BUREAU OF RECLAMATION

Long-Term Operation – Initial Alternatives

# Appendix R – Head of Old River Barrier

## Central Valley Project, California

### Interior Region 10 – California-Great Basin

**U.S. Department of the Interior** **September 2022**

# Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Long-Term Operation – Initial Alternatives

# Appendix R – Head of Old River Barrier

## Central Valley Project, California

### Interior Region 10 – California-Great Basin

Page Intentionally Left Blank

# Contents

Page

Page Intentionally Left Blank

# 1. Introduction

The purpose of the springtime Head of Old River Barrier (HORB) is to improve migration conditions for salmonids entering the Sacramento–San Joaquin Delta (Delta) from the San Joaquin River and its tributaries by preventing salmonids from entering the Old River and being entrained into the Central Valley Project CVP) and State Water Project (SWP) water export facility and by increasing flows in the San Joaquin River.

Bureau of Reclamation's (Reclamation's) management questions for the formulation of an alternative include:

- How does presence of the barrier affect survival to Chipps Island compared to a combined salvage and San Joaquin River route without the barrier?
- What is the effect of flow and fish routing at the Head of Old River on steelhead population viability?
- What is the effect of the barrier on Delta hydrodynamics?
    - Does the barrier cause additional export restrictions to maintain Old and Middle River (OMR) criteria
    - For the same OMR flow, does the barrier increase smelt entrainment?
- How much additional flow is routed down the San Joaquin River when the barrier is present?
- Are the water temperature benefits associated with the installation of the barrier?

Page Intentionally Left Blank

# 2. Performance Metrics

Performance metrics describe criteria that can be measured, estimated, or calculated and used to inform trade-offs for alternative management actions.

## 2.1 Biological

Biological metrics consider direct observations and environmental surrogates including:

- Juvenile survival probability to Chipps Island.
- Larval and juvenile smelt entrainment risk.

## 2.2 Water Supply

Water supply metrics consider the multipurpose beneficial uses of CVP reservoirs including:

- South-of-Delta agricultural deliveries (average and critical/dry years).
- Frequency of when OMR is controlling exports.

## 2.3 NEPA Resources Areas

Analysis of the range of alternatives as required by the National Environmental Policy Act is anticipated to describe changes in the multiple resources areas. Key resources are anticipated to include surface water supply, water quality, air quality, groundwater resources, aquatic resources, terrestrial biological resources, regional economics, land use and agricultural resources, recreation, cultural resources, hazards and hazardous materials, socioeconomics, environmental justice, and climate change.

Page Intentionally Left Blank

# 3. Methods

## 3.1 Datasets

No new analysis of data was performed. Existing literature is described below.

## 3.2 Literature

Interagency coordination resulted in NMFS preparing a knowledge base paper, Head of Old River Barrier, included as an attachment.

## 3.3 Models

### 3.3.1 CalSim II

CalSim II is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets, or goals (Draper et al. 2004). CalSim II represents the best available planning model for CVP and SWP system operations and has been used in previous system-wide evaluations of CVP and SWP operations (Bureau of Reclamation 2015). Reclamation and DWR are advancing CalSim 3, but the model was not ready for these purposes.

### 3.3.2 DSM2

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento–San Joaquin Delta (DWR 2002). DSM2 represents the best-available planning model for Delta tidal hydraulic and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations (Reclamation 2015).

Page Intentionally Left Blank

# 4. Alternative Options

Contrary to other variable components, initial alternatives for HORB address whether to include or exclude the barrier from consideration and not a range of options. If Reclamation and the Department of Water Resources include a barrier in the Proposed Action, the type of barrier would be identified.

Page Intentionally Left Blank

# 5. Lines of Evidence

## 5.1 Analysis of Salmon and Steelhead Survival, Routing, and Salvage

### 5.1.1 Head of Old River Barrier Effects on Survival

The effect of HORB on through-Delta survival of juvenile Chinook salmon was evaluated by analyzing coded wire-tagged (CWT) hatchery fish that were tagged between 1992 and 2006. Acoustic tagging of hatchery fish began in 2009 because this technology has several advantages over CWT, including higher recapture probabilities, ability to estimate survival in reaches delineated by acoustic monitors, and ability to estimate routing probabilities at junctions. Acoustic tagging and release of hatchery steelhead has occurred in the Delta since 2011.

Newman (2008) reviewed analyses of CWT releases between 1985 and 1990 performed by the U.S. Fish and Wildlife Service and found that fish released directly into the Old River had lower recovery rates than fish released into the San Joaquin River. This was used as justification for placing a barrier at Head of Old River, which was expected to increase survival by keeping fish out of the Old River route. Newman (2008) also analyzed an expanded set of CWT releases (1985–2006) that included years with and without the HORB. That analysis concluded that survival probability in the San Joaquin River route was generally greater than in the Old River route and that assuming the HORB kept fish out of the Old River, it was effective at increasing survival (Newman 2008). Additionally, the effect of San Joaquin River flow on survival was significant when the HORB was installed but not when it was not. Thus, the HORB may influence survival by increasing flow in the San Joaquin River route.

Buchanan et al. (2013) analyzed acoustic releases of Chinook salmon performed in 2009 and 2010 and found that there was no significant difference in survival between the Old River route and the San Joaquin River route. This finding indicated that the survival benefit of HORB indicated in the CWT analysis may no longer exist. Buchanan et al. (2018) also analyzed six years of Chinook salmon acoustic tagging and found that in the two years when a significant difference in survival was identified, it was the Old River route where survival was higher. This analysis indicated that keeping fish out of Old River (the function of the barrier) is unlikely to provide the survival benefit identified in the CWT analysis. Another finding from Buchanan et al.'s (2018) analysis was that most of the tagged fish successfully arriving at Chipps Island came through salvage at the CVP. This suggests a mechanism for explaining why survival in the two routes was equivalent or better in the Old River. Under 2018 conditions, salvage and trucking resulted in higher survival compared to migration through the south Delta. Finally, Buchanan and Skalski (2020) analyzed the effects of the HORB and flow on juvenile Chinook salmon and did not find a significant effect of the HORB on survival.

In 2022, Buchanan et al. evaluated the effect of the HORB on juvenile steelhead survival. In that analysis, the effect of the HORB on survival varied by reach and the mechanism of its effect was not obvious. Route-specific effects on survival were not consistent, indicating that keeping steelhead out of the Old River did not improve survival outcomes directly. The effect of the barrier was significant in the reach between the Head of Old River and the Turner Cut Junction but not in the reach between Turner Cut Junction and Chipps Island. Buchanan et al. (2022) suggested this may be a result of increased flow in the San Joaquin River when the HORB was installed because flow in the San Joaquin River had the strongest relationship with survival. Thus, the study concluded that the HORB may increase survival and the likely mechanism is the diversion of most flow into the San Joaquin River. This effect primarily occurs between the Head of Old River and the Turner Cut Junction.

When evaluating the effect of the HORB on survival of juvenile salmonids, it is important to also consider effects on survival upstream because the barrier also has hydrodynamic effects upstream of the barrier by backing up water and reducing instantaneous velocities (see Section 5.2, *Delta Simulation Model II Modeling of Head of Old River*). To examine these effects, this study plotted group survival values for steelhead (Buchanan et al. 2022) and Chinook salmon (Buchanan et al. 2018) across San Joaquin River inflows between ~500 to 3,000 cubic feet per second (cfs) with and without the barrier installed. Observations were limited to similar flow values at a range under which the barrier can be constructed (<5,000 cfs). For steelhead, survival downstream of the Head of Old River was higher when the barrier was in place, consistent with the results of Buchanan et al. (2022; Figure 1). However, upstream of the barrier, survival was lower when the barrier was in place, particularly at flows below 1,500 cfs (Figure 1). Thus, there may be trade-offs in the location of steelhead mortality as a result of barrier placement.

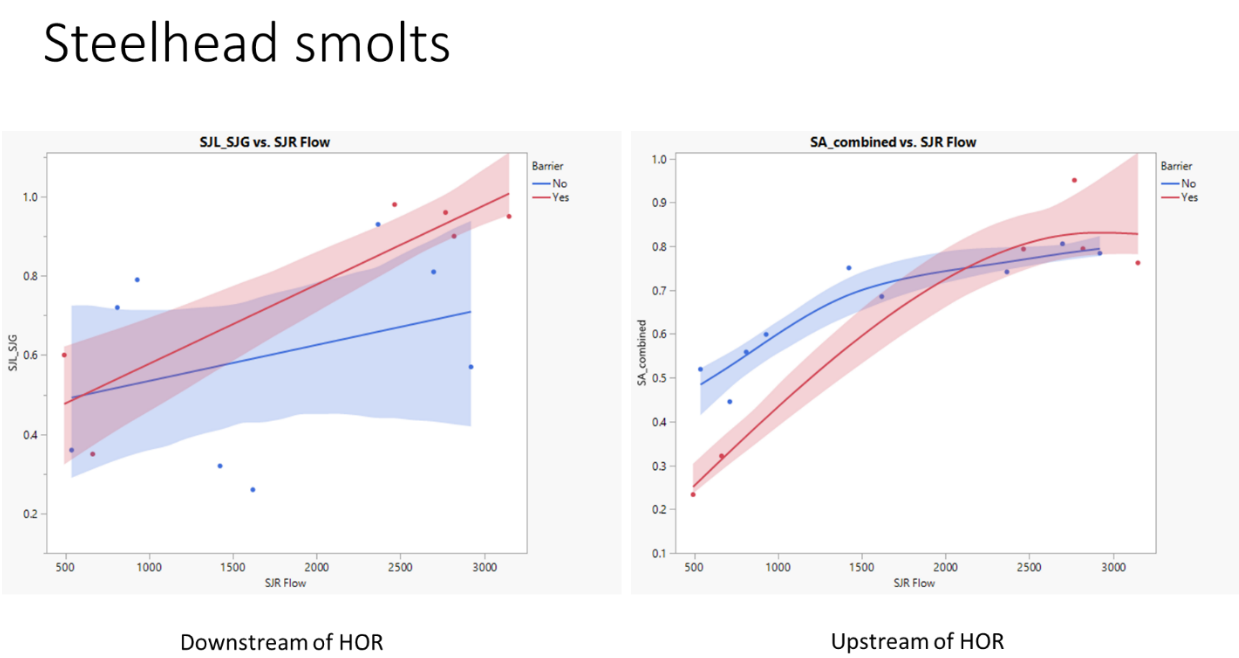



Figure 1. Plots of Group Survival Estimates for Acoustically Tagged Juvenile Steelhead in Relation to San Joaquin River Flow and Head of Old River Barrier Status

For Chinook salmon smolts, a similar pattern was observed (Figure 2). However, few observations of survival were available for San Joaquin River flows below 3,000 cfs with no barrier in place, and this should be considered when interpreting the Chinook salmon plots.

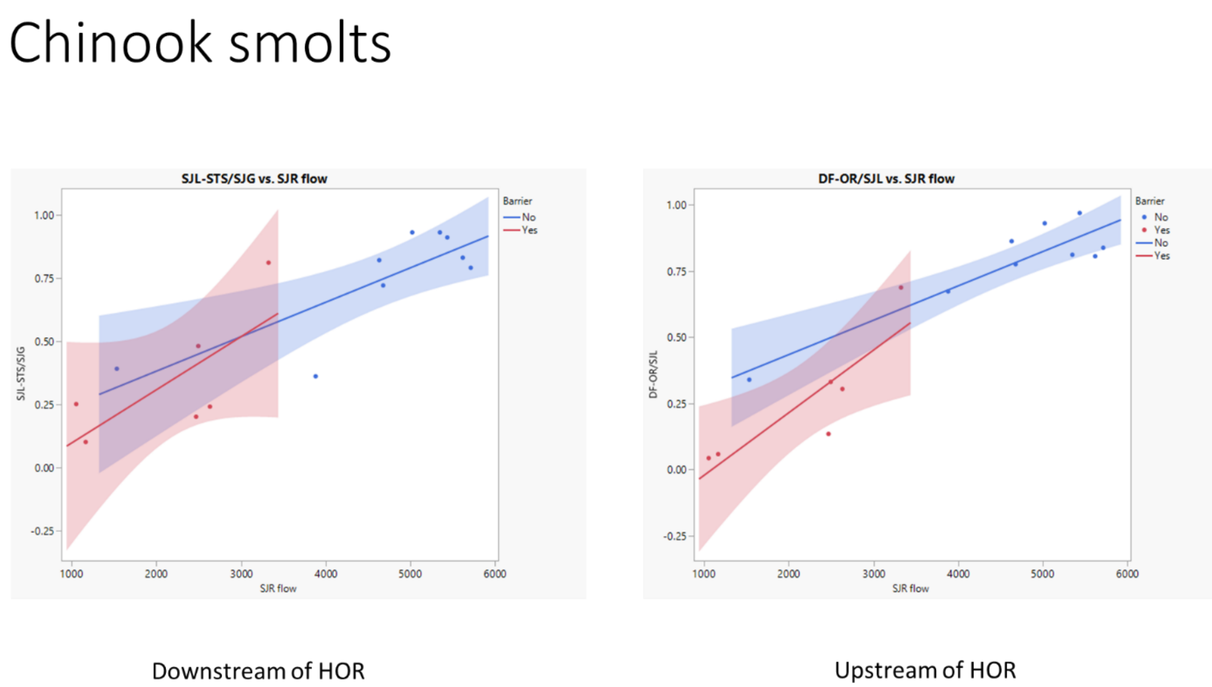



Figure 2. Plots of Group Survival Estimates for Acoustically Tagged Juvenile Chinook Salmon in Relation to San Joaquin River Flow and Head of Old River Barrier Status

### 5.1.2 Head of Old River Barrier Effects on Routing and Salvage

As a physical barrier, the HORB is effective at keeping the majority of juvenile salmonids from entering the Old River route (Buchanan et al. 2018, 2022). Since the salvage facilities are located on the Old River route, the barrier will be effective at reducing salvage of San Joaquin River–origin salmonids. With the barrier installed, more fish would be exposed to entrainment at junctions farther downstream such as Turner Cut, Columbia Cut, Old River, and Middle River Junctions. However, tides dominate hydrology in the reach from Turner Cut downstream, and changes to inflow or exports have only minimal effects on potential entrainment of juvenile salmonids toward the facilities (Cavallo et al. 2015; Buchanan et al. 2022).

San Joaquin River–origin juvenile salmonids are salvaged at the CVP and SWP at much higher rates than fish originating from the Sacramento River (Zeug and Cavallo 2014). As exports and San Joaquin River flow increase, the probability of salvage, and fraction of the population salvaged, increases (Zeug and Cavallo 2014). Thus, when the barrier is not in place, more juveniles will pass by the facilities and salvage will increase with exports and inflow. Increased salvage could be considered a negative effect if the goal is to minimize salvage or considered a positive effect if the goal is to minimize through-Delta mortality. Buchanan et al. (2018) found that most of the acoustic tagged fish arriving at Chipps Island came through the CVP salvage facilities, suggesting that salvage may be the highest survival route through the Delta for San

Joaquin River–origin juvenile salmon in the Delta's current condition. Additionally, the total mortality of San Joaquin River–origin Chinook salmon that can be accounted for by salvage loss is low. Zeug and Cavallo (2014) analyzed 313 releases of CWT Chinook salmon in the San Joaquin River basin and found that entrainment loss accounted for less than 5% of total mortality for the majority of releases.

## 5.2 Delta Simulation Model II Modeling of Head of Old River Barrier

To examine the effect of the HORB on Delta hydrodynamics, the Delta Simulation Model II (DSM2) hydrologic model was employed. Two San Joaquin River inflow levels and two export levels were examined with and without the HORB installed. The two inflow levels were 1,000 and 4,500 cfs. These values are within the range under which the HORB can be constructed (≤ 5,000 cfs). The two export levels modeled were 1,500 and 4,500 cfs. Changes in two hydrologic outputs were examined. The first was the change in flow downstream of the Head of Old River. Flow upstream of the Head of Old River did not change among scenarios. Flow in the San Joaquin River between Head of Old River and Turner Cut has been quantitatively related to survival of steelhead smolts (Buchanan et al. 2022). The difference in flow was plotted for the entire Delta, and detailed information was provided for three key DSM2 channels—one in the Old River just downstream of Head of Old River (channel 55), one in the San Joaquin River just downstream of Head of Old River (channel 8), and one on the San Joaquin River near Turner Cut (channel 25). The second hydrologic output examined was change in velocity. While flow has been most often been used to model survival, instantaneous velocity is what fish are more likely to detect and respond to (Monismith et al. 2014). For the velocity analysis, the overlap in velocity distributions with and without the HORB were calculated for each flow and export combination. An expanded set of channels was selected to provide more detailed data. The channel set was expanded because velocity can be affected by the barrier in regions where flow would not (e.g., upstream of Head of Old River). This expanded set of channels includes the San Joaquin River upstream of Head of Old River (channel 6), the San Joaquin River downstream of Head of Old River (channel 9), the San Joaquin River near Turner Cut (channel 25), the Old River downstream of Head of Old River (channel 55), the Old River near the CVP (channel 80), and the Old River near Railroad Cut (channel 96).

### 5.2.1 Head of Old River Barrier Effects on Flow

In the San Joaquin River downstream of Head of Old River, installation of the HORB resulted in a moderate increase in flow when the San Joaquin River inflow was 1,000 cfs and exports were 1,500 cfs (Figure 3). There was a strong tidal signal at this location regardless of barrier status with bidirectional flows. However, this distribution of flows shifted to be more positive with higher flows when the barrier was present (49.4% overlap). As inflow increased to 4,500 cfs, the barrier effect also increased, with a larger increase in the distribution of flows (0% overlap) and a shift to fully unidirectional flow in the San Joaquin River downstream of Head of Old River (Figure 4).

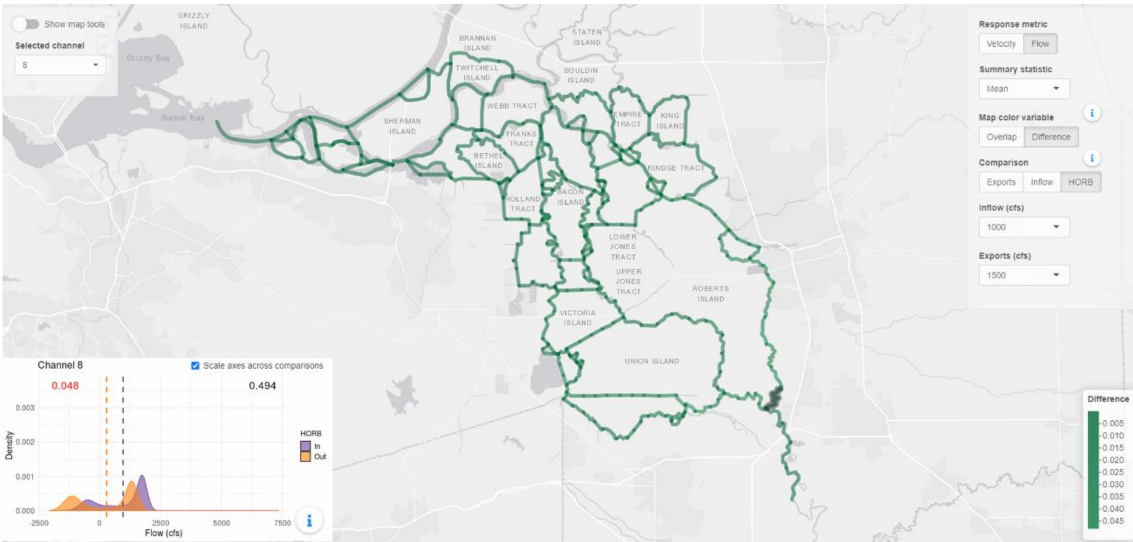



Figure 3. Heat Map of Flow Differences in the Delta and in the San Joaquin River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 1,000 cfs and Exports at 1,500 cfs

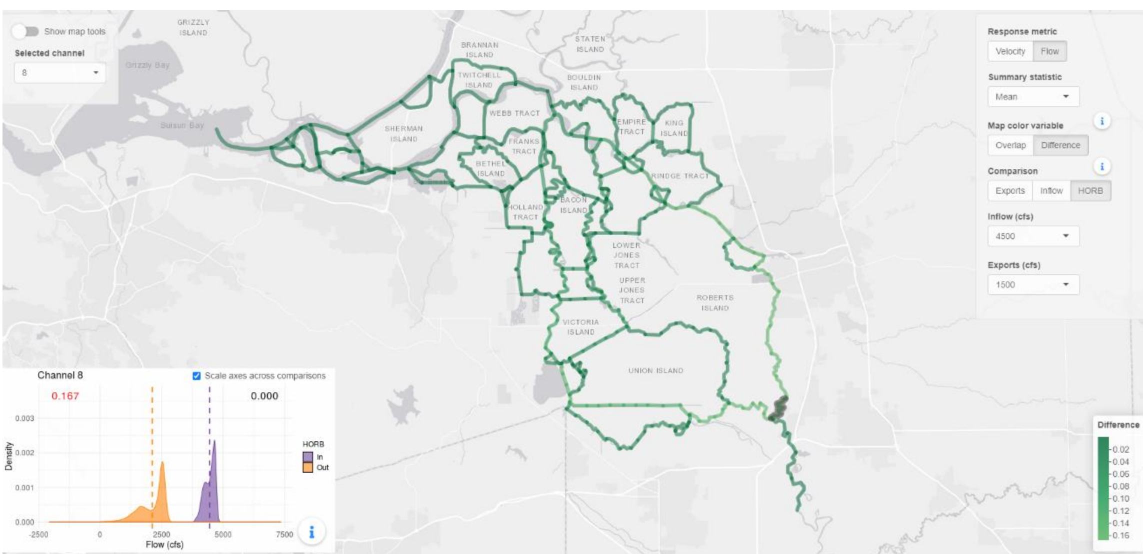



Figure 4. Heat Map of Flow Differences in the Delta and in the San Joaquin River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 4,500 cfs and Exports at 1,500 cfs

In the Old River downstream of Head of Old River, installation of the HORB had the effect of increasing the strength of the tidal signal and reducing the frequency of positive flow values. The distribution of flows with the barrier installed changed little between inflow values of 1,000 and

4,500 cfs, whereas without the barrier, flow became fully unidirectional at inflow of 4,500 cfs (Figure 5 and Figure 6).

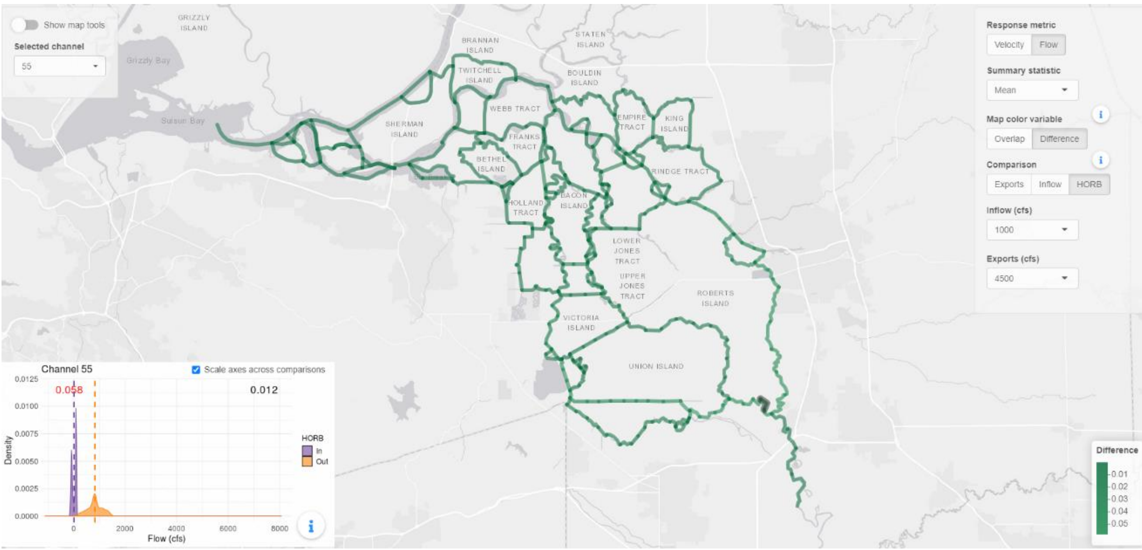



Figure 5. Heat map of flow differences in the Delta and in the Old River downstream of Head of Old River as a result of Head of Old River Barrier installation with San Joaquin River flow at 1,000 cfs and exports at 1,500 cfs.

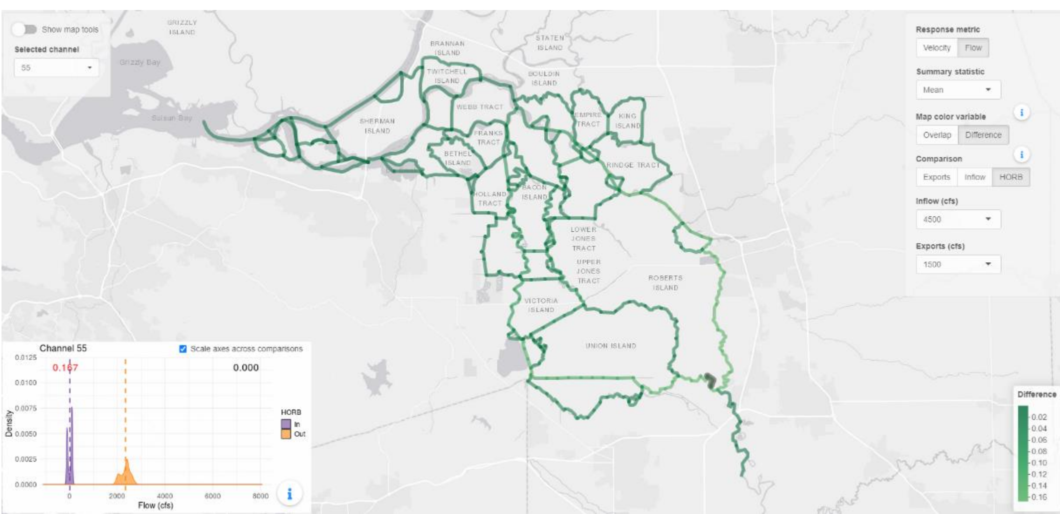



Figure 6. Heat Map of Flow Differences in the Delta and in the Old River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 4,500 cfs and Exports at 1,500 cfs

In the San Joaquin River near Turner Cut, flows were strongly tidal and bidirectional. Installation of the HORB had only minor effects on flow distributions at San Joaquin River inflows of 1,000 cfs with a distribution overlap of 91.2%, and shifted higher when inflows increased to 4,500 cfs (74.6% overlap) (Figures 7 and 8).

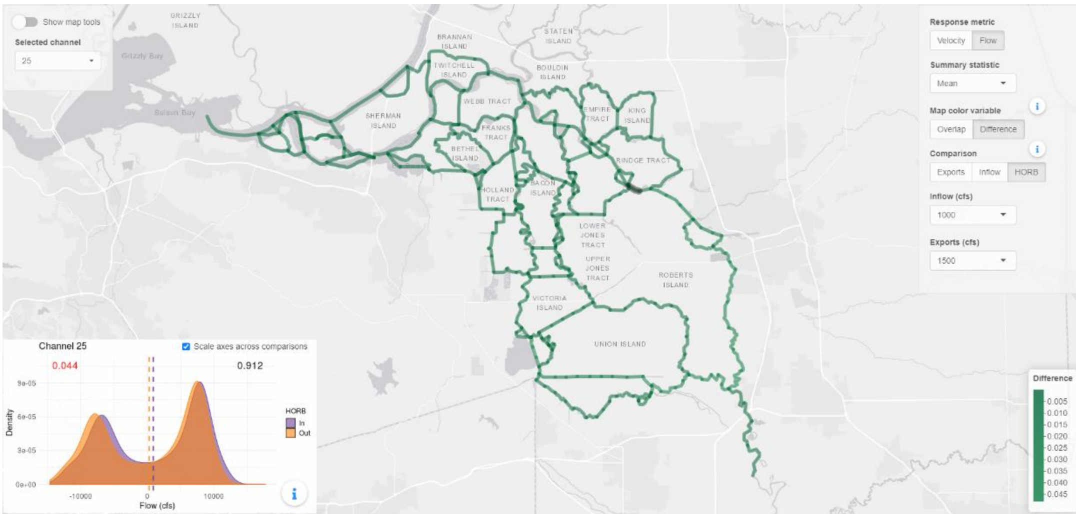



Figure 7. Heat Map of Flow Differences in the Delta and in the San Joaquin River near Turner Cut as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 1,000 cfs and Exports at 1,500 cfs

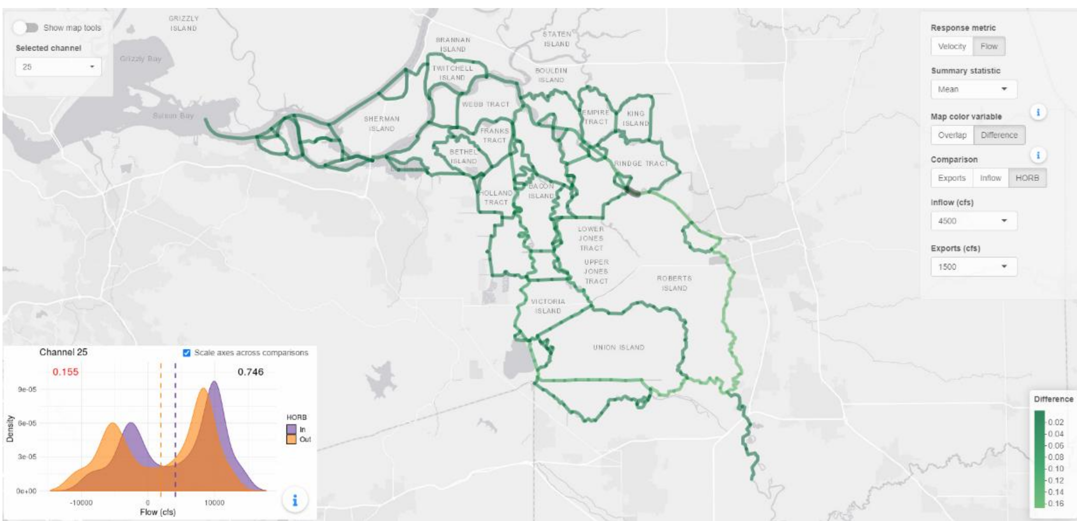



Figure 8. Heat Map of Flow Differences in the Delta and in San Joaquin River near Turner Cut as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 4,500 cfs and Exports at 1,500 cfs

Exports had only minor effects on flow distributions at the two San Joaquin River channels (Figures 5 and 9). The largest effect occurred in the Old River when the barrier was installed. Under this condition, increasing exports from 1,500 to 4,500 cfs resulted in higher flows during the ebb tide and more frequent flows downstream (toward the export and fish salvage facilities).

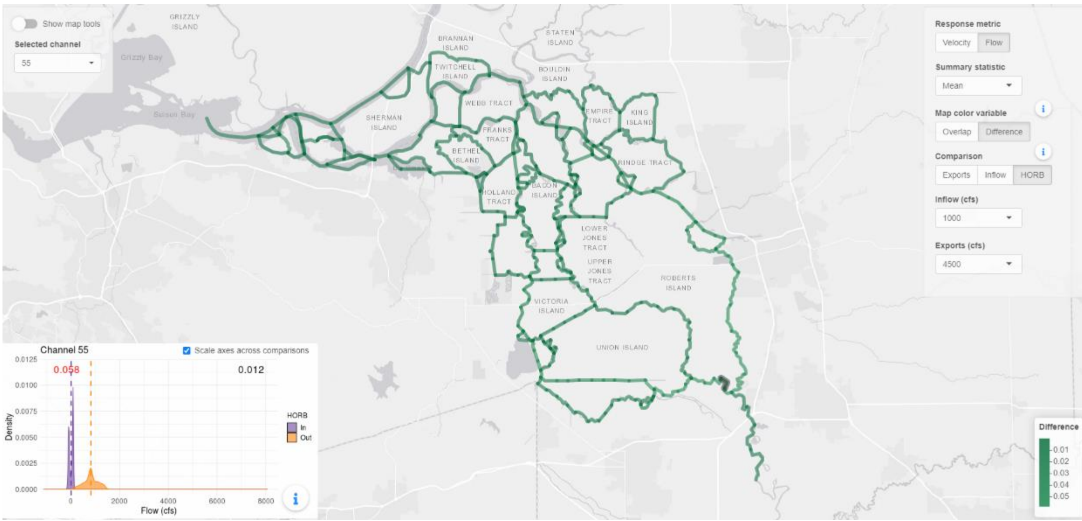



Figure 9. Heat Map of Flow Differences in the Delta and in the Old River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 1,000 cfs and Exports at 4,500 cfs

### 5.2.2 Head of Old River Barrier Effects on Velocity

With San Joaquin River inflow at 1,000 cfs and exports at 1,500 cfs, installation of the HORB altered flow velocities on the San Joaquin River from upstream of Head of Old River to the region near Turner Cut (Figure 10; Table 1). Velocity changes were most pronounced in the Old River downstream of Head of Old River where at channel 55, overlap was only 10 percent, with velocities becoming lower and more strongly bimodal when the HORB was in place. Farther downstream in the Old River at channels near CVP and Railroad Cut, overlap was higher with values of 95.8% and 96.5%, respectively, and the distribution was shifted toward slightly lower velocities with the barrier in place.

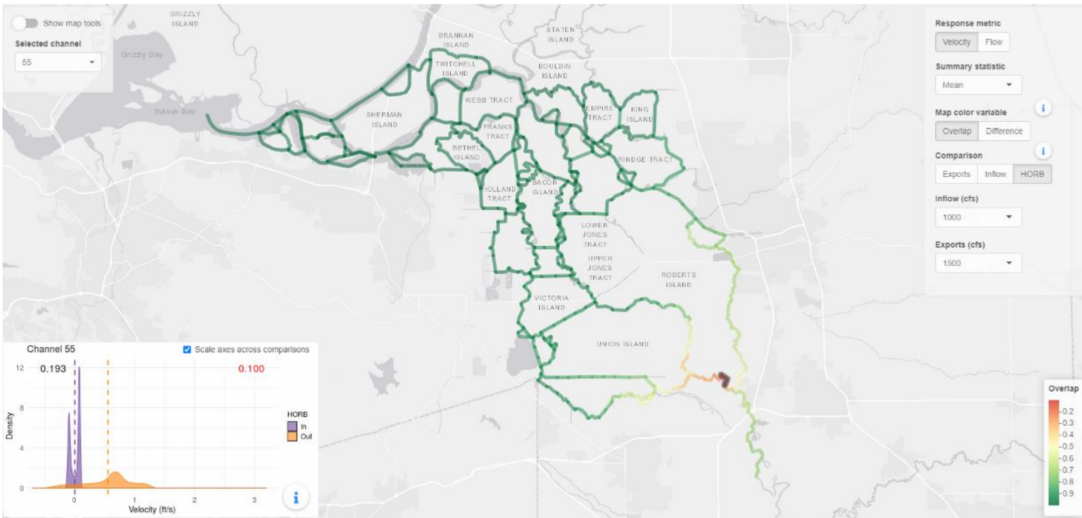



Figure 10. Heat Map of Velocity Overlap in the Delta and in the Old River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 1,000 cfs and Exports at 1,500 cfs

In the San Joaquin River, velocity effects were greatest just downstream of Head of Old River where the distribution of velocities shifted higher with the barrier in place (58.6% overlap; Figure 11). Upstream of Head of Old River, velocities shifted lower with the barrier in place (67.4% overlap), suggesting that the barrier creates a backwater effect upstream of Head of Old River that reduces velocities. Near Turner Cut, overlap in velocity distributions was high (91.0%).

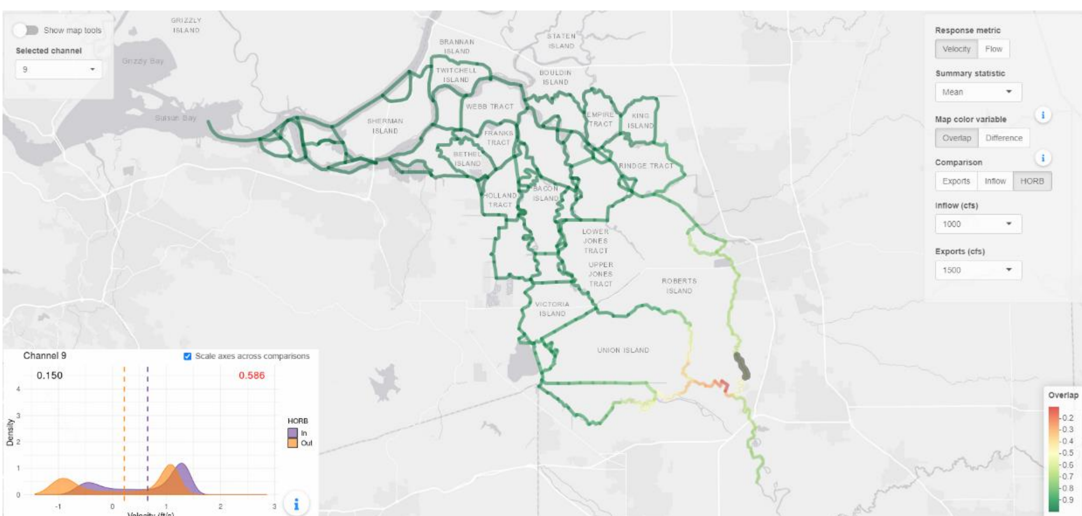



Figure 11. Heat Map of Velocity Overlap in the Delta and in the San Joaquin River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 1,000 cfs and Exports at 1,500 cfs

Table 1. Percent Overlap of Velocity Distributions at Key Locations in the Delta in Response to Head of Old River Barrier Installation under Two San Joaquin Inflow Levels and Two Export levels

| **Inflow** | **1,000 cfs** | | **4,500 cfs** | |
|---|---|---|---|---|
| **Exports** | **1,500 cfs** | **4,500 cfs** | **1,500 cfs** | **4,500 cfs** |
| SJR upstream of HOR | 67.4 | 68.8 | 2.4 | 2.1 |
| SJR downstream of HOR | 58.6 | 52.3 | 4.3 | 3.9 |
| SJR near Turner Cut | 91.0 | 89.2 | 74.2 | 73.7 |
| OR downstream of HOR | 10.0 | 1.8 | 0.0 | 0.0 |
| OR near CVP | 95.8 | 94.5 | 82.8 | 82.0 |
| OR near Railroad Cut | 96.5 | 95.9 | 88.1 | 88.6 |

cfs = cubic feet per second; CVP = Central Valley Project; HOR = Head of Old River; OR = Old River; SJR = San Joaquin River.

Increasing San Joaquin River flow to 4,500 cfs while holding exports at 1,500 cfs increased the magnitude and extent of the effects described above and the pattern and direction of velocity effects were similar (Figure 12; Table 1). Reductions in velocity distribution overlap were greatest at upstream stations in both the Old River and the San Joaquin River (0%–4.3% overlap) and attenuated downstream as velocity distributions became more bimodal (tidal) with overlap values of 74.2% and 88.1% at Turner Cut and Railroad Cut, respectively.

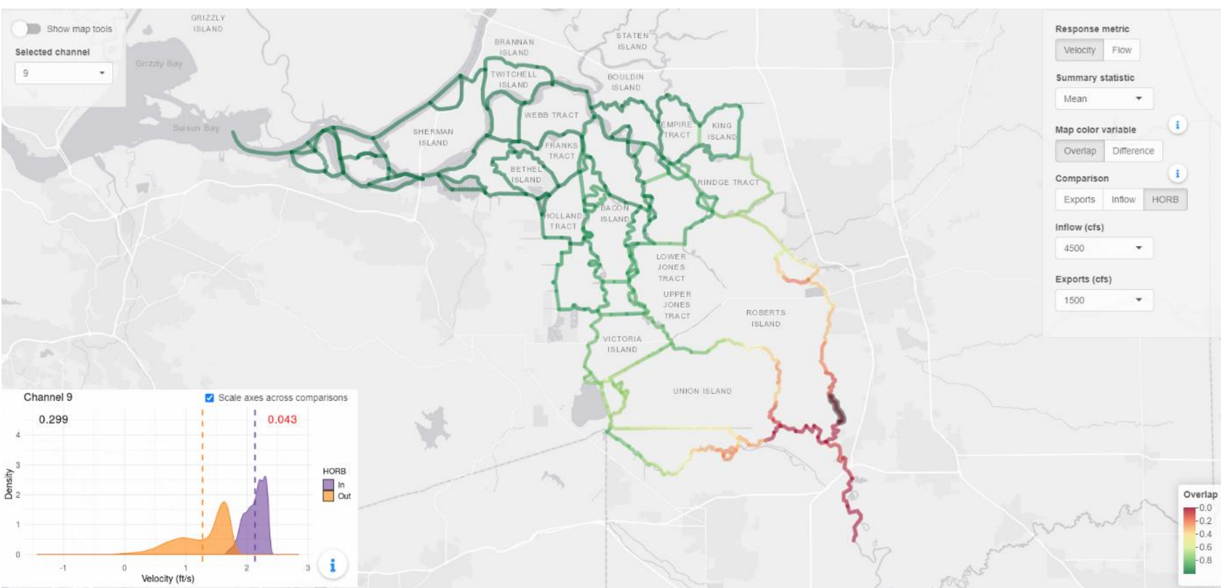



Figure 12. Heat Map of Velocity Overlap in the Delta and in the San Joaquin River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 4,500 cfs and Exports at 1,500 cfs

Increasing exports to 4,500 cfs while keeping San Joaquin River flow at 1,000 cfs did not appreciably change barrier effects on velocity overlap relative to exports at 1,500 cfs (Table 1). The location with the greatest change was in the Old River just downstream of Head of Old River where overlap was 1.8% with exports at 4,500 cfs and 10% with exports at 1,500 cfs. In more downstream areas where hydrology is strongly tidal, the effect of exports was minimal at both inflow levels (Table 1).

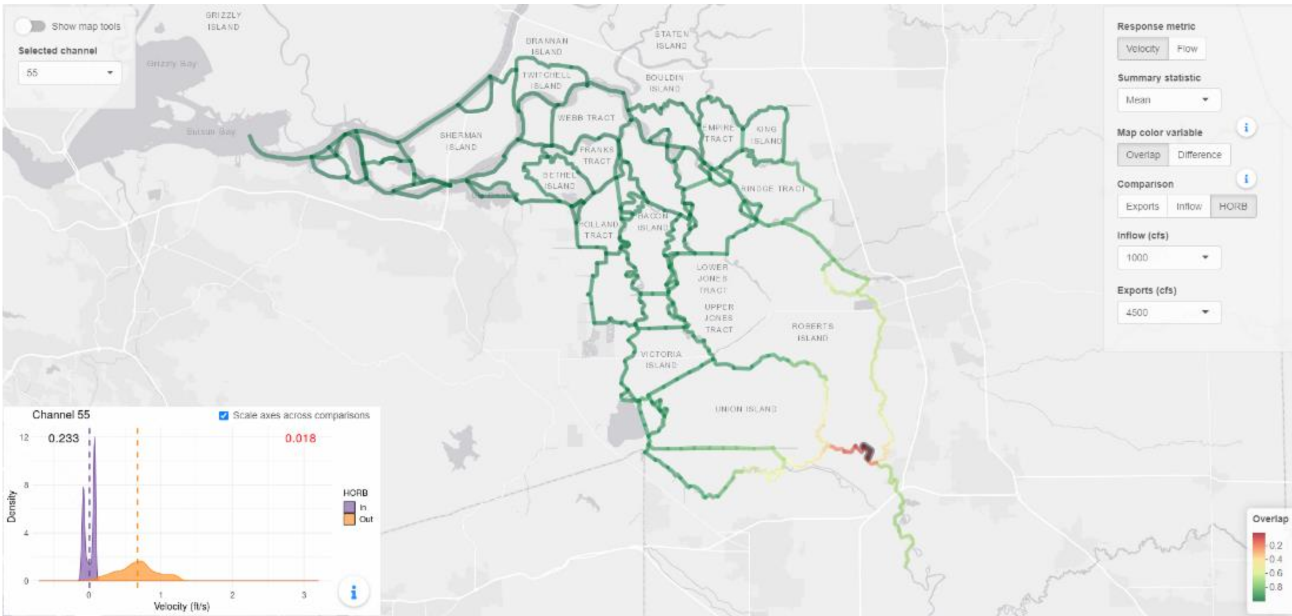



Figure 13. Heat Map of Velocity Overlap in the Delta and in the San Joaquin River Downstream of Head of Old River as a Result of Head of Old River Barrier Installation with San Joaquin River Flow at 1,000 cfs and Exports at 4,500 cfs

### 5.2.3 Summary of DSM2 Analysis

Across the four DSM2 simulations, some general patterns emerged regarding flow and velocity effects of the HORB. With the HORB in place, flows in the Old River upstream of the facilities became more bimodal and more frequently bidirectional. In the San Joaquin River downstream of HORB, flows increased and flow direction was downstream more often. In more tidal reaches of the Delta like the Old River at Railroad Cut and the San Joaquin River at Turner Cut, the barrier had little influence on flows. As inflow increased to 4,500 cfs, the effects of flow at the stations downstream of HORB were amplified whereas more muted effects were seen downstream in the more tidal reaches. Exports appeared to have only minor effects on flows, primarily in the Old River just downstream of Head of Old River.

Analysis of velocity distributions revealed a similar pattern to flow where the strongest effects occurred at the more upstream reaches and more muted effects were seen in tidal reaches. Inflow had a greater influence than exports on velocity changes related to barrier presence. An interesting pattern was revealed in the San Joaquin River upstream of Head of Old River—when the barrier was present, velocities upstream decreased while velocities downstream increased. Thus, the barrier appears to create a backwater condition upstream. Formal survival analyses have focused on reaches downstream of Head of Old River. However, the effect of the HORB on survival upstream of Head of Old River as a result of reduced velocity warrants consideration.

# 6. Initial Options Analysis

Page Intentionally Left Blank

# 7. Conclusions

**How does presence of the barrier affect survival to Chipps Island compared to a combined salvage and San Joaquin route without the barrier?**

With the barrier, fewer fish enter Head of Old River and more fish enter the lower San Joaquin River. This may be a benefit for steelhead, which experience an increase in survival with flow in the reach between Head of Old River and Turner Cut. However, there may be a trade-off in the San Joaquin River upstream of Head of Old River, where velocities decline with the barrier in place and steelhead survival appears to decline. For Chinook salmon, there is little difference in survival between the two routes, and acoustic tagging suggests salvage at CVP may be the route with the highest survival. For both species, survival is lower for fish that enter Turner Cut (and presumably the other junctions) as hydrology at these junctions is primarily affected by tides rather than inflow, exports, or barrier status. When more fish are routed into the San Joaquin River at Head of Old River, more would also be expected to be entrained into Turner Cut and other downstream junctions where survival is reduced. Multiple years of salmonid acoustic telemetry suggest survival through the salvage facilities may be the route with the highest survival for San Joaquin River steelhead. Entrainment loss accounted for less than 5% of the total mortality for a majority of CWT releases of San Joaquin River Chinook salmon.

**What is the effect of flow and fish routing at the Head of Old River on steelhead population viability?**

We do not yet have a model to evaluate this question.

**What is the effect of the barrier on Delta hydrodynamics?**

See summary of results in Attachment R.1.

**How much additional flow is routed down the San Joaquin River when the barrier is present?**

See summary of results in Attachment R.1.

Page Intentionally Left Blank

# 8. References

Buchanan, R. A., and J. R. Skalski. 2020. Relating Survival of Fall-Run Chinook Salmon through the San Joaquin Delta to River Flow. Environmental Biology of Fishes 103(5):389–410.

Buchanan, R.A., J.R. Skalski, P.L. Brandes, and A. Fuller. 2013. Route use and survival of juvenile Chinook salmon through the San Joaquin River Delta. North American Journal of Fisheries Management 33(1).

Buchanan, R., P.Brandes, and J.Skalski. 2018. Survival of juvenile fall-run Chinook Salmon through the San Joaquin River Delta, CA, 2010-2015. North American Journal of Fisheries Management. 38:663-679.

Cavallo, B., P. Gaskill, J. Melgo, and S. C. Zeug. 2015. Predicting Juvenile Chinook Salmon Routing in Riverine and Tidal Channels of a Freshwater Estuary. Environmental Biology of Fishes 98(6):1571–1582.

Monismith, S., M. Fabrizio, M. Healey, J. Nestler, K. Rose, and J. Van Sickle. 2014. Workshop on the Interior Delta Flows and Related Stressors, Panel Summary Report.

Newman, K. 2008. An evaluation of four Sacramento-San Joaquin River Delta juvenile salmon survival studies. USFWS. Stockton, CA.

Zeug, S. C., and B. J. Cavallo. 2014. Controls on the Entrainment of Juvenile Chinook Salmon (Oncorhynchus tshawytscha) into Large Water Diversions and Estimates of Population-Level Loss. PLoS ONE 9(7):e101479.

Page Intentionally Left Blank

# R.1 Attachment 1: Head of Old River Barrier CalSim II Analysis

The purpose of the springtime Head of Old River Barrier (HORB) is to improve migration conditions for salmonids entering the Sacramento–San Joaquin Delta (Delta) from the San Joaquin River and its tributaries by preventing salmonids from entering the Old River and being entrained into the Central Valley Project (CVP) and State Water Project (SWP) water export facility and by increasing flows down the San Joaquin River.

## R.1.1 Assumptions

This CalSim II analysis compares two scenarios: the No Action Alternative (NAA) and the alternative with the HORB (With Barrier alternative). The NAA is described as Revised Alternative 1 in Appendix F1 of the 2019 Reinitiation of Consultation on Long-Term Operation of the CVP and SWP; it also includes additional SWP operations for implementing the 2020 Incidental Take Permit (ITP). The NAA uses hydrology projected at 2035 (2035 Central Tendency). Information on the updated modeling can be found on the CalSim Model Maintenance Management repository at github.com/usbr/cm3. The model assumed full Sacramento River Settlement Contractors (SRSC) contract amounts and that there are no daily components to the Wilkins Slough flow requirement. The With Barrier alternative is based on the NAA, and it includes the HORB being implemented for 16 days in April and the full month of May.

## R.1.2 Results

### R.1.2.1 Flow from Head of Old River

The placement of the barrier is at the Head of Old River where inflows from the San Joaquin River enter the Old River. Flows at the bifurcation are reduced with the barrier in place, which limits the volume of water that flows downstream into the Old River.

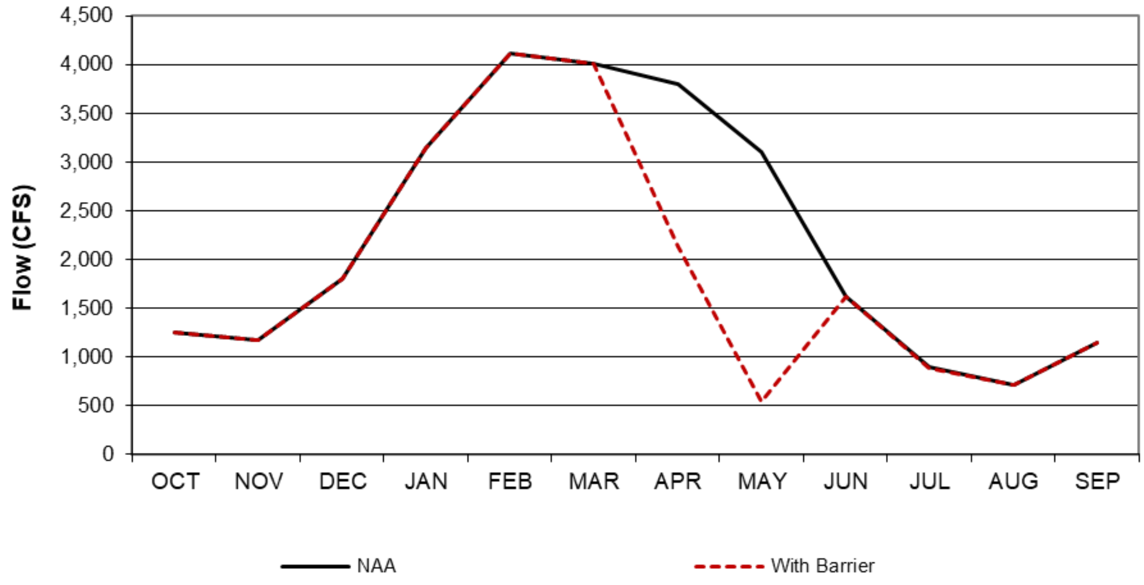



Figure R.1-1. Monthly Pattern of San Joaquin River Inflow into the Head of Old River

Figure R.1-1 shows the average monthly flows at the Head of Old River. Total flow into the south Delta is reduced by an average of 256 thousand acre-feet (TAF) over the April-May period, where monthly reductions could be as high as three times of the long-term average. Because of the loss of flow from the San Joaquin River toward export facilities, pumping at Jones and Banks Pumping Plants results in a more negative Old and Middle River (OMR) flow for the same volume of export in those months.

### R.1.2.2 OMR Flow

During April and May, the addition of the barrier in the With Barrier alternative blocks salmonids from entering the Old River, but also limits flow from the San Joaquin River into the south Delta. In response, there is a more negative OMR flow for an equal volume of export through the south Delta facilities.

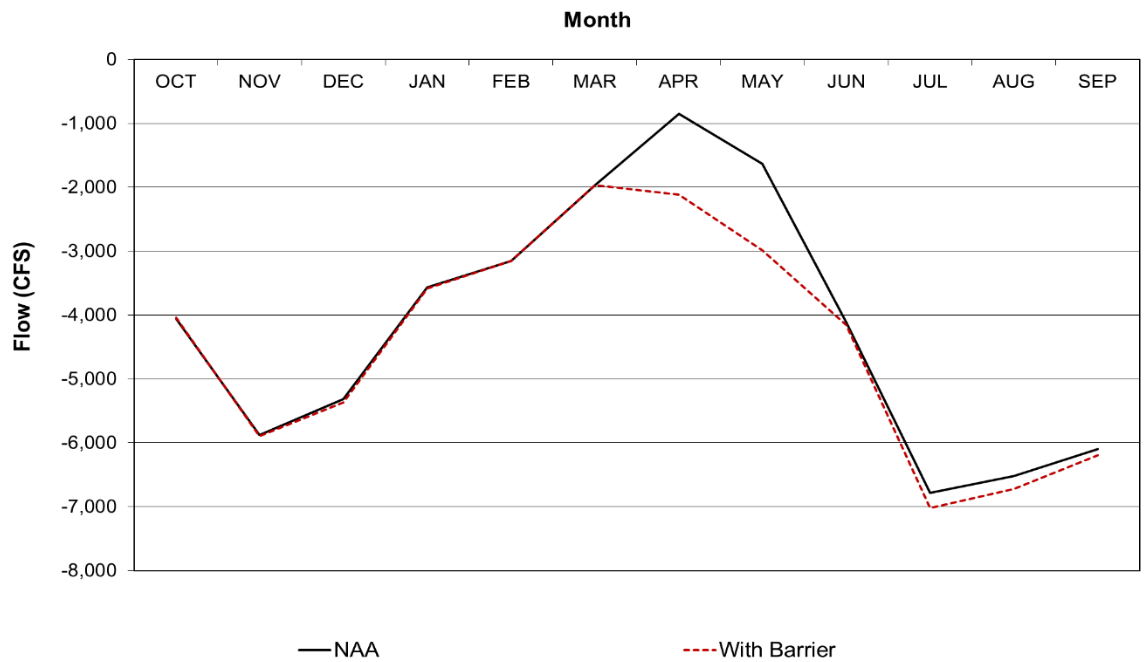



Figure R.1-2. Long-Term Average Monthly Pattern of Old and Middle River Flow

Figure R.1-2 shows the direct effect of the more negative OMR flows under the With Barrier alternative because of the decreased San Joaquin River inflow in April and May.

Table R.1-1. Number of Times that Central Valley Project Exports are Limited by Old and Middle River Constraints

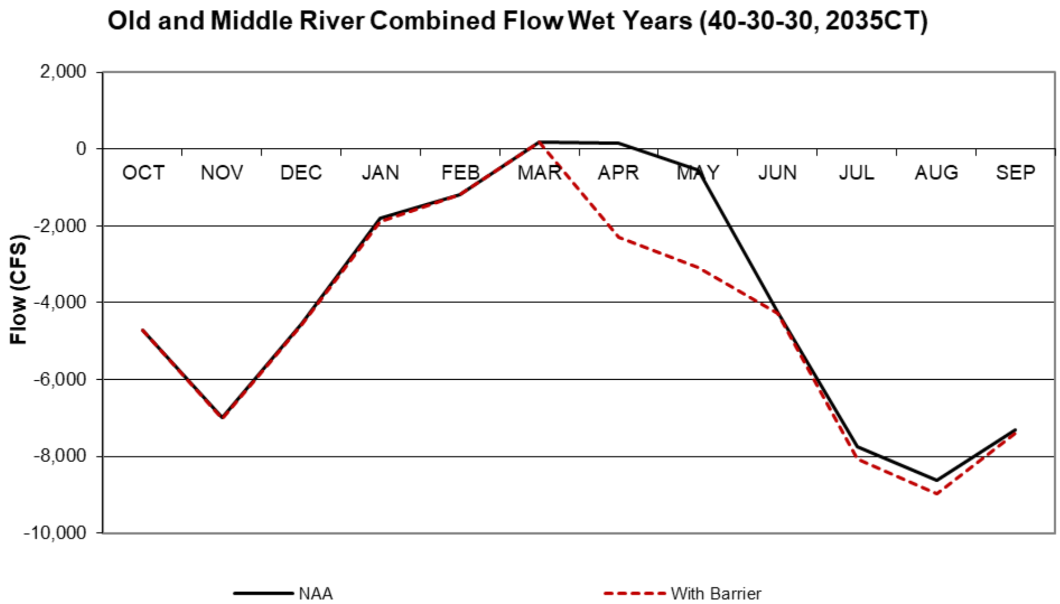
| CVP | December | January | February | March | April | May | June |
|---|---|---|---|---|---|---|---|
| **NAA** | 69 | 82 | 81 | 81 | 52 | 41 | 69 |
| **With Barrier** | 71 | 82 | 80 | 81 | 61 | 53 | 70 |

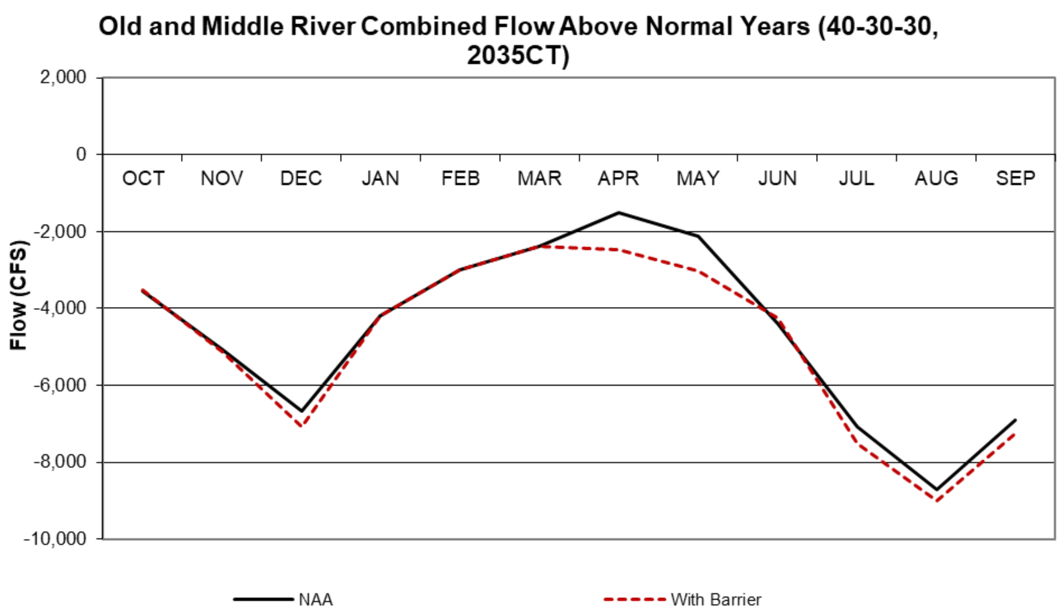
Table R.1-2. Number of Times that State Water Project Exports are Limited by Old and Middle River Constraints

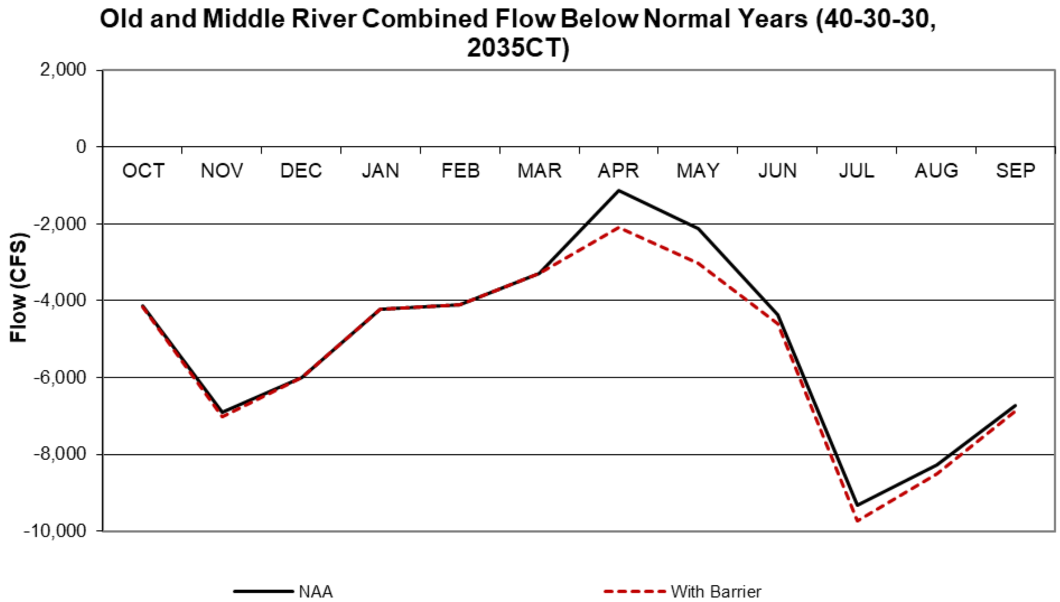
| SWP | December | January | February | March | April | May | June |
|---|---|---|---|---|---|---|---|
| **NAA** | 72 | 81 | 82 | 81 | 24 | 35 | 71 |
| **With Barrier** | 74 | 81 | 81 | 81 | 27 | 37 | 75 |

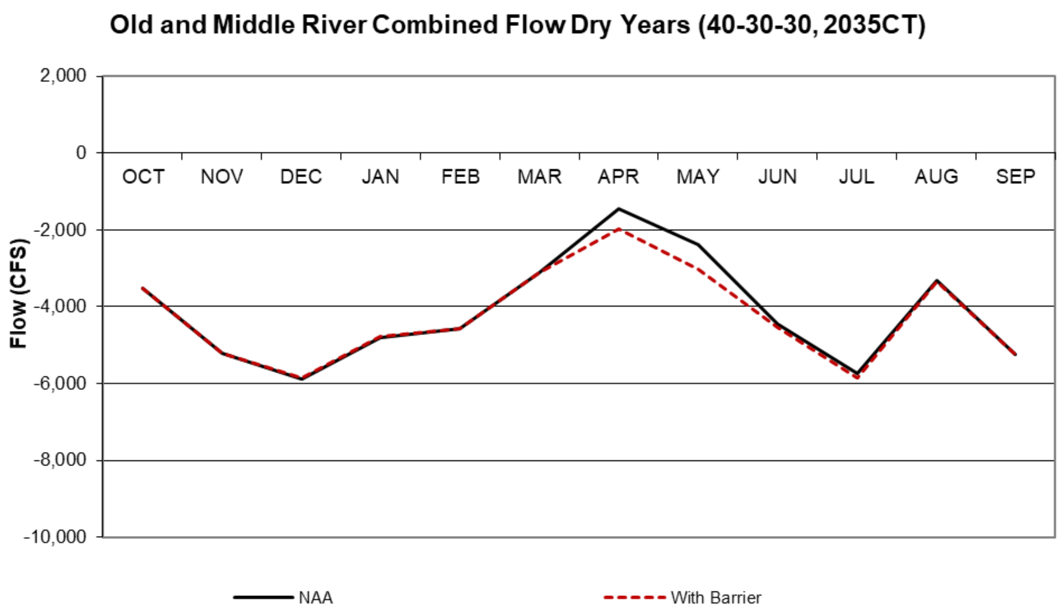
Tables R.1-1 and R.1-2 show the number of times that OMR limits control exports in each month. In the With Barrier scenario, the CVP uses all its share of export capacity until it reaches the OMR limit in 9 additional Aprils and 12 additional Mays. The SWP has less opportunity to use its share of export capacity until it reaches the OMR limit due to SWP 2020 ITP's San

Joaquin River inflow/export–based export limits. Additional OMR flow cannot make up for the total flow change from the Old River, and the overall reduction in exports in April and May results in increased pumping in July through September. Higher pumping in those months is needed to counteract lower volumes of water stored in the San Luis Reservoir in April and May.




Old and Middle River Combined Flow Below Normal Years (40-30-30, 2035CT)
2,000
0
-2,000
-4,000
-6,000
-8,000
-10,000
Flow (CFS)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Old and Middle River Combined Flow Dry Years (40-30-30, 2035CT)
2,000
0
-2,000
-4,000
-6,000
-8,000
-10,000
Flow (CFS)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier

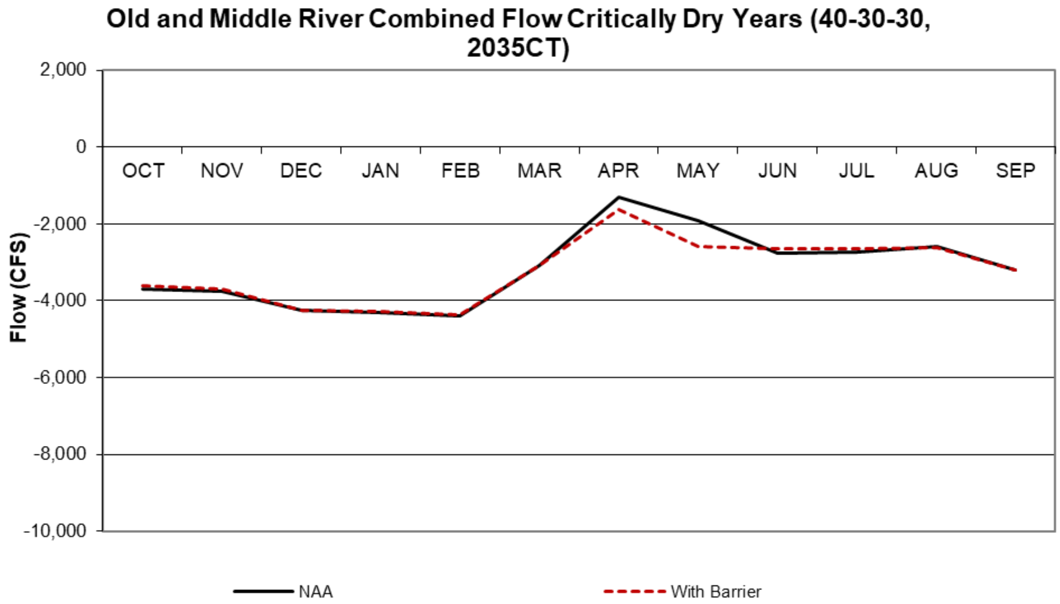



Figure R.1-3. Monthly Pattern of Old and Middle River Flow by Water Year Type

Figure R.1-3 shows that for the most part, the same trends that occur in the long-term average apply in all water year types.

### R.1.2.3 Exports

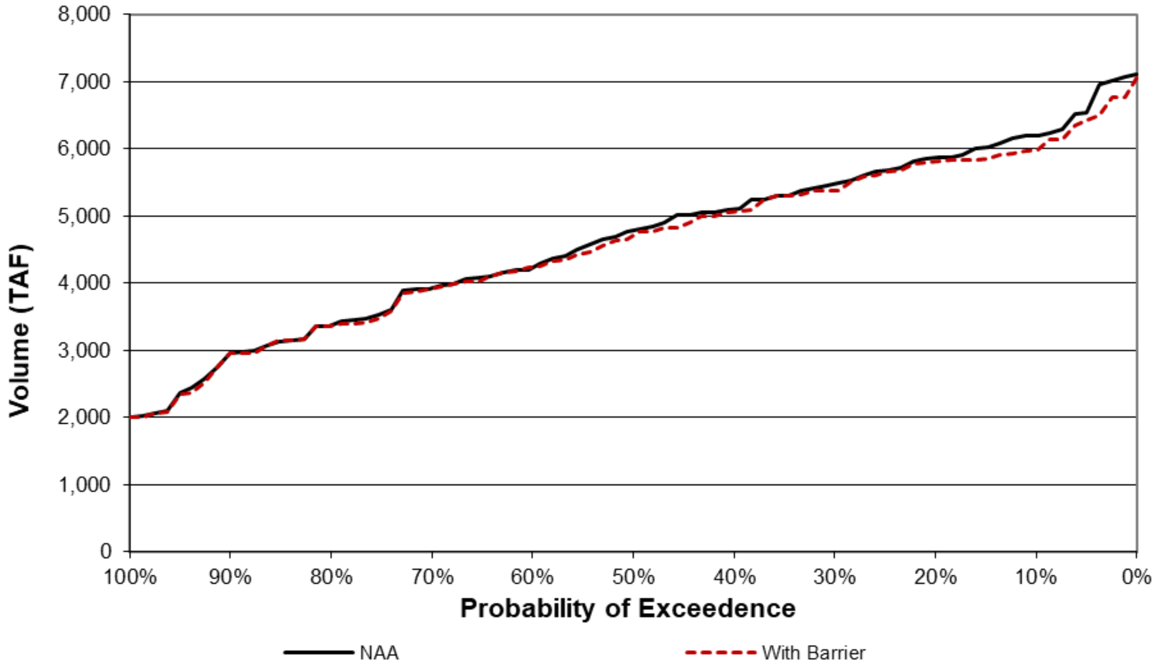
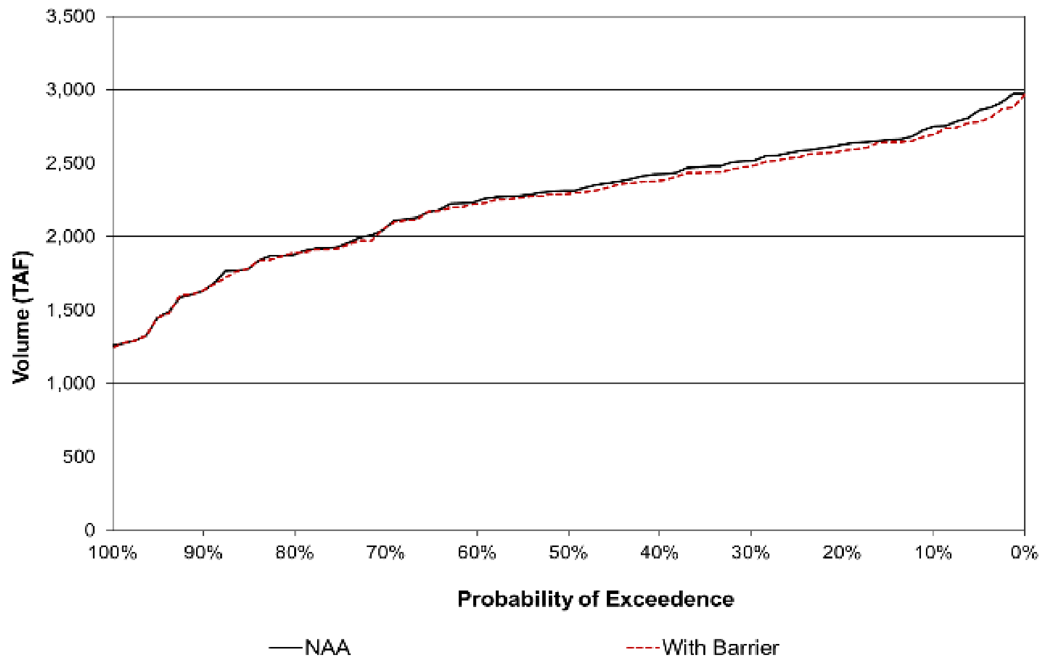



Figure R.1-4. Annual Exceedance of Total Exports (October–September)

Table R.1-3. Annual Total Exports by Water Year Type (October–September) (cfs)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 4,639 | 5,969 | 4,950 | 4,862 | 3,611 | 2,652 |
| **With Barrier** | 4,572 | 5,826 | 4,876 | 4,840 | 3,595 | 2,629 |

In general, the With Barrier alternative has decreased exports when compared to the NAA because more of the export water needs to come through the OMR and restrictions on negative OMR flow are more likely to control exports. Figure R.1-4 shows that the decrease in exports under the With Barrier alternative tends to happen in wetter years while exports are very similar between the two alternatives in the drier 40% of years.



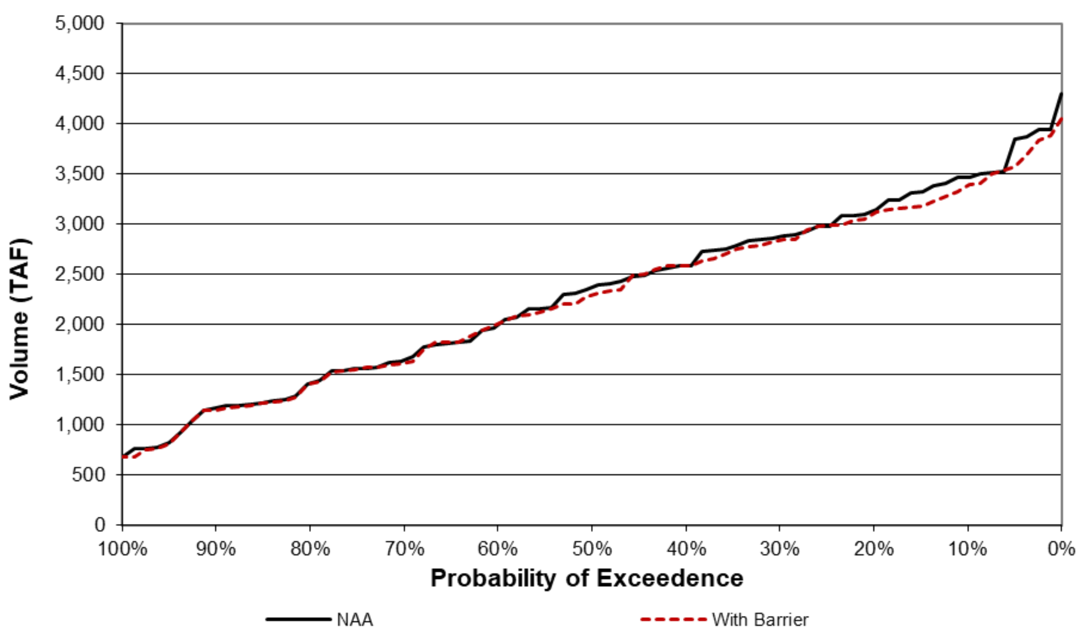




Figure R.1-5. Annual Exceedance of Jones (Above) and Banks (Below) Pumping Plant Exports (October–September)

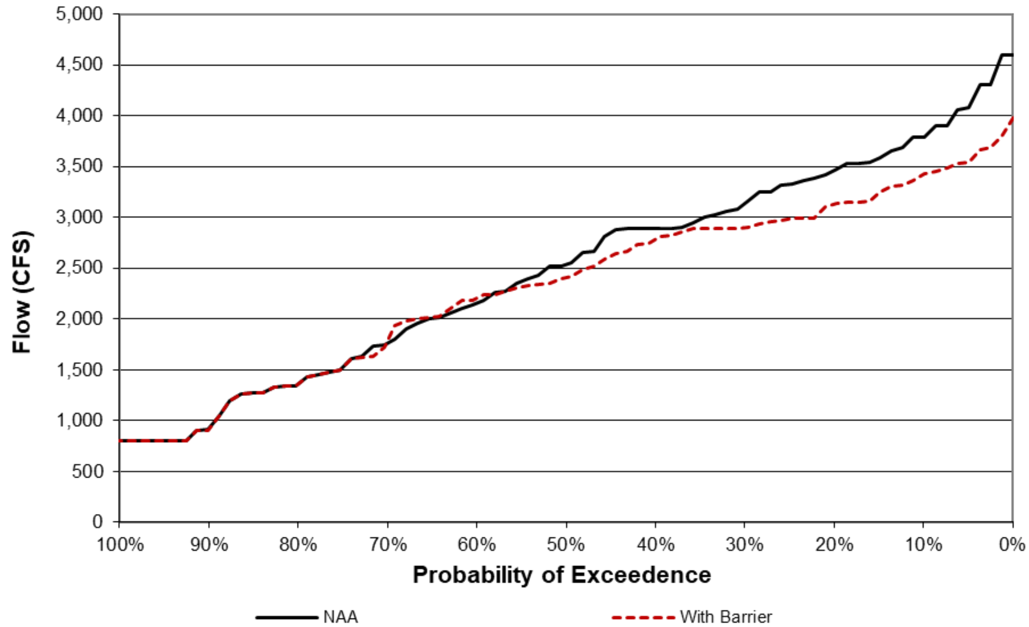
When Banks and Jones annual pumping is split up, Figure R.1-5 shows that they have the same trends as the combined total annual pumping.

Table R.1-4. Annual Jones Pumping Plant Export by Water Year Type (October–September)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 2,257 | 2,621 | 2,347 | 2,343 | 2,056 | 1,557 |
| **With Barrier** | 2,233 | 2,579 | 2,301 | 2,327 | 2,047 | 1,559 |

Table R.1-5. Annual Banks Pumping Plant Export by Water Year Type (October–September) (cfs)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 2,309 | 3,248 | 2,538 | 2,444 | 1,498 | 1,055 |
| **With Barrier** | 2,267 | 3,151 | 2,509 | 2,428 | 1,493 | 1,036 |



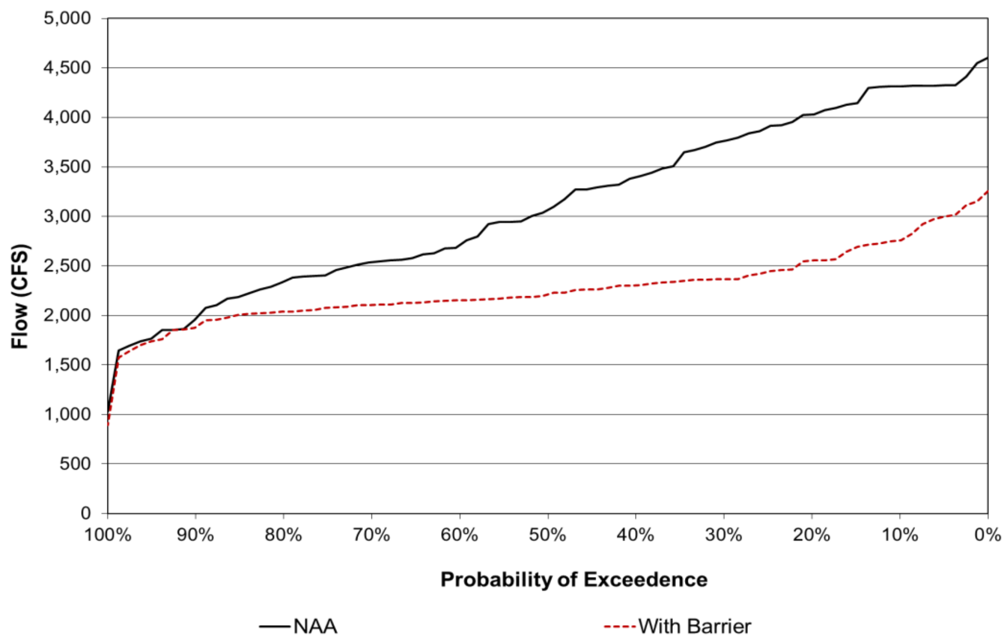




Figure R.1-6. Exceedance for April (Left) and May (Right) Jones Pumping Plant

As shown in Figure R.1-6, during April and May when the barrier is in place under the With Barrier alternative, the barrier has a much larger effect on Jones Pumping Plant pumping in May than it does in April. This is because the barrier is only in place for half of April while it is in place for all of May.

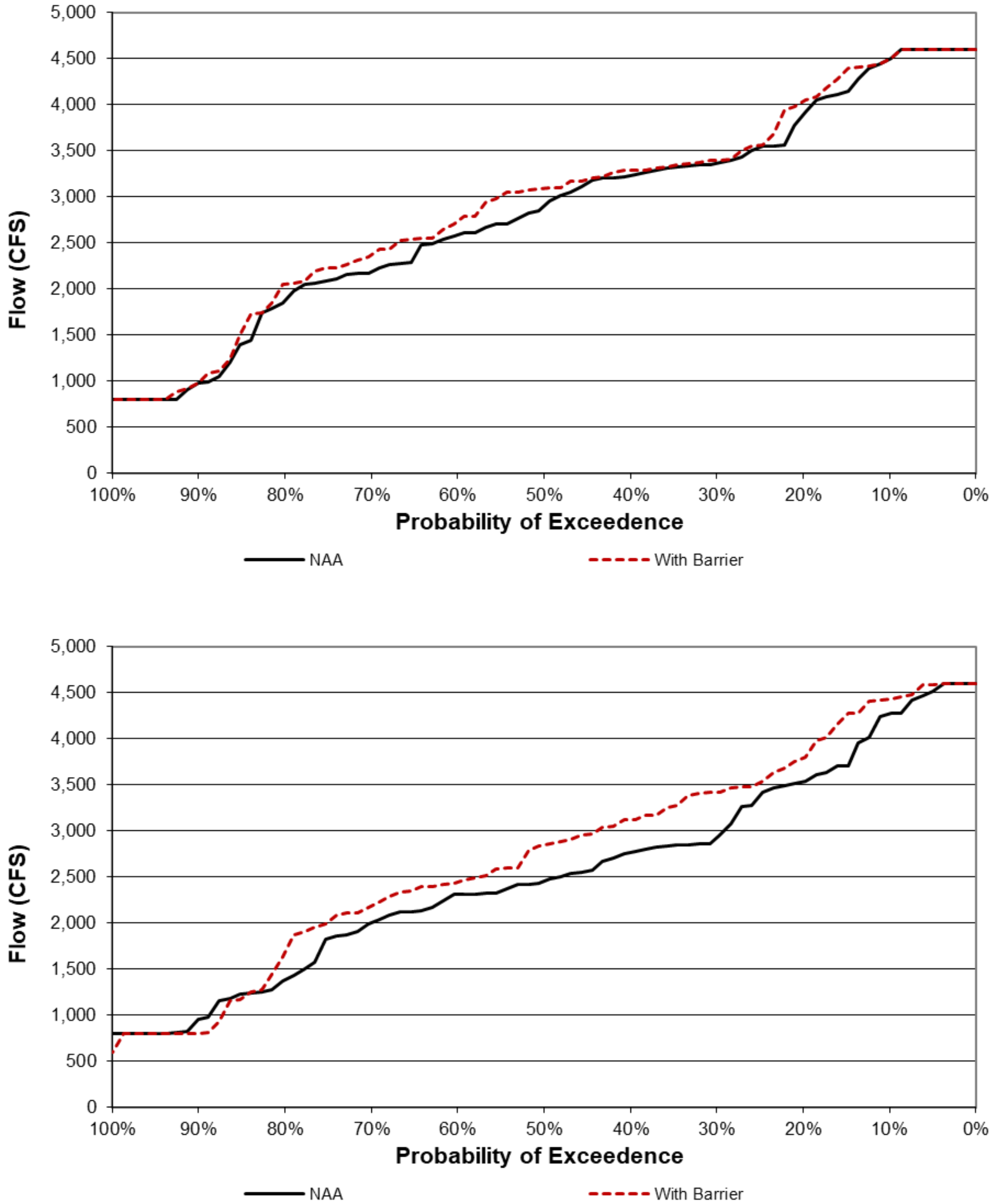
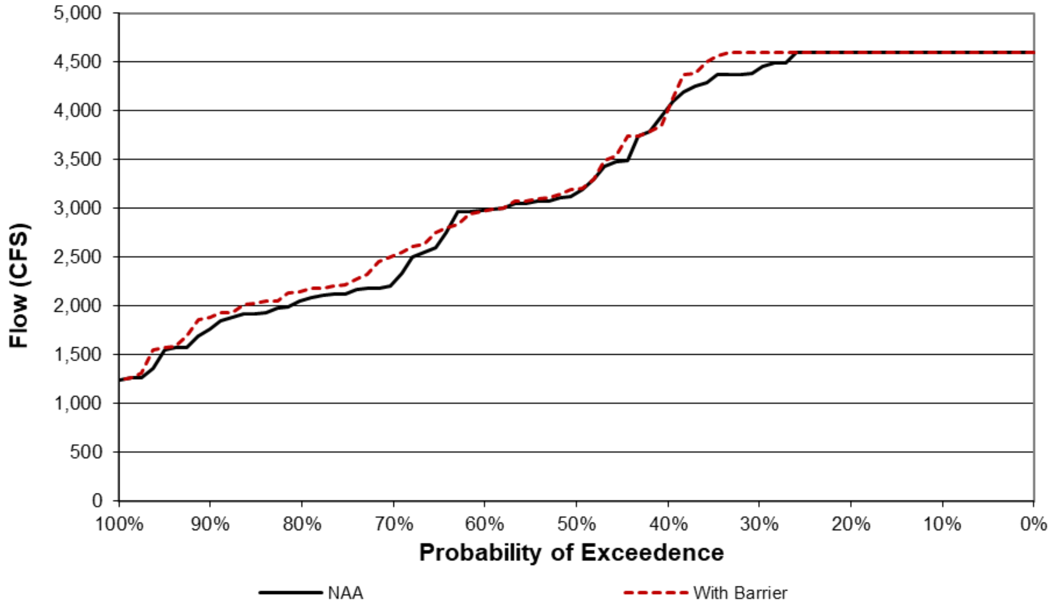



Figure R.1-7. Exceedance for June (Above) and July (Below) Jones Pumping Plant



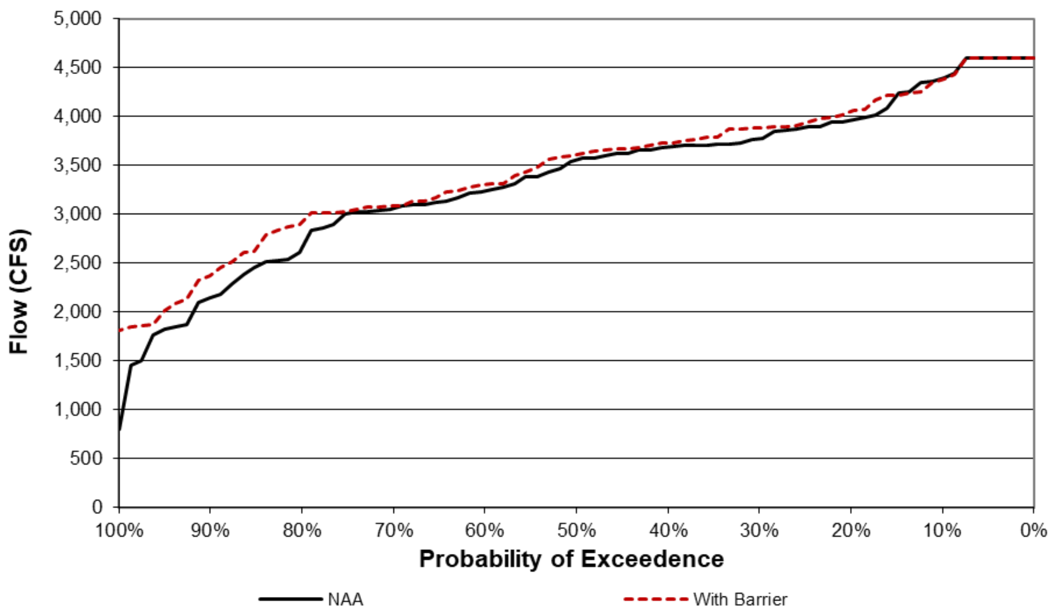
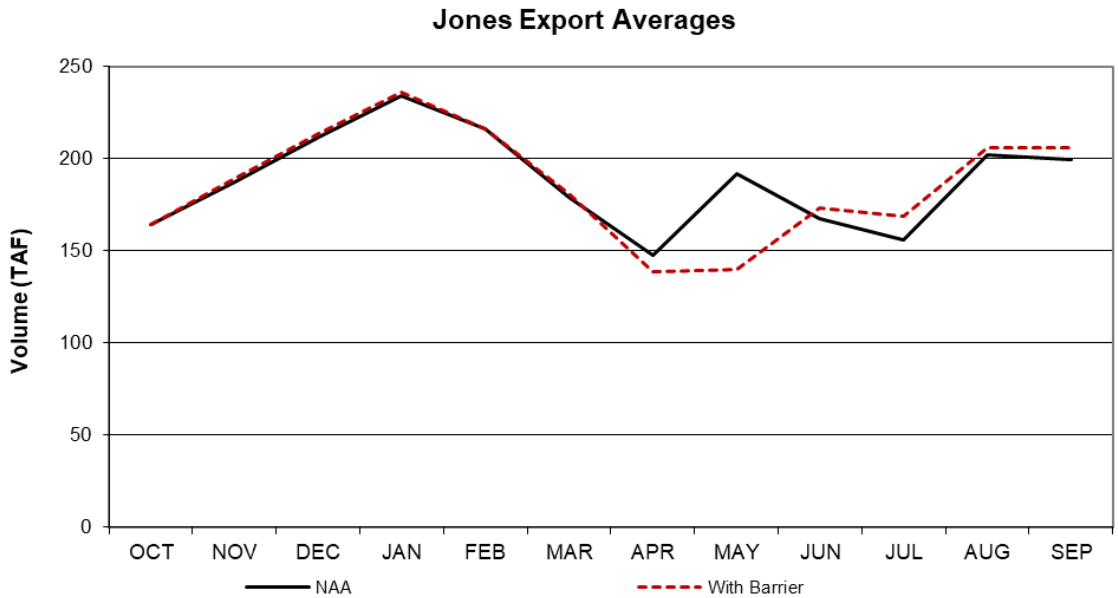
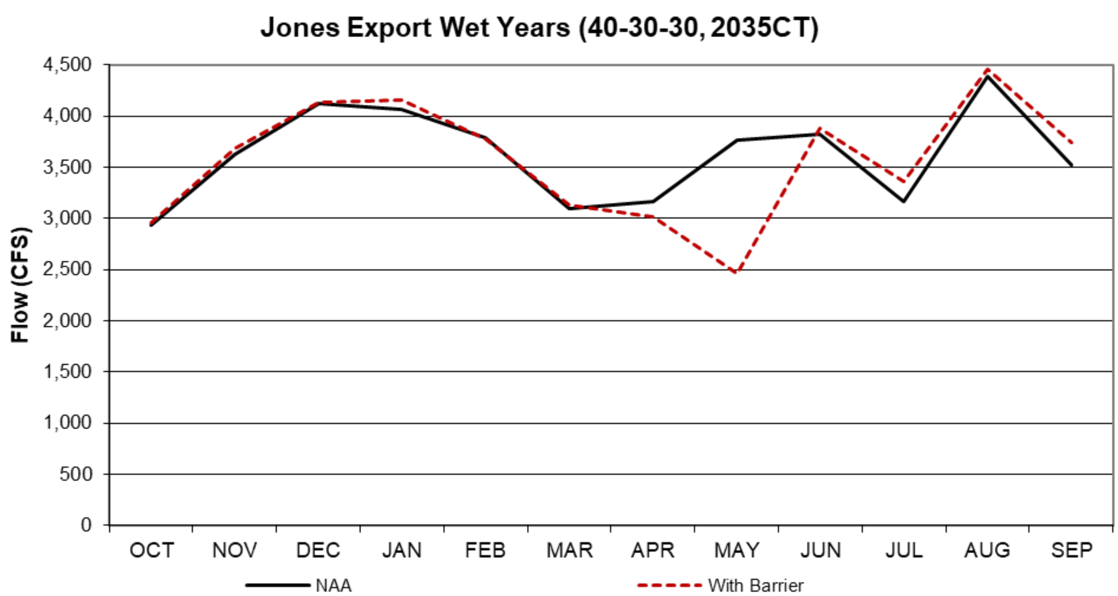
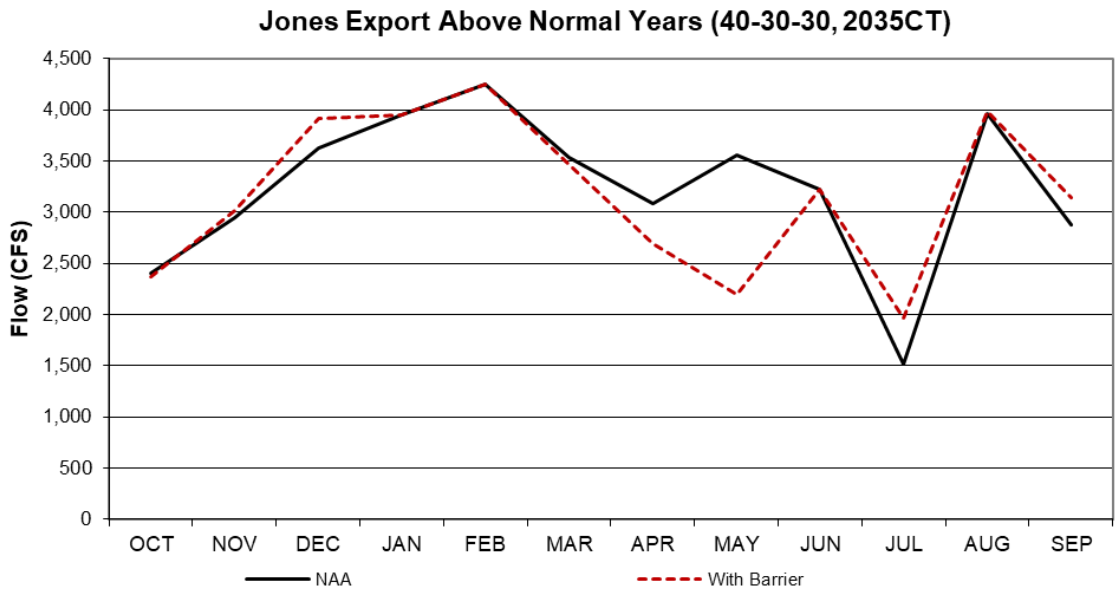



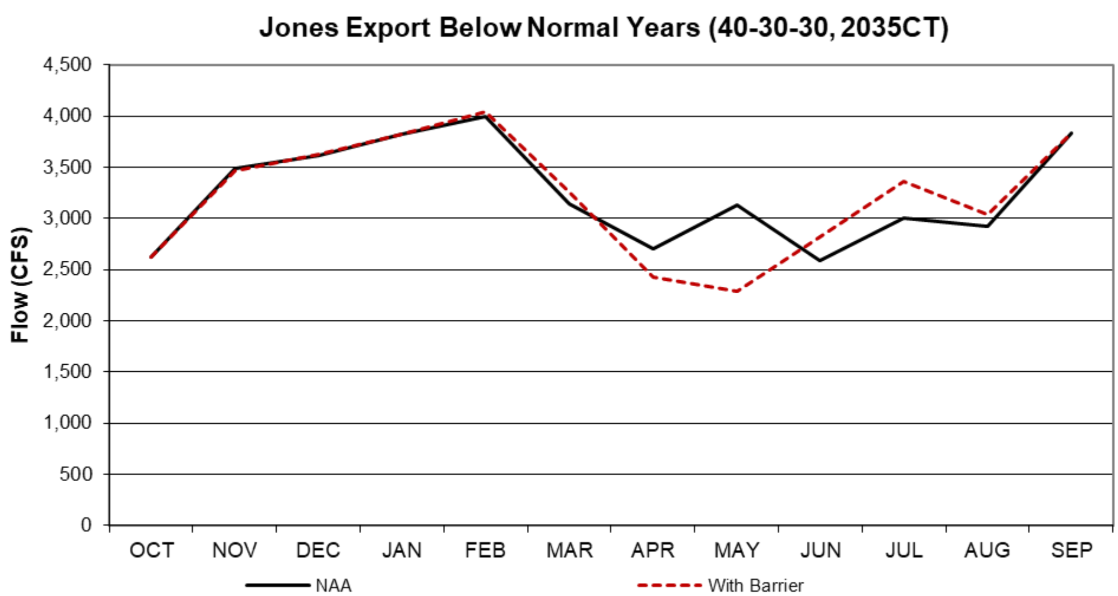

Figure R.1-8. Exceedance for August (Above) and September (Below) Jones Pumping Plant

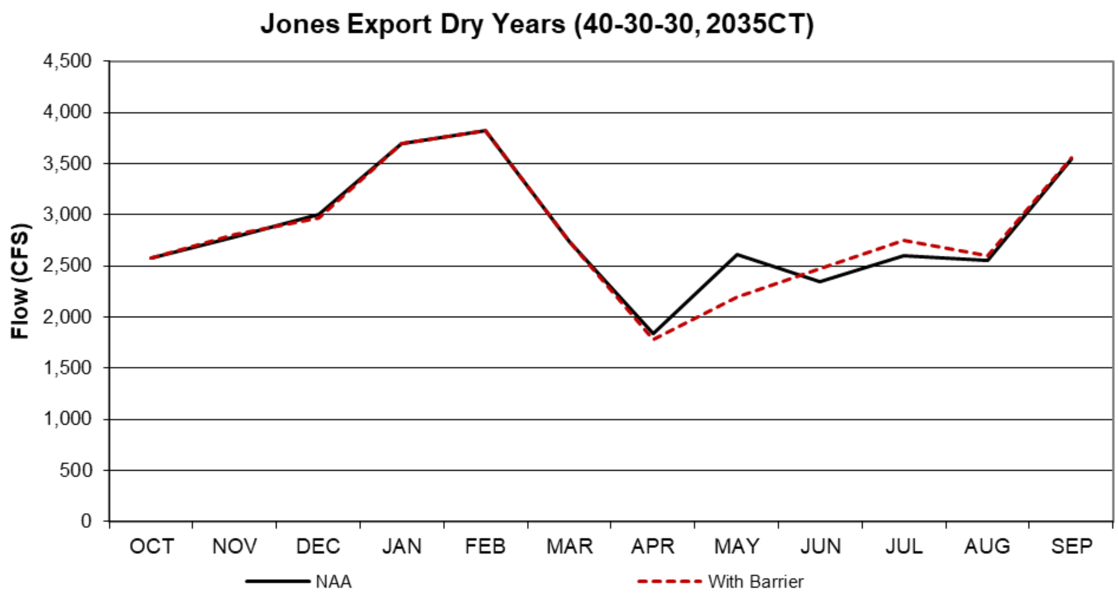
Figures R.1-7 and R.1-8 show that for the remainder of the water year, from June through September, the With Barrier alternative requires increased pumping at the Jones Pumping Plant in response to decreased pumping in April and May. However, the increase in pumping from June through September does not make up for the deficit in pumping during April and May.


Jones Export Averages
Volume (TAF)
250
200
150
100
50
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Jones Export Wet Years (40-30-30, 2035CT)
Flow (CFS)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Jones Export Above Normal Years (40-30-30, 2035CT)
Flow (CFS)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Jones Export Below Normal Years (40-30-30, 2035CT)
Flow (CFS)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier



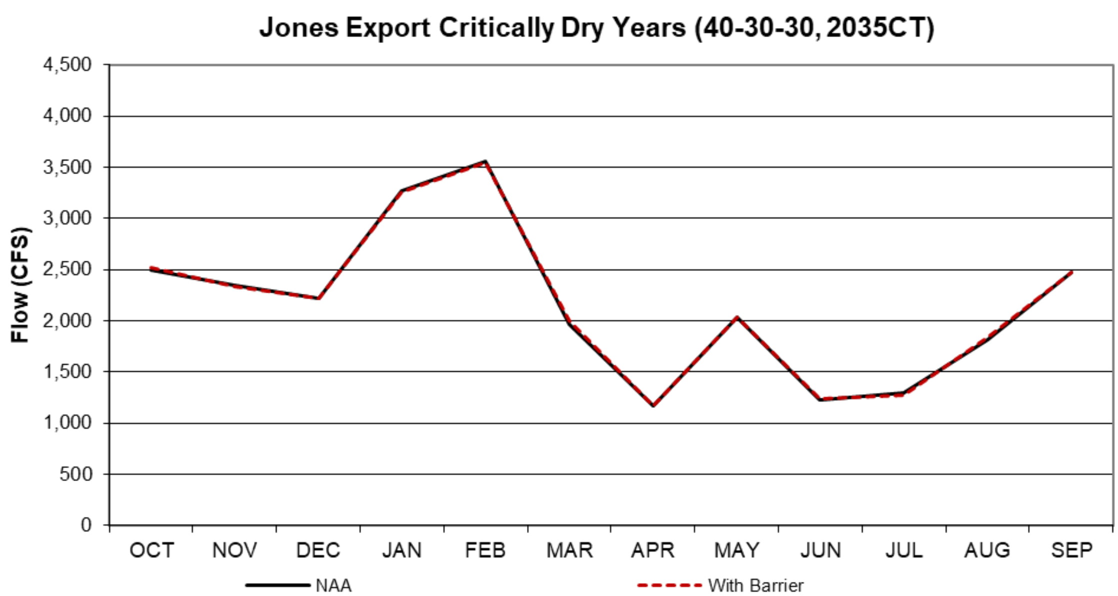




Figure R.1-9. Monthly Pattern of Jones Pumping Plant Pumping by Water Year Type

For Jones Pumping Plant, Figure R.1-9 shows that all water year types except critically dry years show a similar difference in the pumping monthly pattern between the alternatives. For critically dry years, the NAA and With Barrier alternative have the same monthly pattern.

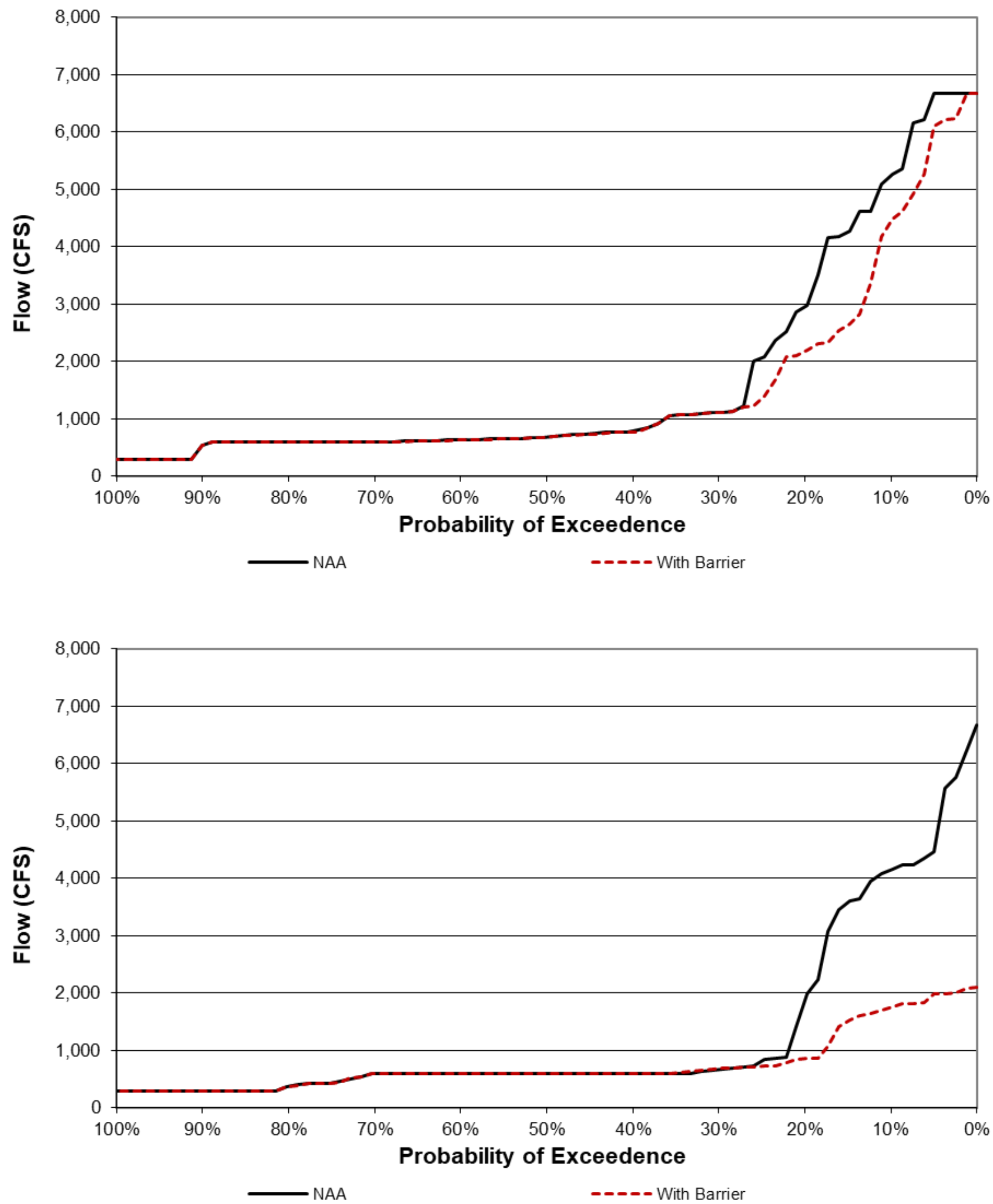



Figure R.1-10. Exceedance for April (Above) and May (Below) Banks Pumping Plant

Similar to the Jones Pumping Plant, pumping at the Banks Pumping Plant has a larger decrease in May than April due to the duration for which the barrier is in place in the respective months. However, Figure R.1-10 shows that the decrease in pumping at the Banks Pumping Plant is primarily in the wetter 25% of years.

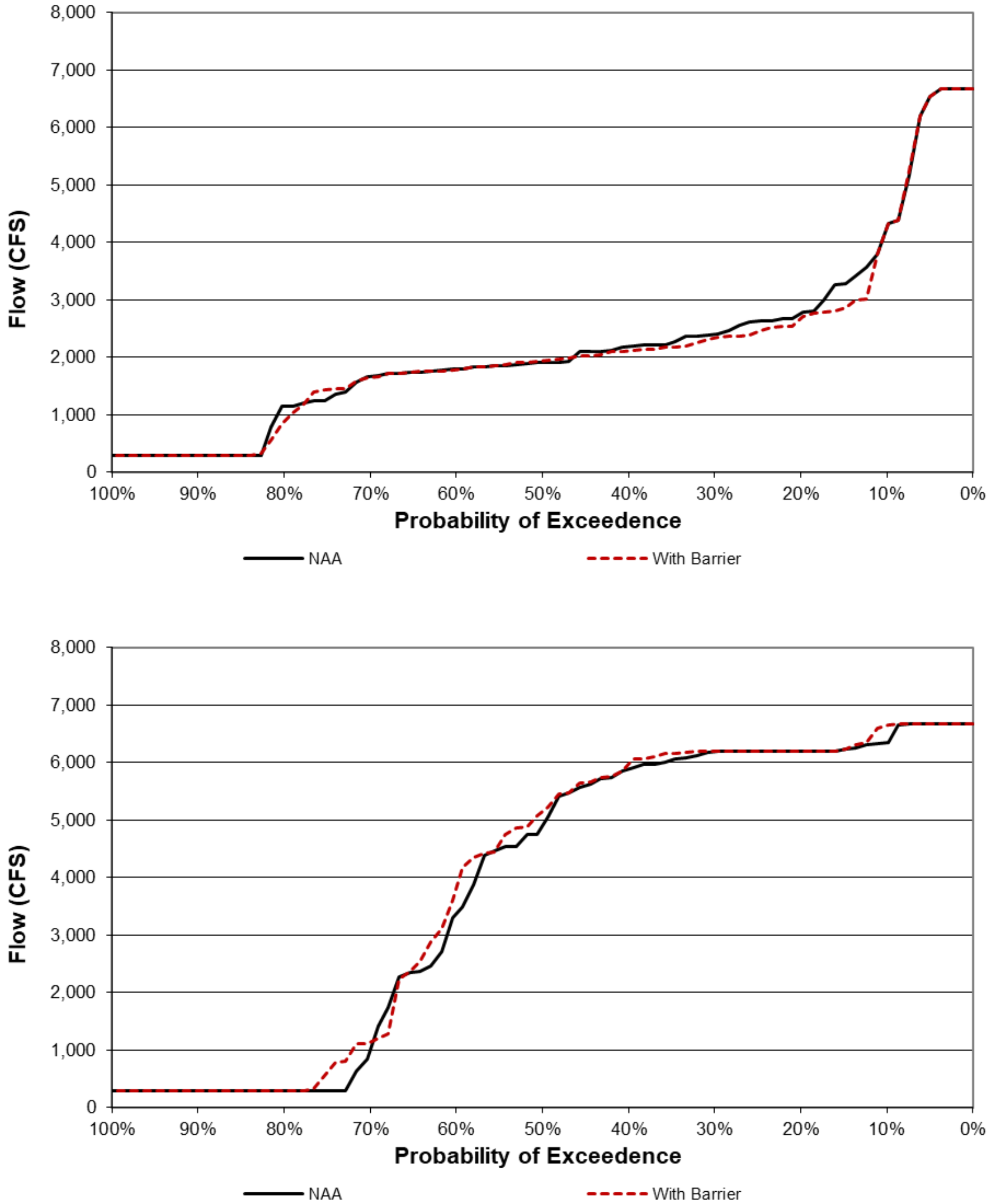



Figure R.1-11. Exceedance for June (Above) and July (Below) Banks Pumping Plant

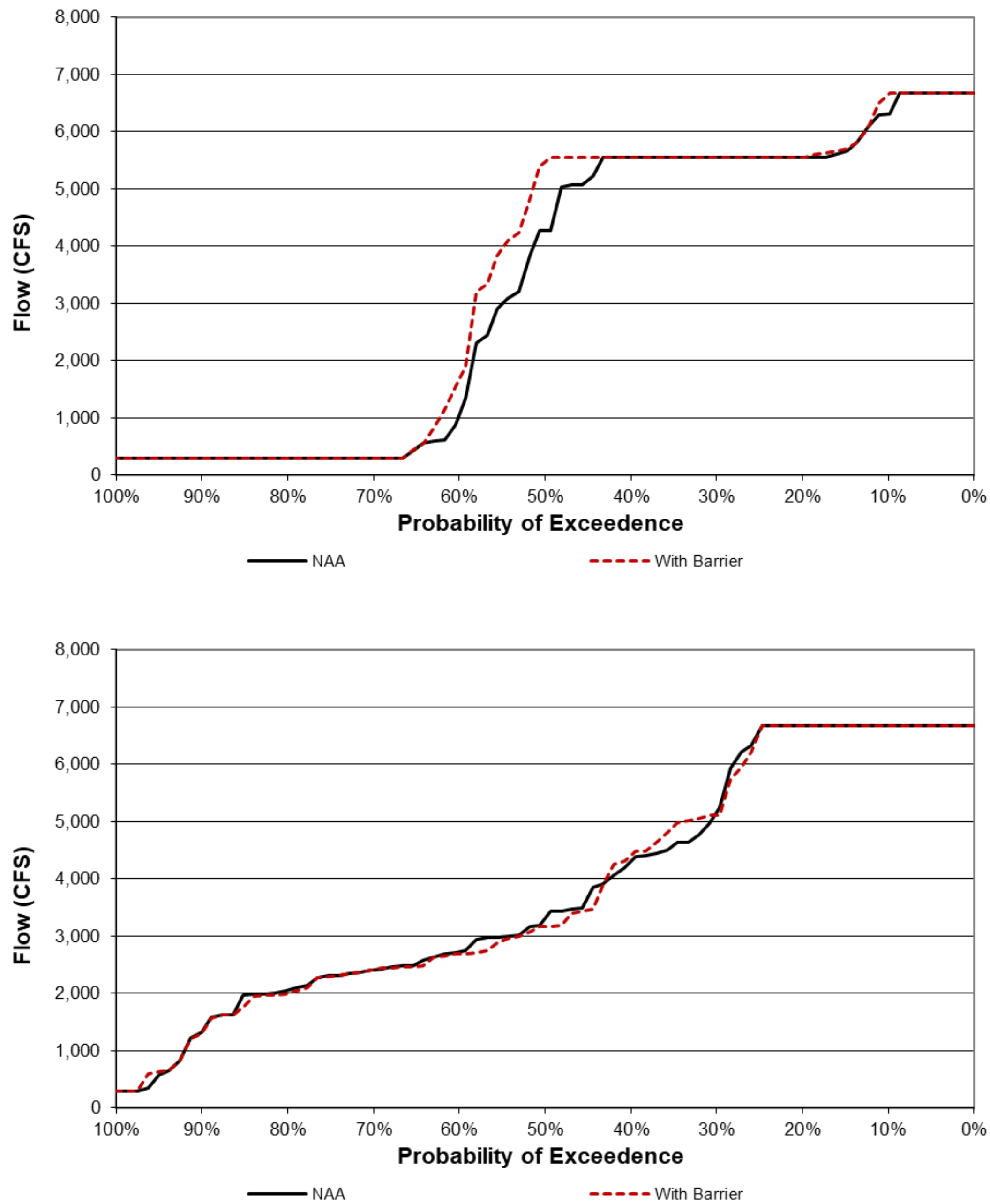
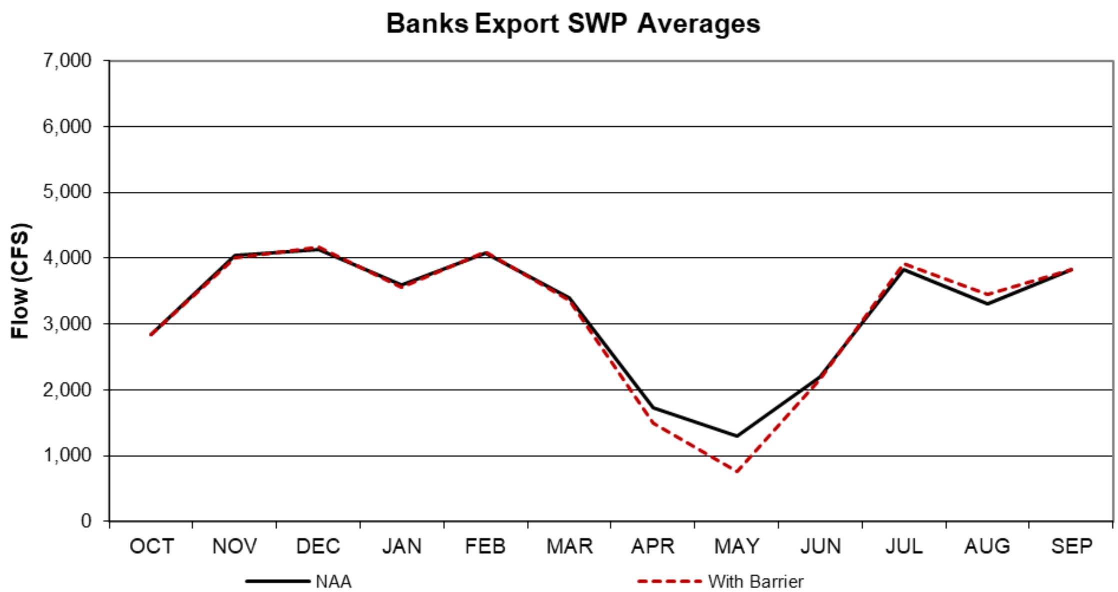
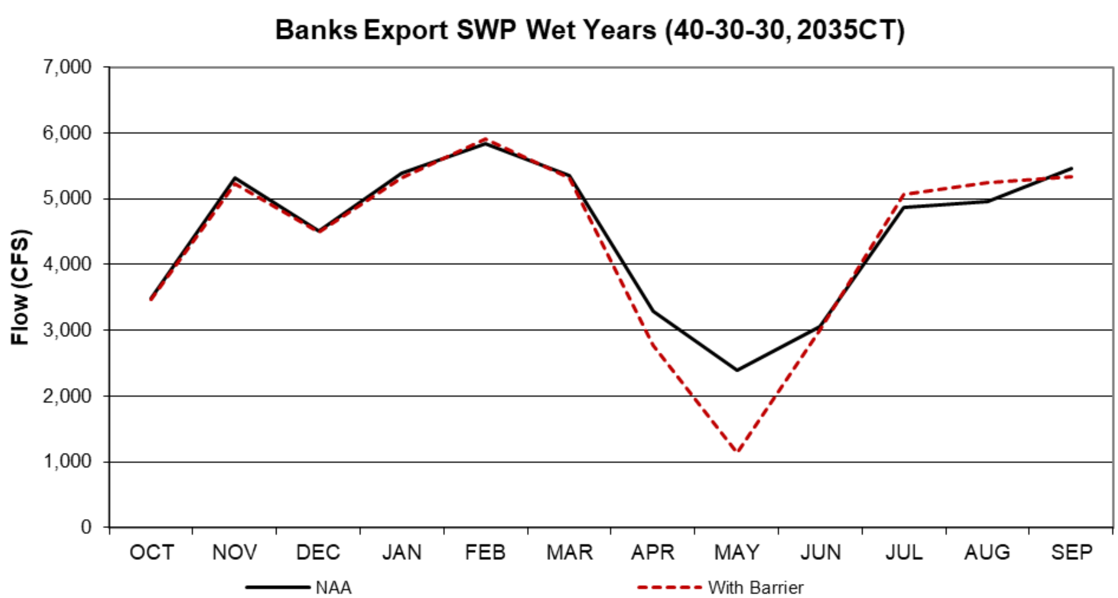
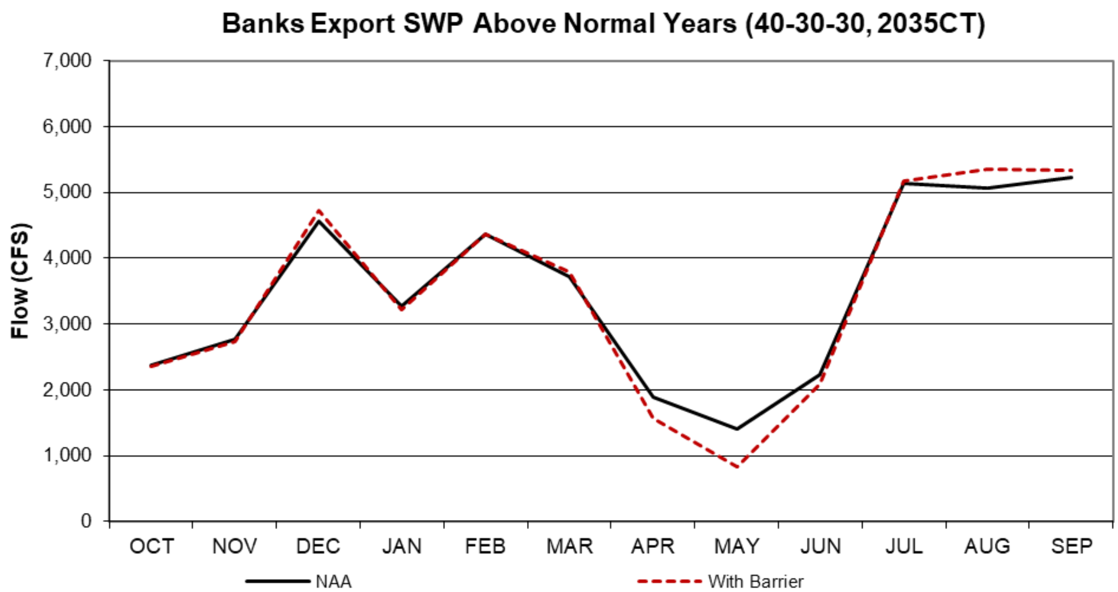


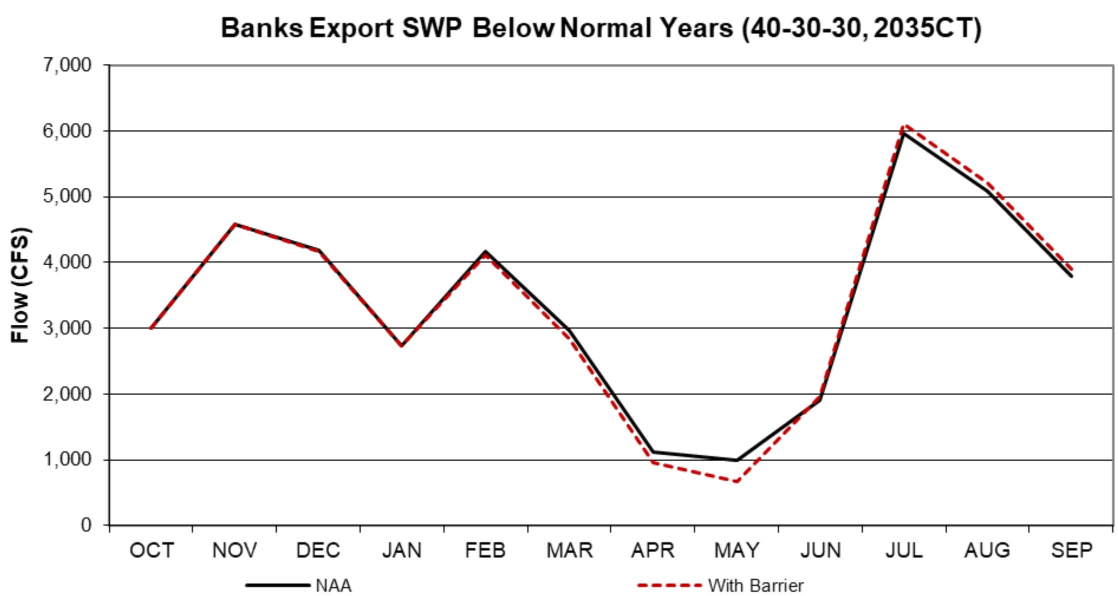

Figure R.1-12. Exceedance for August (Above) and September (Below) Banks Pumping Plant

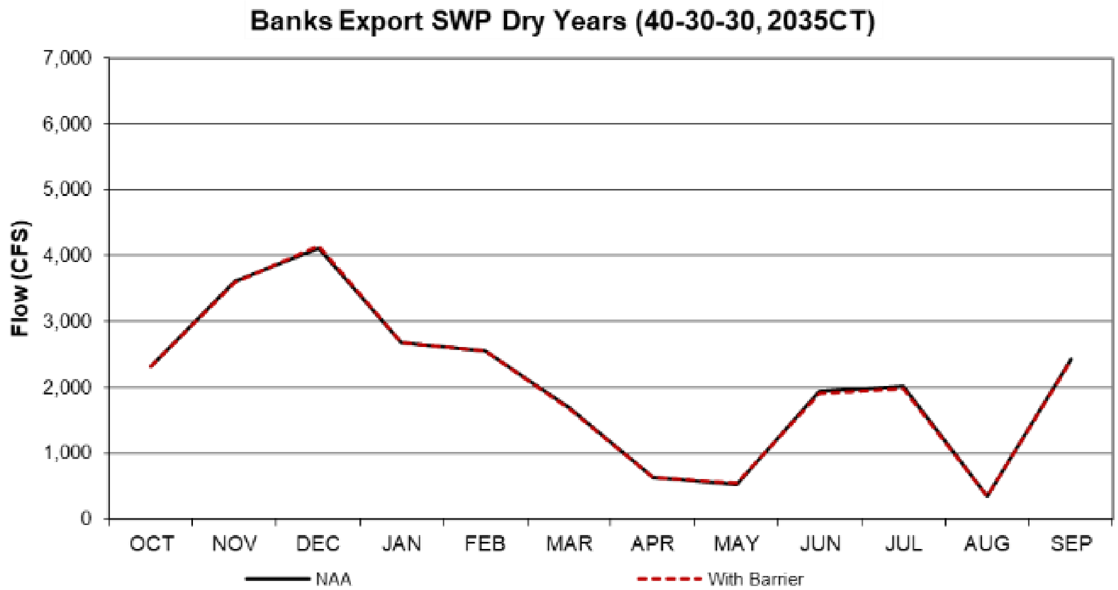
Figures R.1-11 and R.1-12 show that pumping at the Banks Pumping Plant differs from that at the Jones Pumping Plant in that it only increases in July and August to offset decreased pumping in April and May.


Banks Export SWP Averages
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flow (CFS)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Banks Export SWP Wet Years (40-30-30, 2035CT)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flow (CFS)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Banks Export SWP Above Normal Years (40-30-30, 2035CT)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flow (CFS)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier


Banks Export SWP Below Normal Years (40-30-30, 2035CT)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flow (CFS)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
NAA
With Barrier



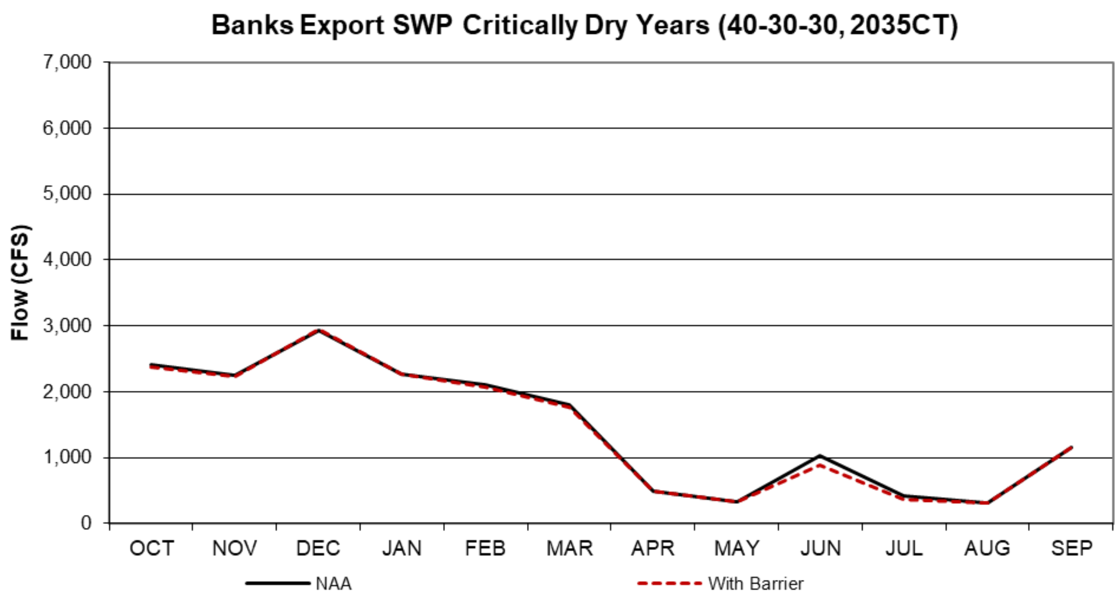




Figure R.1-13. Monthly Pattern of Pumping at Banks Pumping Plant by Water Year Type

For Banks Pumping Plant, Figure R.1-13 shows that mainly Wet, AN, and BN years are affected by the inclusion of the barrier. Dry and Critically Dry years show very little difference in monthly pattern between the alternatives.

### R.1.2.4 Deliveries

Table R.1-6. Annual Central Valley Project North of Delta Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 2,426 | 2,530 | 2,562 | 2,505 | 2,390 | 2,044 |
| **With Barrier** | 2,426 | 2,530 | 2,562 | 2,505 | 2,393 | 2,043 |

In general, the inclusion of the barrier reduces the volume of exports and therefore directly reduces south of Delta (SOD) deliveries. Table R.1-6 shows that the north of Delta (NOD) deliveries are not affected by the barrier.

Table R.1-7. Annual Central Valley Project North of Delta Settlement Contract Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 1,877 | 1,873 | 1,878 | 1,911 | 1,903 | 1,802 |
| **With Barrier** | 1,877 | 1,873 | 1,878 | 1,911 | 1,903 | 1,802 |

Table R.1-8. Annual Central Valley Project North of Delta Refuge Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 84 | 89 | 90 | 88 | 84 | 61 |
| **With Barrier** | 84 | 89 | 90 | 88 | 84 | 61 |

Table R.1-9. Annual Central Valley Project North of Delta Project Agricultural Water Service Contracts Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 247 | 326 | 348 | 276 | 198 | 31 |
| **With Barrier** | 247 | 326 | 348 | 276 | 200 | 31 |

Table R.1-10. Annual Central Valley Project North of Delta Project Municipal and Industrial Water Service Contracts Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 218 | 241 | 247 | 231 | 205 | 149 |
| **With Barrier** | 218 | 241 | 247 | 230 | 205 | 149 |

Tables R.1-7 through R.1-10 split out the NOD deliveries by contract type. Like the total NOD deliveries, all contract types show little difference between the two alternatives, and any difference between water year types is due to differences in demands and allocations.

Table R.1-11. Annual Central Valley Project South of Delta Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 2,377 | 2,994 | 2,635 | 2,354 | 1,934 | 1,487 |
| **With Barrier** | 2,353 | 2,956 | 2,597 | 2,332 | 1,930 | 1,476 |

Table R.1-11 shows that the With Barrier alternative has slightly lower CVP SOD deliveries, ranging from 11 TAF to 38 TAF on average, depending on the water year type, and 24 TAF as the long-term average. The reduced CVP SOD deliveries under the With Barrier alternative is a combination of slightly reduced allocations and increased shortages.

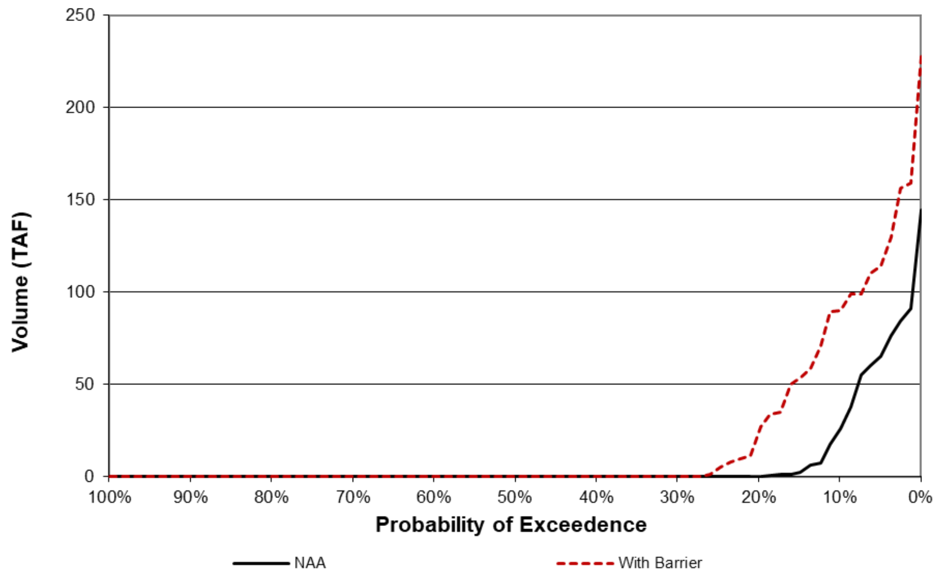



Figure R.1-14. Annual Exceedance of South of Delta Shortages (March–February)

Increased shortages under the With Barrier alternative are due to the OMR controlling more often and reducing the volume of water available for export. In CalSim, the export curve is used to determine an export target as a function of NOD water supply, which then contributes to determining SOD allocations. Figure R.1-14 shows that under the With Barrier alternative, the export curve was not adjusted to maintain similar shortages as under the NAA. Further fine tuning of operations in CalSim would likely result in further reduced CVP SOD deliveries.

Table R.1-12. Annual Central Valley Project South of Delta Exchange Contract Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 855 | 875 | 875 | 875 | 864 | 757 |
| **With Barrier** | 855 | 875 | 875 | 875 | 864 | 757 |

Table R.1-13. Annual Central Valley Project South of Delta Refuge Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 271 | 278 | 278 | 278 | 273 | 237 |
| **With Barrier** | 271 | 278 | 278 | 278 | 273 | 237 |

Table R.1-14. Annual Central Valley Project South of Delta Project Agricultural Water Service Contracts Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 948 | 1,516 | 1,169 | 900 | 510 | 219 |
| **With Barrier** | 925 | 1,479 | 1,132 | 878 | 506 | 209 |

Table R.1-15. Annual Central Valley Project South of Delta Project Municipal and Industrial Water Service Contracts Deliveries by Water Year Type in TAF (March–February)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 120 | 141 | 131 | 117 | 104 | 90 |
| **With Barrier** | 119 | 140 | 128 | 117 | 103 | 89 |

Tables R.1-12 through R.1-15 split out SOD deliveries by contract type. Exchange and refuge deliveries are similar across the two alternatives, and only project agricultural water service contracts and municipal and industrial water service contracts show the effects of reduced exports in the With Barrier alternative.

Table R.1-16. Annual State Water Project Total Deliveries by Water Year Type in TAF (January–December)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 2,342 | 3,275 | 2,758 | 2,566 | 1,460 | 973 |
| **With Barrier** | 2,301 | 3,180 | 2,757 | 2,545 | 1,445 | 960 |

SWP deliveries show a decrease in average annual deliveries ranging from 13 TAF to 95 TAF, depending on the water year type.

### R.1.2.5 Delta Outflow

The differences in restrictions on negative OMR flow across the alternatives can affect how much water is going toward Delta outflow instead of being exported.

Table R.1-17. Annual Delta Outflow by Water Year Type in TAF (October–September)

| | Average | Wet | Above Normal | Below Normal | Dry | Critically Dry |
|---|---|---|---|---|---|---|
| **NAA** | 16,672 | 30,206 | 19,018 | 10,824 | 7,585 | 5,206 |
| **With Barrier** | 16,745 | 30,366 | 19,130 | 10,850 | 2,594 | 5,206 |

As is expected, Table R.1-17 shows there is an increase in Delta outflow on average. However, there is no increase in critically dry years when releases for minimum required Delta outflow are often controlling the system and SOD allocations and exports are low.

Table R.1-18. Difference in Delta Outflow under the With Barrier Alternative and No Action Alternative by Month and Water Year Type

| | With Barrier – NAA (TAF) | | | | | |
|---|---|---|---|---|---|---|
| | April | May | June | July | August | September |
| **Average** | 30 | 65 | -9 | 8 | -2 | 1 |
| **Wet** | 43 | 140 | -17 | 15 | -5 | 2 |
| **Above Normal** | 58 | 88 | -13 | 19 | -1 | 0 |
| **Below Normal** | 33 | 40 | -7 | 6 | 0 | 1 |
| **Dry** | 10 | 5 | 0 | 0 | 0 | 0 |
| **Critically Dry** | 2 | -1 | 0 | 0 | -1 | 0 |

Table R.1-18 shows that in April and May there is an increase in Delta outflow that corresponds with decreases in exports. There is no significant difference in Delta outflow in critically dry years.

### R.1.2.6 Reservoir Storage

The With Barrier alternative provides less flexibility for the CVP and SWP to make use of excess water in the Delta during springtime because of the increased frequency with which the OMR limits control how much water can be exported during this timeframe. As a result, the San Luis Reservoir cannot be filled as much compared to the NAA, and pumping shifts from spring to summer. In summer months, when more of the water needs to come from stored water releases and additional water needs to be released to meet salinity standards for the same level of exports (higher carriage water cost), reservoir release is needed to meet same amount of exports, and the carriage water is high. These factors result in a reduction of end-of-September storage in Shasta and Folsom Lakes and a more muted effect on Trinity Lake.

### R.1.2.7 San Luis Reservoir

Both the CVP and SWP portions of San Luis Reservoir (Figures R.1-15 and R.1-16) experience decreased storage in April and May in the With Barrier alternative due to OMR restrictions occurring more often. From June through September, exports are increased in the With Barrier alternative to recover some of the lost storage.

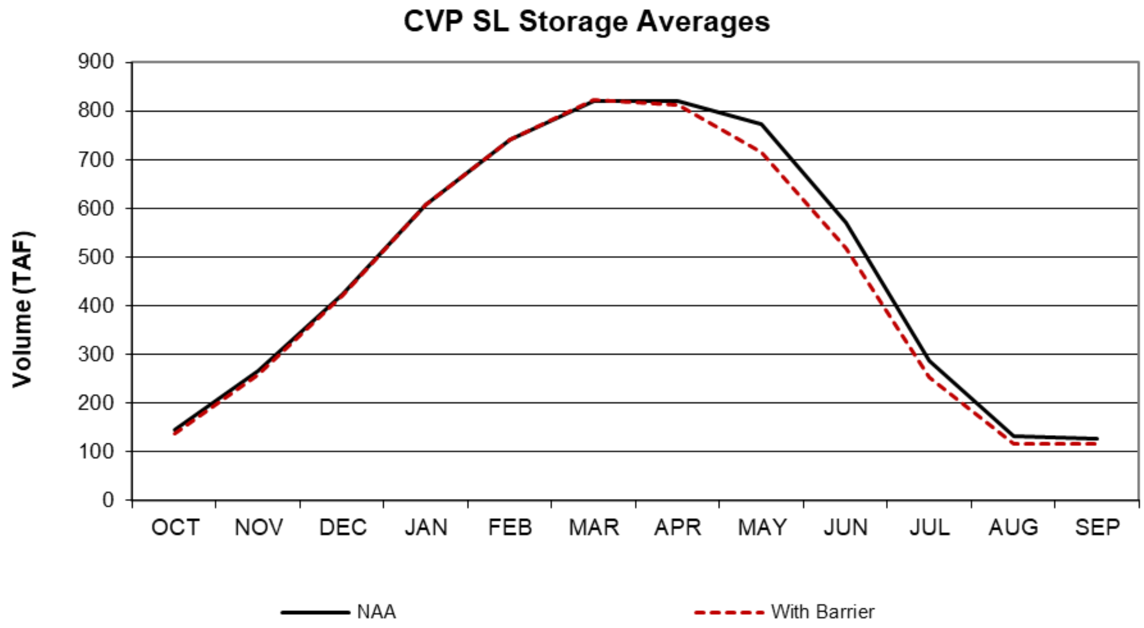



Figure R.1-15. Monthly Pattern of Central Valley Project San Luis Reservoir Storage

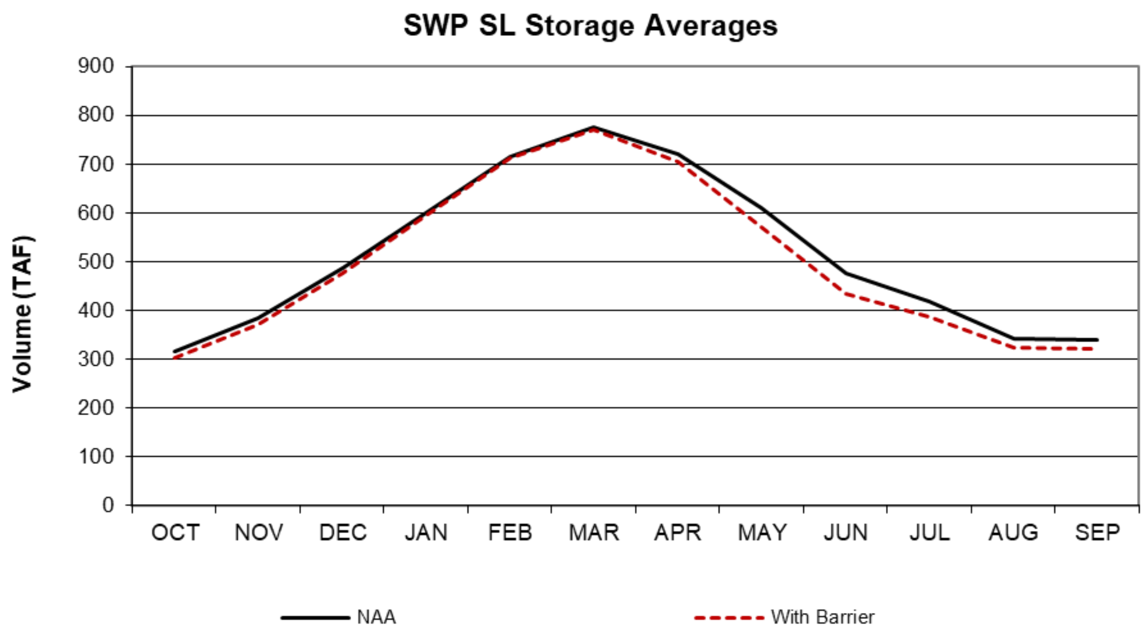



Figure R.1-16. Monthly Pattern of State Water Project San Luis Reservoir Storage

#### R.1.2.8 Upstream Reservoirs

For the most part, the other NOD CVP and SWP reservoirs do not show significant differences in storage between the two alternatives (Figures 17 through 25). When additional releases for exports are made in July through September in the With Barrier alternative, there can be an increased carriage cost for Delta water quality attached to those releases, which can increase the volume released from the reservoirs for the same volume of export.

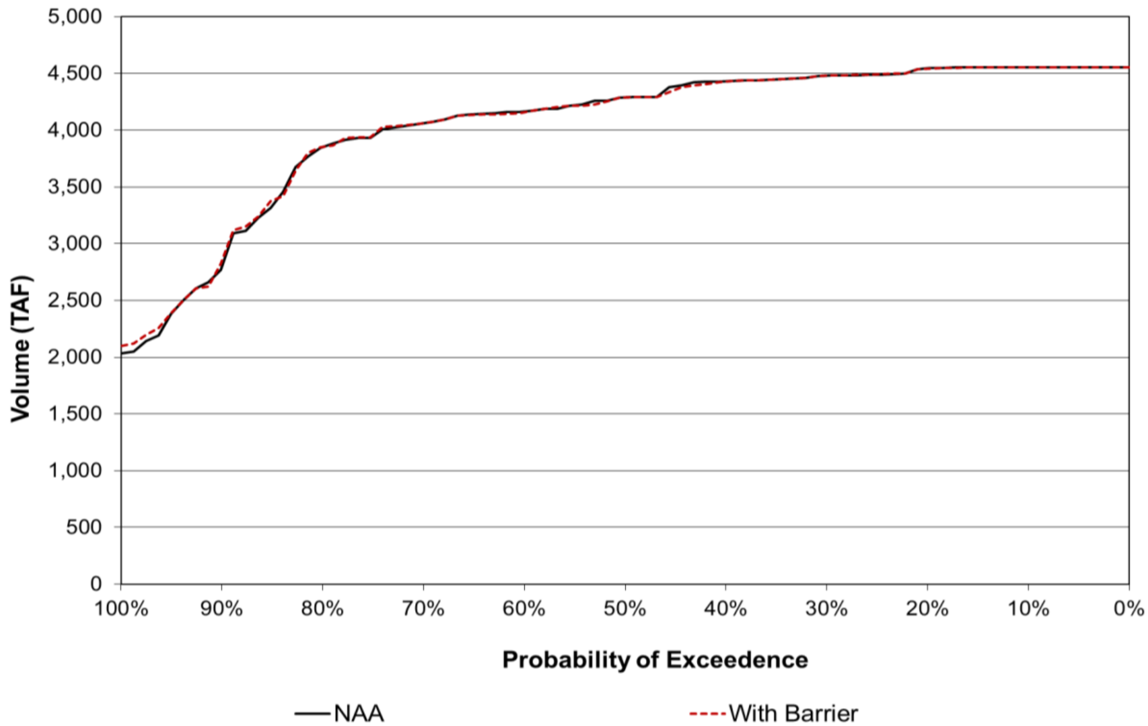



Figure R.1-17. Exceedance of End-of-April Storage in Shasta Lake

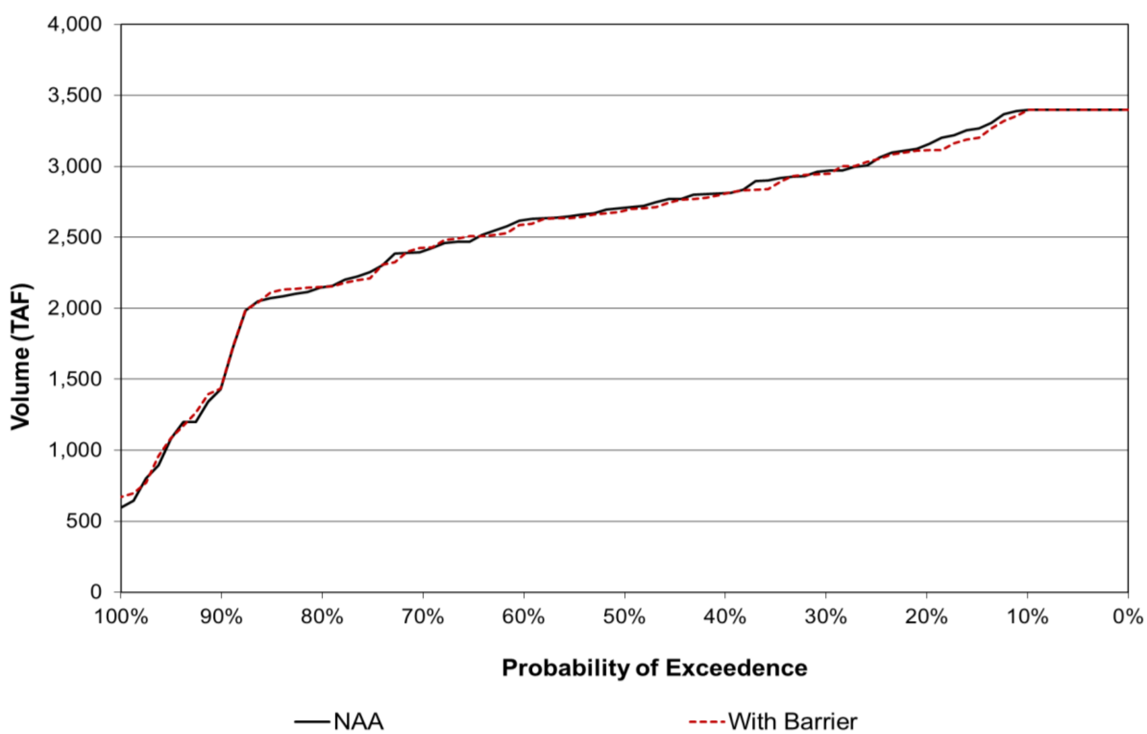



Figure R.1-18. Exceedance of End-of-September Storage in Shasta Lake

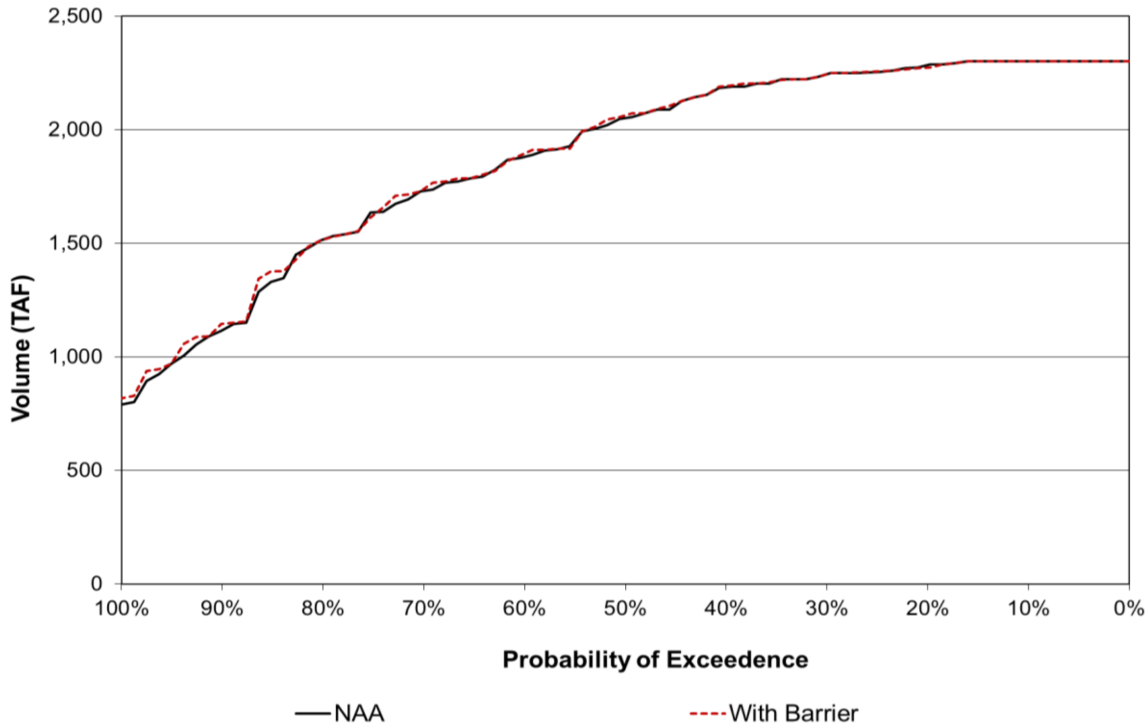



Figure R.1-19. Exceedance of End-of-April Storage in Trinity Lake

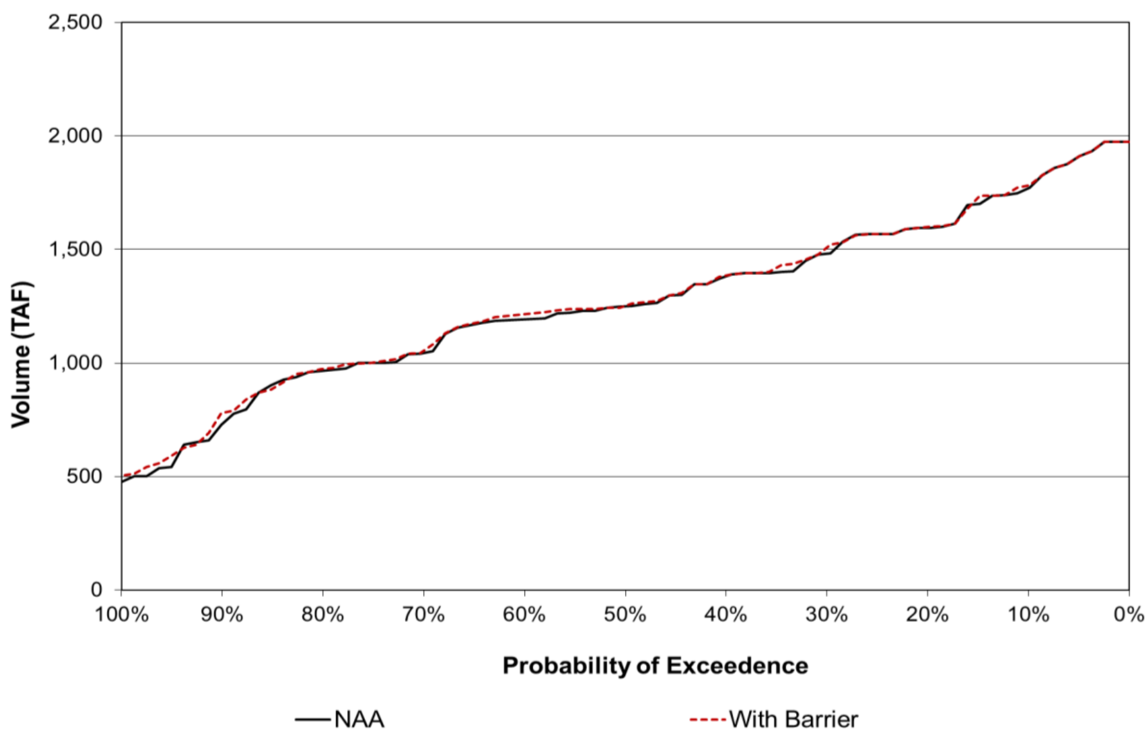



Figure R.1-20. Exceedance of End-of-September Storage in Trinity Lake

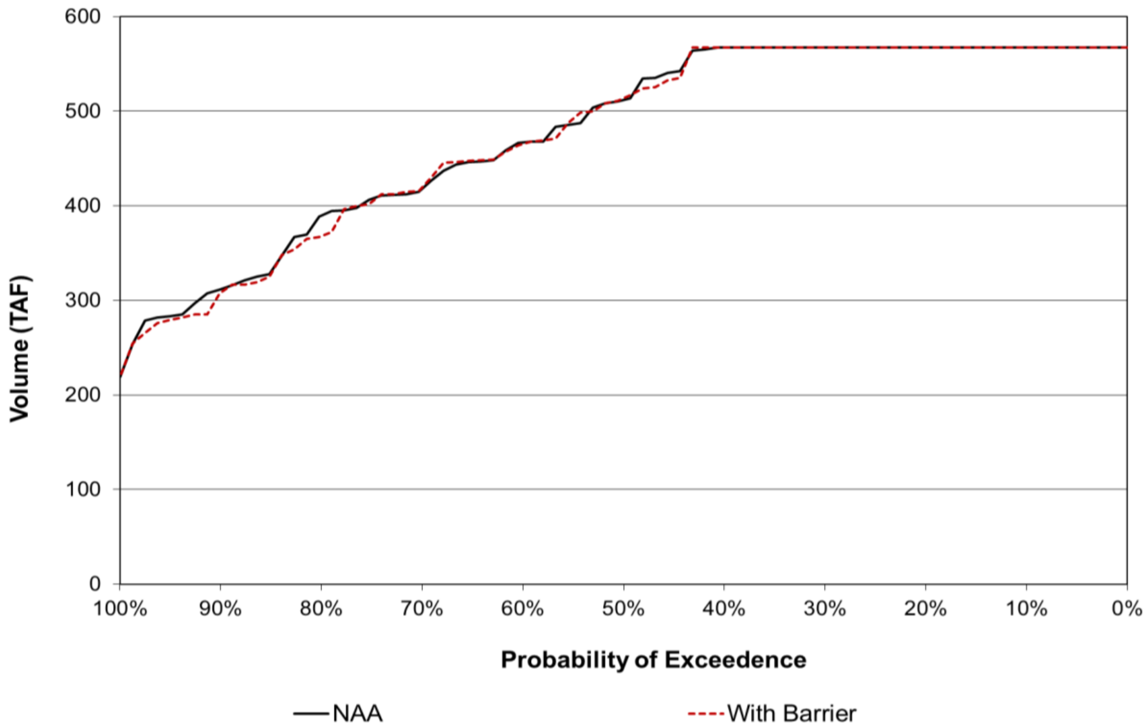



Figure R.1-21. Exceedance of End-of-December Storage in Folsom Lake

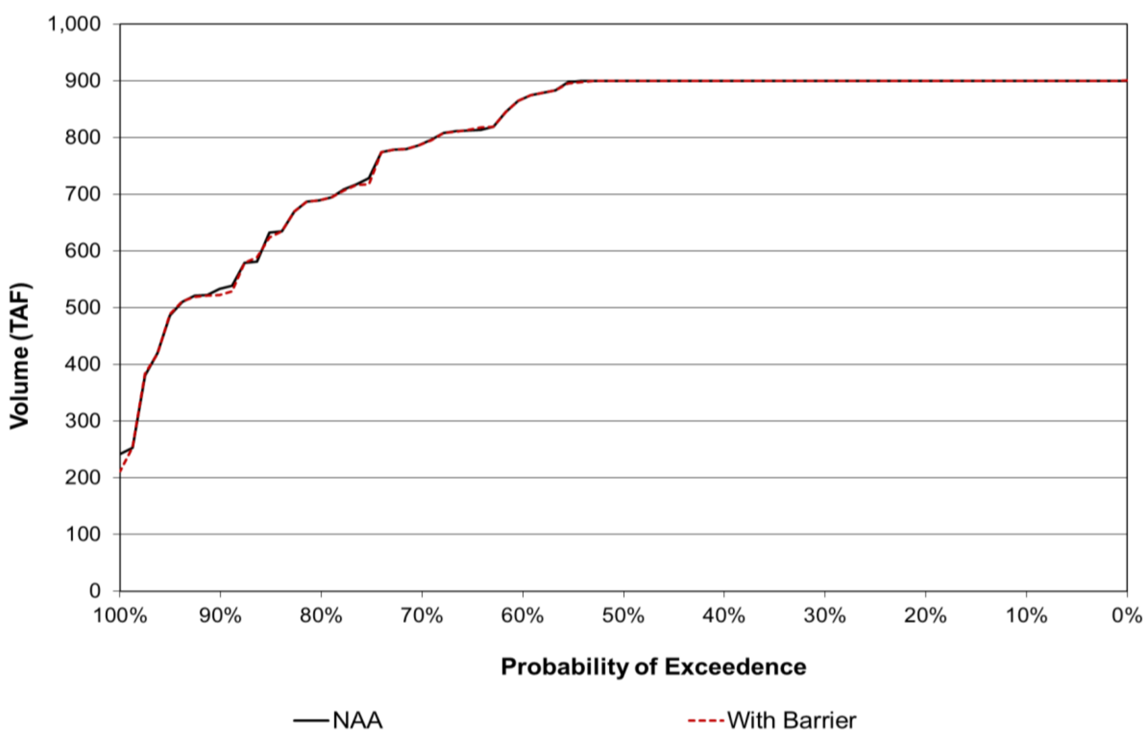



Figure R.1-22. Exceedance of End-of-April Storage in Folsom Lake

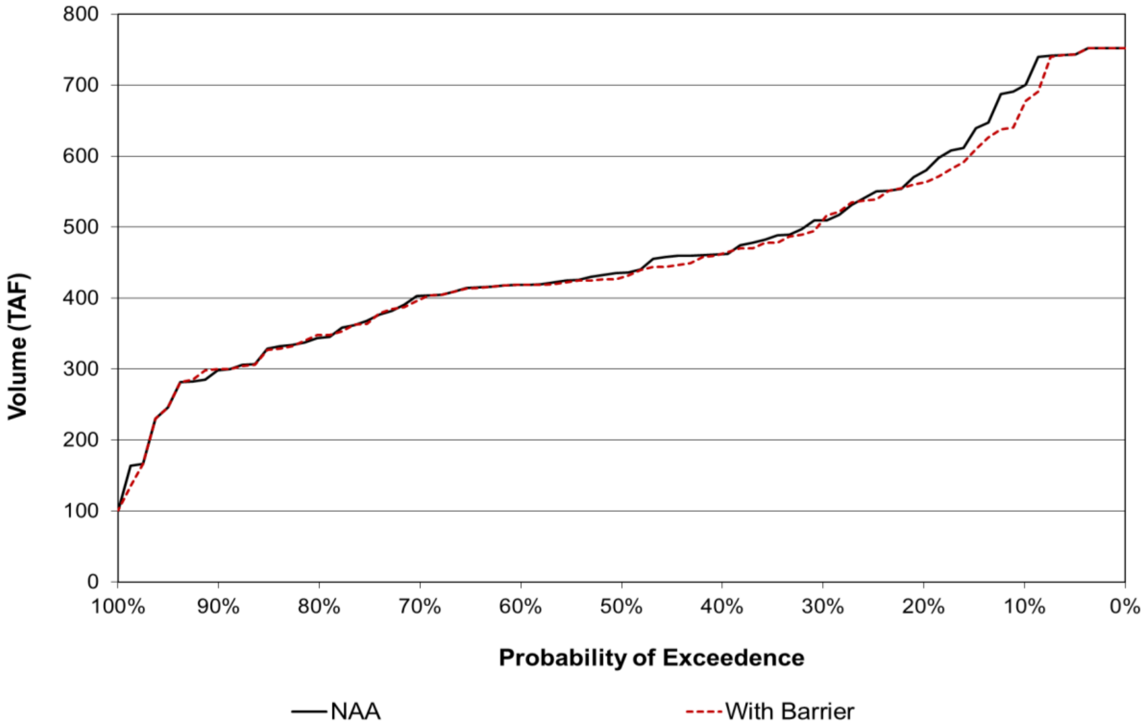



Figure R.1-23. Exceedance of End-of-September Storage in Folsom Lake

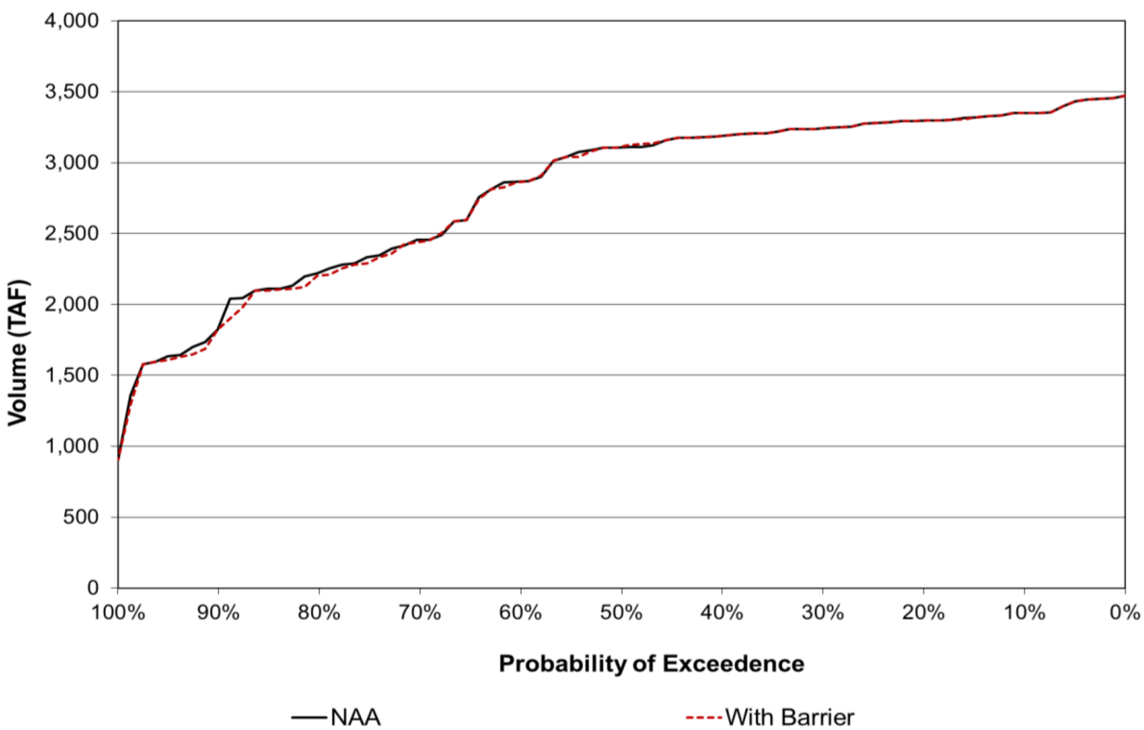



Figure R.1-24. Exceedance of End-of-April Storage in Lake Oroville

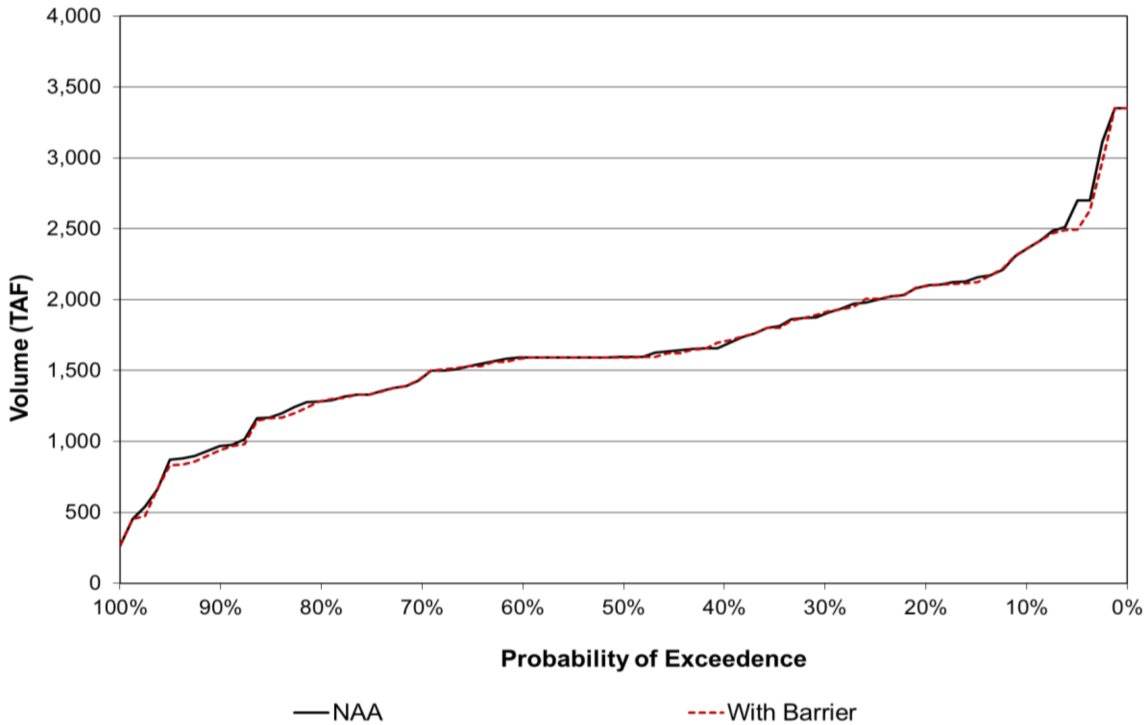



Figure R.1-25. Exceedance of End-of-September Storage in Lake Oroville

### R.1.2.9 Summary of Results

When the HORB is in place for part of April and all of May, it limits the amount of inflow entering the Old River from the San Joaquin River by 256 TAF on average. As a result, OMR flows are more negative in April and May and in other months when exports are increased to make up for the lost water supply in April and May. Increased negative OMR flow causes OMR limits to control exports more often. When comparing the NAA to the With Barrier alternative, CVP export is limited by OMR constraints in 9 additional Aprils and 12 additional Mays. SWP exports are controlled by OMR constraints in 3 additional Aprils and 2 additional Mays. Total export is lower in April and May by 117 TAF overall—61 TAF of CVP export at Jones Pumping Plant, 48 TAF of SWP export at Banks Pumping Plant, and 7 TAF lower export of San Joaquin River restoration recapture. Slightly higher exports in July through September offset the April and May reductions, but exports are lower overall by 74 TAF per year. Lower exports result in higher drawdown on San Luis Reservoir storage and decreases project delivery—24 TAF/year and 41 TAF/year, respectively, for the CVP and SWP. The overall reduction in export is mirrored by the same amount of increase in Delta outflow.