Change Hydrology

5.6. Simulation Results Based on Existing Operations

5.6.1. Assumptions

Existing Operations scenarios were developed that simulate existing operations using each of the projection inputs discussed in Section 5.5. The use of these projection inputs is shown in Table 5-9. The Existing Operations scenarios each contain:

- Future FERC requirements for the Yuba-Bear, Upper Drum-Spaulding, Lower Drum-Spaulding, and Deer Creek Hydroelectric Projects from the 2014 Final Environmental Impact Statement for these projects (FERC 2014).
- 2018 COA accounting mechanisms.
- Existing facilities.
- The current Drought Contingency Plans for both NID deliveries and PG&E deliveries to PCWA.
- Recent historical deliveries are used to estimate PCWA demands.

Table 5-9. Existing Operations Scenario numbering.

	Low Demands	Baseline Demands	High Demands
Dry Climate	1	2	3
Median Climate	4	5	6
Wet Climate	7	8	9

5.6.2. Comparison to Historical Conditions

A modeling study was created to form a basis of comparison for the Existing Operations studies. This modeling study has the following assumptions:

- Historical inflow hydrology discussed in Section 5.1.
- Future FERC requirements for the Yuba-Bear, Upper Drum-Spaulding, Lower Drum-Spaulding, and Deer Creek Hydroelectric Projects from the 2014 Final Environmental Impact Statement for these projects (FERC 2014).
- 2018 COA accounting mechanisms.
- Existing Facilities.
- The current Drought Contingency Plans for both NID deliveries and PG&E deliveries to PCWA.
- Recent historical deliveries are used to estimate NID and PCWA demands.

Direct comparisons of the Existing Operations studies to the historical conditions are not possible due to the different periods of record of the hydrology inputs. Historical hydrology is derived from gage data for the 1976–2021 period. Climate hydrology projection scenarios represent the 2022–2073 period. Comparisons can be made by first calculating daily or annual averages over the respective periods of record. Sections 5.6.2.1 through 5.6.2.4 provide comparisons of selected storage, flows, deliveries, and generation under historic conditions to the climate scenarios using this approach.

5.6.2.1 Reservoir Storage Results

Figure 5-18 shows historic (1976–2021) and projected (2022–2073) average storage for Jackson Meadows as a function of the day of the year under Existing Operations. On average, under climate change, reservoir storage peaks earlier in the season, which is a common feature for all reservoirs due to earlier snow melting. This feature is observed in Figure 5-19 for Bowman Reservoir, Figure 5-20 for Rollins Reservoir, and Figure 5-21 for Scott Flats Reservoir.

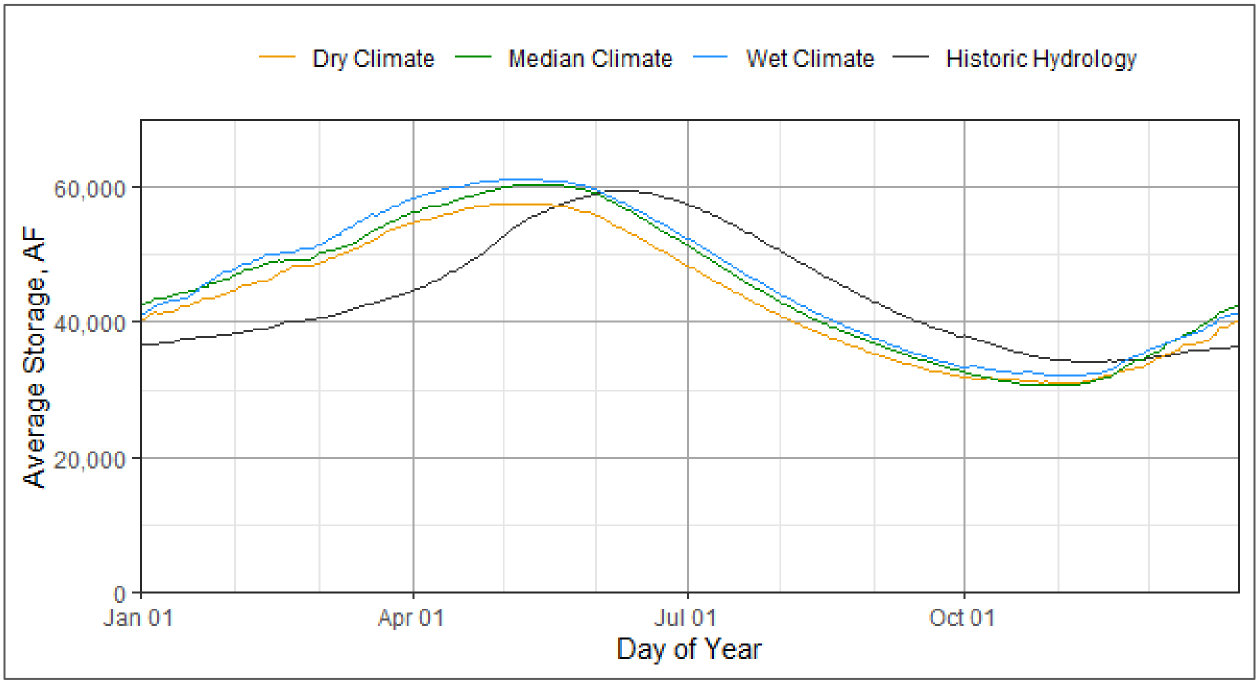


Figure 5-18. Jackson Meadows Reservoir Average Daily Storage, Existing Operations Simulation Results

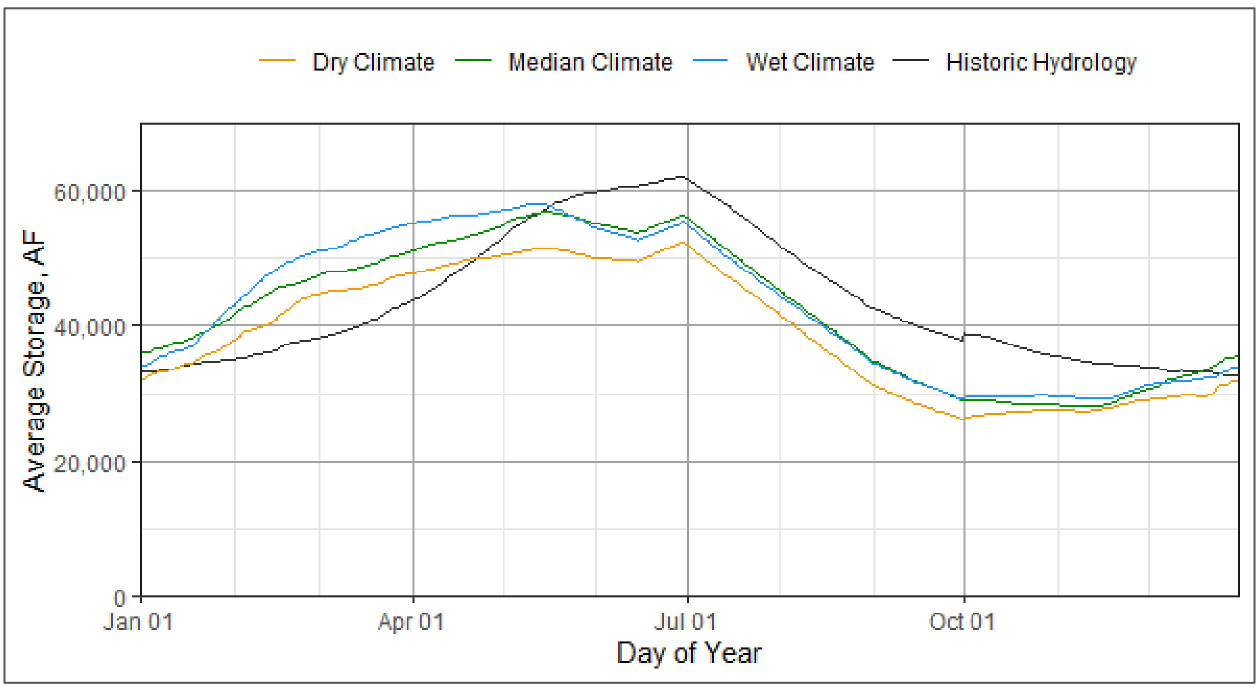


Figure 5-19. Bowman Reservoir Average Daily Storage, Existing Operations Simulation Results

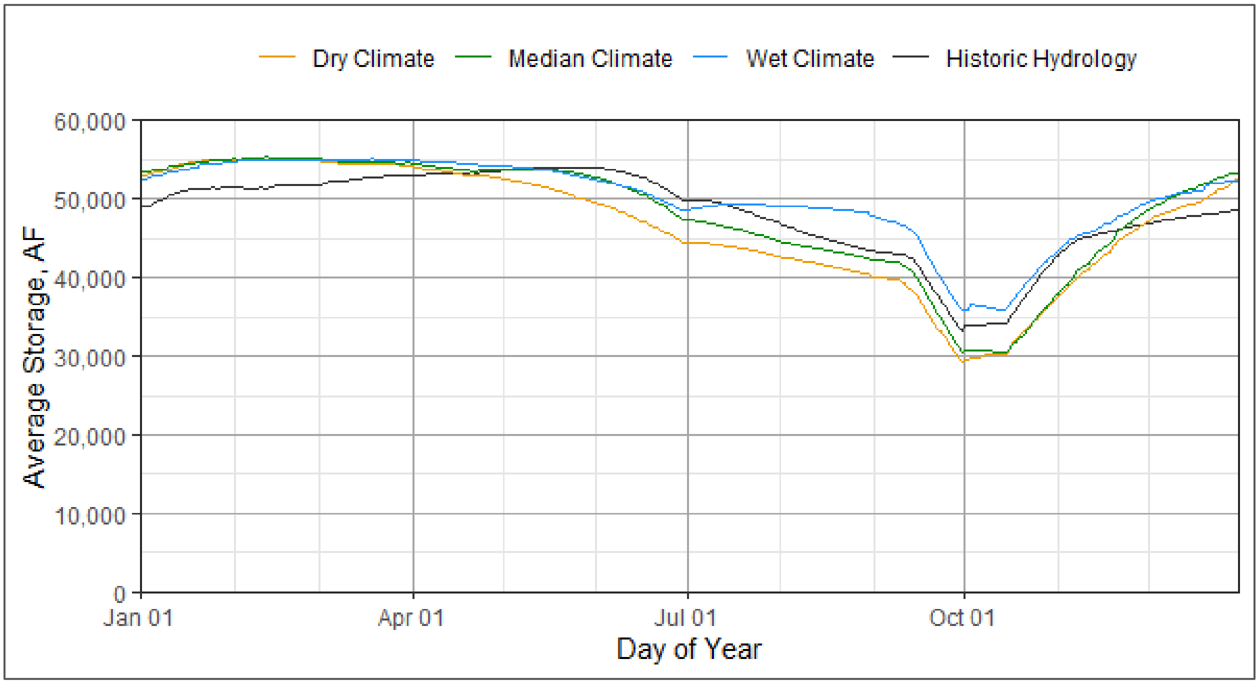


Figure 5-20. Rollins Reservoir Average Daily Storage, Existing Operations Simulation Results

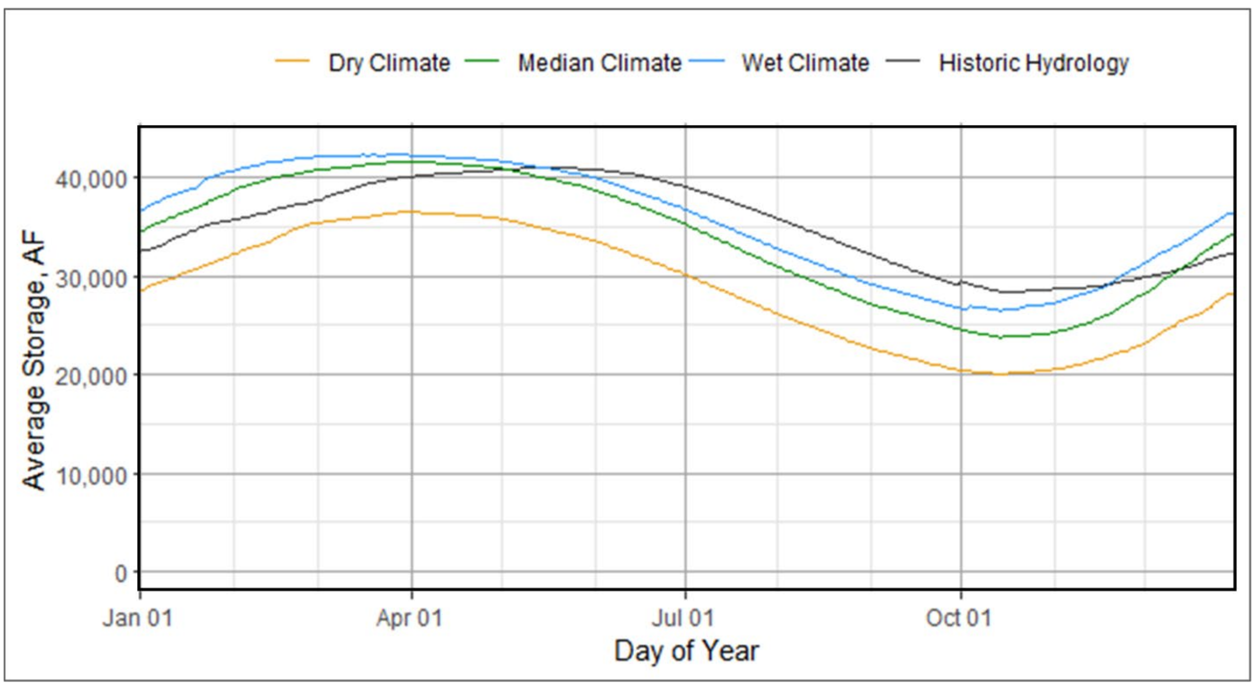


Figure 5-21. Scotts Flat Reservoir Average Daily Storage, Existing Operations Simulation Results

Table 5-10. Average Carryover Storage, Baseline Demands

Reservoir	Carryover Storage with Baseline Demands (AF)			
	Historic Hydrology	Dry Climate	Median Climate	Wet Climate
Jackson Meadows Reservoir	34,366	31,024	30,703	31,934
Bowman Reservoir	35,228	27,600	27,404	31,887
Sawmill Lake	1,670	1,625	1,561	1,548
French Lake	8,503	8,726	8,602	8,650
Faucherie Lake	2,109	2,170	2,144	2,167
Jackson Lake	994	962	891	874
Rollins Reservoir	42,051	36,981	37,339	36,907
Scotts Flat Reservoir	28,525	20,323	24,200	27,124
Lake Combie	1,126	1,857	1,972	2,097
Total	**142,818**	**120,524**	**124,440**	**131,774**

5.6.2.2 Flow Results

Average annual flows through selected conveyance structures are shown in Table 5-11. Figure 5-22 shows the average diversions from the Middle Yuba River to the Milton-Bowman Conduit as a function of day of year. The earlier runoff in the climate change hydrology causes reservoirs to make spill avoidance releases earlier in the year. This pattern is consistent across all major diversions in the system and can be observed for diversions into the Bowman-Spaulding Conduit in Figure 5-23, diversions from the South Yuba River into the Deer Creek Powerhouse in Figure 5-24, diversions from the South Yuba River into the Drum Canal in Figure 5-25, diversions from Rollins Reservoir into the Bear River Canal in Figure 5-26, diversions from Deer Creek into NID's Cascade Canal, DS Canal, Newtown Canal, and Tunnel Canal in Figure 5-27, and diversions from Lake Combie in Figure 5-28.

Table 5-11. Average Annual Diversions into Canals, Baseline Demands, AF

	Historical Hydrology	Dry Climate	Median Climate	Wet Climate
Diversions into Milton-Bowman Conduit	51,018	41,646	48,721	49,751
Diversions into Bowman-Spaulding Conduit	88,236	81,473	89,631	93,029
Diversions through Deer Creek Powerhouse	35,010	40,745	43,225	45,735
NID Diversions into Drum Canal	68,007	50,902	56,222	58,841
NID Diversions into Bear River Canal	38,494	28,969	33,166	31,650

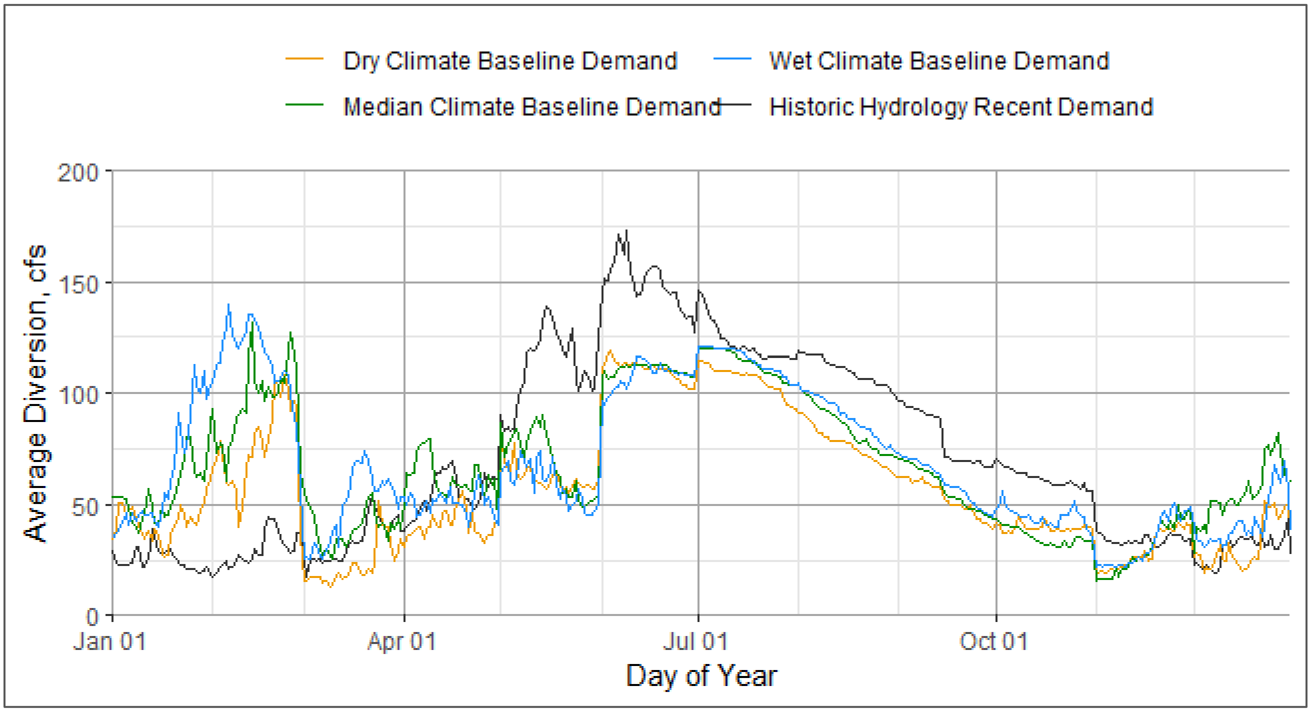


Figure 5-22. Average Daily Flow in Milton-Bowman Conduit, Existing Operations Simulation Results

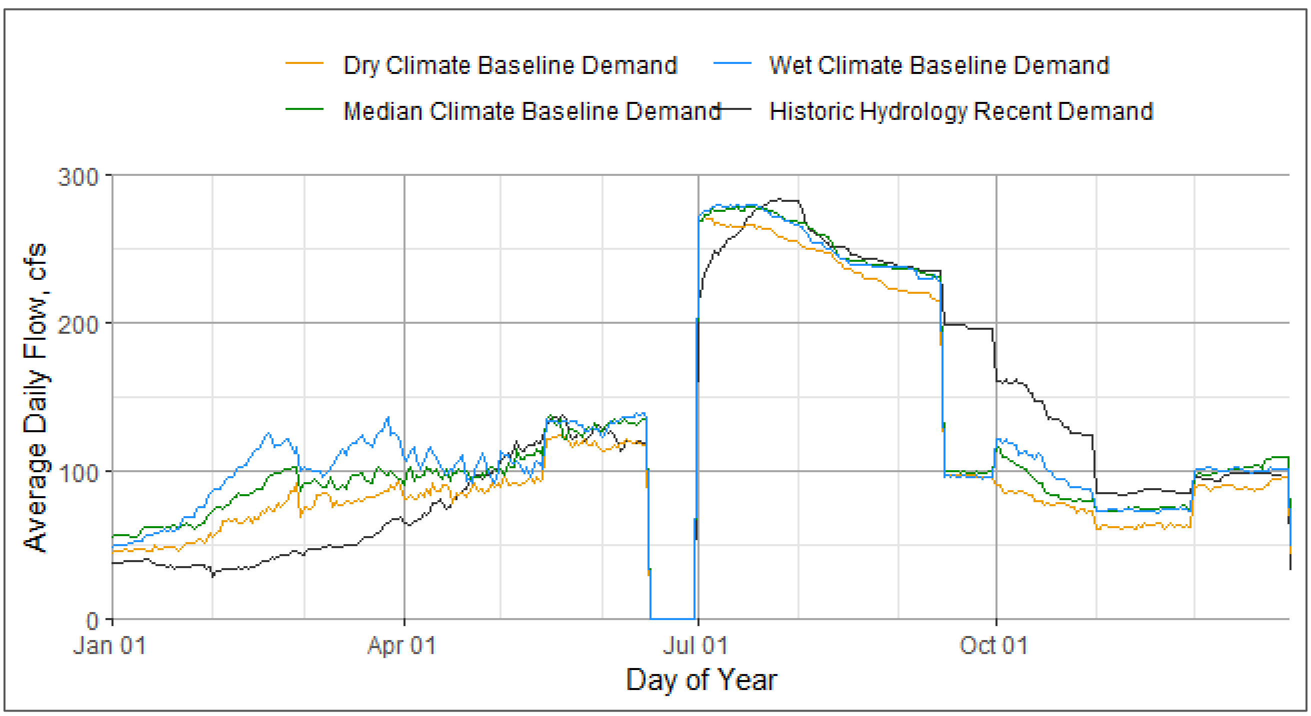


Figure 5-23. Average Daily Flow in Bowman-Spaulding Conduit at Bowman Reservoir, Existing Operations Simulation Results

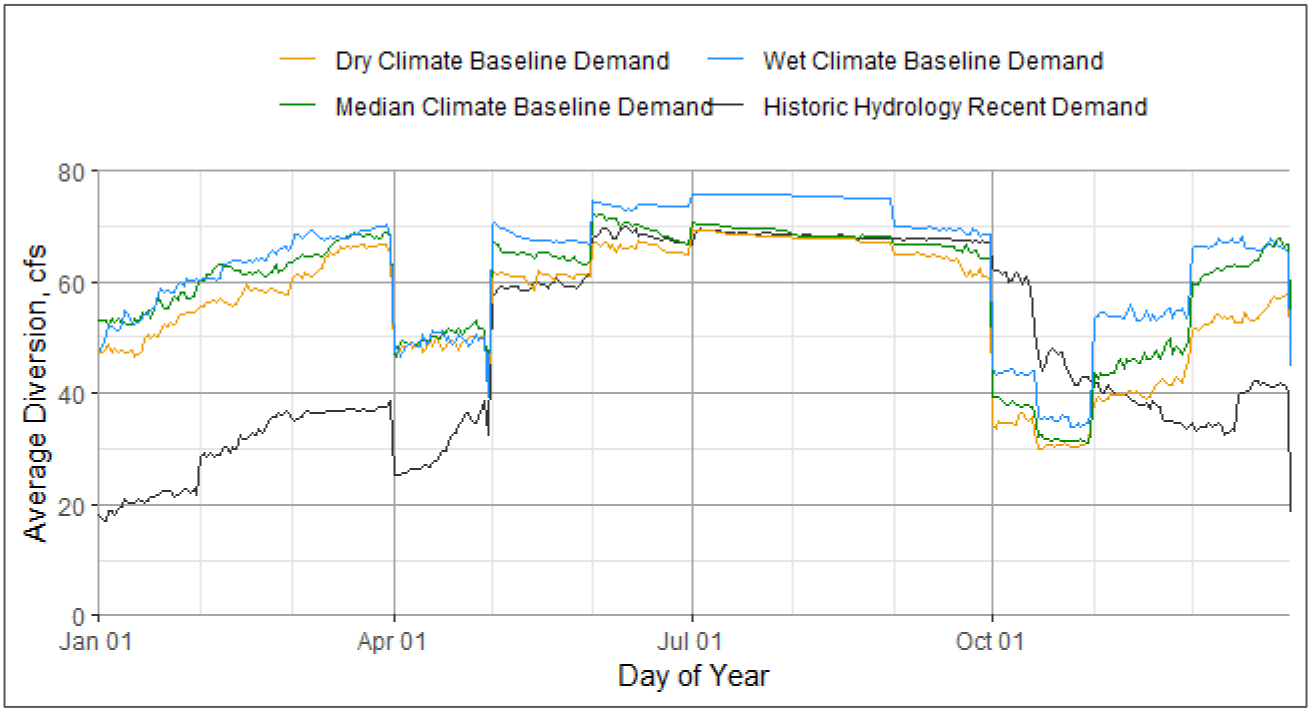


Figure 5-24. Average Daily Flow in Deer Creek Powerhouse, Existing Operations Simulation Results

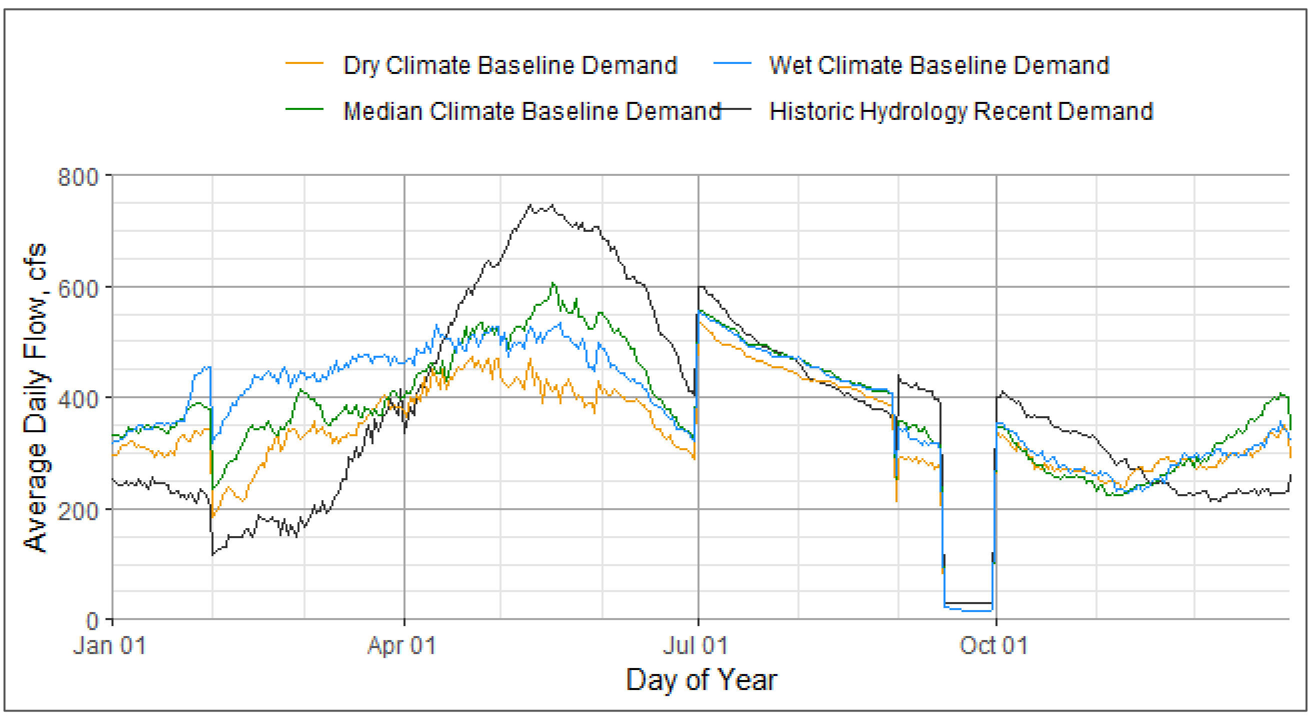


Figure 5-25. Average Daily Flow in Drum Canal below Spaulding Powerhouse No. 1, Existing Operations Simulation Results

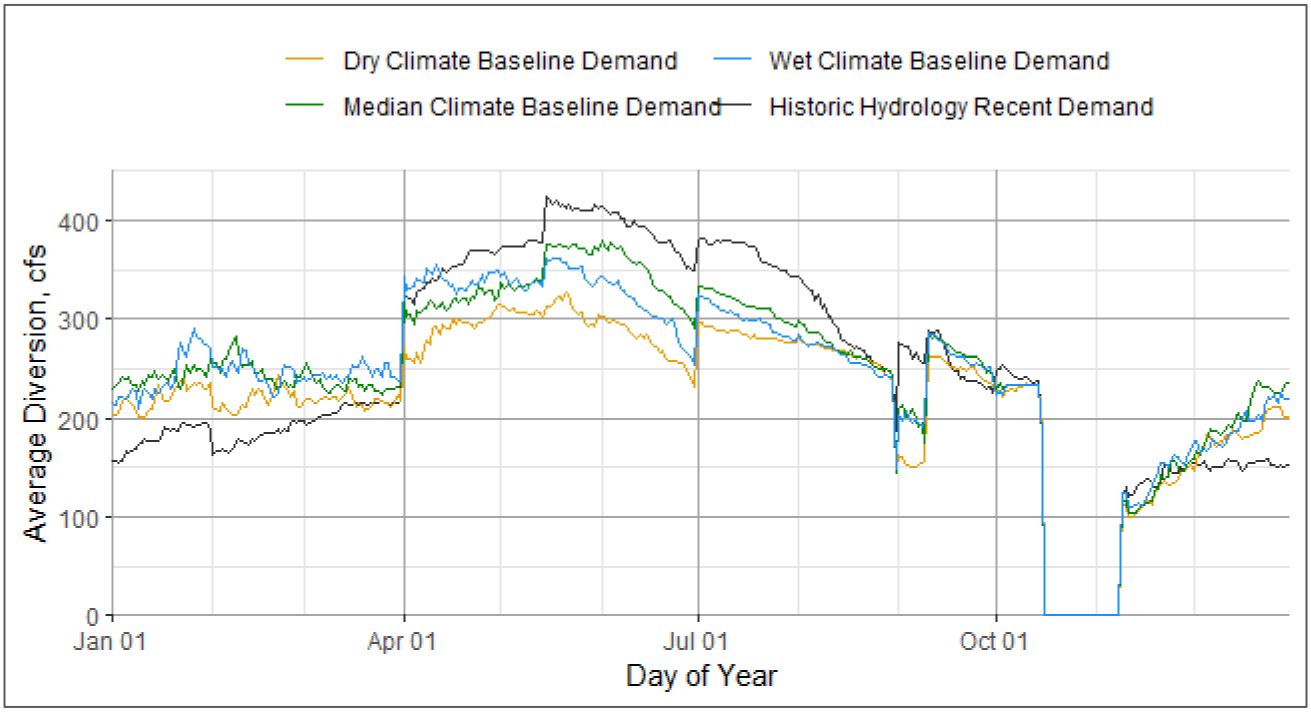


Figure 5-26. Average Daily Flow in Bear River Canal, Existing Operations Simulation Results

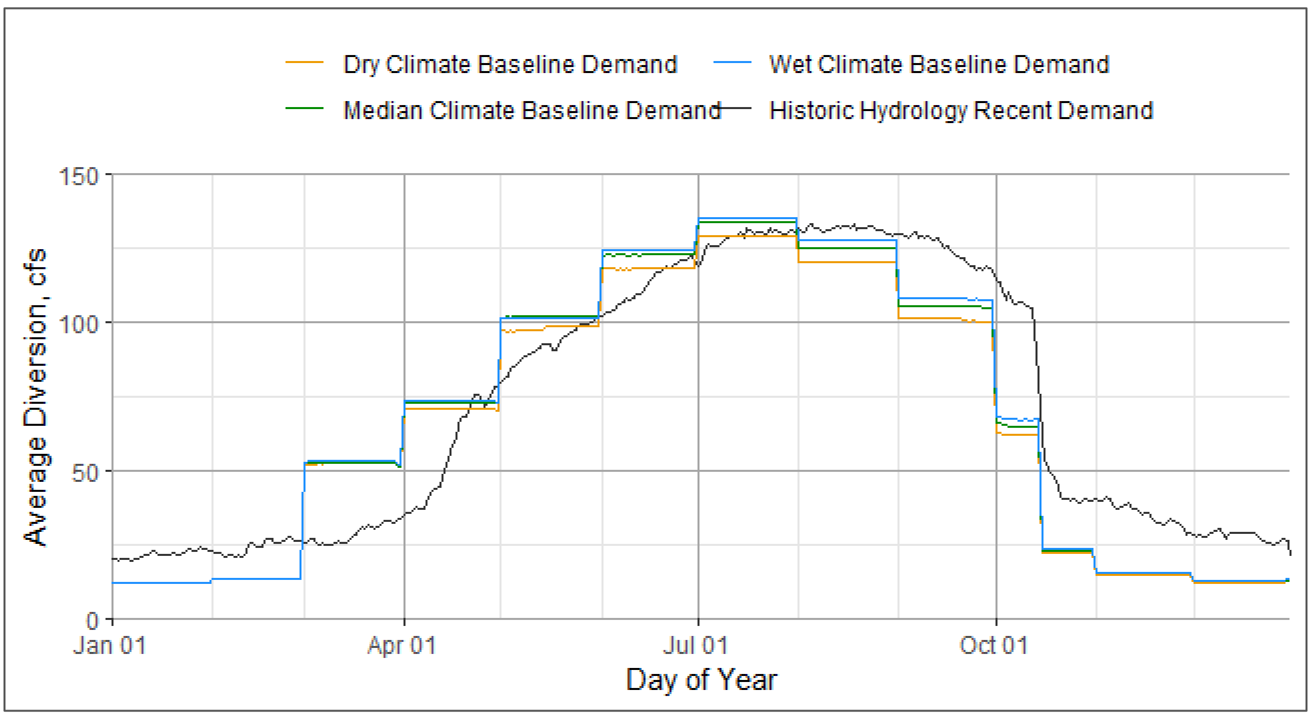


Figure 5-27. Average Daily Diversion from Deer Creek, Existing Operations Simulation Results

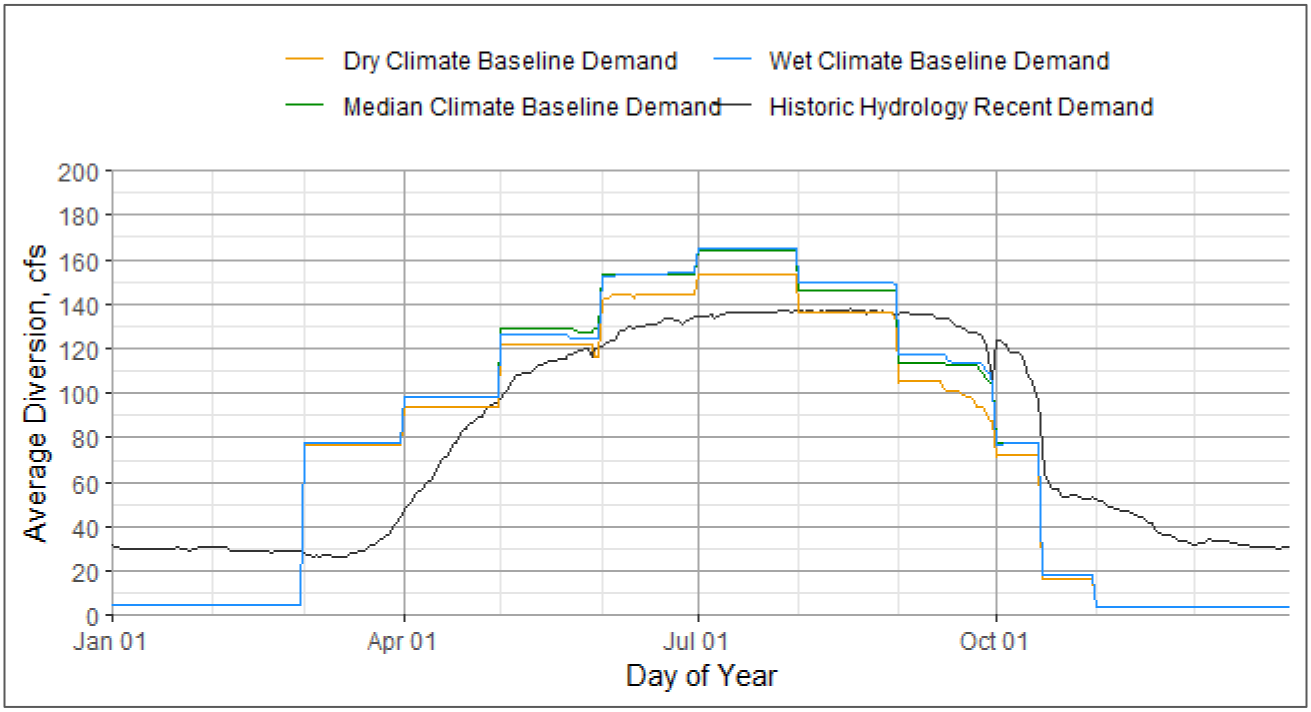


Figure 5-28. Average Daily Diversion from Lake Combie, Existing Operations Simulation Results

5.6.2.3 Deliveries

Average annual deliveries are shown in Table 5-12.

Table 5-12. Average Annual Deliveries in Existing Operations Studies, AF

	Dry Climate	Median Climate	Wet Climate
Low Demand	98,643	103,348	103,942
Baseline Demand	128,991	137,706	137,555
High Demand	146,458	159,371	161,611

Exceedance charts of annual deliveries, separated by demand level, are shown in Figure 5-29 through Figure 5-31. Figure 5-29 shows the low demand simulations, which have lower deliveries than the historic simulation due to the lower total demands. Figure 5-30 shows the baseline demand simulations, which generally have slightly lower deliveries than the historic simulation. Figure 5-31 shows the high demand simulations, which have higher deliveries in wet years due to the higher demands and lower deliveries in dry years than the historic simulation.

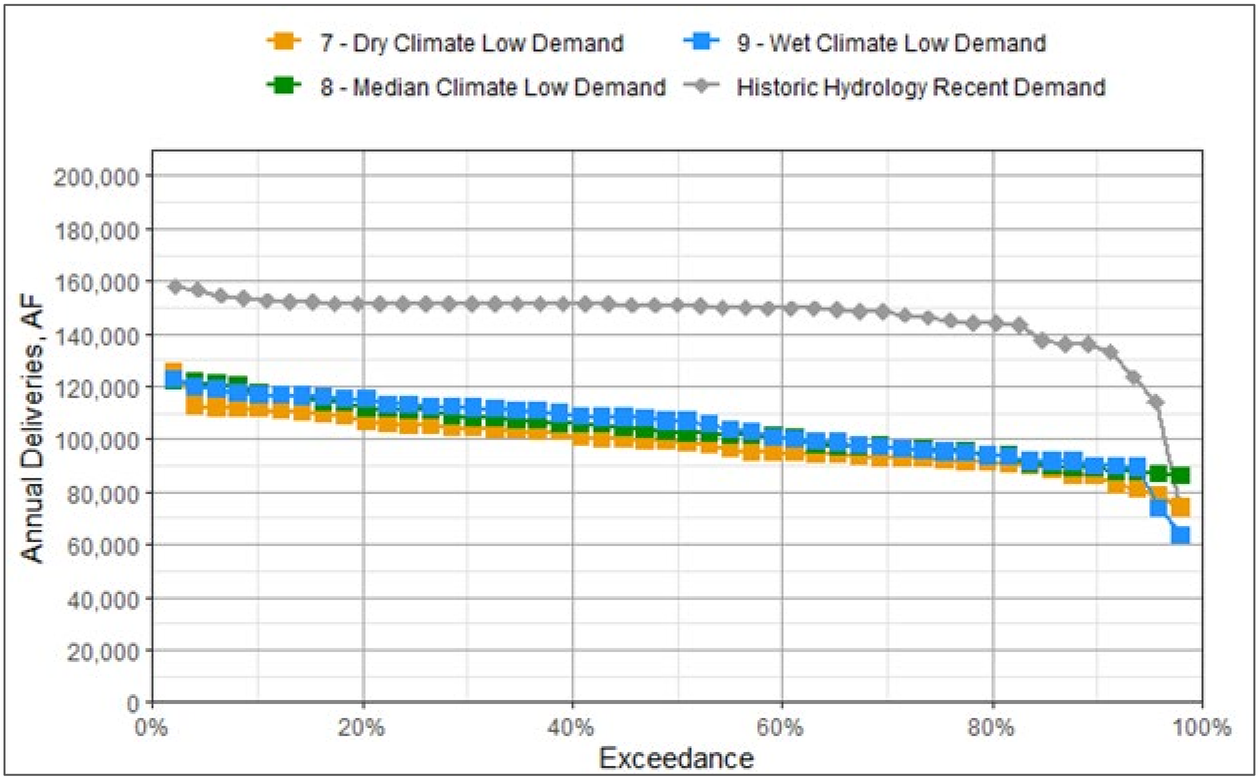


Figure 5-29. Annual Delivery Exceedance, Low Demand Existing Operations Studies

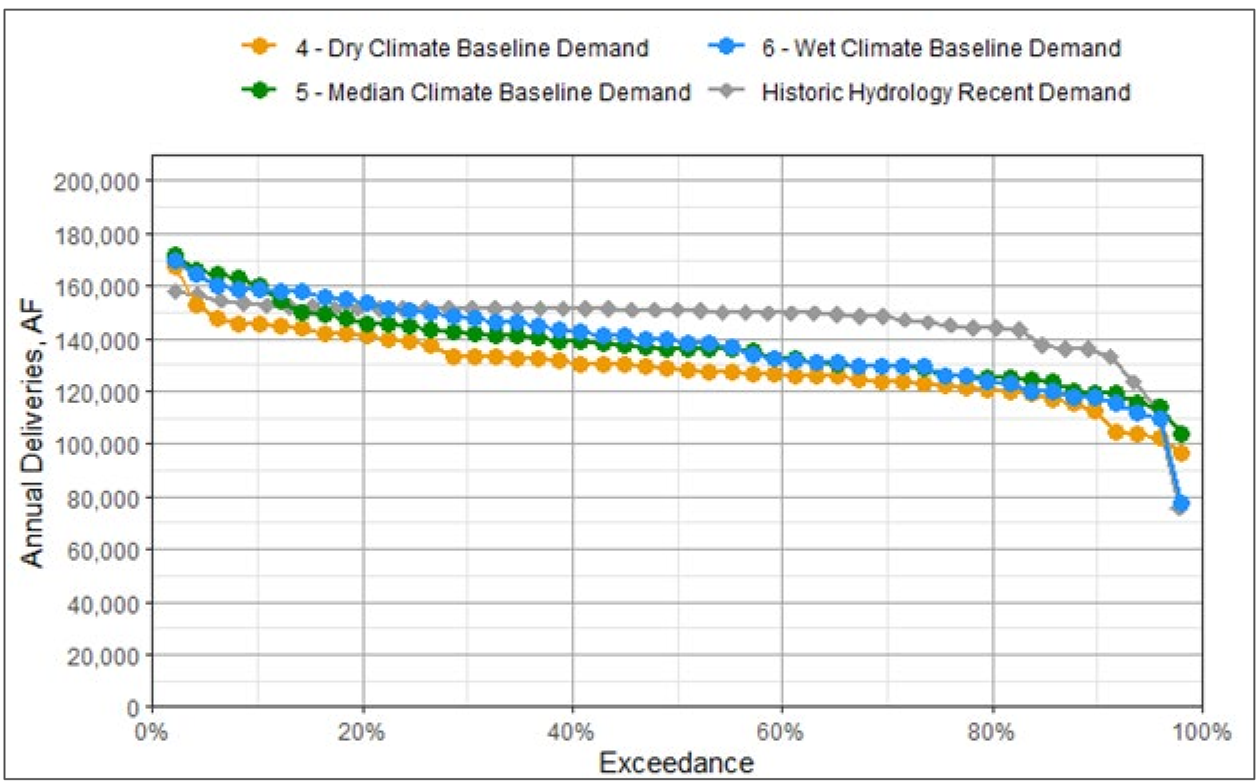


Figure 5-30. Annual Delivery Exceedance, Baseline Demand Existing Operations Studies

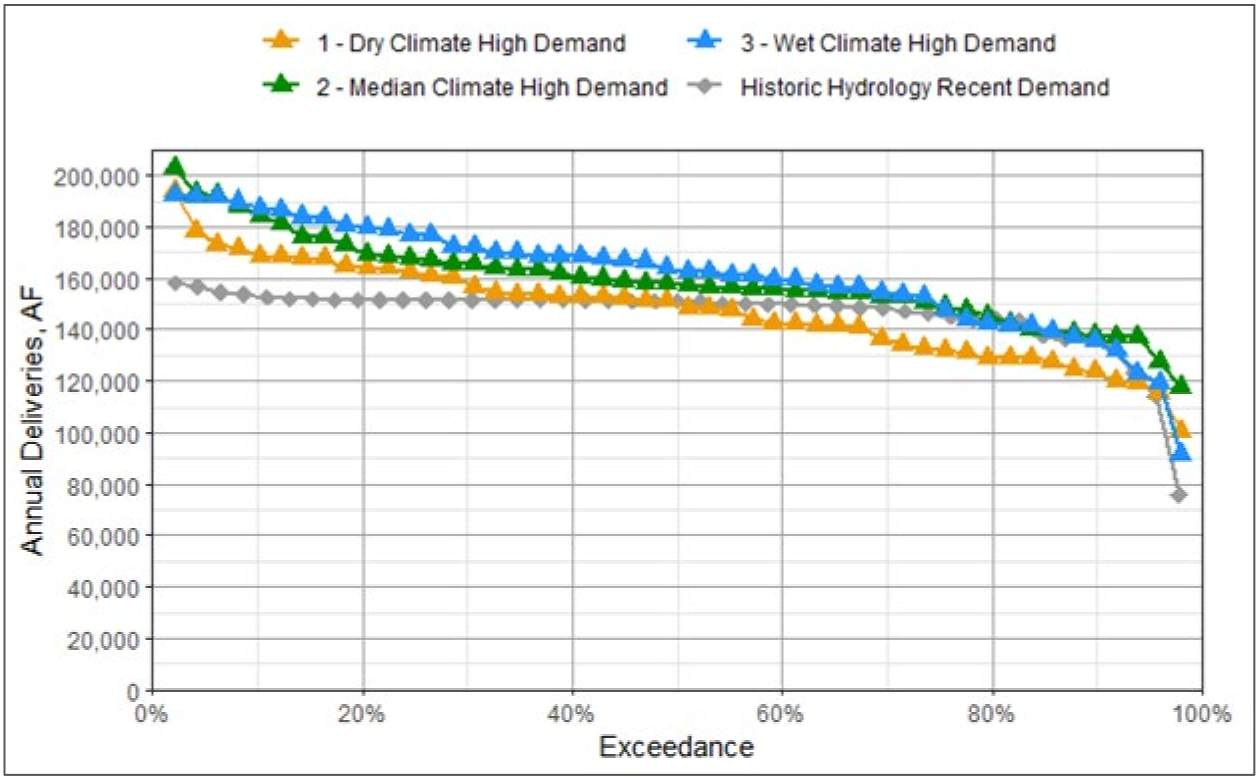


Figure 5-31. Annual Delivery Exceedance, High Demand Existing Operations Studies

Each baseline study results in some amount of unmet demands. Average annual unmet demands are shown in Table 5-13.

Table 5-13. Average Annual Unmet Demands in Existing Operations Studies, AF

	Dry Climate	Median Climate	Wet Climate
Low Demand	9,014	5,740	5,763
Baseline Demand	20,663	14,099	14,683
High Demand	35,158	24,112	23,027

Exceedance charts of annual unmet demand, separated by demand level, are shown in Figure 5-32, Figure 5-33, and Figure 5-34.

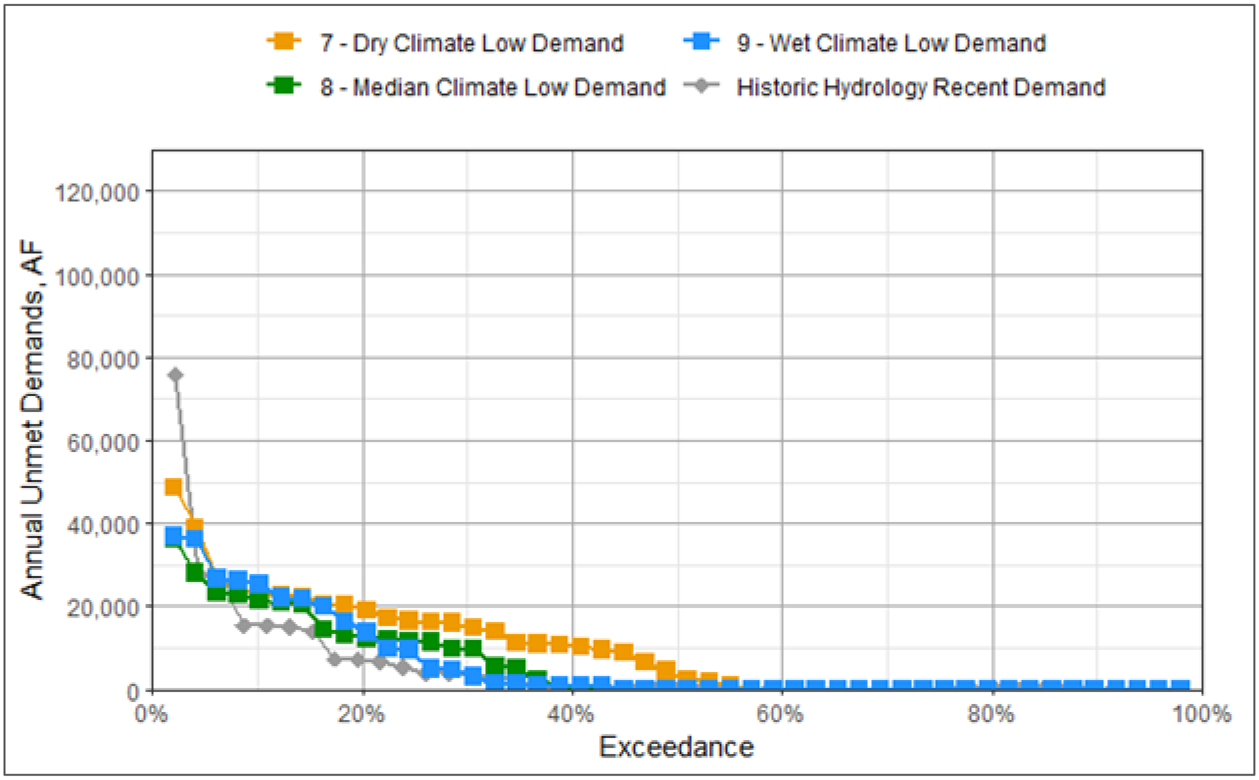


Figure 5-32. Unmet Demands Exceedance, Low Demand Existing Operations Studies

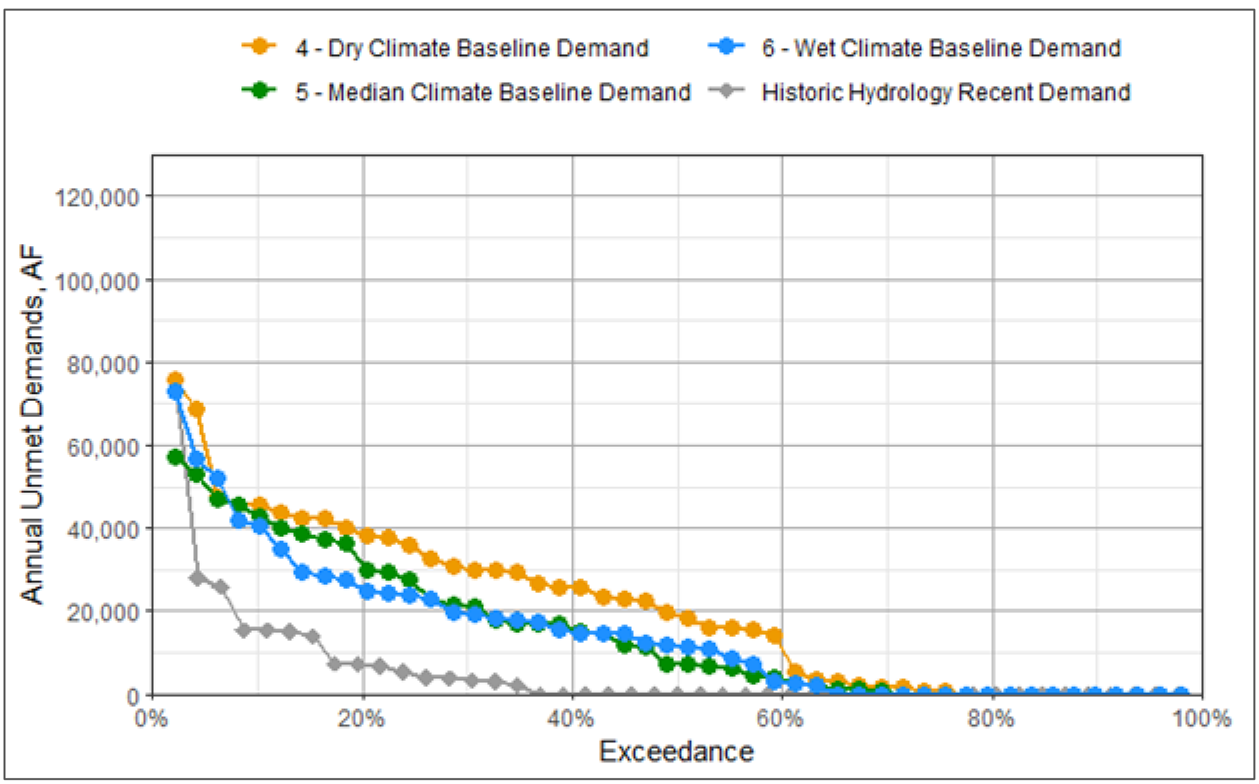


Figure 5-33. Unmet Demands Exceedance, Baseline Demand Existing Operations Studies

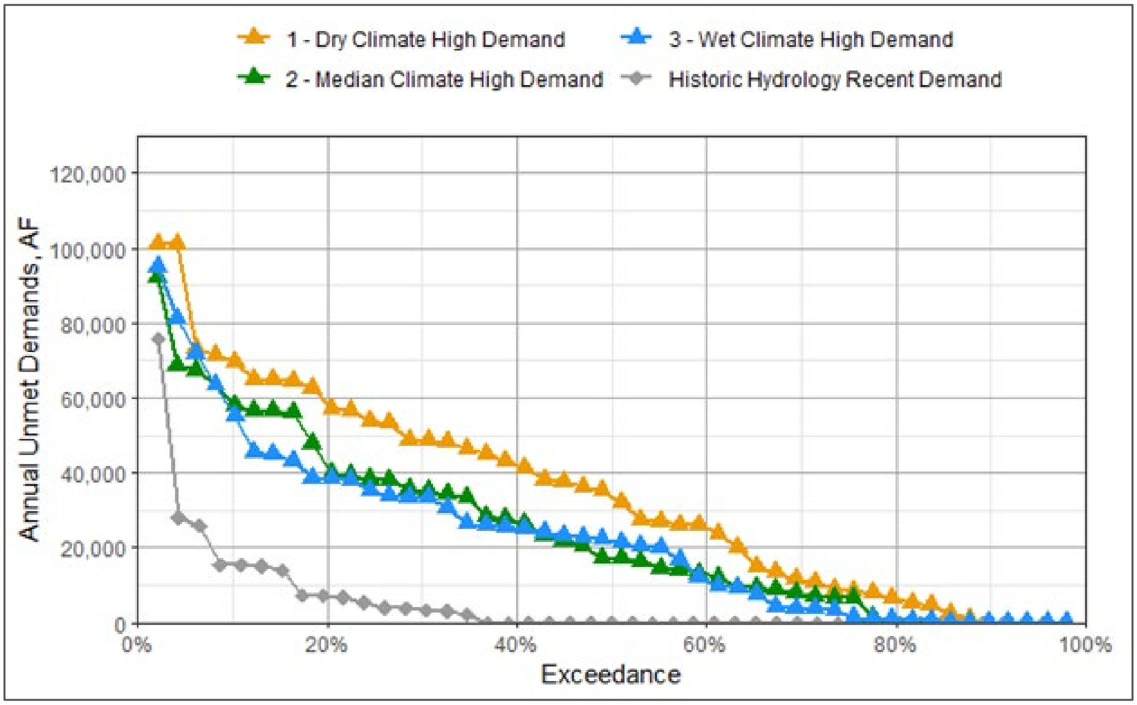


Figure 5-34. Unmet Demands Exceedance, High Demand Existing Operations Studies

5.6.2.4 Generation

Annual average power generation in the baseline studies is shown in Table 5-14. For comparison, the average annual generation in the historic hydrology calibration study is 251.4 GWh.

Table 5-14. Average Annual NID Generation, Existing Operations Studies, GWh

	Dry Climate	Median Climate	Wet Climate
Low Demand	205.7	238.2	254.0
Baseline Demand	205.0	237.5	258.7
High Demand	203.7	236.4	250.0

5.6.3. Results Summary

The results of the nine Existing Operations studies were presented to the NID BOD and stakeholders for consideration to carry forward for evaluation of strategic alternatives. For this evaluation, three of the nine Existing Operations scenarios were chosen. The chosen scenarios were:

- Dry Climate with High Demands
- Median Climate with Baseline Demands
- Wet Climate with Low Demands

These scenarios provide dry and wet bookends with a median climate scenario to represent a mid-point. Use of these scenarios provides a wide range of hydrologic conditions and consumptive demands; the scenarios are suitable for testing the strategic alternatives designed to improve NID's water supply security in the face of shifting runoff patterns and volumes in the projected climate scenarios.

Chapter 6. Strategic Alternatives

Seven strategic alternatives were selected as potential measures to increase NID's future water security. Each strategic alternative was layered onto each of the three Existing Operations scenarios. The benefits of the strategic alternatives were then determined by comparing them to each of the selected Existing Operations studies.

6.1. Existing Operations Studies

As discussed in Section 1.6.3, three Existing Operations scenarios were chosen for measuring the benefit of each of the strategic alternatives.

To establish a basis for measuring benefit, exceedance curves of unmet demands, total NID carryover storage, and total NID generation for these selected Existing Operations scenarios are shown as Figure 6-1 through Figure 6-3. Exceedance curves are graphical representations used to analyze and visualize the likelihood of exceeding a certain threshold or level for a given variable. As an example (Example 1), if one wanted to know how often Annual Unmet Demand exceeds 60,000 AF under the Dry Climate High Demand Scenario, based on Figure 6-1, the answer is 20% of the time.

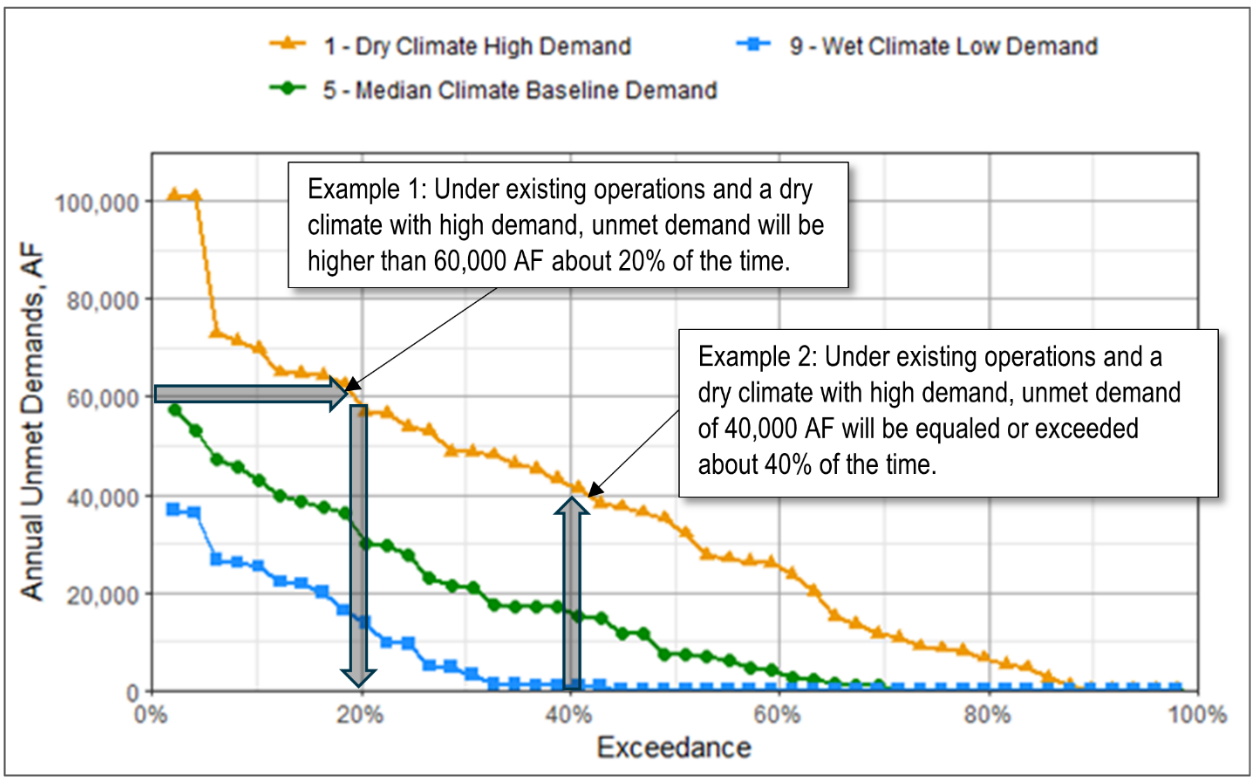


Figure 6-1. Annual Unmet Demands Exceedance, Selected Existing Operations Scenarios

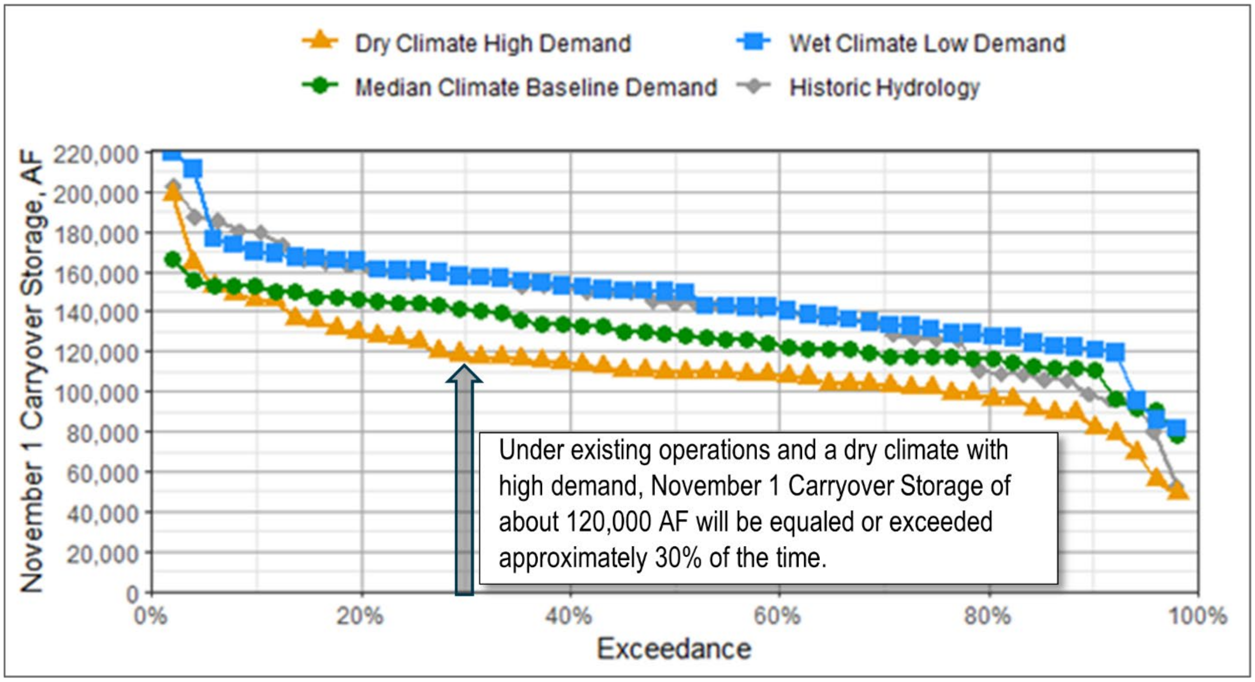


Figure 6-2. November 1 Carryover Storage Exceedance, Selected Existing Operations Scenarios

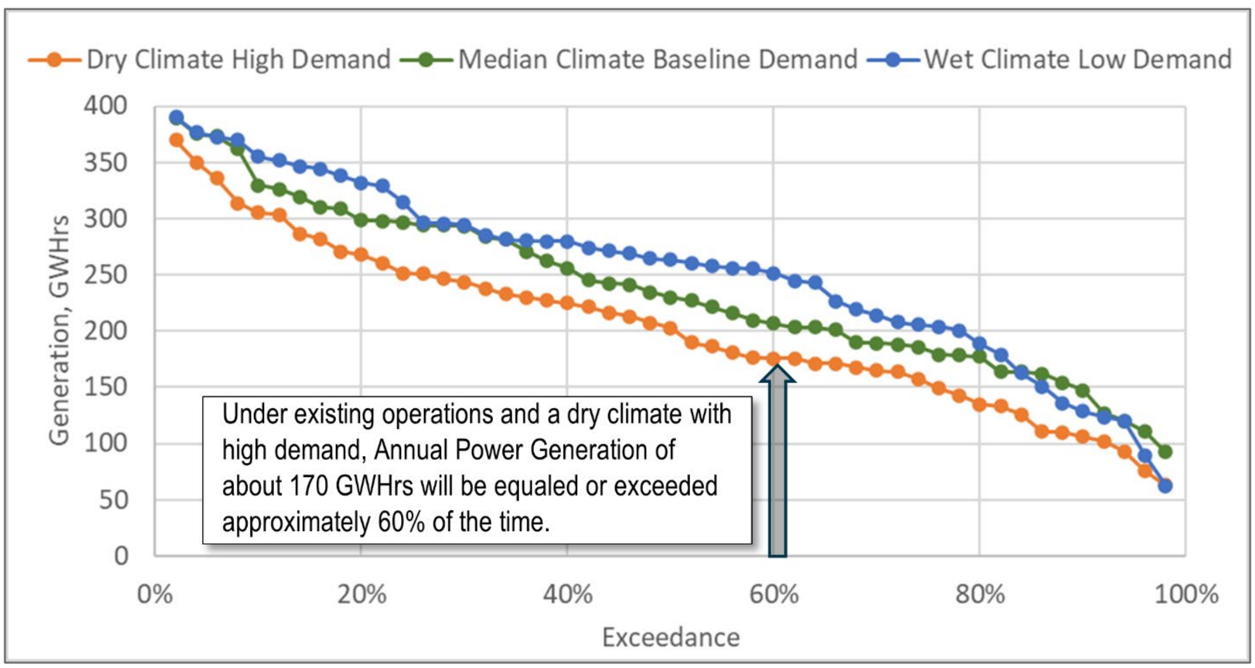


Figure 6-3. Annual NID Generation Exceedance, Selected Existing Operations Scenarios

6.2. Strategic Alternatives Chosen for Modeling

Seven strategic alternatives were chosen for modeling:

- Extended Irrigation Season
- Rollins Reservoir 10,000 AF Storage Increase
- Rollins Reservoir 50,000 AF Storage Increase
- Centennial Reservoir
- Revised Carryover Targets
- Water Purchases from PG&E
- Revised Carryover Targets + Water Purchases from PG&E

Sections 6.3 through 6.9 describe each alternative and provide summary modeling results.

6.3. Extended Irrigation Season

NID's current irrigation season runs through October 15th. The extended irrigation season strategic alternative extends the end of the irrigation season through October 31st. Irrigation deliveries in the second half of October are assumed to match irrigation deliveries in the first half of October. Municipal Deliveries to water treatment plants are left unchanged. Average annual demands are shown in Table 6-1.

Table 6-1. Average Annual Demands, Regular Irrigation Season and Extended Irrigation Season

Scenario	Average Annual Demand, Current Irrigation Season (AF)	Average Annual Demand, Extended Irrigation Season (AF)	Difference (AF)
Dry Climate High Demand	181,616	188,055	6,439
Median Climate Baseline Demand	151,806	157,318	5,512
Wet Climate Low Demand	109,705	113,531	3,826

Modeling of the extended irrigation season shows that this alternative would result in more irrigation deliveries but a reduction in the November 1 carryover storage. This is summarized in Table 6-2. Demand, delivery, and unmet demands for each scenario are shown in Table 6-3. Resulting unmet demand exceedance for the Extended Irrigation Season Alternative is shown in Figure 6-4.

Table 6-2. Increase in Demand and Deliveries in Extended Irrigation Season

Scenario	Increase in Demand	Increase in Deliveries	Change in Carryover Storage
Dry Climate High Demand	6,439	5,193	-265
Median Climate Baseline Demand	5,512	4,001	-2,078
Wet Climate Low Demand	3,826	3,334	-2,656

Table 6-3. Deliveries and Unmet Demand, Extended Irrigation Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Regular Irrigation Season	181,616	146,458	35,158
	Extended Irrigation Season	188,055	151,651	36,405
Median Climate Baseline Demand	Regular Irrigation Season	151,806	137,706	14,099
	Extended Irrigation Season	157,318	141,707	15,611
Wet Climate Low Demand	Regular Irrigation Season	109,705	103,941	5,763
	Extended Irrigation Season	113,531	107,275	6,256

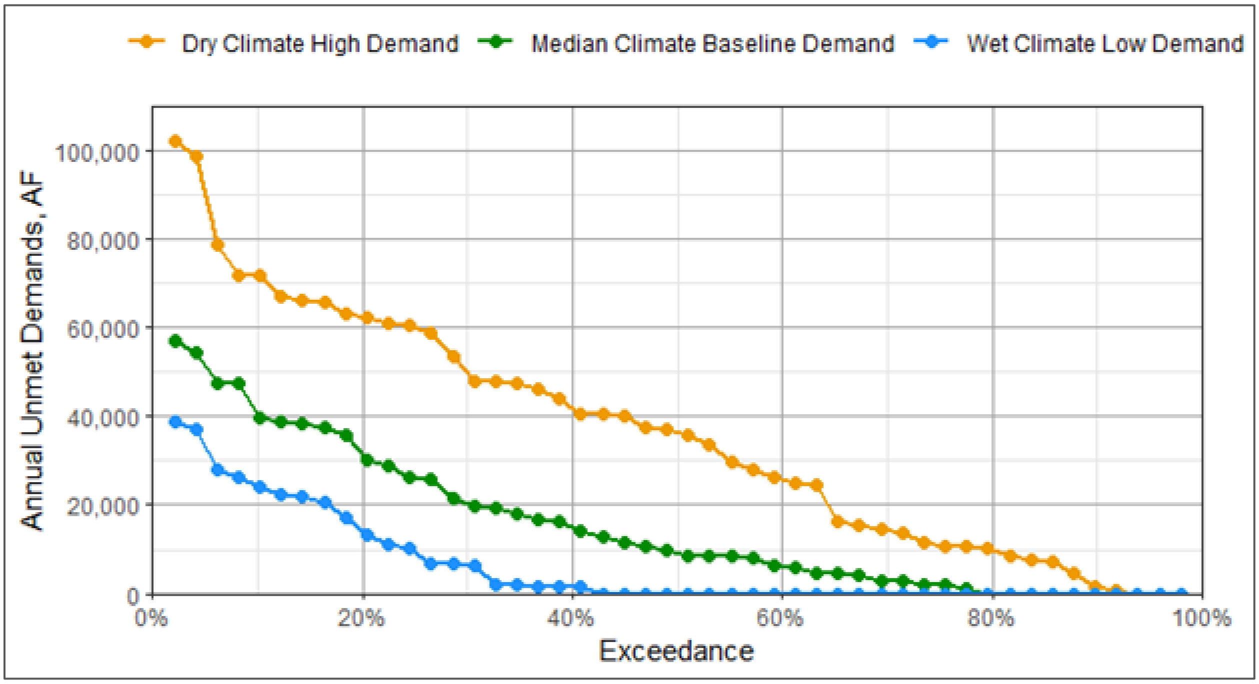


Figure 6-4. Annual Unmet Demand Exceedance, Extended Irrigation Season Alternative

6.4. Rollins Reservoir 10,000 AF Storage Capacity Increase

A modified Rollins Reservoir was built into the model simulating an additional 10,000 AF of usable storage capacity at Rollins Reservoir. All outlet works are assumed to have the same capacities as the current Rollins Reservoir outlet works. Proposed future FERC minimum flow requirements and minimum pool requirements were also assumed.

This strategic alternative allows for more water to be stored in Rollins Reservoir ahead of the summer storage dispatch season, allowing a larger buffer from minimum pool levels. Currently, Rollins Reservoir spills most years, and there is water available to be stored in nearly all years. Rollins Reservoir storage with this strategic alternative is shown for the Dry Climate High Demand scenario in Figure 6-5, for the Median Climate Baseline Demand scenario in Figure 6-6, and for the Wet Climate Low Demand scenario in Figure 6-7. These figures all show that Rollins Reservoir continues to fill and spill in most years with the expanded storage capacity.

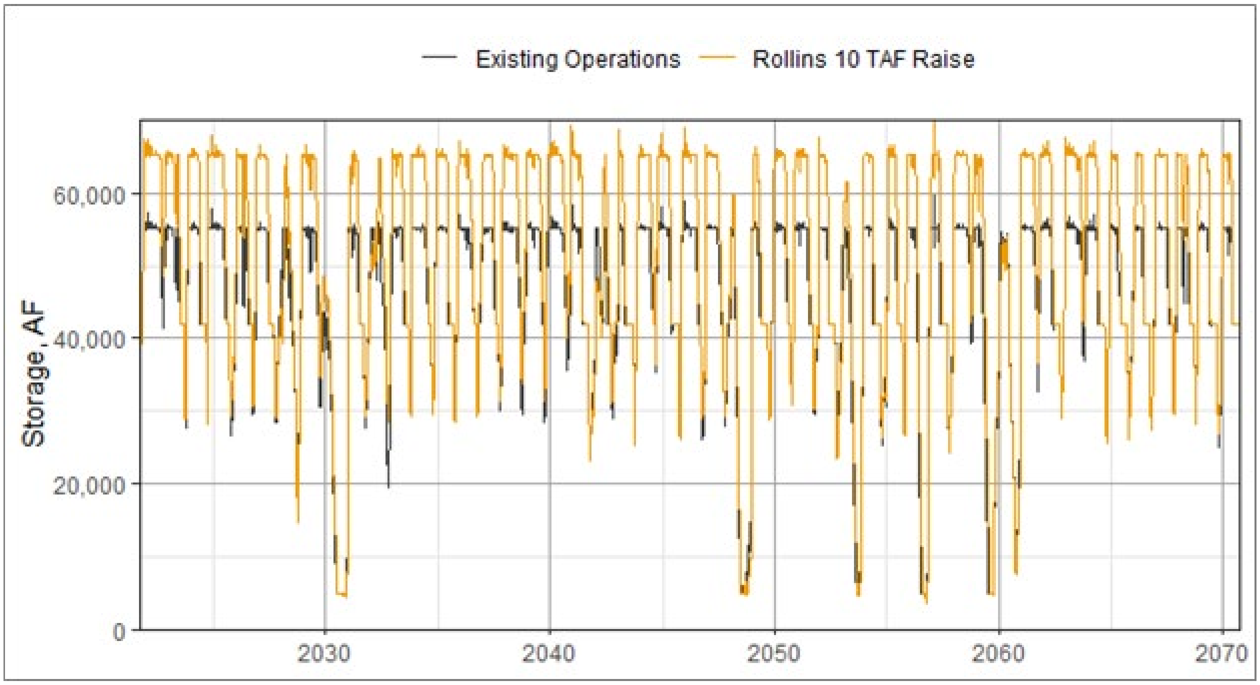


Figure 6-5. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Dry Climate High Demands Scenario

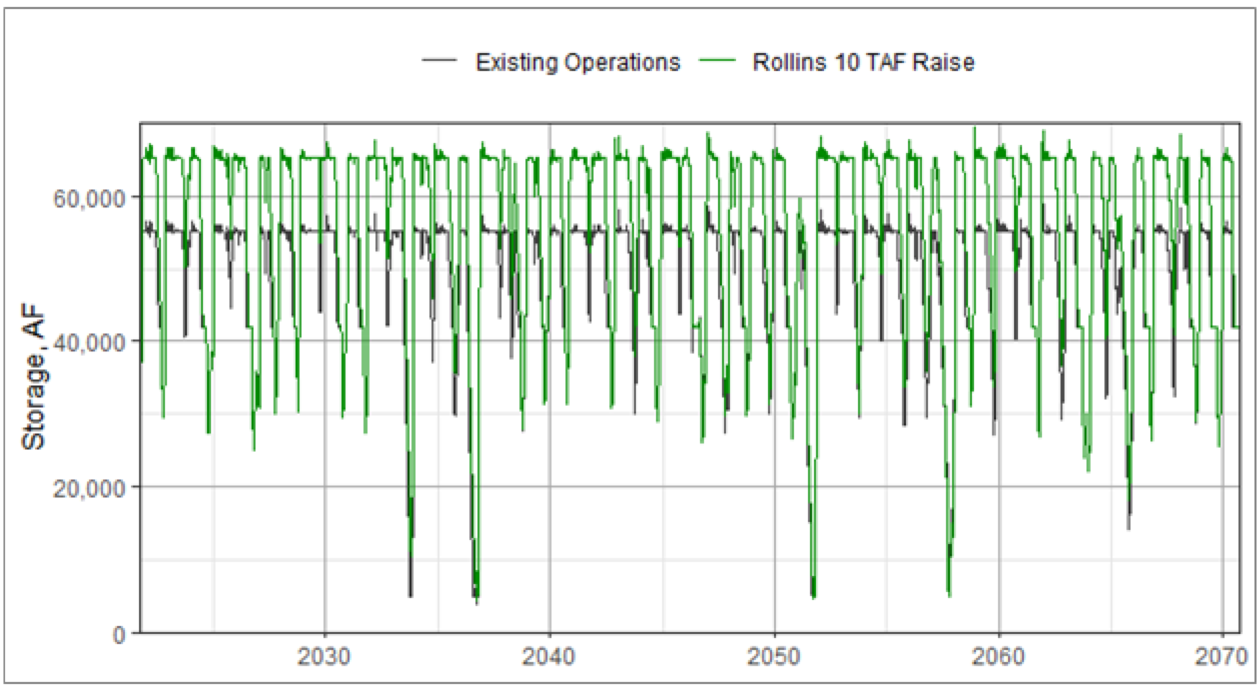


Figure 6-6. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative,
Median Climate Baseline Demands Scenario

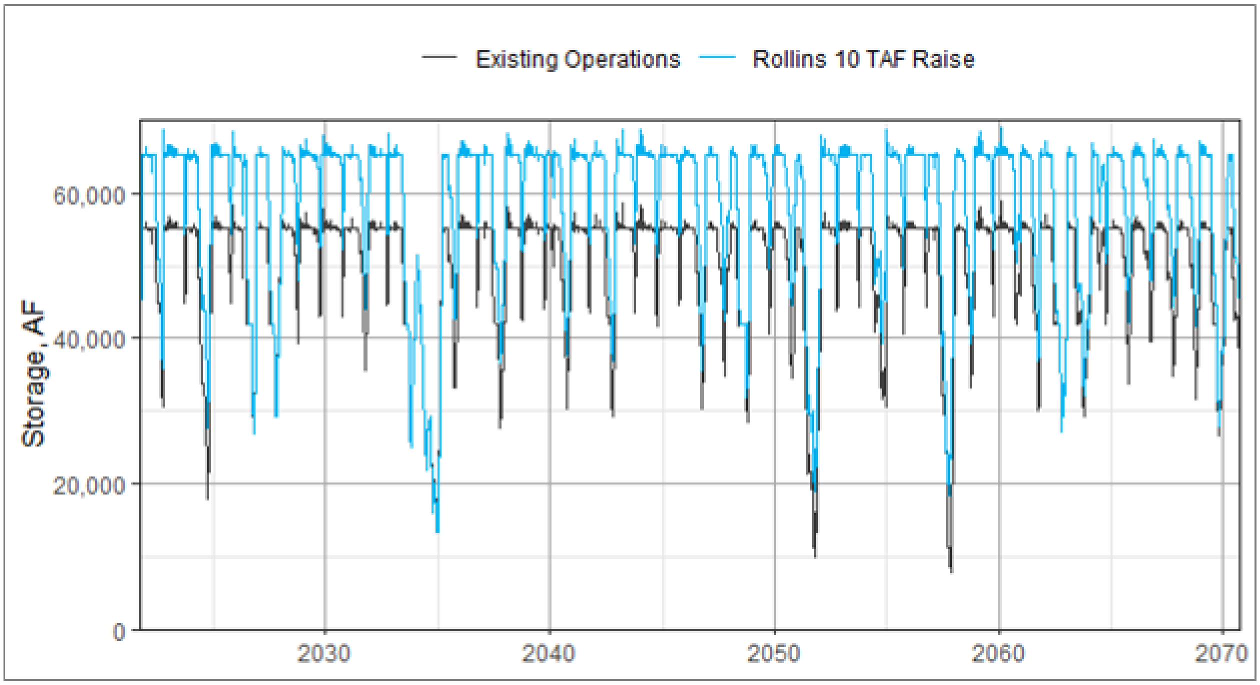


Figure 6-7. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Wet Climate Low Demands Scenario

This additional storage on the Bear River increases NID's ability to make deliveries by increasing delivery allocations and reducing storage constraints at Rollins Reservoir. Demands, deliveries, and unmet demands are shown in Table 6-4. An exceedance plot of the annual unmet demand is shown in Figure 6-8.

Table 6-4. Demand, Delivery, and Unmet Demands, AF, Rollins 10 TAF Raise Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Rollins 10 TAF increase	181,616	152,544	29,072
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Rollins 10 TAF increase	151,806	142,221	9,585
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Rollins 10 TAF increase	109,705	105,485	4,220

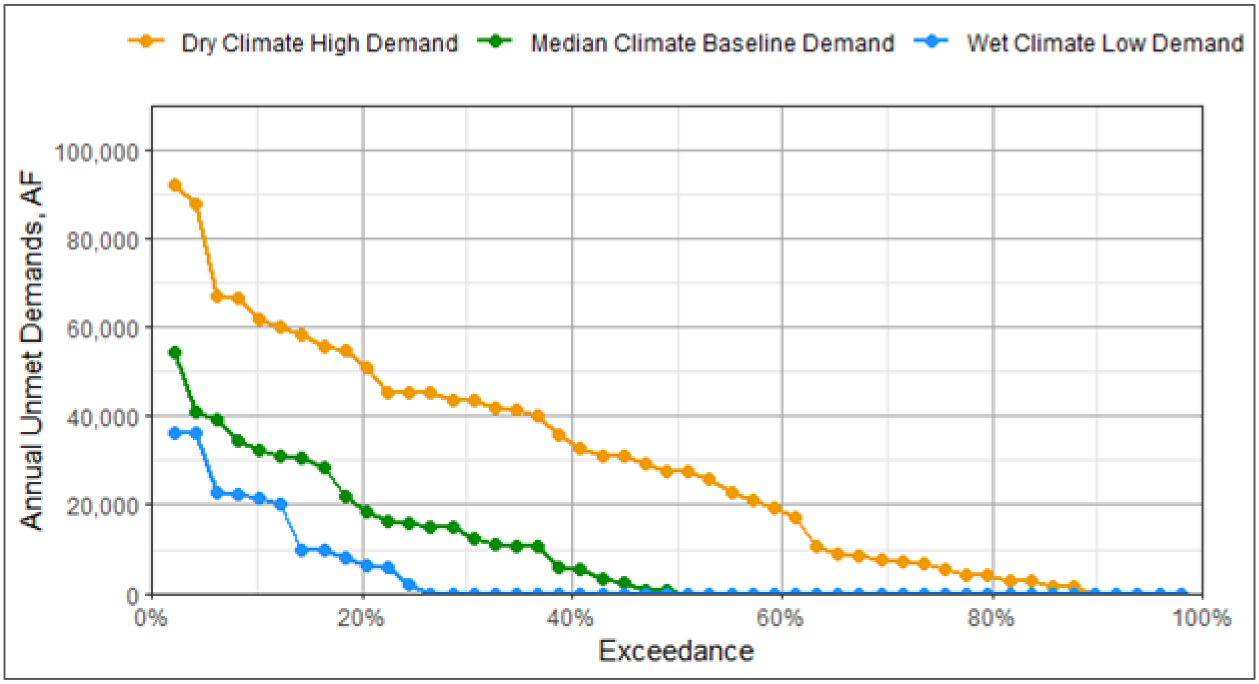


Figure 6-8. Annual Unmet Demand Exceedance, Rollins 10 TAF Raise Alternative

6.5. Rollins Reservoir 50,000 AF Storage Capacity Increase

A modified Rollins Reservoir was built into the model that simulates an additional 50,000 AF of usable storage capacity at Rollins Reservoir. All outlet works are assumed to have the same capacities as the current Rollins Reservoir outlet works. Proposed future FERC minimum flow requirements and minimum pool requirements were also assumed.

This strategic alternative allows for more water to be stored in Rollins Reservoir ahead of the summer storage dispatch season, which allows a larger buffer from minimum pool levels. Currently, Rollins Reservoir spills most years, and there is water available to be stored in nearly all years. Rollins Reservoir storage with the Rollins Reservoir 50 TAF storage increase strategic alternative is shown for the Dry Climate High Demand scenario in Figure 6-9, for the Median Climate Baseline Demand scenario in Figure 6-10, and for the Wet Climate Low Demand scenario in Figure 6-11. These figures show that, under this scenario, Rollins reservoir will not be filled every single year by the additional capacity of 50,000 AF, but storage is higher than the current capacity every year.

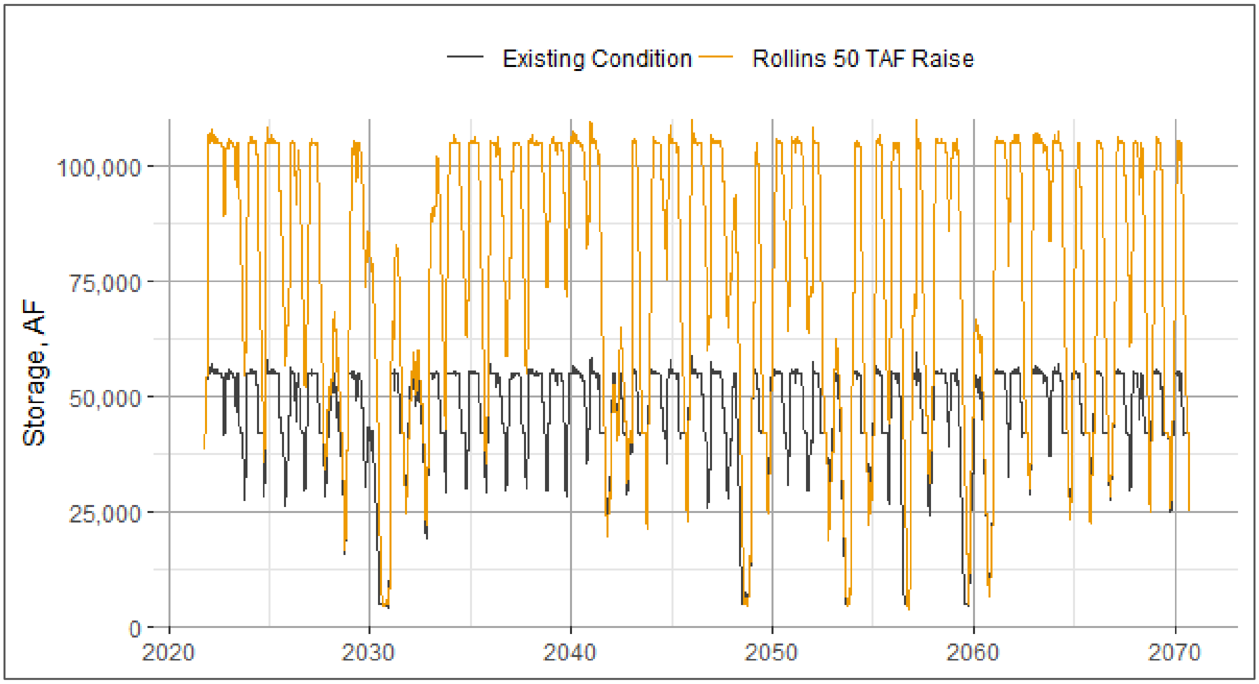


Figure 6-9. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, Dry Climate High Demands Scenario

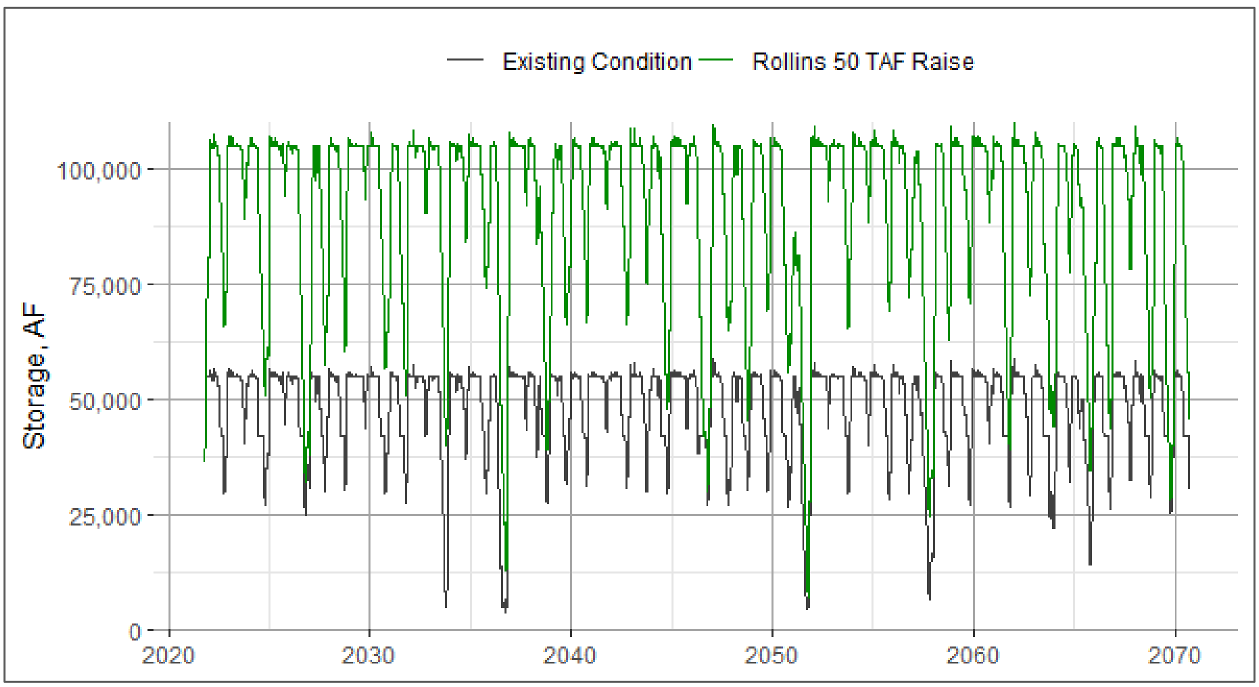


Figure 6-10. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, Median Climate Baseline Demands Scenario

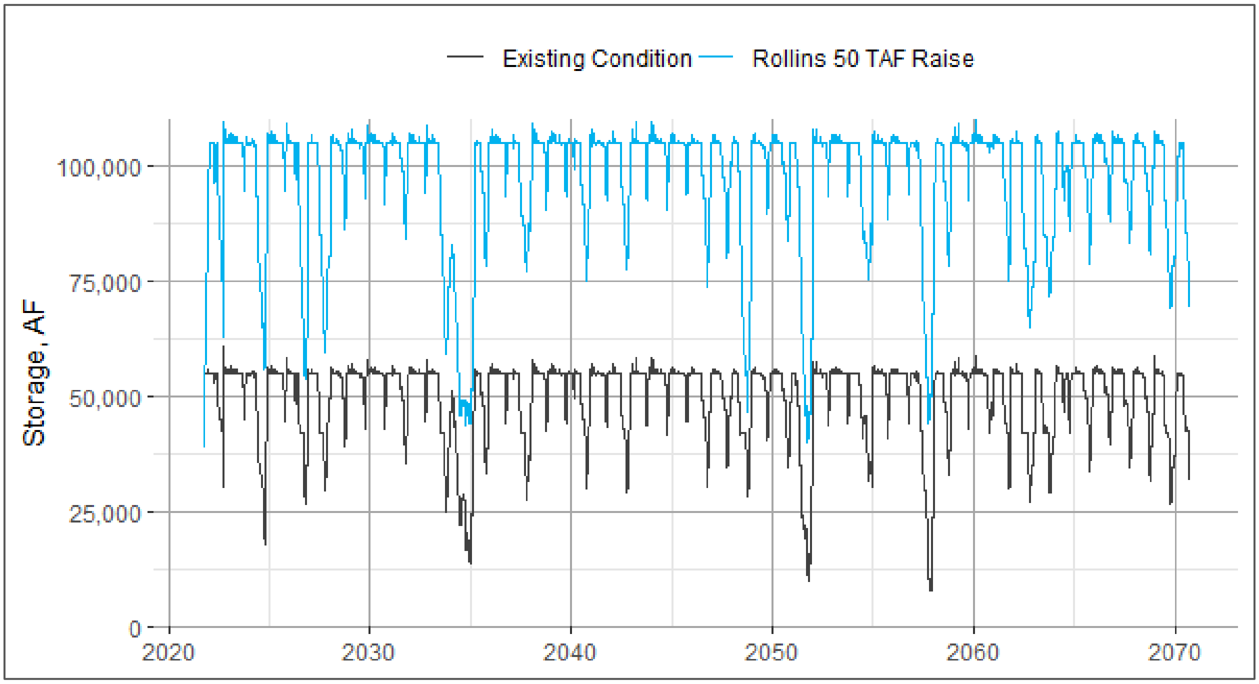


Figure 6-11. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, High Climate Low Demands Scenario

Demand, delivery, and unmet demands for the Rollins 50 TAF Raise Alternative are shown in Table 6-5, and an exceedance plot of unmet demands for the Rollins 50 TAF Raise Alternative is shown in Figure 6-12.

Table 6-5. Demand, Delivery, and Unmet Demands, AF, Rollins 50 TAF Raise Alternative.

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Rollins 50 TAF increase	181,616	167,384	14,232
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Rollins 50 TAF increase	151,806	150,092	1,714
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Rollins 50 TAF increase	109,705	108,892	813

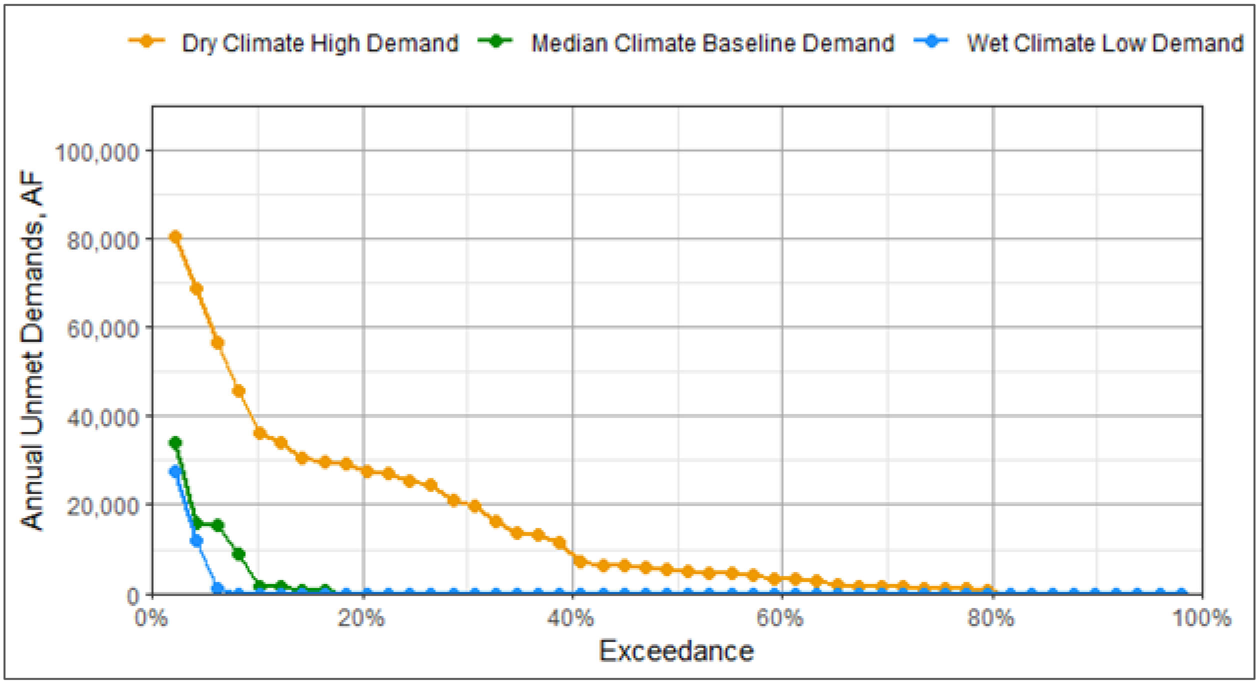
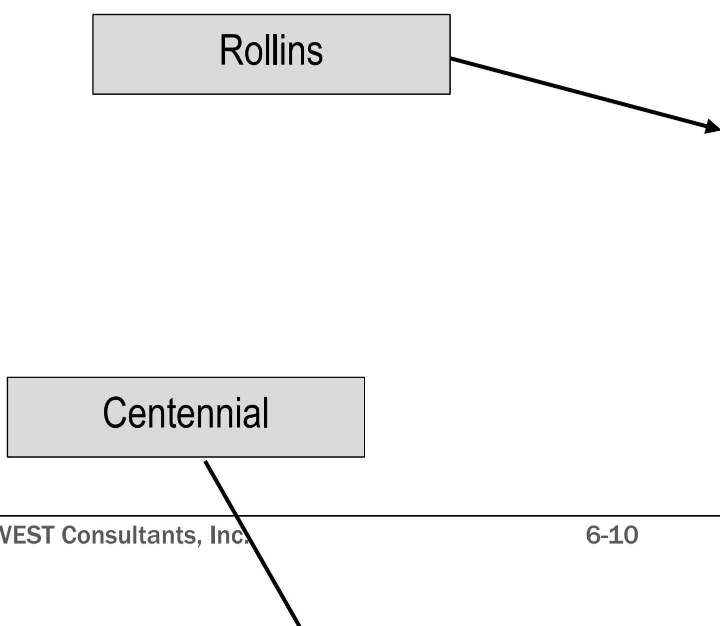


Figure 6-12. Unmet Demands Exceedance, Rollins 50 TAF Raise Alternative

6.6. Centennial Reservoir

A potential Centennial Reservoir was built into the model that provides for 96,660 AF of usable storage on the Bear River below Rollins Reservoir and above Lake Combie. The location of Centennial Reservoir in the Project schematic is shown in Figure 6-13. The reservoir was modeled with a low-level outlet with 300 cfs of capacity, an ungated spillway with a maximum capacity of 30,000 cfs, and no powerhouse. Minimum flow requirements below Centennial Reservoir were assumed to be the same as Lake Combie. Centennial Reservoir would be used to store water in the winter and spring and provide water to Lake Combie for deliveries into the Combie Phase I and Magnolia III canals in the summer and fall. Lake Combie can only drop 5 ft throughout the summer, and currently, these deliveries are made to Lake Combie from Rollins Reservoir. With Centennial Reservoir making these deliveries, Rollins Reservoir inflows and storage can be used exclusively in the Bear River Canal.



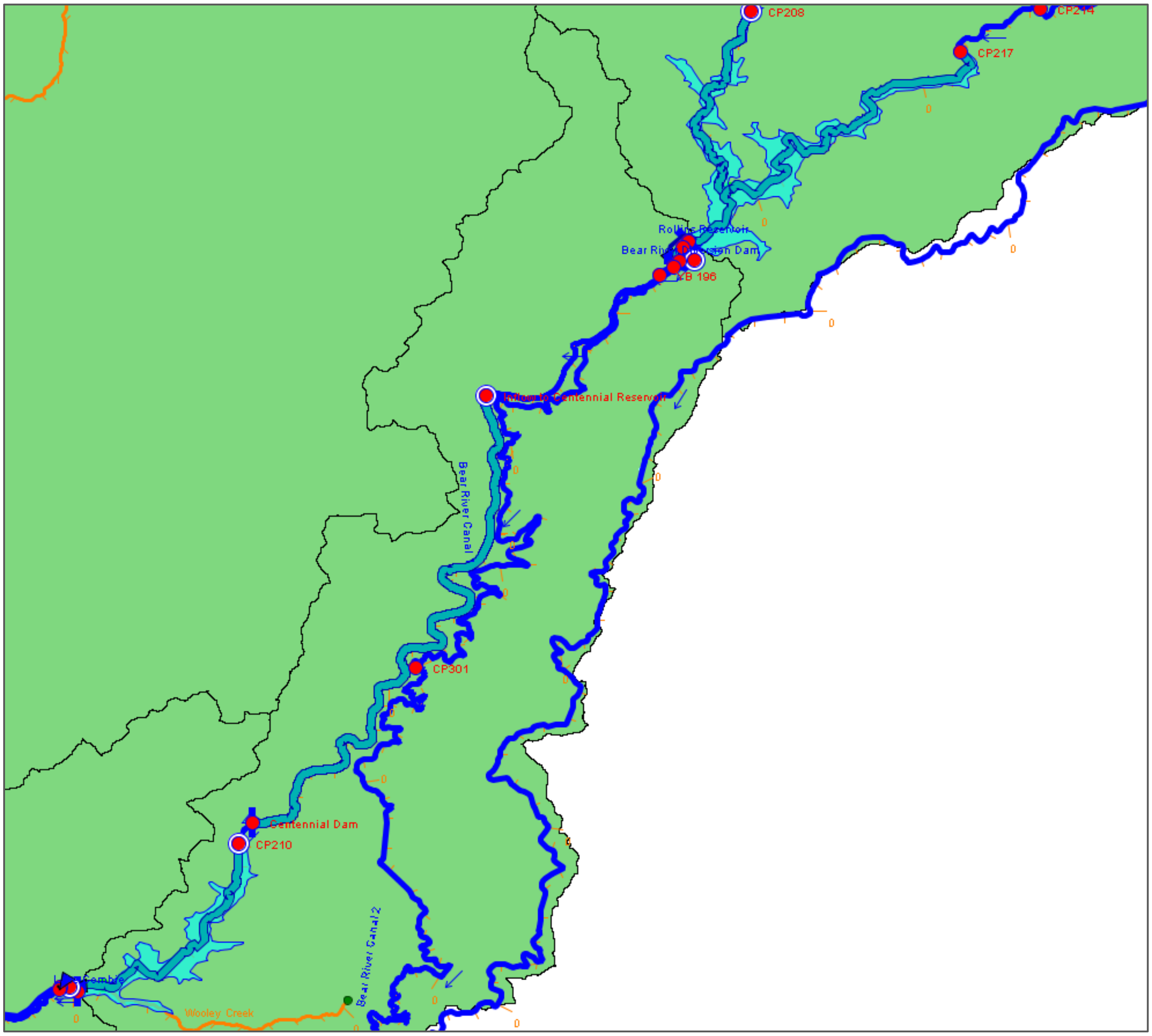


Figure 6-13. Centennial Reservoir Project Schematic

Centennial Reservoir storage is shown in Figure 6-14. The additional delivery and resulting reduction in unmet demand is shown in Table 6-6, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-15.

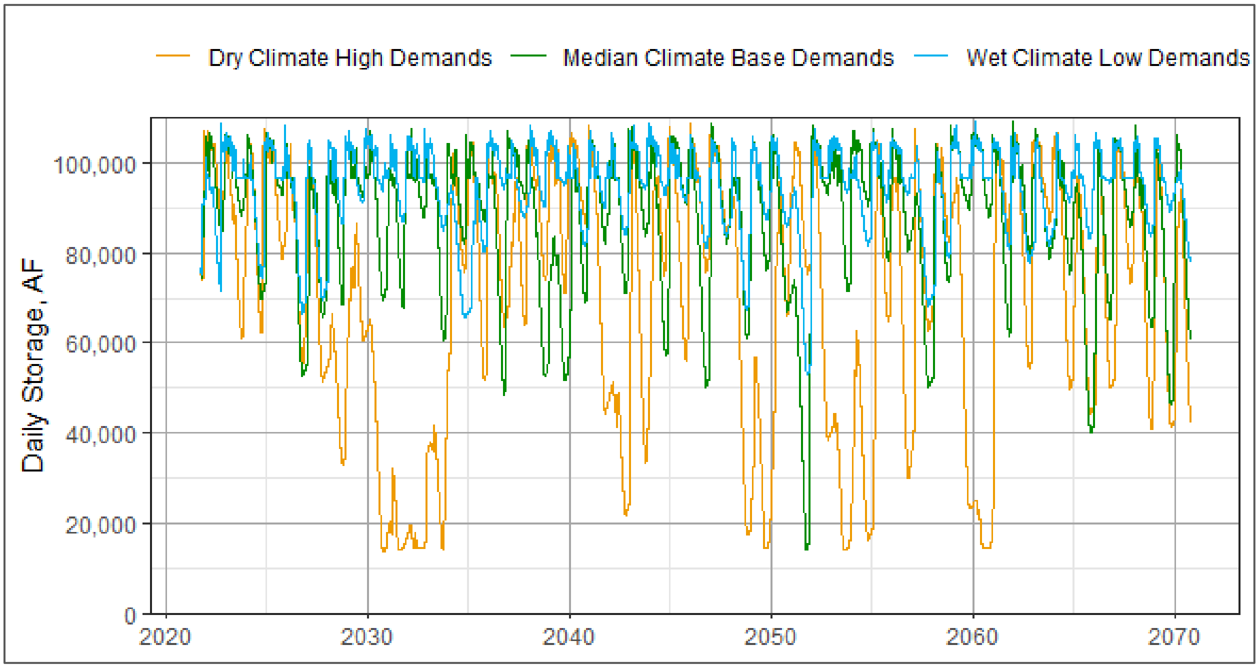


Figure 6-14. Centennial Reservoir Storage

Table 6-6. Demand, Delivery, and Unmet Demands, AF, Centennial Reservoir Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Centennial Reservoir	181,616	165,322	16,294
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Centennial Reservoir	151,806	144,332	7,473
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Centennial Reservoir	109,705	108,815	890

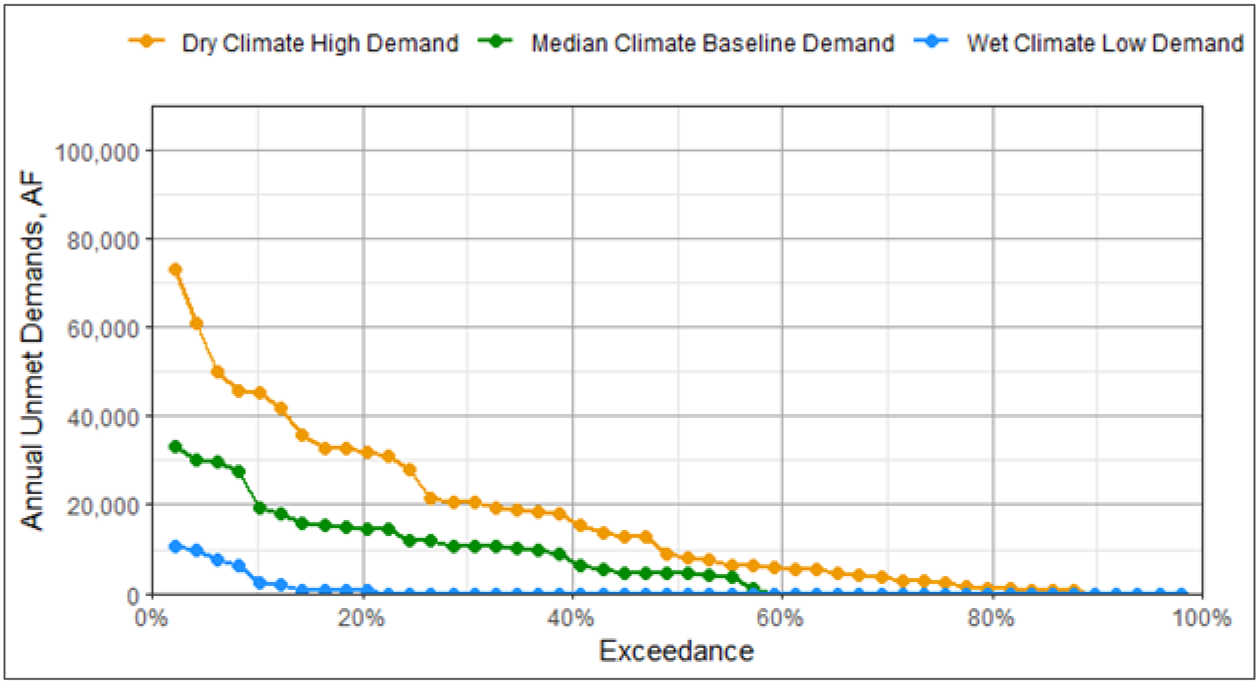


Figure 6-15. Unmet Demands Exceedance, Centennial Reservoir Alternative

6.7. Revised Carryover Targets

The revised carryover targets alternative lowers carryover targets at NID reservoirs. Existing Operations carryover targets use the average historical reservoir carryover level. In dry years, NID draws their reservoirs lower than the average carryover level. The revised carryover targets represent the level that NID would set reservoir carryover levels in a drought and better represent unmet demands in dry years. Existing Operations carryover targets and revised carryover targets are listed in Table 6-7.

Table 6-7. Revised Carryover Targets

Reservoir	Existing Operations Carryover Target	Revised Carryover Target
Jackson Meadows Reservoir	35,000	21,000
Bowman Reservoir	30,000	14,500
Sawmill Lake	1,500	1,000
French Lake	7,000	5,000
Faucherie Lake	2,100	1,500
Jackson Lake	600	1,000
Rollins Reservoir	40,000	25,000
Scotts Flat Reservoir	23,000	17,000
Lake Combie	2,500	2,500
Total	**141,700**	**88,500**

The revised carryover targets result in further drawdown of the reservoirs by the end of the year, and more storage capture in the winter and spring before the initiation of spill. These revised carryover targets did not significantly affect the ability of these reservoirs to fill in most years.

The additional delivery and resulting reduction in unmet demand is shown in Table 6-8, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-16.

Table 6-8. Demand, Delivery, and Unmet Demands, AF, Revised Carryover Targets Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Revised Carryover Targets	181,616	150,528	27,715
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Revised Carryover Targets	151,806	138,963	9,814
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Revised Carryover Targets	109,705	104,218	3,079

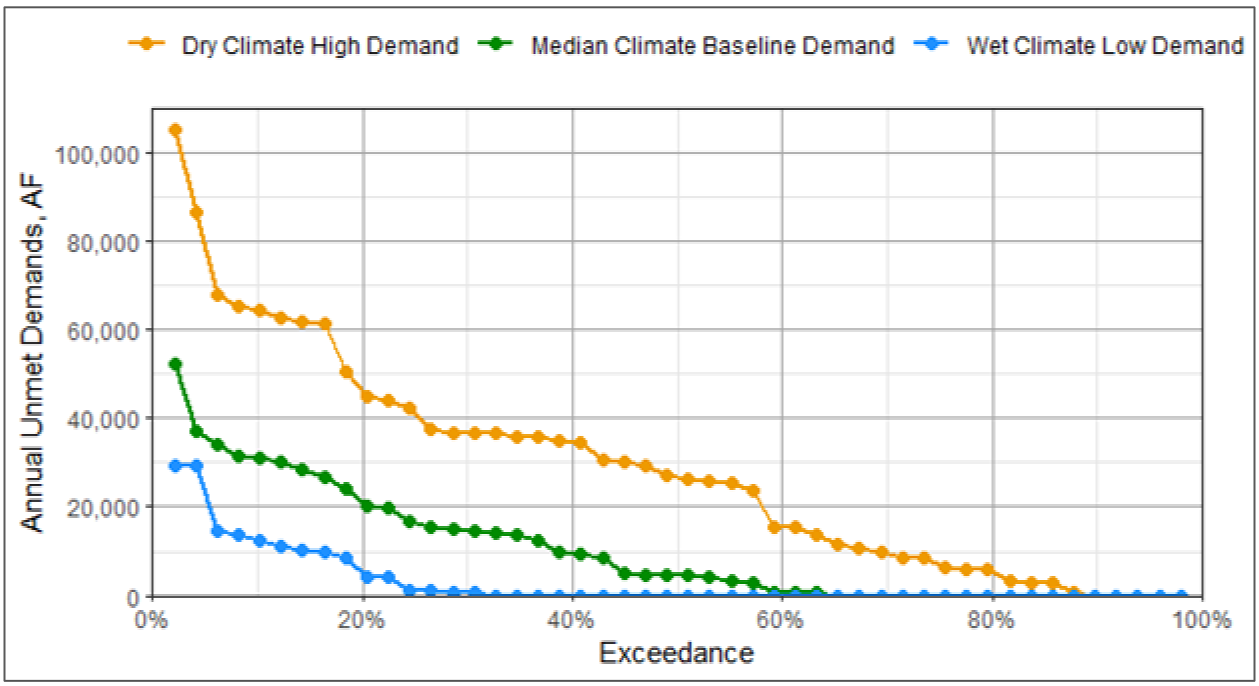


Figure 6-16. Unmet Demands Exceedance, Revised Carryover Targets Alternative

6.8. Purchase of Additional Supply from PG&E

The COA (NID 2018) specifies amounts of water that will be made available for purchase by NID from PG&E. These monthly purchase volumes and maximum flow rates are based on the Sacramento Valley Index, a water year type index defined and calculated by the DWR. Available monthly purchase volumes at the Deer Creek Powerhouse are shown in Figure 6-17, and available monthly purchase volumes on the Bear River Canal are shown in Figure 6-18. In Dry and Critically Dry Years the amount of water available for purchase in July through December are the volumes shown multiplied by the Sacramento Valley Index divided by the 50-year average of the Sacramento Valley Index.

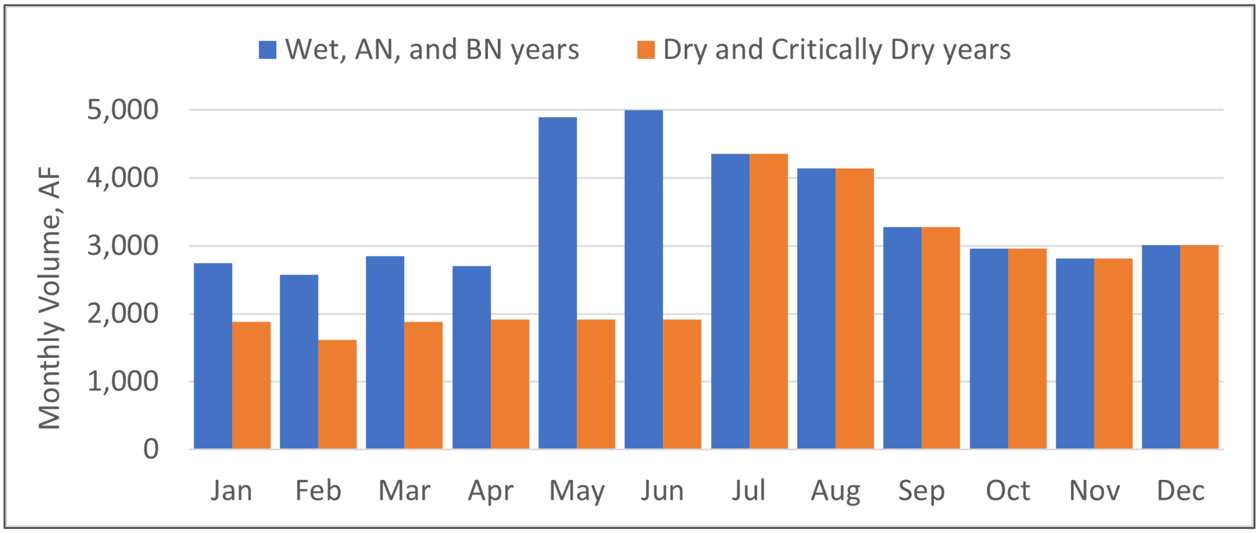


Figure 6-17. Available Monthly Purchase Volumes at the Deer Creek Powerhouse

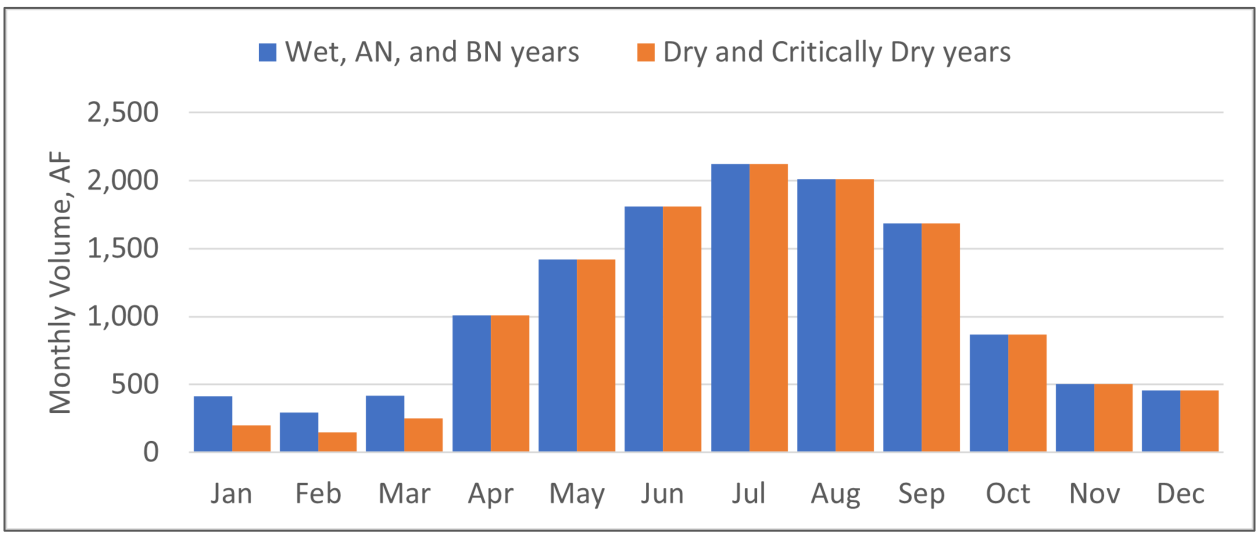


Figure 6-18. Available Monthly Purchase Volumes on the Bear River Canal

Monthly water volumes available for purchase were estimated using a regression for each of the developed climate change hydrology datasets. Current operations modeling study results were used to determine when unmet demands were occurring and identify water that could be purchased to meet or reduce those unmet demands. Identified useful water purchase annual volumes are shown in Figure 6-19.

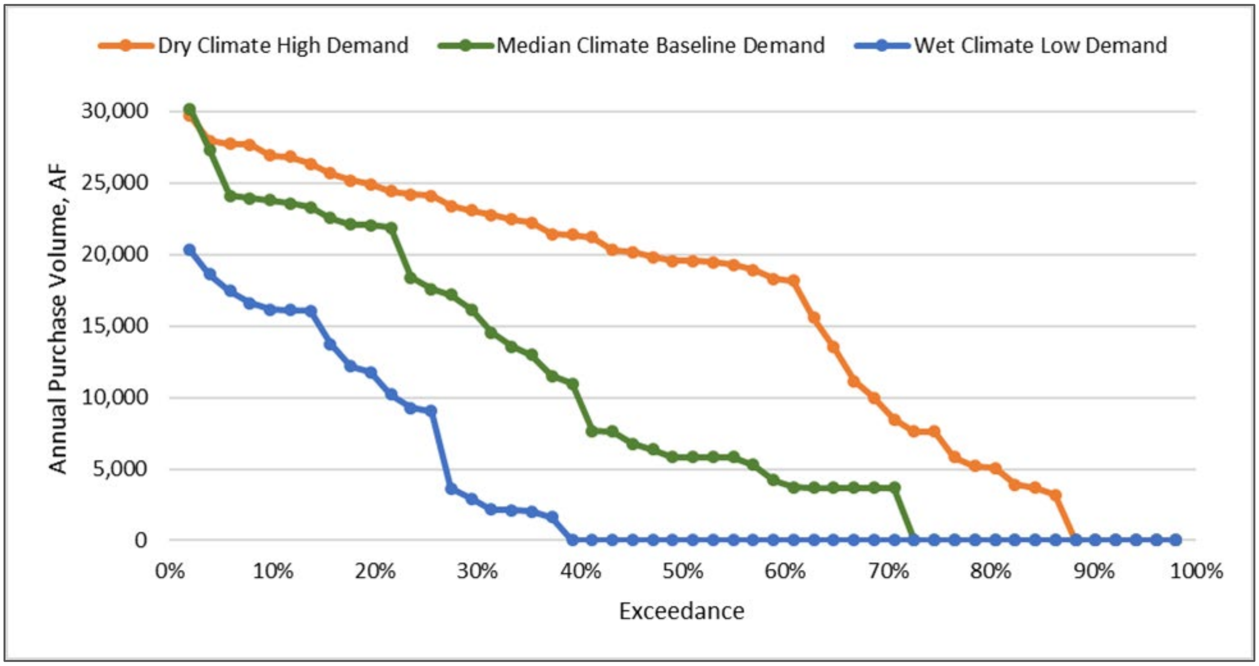


Figure 6-19. Annual Purchase Volumes Exceedance; Purchase of Additional Supply from PG&E Alternative

The model was run adding the identified useful water purchases at Deer Creek Powerhouse to NID diversions to Deer Creek, or displacing NID diversions to Deer Creek with purchase water results in more NID water available to be moved to the Bear River. Water purchases on the Bear River Canal are incorporated into the water balance calculations at Rollins Reservoir. NID allocation calculations incorporated the additional supply when determining annual delivery allocations.

The additional delivery and resulting reduction in unmet demand is shown in Table 6-9, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-20.

Table 6-9. Demand, Delivery, and Unmet Demands, AF, Water Purchases from PG&E Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Purchase of additional supply	181,616	152,344	29,272
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Purchase of additional supply	151,806	141,892	9,914
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Purchase of additional supply	109,705	105,868	3,837

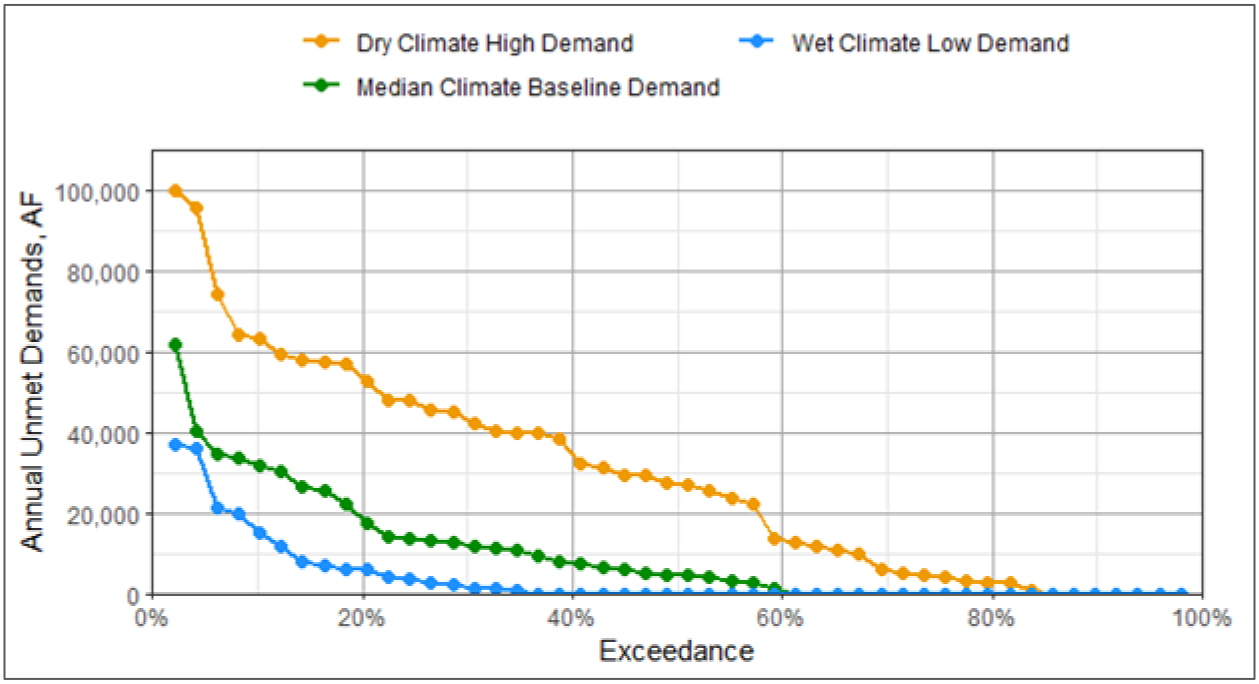


Figure 6-20. Annual Unmet Demands Exceedance, Purchase of Additional Supply from PG&E Scenario

6.9. Revised Carryover Targets and Purchase of Additional Supply from PG&E

An additional modeling study was performed that combined the revised carryover targets with the purchase of additional supply from PG&E. These alternatives work together to reduce the unmet demand further than the individual alternatives. Purchase volumes are reduced slightly, shown in the exceedance plot in Figure 6-21.

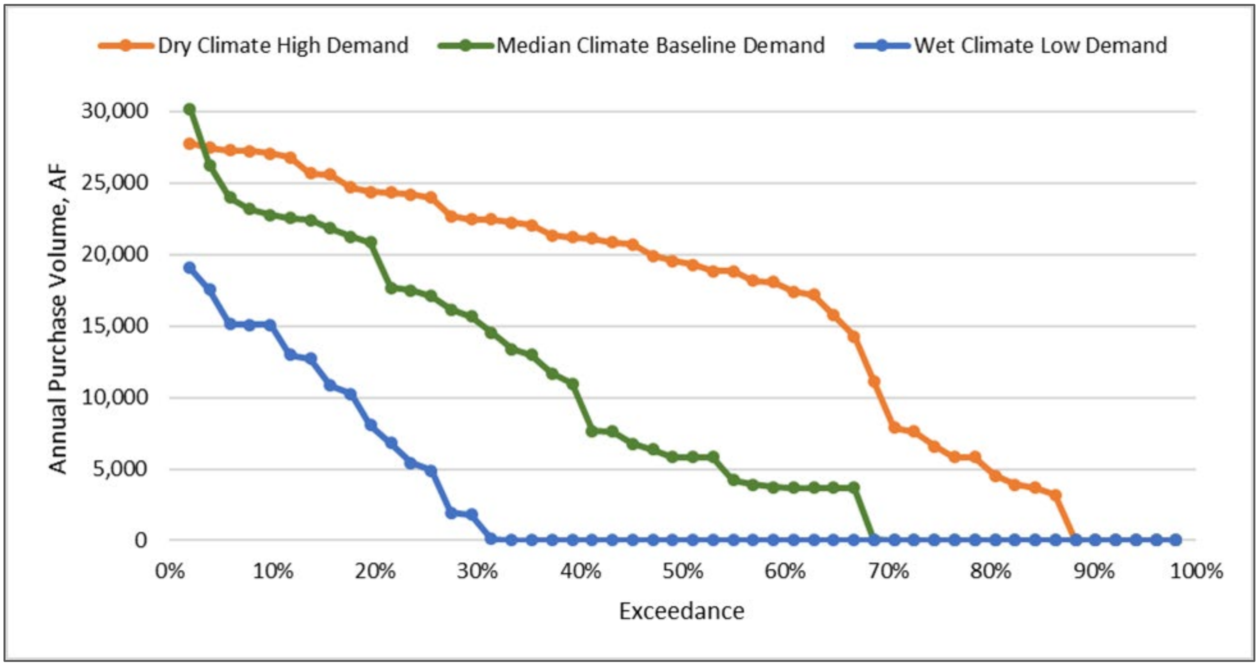


Figure 6-21. Annual purchase volumes exceedance, Revised Carryover Targets and Purchase of additional supply from PG&E alternative

The additional delivery and resulting reduction in unmet demand is shown in Table 6-10, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-22.

Table 6-10. Demand, Delivery, and Unmet Demands, AF, Revised Carryover Targets and Water Purchases from PG&E Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Revised Carryover Targets and Purchase of additional supply	181,616	158,277	23,338
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Revised Carryover Targets and Purchase of additional supply	151,806	145,636	6,170
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Revised Carryover Targets and Purchase of additional supply	109,705	107,762	1,943

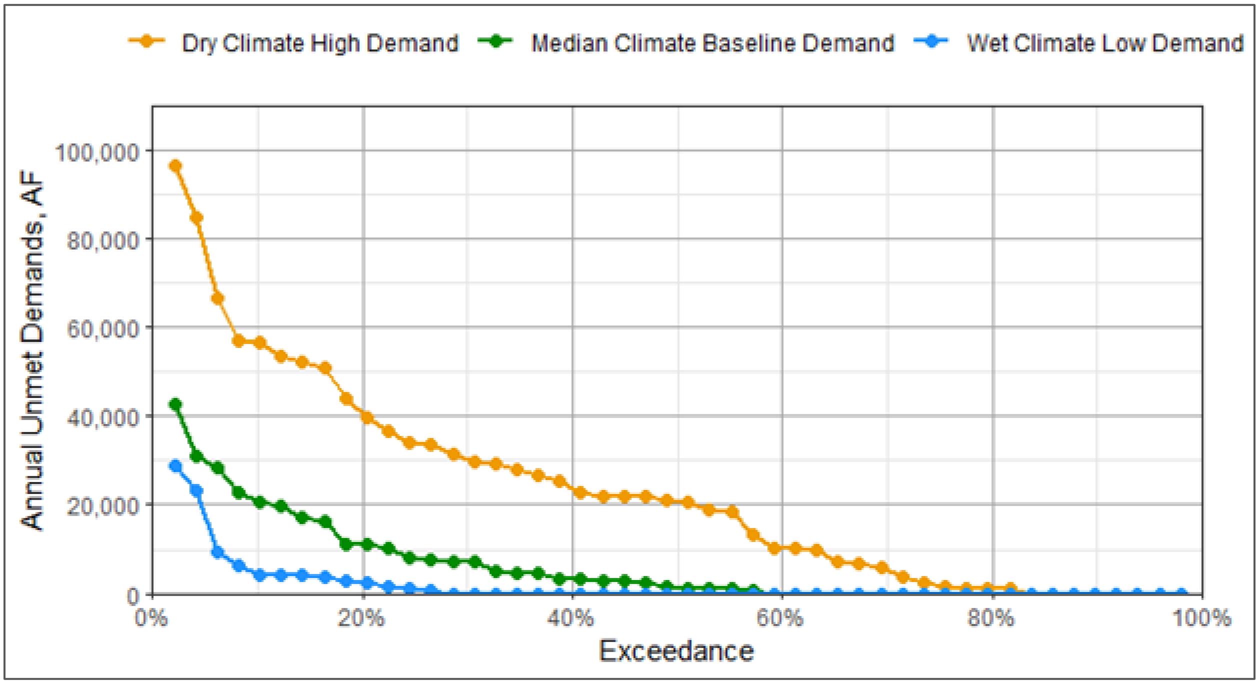


Figure 6-22. Annual Unmet Demands Exceedance, Revised Carryover Targets and Purchase of Additional Supply from PG&E Scenario

6.10. Summary

Deliveries, unmet demands, and carryover storage are summarized for the strategic alternatives for the Wet Climate Low Demand scenarios in Table 6-11, for the Median Climate Low Demand scenarios in Table 6-12, and for the Dry Climate Low Demand scenarios in Table 6-13.

Table 6-11. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Wet Climate Low Demand Scenarios

Strategic Alternative	Average Annual Delivery (AF)	Average Annual Unmet Demand (AF)	Carryover Storage (AF)
Existing Operations	103,941	5,763	147,800
Extended Irrigation Season	107,275	6,256	144,800
Rollins Reservoir 10,000 AF Storage Incr.	105,485	4,220	154,200
Rollins Reservoir 50,000 AF Storage Incr.	108,892	813	190,200
Centennial Reservoir	108,815	890	231,400
Revised Carryover Targets	104,218	3,079	134,300
Water Purchases from PG&E	105,868	3,837	146,700
Revised Carryover Targets + Water Purchases from PG&E	107,762	1,943	135,500

Table 6-12. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Median Climate Baseline Demand Scenarios

Strategic Alternative	Average Annual Delivery (AF)	Average Annual Unmet Demand (AF)	Carryover Storage (AF)
Existing Operations	137,706	14,099	131,400
Extended Irrigation Season	141,707	15,611	126,500
Rollins Reservoir 10,000 AF Storage Incr.	142,221	9,585	132,400
Rollins Reservoir 50,000 AF Storage Incr.	150,092	1,714	162,800
Centennial Reservoir	144,332	7,473	205,900
Revised Carryover Targets	138,963	9,814	114,700
Water Purchases from PG&E	141,892	9,914	129,200
Revised Carryover Targets + Water Purchases from PG&E	145,636	6,170	116,300

Table 6-13. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Dry Climate High Demand Scenarios

Strategic Alternative	Average Annual Delivery (AF)	Average Annual Unmet Demand (AF)	Carryover Storage (AF)
Existing Operations	146,458	35,158	110,800
Extended Irrigation Season	151,651	36,405	106,300
Rollins Reservoir 10,000 AF Storage Incr.	152,544	29,072	117,000
Rollins Reservoir 50,000 AF Storage Incr.	167,384	14,232	129,700
Centennial Reservoir	165,322	16,294	163,100
Revised Carryover Targets	150,528	27,715	91,700
Water Purchases from PG&E	152,344	29,272	115,100
Revised Carryover Targets + Water Purchases from PG&E	158,277	23,338	93,200

Deliveries across all strategic alternatives for the wet hydrology low demand scenarios is shown in Figure 6-23, for the median hydrology baseline demand scenarios in Figure 6-24, and in the dry hydrology low demand scenarios in Figure 6-25.

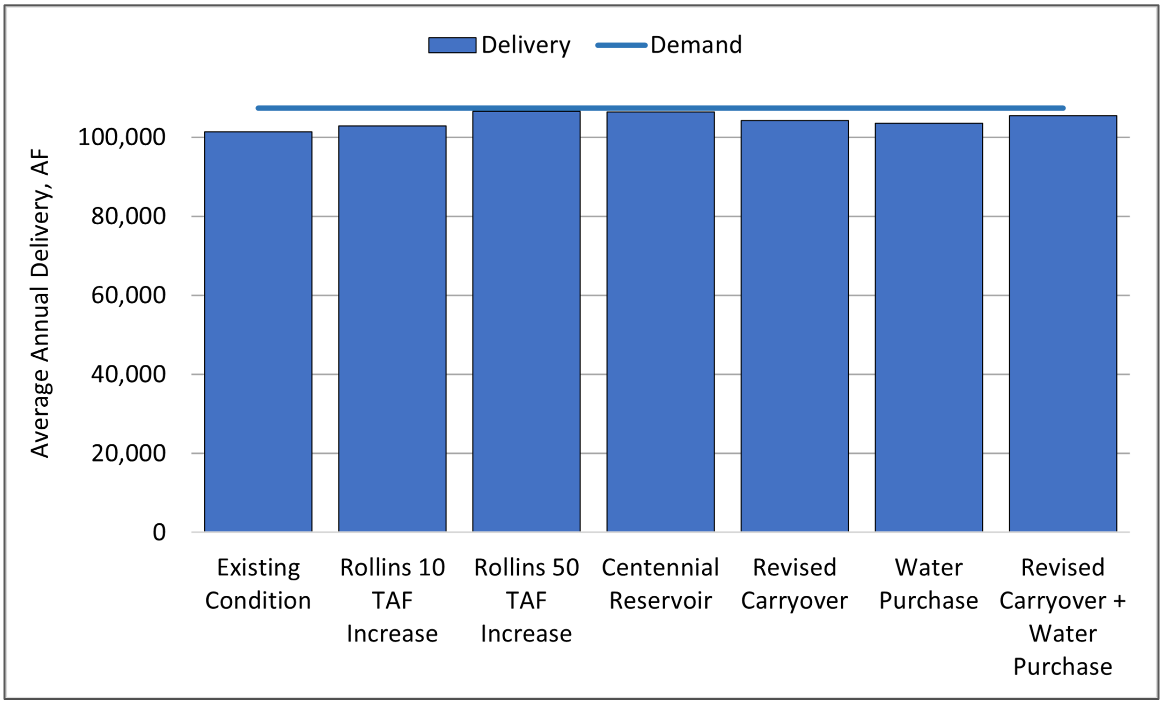


Figure 6-23. Deliveries in Strategic Alternatives, Wet Climate Low Demand Scenarios

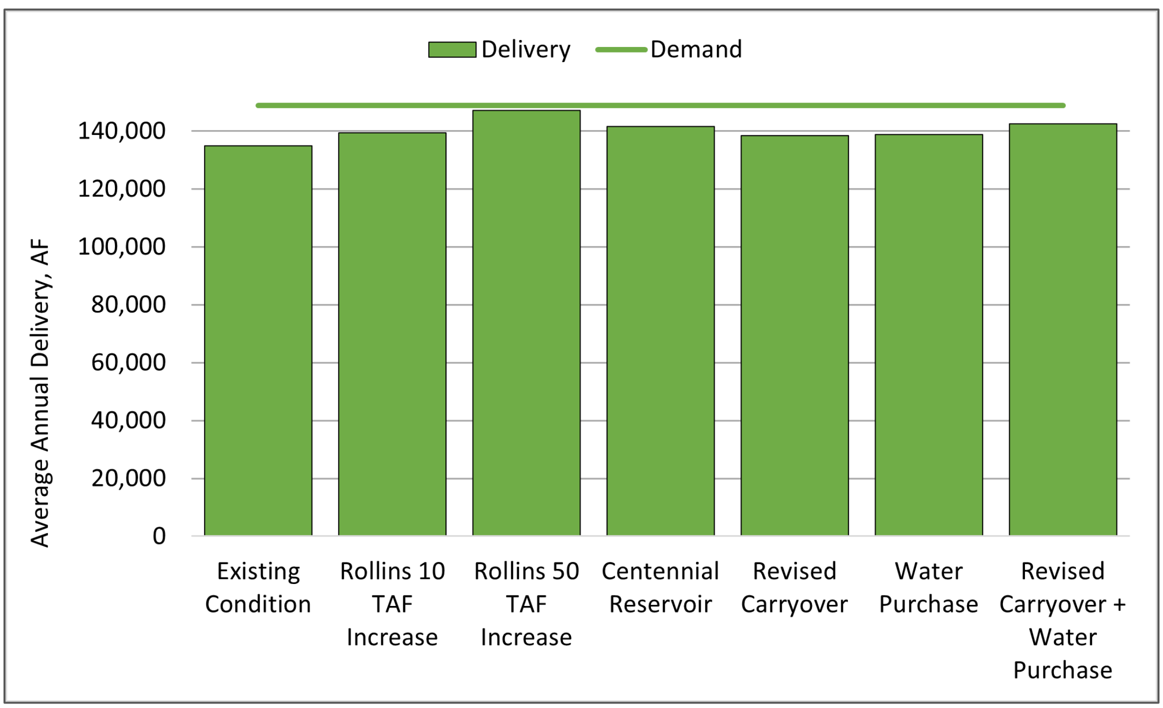


Figure 6-24. Deliveries in Strategic Alternatives, Median Climate Baseline Demand Scenarios

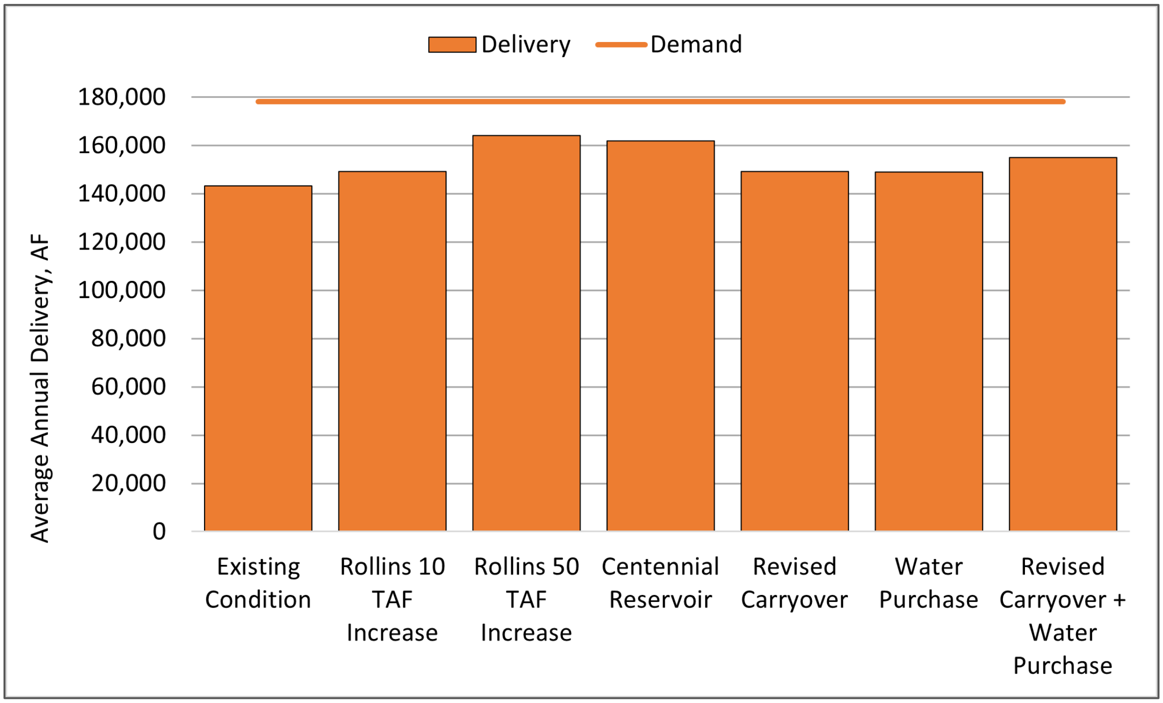


Figure 6-25. Deliveries in Strategic Alternatives, Dry Climate High Demand Scenarios

Unmet demands across all strategic alternatives for the wet hydrology low demand scenarios is shown in Figure 6-26, for the median hydrology baseline demand scenarios in Figure 6-27, and in the dry hydrology low demand scenarios in Figure 6-28.

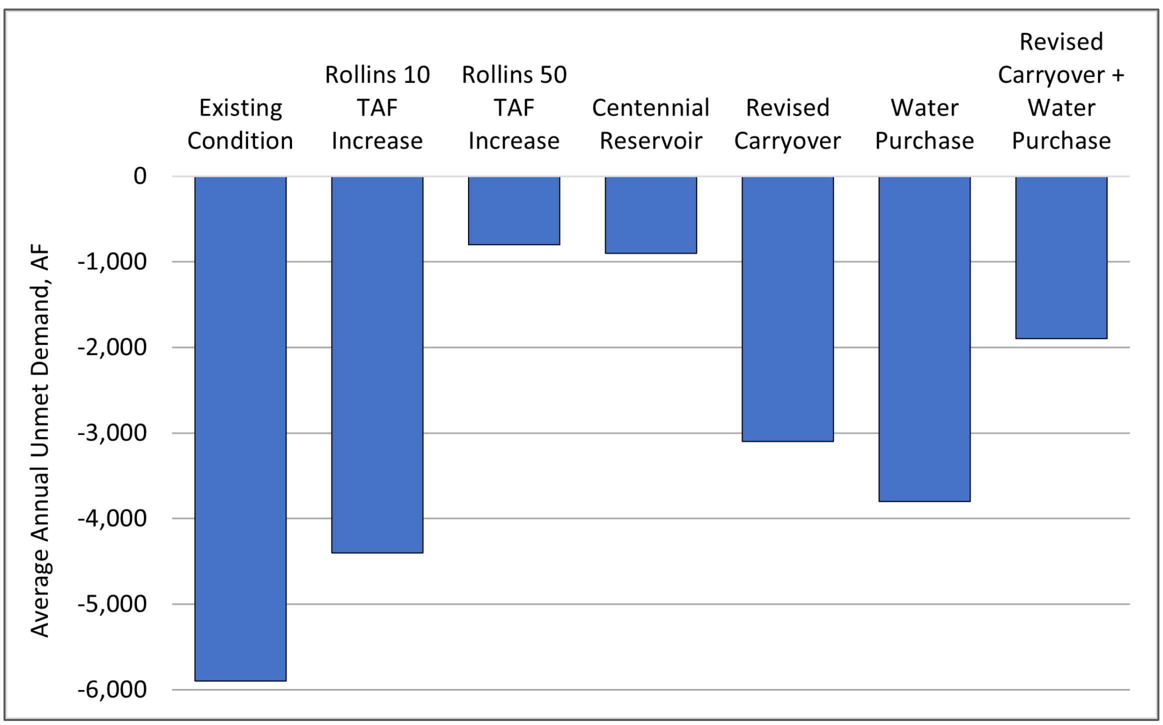


Figure 6-26. Unmet Demands in Strategic Alternatives, Wet Climate Low Demand Scenarios

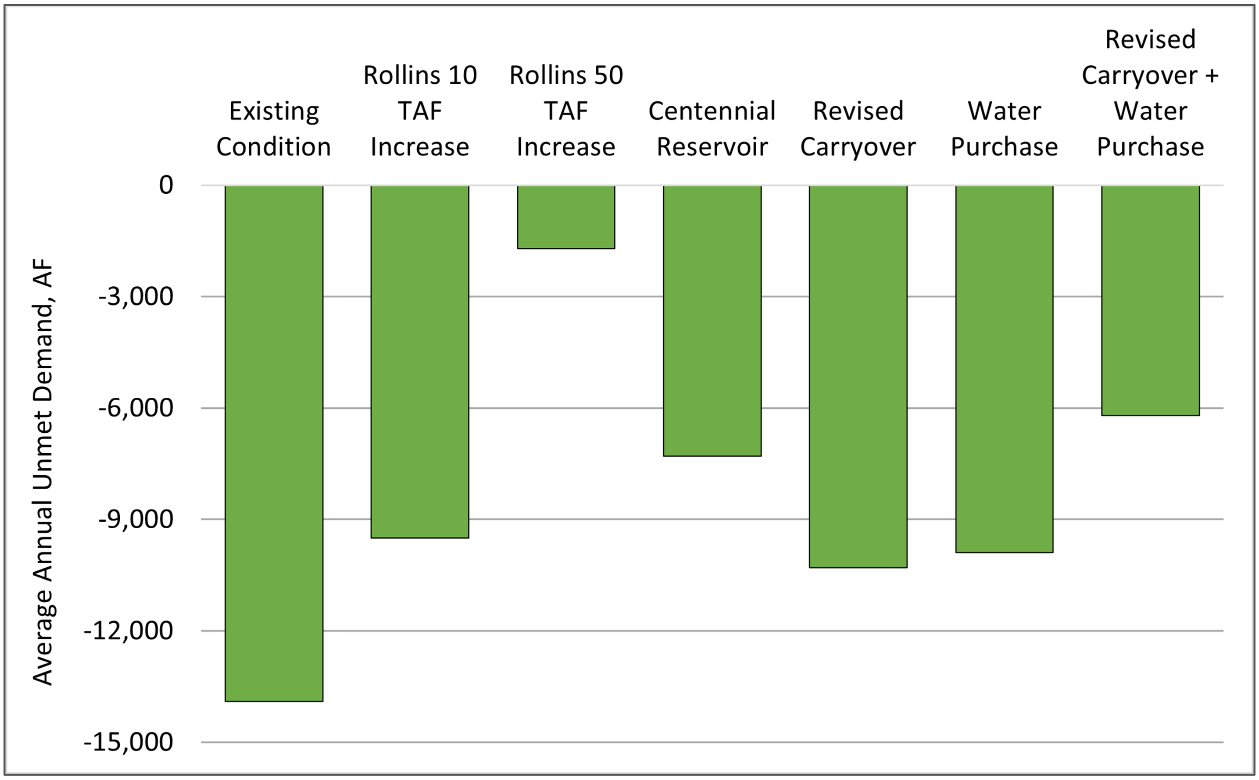


Figure 6-27. Unmet Demands in Strategic Alternatives, Median Climate Baseline Demand Scenarios

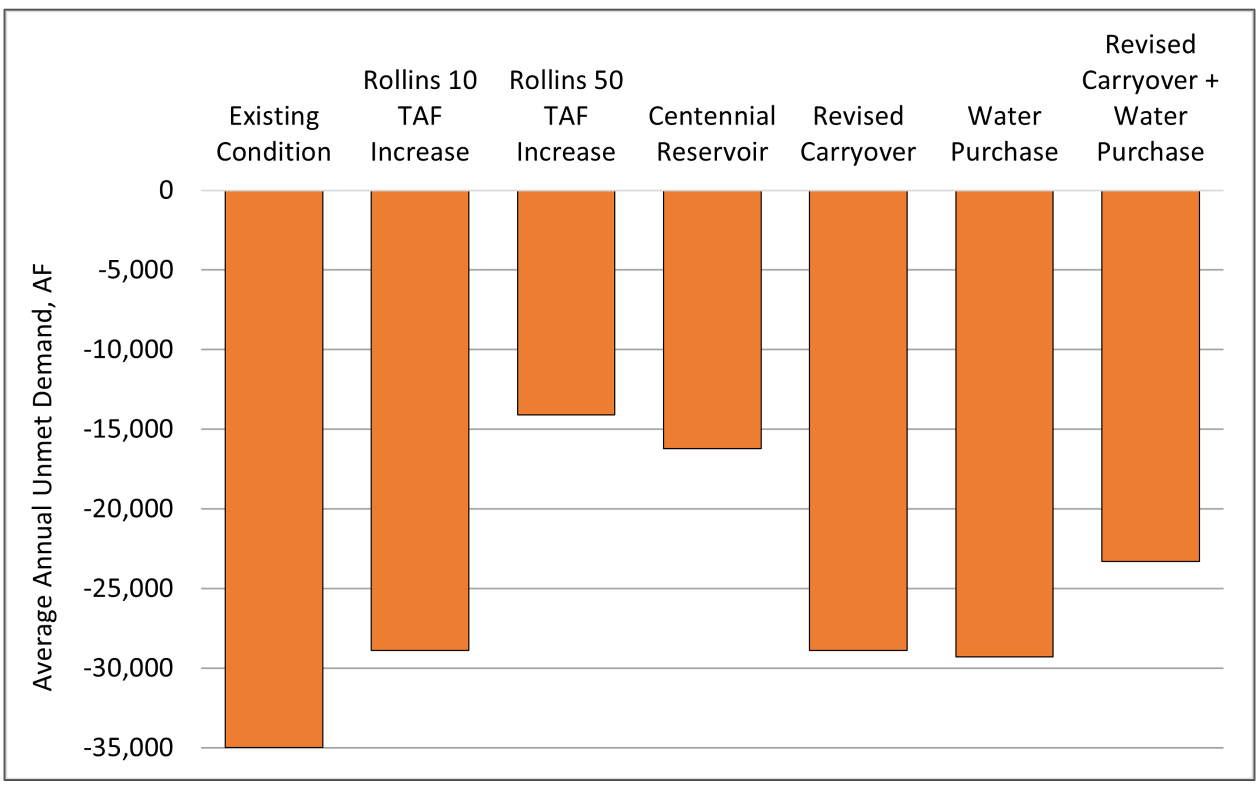


Figure 6-28. Unmet Demands in Strategic Alternatives, Dry Climate High Demand Scenarios

Average November 1 carryover storage across all strategic alternatives for the wet hydrology low demand scenarios is shown in Figure 6-29, for the median hydrology baseline demand scenarios in Figure 6-30, and in the dry hydrology low demand scenarios in Figure 6-31.

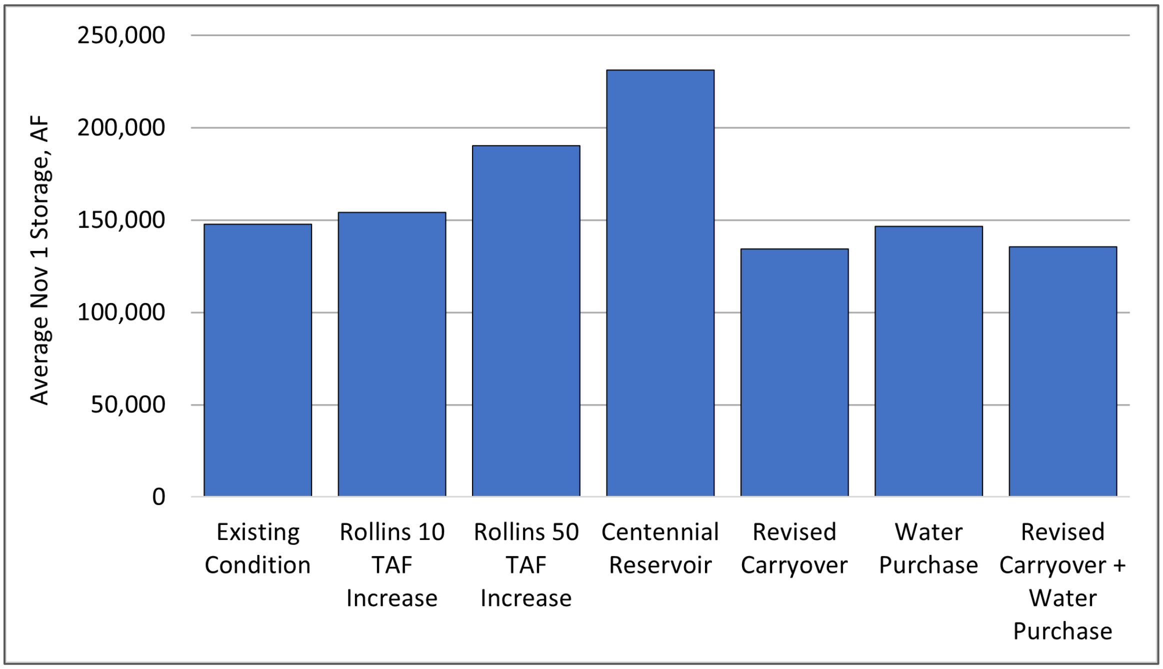


Figure 6-29. Average November 1 Carryover Storage in Strategic Alternatives, Wet Climate Low Demand Scenarios

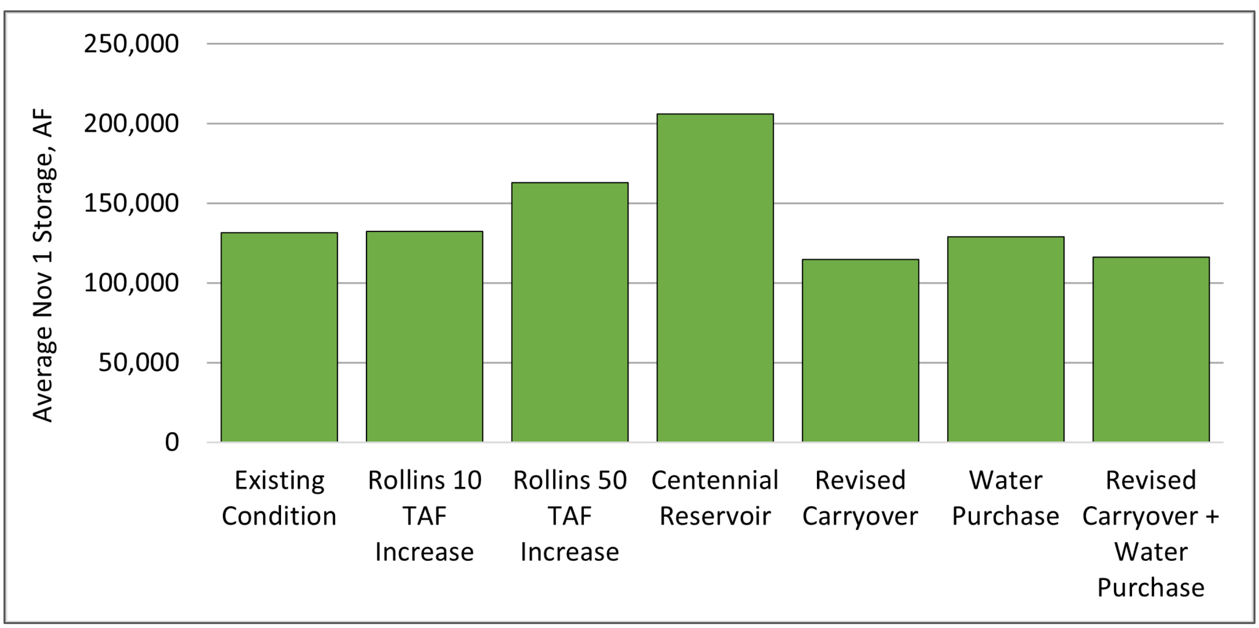


Figure 6-30. Average November 1 Carryover Storage in Strategic Alternatives, Median Climate Baseline Demand Scenarios

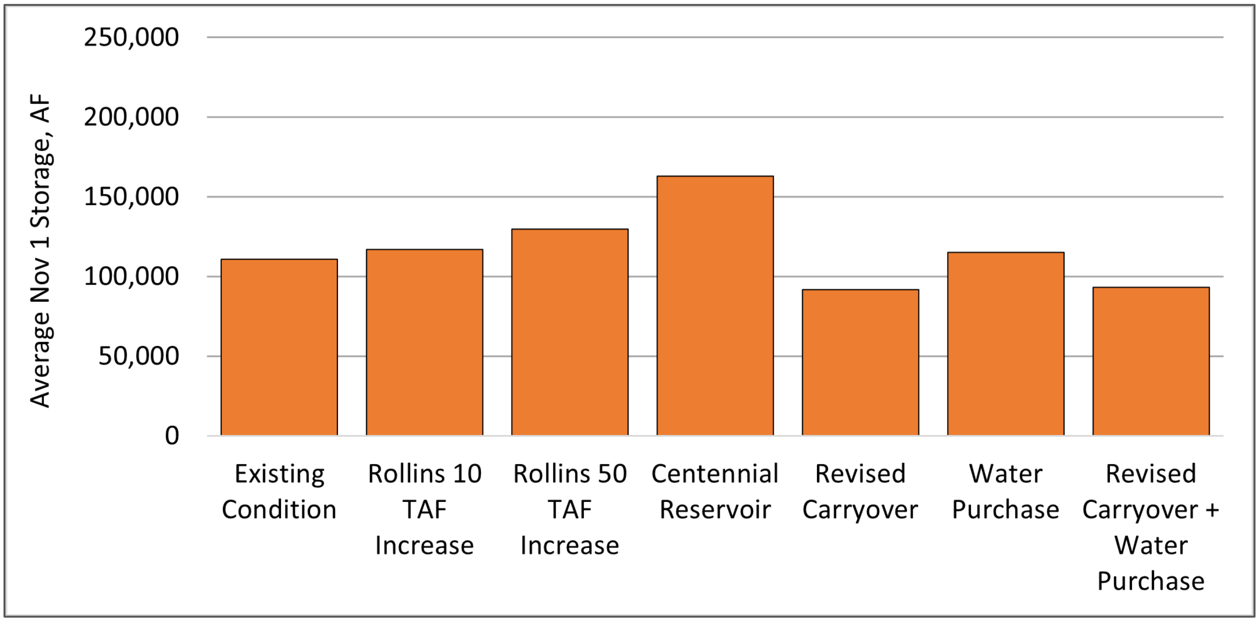


Figure 6-31. Average November 1 Carryover Storage in Strategic Alternatives, Dry Climate High Demand Scenarios

Chapter 7. Summary and Recommendations

The goal of the PFW is to help guide NID's future water management under anticipated changes in climate, runoff, water use, and regulation. The PFW offers a range of potential scenarios for the NID's BOD to consider when assessing ways to best meet customer demands for water over the next 50 years. This report documents the analyses performed to provide actionable information on NID's historical and projected water supply and demand to support the BOD's decision making.

Nine scenarios were initially developed representing various combinations of climate change projections, Dry, Median and Wet, and various combinations of projected customer demands, Low, Baseline and High (Table 5-9). The BOD selected 3 scenarios for further analysis:

- Dry Climate with High Demands
- Median Climate with Baseline Demands
- Wet Climate with Low Demands

These scenarios provide a dry and wet bookend with a median climate scenario to represent a mid-point, and they provide a wide range of hydrologic conditions and consumptive demands. Results of all three scenarios indicate that the ability to meet full customer demands in the future will likely be diminished under existing conditions because of climate change (Figure 6-1).

Seven strategic alternatives were identified by the NID's BOD for investigation to better meet projected customer water demand. The three existing conditions scenarios selected by the BOD for further analysis were used to estimate the relative benefits gained from each of the seven strategic alternatives. The Strategic alternatives analyzed were:

- Extended Irrigation Season
- Rollins Reservoir 10,000 AF Storage Increase
- Rollins Reservoir 50,000 AF Storage Increase
- Centennial Reservoir
- Revised Carryover Targets
- Water Purchases from PG&E
- Revised Carryover Targets + Water Purchases from PG&E

Comparisons of average annual delivery, average annual unmet demand, and carryover were made relative to the three projected climate existing operations scenarios (Table 6-11, Table 6-12, and Table 6-13). While each of the strategic alternatives increased average annual deliveries, some alternatives also resulted in a reduction in carryover storage. A decrease in carryover storage indicates a reduction in available NID water supply in subsequent years. Alternatives that both increase water deliveries and increase carryover storage are much more valuable, from a water supply perspective, than an increase in water deliveries alone.

With the results of the analysis presented in this report, NID's board and directions and community have the necessary information to make scientifically informed decisions.

It is acknowledged that estimating projected water supply and customer demands inherently involves high uncertainties. Uncertainties are also inherent in the social, political, and policy aspects that might influence water resources management. While the most current data and recommended methods were applied in the analysis, uncertainties still exist, and cannot be completely removed from the process. To minimize the effects of uncertainties in decision-making, it is recommended that NID update the analyses in this report as new methods and data become available or policies change. PFW updates every five years is a reasonable and prudent plan going forward.

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Appendix A:

Chapter 2 Supplemental Information

TABLE OF CONTENTS

Appendix A. Chapter 2 Supplemental Information A-1

A.1. HEC-HMS Subbasin A-1

A.2. USGS Schematics A-3

A.3. Calibration Parameters A-6

A.4. Calibration Results for Selected Water Years A-8

A.4.1. Calibration Results for WY1997 .... A-8

A.4.2. Calibration Results for WY2004 .... A-17

A.4.3. Calibration Results for WY2006 .... A-26

A.4.4. Calibration Results for WY2015 .... A-35

A.4.5. Calibration Results for WY2021 .... A-44

A.5. Calibration Refinements Results for Other Water Years A-53

FIGURES

Figure A-1. Diversions and Storage in North and Middle Yuba River Basins, WY2010 .... A-3
Figure A-2. Diversions and Storage in South Yuba River Basin, WY2010 .... A-4
Figure A-3. Diversions and Storage in Bear River Basin, WY2010 .... A-5
Figure A-4. WY1997 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds A-8
Figure A-5. WY1997 Calibration Results for Calibration Location USGS Gage 11413000 .... A-9
Figure A-6. WY1997 Calibration Results for Calibration Location New Bullards Bar Reservoir A-9
Figure A-7. WY1997 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs A-10
Figure A-8. WY1997 Calibration Results for Calibration Location Our House Dam A-10
Figure A-9. WY1997 Calibration Results for Calibration Location Log Cabin Dam A-11
Figure A-10. WY1997 Calibration Results for Calibration Location Bowman Lake A-11
Figure A-11. WY1997 Calibration Results for Calibration Location Lake Spaulding A-12
Figure A-12. WY1997 Calibration Results for Calibration Location USGS Gage 11417500 .... A-12
Figure A-13. WY1997 Calibration Results for Calibration Location Englebright Lake A-13
Figure A-14. WY1997 Calibration Results for Calibration Location Scotts Flat Reservoir A-13
Figure A-15. WY1997 Calibration Results for Calibration Location USGS Gage 11418500 .... A-14
Figure A-16. WY1997 Calibration Results for Calibration Location Yuba River Outlet A-14
Figure A-17. WY1997 Calibration Results for Calibration Location Dutch Flat Afterbay A-15
Figure A-18. WY1997 Calibration Results for Calibration Location Rollins Reservoir A-15
Figure A-19. WY1997 Calibration Results for Calibration Location Camp Far West Lake A-16
Figure A-20. WY2004 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds A-17
Figure A-21. WY2004 Calibration Results for Calibration Location USGS Gage 11413000 .... A-18
Figure A-22. WY2004 Calibration Results for Calibration Location New Bullards Bar Reservoir A-18
Figure A-23. WY2004 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs A-19
Figure A-24. WY2004 Calibration Results for Calibration Location Our House Dam A-19
Figure A-25. WY2004 Calibration Results for Calibration Location Log Cabin Dam A-20
Figure A-26. WY2004 Calibration Results for Calibration Location Bowman Lake A-20
Figure A-27. WY2004 Calibration Results for Calibration Location Fordyce Lake A-21
Figure A-28. WY2004 Calibration Results for Calibration Location Lake Spaulding A-21
Figure A-29. WY2004 Calibration Results for Calibration Location USGS Gage 11417500 .... A-22
Figure A-30. WY2004 Calibration Results for Calibration Location Englebright Lake A-22

Figure A-31. WY2004 Calibration Results for Calibration Location Scotts Flat Reservoir....A-23
Figure A-32. WY2004 Calibration Results for Calibration Location USGS Gage 11418500....A-23
Figure A-33. WY2004 Calibration Results for Calibration Location Yuba River Outlet....A-24
Figure A-34. WY2004 Calibration Results for Calibration Location Dutch Flat Afterbay....A-24
Figure A-35. WY2004 Calibration Results for Calibration Location Rollins Reservoir....A-25
Figure A-36. WY2004 Calibration Results for Calibration Location Camp Far West Lake....A-25
Figure A-37. WY2006 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds....A-26
Figure A-38. WY2006 Calibration Results for Calibration Location USGS Gage 11413000....A-27
Figure A-39. WY2006 Calibration Results for Calibration Location New Bullards Bar Reservoir....A-27
Figure A-40. WY2006 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs....A-28
Figure A-41. WY2006 Calibration Results for Calibration Location Our House Dam....A-28
Figure A-42. WY2006 Calibration Results for Calibration Location Log Cabin Dam....A-29
Figure A-43. WY2006 Calibration Results for Calibration Location Bowman Lake....A-29
Figure A-44. WY2006 Calibration Results for Calibration Location Fordyce Lake....A-30
Figure A-45. WY2006 Calibration Results for Calibration Location Lake Spaulding....A-30
Figure A-46. WY2006 Calibration Results for Calibration Location USGS Gage 11417500....A-31
Figure A-47. WY2006 Calibration Results for Calibration Location Englebright Lake....A-31
Figure A-48. WY2006 Calibration Results for Calibration Location Scotts Flat Reservoir....A-32
Figure A-49. WY2006 Calibration Results for Calibration Location USGS Gage 11418500....A-32
Figure A-50. WY2006 Calibration Results for Calibration Location Yuba River Outlet....A-33
Figure A-51. WY2006 Calibration Results for Calibration Location Dutch Flat Afterbay....A-33
Figure A-52. WY2006 Calibration Results for Calibration Location Rollins Reservoir....A-34
Figure A-53. WY2006 Calibration Results for Calibration Location Camp Far West Lake....A-34
Figure A-54. WY2015 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds....A-35
Figure A-55. WY2015 Calibration Results for Calibration Location USGS Gage 11413000....A-36
Figure A-56. WY2015 Calibration Results for Calibration Location New Bullards Bar Reservoir....A-36
Figure A-57. WY2015 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs....A-37
Figure A-58. WY2015 Calibration Results for Calibration Location Our House Dam....A-37
Figure A-59. WY2015 Calibration Results for Calibration Location Log Cabin Dam....A-38
Figure A-60. WY2015 Calibration Results for Calibration Location Bowman Lake....A-38
Figure A-61. WY2015 Calibration Results for Calibration Location Fordyce Lake....A-39
Figure A-62. WY2015 Calibration Results for Calibration Location Lake Spaulding....A-39
Figure A-63. WY2015 Calibration Results for Calibration Location USGS Gage 11417500....A-40
Figure A-64. WY2015 Calibration Results for Calibration Location Englebright Lake....A-40
Figure A-65. WY2015 Calibration Results for Calibration Location Scotts Flat Reservoir....A-41
Figure A-66. WY2015 Calibration Results for Calibration Location USGS Gage 11418500....A-41
Figure A-67. WY2015 Calibration Results for Calibration Location Yuba River Outlet....A-42
Figure A-68. WY2015 Calibration Results for Calibration Location Dutch Flat Afterbay....A-42
Figure A-69. WY2015 Calibration Results for Calibration Location Rollins Reservoir....A-43
Figure A-70. WY2015 Calibration Results for Calibration Location Camp Far West Lake....A-43
Figure A-71. WY2021 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds....A-44
Figure A-72. WY2021 Calibration Results for Calibration Location USGS Gage 11413000....A-45
Figure A-73. WY2021 Calibration Results for Calibration Location New Bullards Bar Reservoir....A-45
Figure A-74. WY2021 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs....A-46
Figure A-75. WY2021 Calibration Results for Calibration Location Our House Dam....A-46
Figure A-76. WY2021 Calibration Results for Calibration Location Log Cabin Dam....A-47
Figure A-77. WY2021 Calibration Results for Calibration Location Bowman Lake....A-47
Figure A-78. WY2021 Calibration Results for Calibration Location Fordyce Lake....A-48
Figure A-79. WY2021 Calibration Results for Calibration Location Lake Spaulding....A-48
Figure A-80. WY2021 Calibration Results for Calibration Location USGS Gage 11417500....A-49
Figure A-81. WY2021 Calibration Results for Calibration Location Englebright Lake....A-49

Figure A-82. WY2021 Calibration Results for Calibration Location Scotts Flat Reservoir....A-50
Figure A-83. WY2021 Calibration Results for Calibration Location USGS Gage 11418500....A-50
Figure A-84. WY2021 Calibration Results for Calibration Location Yuba River Outlet....A-51
Figure A-85. WY2021 Calibration Results for Calibration Location Dutch Flat Afterbay....A-51
Figure A-86. WY2021 Calibration Results for Calibration Location Rollins Reservoir....A-52
Figure A-87. WY2021 Calibration Results for Calibration Location Camp Far West Lake....A-52
Figure A-88. Cumulative Daily Inflow (1975–2018) for Bowman Lake After Calibration Refinements....A-53
Figure A-89. Cumulative Daily Inflow (1975–2018) for Jackson Meadow Reservoir After Calibration Refinements....A-53
Figure A-90. Cumulative Daily Inflow (1975–2018) for Lake Spaulding After Calibration Refinements....A-54
Figure A-91. Cumulative Daily Inflow (1975–2018) for Middle Yuba-Below Milton Reservoir After Calibration Refinements....A-54
Figure A-92. Cumulative Daily Inflow (1975–2018) for Middle Yuba- Milton Reservoir After Calibration Refinements....A-55
Figure A-93. Cumulative Daily Inflow (1975–2018) for Rollins Reservoir After Calibration Refinements....A-55
Figure A-94. Cumulative Daily Inflow (1975–2018) for Deer Creek- Below Scotts Flat Reservoir After Calibration Refinements....A-56
Figure A-95. Cumulative Daily Inflow (1975–2018) for Scott Flat Reservoir After Calibration Refinements....A-56
Figure A-96. Cumulative Daily Inflow (1975–2018) for South Yuba Lower Watersheds After Calibration Refinements....A-57
Figure A-97. Cumulative Daily Inflow (1975–2018) for Texas Fall Creeks After Calibration Refinements....A-57

TABLES

Table A-1. HEC-HMS Model—Subbasin Summary....A-1
Table A-2. HEC-HMS Calibration Parameters....A-6

Appendix A. Chapter 2 Supplemental Information

A.1. HEC-HMS Subbasin

Table A-1 presents subbasin names and their respective drainage areas, detailed in Appendix A.

Table A-1. HEC-HMS Model—Subbasin Summary

Name	Area (sq. mi.)	Name	Area (sq. mi.)
NY_NorthYuba_S10	33.729	SY_SouthYuba_S80	11.616
NY_NorthYuba_S20	17.091	SY_SouthYuba_S90	22.299
NY_HayPressCreek_S10	31.489	SY_HumbugCreek_S10	10.818
NY_NorthYuba_S30	4.480	SY_SouthYuba_S100	44.248
NY_LavezzolaCreek_S10	28.547	SY_SouthYuba_S110	34.606
NY_DownieRiver_S10	17.511	YR_YubaRiver_S20	18.265
NY_PauleyCreek_S10	25.361	SY_SouthYuba_S120	6.988
NY_DownieRiver_S20	0.556	YR_YubaRiver_S30	23.666
NY_NorthYuba_S40	54.639	YR_DeerCreek_S10	5.761
NY_DownieRiver_S30	0.517	YR_DeerCreek_S20	14.529
NY_NorthYuba_S50	36.229	YR_DeerCreek_S30	13.959
NY_CanyonCreek_S10	60.982	YR_DeerCreek_S40	10.855
NY_NorthYuba_S60	36.442	YR_DeerCreek_S50	10.599
NY_SlateCreek_S10	49.480	DC_SquirrelCreek_S10	25.045
NY_SlateCreek_S20	11.942	YR_DeerCreek_S60	1.462
NY_NorthYuba_S70	2.930	YR_DeerCreek_S70	7.615
NY_NorthYuba_S80	39.059	YR_DryCreek_S10	107.900
NY_BridgerCreek_S10	22.526	YR_YubaRiver_S40	15.403
NY_NorthYuba_S90	15.693	YR_YubaRiver_S50	22.534
MY_PassCreek_S10	18.704	BR_DryCreek_S10	33.032
MY_MiddleYuba_S10	17.706	BR_BestSlough_S10	99.463
MY_MiddleYuba_S20	0.682	BR_BestSlough_S20	45.665
MY_MiddleYuba_S30	2.456	BR_BearRiver_S140	0.438
MY_MiddleYuba_S40	1.052	BR_BearRiver_S150	0.361
MY_MiddleYuba_S50	19.458	BR_BearRiver_S10	1.591
MY_EastForkCreek_S10	13.201	BR_BearRiver_S20	10.637
MY_MiddleYuba_S60	12.964	BR_LittleBearCreek_S10	1.588
MY_WolfCreek_S10	8.693	BR_BearRiver_S30	7.292
MY_MiddleYuba_S70	21.582	BR_BearRiver_S40	0.369
MY_KanakaCreek_S10	17.961	BR_SteephollowCreek_S10	23.798
MY_MiddleYuba_S80	9.734	BR_BearRiver_S50	6.963
MY_OregonCreek_S10	29.175	BR_GreenhornCreek_S10	40.786
MY_MiddleYuba_S90	17.136	BR_BearRiver_S60	4.483
MY_OregonCreek_S20	6.097	BR_BearRiver_S70	5.953

Name	Area (sq. mi.)
MY_MiddleYuba_S100	13.485
NY_NorthYuba_S100	1.698
YR_YubaRiver_S10	14.534
SY_SouthYuba_S10	0.735
SY_SouthYuba_S20	0.289
SY_SouthYuba_S30	0.538
SY_SouthYuba_S40	51.161
SY_FordyceCreek_S10	1.270
NC_WhiteRockCreek_S10	1.147
SY_FordyceCreek_S20	1.009
SY_FordyceCreek_S30	27.502
SY_FordyceCreek_S40	22.538
SY_SouthYuba_S50	6.415
SY_JordanCreek_S10	0.575
SY_JordanCreek_S20	0.246
SY_RuckerCreek_S10	0.282
SY_RuckerCreek_S20	1.226
SY_RuckerCreek_S30	0.291
CC_LakeCreek_S30	5.063
TC_LindseyCreek_S10	0.162
TC_LindseyCreek_S20	0.247
TC_LindseyCreek_S30	0.510
TC_TexasCreek_S10	0.447
TC_TexasCreek_S20	0.186
TC_TexasCreek_S30	0.098
TC_TexasCreek_S40	3.828
SY_ClearCreek_S10	1.765
SY_FallCreek_S10	0.614
CC_LakeCreek_S10	0.433
CC_LakeCreek_S20	0.081
SY_SouthYuba_S60	5.081
CC_CanyonCreek_S10	4.997
CC_CanyonCreek_S20	4.500
CC_CanyonCreek_S30	7.869
CC_JacksonCreek_S10	0.642
CC_CanyonCreek_S40	10.486
SY_SouthYuba_S70	18.625
CC_CanyonCreek_S50	16.498
SY_Poorman_Creek_S10	23.308

Name	Area (sq. mi.)
BR_BearRiver_S80	19.717
BR_BearRiver_S85	12.534
BR_WolfCreek_S10	37.513
WC_SouthWoolfCreek_S10	33.423
BR_BearRiver_S90	13.478
BR_WolfCreek_S20	7.106
BR_BearRiver_S100	30.529
BR_BearRiver_S120	17.705
BR_BearRiver_S110	0.351
BR_BearRiver_S130	16.527
RC_DryCreek_S10	0.978
RC_DryCreek_S20	0.693
RC_DryCreek_S30	1.434
RC_DryCreek_S40	2.148
RC_RaccoonCreek_S10	49.579
RC_DotyCreek_S10	24.846
RC_RaccoonCreek_S20	29.761
RC_BunkhamSlough_S10	26.829
RC_AuburnRavine_S10	36.080
RC_OrchardCreek_S10	22.356
RC_OrchardCreek_S20	18.214
RC_RaccoonCreek_S30	11.270
RC_PleasantGroveCreek_S10	46.578
RC_CurryCreek_S10	16.793
RC_PleasantGroveCreek_S20	6.087
RC_PleasantGroveCreek_S30	1.592
NFA_NFAmerican_S10	75.531
NFA_BigGraniteCreek_S10	17.952
NFA_NFNorthAmerican_S10	4.374
NFA_NFNorthAmerican_S20	0.611
NFA_NFNorthAmerican_S30	3.882
NFNA_EastForkNFAmerican_S10	17.559
NFA_NFNorthAmerican_S40	6.457
NFA_NFAmerican_S20	47.669
NFA_NFNorthAmerican_S50	21.796
NFA_CanyonCreek_S10	1.533
NFA_CanyonCreek_S20	4.095
NFA_NFAmerican_S30	15.897

A.2. USGS Schematics

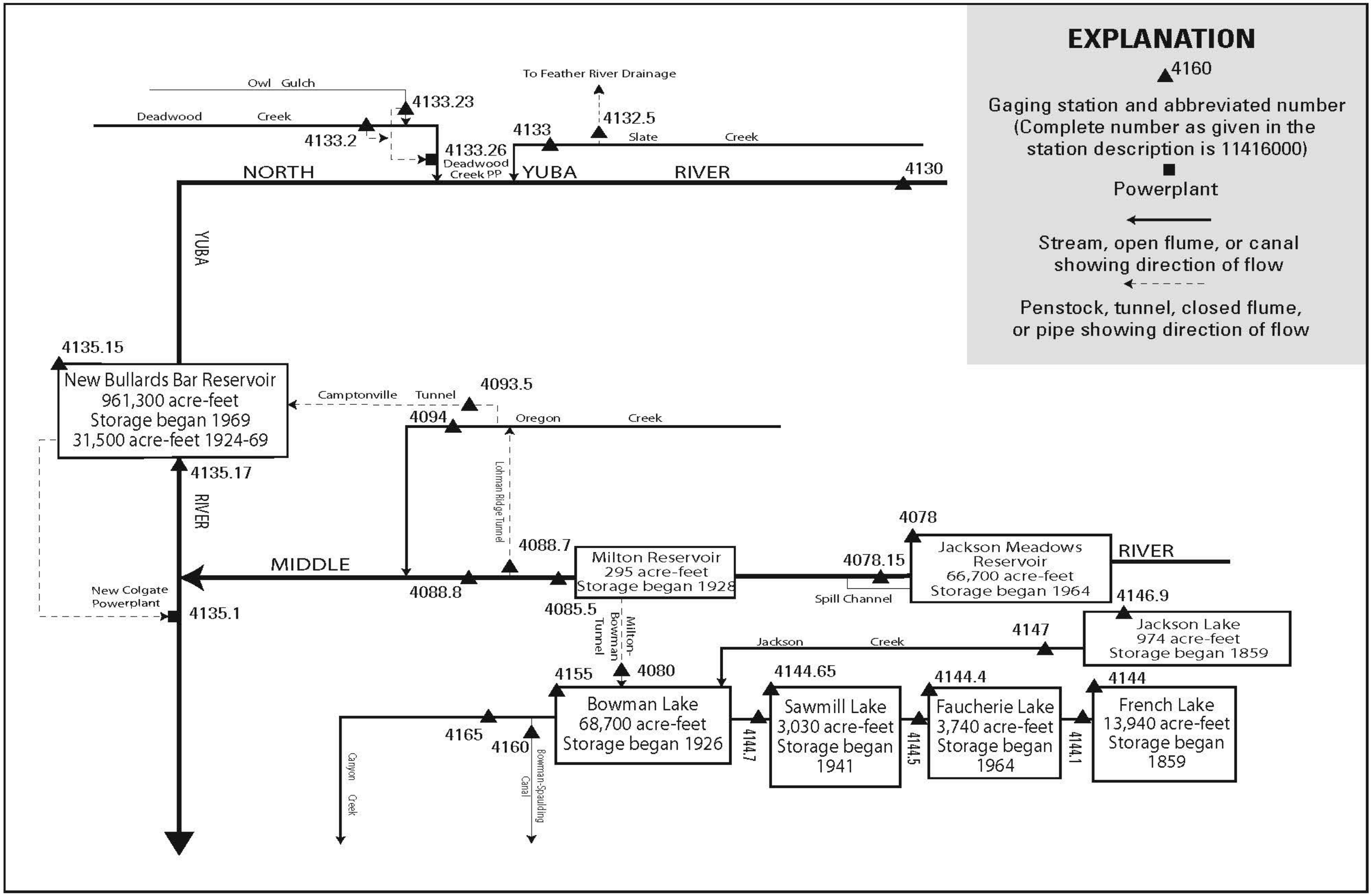

Figure A-1. Diversions and Storage in North and Middle Yuba River Basins, WY2010

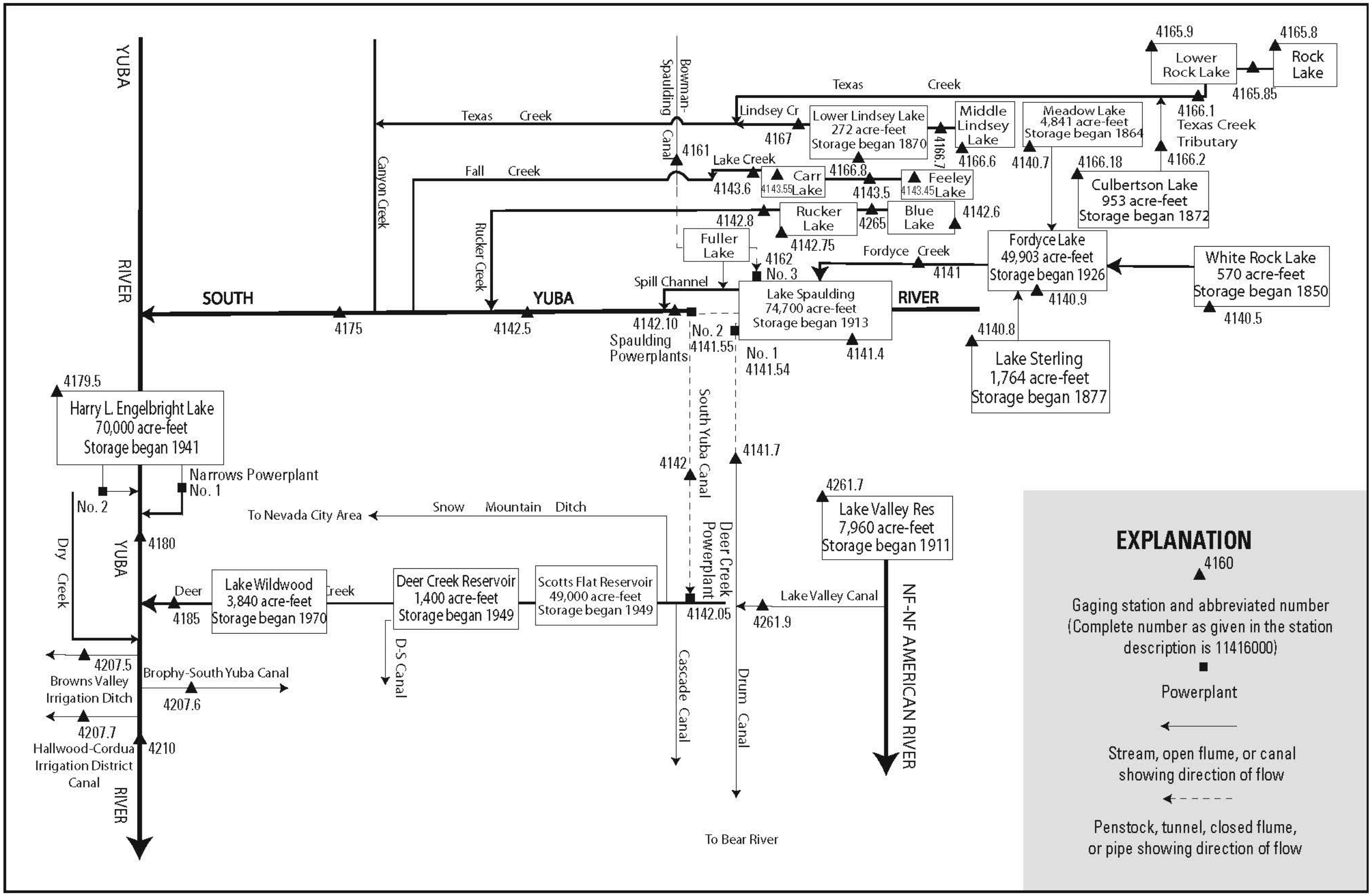

Figure A-2. Diversions and Storage in South Yuba River Basin, WY2010

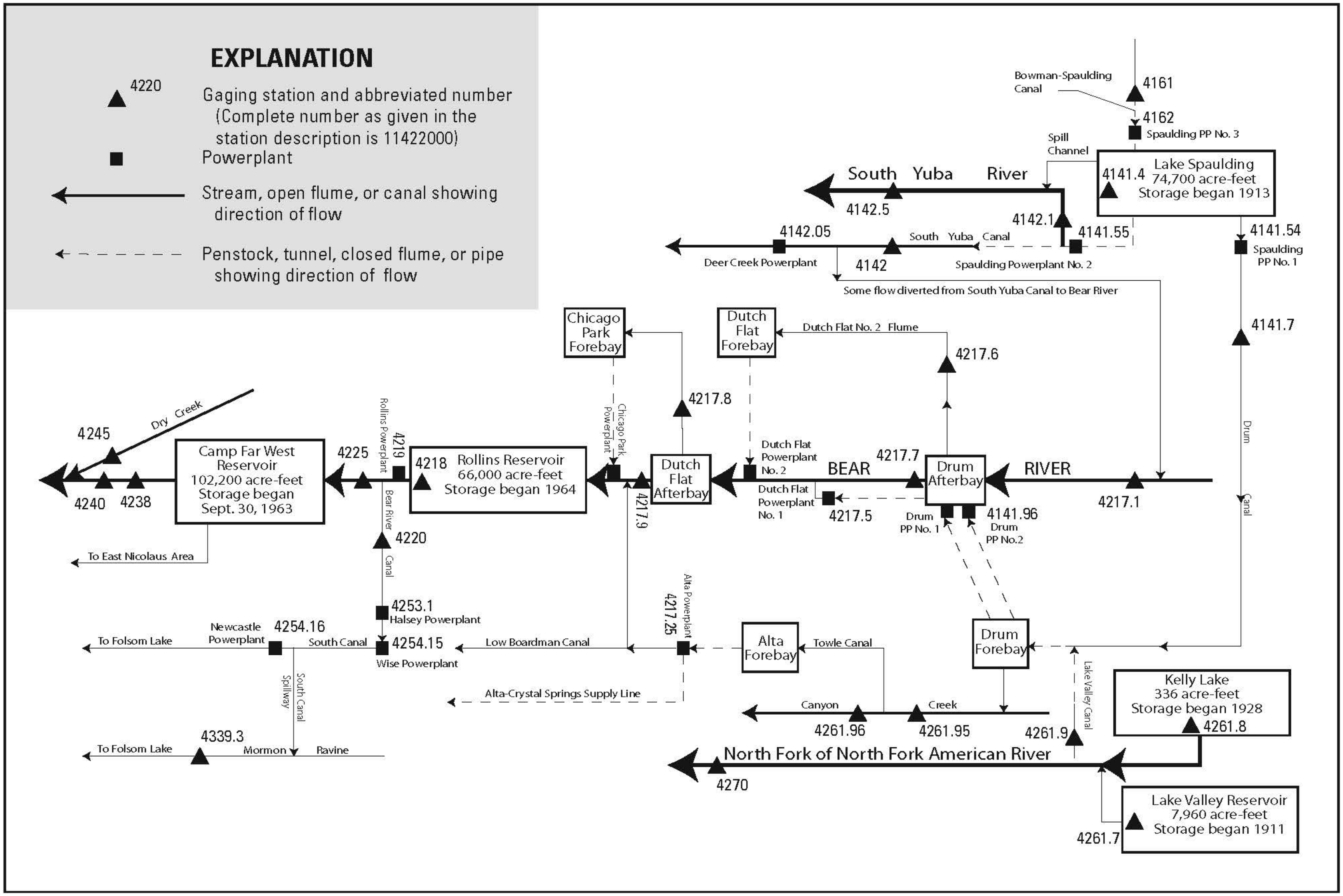

Figure A-3. Diversions and Storage in Bear River Basin, WY2010

A.3. Calibration Parameters

Sensitivity analysis was performed to determine the most sensitive model parameters to improve calibration. The results indicated that the calibration procedure should focus on baseflow groundwater fractions, snow parameters (PX and base temperatures and Wet Meltrate coefficient), and constant loss rate.

Table A-2. HEC-HMS Calibration Parameters

Process	Parameter	Calibration Approach
Streamflow Routing	Length	Not adjusted during model calibration.
	Slope	Not adjusted during model calibration.
	Manning's n	Not adjusted during model calibration.
	Index Celerity	Set to 5 ft/s. Not adjusted during model calibration.
	8-point Cross Section Shape	Not adjusted during model calibration.
	Manning's n (Left and Right)	Set to 0.07. Not adjusted during model calibration.
Evapotranspiration and Canopy	Initial Storage	Set to 0% for each subbasin. Not adjusted during model calibration.
	Max Storage	Specified for each subbasin. Estimated by the Canopy Storage Depths for NLCD Land Cover Classifications. Not adjusted during model calibration.
	Crop Coefficient	Set to 1. Not adjusted during model calibration.
	Hamon Coefficient	Set to 0.0065. Not adjusted during model calibration.
Runoff Transform	Time of Concentration (T_c)	Due to the use of daily average precipitation and a relatively long computational interval, little to no overland flow was generated during any simulation. Therefore, runoff transform parameters were not calibrated as part of this modeling effort.
	Storage Coefficient (R)	Due to the use of daily average precipitation and a relatively long computational interval, little to no overland flow was generated during any simulation. Therefore, runoff transform parameters were not calibrated as part of this modeling effort.
Snowmelt	PX Temperature	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	Base Temperature	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	Wet Meltrate	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	Rain Rate Limit	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.

Process	Parameter	Calibration Approach
Snowmelt, continued	ATI-Meltrate Function	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	ATI-Coldrate Function	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.
	Snowpack Water Capacity	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.
	Ground melt	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.
Infiltration	Initial Deficit	Set to 0. Not adjusted during calibration.
	Maximum Deficit	Set to 2 inches. over the active soil layer depth. Not adjusted during HEC-HMS model calibration.
	Constant Loss Rate	Initially set to 0.1 in/hr. Adjusted to guarantee the generation of minimal to no excess precipitation and maximize runoff using the linear reservoir baseflow routine. The final values all fall between 0.06 and 0.13 in/hr.
	% Impervious Cover	Not adjusted during model calibration
Baseflow	GW 1 Initial Discharge	Initial discharge set to 0.
	GW 1 Fraction	Set to 0.5 adjusted between 0 and 0.5 during HEC-HMS model calibration. Whenever the GW 1 and GW 2 fractions do not equal 1.0, the difference between 1.0 and the sum is the percentage that does not contribute to runoff and is instead lost to a deep aquifer.
	GW 1 Storage Coefficient	GW 1 was conceptualized to represent the fast-responding portion of baseflow. Therefore, this coefficient was set to a smaller value than the GW 2 storage coefficient. This value was set to 2 times the storage coefficient. Minor modifications to this parameter were made during modeling calibration.
	GW 1 # of Reservoirs	Set to 1. Not adjusted during model calibration.
	GW 2 Initial Discharge	Initial discharge is event specific and can vary throughout the year within a single subbasin. Parameter was set to an appropriate value within each subbasin for each water year that provided adequate agreement with observed data.
	GW 2 Fraction	Set to 0.5 and varied between 0 and 0.5 during HEC-HMS model calibration. Whenever the GW 1 and GW 2 fractions do not equal 1.0, the difference between 1.0 and the sum is the percentage that does not contribute to runoff and is instead lost to a deep aquifer.
	GW 2 Storage Coefficient	Set to a larger value than the GW 1 storage coefficient. Minor modifications to this parameter were made during modeling calibration.
	GW 2 # of Reservoirs	Set to 1. Not varied during model calibration.

A.4. Calibration Results for Selected Water Years

A.4.1. Calibration Results for WY1997

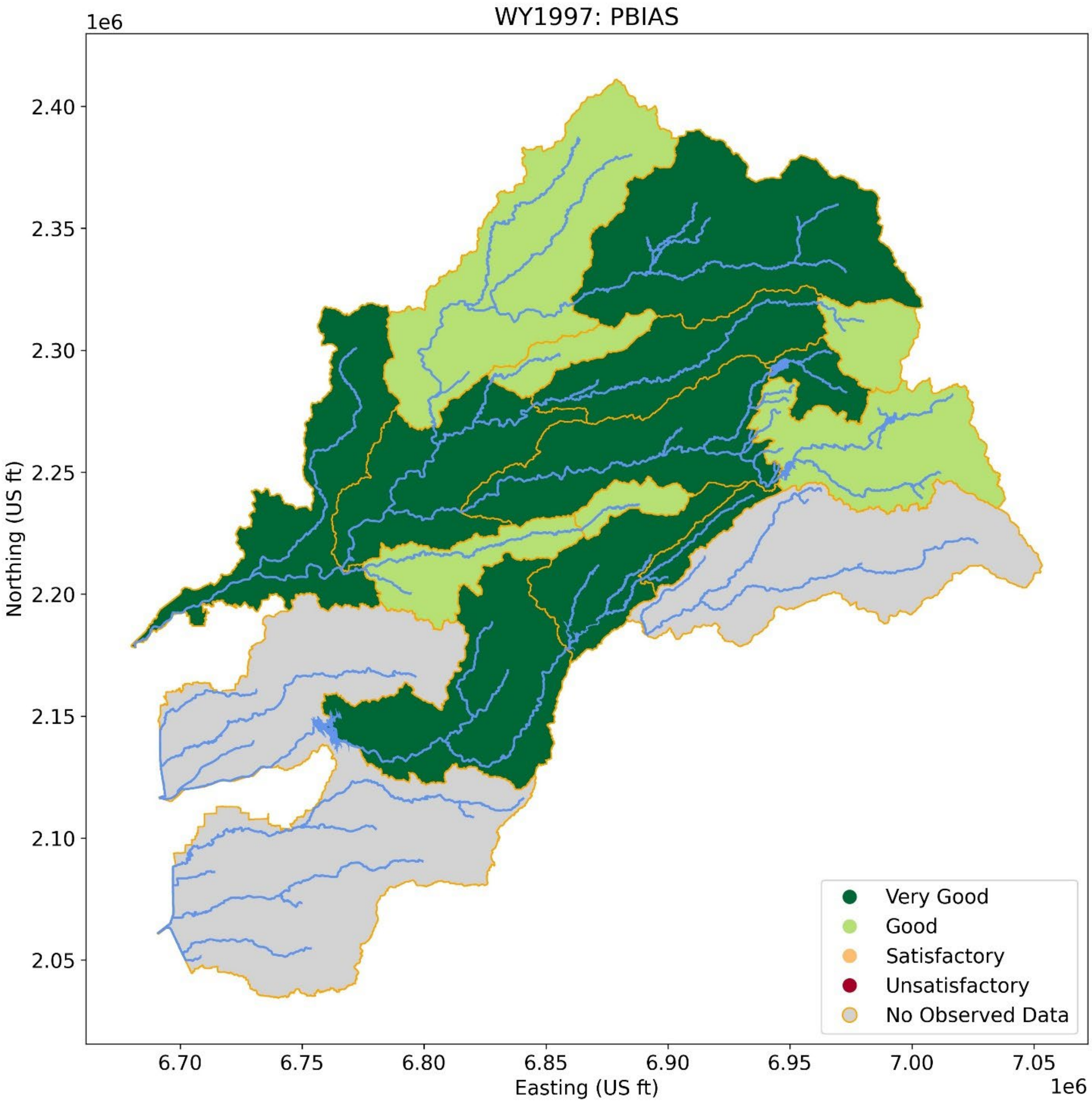

Figure A-4. WY1997 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

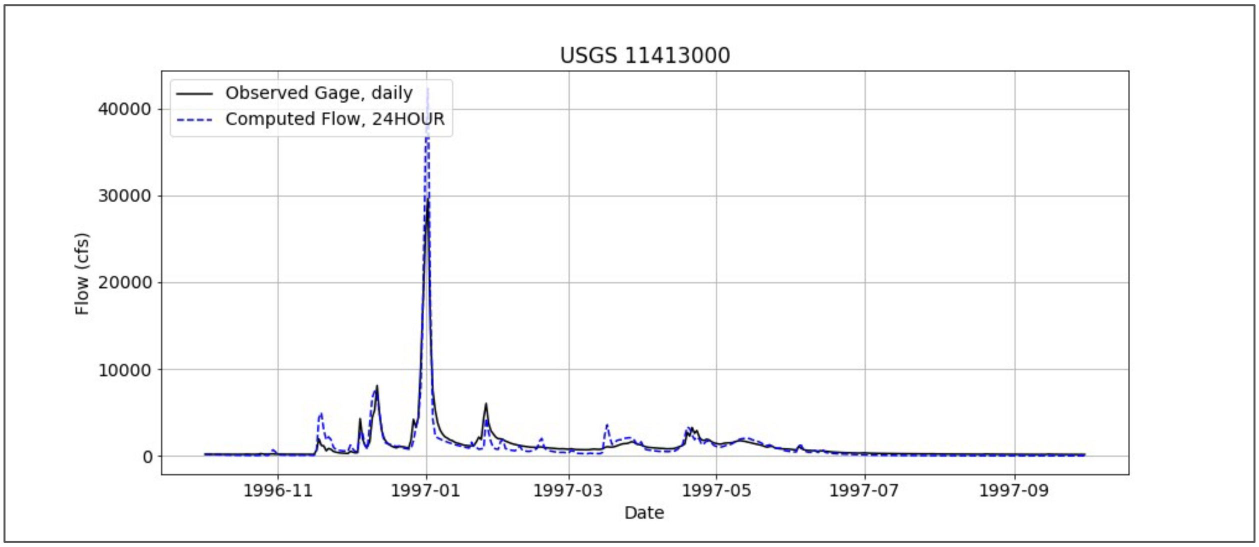

Figure A-5. WY1997 Calibration Results for Calibration Location USGS Gage 11413000

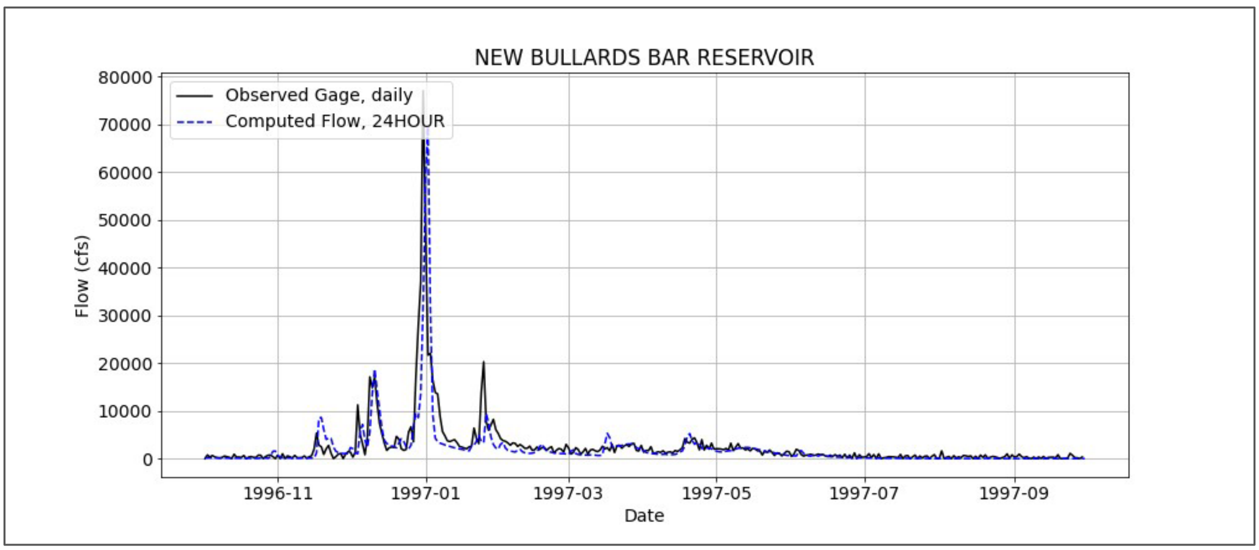

Figure A-6. WY1997 Calibration Results for Calibration Location New Bullards Bar Reservoir

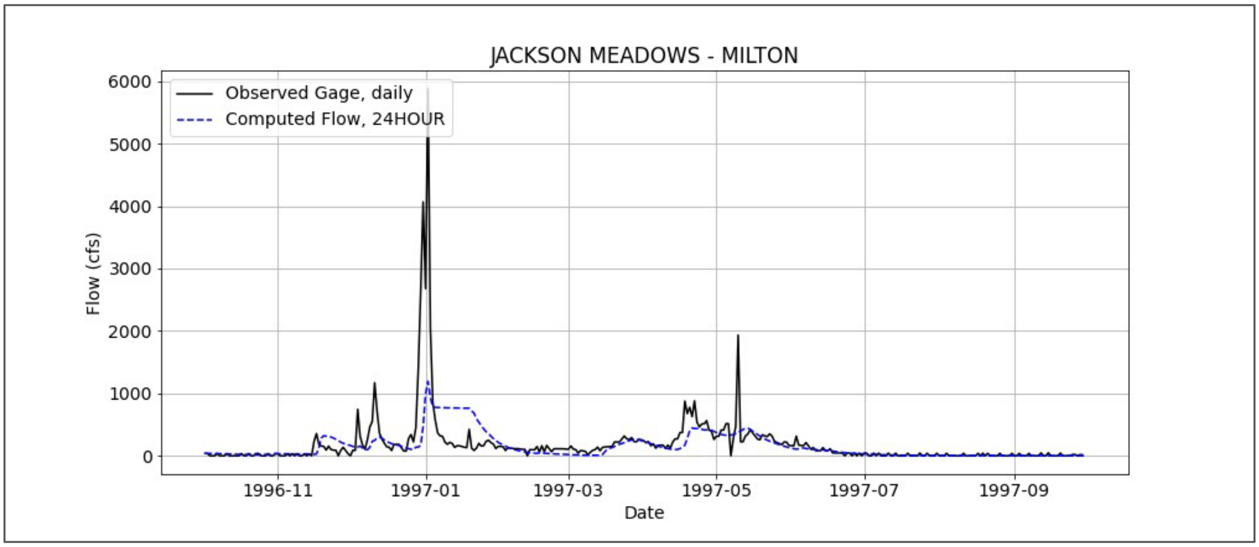

Figure A-7. WY1997 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

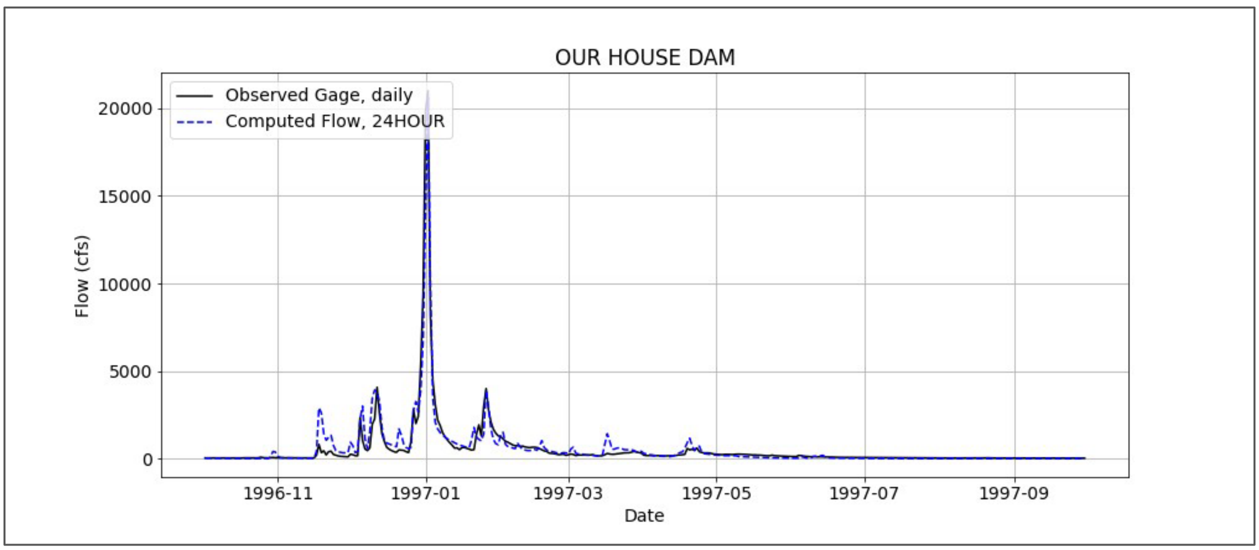

Figure A-8. WY1997 Calibration Results for Calibration Location Our House Dam

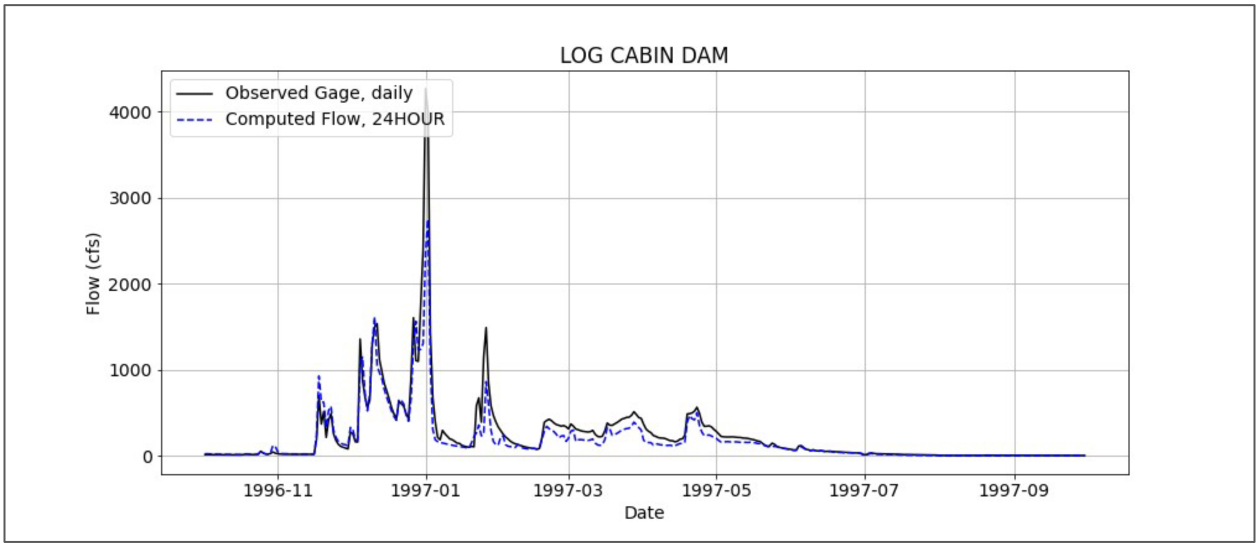

Figure A-9. WY1997 Calibration Results for Calibration Location Log Cabin Dam

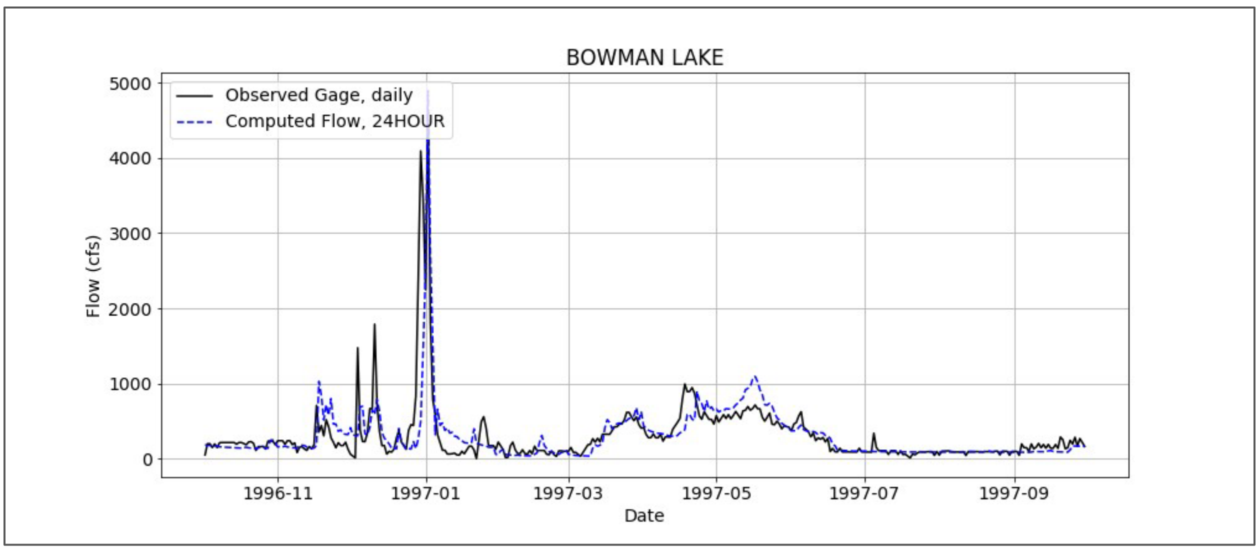

Figure A-10. WY1997 Calibration Results for Calibration Location Bowman Lake

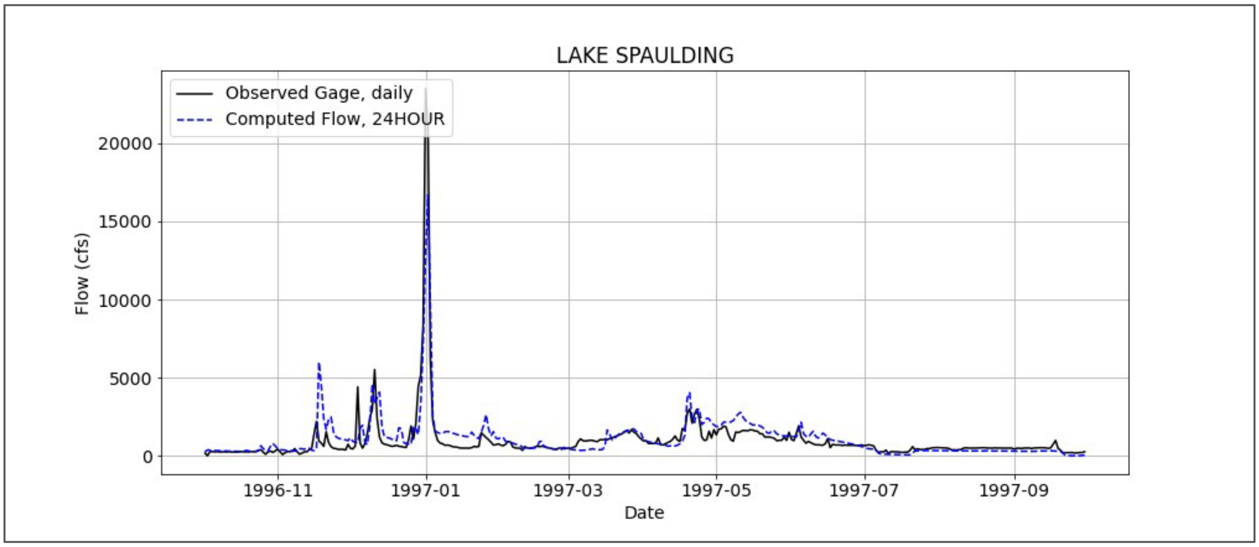

Figure A-11. WY1997 Calibration Results for Calibration Location Lake Spaulding

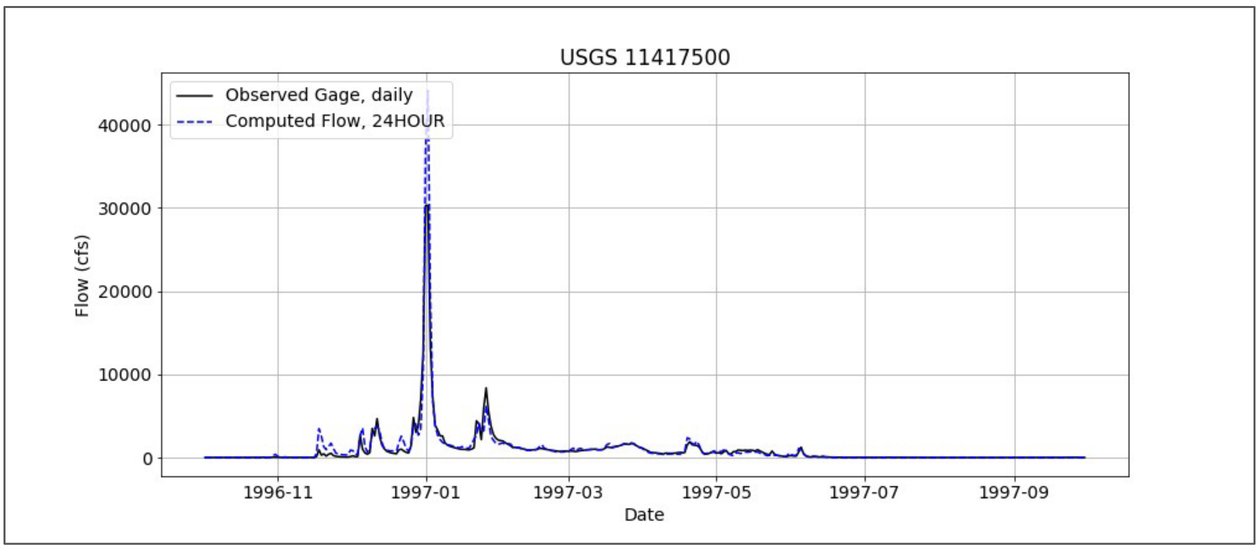

Figure A-12. WY1997 Calibration Results for Calibration Location USGS Gage 11417500

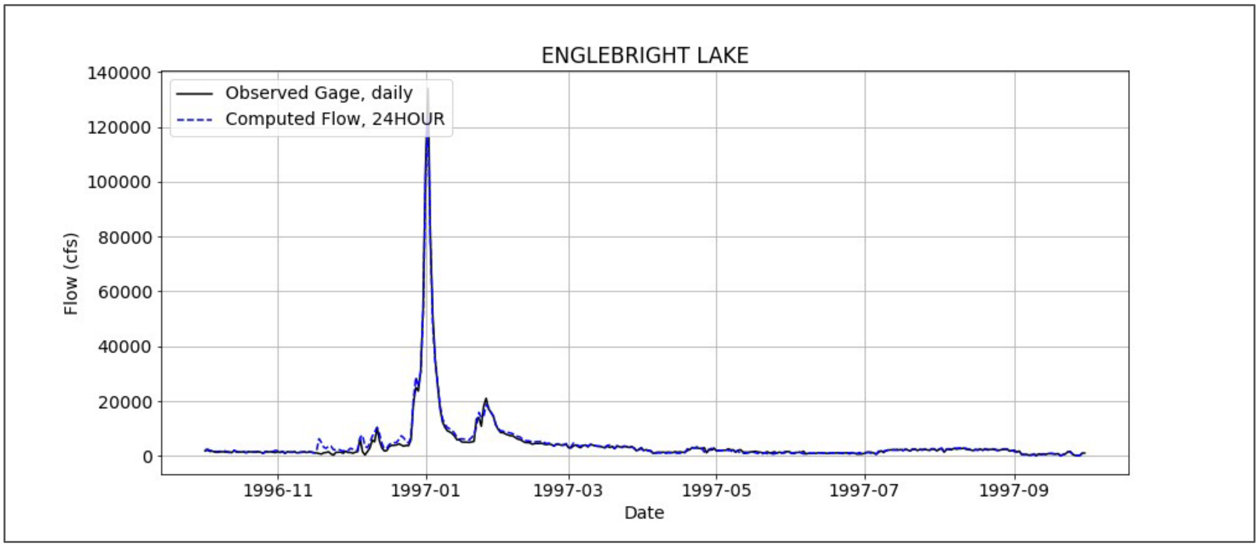

Figure A-13. WY1997 Calibration Results for Calibration Location Englebright Lake

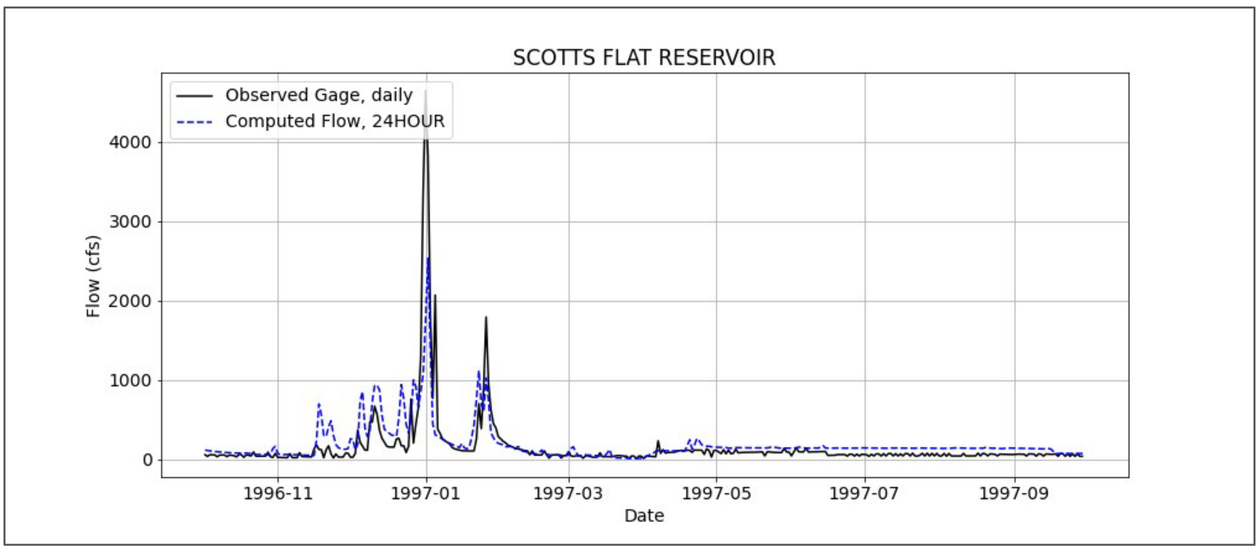

Figure A-14. WY1997 Calibration Results for Calibration Location Scotts Flat Reservoir

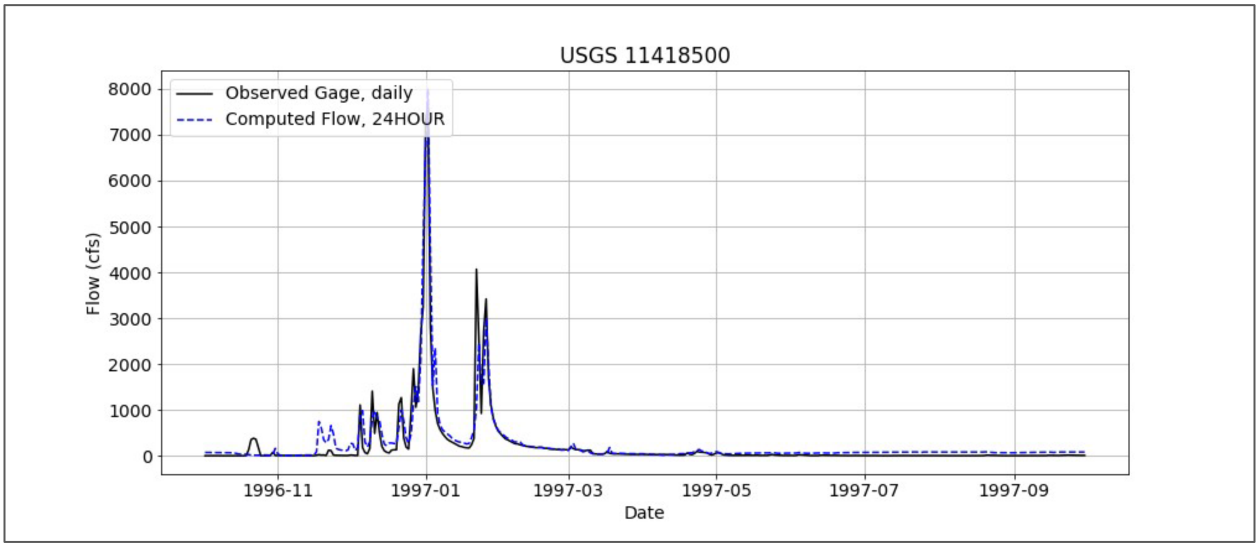

Figure A-15. WY1997 Calibration Results for Calibration Location USGS Gage 11418500

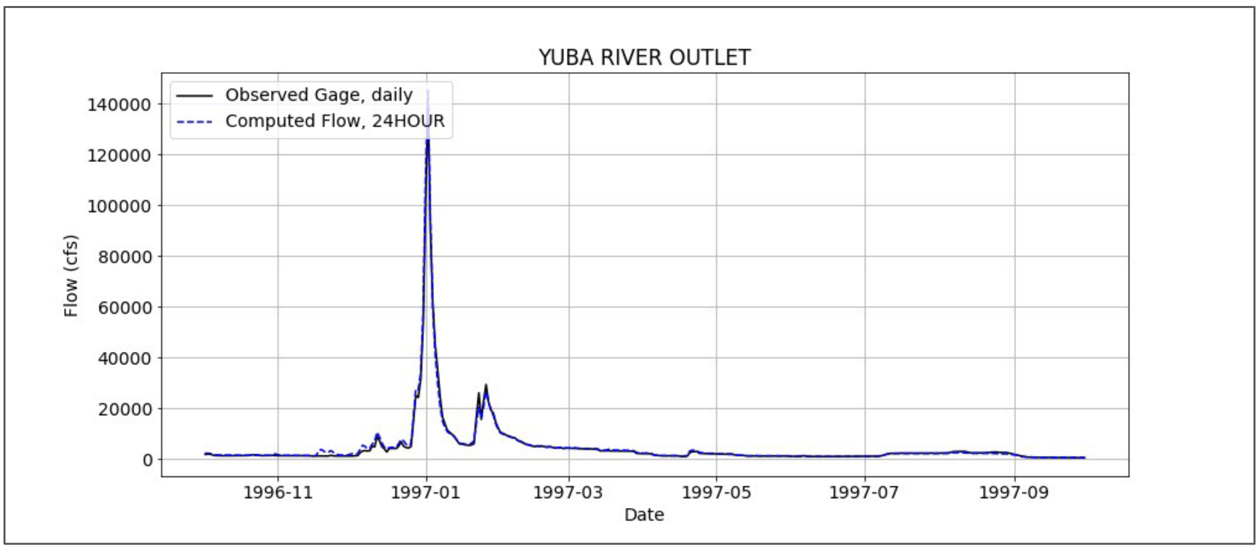

Figure A-16. WY1997 Calibration Results for Calibration Location Yuba River Outlet

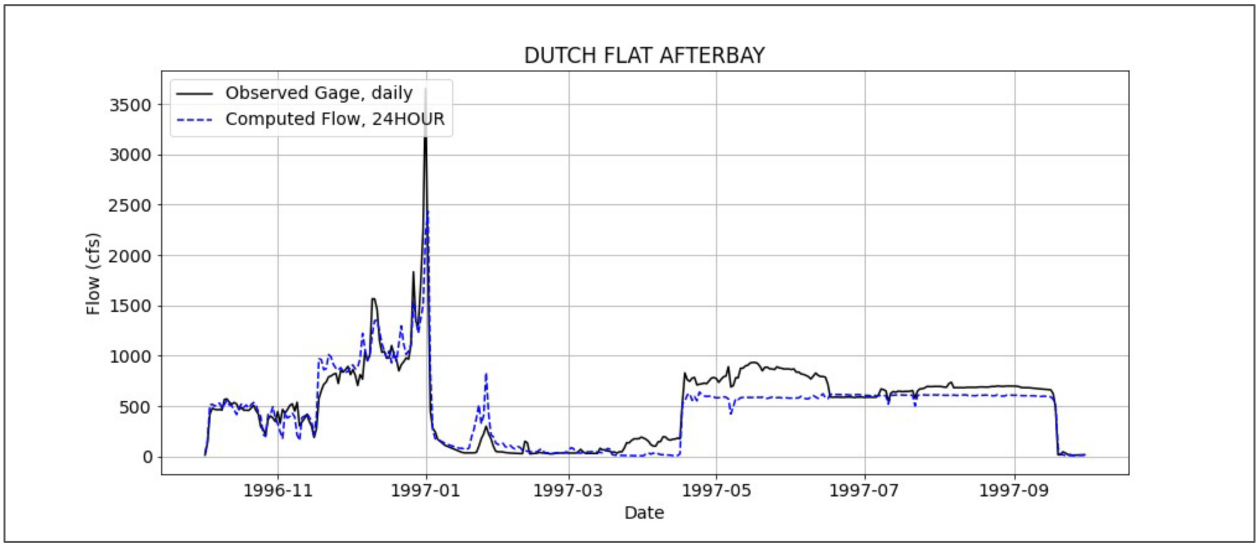

Figure A-17. WY1997 Calibration Results for Calibration Location Dutch Flat Afterbay

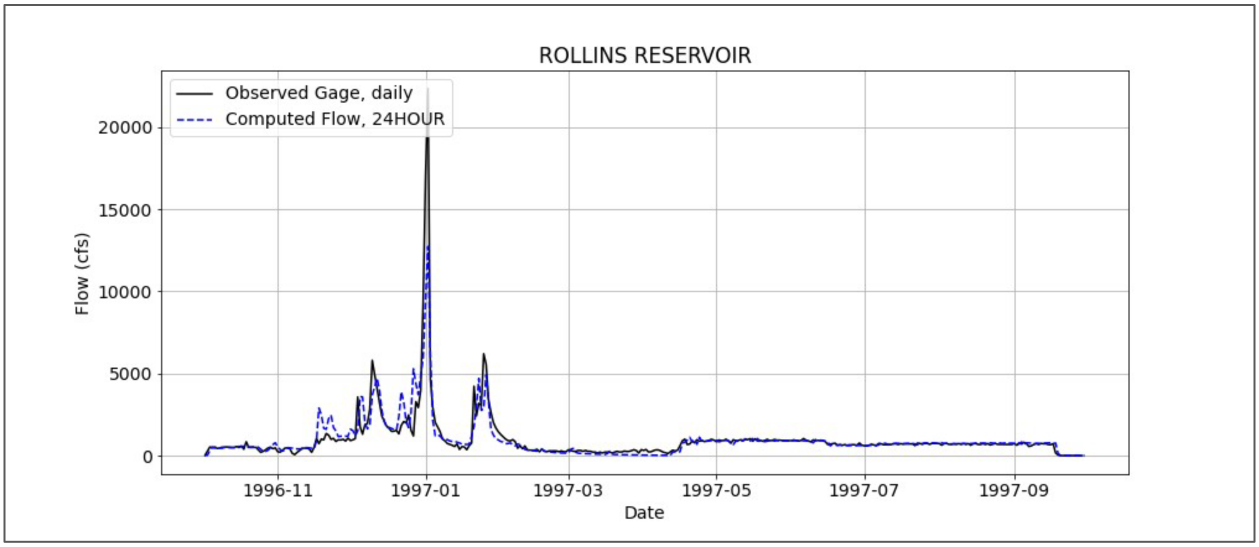

Figure A-18. WY1997 Calibration Results for Calibration Location Rollins Reservoir

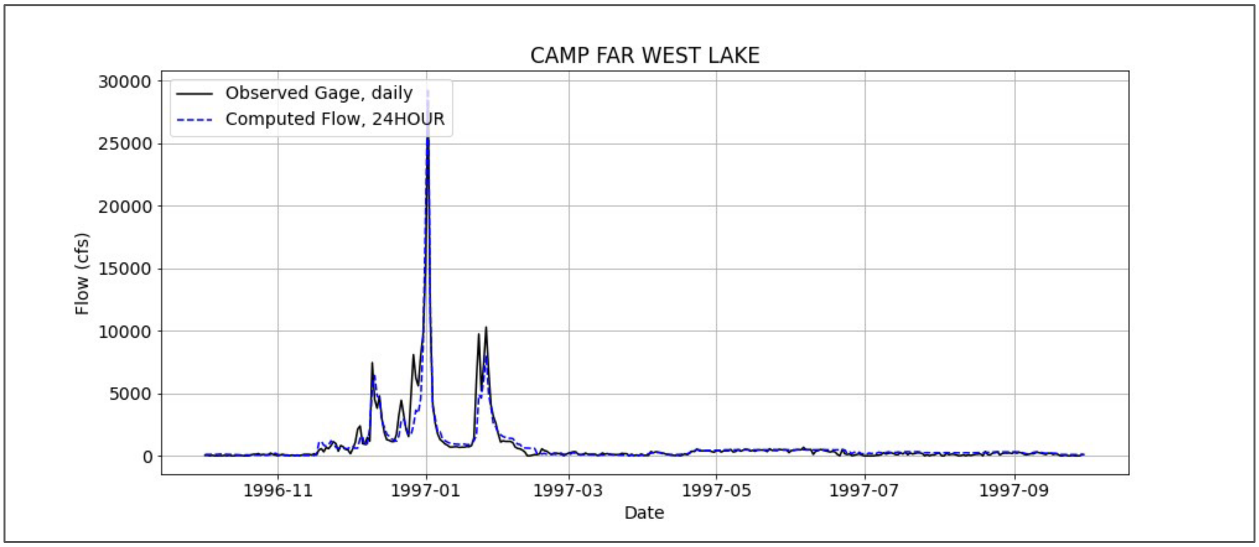

Figure A-19. WY1997 Calibration Results for Calibration Location Camp Far West Lake

A.4.2. Calibration Results for WY2004

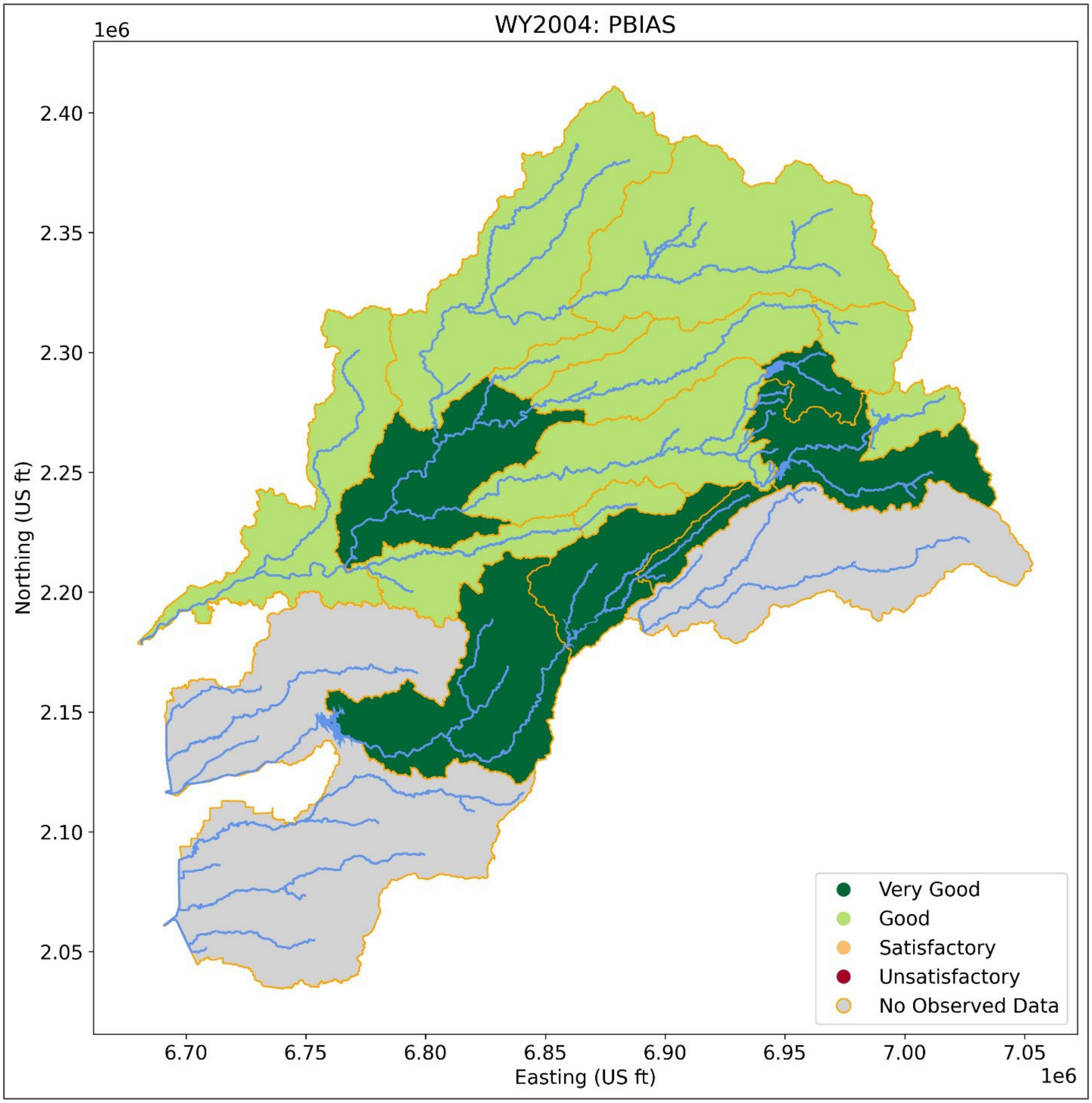

Figure A-20. WY2004 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

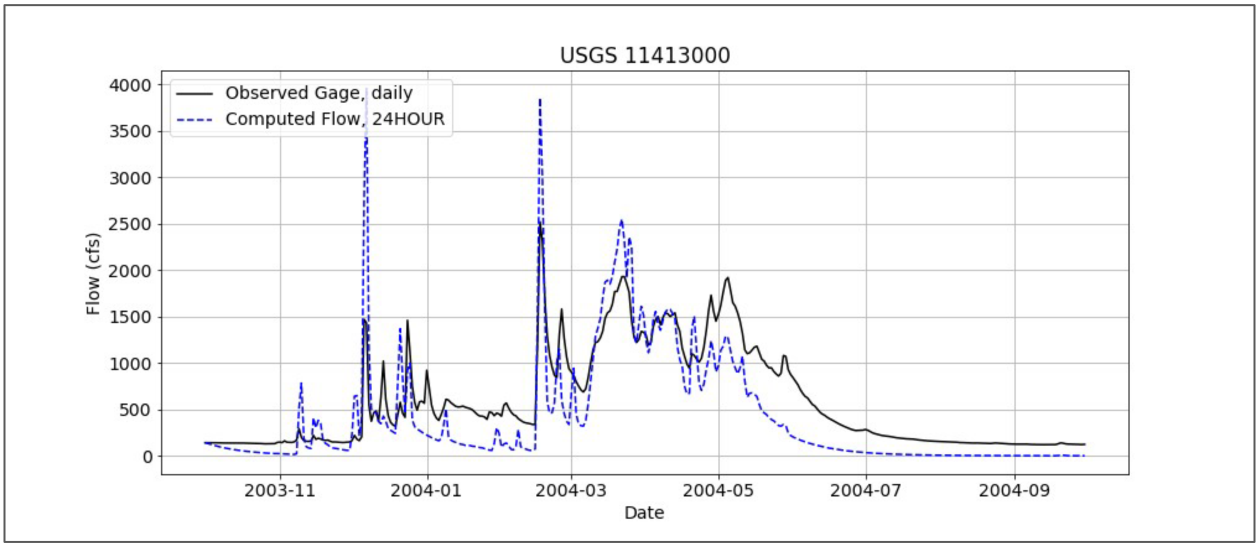

Figure A-21. WY2004 Calibration Results for Calibration Location USGS Gage 11413000

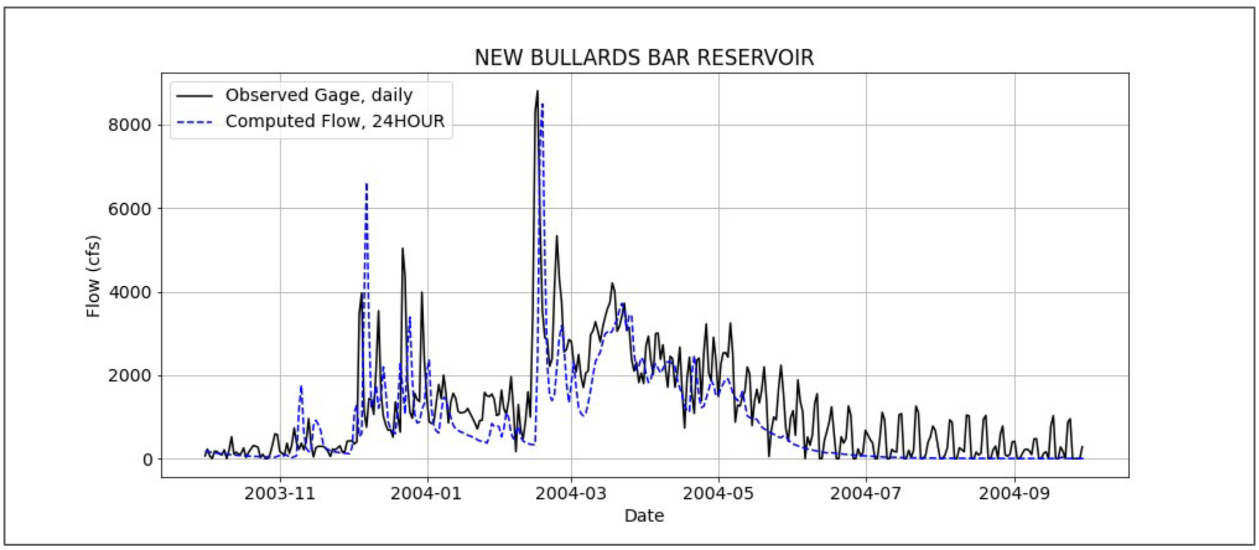

Figure A-22. WY2004 Calibration Results for Calibration Location New Bullards Bar Reservoir

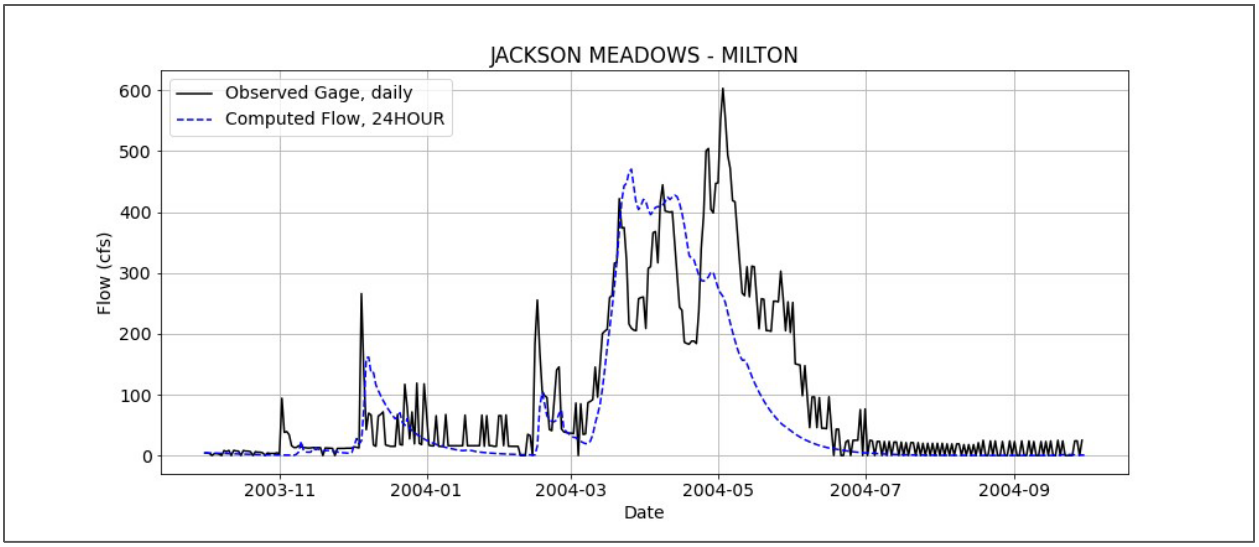

Figure A-23. WY2004 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

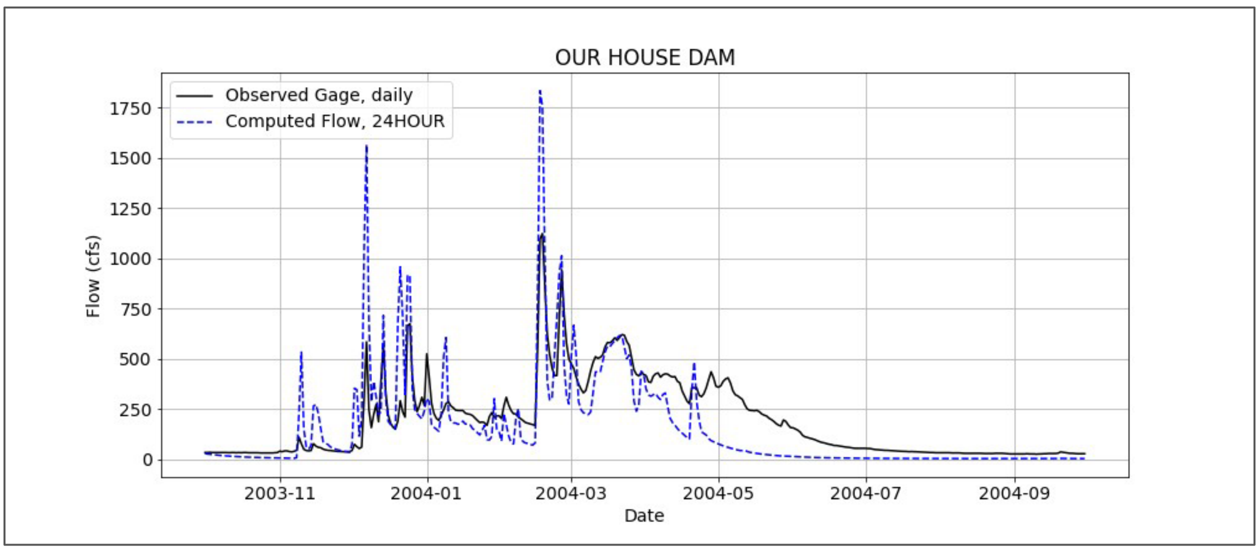

Figure A-24. WY2004 Calibration Results for Calibration Location Our House Dam

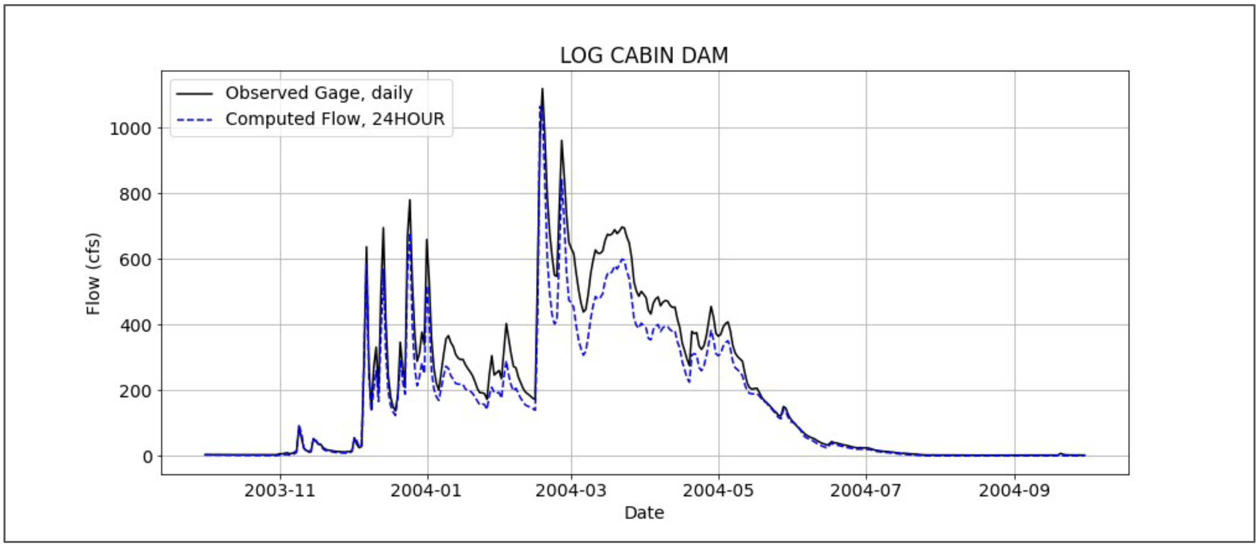

Figure A-25. WY2004 Calibration Results for Calibration Location Log Cabin Dam

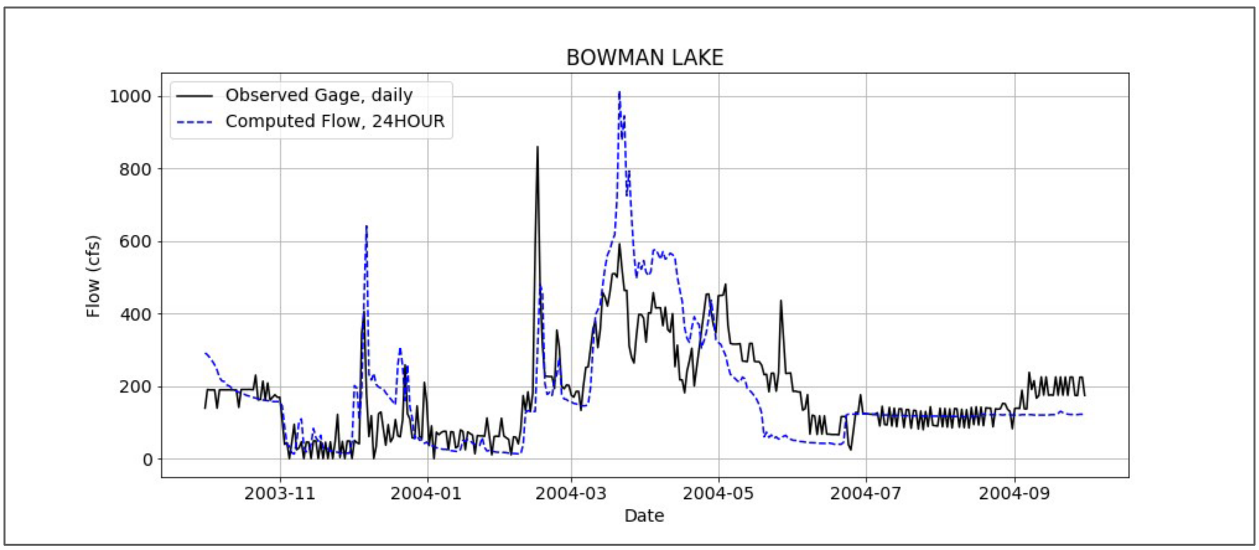

Figure A-26. WY2004 Calibration Results for Calibration Location Bowman Lake

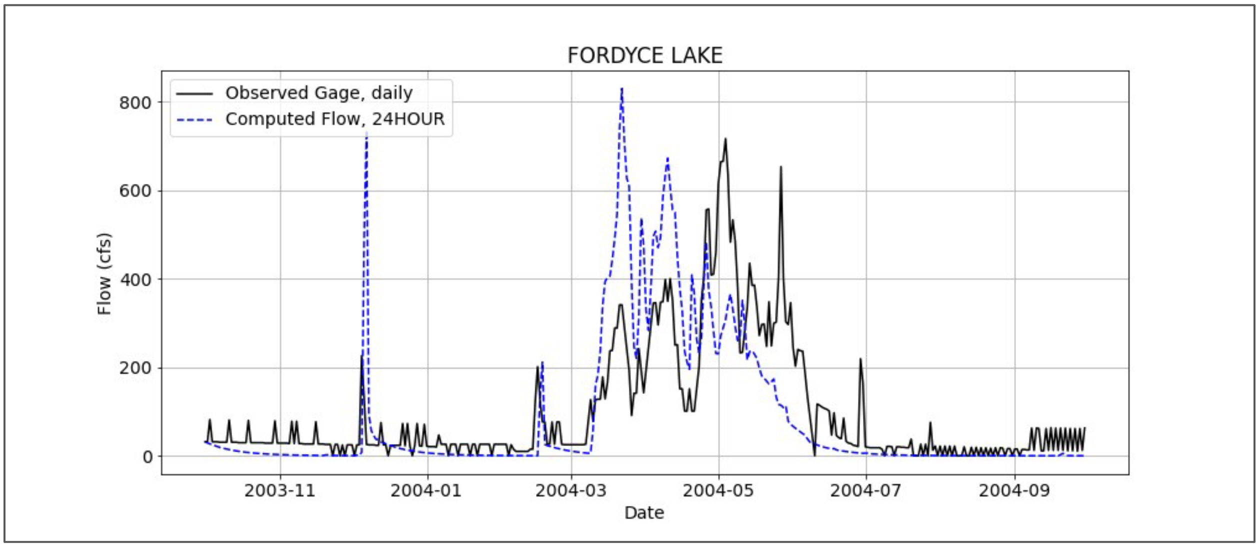

Figure A-27. WY2004 Calibration Results for Calibration Location Fordyce Lake

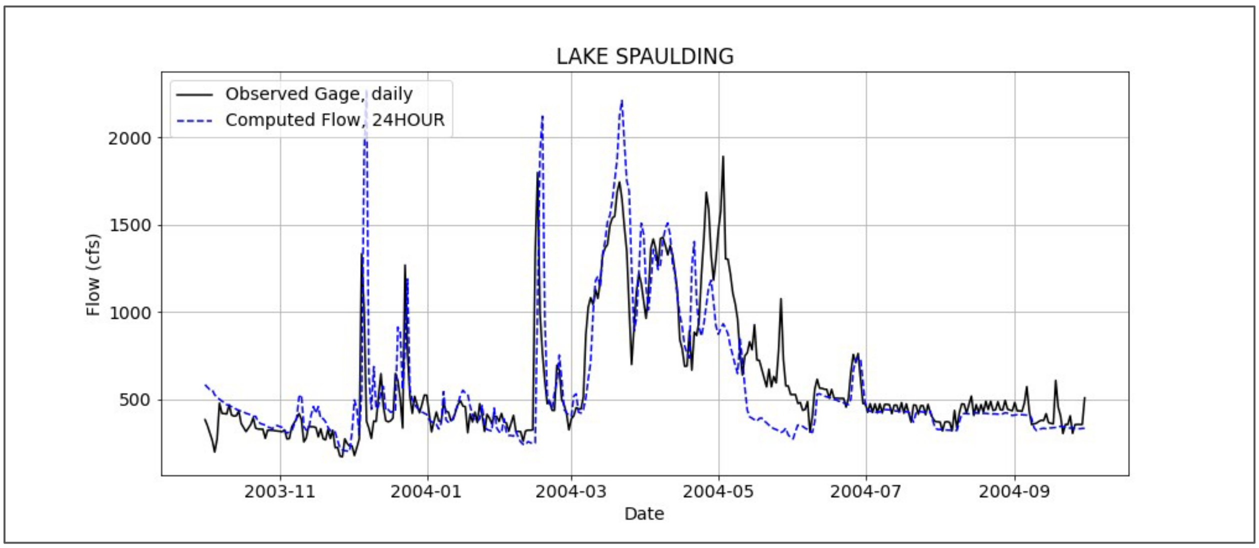

Figure A-28. WY2004 Calibration Results for Calibration Location Lake Spaulding

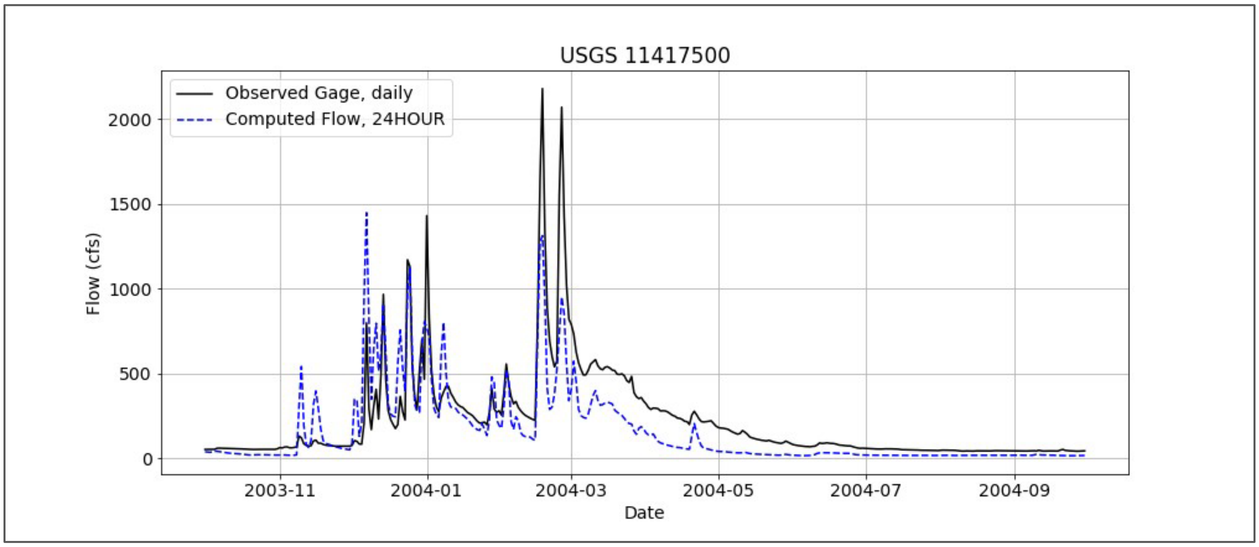

Figure A-29. WY2004 Calibration Results for Calibration Location USGS Gage 11417500

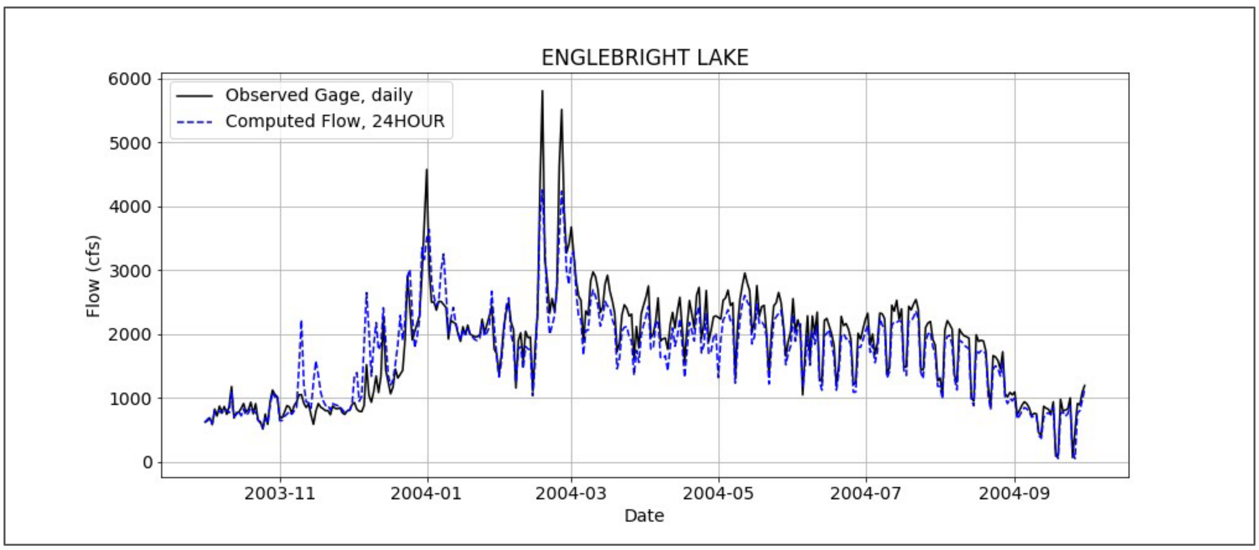

Figure A-30. WY2004 Calibration Results for Calibration Location Englebright Lake

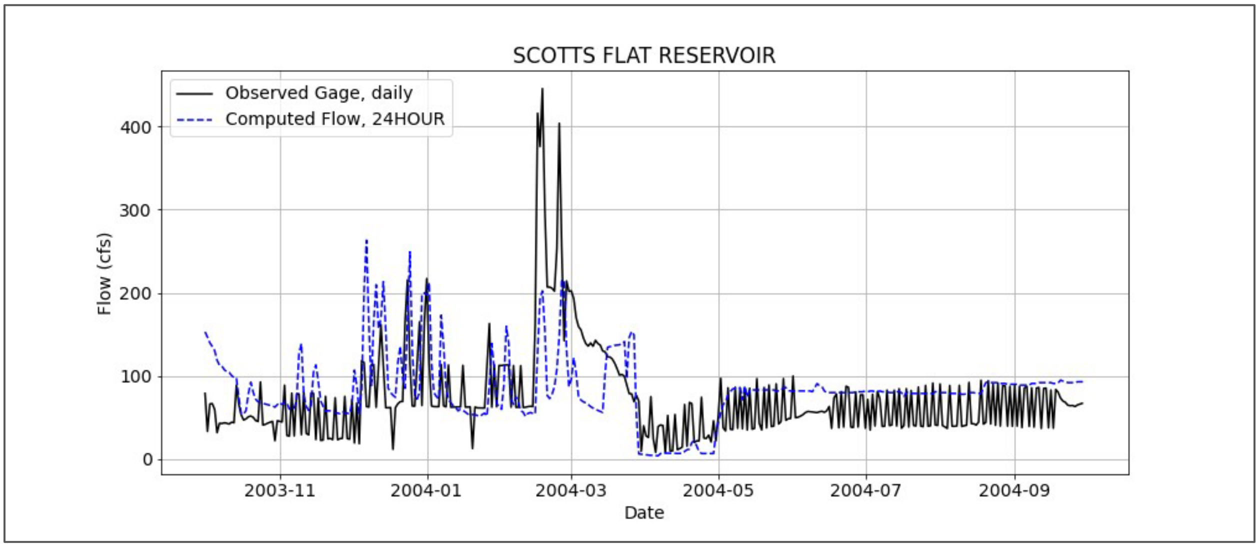

Figure A-31. WY2004 Calibration Results for Calibration Location Scotts Flat Reservoir

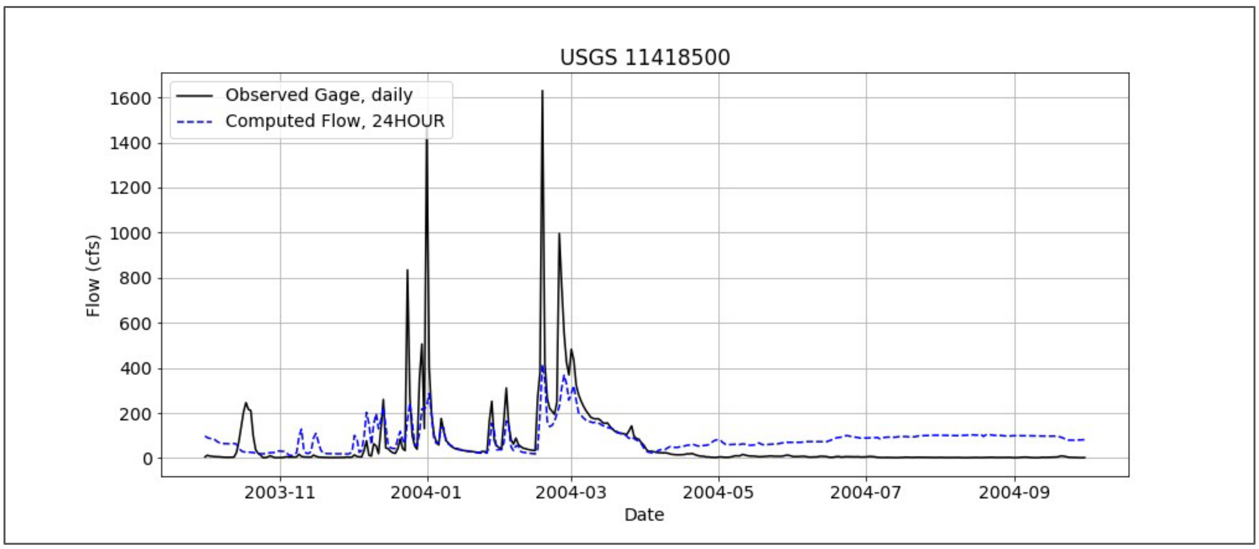

Figure A-32. WY2004 Calibration Results for Calibration Location USGS Gage 11418500

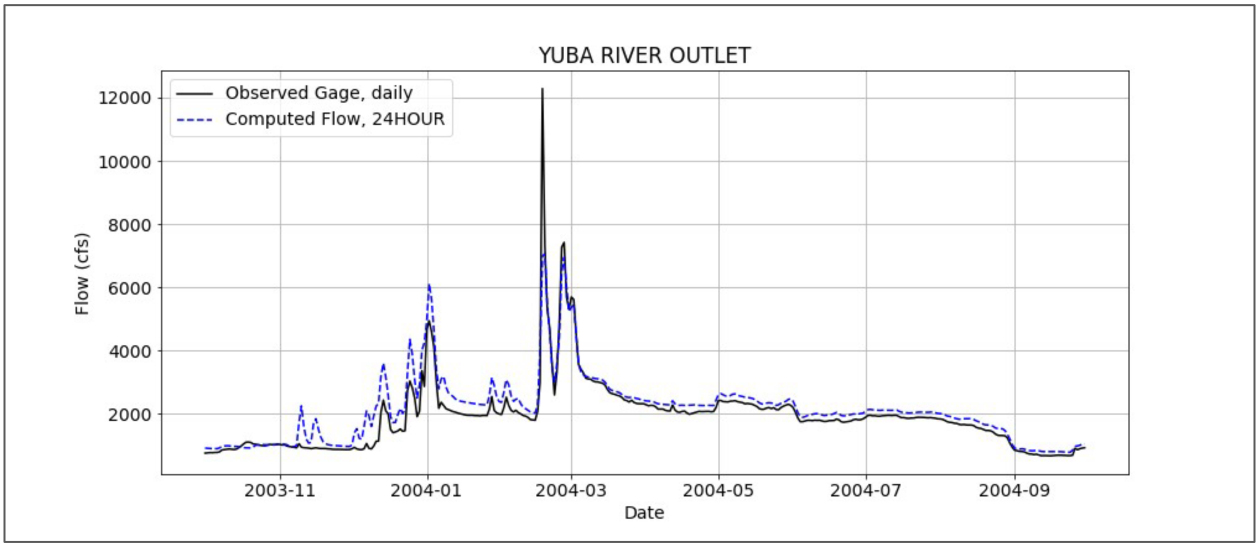

Figure A-33. WY2004 Calibration Results for Calibration Location Yuba River Outlet

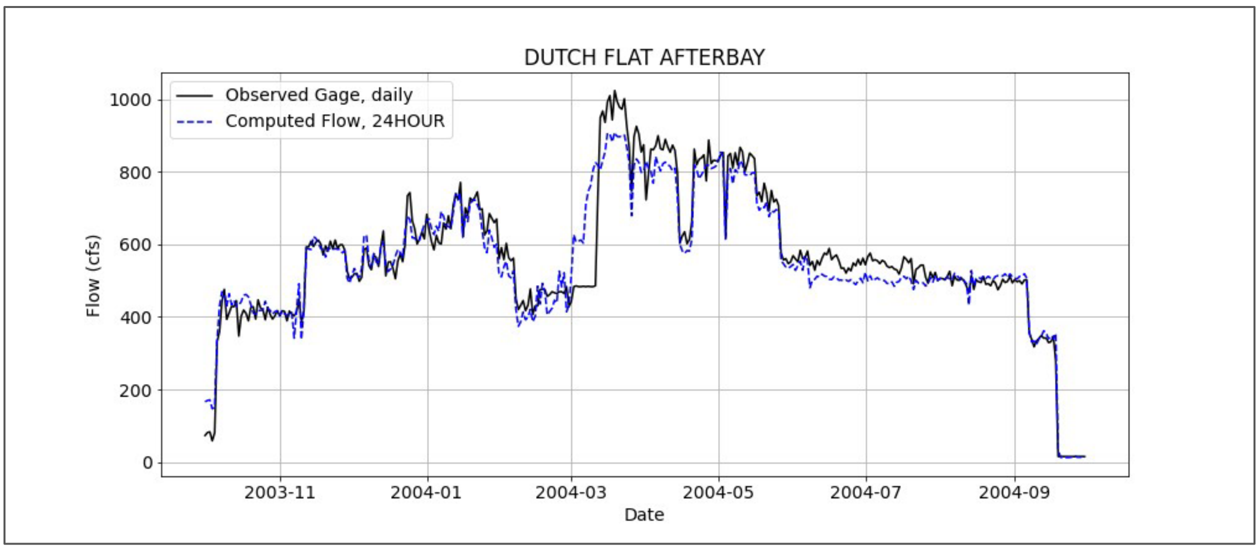

Figure A-34. WY2004 Calibration Results for Calibration Location Dutch Flat Afterbay

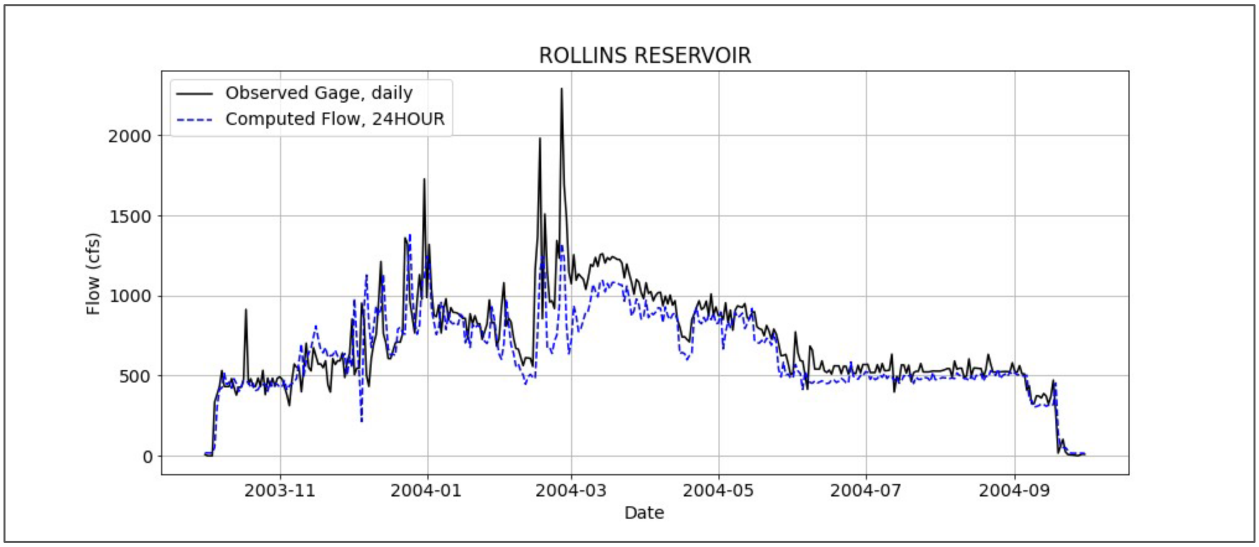

Figure A-35. WY2004 Calibration Results for Calibration Location Rollins Reservoir

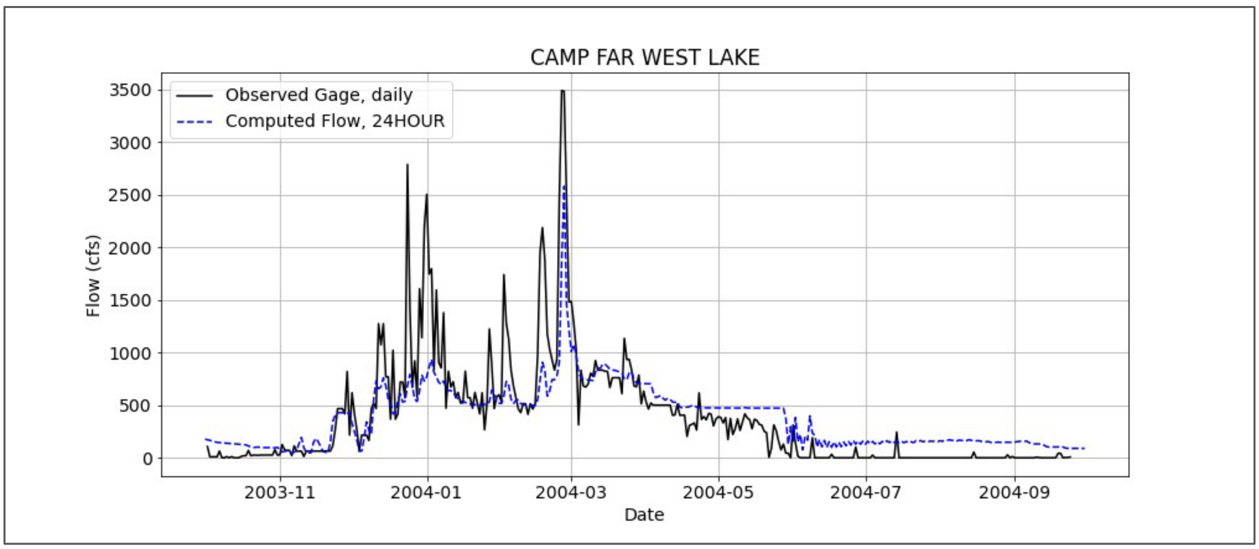

Figure A-36. WY2004 Calibration Results for Calibration Location Camp Far West Lake

A.4.3. Calibration Results for WY2006

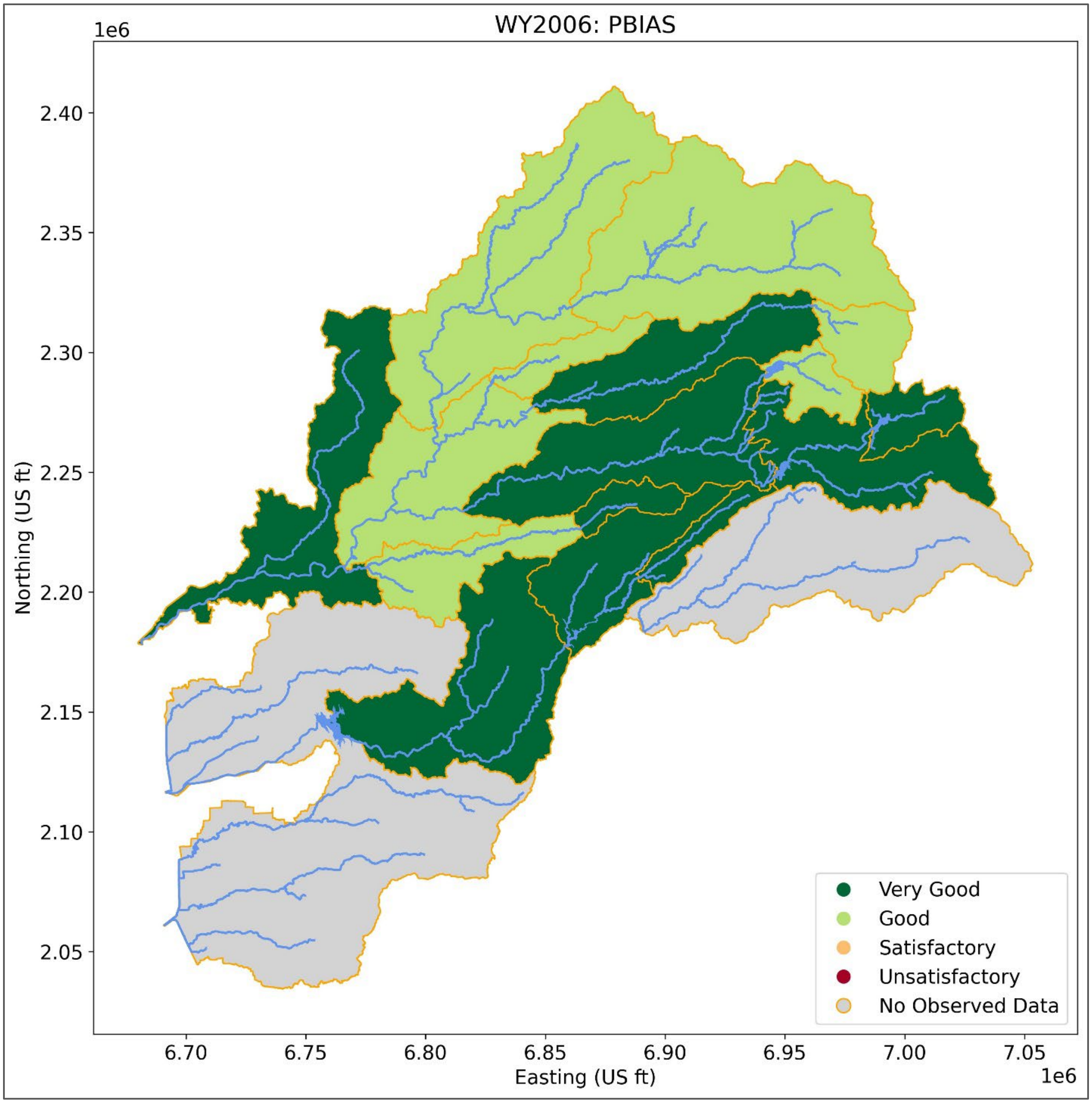

Figure A-37. WY2006 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

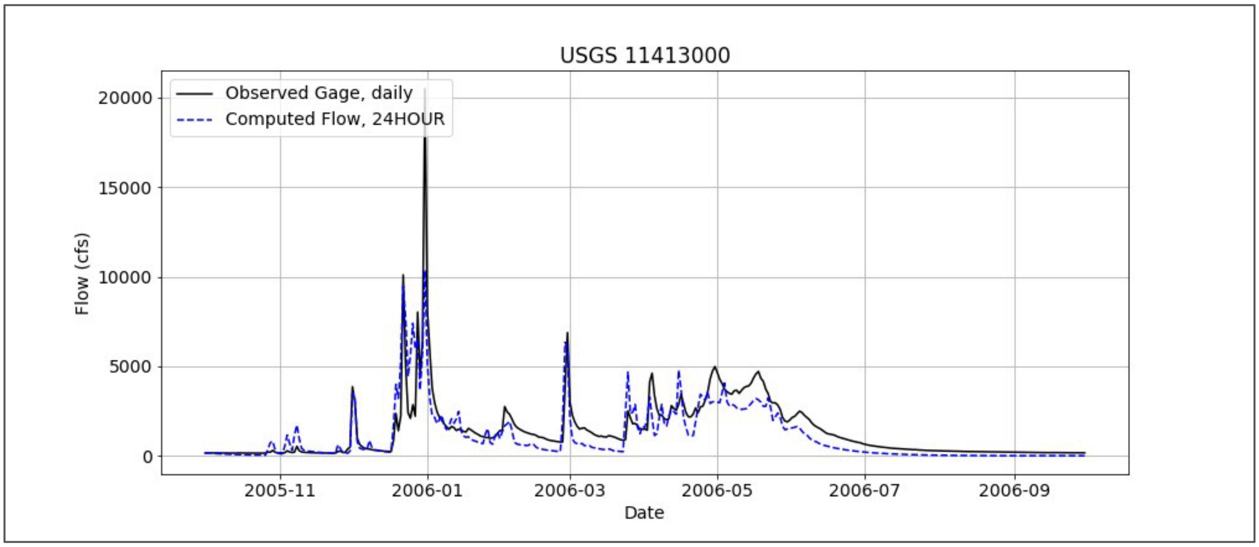

Figure A-38. WY2006 Calibration Results for Calibration Location USGS Gage 11413000

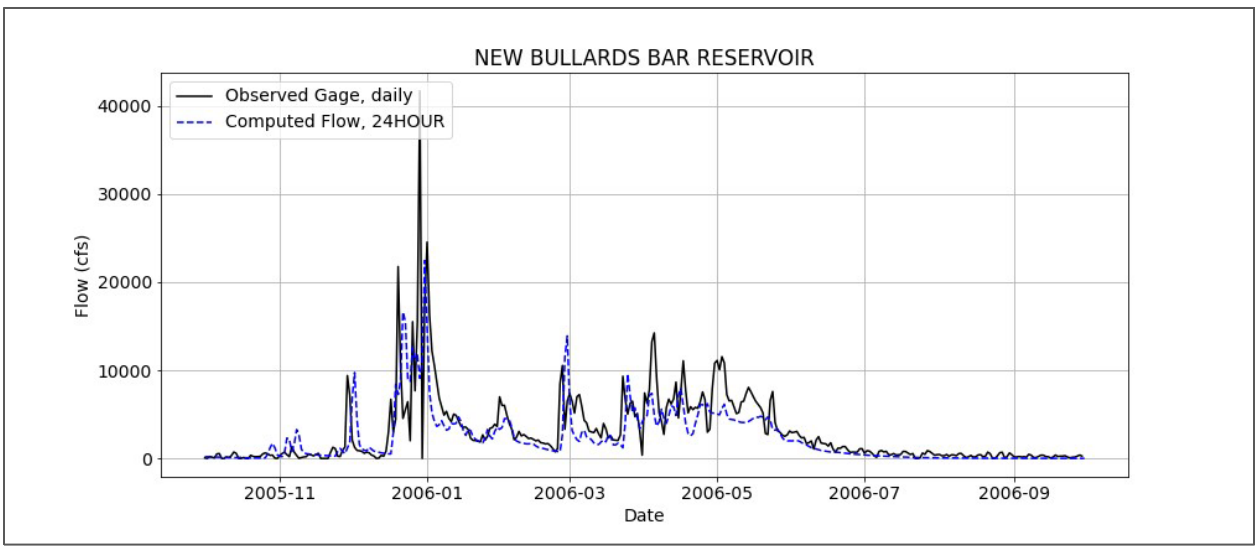

Figure A-39. WY2006 Calibration Results for Calibration Location New Bullards Bar Reservoir

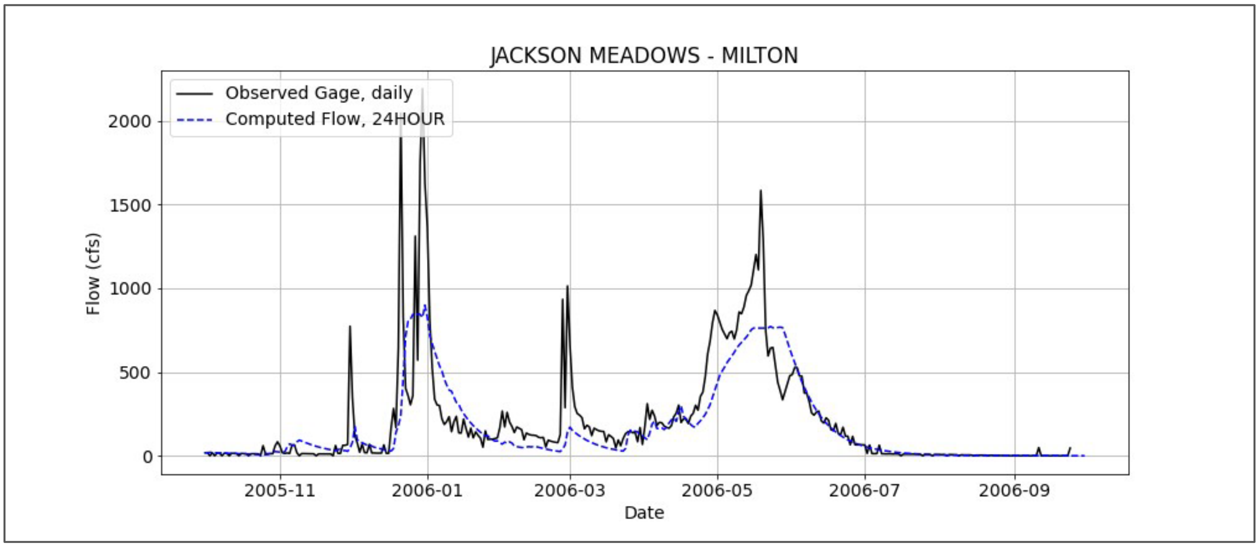

Figure A-40. WY2006 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

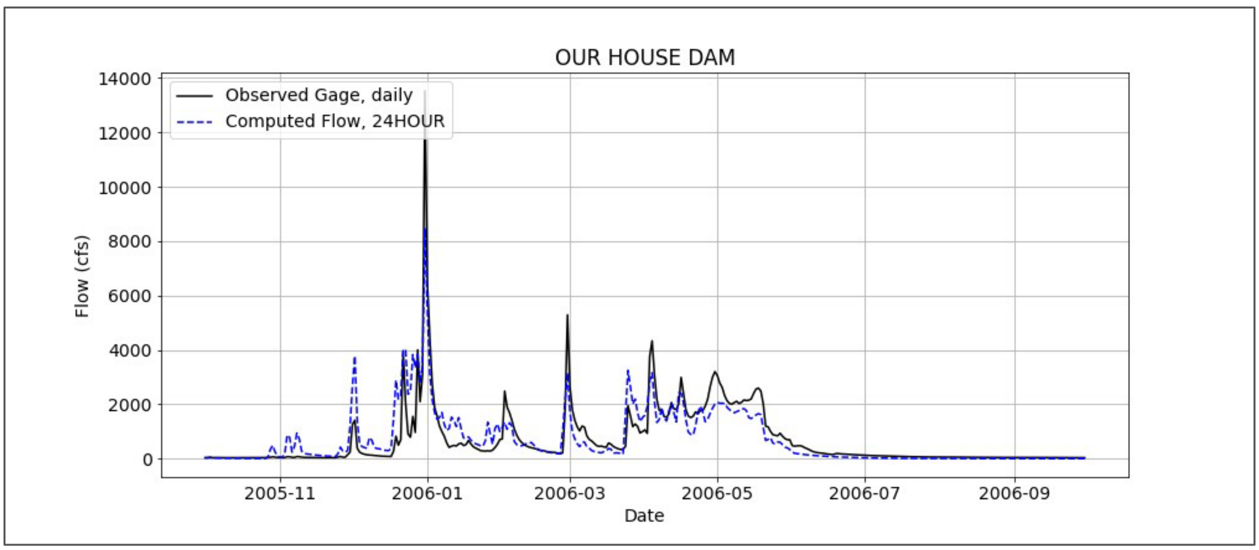

Figure A-41. WY2006 Calibration Results for Calibration Location Our House Dam

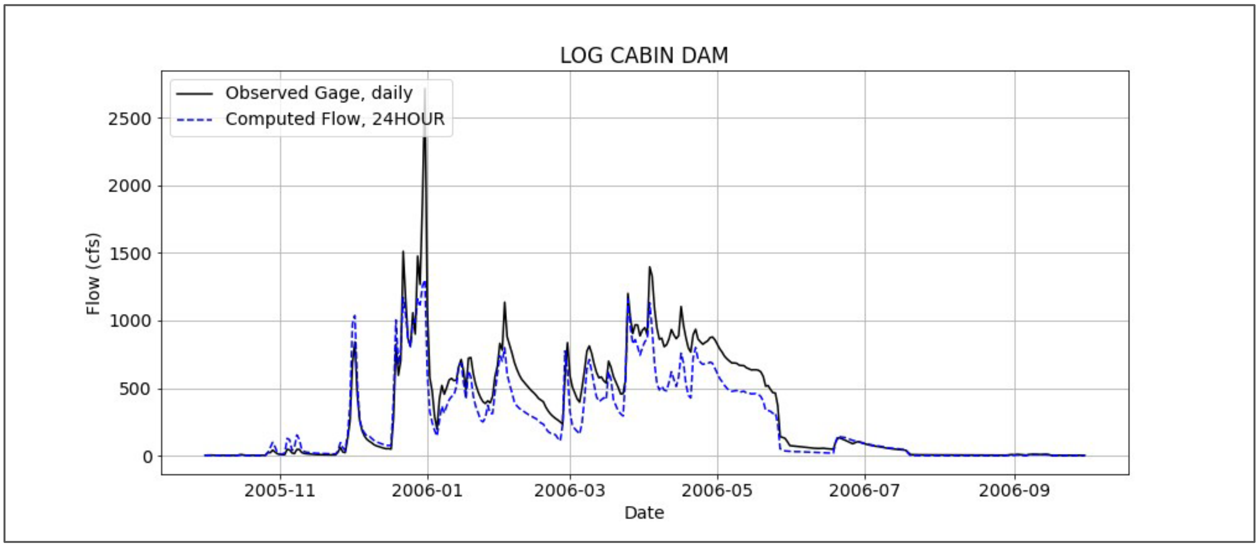

Figure A-42. WY2006 Calibration Results for Calibration Location Log Cabin Dam

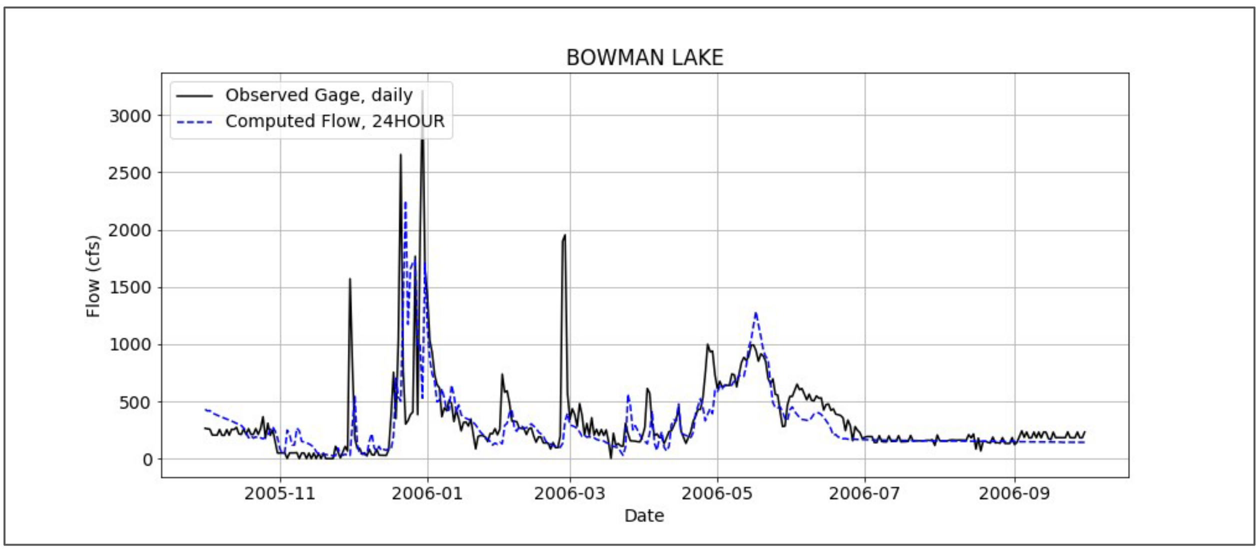

Figure A-43. WY2006 Calibration Results for Calibration Location Bowman Lake

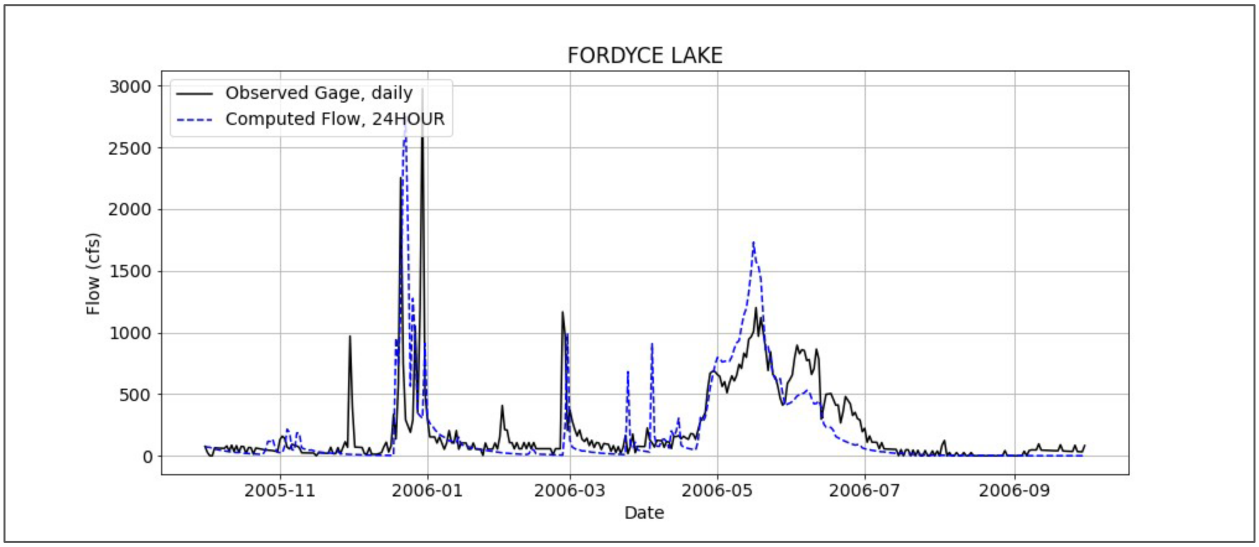

Figure A-44. WY2006 Calibration Results for Calibration Location Fordyce Lake

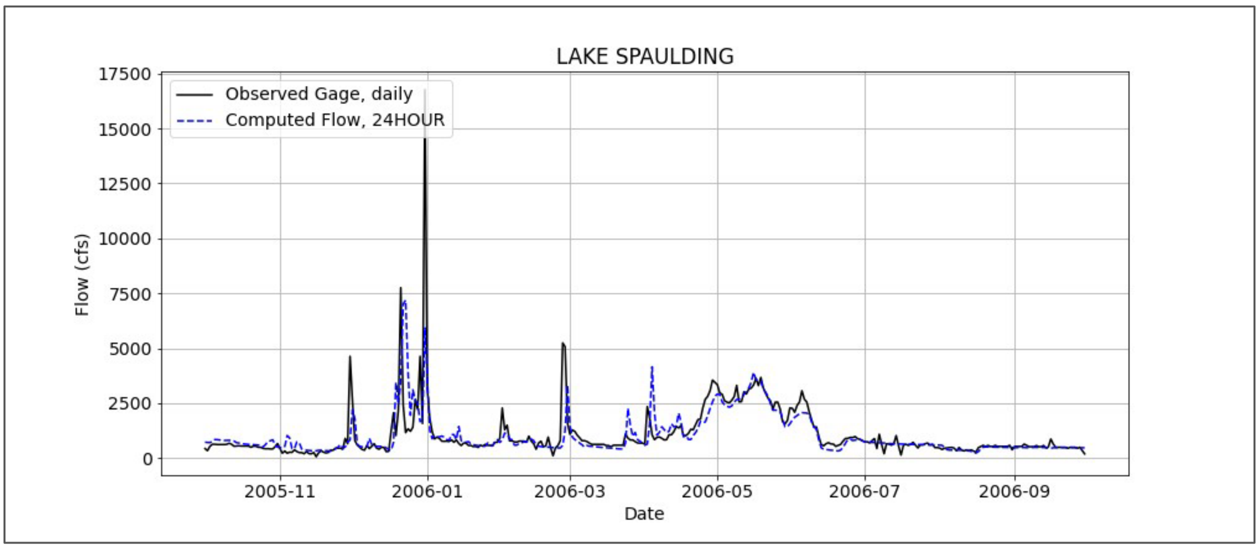

Figure A-45. WY2006 Calibration Results for Calibration Location Lake Spaulding

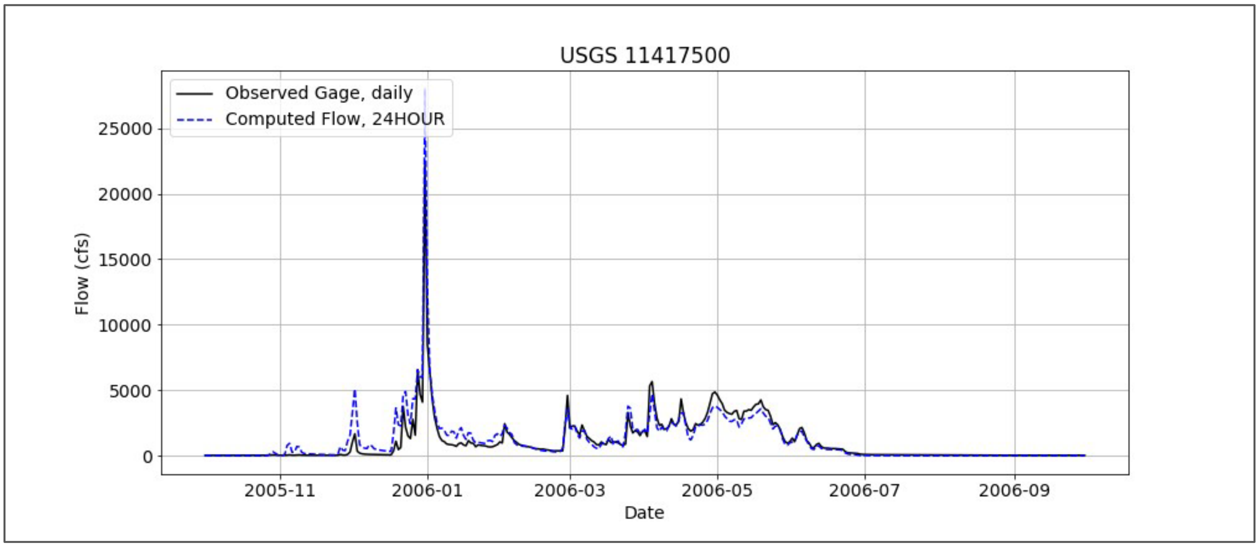

Figure A-46. WY2006 Calibration Results for Calibration Location USGS Gage 11417500

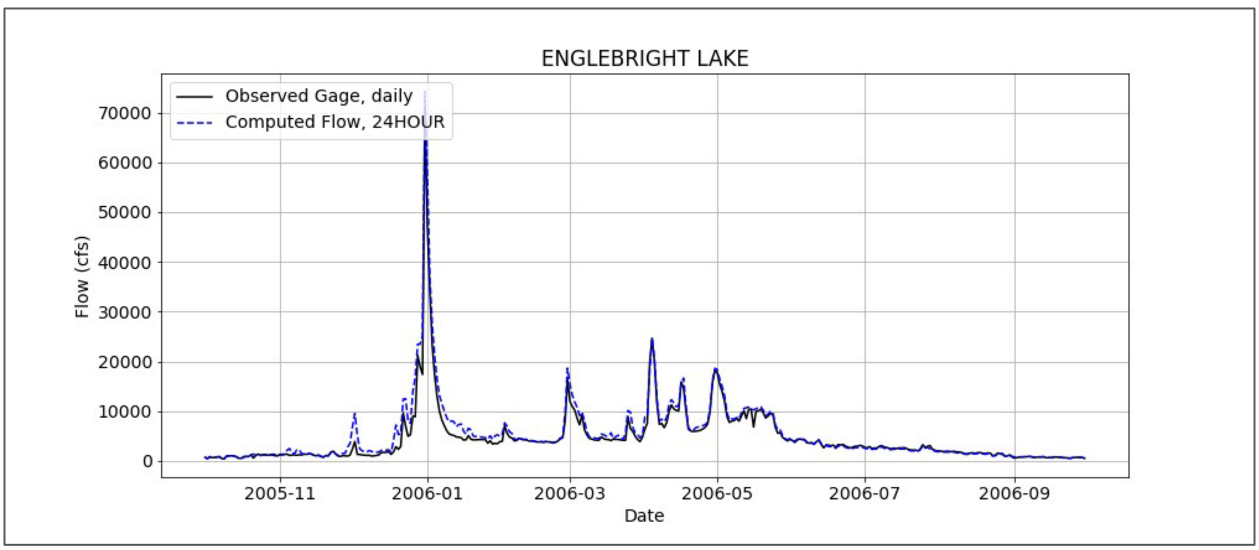

Figure A-47. WY2006 Calibration Results for Calibration Location Englebright Lake

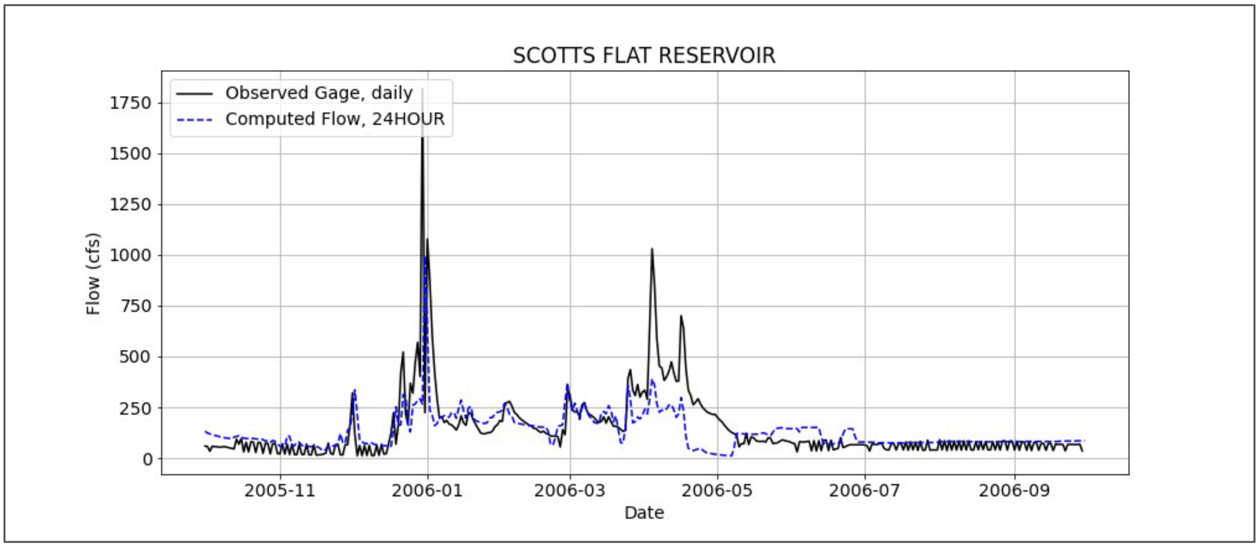

Figure A-48. WY2006 Calibration Results for Calibration Location Scotts Flat Reservoir

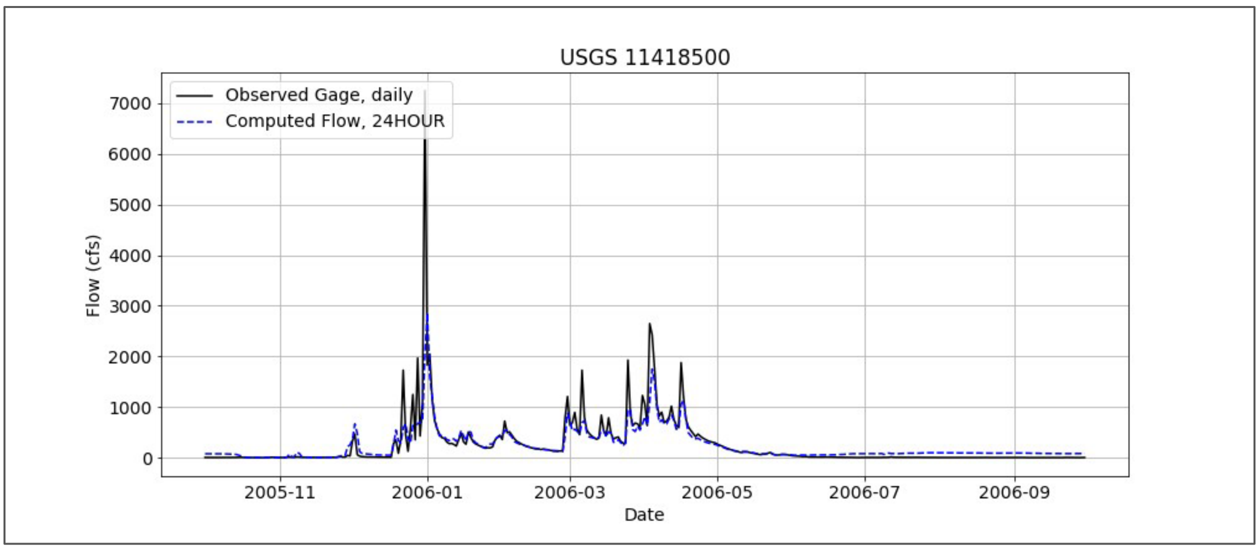

Figure A-49. WY2006 Calibration Results for Calibration Location USGS Gage 11418500

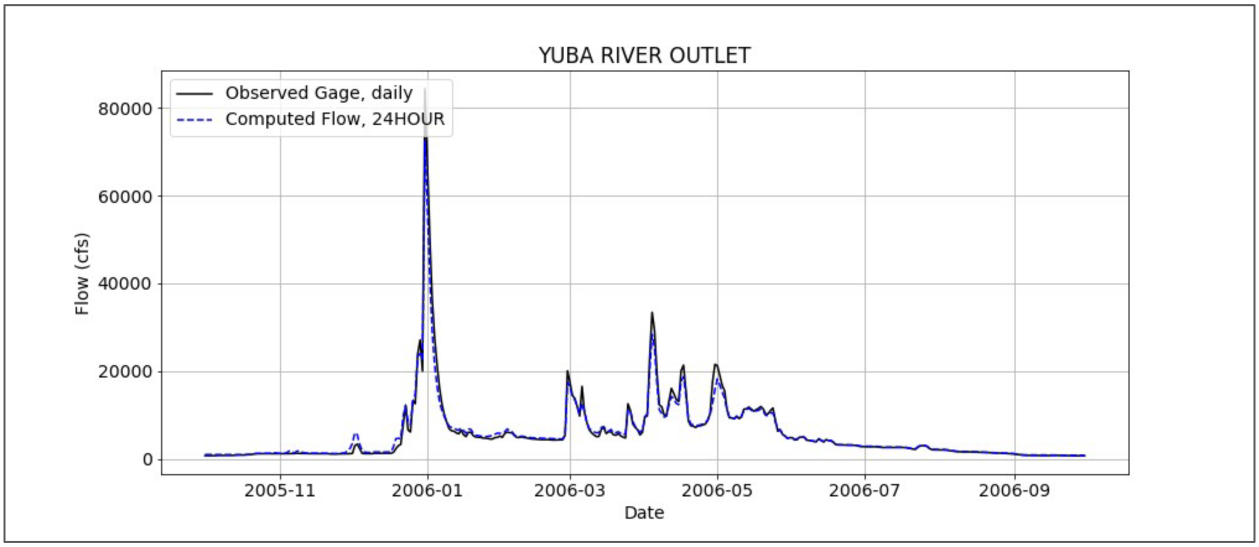

Figure A-50. WY2006 Calibration Results for Calibration Location Yuba River Outlet

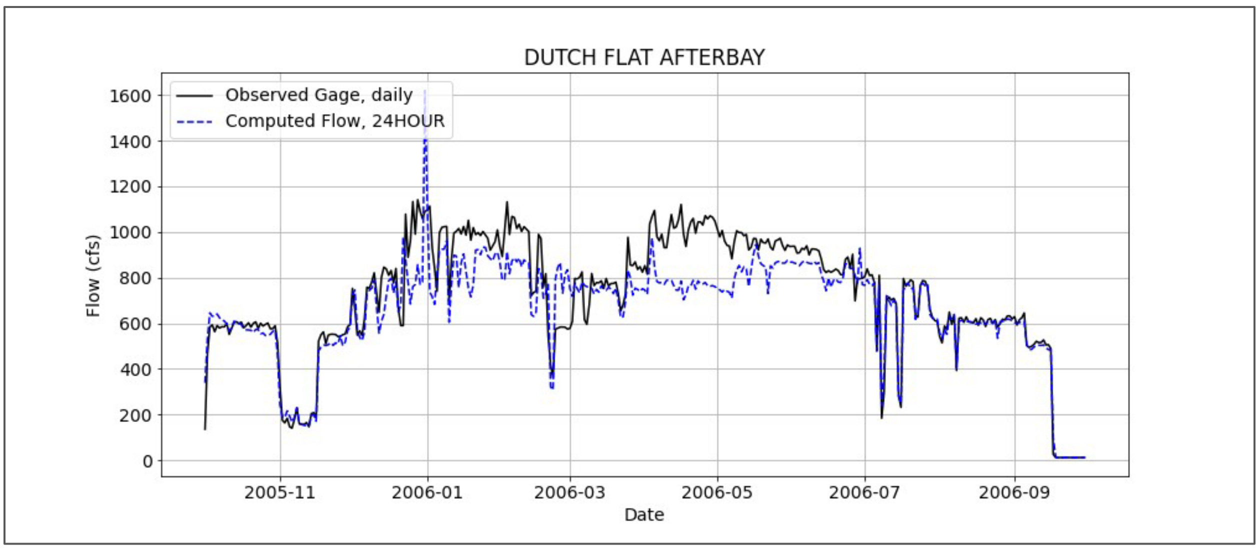

Figure A-51. WY2006 Calibration Results for Calibration Location Dutch Flat Afterbay

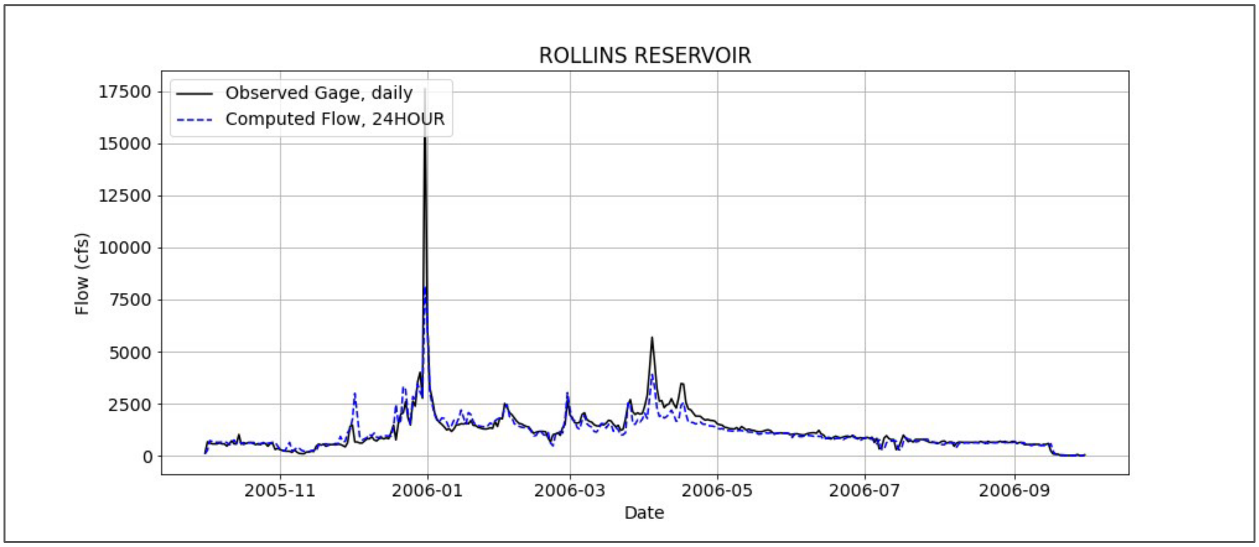

Figure A-52. WY2006 Calibration Results for Calibration Location Rollins Reservoir

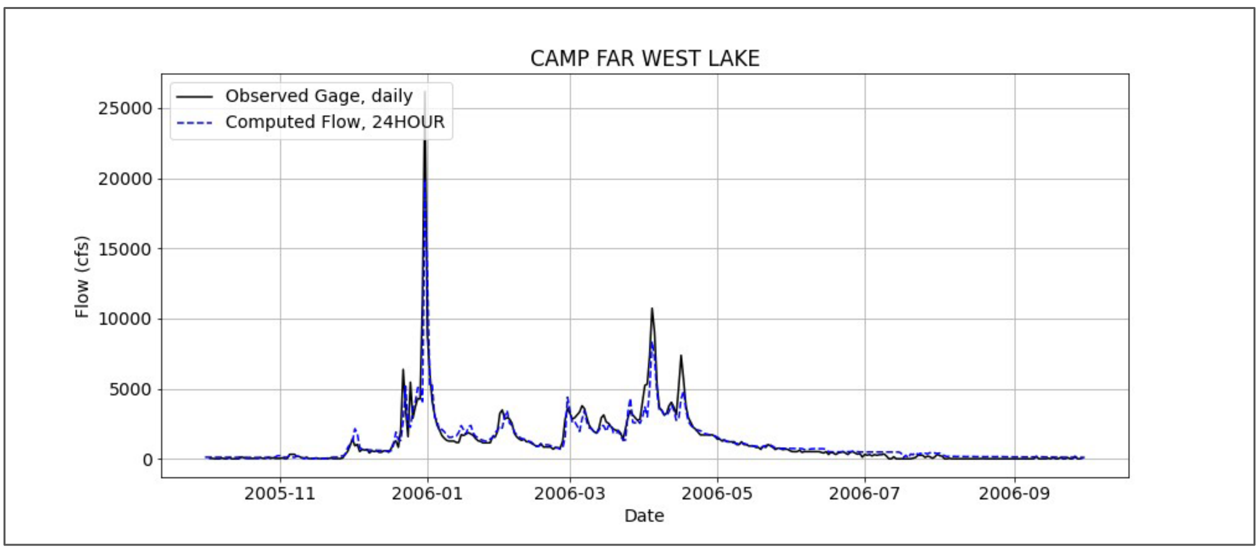

Figure A-53. WY2006 Calibration Results for Calibration Location Camp Far West Lake

A.4.4. Calibration Results for WY2015

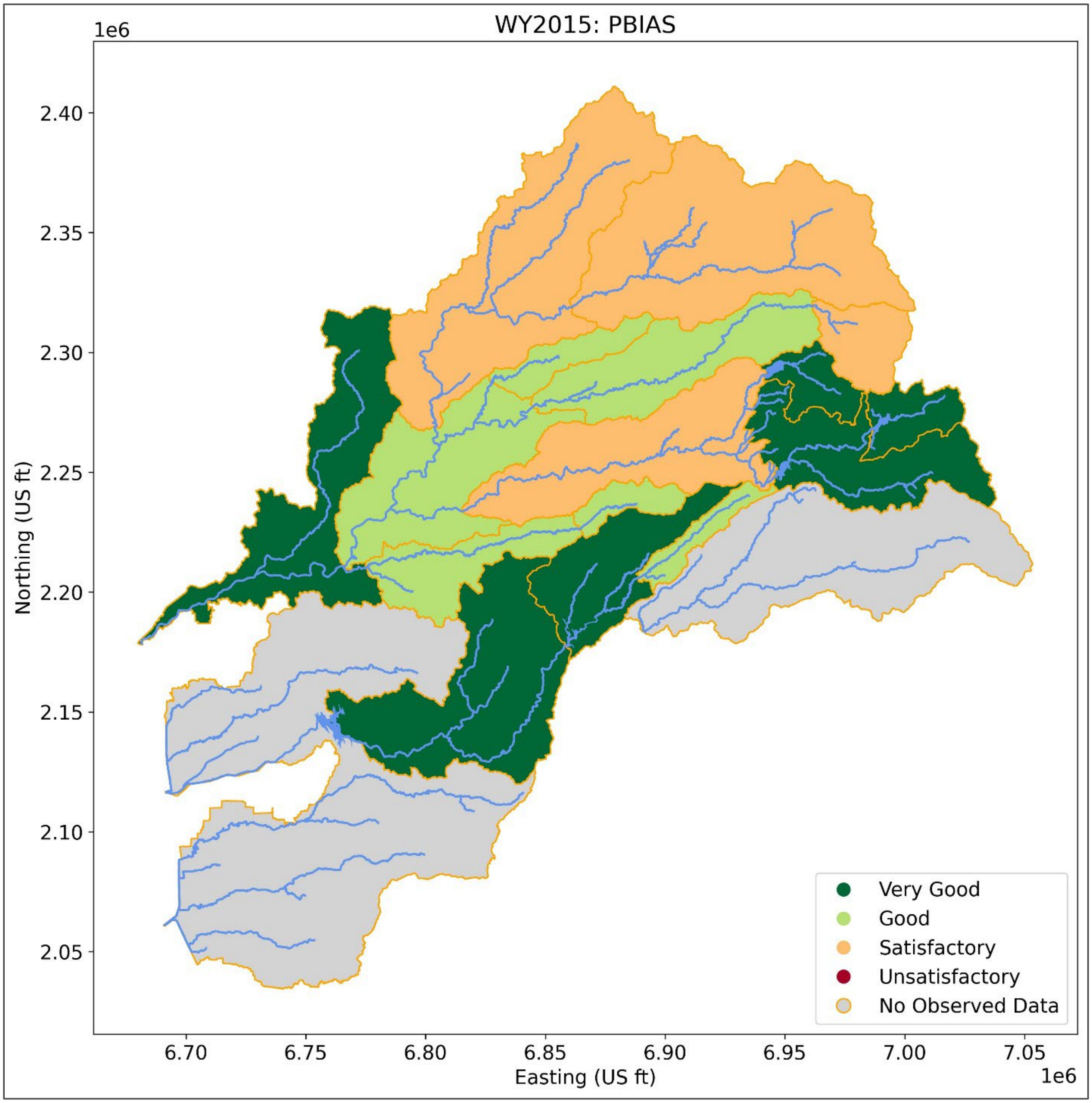

Figure A-54. WY2015 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

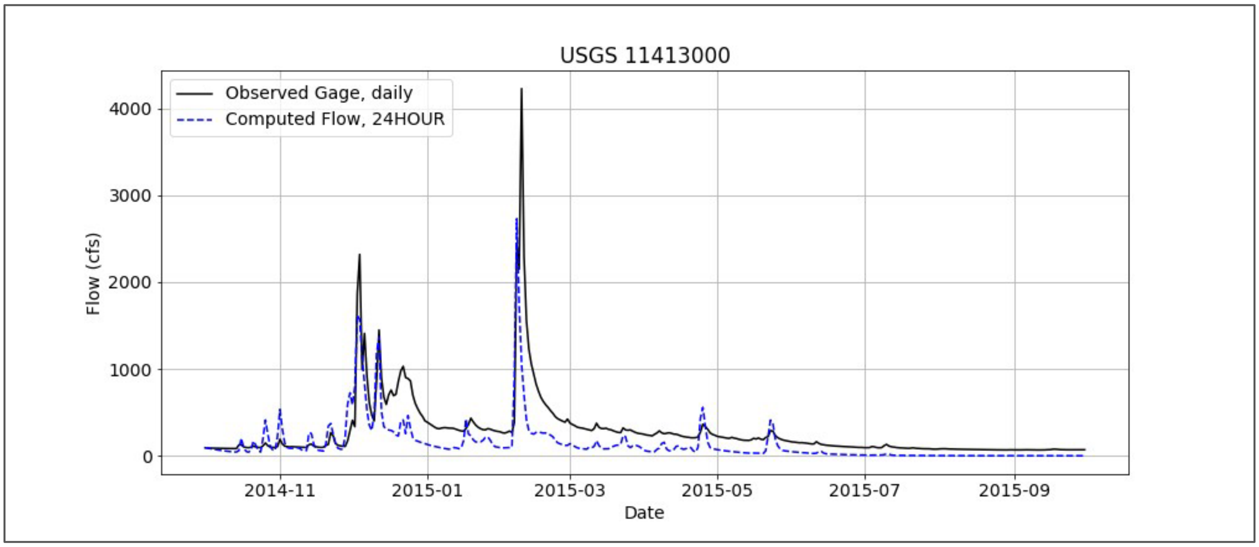

Figure A-55. WY2015 Calibration Results for Calibration Location USGS Gage 11413000

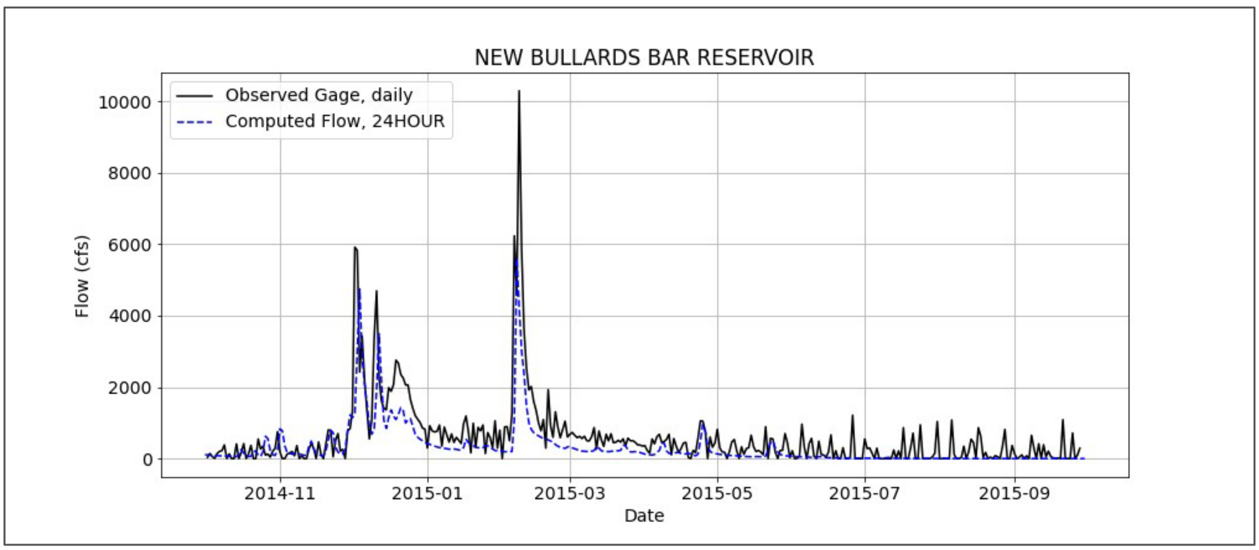

Figure A-56. WY2015 Calibration Results for Calibration Location New Bullards Bar Reservoir

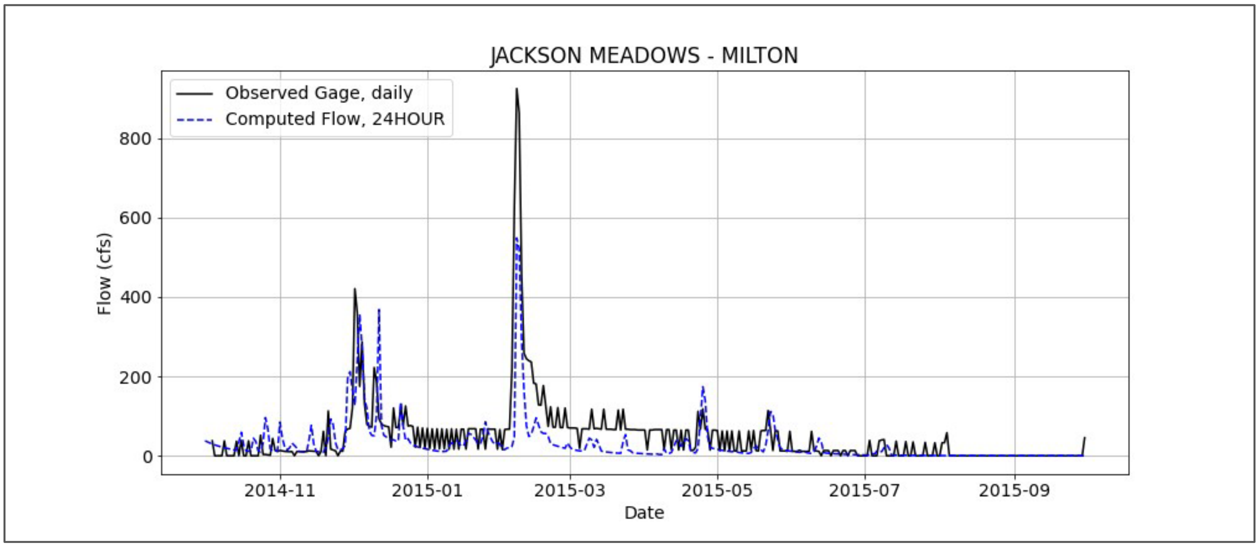

Figure A-57. WY2015 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

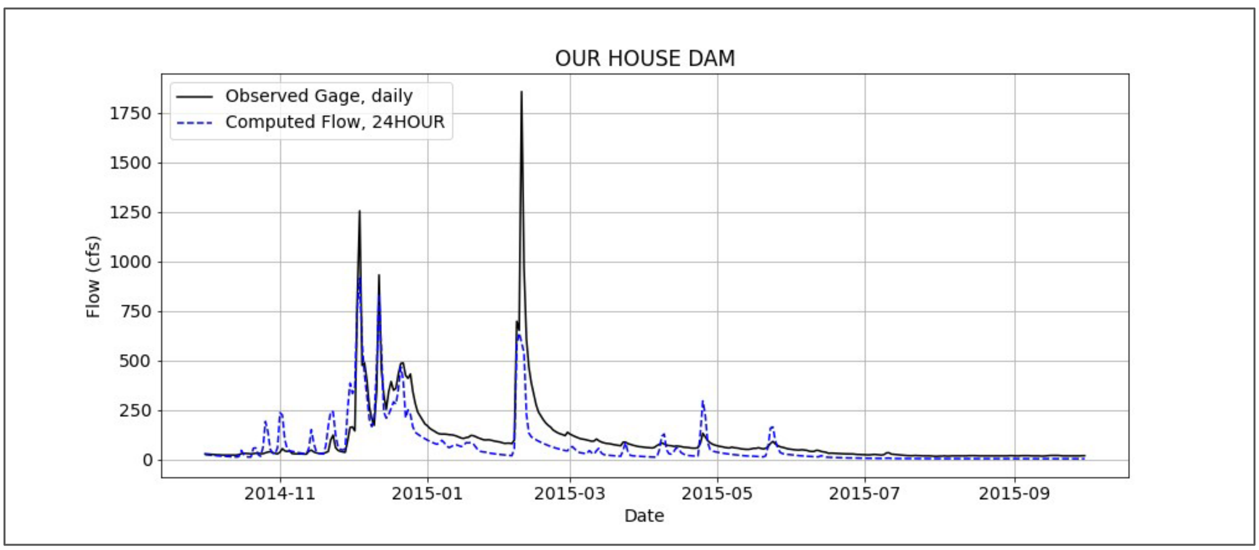

Figure A-58. WY2015 Calibration Results for Calibration Location Our House Dam

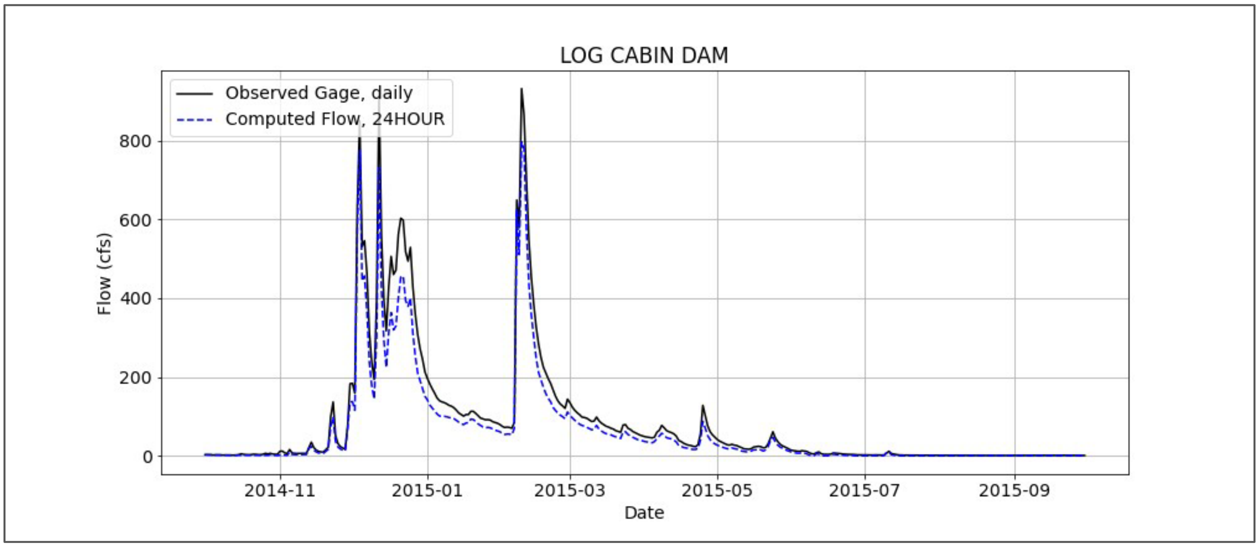

Figure A-59. WY2015 Calibration Results for Calibration Location Log Cabin Dam

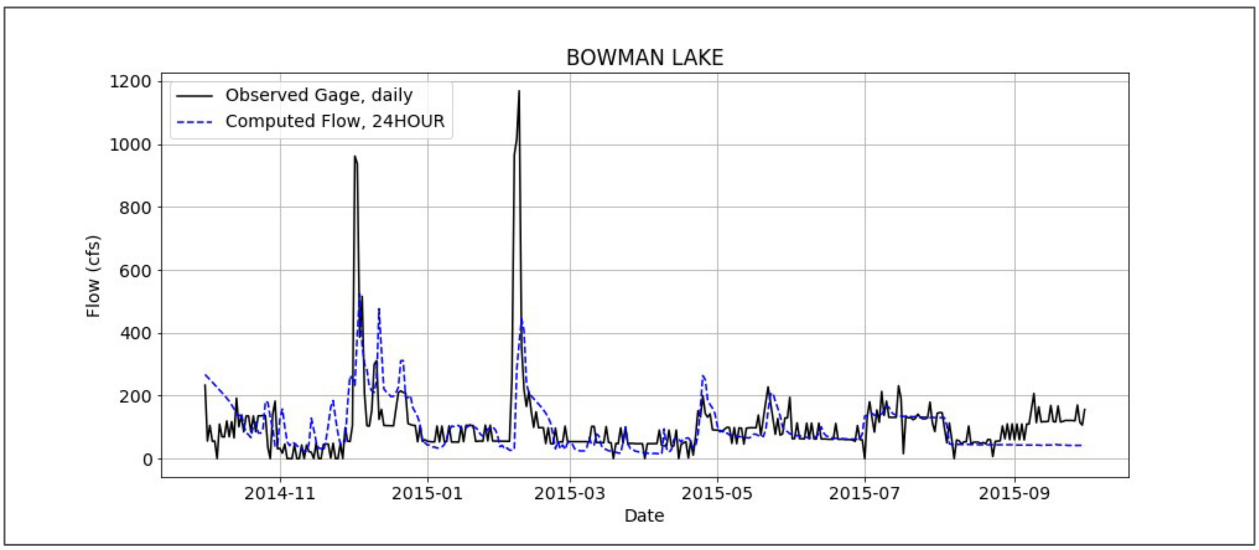

Figure A-60. WY2015 Calibration Results for Calibration Location Bowman Lake

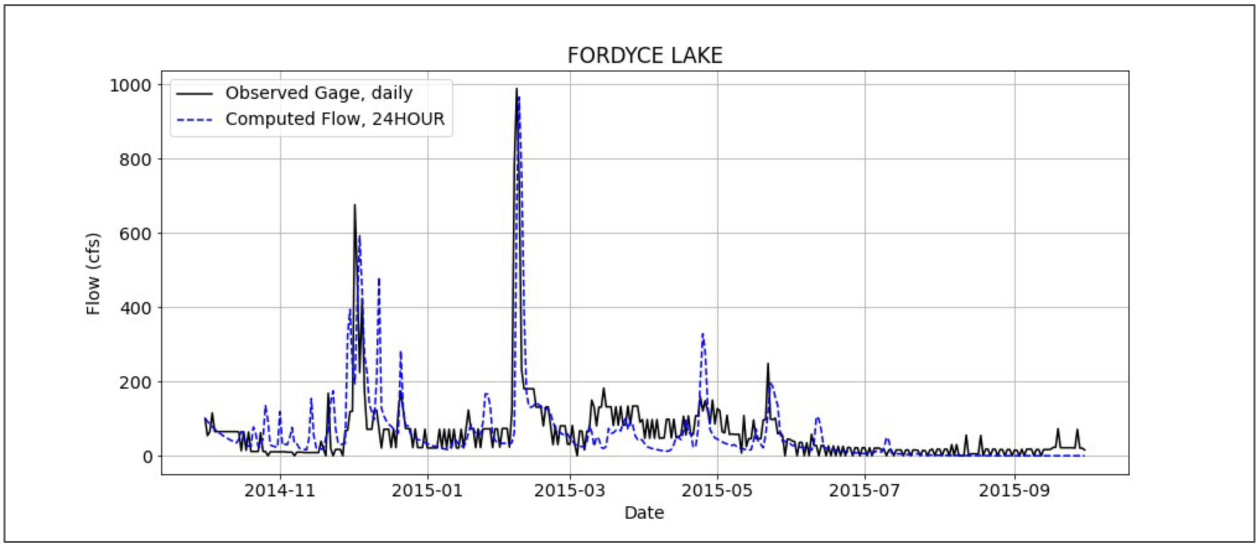

Figure A-61. WY2015 Calibration Results for Calibration Location Fordyce Lake

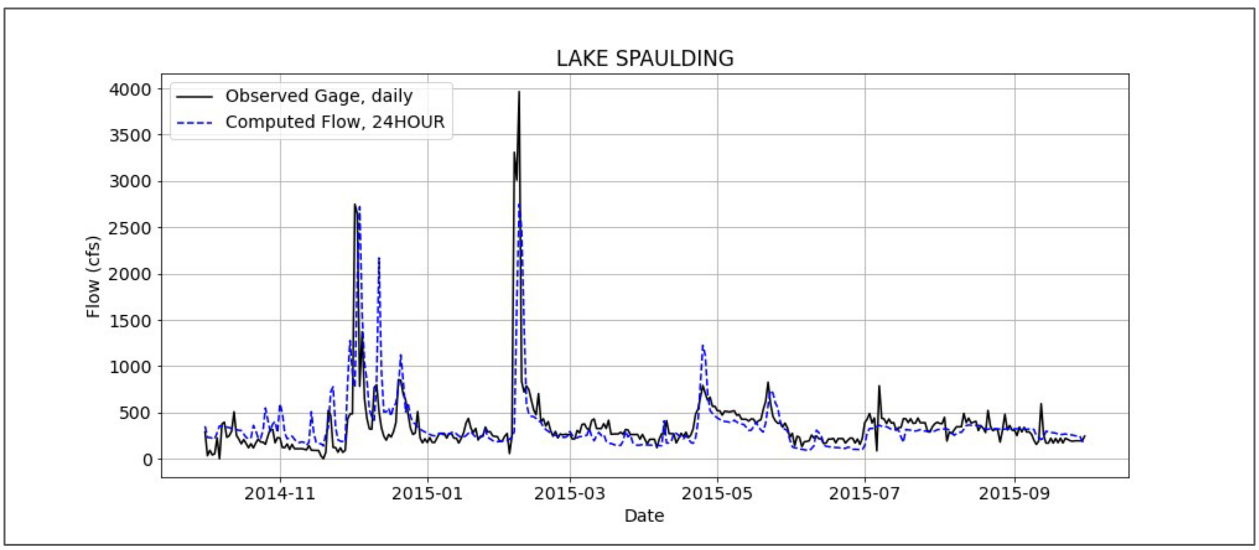

Figure A-62. WY2015 Calibration Results for Calibration Location Lake Spaulding

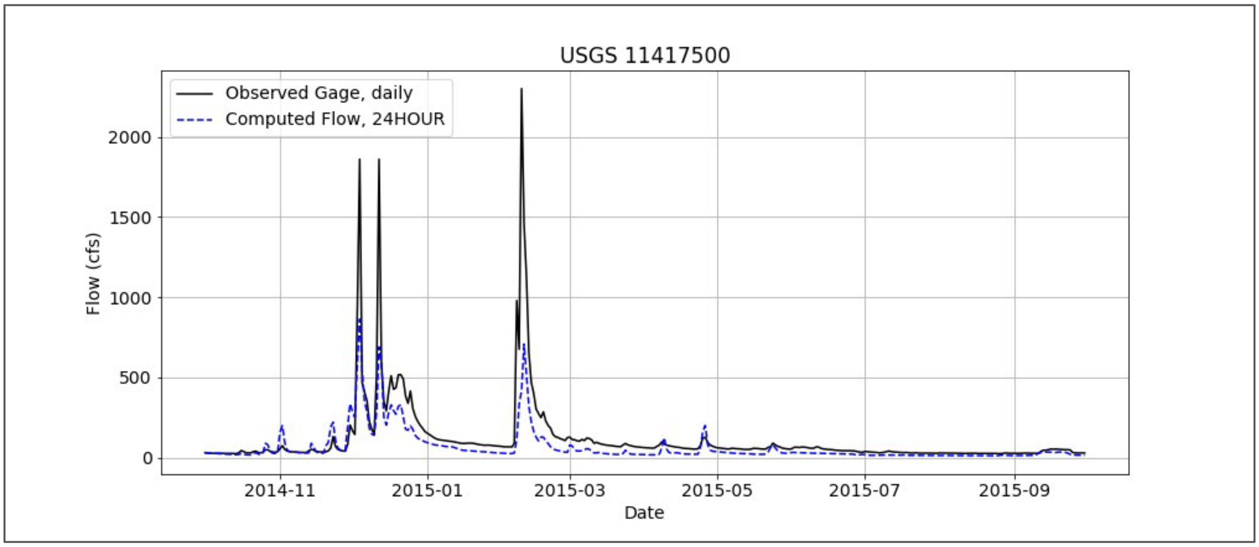

Figure A-63. WY2015 Calibration Results for Calibration Location USGS Gage 11417500

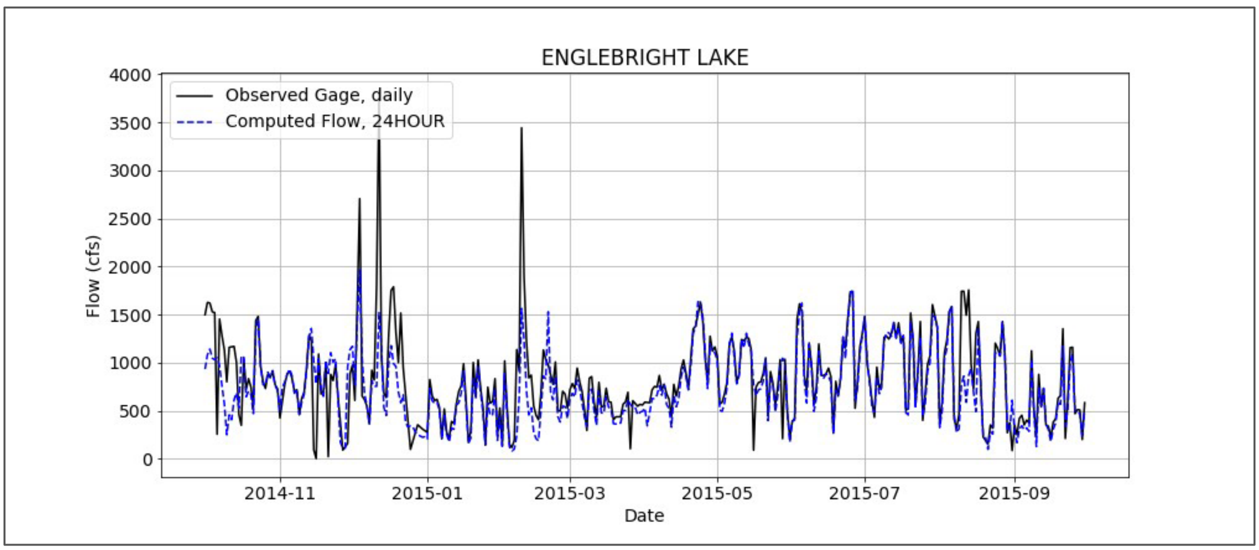

Figure A-64. WY2015 Calibration Results for Calibration Location Englebright Lake

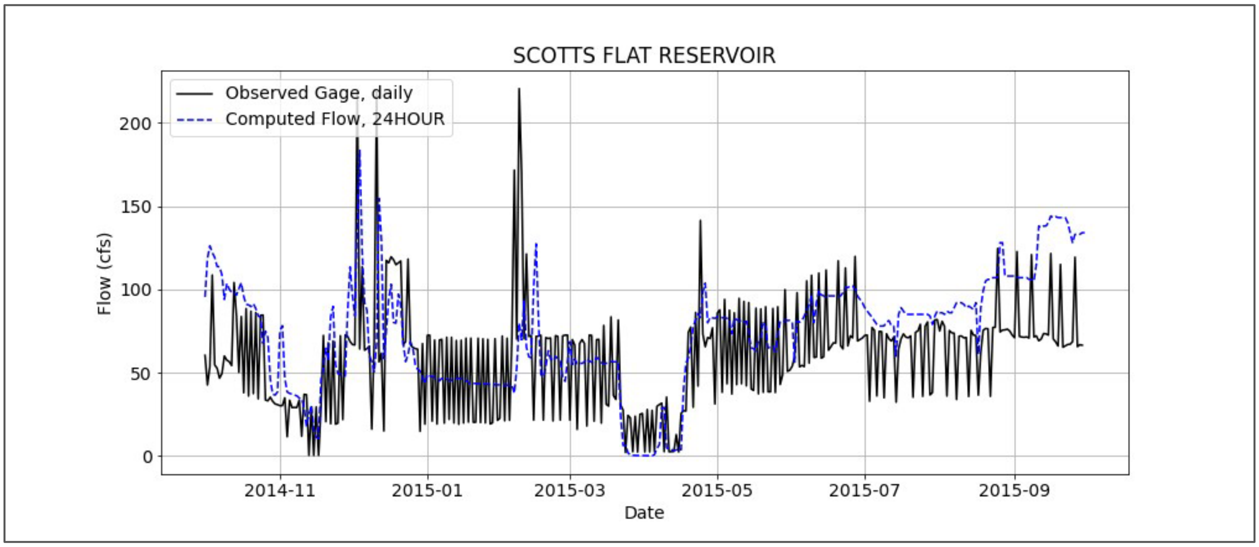

Figure A-65. WY2015 Calibration Results for Calibration Location Scotts Flat Reservoir

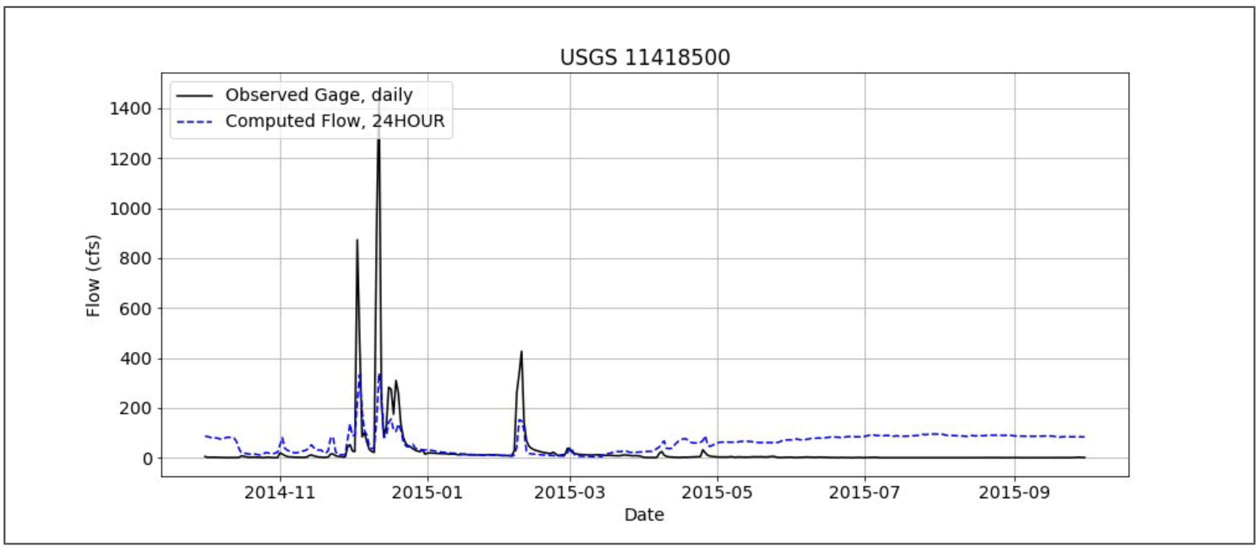

Figure A-66. WY2015 Calibration Results for Calibration Location USGS Gage 11418500

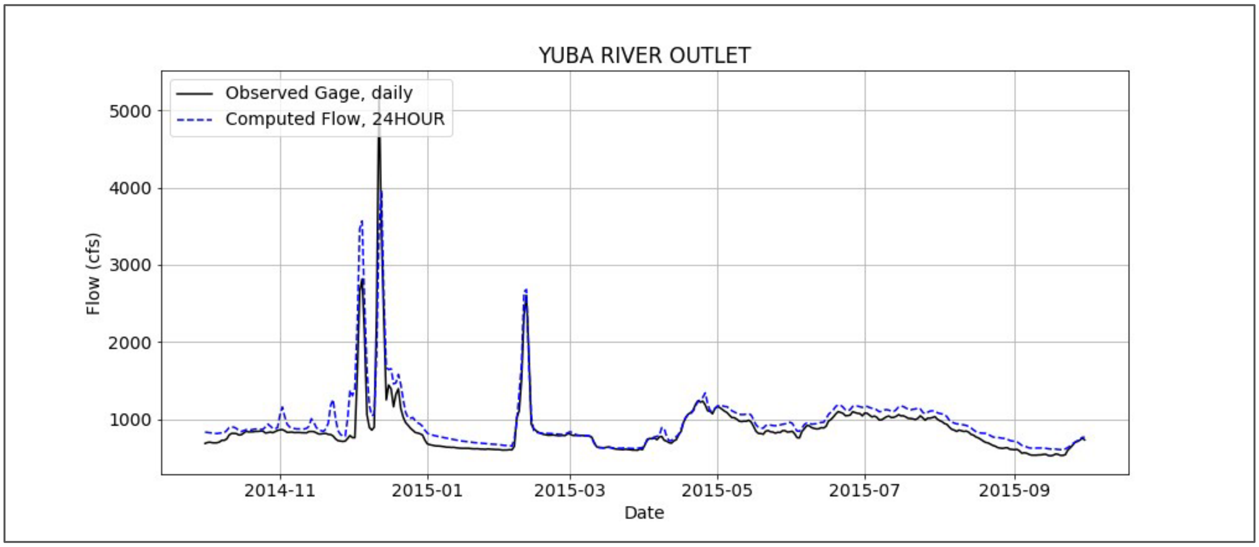

Figure A-67. WY2015 Calibration Results for Calibration Location Yuba River Outlet

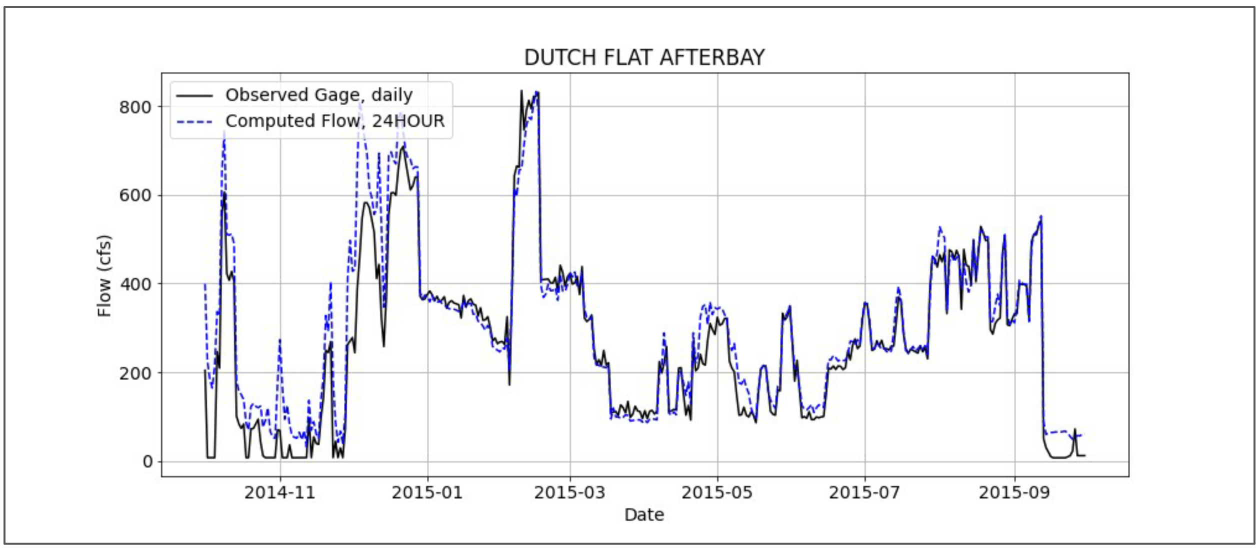

Figure A-68. WY2015 Calibration Results for Calibration Location Dutch Flat Afterbay

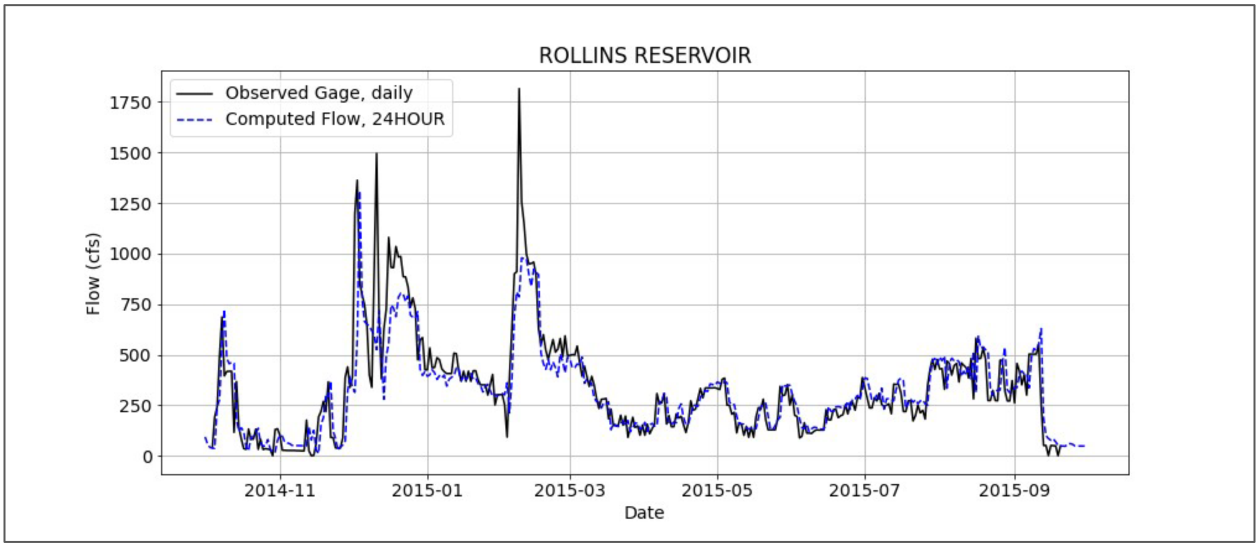

Figure A-69. WY2015 Calibration Results for Calibration Location Rollins Reservoir

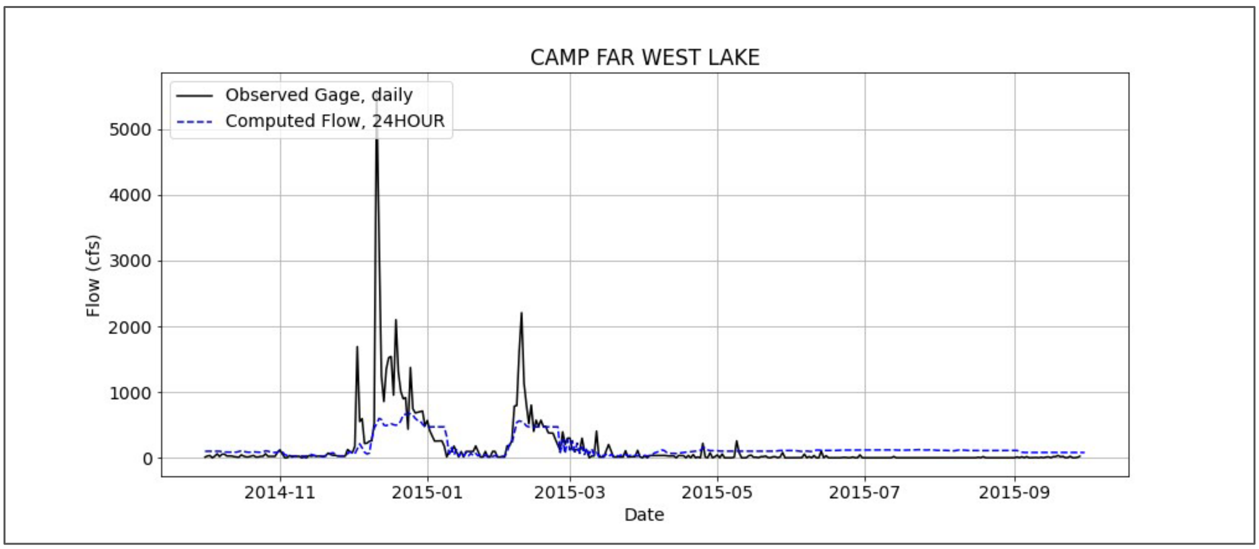

Figure A-70. WY2015 Calibration Results for Calibration Location Camp Far West Lake

A.4.5. Calibration Results for WY2021

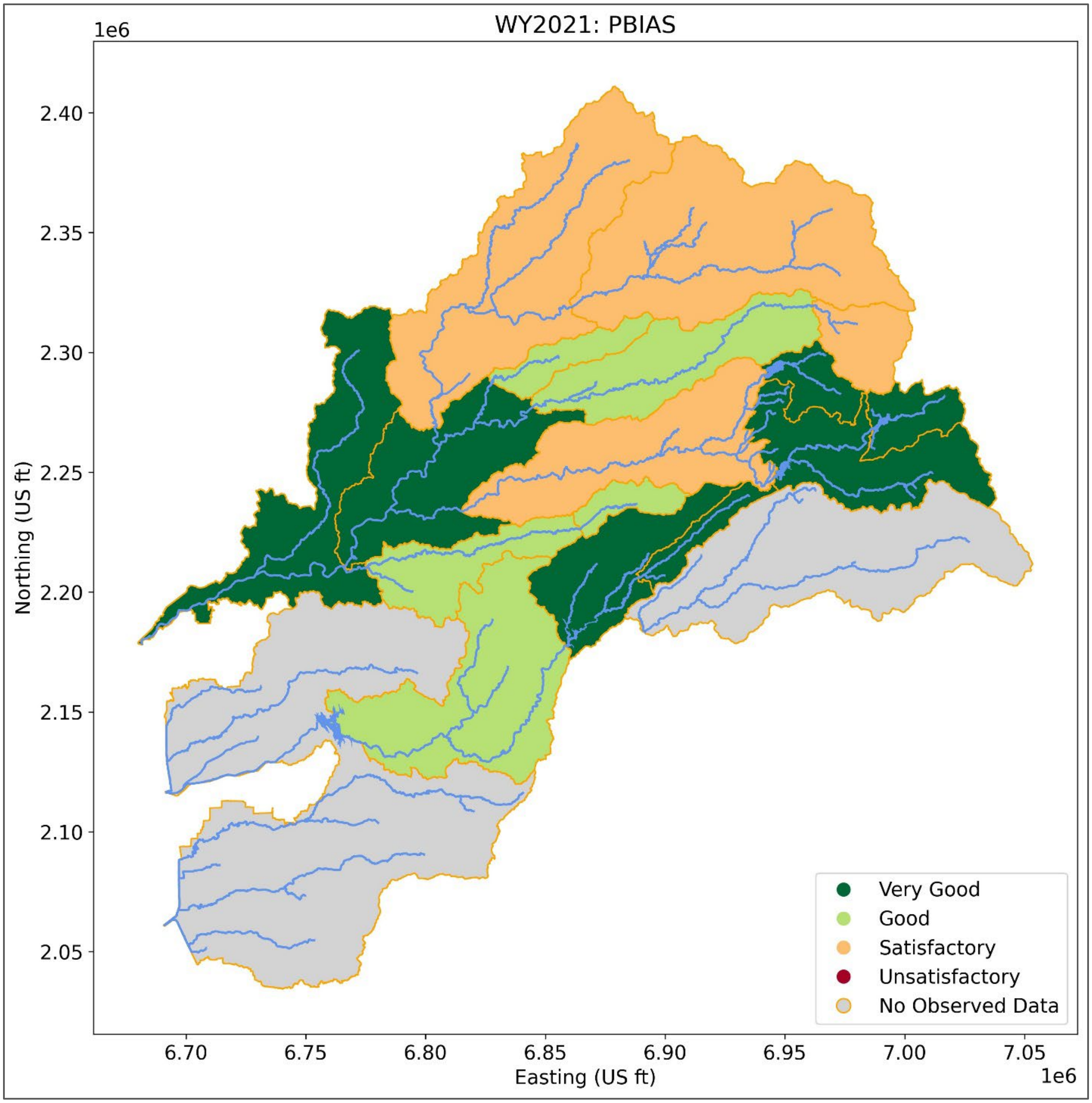

Figure A-71. WY2021 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

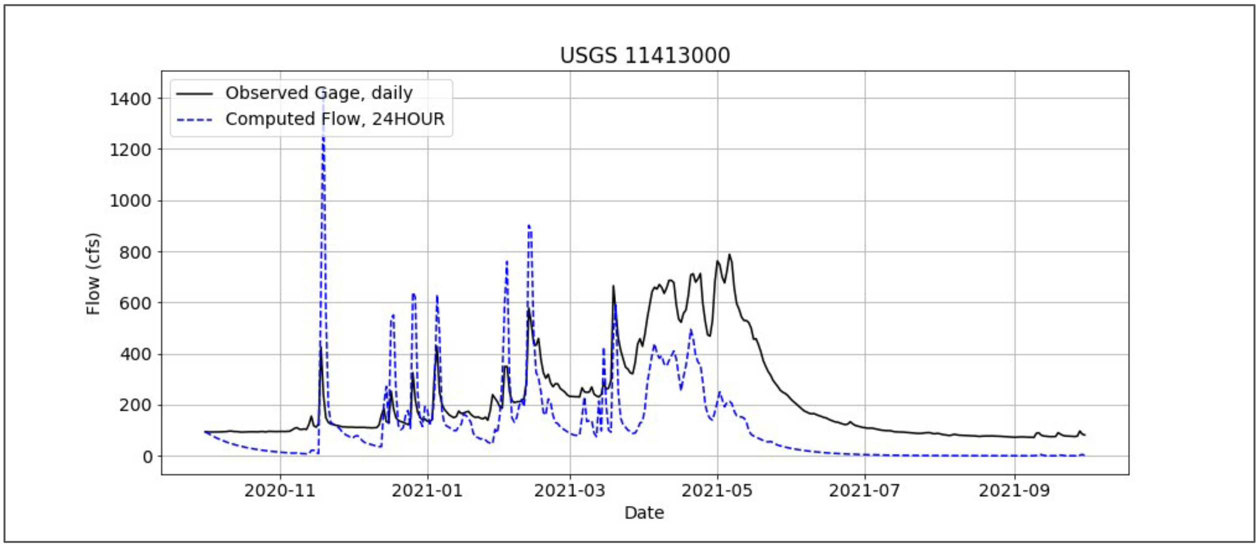

Figure A-72. WY2021 Calibration Results for Calibration Location USGS Gage 11413000

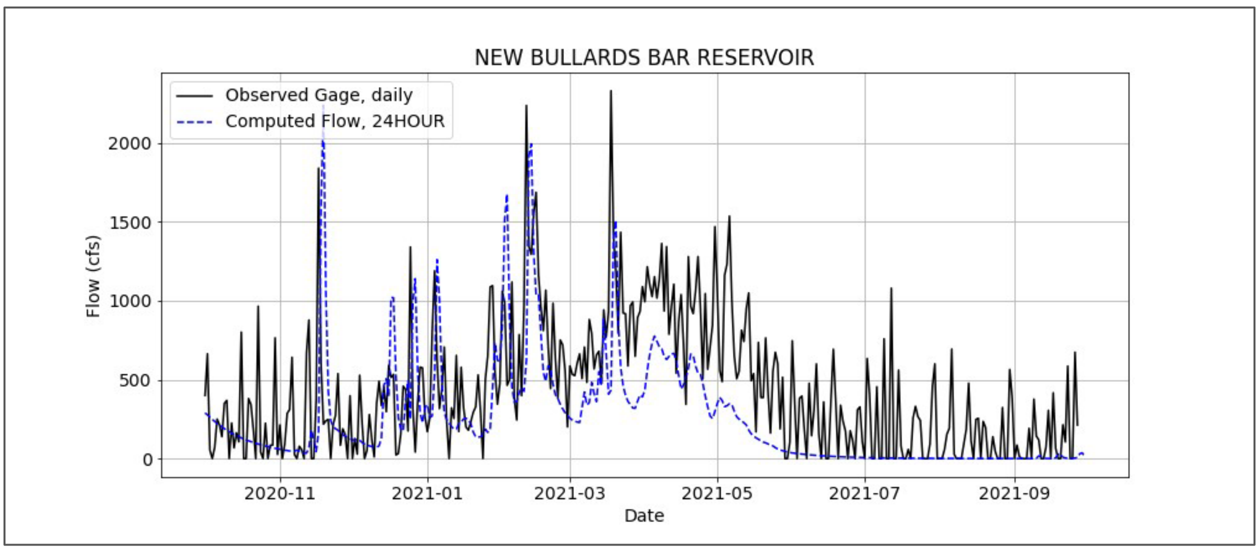

Figure A-73. WY2021 Calibration Results for Calibration Location New Bullards Bar Reservoir

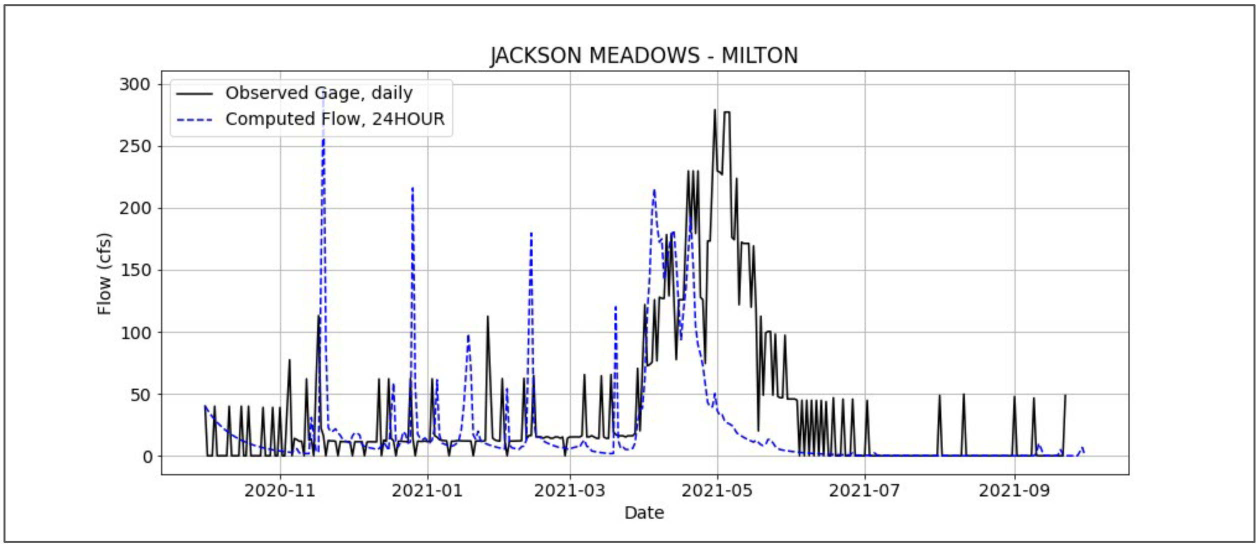

Figure A-74. WY2021 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

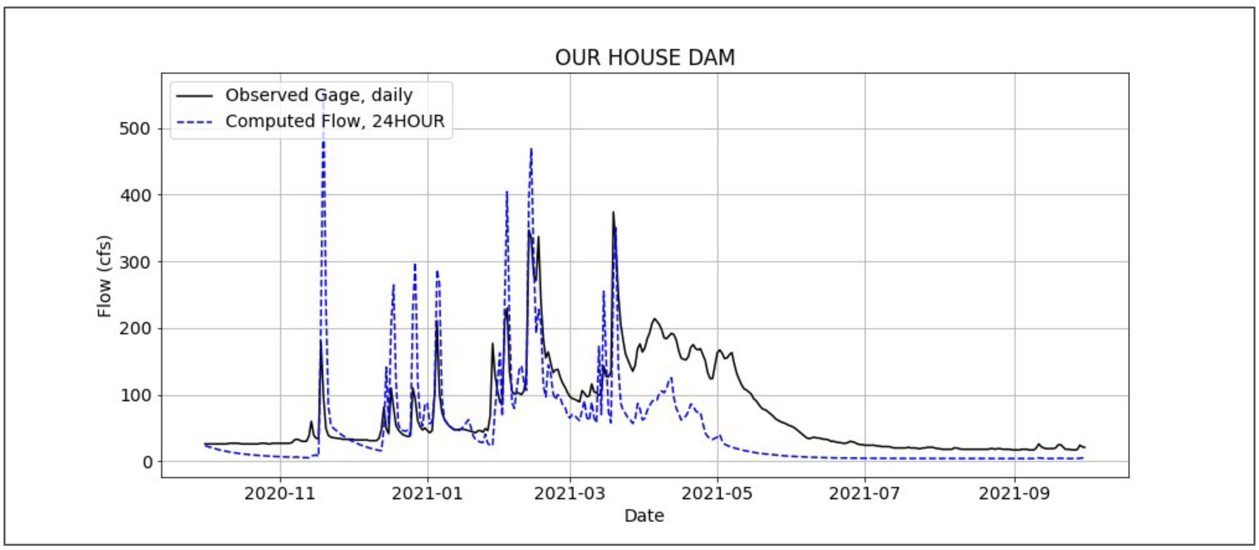

Figure A-75. WY2021 Calibration Results for Calibration Location Our House Dam

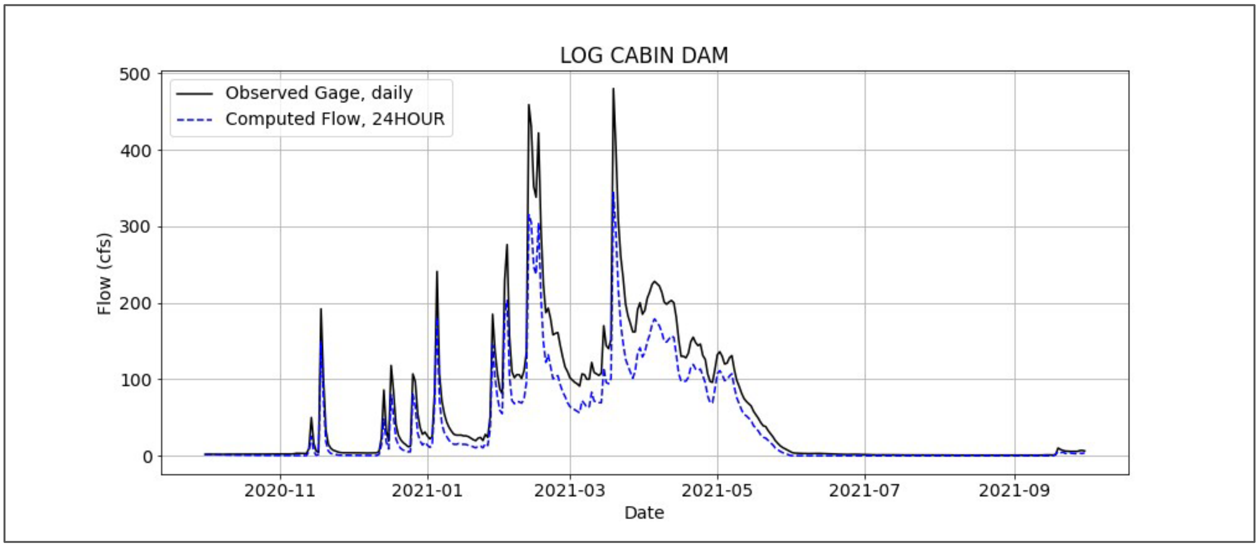

Figure A-76. WY2021 Calibration Results for Calibration Location Log Cabin Dam

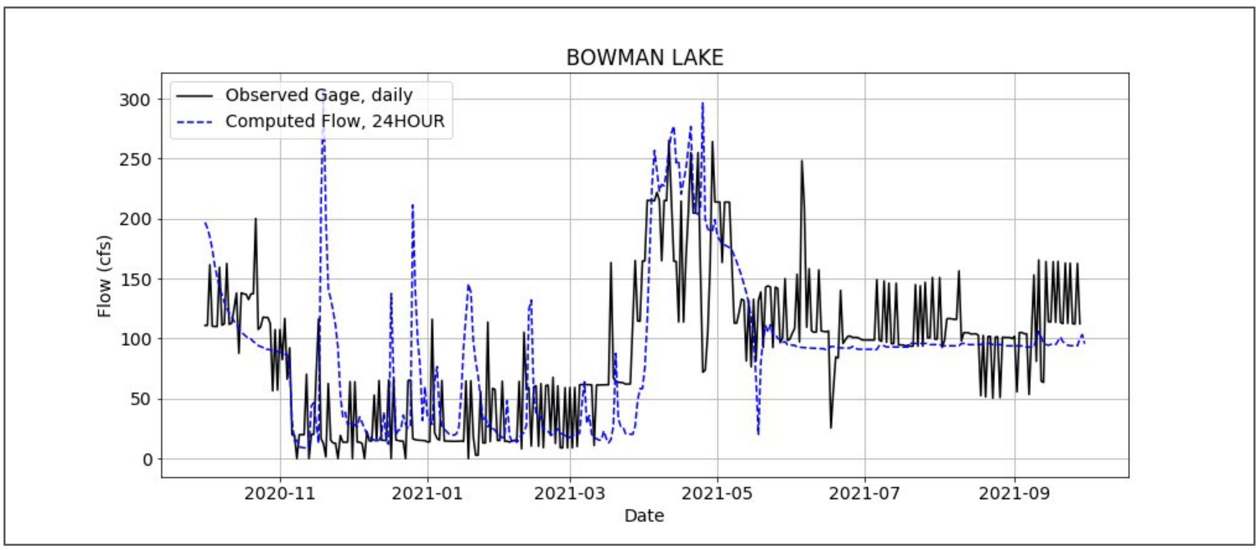

Figure A-77. WY2021 Calibration Results for Calibration Location Bowman Lake

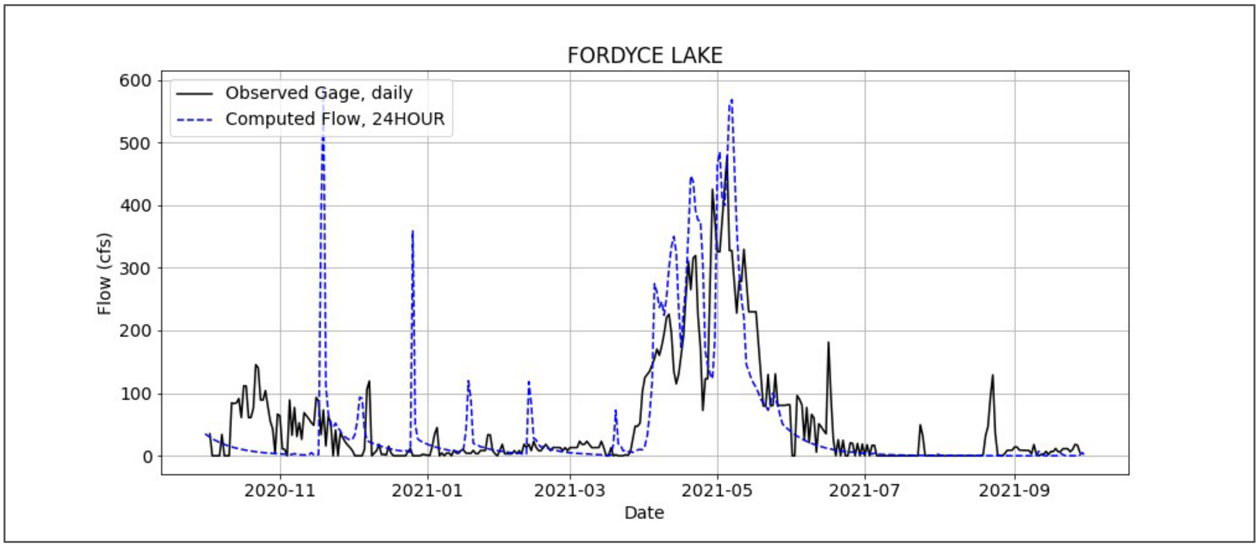

Figure A-78. WY2021 Calibration Results for Calibration Location Fordyce Lake

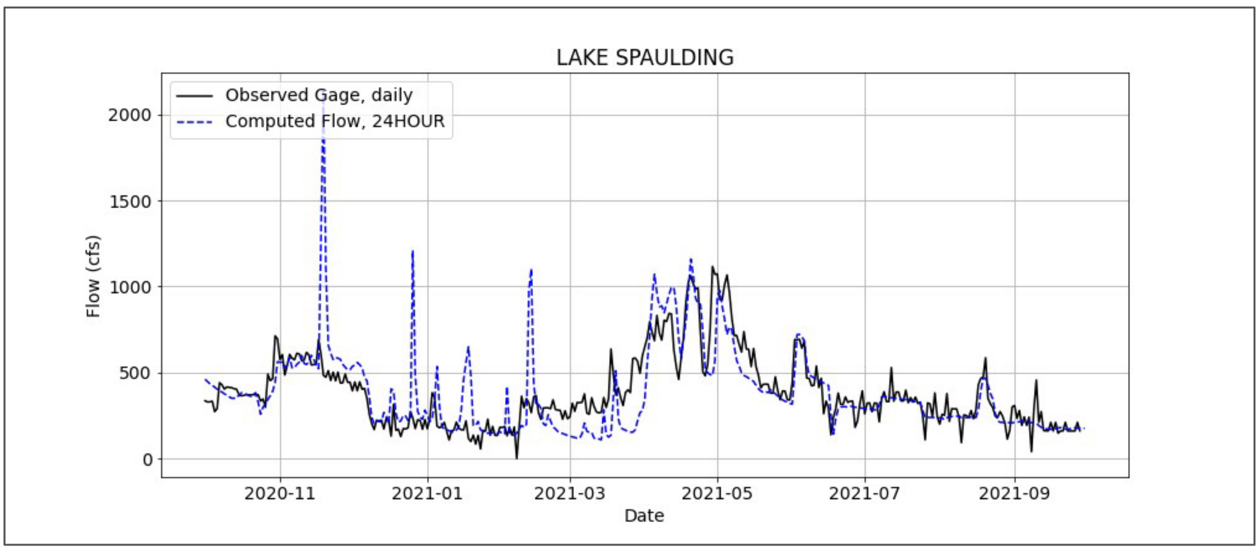

Figure A-79. WY2021 Calibration Results for Calibration Location Lake Spaulding

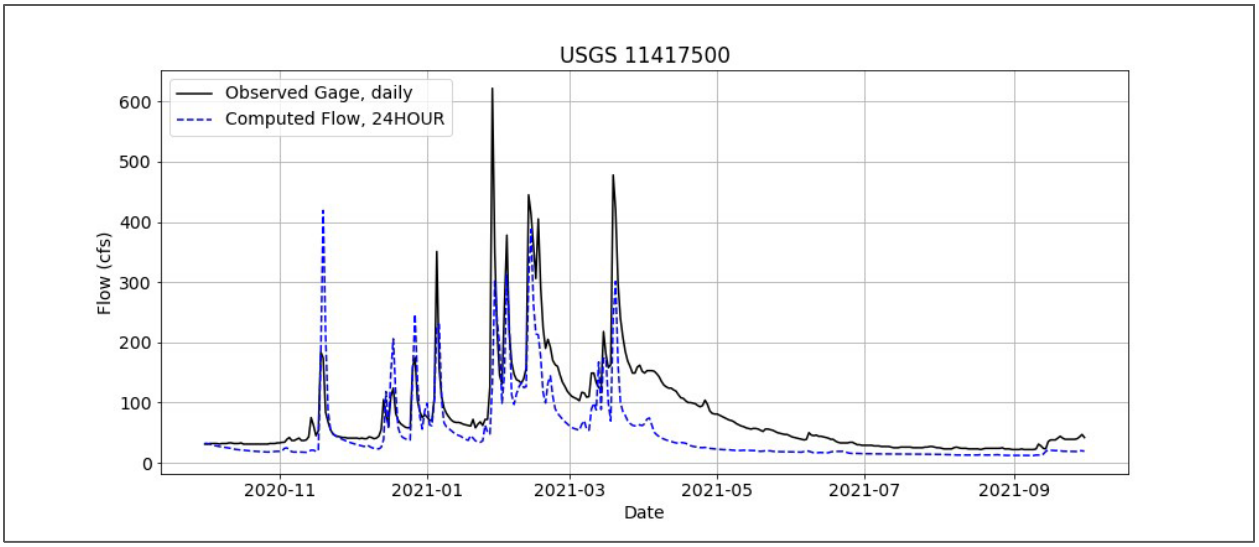

Figure A-80. WY2021 Calibration Results for Calibration Location USGS Gage 11417500

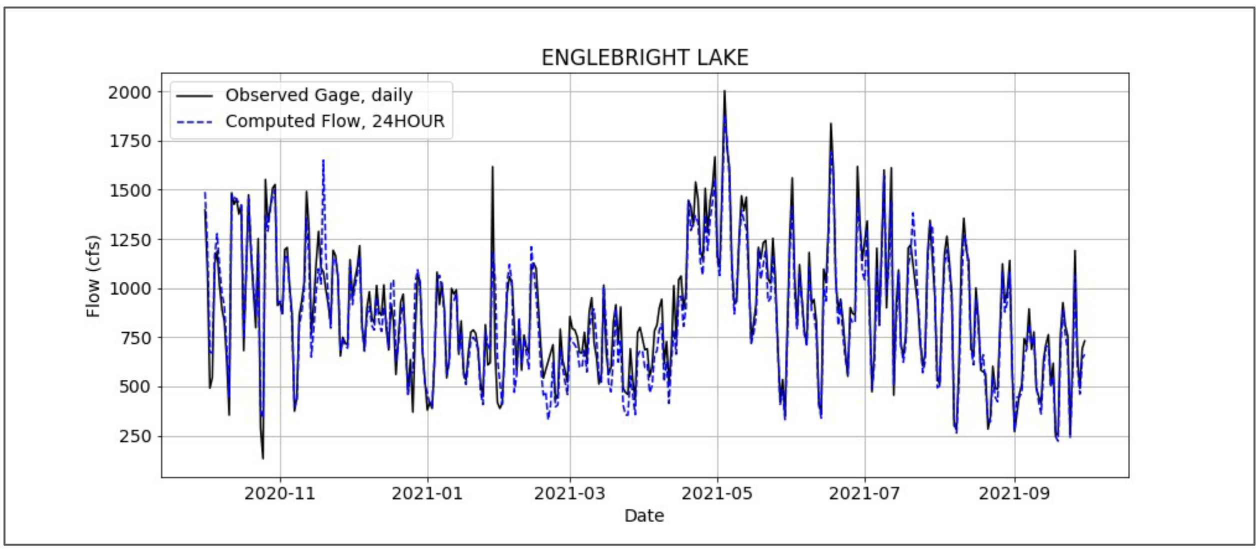

Figure A-81. WY2021 Calibration Results for Calibration Location Englebright Lake

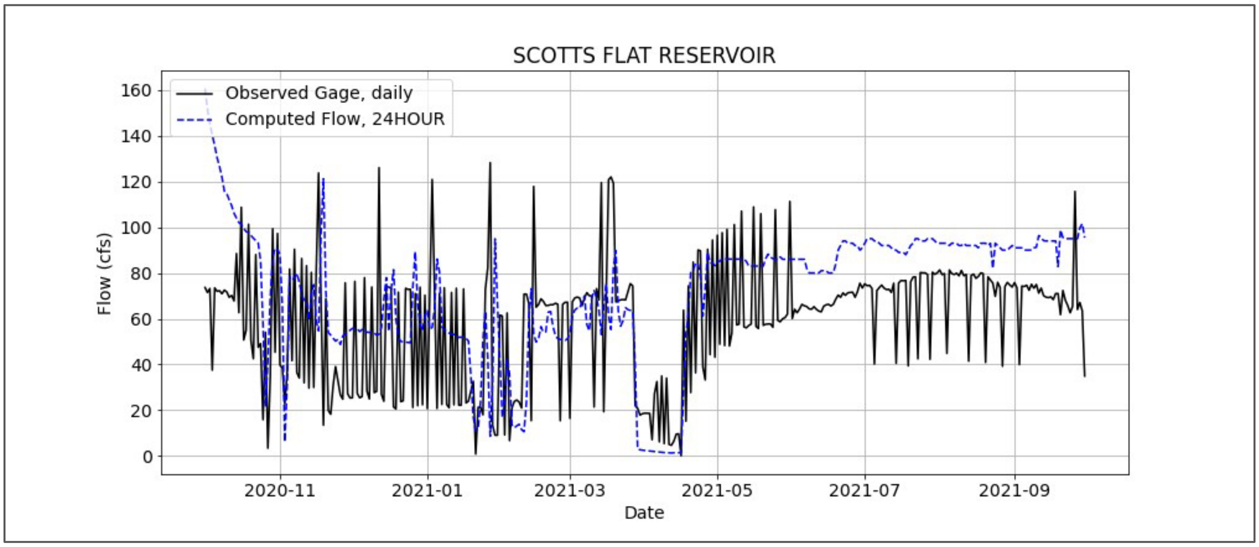

Figure A-82. WY2021 Calibration Results for Calibration Location Scotts Flat Reservoir

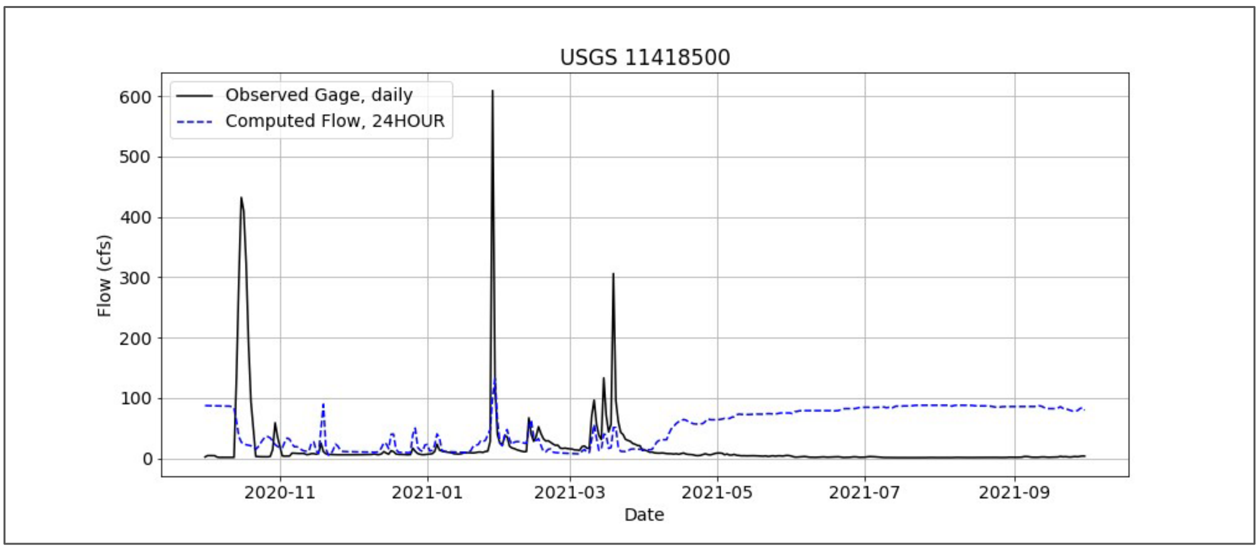

Figure A-83. WY2021 Calibration Results for Calibration Location USGS Gage 11418500

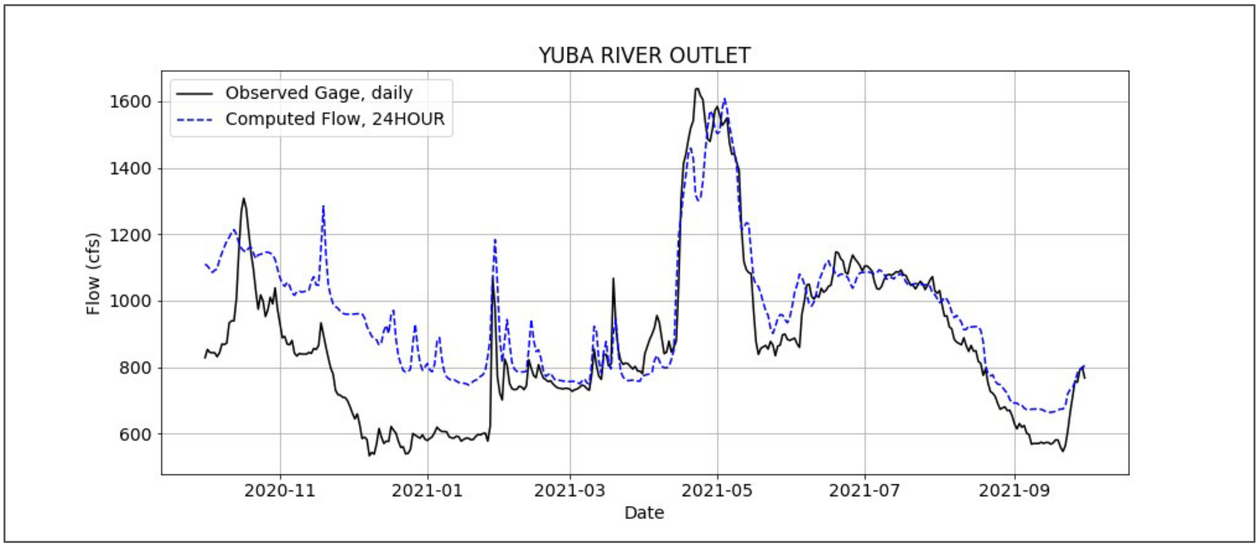

Figure A-84. WY2021 Calibration Results for Calibration Location Yuba River Outlet

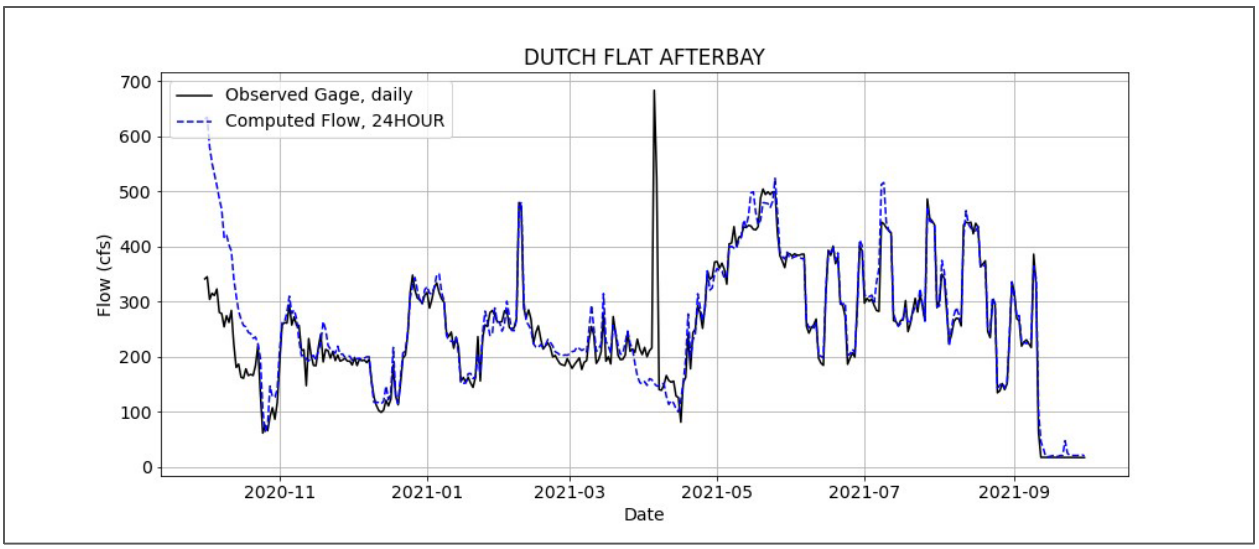

Figure A-85. WY2021 Calibration Results for Calibration Location Dutch Flat Afterbay

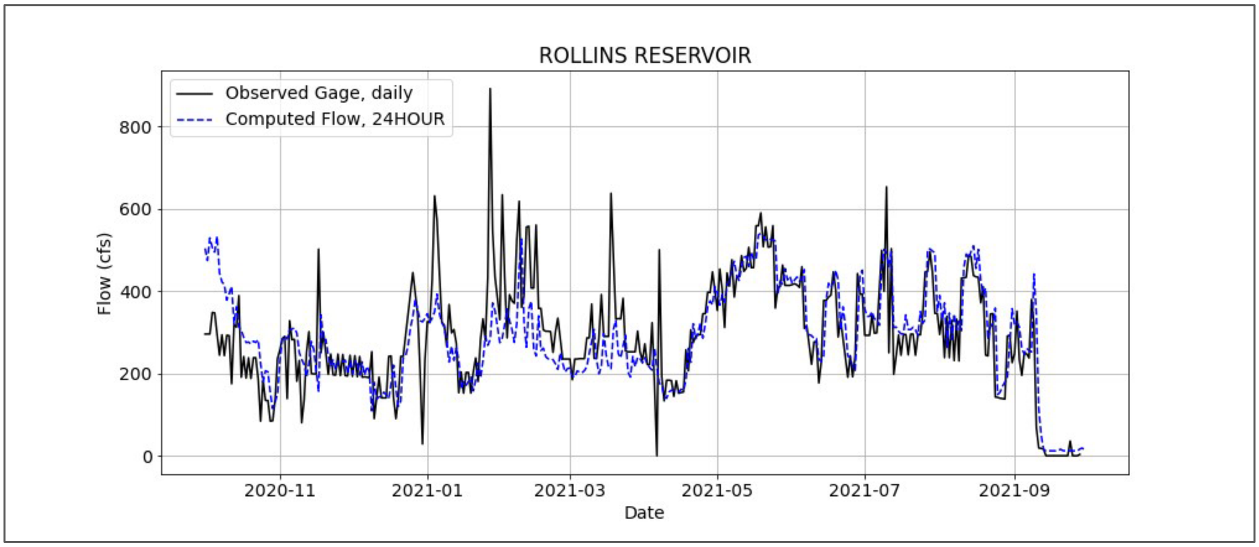

Figure A-86. WY2021 Calibration Results for Calibration Location Rollins Reservoir

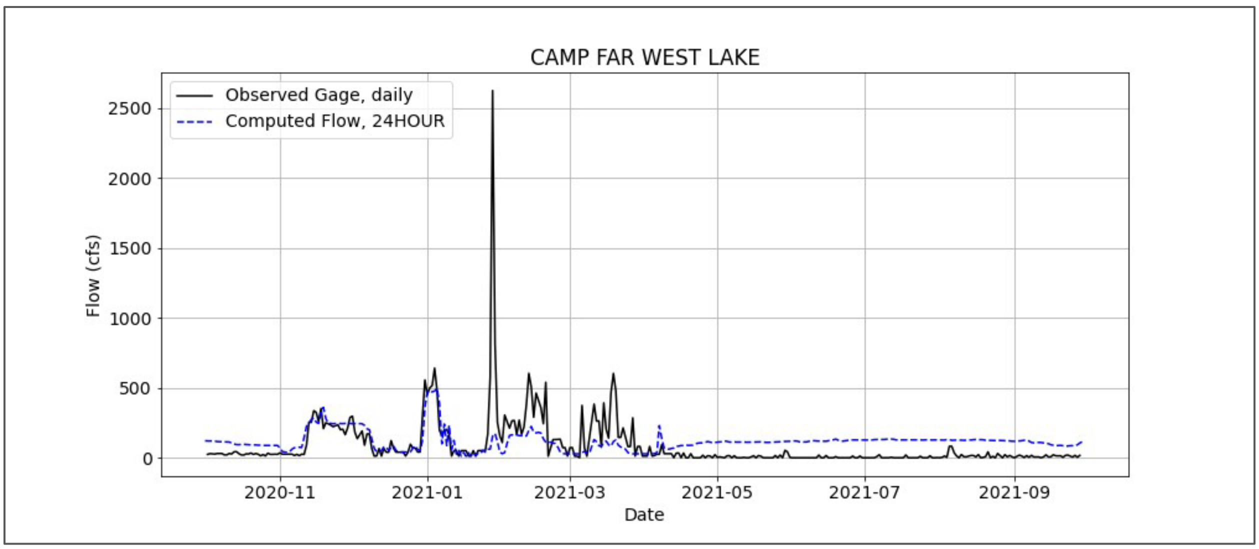

Figure A-87. WY2021 Calibration Results for Calibration Location Camp Far West Lake

A.5. Calibration Refinements Results for Other Water Years

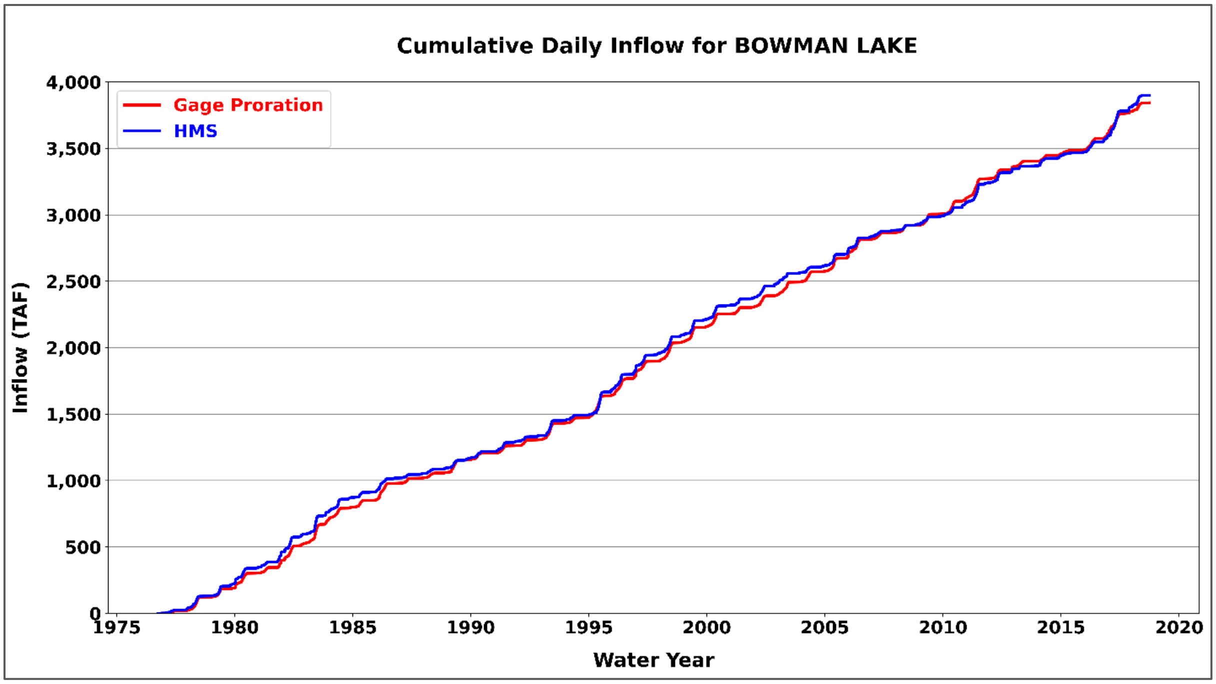

Figure A-88. Cumulative Daily Inflow (1975–2018) for Bowman Lake After Calibration Refinements

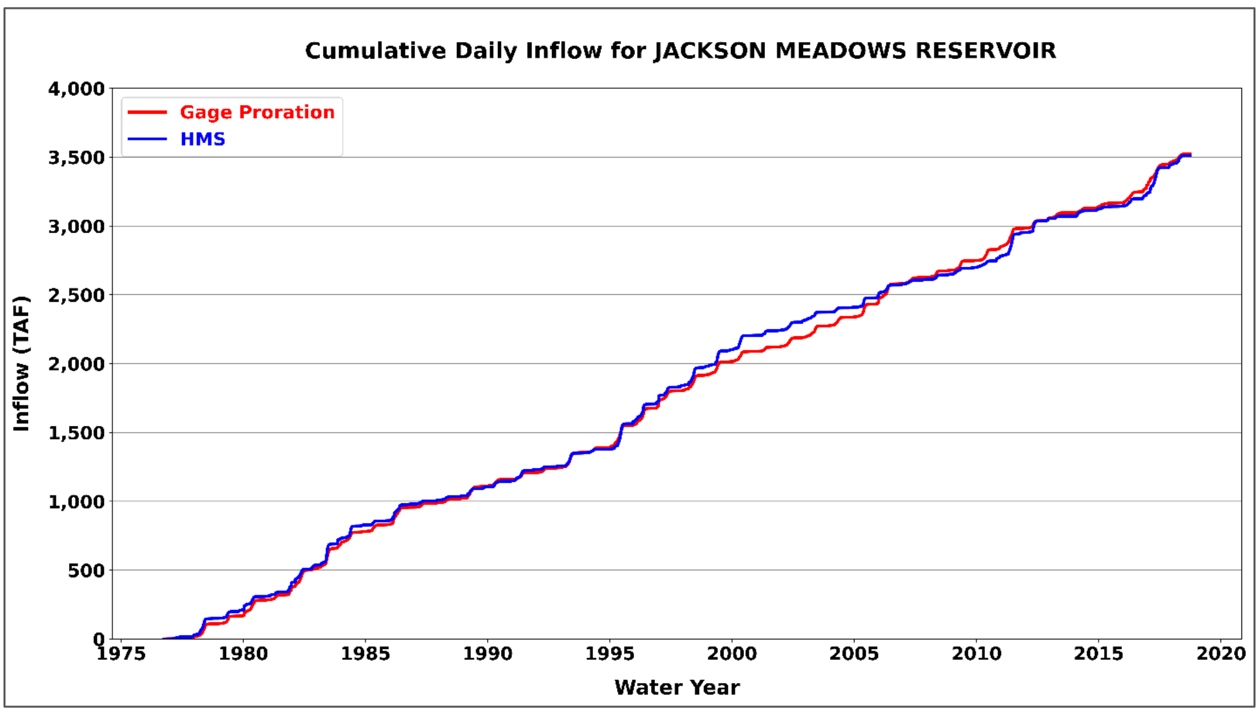

Figure A-89. Cumulative Daily Inflow (1975–2018) for Jackson Meadow Reservoir After Calibration Refinements

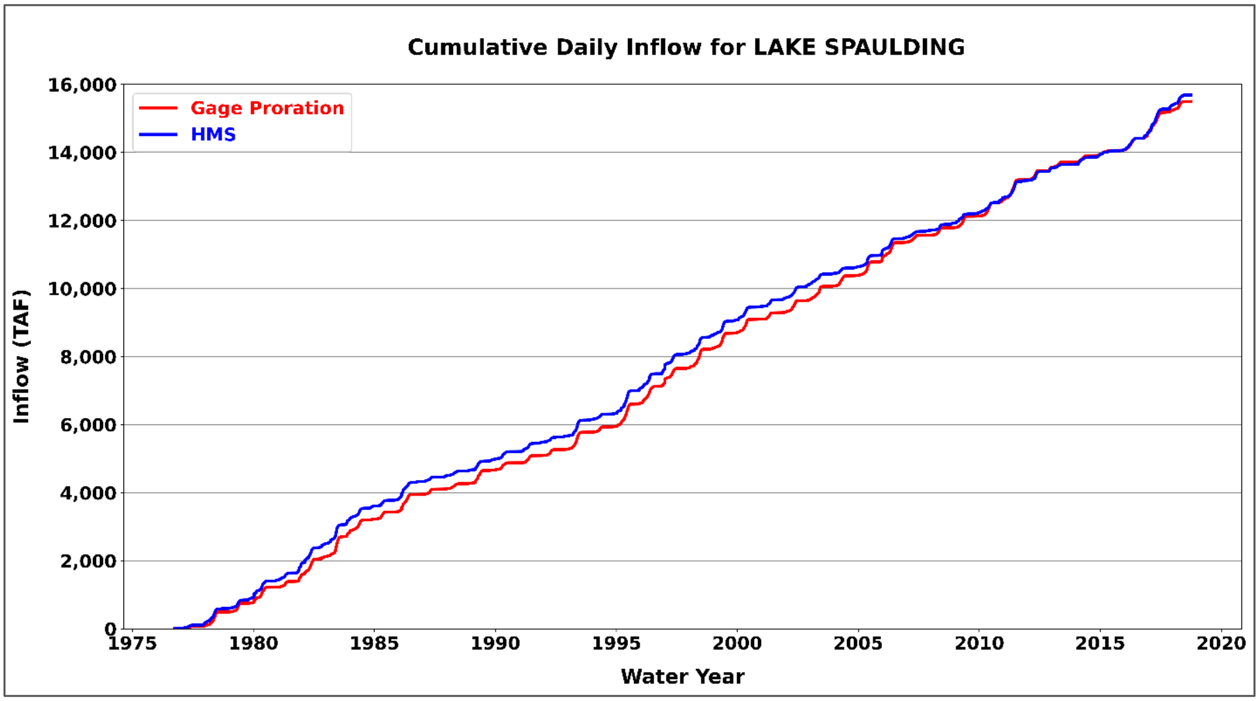

Figure A-90. Cumulative Daily Inflow (1975–2018) for Lake Spaulding After Calibration Refinements

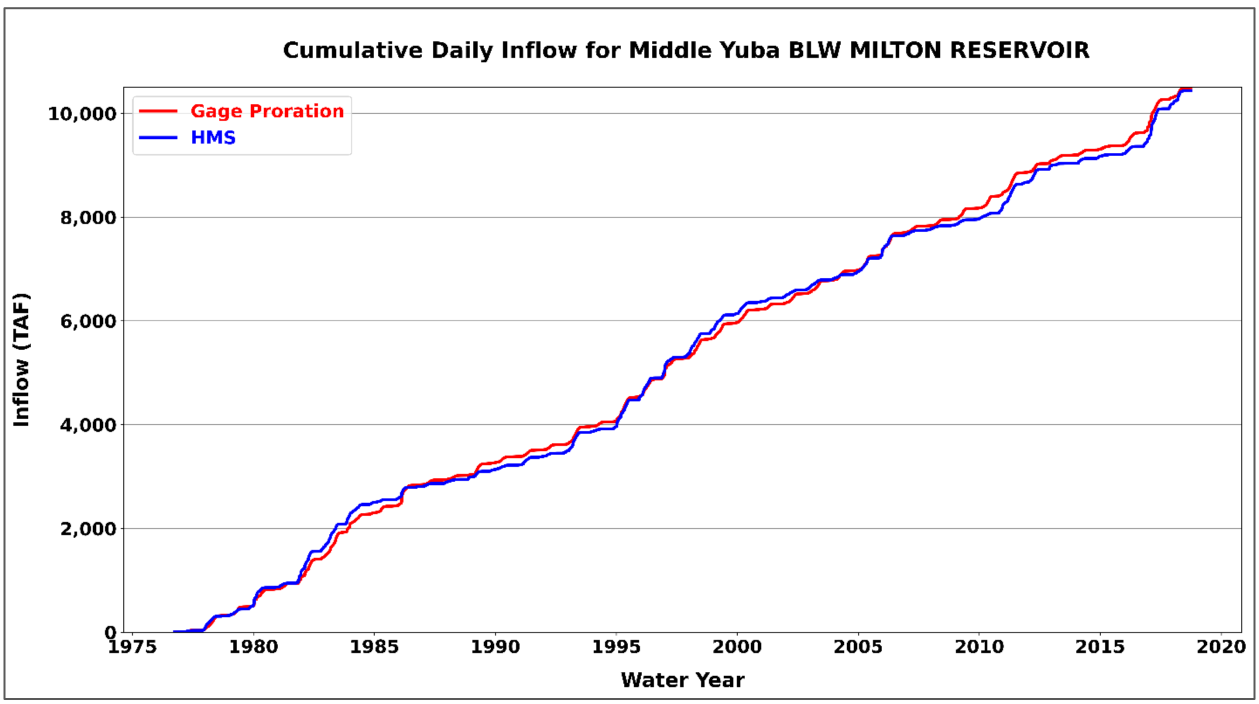

Figure A-91. Cumulative Daily Inflow (1975–2018) for Middle Yuba-Below Milton Reservoir After Calibration Refinements

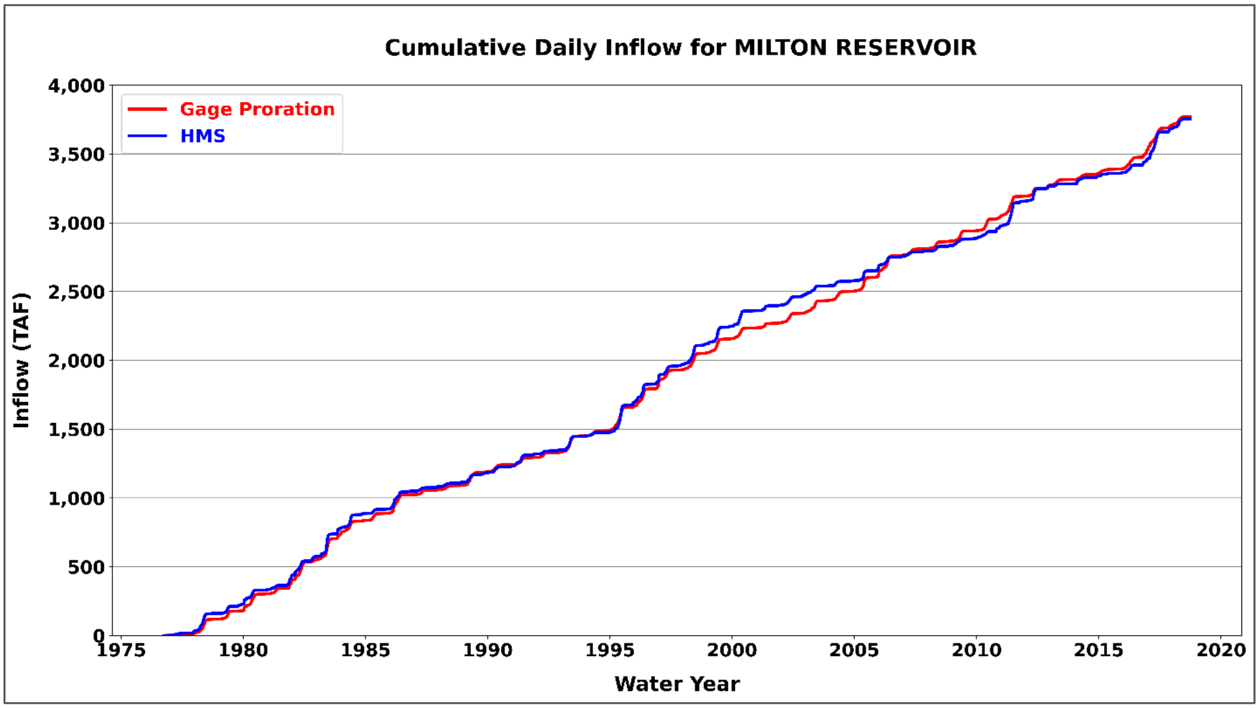

Figure A-92. Cumulative Daily Inflow (1975–2018) for Middle Yuba- Milton Reservoir After Calibration Refinements

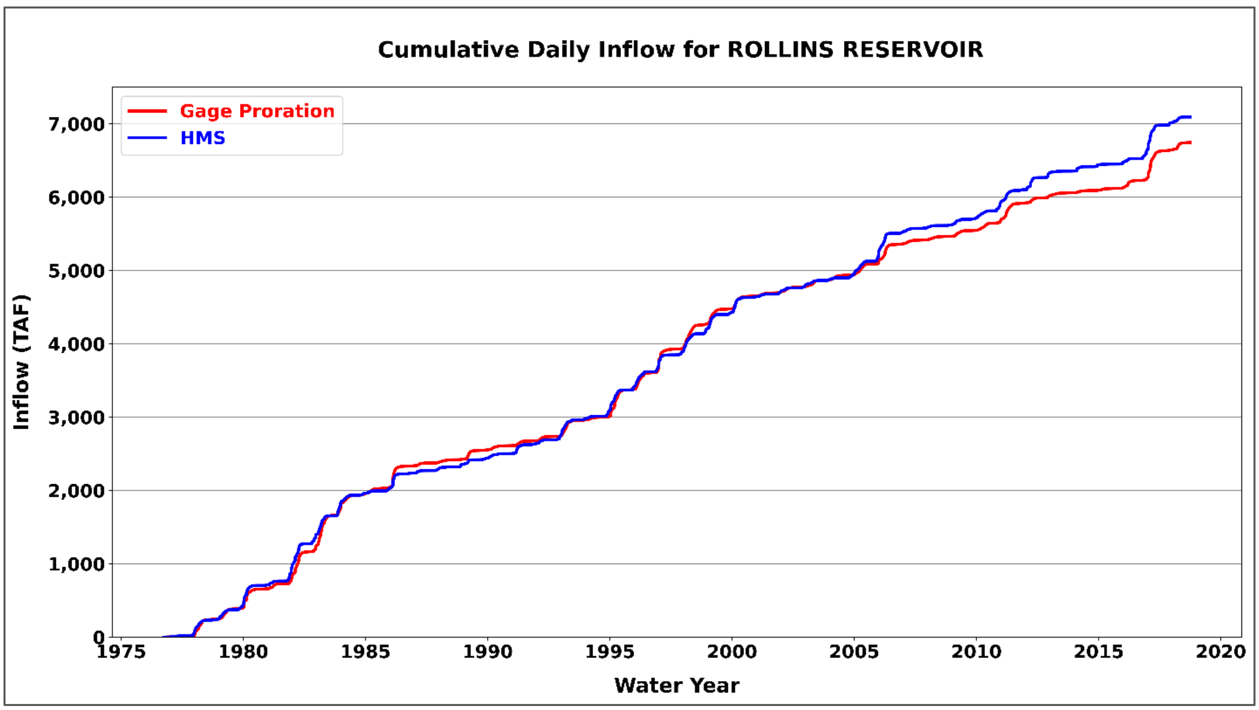

Figure A-93. Cumulative Daily Inflow (1975–2018) for Rollins Reservoir After Calibration Refinements

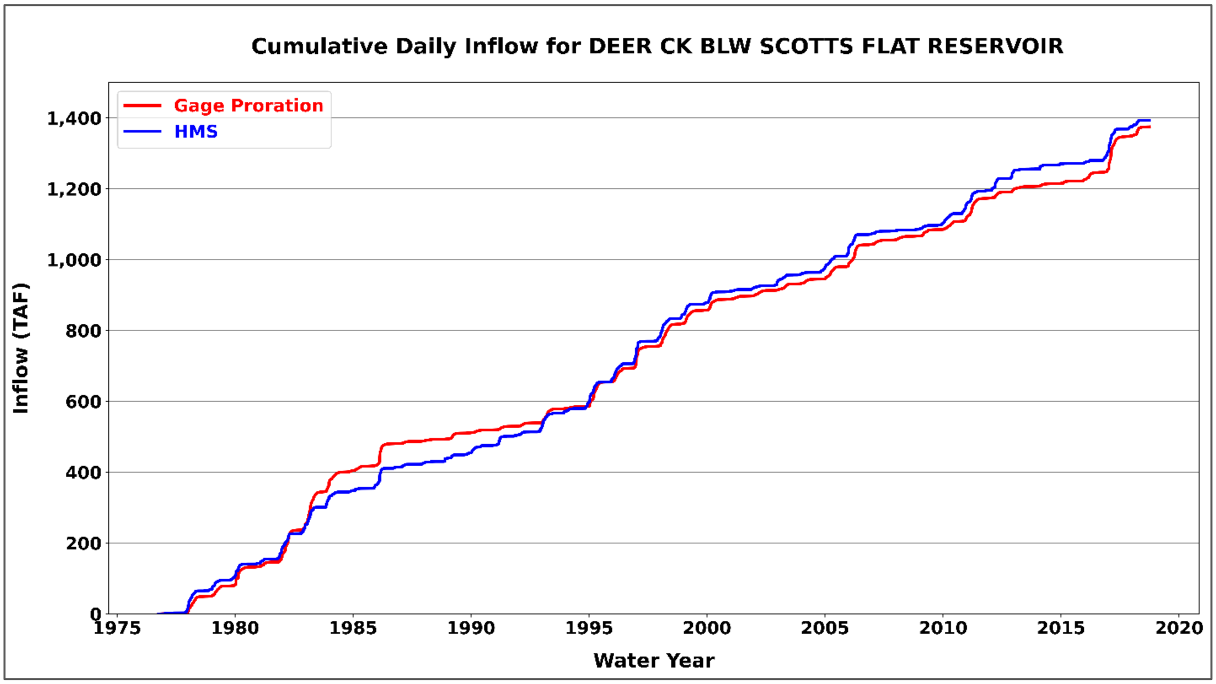

Figure A-94. Cumulative Daily Inflow (1975–2018) for Deer Creek- Below Scotts Flat Reservoir After Calibration Refinements

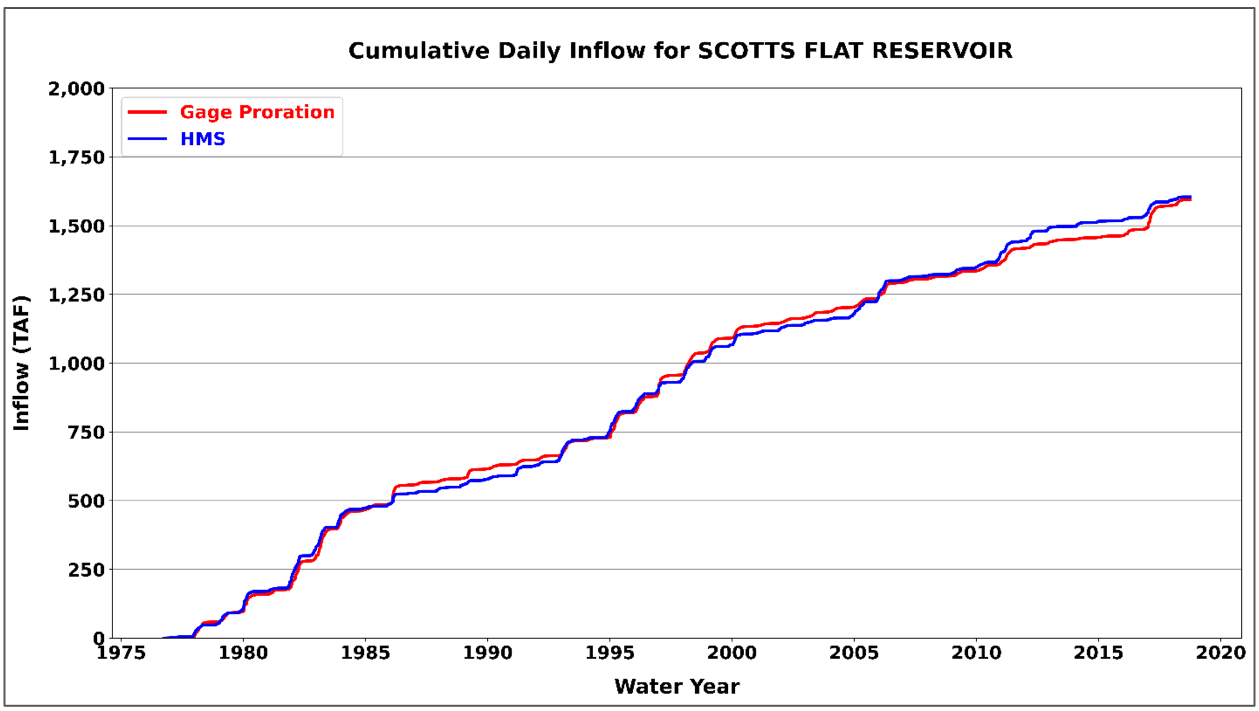

Figure A-95. Cumulative Daily Inflow (1975–2018) for Scott Flat Reservoir After Calibration Refinements

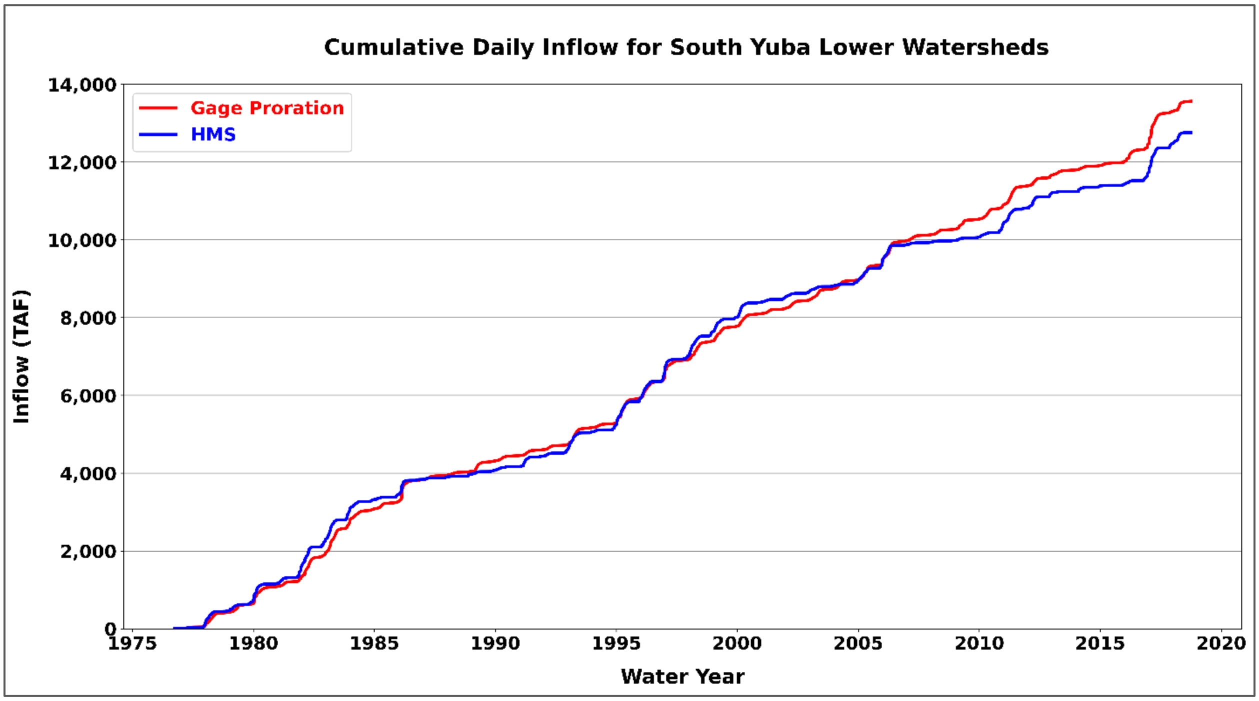

Figure A-96. Cumulative Daily Inflow (1975–2018) for South Yuba Lower Watersheds After Calibration Refinements

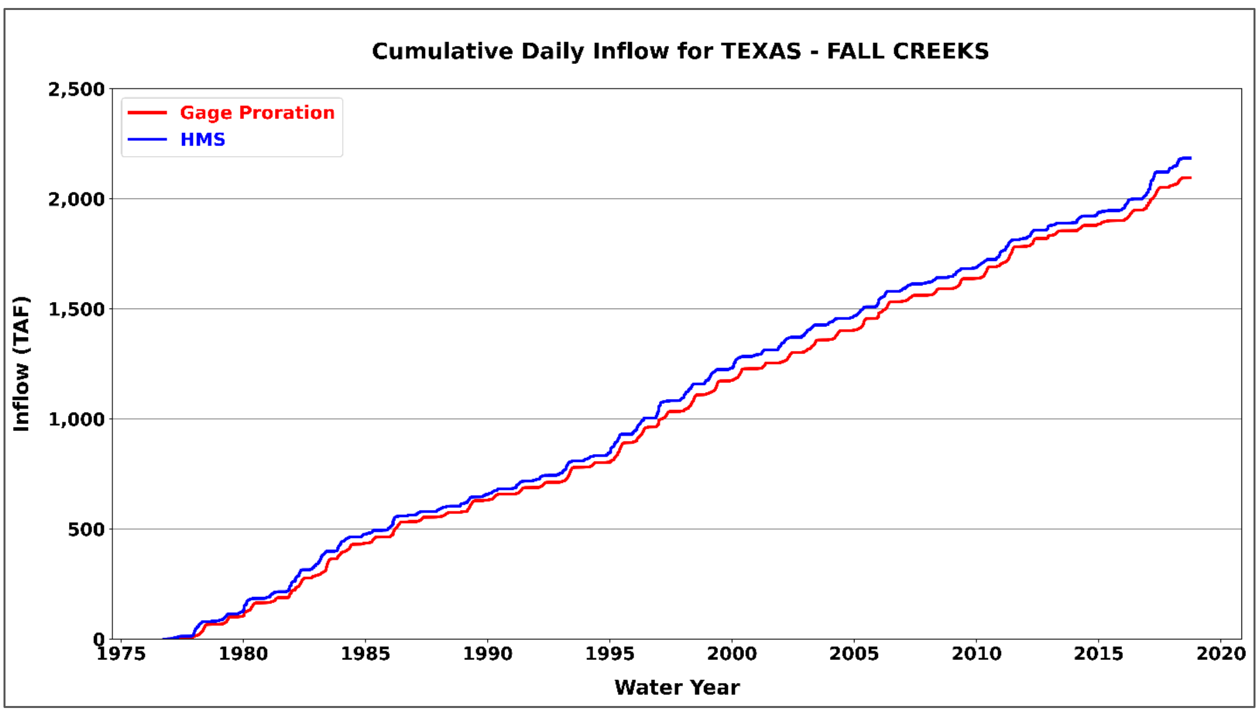

Figure A-97. Cumulative Daily Inflow (1975–2018) for Texas Fall Creeks After Calibration Refinements

Appendix B:

Chapter 4 Supplemental Information

TABLE OF CONTENTS

Appendix B. Chapter 4 Supplemental Information B-1
B.1. Assumptions Used to Develop the Model B-1
B.2. Evapotranspiration and Crop Coefficient Development Process B-3
B.2.1. Introduction B-3
B.2.2. Data Sources B-4
B.2.3. Methods B-4
B.2.4. Results and Conclusions B-7
B.3. Land Use Analysis Process B-14
B.3.1. Introduction B-14
B.3.2. Data Sources B-15
B.3.3. Methods B-15
B.3.4. Results B-16
B.4. Demand Model Input Parameter Sensitivity Analyses B-18
B.4.1. Introduction B-18
B.4.2. Sensitivity Analyses B-20
B.4.3. Comparison of Sensitivity Analyses B-30
B.5. References B-31

FIGURES

Figure B-1. Crop Evapotranspiration (ET) in July 2022 from OpenET B-9
Figure B-2. Sample ET Curve Summarized for all Parcels Categorized as Pasture in Climate Zone 3 (2021), with Comparisons to Other Representative ET Estimates for Pasture from Cal-SIMETAW (DWR 2022a), the Yuba Groundwater Model (YWA 2019), and the Irrigation Training and Research Center ET Data for Water Budget Applications (ITRC 2023). B-10
Figure B-3. Reference Evapotranspiration (ETo) in July 2022 from Spatial CIMIS. B-11
Figure B-4. Median Crop Coefficients for Various Land Use Categories in Water Year 2022, Summarized Across all Climate Zones. B-13
Figure B-5. Comparison of ET Calculated from Representative Kc Curves with OpenET ET for Pasture (2016–2022). B-14
Figure B-6. Land Use Class in the LULC Dataset in 2019 ...... B-17
Figure B-7. Layout of Sensitivity Analysis Runs and Results Summaries. B-20
Figure B-8. Sensitivity Analysis Summary: Raw Water Customers. B-21
Figure B-9. Sensitivity Analysis Summary: Treated Water Customers. B-23
Figure B-10. Sensitivity Analysis Summary: Evapotranspiration with Changes to Climate. B-25
Figure B-11. Sensitivity Analysis Summary: Total Evapotranspiration. B-27
Figure B-12. Sensitivity Analysis Summary: System Losses. B-29
Figure B-13. Comparison of Sensitivity Analyses. B-30

TABLES

Table B-1. General Data Sources and Assumptions B-1

Table B-2. Percent Difference from Median ET Calculated Using the 25th Percentile and 75th Percentile Kc Values for Agricultural Land Use Categories in NID. B-14
Table B-3. Average Land Use Acreage in NID in Water Year 2022. ....B-18
Table B-4. Sensitivity Analysis Summary: Raw Water Customers. B-21
Table B-5. Sensitivity Analysis Summary: Treated Water Customers. B-23
Table B-6. Sensitivity Analysis Summary: Evapotranspiration with Changes to Climate. B-25
Table B-7. Sensitivity Analysis Summary: Total Evapotranspiration. B-27
Table B-8. Sensitivity Analysis Summary: System Losses. B-29

Appendix B. Chapter 4 Supplemental Information

B.1. Assumptions Used to Develop the Model

Table B-1. General Data Sources and Assumptions

Category	Parameter	Current Scenario (Recent Historical) Data Sources, Assumptions	Projected Scenario General Data Sources, Assumptions	Additional Details	References
Demand Model Setup	Demand model platform	Integrated Water Flow Model Demand Calculator (IDC) demand model, linked to a canal system balance model.	Same platform as current scenario.	An IDC demand model was used to quantify treated and raw water demand in NID. Results were linked by parcels to canals to quantify upstream demand at NID's water supply sources (factoring in conveyance system losses and municipal purchases).	[1]
Demand Model Setup	Demand model time step	Monthly	Monthly	IDC was used to simulate demand on a monthly time step. A monthly time step captures intra-annual conditions and interdependencies among different factors that influence demand.	[2] (Section 2.7)
Demand Model Setup	Demand model grid	Unitized grid, results linked to parcels.	Same approach as current scenario.	Demand was simulated in IDC for different combinations of land use, soil, and climate zone characteristics found in NID that impact demand. The IDC results were calculated first on a "unit" depth basis (e.g., feet/month) and were then linked to parcels that most closely matched those combinations of characteristics to quantify the demand "volume" (e.g., acre-feet/month).	[3]
Land Use	Land use types and areas	Summarized from available spatial land use mapping data (DWR, Land IQ, USDA) and survey or crop report data (DWR, counties, NID).	Land use area changes estimated based on county general plan and zoning information, NID "soft service areas" (i.e., areas of potential growth), and recent historical trends (methodologies and/or results verified with counties and NID staff).	Recent historical land use was summarized from available spatial data sources and linked to specific parcels in NID. Projected land use was developed based on recent historical trends in land use, with spatial land use changes informed by county general plan and zoning data and fill in of "soft service areas" where growth opportunities exist within NID. The effects of potential alternate projected scenarios on demand were evaluated through sensitivity analyses to identify "bookend" projected scenarios.	[4]-[17]
Precipitation Simulation	Precipitation	PRISM gridded historical precipitation data, consistent with HEC-HMS model.	Climate change-adjusted precipitation projections, consistent with HEC-HMS model.	Precipitation was simulated for climate zones in NID that share similar historical precipitation rates. Data sources used for the current and projected scenarios were consistent with the data sources used to simulate precipitation in the HEC-HMS model.	[2] (Section 9) [18]-[19]
Precipitation Simulation	Precipitation runoff	Calculated using the modified Soil Conservation Service (SCS) curve number method, routing runoff to the nearest waterway.	Same approach as current scenario, but assuming projected precipitation and projected land use changes.	IDC was used to simulate precipitation runoff using a modification of the United States Department of Agriculture (USDA) SCS curve number method. Curve numbers were derived from technical literature, depending on land use types, soil textures, and typical hydrologic conditions.	[20]
Evapotranspiration	Evapotranspiration (ET)	Calculated from spatial OpenET data, summarized by land use type and climate zones in NID. OpenET data was evaluated in comparison to other technical literature and ET data sources and was used to develop local crop coefficients (Kc) to facilitate estimation of ET in the projected scenarios.	Calculated from reference ET (ETo) and crop coefficients (Kc) following the FAO 56 guidelines. Kc for different land uses was calculated from historical OpenET ETc and spatial CIMIS ETo. Projected ETo was estimated through climate change adjustments, consistent with the climate change scenarios used in the HEC-HMS model.	ET was simulated for different land uses across climate zones in NID that share similar historical ETo rates. The industry-standard crop coefficient approach, documented in FAO 56, was used to estimate ET due to land use characteristics (captured in Kc) and climate effects (captured in ETo). Local Kc values were developed using the available information about local ET and crop water use (e.g., satellite-based ET information from OpenET) to provide locally-accurate representations of ET that account for deficit irrigation or other local factors that impact water needs for different land uses in NID.	[21]-[24], [38]-[39]
Soil Moisture Simulation	Soil textures and soil parameters (wilting point, field capacity, total porosity, pore size distribution, saturated hydraulic conductivity)	Summarized from SSURGO and STATSGO soil data and technical literature. Soil parameters were evaluated and calibrated using industry-standard approaches (e.g., pedotransfer functions) to ensure physically realistic soil water characteristics.	Same approach as current scenario.	Simulated soil textures in NID were classified from USDA National Cooperative Soil Survey (NCSS) SSURGO/STATSGO data. Initial soil parameters were assigned from SSURGO/STATSGO data. Final soil parameters were refined through calibration using pedotransfer functions (standard, predictive methods for translating raw soil data into soil water characteristics that are physically realistic) and were compared with values from technical literature.	[25]-[27]
Soil Moisture Simulation	Initial soil moisture (i.e., soil moisture at the first model time step)	Estimated to be equal to the soil field capacity.	Same approach as current scenario.	Initial soil moisture simulated in IDC depends on irrigation and hydrologic conditions preceding the simulation period. The first model time step was initiated more than one year prior to the current and projected scenario analysis period. This allowed sufficient time for IDC to simulate soil moisture with respect to irrigation and hydrologic conditions preceding the analysis period.	[25]-[26]
Soil Moisture Simulation	Minimum soil moisture (i.e., soil moisture at which irrigation is triggered)	Estimated to be equal to 50% of the available soil moisture.	Same approach as current scenario.	IDC simulates irrigation once the minimum soil moisture is reached. The minimum soil moisture was set to 50% of the available soil moisture to represent typical conditions in California and to avoid simulation of additional water stress within IDC (local Kc values already account for typical water stress, as applicable; see parameter "Evapotranspiration").	[25]-[26]
Agricultural Water Use Inputs	Root depth	Defined for each simulated land use type based on representative values in technical literature.	Same approach as current scenario.	Different land use types have different characteristic root depths, determining where in the soil vegetation can extract moisture. Typical root depths for different land use types are documented in technical literature.	[28]
Agricultural Water Use Inputs	Irrigation period (i.e., months when irrigation occurs)	Defined based on NID's historical irrigation delivery records.	Estimated based on recent historical information with consideration for potential future changes to the irrigation season start/end.	Typical irrigation periods were identified from NID delivery records and through discussion with NID staff.	[29]
Agricultural Water Use Inputs	Tailwater (i.e., runoff of irrigation applied water)	Tailwater for each irrigated land use was simulated as a fraction of the total irrigation applied water (approximately 5% for irrigated land uses in NID).	Estimated to be similar to the current scenario.	Tailwater depends mainly on customer irrigation practices and irrigation methods for different crops and field conditions. Model inputs were set at levels typical of land uses and irrigation methods in NID, with comparison of recent historical demands simulated in IDC to NID delivery records.	
Urban Water Use Inputs	Population	Estimated from California Department of Finance (DOF) population estimates for cities, counties.	Estimated with respect to California DOF population projections for counties, county General Plan information and transportation studies, and NID's projected connections for treated water customers (e.g., from NID's 2020 Urban Water Management Plan).	California DOF population estimates and projections were consistent with methods used to evaluate projected water demands in NID's 2020 Urban Water Management Plan and in county transportation studies.	[30]-[31]

Category	Parameter	Current Scenario (Recent Historical) Data Sources, Assumptions	Projected Scenario General Data Sources, Assumptions	Additional Details	References
Urban Water Use Inputs	Per capita water use	Estimated based on population estimates and potable water production data from NID, cities, and the State Water Resources Control Board (SWRCB).	Estimated to be similar to the current scenario (changes to urban demand were simulated through changes to population and other inputs).	Per capita water use (together with population) drives the IDC simulation of urban demand. Estimates and trends were derived from NID, state, and city data.	[32]-[34]
Urban Water Use Inputs	Urban indoor water use fraction	Estimated based on urban water production and deliveries during winter months, assuming that the minimum monthly use (typically February) is primarily used indoors.	Estimated to be similar to the current scenario.	The urban indoor water use fraction is the fraction of treated water that is assumed to be used indoors (i.e., for drinking water, sanitation, etc.). Urban indoor water use is simulated in IDC separately from urban outdoor water use (i.e., for landscape irrigation).	[32]-[33]
Urban Water Use Inputs	Urban return flow fraction (i.e., urban wastewater and runoff of applied water)	Indoor use is assumed to be approximately 100% return flow (i.e., 100% wastewater inflow). Outdoor use is assumed to have approximately 5% return flow (i.e., tailwater), typical of landscape irrigation.	Estimated to be similar to the current scenario.	Return flow is simulated in IDC as a fraction of the total urban water use. Model inputs were set at levels typical of urban water use, land uses, and irrigation methods in NID.	[1], [35]
Raw Water Demand	Raw water demand	Calculated using IDC as the amount of water needed to meet irrigation demand, after accounting for soil moisture, precipitation, tailwater, ET, etc.	Same approach as current scenario but calculated with projection scenario information.	Irrigation applied water was adaptively calculated using the IDC model, based in part on local land use in NID in conjunction with local ET information and other IDC input data described above. IDC inputs were defined unique to specific, local characteristics observed in NID, to the extent possible. Model inputs were refined to provide for consistency between model results and recent historical delivery records.	[36]
Treated Water Demand	Treated water demand	Calculated as the amount of water needed to meet urban water use requirements, after accounting for population, per capita water use, return flow, etc.	Same approach as current scenario but calculated with projection scenario information.	Urban water demand was adaptively calculated using the IDC model. Model inputs were refined to provide for consistency between model results and recent historical delivery records.	[36]
Municipal Water Demand	Municipal water demand	Summarized from historical municipal purchase records from NID.	Estimated consistent with other NID projections.	Future projections of municipal water purchases from NID were defined consistent with projections in NID's 2020 Urban Water Management Plan.	[36]
Environmental Flows	Environmental flows	***Simulated as part of the ResSim reservoir operations model.***	***Simulated as part of the ResSim reservoir operations model.***	Environmental flows are NID's in-stream flow requirements, as specified in the FERC Final Environmental Impact Statement for Hydropower License. Environmental flows are simulated as part of the ResSim reservoir operations model.	[36]
Conveyance System Losses (Below NID Reservoirs)	Conveyance system losses (below NID reservoirs)	Estimated as a fraction of canal inflows, based on NID operations data.	Same approach as current scenario, with adjustment for different projected scenarios.	System losses from NID conveyance infrastructure (below NID's reservoirs) was estimated as a fraction of NID's canal inflows. Estimates were consistent with previous NID analyses based on NID operations data, calculated from inflows and outflows. These losses include all evaporation, seepage, and other losses from the conveyance system below NID's reservoirs. Evaporation from NID's reservoirs are simulated as part of the ResSim reservoir operations model.	[25]-[26], [36]-[39]

Reference **Source**

[1] California Department of Water Resources (DWR), 2022c. IDC: Integrated Water Flow Model Demand Calculator. Available at: https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model-Demand-Calculator
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B.2. Evapotranspiration and Crop Coefficient Development Process

B.2.1. Introduction

Evapotranspiration (ET), or consumptive water use, is the major driver of agricultural water use, and is impacted by many factors, including:

- The types of crops and vegetation that are grown (reflecting the inherent differences in water needs of different crops and vegetation);
- The quality of crops, vegetation, and land use (including water availability, nutrient and pest management, and other factors); and
- Environment-driven demand for evaporation (related to weather and climate parameters, as a function of temperature, solar radiation, wind speed, and humidity).

Each of these factors are accounted for in the methods used to quantify ET.

In the Nevada Irrigation District (NID) Plan for Water (PFW) demand model, ET was quantified for different land uses and different climate zones in NID for each of the demand model scenarios using the best available local information and standard technical approaches (ASCE 2016). Two key approaches used to quantify ET were:

- **Open ET data**: In the current demand scenario, ET was quantified based on representative ET curves developed for different land uses and climate zones in NID using OpenET data.
- **Crop coefficient approach**: In the projected demand scenarios, ET was calculated following the standard crop coefficient approach described in the United Nations Food and Agriculture Organization (FAO) Irrigation and Drainage Paper 56 (Allen et al. 1998). In this approach, ET is calculated by multiplying a reference evapotranspiration (ETo) value by a crop coefficient (Kc) as seen in Equation 1. ETo captures the environment-driven demand for evaporation, while Kc represents the unique properties of crops and vegetation to accurately estimate the specific crop water use characteristics. Kc thus serves as a scaling factor for modifying ETo, tailoring ET calculations to the unique demands of different land uses under specific climatic and environmental conditions.

$$\mathbf{ET} = \mathbf{Kc} \times \mathbf{ETo} \quad [1]$$

The purpose of this appendix is to document the processes used in analyzing OpenET data and developing Kc values specific to the local conditions within NID. NID covers a diverse landscape, necessitating approaches for quantifying ET that account for local conditions within NID with respect to climate and crop water use characteristics. The approaches described in this appendix aim to provide accurate estimates of crop water use in the NID PFW demand model.

B.2.2. Data Sources

Accurate estimation of crop water use in NID requires comprehensive and reliable data sources that reflect the diverse landscape within the NID service area. This section outlines the primary data sources used in the ET analysis and Kc development process.

B.2.2.1 OpenET

OpenET is a multi-agency web-based geospatial utility that leverages satellite-based remote-sensing technology to provide spatially distributed and continuous ET estimates over vast, diverse regions. While OpenET is a new utility, the underlying methodologies to quantify ET apply a variety of well-established modeling approaches that are widely used in local, state, and Federal government and research applications. Additional information about the OpenET team, data sources, and methodologies are available at: https://openetdata.org/.

The capability of OpenET to deliver timely and large-scale ET datasets played a crucial role in developing ET and Kc estimates that capture the unique crop water use conditions observed within NID in recent years. OpenET information is available in raster coverages of the NID service area with a spatial resolution of 30 meters (m) x 30 m (approximately 0.22 acres). Data is available on both a daily and monthly timestep from 2016 through present. Monthly ensemble mean ET data for the entire NID service area in 2016–2022 was extracted from OpenET and analyzed to support development of the NID PFW demand model.

B.2.2.2 Spatial California Irrigation Management Information System (CIMIS)

Spatial CIMIS is a geospatial data product produced and released by the CIMIS. CIMIS operates an extensive network of weather stations strategically distributed across California that collect and report weather and climate parameters, including ETo estimates. Spatial CIMIS provides spatially continuous ETo estimates throughout California, which are calculated based on available quality-controlled CIMIS station data using advanced interpolation techniques with reference to topography and other factors that impact climate conditions. This approach enables the creation of ETo estimates throughout California, even where direct measurement may not exist. Additional information about the spatial CIMIS data sources and methodologies is available at: https://cimis.water.ca.gov/SpatialData.aspx.

Spatial CIMIS data was used together with OpenET data to calculate Kc curves representing specific land uses and climate conditions within NID. Spatial CIMIS ETo information is available in raster coverages of the NID service area with a spatial resolution of 2 km x 2 km. ETo estimates were extracted from spatial CIMIS on a daily timestep from 2016–2022 and were aggregated to monthly ETo totals to support development of monthly Kc curves.

B.2.3. Methods

B.2.3.1 Representative ET Curves

OpenET data was used to observe recent historical ET trends and develop representative ET curves for each land use category in each climate zone simulated in the demand model. Additional information about the land use categories and climate zones simulated in the demand model are discussed in Chapter 4 of the NID PFW report. The representative ET curves are meant to capture the range of observed ET rates across all pixels (i.e., 30 m x 30 m areas) within each climate zone that correspond to each respective land use category. The representative ET curves were used to determine the average ET and ET percentiles across tens to thousands of pixels in NID, depending on the distribution of each land use within each climate zone in NID. Importantly, OpenET data was not used to directly assign an ET value representing any single point within NID in the demand model, but rather to identify and simulate ET trends.

The development of representative ET curves involved a series of geographic information system (GIS) analyses. The following steps were taken to calculate the representative ET curves:

- **Data Collection**:
    - **ET**: Ensemble mean ET data was downloaded from OpenET for the entire NID service area (monthly timestep, 2016–2022).
    - **Land use**: Spatial land use information was summarized for the entire NID service area (annual timestep, 2016–2022). This information was developed through a land use analysis process based on:
        - Statewide land use mapping, available from the California Department of Water Resources (DWR) (DWR 2023)
        - CropScape Cropland Data Layer coverage, available from the U.S. Department of Agriculture (USDA 2023)

      In total, 11 land use categories were simulated in the demand model. The land use analysis and land use categories are discussed in Chapter 4 of the NID PFW report.
    - **Climate zones**: Climate zones delineated based on analyses of climate-related data to identify regions with similar precipitation and ETo characteristics within the NID service area. In total, three climate zones were simulated in the demand model. The climate zones are discussed in the Chapter 4 of the NID PFW report.
- **ET Summary by Land Use and Climate Zone:**
    - The ET data, land use data, and climate zone boundaries were imported into the same GIS analysis process and were scaled, as necessary, to 30 m x 30 m.
    - Through a month-by-month process, the ET, land use, and climate zones were spatially linked together by location to create a compiled ET dataset containing the monthly ET rate within each 30 m x 30 m pixel, with indicators of the land use and climate zone corresponding to that pixel.
    - An array was created of all ET rates within all pixels, summarized by:
        - Land use
        - Climate zone
        - Year and month
- **Representative ET Curve Calculation and Use in the Demand Model:**

- Representative ET curves (ET rates per month, from 2016–2022) were calculated for each land use and climate zone by calculating the following summary statistics from all pixels linked to each land use and climate zone:
  - 10th percentile
  - 25th percentile
  - 50th percentile (median)
  - 75th percentile
  - 90th percentile
  - Mean
- The representative ET curve for each land use and climate zone was compared against other representative ET curves reported from other sources – including DWR's Cal-SIMETAW (DWR 2022a) and the Irrigation Training and Research Center (ITRC) at California Polytechnic State University – San Luis Obispo (ITRC 2023) – to verify their general consistency with ET trends reported in technical literature.
- The representative ET curve for each land use and climate zone was used within the demand model to represent the monthly ET rates for all areas corresponding to that land use and climate zone between 2016–2022. In earlier years, monthly ET rates from the same month in a hydrologically similar year were used in lieu of available data from OpenET. The 50th percentile (median) ET curve was used in the current demand scenario, and the relative impacts of other percentile curves on demand were evaluated through sensitivity analyses (discussed in the NID PFW report).

B.2.3.2 Representative Kc Curves

OpenET and spatial CIMIS data were combined and used to develop representative Kc curves for each land use category in all climate zones in the demand model. Additional information about the land use categories and climate zones simulated in the demand model are discussed in Chapter 4 of the NID PFW report. The representative Kc curves were developed to capture the range of observed crop-related water use requirements within NID. The representative Kc curves were used to estimate future crop water use requirements for each land use category in NID in the projected demand scenarios.

The development of representative Kc curves involved a series of GIS analyses, building off those used to develop the representative ET curves. The following steps were taken to calculate representative Kc curves:

- **Data Collection:**
  - **ETo**: ETo data was downloaded from spatial CIMIS for the entire NID service area (daily timestep aggregated to monthly values, 2016–2022)
  - **ET**: Ensemble mean ET data was downloaded from OpenET for the entire NID service area (monthly timestep, 2016–2022). See Section B.2.3.1.

- **Land use and climate zones**: Spatial land use information was summarized (annual timestep, 2016–2022), and climate zones were delineated for the entire NID service area. See Section B.2.3.1.

- **Kc Summary by Land Use and Climate Zone:**
  - The ETo data was imported into a GIS analysis process and was downscaled to 30 m x 30 m, consistent with the ET data. Units were converted, as needed, for consistency.
  - The compiled ET data containing monthly ET rates with indicators of the land use and climate zone (developed through the process described in Section B.2.3.1) was imported into the same GIS analysis process.
  - An array was created containing Kc values for each pixel in the NID service area, calculated based on the ratio of ET to ETo (rearranging Equation 1 to solve for Kc). Kc values within all pixels were summarized by:
    - Land use
    - Climate zone
    - Year and month

- **Representative Kc Curve Calculation and Use in the Demand Model:**
  - Representative Kc curves (Kc values each month, summarized across 2016–2022) were calculated for each land use across all climate zones by calculating the following summary statistics from all pixels linked to the corresponding land use:
    - 25th percentile
    - 50th percentile (median)
    - 75th percentile
  - The representative Kc curves for each land use in water year 2022 (October 2021 through September 2022) were used together with projected monthly ETo estimates to calculate monthly ET estimates for all projected demand scenarios following Equation 1. Projected monthly ETo estimates were estimated following the standard Hargreaves-Samani approach (Hargreaves and Samani 1985, Allen et al. 1998), based on spatial projected temperature information in the NID service area derived from the climate change analyses used in the hydrology scenarios (see Chapter 4 of the NID PFW report for more information).

    The following Kc curves were used within each projected demand scenario:
    - Low Demand: 25th percentile
    - Baseline Demand: 50th percentile (median)
    - High Demand: 75th percentile

    The selection of these percentiles is discussed in Section B.2.4.3.

B.2.4. Results and Conclusions

These analyses of representative ET curves and representative Kc curves provide valuable insights into local water use requirements within the NID service area and serve as a solid foundation for water management planning in the NID PFW process. The subsections below present and discuss results of the ET and Kc development process.

B.2.4.1 ET and Representative ET Curves

Figure 1 presents the spatial distribution of ET within NID in July 2022, as an example. The ET values were derived from OpenET data, which provides spatially distributed and continuous ET estimates. The map highlights the diverse consumptive water use patterns across different areas in NID. ET values reflect both the variability in climate conditions across NID as well as the monthly water needs of crops and vegetation, accounting for differences in inherent characteristics, growth stages, agronomic and irrigation practices, and environments across NID. Accurate representation of these qualities is crucial for accurately simulating demand within NID with respect to local, observed conditions.

Figure 2 presents a sample, representative ET curve developed for pasture in climate zone 3 (the lowest elevation zone). As discussed above, the representative ET curves were compared to other representative ET curves reported from other sources (e.g., Cal-SIMETAW, ITRC) to verify their general consistency with ET trends reported in technical literature. In contrast with OpenET, many ET estimation approaches do not directly account for crop stress, which is caused by a variety of factors, and if present, will reduce ET. Consequently, many ET approaches and estimates in technical literature overestimate actual ET. One benefit of using OpenET data to quantify ET is that it captures the variability of ET observed within NID for each land use category, including those factors that may lead to differences in ET values compared to those reported in technical literature. The ET curves from other sources (e.g., Cal-SIMETAW, ITRC) tend to be higher than the OpenET results, especially in the mid- to late-summer period when evaporative demand is highest and when crop stress, if present, will be most noticeable. Differences observed between other sources and OpenET are influenced by those factors, which are captured within this ET analysis.

B.2.4.2 ETo

As described above, ETo serves as a critical parameter for estimating crop water use requirements. Figure 3 shows the spatial distribution of ETo from spatial CIMIS within NID in July 2022, as an example, revealing significant spatial variability in ETo across the NID service area. Differences in ETo across the landscape are influenced by climate and weather-related parameters, as a function of temperature, solar radiation, wind speed, and humidity. Regions with higher ETo values indicate areas with relatively higher consumptive water use requirements (all else equal), whereas lower ETo values correspond to relatively lower consumptive water use requirements. Factoring spatial estimates of ETo into the development of representative ET curves helps to capture these differences across the NID service area.

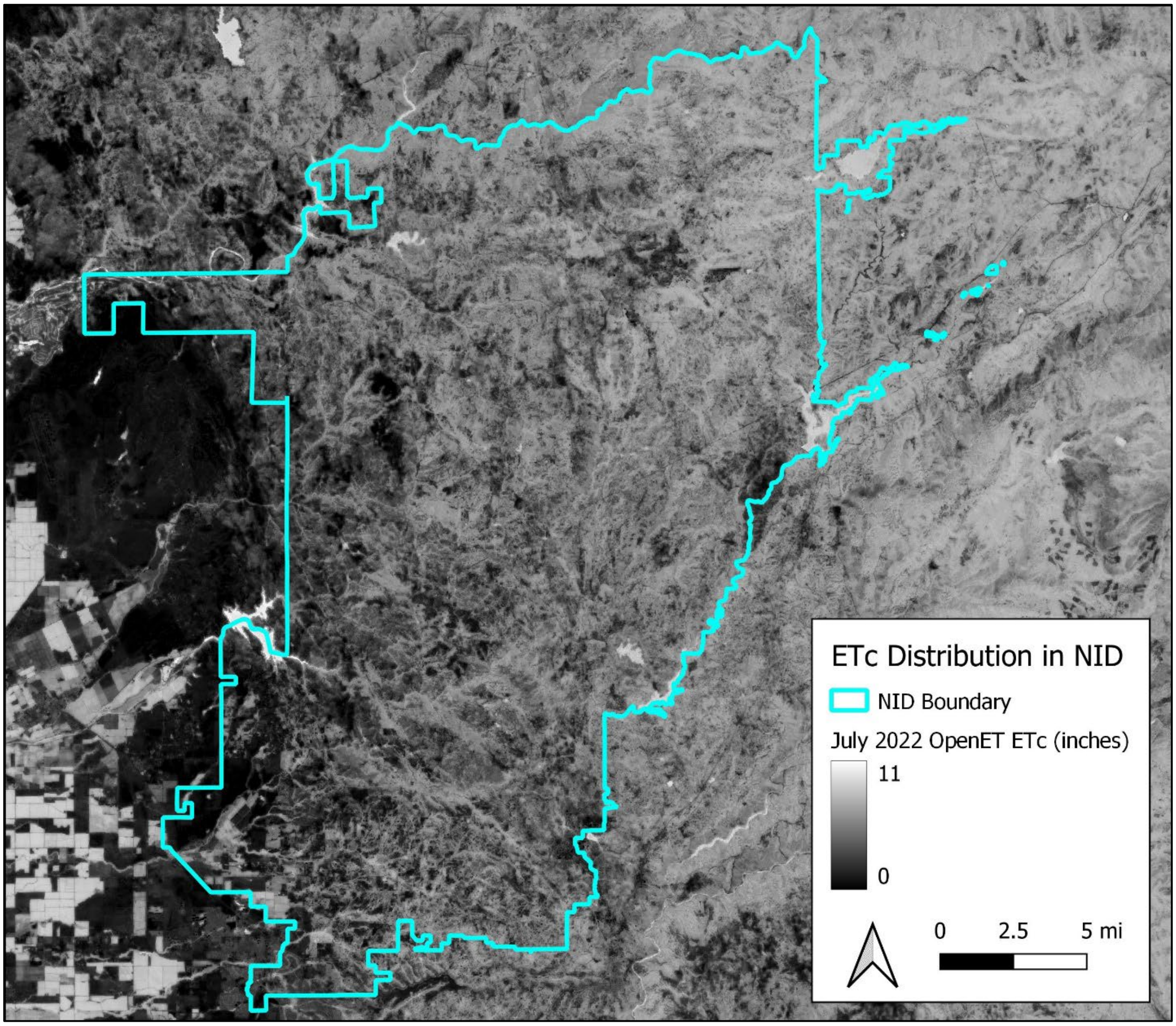

Figure B-1. Crop Evapotranspiration (ET) in July 2022 from OpenET.

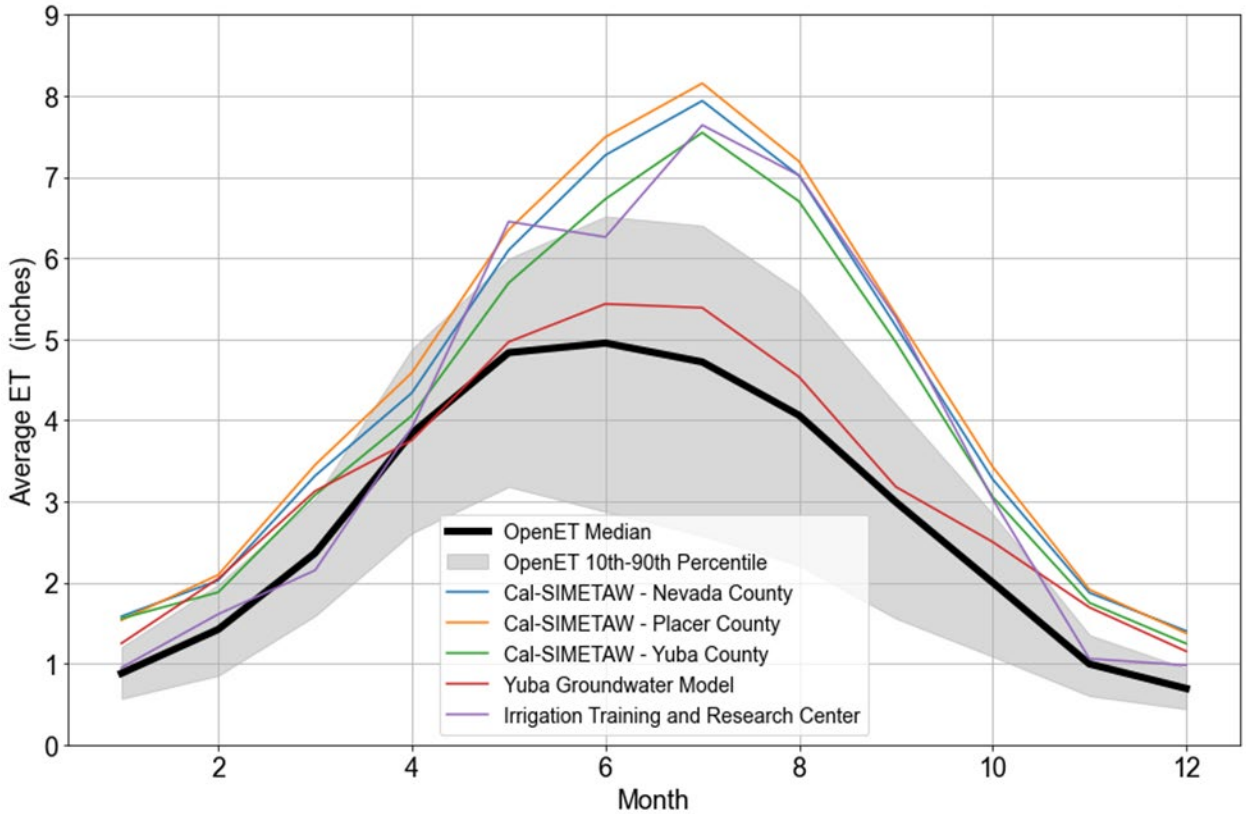

Figure B-2. Sample ET Curve Summarized for all Parcels Categorized as Pasture in Climate Zone 3 (2021), with Comparisons to Other Representative ET Estimates for Pasture from Cal-SIMETAW (DWR 2022a), the Yuba Groundwater Model (YWA 2019), and the Irrigation Training and Research Center ET Data for Water Budget Applications (ITRC 2023).

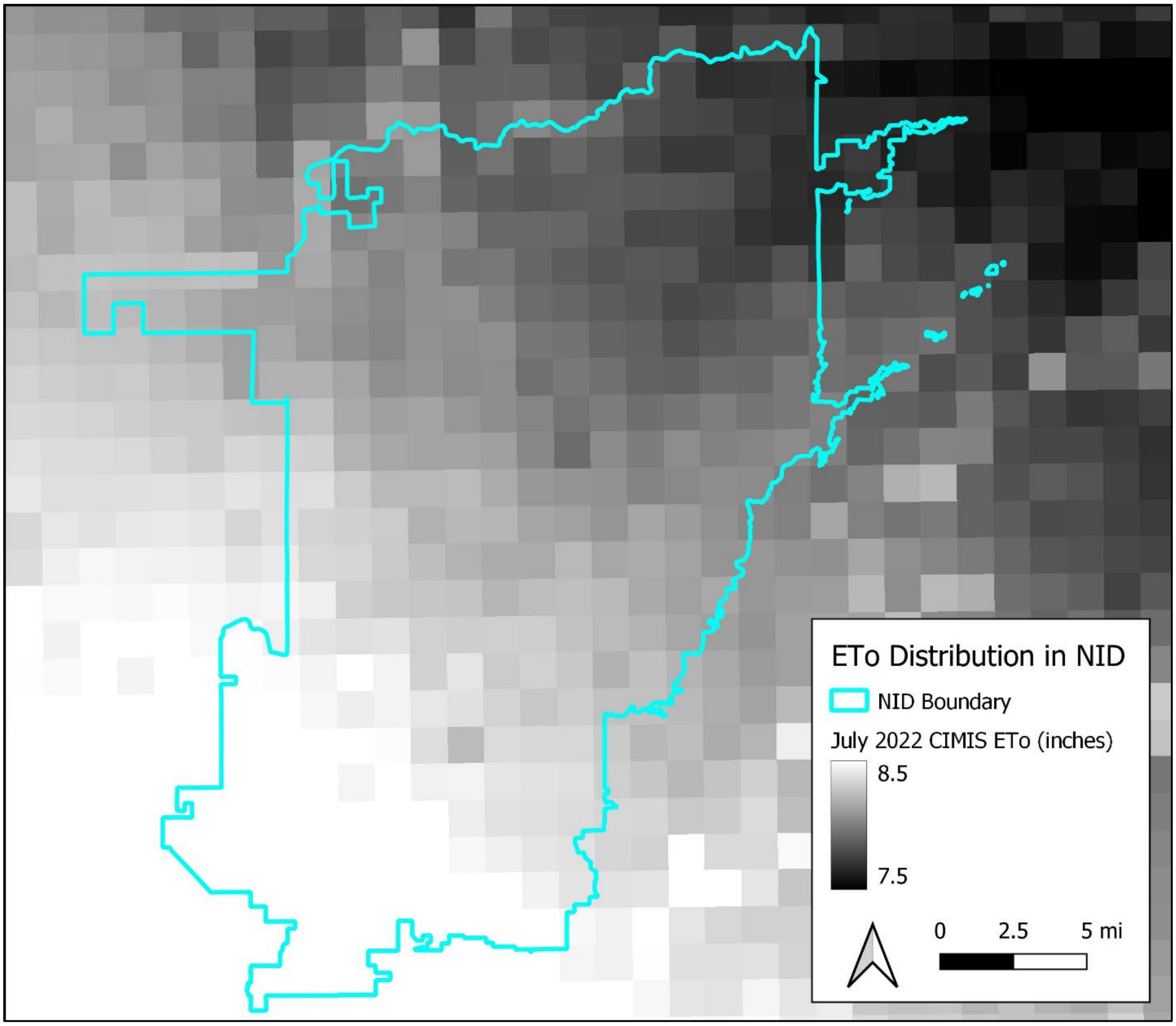

Figure B-3. Reference Evapotranspiration (ETo) in July 2022 from Spatial CIMIS.

B.2.4.3 Representative Kc Curves

Figure 4 illustrates the median Kc values for various land use categories within the NID service area in water year 2022 (October 2021 through September 2022), summarized across all climate zones. The figure showcases the variations in Kc values for different land use categories over the course of the year, as well as relative differences between land use categories. The representative Kc values, such as those depicted in Figure 4, were considered in the demand model development process to quantify ET in the projected scenarios.

Figure 5 provides a comparison of ET values calculated for pasture using the representative Kc curves, versus ET values summarized from OpenET data for pixels representing pasture. The comparison is made for 2016–2022, a period when OpenET data is available, although it is noted that the representative Kc curves shown are those that are also used in the projected demand scenarios:

- Low Demand: 25th percentile (ET in Figure 5 is calculated using ETo summarized from the wet hydrology scenario)
- Baseline Demand: 50th percentile, or median (ET in Figure 5 is calculated using ETo summarized from the median hydrology scenario)
- High Demand: 75th percentile (ET in Figure 5 is calculated using ETo summarized from the dry hydrology scenario)

The comparison in Figure 5 indicates that ET estimates generated by the representative Kc curves are within the range of ET estimates observed from OpenET data during the irrigation season (generally March-October). Additionally, ET estimates calculated using the 25th and 75th percentile Kc curves reflect a reasonable range within the upper and lower bounds of the 25th and 75th percentile ET values observed from OpenET data.

Table 1 summarizes the relative changes in total annual ET from the median Kc for different land use categories if the 25th percentile or 75th percentile Kc curves are used. As compared to ET generated using the median Kc values, these percentiles result in an average change of approximately -18% of total ET (using the 25th percentile Kc values) or +15% of total ET (using the 75th percentile Kc values) overall.

The selection of the 25th percentile and 75th percentile for the “low” and “high” projected demand scenarios was informed by comparison of these ET changes to typical differences in ET under reasonable changes in cultivation and irrigation practices where ET is reduced (in the low bookend scenario) or ET is increased (in the high bookend scenario). Typical differences range from +/-15% or more, depending on conditions. A sample of references considered in this comparison is provided below. Many of the references provided evaluate ET of alfalfa, which serves as a proxy for evaluating ET of pasture – the primary agricultural land use in NID.

- Sanden et al. 2011: Review of alfalfa water requirements and recommendations for irrigation planning from the University of California Cooperative Extension. Normal year ET is considered a good guideline for planning irrigations, but actual ET can be +/-15% of that.
- Andales et al. 2010: ~12% decrease in ET observed between two growing seasons (2008–2009) for alfalfa cultivated under similar conditions each year, but with water stress early in the season when the decrease in ET was observed. ET differences were measured using weighing lysimeters, which are considered to be one of the most accurate ways to measure ET over a small area (ASCE 2016).
- Hunsaker et al. 2002: ~10-30% difference in ET observed between well-watered and water-stressed treatment conditions during the same growing season (1985) for alfalfa cultivated under otherwise similar conditions. A 30% difference in ET from well-watered to water-stressed conditions likely represents +/-15% difference from a "median" condition between those bookend conditions. ET differences were measured using weighing lysimeters.
- Djaman and Irmak 2013: ~5-10% change in ET observed between full irrigation and 50% reduced irrigation conditions during two growing seasons (2009–2010) for corn cultivated under otherwise similar conditions. ET differences were estimated using a soil water balance.
- Tasumi et al. 2005: +/- 10-20% difference in daily Kc values during peak-season irrigation of beans and corn under different cloud cover conditions (higher values in clear sky, lower values in cloudy

conditions). ET differences used to calculate the Kc values were measured using weighing lysimeters.

- Samani et al. 2013: ET was quantified for 751 alfalfa fields in New Mexico using a remote-sensing approach (similar to OpenET) and the range of total ET was observed between ~700-1200 mm/year (27.6-47.2 inches/year, with some outliers). This range translates to a difference in ET of approximately +/- 20-30% around the average, and the 25th and 75th percentiles are approximately 10-15% around the average. Potential reasons cited for ET and Kc variability was determined to include "irrigation methods and technology, lack of knowledge of irrigation scheduling, limited water supply, interference of harvesting schedule with irrigation, cultural practices, and economic factors."

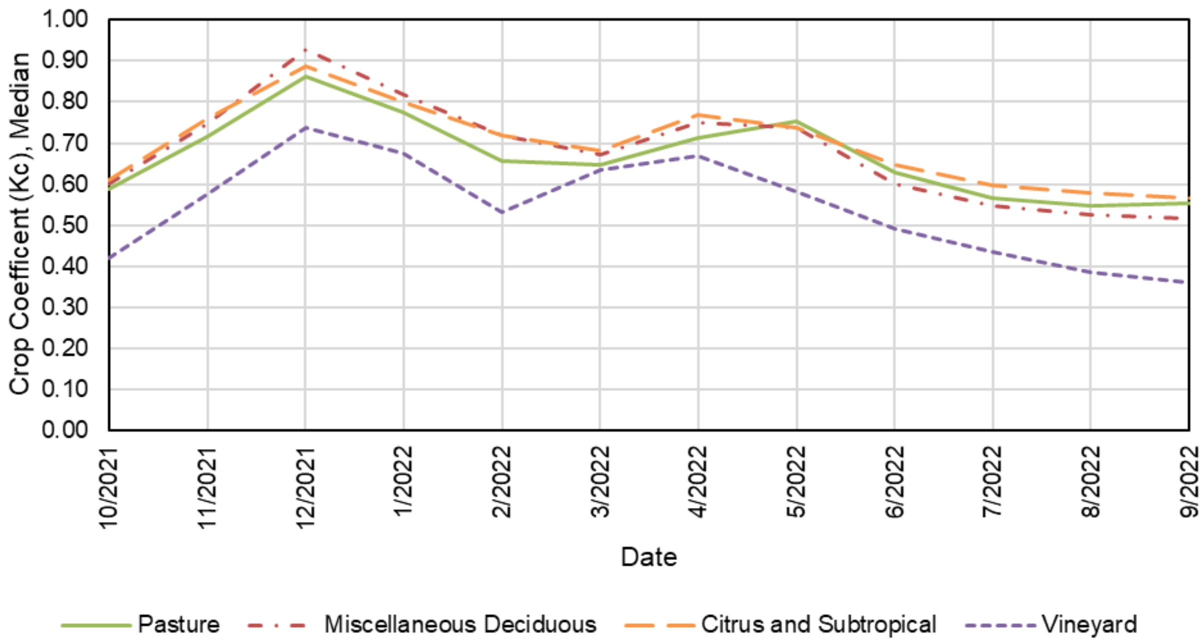

Figure B-4. Median Crop Coefficients for Various Land Use Categories in Water Year 2022, Summarized Across all Climate Zones.

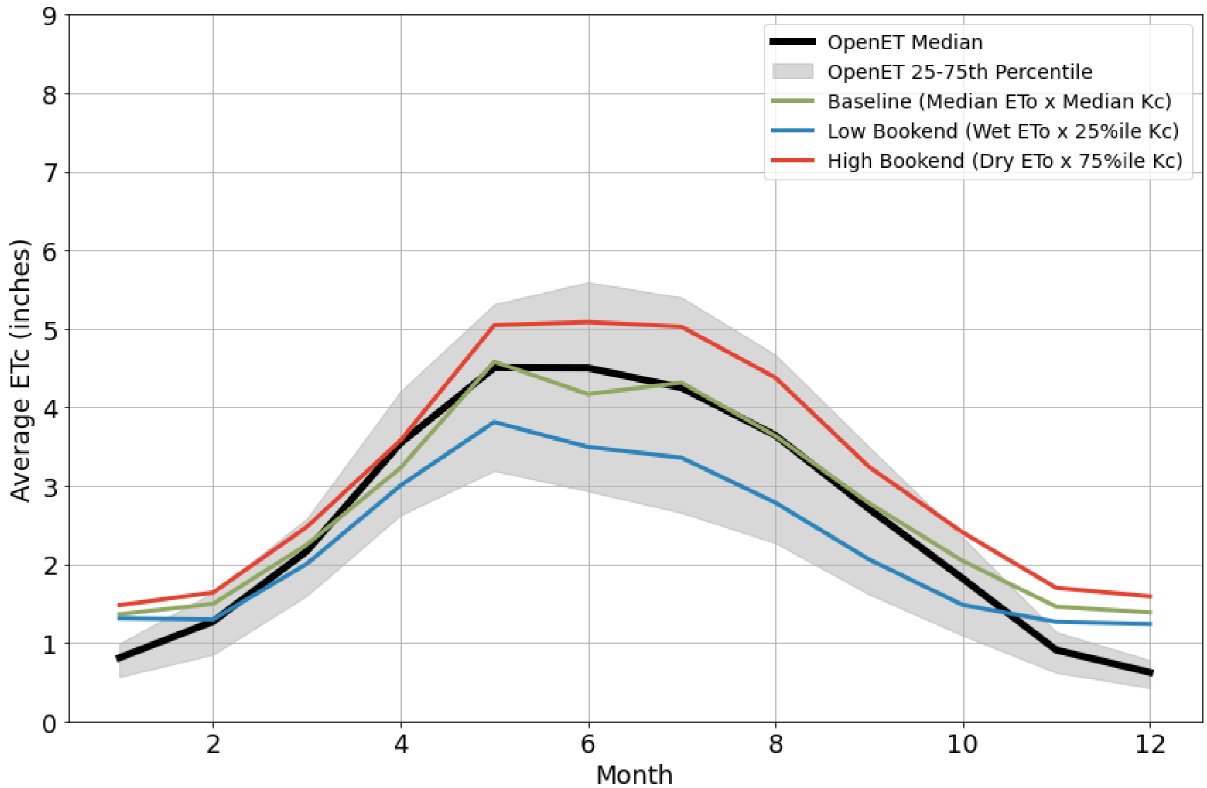

Figure B-5. Comparison of ET Calculated from Representative Kc Curves with OpenET ET for Pasture (2016–2022).

Table B-2. Percent Difference from Median ET Calculated Using the 25th Percentile and 75th Percentile Kc Values for Agricultural Land Use Categories in NID.

Agricultural Land Use Category	Fraction of Total Agricultural Land Use Area Evaluated	Percent Difference in ET in Water Year 2022 (%)	
		25th Percentile Kc vs Median Kc	75th Percentile Kc vs Median Kc
Pasture	88%	-17%	14%
Vineyard	6%	-16%	16%
Misc. Deciduous	3%	-18%	14%
Misc. Truck Crops	2%	-27%	30%
Citrus and Subtropical	1%	-15%	12%
	Average (Area-Weighted)	**-18%**	**15%**

B.3. Land Use Analysis Process

B.3.1. Introduction

The purpose of this appendix is to document the process used to analyze and summarize spatial land use information for the NID service area. This information was used to assemble an annual spatial land use and land cover (LULC) dataset for use in the NID PFW demand model. The spatial LULC dataset was used for a variety of purposes in the demand model, including identifying typical land uses within NID to simulate in the demand model, and identifying where those land uses occur. This spatial representation and understanding of land use provides a crucial linkage between the demand model results and the locations within NID where demand occurs.

B.3.2. Data Sources

The annual spatial LULC dataset was developed primarily using geospatial land use information obtained from the California DWR and the USDA. Both data sources are described below.

B.3.2.1 DWR Statewide Land Use Mapping

DWR provides a statewide land use mapping dataset covering all developed land in California, including cultivated agricultural land, idle agricultural land, and urban areas (DWR 2023). The dataset is generated by Land IQ, in cooperation with DWR, using remotely-sensed imagery and associated analytical techniques. The data is provided in vector-based GIS formats with field-by-field classification of each appropriate land use. The data does not generally include non-developed land (e.g., native vegetation), and leaves gaps outside of areas where developed land uses exist. Currently, statewide land use mapping data is available in 2014, 2016, 2018, 2019, 2020, 2021 and provisionally for 2022. The statewide land use mapping dataset undergoes extensive quality assurance, quality control, and validation processes by Land IQ and DWR to ensure that there is appropriate classification of different land uses throughout California. Additional information about the DWR statewide land use mapping dataset is available online at: https://data.cnra.ca.gov/dataset/statewide-crop-mapping.

B.3.2.2 USDA CropScape Cropland Data Layer

The USDA's CropScape Cropland Data Layer (CDL) is a raster-based data product that allows visualization of land uses throughout the United States (USDA 2023). The CDL dataset is generated using remotely-sensed imagery and analytical methodologies to provide a continuous nationwide land use coverage. Updates are released annually, with new CDL data becoming available each spring for the preceding year. Although validation of the CDL data does occur at the national level, issues have been identified in agricultural land use designations in California through independent, local checks. For this reason, the CDL data is used primarily for identifying non-developed land uses where gaps exist in the DWR statewide land use mapping dataset. Additional information about the USDA CDL data is available online at: https://nassgeodata.gmu.edu/CropScape/.

B.3.3. Methods

The DWR and USDA data were combined through an analysis process to develop the spatial LULC dataset used in the NID PFW demand model. The result was a spatially continuous annual representation of land use in the NID service area for 2013–2022, during the current demand scenario simulation period. As the DWR data is considered the most accurate spatial data source available within the NID service area, the DWR data was prioritized in development of the spatial LULC dataset, while the USDA data was used to fill in gaps in the DWR dataset.

The general process used to create the combined spatial LULC dataset was as follows:

1. The DWR data was rasterized and reprojected to match the USDA data projection and spatial resolution (30 meters (m) x 30 m).
2. The USDA data was masked to exclude any values where DWR data was available (i.e., to include only gaps within the DWR data).
3. For each year of available data, the DWR data and USDA data were combined to create one continuous raster coverage of NID, using:
4. The DWR data for that year (if available), or the DWR data for the most recent or hydrologically similar year (if data for that year was not available).
5. The USDA data for that year, filling in gaps in the DWR data.
6. Land uses in the combined spatial LULC dataset were linked to the appropriate land uses simulated in the demand model.
7. Land use areas (acres) were summarized from the spatial LULC dataset by converting the area of each pixel in continuous raster (30 m x 30 m) to acres.

Results of this analysis process were summarized and used in both raster and tabular format.

B.3.4. Results

Sample results of the land use analysis process are provided in Figure 1 and Table 1 for 2019 and 2022, respectively. Based on this analysis, the majority of land within the NID service area is categorized as either native vegetation or urban (Figure 1). In 2022, pasture was the predominant agricultural land use, encompassing 67% of all agricultural land (Table 1).

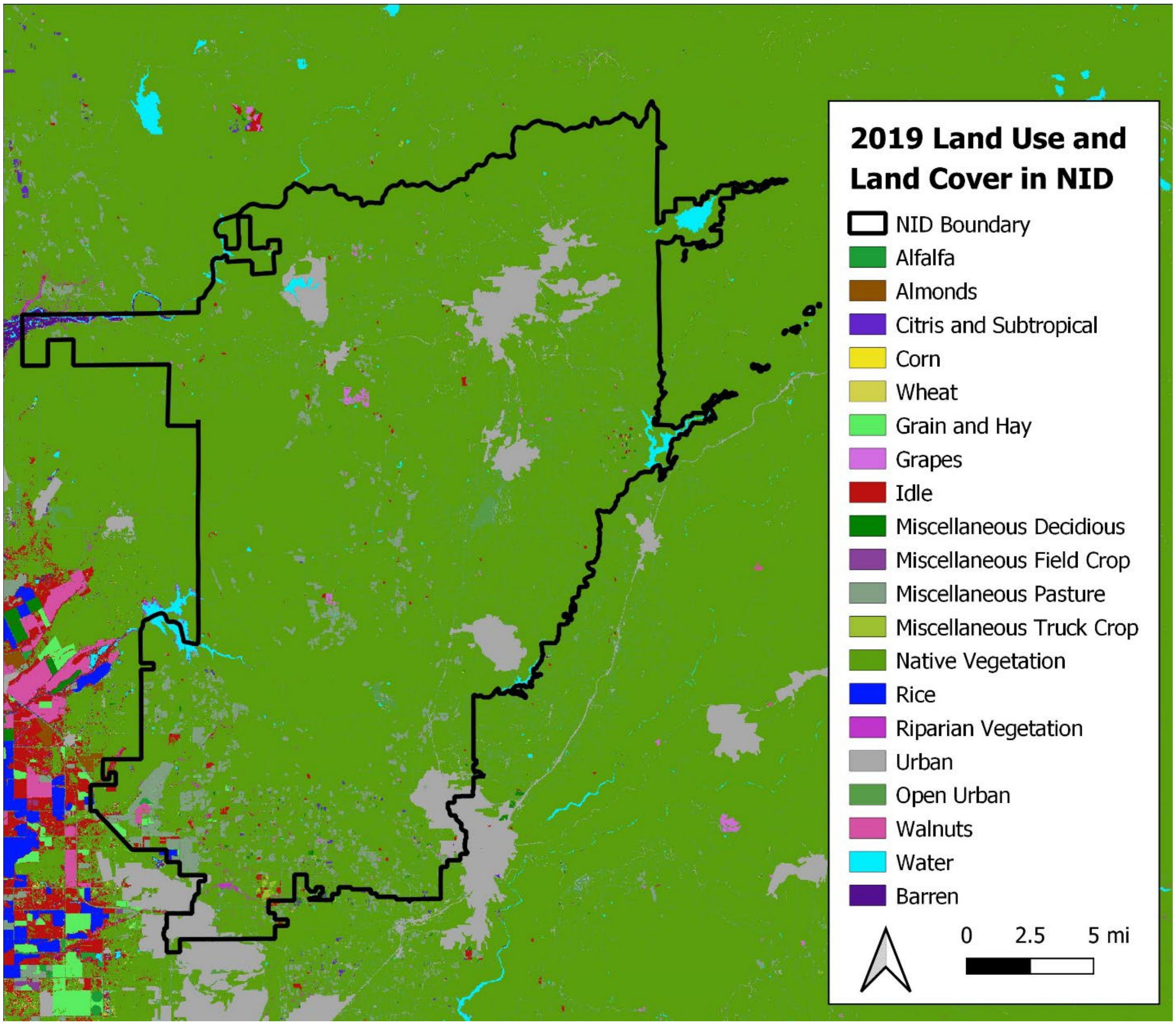

Figure B-6. Land Use Class in the LULC Dataset in 2019

Table B-3. Average Land Use Acreage in NID in Water Year 2022.

Land Use Sector in the Demand Model	Land Use Category in the Demand Model	Land Use Class in the Spatial LULC Dataset	Acres
Agricultural	Citrus and Subtropical	Citrus and Subtropical	68
	Idle	Idle and Barren	804
	Miscellaneous Deciduous	Almond	59
		Miscellaneous Deciduous	144
		Walnuts	115
	Miscellaneous Truck and Nursery	Miscellaneous Field Crops	24
		Miscellaneous Truck Crops	95
		Other Crops	570
	Pasture	Alfalfa	39
		Miscellaneous Pasture	4,432
	Vineyard	Grapes	297
Native and Riparian Vegetation	Native and Riparian Vegetation	Native and Riparian Vegetation	104,933
	Water	Water	1,663
Urban	Urban and Residential	Urban	16,771
		Total	130,014

B.4. Demand Model Input Parameter Sensitivity Analyses

B.4.1. Introduction

The purpose of this appendix is to document the sensitivity analyses that were conducted to test the relative impacts of different input parameters within the demand model that was developed and used to support the NID PFW process. The NID PFW is a public collaboration process to determine the best ways to meet the NID community's demand for water over the coming 50 years and involves a review of NID's available water supply and the long-term impacts on varying water demands. As part of the NID PFW process, a demand model was developed to simulate and test the water demands experienced under potential future demand scenarios – referred to as projected demand scenarios. The projected demand scenarios were developed to simulate a range of high and low demand conditions that may be experienced within the NID service area over the next 50 years.

The objectives of the sensitivity analyses documented in this appendix were to:

- Identify which factors most significantly impact demand, and should be considered in the development of the projected demand scenarios, and to
- Evaluate potential demand changes from current conditions in different "bookend" scenarios (i.e., a potential future range of high demand and low demand conditions), helping to identify reasonable bounds for developing input parameters in the projected demand scenarios.

The input parameters considered in the sensitivity analyses included:

- Raw water customers (with respect to changes in NID’s customer base and areas receiving raw water)
- Treated water customers (with respect to changes in NID’s customer base and parcels receiving treated water)
- Evapotranspiration (ET), with respect to changes in:
  - Climate-related impacts to environment-driven demand for evaporation
  - Crop cultivation practices and environmental stresses
- System losses (in NID’s canals and distribution system downstream of NID’s reservoirs)

In total, five levels of demand conditions were considered in each sensitivity analysis, with incrementally higher and lower demand conditions simulated around a baseline current demand condition (Figure B-7). The baseline current demand condition was developed starting from a historical demand model calibrated within approximately two percent, on average, of recent historical demand (2013–2022) across the NID service area, and was then refined for current conditions assuming: continuation of current land use (2022), current population and urban water use (2022), recent average precipitation (2013–2022) and ET (2016–2022), and 15% system losses (representing NID’s current estimate of canal system losses based on findings from NID’s Raw Water Master Plan and associated analyses by NID of water that is released into NID canals that is not delivered to NID customers).

The sections below identify the assumptions that were used to develop each level of demand conditions in each sensitivity analysis and the equivalent results for each. Results of the sensitivity analyses reported below are the “average water requirement” of NID’s customers, which includes the sum of raw water demand and treated water demand, as well as the system losses in NID’s canals and distribution system downstream of NID’s reservoirs that occur delivering water to NID’s customers (Figure B-7). These sensitivity analysis results do not include municipal water demand or environmental flows. Changes to municipal water demand were included in the projected demand scenarios based on five-year projected changes to municipal water use (2020–2040) from NID’s Urban Water Management Plan, with interpolation or extrapolation in the intervening and following years through the end of the projected period. Regulatory-required environmental flows were included in the reservoir operations model (i.e., the ResSim model) that was developed and used in coordination with the demand model to simulate water supply versus demand and conditions of unmet demand under potential projected scenarios. Additional information about the projected demand scenarios and demand model is provided in the NID PFW report.

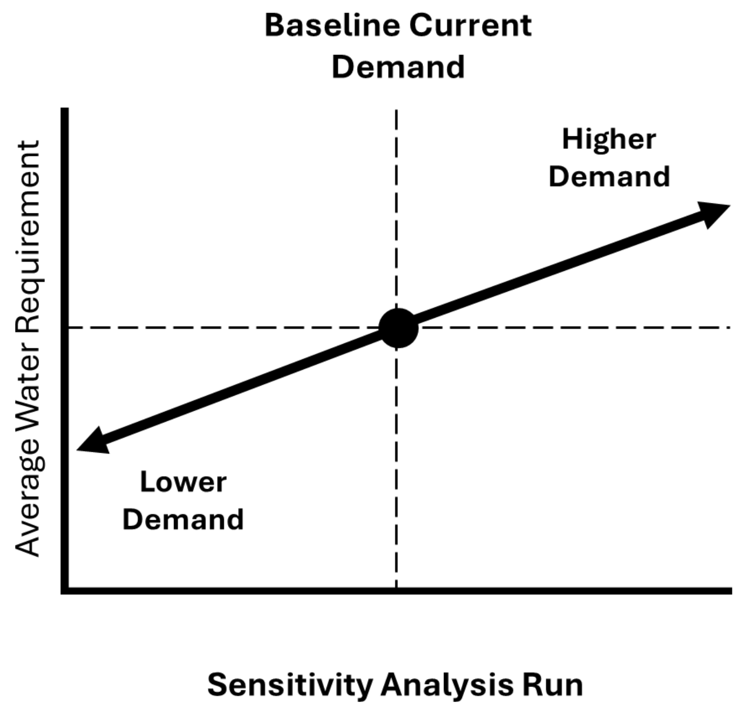

Figure B-7. Layout of Sensitivity Analysis Runs and Results Summaries.

B.4.2. Sensitivity Analyses

B.4.2.1 Raw Water Customers

The first analysis was conducted to evaluate the sensitivity of the demand model to changes in NID's raw water customers, as related to changes in NID's customer base and areas receiving raw water. Around the baseline current demand condition (analysis run 3):

- Higher demand conditions were evaluated through expansion of raw water customers into parcels within 1,000 feet of NID canals that (1) were not already NID customers, per NID delivery records, and (2) have historically been associated with agriculture or irrigated land uses, as identified from land use analyses. Expansion was tested through 50% fill-in to those areas (analysis run 4) and through 100% fill-in to those areas (analysis run 5). These levels of expansion were selected to test potential high-demand bookend scenarios, although actual future growth of NID's raw water customer base is likely to be less than this.
- Lower demand conditions were evaluated through reduction of land irrigated by raw water customers, with no fill-in to additional parcels in the NID service area. The analysis tested 25% reduction (analysis run 2) and 50% reduction (analysis run 1) of non-permanent crop areas. These reductions were selected to test the demand model sensitivity to potential low-demand bookend scenarios. However, potential future reductions in irrigated areas are likely to be less than these changes.

Changes in the average water requirement resulting from this analysis ranged between approximately -55,000 acre-feet per year (AF/yr) and +52,000 AF/yr, as compared to the baseline current demand condition (Figure B-8 and Table B-4).

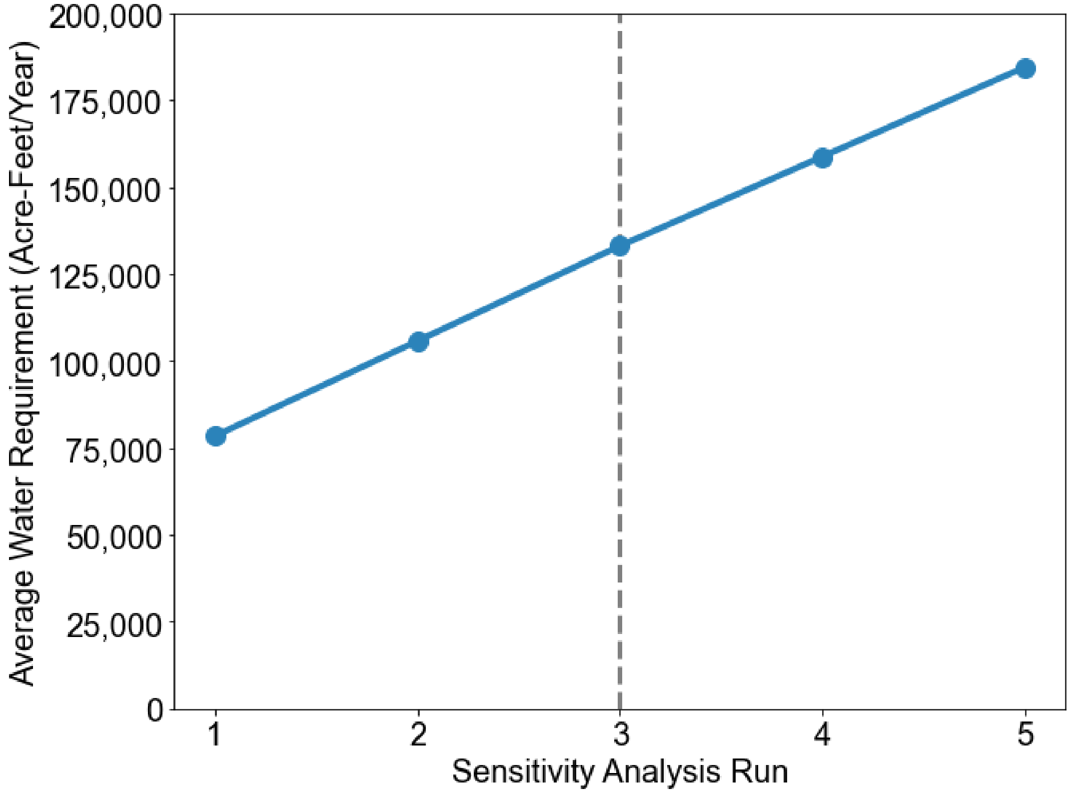

Figure B-8. Sensitivity Analysis Summary: Raw Water Customers.

Table B-4. Sensitivity Analysis Summary: Raw Water Customers.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	50% reduction in non-permanent crop areas, no fill-in to additional parcels	78,000	-55,000
2	25% reduction in non-permanent crop areas, no fill-in to additional parcels	106,000	-27,000
3 (Baseline)	No change (2022 land use)	133,000	--
4	Land use in 2022, plus fill-in to 50% parcels within 1000 feet of NID canals	159,000	26,000
5	Land use in 2022, plus fill-in to 100% parcels within 1000 feet of NID canals	185,000	52,000

B.4.2.2 Treated Water Customers

The second analysis was conducted to evaluate the sensitivity of the demand model to changes in NID's treated water customers, as related to changes in NID's customer base and parcels receiving treated water. Around the baseline current demand condition (analysis run 3):

- Higher demand conditions were evaluated through expansion of treated water customers into soft service areas (i.e., areas where NID has identified potential future growth opportunities for treated water customer service). Expansion was confined to parcels that were not already associated with NID customers, per NID delivery records. Expansion was tested through 50% fill-in (analysis run 4) and 100% fill-in (analysis run 5) to the soft service areas. These levels of expansion were selected to test potential high-demand bookend scenarios, although actual future growth of NID's treated water customer base is likely to be less than this.
- Lower demand conditions were evaluated through population decline in the NID service area, resulting in reduction in NID's treated water customers. The analysis tested population decline to the 2015–2019 average, representing the average population prior to the COVID-19 pandemic (analysis run 2), as well as population decline to the minimum population in the NID service area since 2000 (analysis run 1). These reductions were selected to test the demand model sensitivity to potential low-demand bookend scenarios. However, potential future reductions in NID's treated water customer base is likely to be less than these changes.

This analysis resulted in minimal changes to the average water requirement in NID, representing +/-3,000 AF/yr or less as compared to the baseline current demand condition (Figure B-9 and Table B-5).

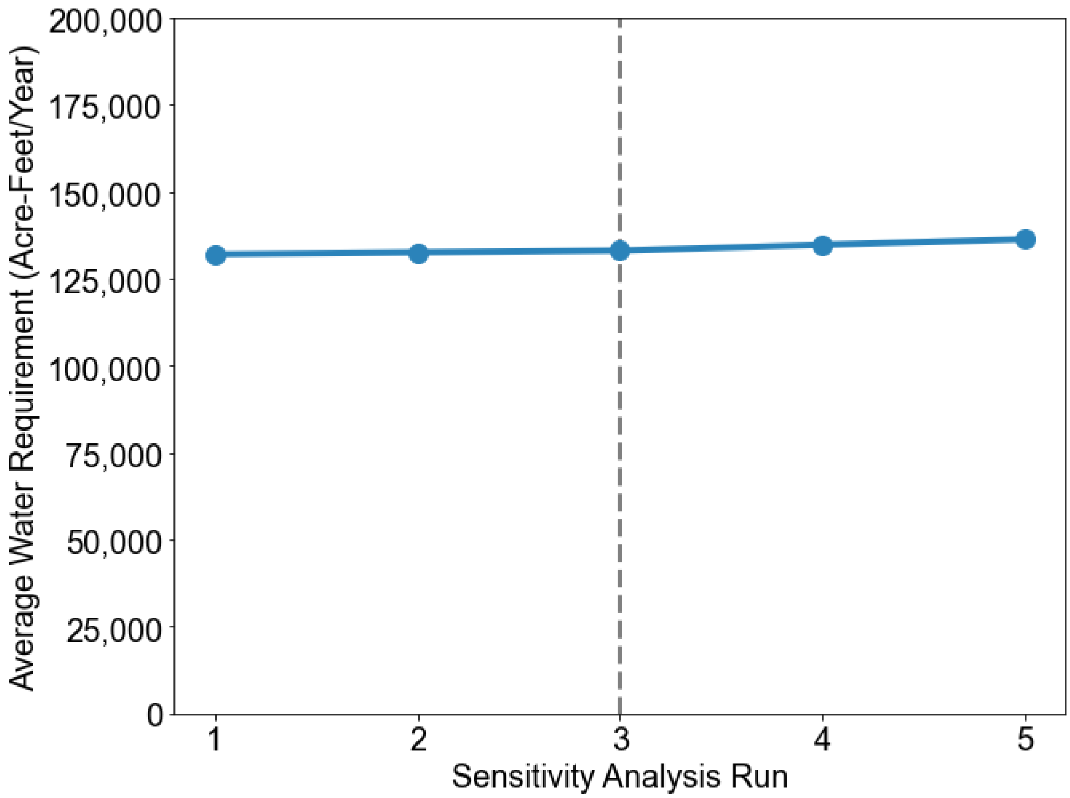

Figure B-9. Sensitivity Analysis Summary: Treated Water Customers.

Table B-5. Sensitivity Analysis Summary: Treated Water Customers.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	Population decline to minimum since 2000 (depending on location, ~80-90% of current)	132,000	-1,000
2	Population decline to 2015–2019 average (pre-pandemic average, ~95% of current)	133,000	0
3 (Baseline)	No change (2022 population)	133,000	--
4	Expansion to fill 50% of soft service areas (~ +20% of current treated water customers)	135,000	2,000
5	Expansion to fill 100% of soft service areas (~ +40% of current treated water customers)	136,000	3,000

B.4.2.3 Evapotranspiration with Changes to Climate

The third analysis was conducted to evaluate the sensitivity of the demand model to changes in ET, as related to potential changes in climate (specifically temperature) within the NID service area. ET and its relationship to climate parameters is described further in Chapter 4 of the NID PFW report. Around the baseline current demand condition (analysis run 2), higher and lower demand conditions were evaluated through increases or decreases (respectively) in the average daily temperature in the NID service area. Temperature changes were used to adjust the median historical ET in the NID service area based on the relationship between ET and temperature described by Hargreaves and Samani. Additional information about the Hargreaves-Samani approach is described in the NID PFW report. The following temperature changes were tested:

- Lower demand:
    - Adjusted for an average -2.2°F (-1.2°C) temperature change (analysis run 1)
- Higher demand:
    - Adjusted for an average +2.2°F (+1.2°C) temperature change (analysis run 3)
    - Adjusted for an average +4.3°F (+2.4°C) temperature change (analysis run 4)
    - Adjusted for an average +6.5°F (+3.6°C) temperature change (analysis run 5)

These changes were selected to test the demand model sensitivity to potential temperature changes in bookend climate change scenarios. However, potential future changes in temperature may be greater or less than these changes. This analysis resulted in changes in the average water requirement ranging between approximately -4,000 AF/yr to +16,000 AF/yr, as compared to the baseline current demand condition (Figure B-10 and Table B-6).

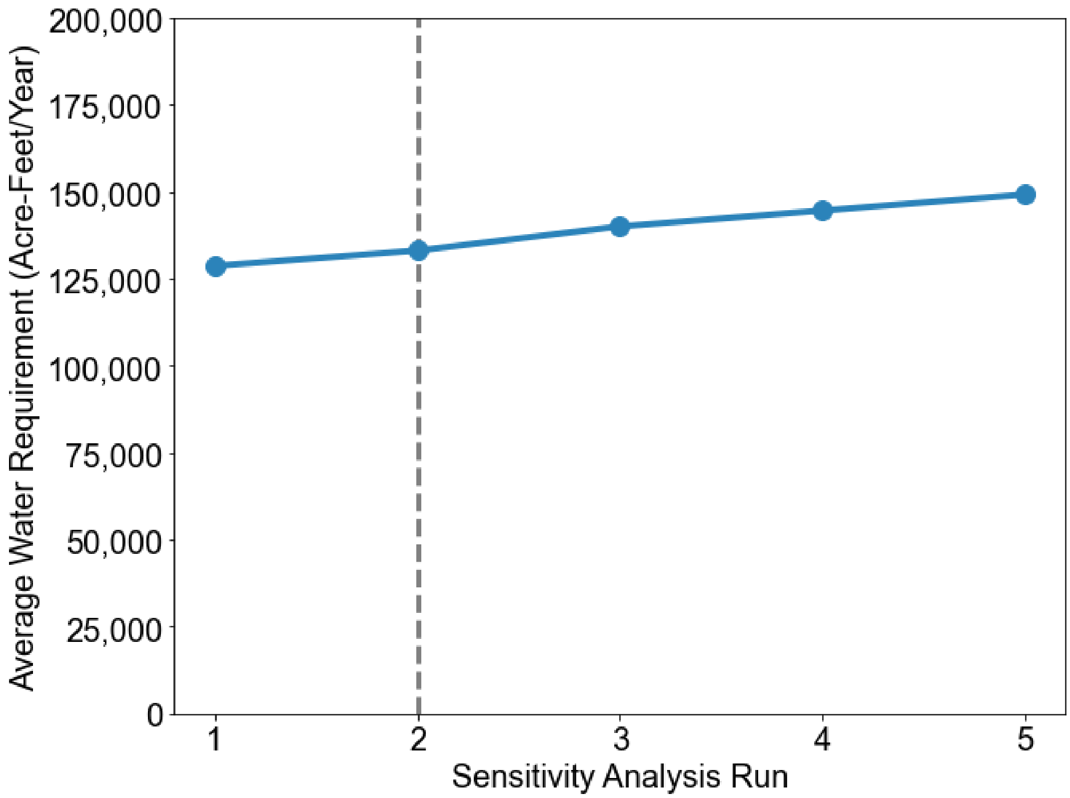

Figure B-10. Sensitivity Analysis Summary: Evapotranspiration with Changes to Climate.

Table B-6. Sensitivity Analysis Summary: Evapotranspiration with Changes to Climate.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	Median historical ET adjusted for -2.2°F (-1.2°C)	129,000	-4,000
2 (Baseline)	No change (median historical ET)	133,000	--
3	Median historical ET adjusted for +2.2°F (+1.2°C)	140,000	7,000
4	Median historical ET adjusted for +4.3°F (+2.4°C)	145,000	12,000
5	Median historical ET adjusted for +6.5°F (+3.6°C)	149,000	16,000

B.4.2.4 Total Evapotranspiration

The fourth analysis was conducted to evaluate the sensitivity of the demand model to changes in total ET. ET is impacted by:

- the types of crops or vegetation that are grown (reflecting the inherent differences in water needs of different crops and vegetation);
- the quality of crops, vegetation, or land use, including water availability, nutrient and pest management, and other factors; and
- the environmental demand for evaporation related to weather and climate parameters, as a function of temperature, solar radiation, wind speed, and humidity.

Each of these factors is accounted for in the methods used to quantify ET in the demand model. Changes in total ET in this analysis were determined through ET data summarized from OpenET. OpenET is a multi-agency web-based geospatial utility that uses satellite imagery to quantify ET over time with a spatial resolution of 30 meters x 30 meters (approximately 0.22 acres). For the NID demand model, OpenET data was used to observe recent historical ET trends and evaluate representative ET rates for land uses in NID (e.g., average ET and percentiles across tens to thousands of pixels in NID). Additional information about OpenET and its application in the demand model is described in the NID PFW report.

Around the baseline current demand condition (analysis run 3), higher and lower demand conditions were evaluated through increases or decreases (respectively) in the average ET value simulated in NID. Potential high and low demand conditions were determined from OpenET data as follows:

- Lower demand:
  - 10^{th} percentile ET from OpenET analyses (analysis run 1)
  - 25^{th} percentile ET from OpenET analyses (analysis run 2)
- Higher demand:
  - 75^{th} percentile ET from OpenET analyses (analysis run 4)
  - 90^{th} percentile ET from OpenET analyses (analysis run 5)

These changes were selected to test the demand model sensitivity to potential ET changes over the range of conditions experienced in NID historically. However, potential future ET changes may be less than these changes. This analysis resulted in changes in the average water requirement ranging between approximately -40,000 AF/yr to +42,000 AF/yr, as compared to the baseline current demand condition (Figure B-11 and Table B-7).

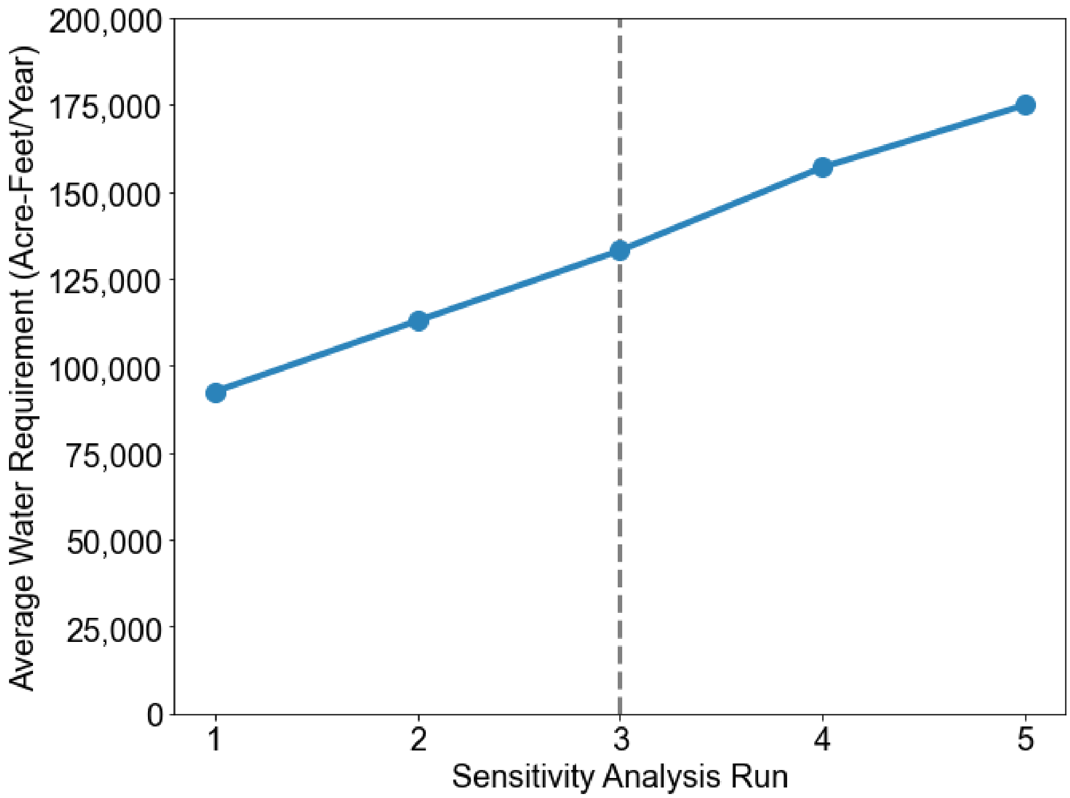

Figure B-11. Sensitivity Analysis Summary: Total Evapotranspiration.

Table B-7. Sensitivity Analysis Summary: Total Evapotranspiration.

Sensitivity Analysis Run	Change from Baseline[1]	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	10th percentile ET	93,000	-40,000
2	25th percentile ET	113,000	-20,000
3 (Baseline)	No change (50th percentile ET)	133,000	--
4	75th percentile ET	157,000	24,000
5	90th percentile ET	175,000	42,000

[1]By percent of parcels, by land use category and climate zone.

B.4.2.5 System Losses

The fifth analysis was conducted to evaluate the sensitivity of the demand model to changes in system losses. In this context, system losses represent water that is lost (whether through seepage, evaporation, or other outflows) from NID's canals and distribution system downstream of NID's reservoirs that occur delivering water to NID's customers.

Around the baseline current demand condition (analysis run 2), higher and lower demand conditions were evaluated through increases or decreases (respectively) in average system losses. The following system losses were tested:

- Lower demand:
  - System losses representing 10% of canal inflows (analysis run 1)
- Higher demand:
  - System losses representing 20% of canal inflows (analysis run 3)
  - System losses representing 30% of canal inflows (analysis run 4)
  - System losses representing 40% of canal inflows (analysis run 5)

These changes were selected to test the demand model sensitivity to uncertainties and potential changes in system losses across a range of conditions. The actual system losses likely differ from these conditions but are expected to generally fall within this range. This analysis resulted in changes in the average water requirement ranging between approximately -7,000 AF/yr to +56,000 AF/yr, as compared to the baseline current demand condition (Figure B-12 and Table B-8).

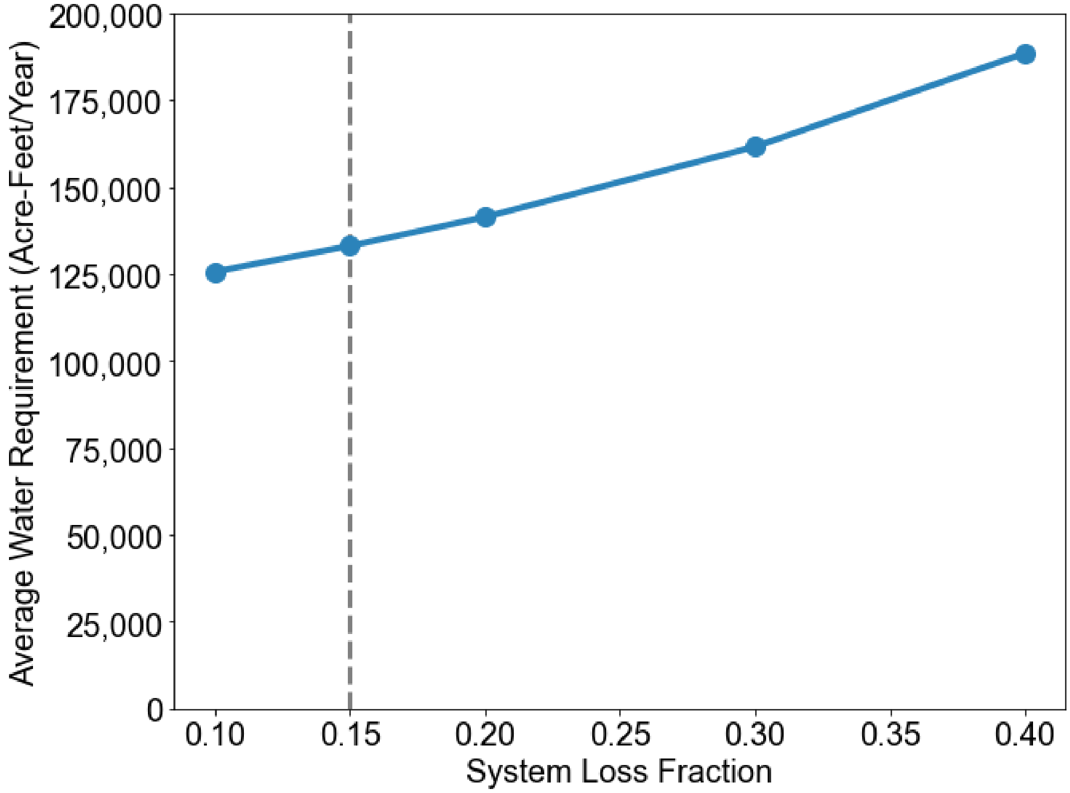

Figure B-12. Sensitivity Analysis Summary: System Losses.

Table B-8. Sensitivity Analysis Summary: System Losses.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	10% system losses	126,000	-7,000
2 (Baseline)	No change (15% system losses)	133,000	--
3	20% system losses	141,000	8,000
4	30% system losses	162,000	29,000
5	40% system losses	189,000	56,000

B.4.3. Comparison of Sensitivity Analyses

Figure B-13 provides a comparison of the results across all five sensitivity analyses, sorted generally from the greatest sensitivity and potential impacts to average water requirements in NID to the lowest sensitivity and potential impacts. This comparison indicates that changes to the raw water customer demand in NID (under those conditions tested) have the most significant potential impacts to the average water requirement. This reflects the significance of raw water use in NID, which represents approximately 90% of NID's annual demand. Following raw water customers, other factors with potentially significant impacts to the average water requirement include system losses and total ET changes. System losses are currently calculated in NID (and in the NID demand model) as a fraction of the total canal inflows, based on the best information currently available. Thus, significant changes to the estimated system losses have widespread effects on the water required in the NID system. Total ET changes are also impactful, mirroring the model sensitivity to raw water customer demand, which is primarily driven by ET. In contrast, temperature-related impacts to ET alone are less impactful than considering the effects of all factors that impact total ET. Treated water customer demand has the lowest potential impact to the demand model results among those parameters tested, as treated water use represents a much smaller portion of NID's demand.

The results of these sensitivity analyses were considered in the development of the projected demand scenarios. Please see Chapter 4 of the NID PFW report for more information about the projected demand scenarios and the assumptions and data sources that were used to develop those.

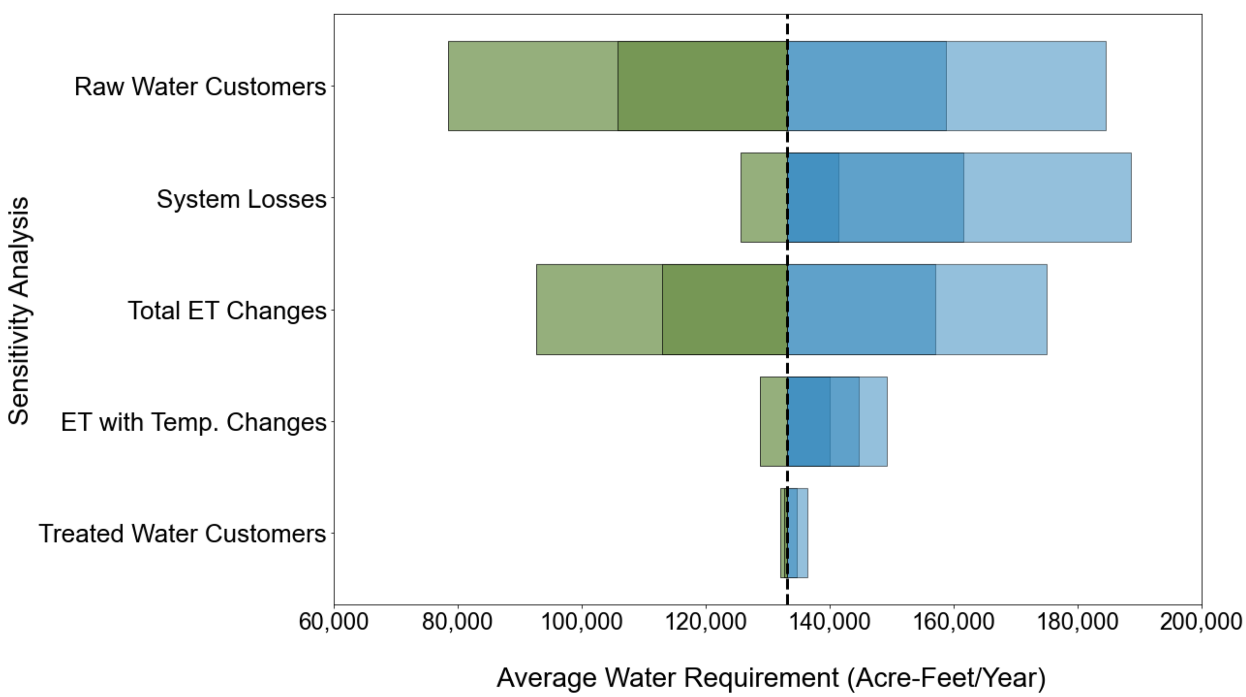

Figure B-13. Comparison of Sensitivity Analyses.

B.5. References

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Appendix C:

Chapter 5 Supplemental Information

TABLE OF CONTENTS

Appendix C. Chapter 5 Supplemental Information C-1

C.1. Middle Yuba River C-1

C.1.1. Jackson Meadows Reservoir C-1

C.1.2. Milton Reservoir C-2

C.2. Canyon Creek C-3

C.3. Texas Fall Creeks C-7

C.3.1. PG&E Reservoirs C-7

C.3.2. Spaulding Powerhouse No. 3 ..... C-13

C.4. South Yuba River C-14

C.4.1. Upstream of Fordyce Lake C-14

C.4.2. Fordyce Lake C-16

C.4.3. Lake Spaulding C-17

C.5. North Fork American River C-20

C.5.1. Lake Valley Reservoir C-20

C.5.2. Kelly Lake C-21

C.5.3. Lake Valley Canal Flows C-21

C.5.4. Diversions from Canyon Creek into the Towle Canal C-23

C.6. Bear River C-24

C.6.1. Drum Forebay C-24

C.6.2. Drum Afterbay C-27

C.6.3. Dutch Flat Afterbay C-30

C.6.4. Rollins Lake C-31

C.6.5. Bear River Canal C-32

C.6.6. Lake Combie C-36

C.7. Deer Creek C-38

C.7.1. Deer Creek Powerhouse C-38

C.7.2. Scotts Flat Reservoir C-39

C.7.3. Cascade Canal C-40

C.7.4. DS Canal C-41

C.7.5. Newtown Canal C-42

C.7.6. Tunnel Canal C-43

FIGURES

Figure C-1. Jackson Meadows Reservoir Storage, Water Years 2012–2021 ..... C-1
Figure C-2. Release from Milton Reservoir to Middle Yuba River, Water Years 2012–2021 ..... C-2
Figure C-3. Diversions to Milton-Bowman Conduit, Water Years 2012–2021 ..... C-2
Figure C-4. French Lake Storage, Water Years 2012–2021 ..... C-3

Figure C-5. Faucherie Lake Storage, Water Years 2012–2021 ... C-4
Figure C-6. Sawmill Lake Storage, Water Years 2012–2021 ... C-4
Figure C-7. Jackson Lake Storage, Water Years 2012–2021 ... C-5
Figure C-8. Bowman Reservoir Storage, Water Years 2012–2021 ... C-6
Figure C-9. Bowman Reservoir releases to Canyon Creek, Water Years 2012–2021 ... C-6
Figure C-10. Bowman Reservoir Diversions to Bowman-Spaulding Conduit, Water Years 2012–2021 ... C-7
Figure C-11. Middle Lindsey Lake Storage, Water Years 2012–2021 ... C-8
Figure C-12. Lower Lindsey Lake Storage, Water Years 2012–2021 ... C-8
Figure C-13. Upper Rock Lake Storage, Water Years 2012–2021 ... C-9
Figure C-14. Lower Rock Lake Storage, Water Years 2012–2021 ... C-9
Figure C-15. Culbertson Lake Storage, Water Years 2012–2021 ... C-10
Figure C-16. Feely Lake Storage, Water Years 2012–2021 ... C-10
Figure C-17. Carr Lake Storage, Water Years 2012–2021 ... C-11
Figure C-18. Blue Lake Storage, Water Years 2012–2021 ... C-11
Figure C-19. Rucker Lake Storage, Water Years 2012–2021 ... C-12
Figure C-20. Fuller Lake Storage, Water Years 2012–2021 ... C-12
Figure C-21. Annual Flows through Spaulding Powerhouse No. 3, Water Years 2012–2021 ... C-13
Figure C-22. Annual Flow Exceedance through Spaulding Powerhouse No. 3, Water Years 2012–2021 ... C-14
Figure C-23. White Rock Lake Storage, Water Years 2012–2021 ... C-14
Figure C-24. Meadow Lake Storage, Water Years 2012–2021 ... C-15
Figure C-25. Lake Sterling Storage, Water Years 2012–2021 ... C-15
Figure C-26. Fordyce Lake Storage, Water Years 2012–2021 ... C-16
Figure C-27. Lake Spaulding Storage, Water Years 2012–2021 ... C-17
Figure C-28. Release from Lake Spaulding to South Yuba River, Water Years 2012–2021 ... C-17
Figure C-29. Annual Flows through Spaulding Powerhouse No. 1, Water Years 2012–2021 ... C-18
Figure C-30. Annual Flow Exceedance through Spaulding Powerhouse No. 1, Water Years 2012–2021 ... C-18
Figure C-31. Annual Flows through Spaulding Powerhouse No. 2, Water Years 2012–2021 ... C-19
Figure C-32. Annual Flow Exceedance through Spaulding Powerhouse No. 2, Water Years 2012–2021 ... C-19
Figure C-33. Lake Valley Reservoir Storage, Water Years 2012–2021 ... C-20
Figure C-34. Kelly Lake Storage, Water Years 2012–2021 ... C-21
Figure C-35. Annual Diversions into Lake Valley Canal, Water Years 2015–2021 ... C-22
Figure C-36. Annual Diversions into Lake Valley Canal Exceedance, Water Years 2015–2021 ... C-22
Figure C-37. Annual Diversions into Towle Canal, Water Years 2012–2021 ... C-23
Figure C-38. Annual Diversions into Towle Canal Exceedance, Water Years 2012–2021 ... C-23
Figure C-39. Annual Flows through Combined Drum Powerhouses, Water Years 2012–2021 ... C-24
Figure C-40. Annual Flow Exceedance through Combined Drum Powerhouses, Water Years 2012–2021 ... C-24
Figure C-41. Annual Flows through Drum Powerhouse No. 1, Water Years 2012–2021 ... C-25
Figure C-42. Annual Flow Exceedance through Drum Powerhouse No. 1, Water Years 2012–2021 ... C-25
Figure C-43. Annual Flows through Drum Powerhouse No. 2, Water Years 2012–2021 ... C-26
Figure C-44. Annual Flow Exceedance through Drum Powerhouse No. 2, Water Years 2012–2021 ... C-26
Figure C-45. Annual Flows through Combined Dutch Flat Powerhouses, Water Years 2012–2021 ... C-27
Figure C-46. Annual Flow Exceedance through Combined Dutch Flat Powerhouses, Water Years 2012–2021 ... C-27
Figure C-47. Annual Flows through Dutch Flat Powerhouse No. 1, Water Years 2012–2021 ... C-28
Figure C-48. Annual Flow Exceedance through Dutch Flat Powerhouse No. 1, Water Years 2012–2021 ... C-28
Figure C-49. Annual Flows through Dutch Flat Powerhouse No. 2, Water Years 2012–2021 ... C-29
Figure C-50. Annual Flow Exceedance through Dutch Flat Powerhouse No. 2, Water Years 2012–2021 ... C-29
Figure C-51. Annual Flows through Chicago Park Powerhouse, Water Years 2012–2021 ... C-30
Figure C-52. Annual Flow Exceedance through Chicago Park Powerhouse, Water Years 2012–2021 ... C-30
Figure C-53. Rollins Lake Elevation, Water Years 2012–2021 ... C-31
Figure C-54. Rollins Lake releases to Bear River, Water Years 2012–2021 ... C-32
Figure C-55. Rollins Lake Diversions to Bear River Canal, Water Years 2012–2021 ... C-32

Figure C-56. Annual Diversion Exceedance to Bear River Canal, Water Years 2012–2021 ..... C-33
Figure C-57. NID Diversions from Rock Creek Reservoir, Water Years 2012–2021 ..... C-33
Figure C-58. Annual Diversion Exceedance to NID from Rock Creek Reservoir, Water Years 2012–2021 ..... C-34
Figure C-59. NID Diversions into Auburn Ravine, Water Years 2012–2021 ..... C-34
Figure C-60. Annual Diversion Exceedance NID into Auburn Ravine, Water Years 2012–2021 ..... C-35
Figure C-61. Annual Diversion Exceedance NID into Auburn Ravine, Water Years 2012–2021 ..... C-35
Figure C-62. Combie Lake Storage, Water Years 2012–2021 ..... C-36
Figure C-63. Combie Lake releases to Bear River, Water Years 2012–2021 ..... C-37
Figure C-64. Combie Lake Diversions to Phase I Canal and Magnolia III Canal, Water Years 2012–2021 ..... C-37
Figure C-65. Annual Flow through Deer Creek Powerhouse, Water Years 2012–2021 ..... C-38
Figure C-66. Annual Flow Exceedance through Deer Creek Powerhouse, Water Years 2012–2021 ..... C-38
Figure C-67. Scotts Flat Reservoir Elevation, Water Years 2012–2021 ..... C-39
Figure C-68. Scotts Flat releases to Deer Creek, Water Years 2012–2021 ..... C-40
Figure C-69. Diversions to Cascade Canal, Water Years 2012–2021 ..... C-40
Figure C-70. Annual Diversion Exceedance to Cascade Canal, Water Years 2012–2021 ..... C-41
Figure C-71. Diversions to DS Canal, Water Years 2012–2021 ..... C-41
Figure C-72. Annual Diversion Exceedance to DS Canal, Water Years 2012–2021 ..... C-42
Figure C-73. Diversions to Newtown Canal, Water Years 2012–2021 ..... C-42
Figure C-74. Annual Diversion Exceedance to Newtown Canal, Water Years 2012–2021 ..... C-43
Figure C-75. Diversions to Tunnel Canal, Water Years 2012–2021 ..... C-43
Figure C-76. Annual Diversion Exceedance to Tunnel Canal, Water Years 2012–2021 ..... C-44

Appendix C. Chapter 5 Supplemental Information

C.1. Middle Yuba River

C.1.1. Jackson Meadows Reservoir

Jackson Meadows Reservoir daily storage matches historical storage well over the calibration period, as shown in Figure C-1. Releases from Milton Reservoir to the Middle Yuba River are shown in Figure C-2 and to the Milton-Bowman Conduit in Figure C-3.

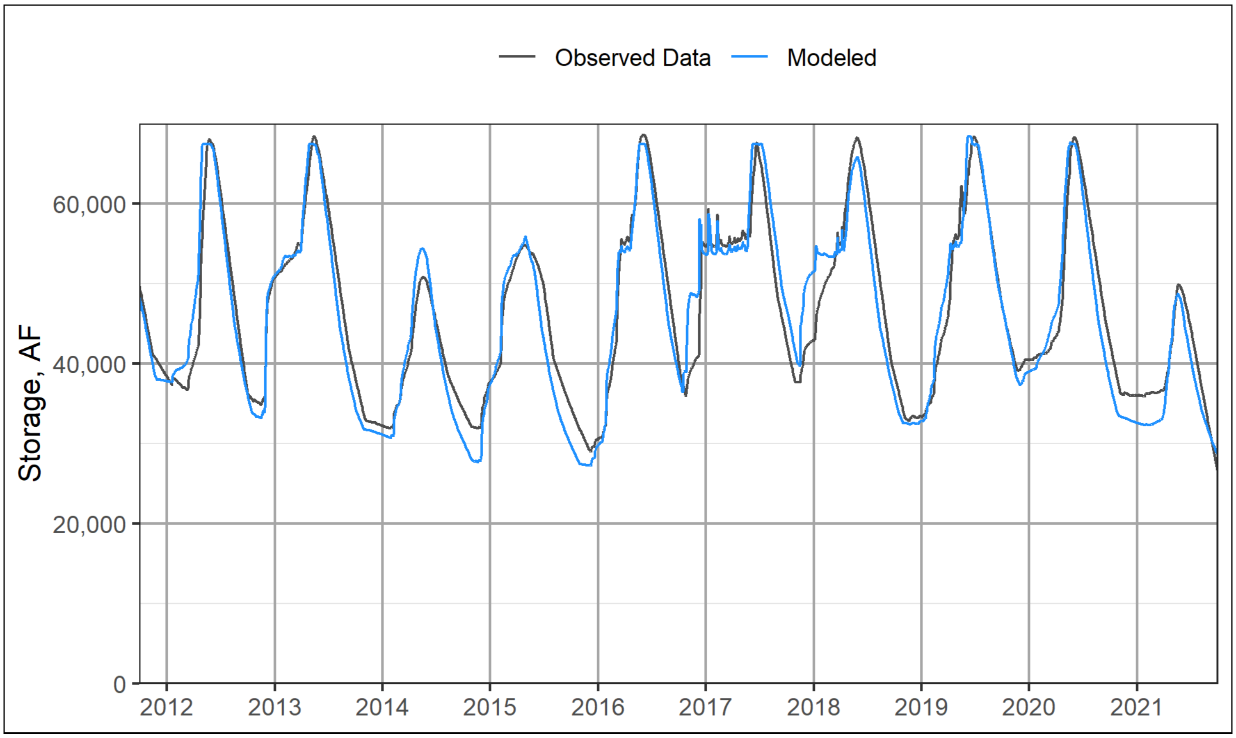

Figure C-1. Jackson Meadows Reservoir Storage, Water Years 2012–2021

C.1.2. Milton Reservoir

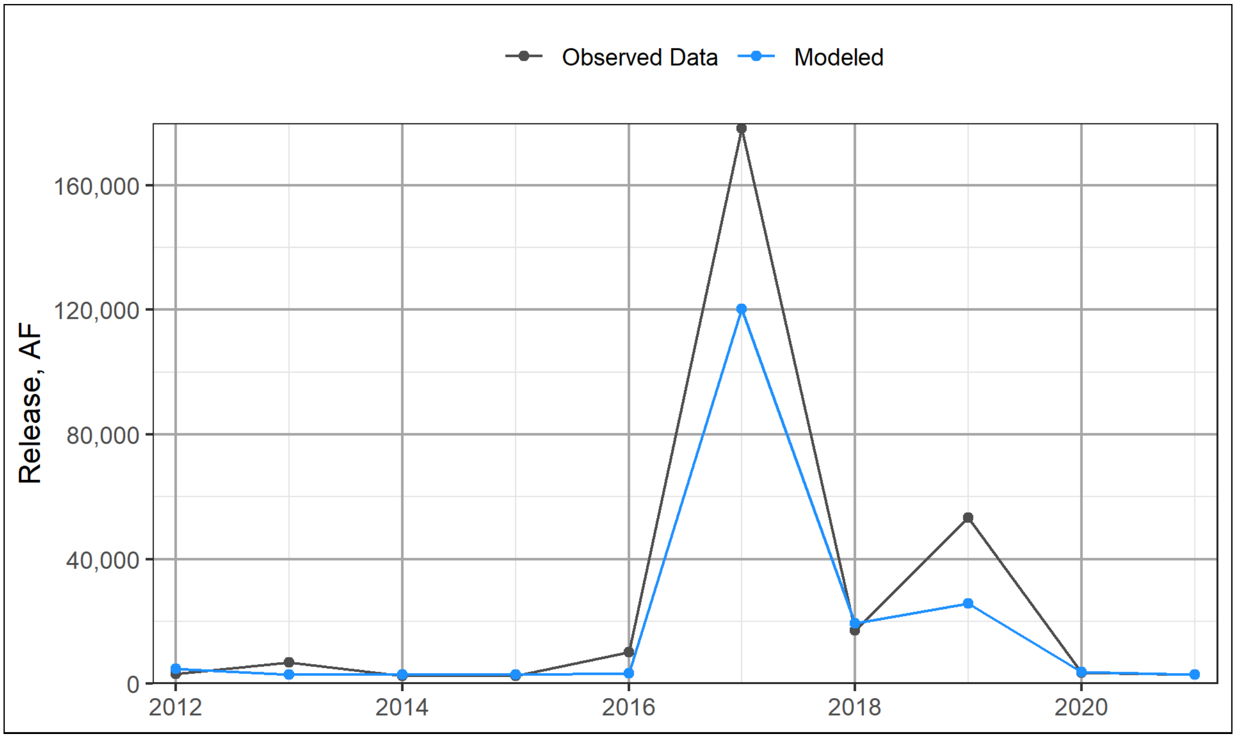

Figure C-2. Release from Milton Reservoir to Middle Yuba River, Water Years 2012–2021

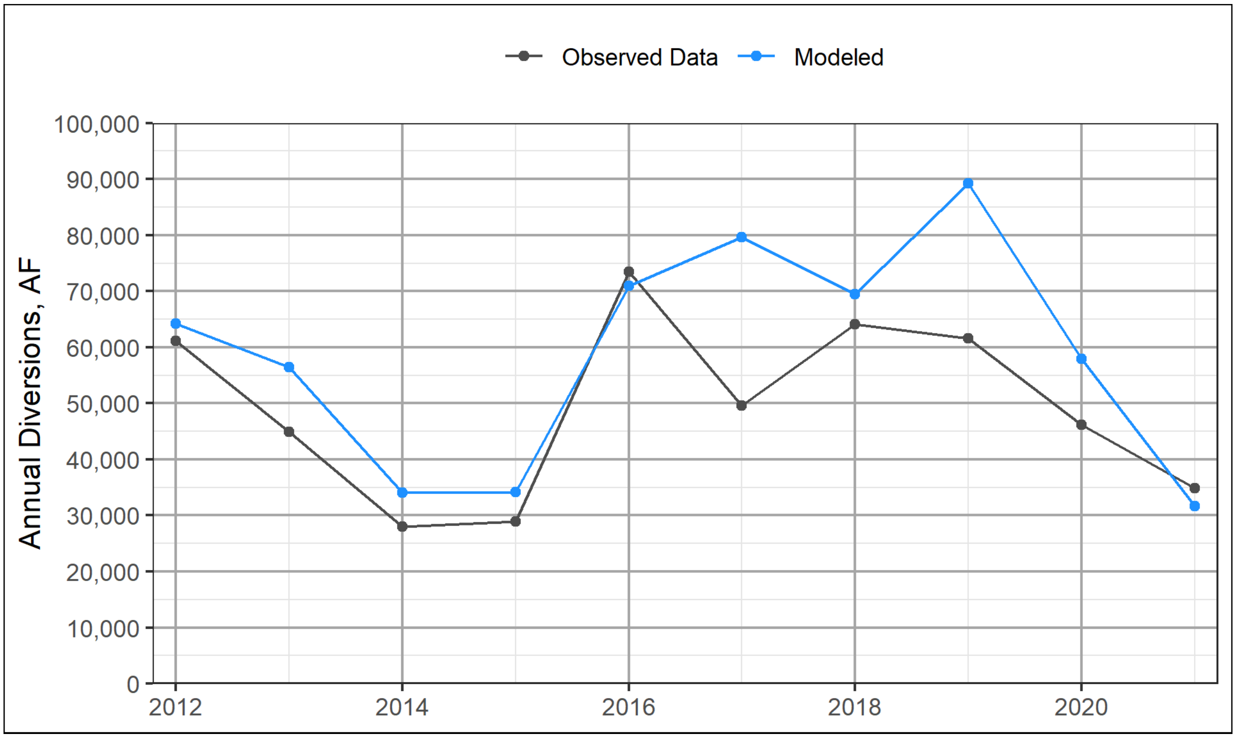

Figure C-3. Diversions to Milton-Bowman Conduit, Water Years 2012–2021

C.2. Canyon Creek

Reservoirs upstream of Bowman Reservoir have daily storage traces that match recent observed data fairly well, as shown in Figure C-4 through Figure C-7. Releases from these reservoirs have limited gauge data with all reservoirs' spills not included in the recorded observed data; therefore, it is not possible to compare reservoir release volumes.

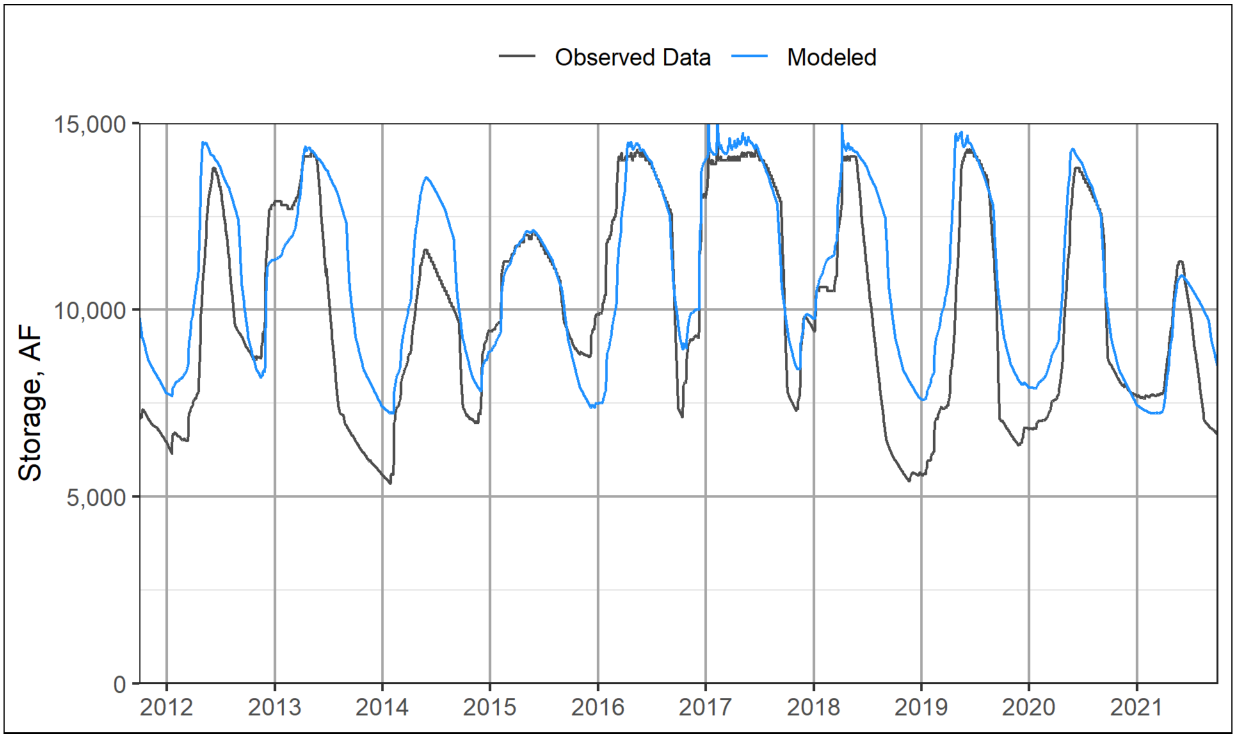

Figure C-4. French Lake Storage, Water Years 2012–2021

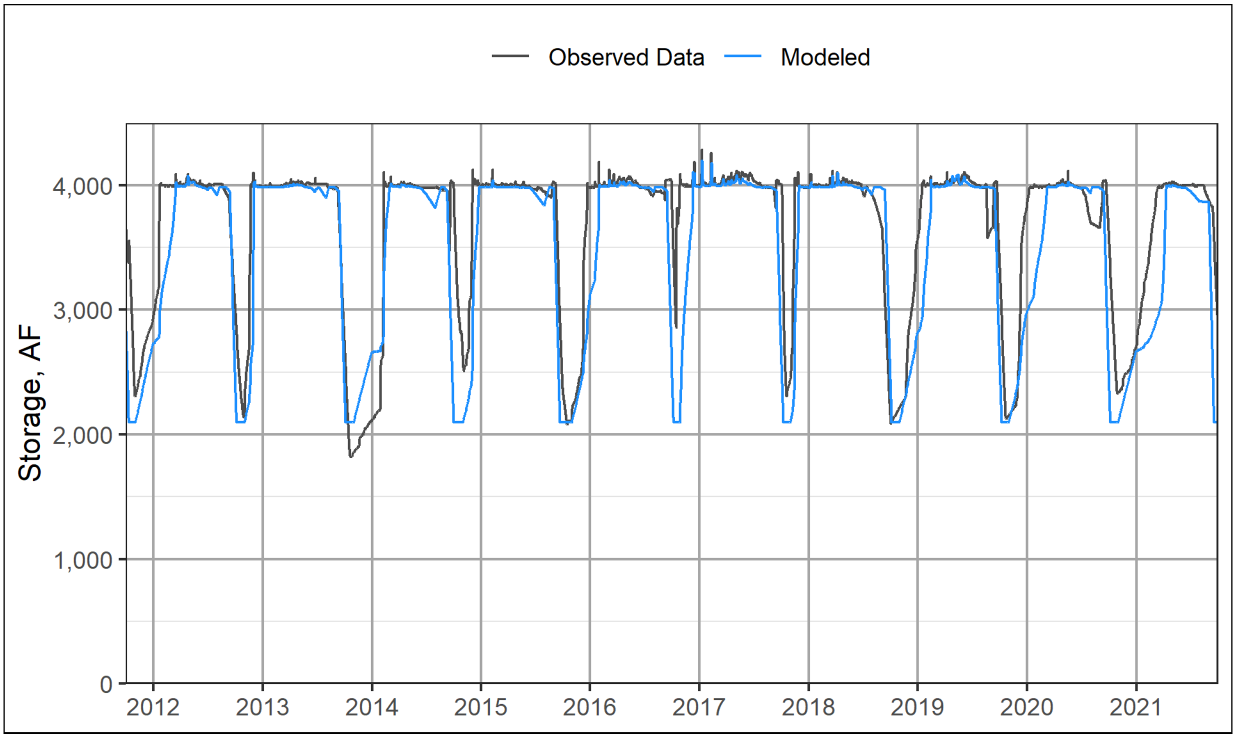

Figure C-5. Faucherie Lake Storage, Water Years 2012–2021

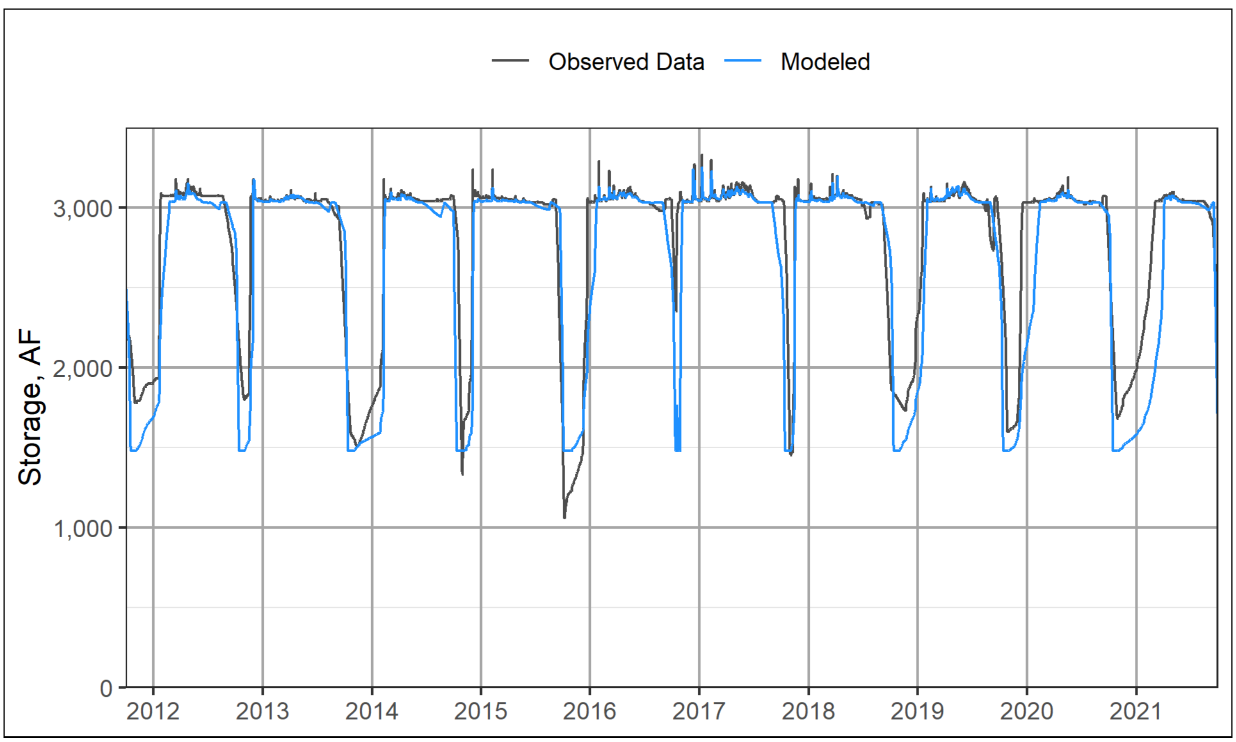

Figure C-6. Sawmill Lake Storage, Water Years 2012–2021

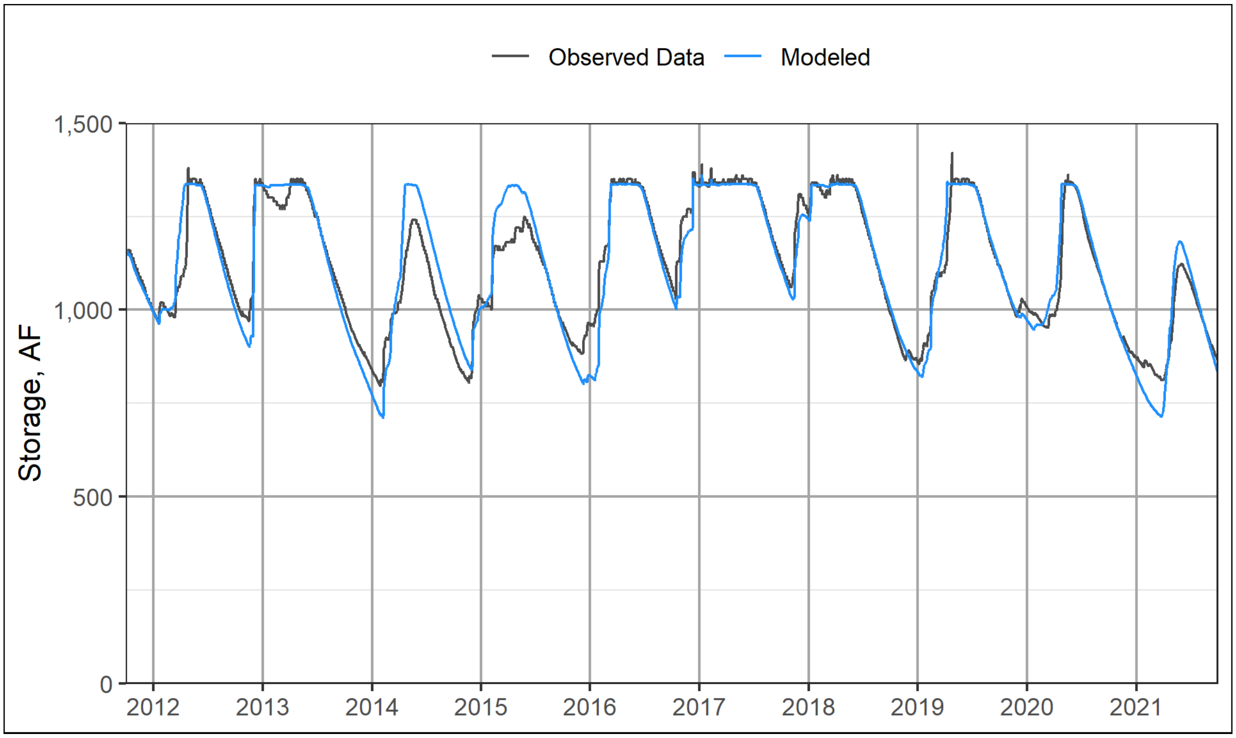

Figure C-7. Jackson Lake Storage, Water Years 2012–2021

Daily storage at Bowman Reservoir matches the recent observed data over the validation period fairly well, as shown in Figure C-8. Releases to Canyon Creek are shown in Figure C-9, and diversions to the Bowman-Spaulding Conduit are shown in Figure C-10.

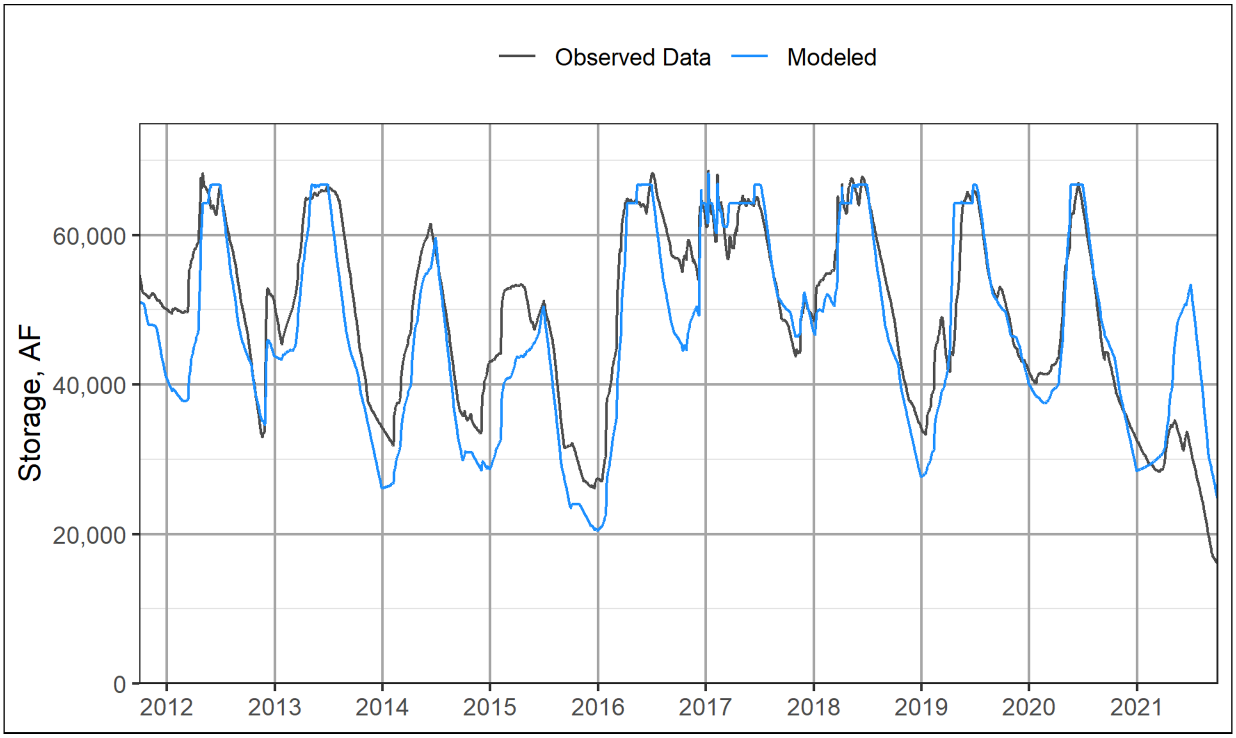

Figure C-8. Bowman Reservoir Storage, Water Years 2012–2021

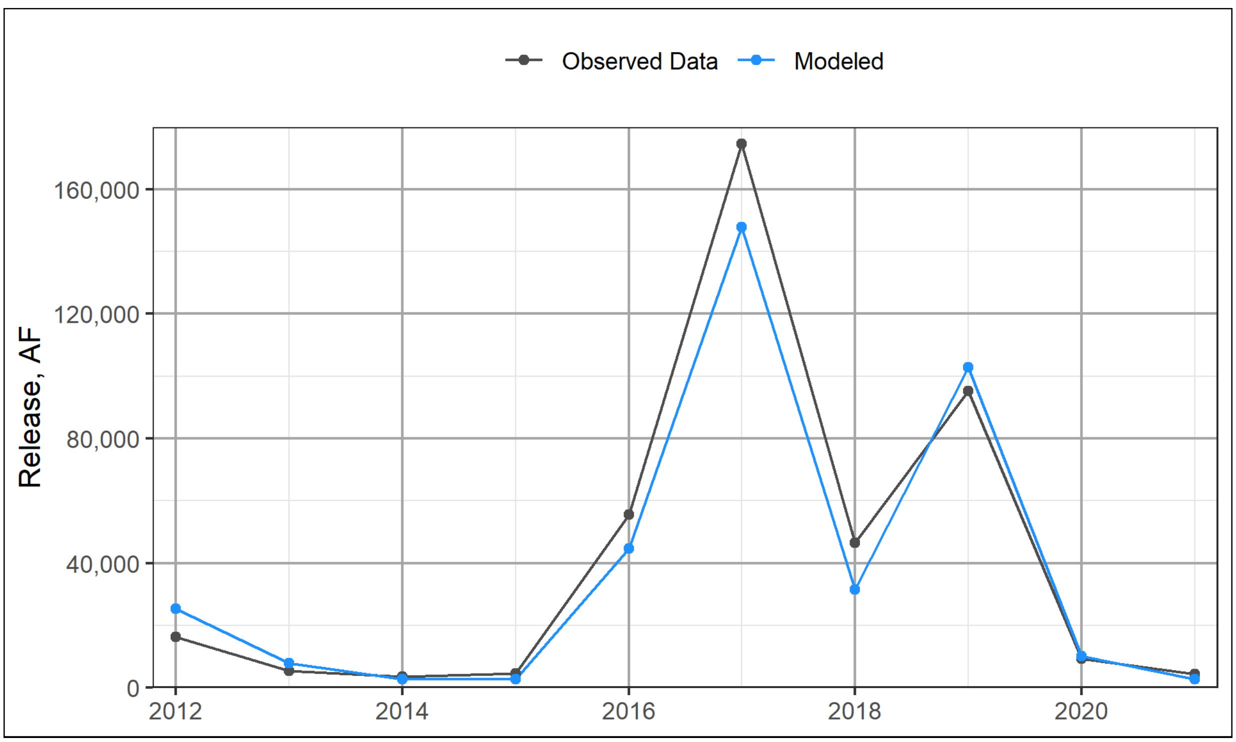

Figure C-9. Bowman Reservoir releases to Canyon Creek, Water Years 2012–2021

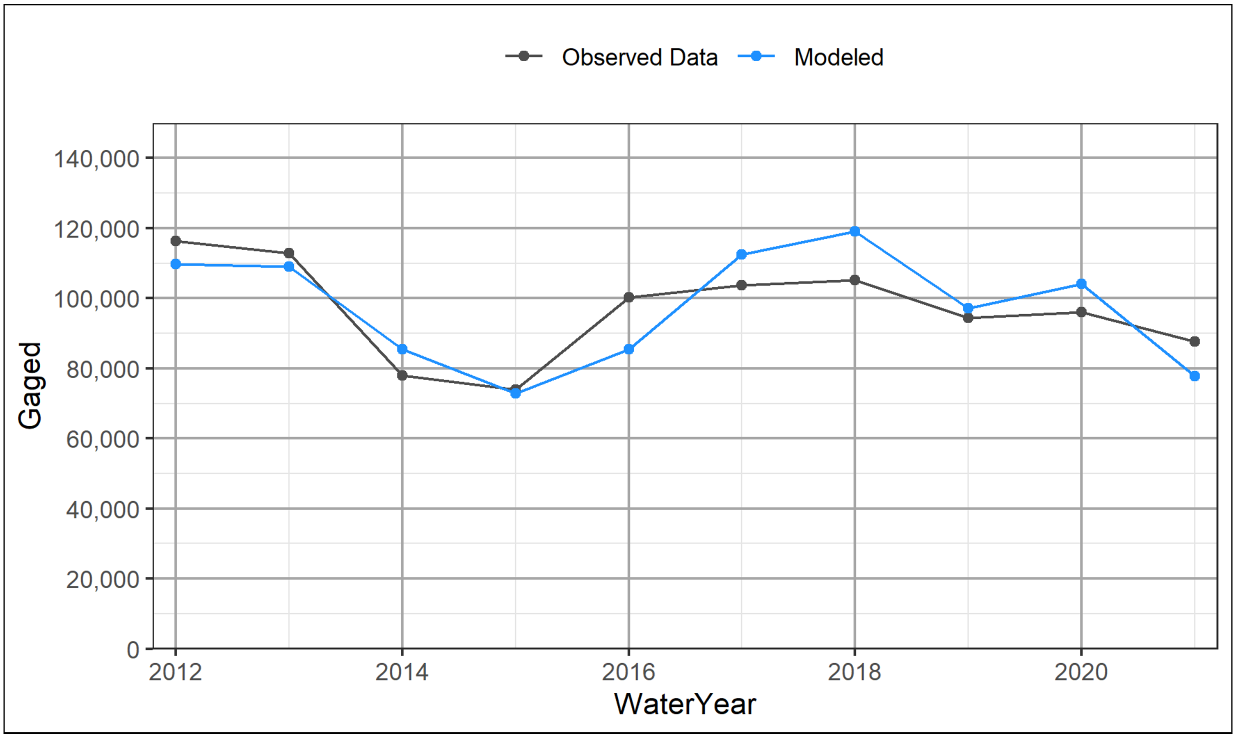

Figure C-10. Bowman Reservoir Diversions to Bowman-Spaulding Conduit, Water Years 2012–2021

C.3. Texas Fall Creeks

C.3.1. PG&E Reservoirs

Many PG&E Reservoirs upstream of the diversions along the Bowman-Spaulding conduit on the collection of streams referred to as the Texas-Fall Creeks are not gauged throughout the year or are not gauged at all. Comparisons to historical observed data are shown where possible. Most reservoirs match the observed data reasonably well, with the exception of Blue Lake. The simple nature of Blue Lake operations, in which the lake only releases discretionary water in wet years and can go 10 years between discretionary releases, suggests that the storage discrepancy is due to the unimpaired hydrology and not reservoir operations. Blue Lake has a very small watershed area, and its unimpaired hydrology could be affected by precision in its estimation parameters.

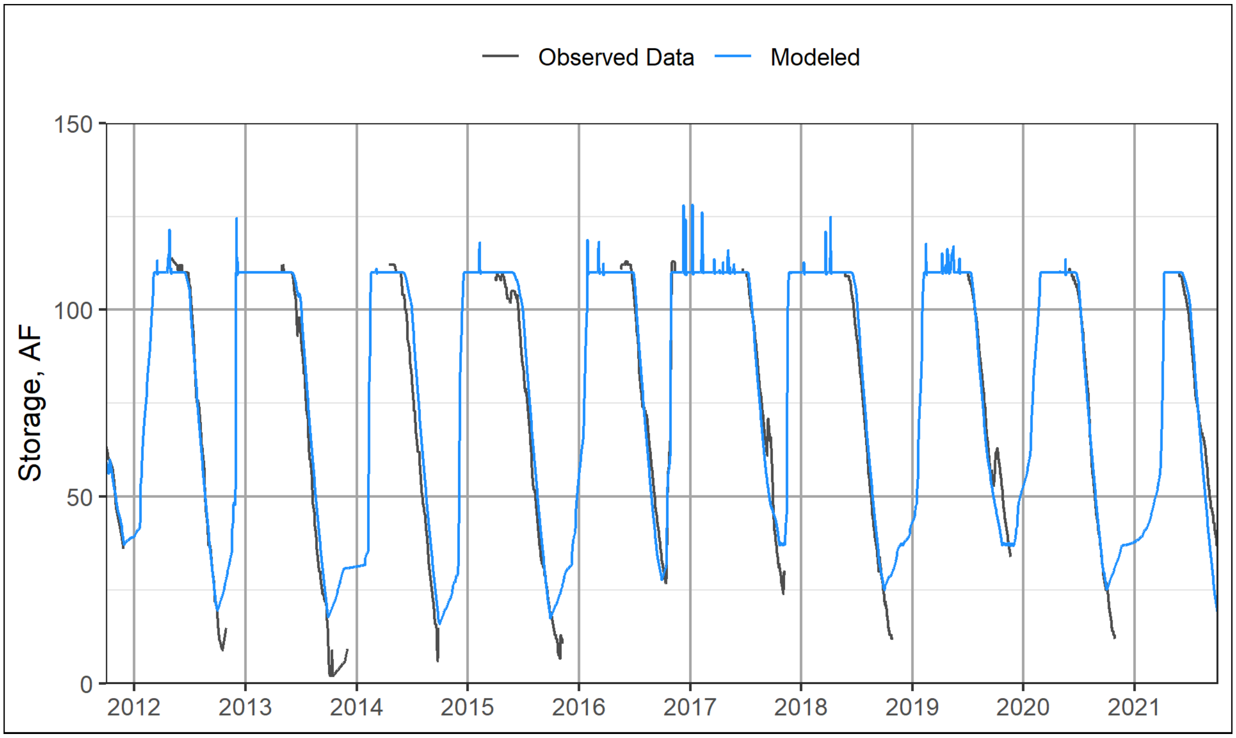

Figure C-11. Middle Lindsey Lake Storage, Water Years 2012–2021

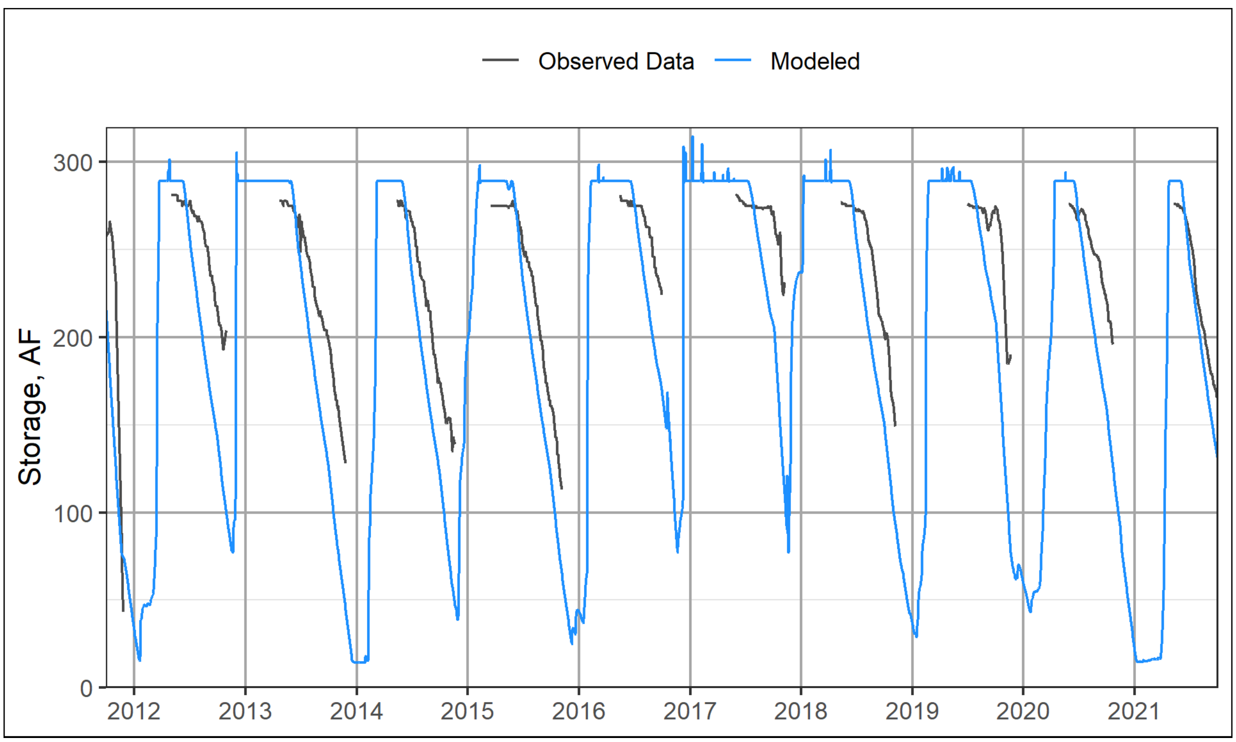

Figure C-12. Lower Lindsey Lake Storage, Water Years 2012–2021

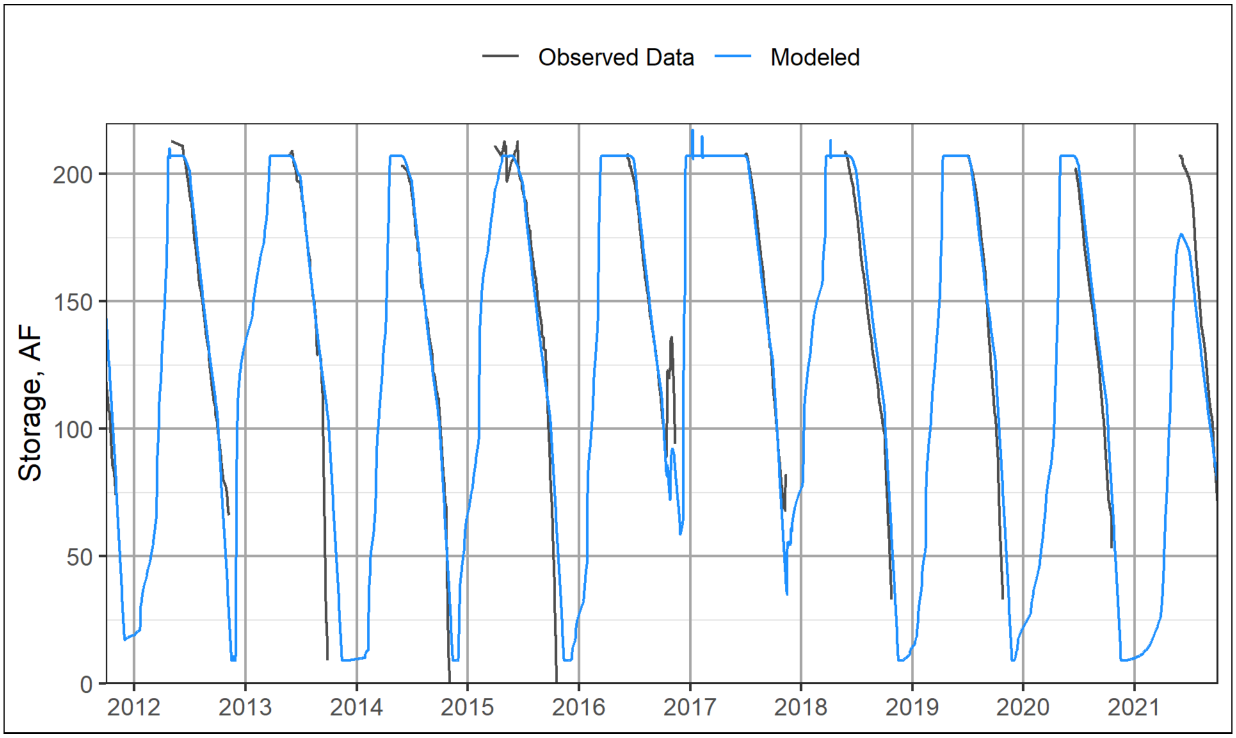

Figure C-13. Upper Rock Lake Storage, Water Years 2012–2021

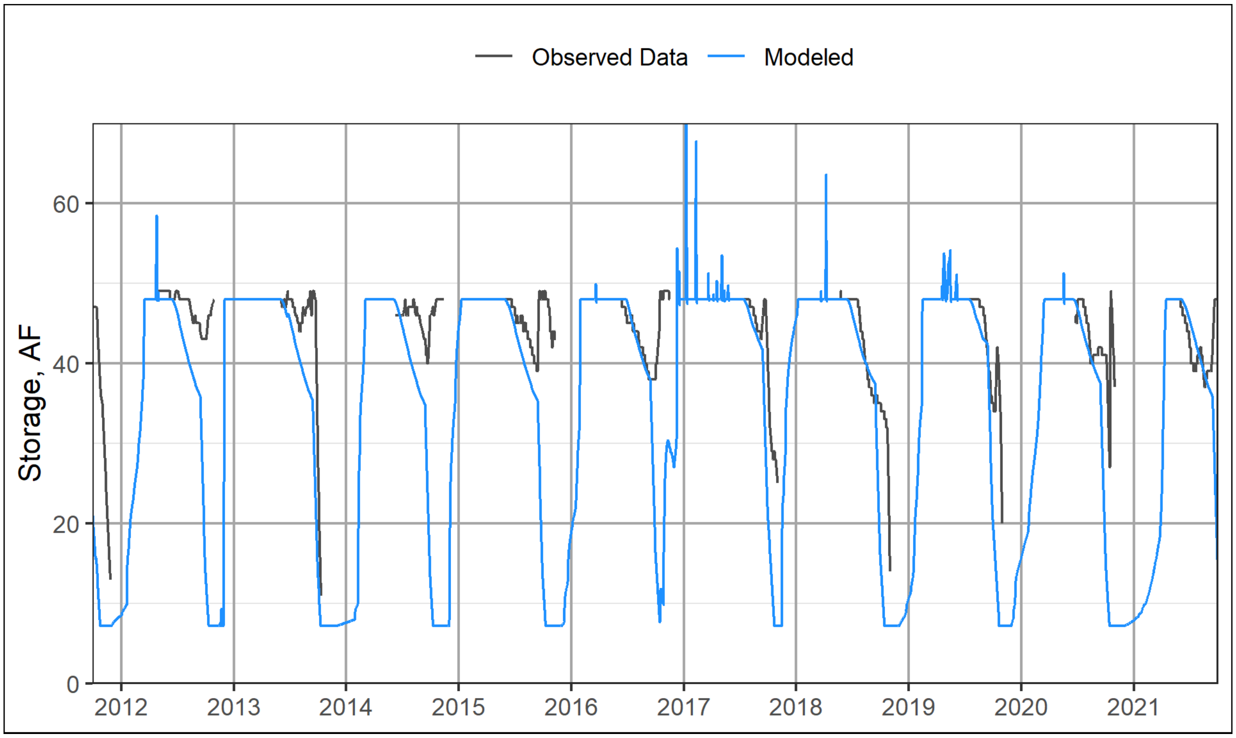

Figure C-14. Lower Rock Lake Storage, Water Years 2012–2021

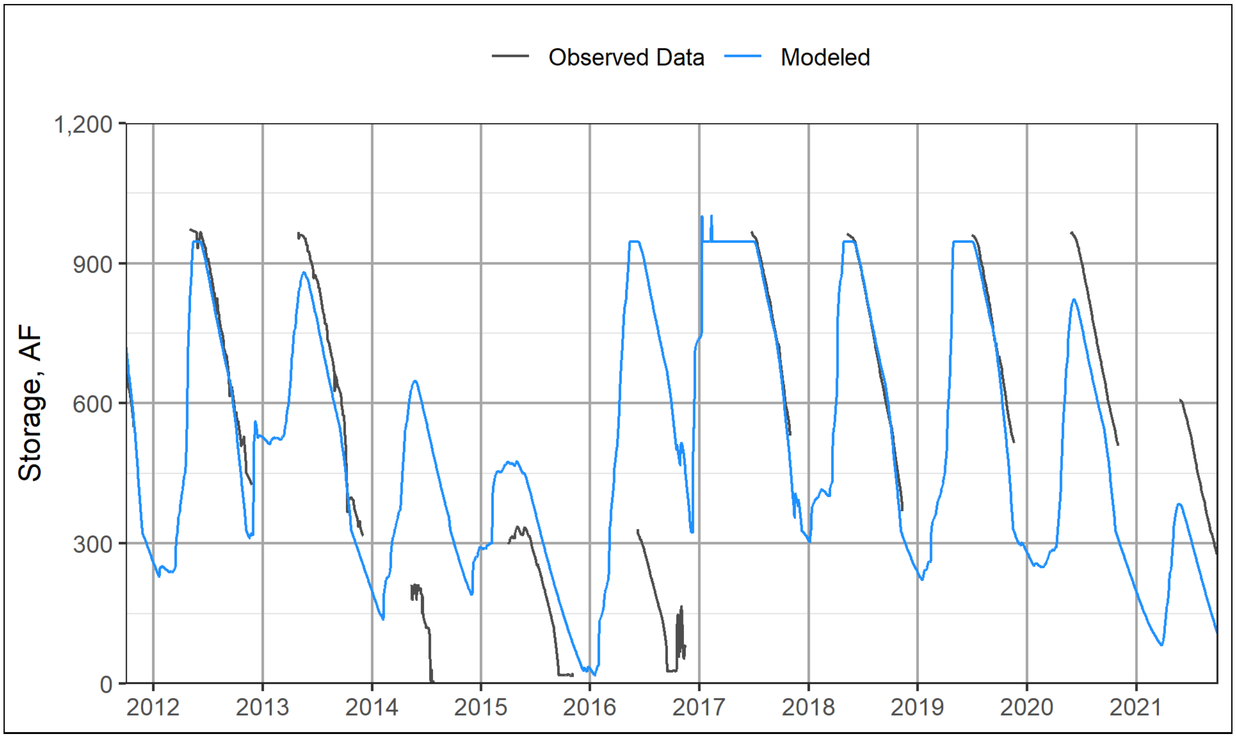

Figure C-15. Culbertson Lake Storage, Water Years 2012–2021

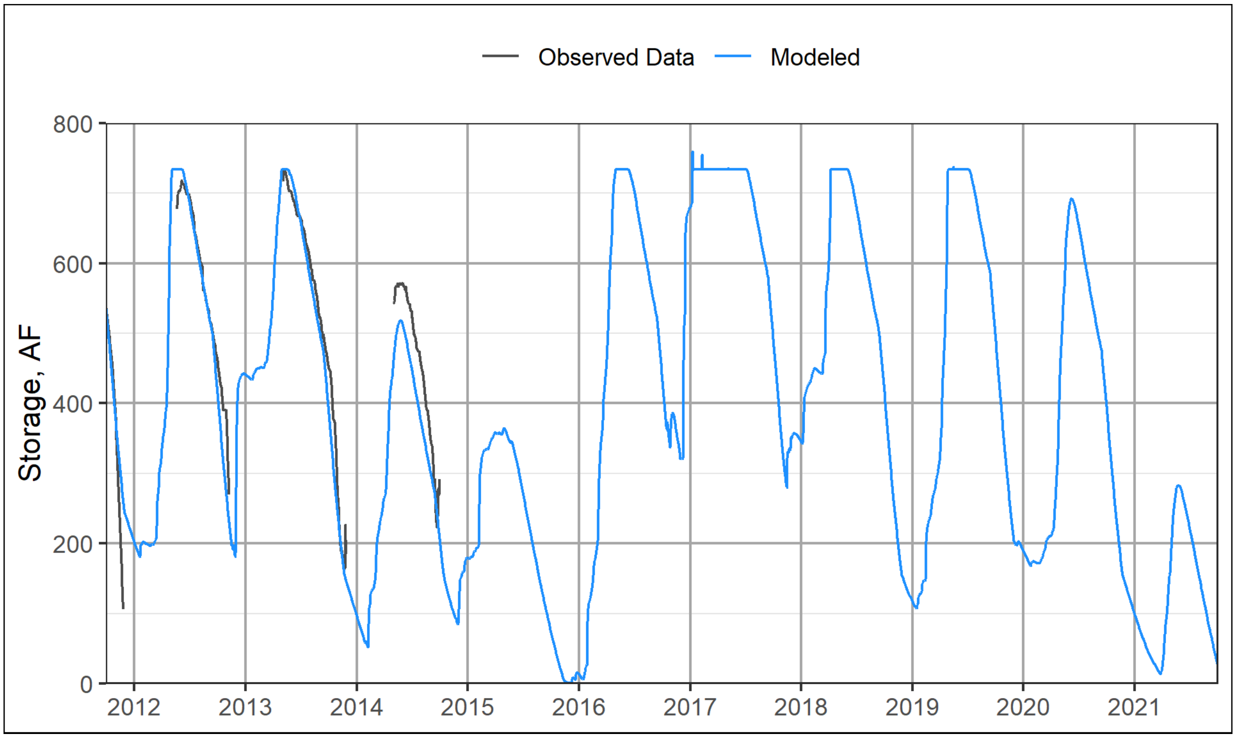

Figure C-16. Feely Lake Storage, Water Years 2012–2021

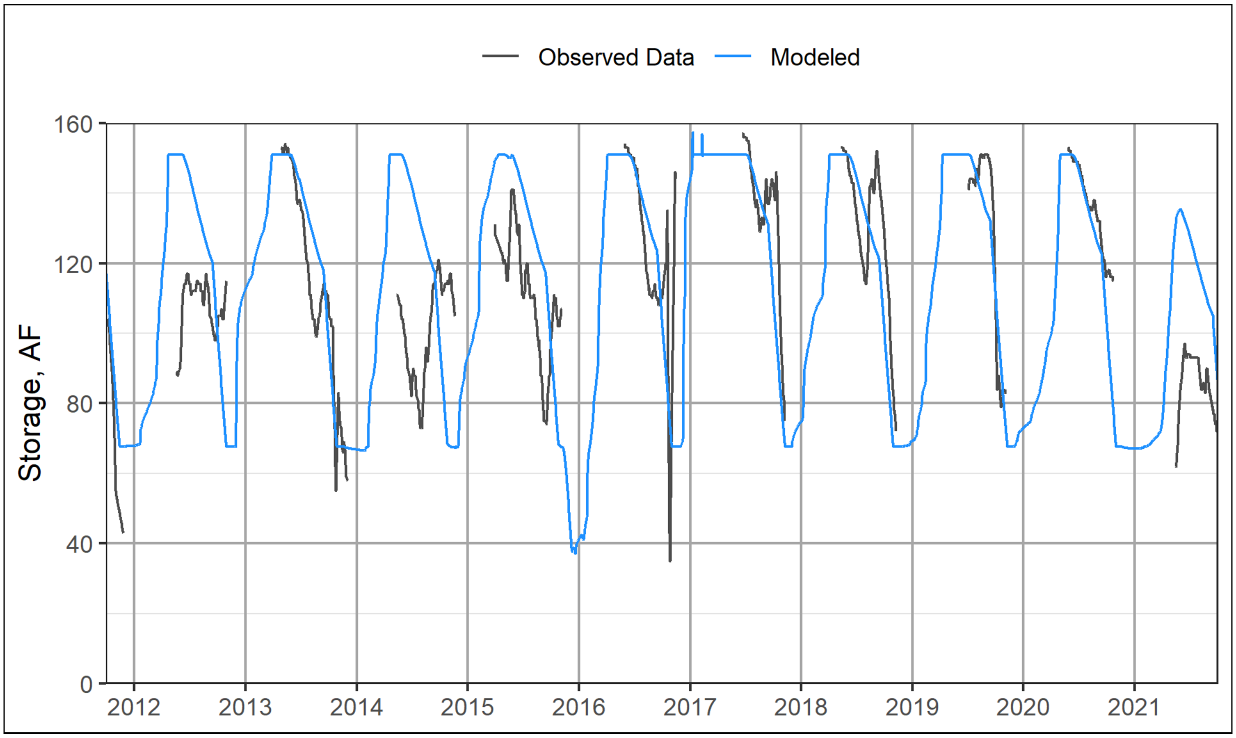

Figure C-17. Carr Lake Storage, Water Years 2012–2021

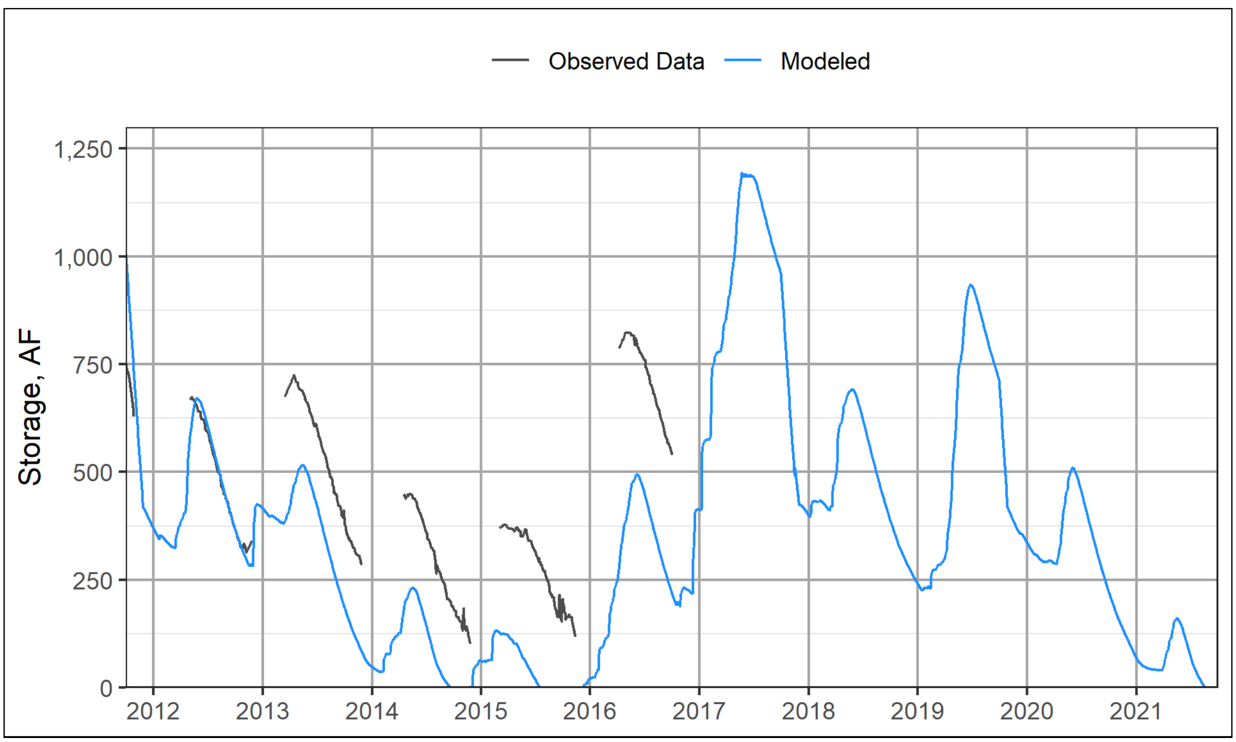

Figure C-18. Blue Lake Storage, Water Years 2012–2021

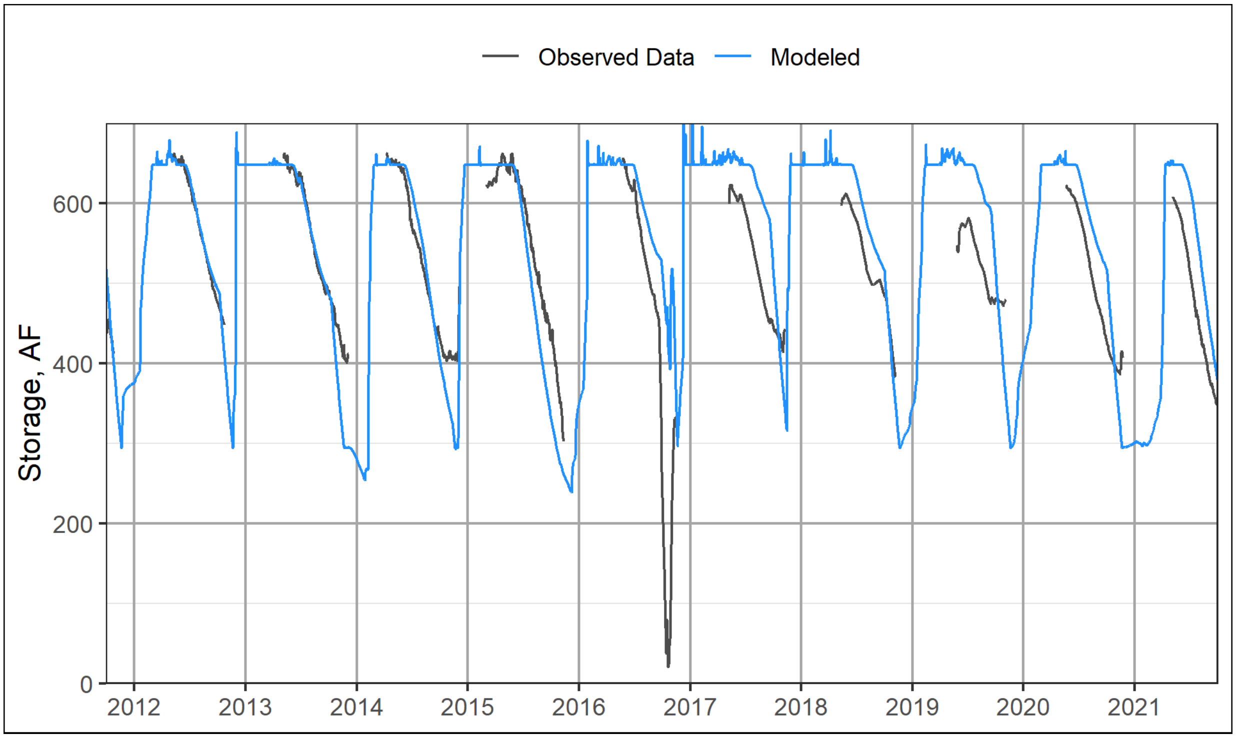

Figure C-19. Rucker Lake Storage, Water Years 2012–2021

Fuller Lake does not have available observed storage, but the reservoir must generally be kept full to maintain head on Spaulding PH No 3.

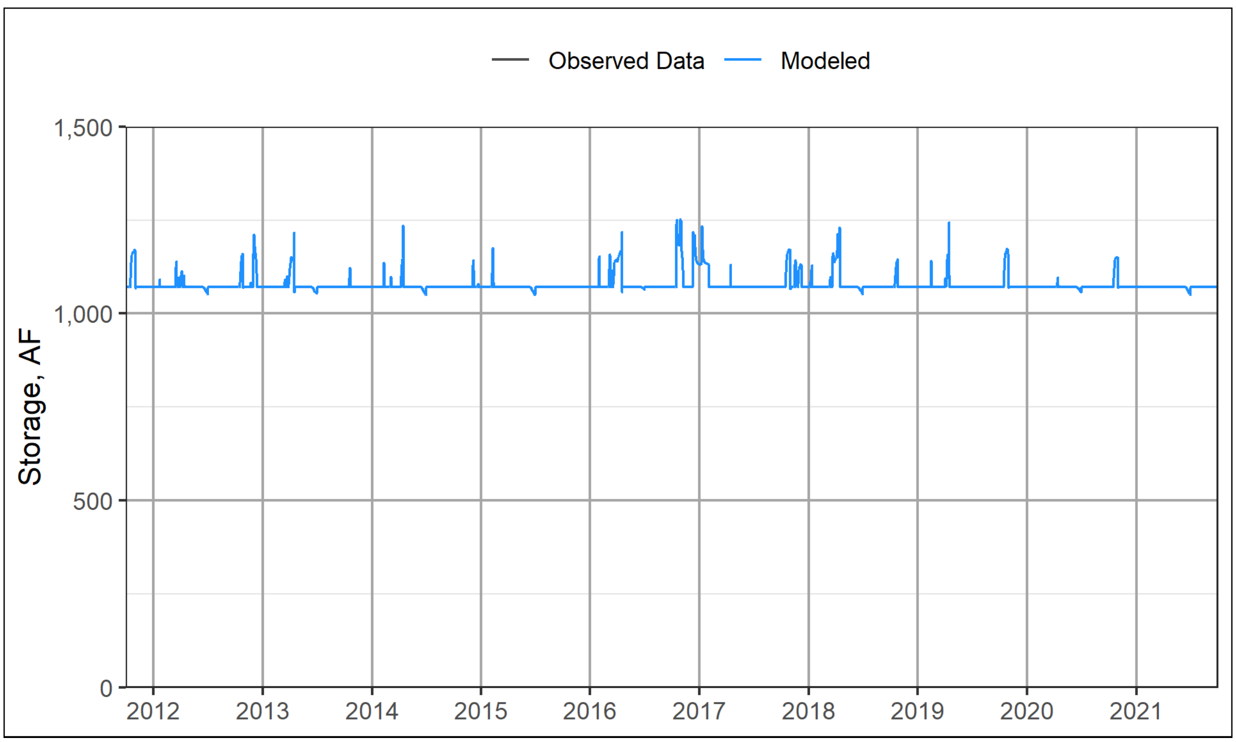

Figure C-20. Fuller Lake Storage, Water Years 2012–2021

C.3.2. Spaulding Powerhouse No. 3

Annual diversions into Spaulding at the end of the Bowman-Spaulding Conduit through Spaulding Powerhouse No 3 are shown in Figure C-21 and Figure C-22.

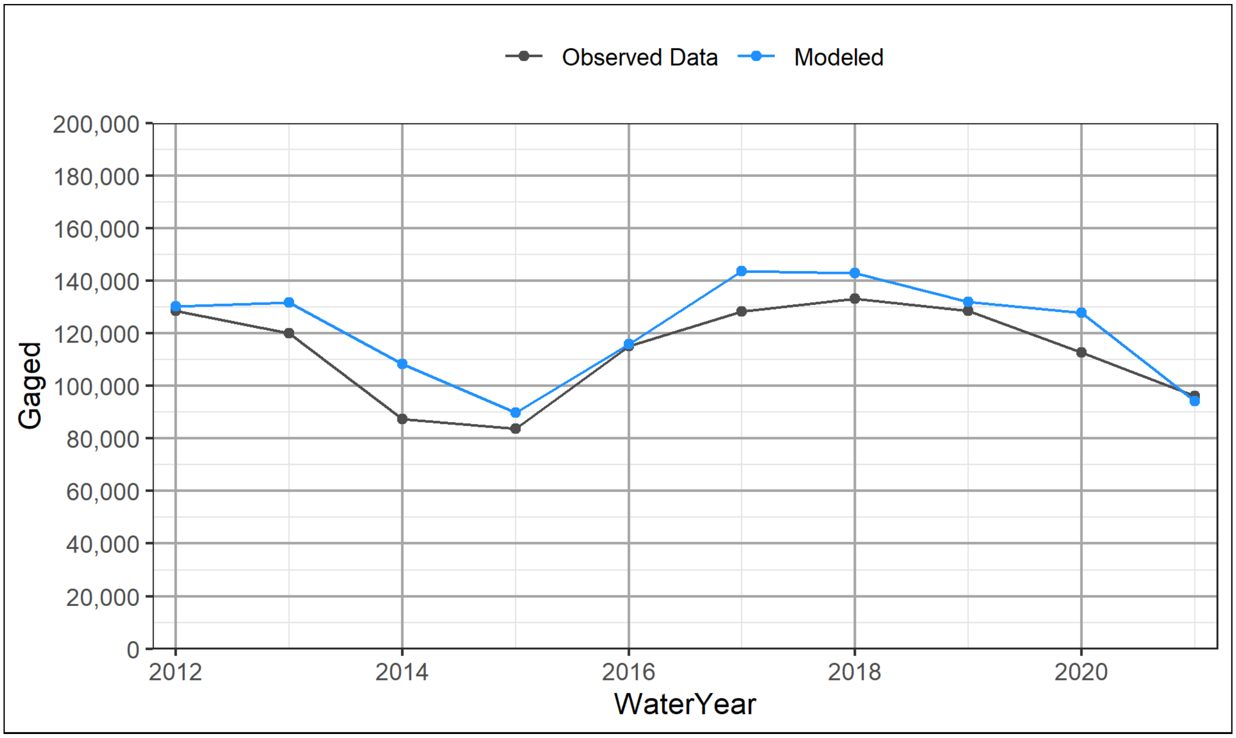

Figure C-21. Annual Flows through Spaulding Powerhouse No. 3, Water Years 2012–2021

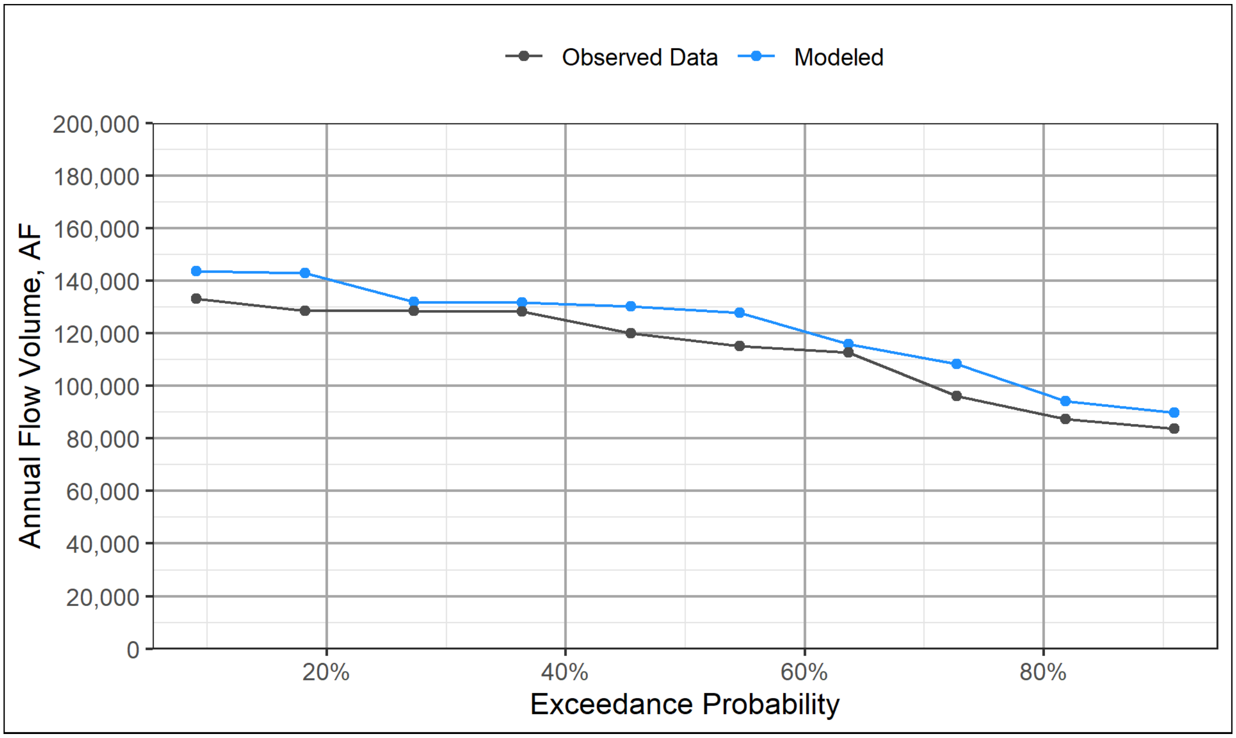

Figure C-22. Annual Flow Exceedance through Spaulding Powerhouse No. 3, Water Years 2012–2021

C.4. South Yuba River

C.4.1. Upstream of Fordyce Lake

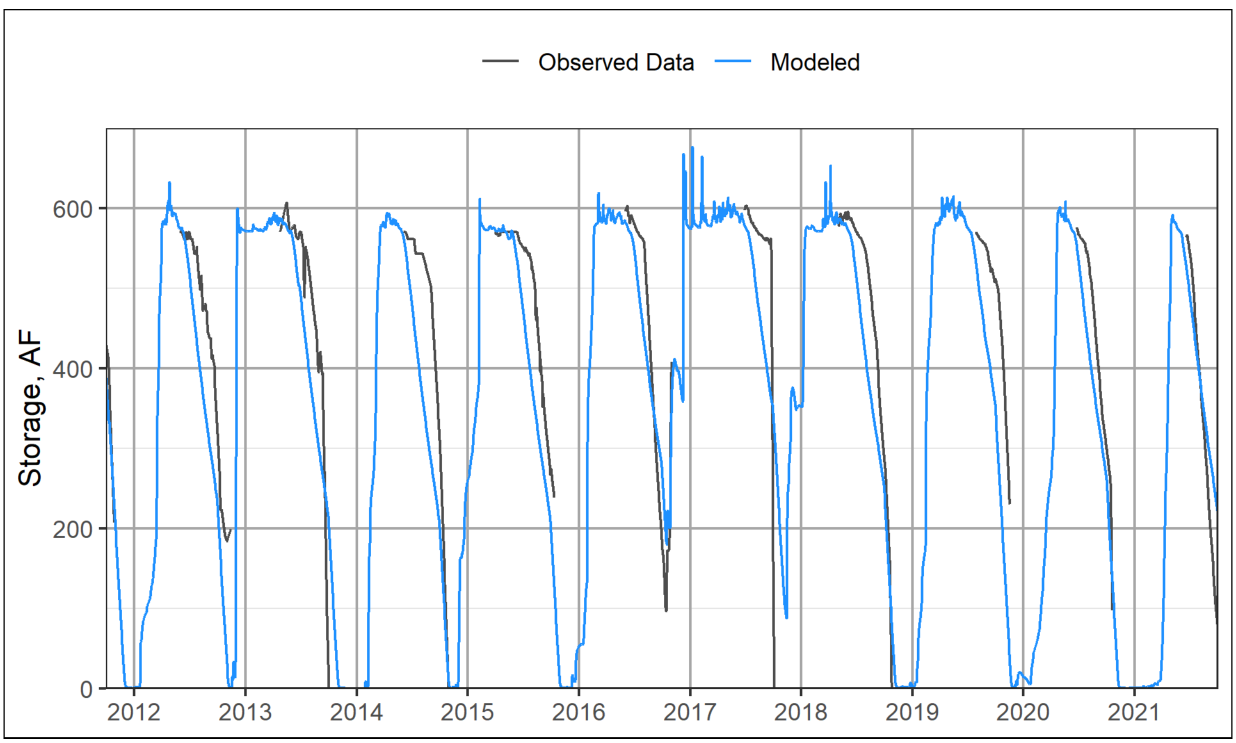

Figure C-23. White Rock Lake Storage, Water Years 2012–2021

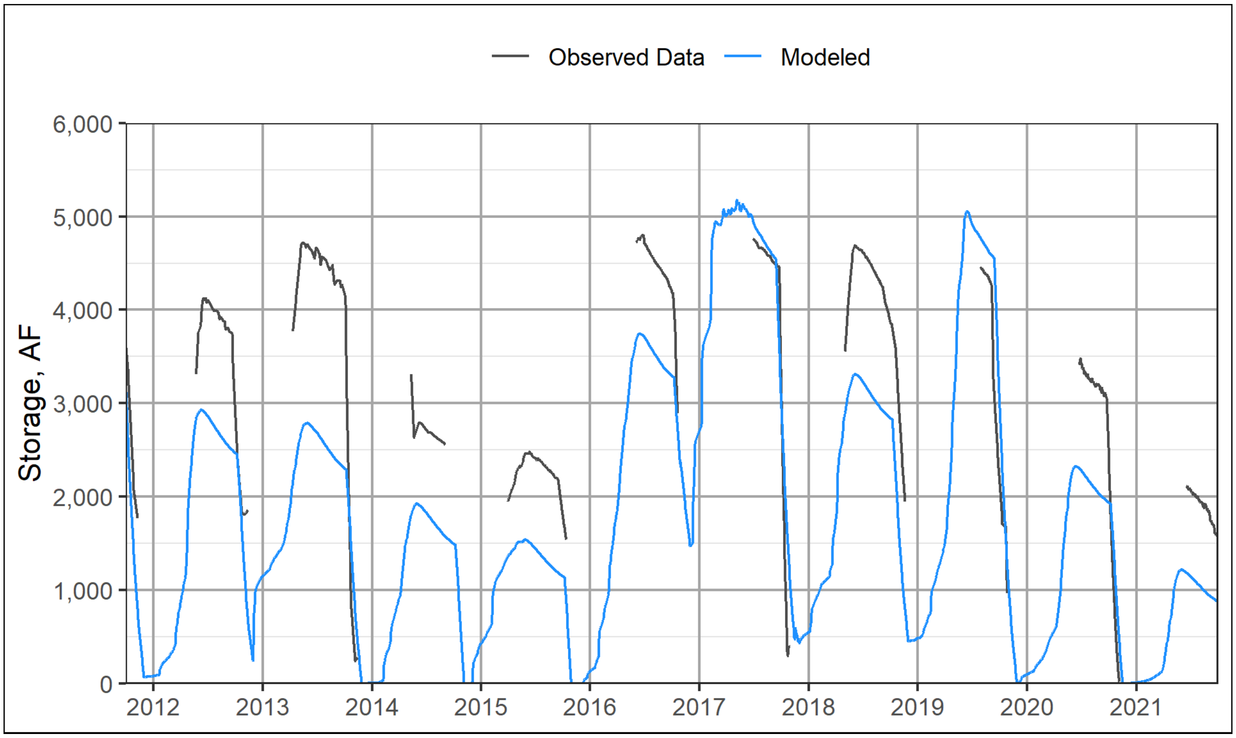

Figure C-24. Meadow Lake Storage, Water Years 2012–2021

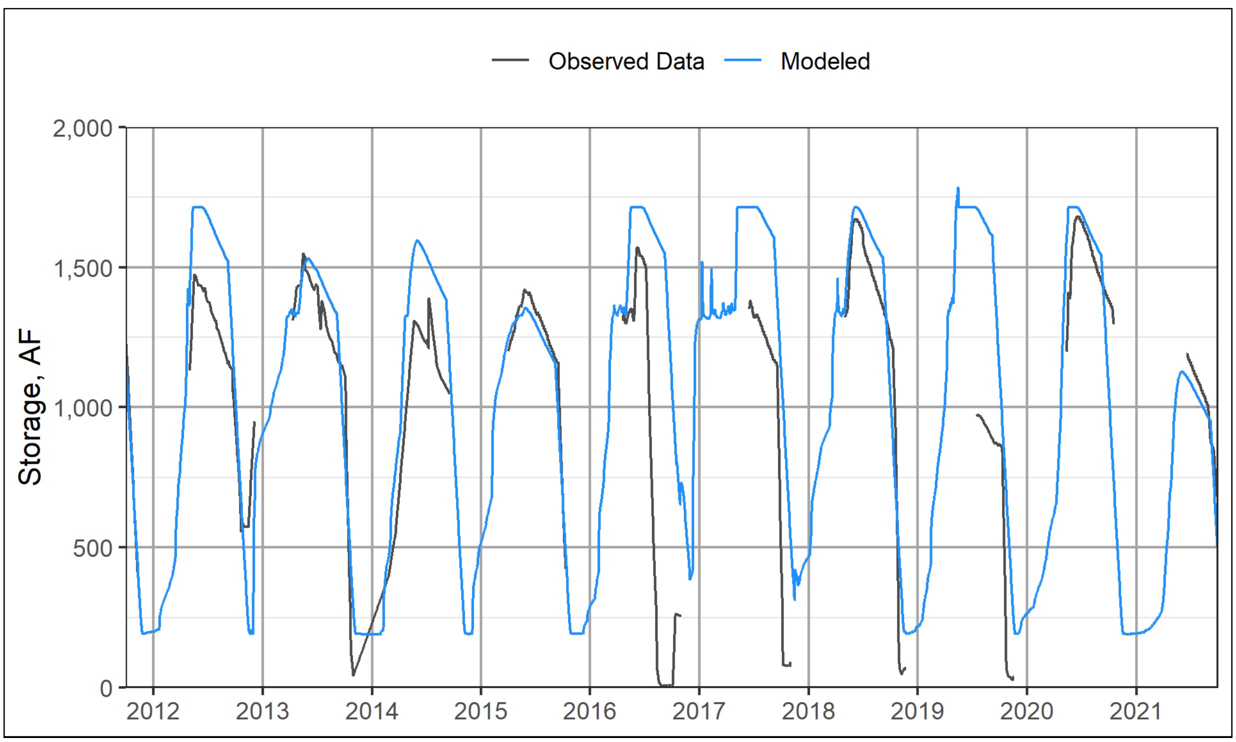

Figure C-25. Lake Sterling Storage, Water Years 2012–2021

C.4.2. Fordyce Lake

Fordyce Lake Operations are difficult to capture. Historical carryover ranges from 4–20 TAF, with no consistency regarding year type. Reservoir fill levels generally match observed values with the notable exception of 2021.

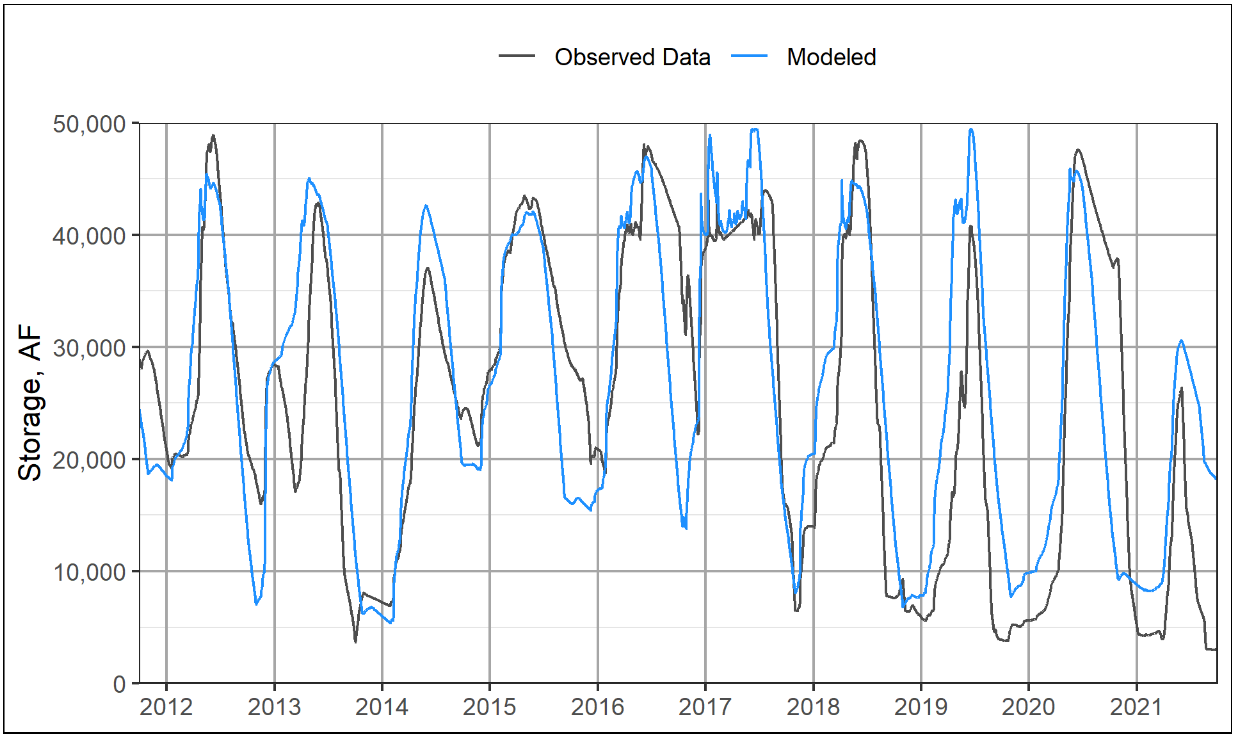

Figure C-26. Fordyce Lake Storage, Water Years 2012–2021

C.4.3. Lake Spaulding

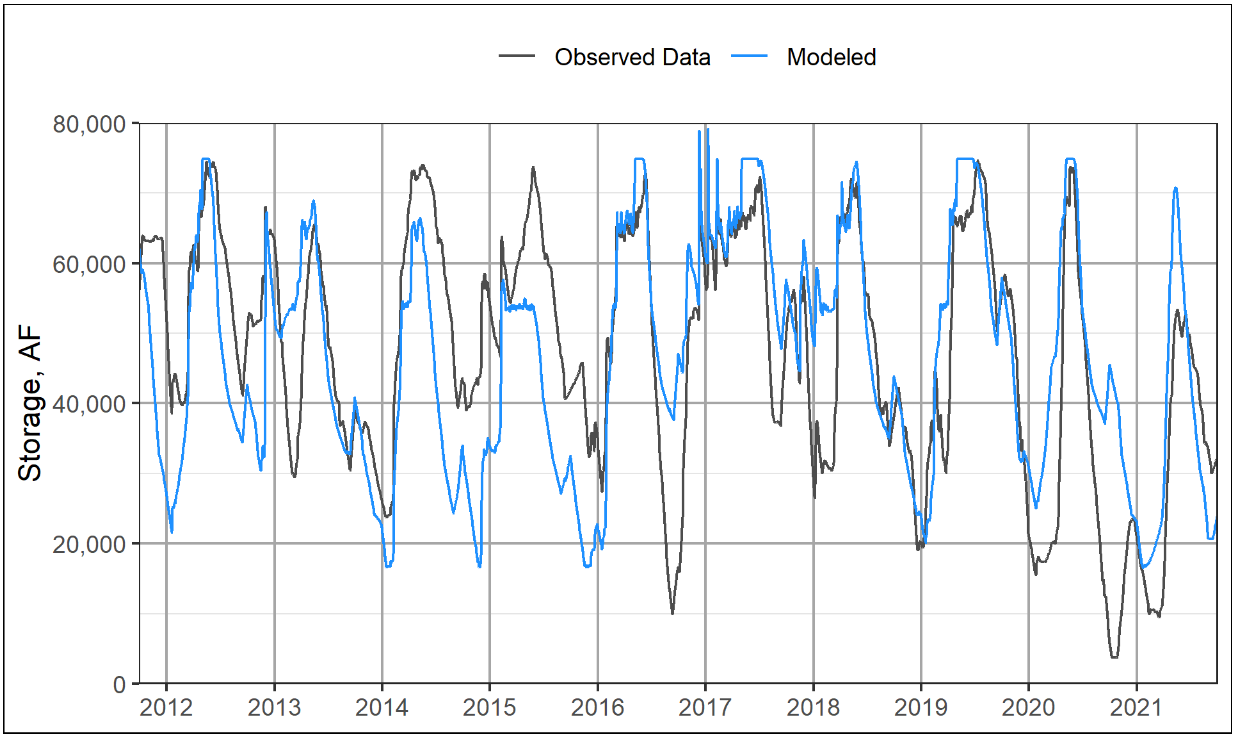

Figure C-27. Lake Spaulding Storage, Water Years 2012–2021

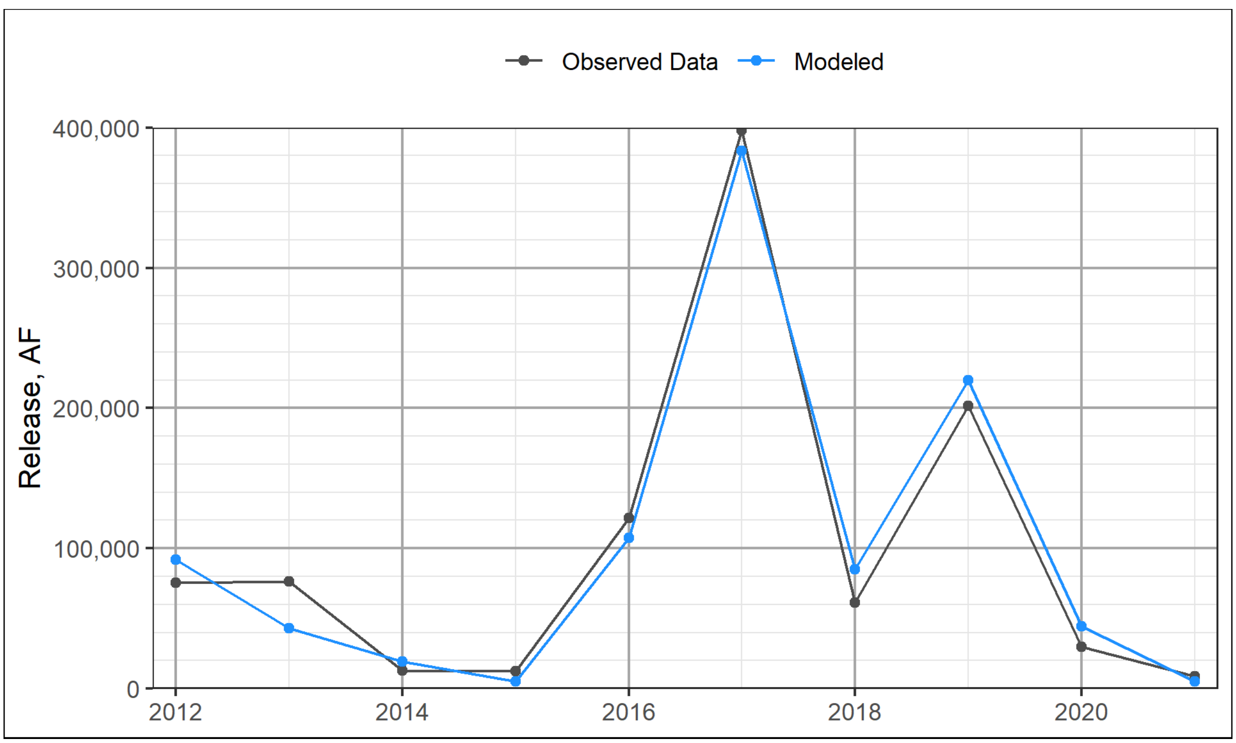

Figure C-28. Release from Lake Spaulding to South Yuba River, Water Years 2012–2021

Annual diversions into Spaulding Powerhouse No. 1 are shown in Figure C-29 and Figure C-30. Annual diversions into Spaulding Powerhouse No. 2 are shown in Figure C-31 and Figure C-32.

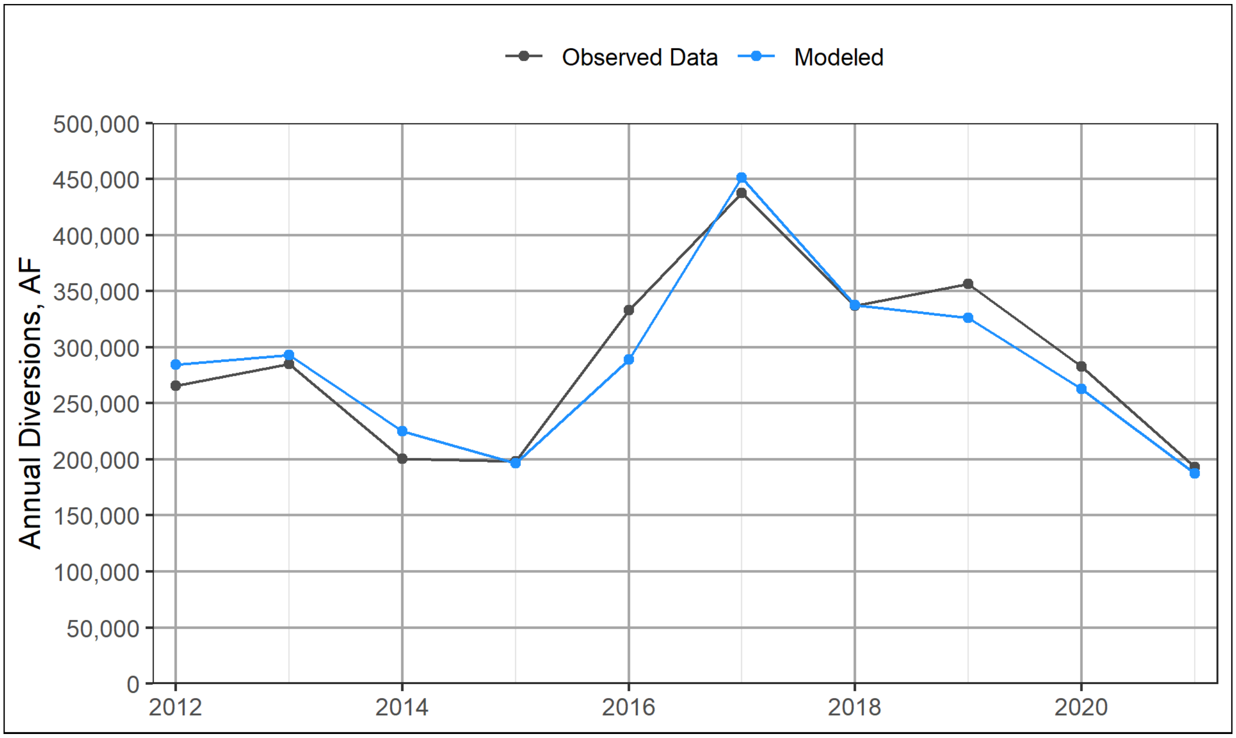

Figure C-29. Annual Flows through Spaulding Powerhouse No. 1, Water Years 2012–2021

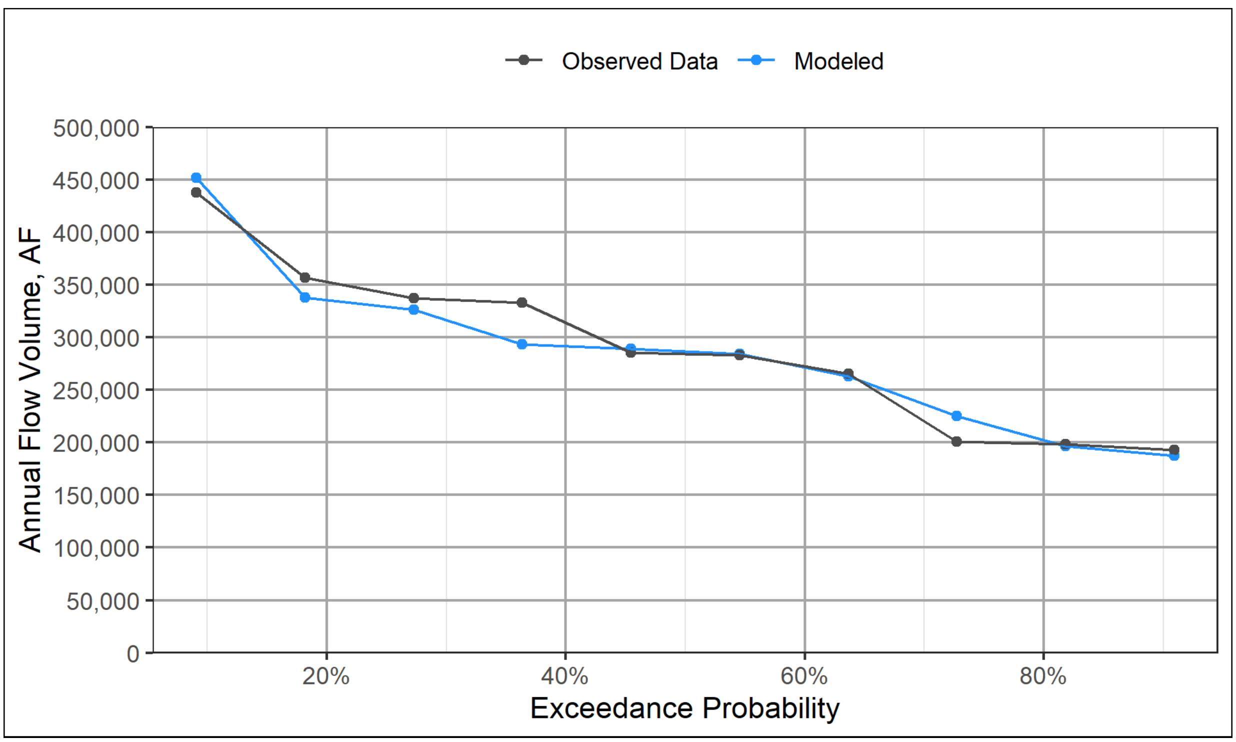

Figure C-30. Annual Flow Exceedance through Spaulding Powerhouse No. 1, Water Years 2012–2021

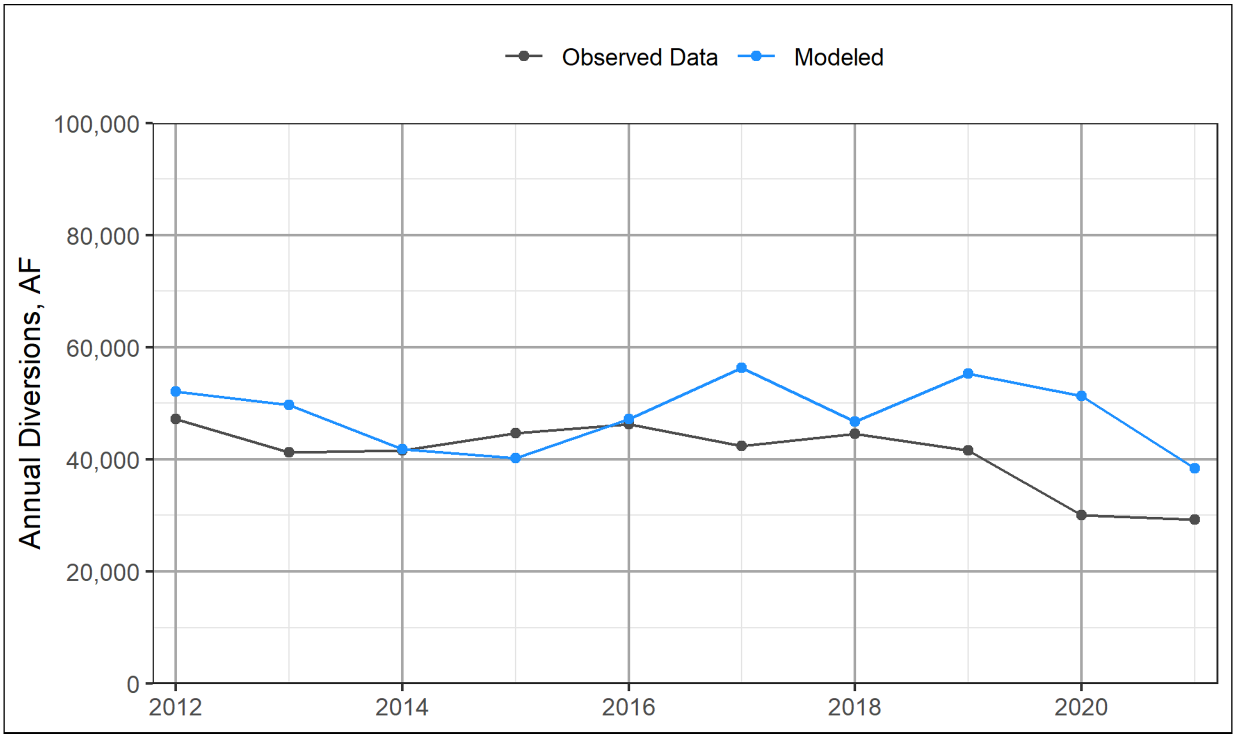

Figure C-31. Annual Flows through Spaulding Powerhouse No. 2, Water Years 2012–2021

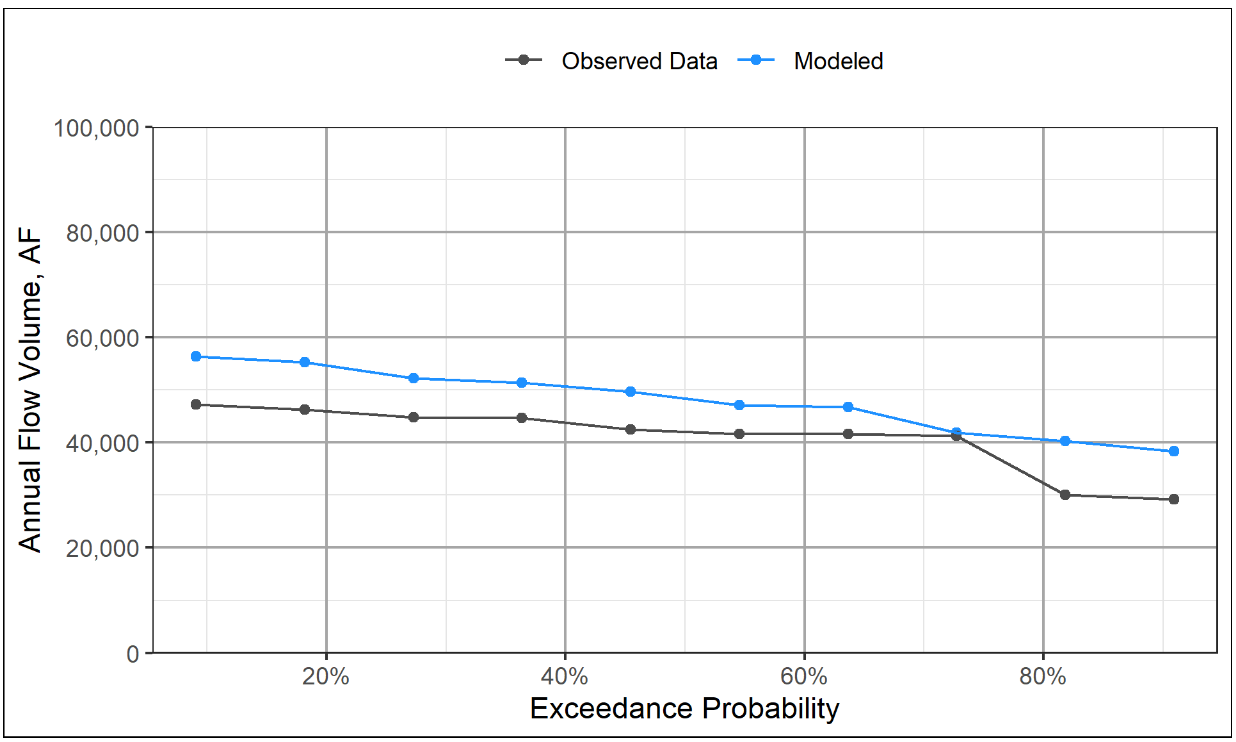

Figure C-32. Annual Flow Exceedance through Spaulding Powerhouse No. 2, Water Years 2012–2021

C.5. North Fork American River

C.5.1. Lake Valley Reservoir

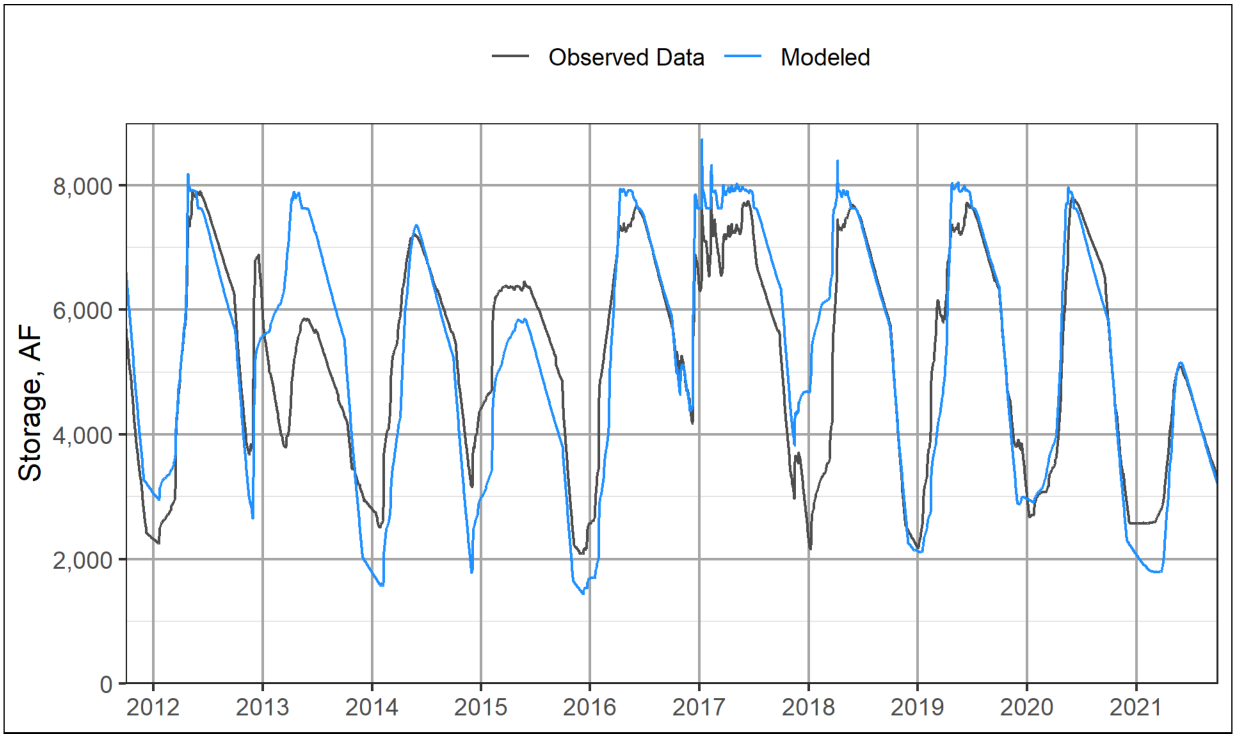

Figure C-33. Lake Valley Reservoir Storage, Water Years 2012–2021

C.5.2. Kelly Lake

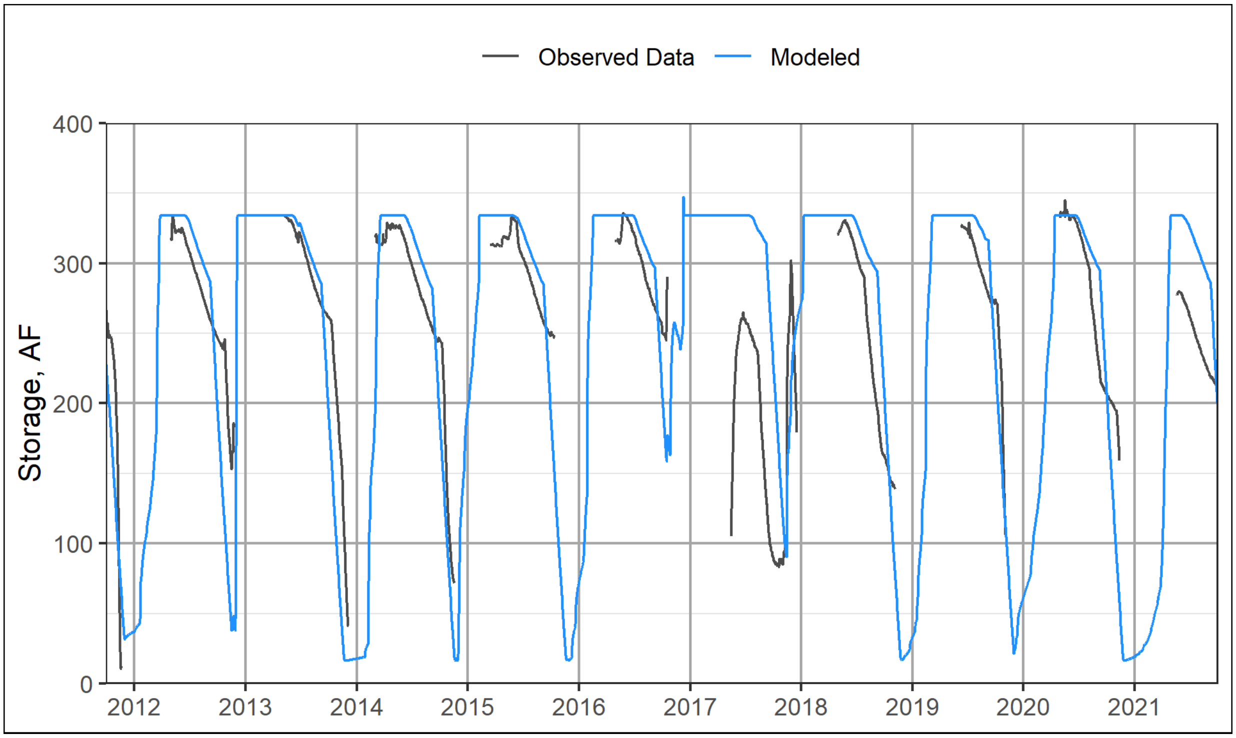

Figure C-34. Kelly Lake Storage, Water Years 2012–2021

C.5.3. Lake Valley Canal Flows

The Lake Valley Canal was piped in 2014, which resulted in a reduced capacity for the conduit. The model reflects the current capacity of the conduit and does not match flows pre-canal piping. For this reason, flows in the Lake Valley Canal are only compared for the period of water years 2015–2021.

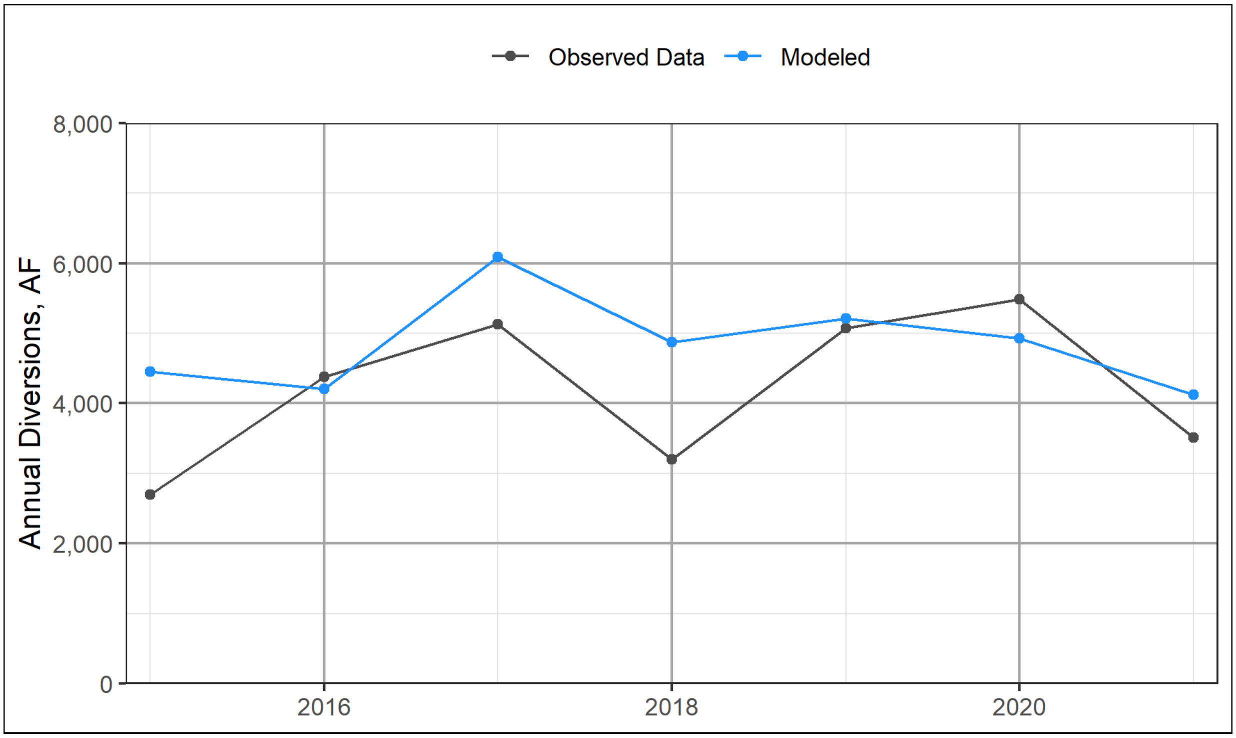

Figure C-35. Annual Diversions into Lake Valley Canal, Water Years 2015–2021

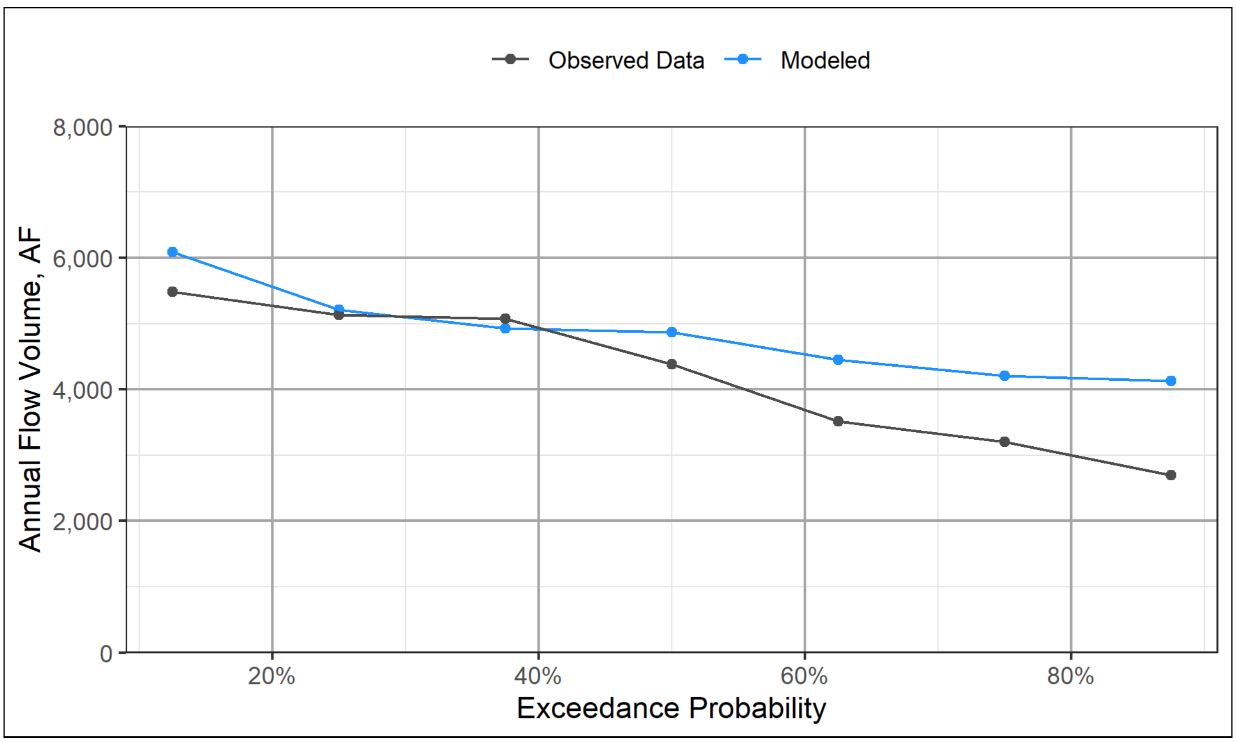

Figure C-36. Annual Diversions into Lake Valley Canal Exceedance, Water Years 2015–2021

C.5.4. Diversions from Canyon Creek into the Towle Canal

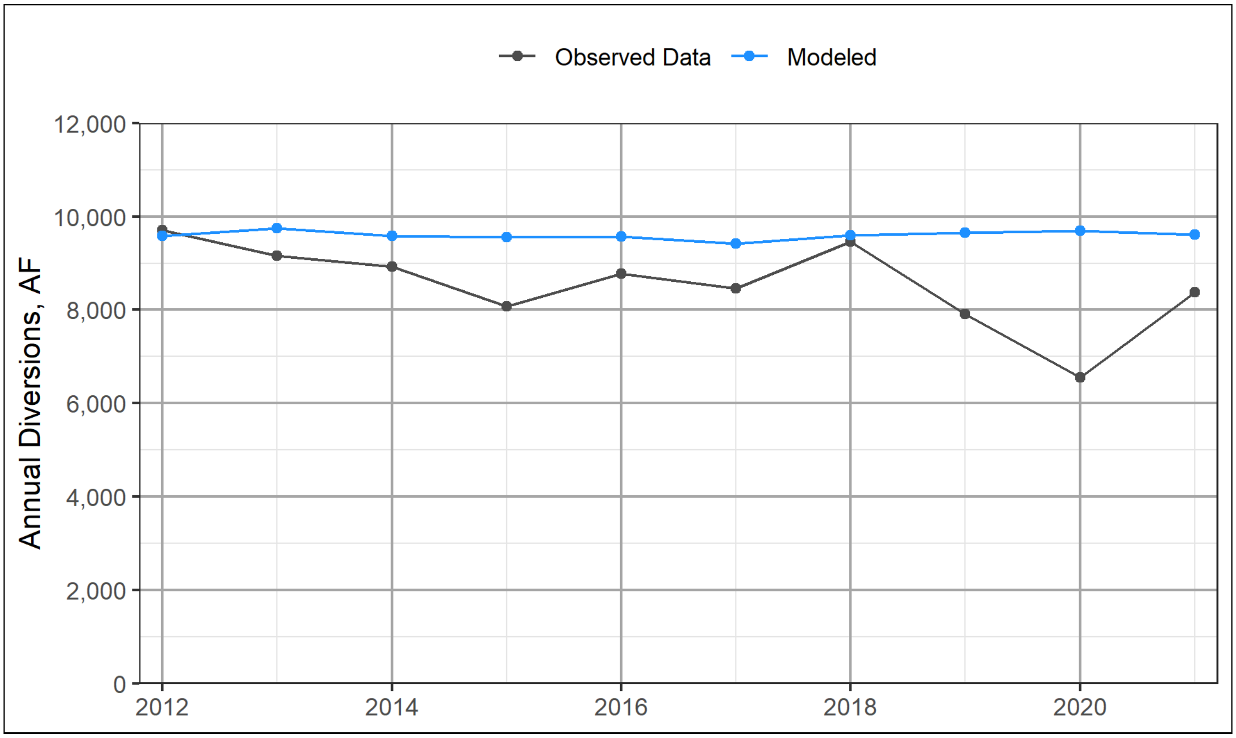

Figure C-37. Annual Diversions into Towle Canal, Water Years 2012–2021

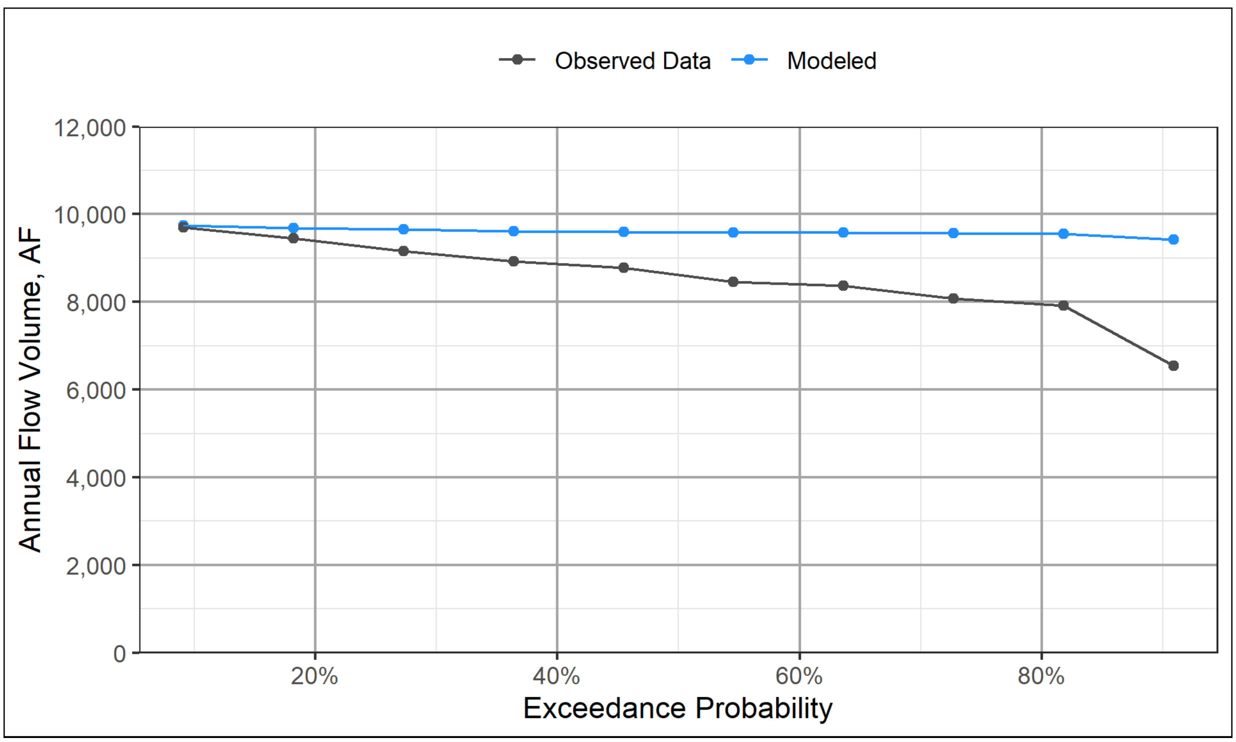

Figure C-38. Annual Diversions into Towle Canal Exceedance, Water Years 2012–2021

C.6. Bear River

C.6.1. Drum Forebay

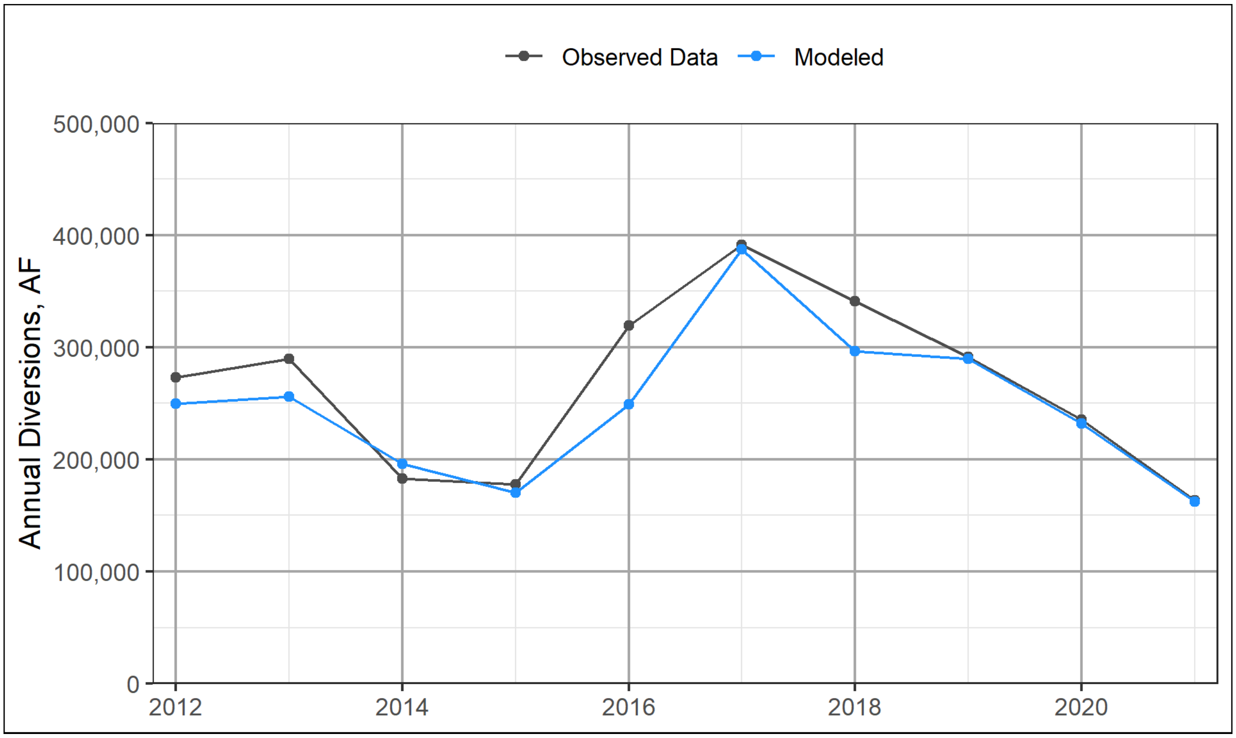

Figure C-39. Annual Flows through Combined Drum Powerhouses, Water Years 2012–2021

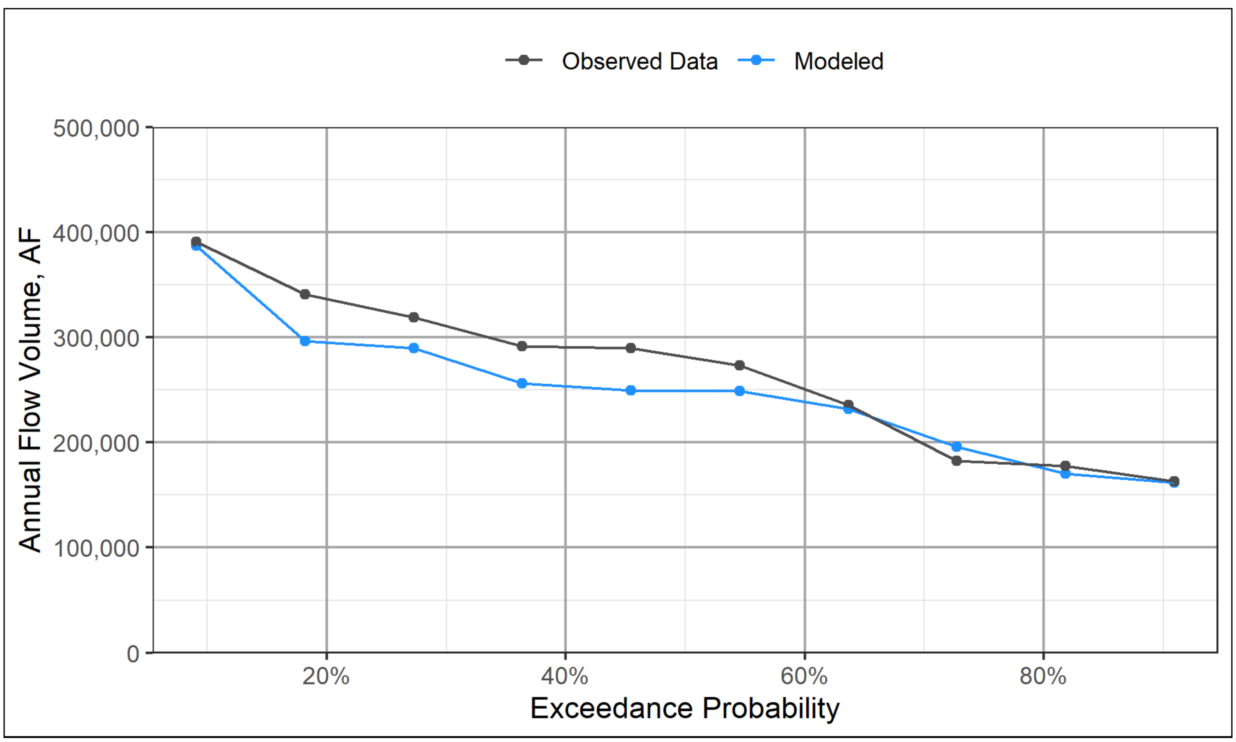

Figure C-40. Annual Flow Exceedance through Combined Drum Powerhouses, Water Years 2012–2021

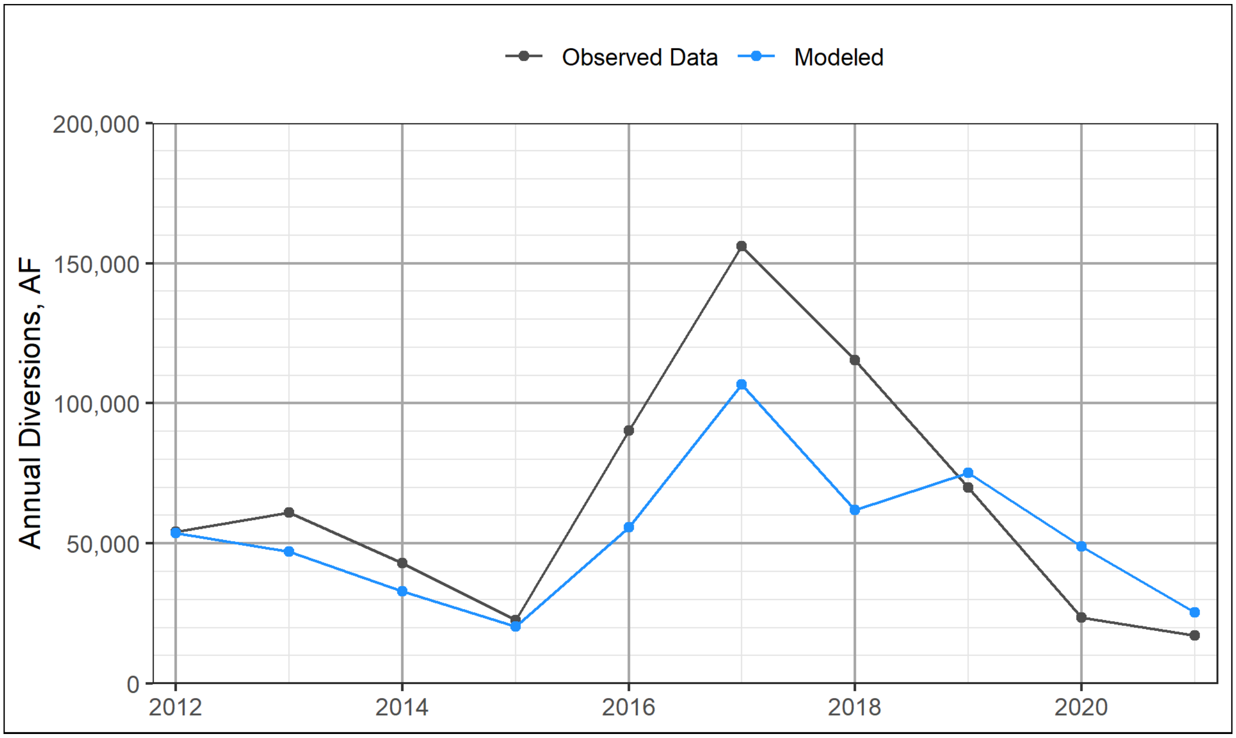

Figure C-41. Annual Flows through Drum Powerhouse No. 1, Water Years 2012–2021

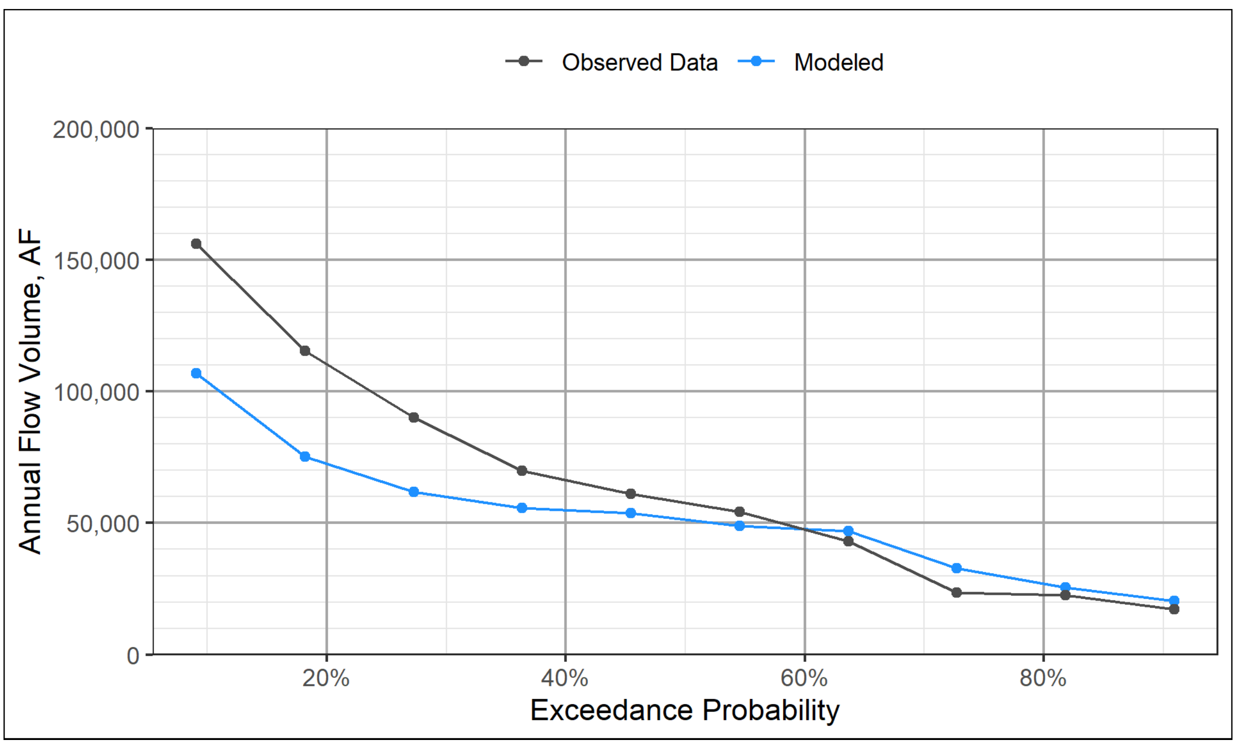

Figure C-42. Annual Flow Exceedance through Drum Powerhouse No. 1, Water Years 2012–2021

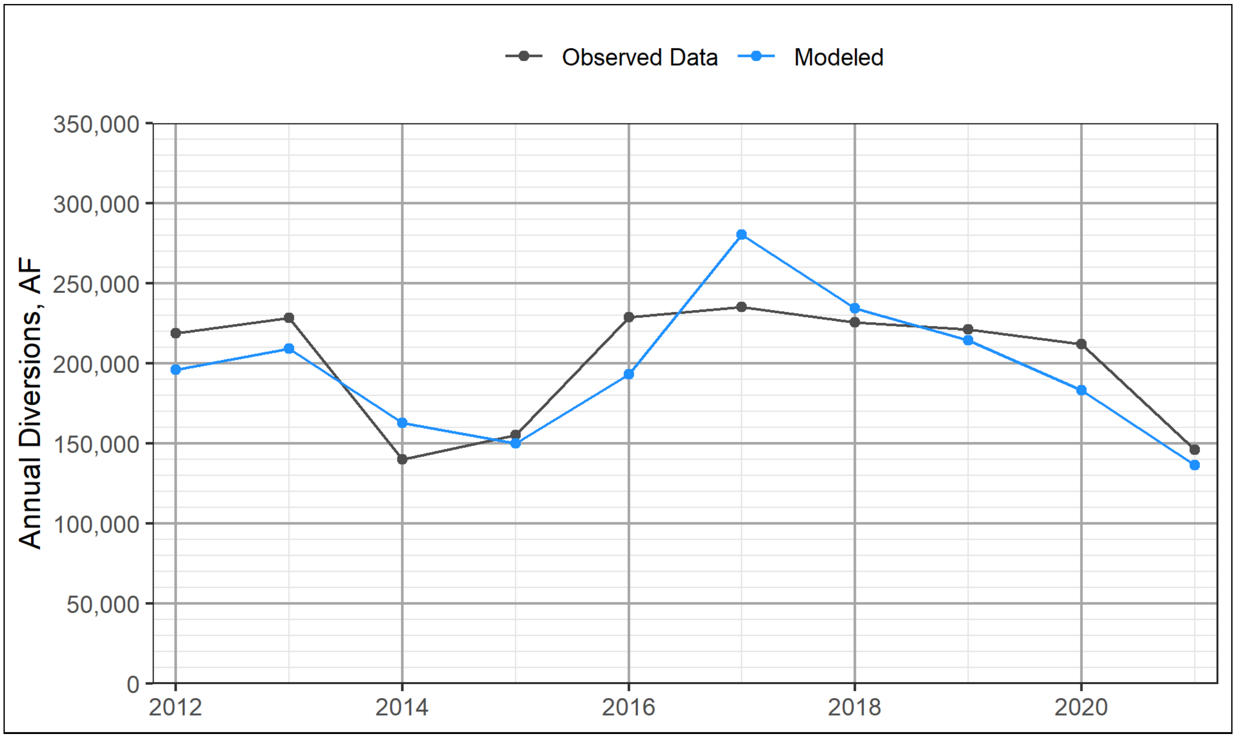

Figure C-43. Annual Flows through Drum Powerhouse No. 2, Water Years 2012–2021

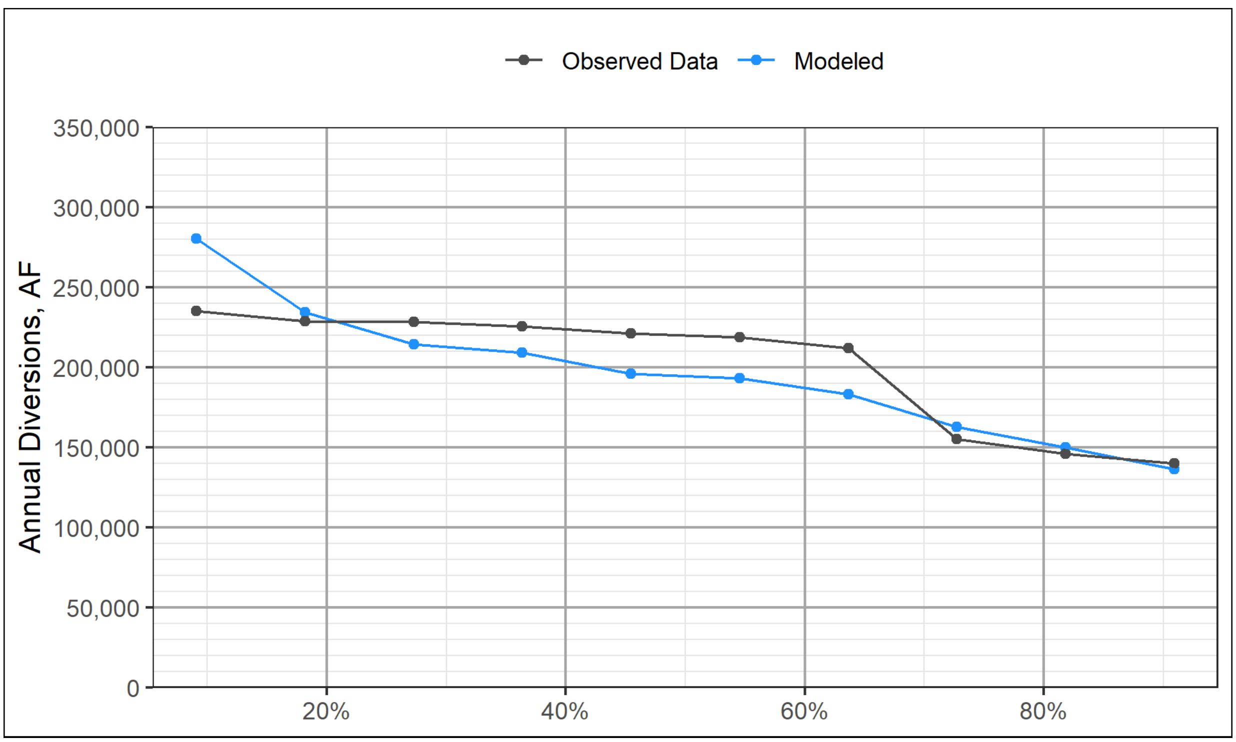

Figure C-44. Annual Flow Exceedance through Drum Powerhouse No. 2, Water Years 2012–2021

C.6.2. Drum Afterbay

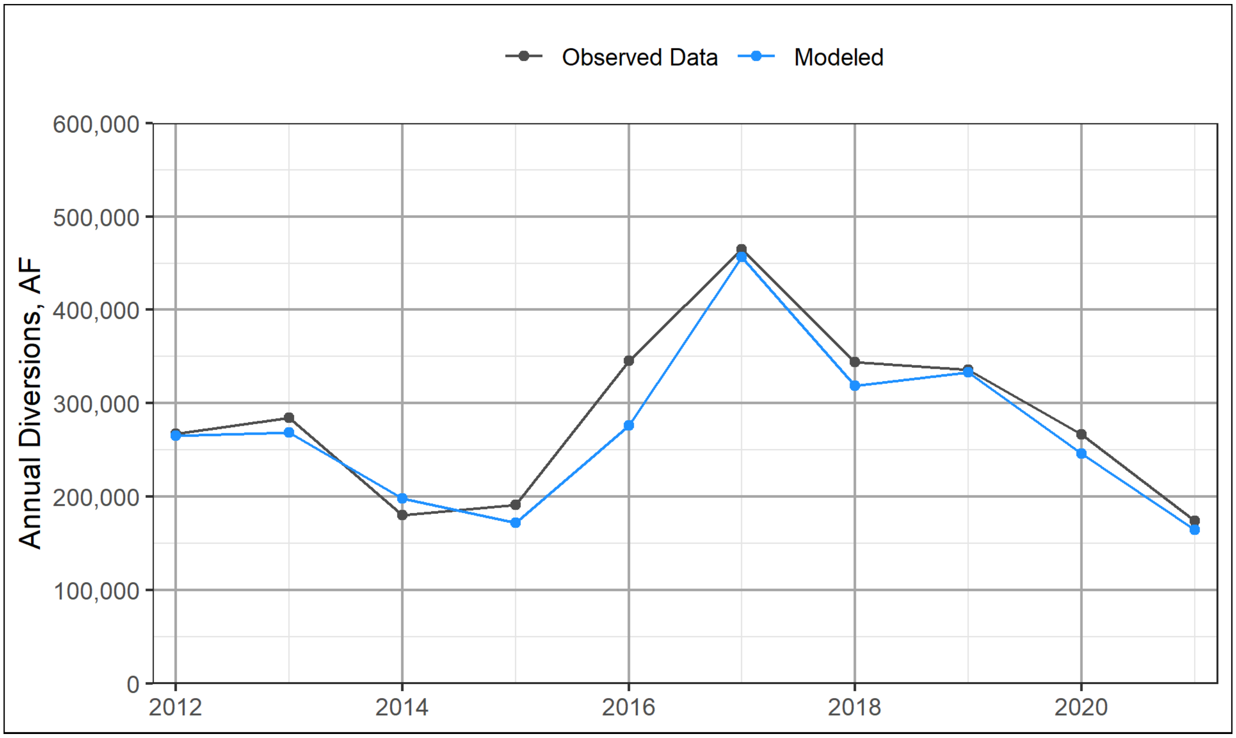

Figure C-45. Annual Flows through Combined Dutch Flat Powerhouses, Water Years 2012–2021

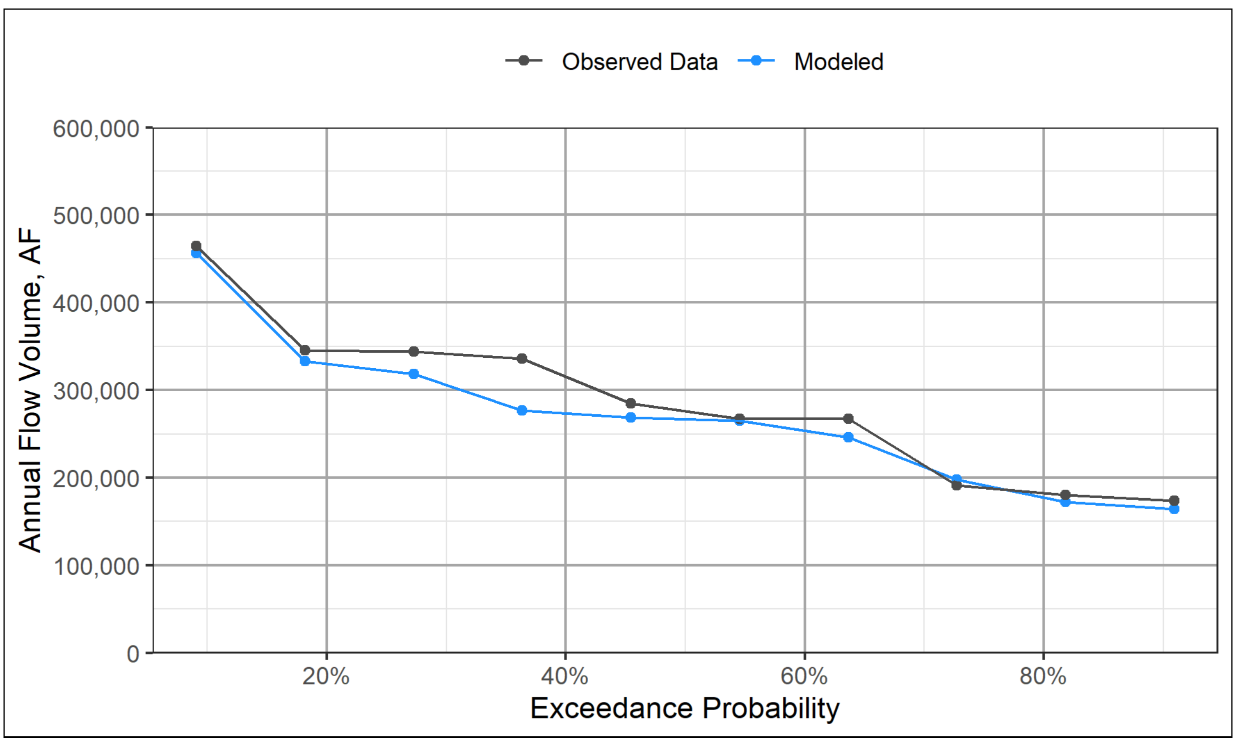

Figure C-46. Annual Flow Exceedance through Combined Dutch Flat Powerhouses, Water Years 2012–2021

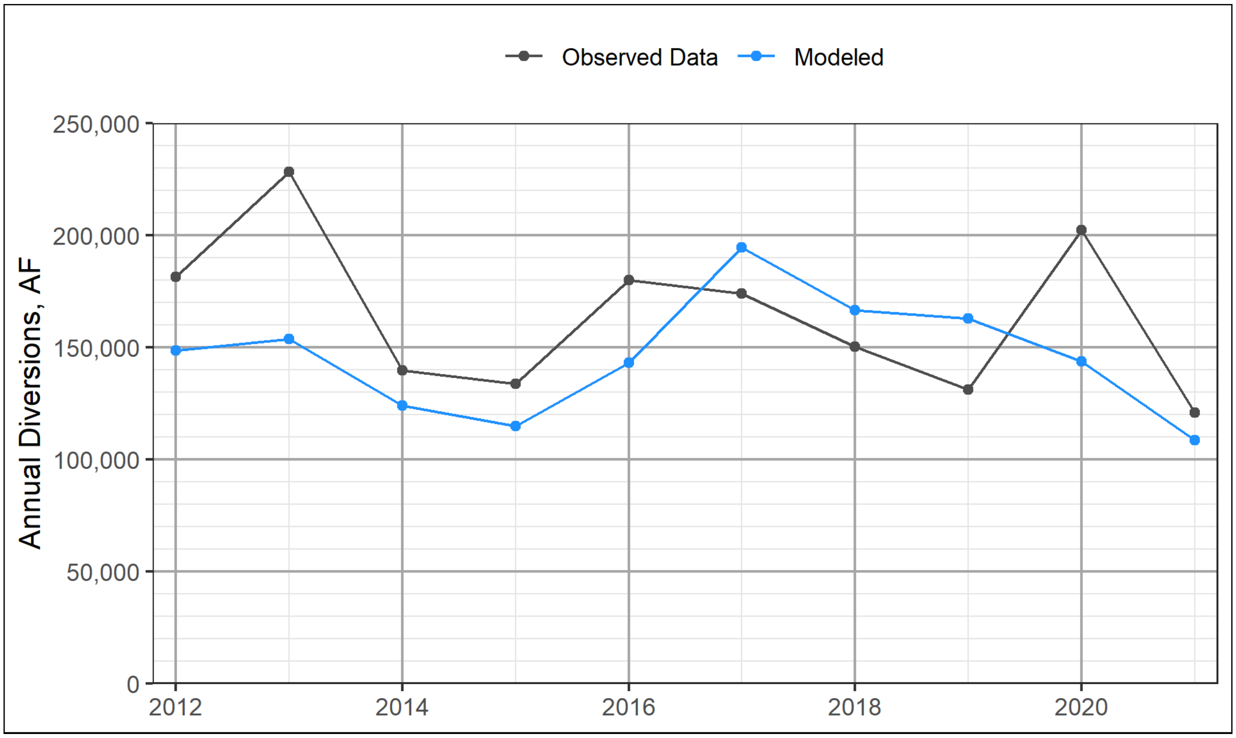

Figure C-47. Annual Flows through Dutch Flat Powerhouse No. 1, Water Years 2012–2021

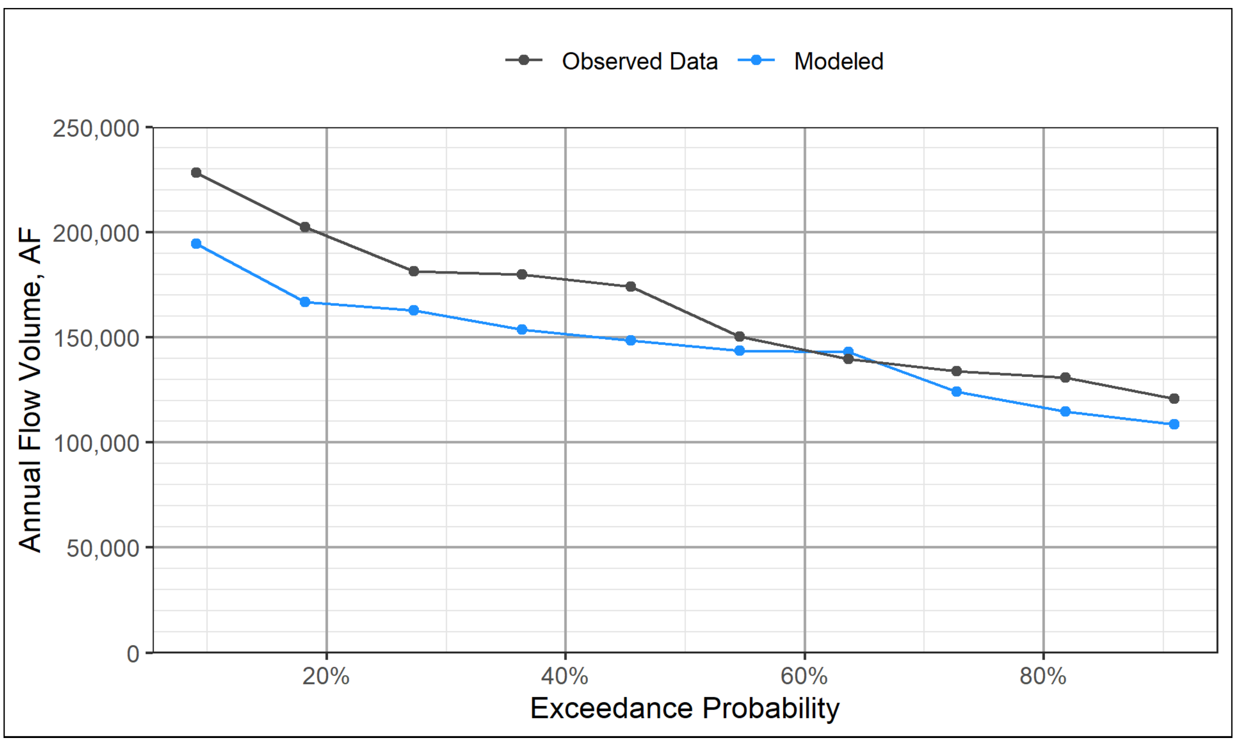

Figure C-48. Annual Flow Exceedance through Dutch Flat Powerhouse No. 1, Water Years 2012–2021

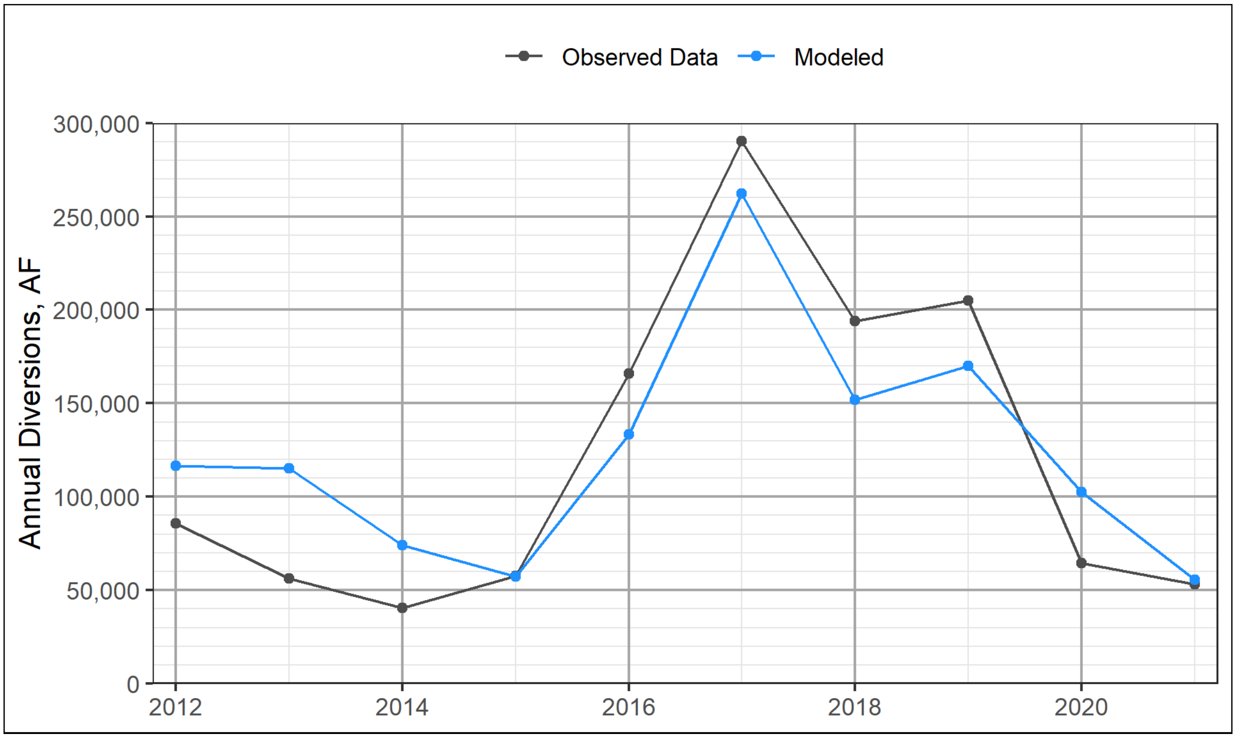

Figure C-49. Annual Flows through Dutch Flat Powerhouse No. 2, Water Years 2012–2021

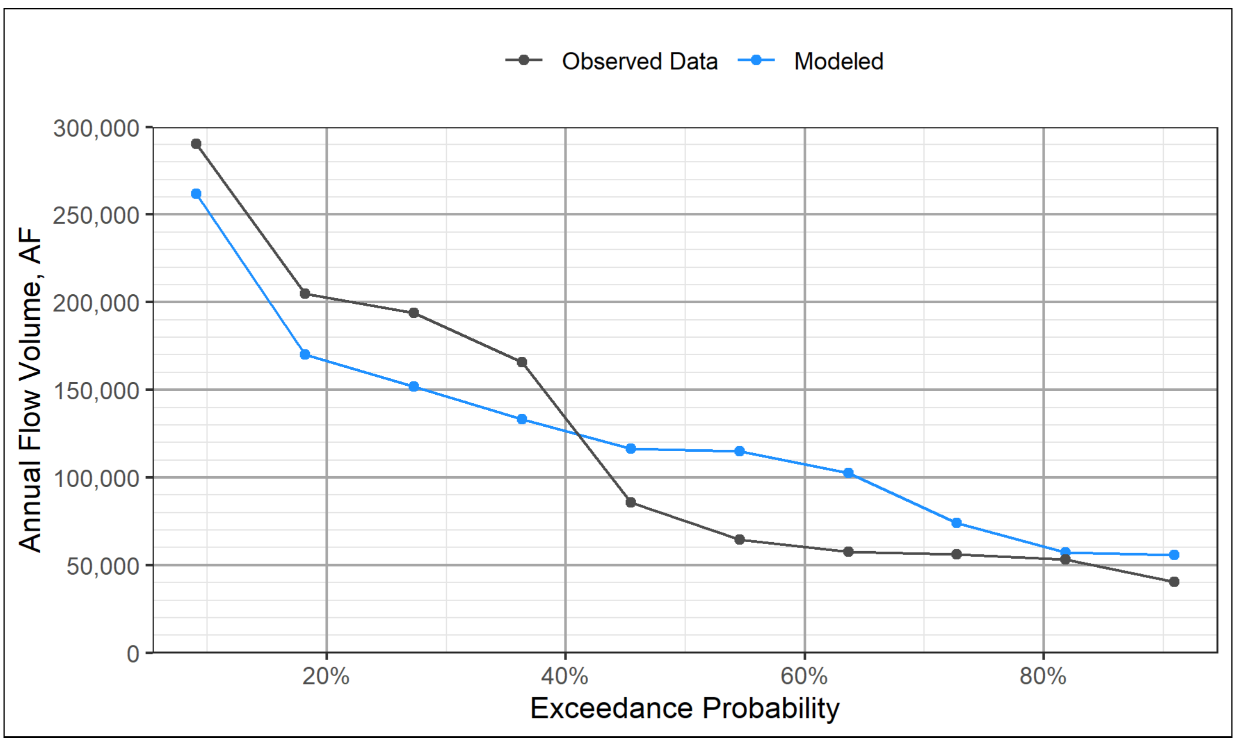

Figure C-50. Annual Flow Exceedance through Dutch Flat Powerhouse No. 2, Water Years 2012–2021

C.6.3. Dutch Flat Afterbay

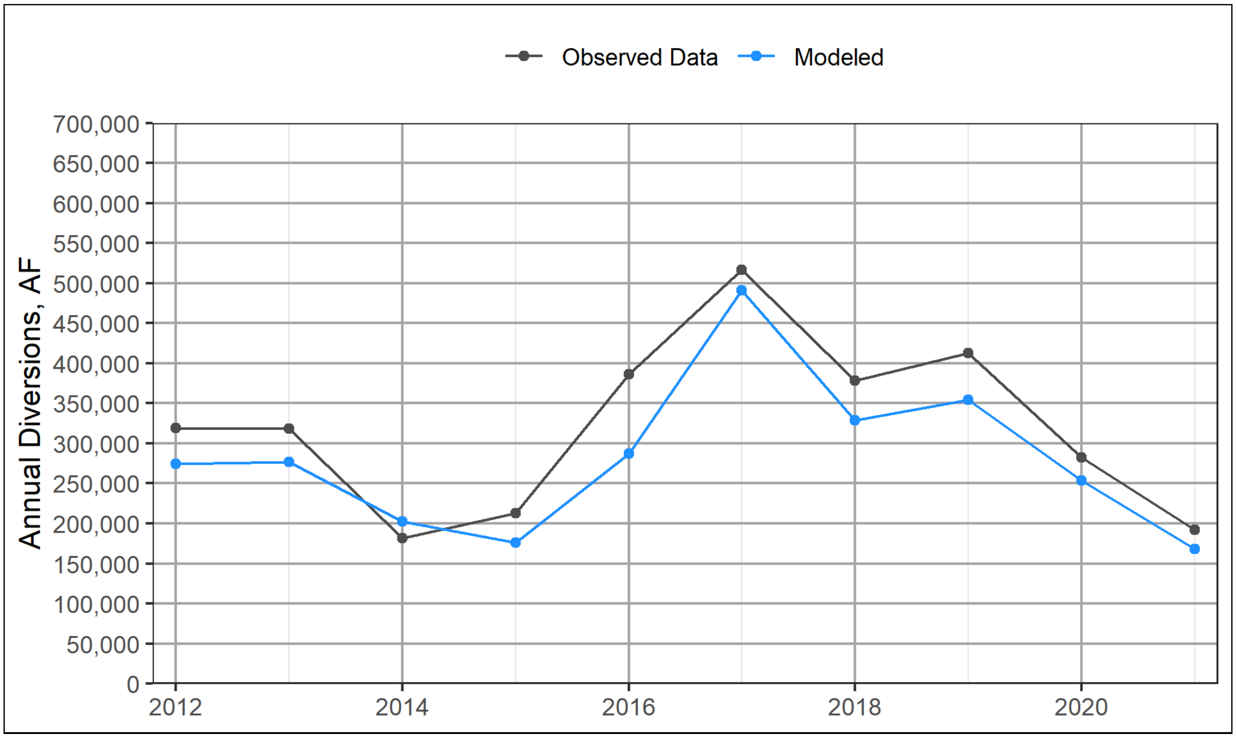

Figure C-51. Annual Flows through Chicago Park Powerhouse, Water Years 2012–2021

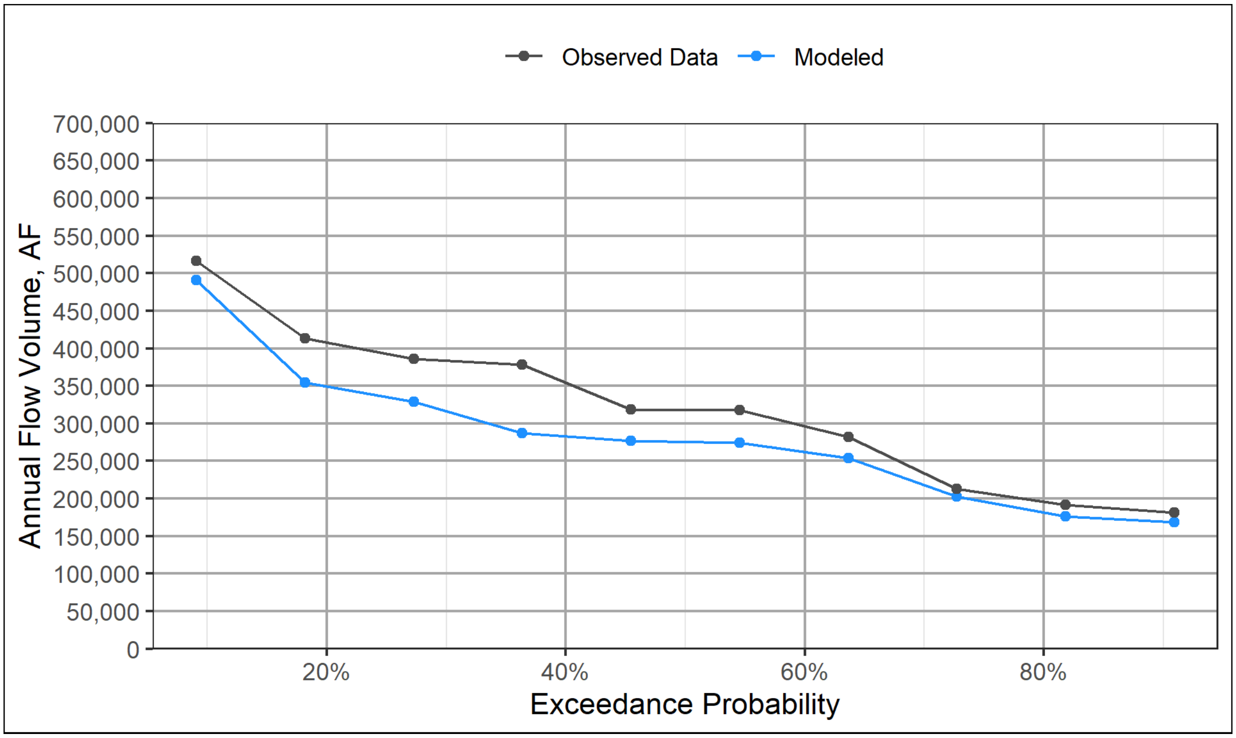

Figure C-52. Annual Flow Exceedance through Chicago Park Powerhouse, Water Years 2012–2021

C.6.4. Rollins Lake

Rollins Lake had a bathymetric survey in 2021, which changed the estimate of storage capacity of the Reservoir. The model uses the new storage-elevation relationship from the updated bathymetric survey, while USGS storage data before 2021 uses the previous storage-elevation relationship. For this reason, Rollins Lake validation uses reservoir elevation rather than storage.

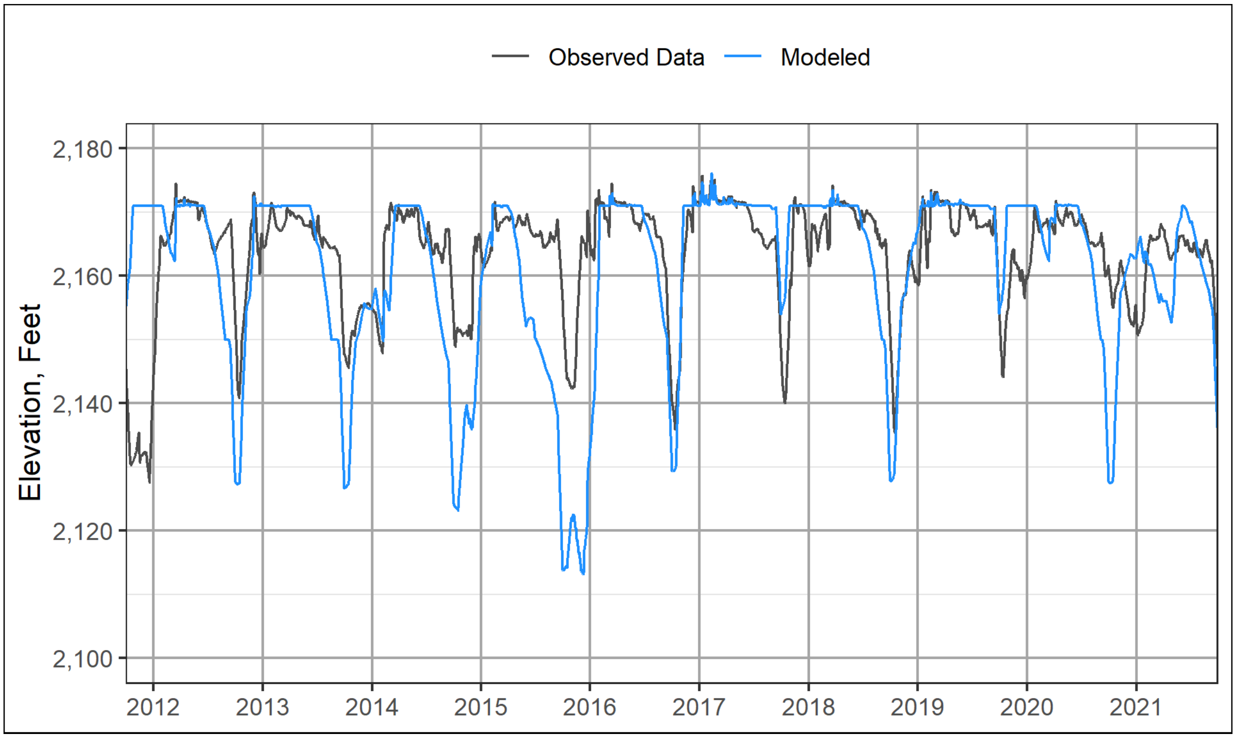

Figure C-53. Rollins Lake Elevation, Water Years 2012–2021

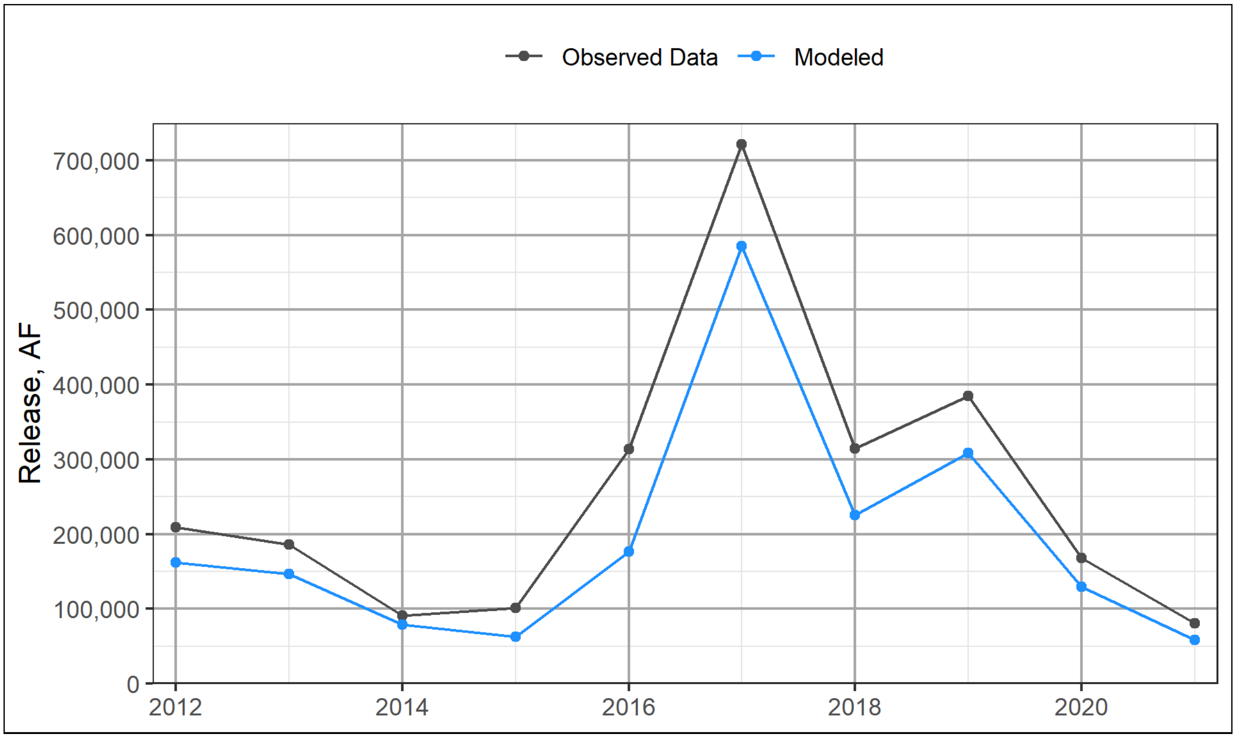

Figure C-54. Rollins Lake releases to Bear River, Water Years 2012–2021

C.6.5. Bear River Canal

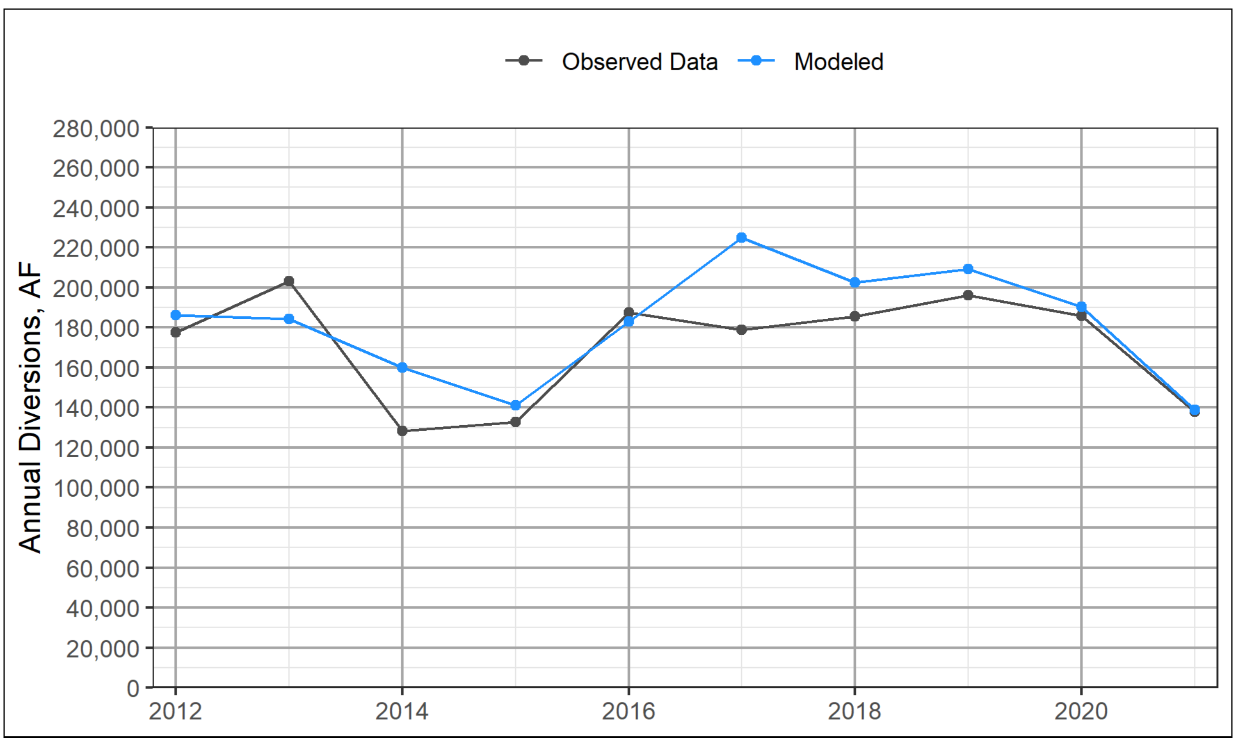

Figure C-55. Rollins Lake Diversions to Bear River Canal, Water Years 2012–2021

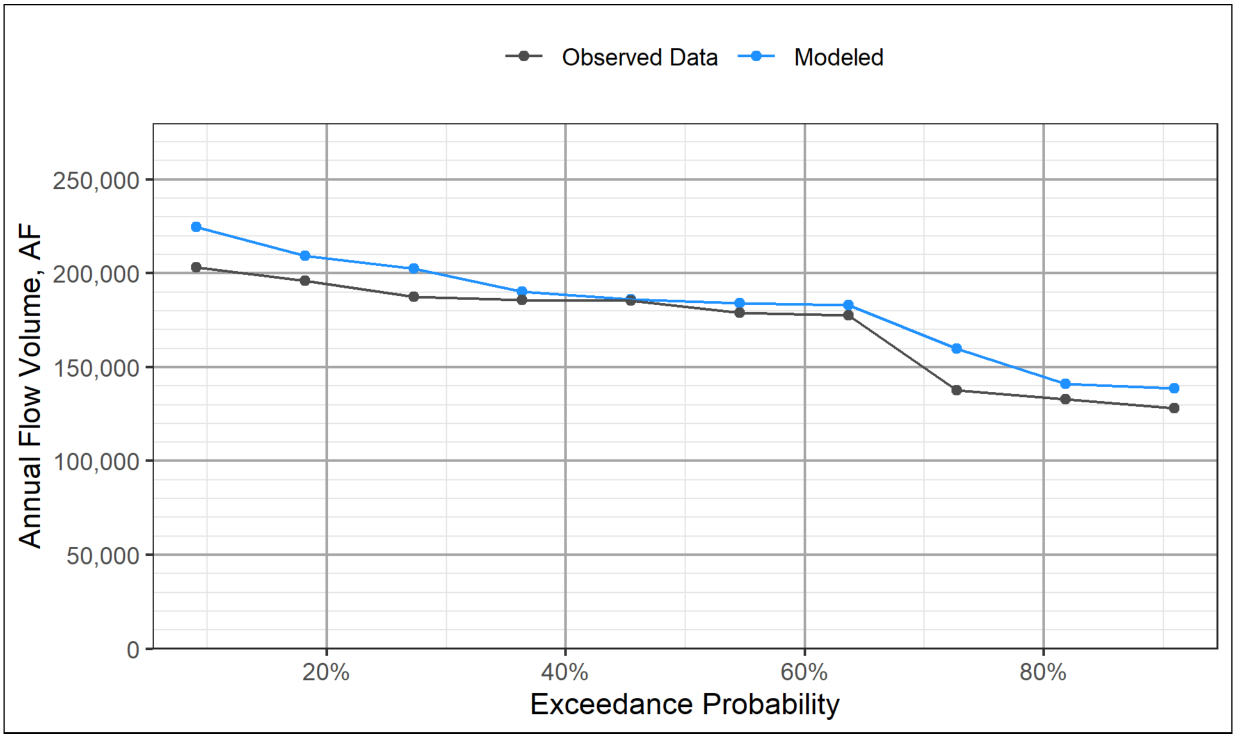

Figure C-56. Annual Diversion Exceedance to Bear River Canal, Water Years 2012–2021

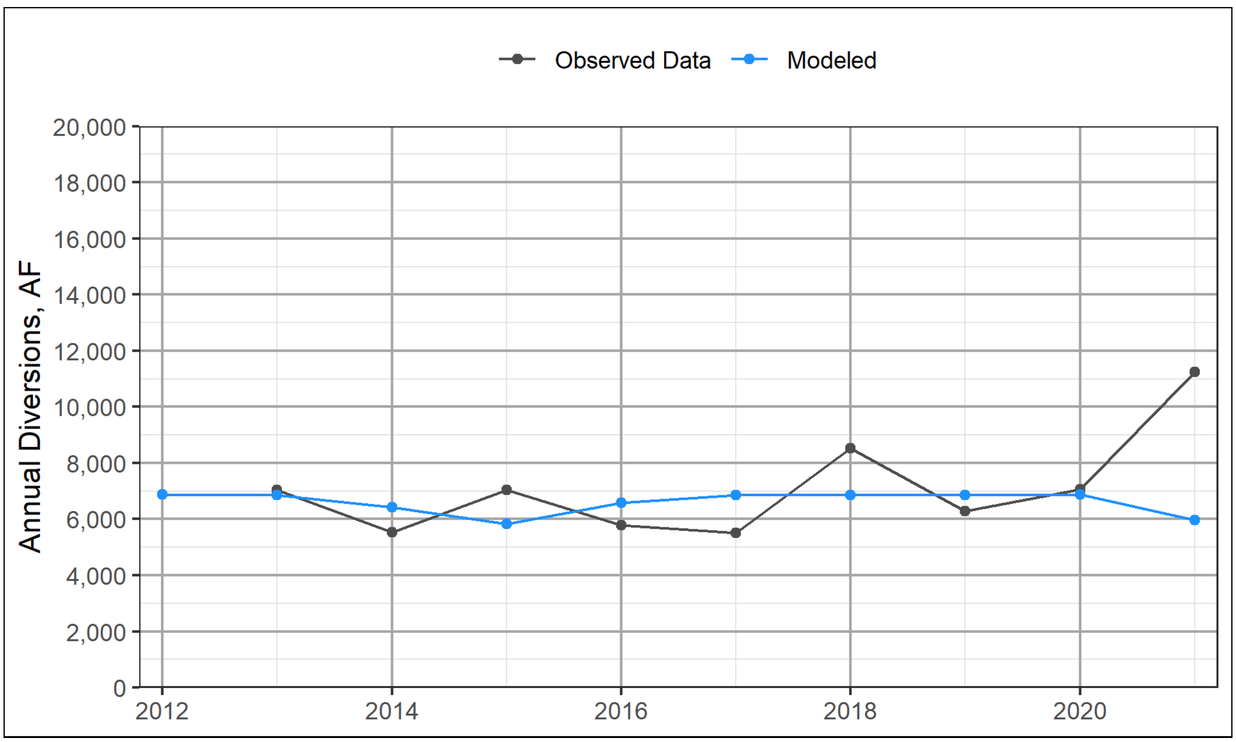

Figure C-57. NID Diversions from Rock Creek Reservoir, Water Years 2012–2021

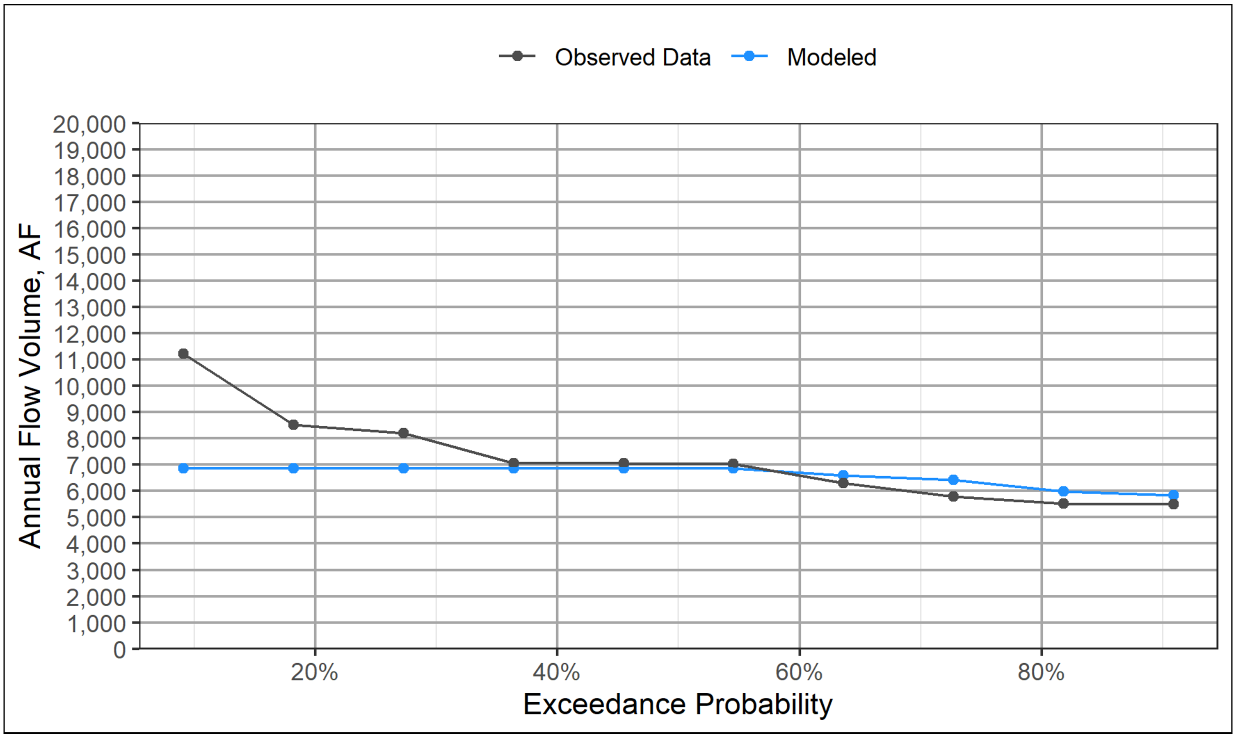

Figure C-58. Annual Diversion Exceedance to NID from Rock Creek Reservoir, Water Years 2012–2021

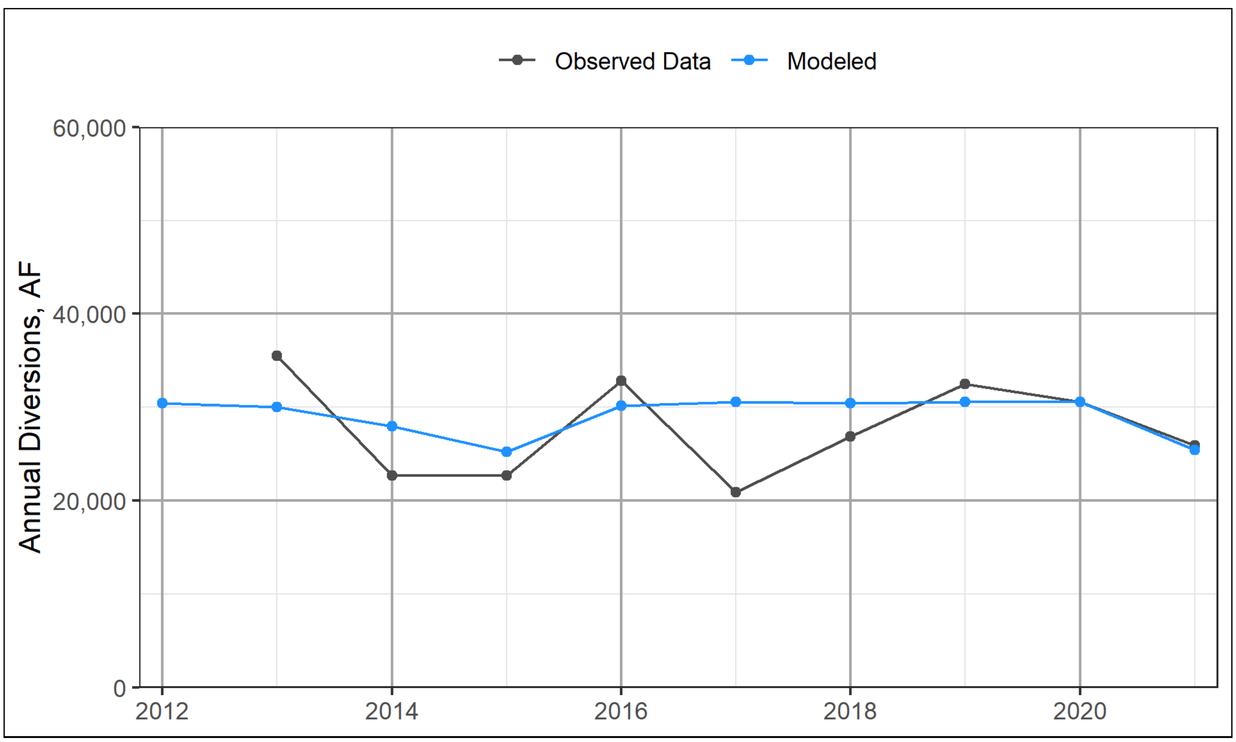

Figure C-59. NID Diversions into Auburn Ravine, Water Years 2012–2021

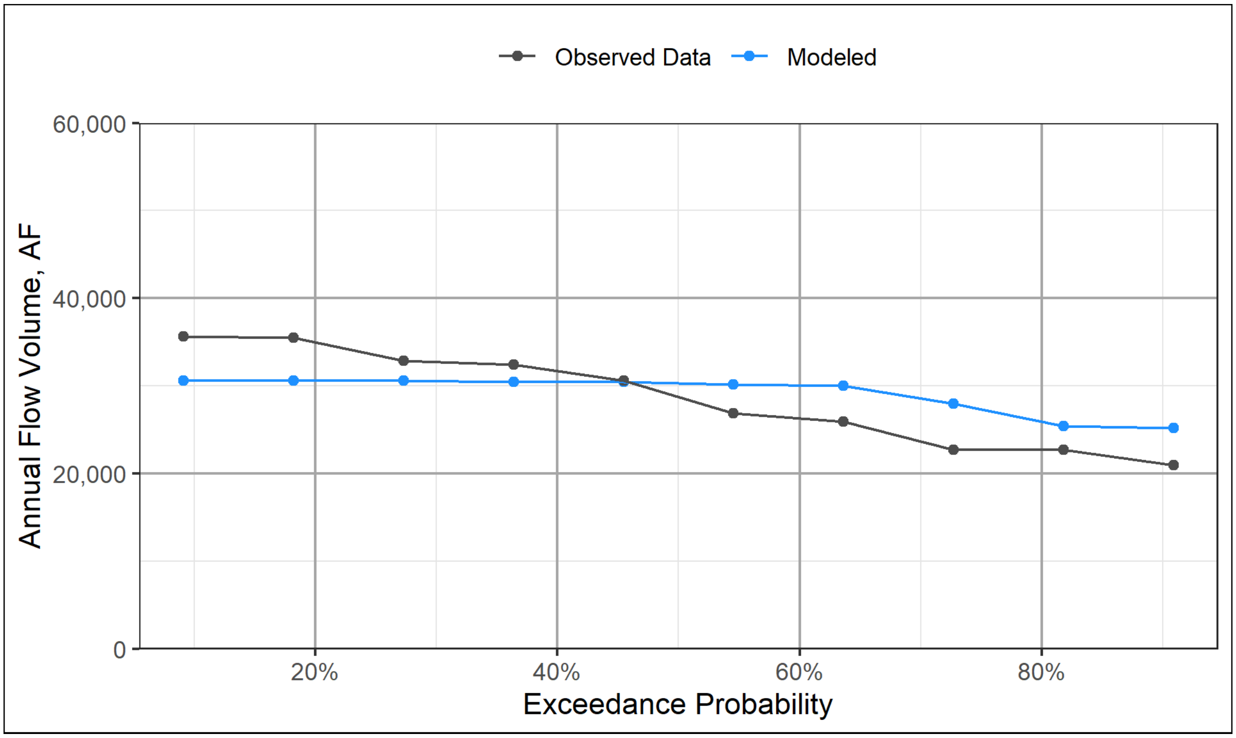

Figure C-60. Annual Diversion Exceedance NID into Auburn Ravine, Water Years 2012–2021

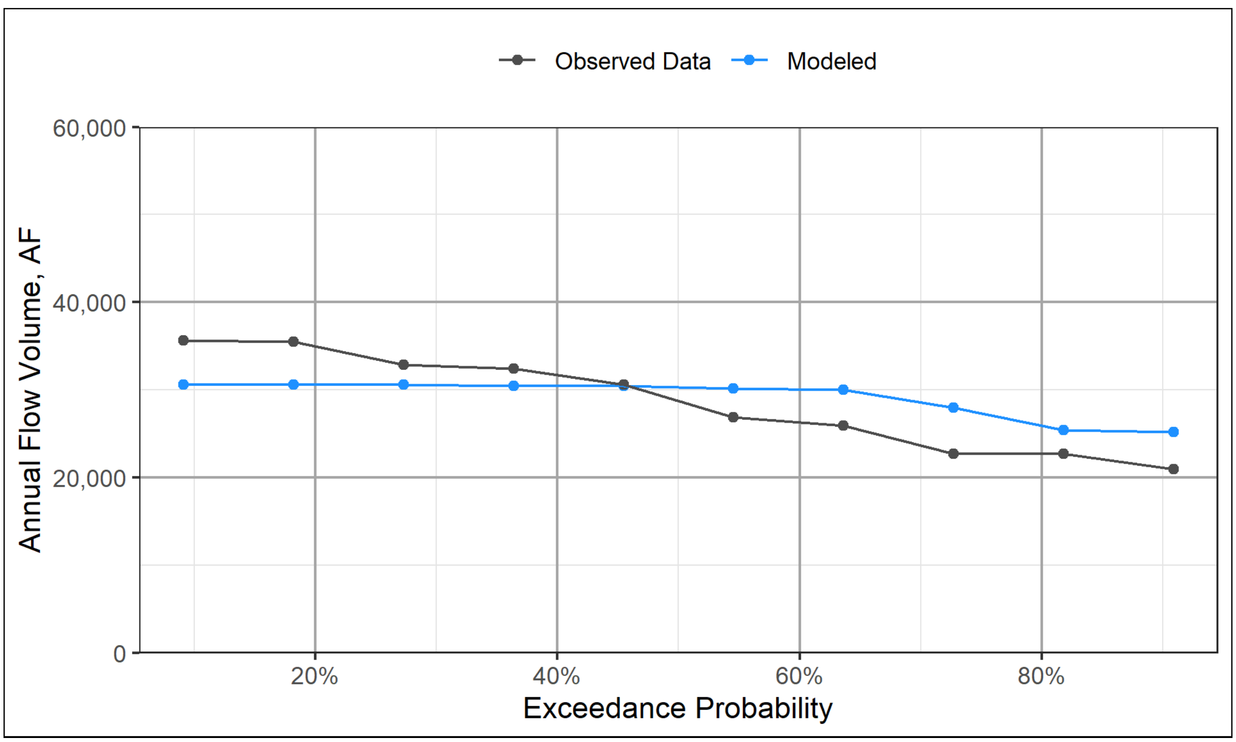

Figure C-61. Annual Diversion Exceedance NID into Auburn Ravine, Water Years 2012–2021

C.6.6. Lake Combie

Lake Combie had a bathymetric survey in 2021, which changed the estimate of storage capacity of the Reservoir. The model uses the new storage-elevation relationship from the updated bathymetric survey, while USGS storage data before 2021 uses the old storage-elevation relationship. For this reason, Lake Combie validation uses reservoir elevation rather than storage.

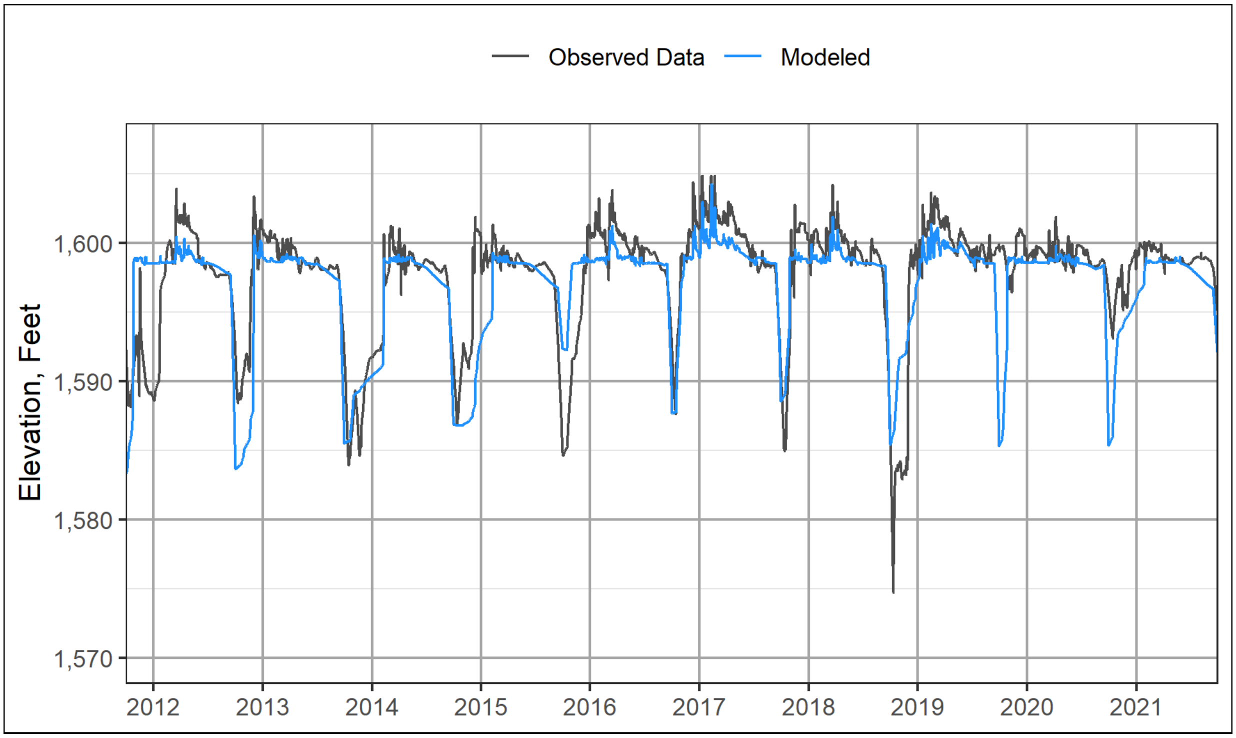

Figure C-62. Combie Lake Storage, Water Years 2012–2021

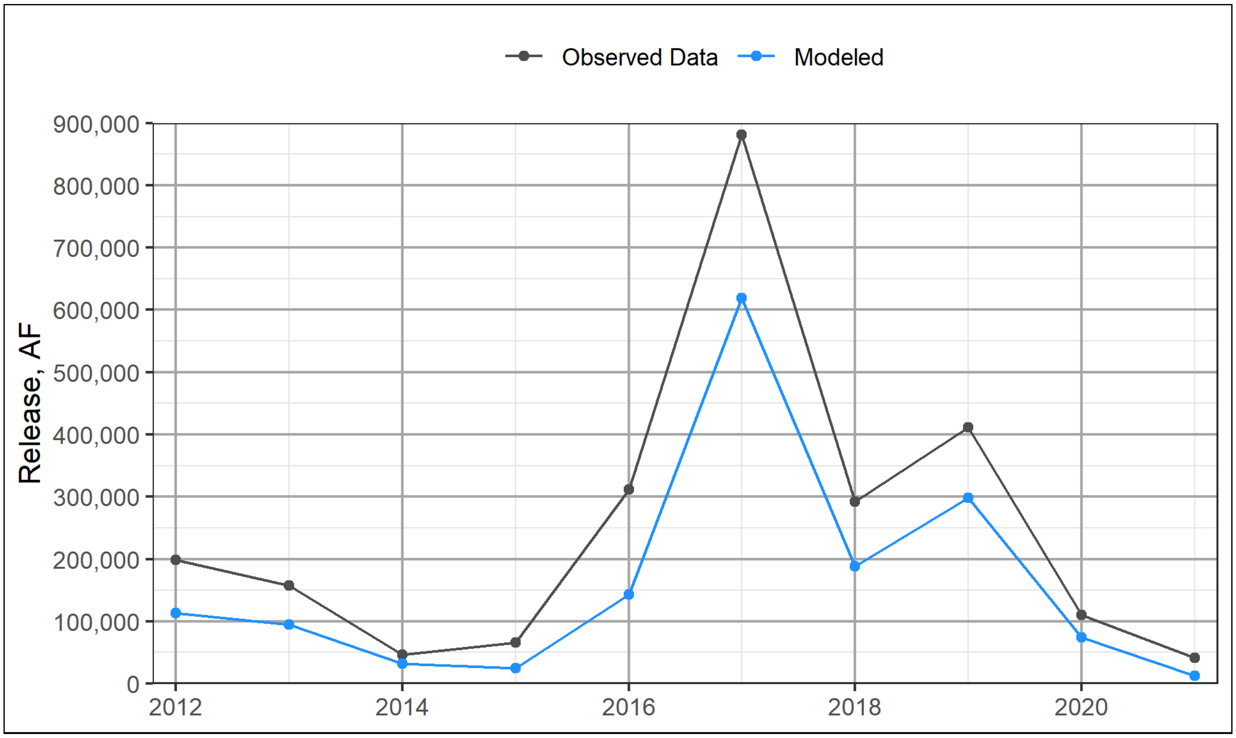

Figure C-63. Combie Lake releases to Bear River, Water Years 2012–2021

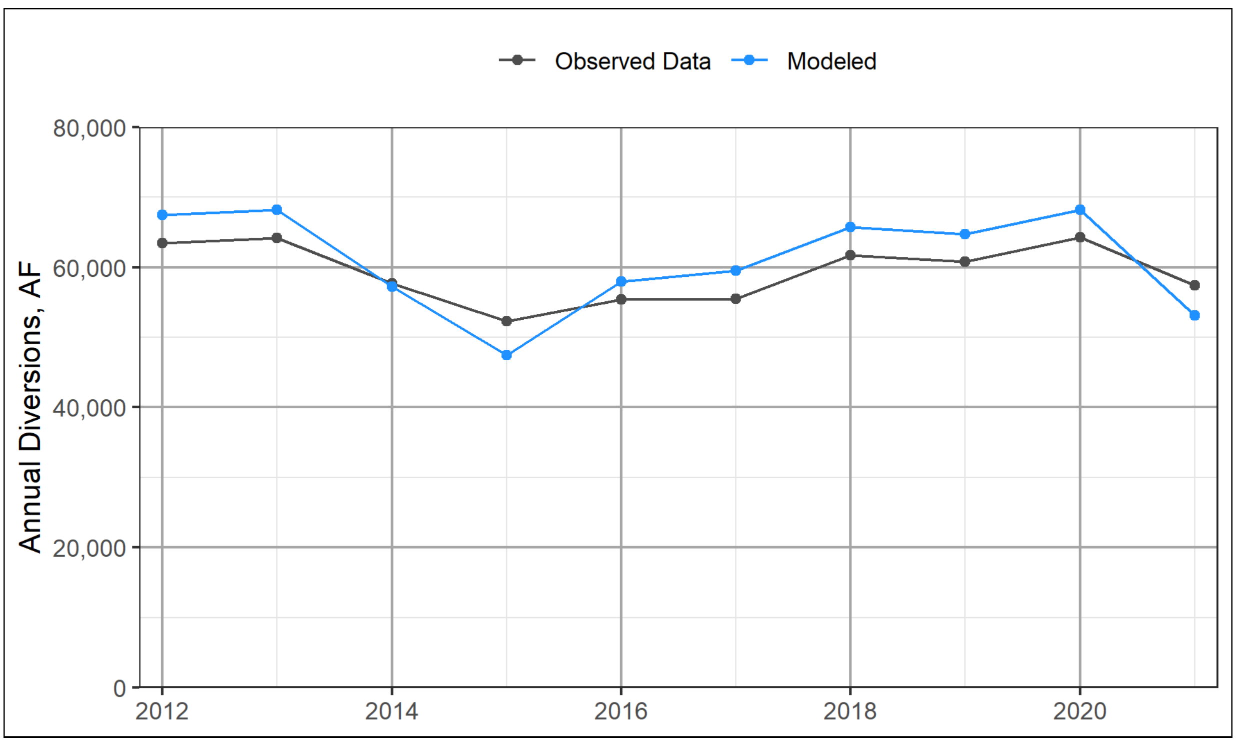

Figure C-64. Combie Lake Diversions to Phase I Canal and Magnolia III Canal, Water Years 2012–2021

C.7. Deer Creek

C.7.1. Deer Creek Powerhouse

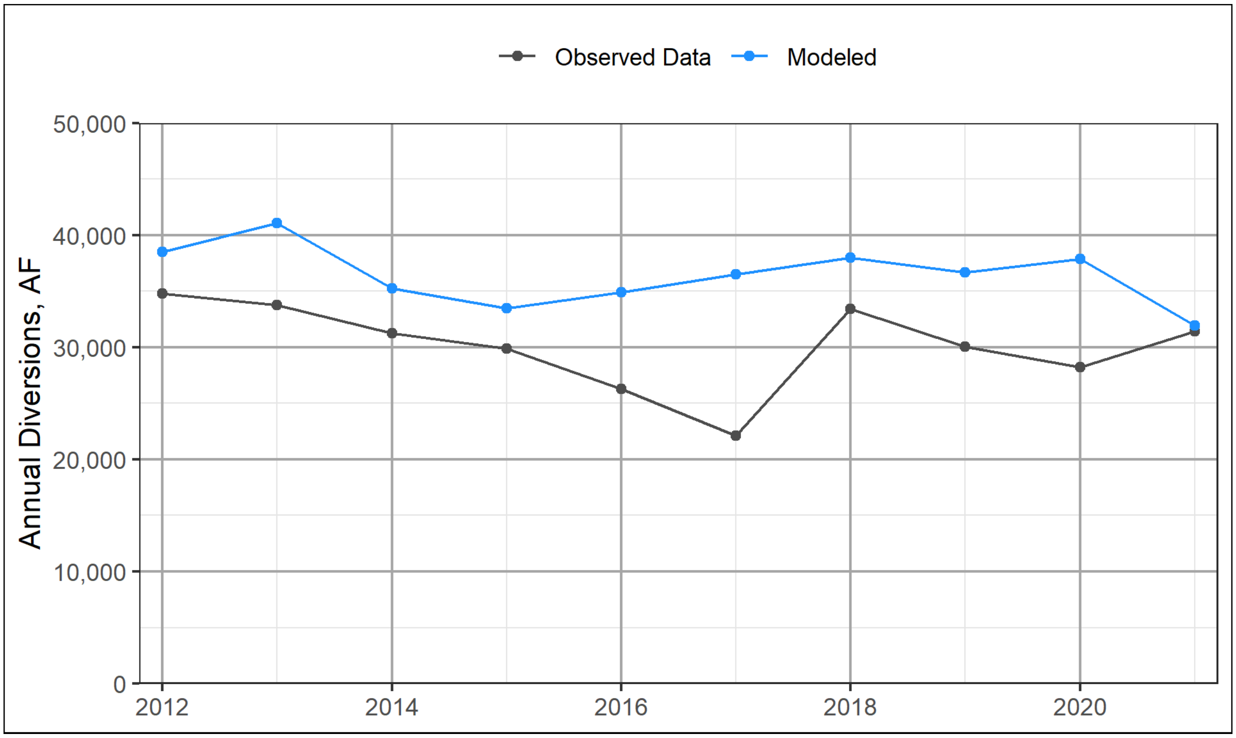

Figure C-65. Annual Flow through Deer Creek Powerhouse, Water Years 2012–2021

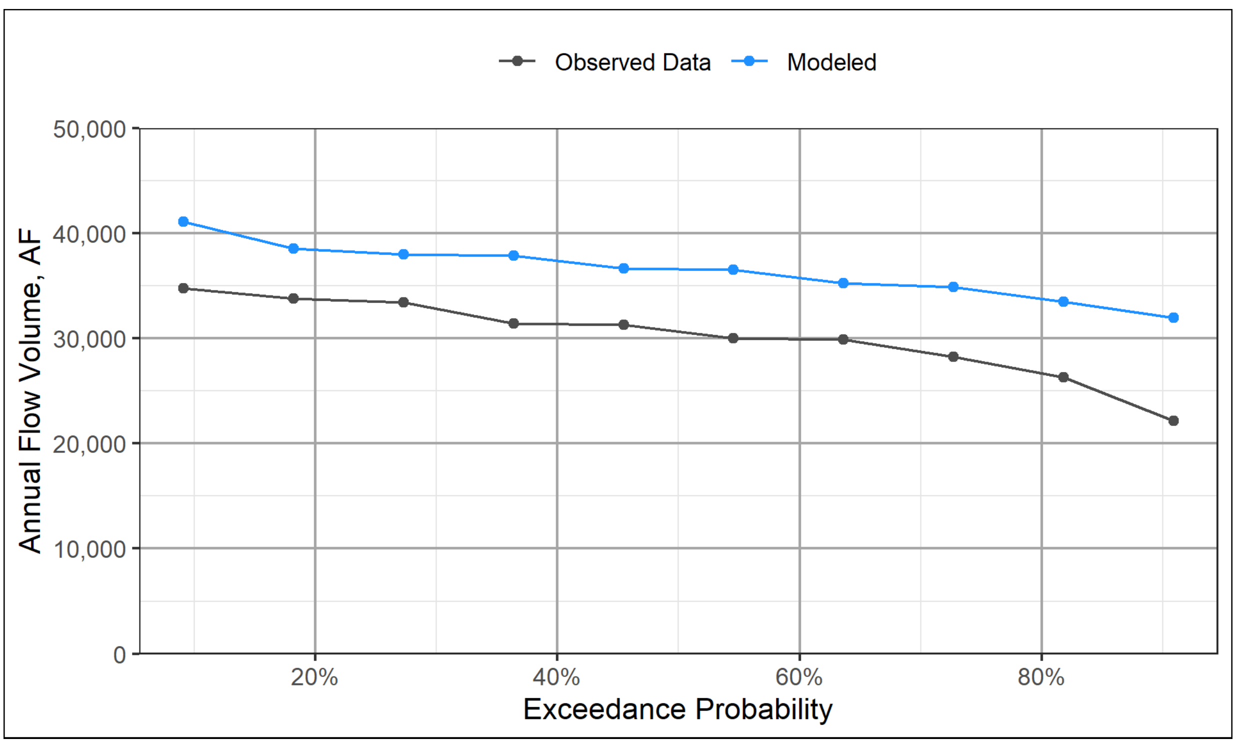

Figure C-66. Annual Flow Exceedance through Deer Creek Powerhouse, Water Years 2012–2021

C.7.2. Scotts Flat Reservoir

Scotts Flat Reservoir had a bathymetric survey in 2021, which changed the estimate of storage capacity of the Reservoir. The model uses the new storage-elevation relationship from the updated bathymetric survey, while USGS storage data before 2021 uses the old storage-elevation relationship. For this reason, Scotts Flat Reservoir validation uses reservoir elevation rather than storage.

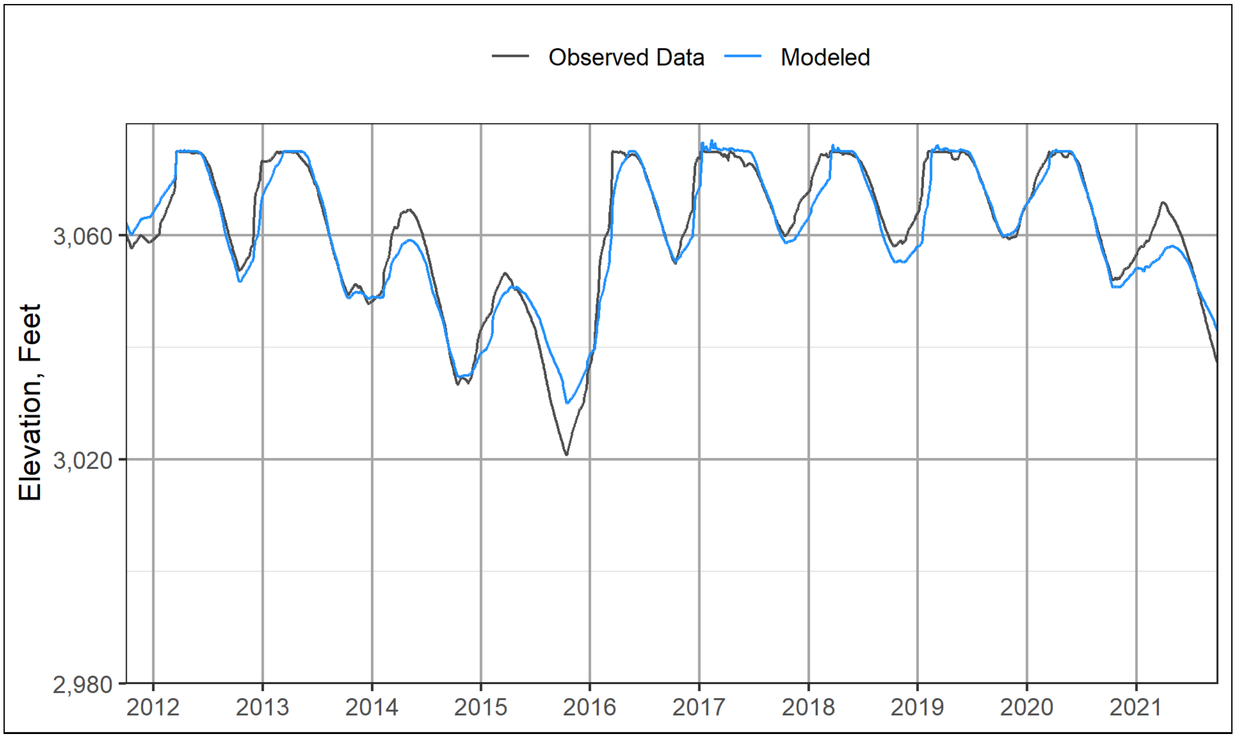

Figure C-67. Scotts Flat Reservoir Elevation, Water Years 2012–2021

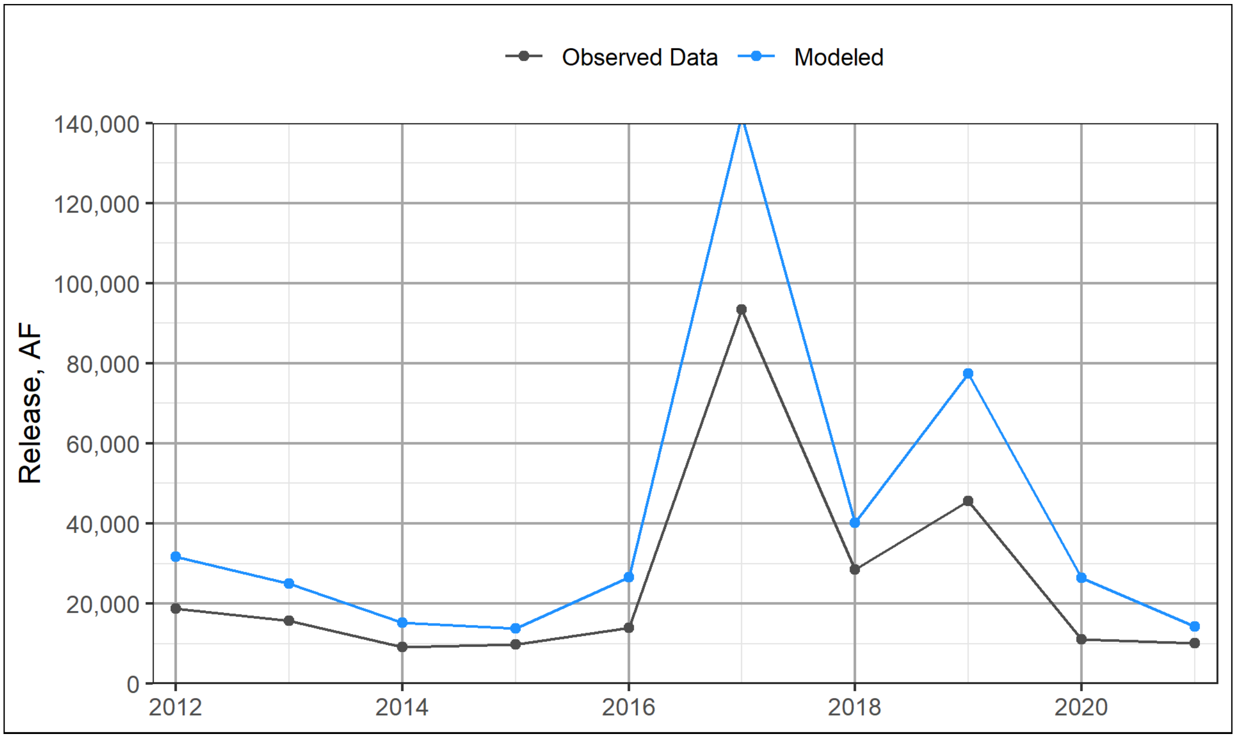

Figure C-68. Scotts Flat releases to Deer Creek, Water Years 2012–2021

C.7.3. Cascade Canal

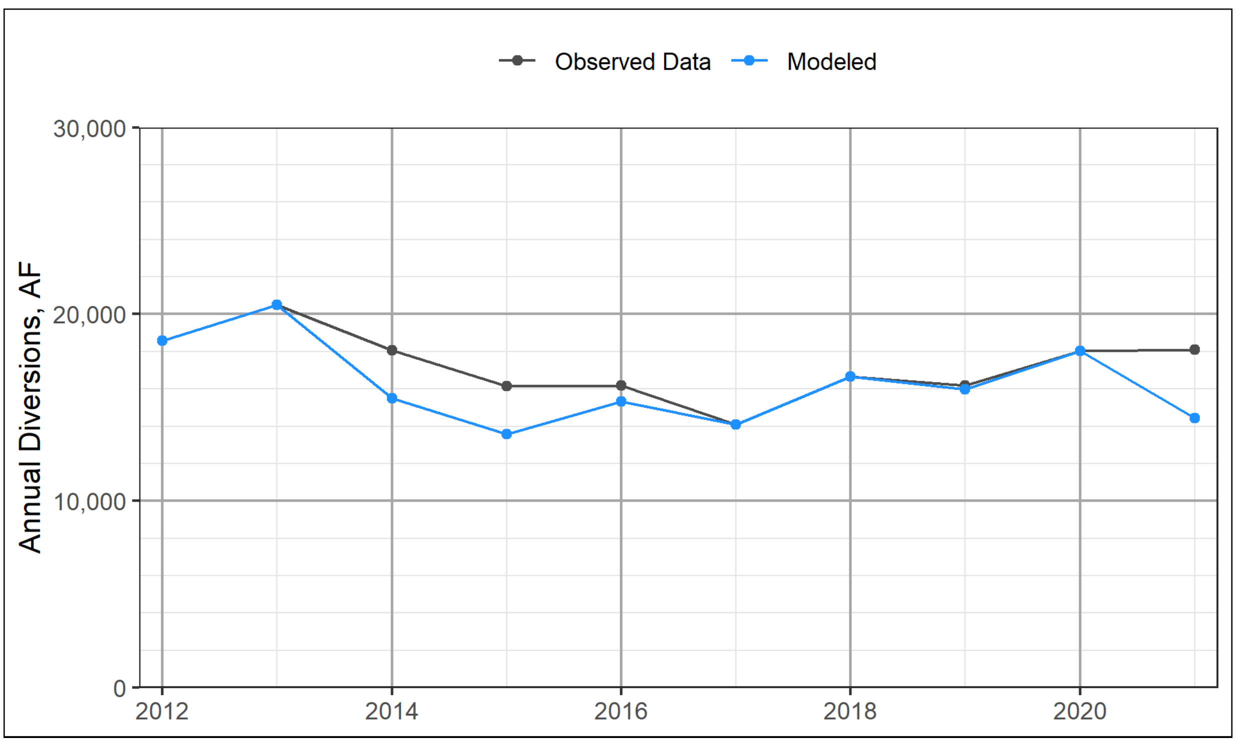

Figure C-69. Diversions to Cascade Canal, Water Years 2012–2021

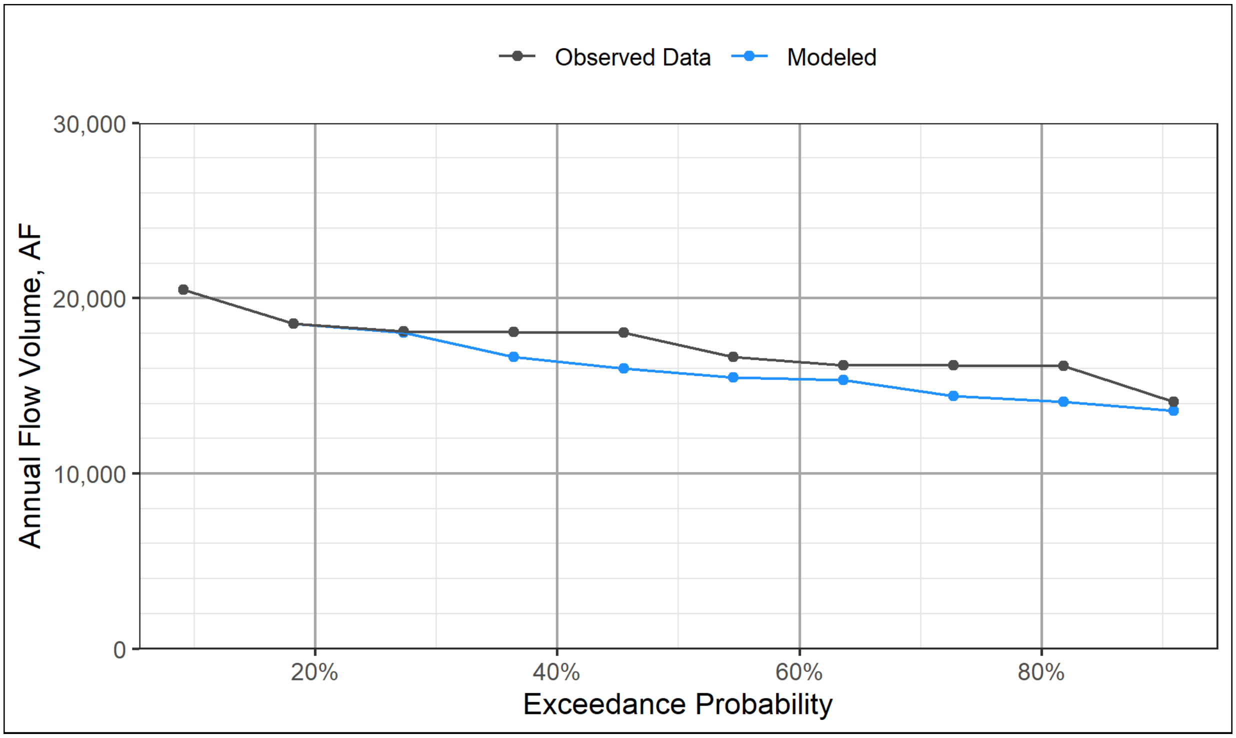

Figure C-70. Annual Diversion Exceedance to Cascade Canal, Water Years 2012–2021

C.7.4. DS Canal

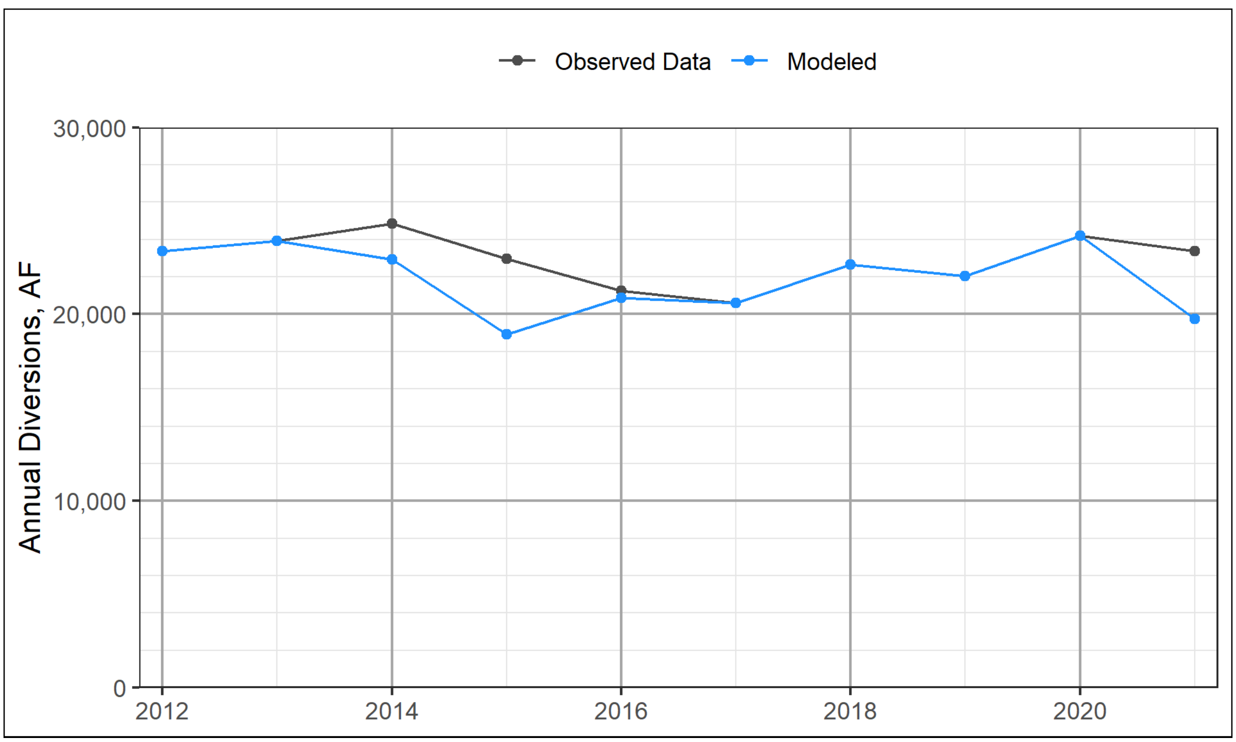

Figure C-71. Diversions to DS Canal, Water Years 2012–2021

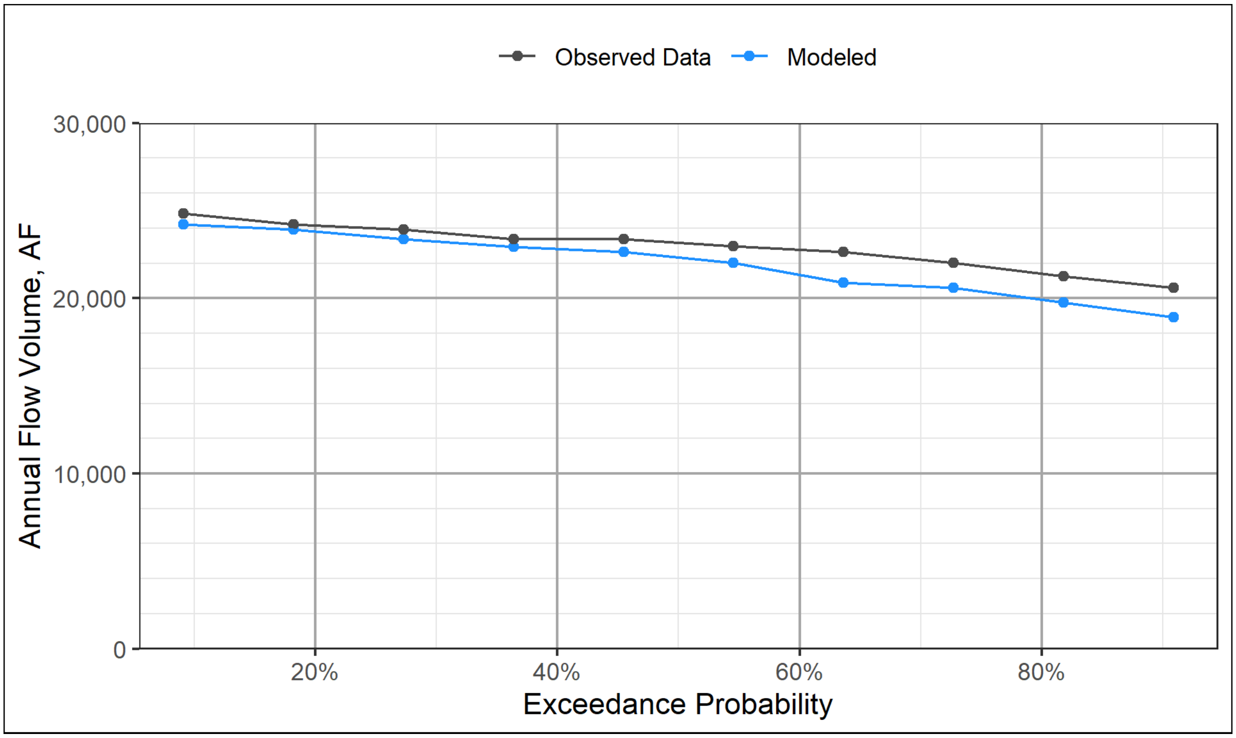

Figure C-72. Annual Diversion Exceedance to DS Canal, Water Years 2012–2021

C.7.5. Newtown Canal

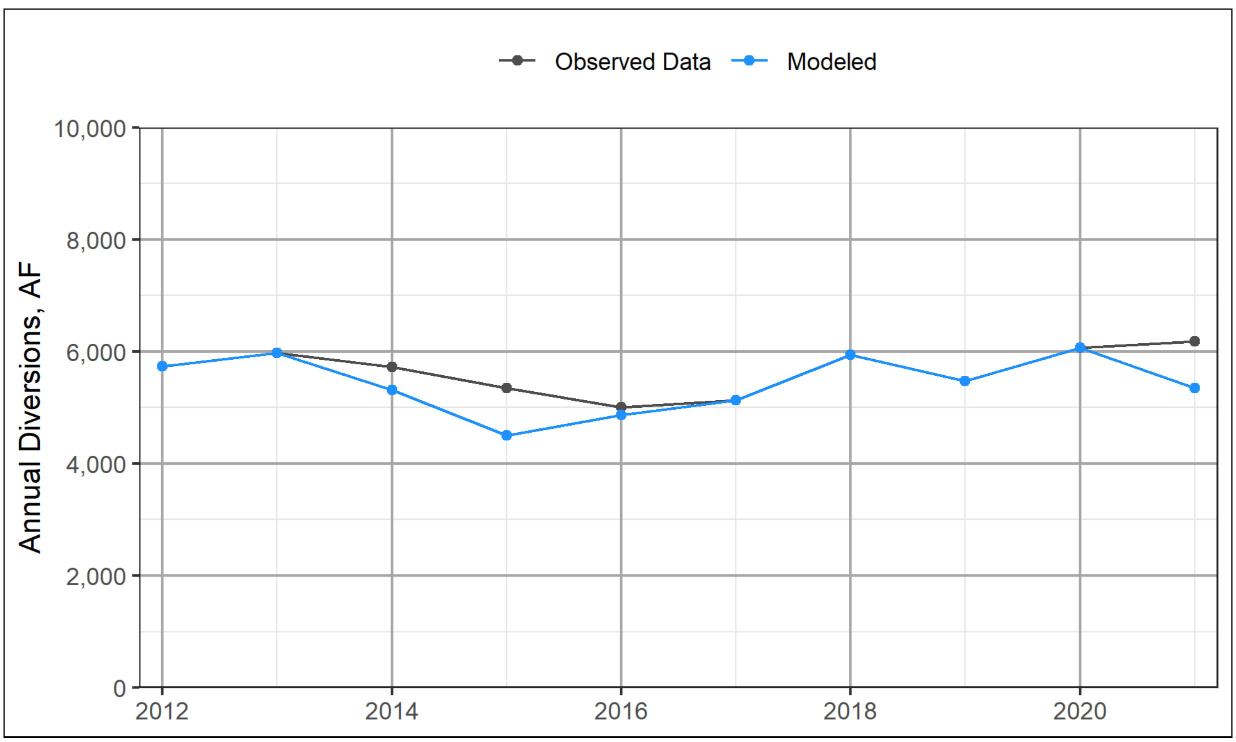

Figure C-73. Diversions to Newtown Canal, Water Years 2012–2021

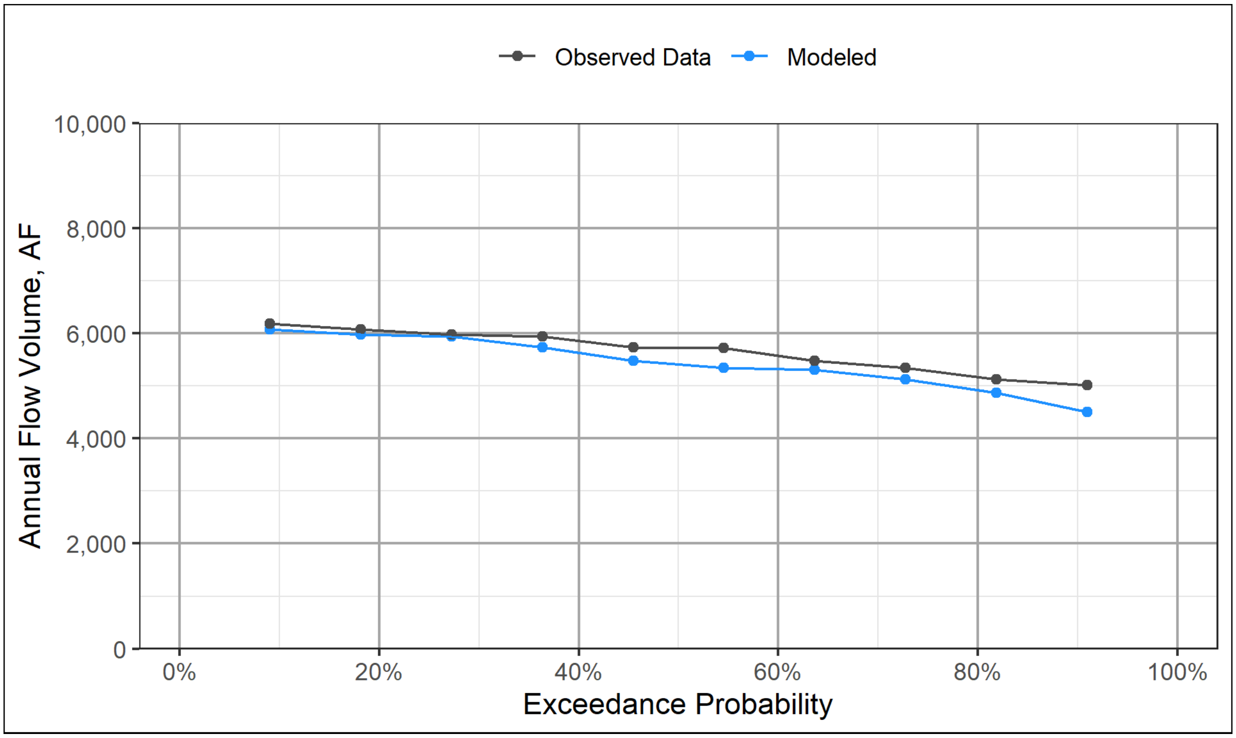

Figure C-74. Annual Diversion Exceedance to Newtown Canal, Water Years 2012–2021

C.7.6. Tunnel Canal

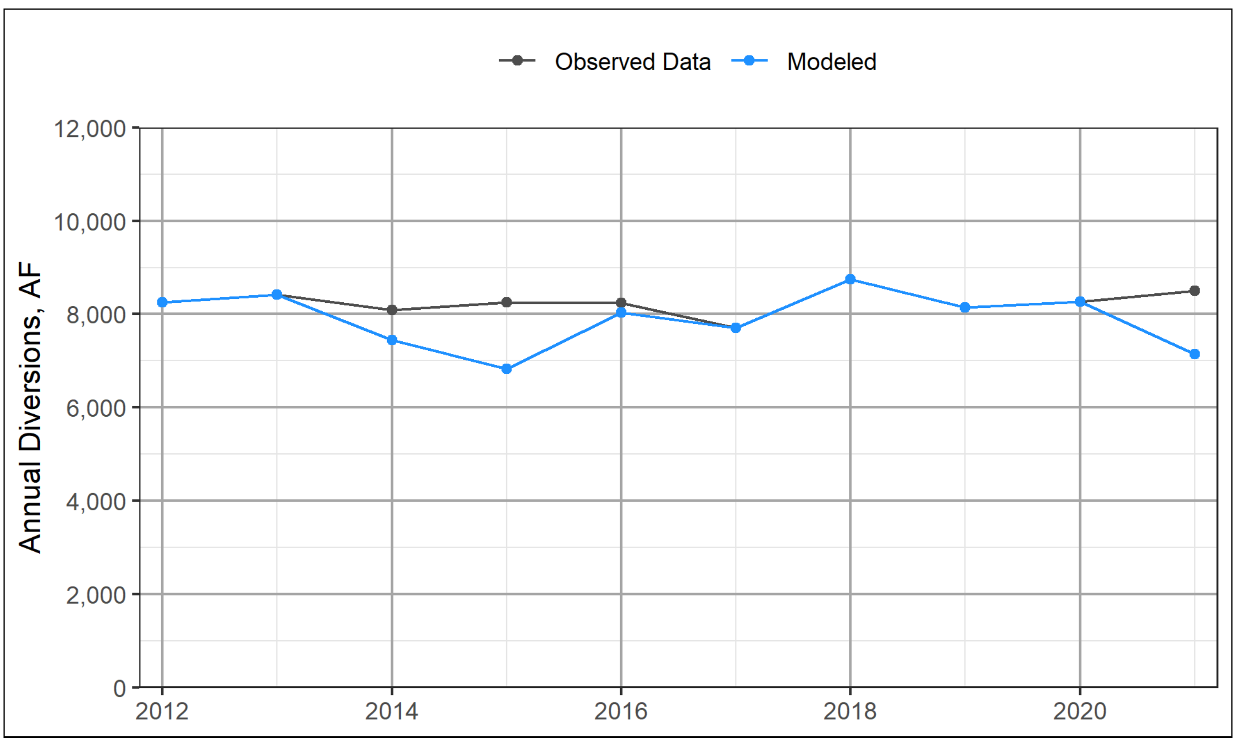

Figure C-75. Diversions to Tunnel Canal, Water Years 2012–2021

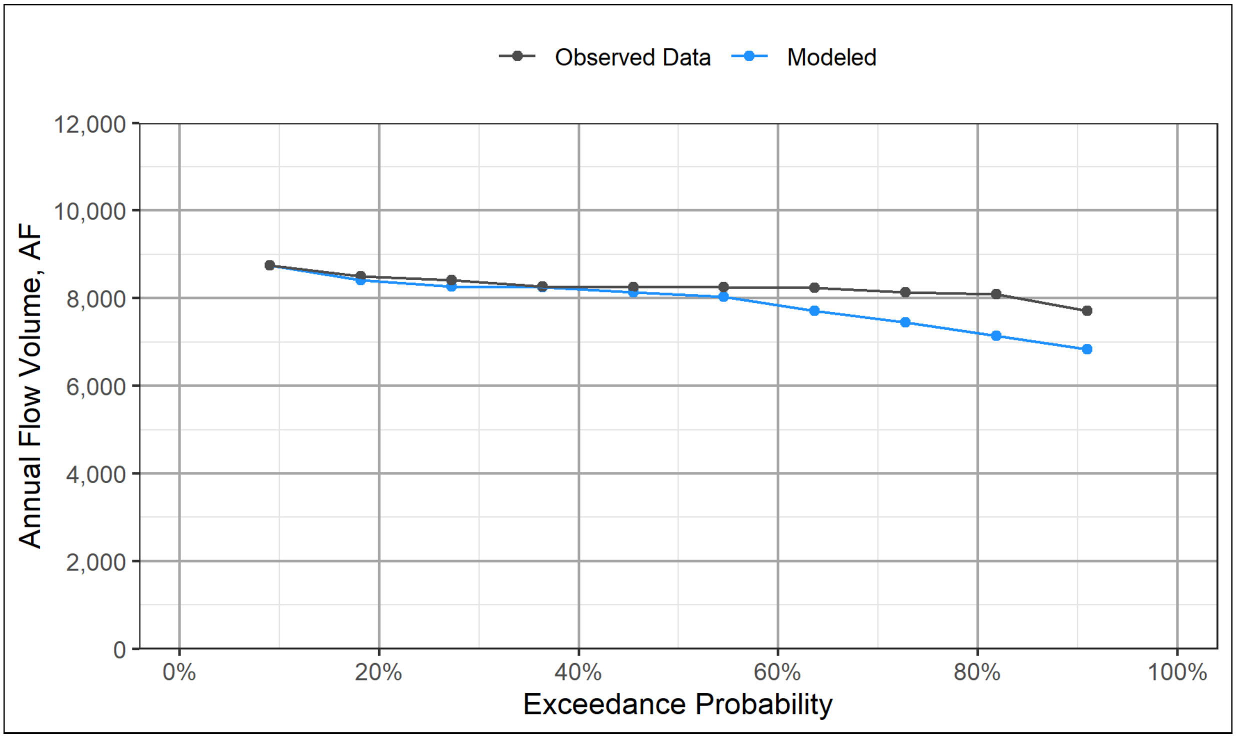

Figure C-76. Annual Diversion Exceedance to Tunnel Canal, Water Years 2012–2021

NEVADA IRRIGATION DISTRICT

ROLLINS RESERVOIR SPILLWAY LABYRINTH WEIR FEASIBILITY REPORT

CH2M HILL

JUNE 1986

CH2M HILL

Engineers
Planners
Economists
Scientists

June 20, 1986

M15742.E0

Mr. Robert Singleton
District Engineer
Nevada Irrigation District
P.O. Box 1019
Grass Valley, CA 95945

Dear Mr. Singleton:

Subject: Rollins Labyrinth Weir Feasibility Review

The attached report represents the results of our review of the feasibility of increasing the capacity of Rollins Reservoir by replacing the existing ogee crest with a labyrinth weir. Based upon our review, it appears that a 6.5-foot increase of the existing spillway crest elevation (from 2,171 to 2,177.5) could produce the largest increase in firm water yield at the lowest cost to the District. The proposed project would include reconstruction of the existing dam crest to raise it by 2.2 feet. This project could produce an additional 4,140 acre-feet of firm water yield and produce an average of 2.6 million additional kilowatt-hours (kwh) annually at Rollins powerhouse. Depending upon the energy price negotiated, the additional firm water supply could cost the District from $20 to $42 per acre-foot.

We have appreciated this opportunity to assist NID in evaluating the Rollins Labyrinth weir project. Please call me if you have further comments or questions.

Sincerely,

Craig E. Crouch

Craig E. Crouch
Project Manager

gc/SAC2/60
Attachment

CH2M HILL Sacramento Office 3840 Rosin Court, Suite 110, Sacramento, California, 95834 916.920.0300

CONTENTS

		Page
1	Summary and Recommendations	1-1
	Introduction	1-1
	Authorization	1-1
	Alternatives Reviewed	1-1
	Summary	1-2
2	Background	2-1
	General	2-1
	Project History	2-1
	Alternative Proposed Projects	2-2
	Project Benefits	2-3
	Water Supply	2-5
	Hydropower	2-7
	Previous Studies	2-7
3	Dam Stability and Hydraulics	3-1
	Dam Safety Analysis	3-1
	Hydraulic Analysis	3-3
	Conceptual Design	3-3
	Hydraulic Model Studies	3-5
	Bascule Gates	3-6
4	Project Benefits and Cost Estimates	4-1
	Firm Water Yield	4-2
	Water Supply	4-3
	Energy Production	4-3
	Cost Estimates	4-4
	Alternatives 1 and 2 - Labyrinth Weir	4-5
	Alternative 3 - Bascule Gates	4-5
5	Economic Analysis and Conclusions	5-1
	Annual Revenues	5-1
	Annual Costs	5-2
	Implementation Schedule	5-2
	Cost of Water	5-5
	Recommended Alternative	5-5

References

Bibliography

Appendix A. Scope of Work
Appendix B. Model Study of the Labyrinth Spillway for Rollins Dam
Appendix C. Incremental Power Production Tables

TABLES

1-1 Water and Power Benefits 1-2

2-1 Rollins Dam Spillway Flood Routing Studies 2-2

2-2 Existing and Proposed Spillway Characteristics 2-4

2-3 Gross Water Demands 2-5

2-4 Bear River Service Area Water Supply Shortages 2-6

2-5 Water Supply Deficiencies 2-7

4-1 Rollins Hydropower Production and Water Yield Effects 4-1

4-2 Alternative 2 Water Shortages and Project Water Yields

5-1 PG&E May 1986 Avoided Cost Energy and Capacity Prices 5-1

5-2 Economic Analysis 5-3

FIGURES
(Bound After Text)

1 Location Map

2 Vicinity Map

3 Dam, Spillway, and Powerhouse

4 Spillway Plan and Profile

5 Spillway Discharge and Reservoir Storage Curves

6 October Probable Maximum Flows

7 Plan of Proposed Nine-Cycle Labyrinth Weir

8 Longitudal Elevation of Nine-Cycle Weir Alternative

9 Existing and Proposed Dam Crest

10 Implementation Schedule

SAT15C/26

Chapter 1
SUMMARY AND RECOMMENDATIONS

INTRODUCTION

This report presents results of a study to determine the feasibility of increasing the elevation of the spillway crest at Rollins Dam, located on the Bear River.

Various alternatives for increasing storage at Rollins Reservoir were considered during its design and since its completion in 1965. In November 1985, results of a reconnaissance-level study of raising the normal pool of Rollins Reservoir by replacing the existing ogee spillway crest with a labyrinth weir were presented to Nevada Irrigation District by CH2M HILL. The potential water supply and power benefits of increasing the height of the spillway crest at Rollins Reservoir appeared to justify further investigations.

AUTHORIZATION

On November 22, 1985, at the request of District Engineer Robert Singleton, CH2M HILL submitted to NID a scope of work for a feasibility study of increasing the height of the spillway crest at Rollins Reservoir.

On December 13, 1985, CH2M HILL received written authorization to proceed with feasibility-level studies for the weir project at Rollins Dam under Services Task Order No. 6 (Appendix A).

In January 1986, Project Task 6 (Equipment Evaluation) was deleted from the project scope and review of a bascule gate alternative was added to the scope of work upon the recommendation of NID staff.

In May 1986, CH2M HILL was authorized to estimate energy production at Rollins Powerhouse for existing and alternative replacement turbine runners, under existing and post-project (elevation 2177.5 weir crest) conditions. Details of that effort (Task 12) are presented in a separate letter report, but results for the existing turbine runner are incorporated in this report.

ALTERNATIVES REVIEWED

This feasibility report considers two fixed-weir alternatives and reviews the feasibility of installation of bascule gates on the spillway. Alternative 1 would increase the spillway crest from elevation 2,171 feet to elevation 2,176 feet and would include no changes to the existing dam structure. Alternative 2 would raise the spillway crest elevation to 2,177.5 feet and would include a 2.2 foot increase in the dam crest height. For both these alternatives, a labyrinth weir would be constructed in place of the present ogee; the weir would pass the Probable Maximum Flood (PMF) without increasing hazard to the dam.

Installation of bascule gates, Alternative 3, would increase the spillway crest elevation to 2,182.2 feet from May 1 through September 30, increasing storage capacity by 9,740 acre-feet (AF). However, in order to pass the PMF over the less hydraulically efficient open bascule gates, it would be necessary to reduce the spillway crest to 2,169.2 feet. This would decrease reservoir capacity and powerhouse head from October 1 through April 30 if the gates are required to be kept completely open during that period.

This report defines the features, impacts, benefits, and feasibility of these alternative projects.

SUMMARY

Increasing the spillway crest of Rollins Reservoir would provide both water and power benefits. Estimates of additional power and firm yield for each alternative, based on data for the 1911-80 period, appear in Table 1-1. Alternative 3 produces marginal water supply benefits due to the reduction in the spillway crest from October 1 through April 30. Water yield effects for each alternative for critical dry years during the period of investigation appear in Table 4-1. Little additional water yield results from Alternative 3, and it reduces firm water yield in 1976-77. Cost of additional water for Alternatives 1 and 2 ranges from $20/AF to $44/AF, depending upon the price obtained for incremental power benefits, by the definition of firm yield used for this study. If the firm yield definition used for the November 1985 Water Supply Development Reconnaissance Study is adopted (based solely upon additional yield in water years 1976 and 1977), unit cost of additional water is increased by approximately 70 percent.

Table 1-1
WATER AND POWER BENEFITS

Alternative	Additional Storage Capacity (AF)	Additional Firm Yield (AF) 1976-77[a]	Additional Firm Yield (AF) Six Bear River Shortage Years[b]	Additional Net Annual Energy at Rollins (million kilowatt-hours)
1 - Labyrinth, crest el. 2176	4,250	1,880	3,280	1.36 (Revised to 1.89)[d]
2 - Labyrinth, crest el. 2177.5	5,550	2,530	4,140	1.88 (Revised to 2.59)[d]
3 - Bascule, crest el. 2182.2	9,740[c]	-740	130	3.08

[a]Based on 1976-77 critical dry period.

[b]Based on the 6 years of the 70-year record which produce water supply shortages within the Bear River Service Area.

[c]Assuming gates are kept open from October 1 through April 30.

[d]Based upon more detailed studies performed in June 1986 under Task 12.

Based on results of this feasibility study and of the recent reconnaissance study of alternative potential water supply projects, the Rollins Labyrinth weir, Alternative 2, appears to be the least cost source of additional water for NID. However, choice of the final weir alternative will be contingent upon FERC and DSOD review.

SAT15C/16

Chapter 2
BACKGROUND

GENERAL

Sources of data for this feasibility review included:

- The November 1985 Water Supply Development Reconnaissance Study (draft).
- Files of California Division of Safety of Dams (DSOD) for Rollins Dam and Spillway.
- Documents developed for the Federal Energy Regulatory Commission relating to dam stability and flood routing, including FERC 5-year safety inspection reports for 1968, 1973, 1978, and 1984, and the August 1983 Probable Maximum Flood Study.
- NID record drawings and geologic reports for the dam, spillway, and powerhouse.
- Preliminary cost estimates (FOB factory) by a bascule gate vendor.
- 1:40 scale hydraulic model analyses by Utah Water Research Laboratory.

The NID operations computer model was used to estimate additional project energy production and the effects of the alternatives upon water supply yield.

PROJECT HISTORY

The Rollins Reservoir and Powerhouse project is located on the Bear River, about 16 miles north of Auburn, in the Sierra Nevada mountains of central California (Figure 1). The dam was completed in 1965 as part of the Yuba-Bear Development Project constructed by the District, and is the principal NID water supply facility on the Bear River. In 1978, construction of Rollins Powerhouse and installation of a 12,700-kilowatt turbine/generator unit began. Between 1980 and 1985, the power project produced an average of 71.5 million kilowatt-hours (kWh) annually. During that wetter-than-average 6-year period, output was reduced by plant commissioning and (in 1984) by transformer failure. Long-term energy output was estimated by Tudor Engineering to average 71.1 million kWh (Ref. 1).

The 242-foot-high rockfill dam has a crest width of 30 feet and a crest elevation of 2187.5 feet (Figures 2 and 3). Based upon the 1984 Sierra Hydrotech flood routing study, the reservoir has a storage capacity of 65,990 acre-feet at the ogee crest elevation of 2,171 feet, with a discharge capacity at maximum flood pool (elevation 2,185) of 65,600 cfs. The spillway plan and profile are shown in Figure 4. A summary of spillway flood routing studies previously performed for Rollins Dam are given in Table 2-1.

Table 2-1
ROLLINS DAM SPILLWAY FLOOD ROUTING STUDIES

Date	Flood	Maximum Inflow (cfs)	Maximum Spill (cfs)	Maximum Water Surface Elevation (ft)	Minimum Freeboard (ft)	Flood Routing Performed by
1963	Design	-	60,000	2,185.0	2.5	EBASCO
1973	PMF	60,000	55,000	2,183.8	3.7	T.J. Corwin, Jr.
1979	20,000-year	41,060	38,860	2,179.6	7.9	DSOD
1984	PMF[a]	67,520	63,900	2,184.8	2.7	Sierra Hydrotech

[a]Does not include Drum Canal import.

ALTERNATIVE PROPOSED PROJECTS

Construction of a labyrinth weir as the crest of the Rollins spillway would raise the normal water surface elevation, providing additional water supply and power benefits. Two alternative labyrinth weir designs have been reviewed. Spillway discharge rating curves are provided for each alternative in Figure 5, and routing results for the controlling October probable maximum flood (PMF) are shown in Figure 6.

Alternative 1 considers increasing the spillway crest elevation by 5 feet (from 2,171 feet to 2,176 feet) with no change to the existing dam structure. This alternative would require that the DSOD normal pool freeboard guideline (freeboard divided by the total downstream dam height) be relaxed from 5 percent to 4.75 percent. Increasing the spillway crest elevation from 2,171 to 2,176 feet would increase the reservoir storage capacity by 4,250 acre-feet. The August 1983 PMF inflow hydrograph was routed through the modified Alternative 1 reservoir and spillway to determine the effects of the project. The resulting outflow hydrograph is displayed in Figure 6. Because the proposed weir would provide higher performance at lower heads, the post-project PMF peak stage would be reduced to 2,184.1 feet, 0.7 feet lower than under existing conditions. Peak outflow would be increased from 63,900 cfs to 64,300 cfs.

Alternative 2 would raise the spillway crest elevation by 6.5 feet (from 2,171 to 2,177.5 feet) and would indicate a 2.2-foot increase in the dam crest elevation (from 2,187.5 to 2,189.7 feet). The additional storage capacity would be 5,450 acre-feet. Alternative 2 would result in a PMF peak outflow of 64,300 cfs at a maximum pool elevation of 2,185.6 feet, 1.4 feet higher than the existing PMF peak stage. However, the proposed higher dam crest of 2,189.7 feet would provide 4.1 feet of freeboard at the PMF peak stage, resulting in an additional 0.8 feet of available freeboard, as compared with existing conditions.

Alternative 3 would require the installation of bascule gates. Because flow over open bascule gates would be less efficient than flow over the existing ogee crest, the crest would be lowered by 1.8 feet to pass the PMF. Three 13-foot by 110-foot gates have been proposed which would increase the spillway crest to 2,182.2 feet from May 1 through September 30, increasing storage capacity by 9,740 acre-feet during that period each year. (Note that increase in storage capacity is based on change in storage from 2,171 feet to 2,182.2 feet.) However, because the spillway crest would be lowered by 1.8 feet, there would be a decrease in head and storage capacity from October 1 through April 30, when the gates will be fully open. Open, the gates will have an outflow capacity of 65,000 cfs at an elevation of 2,184.8, providing 2.7 feet of freeboard.

Table 2-2 summarizes spillway characteristics for existing and proposed designs.

PROJECT BENEFITS

Each of the alternative proposed projects would provide both water and power benefits. The NID model was used to estimate monthly water and energy yields, based upon water demand distribution given in Table 2-3.

Table 2-2
EXISTING AND PROPOSED SPILLWAY CHARACTERISTICS[a]

	Existing	Alternatives 1	2	3
Crest width (ft)[b]	30.0	30.0	20.0	30.0
Dam crest elevation (ft)	2,187.5	2,187.5	2,189.7	2,187.5
Height of dam (ft)[c]	242.0	242.0	244.2	242.0
Spillway crest elevation (Normal pool elevation) (ft)	2,171.0	2,176.0	2,177.5	2,169.3[e] 2,182.2[f]
Normal pool freeboard (ft)	16.5	11.5	12.2	18.3[e] 5.3[f]
Normal pool freeboard (%)[d]	6.82	4.75	5.0	7.6[e] 2.2[f]
PMF peak pool elevation (ft)	2,184.8	2,184.1	2,185.6	2,184.8
PMF freeboard (ft)	2.7	3.4	4.1	2.7
Normal pool volume (AF)	65,990.0	70,230.0	71,540.0	64,510.0[e] 75,730.0[f]
Volume increase (AF)	--	4,250.0	5,550.0	9,740.0[f]

[a]Measurements are in feet except where noted. Probable maximum flood does not include import from Drum Canal.

[b]DSOD minimum width for rockfill = 20 feet.

[c]Defined at downstream location.

[d]DSOD "guideline" = 5% minimum.

[e]October 1 through April 30.

[f]May 1 through September 30.

SAT15C/24

Table 2-3
GROSS WATER DEMANDS*

Delivery Point	Demand (acre-feet/year)
Deer Creek Service Area	
Cascade Ditch	34,280
D-S Canal	40,050
Lower Deer Creek	13,680
Subtotal	88,010
Bear River Service Area	
Auburn W.T.P.	2,710
Auxiliary Canal	13,860
Auburn Ravine	28,740
Combie North Aqueduct	41,580
Subtotal	86,890
Total District Demands	174,900

*Based upon Raw Water Master Plan, Element 1, January 1983. Assumptions: existing agricultural lands served, year 2002 municipal and industrial demands, 30 to 40 percent delivery losses.

WATER SUPPLY

Element 1 (January 1983) of the Raw Water Master Plan discussed, in terms of a graph of water supply versus duration, the adequacy of NID's existing water supply in meeting existing and ultimate demands. Based on the 36 years of hydrologic record then available (water years 1928-1947 and 1965-1980), water supply model analyses showed present NID demands near the limit of firm water supplies. Since those analyses were performed, 70 years of hydrologic record (water years 1911-1980) have been assembled for use in the model. This longer period of record has been used in analyses for this report.

Water supply analyses show that some years, shortages would occur within the Deer River Service Area even though water is spilled from Bear River reservoirs. In 90 percent of the 70 years studied, water supply available from the Bear River is sufficient to meet demands. Shortfalls in water supply within the Bear River Service Area (as a percent of gross demand) are given in Table 2-4 for the driest calendar years of the period of record.

Table 2-4
BEAR RIVER SERVICE AREA WATER SUPPLY SHORTAGES

Calendar Year	Water Supply Shortage Volume (ac-ft)	Percent
1924	17,270	19.9
1931	27,340	31.5
1934	6,780	7.8
1961	3,140	3.6
1976	890	1.0
1977	55,470	63.8

As noted in Element 1 of the Raw Water Master Plan, overall shortages (weighted for all uses) in excess of 50 percent indicate lack of firm supply under USBR guidelines. Such shortages probably cannot be sustained without significant economic dislocation, including severe curtailment of municipal and industrial water use, loss of orchards, and substantial loss of agricultural income.

Each community of water users must define its unique set of water supply requirements. Often these decisions are based on a distribution of economic risk to each user group (e.g., annual crop, orchard, residential, industrial), based on the ability of each group to finance a share of additional water supply development. At the Raw Water Master Plan workshop held on December 14, 1982, NID staff proposed a schedule of maximum allowable deficiencies for each class of District water use during critical dry years (Table 2-5).

Incremental firm yield is defined as the average additional volume delivered during the 6 years of shortage within the Bear River Service Area. Assuming a weighted critical dry-year curtailment of 50 percent, 1,000 acre-feet of firm yield by this definition would provide a supply for 2,000 acre-feet of average annual demand.

Table 2-5
WATER SUPPLY DEFICIENCIES[a]

Water Use	Maximum Allowable Deficiency (%)
Municipal and Industrial	50
Year-Round	50
Agriculture (by crop)	
Rice	75
Pasture	50
Small Farms	50
Field Crops	25
Orchards	25
Miscellaneous Crops	25
Overall Weighted Average	50

[a]Raw Water Master Plan, Element 1, (January 1983)

The objectives of this study include identifying a project at Rollins Reservoir which reduces water shortages. Net cost of delivered water is the key factor in assessing the feasibility of the project alternatives.

HYDROPOWER

Hydropower benefits of the alternative projects are evaluated to assess the potential to reduce the unit cost of new water supplies.

The value of additional energy and capacity developed at Rollins powerhouse will be determined through negotiation with PG&E, which has contracted for power from the plant through June 2013. A range of values for energy and capacity are used is this report to provide a general indication of revenues from the alternative projects.

PREVIOUS STUDIES

A proposal for a gated spillway was considered by DSOD when EBASCO designed Rollins Dam in 1963-64, but this feature was not incorporated into the constructed project.

When the Rollins Power Project was investigated by Tudor in 1974, several alternatives were evaluated, including increasing the normal water surface elevation from 2,171 to 2,185, by addition of spillway gates. The study assumed that the gates would remain open between November 1 and April 1 to provide for safe routing of major floods. Based upon energy prices of the time, the installation of gates was judged infeasible. That study also determined that raising the water surface above 2185 would have an adverse affect on the environment, disrupt existing recreational facilities next to the reservoir and require relocating Old Highway 40 where it crosses an arm of the reservoir.

SAT15C/15

Chapter 3
DAM STABILITY AND HYDRAULICS

DAM SAFETY ANALYSIS

The Rollins Dam is a zoned rockfill structure with a core inclined downstream. The core material, described as a low plastic clay, is surrounded by upstream and downstream filter zones, a zone of river-run sand and gravel, and rock fragments, and an outer shell of rock and cobble fill. The downstream and upstream slopes are 2:1 and 2.5:1, respectively. The dam was completed in 1965.

The dam and spillway are founded on fresh, hard metamorphosed volcanic rock (andesite). Weathered and fractured rock was removed from the excavations during construction. Rock quality was generally considered excellent, especially under the ogee weir (DSOD, September 18, 1964). Grout takes under the ogee were negligible. Water pressure tests beneath the dam also indicated low permeability.

Dam inspections are done by the California Division of Safety of Dams (DSOD) and by Thomas Corwin, consultant. Inspection reports by the DSOD from 1964 to the present indicate that the dam and spillway are in excellent condition. Between 1965 and 1977, dam settlement has been 0.1 foot with about 0.035 foot of movement downstream (DSOD, 1979). Leakage from the toe has been nil to minimal. The spillway concrete is in good condition with no offsets. Minor seepage occurs from weep holes.

The DSOD analyzed dam stability in 1963 with the following results:

Slope	Case	Seismicity	Factor of Safety
Upstream	Submerged	0	1.74
		0.1g	1.27
	Sudden drawdown	0	1.90
Downstream	Steady seepage	0	1.47
		0.1g	1.15

Corwin has inspected Rollins at approximately 5-year intervals since 1968, and has also reported the dam is in excellent condition. In 1984, Corwin evaluated stability using various ground accelerations:

Ground Acceleration (g)	Factor of Safety for: Empty Reservoir	Part Filled Reservoir	Filled Reservoir
0.0	1.80	1.50	1.80
0.10	1.34	1.16	1.34
0.20	1.06	1.0 (0.16g)	1.06
0.23	1.00	--	1.00

Based on other earthquake studies in the site region, Corwin assumed that "probable" values of ground acceleration would be half those indicated by Schnabel and Seed (Ref. 2). Corwin chose a Magnitude 5.75 earthquake on the Melones fault, 6 miles from the site. This would produce an acceleration of 0.14 g at the site.

Both the DSOD and Corwin calculations indicate Rollins Dam is stable for the earthquakes evaluated. At present, however, the Melones fault is considered (Ref. 3) capable of a Magnitude 6.5 earthquake, which would produce an acceleration of 0.21 g (assuming one-half of the maximum rock acceleration).

Three project alternatives are proposed for Rollins Dam:

Alternative	Pool Level Increase (ft)	Changes to Dam
1 - Labyrinth Weir to el. 2,176	5	None
2 - Labyrinth Weir to el. 2,177.5	7.2	Raise crest 2.2 feet
3 - Bascule Gates to el. 2,182.2	13	None

Raising the dam crest for Alternative 2 will require removal of the upper existing crest, and extension of the core, filter, and rock shell (Figure 9). This will reduce the crest width to 20 feet, which is the minimum acceptable to DSOD. The additional 2.2 feet is less than a one percent increase to the dam height. Borrow sources for additional core, filter, and shell materials are required, and can be found locally within the reservoir area.

DSOD and FERC approval is required for modifications to existing dams. Approvals are based on review of the original design, foundation conditions, construction, materials, condition of structures, proposed modifications, and an evaluation of dam stability. Because of the higher ground accelerations now expected, and the increase in pool level/

dam height, a dam stability analysis is recommended. This would evaluate the following:

- Steady state seepage on downstream face under static conditions
- Steady state seepage on downstream face under higher seismicity
- Sudden drawdown

In addition, stability of the spillway with respect to sliding, uplift, and drainage should be done. Seepage analysis of the core and foundation is also recommended.

HYDRAULIC ANALYSIS

The literature contains references to labyrinth spillways constructed at Quincy Dam, Aurora, Colorado (Ref. 4); Mercer Dam, Dallas, Oregon (Ref. 5); Woronora and Avon Dams, Sydney, Austrailia (Ref. 6); Bartletts Ferry Dam, Columbus, Georgia (Ref. 7); and Ute Dam, Logan, New Mexico (Ref. 6,8). Hydraulic model studies are reported for the Navet Pumped-Storage Project, West Indies (Ref. 9); Mercer Dam, Oregon (Ref. 5); Bartletts Ferry Project, Georgia (Ref. 7); Ute Dam, New Mexico (Ref. 6,8); Hyrum Dam, Utah (Ref. 10); and Boardman Project, Oregon (Ref. 11). Most of the studies and reports cited above are based upon the work of Hay and Taylor (Ref. 12), which was published in 1970.

CONCEPTUAL DESIGN

The existing spillway at Rollins Dam has a total width of 316.3 feet. It is proposed to utilize approximately 10 feet of this width as a debris sluiceway. The remaining width available for installation of the labyrinth spillway is about 306 feet.

The reconnaissance study proposed to set the new spillway crest at elevation 2,176, a 5-foot increase over the present crest elevation of 2,171. With a maximum allowable water surface elevation of 2,185, total head (H) available to pass the spillway design flood (65,000 cfs) is 9 feet (Figures 7 and 8).

Assuming the existing ogee spillway to be demolished to grade and the new labyrinth spillway to be constructed over and upstream of the existing crest, with no modification of the approach channel, the height of the labyrinth weir (P) would be about 11 feet. The resulting net head-to-weir height (H/P) ratio is 0.82.

A conceptual labyrinth design has been prepared, utilizing the design procedure presented by Hay and Taylor, as modified by United States Bureau of Reclamation (Ref. 6). Some important design parameters from this preliminary design are compared below with ranges for these parameters from structures reported in the literature.

Parameter	Range	Rollins Labyrinth
Weir length/channel width (l/w)	1.9-5.0	5.0
Net head/weir height (H/P)	0.40-0.72	0.82
Weir height (H)	3.7-19.0	9.0
Channel width/net head (w/P)	1.2-6.6	3.1
Number of cycles (n)	2-40	9

The above comparison demonstrates that the net head to weir height ratio (H/P) for the Rollins labyrinth is outside the range of experience for operating labyrinths reported in the literature. This parameter is central to the design procedures for labyrinth weirs, as it is used to represent approach conditions.

The U.S. Bureau of Reclamation (USBR) Engineering and Research Center in Denver, Colorado, conducted a series of model studies in conjunction with the installation of the Ute labyrinth. These tests covered H/P ratios from 0 to 1.0, but length magnification ratios (l/w) above 5 were not used in these tests. This limitation prevents the development of a reliable rating curve for the labyrinth weir. In addition, approach conditions at the Rollins site (with the broad, curved approach channel) are such that lateral flow distributions can be expected to depart from the uniform lateral distribution used in these model studies. There is some question about downstream hydraulic conditions. Initially a proposal had been made to leave part of the existing ogee crest in place and provide a flat apron between the weir folds. Just what downstream conditions would be required to provide adequate capacity to prevent adverse effects on the operation of the labyrinth was not clear from the literature.

For these reasons, it was recommended that a hydraulic model study of the labyrinth weir be conducted.

Hydraulic Model Studies

Dr. Paul Tullis, of Utah Water Research Laboratory (UWRL) at Utah State University in Logan, Utah, was subsequently authorized to conduct scale model studies of the elevation 2176.0 labyrinth weir and the approach channel. The UWRL memo report is attached as Appendix B.

Sectional studies were conducted in a small flume to evaluate alternative weir crest configurations. From this effort it was concluded that a semicircular crest provided good stability of flow while maintaining a high coefficient of discharge. This crest section was used in subsequent model studies.

A 40-scale model was constructed of the labyrinth weir and enough of the dam and reservoir area to simulate flow conditions in the approach channel. Four different weir configurations were modeled:

- 9-cycle with flat downstream apron (P=11 feet)
- 9-cycle with flat downstream apron (P=15 feet, with deepened approach channel)
- 9-cycle with 9% sloping downstream apron (P=11 feet)
- 7-cycle with 7% sloping downstream apron (P=11 feet)

It was found from the first two sets of runs that the flat downstream apron resulted in the labyrinth weir being drowned out at higher flows. Increasing the approach channel depth improved performance slightly, but it was still not possible to pass the 65,000 cfs PMF at a maximum pool elevation of 2,185.

Adequate performance was exhibited by both the 9-cycle and 7-cycle configurations with sloping downstream aprons. In both cases 65,000 cfs was passed with maximum pool elevations of less than 2,185.

The approach channel configuration caused considerable crossflow at the weir. This was most noticeable at the higher rates of flow. While this condition no doubt resulted in a reduction of the coefficient of discharge for the weir, and some variation in discharge rate across the length of the weir, no significant problems were observed. Standing waves were observed in the vicinity of the upstream apexes, particularly on the left side of the spillway, but appeared to present no significant problem.

One potential problem relates to the 10-foot wide trash gate proposed for the left end of the spillway. A rather large standing wave was observed downstream from this gate. This wave mounted rather high on the sidewall of the spillway, and could be a source of trouble under very high flows (approaching the PMF). An alternate design, which should be considered during final design, would be to make the trash gate an integral part of the first labyrinth wall. This could be accomplished by mounting a bascule-type gate on the wall near the downstream end of the wall.

Rating curves for the three configurations with P=11 feet may be found in Appendix B. A weir with crest at elevation 2177.5 (P=12.5 feet) was not modeled. However, performance of the higher weir (Alternative No. 2) is not expected to significantly vary with the small (14 percent) increase in P.

Bascule Gates

Alternative No. 3 considers installing bascule gates on the spillway. Engineering and cost data relating to this proposal were provided by a bascule gate manufacturer. The meeting held with DSOD included discussion of bascule gates and a review of the history of earlier (1964-74) applications to DSOD for addition of tainter gates at Rollins.

It is the gate manufacturer's contention that bascules will allay concerns that spillway gates might not operate due to a power or equipment failure, since they open with loss (or emergency release) of hydraulic fluid. However, DSOD is concerned that opening the gates in such a manner would essentially constitute a controlled release of a large stored volume, and therefore DSOD is not generally receptive to gated spillways, fuse-plug dam sections, and similar proposals. However, if the gates were operated only when risk of a major flood is small (say May through September), this concern would be addressed. Such a proposal must demonstrate that the summer flood can be passed over the top of the gates with minimum freeboard.

Data provided by the gate manufacturer suggests bascule gates limited to a maximum height of 13 feet. As described in Chapter 2, because the gates would be less efficient than the existing ogee section at passing flows, the new crest (with gates fully open) must be limited to elevation 2,169.2, or 1.8 feet below the existing crest. When closed, the 13-foot high gates could impound water to elevation 2,182.2, with an increase in storage capacity of 9,740 acre-feet. The effectiveness of this storage is decreased by its limited availability (after the peak runoff season in many dry years), and because the lower crest results in loss of approximately 1,500 acre-feet of storage between October 1 and April 30.

Installation of the gates would require demolition of the existing ogee, and reconstruction of substantial foundations to support the three 110-foot long gates. No hydraulic problems should result from this alternative.

SAT15C/20

Chapter 4
PROJECT BENEFITS AND COST ESTIMATES

WATER SUPPLY

Water yield for critical dry years during the 1911 through 1980 period of investigation is shown in Table 4-1 for all alternatives. Effects of evaporation have been included in the analysis. Alternatives 1 and 2 provide the largest additional supply of water during critical dry periods. Lower water yields during 1961, 1976, and 1977 are a result of the reservoir not completely filling before entering the critical dry year.

Table 4-1
ROLLINS HYDROPOWER PRODUCTION AND WATER YIELD EFFECTS

	Existing Conditions	Alternative No. 1	Alternative No. 2	Alternative No. 3
Rollins Average Annual Energy Production				
1. In Million kWh	71.472	72.837	73.350	74.628
2. Increase Over Existing Conditions (Million kWh)	--	+1.365	+1.878 (+2.594)[a]	+3.156
Rollins Firm Capacity Increase (megawatts)	--	+0.4	+0.4	-0.2
Water Yield Effects (acre-feet)				
1924	--	4,050	5,350	2,760
1931	--	4,050	5,350	-1,480
1934	--	4,050	5,350	1,800
1961	--	3,750	3,750	-800
1976	--	1,930	2,580	-1,480
1977	--	1,820	2,470	0
Average (Adopted firm yield)		3,280	4,140	130

[a]Revised during Task 12 detail studies, June 1986.

Alternative 3 provides additional storage for water which would have spilled after May 1. Critical dry years with negative water yield effects indicate that no additional water was available to fill the reservoir once the gates were closed. The storage lost between October 1 and April 30 is 1,480 acre-feet, the difference between storage at the existing crest elevation and the proposed lower crest. Because the water elevation remained below the proposed lower crest elevation of 2,169.2 feet throughout 1977, no additional water was lost under Alternative 3 in 1977.

FIRM WATER YIELD

There are a number of valid approaches to determine the incremental water yield made available by the proposed project. Reasoning and results of 4 approaches are reviewed below; the basis adopted for this report does not necessarily reflect District Policy.

This report defines firm water yield as the average volume of additional water supplied to the Bear River Service Area in the 6 years of water shortage which would have occurred during the period 1911-80 under ultimate Master Plan demands. The average project firm water supply for Alternative 2 by this definition is 4,140 acre-feet. As noted in Table 4-2, this analysis assumes that water supplies available at the beginning of the 1976-77 drought would be husbanded for delivery over the 2 years, with an average Bear River shortage of approximately 30 percent.

Table 4-2
ALTERNATIVE 2 WATER SHORTAGES AND PROJECT WATER YIELDS

Calendar Year	Existing Shortages (percent)	Project Water Yields (acre-feet)	Remaining Bear River[a] Shortages (acre-feet)	(percent)
1924	19.9	5,350	11,920	13.7
1931[b]	31.5	5,350	21,990	25.3
1934	7.8	5,350	1,430	1.7
1961	3.6	3,750	0	0
1976[b]	1.0	2,580	25,600[c]	29.5[c]
1977[b]	63.8	2,470	25,710[c]	29.6[c]
Average		4,140		

[a]Water shortages are based upon a Bear River Service Area gross demand of 86,890 acre-feet annually.

[b]Rollins Reservoir would not fill these years. Supply is assumed to be reserved for delivery in 1977.

[c]The 1976-77 shortages are assumed to be distributed over 2 years and one half of the 1976-77 additional storage is assumed to be reserved for delivery in 1977.

A different definition of firm yield was used in the Water Supply Development Reconnaissance Study for comparison of alternative projects: firm yield was taken to be the average annual volume of additional water delivered during the 1976-77 drought. By this definition, firm yield for Alternative 2 is 2,525 acre-feet.

A third firm yield definition would assume that no reserve of water would be carried through the winter by the District in future 1976-like droughts. Under such conditions, there would be minimal Bear River shortages the first year, and the very severe shortages in the second (1977-like) year would be reduced approximately 4,940 acre-feet, from 63.8 to 58.2 percent. Firm yield would be 4,940 acre-feet.

A fourth approach to estimating the cost of developed water assumes a maximum District-wide curtailment of 50 percent, so that additional water delivered in both years of the 1976-77 drought (approximately 2,500 acre-feet each year) would allow sale of twice that volume of water in 67 years of the 70-year period of record studied. An annual yield of approximately 5,000 acre-feet would result in most years.

ENERGY PRODUCTION

Energy production for the existing powerplant at Rollins and at Pacific Gas and Electric powerhouses downstream was estimated using the CH2M HILL-developed water and power operations model. Data utilized by this program and the method of simulation are described in the program user manual (Ref. 13). Francis turbine efficiency curves utilized by the model for Rollins were developed from a Pacific Gas and Electric efficiency test performed on May 15, 1985.

The program used a maximum power release of 880 cfs. A design head of 225 feet was utilized in the Pacific Gas and Electric (PG&E) efficiency test and has been used for this feasibility review. Energy production at Rollins Powerhouse and water yield for existing and alternative conditions appear in Table 4-1. A revised (June 1986) energy production estimate is included in Table 4-1 for Alternative 2 based upon the detailed studies completed under Task 12. Incremental energy production at downstream PG&E powerhouses should be minimal during normal and wet years, but could exceed 0.80 million kilowatt-hours (kwh) for Alternative 1 and 1.05 million kwh for Alternative 2 in critical dry years such as 1924, 1931, and 1934.

COST ESTIMATES

Cost estimates for each alternative are presented below. The cost estimates shown, and any resulting conclusions on project financial or economic feasibility or funding requirements, have been prepared for guidance in project evaluation and implementation from the information available at the time of the estimate. The final costs of the project and resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. As a result, the final project costs will vary from the estimates presented herein. Because of these factors, project feasibility, benefit/cost ratios, risks, and funding needs must be carefully reviewed prior to making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

Construction costs for the civil items were derived by calculating the quantities of various types of work and applying estimated unit prices to each type of work. Unit prices are based upon experience and published estimating guides for similar work.

The preliminary cost estimates were prepared using April 1986 cost levels, and include a 20-percent construction contingency and 15 percent for engineering, legal, and administrative (indirect) costs. The indirect costs include efforts to secure water rights and satisfy environmental review requirements (assuming a negative declaration), engineering studies to meet state and federal dam safety requirements, and design, bidding, and engineering services during construction.

ALTERNATIVES 1 AND 2 - LABYRINTH WEIR

Alternatives 1 and 2 are the labyrinth weir proposals for crest elevations 2,176 feet and 2,177.5 feet, respectively. Both Alternatives 1 and 2 require demolishing the spillway down to the grade break. The proposed concrete slab and labyrinth weir require excavating rock from the existing spillway to 75 feet upstream of the spillway. The following is an estimate of total costs for Alternatives 1 and 2.

	Alternative No. 1	Alternative No. 2
Rock Excavation & Spillway Demolition	$ 192,000	$ 192,000
Labyrinth Weir		
Slab	491,000	491,000
Weir	609,000	696,000
Trash Gate	50,000	50,000
Revisions to Dam Crest	-	200,000
Total	$1,342,000	$1,629,000
Contingencies (20%)	268,000	326,000
Estimated Construction Cost	$1,610,000	$1,955,000
Indirect Costs (15%)	242,000	293,000
Total Investment Cost	$1,852,000	$2,248,000

ALTERNATIVE 3 - BASCULE GATES

Alternative 3 would employ Bascule-type gates about 77 feet upstream from the existing ogee crest, which would be removed. The estimated cost of three 13-foot high by 110-foot long gates is $2,400,000. The following is an estimate of the total cost of converting to a gated spillway:

Demolish existing spillway crest	$ 100,000
Fabricate three 13-foot by 110-foot gates (FOB factory)	2,400,000
Shipping and installation of gates	1,000,000
Concrete gate structure and walls	2,000,000
Total	$5,500,000
Contingencies (20%)	1,100,000
Estimated Construction Cost	$6,600,000
Indirect Costs (15%)	990,000
Total Investment Cost	$7,590,000

Based upon this high estimated cost and in view of the limited benefits, Alternative 3 was determined not comparable in feasibility to Alternatives 1 and 2 and was not examined further in this study.

SAT15C/17

Chapter 5
ECONOMIC ANALYSIS AND CONCLUSIONS

ANNUAL REVENUES

Estimated project revenues for three economic analyses per alternative are based on the assumption that incremental Rollins energy and generating capacity will be sold to Pacific Gas and Electric Company (PG&E) for 50, 75, or 100 percent of the May 1986 avoided cost rates. It was assumed that the negotiated energy and capacity prices would be fixed over the remaining years of the Yuba-Bear Consolidated Contract, through June 2013.

Table 5-1
PG&E MAY 1986 AVOIDED COST ENERGY AND CAPACITY PRICES

Item	Energy Prices For Meter Readings During May 1986
Energy	
I. Time of Delivery Basis:	
On-Peak, per kWh	$0.04500
Partial Peak, per kWh	0.04176
Off-Peak, per kWh	0.03573
II. Seasonal Average Price Basis	0.03923
Capacity	$56/kW-year

Additional annual energy production of 2.59 million kwh was assumed for Alternative 2, based upon the revised Task 12 estimate. Although no Task 12-type analysis was done, the energy production for Alternative 1 is likely to be proportionally increased to 1.89 million kwh. Annual firm capacity revenue is $22,400 for both alternatives.

Annual revenues for Alternatives 1 and 2 are displayed in Table 5-2. With the recent (May 1986) 20 percent decline in awarded cost rates, and with inflation of energy costs assumed to be zero, the projected revenue may be assumed to be conservatively estimated. No revenues were assumed to accrue as a result of additional dry-year energy production at downstream PG&E powerplants.

ANNUAL COSTS

Annual maintenance costs for the labyrinth weir alternatives would be minimal and are therefore neglected for these analyses.

Annualized capital cost, including two years of cost escalation at 4 percent per year from 1986 through 1988, was computed for each alternative at both a 7 and 9 percent annual interest rate for a period of 25 years and appear in Table 5-2.

IMPLEMENTATION SCHEDULE

The implementation schedule (Figure 10) for Rollins Labyrinth Weir Project is dependent upon funding availability and permit requirements. Negotiations with PG&E to obtain a favorable power sales agreement should begin immediately, and in coordination with the proposed turbine runner replacement project negotiations.

Permits and reviews required by the project involve issues of dam safety, water rights, and environmental impact. Revisions to the dam crest and spillway will require approval of DSOD and FERC. On May 30, 1986, representatives of NID and CH2M HILL met with key DSOD staff to review the project concept and to discuss the agency's permit requirements. The following issues were identified by DSOD as requiring assessment or review:

- Does the proposed lesser detention of the probable maximum flood volume increase risk to downstream lives and property?
- Does the proposed higher pool elevation impact private property or result in other environmental impacts along the shoreline?
- Floating and stability problems have occurred on similar (but much higher) USBR structures; is the weir foundation and anchorage adequate?

Further comments by DSOD included:

- The 5 percent normal pool freeboard requirement guideline cannot be relaxed. Therefore, a maximum weir crest elevation of 2,174.4 is possible without modification of the dam crest (versus 2176.0 for Alternative 1). However, because the portion of that freeboard above the PMF water surface level need not incorporate an extension of the clay core (minimum elevation 2186.5), raising of the dam crest could be much simplified.

Table 5-2
ECONOMIC ANALYSIS

	Alternative 1						Alternative 2					
	7 Percent Interest % Avoided Cost			9 Percent Interest % Avoided Cost			7 Percent Interest % Avoided Cost			9 Percent Interest % Avoided Cost		
	50	75	100	50	75	100	50	75	100	50	75	100
Annualized Capital Cost[a] ($)	171,900	171,900	171,900	203,900	203,900	203,900	208,600	208,600	208,600	247,500	247,500	247,500
Annual Power Revenue ($)	59,500	78,000	96,500	59,500	78,000	96,500	73,200	98,600	124,000	73,200	98,600	124,000
Net Annual Costs ($)	112,400	93,900	75,400	144,400	125,900	107,400	135,400	110,000	84,600	174,300	148,900	123,500
Cost of Additional Firm Water ($/AF)	34	29	23	44	38	33	33	27	20	42	36	30

[a]Including two years of cost escalation at 4% per year from 1986 to 1988.

Furthermore, camber needs (and a potential reduction of earthwork needed to raise the crest) would be reviewed based upon the history of dam settlement (this settlement has been minor).

- o Regarding the need for further stability analysis, slopes of the dam are considered not conservative, but adequate. Although Rollins Dam is not currently scheduled for preparation of a safety review report, there is a risk that a review could be required as a result of the proposed project application.

- o The hydraulic performance of the weir must be addressed, possibly requiring further and more detailed model studies. Specific concerns are whether air entrainment (bulking) might choke flow, drowning the weir from downstream under high flows. DSOD would expect any required model testing to be completed prior to a demonstration for DSOD staff.

- o The likely time constraint to start of project construction is the water rights process, if DSOD is kept updated on dam safety concerns.

An initial contact was made on June 17, 1986 with Mr. Noel Folsom of the FERC (San Francisco), regarding that agency's requirements. Mr. Folsom recommended that NID submit a letter to FERC inquiring whether a license amendment is needed for the project. This submittal should address potential environmental impacts and should include results of consultation with (at minimum) California Department of Fish and Game, the Regional Water Quality Control Board, and the State Office of Historic Preservation. He presumes that evidence of agreement with these agencies regarding a negative declaration would obviate the need for a FERC license amendment. The Office of Hydropower Licensing would require that plans and specifications for construction be submitted for approval at least 60 days prior to bid.

The requirements of the California Environmental Quality Act would likely be met by filing a negative declaration. It will also be necessary to obtain water rights from the State Water Resources Control Board, and this may include an environmental review. The implementation schedule utilized for the economic analyses assumes that approvals could be obtained by late 1987. The schedule assumes that NID would utilize its annual budget resources and its standing line of credit for funding all phases of project. Assuming design and construction bidding are completed by June 1987, the project would be completed by October 1988.

COST OF WATER

The unit cost of project water is computed for each alternative by reducing gross annual costs by annual energy revenues, and by then dividing the net annual cost by the incremental firm water supply. Project annual costs vary from $20/AF to $44/AF depending upon alternative chosen, percent of avoided cost obtained for energy, and the interest rate (Table 5-2). Since firm water yield in 1976 and 1977 (the definition used in the November 1985 Water Supply Development Reconnaissance Study) is approximately 60 percent of firm yield as defined for this study, unit costs of water may be increased by 70 percent to make them comparable to the 1985 study.

RECOMMENDED ALTERNATIVE

The economic analysis indicates that additional construction costs for Alternative 2 over Alternative 1 will be offset by increased power revenues and additional water yield. Therefore, Alternative 2 is recommended, which would provide 4,140 AF of additional firm water at a cost of $20/AF to $42/AF.

SAT15C/18

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SAT15C/22

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FIGURES

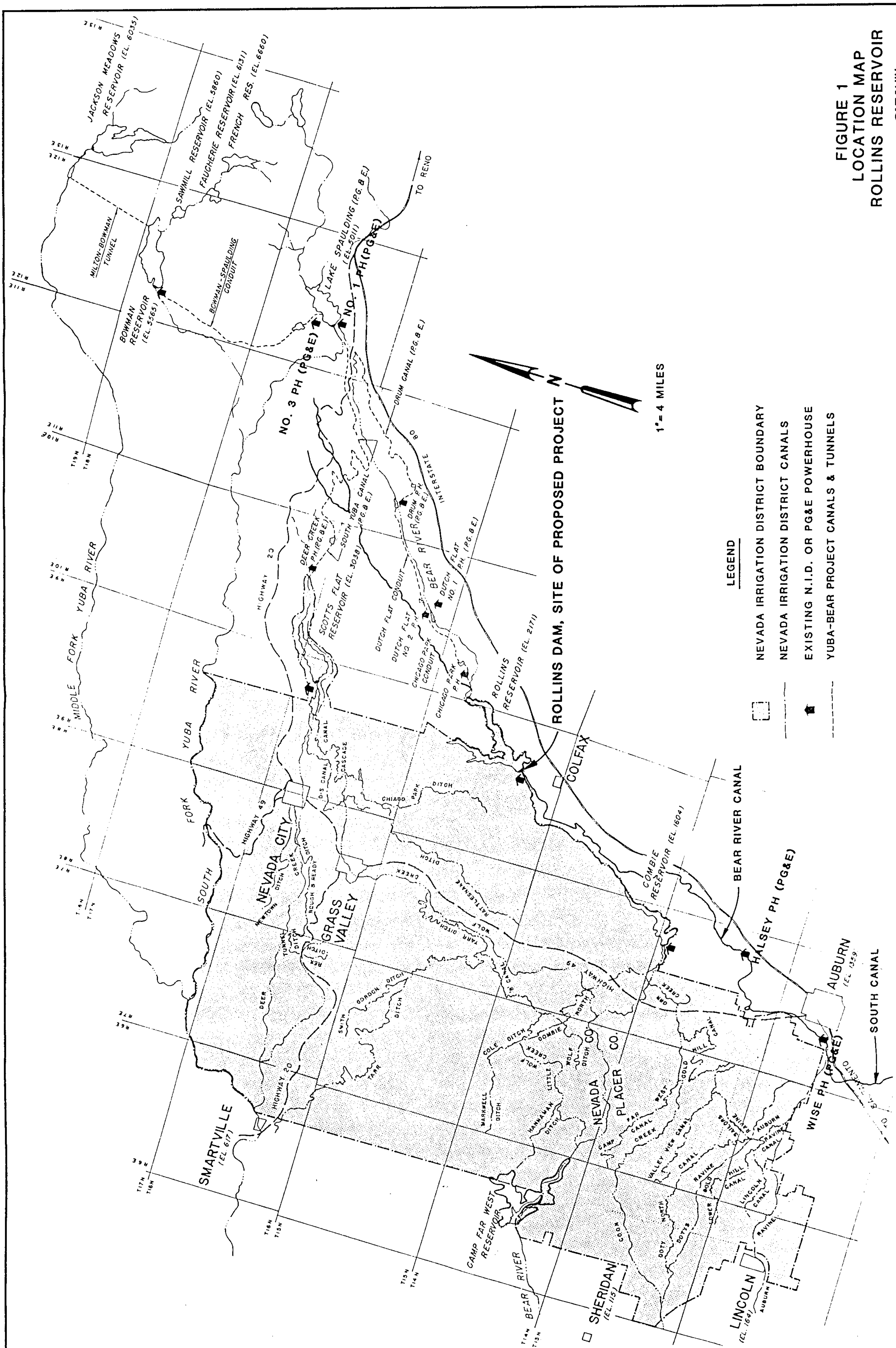


FIGURE 1
LOCATION MAP
ROLLINS RESERVOIR
CH2M HILL
LEGEND
NEVADA IRRIGATION DISTRICT BOUNDARY
NEVADA IRRIGATION DISTRICT CANALS
EXISTING N.I.D. OR PG&E POWERHOUSE
YUBA-BEAR PROJECT CANALS & TUNNELS
1" = 4 MILES
N
ROLLINS DAM, SITE OF PROPOSED PROJECT
ROLLINS RESERVOIR (EL. 2171)
JACKSON MEADOWS RESERVOIR (EL. 6035)
SAWMILL RESERVOIR (EL. 5860)
FAUCHERIE RESERVOIR (EL. 6131)
FRENCH RES. (EL. 6660)
BOWMAN RESERVOIR (EL. 5565)
MILTON-BOWMAN TUNNEL
BOWMAN-SPAULDING CONDUIT
LAKE SPAULDING (PG.& E.) (EL. 5011)
NO. 1 PH (PG&E)
NO. 3 PH (PG&E)
DRUM CANAL (PG.& E.)
TO RENO
INTERSTATE 80
DRUM PH (PG.& E.)
SOUTH YUBA CANAL (PG.& E.)
DEER CREEK PH (PG.& E.)
SCOTTS FLAT RESERVOIR (EL. 3038)
DUTCH FLAT CONDUIT
BEAR RIVER
DUTCH FLAT NO. 1 PH
DUTCH FLAT NO. 2 PH
CHICAGO PARK CONDUIT
CHICAGO PARK PH
HIGHWAY 20
MIDDLE FORK YUBA RIVER
SOUTH FORK YUBA RIVER
HIGHWAY 49
NEVADA CITY
GRASS VALLEY
COLFAX
COMBIE RESERVOIR (EL. 1604)
BEAR RIVER CANAL
HALSEY PH (PG&E)
AUBURN (EL. 1359)
SOUTH CANAL
WISE PH (PG&E)
NEVADA CO.
PLACER CO.
SMARTVILLE (EL. 617)
CAMP FAR WEST RESERVOIR
BEAR RIVER
SHERIDAN (EL. 115)
LINCOLN (EL. 164)
CHICAGO PARK DITCH
CASCADE CANAL
D-S CANAL
RATTLESNAKE DITCH
WOLF CREEK
TARR DITCH
SMITH GORDON DITCH
COLE DITCH
COMBIE NORTH DITCH
WARKWELL DITCH
HANNAMAN LITTLE DITCH
CAMP FAR WEST CANAL
VALLEY VIEW CANAL
GOLD HILL CANAL
LINCOLN CANAL
AUBURN RAVINE
COON CREEK
DOTY'S RAVINE

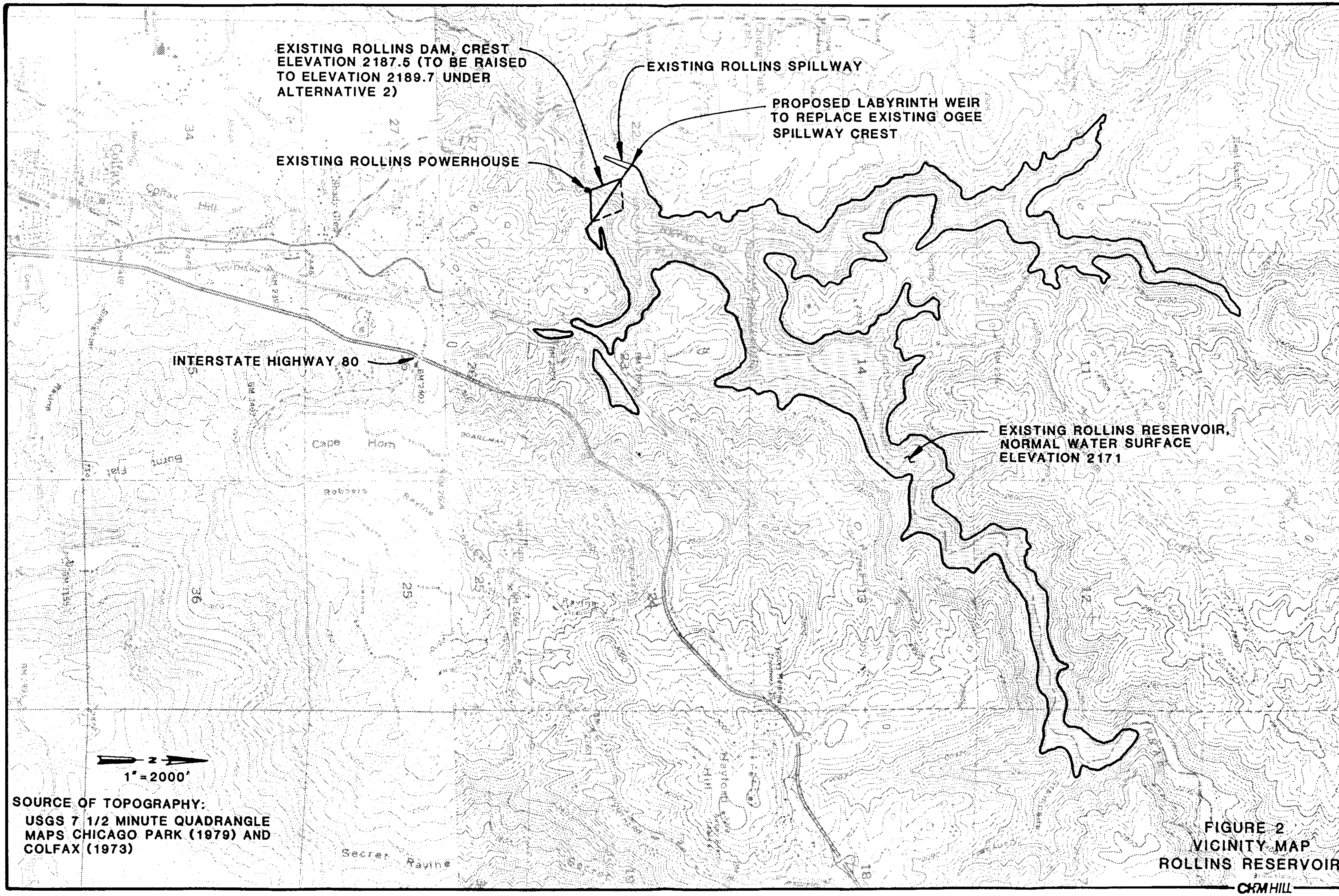
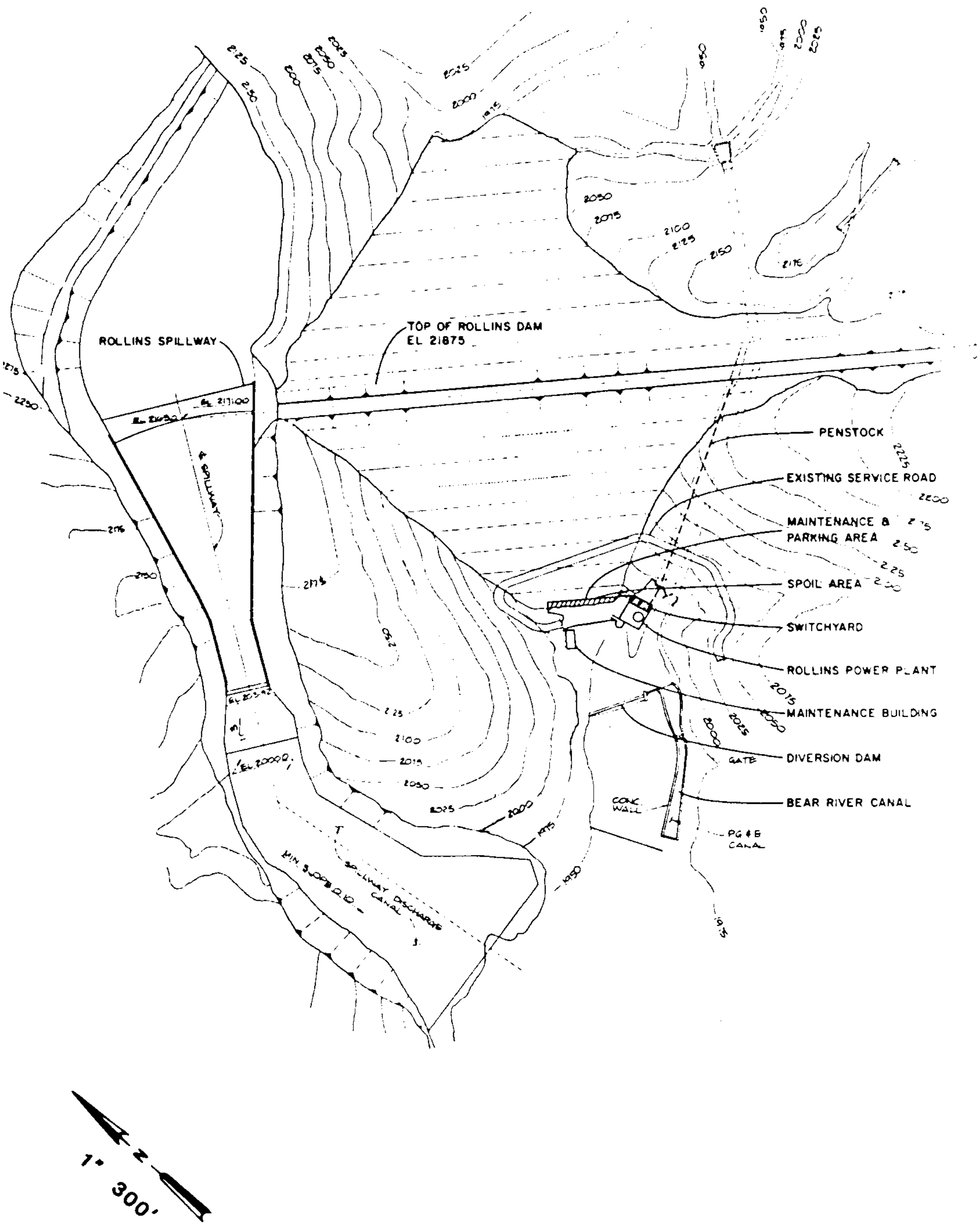


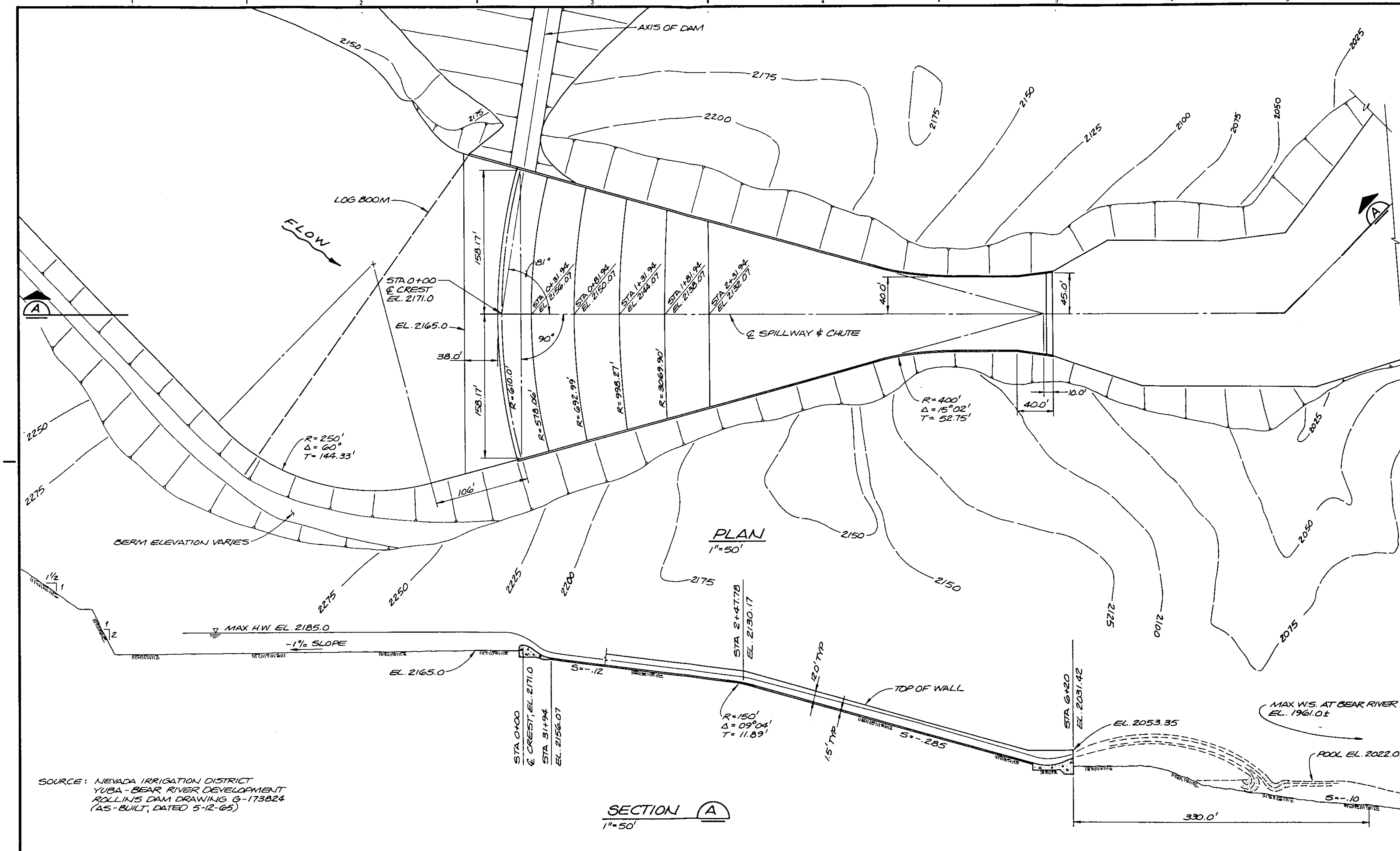
FIGURE 2
VICINITY MAP
ROLLINS RESERVOIR



MAP SOURCE: REFERENCE 14

FIGURE 3
DAM, SPILLWAY AND POWERHOUSE
ROLLINS RESERVOIR

CH2M HILL



CH2M HILL

DSGN	
DR	G.L. TRIPLAT
CHK	
APVD	

NO.	DATE	REVISION	BY	APVD
		-		

REUSE OF DOCUMENTS

THIS DOCUMENT, AND THE IDEAS AND DESIGNS INCORPORATED HEREIN, AS AN INSTRUMENT OF PROFESSIONAL SERVICE, IS THE PROPERTY OF CH2M HILL AND IS NOT TO BE USED, IN WHOLE OR IN PART, FOR ANY OTHER PROJECT WITHOUT THE WRITTEN AUTHORIZATION OF CH2M HILL.

VERIFY SCALES

BAR IS ONE INCH ON ORIGINAL DRAWING.

0 1"

IF NOT ONE INCH ON THIS SHEET, ADJUST SCALES ACCORDINGLY.

NEVADA IRRIGATION DISTRICT

ROLLINS SPILLWAY LABYRINTH WEIR

FIGURE 4
SPILLWAY PLAN & PROFILE

SHEET

DATE

PROJ NO. M15742.E0

PRELIMINARY

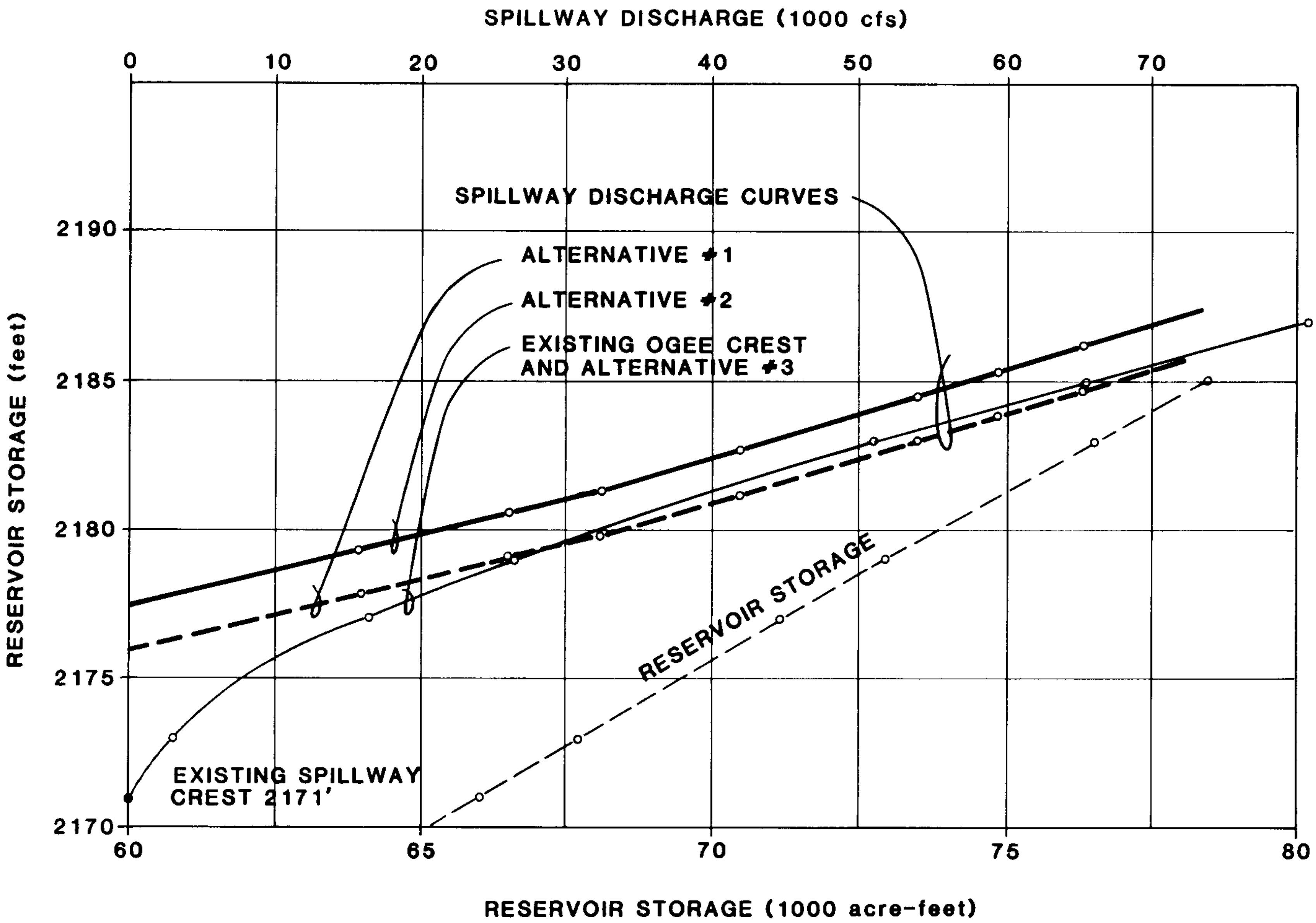


FIGURE 5
SPILLWAY DISCHARGE AND
RESERVOIR STORAGE CURVES
ROLLINS RESERVOIR

CH2M HILL

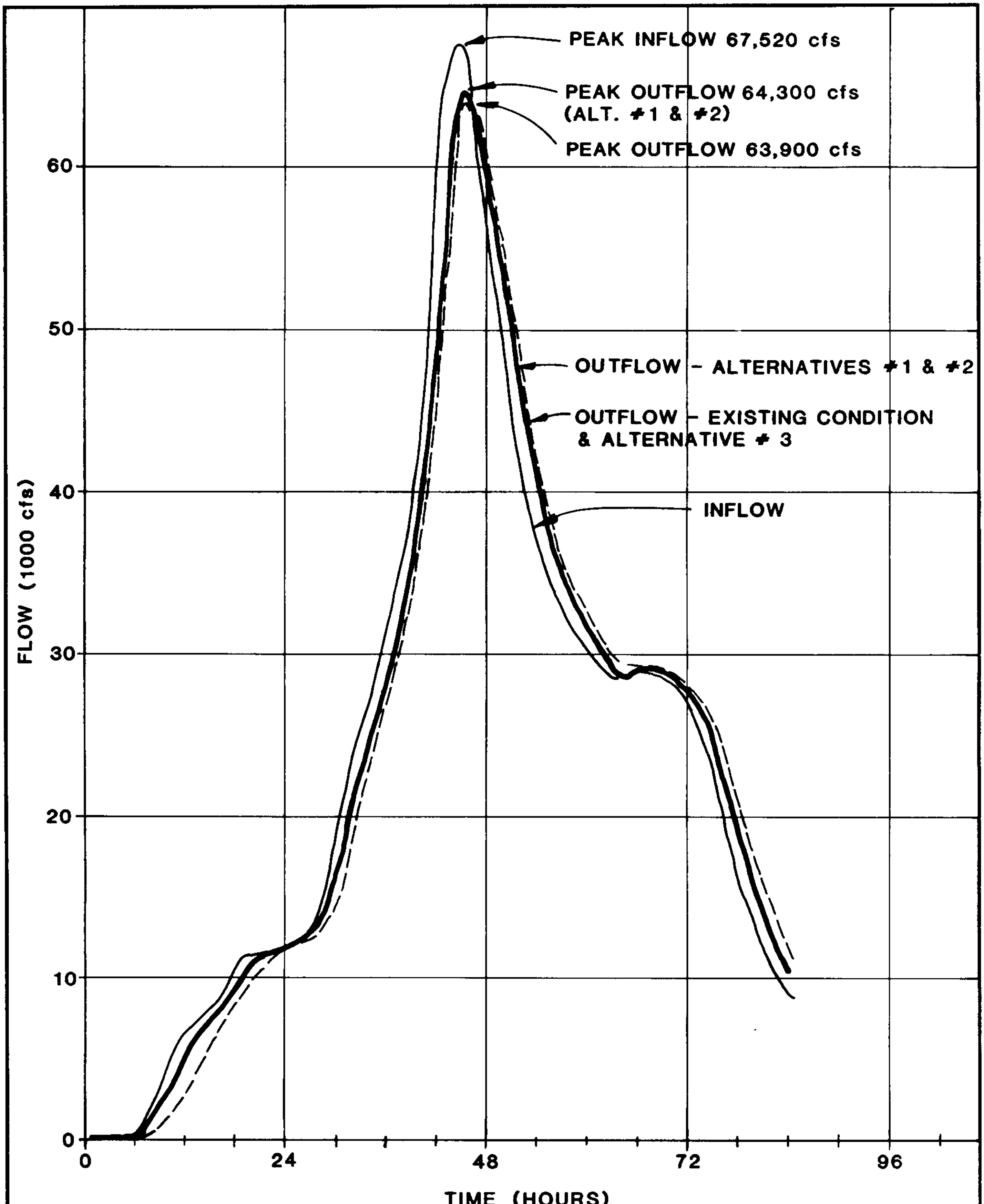


FIGURE 6
OCTOBER PROBABLE MAXIMUM FLOWS
ROLLINS RESERVOIR

CH2M HILL

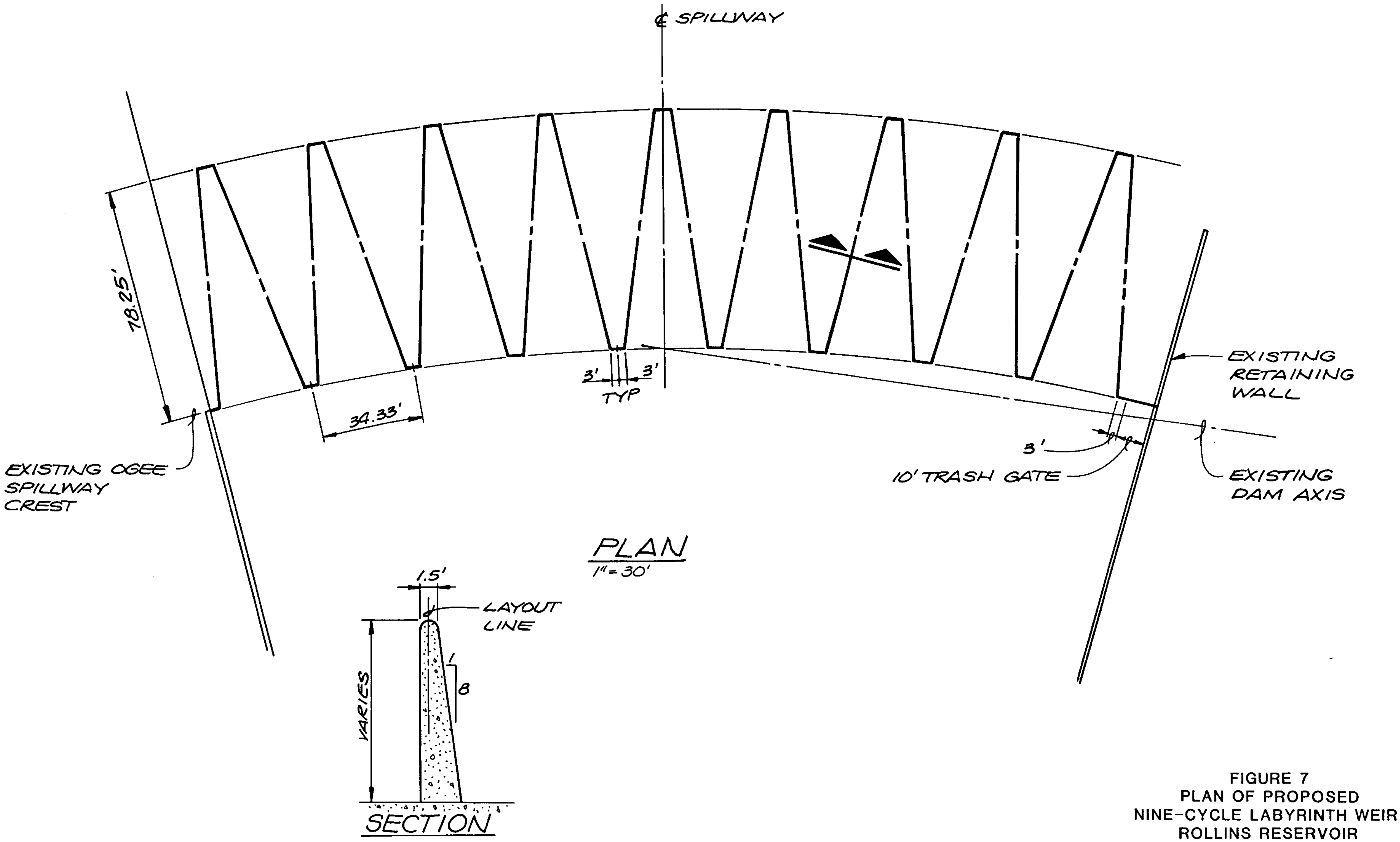


FIGURE 7
PLAN OF PROPOSED
NINE-CYCLE LABYRINTH WEIR
ROLLINS RESERVOIR
CH2M HILL

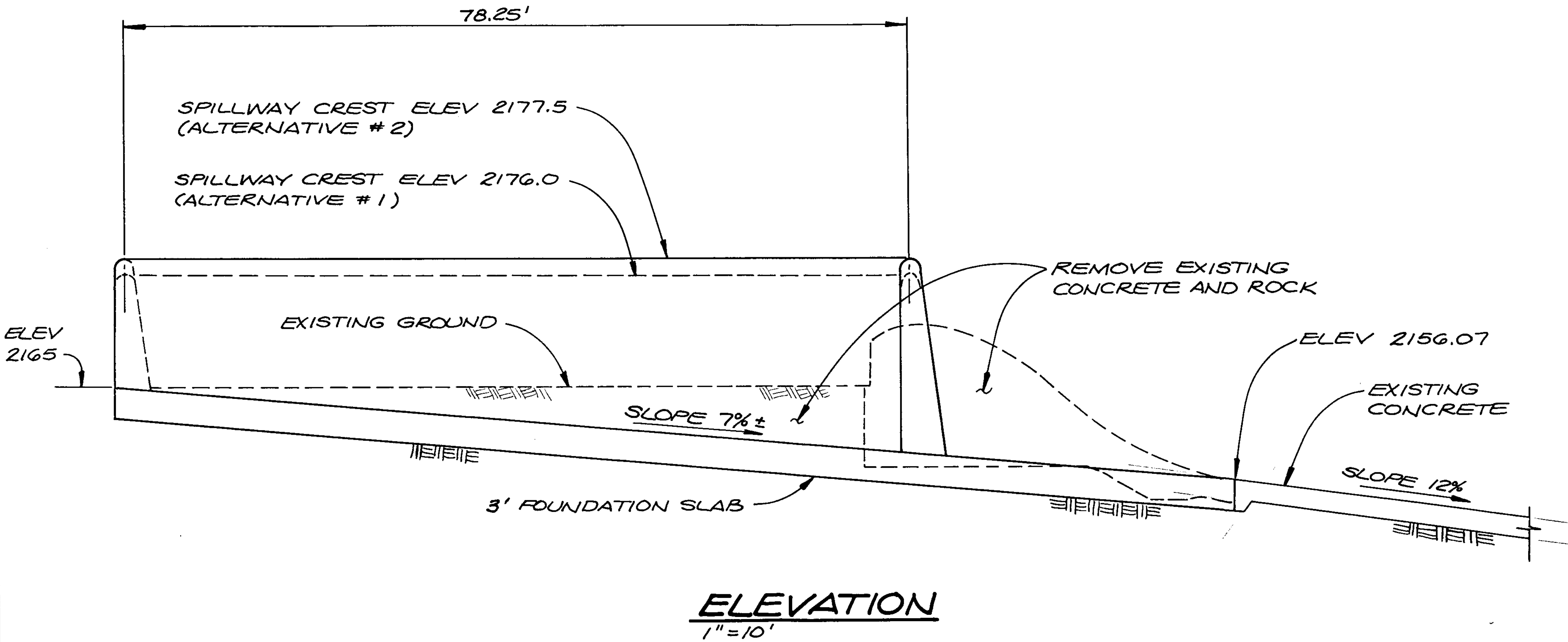
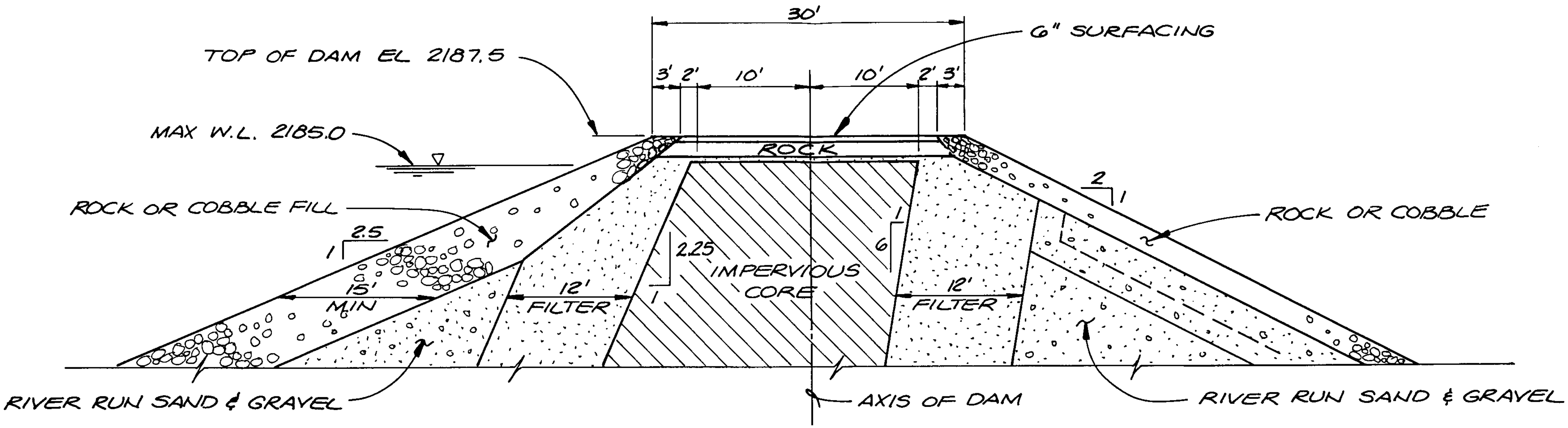


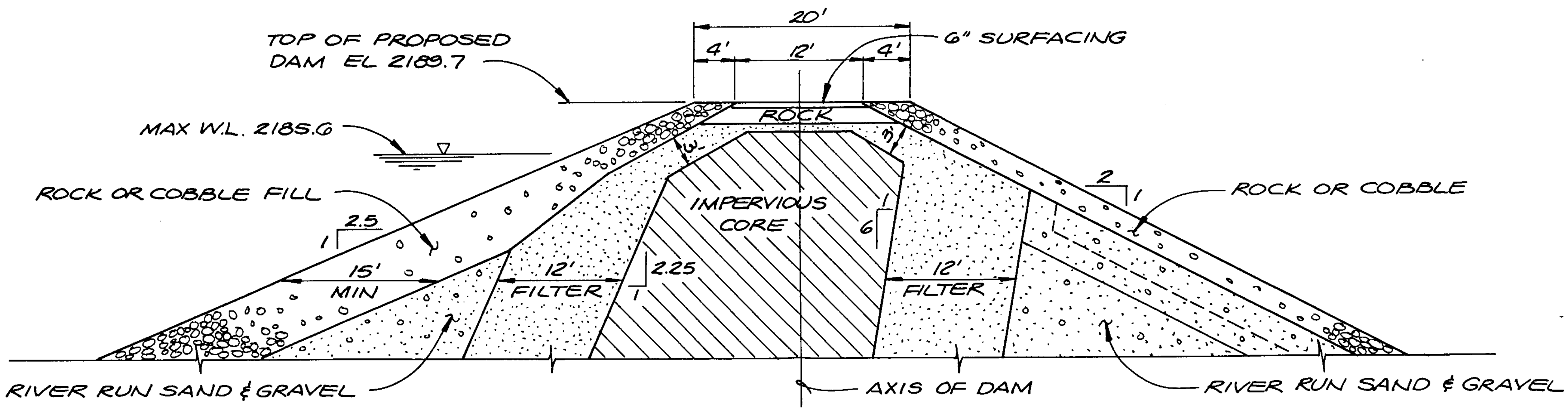
FIGURE 8
LONGITUDINAL ELEVATION OF
NINE-CYCLE WEIR ALTERNATIVE
ROLLINS RESERVOIR

CH2M HILL



EXISTING CREST

1"=10'



PROPOSED CREST

1"=10'

FIGURE 9
EXISTING & PROPOSED DAM CREST
ROLLINS RESERVOIR
CH2M HILL

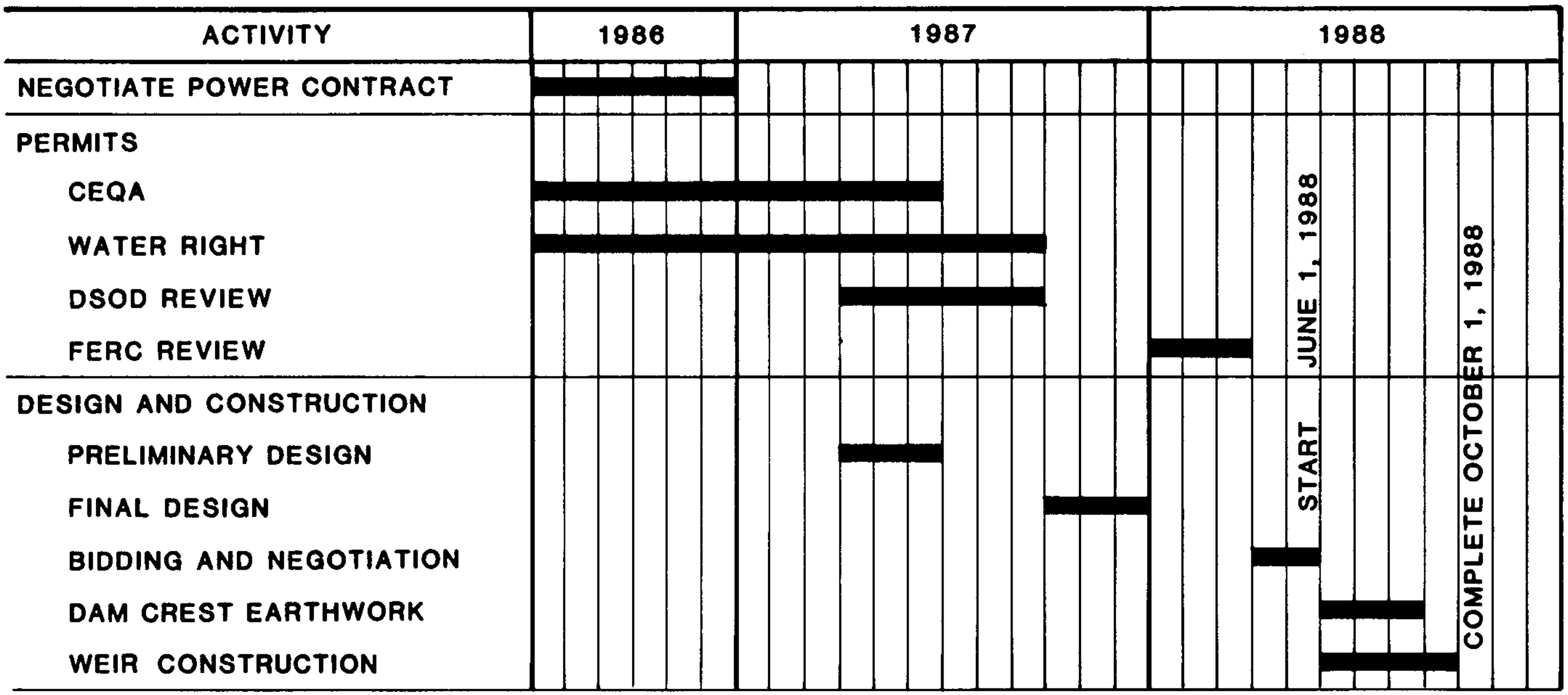


FIGURE 10

IMPLEMENTATION SCHEDULE
ROLLINS LABYRINTH WEIR

CH2M HILL

APPENDIX A

Appendix A

TASK ORDER NO. 6 DETAIL
NEVADA IRRIGATION DISTRICT

PRELIMINARY FEASIBILITY STUDY FOR
ROLLINS LABYRINTH WEIR ADDITION

OBJECTIVES

The Reconnaissance Water Supply Study identified addition of a labyrinth weir to the Rollins Dam Spillway as a potential source of additional firm water supply for Nevada Irrigation District (NID). NID is now contemplating a project to increase the capacity of the existing generating equipment at Rollins Powerhouse. The proposed study would assess the feasibility of the labyrinth weir and identify potential hydraulic and electrical impacts on the existing hydropower facilities.

WORK TASKS

A description of tasks included in the study follows:

Task 1. Data Collection

CH2M HILL has assembled some published and unpublished data on the project. Additional data to be collected and organized for the study include:

- Files of California Division of Dam Safety (DODS) for Rollins Dam and Spillway.
- Documents developed for the Federal Energy Regulatory Commission relating to dam stability.
- NID record drawings and geologic reports for the dam, spillway, and powerhouse.
- Data on existing and planned generating equipment and transformers.
- NID October 1985 aerial photography of Rollins Reservoir and shoreline.
- Recent studies of labyrinth weir hydraulic design.

Task 2. Field Review

CH2M HILL will conduct an onsite investigation to augment data gathered in Task 1. This reconnaissance investigation will include observation of the physical characteristics and conditions at affected facilities, including the spillway and existing ogee crest, the generating equipment, and lakeside recreation facilities. Special attention will be paid to factors influencing cost of ogee demolition and weir construction.

Task 3. Project Formulation

Following a review of geologic, geotechnical, hydrologic, and dam stability data, a preliminary weir structure design will be selected. This conceptual design will be based on review of published hydraulic performance investigations for alternative weir geometries, with the goal of providing a substantial increase in usable reservoir storage with no impairment of existing spillway capacity. Potential impacts of the project on recreation and other shoreline facilities will be identified. Conceptual drawings of the proposed facilities will be prepared.

Task 4. Dam Safety Analyses

The most recent DODS routing analysis for the Probable Maximum Flood (PMF) will be reviewed. A similar analysis will be performed for the proposed weir. The existing dam stability analysis will be reviewed in accordance with requirements of DODS and FERC. Results of these analyses will be submitted to DODS for review.

Task 5. Water and Power Yields

The NID water and power operations computer model will be used to estimate water supply and energy yields of the proposed project for 70 years of monthly record. Increases in as-delivered and firm capacity will be estimated using the model. Expected increases in energy and capacity at downstream PG&E powerhouses will be computed. Results of these analyses will be included as an appendix to the study report.

Task 6. Equipment Evaluation

Expected impacts of the project upon the existing generating equipment will be assessed based upon a review of available design, condition, and performance data. Preliminary recommendations regarding replacement or reconditioning of existing equipment will be made.

Task 7. Cost/Benefit Analysis

A feasibility-level construction cost estimate will be developed for civil construction and (if applicable) for electrical/mechanical improvements. Manufacturers' quotations and recent national bid experience will be used to estimate the costs of generating equipment. Civil and structural costs will be developed by quantity takeoff from the drawings. The cost estimates will be escalated to the anticipated time of construction and will include a listing and explanation of items of indirect costs.

Based upon one set of assumed values of energy and capacity to be selected by NID staff, a reconnaissance-level economic assessment of project feasibility will be made, including an estimate of the cost/benefit ratio.

Task 8. Permit Requirements

Procedures will be defined for obtaining the necessary permits for construction of the weir and for modification of the existing power facilities.

Task 9. Implementation Schedule

A plan for project implementation will be developed with a sequence of events from preliminary design, acquisition of necessary permits, final design, and preparation of construction documents to construction, performance testing and equipment startup. Milestone dates for accomplishing principal activities will be shown on this schedule.

Task 10. Report

Results of Tasks 1 through 11 will be documented in a report. The preliminary draft report will be reviewed by an inhouse Dam Review Board, as required under CH2M HILL operating policy. Five copies of the draft report will be submitted for review and comment. Twenty copies of the final report will be submitted to NID.

Task 11. Hydraulic Modeling

A hydraulic similitude (physical) model will be constructed and calibrated to the existing spillway design. A minimum of four alternative project designs will be model-tested to evaluate effects of alternative labyrinth weir heights and approahc channel depths upon the hydraulic capacity of the spillway. Results will be submitted by the modeling laboratory to CH2M HILL in a letter report, which shall be appended to the study report. Results of the model studies will be considered in selection of a preliminary project design.

APPENDIX B

Model Study

of the

Labyrinth Spillway

for

Rollins Dam

Submitted to:

CH2M Hill, Inc.

By:

J. Paul Tullis, Ph.D.
Utah Water Research Laboratory

and

Utah State University Foundation
Logan, Utah 84322-9300

March 1986

INTRODUCTION

A study is under way by CH2M Hill to determine the feasibility of raising the water surface elevation at Rollins Dam, five feet above the present elevation. The present crest is at elevation 2171, and the proposed new crest would be at 2176. One constraint on this modification is that the new spillway must be able to pass the maximum probable flood of 65,000 cfs at a maximum water surface elevation of 2185.

One alternative being considered is installation of a labyrinth weir. Since the design parameters for the weir place it just outside the limits of most available information in the literature, it was decided to conduct a limited 1:40 scale model study to determine if the proposed design would be able to meet the design constraints. A contract was negotiated with the Utah Water Research Laboratory, through the Utah State University Foundation, to conduct this model study.

The model included a section of the reservoir approximately 800 ft. square, all of the approach channel, the entire labyrinth weir and the upper portion of the spillway chute. The scope of work including design parameters and the various tasks included in the model study are contained Appendix A.

Tests were conducted on a 9-cycle and a 7-cycle labyrinth weir. The only modification from the original design required was that the downstream apron was placed at a slope to prevent the weir from being submerged at high discharges. Results showed that both the 9 or 7-cycle labyrinth have the capacity for providing the 65,000 cfs at a water surface slightly below the acceptable maximum level. There appeared to be no major hydraulic difference between the two designs and so the choice would be likely made on basis of an economic analysis, or which one fits in better at the site.

SIMILARITY CRITERIA

For hydraulic models of spillways and stilling basins, gravity forces are predominant and such models are operated based on the Froude similitude. The Froude number is a dimensionless number proportional to the ratio of inertia forces to gravity (or weight) forces. Data obtained on Froude models can be scaled to the prototype using the following relationships:

$$L_r = L_p/L_m = 40 \text{ (for this model)}$$

(subscripts p & m refer to prototype and model)

Discharge: $Q_p = L_r^{2.5}\ Q_m$

Velocity: $V_p = L_r^{.5}\ V_m$

Head: $H_p = L_r\ H_m$ (or depth)

Pressure: $P_p = L_r\ P_m$

Depth or wave height: $L_p = L_r\ L_m$

Time: $T_p = L_r^{.5}\ T_m$

MODEL CONSTRUCTION

The labyrinth weir and the spillway chute were fabricated of wood. The approach channel was formed of sand and gravel. Photographs and video tape have been provided to show the configuration of the modeling arrangement.

EXPERIMENTAL RESULTS

Crest Coefficient

The equation used to calculate the flow over the crest is:

$$Q = C\ L\ H^{1.5}$$

in which C equals the crest coefficient, L is the total length of the weir and H is the piezometric head above the weir crest.

Original Weir Configuration

The first configuration tested followed the parameters outlined in the Appendix. The apron was horizontal at elevation 2165 and the crest at 2176. The downstream apex was placed on the center line of the existing spillway. The top of the weir was semi-circular and the width of the wall was 2 ft. The weir had 9-cycles. Runs 1-3 in Table 1 and Figures 1 and 2 show the data for this original configuration. This original configuration was not able to supply the required flow. For run 4 the upstream channel was excavated to elevation 2157 for approximately 100 ft. upstream of the upstream apex. The results of run 4 indicate that increasing the depth of flow upstream, did not measurably increase the capacity of the spillway. The problem appeared to be excess downstream submergence.

Modified 9-cycle Weir

To eliminate the submergence problem, the downstream apron was placed at a 9% slope with P = 11 ft. at the upstream apex. Table 2 and Figures 3 and 4 for runs 5-11 show that the modified

TABLE 1.

MODEL DATA FOR 9 CYCLE LABRYINTH WEIR, APRON FLAT, P=11'

RUN NO.	WEIGHT LB	TIME SEC.	MODEL FLOW,CFS	PROTO FLOW,CFS	RES. PT GAGE FT.	REF PLATE FT.	DIFF IN EL. FT.	HEAD FT. MODEL FT.	RES. EL. FT.	MODEL CREST L FT.	CREST COEF.
1	76200	515.2	2.37	23985	2.292	1.64	0.568	0.084	2179.36	38.25	2.55
2	65420	281.83	3.72	37643	2.341	1.64	0.568	0.133	2181.32	38.25	2.01
3	73550	202.43	5.82	58921	2.43	1.64	0.568	0.222	2184.88	38.25	1.46
4	75660	200.19	6.06	61290	2.438	1.64	0.568	0.230	2185.20	38.75	1.42

TABLE 2.

MODEL DATA FOR 9 CYCLE LABRYINTH WEIR, APRON SLOPING 9%, P=11' AT US.APEX

RUN NO.	ORIFICE MANO	CONV TO PSI	MODEL FLOW,CFS	PROTO FLOW,CFS	RES. PT GAGE FT.	REF PLATE FT.	DIFF IN EL. FT.	HEAD FT. MODEL FT.	RES. EL. FT.	MODEL CREST L FT.	CREST COEF.
5	10	0.179	6.64	67152	2.428	1.64	0.568	0.220	2184.80	38.25	1.68
6	6.95	0.01066	1.35	13662	2.28	1.646	0.589	0.045	2177.80	38.75	3.65
7	26.5	0.01066	2.64	26677	2.317	1.646	0.589	0.082	2179.28	38.75	2.90
8	75.6	0.01066	4.45	45058	2.372	1.644	0.589	0.139	2181.56	38.75	2.22
9	115	0.01066	5.49	55572	2.408	1.644	0.589	0.175	2183.00	38.75	1.94
10	8.3	0.179	6.05	61178	2.426	1.644	0.589	0.193	2183.72	38.75	1.84
11	8.95	0.179	6.28	63529	2.436	1.644	0.589	0.203	2184.12	38.75	1.77

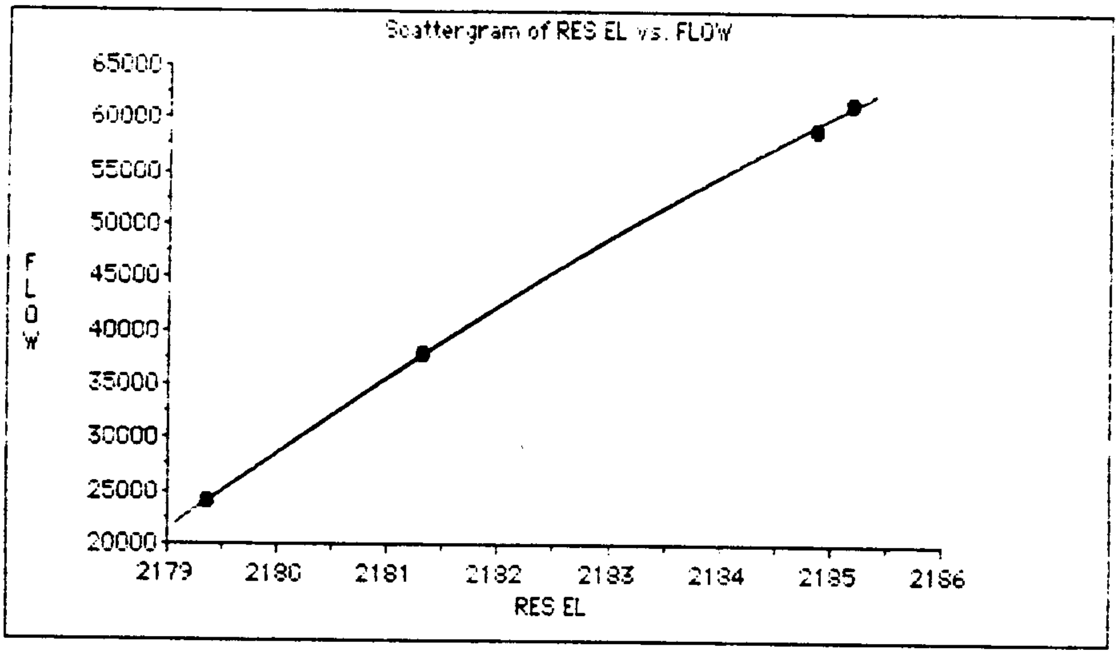


Figure 1. Discharge capacity of original 9-cycle labyrinth.

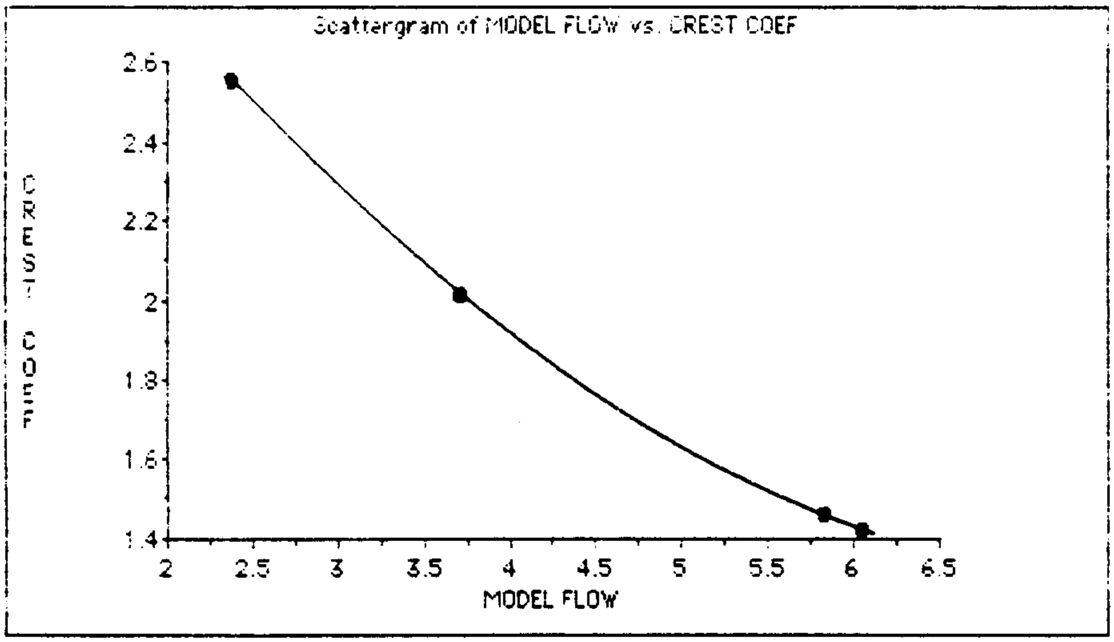


Figure 2. Crest coefficient of original 9-cycle labyrinth.

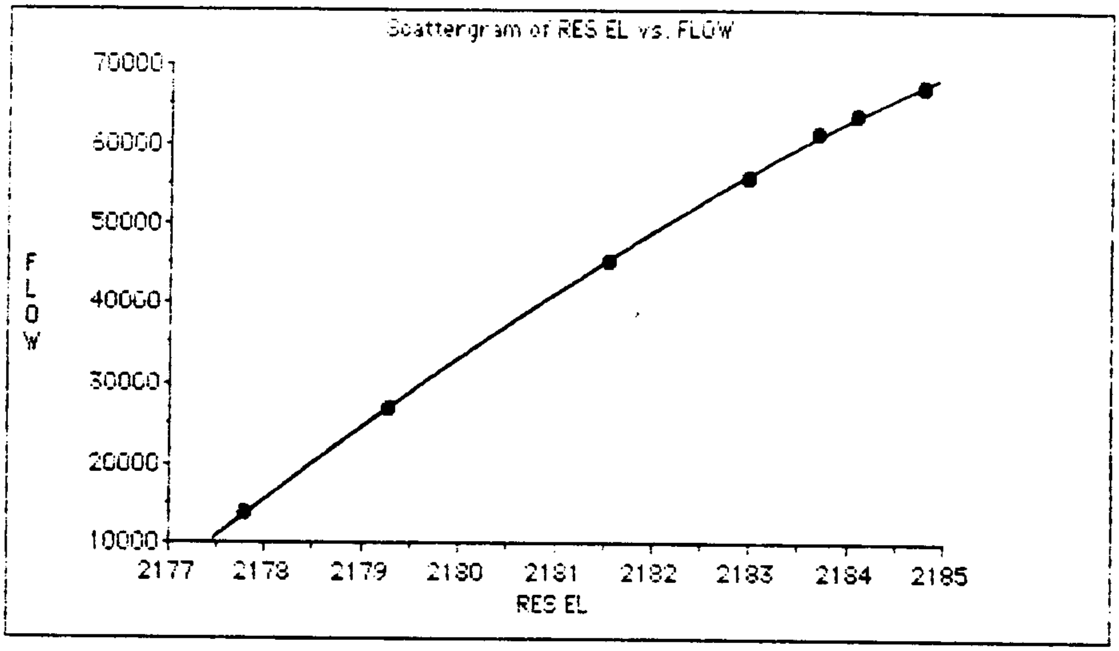


Figure 3. Discharge capacity of modified 9-cycle labyrinth.

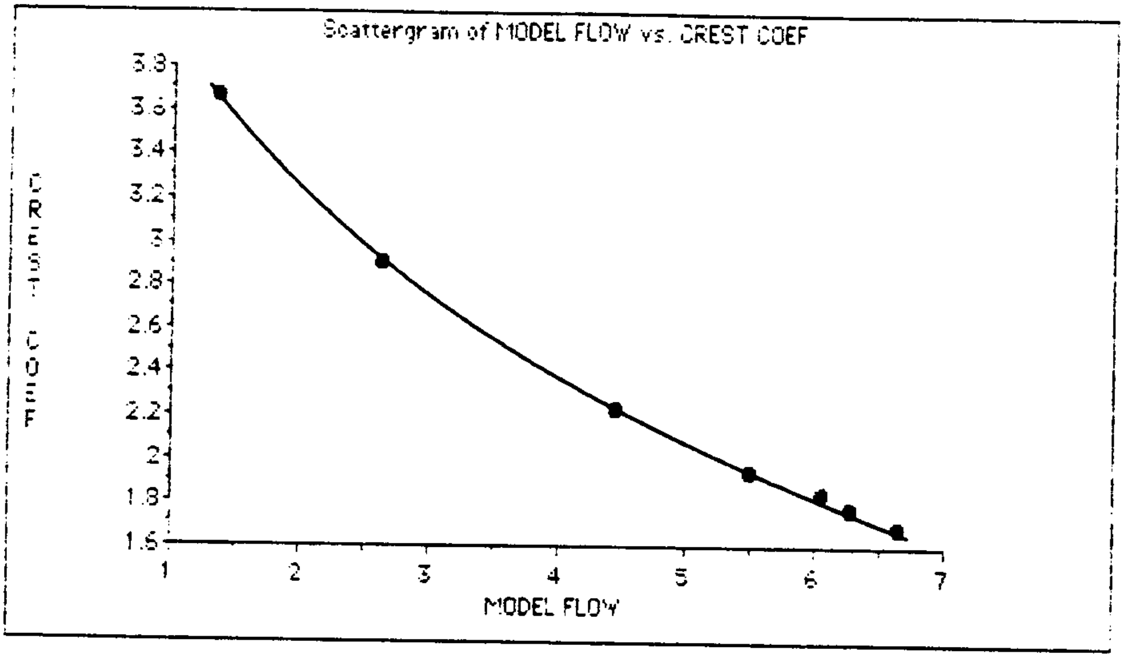


Figure 4. Crest coefficient of modified 9-cycle labyrinth.

configuration will supply over 65,000 cfs at a water surface elevation 2135.

7-cycle Weir

Table 3 and Figures 5 and 6 show the data for the 7-cycle weir. The slope of the apron was reduced to 7% and the width of the wall increased to 3 ft. The crest of the weir and the upstream channel were as for the other tests. The data in Table 3 and Figures 5 and 6 also show that the 7-cycle weir can provide for 65,000 cfs at the water surface elevation 2135.

Description of Flow Conditions

Photographs and video tapes were made of flow conditions. These should be reviewed as a part of this report.

At flows up to approximately half the probable maximum, the weir functioned normally with little influence of the approach flow direction. As the flow increased, the side flow approaching the weir created relatively large waves near the upstream apex of the labyrinths. This however did not deteriorate the performance of the weir nor did it appear to affect the flow conditions in the spillway chute. Small standing waves were noted downstream from the downstream apex of each cycle, but these waves were spread laterally and rapidly dissipated so that the water surface in the chute within 40 ft. of the weir was turbulent on the surface but contained no large standing waves.

One point of concern was the presence of the trash gate on the left side of the spillway. The model showed that at high flow rates, a fairly large standing wave would be reflected off

TABLE 3.

MODEL DATA FOR 7 CYCLE LABYRINTH WEIR APRON SLOPING 7%, P=11' AT US.APEX

RUN NO.	ORIFICE MANO.	CONV TO PSI	MODEL FLOW,CFS	PROTO FLOW,CFS	RES. PT GAGE FT.	REF PLATE FT.	DIFF IN EL. FT.	HEAD FT. MODEL FT.	RES. EL. FT.	MODEL CREST L FT.	CREST COEF.
12	9.8	0.01066	1.60	16223	2.285	1.649	0.589	0.047	2177.88	38.6	4.08
13	27	0.01066	2.66	26927	2.318	1.649	0.589	0.080	2179.20	38.6	3.05
14	38.8	0.01066	3.19	32279	2.334	1.649	0.589	0.096	2179.84	38.6	2.78
15	49	0.01066	3.58	36275	2.346	1.649	0.589	0.108	2180.32	38.6	2.62
16	65.5	0.01066	4.14	41940	2.364	1.649	0.589	0.126	2181.04	38.6	2.40
17	108.5	0.01066	5.33	53979	2.407	1.649	0.589	0.169	2182.76	38.6	1.99
18	9.45	0.179	6.45	65279	2.445	1.649	0.589	0.207	2184.28	38.6	1.77
19	7.8	0.179	5.86	59307	2.422	1.649	0.589	0.184	2183.36	38.6	1.92

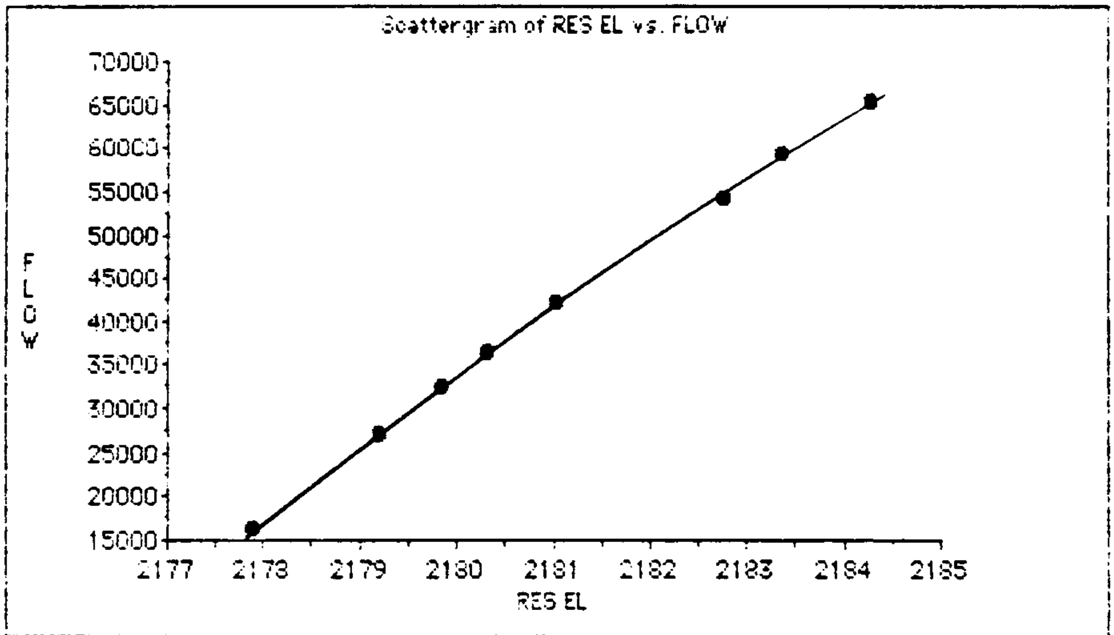


Figure 5. Discharge capacity of 7-cycle labyrinth.

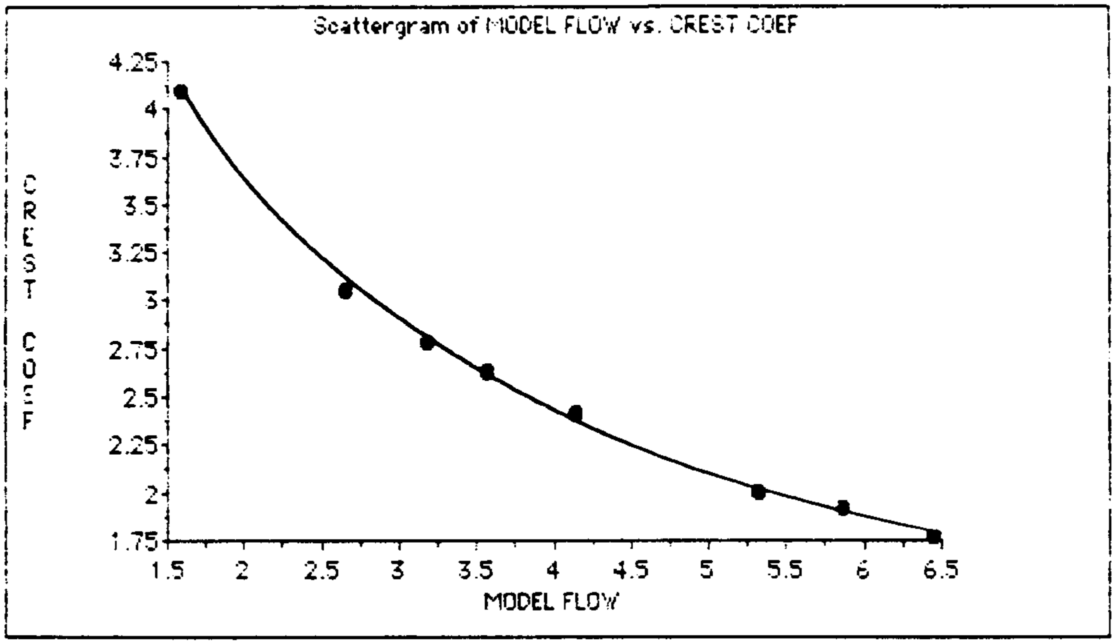


Figure 6. Crest coefficient of 7-cycle labyrinth.

the left wall due to the spreading of the flow at the trash gate. It is suggested that consideration be given to incorporating the trash gate as part of one cycle of the labyrinth by having a section of the labyrinth be lowered by cables to allow the trash to overflow the weir and not create any obstruction or nonsymmetry of the labyrinth at the left wall.

APPENDIX A

SCOPE OF WORK
ROLLINS DAM
LABYRINTH SPILLWAY HYDRAULIC MODEL

The intent of these hydraulic model studies is to verify the applicability of the labyrinth weir spillway as a means of increasing normal pool elevation at Rollins Dam and Reservoir without increasing maximum pool elevation. Preliminary calculations have been made utilizing design criteria established by the U.S. Bureau of Reclamation (Ref. 1), which is based on the work of Hay and Taylor (Ref. 2).

The proposed structure would be characterized as follows:

Parameter	Value
l/w	5.0
H/P	0.82
H	9.0
w/P	3.1
N	9

TASK 1

Hydraulic Analysis--Review initial design calculations. Copies of initial design calculations will be provided by CH2M HILL for review by Dr. Paul Tullis of UWRL.

TASK 2

Model Construction--Construct a scale model (approximately 1 to 50 scale) of the initial design of a labyrinth weir for the Rollins Dam spillway, exclusive of the spillway chute and energy dissipator. The model shall include a portion of the reservoir, all of the approach channel, the initial labyrinth weir spillway crest design, and the entire width of the upper portion of the spillway chute.

TASK 3

Evaluation of Initial Labyrinth Spillway Design--Evaluate the performance of the initial labyrinth design in terms of head to crest height ratio (H/P), discharge magnification ratio (QL/QNS), and length magnification ratio (l/w). (See Reference 1.)

TASK 4

Additional Alternatives--Modify the initial model configuration and evaluate 4 to 5 alternative configurations. Details of subsequent configurations will be established at the time of the initial model run, but will probably include modification of the approach channel and/or relocation of the weir to decrease the H/P ratio, and variation of the number of weir cycles (and thus the w/P ratio).

Model runs shall be recorded on video cassette for later viewing by interested parties. CH2M HILL shall be notified of the schedule of model runs to allow visits to the laboratory for observation of the model in operation.

RD/R37/022

REFERENCES

1. Houston, K. L., and C. S. DeAngelis, "A Site Specific Study of a Labyrinth Spillway," Proceedings of the Conference Applying Research to Hydraulic Practice, Hydraulics Division of ASCE, pp. 86-95, August 1982.

2. Hay, N., and G. Taylor, "Performance and Design of Labyrinth Weirs," Journal of the Hydraulics Division, ASCE, pp. 2337-2357, November 1970.

RD/R37/022

APPENDIX C

TABLE C-1

ENERGY OUTPUT

NEVADA IRRIGATION DISTRICT
WATER-POWER OPERATIONS MODEL
ROLLINS LABYRINTH WEIR FEASIBILITY STUDY - M15742.EO
ALTERNATIVE #1: CREST ELEVATION 2176'
WATER DEMAND LEVEL #B

WATER YEARS ANALYZED: 1911 TO 1980

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1911	4.629	5.350	6.019	9.522	8.601	9.522	9.215	9.522	9.215	9.294	5.874	4.647	91.411
1912	3.511	0.000	5.653	6.107	4.801	7.522	8.343	9.401	6.091	5.872	5.593	4.264	67.159
1913	3.294	0.000	4.588	4.234	3.781	5.178	9.113	5.994	5.848	5.876	5.601	4.253	57.759
1914	2.953	3.212	9.522	9.522	8.601	8.280	7.096	9.522	9.215	5.960	5.691	4.400	83.975
1915	3.371	0.000	5.048	7.855	8.601	6.635	6.133	9.522	9.215	6.066	5.785	4.535	72.766
1916	3.469	0.000	7.212	9.522	8.601	9.522	9.215	9.522	9.215	5.956	5.697	4.415	82.347
1917	3.382	0.000	9.286	7.918	8.601	9.522	9.129	9.230	9.215	5.962	5.706	4.417	82.368
1918	3.349	0.000	4.177	5.370	7.104	9.518	9.129	5.759	5.669	5.815	5.536	4.238	65.664
1919	3.307	0.000	5.389	4.103	8.592	9.522	8.179	9.522	5.748	5.862	5.586	4.249	70.060
1920	3.272	0.000	4.034	3.726	2.778	3.788	7.424	5.512	6.192	5.862	5.581	4.226	52.395
1921	3.271	3.166	9.522	9.522	8.601	9.522	8.046	9.522	9.215	5.943	5.650	4.302	86.282
1922	3.272	0.000	5.599	6.602	8.601	9.522	9.129	9.522	9.215	5.938	5.673	4.350	77.424
1923	3.405	0.000	9.522	9.491	8.152	7.181	9.129	9.522	9.215	6.006	5.805	4.607	82.036
1924	3.550	3.023	5.882	6.183	6.969	5.369	5.998	6.171	5.290	3.137	0.000	0.000	51.573
1925	0.000	0.000	0.000	0.000	3.468	6.129	9.129	9.522	8.546	6.080	5.804	4.577	53.256
1926	3.537	3.399	6.094	6.451	8.601	6.105	9.129	5.921	5.687	5.857	5.604	4.288	70.672
1927	3.339	5.318	7.218	9.159	8.601	9.453	9.129	9.522	9.215	5.980	5.751	4.507	87.193
1928	3.429	3.365	7.577	6.404	7.307	9.522	9.215	9.522	6.164	5.857	5.663	4.425	78.451
1929	3.418	0.000	5.642	4.046	4.147	7.895	6.473	5.845	5.621	5.774	5.490	4.069	58.420
1930	2.876	0.000	3.792	5.216	6.739	9.399	7.454	9.522	7.554	5.965	5.723	4.445	68.685
1931	3.382	0.000	4.765	3.549	2.716	3.447	3.814	4.614	4.820	0.000	0.000	0.000	31.107
1932	0.000	0.000	0.000	0.000	3.088	4.113	6.565	9.522	9.215	5.953	5.686	4.442	48.584
1933	3.412	0.000	5.331	4.135	3.298	3.901	5.836	7.573	5.649	5.800	5.511	4.106	54.553
1934	2.901	0.000	6.258	4.675	7.427	6.506	5.308	5.456	5.651	5.801	3.548	0.000	53.532
1935	0.000	0.000	0.000	0.000	0.000	2.911	8.024	9.522	9.215	5.998	5.765	4.539	45.973
1936	3.578	3.108	6.806	9.522	8.601	9.522	9.215	9.522	9.215	5.932	5.643	4.390	85.054
1937	3.372	0.000	5.520	6.333	8.592	9.522	9.129	9.522	9.215	5.985	5.734	4.478	77.403
1938	3.448	3.504	9.522	8.243	8.601	9.522	9.215	9.522	9.215	5.994	5.762	4.488	87.036
1939	3.460	0.000	6.197	6.291	6.422	8.487	6.463	5.502	5.597	5.731	5.338	0.000	59.489
1940	0.000	0.000	0.000	3.314	8.601	9.522	9.215	9.522	8.118	5.950	5.679	4.383	64.304
1941	3.329	0.000	9.398	9.522	8.601	9.522	9.129	9.522	9.215	5.975	5.739	4.447	84.399
1942	3.425	0.000	9.522	9.522	8.601	9.231	9.215	9.522	9.215	6.001	5.766	4.535	84.556
1943	3.460	3.929	8.678	9.522	8.601	9.522	9.215	9.522	9.215	5.975	5.724	4.452	87.814
1944	3.413	0.000	4.829	6.771	8.592	9.522	7.202	5.869	5.702	5.869	5.582	4.258	67.609
1945	3.294	3.223	7.441	6.247	8.601	9.480	7.676	9.522	9.215	5.973	5.712	4.468	80.853
1946	3.485	4.079	9.522	8.995	6.968	9.254	7.850	9.498	7.509	5.953	5.687	4.441	83.252
1947	3.433	3.228	7.201	5.820	7.742	9.450	6.692	5.424	5.614	5.755	5.473	4.066	69.897
1948	3.301	0.000	0.000	3.261	3.159	3.584	7.181	8.143	9.215	5.970	5.723	4.403	54.000
1949	3.408	0.000	6.020	4.138	3.534	8.950	7.075	8.878	5.686	5.837	5.553	4.156	63.234
1950	3.234	0.000	3.586	6.260	8.601	9.393	8.742	9.522	9.215	5.976	5.697	4.402	74.[illegible]
1951	3.403	6.813	9.522	9.522	8.601	9.522	9.215	9.522	5.718	5.892	5.624	4.273	87.625
1952	3.269	0.000	9.522	9.522	8.601	9.522	9.129	9.522	9.215	9.522	5.847	4.605	88.276
1953	3.454	0.000	7.452	9.522	6.283	8.908	9.129	9.522	9.215	7.356	5.832	4.575	81.250
1954	3.476	3.023	6.693	9.284	8.601	9.522	9.215	9.522	5.731	5.873	5.607	4.284	80.831
1955	3.321	0.000	6.791	7.892	3.779	4.737	8.200	6.245	5.788	5.832	5.531	4.126	62.242
1956	3.203	0.000	9.522	9.522	8.601	9.522	9.215	9.522	9.215	5.947	5.678	4.416	84.363

TABLE C-1

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1957	3.431	0.000	5.445	6.377	8.565	9.522	7.244	9.522	9.215	5.967	5.684	4.395	75.367
1958	3.450	0.000	7.119	8.627	8.601	9.522	9.129	9.522	9.215	5.964	5.678	4.399	81.226
1959	3.351	0.000	4.136	7.283	8.601	6.972	6.245	5.421	5.614	5.747	5.450	4.072	62.892
1960	3.177	0.000	3.092	0.000	3.606	8.593	8.922	9.522	9.215	5.979	5.735	4.461	62.302
1961	3.375	0.000	4.141	3.399	3.248	4.059	5.573	5.475	5.672	5.810	5.507	3.945	50.204
1962	0.000	0.000	0.000	0.000	3.620	6.458	6.963	9.522	9.101	5.926	5.634	4.277	51.502
1963	7.040	5.787	8.720	7.871	8.601	9.414	9.215	9.522	9.215	5.926	5.633	4.330	91.274
1964	3.355	0.000	9.522	9.522	6.560	6.900	6.414	9.522	7.942	5.943	5.686	4.358	75.724
1965	3.378	0.000	9.522	9.522	8.515	9.481	9.215	9.522	9.215	6.631	6.547	4.915	86.463
1966	3.735	6.690	7.130	8.518	7.119	8.874	8.283	7.889	5.758	5.908	5.718	4.566	80.188
1967	3.503	4.569	9.522	9.522	8.273	9.522	9.129	9.522	9.215	9.522	6.662	4.834	93.796
1968	3.689	4.543	6.584	7.560	8.601	9.489	7.452	9.522	5.667	5.875	5.647	4.454	79.082
1969	3.416	0.000	8.191	9.522	8.601	9.522	9.129	9.522	9.215	6.331	5.768	4.533	83.751
1970	3.477	0.000	9.522	9.522	8.601	9.522	8.774	9.522	8.642	6.083	5.802	4.656	84.124
1971	3.544	6.196	9.522	9.522	7.669	9.522	9.129	9.522	9.215	8.760	6.276	4.839	93.717
1972	3.618	3.910	7.580	7.834	8.601	9.107	8.701	9.522	7.806	6.160	5.760	4.511	83.109
1973	3.421	3.605	8.424	9.522	8.601	9.522	9.215	9.522	9.215	6.508	5.877	4.611	88.042
1974	3.494	6.813	9.522	9.522	8.601	9.522	9.215	9.522	9.215	7.738	6.255	4.869	94.288
1975	3.623	3.221	5.832	6.692	8.592	9.522	9.129	9.522	9.215	6.502	6.069	4.750	82.670
1976	3.674	5.043	6.020	6.735	5.970	6.510	6.647	5.383	5.565	5.724	5.525	3.617	66.412
1977	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.000	0.000	0.000	7.356	8.601	9.522	9.129	9.522	9.215	8.313	5.868	4.807	72.333
1979	3.588	3.537	5.713	8.522	8.601	9.522	8.941	9.522	8.643	6.404	8.122	4.729	85.843
1980	3.608	4.616	8.365	9.522	8.601	9.522	9.215	9.522	9.215	9.522	5.887	4.949	92.543
TOTALS	3.129	1.661	6.221	6.783	7.014	8.090	8.053	8.468	7.745	6.074	5.486	4.113	72.837

TABLE C-2

ENERGY OUTPUT

NEVADA IRRIGATION DISTRICT
WATER-POWER OPERATIONS MODEL
ROLLINS LABYRINTH WEIR FEASIBILITY STUDY - M15742.E0
ALTERNATIVE #2: CREST ELEVATION 2177.5'
WATER DEMAND LEVEL #B

WATER YEARS ANALYZED: 1911 TO 1980

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1911	4.383	5.389	6.065	9.593	8.664	9.593	9.283	9.593	9.283	9.360	5.920	4.702	91.829
1912	3.545	0.000	5.695	6.153	4.836	7.578	8.408	9.472	6.123	5.921	5.645	4.344	67.721
1913	3.333	0.000	4.615	4.268	3.808	5.216	9.184	6.037	5.891	5.925	5.653	4.333	58.262
1914	2.987	3.229	9.593	9.593	8.664	8.341	7.150	9.593	9.283	6.008	5.740	4.458	84.638
1915	3.408	0.000	5.078	7.916	8.664	6.684	6.179	9.593	9.283	6.110	5.833	4.592	73.340
1916	3.504	0.000	7.264	9.593	8.664	9.593	9.283	9.593	9.283	6.004	5.747	4.473	83.001
1917	3.419	0.000	9.351	7.977	8.664	9.593	9.200	9.297	9.283	6.009	5.756	4.475	83.024
1918	3.386	0.000	4.199	5.409	7.160	9.588	9.200	5.799	5.713	5.866	5.591	4.318	66.229
1919	3.345	0.000	5.421	4.136	8.656	9.593	8.241	9.593	5.790	5.911	5.639	4.328	70.652
1920	3.311	0.000	4.066	3.768	2.836	3.827	7.476	5.550	6.237	5.912	5.634	4.306	52.924
1921	3.310	3.184	9.593	9.593	8.664	9.593	8.106	9.593	9.283	5.991	5.701	4.381	86.991
1922	3.311	0.000	5.635	6.652	8.664	9.593	9.200	9.593	9.283	5.986	5.723	4.416	78.055
1923	3.441	0.000	9.593	9.563	8.212	7.233	9.200	9.593	9.283	6.053	5.852	4.663	82.684
1924	3.583	3.037	5.926	6.230	7.022	5.408	6.043	6.227	5.343	3.233	0.000	0.000	52.050
1925	0.000	0.000	0.000	0.000	3.468	5.882	9.200	9.593	8.607	6.124	5.852	4.633	53.359
1926	3.570	3.419	6.139	6.501	8.664	6.148	9.200	5.963	5.731	5.906	5.655	4.367	71.262
1927	3.377	5.349	7.271	9.229	8.664	9.523	9.200	9.593	9.283	6.027	5.800	4.563	87.879
1928	3.465	3.383	7.634	6.451	7.361	9.593	9.283	9.593	6.209	5.972	5.699	4.467	79.109
1929	3.444	0.000	5.597	4.080	4.178	7.953	6.523	5.889	5.667	5.826	5.546	4.150	58.853
1930	2.911	0.000	3.843	5.231	6.790	9.470	7.511	9.593	7.607	6.012	5.772	4.503	69.241
1931	3.419	0.000	4.792	3.593	2.777	3.493	4.025	4.621	4.697	0.000	0.000	0.000	31.416
1932	0.000	0.000	0.000	0.000	3.088	4.113	6.336	9.593	9.283	6.001	5.735	4.500	48.649
1933	3.448	0.000	5.362	4.166	3.338	3.938	5.885	7.640	5.692	5.848	5.564	4.183	55.064
1934	2.933	0.000	6.284	4.711	7.483	6.553	5.348	5.496	5.696	5.852	3.665	0.000	54.022
1935	0.000	0.000	0.000	0.000	0.000	0.000	6.876	9.593	9.283	6.044	5.813	4.595	42.204
1936	3.610	3.123	6.857	9.593	8.664	9.593	9.283	9.593	9.283	5.980	5.693	4.449	85.721
1937	3.409	0.000	5.553	6.382	8.656	9.593	9.200	9.593	9.283	6.032	5.783	4.535	78.018
1938	3.484	3.523	9.593	8.305	8.664	9.593	9.283	9.593	9.283	6.040	5.810	4.545	87.717
1939	3.496	0.000	6.234	6.339	6.470	8.551	6.511	5.544	5.643	5.783	5.396	0.000	59.968
1940	0.000	0.000	0.000	3.327	8.664	9.593	9.283	9.593	8.175	5.997	5.729	4.442	64.803
1941	3.367	0.000	9.466	9.593	8.664	9.593	9.200	9.593	9.283	6.023	5.787	4.505	85.073
1942	3.461	0.000	9.593	9.593	8.664	9.300	9.283	9.593	9.283	6.047	5.814	4.592	85.223
1943	3.496	3.950	8.744	9.593	8.664	9.593	9.283	9.593	9.283	6.022	5.773	4.509	88.503
1944	3.450	0.000	4.857	6.822	8.656	9.593	7.257	5.911	5.745	5.918	5.634	4.337	68.180
1945	3.332	3.239	7.498	6.293	8.664	9.552	7.734	9.593	9.283	6.020	5.761	4.525	81.495
1946	3.520	4.102	9.593	9.062	7.020	9.324	7.909	9.567	7.561	6.001	5.746	4.499	83.905
1947	3.469	3.245	7.255	5.862	7.800	9.522	6.742	5.465	5.660	5.806	5.528	4.156	70.510
1948	3.336	0.000	0.000	3.318	3.196	3.623	7.206	8.203	9.283	6.017	5.771	4.521	54.475
1949	3.445	0.000	6.057	4.170	3.568	9.021	7.128	8.943	5.729	5.887	5.607	4.235	63.790
1950	3.273	0.000	3.628	6.299	8.664	9.464	8.809	9.593	9.283	6.023	5.747	4.460	75.244
1951	3.439	6.863	9.593	9.593	8.664	9.593	9.283	9.593	5.761	5.940	5.674	4.352	88.347
1952	3.308	0.000	9.593	9.593	8.664	9.593	9.200	9.593	9.283	9.593	5.893	4.661	88.972
1953	3.490	0.000	7.506	9.593	6.329	8.976	9.200	9.593	9.283	7.406	5.879	4.631	81.885
1954	3.511	3.041	6.742	9.356	8.664	9.593	9.283	9.593	5.772	5.923	5.659	4.364	81.500
1955	3.359	0.000	6.836	7.952	3.807	4.772	8.264	6.289	5.829	5.883	5.587	4.207	62.785
1956	3.243	0.000	9.593	9.593	8.664	9.593	9.283	9.593	9.283	5.995	5.728	4.474	85.042

TABLE C-2

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1957	3.467	0.000	5.477	6.426	8.631	9.593	7.299	9.593	9.283	6.014	5.734	4.454	75.971
1958	3.486	0.000	7.174	8.694	8.664	9.593	9.200	9.593	9.283	6.011	5.728	4.458	81.884
1959	3.389	0.000	4.166	7.333	8.664	7.023	6.291	5.462	5.659	5.799	5.506	4.153	63.446
1960	3.217	0.000	3.154	0.000	3.638	8.656	8.990	9.593	9.283	6.026	5.783	4.518	62.859
1961	3.412	0.000	4.173	3.449	3.286	4.091	5.611	5.515	5.716	5.860	5.562	4.027	50.701
1962	0.000	0.000	0.000	0.000	3.620	6.209	7.015	9.593	9.166	5.974	5.684	4.357	51.619
1963	7.092	5.829	8.786	7.931	8.664	9.486	9.283	9.593	9.283	5.974	5.684	4.402	92.006
1964	3.392	0.000	9.593	9.593	6.608	6.951	6.462	9.593	7.998	5.991	5.735	4.422	76.337
1965	3.415	0.000	9.593	9.593	8.578	9.551	9.283	9.593	9.283	6.870	6.468	4.942	87.169
1966	3.750	6.609	7.186	8.584	7.172	8.939	8.346	8.296	5.799	5.957	5.767	4.622	81.026
1967	3.537	4.597	9.593	9.593	8.334	9.593	9.200	9.593	9.283	9.593	6.815	4.862	94.592
1968	3.705	4.444	6.634	7.619	8.664	9.560	7.507	9.593	5.712	5.924	5.697	4.511	79.571
1969	3.452	0.000	8.255	9.593	8.664	9.593	9.200	9.593	9.283	6.525	5.786	4.554	84.498
1970	3.490	0.000	9.593	9.593	8.664	9.593	8.838	9.593	8.704	6.127	5.850	4.711	84.755
1971	3.577	6.239	9.593	9.593	7.725	9.593	9.200	9.593	9.283	8.822	6.318	4.892	94.426
1972	3.650	3.936	7.639	7.893	8.664	9.174	8.768	9.593	7.860	6.205	5.808	4.568	83.759
1973	3.457	3.629	8.488	9.593	8.664	9.593	9.283	9.593	9.283	6.552	5.923	4.666	88.724
1974	3.529	6.863	9.593	9.593	8.664	9.593	9.283	9.593	9.283	7.793	6.372	4.906	95.064
1975	3.645	3.165	5.877	6.742	8.656	9.593	9.200	9.593	9.283	6.546	6.225	4.779	83.304
1976	3.690	4.943	6.065	6.784	6.015	6.558	6.698	5.425	5.612	5.776	5.580	3.700	66.844
1977	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.000	0.000	0.000	7.123	8.664	9.593	9.200	9.593	9.283	8.371	5.914	4.859	72.599
1979	3.619	3.559	5.755	8.588	8.664	9.593	9.009	9.593	8.705	6.447	8.178	4.783	86.494
1980	3.639	4.648	8.429	9.593	8.664	9.593	9.283	9.593	9.283	9.593	5.932	4.999	93.249
TOTALS	3.156	1.665	6.266	6.830	7.067	8.100	8.094	8.535	7.800	6.128	5.537	4.170	73.350

TABLE C-3

ENERGY OUTPUT

NEVADA IRRIGATION DISTRICT
WATER-POWER OPERATIONS MODEL
ROLLINS LABYRINTH WEIR FEASIBILITY STUDY - M15742.EO
ALTERNATIVE #3: CREST ELEVATION 2169.2 AND 2184' (BASCULE)
WATER DEMAND LEVEL #B

WATER YEARS ANALYZED: 1911 TO 1980

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1911	5.668	5.169	5.798	9.195	8.305	9.195	8.898	9.471	9.487	9.557	5.624	5.069	91.437
1912	3.770	5.335	5.447	5.895	4.627	7.283	7.781	7.899	6.358	5.633	5.966	4.852	70.848
1913	3.553	4.934	5.230	4.007	3.603	4.577	8.804	5.416	5.579	5.750	5.627	4.377	61.455
1914	3.128	3.963	9.195	9.195	8.305	8.000	6.584	8.931	9.487	5.644	5.981	4.871	83.285
1915	3.566	4.308	5.840	7.590	8.305	6.409	5.638	9.804	9.487	5.701	6.068	5.006	77.722
1916	3.654	5.215	7.009	9.195	8.305	9.195	8.898	9.380	9.487	5.634	5.988	4.897	86.859
1917	3.575	4.913	9.195	7.646	8.305	9.195	8.898	8.182	9.487	5.629	5.997	4.899	85.923
1918	3.547	3.923	5.346	5.191	6.839	9.195	8.898	5.379	5.575	5.665	5.432	4.166	69.156
1919	3.210	0.000	5.611	3.873	8.305	9.195	7.658	8.938	5.607	5.978	5.877	4.750	69.002
1920	3.467	3.096	4.703	3.654	2.661	3.712	7.657	5.335	5.600	5.688	5.558	4.279	55.410
1921	3.229	3.933	9.195	9.195	8.305	9.195	7.529	9.087	9.487	5.607	5.950	4.789	85.501
1922	3.484	3.530	7.224	6.390	8.305	9.195	8.898	9.804	9.487	5.603	5.931	4.807	82.658
1923	3.610	5.366	9.195	9.161	7.873	6.941	8.898	9.269	9.487	5.655	5.957	5.025	86.437
1924	4.361	5.093	5.667	5.973	6.717	5.122	5.474	5.403	5.290	0.000	0.000	0.000	49.100
1925	0.000	0.000	0.000	0.000	3.468	7.115	8.898	9.271	8.706	5.715	5.852	5.010	54.035
1926	4.396	5.592	5.885	6.224	8.305	5.902	8.898	5.396	5.312	5.674	5.637	4.407	71.629
1927	3.368	6.545	6.973	8.838	8.305	9.126	8.898	9.804	9.487	5.636	5.891	4.949	87.820
1928	3.647	6.180	7.313	6.185	7.054	9.195	8.898	8.802	5.938	5.649	5.990	4.902	79.753
1929	3.663	5.266	5.492	3.890	3.987	7.645	5.943	5.309	5.569	5.603	5.455	4.095	61.916
1930	2.832	0.000	3.742	5.897	6.506	9.072	6.938	8.128	7.762	5.624	5.983	4.874	67.357
1931	3.592	4.866	5.131	3.330	0.000	3.204	3.496	4.448	4.405	0.000	0.000	0.000	32.472
1932	0.000	0.000	0.000	0.000	3.024	4.169	6.831	9.194	9.487	5.615	5.951	4.873	49.144
1933	3.616	4.825	5.679	3.980	3.103	3.727	5.371	5.498	5.869	5.948	5.797	4.617	58.032
1934	3.220	3.224	7.747	4.513	7.166	6.288	4.845	5.324	5.506	5.554	0.000	0.000	53.386
1935	0.000	0.000	0.000	0.000	0.000	0.000	7.761	9.804	9.487	5.649	5.988	4.943	43.631
1936	4.526	4.954	6.571	9.195	8.305	9.195	8.898	9.524	9.487	5.598	5.879	4.831	86.963
1937	3.587	4.345	6.396	6.111	8.305	9.195	8.898	9.575	9.487	5.639	5.969	4.897	82.406
1938	3.652	6.228	9.195	7.953	8.305	9.195	8.898	9.804	9.487	5.646	5.985	4.920	89.269
1939	3.662	5.378	6.061	6.056	6.188	8.213	5.939	5.250	5.486	5.531	5.180	0.000	62.944
1940	0.000	0.000	0.000	3.262	8.305	9.195	8.898	9.041	8.241	5.612	5.975	4.853	63.382
1941	3.535	4.345	9.195	9.195	8.305	9.195	8.898	9.804	9.487	5.632	5.976	4.900	88.467
1942	3.627	5.104	9.195	9.195	8.305	8.914	8.898	9.804	9.487	5.651	5.958	4.943	89.082
1943	3.669	6.582	8.393	9.195	8.305	9.195	8.898	9.449	9.487	5.631	5.952	4.893	89.650
1944	3.621	4.567	5.525	6.481	8.305	9.195	6.683	5.388	5.510	5.665	5.556	4.288	70.785
1945	3.255	4.008	7.180	6.035	8.305	9.149	7.171	9.055	9.487	5.630	5.965	4.868	80.108
1946	3.790	6.582	9.195	8.686	6.728	8.933	7.340	8.722	7.626	5.615	5.969	4.859	84.044
1947	3.635	5.908	6.952	5.624	7.474	9.120	6.197	5.278	5.468	5.486	5.324	3.866	70.332
1948	3.142	0.000	0.000	2.987	2.831	3.256	6.171	6.256	9.487	5.628	5.949	4.886	50.593
1949	3.620	4.805	6.444	3.989	3.373	8.626	6.567	7.237	5.523	5.927	5.861	4.691	66.663
1950	3.441	3.310	3.692	7.972	8.305	9.065	8.293	9.196	9.487	5.632	5.972	4.825	79.191
1951	3.609	6.582	9.195	9.195	8.305	9.195	8.898	9.804	5.539	5.965	5.892	4.678	86.857
1952	3.464	4.830	9.195	9.195	8.305	9.195	8.898	9.804	9.487	9.804	5.600	4.935	92.711
1953	3.649	5.067	7.447	9.195	6.073	8.596	8.767	9.804	9.487	7.554	5.589	4.917	86.144
1954	3.666	5.632	6.465	8.954	8.305	9.195	8.898	8.896	5.528	5.975	5.911	4.743	82.167
1955	3.532	4.168	7.700	7.616	3.638	4.479	7.669	5.442	5.597	5.700	5.589	4.292	65.423
1956	3.221	0.000	9.195	9.195	8.305	9.195	8.898	9.804	9.487	5.610	5.974	4.852	83.736

TABLE C-3 (CONT)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1957	3.628	4.869	5.764	6.152	8.261	9.195	6.723	9.804	9.487	5.625	5.979	4.819	80.308
1958	3.646	5.427	6.865	8.319	8.305	9.195	8.898	9.804	9.487	5.645	5.971	4.862	86.425
1959	3.544	3.840	5.192	7.203	8.305	6.735	5.749	5.286	5.466	5.574	5.269	3.889	66.052
1960	2.999	0.000	0.000	0.000	3.369	7.862	8.471	9.383	9.487	5.658	6.019	4.944	58.192
1961	3.566	4.776	4.056	3.235	3.146	3.958	5.605	5.328	5.520	5.523	5.372	3.776	53.861
1962	0.000	0.000	0.000	0.000	3.562	7.200	6.458	8.492	9.360	5.603	5.934	4.800	51.410
1963	6.801	5.591	8.415	7.595	8.305	9.085	8.898	9.804	9.487	5.603	5.933	4.810	90.328
1964	3.556	5.274	9.195	9.195	6.339	6.664	5.922	9.726	8.164	5.607	5.981	4.826	80.449
1965	3.578	5.488	9.195	9.195	8.223	9.154	8.898	9.477	9.487	6.499	6.786	5.130	91.111
1966	5.762	6.582	6.900	8.218	6.873	8.570	7.756	6.437	5.619	6.019	5.991	5.021	79.748
1967	3.668	6.582	9.195	9.195	7.990	9.195	8.898	9.804	9.487	9.804	6.534	5.062	95.414
1968	5.346	5.428	6.353	7.289	8.305	9.160	6.941	8.955	5.578	5.989	5.921	4.868	80.133
1969	3.595	5.395	7.897	9.195	8.305	9.195	8.898	9.804	9.487	6.126	5.594	4.967	88.458
1970	4.014	5.287	9.195	9.195	8.305	9.195	8.476	9.103	8.833	5.719	6.083	5.073	88.477
1971	4.157	6.582	9.195	9.195	7.408	9.195	8.898	9.804	9.487	9.006	6.442	5.008	94.377
1972	4.374	5.424	7.308	7.563	8.305	8.796	8.250	9.452	7.849	5.796	6.007	4.925	84.050
1973	3.630	6.340	8.129	9.195	8.305	9.195	8.898	9.804	9.487	6.681	5.624	4.927	90.216
1974	3.793	6.582	9.195	9.195	8.305	9.195	8.898	9.804	9.487	7.954	6.059	5.098	93.566
1975	4.807	4.690	5.615	6.478	8.305	9.195	8.898	9.804	9.487	6.675	5.913	4.990	84.858
1976	5.216	6.057	5.815	6.507	5.734	6.310	6.119	5.256	5.425	5.561	5.360	3.347	66.707
1977	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.000	0.000	0.000	8.251	8.305	9.195	8.898	9.804	9.487	8.541	5.616	5.099	73.197
1979	4.526	5.297	5.527	8.220	8.305	9.195	8.490	9.336	8.888	6.574	8.345	4.927	87.630
1980	4.269	6.223	8.067	9.195	8.305	9.195	8.898	9.804	9.487	9.804	5.631	5.260	94.138
TOTALS	3.436	4.277	6.184	6.601	6.730	7.788	7.697	8.204	7.855	5.873	5.556	4.426	74.628

NEVADA IRRIGATION DISTRICT
WATER-POWER OPERATIONS MODEL
ROLLINS LABYRINTH WEIR FEASIBILITY STUDY - M15742.EO
ALTERNATIVE #0: CREST ELEVATION 2171' (EXISTING)
WATER DEMAND LEVEL #B

WATER YEARS ANALYZED: 1911 TO 1980

1911	20	5.411	5.217	5.853	9.283	8.384	9.283	8.983	9.283	8.983	9.067	5.327	4.660	89.736
1912	20	3.439	3.205	5.499	5.952	4.670	7.353	7.856	9.283	6.045	5.330	5.614	4.379	68.625
1913	20	3.285	0.000	5.280	4.122	3.686	5.048	8.888	6.242	5.363	5.623	5.551	4.260	57.349
1914	20	3.076	3.325	9.283	9.283	8.384	8.076	6.645	9.283	8.983	5.343	5.631	4.404	81.717
1915	20	3.301	0.000	5.308	7.665	8.384	6.470	5.691	9.283	8.983	5.429	5.731	4.567	70.813
1916	20	3.408	3.038	7.056	9.283	8.384	9.283	8.983	9.283	8.983	5.333	5.639	4.435	83.109
1917	20	3.312	0.000	9.283	7.719	8.384	9.283	8.983	9.226	8.983	5.330	5.651	4.440	80.595
1918	20	3.280	0.000	4.451	5.239	6.907	9.283	8.983	5.945	5.284	5.567	5.456	4.201	64.596
1919	20	3.226	0.000	5.588	3.991	8.384	9.283	7.729	9.283	5.314	5.638	5.509	4.225	68.171
1920	20	3.189	0.000	3.963	3.637	2.639	3.697	7.338	5.700	5.696	5.372	5.590	4.326	51.148
1921	20	3.251	3.817	9.283	9.283	8.384	9.283	7.599	9.283	8.983	5.305	5.595	4.293	84.359
1922	20	3.206	0.000	5.890	6.451	8.384	9.283	8.983	9.283	8.983	5.301	5.583	4.339	75.686
1923	20	3.354	3.148	9.283	9.249	7.948	7.006	8.983	9.283	8.983	5.370	5.632	4.628	82.866
1924	20	3.522	3.571	5.721	6.030	6.781	5.256	5.524	6.037	4.942	0.000	0.000	0.000	47.384
1925	20	0.000	0.000	0.000	0.000	3.468	6.871	8.983	9.283	8.337	5.443	5.520	4.615	52.520
1926	20	3.527	4.102	5.941	6.284	8.384	5.957	8.983	6.106	5.241	5.593	5.548	4.270	69.936
1927	20	3.281	5.667	7.039	8.924	8.384	9.214	8.983	9.283	8.983	5.340	5.566	4.540	85.204
1928	20	3.398	3.936	7.384	6.244	7.122	9.283	8.983	9.283	5.649	5.356	5.649	4.490	76.777
1929	20	3.419	3.061	5.970	3.933	4.025	7.718	5.999	5.707	5.249	5.617	5.516	4.186	60.400
1930	20	2.870	0.000	3.785	5.936	6.569	9.159	7.004	9.128	7.457	5.325	5.643	4.448	67.323
1931	20	3.332	0.000	5.157	3.391	2.538	3.294	3.562	4.582	4.509	0.000	0.000	0.000	30.364
1932	20	0.000	0.000	0.000	0.000	3.057	4.094	6.857	9.283	8.983	5.315	5.605	4.445	47.638
1933	20	3.362	0.000	5.710	4.019	3.149	3.773	5.425	7.423	5.313	5.607	5.532	4.219	53.531
1934	20	3.034	0.000	6.708	4.556	7.235	6.347	4.889	5.524	5.455	5.531	3.406	0.000	52.685
1935	20	0.000	0.000	0.000	0.000	0.000	0.000	7.830	9.283	8.983	5.356	5.657	4.537	41.647
1936	20	3.543	3.598	6.634	9.283	8.384	9.283	8.983	9.283	8.983	5.295	5.529	4.384	83.182
1937	20	3.327	0.000	5.945	6.171	8.384	9.283	8.983	9.283	8.983	5.344	5.633	4.483	75.820
1938	20	3.405	3.980	9.283	8.031	8.384	9.283	8.983	9.283	8.983	5.352	5.654	4.505	85.126
1939	20	3.417	3.169	6.118	6.115	6.247	8.292	5.994	5.367	5.518	5.526	5.285	0.000	61.049
1940	20	0.000	0.000	0.000	3.262	8.384	9.283	8.983	9.283	7.924	5.311	5.624	4.383	62.438
1941	20	3.264	0.000	9.283	9.283	8.384	9.283	8.983	9.283	8.983	5.335	5.640	4.472	82.194
1942	20	3.375	0.000	9.283	9.283	8.384	8.999	8.983	9.283	8.983	5.359	5.631	4.539	82.103
1943	20	3.426	4.430	8.475	9.283	8.384	9.283	8.983	9.283	8.805	5.334	5.615	4.472	85.775
1944	20	3.368	0.000	5.260	6.600	8.384	9.283	6.746	6.054	5.232	5.637	5.524	4.241	66.328
1945	20	3.232	3.587	7.250	6.092	8.384	9.237	7.238	9.283	8.983	5.333	5.623	4.455	78.698
1946	20	3.444	4.546	9.283	8.769	6.793	9.019	7.408	9.283	7.330	5.315	5.623	4.433	81.244
1947	20	3.384	3.660	7.019	5.677	7.545	9.208	6.255	5.327	5.523	5.548	5.390	4.021	68.558
1948	20	3.219	0.000	0.000	3.128	3.069	3.490	7.050	8.248	8.983	5.330	5.612	4.470	52.599
1949	20	3.366	0.000	6.464	4.029	3.416	8.712	6.628	8.889	5.231	5.587	5.489	4.143	61.955
1950	20	3.161	0.000	3.495	6.503	8.384	9.153	8.371	9.283	8.983	5.336	5.626	4.380	72.676
1951	20	3.352	6.644	9.283	9.283	8.384	9.283	8.983	9.283	5.281	5.643	5.556	4.215	85.190
1952	20	3.206	0.000	9.283	9.283	8.384	9.283	8.983	9.283	8.983	9.283	5.298	4.534	85.803
1953	20	3.398	0.000	7.500	9.283	6.129	8.680	8.851	9.283	8.983	7.183	5.284	4.512	79.087
1954	20	3.418	3.379	6.526	9.042	8.384	9.283	8.983	9.283	5.241	5.641	5.550	4.254	78.984
1955	20	3.264	0.000	7.110	7.690	3.684	4.618	7.743	6.420	5.331	5.593	5.469	4.110	61.032
1956	20	3.133	0.000	9.283	9.283	8.384	9.283	8.983	9.283	8.983	5.309	5.623	4.405	81.954
1957	20	3.375	0.000	5.792	6.212	8.342	9.283	6.787	9.283	8.983	5.327	5.629	4.367	73.381
1958	20	3.397	3.209	6.933	8.401	8.384	9.283	8.983	9.283	8.983	5.344	5.619	4.403	82.224
1959	20	3.281	0.000	4.265	7.258	8.384	6.799	5.802	5.336	5.520	5.638	5.335	4.000	61.619
1960	20	3.055	0.000	2.914	0.000	3.488	8.522	8.551	9.283	8.983	5.360	5.676	4.501	60.334
1961	20	3.302	0.000	4.080	3.279	3.174	3.982	5.534	5.656	5.252	5.579	5.434	3.905	49.177

1962	20	0.000	0.000	0.000	0.000	3.562	6.956	6.518	9.283	8.878	5.298	5.575	4.285	50.355
1963	20	6.865	5.643	8.497	7.669	8.384	9.173	8.983	9.283	8.983	5.298	5.574	4.322	88.675
1964	20	3.290	3.053	9.283	9.283	6.398	6.727	5.977	9.283	7.750	5.305	5.631	4.349	76.329
1965	20	3.316	3.260	9.283	9.283	8.301	9.242	8.983	9.283	8.983	6.186	6.451	4.776	87.347
1966	20	3.683	6.644	6.968	8.298	6.939	8.652	7.829	8.016	5.326	5.686	5.647	4.606	78.293
1967	20	3.427	4.754	9.283	9.283	8.066	9.283	8.983	9.283	8.983	9.283	6.217	4.694	91.539
1968	20	3.635	4.843	6.415	7.361	8.384	9.248	7.005	9.283	5.276	5.649	5.562	4.424	77.086
1969	20	3.337	3.185	7.976	9.283	8.384	9.283	8.983	9.283	8.983	5.832	5.291	4.549	84.370
1970	20	3.475	3.410	9.283	9.283	8.384	9.283	8.556	9.283	8.430	5.446	5.748	4.655	85.236
1971	20	3.495	6.536	9.283	9.283	7.478	9.283	8.983	9.283	8.983	8.548	6.130	4.630	91.914
1972	20	3.518	3.871	7.381	7.636	8.384	8.880	8.329	9.283	7.619	5.520	5.649	4.514	80.583
1973	20	3.378	4.080	8.208	9.283	8.384	9.283	8.983	9.283	8.983	6.357	5.327	4.528	86.077
1974	20	3.441	6.644	9.283	9.283	8.384	9.283	8.983	9.283	8.983	7.552	5.767	4.739	91.624
1975	20	3.572	3.577	5.669	6.540	8.384	9.283	8.983	9.283	8.983	6.351	5.624	4.609	80.858
1976	20	3.619	5.325	5.870	6.568	5.789	6.370	6.176	5.350	5.471	5.603	5.417	3.445	65.004
1977	20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1978	20	0.000	0.000	0.000	8.033	8.384	9.283	8.983	9.283	8.983	8.116	5.318	4.729	71.112
1979	20	3.540	3.917	5.579	8.302	8.384	9.283	8.570	9.283	8.432	6.255	7.928	4.530	84.003
1980	20	3.503	4.534	8.147	9.283	8.384	9.283	8.983	9.283	8.983	9.283	5.336	4.911	89.913
TOTALS		3.096	2.222	6.180	6.642	6.835	7.872	7.775	8.312	7.481	5.613	5.347	4.097	71.472

WESTERN HYDROLOGICS
WATER & HYDROPOWER CONSULTING

TO: Jennifer Hanson, Chip Close, Thor Larsen

FROM: Jeff Meyer

DATE: April 25, 2024

RE: **Nevada Irrigation District – Water Rights Assessment to Support A 50 TAF Expansion of Rollins Reservoir**

Per your request, this memorandum documents assumptions, methodology, conclusions, and recommendations for the need for any additional water rights in support of a 50 thousand acre-foot (TAF) expansion of Rollins Reservoir as described in the Strategic Alternative developed in the Plan for Water.

Assumptions

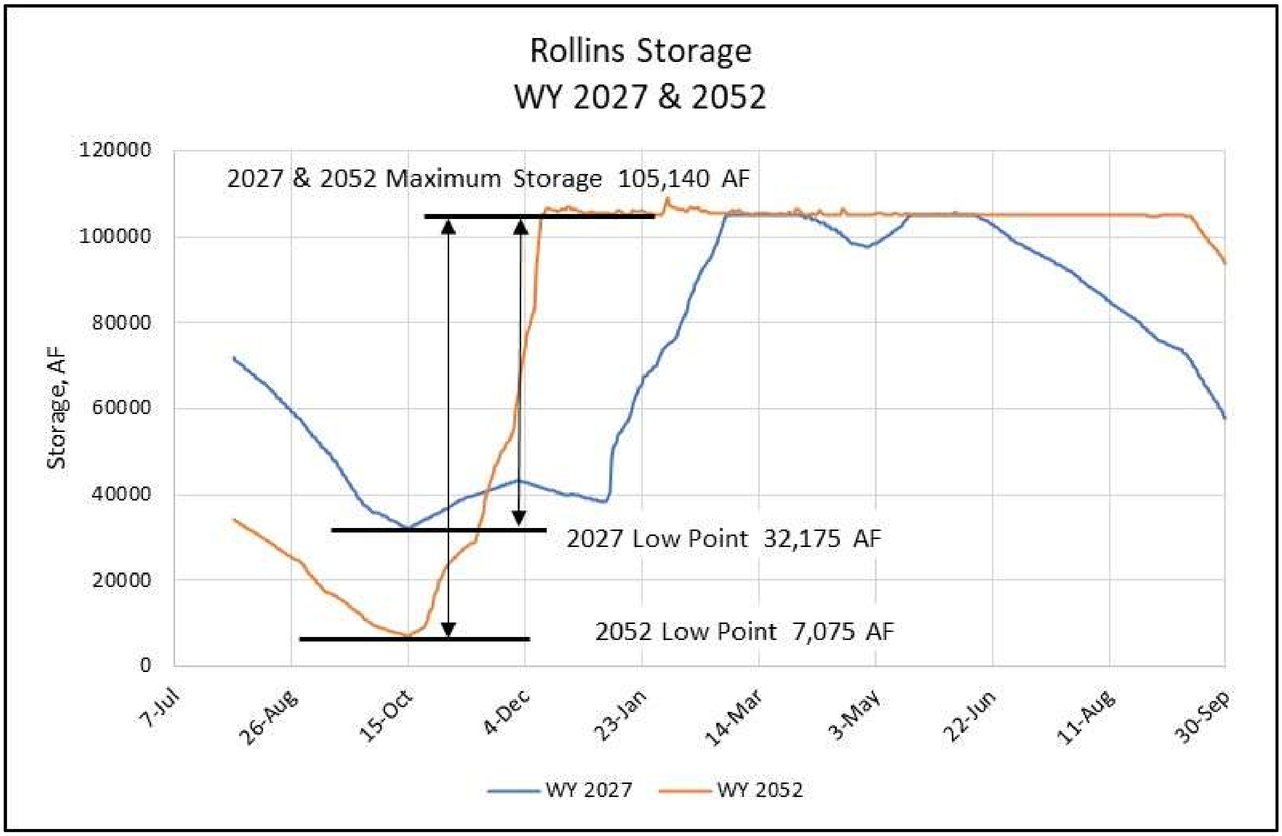
Through the Plan for Water process, several climate conditions and consumptive demands were chosen for testing the effectiveness of Strategic Alternatives to develop additional water supplies to serve the projected demands. The scenarios chosen were the Dry Climate Condition with High Demand, Median Climate Conditions with Baseline Demand (Median scenario) and the Wet Climate Condition with Low Demand. For this initial water rights analysis, the Median Climate Condition with the Baseline Demand was chosen.

According to the January 2021 Bathymetric Survey determined that Rollins Reservoir has a current capacity of 55,140 AF. Since current capacity is about 55,140 AF, an additional 50,000 AF would result in a total of 105,140 AF. For this study, 105,140 AF was assumed as the capacity of Rollins Reservoir.

Methodology

The Strategic Alternative assuming a 50 TAF Rollins Reservoir storage increase was studied during the Plan for Water Process. After evaluating the Rollins Reservoir operations from the Strategic Alternative, Water Years 2027 and 2052 were chosen from the Median scenario for an in-depth analysis of existing water rights and how they may be used to support future operations of 105,140 AF Rollins Reservoir. Both years follow a year of significant use of stored water. Both 2027 and 2052 are wet years that result in a refill of the storage space. The runoff patterns of these two years are significantly different and are a good test of the rights. Figure 1. illustrates the storage trace for each year. Notice that the WY 2052 refill of Rollins Reservoir starts much earlier than WY 2027.

Figure 1 - Rollins Storage, Water Years 2027 and 2052



The necessary operational data was extracted from the Plan for Water HEC ResSim model of the 50 TAF Rollins Storage Increase and placed into the NID Water Right Program. The NID Water Right Program is used annually to perform an analysis of NID operations assigning use to its many water rights. The output from this model is used to complete the Annual Progress reports as required by the State Water Resources Control Board.

The version of the Water Right Program used for this analysis has limits imposed on some of the water rights that are less than the full face value of the rights. Those limits were the result of a water right licensing process that includes a review of historic use of each of the rights. For this licensing process, the assumption is that the maximum historical use reflects the full practical use of the rights and that no additional water would be needed. Under the Median scenario used for this analysis, study results indicate there is a greater need for storage than what has been historically used. To evaluate the potential for more use of NID's rights, the limits were raised to the full face value.

Results

There are 6 water rights that entitle NID to store water at Rollins Reservoir. Five of those rights are for consumptive use and the 6th is for power generation. Combined, this suite of water rights allows NID to fill Rollins Reservoir even under the projected median climate conditions. Populating the Water Right Program with the output data from the HEC ResSim model provides an indication of what rights could be used to store water at Rollins and where NID may need to consider additional water rights. Table 1 shows summary results of the use of the storage rights for water years 2027 and 2052 with associated water right limits below.

Table 1 - Summary of Rollins Reservoir Water Right Use

Water Year	Rollins Reservoir Water Right Use by Application Number					
	A002652A Bear River CU	A002652B Bear River CU	A005193 M Yuba R. CU	A008180 S. Yuba R. CU	A020017 S Yuba R. CU	A024983 Bear River Power
2027	6,945	53,598	741	1,799	3,915	70,291
2052	6,945	40,764	357	2,543	8,146	53,919
Storage Limits	6,945	65,000	50,000[1]	45,000[1]	18,000[1]	62,080

[1] Combined limit on multiple sources and reservoirs.

Water Right Application A002652A allows for storage at Rollins and Combie Reservoirs. It was licensed 11/26/1968. The Allowable storage at Rollins under this right is 6,945 AF per year. In 2027 and 2052, the use of this right is maximized.

Water Right Application A002652B allows for 65,000 AF of diversion to storage of Bear River Water at Rollins Reservoir. In 2027 and 2052, this storage right is the primary right used for storage of the consumptive supply. The use of the right is within the limits of the water right.

Water Right Application A005193 allows for rediversion of Middle Yuba Water stored at Jackson Meadows to be rediverted into storage at Bowman Lake, Scotts Flat Lake, Rollins Lake and Combie Lake. For 2027 and 2052, the quantity of Middle Yuba River water stored at Rollins is 741 AF and 357 AF, respectively. The use of the right is within the limits of the water right.

Water Right Application A008180 allows diversion to storage of South Yuba River and Canyon Creek (and other system creeks) to Scotts Flat and Parker Reservoirs. For the purposes of this analysis, water is diverted at Rollins Reservoir rather than Parker. Under the Climate Conditions used for this study, this quantity of water stored at Rollins Reservoir for 2027 and 2052 is 1,799 AF and 2,543 AF, respectively. The use of the right is within the limits of the water right.

Water Right Application 20017 allows storage of South Yuba River water at Rollins and Scotts Flat up to a combined 18,000 AF. In 2027 and 2052, the quantity of South Yuba River water stored at Rollins is 3,915 AF and 8,146 AF, respectively. The use of the right is within the limits of the water right.

Water Right Application A024983 is a storage right for power generation of Bear River water at Rollins Reservoir. This supply is specifically for power production but may, at times, overlap with the consumptive use storage. This can mean that water used to generate power can also be used to meet consumptive demands. The storage limit on this right is 62,080 AF. In 2027, the storage hit its storage maximum. To identify the need for additional rights, the limit was removed to allow the program to determine the volume needed. Table 1 shows the volume in red as 70,291 AF which exceeds the maximum of 62,080 AF, indicating that an additional storage right of at least 8,211 AF may be needed.

Conclusions

This limited analysis was based upon two water years in one of three climate and demand scenarios chosen for future evaluation of the Strategic Alternatives. The Plan for Water uses a forward-looking approach considering projected climate conditions and growth patterns including hydrology and consumptive demands. The results of the Plan for Water Strategic Alternatives indicate additional supplies will be needed in the future.

Based on the results of this limited analysis, it appears that for consumptive purposes, the District will need to develop additional water supply to offset the impacts of a changing climate. The most promising of the Strategic Alternatives was the 50 TAF Rollins Reservoir Dam raise. Fortunately, the District may already have the **consumptive** storage rights needed.

For the purpose of **power generation**, it appears the District will need to consider a new storage right. Application A024983, the District's water right allowing storage for power, was exceeded in water year 2027 by 8,211 AF. The District may want to consider pursuing an additional storage right to support projected power generation.

In 2008, the District began pursuing licensing of several of their water rights including A2652B, A05193, A08180, A020017, and A024983. The licensing request in 2008 was based upon historic usage of the rights. Historically, the beneficial use of these rights was less than the face value. The analysis of this Strategic Alternative indicates that in at least one case, the need for storage will exceed the face value of the rights.

Recommendations

Based upon the results of this study, it appears the District should contact the SWRCB to request the withdrawal of licensing the suite of Rollins Reservoir storage rights and instead pursue a petition for extension. Prior to any action, I suggest meeting with SWRCB staff for guidance. Pursuit of extensions may be denied because the period to put water to beneficial use for this suite of rights ended between 1966 and 1985.

In addition, NID will need to file for a new storage right for the purpose of power generation. Any extensions granted will allow the District time to perform a more rigorous evaluation of the projected need for storage while continuing to put more water to beneficial use. The purpose of the evaluation will be to identify the magnitude of the additional storage right for power generation and determination of the need, if any, for additional storage to support consumptive demands.

Submitted to:
Nevada Irrigation District
1036 W. Main Street
Grass Valley, CA 95945

Submitted by:
AECOM
300 Lakeside Dr.
Suite 400
Oakland, CA 94612
January 7, 2020

Enlarged Rollins Reservoir Concepts Opinion of Probable Construction Costs - Draft

60617991

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January 7, 2020

Nevada Irrigation District
1036 W. Main Street
Grass Valley, CA 95945

Attention: Mr. Doug Roderick, P.E.

Subject: Enlarged Rollins Reservoir Concepts – Opinion of Probable Construction Costs Draft

Dear Mr. Roderick:

We are very pleased to submit this Technical Memorandum (TM) documenting the Opinion of Probable Construction Costs (OPCC's) for the Enlarged Rollins Reservoir Concepts. The work described in this TM was authorized by the Nevada Irrigation District (NID) under Task Order 12 executed on October 29, 2019.

This TM was prepared to support NID's planning efforts for water supply and presents OPCC's for the following enlarged Rollins Reservoir concepts:

- Raise Rollins Embankment Dam to store an additional 50,000 acre-feet.
- Roller Compacted Concrete (RCC) Dam, downstream location – RCC Dam Concept 1, to store an additional 80,000 acre-feet. This concept would make use of the existing dam as a cofferdam during RCC dam construction.
- RCC Dam, existing dam location – RCC Dam Concept 2 to store an additional 76,000 acre-feet. This concept would involve emptying the reservoir and diverting flows around the RCC dam construction site and removing the existing embankment dam, the shell zones of which could be processed to provide RCC aggregate.

This TM discusses the following:

- RCC dam Concepts 1 and 2 and the raised embankment dam concept including foundation treatment, spillway, outlet works and diversion facilities, required construction materials, and conceptual construction site layouts.
- Construction sequencing and durations for each concept.
- The basis for and the results of the OPCC's for each concept.
- Conclusions of our work.

We are available to meet to discuss this technical memorandum with you. Please contact me at (510) 874-3012 if you have any questions.

Sincerely,
AECOM Technical Services, Inc.

M.P. Forrest.

M.P. Forrest, P.E., G.E.
Project Manager

Enclosure:
Enlarged Rollins Reservoir Concepts – Opinion of Probable Construction Costs - Draft

Cc: Ted Feldsher (AECOM)

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Table of Contents

1 Introduction 1-1

1.1 Background and Purpose 1-1
1.2 Scope of Work 1-1
1.3 Organization of Technical Memorandum 1-2
1.4 Acknowledgements 1-2
1.5 Limitations 1-2

2 Roller Compacted Concrete Dam 2-1

2.1 Dam Foundation Treatment 2-1
2.2 Conceptual Layout of Dam and Appurtenant Structures 2-2

2.2.1 Spillway Configurations 2-2
2.2.2 Outlets 2-3
2.2.3 Diversion 2-3

2.3 Construction Materials 2-3
2.4 Conceptual Layout of Site Construction Plan 2-4

3 Rollins Embankment Dam Raise 3-1

3.1 Dam Foundation Treatment 3-1
3.2 Conceptual Layout of Dam and Appurtenant Structures 3-1
3.3 Earth and Rock Construction Materials 3-2
3.4 Conceptual Layout of Site Construction Plan 3-3

4 Construction Sequencing and Durations 4-1

4.1 General 4-1
4.2 RCC Dam Concept 1 4-1
4.3 RCC Dam Concept 2 4-2
4.4 Embankment Dam Raise Concept 4-4

5 Construction Cost Estimates 5-1

5.1 General 5-1
5.2 Project Features 5-1

5.2.1 Mobilization and Site Development 5-1
5.2.2 River Diversion 5-2
5.2.3 Dam Foundation Excavation and Preparation 5-2
5.2.4 RCC Dam and Concrete Facing 5-2
5.2.5 Embankment Dam Raise 5-3
5.2.6 Spillway and Bridge 5-3
5.2.7 Outlet and Intake Structures 5-3
5.2.8 Miscellaneous Civil Works 5-3
5.2.9 Instrumentation and SCADA 5-3

5.3 Quantity Estimates 5-4
5.4 Material Balance Diagrams 5-4
5.5 Pricing 5-4

5.5.1 Class of Cost Estimate 5-4
5.5.2 Basis of OPCC's 5-4

5.6 Design Contingency 5-5
5.7 Allowances and Exclusions 5-6
5.8 Opinion of Probable Construction Cost 5-7

6 Summary and Conclusions **6-1**
7 References **7-1**

List of Tables

1 Rollins Dam and Reservoir, Concepts Comparison Matrix
2 RCC Dam Concepts 1 and 2 – Summary of Material Requirements
3 Materials for Embankment Dam Raise
4 Estimated Embankment Dam Raise Quantities
5 Opinion of Probable Construction Cost Summary, Rollins Reservoir Raise Concepts
6 Other Owner-related Cost Allowances
7 Summary of Comparative Construction Costs

List of Figures

1 Site Vicinity Map - Rollins Reservoir
2 RCC Dam Concept 1, Plan of Dam
3 RCC Dam Concept 1, Dam Axis Profile
4 RCC Dam Concept 1, RCC Dam Sections
5 RCC Dam Concept 1, Site Area
6 RCC Dam Concept 1, Material Balance Diagram
7 RCC Dam Concept 2, Plan of Dam
8 RCC Dam Concept 2, Dam Axis Profile
9 RCC Dam Concept 2, RCC Dam Sections
10 RCC Dam Concept 2, Site Area
11 RCC Dam Concept 2, Material Balance Diagram
12 Embankment Dam Raise Concept, Plan of Dam
13 Embankment Dam Raise Concept, Dam Axis Profile
14 Embankment Dam Raise Concept, Maximum Dam Section
15 Embankment Dam Raise Concept, Site Area
16 Embankment Dam Raise Concept, Material Balance Diagram

List of Appendices

Appendix A. Opinions of Probable Construction Costs for Conceptual Rollins Reservoir Enlargements
Appendix B. Opinion of Probable Construction Cost for Centennial Dam

List of Acronyms and Abbreviations

AACE	Association for the Advancement of Cost Engineering
ADAS	automated data acquisition system
cy	cubic yards
DSOD	California Division of Safety of Dams
FERC	Federal Energy Regulatory Commission
G&A	general and administrative
GE-RCC	grout-enriched roller compacted concrete (facing)
lbs	pounds
lf	lineal feet
NID	Nevada Irrigation District
OPCC	opinion on probable construction cost
RCC	roller compacted concrete
SCADA	supervisory control and data acquisition
STID	Supporting Technical Information Document
sy	square yards
TM	Technical Memorandum
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation

1 Introduction

1.1 Background and Purpose

The Nevada Irrigation District (NID) is identifying and evaluating potential water supply project concepts for consideration and analysis in its environmental review process. This Technical Memorandum (TM) presents opinions of probable construction costs (OPCC's) for the following enlarged Rollins Reservoir concepts:

- Raise Rollins Embankment Dam to store an additional 50,000 acre-feet. This concept for raising the existing embankment dam was prepared in February 2018 (AECOM 2018a) to provide information for environmental support.
- Roller Compacted Concrete (RCC) Dam, downstream location – RCC Dam Concept 1, to store an additional 80,000 acre-feet (draft TM, AECOM 2018b). This concept would keep the existing reservoir in service during construction and make use of the existing dam as a cofferdam so that downstream construction could proceed.
- RCC Dam, existing dam location – RCC Dam Concept 2 to store an additional 76,000 acre-feet (draft TM, AECOM 2019). This concept would involve emptying the reservoir and diverting flows around the RCC dam construction site and removing the existing embankment dam, the shell zones of which could be processed to provide RCC aggregate.

These concepts are compared in Table 1, Rollins Dam and Reservoir, Concepts Comparison Matrix. The Rollins Reservoir Site Vicinity Map is shown in Figure 1.

The work described in this TM was authorized by NID under Task Order 12 executed on October 29, 2019, and the agreement between AECOM and NID dated April 15, 2015.

1.2 Scope of Work

The scope of work for this OPCC TM included the following tasks:

- Prepared conceptual figures for the Rollins Embankment Dam Raise. Similar figures have been prepared previously for RCC dam Concepts 1 and 2 (AECOM, 2018b and 2019). Stability, hydraulic, structural, and all other design-level analyses are beyond the scope of work for this TM.
- Prepared quantity estimates and OPCC's for the three concepts. The OPCC's were prepared so that the costs can be compared to those reported in the Centennial Reservoir Project, Roller Compacted Concrete Dam, Opinion of Probable Construction Cost – Final (AECOM 2017). The base year for the estimates is 2017; the estimates were escalated to 2019 dollars to compare the OPCC's of the concepts. The OPCC's were developed to a Class 4 level in accordance with the Association for the Advancement of Cost Engineering (AACE). For the RCC dam concepts, unit prices were based on those for Centennial Reservoir RCC dam (AECOM, 2017). Detailed "bottom-up" estimates are beyond the scope of work for the OPCC's described in this TM.

- Prepared this TM to compare the concepts on the basis of the OPCC's and quantities. Constructability issues are discussed, and approximate construction durations are presented for each concept.

1.3 Organization of Technical Memorandum

After this introductory section, this TM is organized into the following sections:

- Section 2 discusses the RCC dam Concepts 1 and 2 including foundation treatment, spillway, outlet works and diversion facilities, required construction materials, and conceptual site layout.
- Section 3 discusses the raised embankment dam concept including foundation treatment, spillway, outlet works and diversion facilities, required construction materials, and conceptual site layout.
- Section 4 describes the construction sequencing and durations for each concept.
- Section 5 presents the basis for and the results of the OPCC's for each concept.
- Section 6 presents the summary and conclusions.
- Section 7 lists the references used to prepare this TM.

1.4 Acknowledgements

The following key AECOM personnel contributed to this OPCC TM:

- Project Manager: Michael Forrest, P.E., G.E.
- Principal-in-Charge: Theodore Feldsher, P.E.
- Construction Cost Estimator: Roy Watts
- Civil Engineer: Steve Tough, P.E.
- Independent Technical Reviewer: Joseph Barnes, P.E.

1.5 Limitations

The estimates presented in this TM reflect a professional conceptual-level OPCC, based on conceptual-level design layouts developed using limited available information on the surface and subsurface site conditions. While adequate to compare concepts, costs presented herein should not be used for financial planning for project construction.

AECOM represents that its services were conducted in a manner consistent with the standard of care ordinarily applied as the state of practice in the profession, within the limits prescribed by our client. No other warranties, either expressed or implied, are included or intended in this TM.

Information provided is solely for the use of NID within the defined intent and scope of work stated in this TM.

Table 1. Rollins Dam and Reservoir Concepts Comparison Matrix

Item	Existing Rollins Embankment Dam (STID, NID, 2014)	Raised Rollins Embankment Dam (NID Water Supply Project Alternatives, Draft Environmental Support, AECOM, 2018a)	RCC Dam Concept 1 (Draft Tech Memo, AECOM, 2018b)	RCC Dam Concept 2 (Draft Tech Memo, AECOM, 2019)
Max. Structural Height (ft)	252.5	306	322	320
Dam Crest El. (ft)*	2,190.1	2,243.5	2,262.0 (est.)	2,262.0 (est.)
Crest Length (ft)	1,260	1,500 (approx.)	3,300	2,650
Crest Width (ft)	30	30	25	25
Upstream Slope	2.5H:1V	2.0 – 2.5H:1V	Vertical	Vertical
Downstream Slope	2.0H:1V	1.8H:1V	0.8H:1V	0.8H:1V
Estimated Dam Volume (cy)	2.4 million	2.1 million (increase)	2 million	1.3 million
Spillway Crest El. (ft)*	2,173.6	2,226 (52.4-foot raise)	2,242.4	2,242.4
Reservoir Area at Spillway Crest (acres)	826	1,301 (475-acre increase)	1,545 (719-acre increase)	1,500 (674-acre increase)
Reservoir Storage at Spillway Crest (acre-feet)	60,000	110,000 (50,000-acre-foot increase)	140,000 (80,000-acre-foot increase)	136,000 (76,000-acre-foot increase)
Spillway Description	Right abutment, 316 feet long, ungated ogee crest	Right abutment, 316 feet long, ungated ogee crest (raised)	New spillway over west side of dam, 250 feet long, ungated ogee crest	New spillway over west side of dam, 250 feet long, ungated ogee crest; utilizes existing spillway chute
Outlet Works	72- to 60-in. pipe to Howell-Bunger valve discharge into tunnel	May need to modify existing outlet works	Extend existing water supply and power conduits through RCC dam	Utilizes existing water supply and power conduits
Cofferdam	N/A	None	Existing dam acts as cofferdam	Construct cofferdam after reservoir is dewatered
Total Disturbance Area, permanent and temporary,	N/A	130	120	75

beyond reservoir area (acres)**				
Reservoir Level During Construction	N/A	~El. 2140 for excavation of existing dam crest - one season	El. 2040 to excavate notch through existing dam after RCC dam completed	Empty reservoir
Power Generation during Construction	N/A	No	Yes	No
Water Deliveries to Bear River Canal	N/A	Yes, may be limited due to reduced reservoir storage	Yes	Yes, may be limited due to reduced reservoir storage

*Vertical datum is NAVD 88
**Approximate area of restoration

2 Roller Compacted Concrete Dam

Conceptual-level designs were developed to illustrate the general arrangement and the main features for RCC dam Concepts 1 and 2. These concepts are described in draft TMs by AECOM referenced as 2018b (Concept 1) and 2019 (Concept 2) and are summarized below:

- RCC Dam Concept 1: A downstream dam location was considered to allow use of the existing Rollins Reservoir during construction. The existing dam would act as a cofferdam during construction of the downstream RCC dam. The location of RCC Dam Concept 1, downstream of the existing Rollins Dam, was selected based on the following considerations: (1) continue to provide water delivery to the Bear River Canal during construction of the downstream RCC dam; (2) continue to operate the existing hydropower plant during construction of the downstream RCC dam; and (3) continue to use the existing spillway to pass spill events safely through the downstream construction site.
- RCC Dam Concept 2: RCC Dam Concept 2 would require taking the reservoir out of service during construction, diverting flows around the dam site, and removing the existing embankment dam. The location of the RCC Dam Concept 2 was established to (1) keep the dam axis as far downstream as possible to minimize reservoir storage loss; (2) maximize utilization of the foundation excavation of the existing embankment dam; and (3) enable utilization of the existing spillway chute. The RCC dam footprint was located to include the existing dam core trench to reduce the foundation excavation volume. The dam axis bends perpendicularly to the existing spillway chute, so that the new RCC dam spillway would discharge down the existing spillway chute alignment.

The conceptual plans, sections, dam site areas and material balance diagrams for the RCC dam concepts are shown on Figures 2 to 6 (Concept 1) and on Figures 7 to 11 (Concept 2). The main features of the RCC dam and enlarged reservoir concepts are summarized in Table 1.

2.1 Dam Foundation Treatment

The dam layouts and assumed depths of foundation excavation are based on the results of the geotechnical reconnaissance (AECOM, 2018c) and on the as-built Rollins Dam Drawings (NID, 1966). As discussed in the 2018 and 2019 TMs, the foundation for an RCC dam would require slightly weathered to fresh, hard rock. Excavation depths up about 50 feet are expected in portions of both potential axis locations. Shallower excavation depths are anticipated in the river channel areas based on outcrop observations. Additional geotechnical investigations are needed to better define the necessary excavation depths.

Grouting would be needed to control seepage through the foundation rock. Based on a the as-built Rollins Dam drawings (NID, 1966), the grout curtain holes were drilled and grouted to a depth of 50 percent of the reservoir head, but not less than 25 feet deep. The grouting records show that the maximum grout hole depth was about 145 feet. The conceptual RCC dam design layouts include two grout curtains, each 150 feet deep in the central part of the dam foundation and 100 feet deep on the abutments as shown on Figures 3 and 8 (AECOM, 2018b and 2019). Grout hole spacing within a curtain was assumed to be 12 feet between primary and secondary holes, with tertiary and higher-order holes split-spaced between the primary and secondary holes. The grout holes in each curtain would be angled in opposing directions to more effectively intersect rock discontinuities in the foundation.

For conceptual design, the grout curtain will be located along a concrete plinth, anchored into the rock foundation, at the upstream toe of the dam as shown on Figures 4 and 9. The plinth will act as a grout cap and will be sealed against the upstream face of the RCC dam with waterstops. This grout curtain location would remove grouting from the critical path and can be undertaken as the dam is constructed.

The foundation for an RCC dam at either axis could also require consolidation grouting of fractured rock areas within the footprint. The purpose of this is to strengthen the rock mass and increase the stiffness of the foundation. The conceptual design layout includes consolidation grouting over 30% of the dam foundation footprint area, with 30-foot deep grout holes spaced on a 10 x 10-foot pattern.

Drain holes to control uplift pressures beneath the RCC dam would also be required. The conceptual design includes drain holes drilled from a gallery within the dam, spaced on 10-foot centers and extending to an average depth of 80 feet into the foundation rock.

The construction costs for an RCC dam would also include foundation cleaning for geologic mapping, final foundation cleaning prior to RCC placement, surface preparation (i.e., dental excavation of joints and shear zones and replacement with concrete), and leveling concrete placed on the foundation to provide a platform to commence RCC placement.

2.2 Conceptual Layout of Dam and Appurtenant Structures

The conceptual plans, profiles, and sections of the RCC dam are shown on Figures 2 to 4 for Concept 1 and on Figures 7 to 9 for Concept 2. The descriptions of the design for these RCC dam concepts are discussed in draft TM's (AECOM, 2018b, for Concept 1, and AECOM, 2019, for Concept 2). The conceptual section has a vertical upstream face, a 0.8H:1V stepped downstream face, and a 25-foot-wide crest. For the purpose of this OPCC, grout-enriched RCC (GE-RCC) facings on the upstream and downstream sides were assumed. The spillways were assumed to be faced with concrete.

2.2.1 Spillway Configurations

The conceptual RCC dam layouts for Concepts 1 and 2 include a spillway integral with the body of the dam, aligned to discharge flows directly into the Bear River channel. RCC Dam Concept 1 includes a spillway on the right side of the dam at the location of the existing spillway discharge, in a 250-foot wide overflow bay (Figure 2).

For Concept 2, the 250-foot wide spillway overflow bay is located immediately upstream of the existing spillway crest and would discharge down the existing chute alignment. The existing spillway chute was assumed to be demolished and replaced with a new reinforced concrete chute that meets current spillway design standards that would include underdrains, anchors to resist uplift forces and appropriate joint design. The lower end of the spillway chute would be widened from its present 80 feet to 150 feet to reduce the flow convergence from the 250-foot-wide crest at the top of the spillway. This is done to reduce the potential for cross waves during high flows under the increased spillway head of the raised dam. The existing spillway chute would need to be evaluated to confirm that it satisfies hydraulic design criteria. Also, a condition assessment of the existing spillway chute would be needed to confirm whether it would require modifications to bring it to current structural design standards (AECOM, 2019).

2.2.2 Outlets

For both RCC dam concepts, the two outlet works tunnels in the left abutment of Rollins Dam would be utilized for reservoir release (Figure 2 for Concept 1 and Figure 7 for Concept 2). The water supply outlet discharges to a forebay that feeds the Bear River Canal and the other outlet connects with the power plant at the downstream toe of the dam. The water supply outlet would be extended across the RCC Dam Concept 1 footprint to discharge into a relocated forebay that would feed the Bear River Canal. The headworks for the canal would also be relocated downstream of the construction area for Concept 1. The forebay would require a small canal forebay dam between the canal headworks and the RCC dam (Figure 2).

This OPCC TM also includes costs for a low-level outlet. The layout includes an assumed 8-foot diameter steel outlet pipe, which would be cast into the body of the RCC dam. The conceptual layout includes a single low-level intake, located near the base of the dam.

2.2.3 Diversion

For construction of RCC Dam Concept 1, the existing spillway would need to remain operable to safely convey spill events through the construction site. To accomplish this, a reinforced concrete box culvert structure would be constructed in the spillway discharge channel within the footprint of the RCC dam (Figures 2 and 3). This box structure would be required until the RCC dam is completed, and then filled with concrete and contact grouted to form a seal around the plug and the interior surface of the box structure.

To construct RCC Dam Concept 2 at the existing dam location, diversion would be needed through the existing tunnels in the left abutment. A cofferdam constructed within the emptied reservoir would be needed as was the case for the original dam construction in the 1960s (see Figure 7). The adequacy of the cofferdam height and tunnel capacity would need to be confirmed. Sediment scour within the emptied reservoir upstream of the cofferdam for this concept would need to be addressed.

2.3 Construction Materials

For RCC Concept 1, rock for RCC aggregate was assumed to be obtained from an on-site rock borrow area (see material balance diagram for RCC Dam Concept 1 on Figure 6). The rock borrow area would first need to be stripped of overburden and weathered rock. The underlying fresh rock would be drilled, blasted, crushed and screened to produce the RCC aggregate. Waste material would be placed in an on-site disposal area as discussed in Section 2.4.

For RCC Concept 2, the existing embankment dam shell materials would be stockpiled for use as RCC dam aggregate, and the clayey core materials would be wasted in disposal sites (see material balance diagram for RCC Dam Concept 2 on Figure 11). Once the existing dam has been removed, the foundation excavation for the RCC dam would proceed in the existing dam foundation.

The RCC, concrete, aggregate, cement and fly ash requirements are summarized in Table 2.

Table 2. RCC Dam Concepts 1 and 2 – Summary of Material Requirements

RCC Dam Concept	RCC Volume (cy)	Concrete Volume (cy)	Aggregate (process on-site) (cy)	Total Cement (import) (tons)	Total Fly Ash (import) (tons)
1	2,000,000	95,000	1,781,000	166,000	156,000
2	1,300,000	49,000	1,146,000	106,500	100,500

Note: See also Material Balance Diagrams, Figure 6 (Concept 1) and Figure 11 (Concept 2).
Cement and fly ash contents for RCC are each 150 lbs/cy.

The highest demand for cement and fly ash would be during RCC placement. The cement and fly ash would be imported and trucked to the RCC batch plant. Over the estimated 26-month and 17-month RCC placement periods for Concept 1 and Concept 2, respectively (see Sections 4.2 and 4.3), this would necessitate importing a total amount of about 560 tons per day of cement and fly ash. This hauling could potentially be limited to Monday through Friday during daylight hours if necessary. In that case, an estimated 14 truck loads per day would be required, at 40 tons per load.

The RCC would be mixed in an on-site batch plant, transported to the dam with a conveyor system, placed in 12-inch-thick lifts, and compacted with 10-ton smooth drum vibratory rollers. It was assumed that the RCC would be faced with grout enriched (GE) RCC and concrete (in the spillway) placed at the same time as the RCC.

RCC would not be placed during rainy weather. During hot weather, RCC placement may be limited to night-time placements or the aggregates may need to be cooled for mixing to stay below maximum allowable placement temperature requirements. This can be achieved by shading, water spraying, and/or by liquid nitrogen injection into the mix at the batch plant.

2.4 Conceptual Layout of Site Construction Plan

Conceptual site layouts for RCC dam construction are shown on Figure 5 for Concept 1 and Figure 10 for Concept 2. These figures show the assumed rock borrow area and disposal and staging areas. The estimated disposal volumes for the RCC dam concepts are approximately 4.6 million cy and 1.5 million cy for Concepts 1 and 2, respectively (refer to material balance diagrams, Figures 6 and 11 for Concepts 1 and 2, respectively). The disposal volume for Concept 1 is much greater than for Concept 2 mainly due to the borrow area stripping volume and greater foundation excavation.

The main construction site features would include the rock borrow area (for Concept 1), aggregate crushing and screening plant, disposal area, RCC batch plant, concrete batch plant, and staging areas. The staging area would contain the contractor and construction management offices, site geotechnical and RCC/concrete laboratory, fuel depot, and equipment laydown and storage areas. The conceptual locations of the site features were developed based on access and proximity to the dam sites.

Access routes for construction would be the responsibility of the construction contractor. Two-lane all-weather road access would be needed to connect the rock borrow area (for RCC Dam Concept 1) with the aggregate crushing and screening plant areas, the RCC batch plant site on the left abutment of the dam, and the concrete batch plant.

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3 Rollins Embankment Dam Raise

The conceptual design for the raised embankment dam to store an additional 50,000 acre-feet was prepared in February 2018 to provide information for environmental support (AECOM, 2018a). Figures prepared for this OPCC TM showing the conceptual plan, section, dam site area and material balance diagram are included as Figures 12 to 16. The main features of the raised embankment dam and enlarged reservoir concept are summarized in Table 1.

3.1 Dam Foundation Treatment

The raised dam would extend beyond the end of the left end of the existing dam. In this area, the excavation would extend about 30 to 50 feet below the ground surface. The core zone would extend down to moderately weathered or better rock conditions. The raised downstream dam shell zone would be founded on weathered rock. The right abutment would include a concrete gravity wall (see Section 3.2) founded on moderately weathered or better rock conditions.

Grouting would be needed to control seepage through the abutment rock that would tie into the existing grout curtain. For estimating purposes, the average depth was assumed to be 50 feet on the left abutment and 100 feet on the right abutment, with two curtains composed of holes angled in opposing directions to more effectively intersect rock discontinuities in the foundation. Grout hole spacing within a curtain was assumed to be 12 feet between primary and secondary holes, with tertiary and higher-order holes split-spaced between the primary and secondary holes.

3.2 Conceptual Layout of Dam and Appurtenant Structures

The conceptual plan, profile and section of the raised dam concept are shown on Figures 12 to 14. The top of the existing embankment would be excavated to allow for the dam raise (Figure 14). The 53.4-foot dam crest raise would include an inclined core zone that would be flanked by inclined filters and by rockfill shell zones. The raised embankment dam conceptual section has a 2H:1V upstream slope, a 1.8H:1V downstream slope, and a 30-foot-wide crest. Riprap would be placed on the upstream shell zone for wave erosion protection.

The existing spillway would need to remain functional throughout construction of the raised dam. The raise would begin by excavating the top of the dam to establish the inclined core zone and rebuilding the dam back to original crest elevation 2190.1 feet during the dry season to allow use of the spillway during the winter season (Section 4.4).

As stated in Section 3.1, the right abutment of the dam would include a concrete gravity wall to retain the raised embankment at the spillway location that would also form the left side of the spillway (Figure 13). The wall would be about 86 feet high and have a vertical face adjacent to the spillway and a backslope of 0.8H:1V against which the raised embankment would be placed.

The existing spillway chute was assumed to be demolished and replaced with a new reinforced concrete chute that meets current spillway design standards and would include underdrains, anchors and appropriate joint design. The spillway chute would be widened from its present 80 feet to 150 feet at the lower end of the spillway to reduce flow convergence from the 316-foot-wide crest at the top end of the spillway (NID, 1966). This is done to reduce the potential for cross waves during high flows under the increased spillway head of the raised dam. Similar to RCC Dam Concept 2, further analyses would be needed to define hydraulic conditions, rating curve, and the configuration of the spillway chute and its structural condition.

The two existing outlet conduits would be extended through the downstream raised embankment; one for the relocated powerhouse and one for the river outlet. The capacity of the outlet conduits would need to be evaluated to confirm that California Division of Safety of Dams (DSOD) reservoir drawdown criteria can be met.

3.3 Earth and Rock Construction Materials

Rockfill would be quarried from an on-site rock borrow area (Figure 15) and would provide the materials indicated in Table 3. Rockfill shell zones would be placed in 2- to 3-foot-thick loose lifts and compacted by heavy (12-ton) vibratory rollers. Lesser quality (weathered) rock can also be utilized in the downstream shell zone, but above the foundation surface, to allow for drainage through the underlying better quality rockfill. Filter zones could be imported from commercial quarries, or processed from on-site rock. The core materials would be obtained from the rock borrow area stripping as indicated on the material balance diagram shown on Figure 16.

Table 3. Materials for Embankment Dam Raise

Description	Material	Lift Thickness (in.)
Core	Colluvial clayey soils from borrow area stripping	8
Filters	Crushed and screened to sand and gravel sizes – imported or processed from on-site rock	12
Rockfill	Quarried pit-run rockfill	24-36
Riprap	Quarried and sorted rockfill	36 (layer on upstream slope)

*Refer to Figure 14 for zoning.

In order to produce the necessary quality of rockfill materials, the rock borrow area would need to be stripped of overburden and highly weathered rock. The wasted material would be placed in an on-site disposal area (Section 3.4). The underlying moderately weathered to fresh rock would be drilled and blasted to produce rockfill.

The summary of embankment dam raise material requirements is summarized in Table 4.

Table 4. Estimated Embankment Dam Raise Quantities

Description	In-place Material Volume cy)
Interim Raise:	
Exist dam crest excavation	333,000
Final Dam:	
Total volume of raise	1,646,000
Core zone	125,000
Filter and drain chimney zones (imported)	121,000
Rockfill and riprap	1,400,000
Concrete aggregate	54,000

Cement and fly ash would need to be imported for the concrete structures that total approximately 64,000 cy. It is estimated that approximately 10,000 tons of cement and 3,500 tons of fly ash would be required for the spillway chute, raised ogee crest and gravity wall. Hauling traffic for cement and fly ash would be heaviest during periods when these features are being constructed. It is estimated that up to about six 40-ton-loads per week would be needed to meet the demand to construct these features.

3.4 Conceptual Layout of Site Construction Plan

A conceptual site layout for the Rollins embankment dam raise construction is shown on Figure 15. This figure shows the assumed rock borrow area, disposal areas and staging areas. The estimated disposal volumes for the embankment dam raise concept is approximately 1.4 million cy (refer to the material balance diagram, Figure 16).

The main construction site features would include the rock borrow area, disposal area, concrete batch plant, and staging areas. The staging area would contain the contractor and construction management offices, site geotechnical and concrete laboratory, fuel depot, and equipment laydown and storage areas. The conceptual locations of the site features were developed based on access and proximity to the dam site.

Access routes for construction would be the responsibility of the construction contractor. Two-lane all-weather road access would be needed to connect the rock borrow area with the dam site and aggregate crushing and screening plant areas, and the concrete batch plant site.

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4 Construction Sequencing and Durations

4.1 General

The construction sequencing and durations discussed in this section provide a means to comparatively assess the relative logistics and construction durations of the activities of the Rollins dam concepts. The estimated construction durations focus on the major activities most likely to influence the total construction durations.

Many variables were considered in estimating the construction durations including productivities (which depend on crew sizes, equipment spreads, access conditions, etc.), approaches to sequencing of activities, number of shifts per day and days per work week, and other factors. The resulting construction duration estimates are approximate, and are consistent with the conceptual level of the corresponding OPCC's for each concept. The estimated construction durations discussed below may be conservative; optimization is possible once the project and geotechnical conditions are better defined in future phases of investigation and design.

The construction sequencing discussed in this section is our conceptual assessment of how the work could be executed. For this conceptual level estimate, durations of construction were estimated for the major work activities based on the work quantities and typical productivity rates. Productivity rates were estimated based on experience on other projects of similar type and magnitude. The following points summarize general assumptions and average productivity rates used to develop the estimated construction activity durations:

- Work performed six days per week, up to two shifts per day
- Placement of RCC and earthfill would occur between April 1 and November 15.
- No overly restrictive constraints on trucking materials to the site
- Dam foundation excavation: 30,000 cy/week
- Existing dam excavation: 30,000 cy/week
- Foundation grouting: 600 lineal feet per week per drill rig/grout plant
- RCC construction: 18,000 cy per week (based on information in AECOM, 2018d)
- Embankment dam raise construction: 50,000 cy per week below existing dam crest and 25,000 cy per week above existing dam crest

4.2 RCC Dam Concept 1

The main construction activities for RCC Dam Concept 1 for each year of construction are summarized below.

<u>Year 1:</u>
- Mobilize equipment and personnel to site
- Site development includes establishing BMPs and environmental protection features, access roads, and staging, stockpile, and disposal areas

- Develop borrow area
- Begin foundation excavation
- Construct temporary spillway bypass

Year 2:
- Complete foundation excavation
- Begin RCC placement and foundation surface preparation
- Begin foundation grouting
- Start construction of new intake structure and outlet

Year 3:
- Continue RCC placement and foundation surface preparation
- Continue foundation grouting
- Complete construction of new intake structure and outlet

Year 4:
- Complete RCC placement and foundation surface preparation
- Complete foundation grouting
- Drill drain holes from gallery
- Start construction of spillway training walls on RCC dam
- Lower reservoir and excavate notch through existing dam

Year 5:
- Complete construction of spillway training walls on RCC dam, dam crest slab and parapet walls
- Construct bridge
- Plug temporary spillway bypass
- Construct misc. civil works
- Install electrical, instrumentation and SCADA
- Site restoration and demobilize from site

It is estimated that the RCC Concept 1 could be constructed in about 4½ to 5 years (excluding any environmental mitigations).

4.3 RCC Dam Concept 2

The main construction activities for RCC Dam Concept 2 for each year of construction are summarized below.

Year 1:
- Mobilize equipment and personnel to site
- Site development includes establishing BMPs and environmental protection features, access roads, and staging, stockpile, and disposal roads
- Construct cofferdam for diversion
- Remove powerhouse and equipment.
- Begin excavation of existing dam and stockpile for RCC aggregate.

Year 2:
- Complete excavation of existing dam and stockpile for RCC aggregate.
- Excavate dam foundation

Year 3:
- Begin RCC placement and foundation surface preparation
- Begin foundation grouting
- Start construction of spillway walls

Year 4:
- Complete RCC placement and foundation surface preparation
- Complete foundation grouting
- Drill drain holes from gallery
- Construct spillway training walls on RCC dam and dam crest slab and parapet walls
- Complete construction of new intake structure and outlet
- Demolish existing chute spillway and excavate for new spillway
- Start construction of new spillway chute

Year 5:
- Complete new spillway chute
- Construct bridge
- Construct misc. civil works
- Install electrical, instrumentation and SCADA
- Site restoration and demobilize from site

Similar to RCC Dam Concept 1, it is estimated that the RCC Concept 2 could be constructed in about 4½ to 5 years (excluding any environmental mitigations).

4.4 Embankment Dam Raise Concept

The main construction activities for the embankment dam raise concept for each year of construction are summarized below.

Year 1:
- Mobilize equipment and personnel to site
- Site development includes establishing BMPs and environmental protection features, access roads, and staging, stockpile, and disposal roads
- Develop borrow areas
- Construct lower portion of right abutment gravity wall

Year 2:
- Lower reservoir level to interim elevation 2142.6 feet by May 1 for interim dam crest construction
- Start importing and stockpiling filter and drain materials for dam raise
- Excavate foundation and abutments
- Begin grouting of abutments
- Excavate dam crest to interim level (above reduced reservoir level) and haul to stockpile
- Rebuild dam back to original crest elevation 2190.1 feet to allow spillway use during winter season and construct rockfill shell on downstream side of dam
- Construct remaining portion of right abutment gravity wall

Year 3:
- Complete grouting of abutments
- Complete importing and stockpiling filter and drain materials for dam raise
- Complete embankment construction to final crest elevation
- Demolish existing chute spillway and excavate for new spillway

Year 4:
- Construct new spillway chute
- Construct bridge
- Construct misc. civil works
- Install electrical, instrumentation and SCADA
- Site restoration and demobilize from site

It is estimated that the Rollins dam raise could be constructed in about 4 years (excluding any environmental mitigations).

5 Construction Cost Estimates

5.1 General

This section describes the cost estimating methodology and basis for development of comparative conceptual-level OPCC's for both RCC dam concepts and the embankment dam raise concept.

5.2 Project Features

The OPCC's were developed by dividing the project into the following major features or cost categories for each dam type:

A. Mobilization and demobilization

B. Site development

C. River diversion

D. Dam foundation

E. RCC, facing concrete and gallery for the two RCC dam concepts, or embankment construction for the Embankment Dam Raise Concept

F. Spillway and dam crest

G. Spillway bridge

H. Outlet and intake structures and pipe

I. Misc. civil

J. Instrumentation and SCADA

The following sections describe the major cost components and estimating assumptions applicable to each of the above features and construction activities.

5.2.1 Mobilization and Site Development

Mobilization expenses include contract administration, temporary facilities (e.g., site offices and materials laboratory), transporting equipment to the site, and contract execution costs. Expenses associated with contract administration include preparation of submittals, coordination and meetings, insurance, taxes, and bonds. Expenses associated with temporary facilities include costs to furnish and set up temporary facilities, utilities, and roads at the site preparatory to undertaking construction work. Also included are costs for transporting construction equipment to site, unloading and assembly of the equipment, and break down and load out at the end of construction. Expenses associated with contract execution include layout and survey and contract closeout.

Site development includes construction and improvement of existing access roads, layout and construction of new haul roads, environmental protection, erosion and sediment control, stripping of surface soils prior to excavation, and borrow area development.

5.2.2 River Diversion

As stated in Section 2.2.3, for construction of RCC Dam Concept 1, the existing spillway would remain operable to convey spill events through the construction site. A reinforced concrete box culvert structure would be constructed in the spillway discharge channel within the footprint of the RCC dam. The existing tunnels would also be used for diversion. For RCC Dam Concept 2, a cofferdam would be constructed within the emptied reservoir so that flows could be diverted through the existing tunnels in the left abutment. The existing spillway would be used to discharge flows during construction of the raised embankment dam concept (Section 3.2). The existing tunnels would also be used for diversion.

5.2.3 Dam Foundation Excavation and Preparation

The dam foundation work would include excavating, loading, and hauling the materials that are removed from the foundation and abutments to the disposal area shown on Figure 5 (RCC Dam Concept 1), Figure 10 (RCC Dam Concept 2), and Figure 15 (Embankment Dam Raise Concept). This would be followed by foundation clean-up; preparation; leveling concrete for the RCC dam foundation; dewatering and groundwater control; and setting up, mixing and injecting grout for the grout curtain. Construction pricing assumptions for the dam foundation excavation and preparation work include the following:

- Foundation excavation was broken out as “common excavation” assuming large haul trucks and loader/excavator equipment spreads, but no drilling and blasting, and “rock excavation” requiring systematic drilling and blasting. The developed unit prices per cubic yard were compared with historical and database unit prices for consistency.
- Cleaning and preparation of the foundation surfaces were estimated per square yard using historical and database unit prices.
- Grout hole depths and primary and secondary hole spacing are indicated in Section 2.1 for the RCC dam concepts and in Section 3.1 for the embankment dam raise concept. An allowance of 50% for tertiary and higher-order holes are included in the OPCC’s. Costs for the grout curtain construction were estimated based on the lineal feet of grout holes drilled; verification holes, water pressure tests and the estimated weight of cement injected into the drill holes (0.35 sacks of cement/lf) are included in the drill hole footage price. An allowance for consolidation grouting is also included in the OPCC’s for the RCC dam concepts at 30% of the foundation area.

5.2.4 RCC Dam and Concrete Facing

The estimated cost for RCC construction assumes that the concrete aggregate would be processed from rock obtained from the on-site rock borrow area (for RCC Dam Concept 1) and from the existing dam shell zones (for RCC Dam Concept 2). The aggregate cost includes drill and blast excavation at the rock borrow area, crushing and screening, transporting and placing in stockpiles, loading from stockpiles, and hauling to the RCC batch plant at the top of the left abutment of the dam. The RCC cost also includes mixing the aggregate, cement and fly ash, transporting the RCC mix to the dam by conveyor, spreading and leveling the RCC to 12-inch thick lifts, and compacting with heavy smooth drum vibratory rollers. The estimate assumes the concrete facing/GE-RCC zones would be formed and placed simultaneously with the RCC placement and compaction.

5.2.5 Embankment Dam Raise

The rockfill embankment construction cost includes materials, labor, and equipment components. The estimated costs for rockfill materials include drill and blast excavation, loading, hauling, placing, and compaction of rockfill material obtained from the on-site rock borrow area for the embankment raise concept. Estimated costs for the imported filter/drain zones include purchasing from a commercial quarry, transporting and stockpiling the materials, loading from the stockpiles, hauling, placing, and compacting in the dam. The assumed placement lift thicknesses for each material zone are indicated in Table 3. Compaction of rockfill and filter/drain zones would be performed with heavy smooth drum vibratory rollers.

The core materials would be stripped from the surface of the rock borrow area and stockpiled until they are ready for placement in the dam, when the embankment fill reaches the base of the core (elevation 2142.6 feet on Figure 14). Moisture conditioning of these materials would take place in the stockpile area.

5.2.6 Spillway and Bridge

The chute spillway construction costs include demolition of the existing spillway concrete; rock excavation to widen the lower end of the spillway chute (with both drill and blast and mechanical methods); installation of anchors and subdrainage facilities; and structural concrete placement for the base slab and sidewalls. Historical database unit prices were used to estimate the cost of the spillway structural concrete walls and slab. Demolished concrete was assumed to be disposed in the on-site disposal area (Figures 10 and 15), but encapsulated within the earth and rock materials placed in the disposal area. Alternatively, the demolished concrete could be disposed off site in a landfill or recycling facility; this would result in additional hauling costs and facility/landfill disposal fees. The spillway bridge includes pre-fabricated segmental box-girder construction and piers.

5.2.7 Outlet and Intake Structures

The outlet works components for the RCC dam concepts include an intake at the base of the dam and a steel outlet pipe through the dam. In addition, major components were assumed to include the intake trashrack, control gates and valves, and associated electrical and mechanical systems. Detailed conceptual design layouts were not developed for the outlet works structure, so costs were estimated from experience on other similar projects. For the embankment dam raise concept, the two existing outlet conduits (power and river outlet) would be extended through the raised embankment.

5.2.8 Miscellaneous Civil Works

The cost category includes backfill, channel riprap, light duty paved maintenance roads, and site restoration (erosion control, grading and seeding).

5.2.9 Instrumentation and SCADA

The dam concepts would include instrumentation to monitor dam performance such as piezometers, survey monuments to monitor settlement and movement, inclinometers, and accelerographs. An automated data acquisition system (ADAS) is also assumed, to transmit the data to a central receiving location. Both dam concepts are also assumed to include supervisory control and data acquisition (SCADA) systems to operate the outlet works gates and valves. ADAS and SCADA data transmission would be via telemetry or land line. The estimates include cost allowances for these systems based on experience on other similar projects.

5.3 Quantity Estimates

The major project features were identified and broken down into separate work items for which quantities were then estimated for construction costing. The quantity estimates are dependent on the level of conceptual design detail as discussed in Sections 2 and 3. At the conceptual design level, the focus is on major features and related items of work. For development of the OPCC's, the earthwork quantities (foundation excavation, rockfill embankment and RCC) were calculated from the estimated conceptual design cross sections using average end area methods for sections cut on up to 200-foot spacings. The quantities represent in-place volumes, either in-situ or in-dam, as appropriate. Quantities for the spillways were estimated based on the layouts shown on the conceptual design figures presented in Sections 2 and 3.

5.4 Material Balance Diagrams

The material balance diagrams on Figures 6, 11 and 16 for RCC Dam Concept 1, RCC Dam Concept 2, and Embankment Dam Raise Concept, respectively, show the flow of materials from source to destination. They indicate the estimated amount of required rock borrow material, RCC dam and embankment quantities, excavated waste materials to be disposed, and the amount of imported cement and fly ash. Estimates for material bulking and shrink factors are also indicated on the figures. Materials to be run through aggregate processing and RCC and concrete batch plants are also indicated.

5.5 Pricing

5.5.1 Class of Cost Estimate

The conceptual-level OPCC's presented in this TM are intended to represent bid prices received from qualified contractors. The OPCC's are generally consistent with Class 4 estimates, which are described by the Association for the Advancement of Cost Engineering (AACE, 2005) as follows:

> "Class 4 estimates are generally prepared based on limited information and subsequently have fairly wide accuracy ranges. They are typically used for project screening, determination of feasibility, concept evaluation, and preliminary budget approval. Typically, engineering is from 1% to 15% complete."
>
> "Typical accuracy ranges for Class 4 estimates are -15% to -30% on the low side, and +20% to +50% on the high side."

Accordingly, the conceptual level Class 4 OPCC's presented in this TM are expected to fall within a range from 20% below to 20% above the actual construction cost for a given concept.

5.5.2 Basis of OPCC's

An experienced cost estimator with construction and hard dollar contract bid experience prepared the OPCC's, using logic, methods, and procedures that are typical for the heavy civil construction industry. Costs were estimated based on historical and database unit prices, and on built-up unit prices for Centennial Dam (AECOM, 2017). Other elements not detailed in the conceptual designs were priced as lump sum allowances in the estimated construction cost based on experience on similar projects. Construction costs from similar projects were considered in developing the estimate, including projects under construction and already completed.

For comparative OPCC's in this TM, the unit prices developed in mid-2017 (Quarter 2) for the Centennial Reservoir Project (AECOM, 2017) were used for the corresponding items for RCC dam Concepts 1 and 2, and for similar items for the Rollins Dam enlargement. The total construction costs were escalated to the end of 2019 (Quarter 4) using published indices from the U.S. Bureau of Reclamation's (USBR) Construction Cost Trends. Using the indices, the escalation from mid-2017 to the end of 2019 is about 8%.

Construction costs for the features and items were estimated by developing unit costs and multiplying these by the estimated quantities. Unit prices in the OPCC's were based on recently completed similar work and checked using the labor and equipment rates from the U.S. Army Corps of Engineers (USACE) Region VII Construction Equipment Ownership and Operation Expense Schedule (USACE, 2014). Vendor quotes were used for materials obtained off-site. Concrete costs were based on the use of an on-site concrete batch plant.

Cost breakdowns are presented in Appendix A. Direct and indirect costs were estimated for each of the main work items of the project. The direct costs include the quantity of work, labor, equipment, material and other costs estimated for each item. The general requirements of the contract (supervision and office staff, offices, utilities, etc.) are estimated to be about 20% of the direct construction cost. The contractor's markup at 15% of the direct construction cost includes general and administrative costs (G&A) and profit. G&A covers home office overhead cost and typically is in the range of 3 to 5% of the direct construction cost. G&A costs were assumed to comprise 5% of the estimated direct construction cost and profit was assumed to be 10% of the estimated direct construction cost. Prevailing wage (Davis-Bacon) rates were used to estimate labor costs. The direct and indirect costs (general requirements and markup) were added together to arrive at total unit costs.

All pricing assumes that the contractor is qualified and experienced in the construction of large RCC and embankment dams. The OPCC's also assume that the contractor would calculate and offer construction pricing from an open and competitive design-bid-build approach under one general construction contract utilizing industry standard specifications.

5.6 Design Contingency

The OPCC's presented in this TM include items, quantities, requirements, and constraints that have not been fully identified, or else are not fully investigated or designed. In later stages of design, the scope of the project also tends to expand as more detail is developed and as regulatory agencies undertake more detailed reviews. To account for the items that have not yet been fully developed, a design contingency allowance has been included in each OPCC.

The amount of design contingency reflects the degree of risk associated with uncertainties, particularly with respect to geotechnical conditions, as well as the completeness of the design detail for the major categories. The design contingency is based on, and added to, the subtotal of construction costs because it represents an unknown portion of the total estimated construction cost. The recommended design contingency normally decreases as the project design advances, more information becomes available, project requirements become better defined, and more design detail is captured in the subtotal of construction costs.

The OPCC's presented in this TM each include a design contingency, incorporated as an integral part of the estimated construction cost to accommodate those features and items of the work that cannot yet be fully assessed due to the conceptual level of the current design. In the OPCC's presented in Appendix A, the estimated percent contingencies are distributed to the various line items to reflect uncertainty in each item. The weighted average contingencies for the three concepts are as follows:

- RCC Dam Concept 1: 27.2%
- RCC Dam Concept 2: 26.4%
- Rollins Embankment Dam Raise: 29.8%

These contingencies are considered to be in the appropriate range (25% to 30%) for AACE Class 4 cost estimates.

5.7 Allowances and Exclusions

In order to assist NID to evaluate some of the other owner-related project costs, the allowances included below for design engineering, construction management, and engineering services during construction are provided. These are approximated as percentages of the total construction cost, based on recent experience with similar large infrastructure projects in California. Typical ranges for these costs depend in large part on the specific project details and total costs:

- Design engineering (includes geotechnical investigations): 5 to 8%
- Construction management and engineering services during construction: 8 to 10%

There are other potential owner-related project costs, but they are excluded from the OPCC's presented in this TM. These include NID's project management and administration costs, reservoir clearing[1], relocation of utilities, rebuilding of the power plant, land acquisition, legal, DSOD and FERC permitting fees, environmental permitting, environmental review and documentation, and mitigation. Other excluded items are cost to manage/regulate water for operations when reservoir is out of service during construction and loss of power generation for concepts when the hydropower plant is out of service.

In addition, potential construction cost growth due to change orders is not included in the OPCC's. Typical budgetary allowances for such costs can amount to 10% to 15% of the total construction cost, particularly for projects that involve relatively large amounts of geotechnical uncertainty.

[1] Reservoir clearing is assumed to occur under a separate timber harvesting contract.

5.8 Opinion of Probable Construction Cost

The conceptual design level OPCC's for the RCC dam and embankment raise concepts are summarized in Table 5. The OPCC details are presented in Appendix A. For comparison, the OPCC for Centennial dam is included in Appendix B. Breakdowns are presented for each of the categories and features described in Section 5.2. The recommended design contingency is distributed to each line item of the OPCC's as discussed in Section 5.6.

Although the project construction would occur a number of years in the future, the OPCC's presented in this TM were prepared in 2019 dollars and escalation to mid-point of construction is not considered. Potential issues that could impact future construction costs include changes in the construction industry bidding climate at the time the work is actually bid, increases in prevailing wage rates, and unpredictable fluctuations in material, equipment, and/or fuel prices.

Based on the approximate percentages indicated in Section 5.7, the total costs for design engineering and for construction management and engineering services during construction for the dam concepts are roughly estimated in Table 6.

Table 5. Opinion of Probable Construction Cost Summary

Rollins Reservoir Raise Concepts

Category	Description	RCC Dam Concept 1		RCC Dam Concept 2		Embankment Dam Raise Concept	
		Category Total	Category % of Total	Category Total	Category % of Total	Category Total	Category % of Total
A	Mobilization & Demobilization	$42,681,000	7.1	$30,367,000	7.2	$13,905,000	7.0
B	Site Development	$44,441,000	7.4	$21,389,000	5.1	$27,843,000	14.0
C	River Diversion	$1,950,000	0.3	$2,150,000	0.5	$2,600,000	1.3
D	Dam Foundation	$90,212,000	15.1	$88,884,000	21.1	$11,846,000	6.0
E	RCC & Facing Concrete	$349,440,000	58.5	$227,136,000	53.8	NA	NA
E	Embankment Dam Raise	NA	NA	NA	NA	$38,335,000	19.3
F	Spillway	$17,102,000	2.9	$32,585,000	7.7	$87,539,000	44.1
G	Spillway Bridge	$2,779,000	0.5	$2,779,000	0.7	$3,510,000	1.8
H	Outlet & Intake Structures & Pipe	$29,636,000	5.0	$10,482,000	2.5	$,8,332,000	4.2
I	Misc. Civil	$16,536,000	2.8	$4,434,000	1.1	$2,649,000	1.3
J	Instrumentation & SCADA	$2,210,000	0.4	$1,950,000	0.5	$1,950,000	1.0
	Total OPCC (Q2 2017)	$597,000,000	100.0	$422,200,000	100.0	$195,200,000	100.0
	Total OPCC (Q4 2019)	$644,800,000		$456,000,000		$210,800,000	
	Estimated Range – Low (-20%)	$515,800,000		$364,800,000		$168,700,000	
	Estimated Range – High (+20%)	$773,700,000		$547,200,000		$253,000,000	

Table 6. Other Owner-related Cost Allowances[1]

Concept	Design Engineering (includes geotechnical investigations)	Construction Management and Engineering Services during Construction
RCC Dam Concept 1	$32 - $52 million	$52 - $65 million
RCC Dam Concept 2	$23 - $36 million	$36 - $46 million
Embankment Dam Raise	$11 - $17 million	$17 - $21 million

[1] Not included in OPCC's.

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6 Summary and Conclusions

This TM presents opinions of probable construction costs (OPCC's) for the following enlarged Rollins Reservoir concepts:

- Raise Rollins Embankment Dam to store an additional 50,000 acre-feet.
- Roller Compacted Concrete (RCC) Dam, downstream location – RCC Concept 1, to store an additional 80,000 acre-feet. This concept would make use of the existing dam as a cofferdam during RCC dam construction.
- RCC Dam, existing dam location – RCC Concept 2 to store an additional 76,000 acre-feet. This concept would involve emptying the reservoir and diverting flows around the RCC dam construction site and removing the existing embankment dam, the shell zones of which could be processed to provide RCC aggregate.

This TM includes the conceptual plans and sections developed for the two RCC dam concepts and for the embankment raise concept, with conceptual construction site layouts for each of these concepts. The construction site layouts show the assumed rock borrow areas, disposal areas for surplus materials, and staging and laydown areas. The OPCC's assume that the on-site rock borrow area contains a sufficient amount of suitable material to produce the needed quantities of rockfill for the embankment dam raise or aggregate for RCC Dam Concept 1, or that the existing dam can be used to produce aggregate for RCC Dam Concept 2.

As part of preparing the OPCC's, conceptual level construction sequencing and durations were estimated for each dam type, to provide a comparative assessment of the relative construction durations of the RCC and embankment dam raise concepts. These assessments focus on the major construction activities and provide estimates of the total construction durations based on the current level of project development. These assessments indicate that the RCC dams could potentially be constructed in about 4½ to 5 years, and the embankment dam raise could take about 4 years to construct. These construction durations may be conservative.

The conceptual-level OPCC's presented in this TM are consistent with Class 4 estimates as described by the Association for the Advancement of Cost Engineering (AACE, 2005). The estimated accuracy range of the OPCC's is from 20% below to 20% above the actual construction cost for a given concept.

The OPCC's include design contingencies in the range of about 27% to 30%, to accommodate those features and items of the work that have not been defined at the current conceptual level of design development. This level of contingency is consistent with the typical range for an AACE Class 4 cost estimate.

Allowances are suggested for non-construction project costs including design engineering and for construction management and engineering services during construction. Other expected project costs, which are excluded from the OPCC's, but should be considered by NID include NID project administration and management, reservoir clearing, relocation of utilities, rebuilding of the power plant, land acquisition, legal, permitting, environmental review studies, and mitigation. Potential cost growth during construction due to unexpected changes and unforeseen conditions is also excluded from the OPCC's but should be considered in NID's future budget planning.

The relative OPCC's for the RCC dam and embankment dam raise concepts, in 2019 dollars, are summarized below in Table 7. As expected, RCC Dam Concept 2 would have a much lower cost than RCC Concept 1 due to its much lower RCC volume.

Table 7. Summary of Comparative Construction Costs

Concept	Reservoir Storage (acre-feet)	OPCC Range (2019)	Construction Cost Range per Acre-foot of Total Reservoir Storage
RCC Dam Concept 1	80,000	$645 million ($516 - $774 million)	$8,060 ($6,448 - $9,671)
RCC Dam Concept 2	76,000	$456 million ($365 - $547 million)	$6,000 ($4,800 - $7,200)
Embankment Dam Raise	50,000	$211 million ($169 - $253 million)	$4,216 ($3,374 - $5,060)

Development of more detailed designs is not warranted at this stage and so was not included in the scope of work. Significant geotechnical investigation and engineering and design analyses would be needed in future phases of work to further develop and refine the design layouts, dimensions, and sizes of the various project facilities.

In addition to further development of the dam and foundation designs, other important design elements would need to be considered and further developed as the project is advanced. These design elements, which each significantly affect the overall project cost and schedule, include the following:

- Foundation excavation requirements and resulting dam volume.
- Suitability of the existing dam shell zones for use in RCC aggregate.
- Required diversion requirements during construction (diversion design flood inflow and routed outflow) and outlet capacity requirements for emergency reservoir drawdown.
- Hydraulic analyses (including computational fluid dynamics modeling) and a condition assessment of the existing spillway to determine whether it would need to be upgraded to meet current standards (for RCC dam Concept 2 and the embankment dam raise).
- For the embankment dam raise concept, confirmation of stability of the inclined raised core concept and acceptance by the regulatory agencies.

7 References

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Figures

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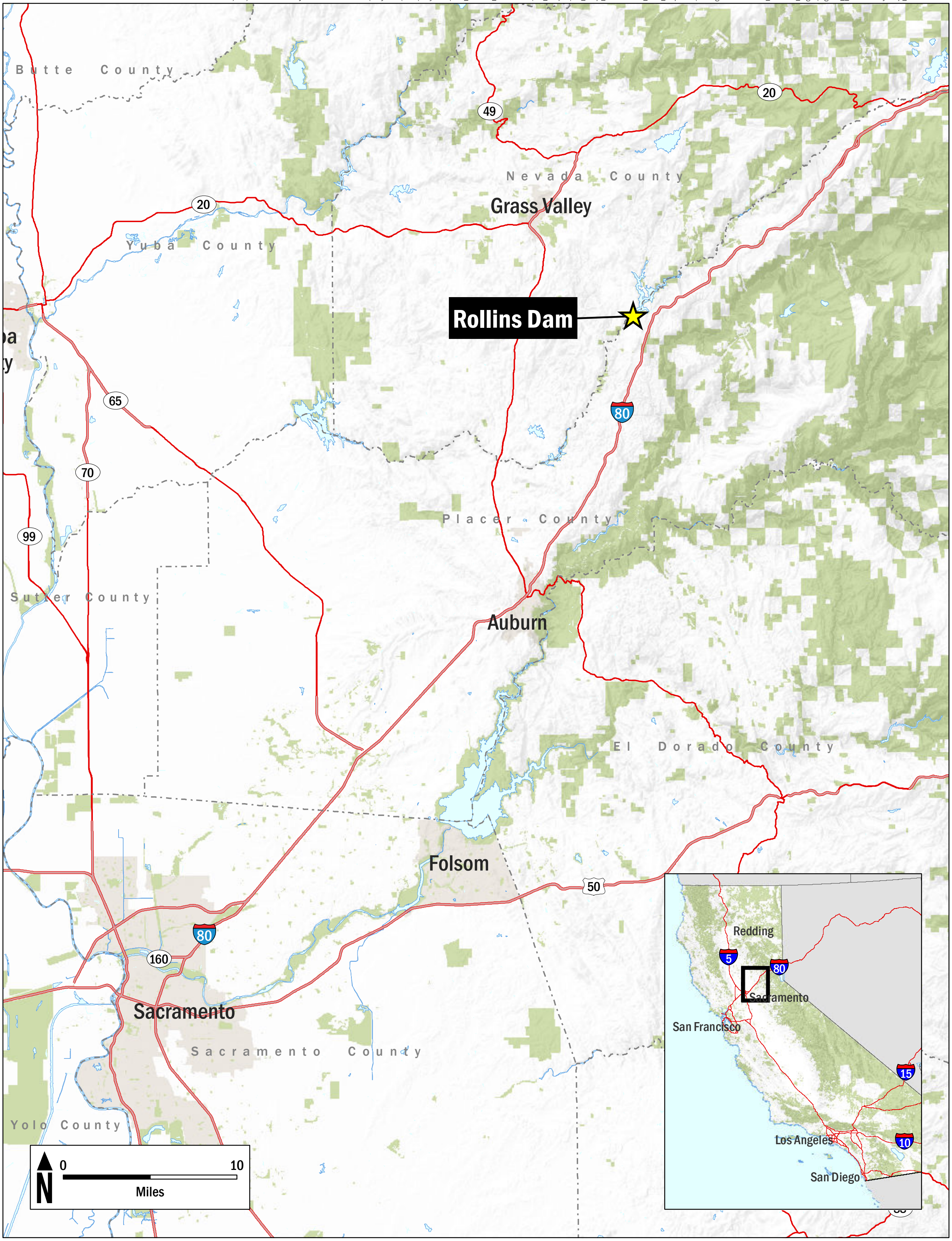

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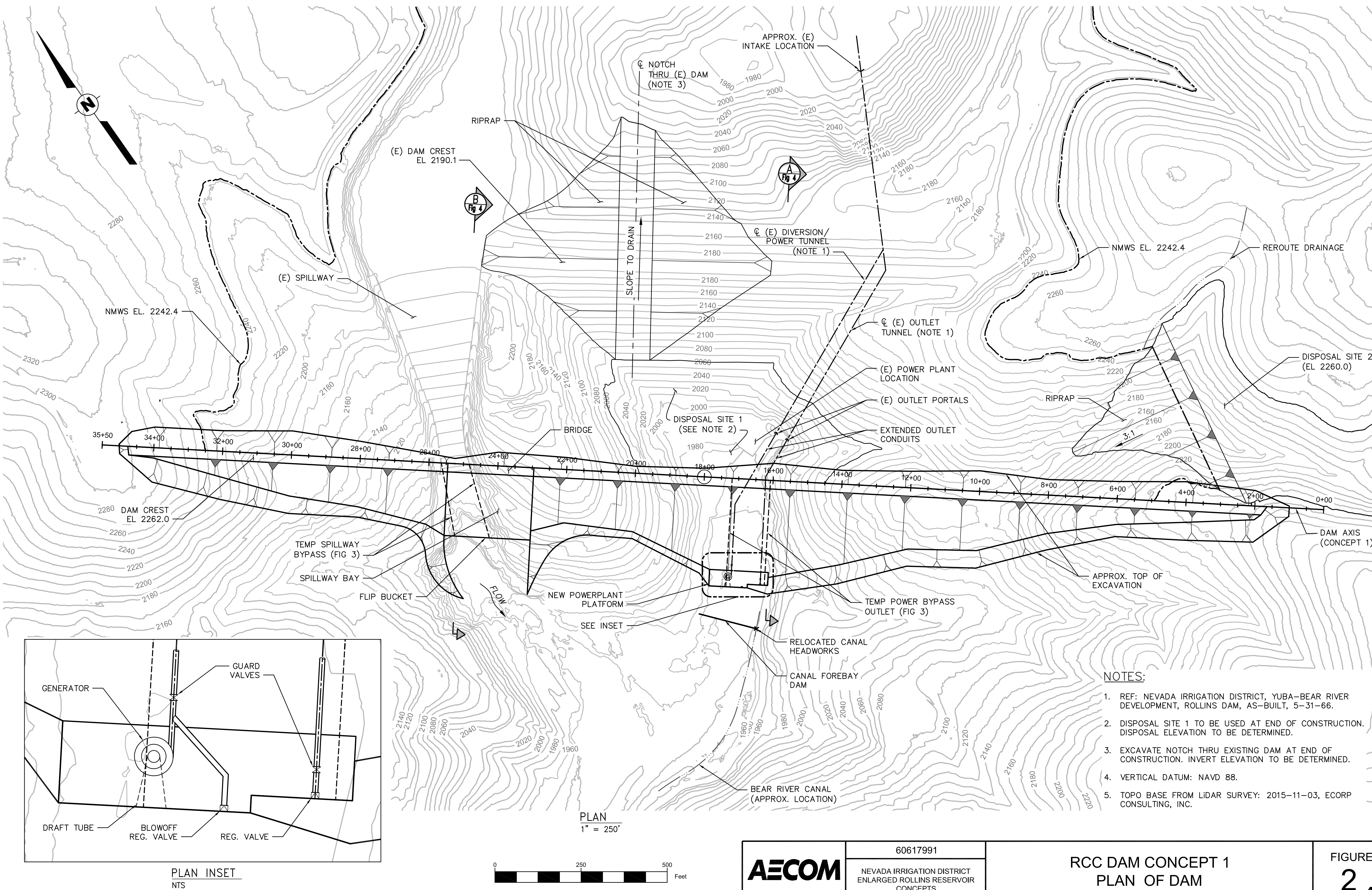
FIGURE 1

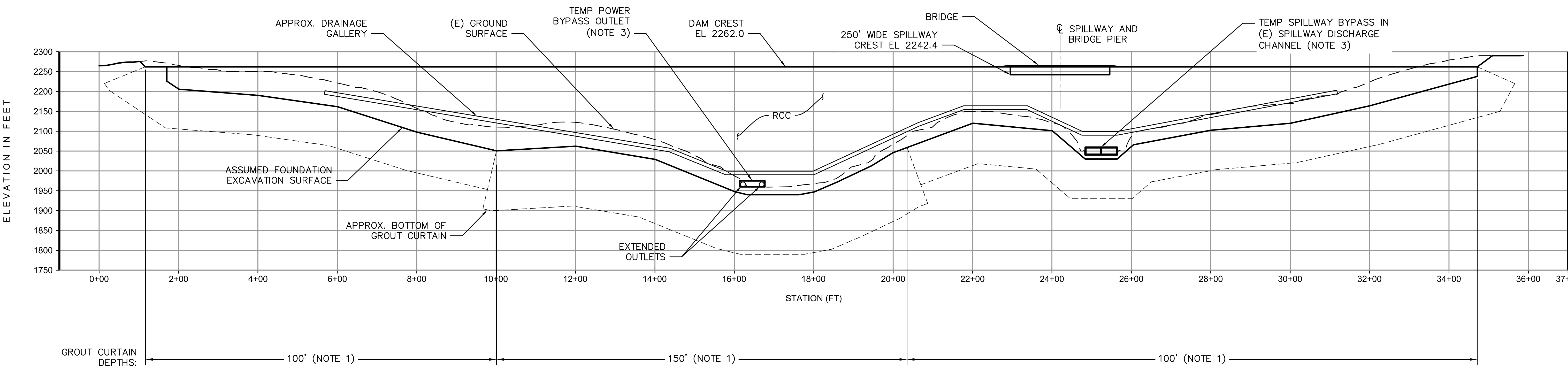
Site Vicinity Map - Rollins Reservoir



NOTES:

1. REF: NEVADA IRRIGATION DISTRICT, YUBA–BEAR RIVER DEVELOPMENT, ROLLINS DAM, AS–BUILT, 5–31–66.
2. DISPOSAL SITE 1 TO BE USED AT END OF CONSTRUCTION. DISPOSAL ELEVATION TO BE DETERMINED.
3. EXCAVATE NOTCH THRU EXISTING DAM AT END OF CONSTRUCTION. INVERT ELEVATION TO BE DETERMINED.
4. VERTICAL DATUM: NAVD 88.
5. TOPO BASE FROM LiDAR SURVEY: 2015–11–03, ECORP CONSULTING, INC.

AECOM	60617991 NEVADA IRRIGATION DISTRICT ENLARGED ROLLINS RESERVOIR CONCEPTS	RCC DAM CONCEPT 1 PLAN OF DAM	FIGURE 2

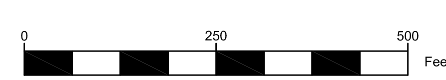


PROFILE ALONG DAM AXIS (LOOKING DOWNSTREAM)

1" = 250'

NOTES:

1. GROUT CURTAIN DEPTHS ARE PERPENDICULAR TO FOUNDATION SURFACE.
2. VERTICAL DATUM: NAVD 88.
3. FILL TEMPORARY BYPASSES WITH CONCRETE UPON COMPLETION OF CONSTRUCTION, AND PRIOR TO RESERVOIR FILLING.



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NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

RCC DAM CONCEPT 1
DAM AXIS PROFILE

FIGURE 3

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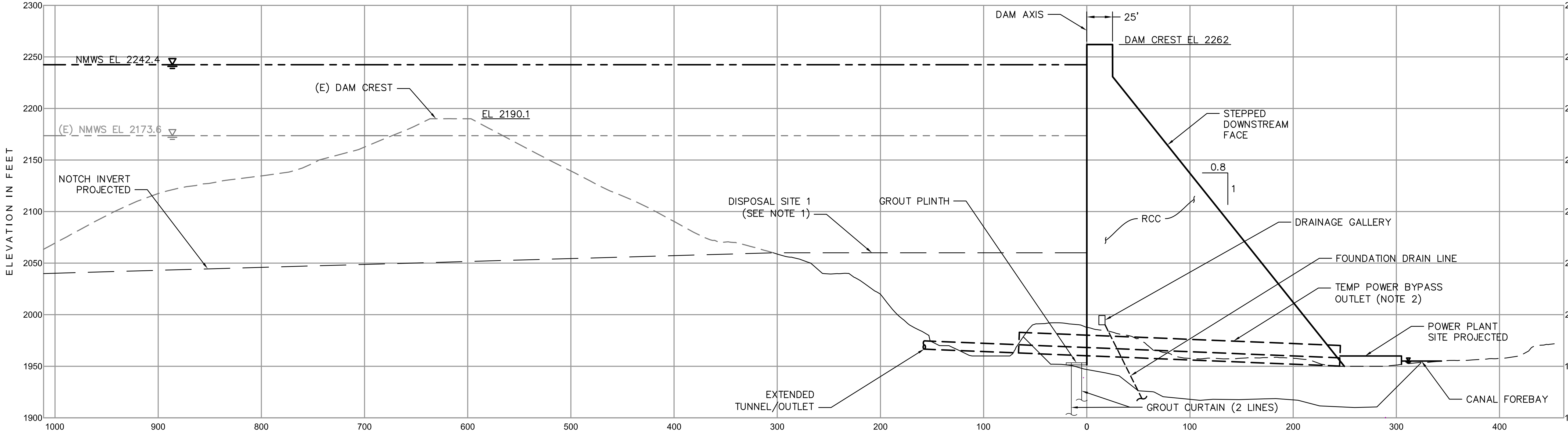
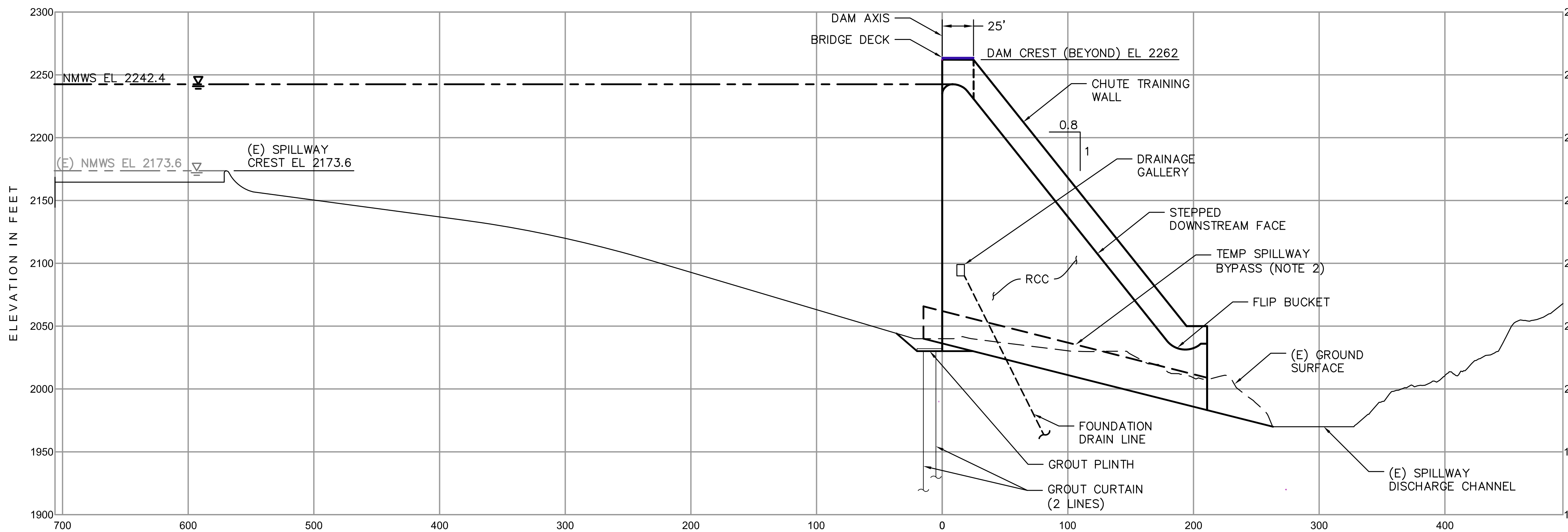


SECTION @ STA. 16+00
1" = 100'
A
Fig 2



SECTION @ STA. 25+00
1" = 100'
B
Fig 2

NOTES:

1. DISPOSAL SITE 1 TO BE USED AT END OF CONSTRUCTION. DISPOSAL ELEVATION TO BE DETERMINED.
2. TEMPORARY BYPASSES TO BE FILLED WITH CONCRETE AT END OF CONSTRUCTION.
3. VERTICAL DATUM: NAVD 88.

0 100 200 Feet

AECOM	60617991 NEVADA IRRIGATION DISTRICT ENLARGED ROLLINS RESERVOIR CONCEPTS	RCC DAM CONCEPT 1 RCC DAM SECTIONS	FIGURE 4

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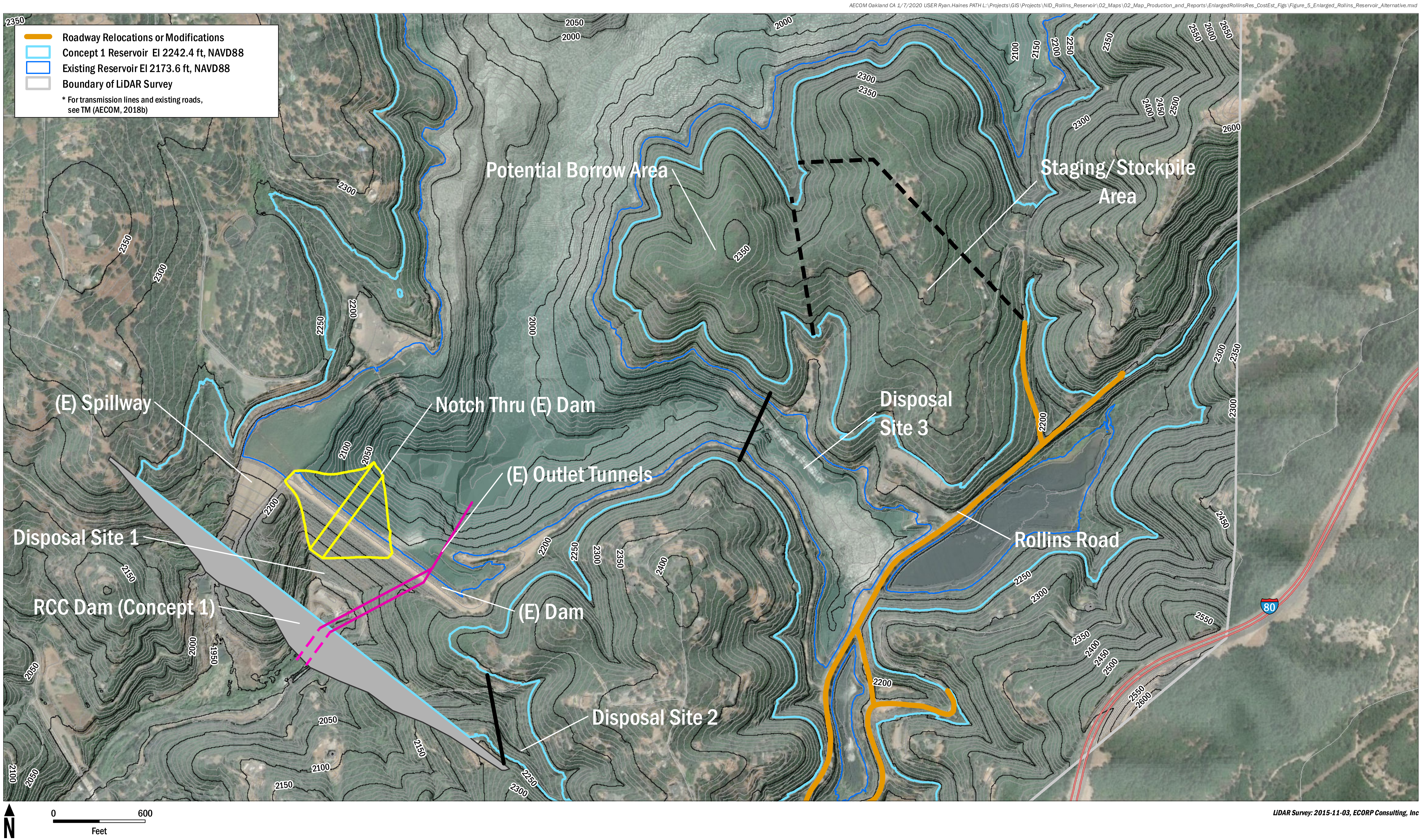

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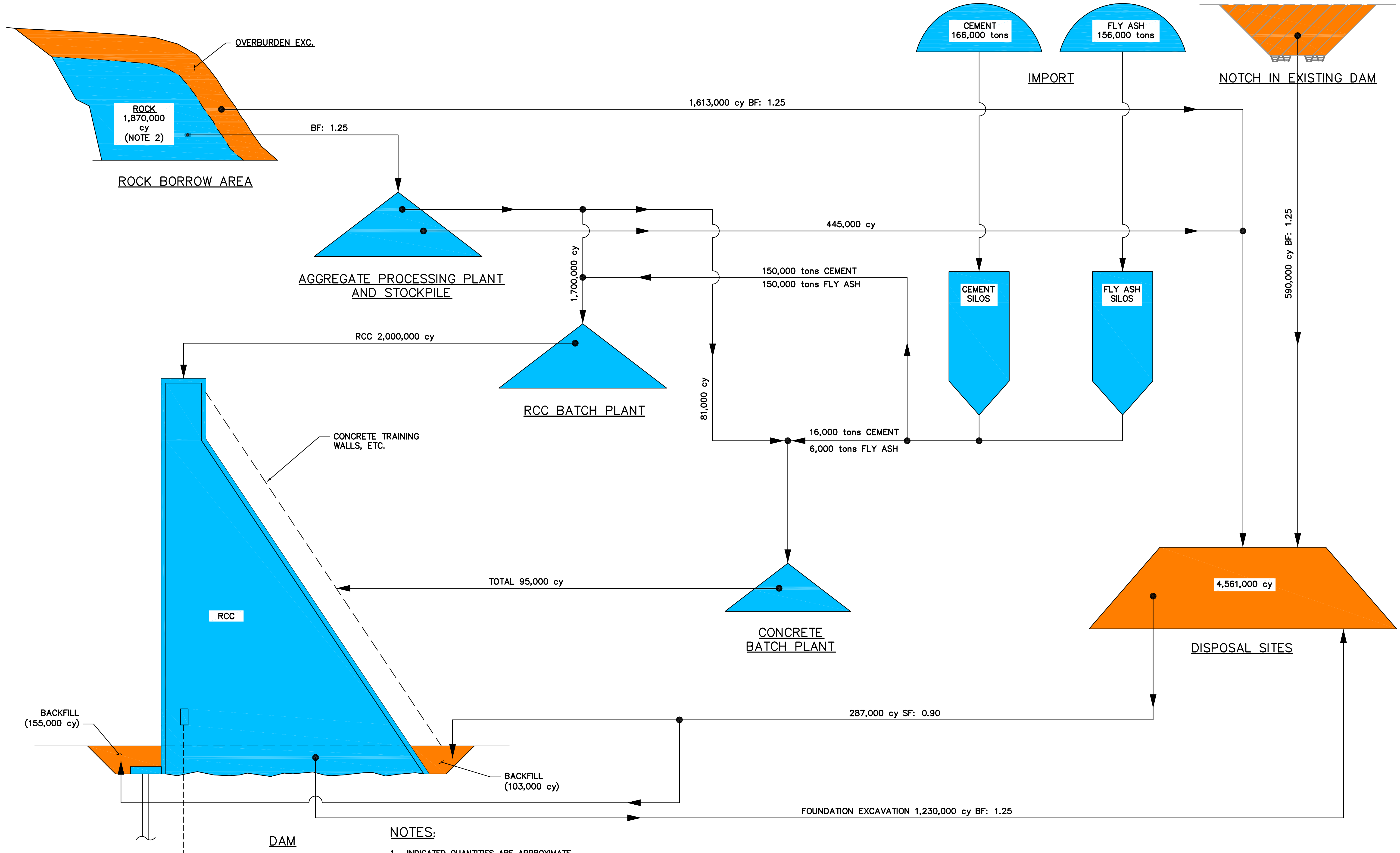
FIGURE 5
RCC Dam Concept 1
Site Area



NOTES:

1. INDICATED QUANTITIES ARE APPROXIMATE.
2. ROCK TO BE QUARRIED IS BASED ON REQUIRED AGGREGATE IN-PLACE IN DAM, WITH 25% BULK FACTOR PLUS 25% WASTE.
3. VOLUMES SHOWN ON THE ARROWS ARE PRIOR TO APPLYING THE BF OR SF.

BF = BULK FACTOR
SF = SHRINK FACTOR

AECOM	60617991 NEVADA IRRIGATION DISTRICT ENLARGED ROLLINS RESERVOIR CONCEPTS	RCC DAM CONCEPT 1 MATERIAL BALANCE DIAGRAM (CONCEPTUAL)	FIGURE 6

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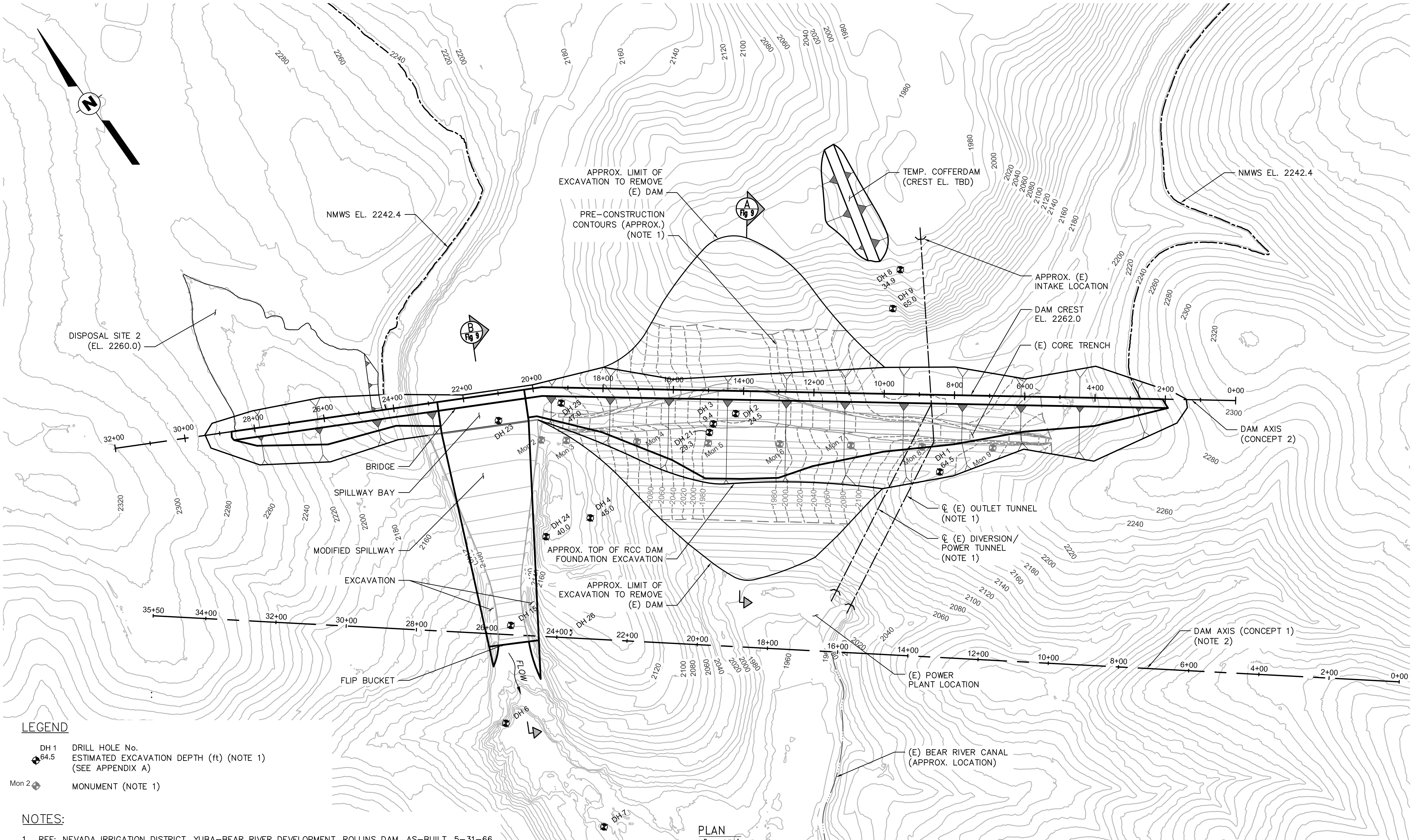

LEGEND

DH 1 64.5 — DRILL HOLE No. ESTIMATED EXCAVATION DEPTH (ft) (NOTE 1) (SEE APPENDIX A)

Mon 2 — MONUMENT (NOTE 1)

NOTES:

1. REF: NEVADA IRRIGATION DISTRICT, YUBA-BEAR RIVER DEVELOPMENT, ROLLINS DAM, AS-BUILT, 5-31-66.
2. REFER TO FIGURE 2.
3. VERTICAL DATUM: NAVD 88.
4. TOPO BASE FROM LiDAR SURVEY: 2015-11-03, ECORP CONSULTING, INC.

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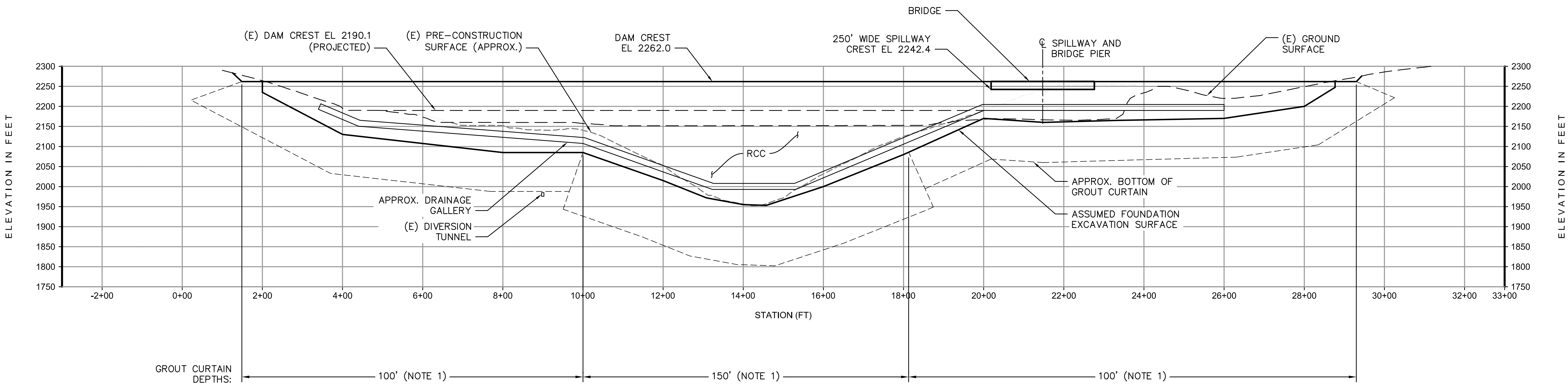
NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

RCC DAM CONCEPT 2
PLAN OF DAM

FIGURE 7



PROFILE ALONG DAM AXIS (LOOKING DOWNSTREAM)
1" = 250'

NOTES:

1. GROUT CURTAIN DEPTHS ARE PERPENDICULAR TO FOUNDATION SURFACE.
2. VERTICAL DATUM: NAVD 88.

0 250 500 Feet

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NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS
RESERVOIR CONCEPTS

RCC DAM CONCEPT 2
DAM AXIS PROFILE

FIGURE
8

Jan 07, 2020 - 1:00pm
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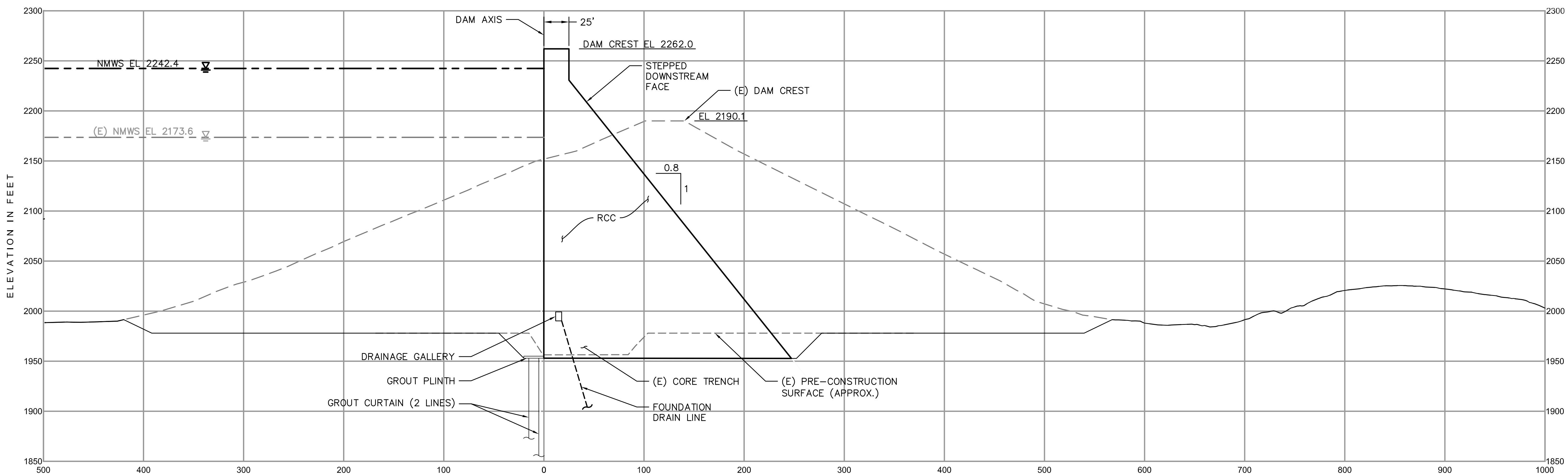
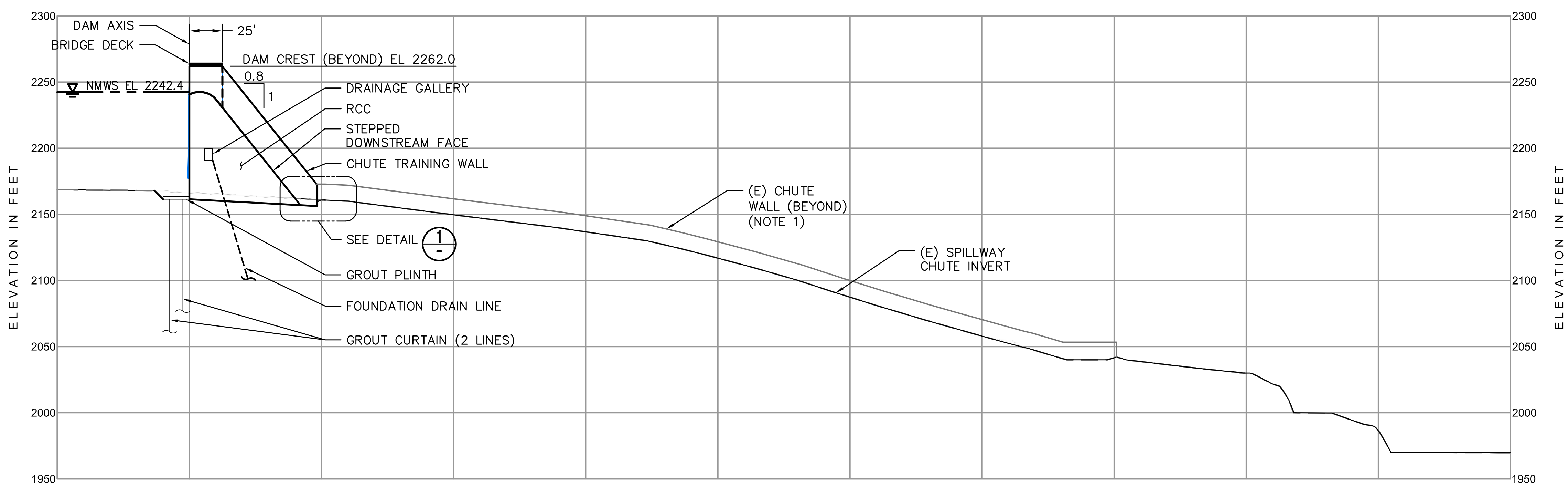
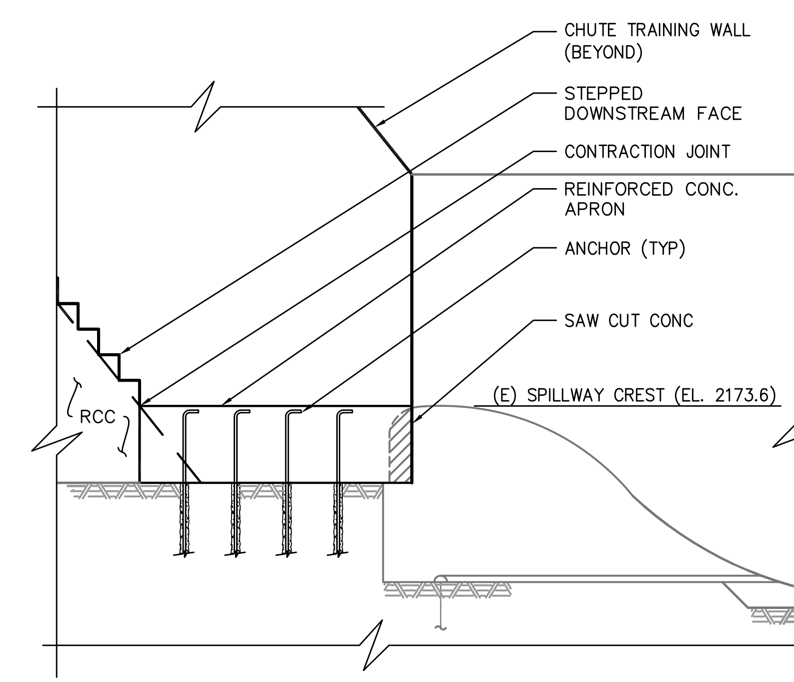


SECTION @ STA. 14+00 (A / Fig 7)
1" = 100'



SECTION @ STA. 21+50 (B / Fig 7)
1" = 100'



DETAIL 1/–
N.T.S.

NOTES:

1. ADEQUACY OF EXISTING SPILLWAY TO BE DETERMINED. (SEE DRAFT TECH MEMO, AECOM, 5/20/19).
2. VERTICAL DATUM: NAVD 88.

0 100 200 Feet

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NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

RCC DAM CONCEPT 2
RCC DAM SECTIONS

FIGURE 9

Jan 07, 2020 - 1:06pm
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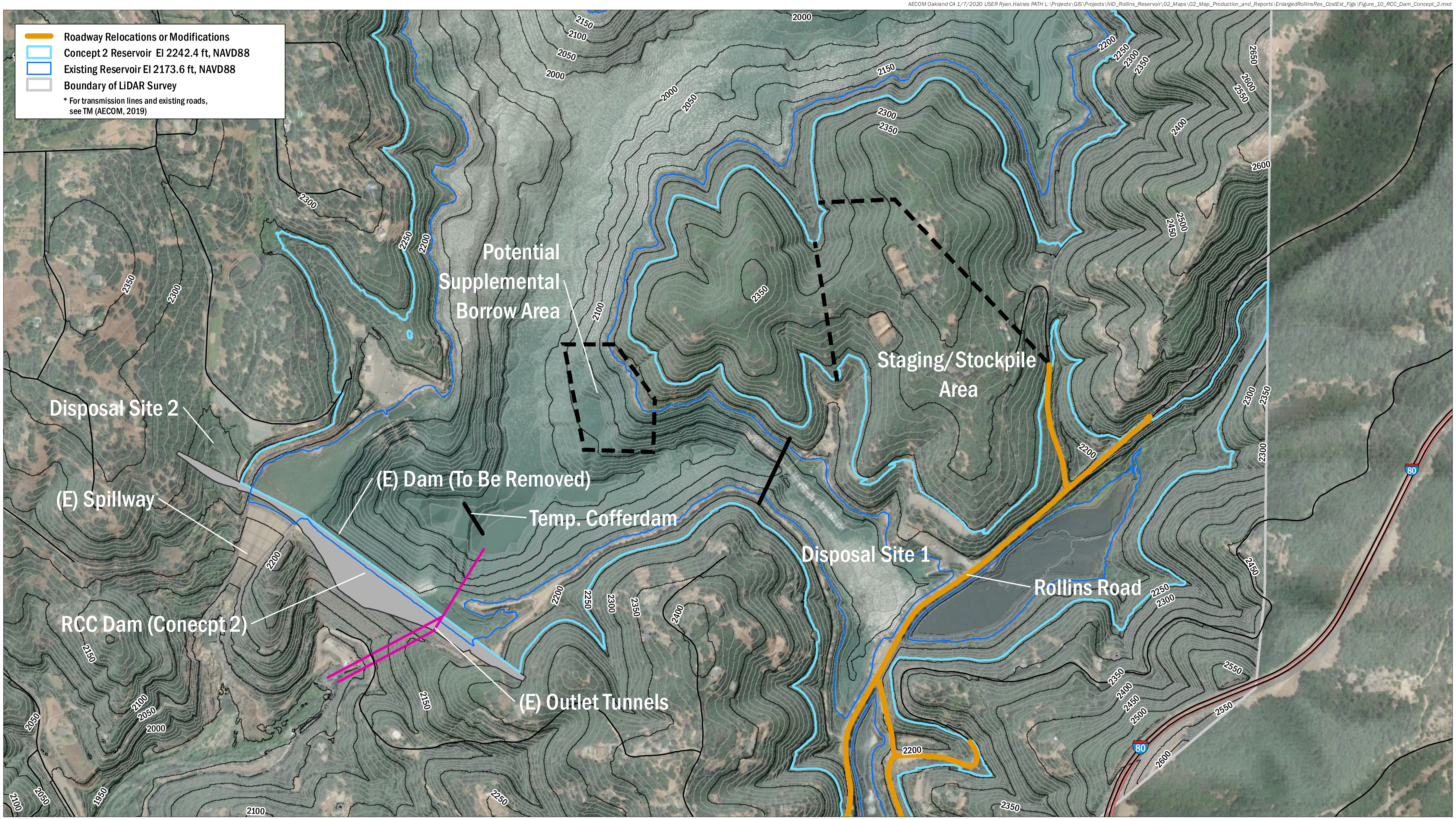

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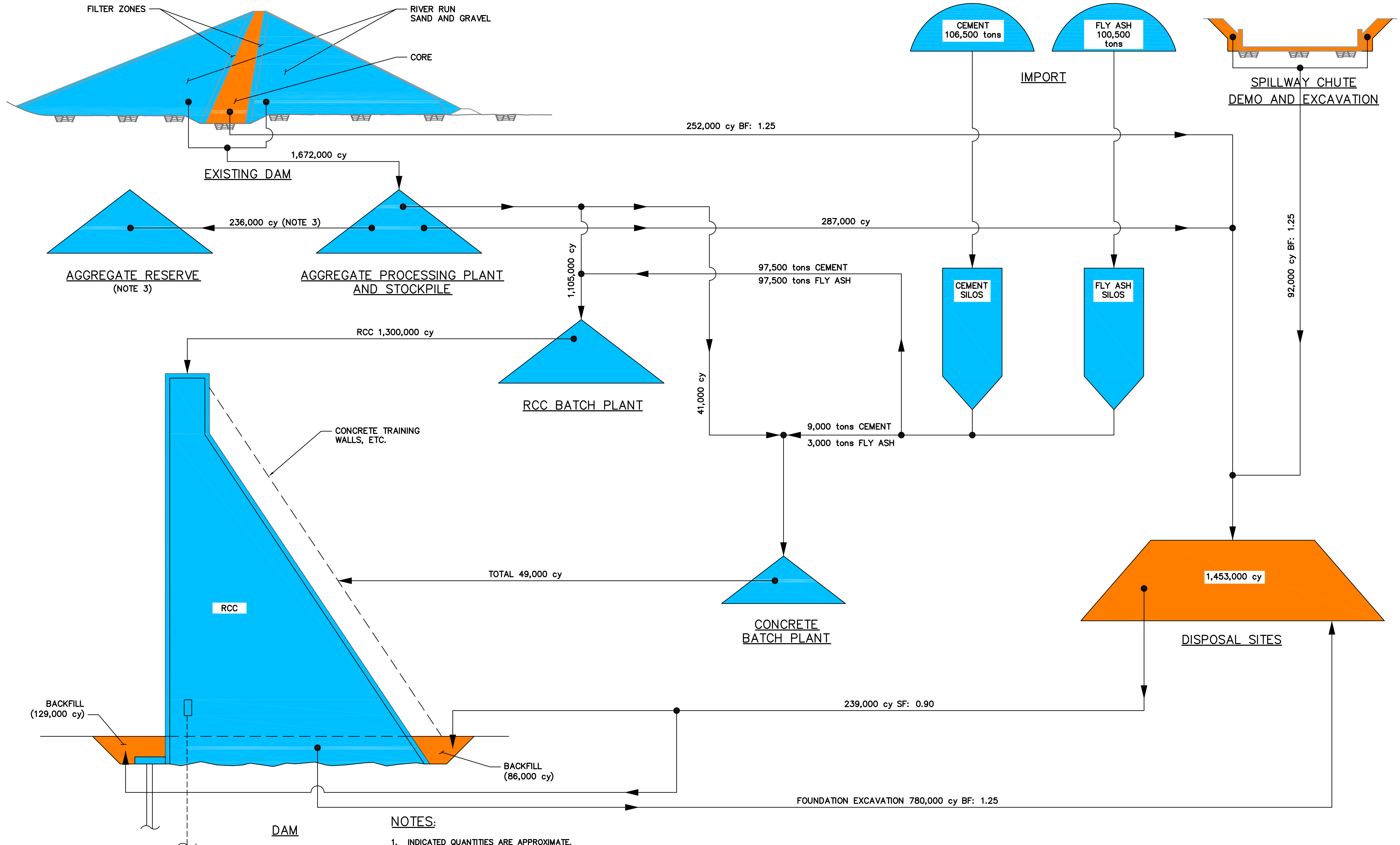
FIGURE 10
RCC Dam Concept 2
Site Area



NOTES:

1. INDICATED QUANTITIES ARE APPROXIMATE.
2. ROCK TO BE QUARRIED IS BASED ON REQUIRED AGGREGATE IN-PLACE IN DAM, WITH 25% WASTE.
3. PLAN FOR GREATER RESERVE.
4. VOLUMES SHOWN ON THE ARROWS ARE PRIOR TO APPLYING THE BF OR SF.

BF = BULK FACTOR
SF = SHRINK FACTOR

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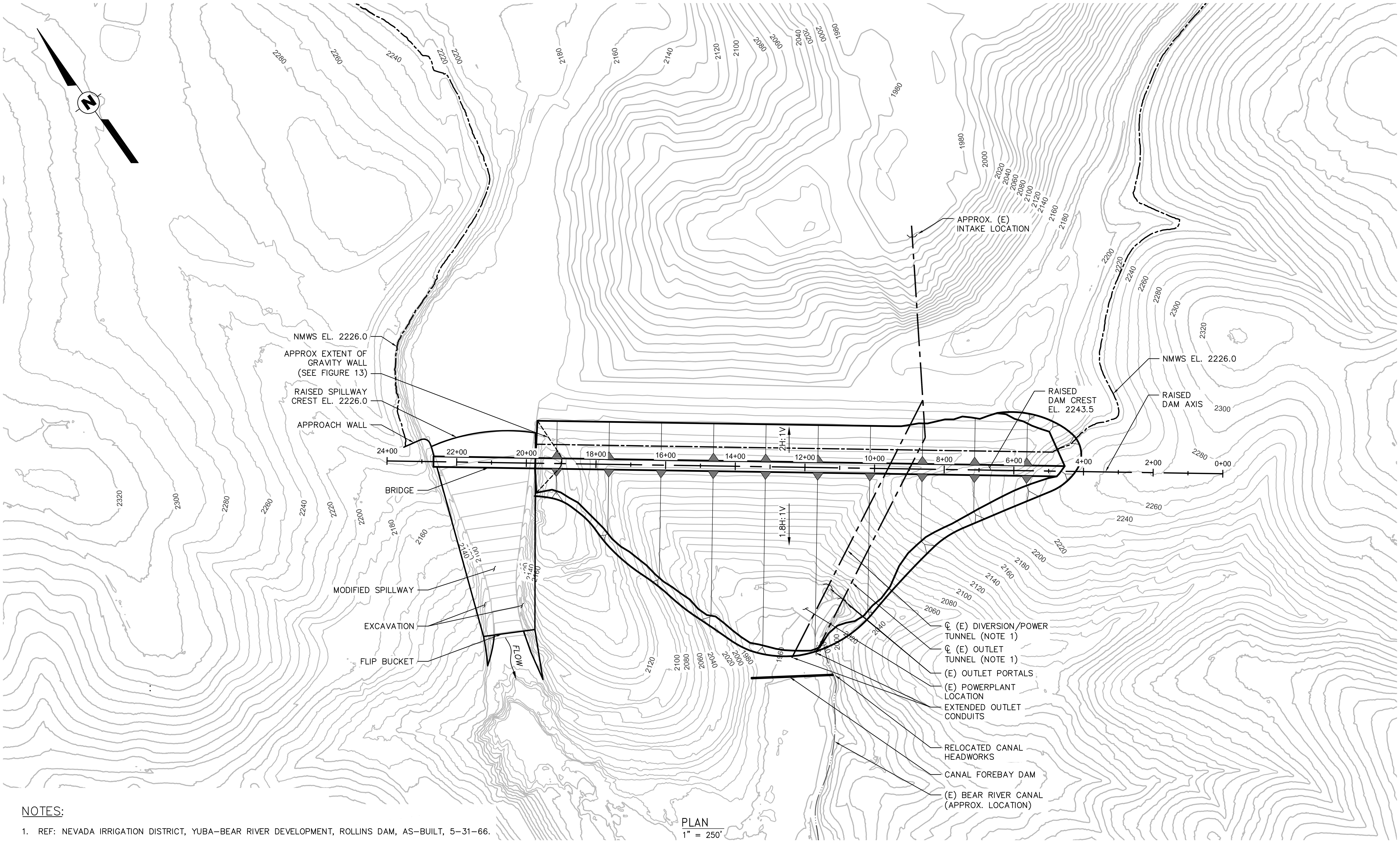
NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

RCC DAM CONCEPT 2
MATERIAL BALANCE DIAGRAM
(CONCEPTUAL)

FIGURE 11



NOTES:

1. REF: NEVADA IRRIGATION DISTRICT, YUBA–BEAR RIVER DEVELOPMENT, ROLLINS DAM, AS-BUILT, 5–31–66.
2. VERTICAL DATUM: NAVD 88.
3. TOPO BASE FROM LiDAR SURVEY: 2015–11–03, ECORP CONSULTING, INC.

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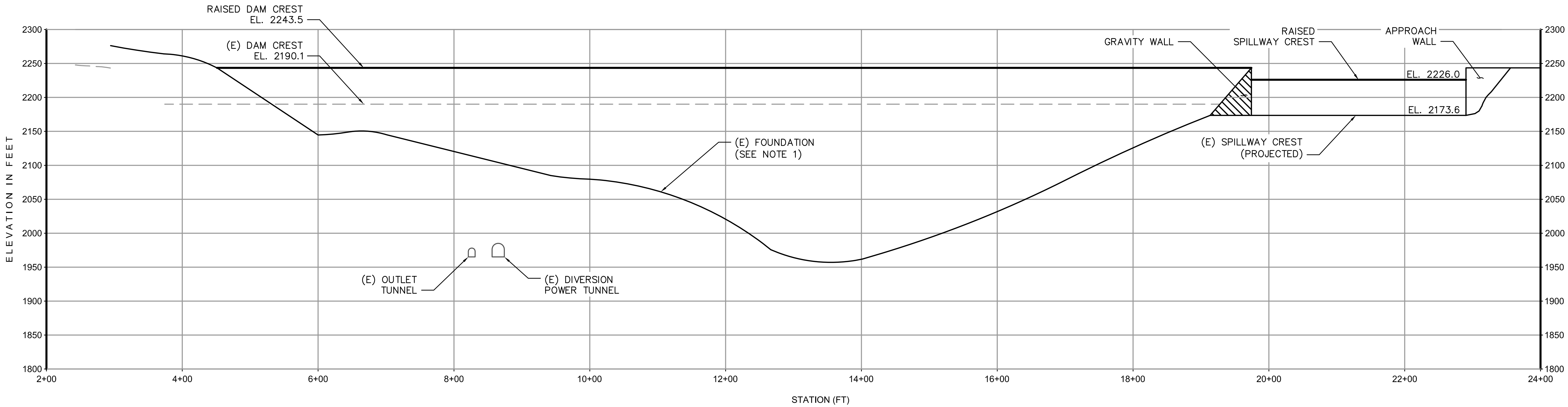
NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

EMBANKMENT DAM RAISE CONCEPT
PLAN OF DAM

FIGURE
12



PROFILE ALONG DAM AXIS (LOOKING DOWNSTREAM)
1" = 150'

NOTES:

1. PROFILE IS ALONG EXISTING DAM CORE TRENCH, PROJECTED ONTO THIS SECTION.
2. VERTICAL DATUM: NAVD 88.

0 150 300 Feet

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NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

EMBANKMENT DAM RAISE CONCEPT
DAM AXIS PROFILE

FIGURE
13

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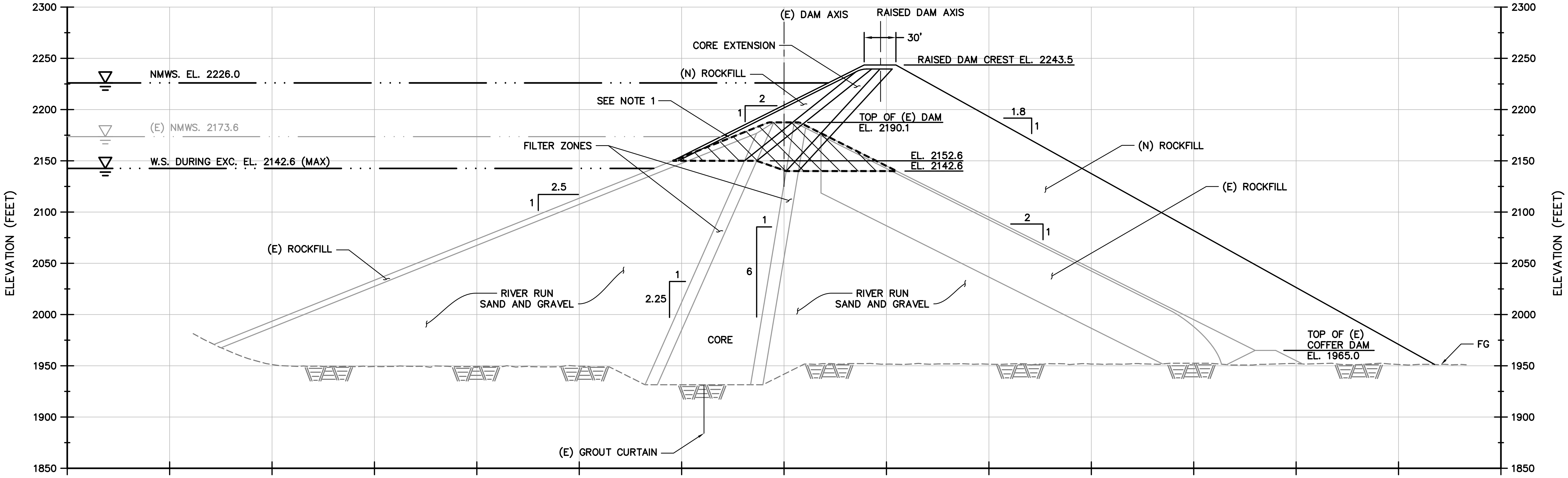
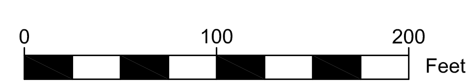


SECTION
1" = 100'

NOTES:

1. EXCAVATE EXISTING DAM CREST AND REPLACE FOR INTERIM DAM, ONE SEASON CONSTRUCTION.
2. VERTICAL DATUM: NAVD 88.



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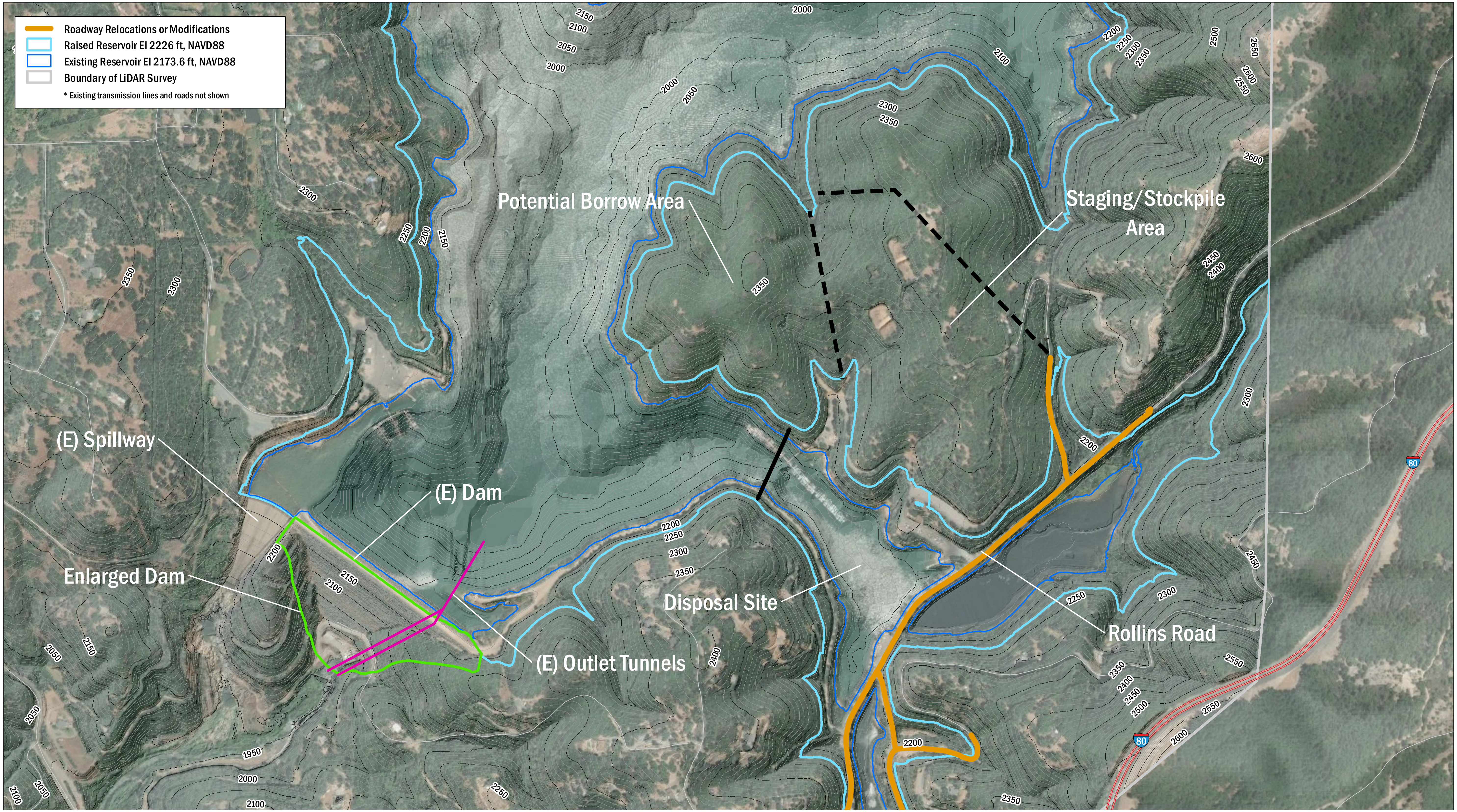
NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS RESERVOIR
CONCEPTS

EMBANKMENT DAM RAISE CONCEPT
MAXIMUM SECTION

FIGURE
14



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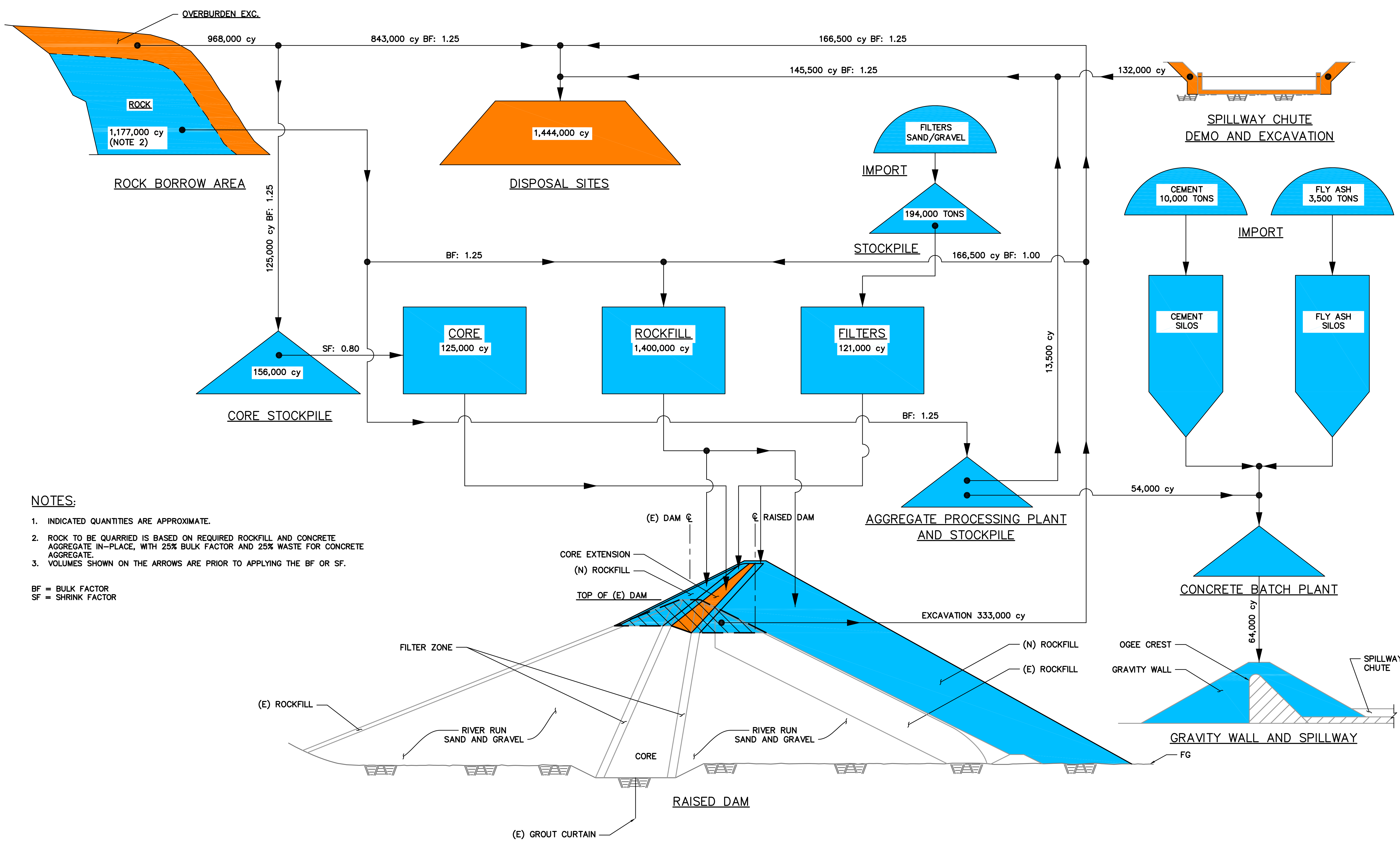
Nevada Irrigation District
60617991

FIGURE 15
Embankment Dam Raise Concept
Site Area



NOTES:

1. INDICATED QUANTITIES ARE APPROXIMATE.
2. ROCK TO BE QUARRIED IS BASED ON REQUIRED ROCKFILL AND CONCRETE AGGREGATE IN-PLACE, WITH 25% BULK FACTOR AND 25% WASTE FOR CONCRETE AGGREGATE.
3. VOLUMES SHOWN ON THE ARROWS ARE PRIOR TO APPLYING THE BF OR SF.

BF = BULK FACTOR
SF = SHRINK FACTOR

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NEVADA IRRIGATION DISTRICT
ENLARGED ROLLINS
RESERVOIR CONCEPTS

EMBANKMENT DAM RAISE CONCEPT
MATERIAL BALANCE DIAGRAM
(CONCEPTUAL)

FIGURE
16

Appendix A.
Opinions of Probable Construction Costs for Conceptual Rollins Reservoir Enlargements

NID ROLLINS RESERVOIR - RCC DAM CONCEPT 1
Opinion of Probable Construction Cost (AACE Class 4)
Base Year: 2017
Axis: Rollins Site 1

Category/Item (WBS) No.	Description	Est. Pay Quantity	Units	Unit Price	Extension	% Contingency	Contingency Amount	Extension + Contingency	Line Item % of Total	Category Total	Category % of Total
A	Mobilization & Demobilization				$ 42,681,225	0%	$ -	$ 42,681,225		$ 42,681,225	7.1%
1	Mobilization & demobilization	1	LS	$ 42,681,225	$ 42,681,225	0.0%	$ -	$ 42,681,225	7.1%		
B	Site Development				$ 32,956,000	34.8%	$ 11,484,600	$ 44,440,600		$ 44,440,600	7.4%
2	Site preparation	1	LS	$ 1,000,000	$ 1,000,000	30.0%	$ 300,000	$ 1,300,000	0.2%		
3	Borrow area stripping	1,613,000	cy	$ 10.50	$ 16,936,500	35.0%	$ 5,927,775	$ 22,864,275	3.8%		
4	Quarry drill & blast	1,767,000	cy	$ 8.50	$ 15,019,500	35.0%	$ 5,256,825	$ 20,276,325	3.4%		
C	River Diversion				$ 1,500,000	30%	$ 450,000	$ 1,950,000		$ 1,950,000	0.3%
5	Diversion during construction	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.1%		
6	Cofferdams - upstream & downstream	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.1%		
7	Dewatering	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.1%		
D	Dam Foundation				$ 69,637,650	30%	$ 20,574,848	$ 90,212,498		$ 90,212,498	15.1%
8.1	Foundation excavation - common	922,500	cy	$ 11.00	$ 10,147,500	35.0%	$ 3,551,625	$ 13,699,125	2.3%		
8.2	Foundation excavation - rock	307,500	cy	$ 21.50	$ 6,611,250	35.0%	$ 2,313,938	$ 8,925,188	1.5%		
9	Initial cleaning	62,100	sy	$ 20.00	$ 1,242,000	20.0%	$ 248,400	$ 1,490,400	0.2%		
10	Final cleaning	62,100	sy	$ 20.00	$ 1,242,000	20.0%	$ 248,400	$ 1,490,400	0.2%		
11	Surface preparation (includes dental concrete)	62,100	sy	$ 25.00	$ 1,552,500	25.0%	$ 388,125	$ 1,940,625	0.3%		
12	Levelling concrete	37,260	cy	$ 280.00	$ 10,432,800	30.0%	$ 3,129,840	$ 13,562,640	2.3%		
13	Grout curtains (825 holes; cement @ 0.35 lb/lf)	95,500	lf	$ 155.00	$ 14,802,500	35.0%	$ 5,180,875	$ 19,983,375	3.3%		
14	Structural concrete - grouting plinth	9,200	cy	$ 1,230.00	$ 11,316,000	20.0%	$ 2,263,200	$ 13,579,200	2.3%		
15	Grouting plinth - anchors (fully grouted, 20' long, #9 bars)	13,200	lf	$ 205.00	$ 2,706,000	20.0%	$ 541,200	$ 3,247,200	0.5%		
16	Consolidation grouting (30' deep; 1680 holes; cement @ 0.35 lb/lf)	50,300	lf	$ 105.00	$ 5,281,500	35.0%	$ 1,848,525	$ 7,130,025	1.2%		
17	Drain holes (330 holes)	37,100	lf	$ 116.00	$ 4,303,600	20.0%	$ 860,720	$ 5,164,320	0.9%		
E	RCC, Facing Concrete & Gallery				$ 268,800,000	30%	$ 80,640,000	$ 349,440,000		$ 349,440,000	58.5%
18	RCC, facing concrete & gallery	2,000,000	cy	$ 108.00	$ 216,000,000	30.0%	$ 64,800,000	$ 280,800,000	47.0%		
19	Cement for RCC - Type II	150,000	ton	$ 210.00	$ 31,500,000	30.0%	$ 9,450,000	$ 40,950,000	6.9%		
20	Class F fly ash for RCC	150,000	ton	$ 142.00	$ 21,300,000	30.0%	$ 6,390,000	$ 27,690,000	4.6%		
F	Spillway & Dam Crest				$ 14,057,300	22%	$ 3,044,925	$ 17,102,225		$ 17,102,225	2.9%
21	Spillway walls (reinforced concrete)	510	cy	$ 1,230.00	$ 627,300	25.0%	$ 156,825	$ 784,125	0.1%		
22	Spillway crest	1,950	cy	$ 1,000.00	$ 1,950,000	25.0%	$ 487,500	$ 2,437,500	0.4%		
23	Crest slab	3,100	cy	$ 740.00	$ 2,294,000	15.0%	$ 344,100	$ 2,638,100	0.4%		
24	Parapet walls (reinforced concrete)	1,280	cy	$ 1,250.00	$ 1,600,000	10.0%	$ 160,000	$ 1,760,000	0.3%		
25	Temp. spillway bypass (reinforced concrete)	3,200	cy	$ 1,230.00	$ 3,936,000	25.0%	$ 984,000	$ 4,920,000	0.8%		
26	Plug temp. spillway bypass (mass concrete)	7,300	cy	$ 500.00	$ 3,650,000	25.0%	$ 912,500	$ 4,562,500	0.8%		

G	Spillway Bridge				$ 2,137,500	30%	$ 641,250	$ 2,778,750		$ 2,778,750	0.5%
27	Deck & pier	4,750	sf	$ 450.00	$ 2,137,500	30%	$ 641,250	$ 2,778,750	0.5%		
H	Outlet & Intake Structures & Pipe				$ 22,646,000	31%	$ 6,990,100	$ 29,636,100		$ 29,636,100	5.0%
28	New Outlet structure (reinforced concrete)	1	LS	$ 2,500,000	$ 2,500,000	40.0%	$ 1,000,000	$ 3,500,000	0.6%		
29	Temp. power bypass (reinforced concrete)	5,800	cy	$ 1,230.00	$ 7,134,000	30.0%	$ 2,140,200	$ 9,274,200	1.6%		
30	Plug temp. power bypass (mass concrete)	14,200	cy	$ 500.00	$ 7,100,000	30.0%	$ 2,130,000	$ 9,230,000	1.5%		
31	Steel outlet pipe extensions (8' dia.)	300	lf	$ 3,040.00	$ 912,000	20.0%	$ 182,400	$ 1,094,400	0.2%		
32	Intake/trashrack	1	LS	$ 750,000	$ 750,000	35.0%	$ 262,500	$ 1,012,500	0.2%		
33	Mechanical (gates, valves, actuators, ventilation)	1	LS	$ 3,000,000	$ 3,000,000	30.0%	$ 900,000	$ 3,900,000	0.7%		
34	Electrical controls and lighting	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.2%		
35	Canal forebay dam & headworks	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.1%		
I	Misc. Civil				$ 13,377,800	24%	$ 3,157,840	$ 16,535,640		$ 16,535,640	2.8%
36	Backfill	257,000	cy	$ 10.40	$ 2,672,800	30.0%	$ 801,840	$ 3,474,640	0.6%		
37	Roadways (paved)	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.1%		
38	Excavate notch in existing dam	590,000	cy	$ 14.50	$ 8,555,000	20.0%	$ 1,711,000	$ 10,266,000	1.7%		
39	Gallery portals	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.1%		
40	Heavy riprap (on-site borrow)	5,000	cy	$ 60.00	$ 300,000	30.0%	$ 90,000	$ 390,000	0.1%		
41	Site Restoration	120	Acres	$ 5,000	$ 600,000	30.0%	$ 180,000	$ 780,000	0.1%		
42	Forebay & canal headworks	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.2%		
J	Instrumentation & SCADA				$ 1,700,000	30%	$ 510,000	$ 2,210,000		$ 2,210,000	0.4%
43	Instrumentation & ADAS	1	LS	$ 850,000	$ 850,000	30.0%	$ 255,000	$ 1,105,000	0.2%		
44	SCADA	1	LS	$ 850,000	$ 850,000	30.0%	$ 255,000	$ 1,105,000	0.2%		
Total Estimated Construction Cost (2017 dollars)					$ 469,493,475		$ 127,493,563	$ 596,987,038	100.0%	$ 596,987,038	100.0%
Overall Design Contingency						27.2%		$ 596,987,038			
Note: See Tech Memo for cost exclusions.									Q2 2017	Q4 2019*	Cost per AF
							Opinion of Probable Construction Cost		$ 597,000,000	$ 644,800,000	$ 8,060
							Estimated Range - Low (-20%)		$ 477,600,000	$ 515,800,000	$ 6,448
							Estimated Range - High (+20%)		$ 716,400,000	$ 773,700,000	$ 9,671
							Storage Increase (AF)				80,000
							* 8% escalation				

NID ROLLINS RESERVOIR - RCC DAM CONCEPT 2
Opinion of Probable Construction Cost (AACE Class 4)
Base Year: 2017
Axis: Rollins Site 2

Category/Item (WBS) No.	Description	Est. Pay Quantity	Units	Unit Price	Extension	% Contingency	Contingency Amount	Extension + Contingency	Line Item % of Total	Category Total	Category % of Total
A	Mobilization & Demobilization				$ 30,367,430	0%	$ -	$ 30,367,430		$ 30,367,430	7.2%
1	Mobilization & demobilization	1	LS	$ 30,367,430	$ 30,367,430	0.0%	$ -	$ 30,367,430	7.2%		
B	Site Development				$ 15,880,800	34.7%	$ 5,508,280	$ 21,389,080		$ 21,389,080	5.1%
2	Site preparation	1	LS	$ 1,000,000	$ 1,000,000	30.0%	$ 300,000	$ 1,300,000	0.3%		
3	Borrow area stripping (NA)	-	cy	$ 10.50	$ -	35.0%	$ -	$ -	0.0%		
4.1	Quarry drill & blast (NA)	-	cy	$ 8.50	$ -	35.0%	$ -	$ -	0.0%		
4.2	Process Existing Dam Gravel for RCC Aggregate	1,672,000	cy	$ 8.90	$ 14,880,800	35.0%	$ 5,208,280	$ 20,089,080	4.8%		
C	River Diversion				$ 1,500,000	43%	$ 650,000	$ 2,150,000		$ 2,150,000	0.5%
5	Diversion during construction	1	LS	$ 500,000	$ 500,000	50.0%	$ 250,000	$ 750,000	0.2%		
6	Cofferdams - upstream & downstream	1	LS	$ 500,000	$ 500,000	50.0%	$ 250,000	$ 750,000	0.2%		
7	Dewatering	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.2%		
D	Dam Foundation				$ 70,320,400	26%	$ 18,563,865	$ 88,884,265		$ 88,884,265	21.1%
8.1	Foundation excavation - common	585,000	cy	$ 11.00	$ 6,435,000	35.0%	$ 2,252,250	$ 8,687,250	2.1%		
8.2	Foundation excavation - rock	195,000	cy	$ 21.50	$ 4,192,500	35.0%	$ 1,467,375	$ 5,659,875	1.3%		
8.3	Existing Dam (total volume, includes No. 4.2)	1,925,000	cy	$ 11.00	$ 21,175,000	20.0%	$ 4,235,000	$ 25,410,000	6.0%		
9	Initial cleaning	34,700	sy	$ 20.00	$ 694,000	20.0%	$ 138,800	$ 832,800	0.2%		
10	Final cleaning	34,700	sy	$ 20.00	$ 694,000	20.0%	$ 138,800	$ 832,800	0.2%		
11	Surface preparation (includes dental concrete)	34,700	sy	$ 25.00	$ 867,500	25.0%	$ 216,875	$ 1,084,375	0.3%		
12	Levelling concrete	20,820	cy	$ 280.00	$ 5,829,600	30.0%	$ 1,748,880	$ 7,578,480	1.8%		
13	Grout curtains (690 holes; cement @ 0.35 lb/lf)	79,000	lf	$ 155.00	$ 12,245,000	35.0%	$ 4,285,750	$ 16,530,750	3.9%		
14	Structural concrete - grouting plinth	7,650	cy	$ 1,230.00	$ 9,409,500	20.0%	$ 1,881,900	$ 11,291,400	2.7%		
15	Grouting plinth - anchors (fully grouted, 20' long, #9 bars)	11,000	lf	$ 205.00	$ 2,255,000	20.0%	$ 451,000	$ 2,706,000	0.6%		
16	Consolidation grouting (30' deep; 940 holes; cement @ 0.35 lb/lf)	28,100	lf	$ 105.00	$ 2,950,500	35.0%	$ 1,032,675	$ 3,983,175	0.9%		
17	Drain holes (275 holes)	30,800	lf	$ 116.00	$ 3,572,800	20.0%	$ 714,560	$ 4,287,360	1.0%		
E	RCC, Facing Concrete & Gallery				$ 174,720,000	30%	$ 52,416,000	$ 227,136,000		$ 227,136,000	53.8%
18	RCC, facing concrete & gallery	1,300,000	cy	$ 108.00	$ 140,400,000	30.0%	$ 42,120,000	$ 182,520,000	43.2%		
19	Cement for RCC - Type II	97,500	ton	$ 210.00	$ 20,475,000	30.0%	$ 6,142,500	$ 26,617,500	6.3%		
20	Class F fly ash for RCC	97,500	ton	$ 142.00	$ 13,845,000	30.0%	$ 4,153,500	$ 17,998,500	4.3%		
F	Spillway & Dam Crest				$ 26,292,600	24%	$ 6,292,400	$ 32,585,000		$ 32,585,000	7.7%
21	Spillway walls (reinforced concrete, on RCC dam)	220	cy	$ 1,230.00	$ 270,600	25.0%	$ 67,650	$ 338,250	0.1%		
22	Spillway crest (reinforced concrete, on RCC dam)	1,950	cy	$ 1,000.00	$ 1,950,000	25.0%	$ 487,500	$ 2,437,500	0.6%		
23	Demo existing slab & spillway walls (reinforced concrete)	7,500	cy	$ 450.00	$ 3,375,000	25.0%	$ 843,750	$ 4,218,750	1.0%		
24	Common excavation	42,500	cy	$ 15.00	$ 637,500	30.0%	$ 191,250	$ 828,750	0.2%		
25	Rock excavation	42,500	cy	$ 25.00	$ 1,062,500	30.0%	$ 318,750	$ 1,381,250	0.3%		
26	Foundation cleaning	14,000	sy	$ 20.00	$ 280,000	25.0%	$ 70,000	$ 350,000	0.1%		
27	Chute spillway concrete walls	1,000	cy	$ 1,230.00	$ 1,230,000	30.0%	$ 369,000	$ 1,599,000	0.4%		

28	Chute spillway invert slab	9,200	cy	$ 740.00	$ 6,808,000	30.0%	$ 2,042,400	$ 8,850,400	2.1%		
29	Crest slab	2,600	cy	$ 740.00	$ 1,924,000	15.0%	$ 288,600	$ 2,212,600	0.5%		
30	Parapet walls (reinforced concrete)	1,100	cy	$ 1,250.00	$ 1,375,000	10.0%	$ 137,500	$ 1,512,500	0.4%		
31	Anchors (fully grouted, 20' long, #9 bars)	36,000	lf	$ 205.00	$ 7,380,000	20.0%	$ 1,476,000	$ 8,856,000	2.1%		
G	Spillway Bridge				$ 2,137,500	30%	$ 641,250	$ 2,778,750		$ 2,778,750	0.7%
32	Deck & pier	4,750	sf	$ 450.00	$ 2,137,500	30%	$ 641,250	$ 2,778,750	0.7%		
H	Outlet & Intake Structures & Pipe				$ 7,912,000	32%	$ 2,569,900	$ 10,481,900		$ 10,481,900	2.5%
33	New outlet structure (reinforced concrete)	1	LS	$ 2,500,000	$ 2,500,000	40.0%	$ 1,000,000	$ 3,500,000	0.8%		
34	Steel outlet pipe (8' dia.)	300	lf	$ 3,040.00	$ 912,000	20.0%	$ 182,400	$ 1,094,400	0.3%		
35	Intake/trashrack	1	LS	$ 750,000	$ 750,000	35.0%	$ 262,500	$ 1,012,500	0.2%		
36	Mechanical (gates, valves, actuators, ventilation)	1	LS	$ 3,000,000	$ 3,000,000	30.0%	$ 900,000	$ 3,900,000	0.9%		
37	Electrical controls and lighting	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.2%		
I	Misc. Civil				$ 3,411,000	30%	$ 1,023,300	$ 4,434,300		$ 4,434,300	1.1%
38	Backfill	215,000	cy	$ 10.40	$ 2,236,000	30.0%	$ 670,800	$ 2,906,800	0.7%		
39	Roadways (paved)	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.1%		
40	Gallery portals	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.1%		
41	Heavy riprap (on-site borrow)	5,000	cy	$ 60.00	$ 300,000	30.0%	$ 90,000	$ 390,000	0.1%		
42	Site Restoration	75	Acres	$ 5,000	$ 375,000	30.0%	$ 112,500	$ 487,500	0.1%		
J	Instrumentation & SCADA				$ 1,500,000	30%	$ 450,000	$ 1,950,000		$ 1,950,000	0.5%
43	Instrumentation & ADAS	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.2%		
44	SCADA	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.2%		
Total Estimated Construction Cost (2017 dollars)					$ 334,041,730		$ 88,114,995	$ 422,156,725	100.0%	$ 422,156,725	100.0%
Overall Design Contingency						26.4%		$ 422,156,725			
Note: See Tech Memo for cost exclusions.									Q2 2017	Q4 2019*	Cost per AF
							Opinion of Probable Construction Cost		$ 422,200,000	$ 456,000,000	$ 6,000
							Estimated Range - Low (-20%)		$ 337,760,000	$ 364,800,000	$ 4,800
							Estimated Range - High (+20%)		$ 506,640,000	$ 547,200,000	$ 7,200
							Storage Increase (AF)				76,000
							* 8% escalation				

NID ROLLINS RESERVOIR - EMBANKMENT DAM RAISE
Opinion of Probable Construction Cost (AACE Class 4)
Base Year: 2017
Axis: Existing

Category/Item (WBS) No.	Description	Est. Pay Quantity	Units	Unit Price	Extension	% Contingency	Contingency Amount	Extension + Contingency	Line Item % of Total	Category Total	Category % of Total
A	Mobilization & Demobilization				$ 13,676,820	0%	$ -	$ 13,676,820		$ 13,676,820	7.0%
1	Mobilization & demobilization	1	LS	$ 13,676,820	$ 13,676,820	0.0%	$ -	$ 13,676,820	7.0%		
B	Site Development				$ 20,643,000	34.9%	$ 7,200,050	$ 27,843,050		$ 27,843,050	14.3%
2	Site preparation	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
3	Borrow area stripping	968,000	cy	$ 10.50	$ 10,164,000	35.0%	$ 3,557,400	$ 13,721,400	7.0%		
4	Quarry drill & blast	1,174,000	cy	$ 8.50	$ 9,979,000	35.0%	$ 3,492,650	$ 13,471,650	6.9%		
C	River Diversion				$ 2,000,000	30%	$ 600,000	$ 2,600,000		$ 2,600,000	1.3%
5	Diversion during construction	1	LS	$ 1,000,000	$ 1,000,000	30.0%	$ 300,000	$ 1,300,000	0.7%		
6	Cofferdams - upstream & downstream	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
7	Dewatering	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
D	Dam Foundation				$ 9,164,200	29%	$ 2,681,670	$ 11,845,870		$ 11,845,870	6.1%
8.1	Excavate existing dam crest	333,000	cy	$ 15.00	$ 4,995,000	30.0%	$ 1,498,500	$ 6,493,500	3.3%		
8.2	Foundation excavation	30,000	cy	$ 20.00	$ 600,000	30.0%	$ 180,000	$ 780,000	0.4%		
9	Initial cleaning - ogee & left abutment core foundation	6,000	sy	$ 20.00	$ 120,000	10.0%	$ 12,000	$ 132,000	0.1%		
10	Final cleaning - ogee & left abutment core foundation	6,000	sy	$ 20.00	$ 120,000	10.0%	$ 12,000	$ 132,000	0.1%		
11	Ogee & core surface prep (includes dental concrete)	6,000	sy	$ 25.00	$ 150,000	25.0%	$ 37,500	$ 187,500	0.1%		
12	Shell foundation surface cleaning	40,300	sy	$ 14.00	$ 564,200	10.0%	$ 56,420	$ 620,620	0.3%		
13	Backfill concrete	1,200	cy	$ 500.00	$ 600,000	30.0%	$ 180,000	$ 780,000	0.4%		
14	Abutment grout curtains	13,000	lf	$ 155.00	$ 2,015,000	35.0%	$ 705,250	$ 2,720,250	1.4%		
E	Embankment Dam Raise				$ 28,396,000	35%	$ 9,938,600	$ 38,334,600		$ 38,334,600	19.6%
15	Core zone (excavate, load, haul, place, compact)	125,000	cy	$ 16.00	$ 2,000,000	35.0%	$ 700,000	$ 2,700,000	1.4%		
16	Rockfill zones (haul, place, compact)	1,400,000	cy	$ 12.00	$ 16,800,000	35.0%	$ 5,880,000	$ 22,680,000	11.6%		
17.1	Filter/drain zones (purchase & deliver)	194,000	ton	$ 32.00	$ 6,208,000	35.0%	$ 2,172,800	$ 8,380,800	4.3%		
17.2	Filter/drain zones (haul from stockpile, place, compact)	121,000	cy	$ 28.00	$ 3,388,000	35.0%	$ 1,185,800	$ 4,573,800	2.3%		
F	Spillway				$ 63,915,000	32%	$ 20,546,250	$ 84,461,250		$ 84,461,250	43.3%
18	Demo existing slab & spillway walls (reinforced concrete)	7,500	cy	$ 450.00	$ 3,375,000	25.0%	$ 843,750	$ 4,218,750	2.2%		
19	Common excavation	62,500	cy	$ 15.00	$ 937,500	30.0%	$ 281,250	$ 1,218,750	0.6%		
20	Rock excavation	62,500	cy	$ 25.00	$ 1,562,500	30.0%	$ 468,750	$ 2,031,250	1.0%		
21	Foundation cleaning	16,000	sy	$ 20.00	$ 320,000	25.0%	$ 80,000	$ 400,000	0.2%		
22	Chute spillway concrete walls (reinforced concrete)	1,000	cy	$ 1,230.00	$ 1,230,000	30.0%	$ 369,000	$ 1,599,000	0.8%		
23	Chute spillway invert slab (reinforced concrete)	11,000	cy	$ 740.00	$ 8,140,000	30.0%	$ 2,442,000	$ 10,582,000	5.4%		
24	Ogee crest raise (mass concrete)	25,000	cy	$ 860.00	$ 21,500,000	35.0%	$ 7,525,000	$ 29,025,000	14.9%		
25	Left abutment gravity wall (mass concrete)	24,000	cy	$ 760.00	$ 18,240,000	35.0%	$ 6,384,000	$ 24,624,000	12.6%		
26	Anchors (fully grouted, 20' long, #9 bars)	42,000	lf	$ 205.00	$ 8,610,000	25.0%	$ 2,152,500	$ 10,762,500	5.5%		
G	Spillway Bridge				$ 2,700,000	30%	$ 810,000	$ 3,510,000		$ 3,510,000	1.8%
27	Deck & pier	6,000	sf	$ 450.00	$ 2,700,000	30.0%	$ 810,000	$ 3,510,000	1.8%		

H	Outlet & Intake Structures & Pipe				$ 6,412,000	30%	$ 1,919,900	$ 8,331,900		$ 8,331,900	4.3%
28	Power/outlet structure	1	LS	$ 1,000,000	$ 1,000,000	35.0%	$ 350,000	$ 1,350,000	0.7%		
29	Steel outlet pipe (8' dia.)	300	lf	$ 3,040.00	$ 912,000	20.0%	$ 182,400	$ 1,094,400	0.6%		
30	Intake/trashrack	1	LS	$ 750,000	$ 750,000	35.0%	$ 262,500	$ 1,012,500	0.5%		
31	Mechanical (gates, valves, actuators, ventilation)	1	LS	$ 3,000,000	$ 3,000,000	30.0%	$ 900,000	$ 3,900,000	2.0%		
32	Electrical controls and lighting	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.5%		
I	Misc. Civil				$ 2,038,000	30%	$ 611,400	$ 2,649,400		$ 2,649,400	1.4%
33	Backfill	20,000	cy	$ 10.40	$ 208,000	30.0%	$ 62,400	$ 270,400	0.1%		
34	Roadways (paved)	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.2%		
35	Heavy riprap (on-site borrow)	3,000	cy	$ 60.00	$ 180,000	30.0%	$ 54,000	$ 234,000	0.1%		
36	Site Restoration	130	Acres	$ 5,000	$ 650,000	30.0%	$ 195,000	$ 845,000	0.4%		
37	Forebay & canal headworks	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.5%		
J	Instrumentation & SCADA				$ 1,500,000	30%	$ 450,000	$ 1,950,000		$ 1,950,000	1.0%
38	Instrumentation & ADAS	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.5%		
39	SCADA	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.5%		
Total Estimated Construction Cost (2017 dollars)					$ 150,445,020		$ 44,757,870	$ 195,202,890	100.0%	$ 195,202,890	100.0%
Overall Design Contingency						29.8%		$ 195,202,890			
Note: See Tech Memo for cost exclusions.									Q2 2017	Q4 2019*	Cost per AF
							Opinion of Probable Construction Cost		$ 195,200,000	$ 210,800,000	$ 4,216
							Estimated Range - Low (-20%)		$ 156,160,000	$ 168,700,000	$ 3,374
							Estimated Range - High (+20%)		$ 234,240,000	$ 253,000,000	$ 5,060
							Storage Increase (AF)				50,000
							* 8% escalation				

Appendix B
Opinion of Probable Construction Cost for Centennial Dam

NID CENTENNIAL RESERVOIR - RCC DAM CONCEPT
Opinion of Probable Construction Cost (AACE Class 3-4), 5/12/17
Base Year: 2017
Axis: Centennial Site 2

Category/Item (WBS) No.	Description	Est. Pay Quantity	Units	Unit Price	Extension	% Contingency	Contingency Amount	Extension + Contingency	Line Item % of Total	Category Total	Category % of Total
A	Mobilization & Demobilization				$ 18,736,890	0%	$ -	$ 18,736,890		$ 18,736,890	7.3%
1	Mobilization & demobilization	1	LS	$ 18,736,890	$ 18,736,890	0.0%	$ -	$ 18,736,890	7.3%		
B	Site Development				$ 15,942,500	34.8%	$ 5,554,875	$ 21,497,375		$ 21,497,375	8.4%
2	Site preparation	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
3	Borrow area stripping	900,000	cy	$ 10.50	$ 9,450,000	35.0%	$ 3,307,500	$ 12,757,500	5.0%		
4	Quarry drill & blast	705,000	cy	$ 8.50	$ 5,992,500	35.0%	$ 2,097,375	$ 8,089,875	3.2%		
C	River Diversion				$ 2,000,000	30%	$ 600,000	$ 2,600,000		$ 2,600,000	1.0%
5	Diversion during construction	1	LS	$ 1,000,000	$ 1,000,000	30.0%	$ 300,000	$ 1,300,000	0.5%		
6	Cofferdams - upstream & downstream	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
7	Dewatering	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
D	Dam Foundation				$ 32,743,000	28%	$ 9,118,850	$ 41,861,850		$ 41,861,850	16.3%
8.1	Foundation excavation - common	450,000	cy	$ 11.00	$ 4,950,000	30.0%	$ 1,485,000	$ 6,435,000	2.5%		
8.2	Foundation excavation - rock	150,000	cy	$ 21.50	$ 3,225,000	30.0%	$ 967,500	$ 4,192,500	1.6%		
9	Initial cleaning	30,000	sy	$ 20.00	$ 600,000	10.0%	$ 60,000	$ 660,000	0.3%		
10	Final cleaning	30,000	sy	$ 20.00	$ 600,000	10.0%	$ 60,000	$ 660,000	0.3%		
11	Surface preparation	30,000	sy	$ 25.00	$ 750,000	25.0%	$ 187,500	$ 937,500	0.4%		
12	Levelling concrete	18,000	cy	$ 280.00	$ 5,040,000	30.0%	$ 1,512,000	$ 6,552,000	2.6%		
13	Grout curtains	41,000	lf	$ 155.00	$ 6,355,000	35.0%	$ 2,224,250	$ 8,579,250	3.4%		
14	Structural concrete - grouting plinth	4,500	cy	$ 1,230.00	$ 5,535,000	20.0%	$ 1,107,000	$ 6,642,000	2.6%		
15	Grouting plinth anchors	6,400	lf	$ 205.00	$ 1,312,000	20.0%	$ 262,400	$ 1,574,400	0.6%		
16	Consolidation grouting	24,000	lf	$ 105.00	$ 2,520,000	35.0%	$ 882,000	$ 3,402,000	1.3%		
17	Drain holes	16,000	lf	$ 116.00	$ 1,856,000	20.0%	$ 371,200	$ 2,227,200	0.9%		
E	RCC, Facing Concrete & Gallery				$ 109,060,000	25%	$ 27,265,000	$ 136,325,000		$ 136,325,000	53.2%
18	RCC, facing concrete & gallery	811,000	cy	$ 108.00	$ 87,588,000	25.0%	$ 21,897,000	$ 109,485,000	42.8%		
19	Cement for RCC - Type II	61,000	ton	$ 210.00	$ 12,810,000	25.0%	$ 3,202,500	$ 16,012,500	6.3%		
20	Class F fly ash for RCC	61,000	ton	$ 142.00	$ 8,662,000	25.0%	$ 2,165,500	$ 10,827,500	4.2%		
F	Spillway & Dam Crest				$ 10,464,400	22%	$ 2,301,225	$ 12,765,625		$ 12,765,625	5.0%
21	Spillway & stilling basin walls	3,650	cy	$ 1,230.00	$ 4,489,500	25.0%	$ 1,122,375	$ 5,611,875	2.2%		
22	Stilling basin slab	3,260	cy	$ 740.00	$ 2,412,400	25.0%	$ 603,100	$ 3,015,500	1.2%		
23	Crest slab	1,500	cy	$ 740.00	$ 1,110,000	15.0%	$ 166,500	$ 1,276,500	0.5%		
24	Parapet walls	650	cy	$ 1,250.00	$ 812,500	10.0%	$ 81,250	$ 893,750	0.3%		
25	Stilling basin anchors	8,000	lf	$ 205.00	$ 1,640,000	20.0%	$ 328,000	$ 1,968,000	0.8%		
G	Spillway Bridge				$ 1,800,000	30%	$ 540,000	$ 2,340,000		$ 2,340,000	0.9%
26	Deck & pier	4,000	sf	$ 450.00	$ 1,800,000	30%	$ 540,000	$ 2,340,000	0.9%		
H	Outlet & Intake Structures & Pipe				$ 11,379,000	30%	$ 3,379,600	$ 14,758,600		$ 14,758,600	5.8%
27	Outlet structure	1	LS	$ 2,500,000	$ 2,500,000	35.0%	$ 875,000	$ 3,375,000	1.3%		

28	Outlet chute walls	1,300	cy	$ 1,230.00	$ 1,599,000	30.0%	$ 479,700	$ 2,078,700	0.8%		
29	Outlet chute slab	1,100	cy	$ 740.00	$ 814,000	30.0%	$ 244,200	$ 1,058,200	0.4%		
30	Outlet chute anchors	4,400	lf	$ 205.00	$ 902,000	20.0%	$ 180,400	$ 1,082,400	0.4%		
31	Steel outlet pipe	350	lf	$ 3,040.00	$ 1,064,000	20.0%	$ 212,800	$ 1,276,800	0.5%		
32	Intake/trashrack	1	LS	$ 750,000	$ 750,000	35.0%	$ 262,500	$ 1,012,500	0.4%		
33	Mechanical (gates, valves, actuators, ventilation)	1	LS	$ 3,000,000	$ 3,000,000	30.0%	$ 900,000	$ 3,900,000	1.5%		
34	Electrical controls and lighting	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.4%		
I	Misc. Civil				$ 2,480,000	30%	$ 744,000	$ 3,224,000		$ 3,224,000	1.3%
35	Backfill	125,000	cy	$ 10.40	$ 1,300,000	30.0%	$ 390,000	$ 1,690,000	0.7%		
36	Roadways	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.1%		
37	Gallery portals	1	LS	$ 250,000	$ 250,000	30.0%	$ 75,000	$ 325,000	0.1%		
38	Heavy riprap	3,000	cy	$ 60.00	$ 180,000	30.0%	$ 54,000	$ 234,000	0.1%		
39	Site Restoration	1	LS	$ 500,000	$ 500,000	30.0%	$ 150,000	$ 650,000	0.3%		
J	Instrumentation & SCADA				$ 1,500,000	30%	$ 450,000	$ 1,950,000		$ 1,950,000	0.8%
40	Instrumentation & ADAS	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.4%		
41	SCADA	1	LS	$ 750,000	$ 750,000	30.0%	$ 225,000	$ 975,000	0.4%		
Total Estimated Construction Cost (2017 dollars)					$ 206,105,790		$ 49,953,550	$ 256,059,340	100.0%	$ 256,059,340	100.0%
Overall Design Contingency						24.2%		$ 256,059,340			
Note: See Tech Memo for cost exclusions.									Q2 2017	Q4 2019*	Cost per AF
							Opinion of Probable Construction Cost		$ 256,100,000	$ 276,600,000	$ 2,515
							Estimated Range - Low (-15%)		$ 217,685,000	$ 235,100,000	$ 2,137
							Estimated Range - High (+20%)		$ 307,320,000	$ 331,900,000	$ 3,017
							Storage Increase (AF)				110,000
							* 8% escalation				

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AECOM
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510-893-3600

RESOLUTION NO. 2024-36

OF THE BOARD OF DIRECTORS OF THE NEVADA IRRIGATION DISTRICT

Authorizing Filing an Amended Petition for Extension of Time on Permit 11626; Withdrawing, Application for Assignment of State-Filed Right 5634; and Discontinuing all Feasibility, Environmental and Other Analyses in Support of the Proposed Centennial Reservoir Project

WHEREAS, the Nevada Irrigation District (NID) is a California Irrigation District formed and existing pursuant to Division 11 of the California Water Code and is empowered to provide a safe, stable and reliable water supply for residential, commercial, industrial, agricultural, environmental, fire protection and prevention and other beneficial uses of water; and

WHEREAS, on August 13, 2014, NID's Board of Directors adopted Resolution No. 2014-43 "Authorizing Application for the Water Rights for Diversion, Storage, and Use of Water of the Bear River"; and

WHEREAS, Resolution 2014-43 found that the "State of California has entered its third consecutive year of drought and recent studies indicate that current climate conditions are changing, requiring our region to prepare for longer dry periods, shorter more intense rain events, reduced and less reliable snowpack" and climate change "require the District to develop additional storage and diversion capacity in order to serve our community during times of shortage"; and

WHEREAS, Resolution 2014-43 authorized and directed NID to (1) make application to the California State Water Resources Control Board (State Water Board) for unappropriated water on the Bear River, including filing a petition for assignment of available State filings; and (2) that NID's General Manager "prepare the necessary reconnaissance studies to determine project feasibility which include but are not limited to preliminary design, financial feasibility, site surveys, hydrologic and geologic site suitability"; and

WHEREAS, as directed by Resolution 2014-43, NID made petition to the State Water Board for assignment of state-filed application 5634 (Application), with a priority date of 1927 and filed accompanying water right application 5634X01, for the proposed construction of a new onstream water storage facility located at the Parker Dam site, approximately 8 miles downstream of NID's existing Rollins Dam and upstream of NID's existing Combie Dam; and

WHEREAS, the Parker Dam site for the proposed reservoir became known as the proposed Centennial Reservoir; and

WHEREAS, NID's Application identified NID as the lead agency for development of an environmental impact report (EIR) under the California Environmental Quality Act (CEQA) and stated that the "EIR will consider a range of reasonable alternatives to the project, a no project alternative, and potential impacts, mitigation measures and monitoring requirements"; and

WHEREAS, the State Water Board decided in 2016, prior to NID's completion of feasibility studies and development of an EIR under CEQA, to publicly notice NID's Application which initiated a deadline by which parties interested in the potential Centennial Project and proceedings on NID's Application were required to submit a "protest" to formally participate; and

WHEREAS, fourteen agencies, non-governmental organizations, and individual parties timely submitted protests; and

WHEREAS, many protesting parties expressed environmental concerns with the proposed Centennial Reservoir and that NID had not yet completed feasibility analyses and environmental review under CEQA; and

WHEREAS, in 2021 NID initiated a public collaboration process known as the Plan for Water to determine the best ways to meet the community's demand for water over the coming decades by comprehensively assessing available water resources, new regulations, changes in land use, varying climate, and community aspirations; and

WHEREAS, the Plan for Water included over25 public meetings covering eleven stages of work, as follows: (1) system overview; (2) water rights overview; (3) watersheds; (4) risk; (5) strategic planning; (6) basis for plan water; (7) hydrology and hydrography; (8) demand; (9) supply needs; (10) strategy options; and (11) evaluate strategies; and

WHEREAS, in August 2024, NID publicly released the Plan for Water Final Technical Memorandum summarizing much of the technical analyses developed through the Plan for Water process; and

WHEREAS, the Final Technical Memorandum forecasts NID's annual average unmet demand of 35,000 acre-feet in a high demand/dry climate scenario, 14,500 acre-feet in a baseline demand/medium climate scenario, and 6,000 acre-feet in a low demand/wet climate scenario; and and

WHEREAS, to address and mitigate the effects of unmet demands, the Final Technical Memorandum analyzes seven strategic alternatives: (1) extended irrigation season; (2) Rollins Reservoir 10,000 acre-foot storage increase; (3) Rollins Reservoir 50,000 acre-foot storage increase; (4) Centennial Reservoir; (5) revised carryover storage targets; (6) water purchases from Pacific Gas & Electric Co. (PG&E), and (7) revised carryover storage targets plus water purchases from PG&E; and

WHEREAS, the Plan for Water process, including the Final Technical Memorandum, demonstrates that alternatives other than the proposed Centennial Reservoir are best suited to address forecasted annual unmet water demands within NID; and

WHEREAS, the proposed Centennial Reservoir, as revealed in the Plan for Water analyses, is not currently financially feasible given other alternatives and is not sited in the best location to meet the anticipated future water needs of NID; and

WHEREAS, alternatives to the proposed Centennial Reservoir analyzed in the Final Technical Memorandum do not currently require continued pursuit of the Application for their potential future implementation; and

WHEREAS, NID holds water right Permit No. 11626 (Application No. 2652B) with a priority date of November 22, 1921 for diversion to and from storage at Rollins Reservoir of up to 65,000 acre-feet from about November 30 to about June 1; and

WHEREAS, in 2009 NID filed a change petition and extension of time for Permit 11626 to allow for NID to go to license in the amounts of 29,000 acre-feet diverted from the Bear River, 54,600 acre-feet under Permit 11626 and other NID water rights, and a total of 47,100 acre-feet of withdraws under Permit 11626 and other NID water rights; and

WHEREAS, the State Water Board noticed NID's petition under Permit 11626 and protests from interested parties were received; and

WHEREAS, after good faith negotiations to resolve those protests, in 2019 NID requested that the State Water Board conduct a hearing on, among other things, NID's petition related to Permit 11626; and

WHEREAS, the State Water Board has not acted on NID's 2019 request for hearing, and the petition related to Permit 11626 remains pending; and

WHEREAS, given changed circumstances since 2009, including a better understanding of the impacts of climate change, the Plan for Water analyses demonstrating significant unmet demands within NID, and the potential need to enlarge Rollins Reservoir, NID can no longer justify requesting licensure of Permit 11626 and, instead, will request an extension of time to allow for further development and use under Permit 11626; and

WHEREAS, this Resolution reflects the independent judgment of the Board of Directors of NID and is in the best interest of NID customers by continuing to ensure a safe, stable and reliable water supply for all beneficial uses of water served by NID.

NOW THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF THE NEVADA IRRIGATION DISTRICT AS FOLLOWS:

1. The above recitals are true and correct and are declared to be findings of NID.

2. NID's General Manager, or her designee, is authorized and directed to file an amended petition on Permit 11626 for an extension of time to further develop and use water under Permit 11626.

3. NID's General Manager, or her designee, is authorized and directed to withdraw the Application and discontinue further feasibility, environmental or other analyses in pursuit of the proposed Centennial Reservoir Project as authorized in Resolution 2014-43.

4. NID's General Manager, or her designee, is authorized and directed to withdraw the Application for assignment of state-filed water right 5634.

5. NID's General Manager, or designee is authorized to continue NID's protest of South Sutter Water District's pending petition for release from priority of State-Filed Applications 5633 and 5634 in favor of water-right License 11120 (Application 10221) to, among other items, protect NID's future county-of-origin water supply needs.

6. The actions directed by this Resolution are either not a project under the California Environmental Quality Act or are an exempt project under the California Environmental Quality Act. NID's General Manager is authorized to file a notice of exemption pursuant to applicable law.

7. NID's General Manager is authorized and directed to take such further actions as reasonably necessary to implement the terms of this Resolution.

PASSED AND ADOPTED by the Board of Directors of the Nevada Irrigation District at a regular meeting held on the 25th day of September 2024, by the following vote:

AYES:
NOES:
ABSTAINING:
ABSENT:

President

ATTEST:

Board Secretary