DRAFT Technical Memorandum

Flow Loss Analysis

SAN JOAQUIN RIVER RESTORATION PROGRAM

August 2013

Table of Contents

Tables

Figures

List of Abbreviations and Acronyms

CDEC	California Data Exchange Center
cfs	cubic feet per second
QA/QC	Quality Assurance/Quality Control
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RFG	Restoration Flow Guidelines
RY	Restoration Year
Settlement	Stipulation of Settlement in *NRDC, et al., v. Kirk Rodgers, et al.*
SJRRP	San Joaquin River Restoration Program
TAF	thousand acre-feet

1.0 Purpose

The U.S. Department of the Interior, Bureau of Reclamation (Reclamation), manages releases from Friant Dam to meet San Joaquin River Restoration Program (SJRRP) flow targets at the Gravelly Ford gage and five other flow targets along the lower reaches up to the confluence of the San Joaquin and Merced rivers. The six flow target locations are specified in Exhibit B of the Stipulation of Settlement in *NRDC, et al., v. Kirk Rodgers, et al.* (Settlement). Managing releases from Friant Dam to meet these targets requires anticipating the rates and volumes of losses and diversions within each reach.

In consultation with the Settling Parties, Reclamation has developed the SJRRP Restoration Flow Guidelines (RFG) that, among other things, provides guidelines for complying with each flow target. The RFG is organized into sections that reference specific paragraphs of the Settlement. The guidelines specific to managing flows for each target are described in sections for Paragraphs 13(c), 13(f), 13(j)(i), and 13(j)(iv). The relevant text from these portions of the Settlement has been included in the following section.

The primary purpose of this study is to provide information consistent with the requirements described in the RFG. Additionally, the data and results from this study will be used to inform designs for SJRRP projects to increase the conveyance capacity of the San Joaquin River by reducing the effect of seepage losses between Friant Dam and the river's confluence with the Merced River.

The primary purposes of this study are achieved through a comparison of flow records at the head and end of each reach to assess whether seepage losses and/or downstream surface water or diversions have increased beyond levels assumed in Exhibit B.

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2.0 Relevant Settlement Text

Relevant provisions of the Settlement include Paragraph 13(c), 13(f), 13(j)(i), 13(j)(iv), as follows:

Paragraph 13(c)

In the event that the level of diversions (surface or underground) or seepage losses increase beyond those assumed in Exhibit B, the Secretary shall, subject to Paragraphs 13(c)(1) and 13(c)(2) relating to unexpected seepage losses, release water from Friant Dam in accordance with the guidelines provided in Paragraph 13(j) such that the volume and timing of the Restoration Flows are not otherwise impaired. With respect to seepage losses downstream of Gravelly Ford that exceed the assumptions in Exhibit B ("Unexpected Seepage Losses"), the Parties agree that any further releases or transfers within the hydrograph required by this Paragraph 13(c) and implementation of the measures set forth in Paragraphs 13(c)(1) and 13(c)(2) shall not increase the water delivery reductions to any Friant Division long-term contractor beyond that caused by releases made in accordance with the hydrographs (Exhibit B) and Buffer Flows. The measures set forth in Paragraphs 13(c)(1) and 13(c)(2) shall be the extent of the obligations of the Secretary to compensate for Unexpected Seepage Losses. The Secretary shall follow the procedures set forth in Paragraphs 13(c)(1) and 13(c)(2) to address Unexpected Seepage Losses:

(1) In preparation for the commencement of the Restoration Flows, the Secretary initially shall acquire only from willing sellers not less than 40,000 acre feet of water or options on such quantity of water prior to the commencement of full Restoration Flows as provided in Paragraph 13(i), which amount the Secretary shall utilize for additional releases pursuant to this Paragraph 13(c)(1), unless the Restoration Administrator recommends that a lesser amount is required.

(2) The Secretary shall take the following steps, in the following order, to address Unexpected Seepage Losses:

a. First, use any available, unstorable water not contracted for by Friant Division long-term contractors;

b. Next, use water acquired from willing sellers, including any such water that has been stored or carried over, until it has been exhausted. This Paragraph 13(c)(2)(B) shall be implemented as follows:

i. The Secretary shall first use water acquired pursuant to Paragraph 13(c)(1) until such water is exhausted.

Thereafter, as of January 1st of each year, the Secretary shall have available at least 28,000 acre feet of water acquired only from willing sellers, or options on such quantity of water from willing sellers, which amount the Secretary shall utilize for additional releases pursuant to this Paragraph 13(c)(2)(B)(i). However, the Restoration Administrator may recommend that an additional amount, not to exceed 10,000 acre feet is needed; and the Secretary shall acquire up to that amount recommended by the Restoration Administrator only from willing sellers, or options on such quantity of water from willing sellers;

ii. *Any water acquired from willing sellers pursuant to this Paragraph 13(c)(2)(ii) that is not used in a given year shall be stored, to the extent such storage is reasonably available, to assist in meeting the Restoration Goal;*

iii. *In the event the Secretary has acquired water from willing sellers under this Settlement that the Restoration Administrator recommends is no longer necessary to address Unexpected Seepage Losses, such water shall be available to augment the Restoration Flows;*

iv. *The Secretary shall provide notice to the Plaintiffs and Friant Parties not later than December 1 of each year regarding the status of acquisitions of water from willing sellers pursuant to the provisions of this Paragraph 13(c);*

c. *Next, if the Restoration Administrator recommends it and the Secretary determines it to be practical, acquire additional water only from willing sellers, in an amount not to exceed 22,000 acre feet;*

d. *Next, in consultation with the Restoration Administrator and NMFS and consistent with Exhibit B, transfer water from the applicable hydrograph for that year;*

e. *Next, in consultation with the Restoration Administrator, use any available Buffer Flows for that year.*

Paragraph 13(f)

The Parties agree to work together in identifying any increased downstream surface or underground diversions and the causes of any seepage losses above those assumed in Exhibit B and in identifying steps that may be taken to prevent or redress such increased downstream surface or underground diversions or seepage losses. Such steps may include, but are not limited to, consideration and review of appropriate enforcement proceedings.

Paragraph 13(j)(i)

Procedures for determining water-year types and the timing of the Restoration Flows consistent with the hydrograph releases (Exhibit B);

Paragraph 13(j)(iv)

Developing a methodology to determine whether seepage losses and/or downstream surface or underground diversions increase beyond current levels assumed in Exhibit B.

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3.0 Background

Exhibit B of the Settlement describes the anticipated losses between each SJRRP flow target location (Table 3-1). The losses anticipated by Exhibit B were proposed based on information and studies conducted at the time of the Settlement, and various provisions were incorporated into the Settlement to assure that flow targets would be met in the event that actual losses and diversions deviated from the anticipated losses and diversions.

Table 3-1.
Losses and Gains Estimated by Exhibit B

	Reach 1	Reach 2	Reach 3	Reach 4
	Riparian Releases[1,2] (cfs)	**Losses[3] (cfs)**	**Losses[4,5] (cfs)**	**Losses[6] (cfs)**
Oct 1 – Oct 31	160	80–100	0	0
Nov 1 – Nov 6	130	80–100	0	0
Nov 7 – Dec 31	120	80–100	0	0
Jan 1 – Feb 28	100	80–100	0	0
Mar 1 – Mar 15	130	80–100	0	0
Mar 16 – Mar 31	130	80–100	0	0
Apr 1 – Apr 15	150	80–100	0	0
Apr 16 – Apr 30	150	80–100	0	0
May 1 – Jun 30	190	80–100	0	0
Jul 1 – Aug 31	230	80–100	0	0
Sept 1 – Sep 30	210	80–100	0	0

Notes:

[1] Adapted from Exhibit B, Table 1A, for a critical low year type on the San Joaquin River. Note that timing of riparian releases shifts slightly in Exhibit B for the fall pulse, depending on year type, but the above dates and releases were used for this study.

[2] Assumed to be equal to the sum of the diversion and seepage losses.

[3] Anticipated losses based on flow at the Gravelly Ford gage station. Flows less than 300 cfs at the head of the reach lose 80 cfs. Flows between 300 and 400 cfs lose 90 cfs. Flows above 400 and below 800 cfs lose 100 cfs. Refer to Figure 2-4 of the *San Joaquin River Restoration Study Background Report* (McBain & Trush Inc. [eds]), 2002) when flows are greater than 800 cfs.

[4] Reach 3 ignores contributions from Delta-Mendota Canal added at Mendota Pool, which is subsequently diverted at the bottom of Reach 3 at Sack Dam into the Arroyo Canal and therefore assumes no net gain. Actual inflows could be greater, particularly during the irrigation season.

[5] No losses are assumed although Reach 3 appears to be a small losing reach at this time. May become a gaining reach over time if losses in Reach 2 fill sufficient aquifer storage.

[6] Seasonal losses in Reach 4A and gains in Reach 4B. Although likely a net gain in Reach 4 flow, assumed no gain for simplicity.

Key:

cfs = cubic feet per second

Reclamation manages SJRRP releases from Friant Dam to meet the flow target at Gravelly Ford and simultaneously provide for diversions for riparian water users in Reach 1. The Settlement stipulates that Reclamation will purchase and release additional water to make up for any losses beyond what were anticipated by Exhibit B (termed

Unexpected Seepage Losses). The calculation of losses is generally suspended during periods of flood control, when flows in the San Joaquin River are in excess of SJRRP flow targets. Provisions for managing these flows are described in the RFG.

4.0 Methods

As stated above, a methodology for calculating losses was developed by Reclamation in consultation with the Settling Parties and is documented in the RFG. In assessing seepage losses and/or downstream surface or underground diversions, Reclamation will use final flow records (or best available information) for Reaches 1 through 5, as defined in the Settlement. The availability and reliability of gaging stations were considered in determining segments of the San Joaquin River where seepage would be evaluated in Reaches 1 through 5. Figure 4-1 provides the relative location of these gages to each other, the reaches of the San Joaquin River as defined by the Settlement, and the segments selected to calculate losses in each reach. Table 4-1 presents reach lengths used in this study.

Consistent with the RFG and for the purposes of this study, the determination of seepage losses and/or downstream surface or underground diversions will be measured at these gage locations, as follows:

- **Reach 1 –** Friant Dam flows, Little Dry Creek (LDC) inflows, and Cottonwood Creek (CTK) inflows were compared with Gravelly Ford (GRF) flows.[1]
- **Reach 2 –** Gravelly Ford (GRF) flows were compared with below the Chowchilla Bifurcation Structure (SJB) flows, with consideration of diversions into the Chowchilla Bypass (CBP).[2]
- **Reach 3 –** Below the Chowchilla Bifurcation Structure (SJB) flows were compared with below Sack Dam (SDP) flows, with consideration of James Bypass (JBP) flood flows.[3,4]
- **Reach 4 –** Below Sack Dam (SDP) flows were compared with the top of Reach 4B (Washington Road) (SWA) flows.[5]
- **Reach 5 –** Top of Reach 4B (Washington Road) (SWA) flows were compared with the confluence of the Merced River (SMN) flows.[6]

[1] The San Joaquin River Restoration Study Background Report (SJR Background Report) defines Reach 1 as between Millerton Lake and the Gravelly Ford gage.
[2] The SJR Background Report defines Reach 2 as between the Gravelly Ford gage and Mendota Dam.
[3] The SJR Background Report defines Reach 3 as between Mendota Dam and Sack Dam.
[4] Assumes that all inflow into Mendota Pool (e.g., Delta-Mendota Canal inflows) are offset by diversions (e.g., Sack Dam and Arroyo Canal).
[5] The SJR Background Report defines Reach 4 as between Sack Dam and the Bear Creek confluence.
[6] The SJR Background Report defines Reach 5 as between the Bear Creek and Merced River confluences.

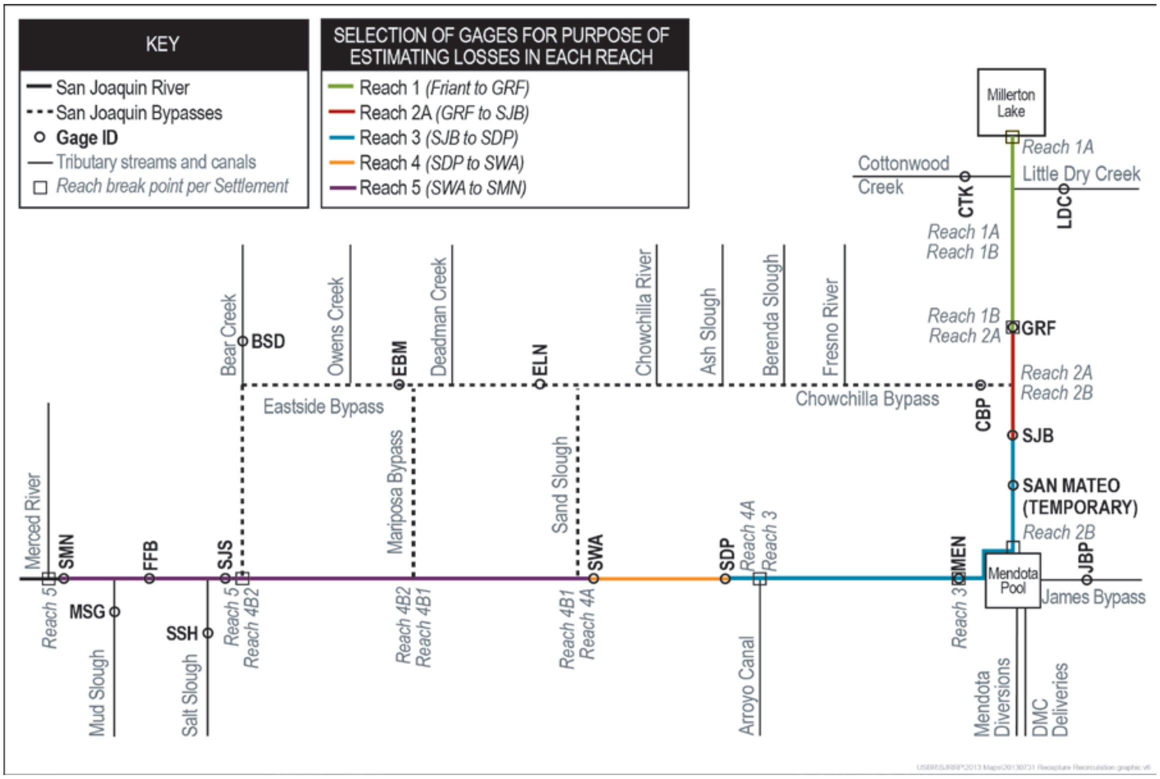

Figure 4-1. Location of Gaging Stations, Reaches, and River Segments Selected to Calculate Losses in Each Reach

Table 4-1.
Reach Lengths Used to Calculate Losses

Reach	Gages Selected to Calculate Losses[1]	Gage Location (River Mile)[2]		Segment Length (miles)[2]
		Start	End	
1	Friant Dam to GRF	0	40	40
2	GRF to SJB	40	52	12
3	SJB to SDP	52	86	34
4	SDP to SWA	86	98	12
5	SWA to SMN	98	149	51

Notes:
[1] Gages selected to calculate losses are consistent with the Restoration Flow Guidelines based on the availability and reliability of gaging stations. This is different from the reaches specified by the Settlement.
[2] Rounded to the nearest mile

Key:
GRF = Gravelly Ford
SDP = Below Sack Dam
SJB = San Joaquin River below Chowchilla Bifurcation Structure
SMN = San Joaquin and Merced Rivers Confluence
SWA = Washington Road

For Reach 3, the RFG does not explicitly specify consideration of James Bypass flood flows, but are included in this study when cumulatively computing losses because flows in Reach 3 are influenced by the North Fork of the Kings River, which produces inflows to the San Joaquin River during periods of flooding. The inflow data for the Kings River is based on gage measurements at the James Bypass. Figure 4-2 shows the inflow from the Kings River from October 2009 to February 2013.

Note that losses for Reach 5 are not calculated in this study because of the flow contributions from the Eastside Bypass on the San Joaquin River. In addition, an evaluation of the Washington Road gage is ongoing to determine the appropriateness of its use in these measurements, and this approach may change in the future pending the findings.

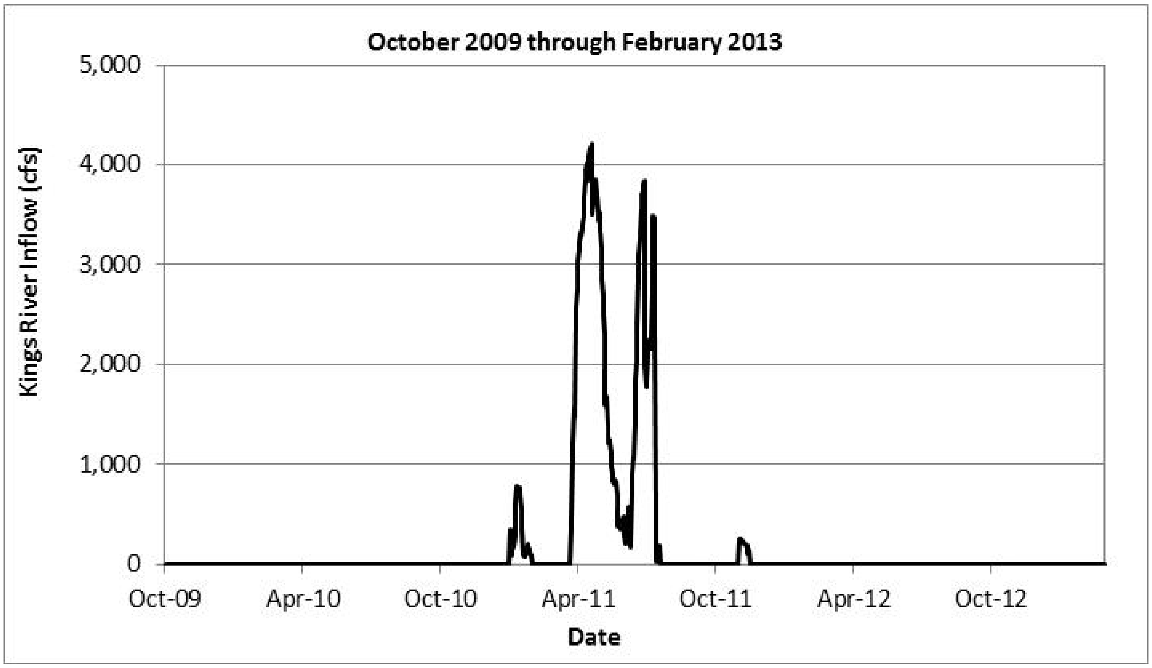

Figure 4-2.
Kings River Inflows Measured at James Bypass to Reach 3

4.1 Period for Calculating Losses

Two different periods were used to compute losses. Historical flow data from both the final flow records (referred to in this study as the Quality Assurance/Quality Control [QA/QC] data), and California Data Exchange Center (CDEC) data were used for the entire period of record, which varied by reach based on the installation date of the corresponding gages to understand historical losses at different flow rates (Table 4-4). CDEC data were used only when the period of record for the QA/QC data were shorter than the CDEC period of record. For some gaging stations, data gaps existed in the flow record. On dates when these gaps occurred, the analysis skipped these dates to directly compare flow at the head and end of each reach. To determine the cumulative annual loss, missing values were estimated based on the surrounding flow data to provide a summed estimate of losses to compare with the annual expected losses from Exhibit B. For example, Cottonwood Creek is missing data from April 20, 1999, through January 23, 2010. The flow in Cottonwood Creek before and after the data gap is 0 cubic feet per second (cfs) and 1 cfs, respectively. As a result, it was assumed that the flow during the missing period was 0 cfs. A list of dates during which data were unavailable is in Table 4-2.

Table 4-2.
Historical Data Used for Analysis

Gage Name	Period of Record
Friant Dam	1/1/1962–present (QA/QC)
CTK – Cottonwood Creek	2/5/1997–12/31/2009 (CDEC) 1/1/2010–present (QA/QC) *(missing data from 3/1/2009–12/31/2009 and 5/1/2011–12/31/2011)*
LDC – Little Dry Creek	2/5/1997–12/31/2009 (CDEC) 1/1/2010–present (QA/QC) *(missing data from 3/1/2009–12/31/2009)*
GRF – Gravelly Ford	7/10/1997–9/30/2009 (CDEC) 10/1/2009–present (QA/QC) *(missing data from 3/1/2009–3/9/2009, 4/25/2009–4/27/2009, 5/18/2009–5/29/2009, 6/12/2009–6/14/2009, and 7/19/2009–7/23/2009)*
SJB – San Joaquin River below Chowchilla Bifurcation Structure	7/10/1997–9/30/2009 (CDEC) 10/1/2009–present (QA/QC)
CBP – Chowchilla Bypass	7/10/1997–7/18/2011 (CDEC) *(missing data from 3/1/2009–1/1/2011, 2/1/2011–3/20/2011, and 7/19/2011–2/28/2013)*
SDP – Below Sack Dam	10/1/2009–3/31/2012 (QA/QC) 4/11/2012–present (CDEC) *(missing data from 4/17/2012–5/11/2012, 6/19/2012–6/26/2012, 6/28/2012–6/29/2012, 7/5/2012–7/11/2012, 7/22/2012–7/28/2012, 7/30/2012–8/6/2012, 8/9/2012–8/18/2012, 8/21/2012–8/26/2012, 9/12/2012–9/16/2012, 10/15/2012–10/17/2012, 10/31/2012–11/30/2012, 12/2/2012–12/6/2012, 2/6/2013–2/7/2013, and 2/10/2013–2/28/2013)*
JBP – James Bypass	10/1/2009–present (San Joaquin River Operations)
SWA – Washington Road	10/1/2009–3/31/2012 (QA/QC) 4/11/2012–present (CDEC) *(missing data from 3/24/2012, 3/26/2012–3/30/2012, 4/1/2012–4/16/2012, 4/26/2012, and 8/27/2012–1/13/2013)*
SLCC – San Luis Canal Company Diversions	10/1/2009–present (San Luis Canal Company)

Notes:
CDEC = California Data Exchange Center data; available at: http://cdec.water.ca.gov/queryTools.html.
San Joaquin River Operations = Data provided via request by Reclamation.
San Luis Canal Company = Data provided via request by the San Luis Canal Company. Represents diversions at the head of the Arroyo Canal.
QA/QC = quality assurance/quality control data provided by the San Joaquin River Restoration Program; available at: http://restoresjr.net/flows/Data/index.html.

This study also synthesized Restoration Year (RY) 2009 through RY 2012 flow gage data, as available, for each reach in an attempt to improve estimates of losses since Interim Flows began for use in the SJRRP operations. These data are from the QA/QC data and are available on the SJRRP Web site by Reclamation.

4.2 Assumptions

The following assumptions were made when computing losses in each reach:

- Losses are the difference in daily flow between upstream (head of reach) and downstream (end of reach) gaging locations, with inclusion of only the diversions noted above.
- Losses are based on a 1-day lag period to account for travel time from the head to the end of each reach.[7]

[7] A 1-day lag period was selected because when computing losses between flow at the head and end of a reach, the 1-day lag period had the highest R^2 value for fitting the data to a trendline. For Reach 1, the R^2 value for no lag, a 1-day lag, and a 5-day lag is 0.97, 0.99, and 0.94, respectively (refer to Section 1.4.1).

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5.0 Results

The following section describes the results of this analysis by comparing for each reach (1) flow at the head versus end of each reach, (2) losses based on magnitude of flow at the head, and (3) cumulative annual losses. For Reach 1, an additional comparison of seasonal losses to Exhibit B assumptions was made.

5.1 Loss Comparison Between Flow at the Head and End of the Reach

Figures 1-3 through 1-6 compare the flow at the end of each reach against the flow at the head over the historical record. For Reaches 1 and 2, any riparian releases and losses estimated by Exhibit B were first subtracted from the flow at the head to account for the varying loss schedule throughout the year. For Reaches 3 and 4, no flow was subtracted since Exhibit B assumes no losses to be present in these reaches.[8]

[8] For Reach 3, there is a negotiated operational agreement between Reclamation and San Luis Delta Mendota Water Authority, in advance of the completion of the Mendota Pool Bypass. This loss has been calculated to be 10 cfs downstream from the Chowchilla Bifurcation Structure (SJB) gage station, and an additional 5 percent loss in Mendota Pool. Changes to losses in this reach may result from future monitoring evaluations, or implementation of the Reach 2B and Mendota Pool Bypass project.

5.1.1 Reach 1 Loss Comparison

A linear trendline was developed to describe the historical flow data for Reach 1, as shown in Figure 5-1. Flows at the downstream end of Reach 1, measured at Gravelly Ford, show a strong correlation with the flow at the head (combined inflows from Friant Dam, Cottonwood Creek, and Little Dry Creek, less Exhibit B riparian releases), as evidenced by the coefficient of determination (R^2 value) of 0.99. As shown by the trendline equation, the flows at the end of Reach 1 are generally 2 percent lower than the expected flows, after consideration of the Exhibit B riparian releases.

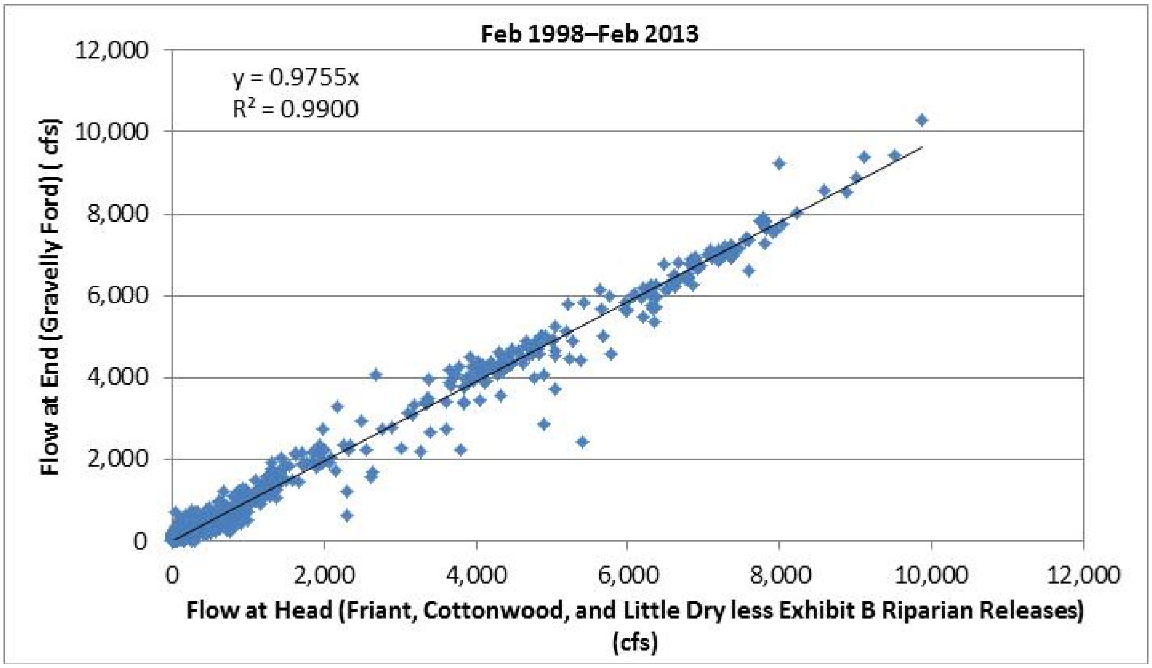


Figure 5-1.
Losses at the End Versus Losses at the Head for Reach 1

5.1.2 Reach 2 Loss Comparison

Figure 5-2 suggests that the flows at the upstream end of Reach 2, measured at Gravelly Ford, less Exhibit B losses, are strongly correlated to the combined flows at the end, measured at below the Chowchilla Bifurcation Structure and the Chowchilla Bypass. However, greater variability exists at flows between 4,000 cfs and 6,000 cfs, which occurred during a flood period in June 2006. The flood releases during this time may explain why the reach appears to gain flow. The flows at the end of Reach 2 are generally less than 1 percent lower than the flows at the head, after consideration of the Exhibit B assumed losses.

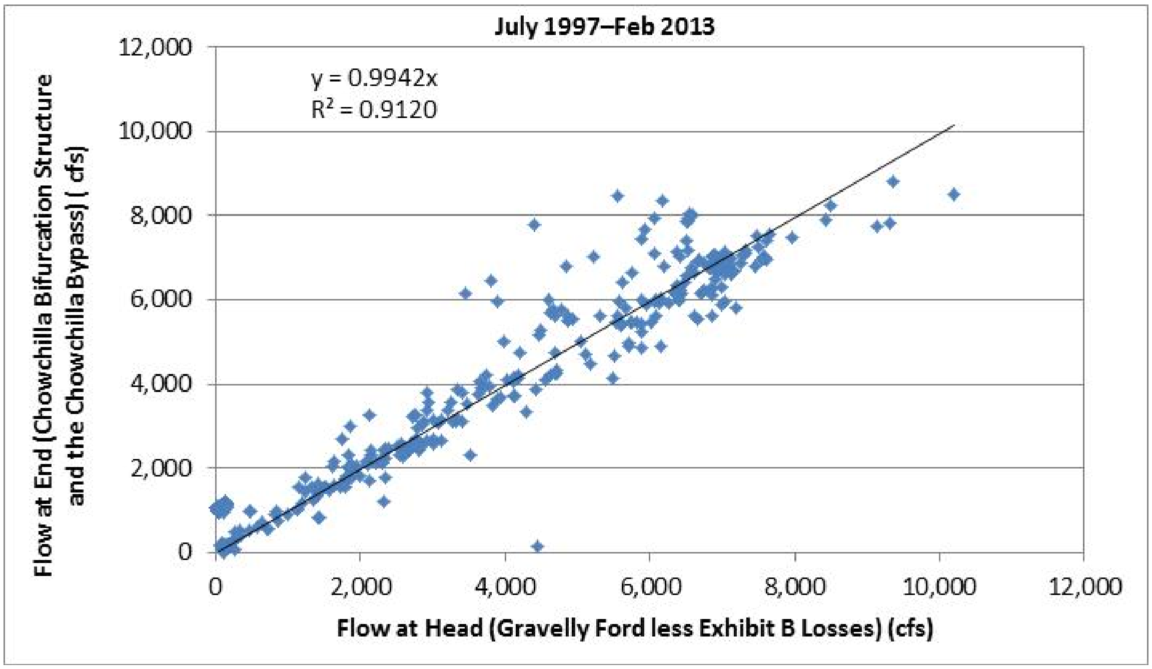


Figure 5-2.
Losses at the End Versus Losses at the Head for Reach 2

5.1.3 Reach 3 Loss Comparison

There is not a strong linear correlation between flows at the head (below the Chowchilla Bifurcation Structure) and flows at the end (below Sack Dam), even when excluding James Bypass flood release periods because the 1-day travel time assumption was too generalized. Figure 5-3 does not include the period when flood releases were made, and shows that flows at the end are generally 53 percent lower than flows at the head (R^2 of 0.58). As noted earlier, this variability in data may be a result of the negotiated operational loss that has been accepted for Reach 3.

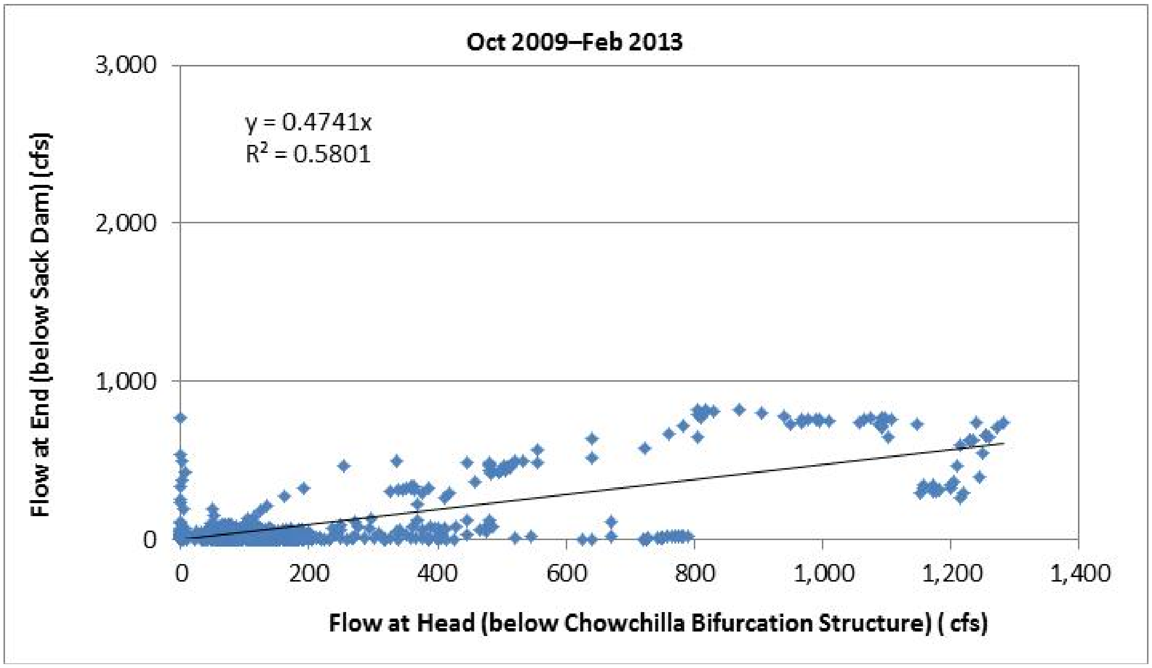


Figure 5-3.
Losses at the End Versus Losses at the Head for Reach 3

5.1.4 Reach 4 Loss Comparison

The flows in Reach 4 show much greater variability between flows at the head (below Sack Dam) and flows at the end (Washington Road), especially at higher flow rates. Flows at the head between 1,000 cfs and 2,000 cfs occurred only during the flood period from January through June 2011. In these instances where flow changes quickly and dramatically, a 1-day travel time assumption may not be appropriate, which may explain why Reach 4 appears to gain flow in this range. Flows above 2,500 cfs, which exhibit higher losses, occurred mainly in April 2011. The greater variability in this data may be a result of the fact that RY 2011 was a wet year characterized by more frequent high-flow events and flooding.

Flows at the end of Reach 4 are generally about 14 percent lower than flows at Sack Dam. When flows above 1,000 cfs are excluded, average losses are about 11 percent. Many of the low flows (less than 500 cfs) at the head are accompanied by zero flow readings at the end of the reach, suggesting a 100 percent loss of flow and contributing to the larger estimated losses in Reach 4. For these lower flows, unaccounted for diversions may also contribute to this loss pattern at low flows, such as diversions in Reach 4 with a total maximum capacity of 185 cfs.[9]

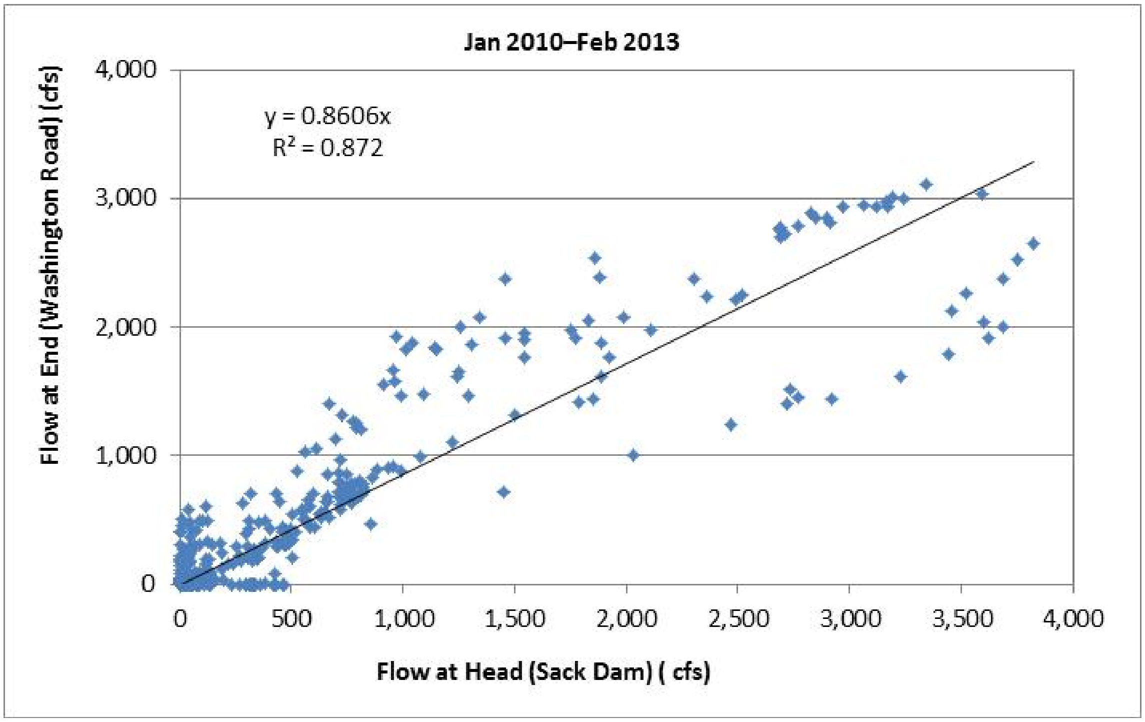


Figure 5-4.
Losses at the End Versus Losses at the Head for Reach 4

[9] Source: California Department of Fish and Game Fish Screen and Fish Passage Project, 2006

5.1.5 Summary of Loss Comparison

Table 5-1 summarizes the losses that occur by reach when averaged over the historical flow record. If there were no additional losses beyond those assumed in Exhibit B, then the flow at the head minus any Exhibit B losses would equal the flow at the end. Therefore, to identify any differences between losses assumed by the Settlement in Exhibit B and actual losses, a linear correlation was used. In general, the upper reaches show a small (1 percent to 2 percent) loss. In Reach 4, there is much more variability. This may be a result of the shorter period of record, which provides only 21 months of flow data and includes only two periods of high flow, thus limiting the data available for analysis.

Table 5-1.
Average Losses by Reach Above Exhibit B Assumptions

Reach	Estimated Losses (Percent of Flow at Head)[1]
1 – Friant Dam to Gravelly Ford	2 percent
2 – Gravelly Ford to Below Chowchilla Bifurcation Structure	Less than 1 percent
3 – Below Chowchilla Bifurcation Structure to Below Sack Dam	53 percent[2]
4 – Below Sack Dam to Washington Road	14 percent

Notes:
[1] Calculated as 1 minus the slope of line. Equations for each line are shown in the above figures.
[2] Excludes periods when there were James Bypass flood flows.

Figures 1-7 through 1-11 show the daily losses as a function of the flow at the head of each reach over the historical flow record.

In Reach 1, the differences in flow at the head (combined Friant Dam, Cottonwood Creek, and Little Dry Creek, less Exhibit B riparian releases) and the end (Gravelly Ford) are generally less than 1,000 cfs, regardless of the flow at the head (Figure 5-5).

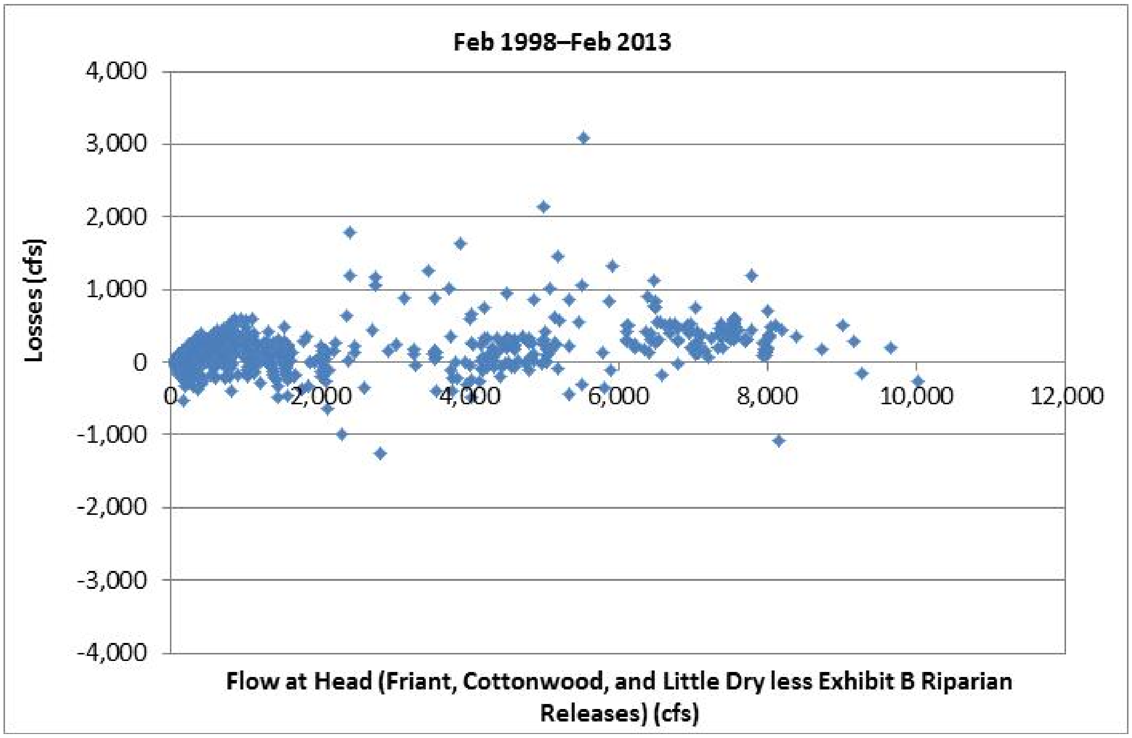


Figure 5-5.
Daily Losses Versus Flow at the Head for Reach 1

For Reach 2, the variability in losses is larger than for Reach 1 (Figure 5-6). As with Figure 5-1, the greatest variability occurred when flows at the head (Gravelly Ford) were between 4,000 cfs and 6,000 cfs, which correspond to flood releases in June 2006.

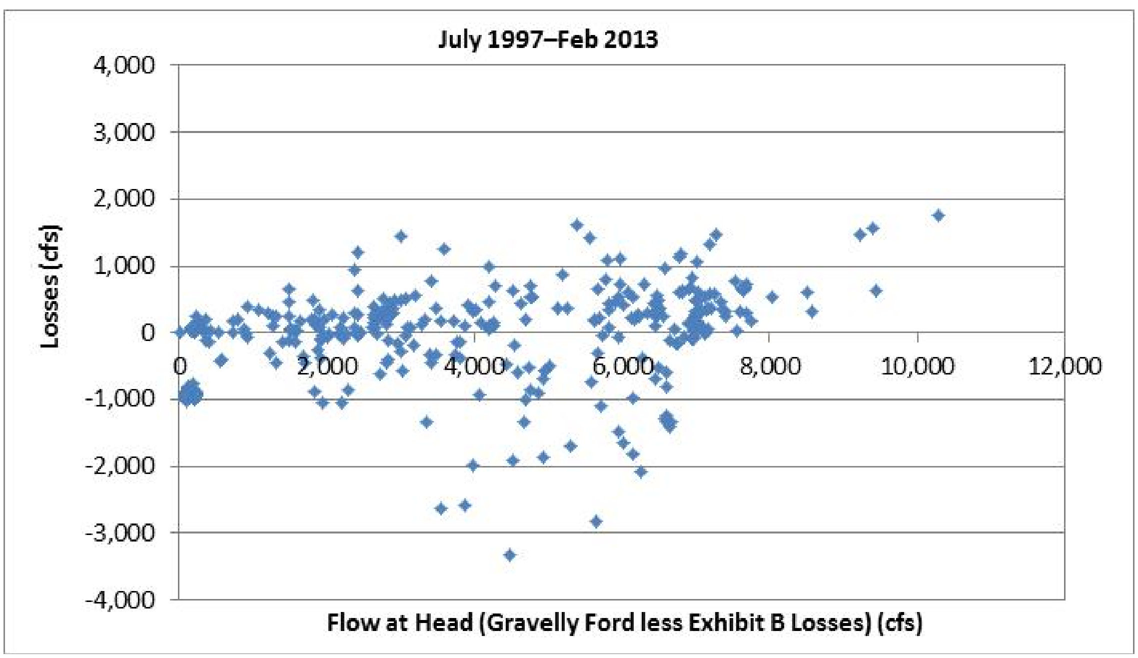


Figure 5-6.
Daily Losses Versus Flow at the Head for Reach 2

In Reach 3, losses generally increase as flows at the head (below the Chowchilla Bifurcation Structure) increase (Figure 5-7). Note that periods when the James Bypass is contributing flood flows, these periods are excluded as a 1-day travel time assumption is too generalized.

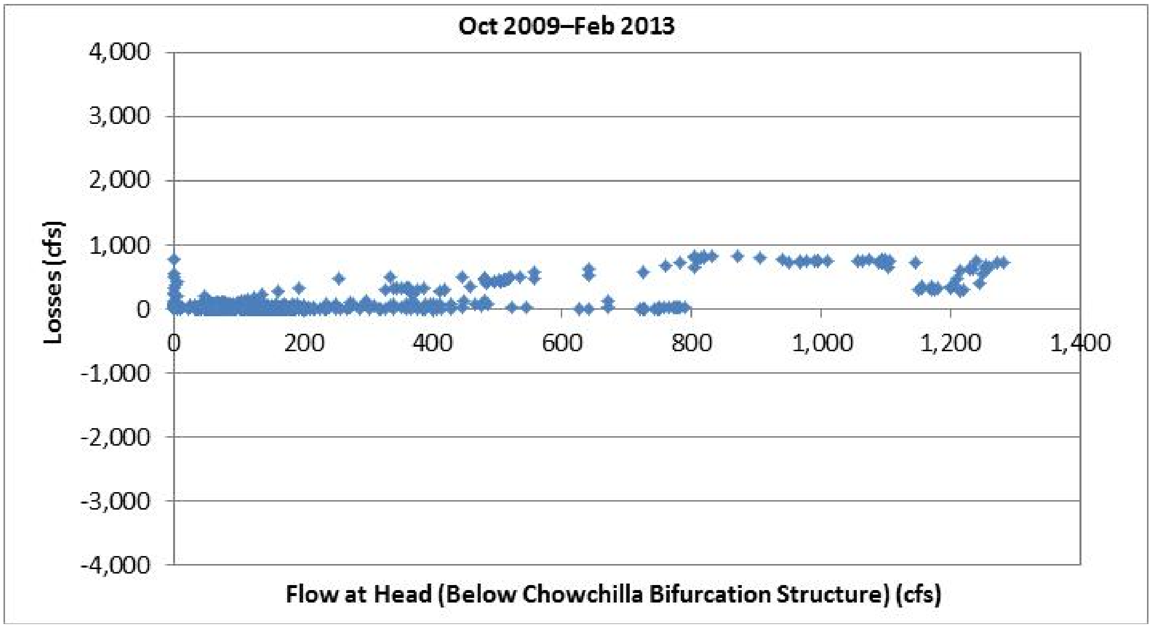


Figure 5-7.
Daily Losses Versus Flow at the Head for Reach 3

In Reach 4, losses are generally less than 500 cfs when flows at the head (below Sack Dam) are less than 1,000 cfs (Figure 5-8). However, flows greater than 2,000 cfs exhibit much higher losses.

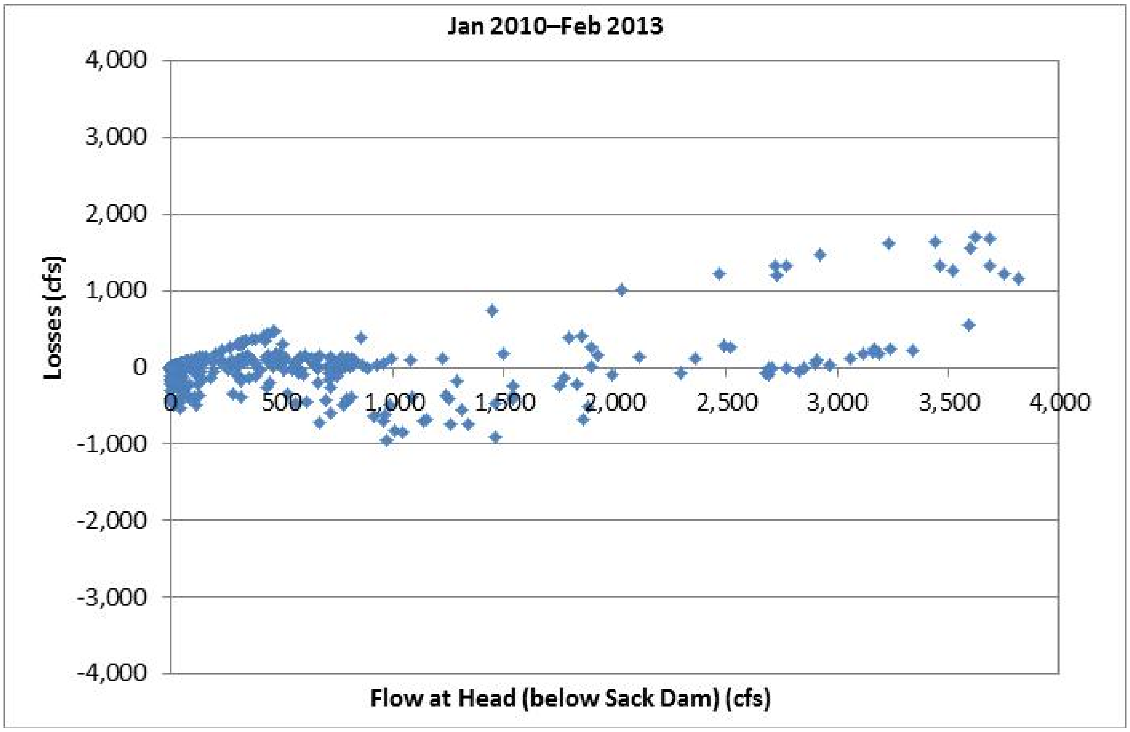


Figure 5-8.
Daily Losses Versus Flow at the Head for Reach 4

As evidenced by Figures 1-7 through 1-10, losses are not directly proportional to the magnitude of flows. However, as the flow at the head increases, greater variability is present, as evidenced by the greater spread in the data. These differences in flow could represent dramatic changes in river conditions and flow magnitude, or seepage losses, illegal diversions, or other losses that are unknown.

5.2 Reach 1 Annual Loss Trends

To further analyze Reach 1 losses, which are influenced by riparian releases, the monthly moving average of the observed losses was graphed simultaneously for each year between RY 1999 and RY 2011 to understand the variance of losses at different times of the year (Figure 5-9). Each year is shown as a separate blue line in the figure. A monthly moving average was used to plot average losses to account for varying travel times based on flow magnitude and river conditions. These average losses were plotted in conjunction with the Exhibit B schedule of riparian releases (black line) to confirm whether the seasonal trend in losses agrees with the Exhibit B assumptions. As is visible, the annual trend in historical losses appears to follow the general pattern of Exhibit B riparian releases, although higher variability exists from March through mid-July.

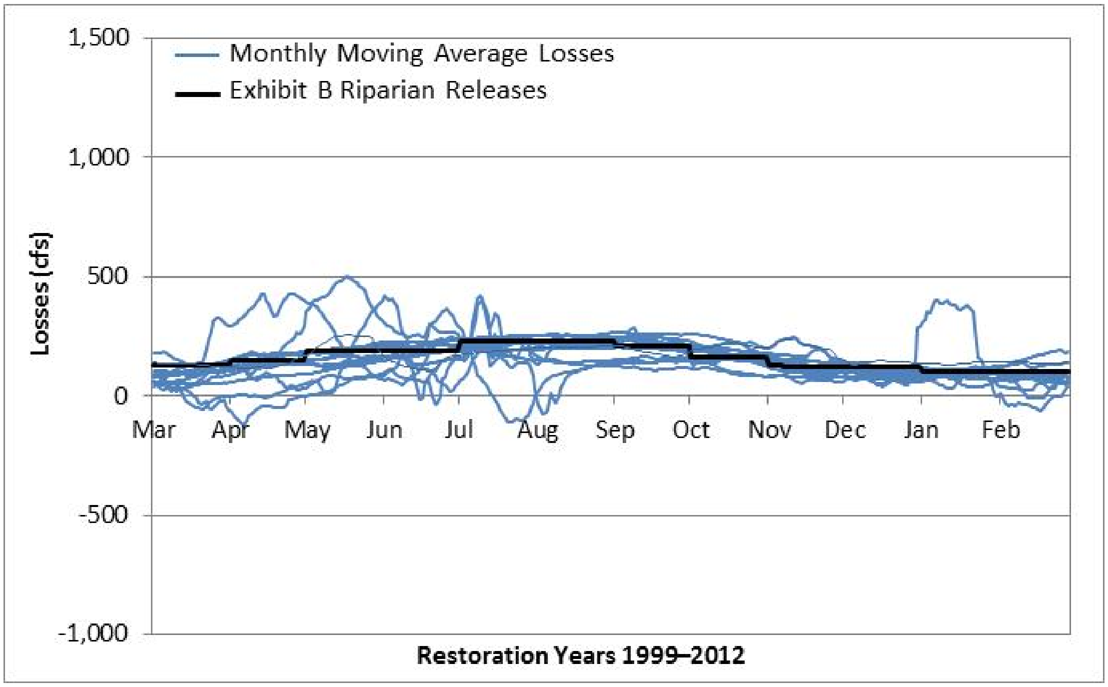


Figure 5-9.
Historical Losses and Exhibit B Riparian Releases in Reach 1

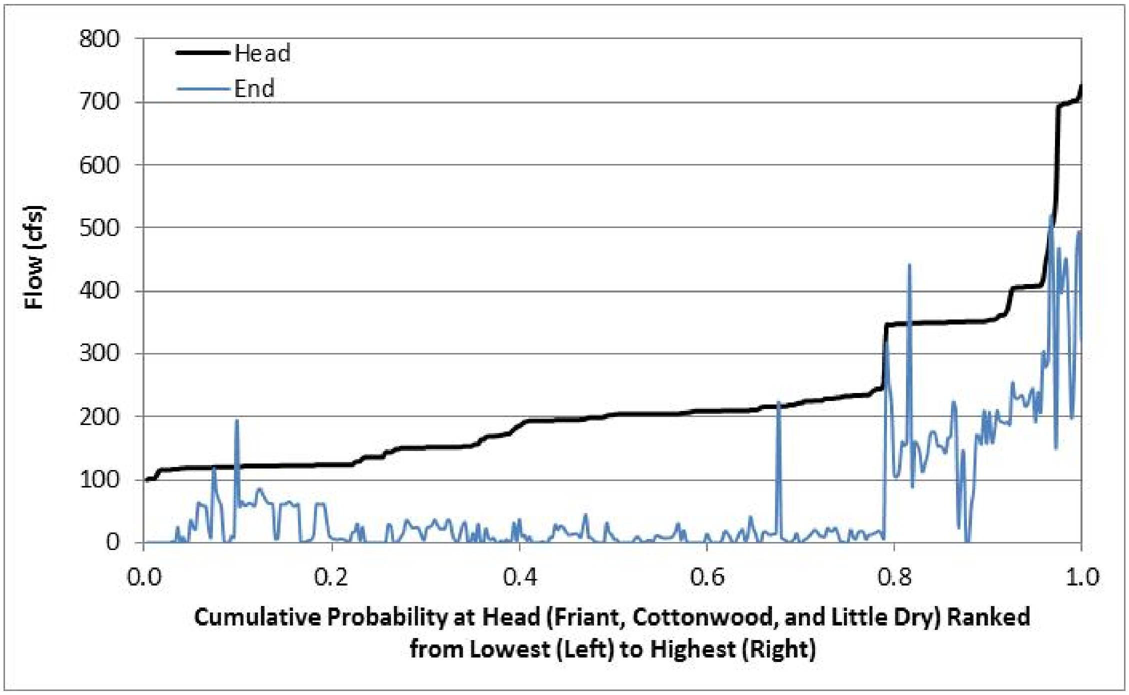
5.3 Losses Based on Flow at the Head

Figures 1-12 through 1-15 show the ranked flow at the head of each reach graphed with the corresponding flow at the end of the reach. Flows at the head were first ranked from smallest to largest and then plotted. The flow at the end, which occurred the day after each of the ranked flows at the head, was then plotted on the same axis to show the losses that occur at various flows at the head values, as well as the variability that is present in these losses. Note that Exhibit B assumptions are not subtracted from the flow at the head for this comparison. If losses experienced were exactly those assumed in Exhibit B, the difference in flow at the head and the end should be equal to Exhibit B assumptions. For Reaches 1 and 2A, RY 2009 through RY 2012 are shown. For Reaches 3 and 4A, data were not available for RY 2009.

5.3.1 Reach 1 Losses Based on Flow at the Head

For RY 2009, the flow at the end (Gravelly Ford) follows the same pattern as the flow at the head (combined Friant Dam, Cottonwood Creek, and Little Dry Creek) of Reach 1, but the flows at the end are approximately 200 cfs lower than the flows at the head, matching Exhibit B assumptions (Figure 5-10a). The higher flows at the head, which are much lower than those for subsequent years, also exhibit greater variability in flows at the end values.

Losses in RY 2010 are fairly consistent, falling between approximately 100 and 200 cfs (Figure 5-10b). This corresponds with the Exhibit B schedule of riparian releases for Reach 1. For RY 2011 and RY 2012, losses are again around 150 cfs, although higher flows at the head exhibit greater losses and higher variability throughout Reach 1 (Figures 1-12c and 1-12d, respectively).



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-10a.
RY 2009: Comparison of Flow in Reach 1 at the Head and End

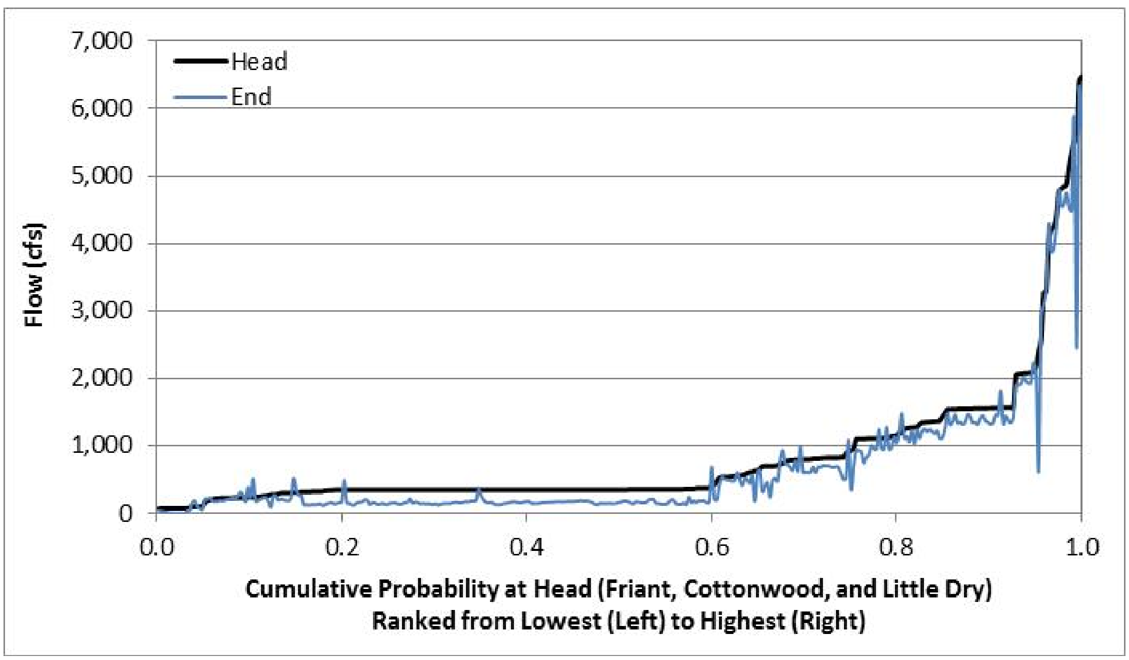
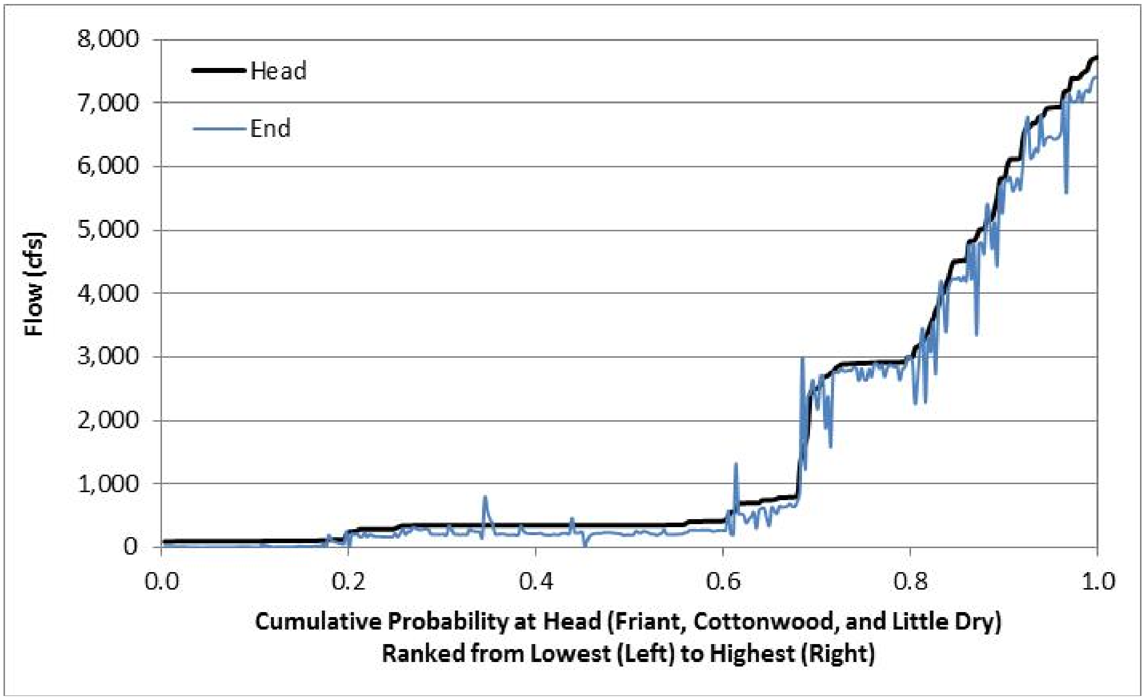


Figure 5-10b.
RY 2010: Comparison of Flow in Reach 1 at the Head and End



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-10c.
RY 2011: Comparison of Flow in Reach 1 at the Head and End

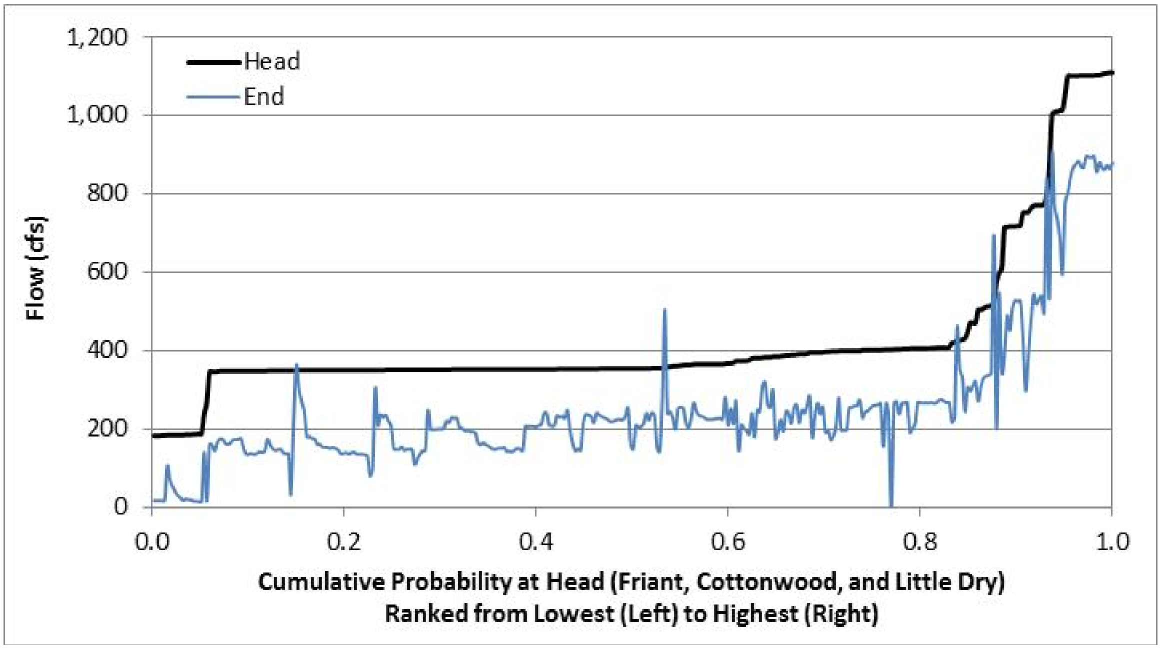


Figure 5-10d.
RY 2012: Comparison of Flow in Reach 1 at the Head and End

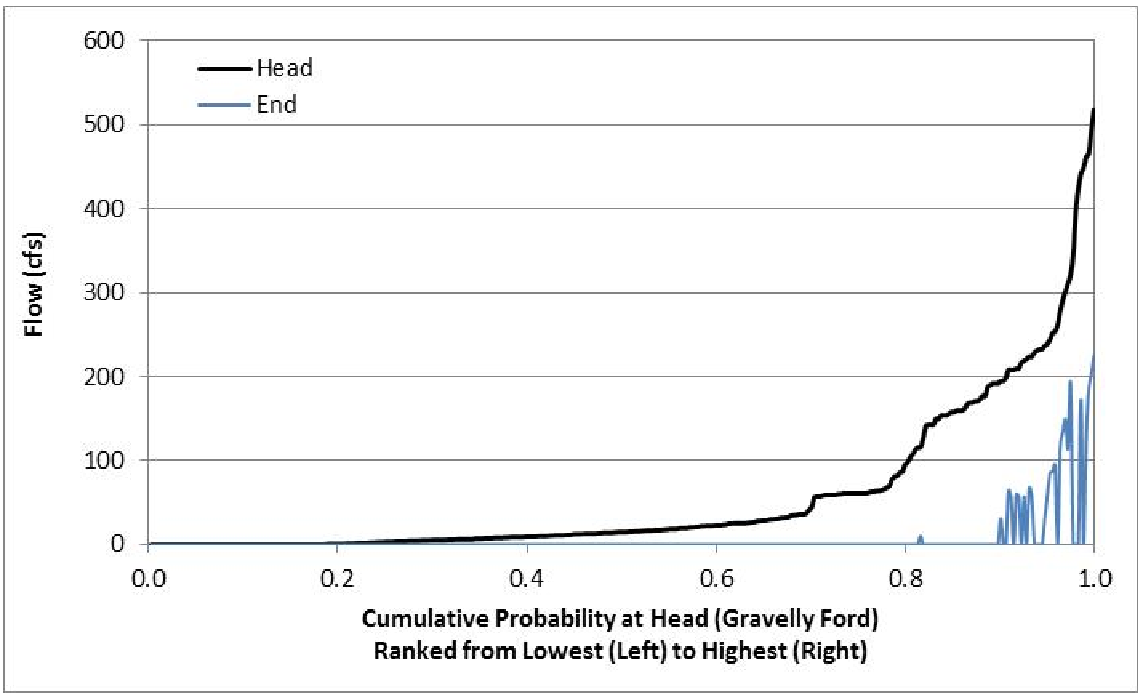
5.3.2 Reach 2 Losses Based on Flow at the Head

Similar to Reach 1, the magnitude of Reach 2 flows for RY 2009 are overall much lower than in subsequent years (Figure 5-11a). The flows at the end (below the Chowchilla Bifurcation Structure) do not appear to closely follow the pattern of the flow at the head (Gravelly Ford).

For RY 2010, losses in Reach 2 are small, generally falling under 100 cfs (Figure 5-11b). This is consistent with the expected Exhibit B schedule of losses. However, these losses increase in magnitude and variability at flows at the head greater than 2,000 cfs.

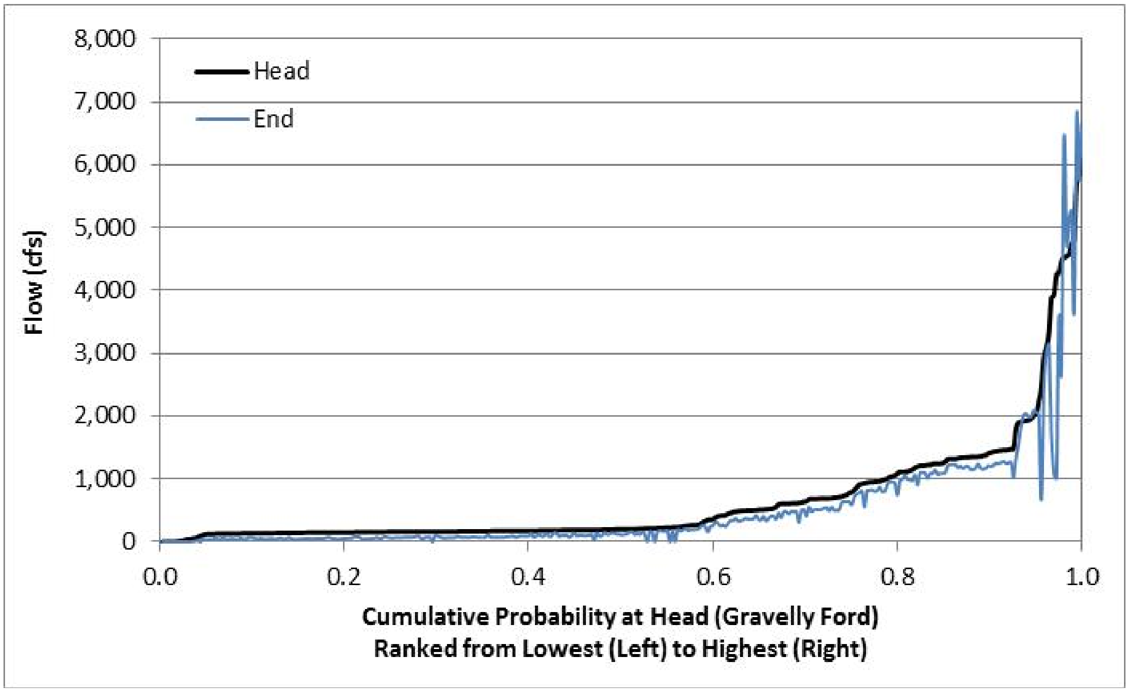
RY 2011 was a Wet Year Type and subsequently experienced a greater number of high-flow events (above 2,000 cfs) where the variability in losses increases (Figure 5-11c). However, at low flows at the head, losses generally appear to be less than 100 cfs.

RY 2012 is characterized by a relatively constant magnitude of losses regardless of flow at the head and are around 100 cfs (Figure 5-11d).



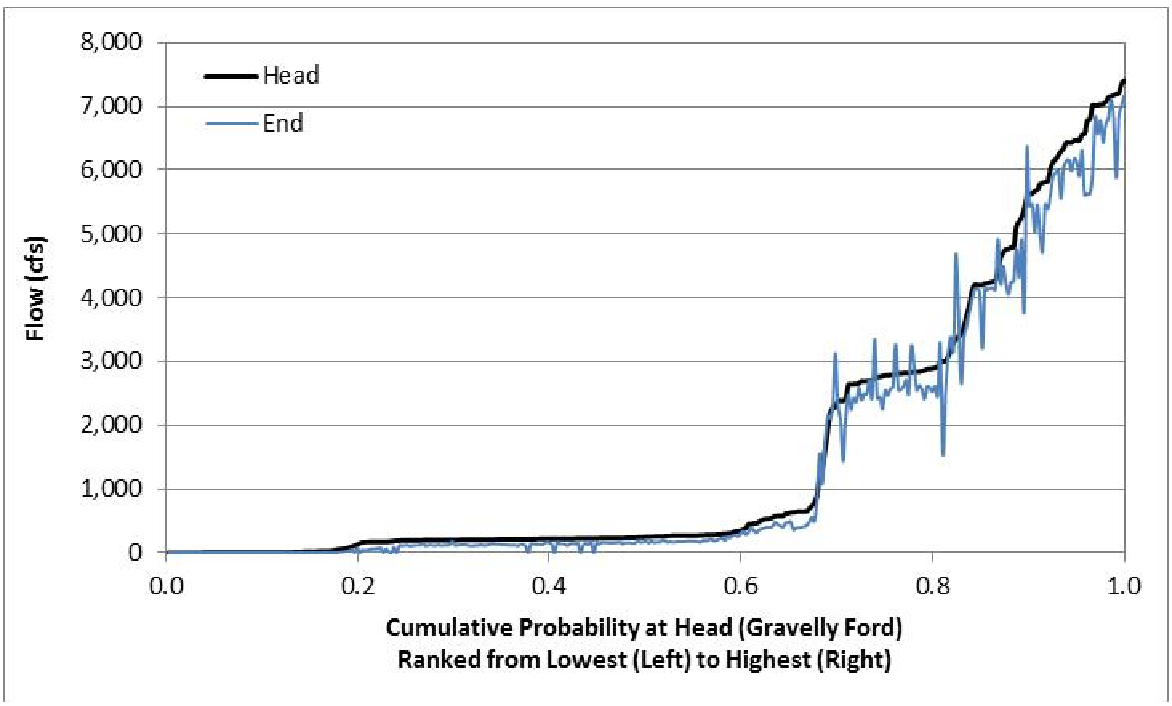
*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-11a.
RY 2009: Comparison of Flow in Reach 2 at the Head and End



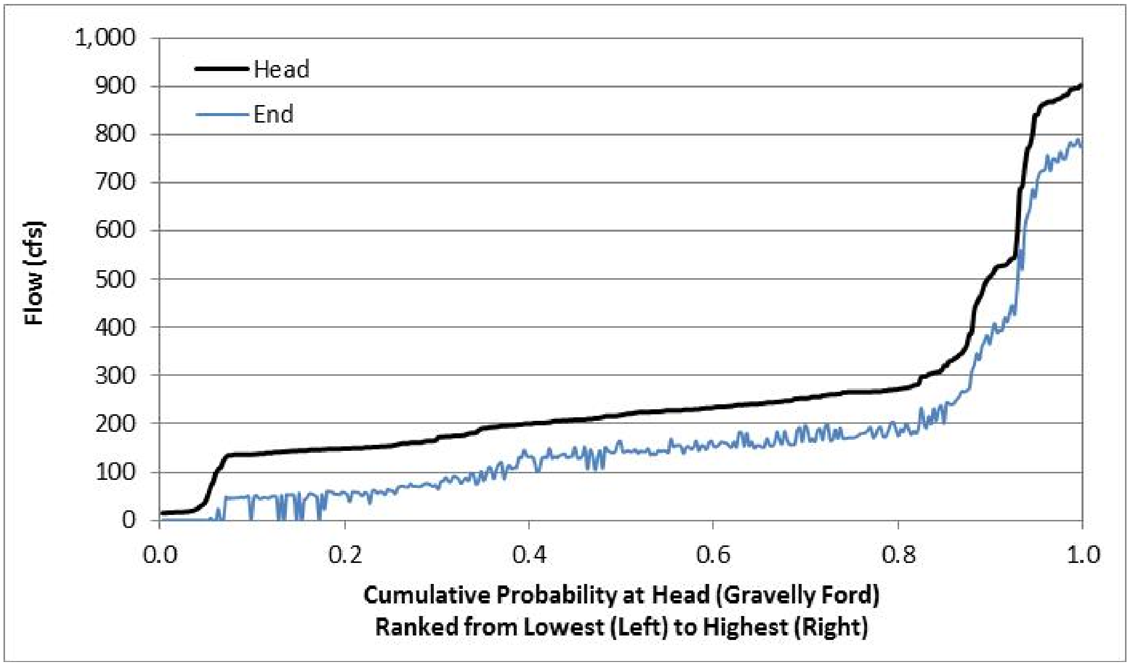
*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-11b.
RY 2010: Comparison of Flow in Reach 2 at the Head and End



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-11c.
RY 2011: Comparison of Flow in Reach 2 at the Head and End



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-11d.
RY 2012: Comparison of Flow in Reach 2 at the Head and End

5.3.3 Reach 3 Losses Based on Flow at the Head

When comparing flows at the head of Reach 2B (below the Chowchilla Bifurcation Structure plus the James Bypass) and at the end of Reach 3 (below Sack Dam), losses in RY 2010 vary greatly at higher flows at the head (Figure 5-12a).

Similar to RY 2011, losses vary greatly at higher flows at the head (Figure 5-12b). At lower flows at the head, there is often no flow released from Sack Dam (flow at the end).

For RY 2012, flows at the end (below Sack Dam) are on average 15 cfs regardless of flow at the head (Figure 5-12c). No Interim Flows were released below Sack Dam and data are unavailable for much of RY 2012, both of which likely influence the difference in flows at the head and the end of the reach.

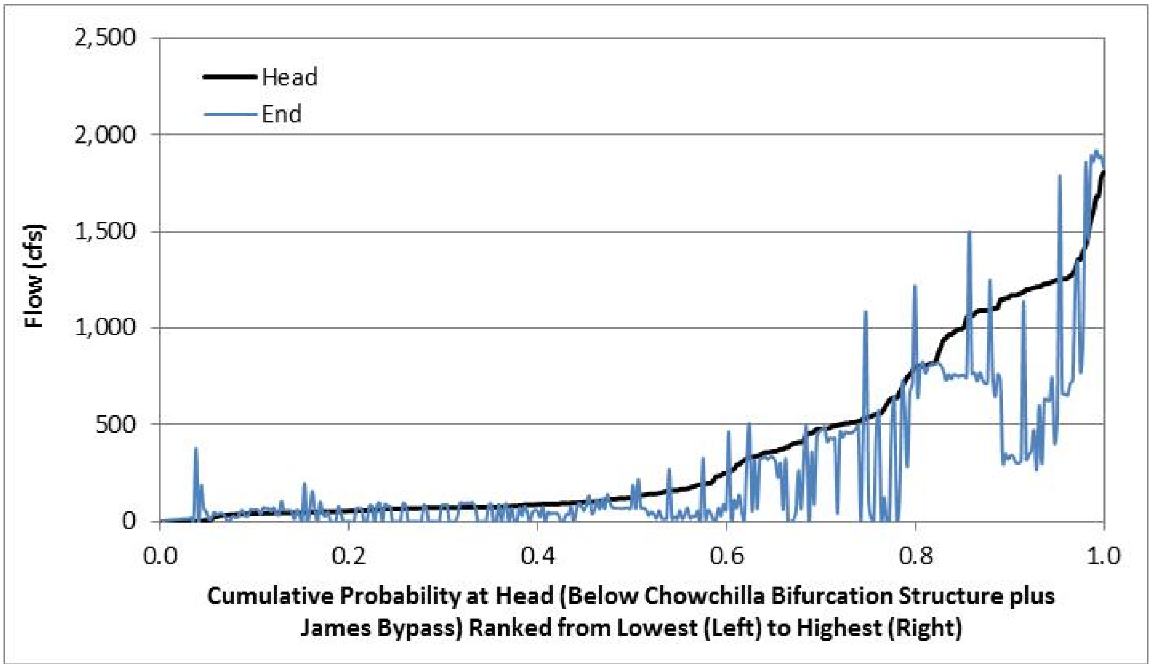


Figure 5-12a.
RY 2010: Comparison of Flow in Reach 3 at the Head and End

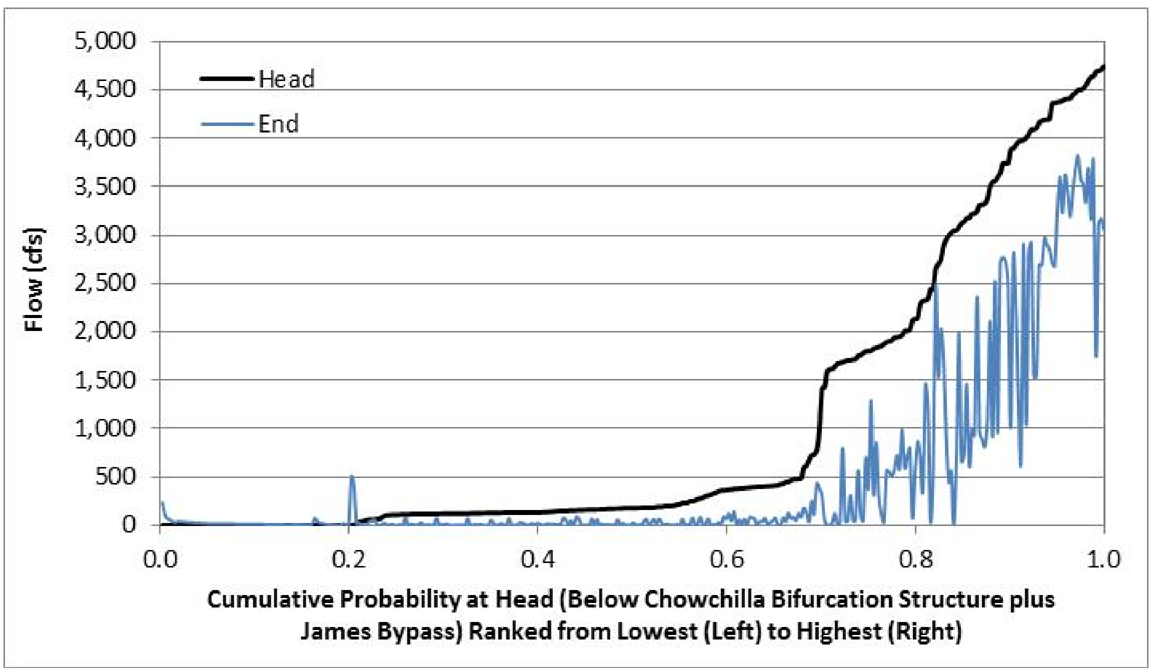
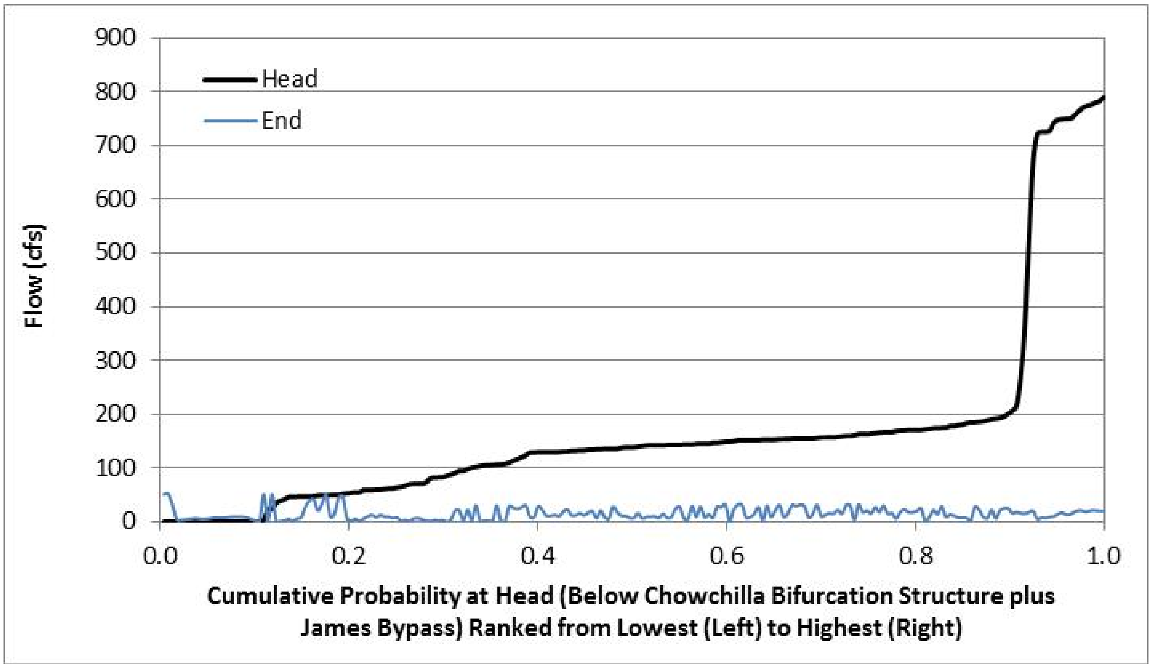


Figure 5-12b.
RY 2011: Comparison of Flow in Reach 3 at the Head and End



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-12c.
RY 2012: Comparison of Flow in Reach 3 at the Head and End

5.3.4 Reach 4 Losses Based on Flow at the Head

For RY 2010, Reach 4 exhibits substantial variability at low-flow values, especially between flows at the head (below Sack Dam) of 200 cfs and 500 cfs (Figure 5-13a). A similar pattern is visible at flows greater than 800 cfs.

For RY 2011, high variability is present for Reach 4 flows at the head above 100 cfs (Figure 5-13b). Substantial losses, in excess of 1,000 cfs, occur at high flows.

For RY 2012, high variability is present for Reach 4 regardless of flows at the head (Figure 5-13c). Note that no Interim Flows were released below Sack Dam for RY 2012 and that there are substantial data gaps throughout the year (i.e., only 109 days had gage data at both Sack Dam and Washington Road).

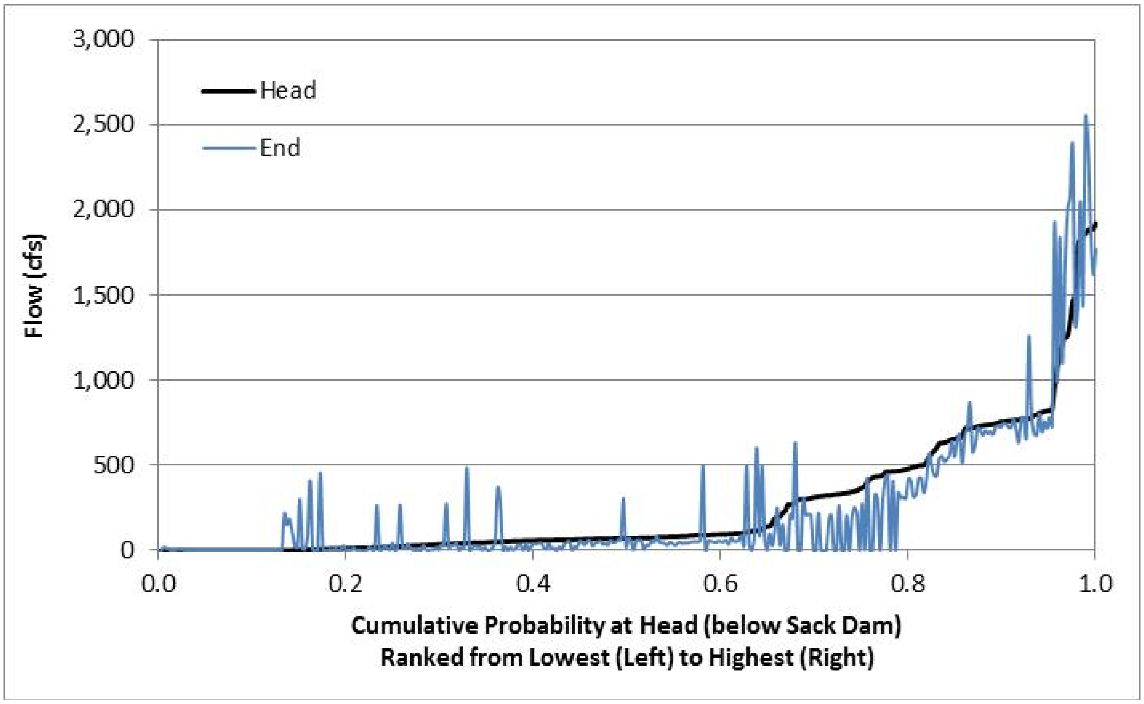


Figure 5-13a.
RY 2010: Comparison of Flow in Reach 4 at the Head and End

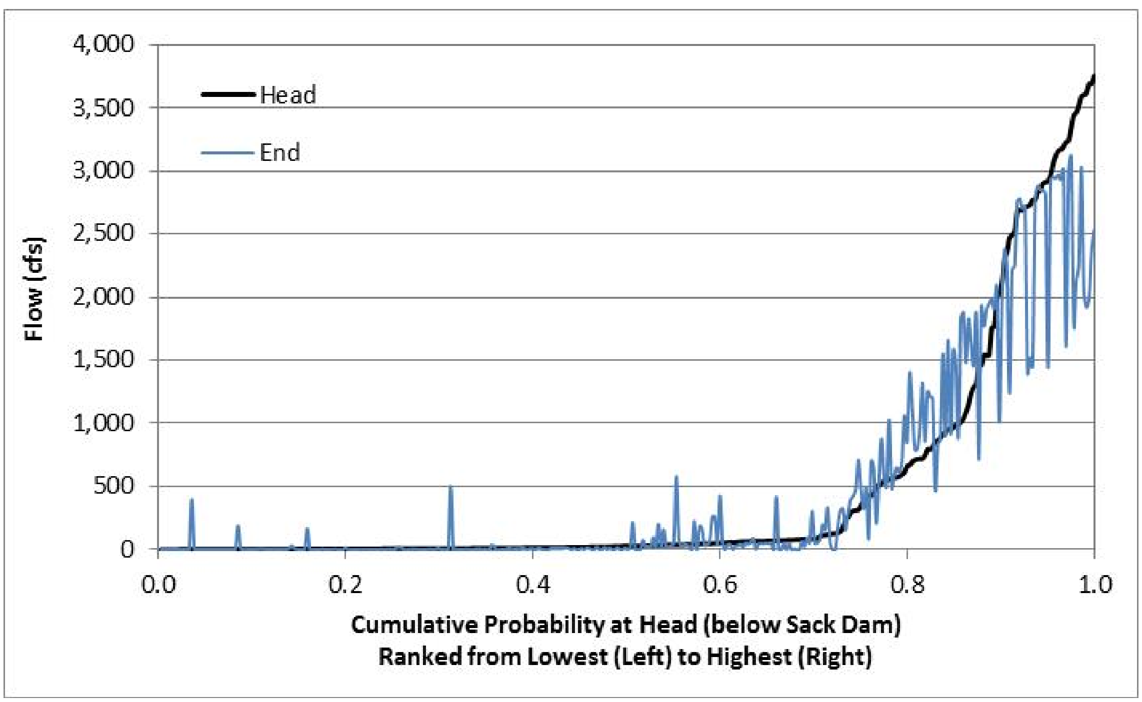
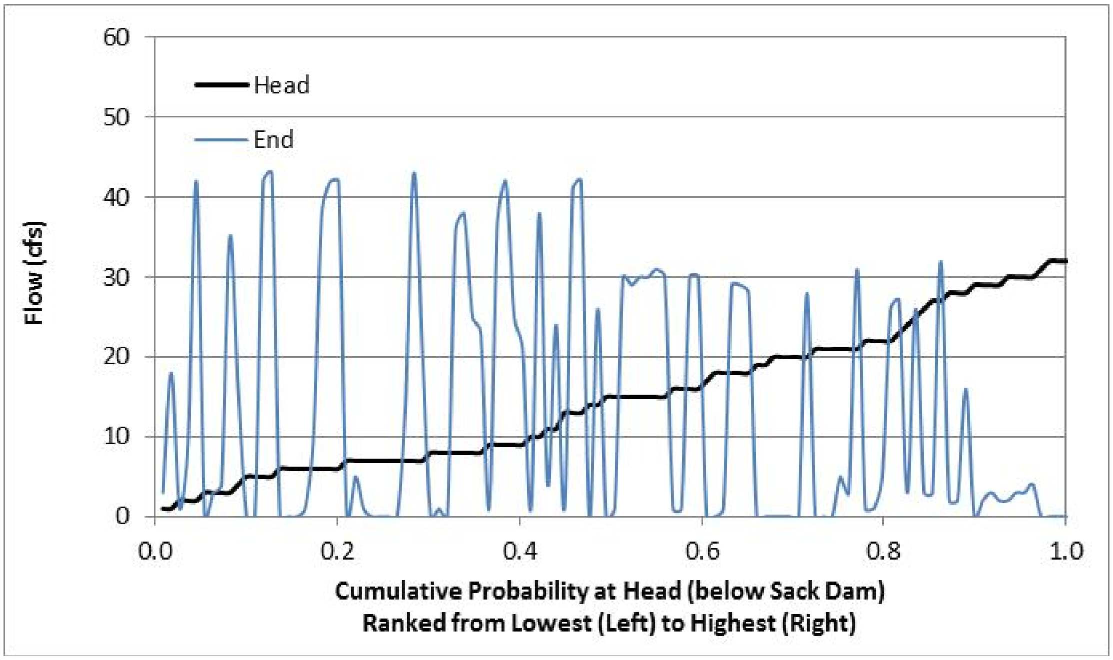


Figure 5-13b.
RY 2011: Comparison of Flow in Reach 4 at the Head and End



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-13c.
RY 2012: Comparison of Flow in Reach 4 at the Head and End

5.3.5 Losses Based on Flow at the Head Summary

As these graphs indicate, with the exception of RY 2009, the flow at the end of each reach generally follows the same pattern as the flow at the head, although greater variability in losses exists for higher flow at the head. Because RY 2009 was the first year of Interim Flows and had lower flows at the head than subsequent years, more variability existed as water began to run through the previously dry river channel. With regards to the greater variability in Reach 4, this may be a result of the higher losses that occur in this reach or because there was a significant amount of missing data for some years.

5.4 Cumulative Annual Losses

Figures 1-16 through 1-19 show the daily losses and cumulative annual losses in each reach for RY 2009 through RY 2012. As mentioned previously, data were not available for Reaches 3 and 4 in RY 2009. Cumulative losses were calculated for both the entire year (designated as a star in the figures), and also the entire year less any losses during flood periods (shown in the figures as grey dashed boxes).

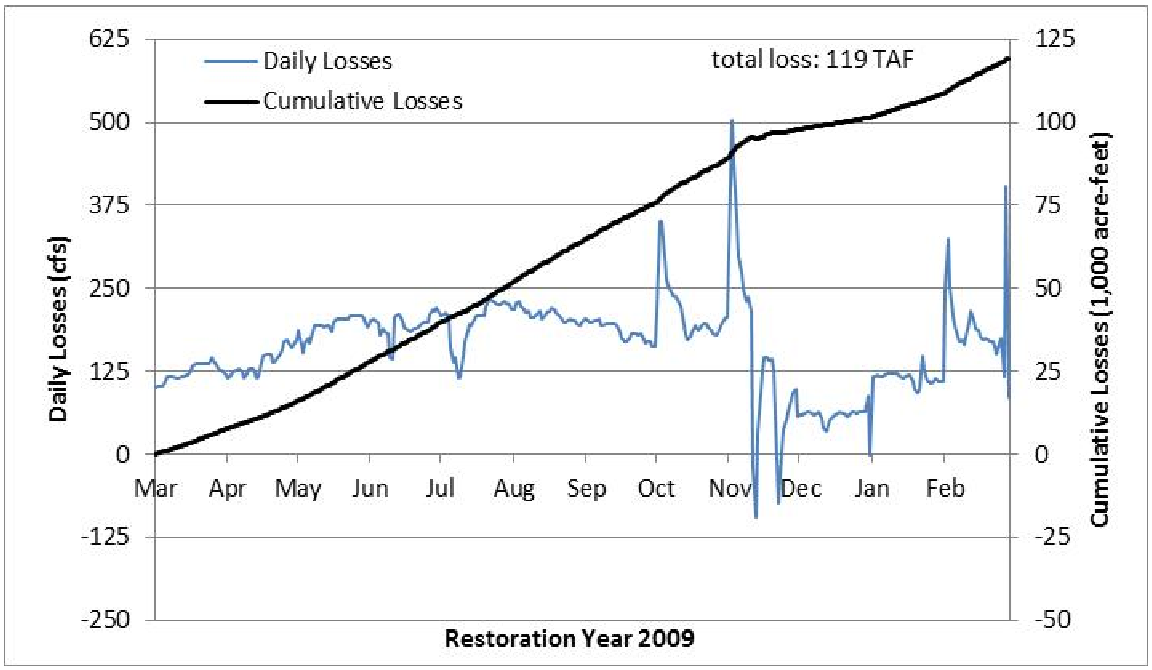
5.4.1 Reach 1 Cumulative Annual Losses

In RY 2009, Reach 1 exhibited average daily losses around 150 cfs, as seen in Figure 5-14a. The measured losses of 119 thousand acre-feet (TAF) are 6 TAF greater than the riparian releases anticipated in Exhibit B (estimated as 117 TAF).

During RY 2010 (shown in Figure 5-14b), there was one flood period (December 26, 2010, to January 27, 2011) during which seepage losses are not accounted for. Excluding flood periods in RY 2010, Reach 1 experienced 13 TAF less seepage and diversion losses (calculated as 94 TAF) than anticipated in Exhibit B (estimated as 110 TAF).

In RY 2011, there was one flood period (March 21, 2011, to July 16, 2011) during which seepage losses are not accounted for. Excluding flood periods in RY 2011, Reach 1 experienced 15 TAF less seepage and diversion losses (calculated as 56 TAF) than anticipated in Exhibit B (estimated as 75 TAF), as seen in Figure 5-14c.

In RY 2012 (Figure 5-14d), daily losses were around 150 cfs. Reach 1 experienced 10 TAF greater seepage and diversion losses (calculated as 123 TAF) than anticipated in Exhibit B (estimated as 117 TAF).



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-14a.
Reach 1 Cumulative and Daily Losses for RY 2009

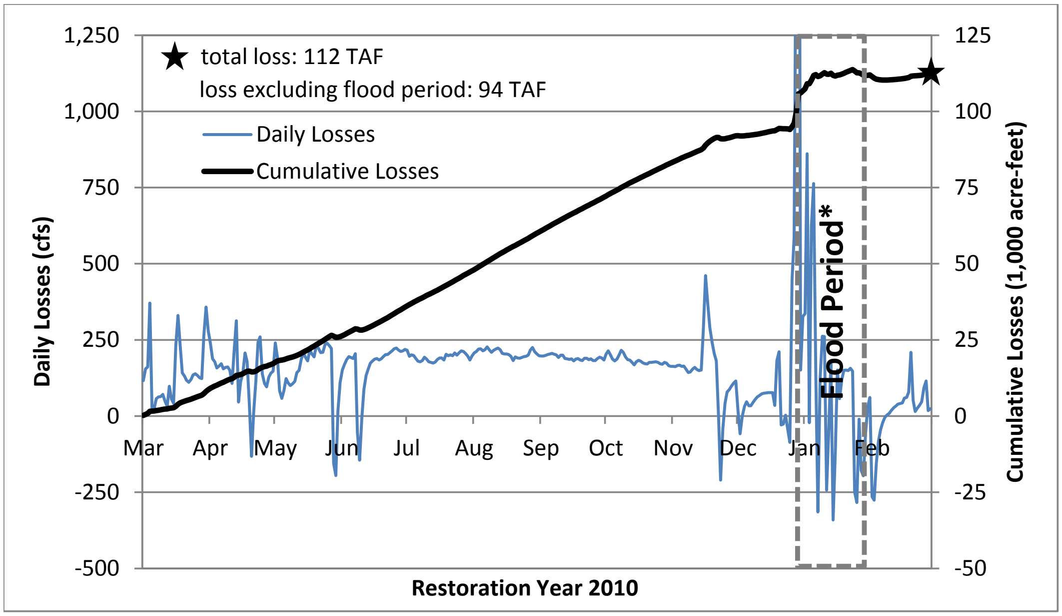
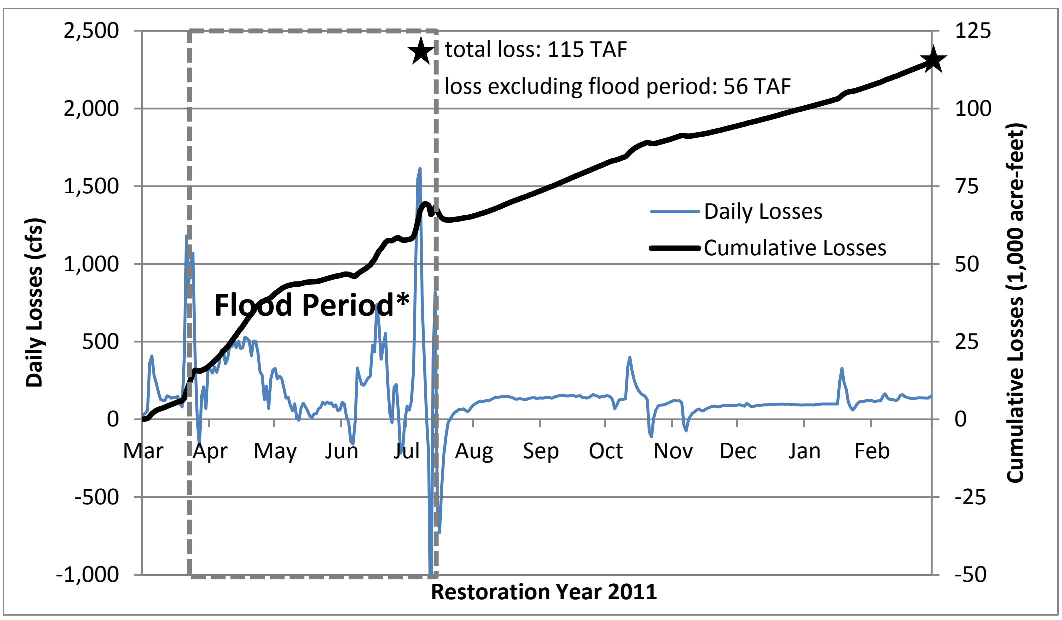


Figure 5-14b.
Reach 1 Cumulative and Daily Losses for RY 2010



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-14c.
Reach 1 Cumulative and Daily Losses for RY 2011

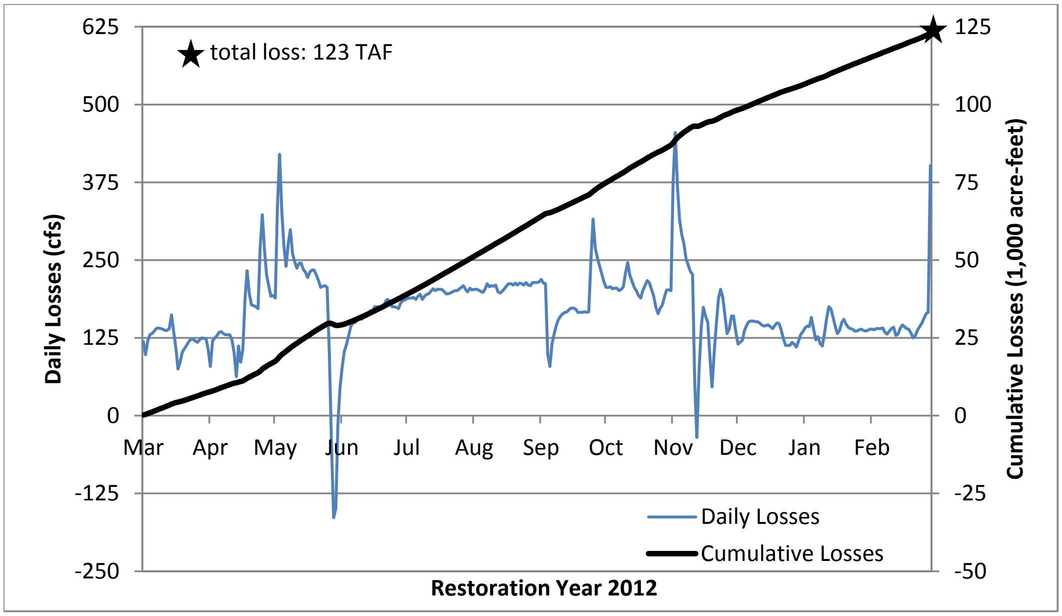


Figure 5-14d.
Reach 1 Cumulative and Daily Losses for RY 2012

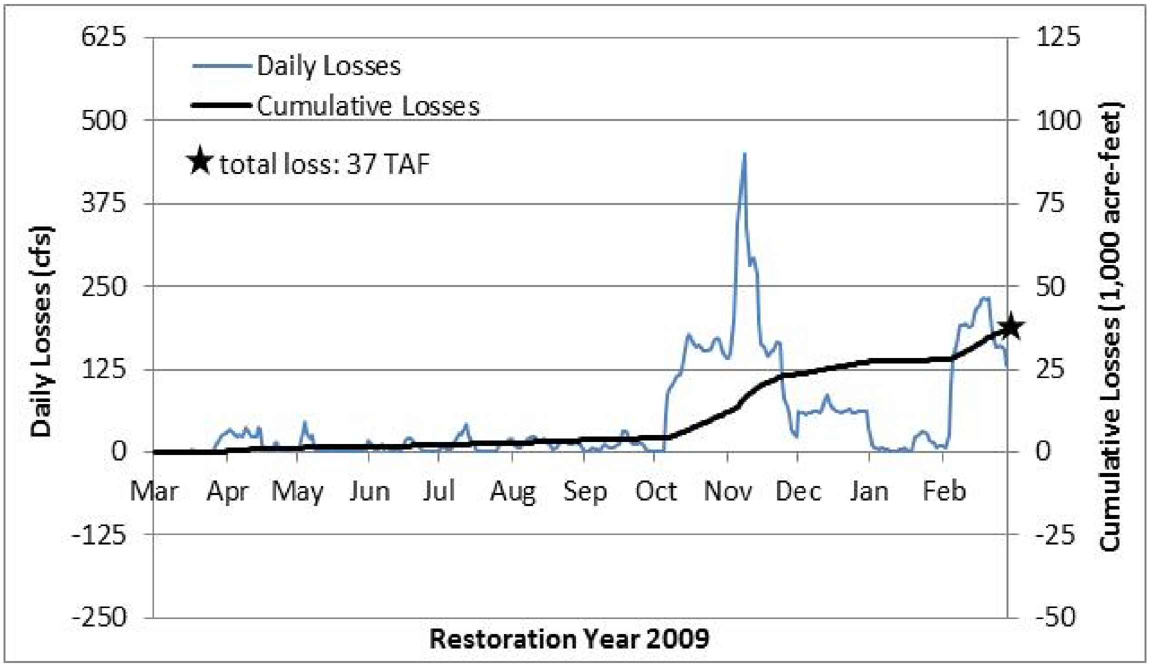
5.4.2 Reach 2 Cumulative Annual Losses

In RY 2009, daily losses in Reach 2 were very small except from October to March, which may be due to missing data, as shown in Figure 5-15a. This reach had 37 TAF of losses in RY 2009, 30 TAF less than the anticipated Exhibit B losses of 67 TAF.

In RY 2010, excluding the flood release period, Reach 2 exhibited 8 TAF greater losses (calculated as 70 TAF) than the Exhibit B anticipated losses (estimated as 62 TAF). Daily losses were less than 500 cfs, except in the flood period, as seen in Figure 5-15b.

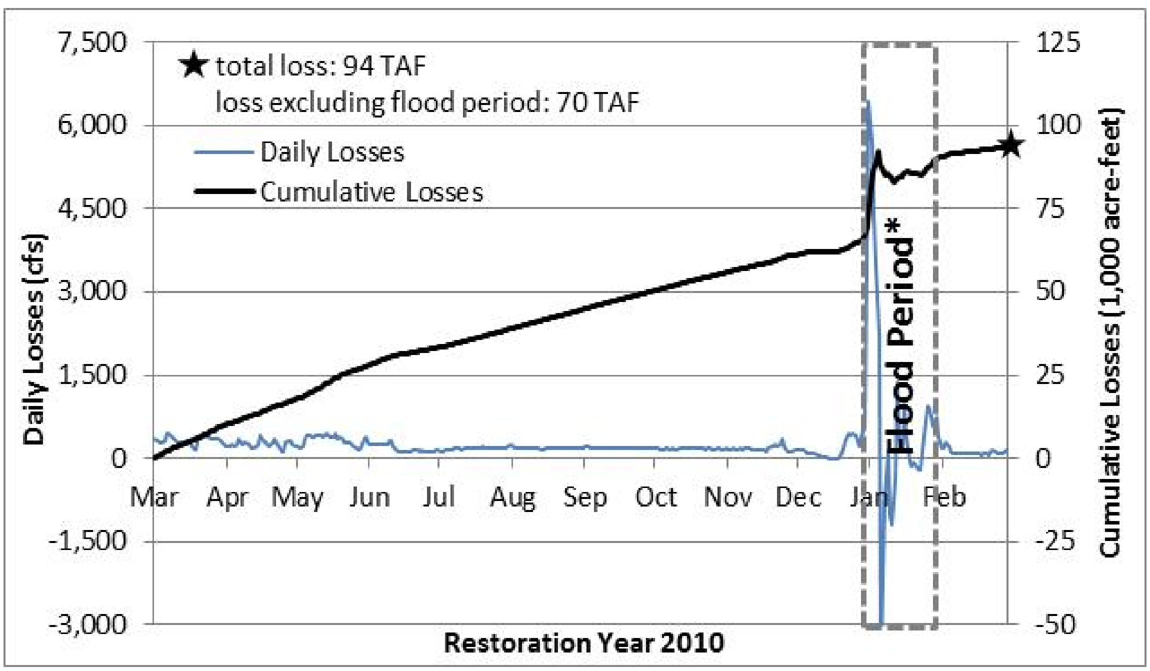
For RY 2011 (Figure 5-15c), the calculated losses (38 TAF) were 3 TAF less than the losses anticipated by Exhibit B (41 TAF). Similar to Reach 1, Reach 2 losses may also be higher than computed because of the January flood releases. In addition, the anticipated losses from Exhibit B are for the entire Reach 2, whereas the calculated losses only include Reach 2A, as specified by the RFG.

For RY 2012, daily losses were typically less than 250 cfs, and there were no gains in flow, as shown in Figure 5-15d. Calculated losses for RY 2012 were 64 TAF, which is 3 TAF greater than the Exhibit B anticipated losses of 61 TAF.



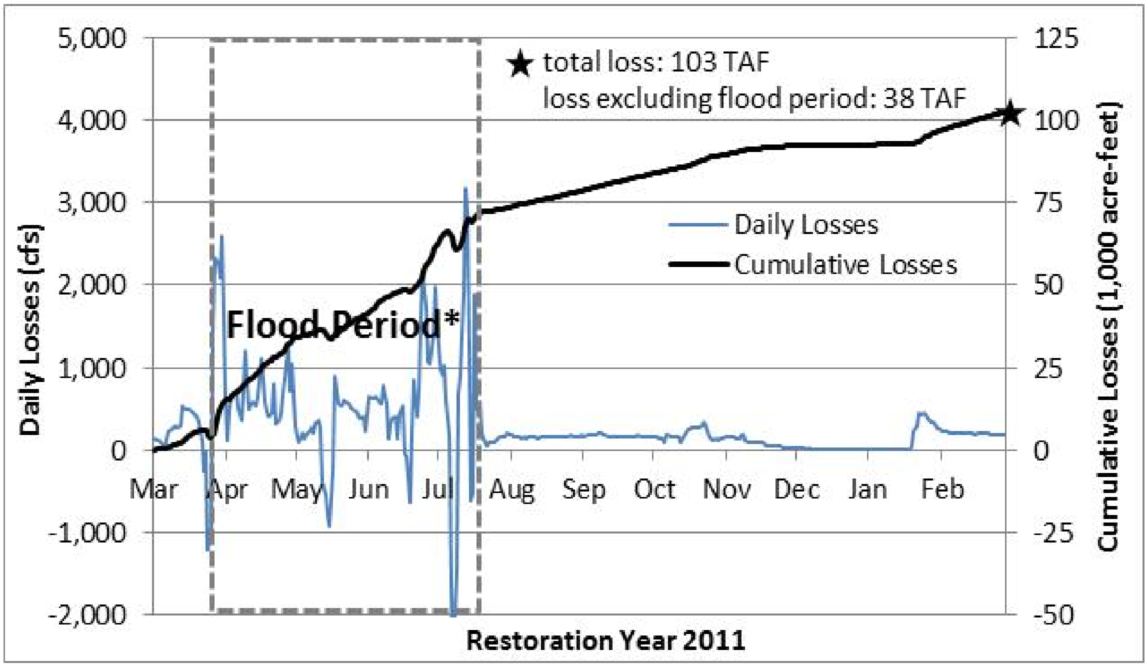
*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-15a.
Reach 2 Cumulative and Daily Losses for RY 2009



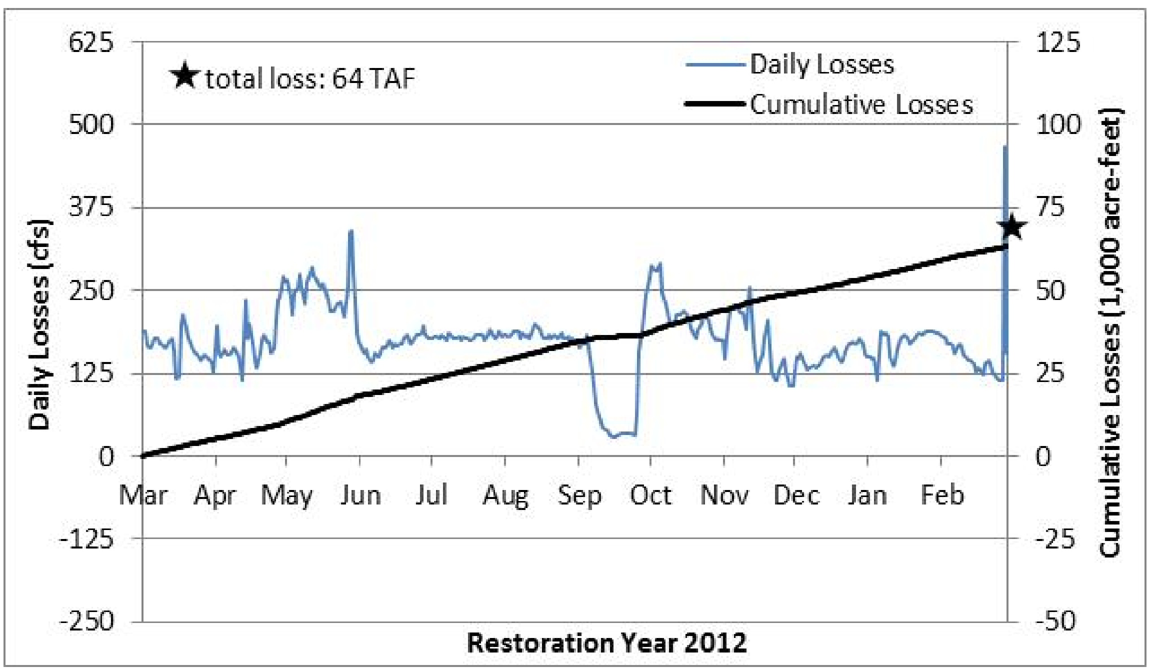
*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-15b.
Reach 2 Cumulative and Daily Losses for RY 2010



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-15c.
Reach 2 Cumulative and Daily Losses for RY 2011



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-15d.
Reach 2 Cumulative and Daily Losses for RY 2012

5.4.3 Reach 3 Cumulative Annual Losses

For RY 2010, losses were 81 TAF (excluding flood period), with the highest losses seen in the spring months, as shown in Figure 5-16a. Exhibit B anticipated no losses in this reach.

In RY 2011 (Figure 5-16b), there was a loss of 55 TAF between the head and the end of the reach. Excluding the flood period, losses were generally around 200 cfs or less.

For RY 2012, there were only 227 days of data for both the flow at the head and the end of reach. The total loss was 68 TAF. The largest losses occurred in late May and June, as shown in Figure 5-16c, which corresponds to dates when data were interpolated because it was not originally available.

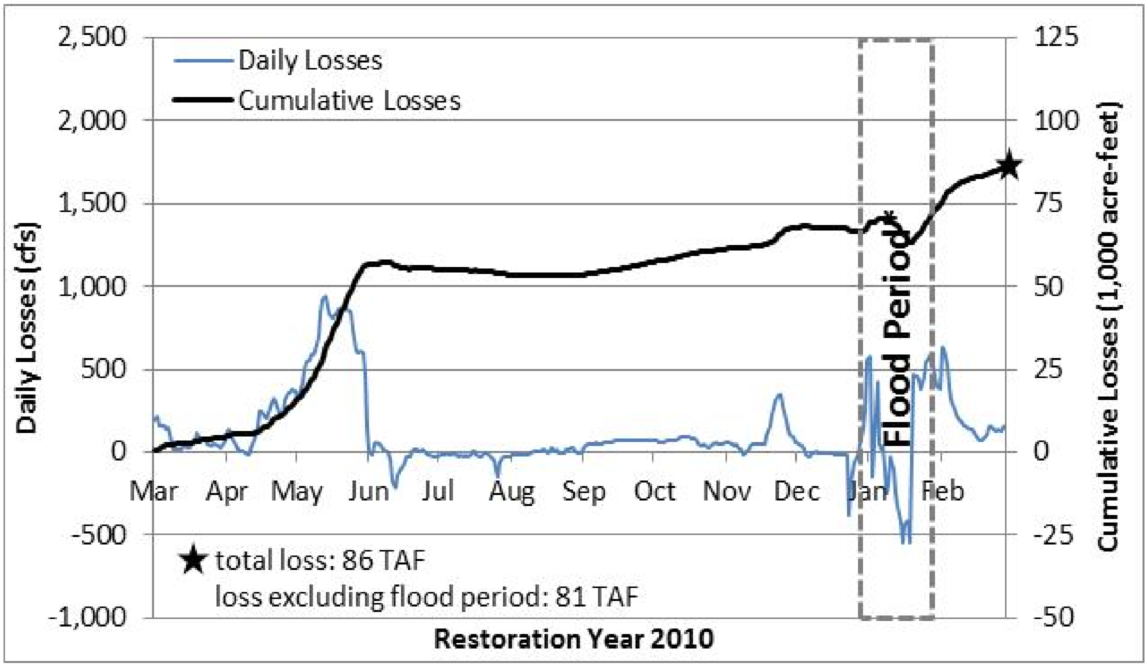


Figure 5-16a.
Reach 3 Cumulative and Daily Losses for RY 2010

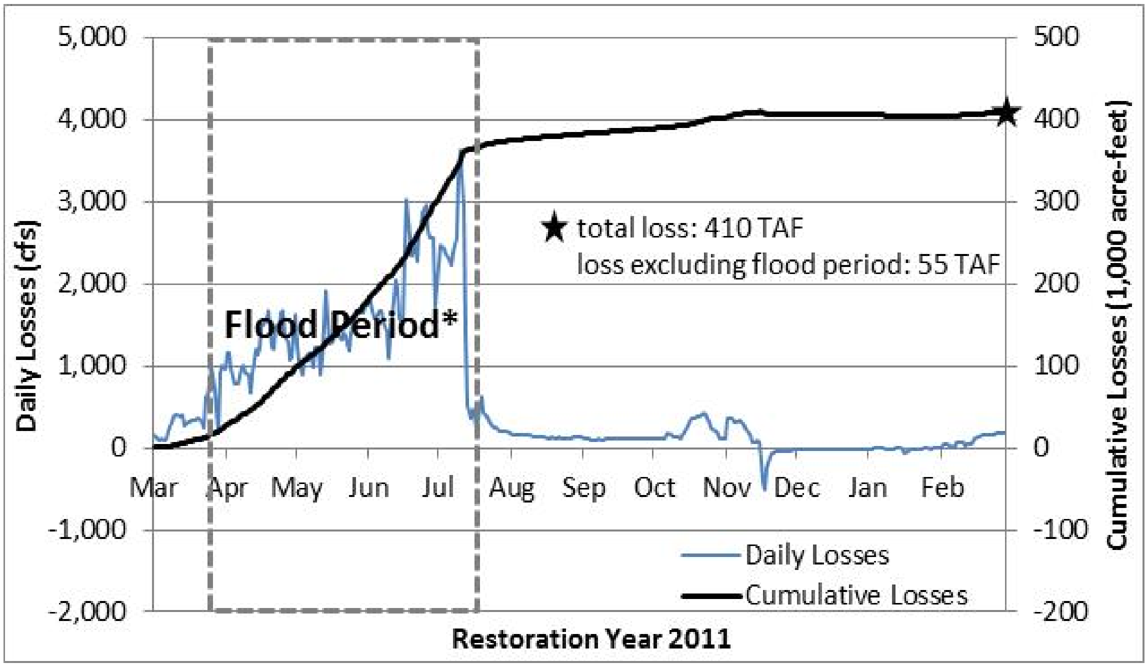
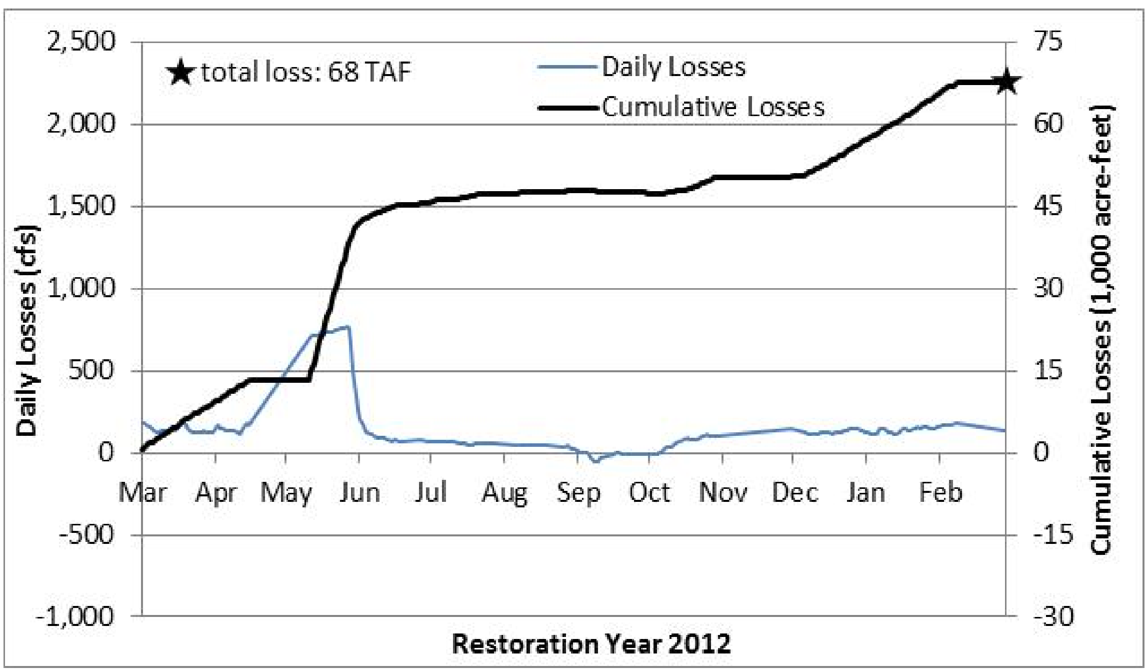


Figure 5-16b.
Reach 3 Cumulative and Daily Losses for RY 2011



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-16c.
Reach 3 Cumulative and Daily Losses for RY 2012

5.4.4 Reach 4 Cumulative Annual Losses

Reach 4 experienced a loss of 34 TAF in RY 2010 (Figure 5-17a) (excluding flood periods), with the majority of the daily losses occurring between March and July. Exhibit B anticipates no losses in this reach.

For RY 2011, Reach 4 experienced a total loss of 6 TAF (excluding flood periods), with very small daily losses outside the flood period, shown in Figure 5-17b. The significant reduction in losses in June may be a result of return flows, which would contribute additional flow to the reach.

For RY 2012, the calculated loss was 0.4 TAF (Figure 5-17c). This value likely underestimates the total cumulative loss because data were unavailable for most of the year; only 109 days of data were available. Periods when data were unavailable occurs when the daily loss is 0 cfs (i.e., a flat line).

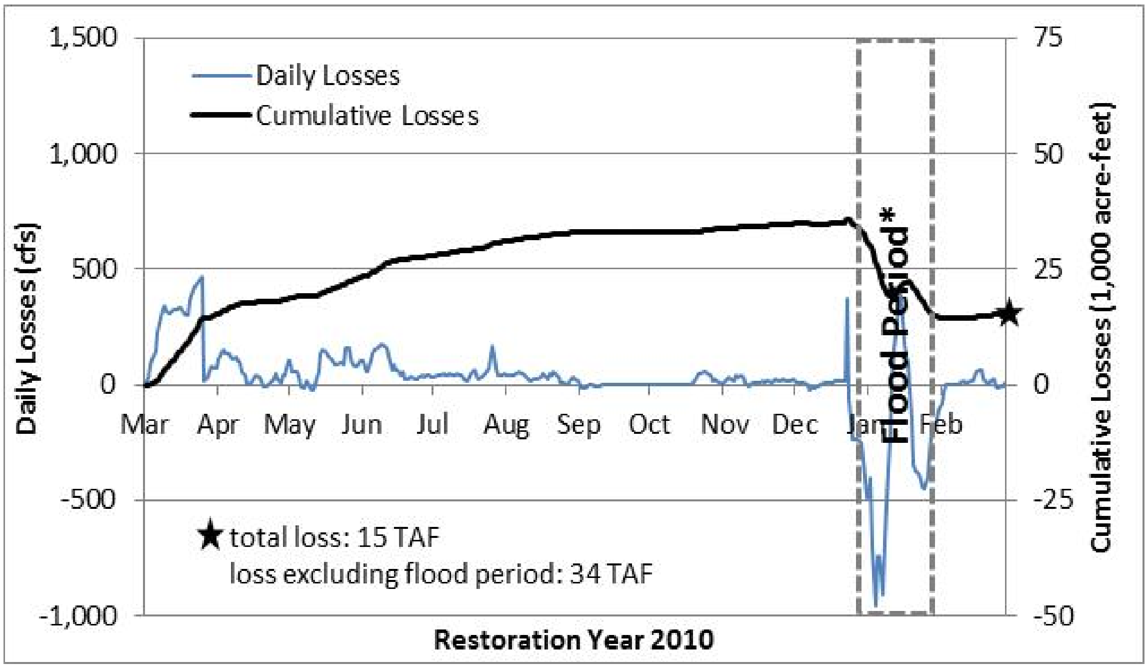


Figure 5-17a.
Reach 4 Cumulative and Daily Losses for RY 2010

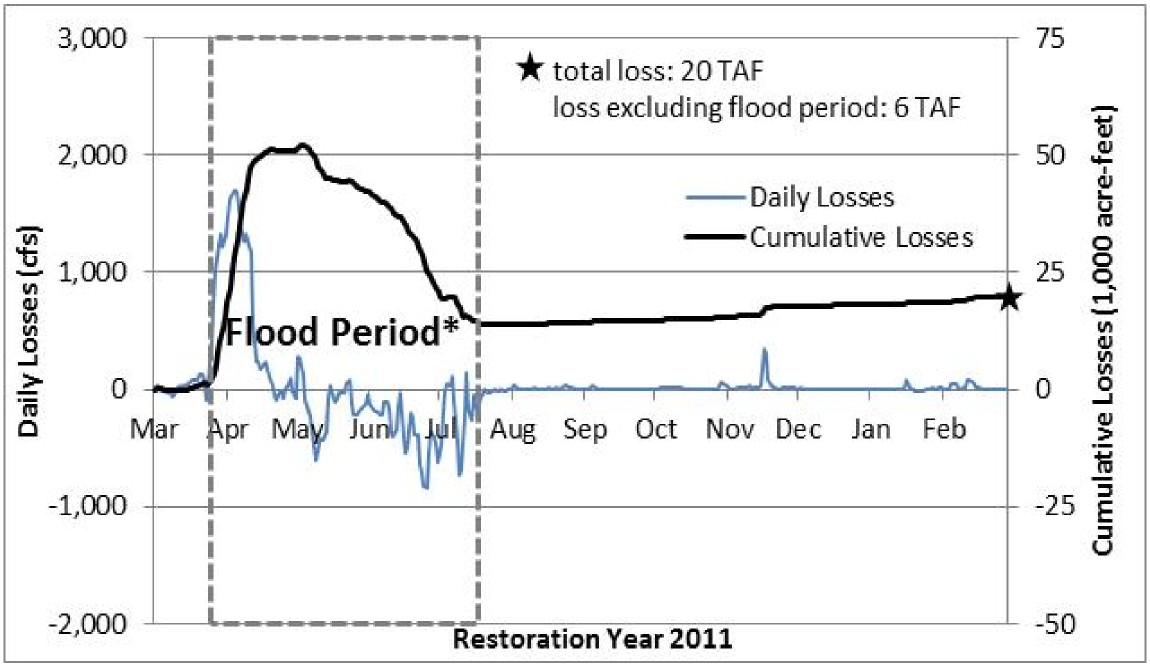
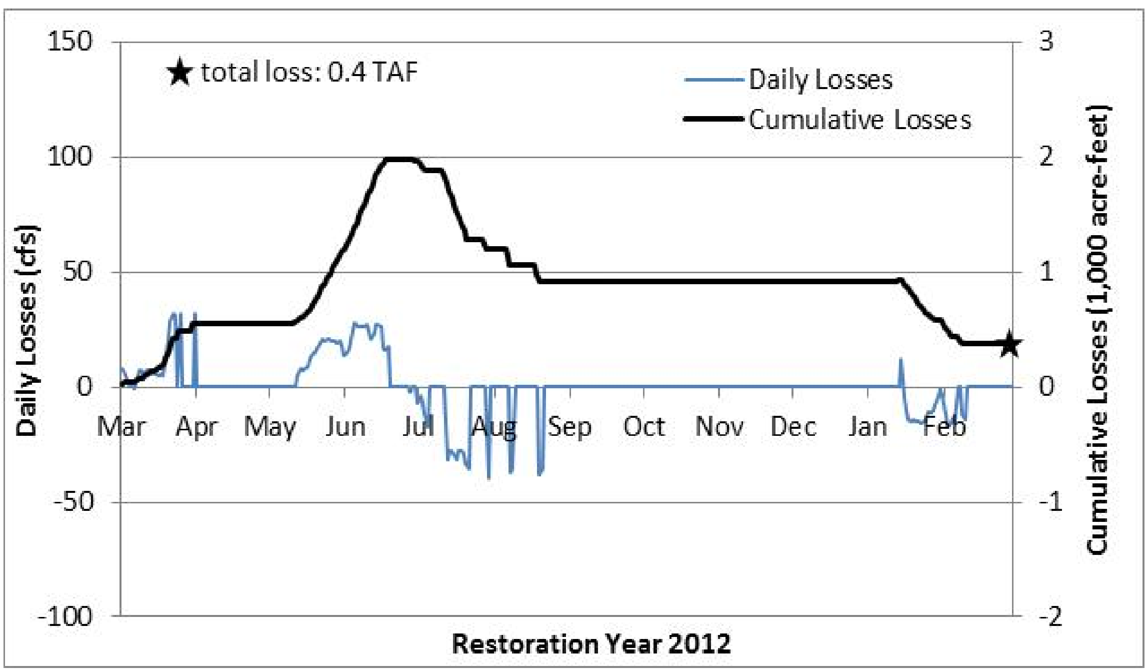


Figure 5-17b.
Reach 4 Cumulative and Daily Losses for RY 2011



*Interpolated data were used for periods when gage station data were unavailable. These dates are listed in Table 4-2.

Figure 5-17c.
Reach 4 Cumulative and Daily Losses for RY 2012

5.4.5 Cumulative Annual Losses Summary

The cumulative losses are summarized by RY in Tables 1-5 through 1-8. As shown in Table 5-2, the computed and anticipated losses for Reach 1 in RY 2009 are fairly consistent. However, for Reach 2, greater discrepancies exist between the two values.

Table 5-2.
Restoration Year 2009 Losses by Reach

Reach	Computed Losses (TAF)	Exhibit B Anticipated Losses (TAF)
1 – Friant Dam to Gravelly Ford	119	117
2 – Gravelly Ford to Below Chowchilla Bifurcation Structure	37	67
3 – Below Chowchilla Bifurcation Structure to Below Sack Dam	N/A	0
4 – Below Sack Dam to Washington Road	N/A	0
Total	**156**	**184**

Key:
N/A = not available
TAF = thousand acre-feet

In 2010, the computed losses excluding flood events for Reach 1 was less than anticipated by Exhibit B, but losses exceeded Exhibit B losses for all other reaches (Table 5-3).

Table 5-3.
Restoration Year 2010 Losses by Reach

Reach	Computed Losses (TAF)	Computed Losses Excluding Flood (TAF)	Exhibit B Anticipated Losses (TAF)[1]
1 – Friant Dam to Gravelly Ford	112	94	110
2 – Gravelly Ford to Below Chowchilla Bifurcation Structure	94	70	62
3 – Below Chowchilla Bifurcation Structure to Below Sack Dam	86	81	0
4 – Below Sack Dam to Washington Road	15	34	0
Total	**306**	**296**	**172**

Notes:
[1] Modified to exclude periods of flood releases when applicable.
Key:
TAF = thousand acre-feet

In RY 2011, the computed losses excluding flood events for Reaches 1 and 2 were less than anticipated Exhibit B losses (Table 5-4). For Reach 4, losses were closer to zero than in RY 2010, as anticipated by Exhibit B.

Table 5-4.
Restoration Year 2011 Losses by Reach

Reach	Computed Losses (TAF)	Computed Losses Excluding Flood (TAF)	Exhibit B Anticipated Losses (TAF)[1]
1 – Friant Dam to Gravelly Ford	115	56	75
2 – Gravelly Ford to Below Chowchilla Bifurcation Structure	103	38	41
3 – Below Chowchilla Bifurcation Structure to Below Sack Dam	410	55	0
4 – Below Sack Dam to Washington Road	20	6	0
Total	**137**	**133**	**115**

Notes:
[1] Modified to exclude periods of flood releases when applicable.
Key:
TAF = thousand acre-feet

In RY 2012, losses computed exceeded Exhibit B anticipated losses in all reaches, but losses in Reach 2 were very close to anticipated losses (Table 5-5). Losses in Reaches 3 and 4 may be different than reported because of missing data.

Table 5-5.
Restoration Year 2012 Losses by Reach

Reach	Computed Losses (TAF)	Exhibit B Anticipated Losses (TAF)
1 – Friant Dam to Gravelly Ford	123	117
2 – Gravelly Ford to Below Chowchilla Bifurcation Structure	64	61
3 – Below Chowchilla Bifurcation Structure to Below Sack Dam	68[1]	0
4 – Below Sack Dam to Washington Road	0.4[1]	0
Total	**211**	**178**

Notes:
[1] Annual losses are likely different as data were not available for the entire year.
Key:
TAF = thousand acre-feet

6.0 Discussion

Tables 1-9 through 1-12 summarize the total flow at the head, flow at the end, and losses by reach for each RY, including flood release periods.

In Reach 1, the losses are proportional across the range of flows (Table 6-1). Exhibit B appears to be accurate in describing both the volume of losses, which in actuality are approximately 2 percent greater than the Exhibit B riparian releases (117 TAF per year), and the timing of riparian diversions, as illustrated by the annual loss pattern shown in Figure 5-9.

Table 6-1.
Reach 1 Total Flow at the Head, Flow at the End, and Losses

RY	RY Year Type	Total Flow at Head[1] (TAF)	Total Flow at End[2] (TAF)	Total Losses[3]	
				(TAF)	(cfs/mi)
2009	normal-wet	162	43	119	4
2010	normal-wet	755	518	112	4
2011	wet	1,228	1,113	115	4
2012	dry	310	187	123	4

Notes:
[1] Friant, Cottonwood, and Little Dry
[2] Gravelly Ford
[3] Rounded to nearest whole number
Key:
cfs/mi = cubic feet per second per river mile
RY = Restoration Year
TAF = thousand acre-feet

Losses in Reach 2 correspond to the Exhibit B anticipated release schedule (approximately 60 TAF per year depending on flow at the head) with excess losses of less than 1 percent (Table 6-2). Greater variability is present at higher flows, which correspond to flood releases in RY 2010 and 2011.

Table 6-2.
Reach 2 Total Flow at the Head, Flow at the End, and Losses

RY	RY Year Type	Total Flow at Head[1] (TAF)	Total Flow at End[2] (TAF)	Total Losses[3]	
				(TAF)	(cfs/mi)
2009	normal-wet	42	5	37	4
2010	normal-wet	474	380	94	11
2011	wet	1,113	1,010	103	12
2012	dry	187	124	64	8

Notes:
[1] Gravelly Ford
[2] Below Chowchilla Bifurcation Structure plus Chowchilla Bypass
[3] Rounded to nearest whole number
Key:
cfs/mi = cubic feet per second per river mile
RY = Restoration Year
TAF = thousand acre-feet

Reach 3 shows high variability in losses, which generally occur during flood periods and when no flows are being released from Sack Dam (Table 6-3). Exhibit B anticipates no losses in this reach.

Table 6-3.
Reach 3 Total Flow at the Head, Flow at the End, and Losses

RY	RY Year Type	Total Flow at Head[1] (TAF)	Total Flow at End[2] (TAF)	Total Losses[3]	
				(TAF)	(cfs/mi)
2010	normal-wet	254	186	86	7
2011	wet	266	345	410	-9
2012	dry	124	7	68	7

Notes:
[1] Below Chowchilla Bifurcation Structure
[2] Below Sack Dam
[3] Rounded to nearest whole number
Key:
cfs/mi = cubic feet per second per river mile
RY = Restoration Year
TAF = thousand acre-feet

Reach 4 exhibits the greatest variability in flows and losses of the individual reaches (Table 6-4). This may be a result of diversions that exist along the length of the reach but have not been accounted for in this study, or because of extended periods of data being unavailable. Exhibit B anticipates no losses in this reach.

Table 6-4.
Reach 4 Total Flow at the Head, Flow at the End, and Losses

RY	RY Year Type	Total Flow at Head[1] (TAF)	Total Flow at End[2] (TAF)	Total Losses[3]	
				(TAF)	(cfs/mi)
2010	normal-wet	186	171	15	0
2011	wet	345	325	20	1
2012*	dry	7	7	0.4	0

Notes:
[1] Below Sack Dam
[2] Washington Road
[3] Rounded to nearest whole number
* Losses are likely underestimated as data were only available for 109 days out of the year.
Key:
cfs/mi = cubic feet per second per river mile
RY = Restoration Year
TAF = thousand acre-feet

Table 6-5 compares the average total losses (including flood events) with the Exhibit B anticipated losses over RY 2009 through 2012. In all reaches, the average total losses are higher than anticipated by Exhibit B.

Table 6-5.
Losses by Reach Averaged Over Restoration Years 2009 through 2012

Reach	Average Total Losses (TAF/yr)	Average Exhibit B Anticipated Losses (TAF/yr)
1	117	105
2	74	58
3	19	0
4	12	0

Key:
TAF/yr = thousand acre-feet per year

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