Environmental Factors Affecting Russian River Chinook Salmon Adult Migration

Sonoma Water
404 Aviation Boulevard, Santa Rosa,
California, 95403

Prepared by Justin Smith – Senior Environmental Specialist

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Introduction

There is some uncertainty as to whether Forecast Informed Reservoir Operations (FIRO) may negatively affect migration cues that trigger upstream movement of Chinook salmon. FIRO may effectively reduce the frequency of flood control releases during the fall months. One potential unintended consequence of FIRO is that there may be fewer moderate to high flow events that trigger adult salmon upstream migration. In order to explore this hypothesis we compiled daily video counts of Chinook salmon along with daily summaries of multiple environmental conditions to determine if Coyote Valley Dam flood control releases were an important factor in triggering upstream migration of Russian River Chinook salmon.

Chinook salmon are native to the Russian River and part of the California Coastal Chinook ESU, which was listed under the federal ESA as threatened in 1999. Adult fall run Chinook salmon have been monitored by Sonoma Water since the year 2000. Sonoma Water operates a seasonal dam on the Russian River (river Kilometer (rKm) 39.7) and uses underwater video cameras located in two fish ladders that provide fish passage at the dam to count Chinook salmon as they move upstream (Chase et al. 2007). The adult population ranges from approximately 1,400 to 6,700 fish (Martini-Lamb and Manning 2014). Based on run timing Russian River Chinook salmon are ocean type fall run (Moyle 2002). Adult Chinook have been observed in the Russian River from August through February, with peak migration from October 15 to December 31 (SCWA 2016). In the Russian River, Chinook spawning takes place from November through January (SCWA 2008). Based on video counts Chinook have been observed ascending the river when instream flow is as low as 135 cubic feet per second (cfs) at the USGS stream gage at Hacienda (USGS gage number 11467000). Based on spawner surveys adult Chinook salmon can transverse the upper Russian River when flow is as low as 105 cfs (USGS stream gage at Digger Bend near Healdsburg, Ca. Gage number 11463980, Smith 2013).

Methods

Daily fish counts from the underwater video cameras were compiled along with: daily average flow (cfs) from Coyote Valley Dam releases, daily average flow from the United States Geological Survey (USGS) stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), and Hacienda (USGS gage number 11467000); rainfall at the Venado rainfall gage; and stage at the USGS stream gage at the Highway One Bridge near Jenner (USGS gage number 11467270). Stage data from the Jenner Visitor's Center gage was also used to identify the occurrence of river mouth closures, which temporarily block Chinook salmon in the ocean from entering the Russian River. During river mouth closures stage in the Russian River Estuary gradually increases on a daily basis until the river mouth breaches, when stage then rapidly decreases. These data were displayed graphically and migration patterns were visually compared to environmental patterns. In total, 17 years of Chinook migration data and 19 years of environmental data were investigated.

Results

Sonoma Water operated underwater video cameras on the Russian River typically from the early fall until early winter for return years 2000-2019 with the exceptions of return years 2014 and 2015 when the cameras were not operated due to a major construction project at the Mirabel dam (Figure 1 through Figure 19). During this 20 year period only two flood control releases were made during the fall (return years 2010 and 2011; Figure 10 and Figure 11). River mouth closures were frequent in almost all years as were rain events.

The following figures show daily Chinook counts including periods of high migration rates in relation to several factors including river flow, rainfall, and estuary stage. Reservoir releases from the Coyote Valley Dam (CVD) at Lake Mendocino are shown in order to identify periods of time where abrupt increases in release rates for flood control purposes may have encouraged Chinook to migrate upstream. Stream gages at three sites: USGS stream gages at Hopland (USGS gage number 11462500); Healdsburg (USGS gage number 11464000); and Hacienda (USGS gage number 11467000) downstream of Lake Mendocino display the influence of reservoir releases on stream flow. Flows of 135 cfs in the lower river and a flow of 105 cfs in the upper river have been shown to provide sufficient depth for Chinook passage in previous years (SCWA 2016 and Smith 2013). Rainfall data is useful in explaining periods of time when streamflow is high and reservoir releases are low (i.e., unimpaired flow). Furthermore, rainfall may increase upstream migration rates in adult Chinook. Finally, estuary stage is useful to the reader in that periods of high water stage typically indicate that the river mouth is closed and is blocking Chinook from entering the river. Rapid decreases in stage are typically associated with river mouth breaches. Following a breach, Chinook that did not have access to the river for days or weeks gain access to the river again. The combination of these environmental factors can be used to explain periods of high migration rates.

Periods of high migration rates occurred in: October and November 2001 (Figure 1); late September and early November 2002 (Figure 2); early and late October and in early November 2003 (Figure 3); late October 2004 (Figure 4); mid and late October and in early November 2005 (Figure 5); early November 2006 (Figure 6); mid-November and early December 2007 (Figure 7); early November 2008 (Figure 8); mid and late October, early November and late November 2009 (Figure 9); early October and mid October 2010 (Figure 10); and mid October 2011 (Figure 11). In 2012 there were five periods of high migration rates between mid-October and mid-November (Figure 12). In 2013 high rates of migration occurred in late October, early November and mid-November. In 2014 and 2015 Chinook counts were not collected at the Mirabel dam. In 2016 most Chinook migration occurred in mid to late October (Figure 16). High migration rates occurred in early to mid-November in 2017 and 2018.

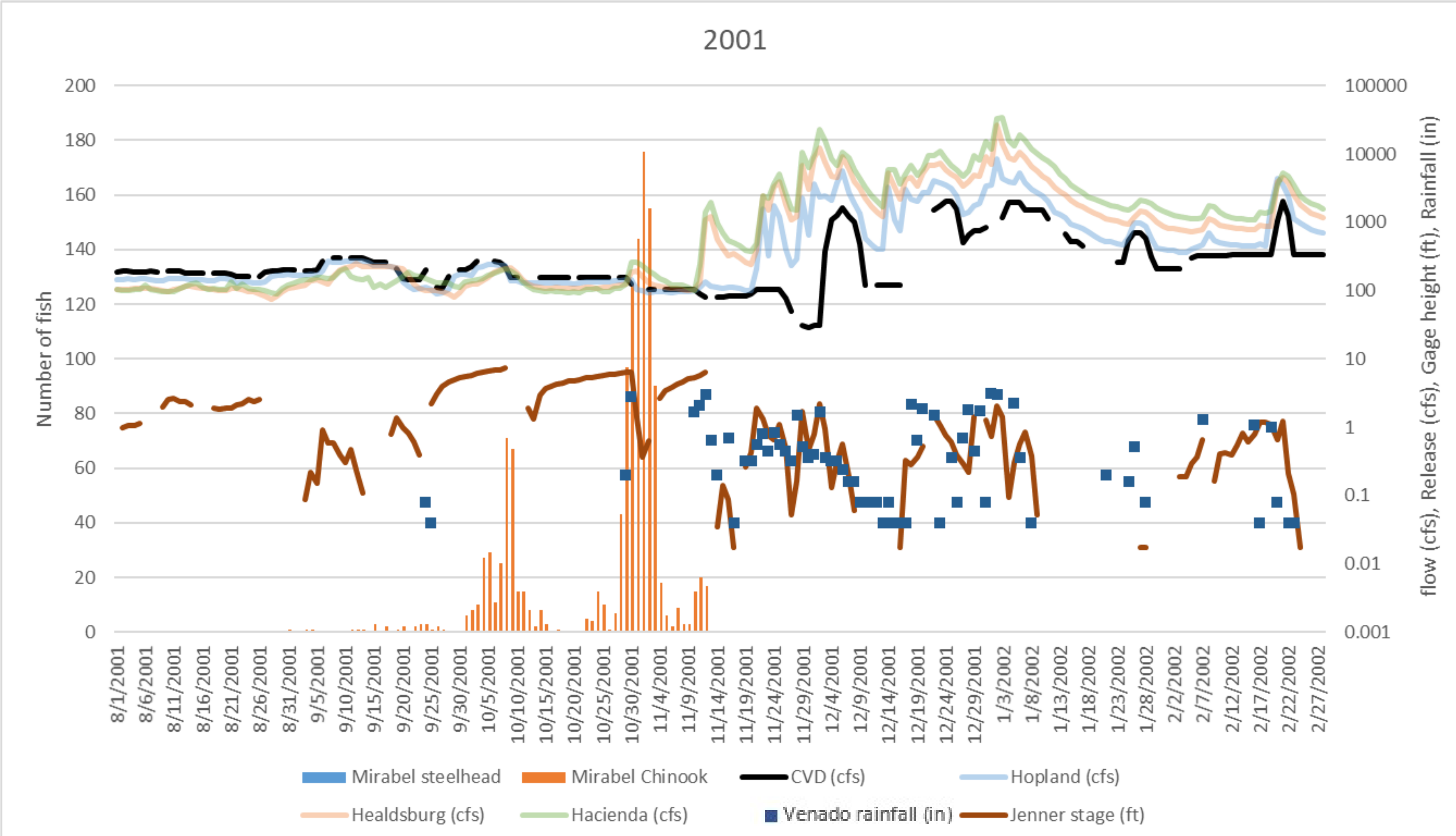

Figure 1. Chinook salmon counts from the underwater video cameras (return year 2001) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's.

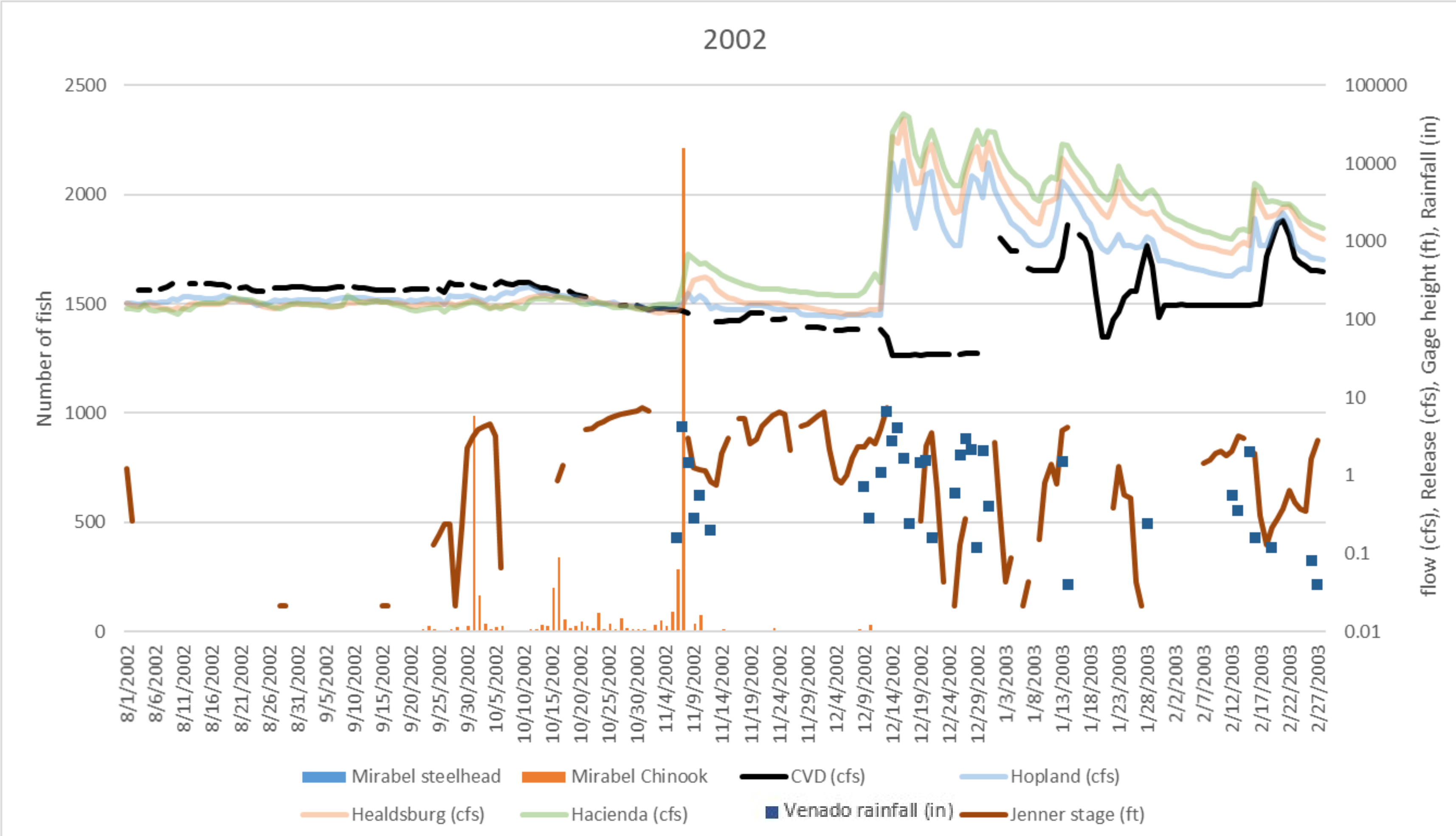

Figure 2. Chinook salmon counts from the underwater video cameras (return year 2002) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center .

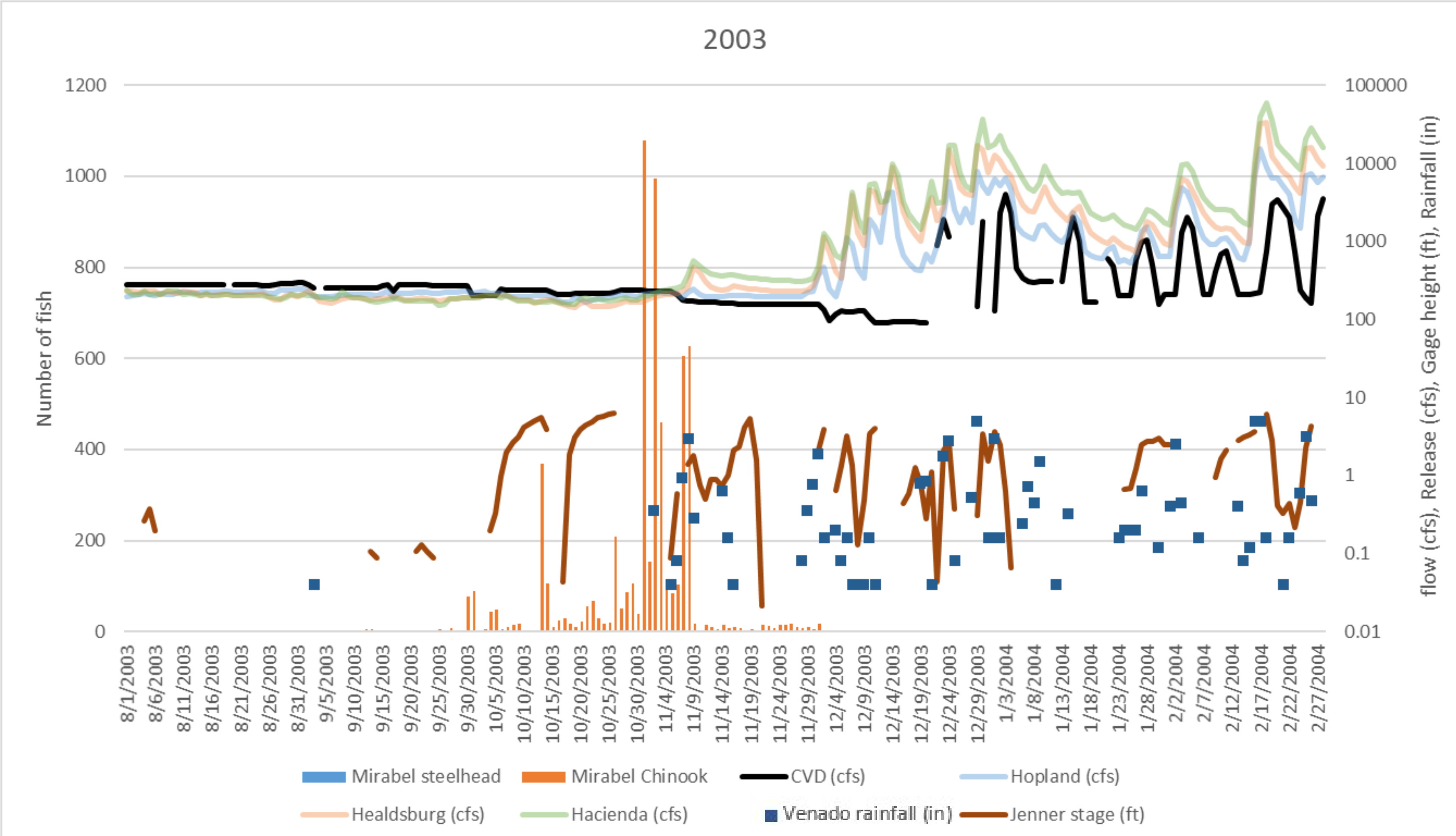

Figure 3. Chinook salmon counts from the underwater video cameras (return year 2003) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

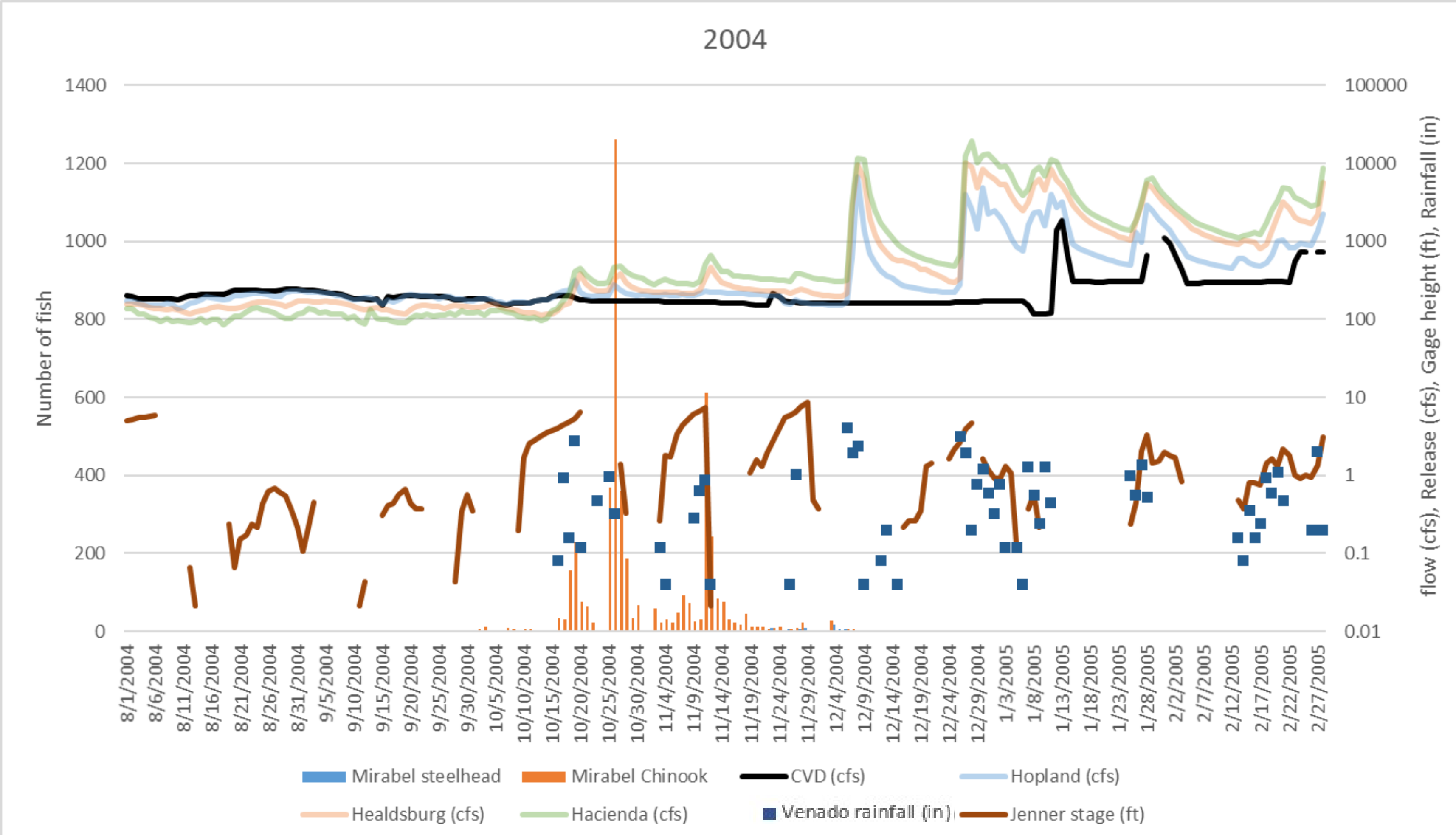

Figure 4. Chinook salmon counts from the underwater video cameras (return year 2004) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

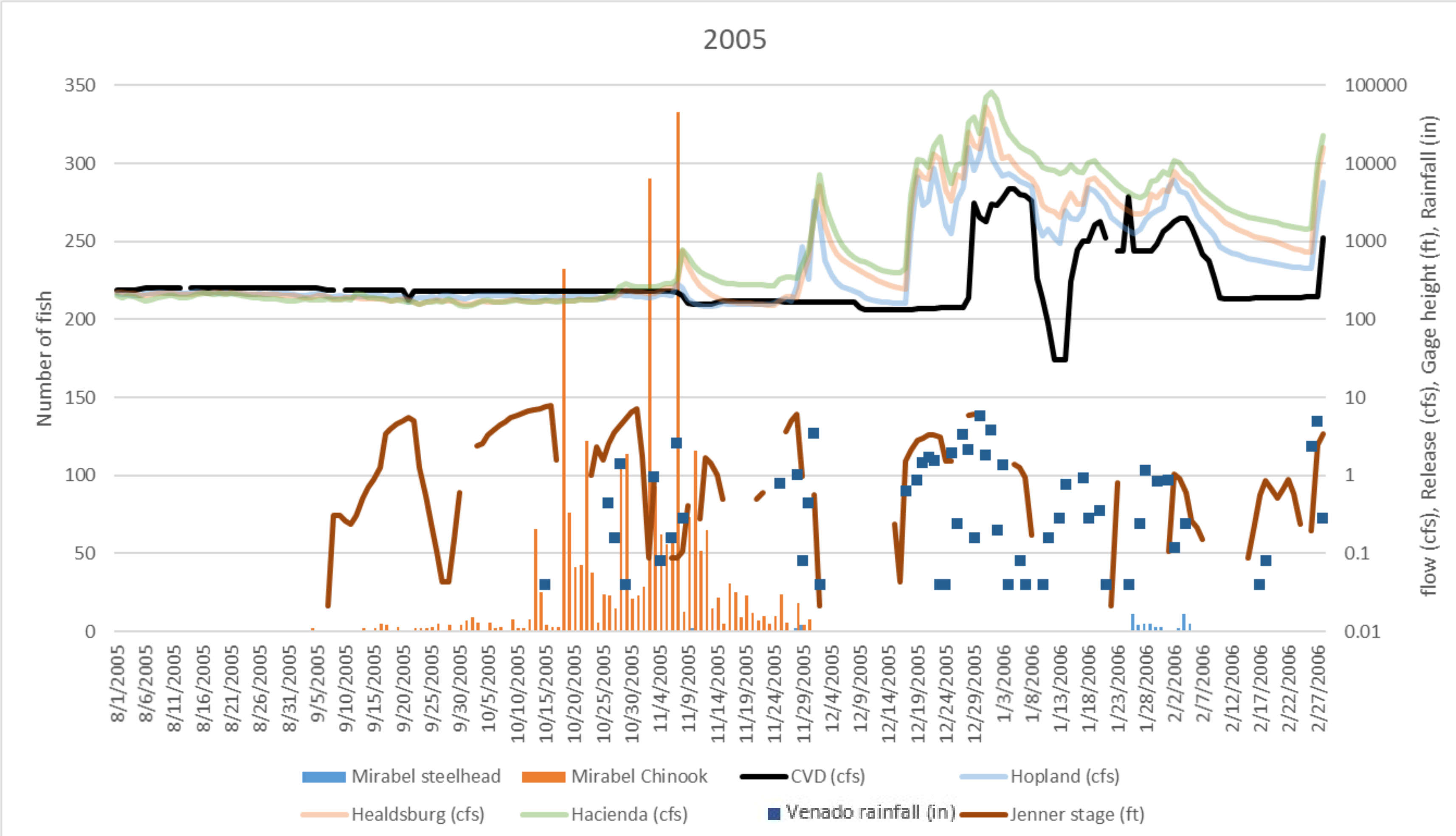

Figure 5. Chinook salmon counts from the underwater video cameras (return year 2005) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor’s Center.

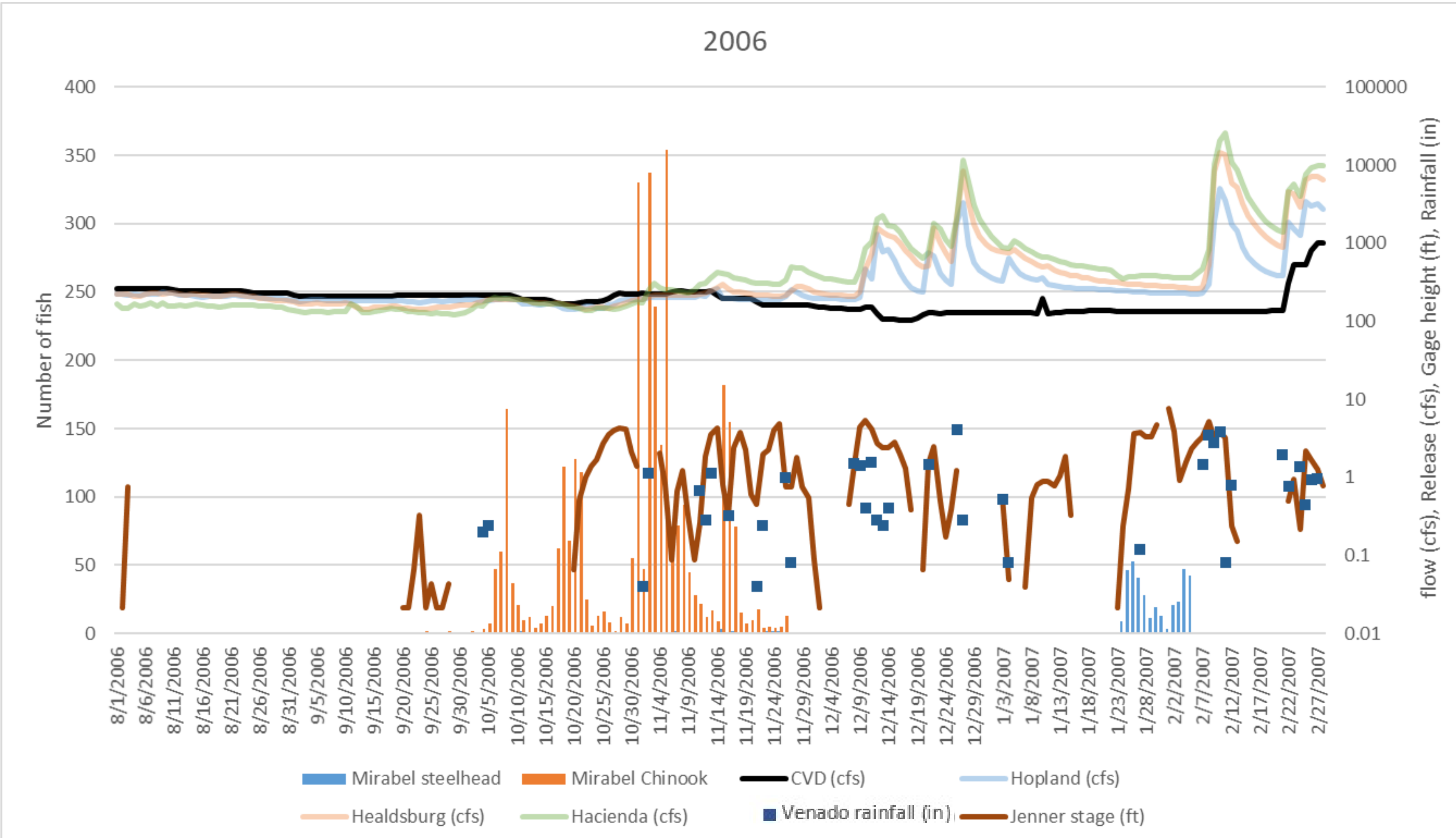

Figure 6. Chinook salmon counts from the underwater video cameras (return year 2006) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

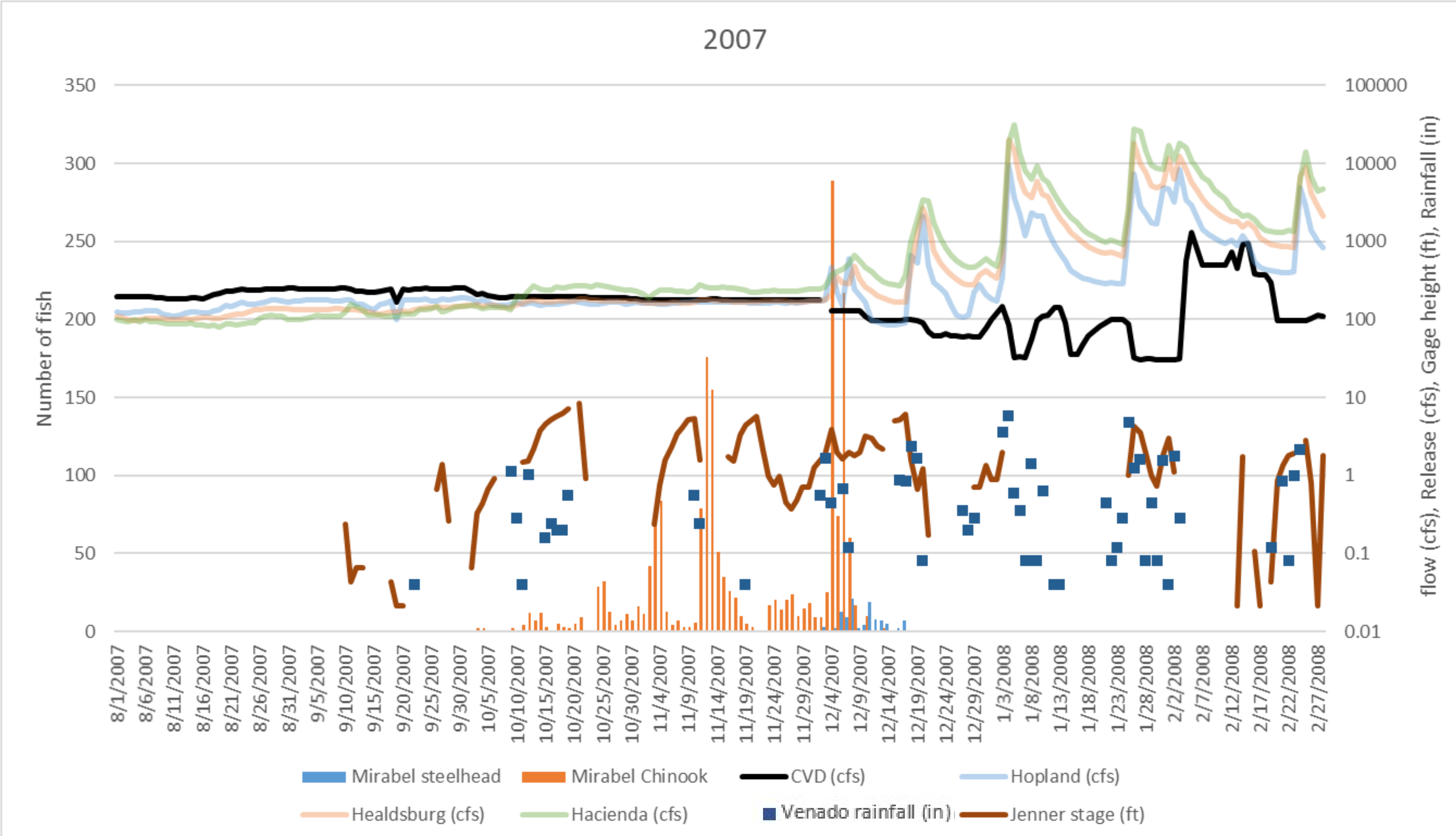

Figure 7. Chinook salmon counts from the underwater video cameras (return year 2007) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

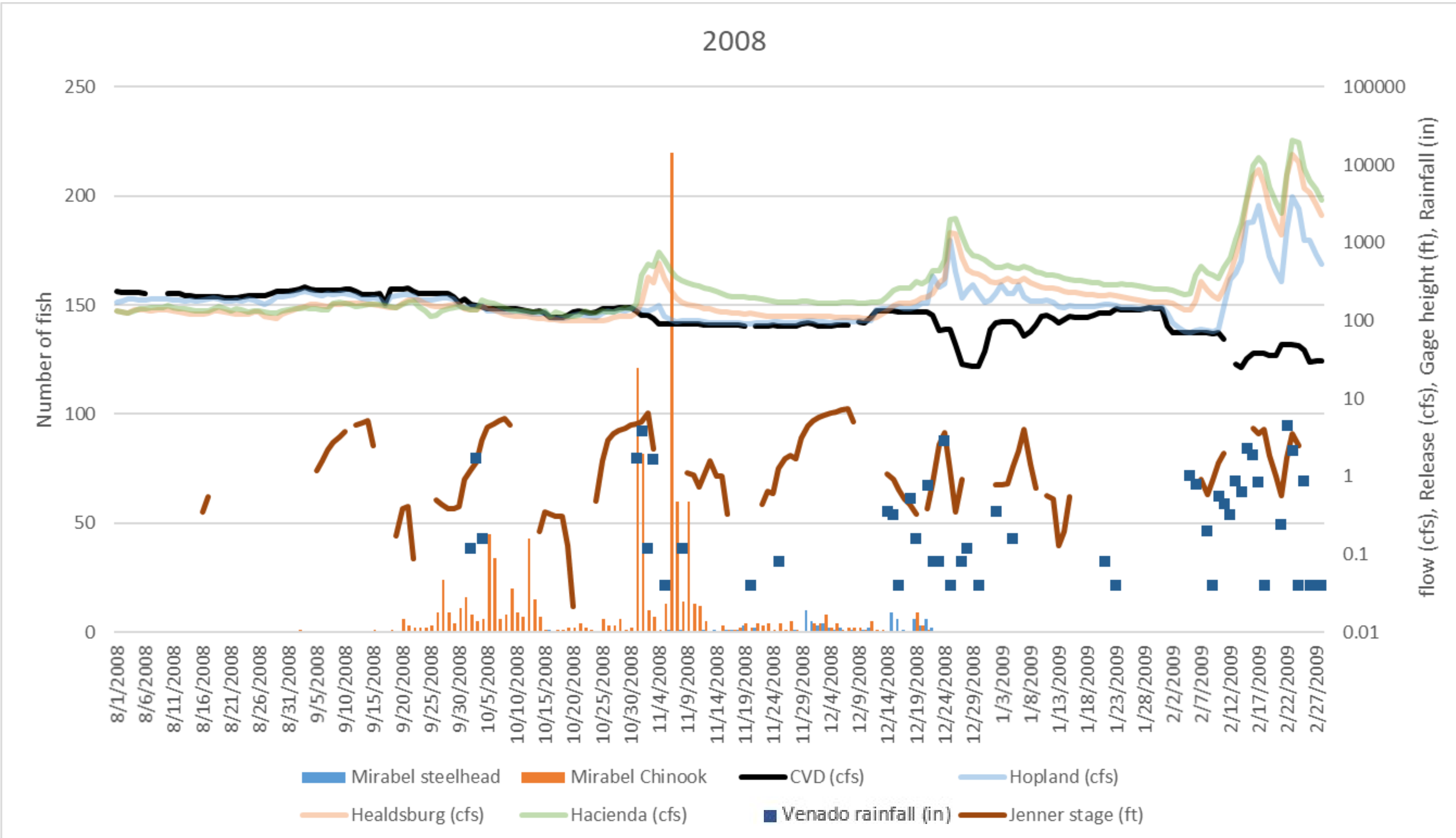

Figure 8. Chinook salmon counts from the underwater video cameras (return year 2008) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

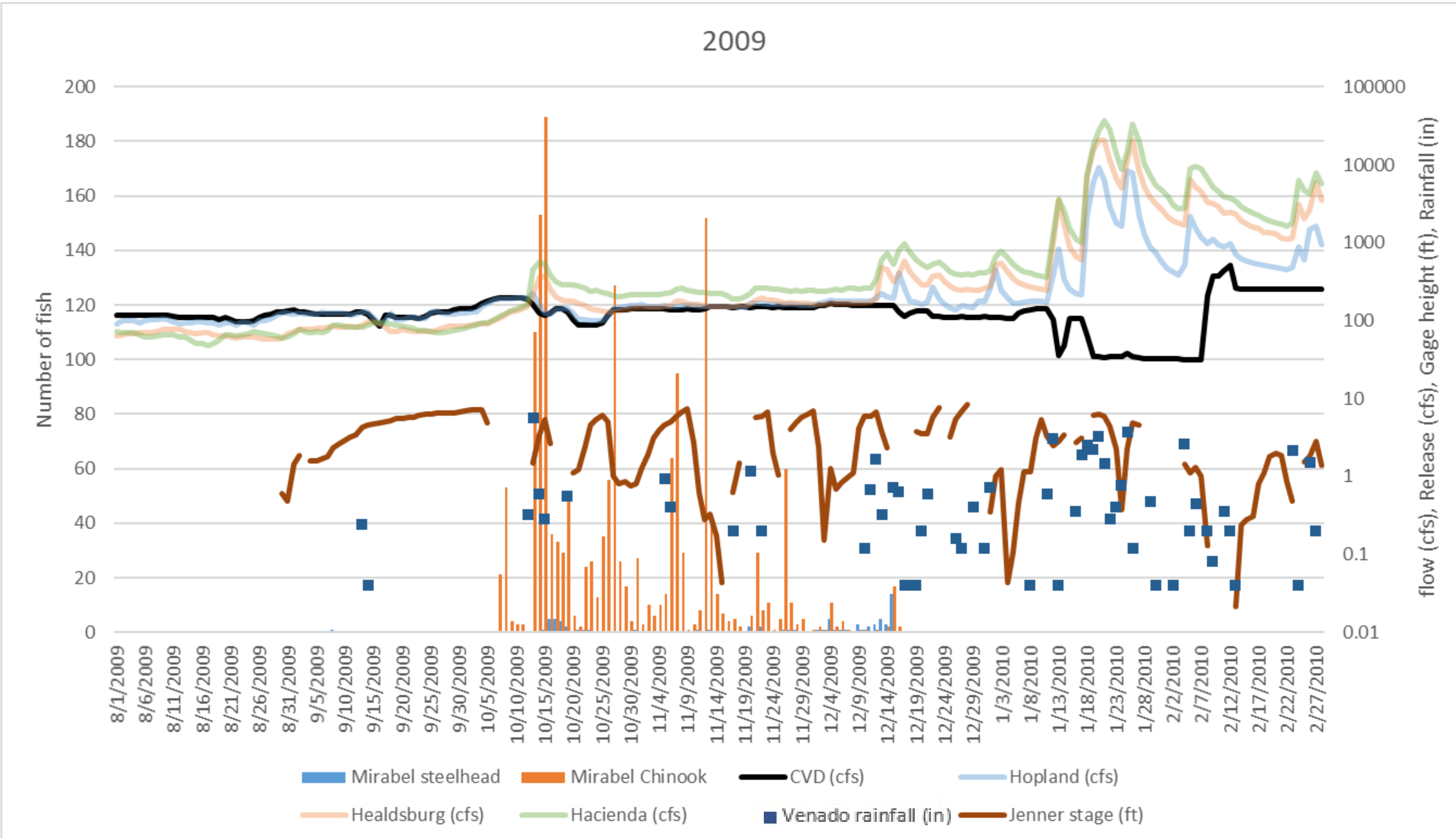

Figure 9. Chinook salmon counts from the underwater video cameras (return year 2009) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

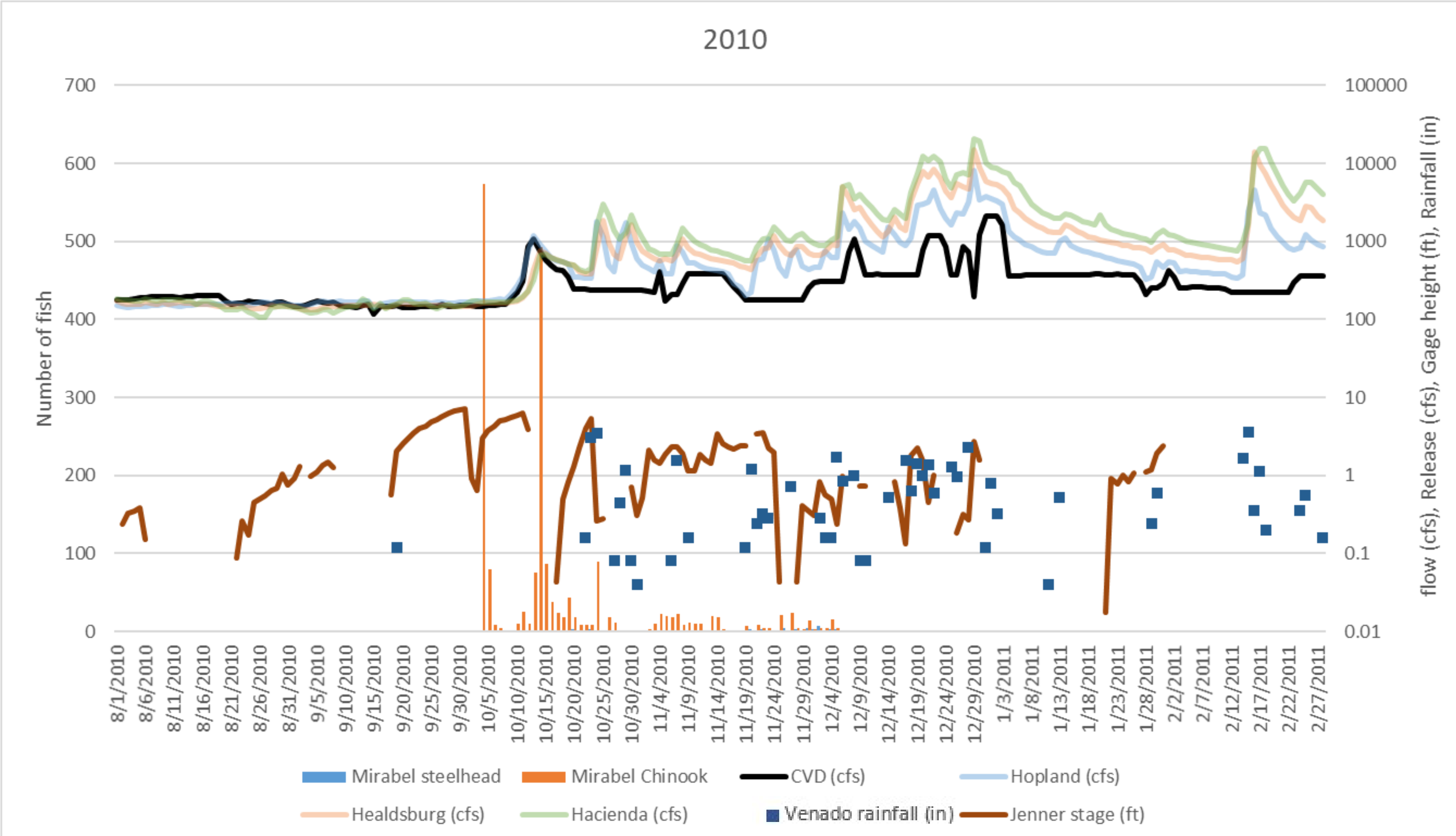

Figure 10. Chinook salmon counts from the underwater video cameras (return year 2010) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

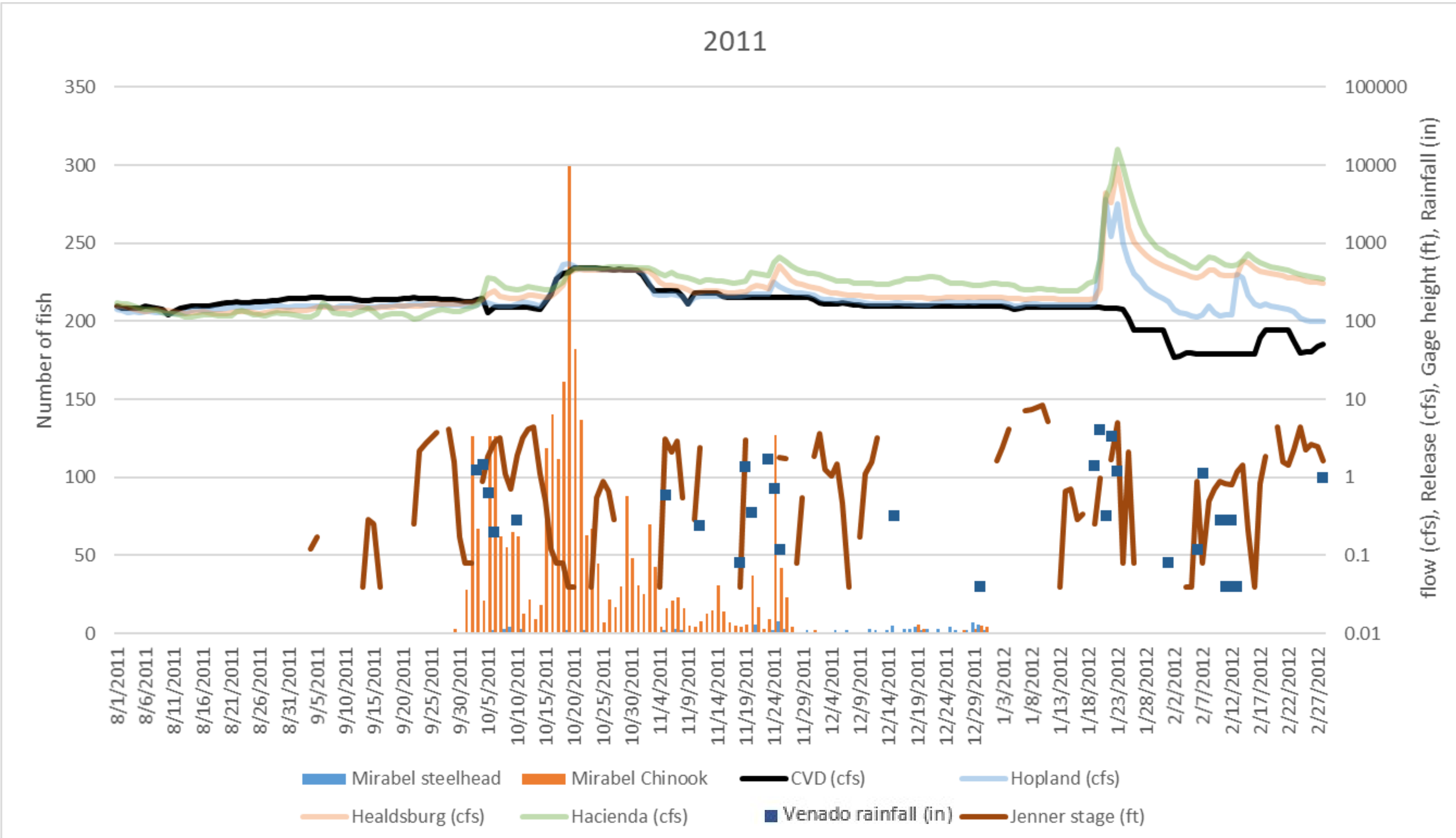

Figure 11. Chinook salmon counts from the underwater video cameras (return year 2011) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor’s Center.

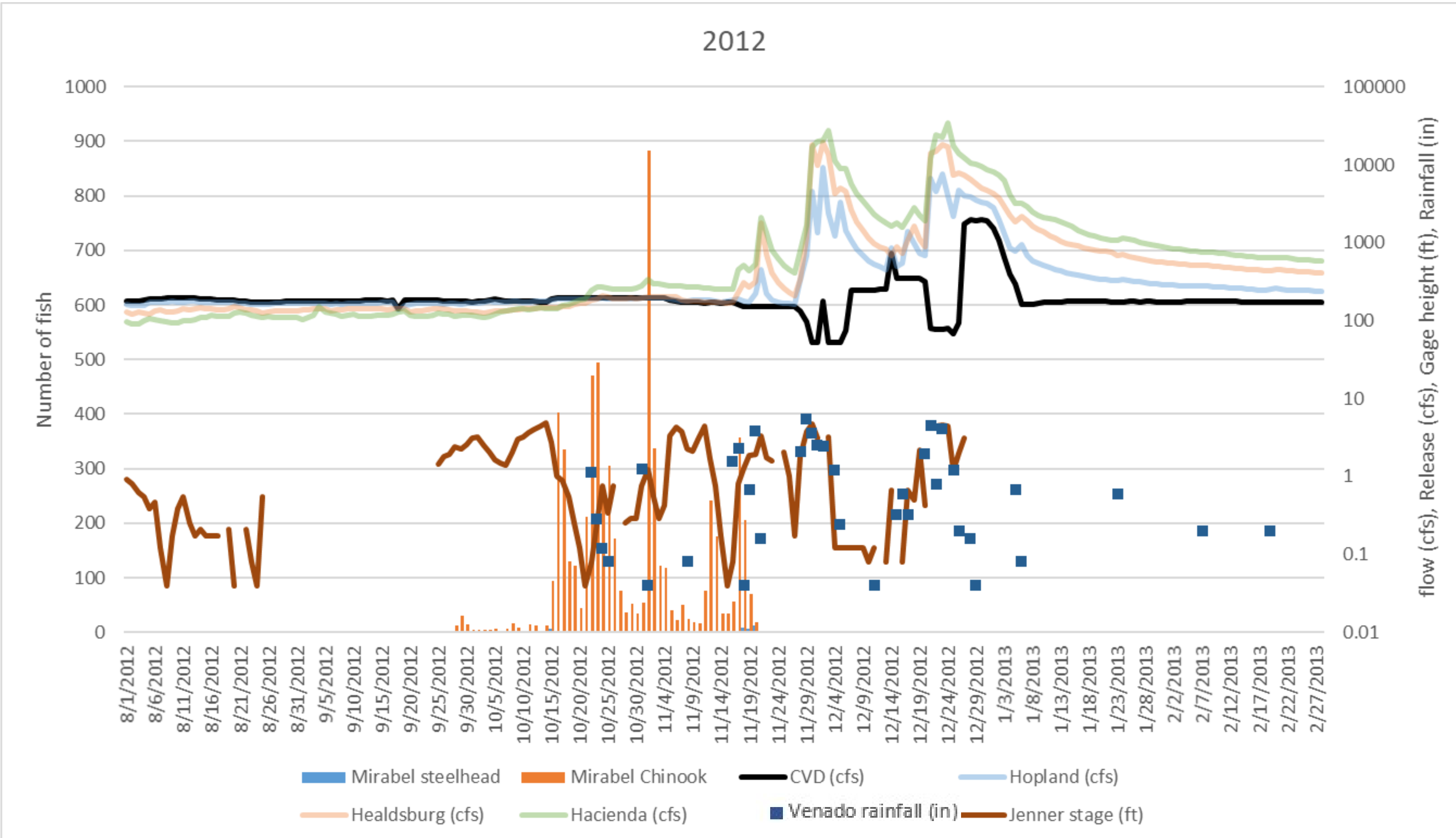

Figure 12. Chinook salmon counts from the underwater video cameras (return year 2012) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

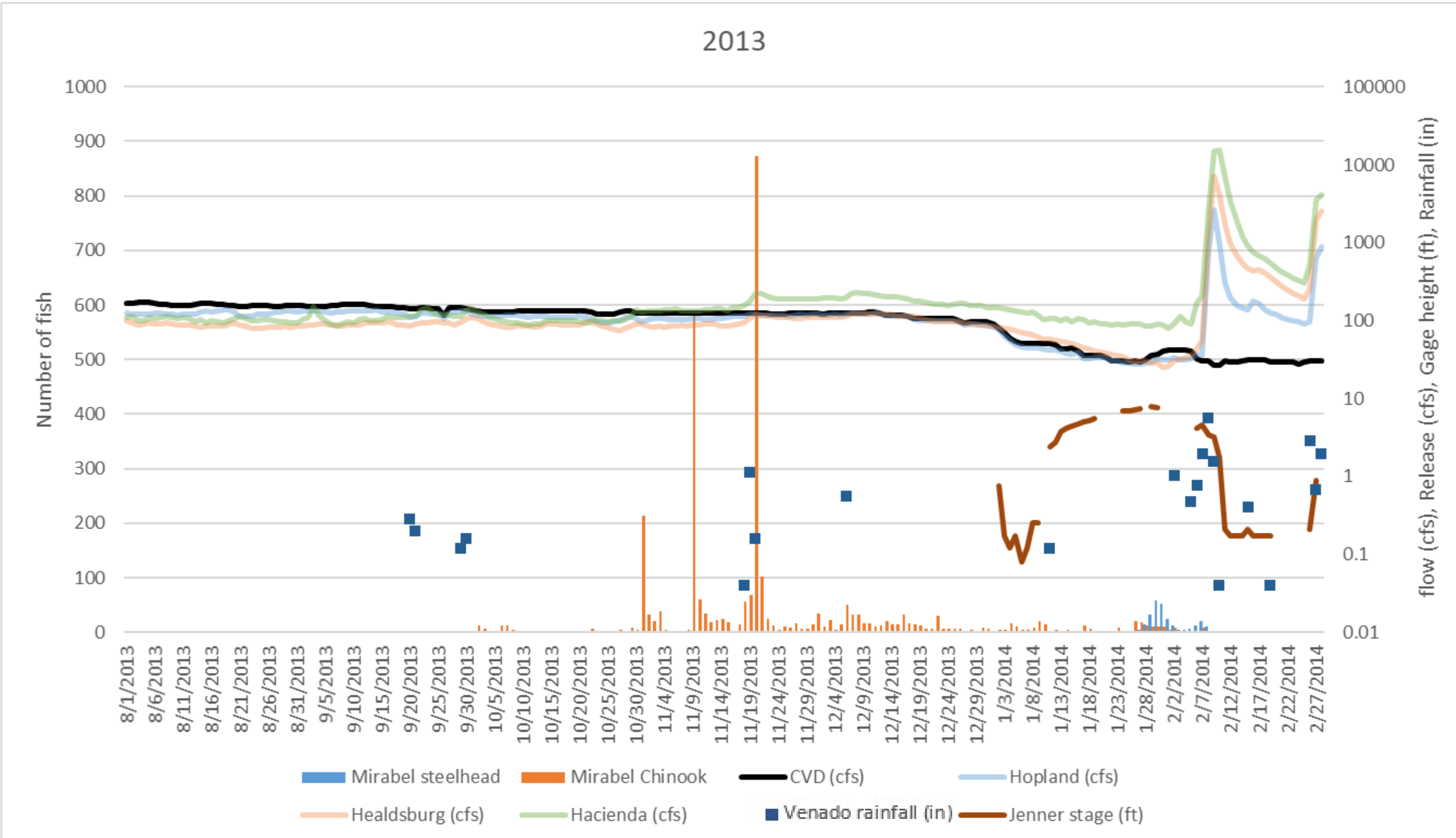

Figure 13. Chinook salmon counts from the underwater video cameras (return years 2013) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

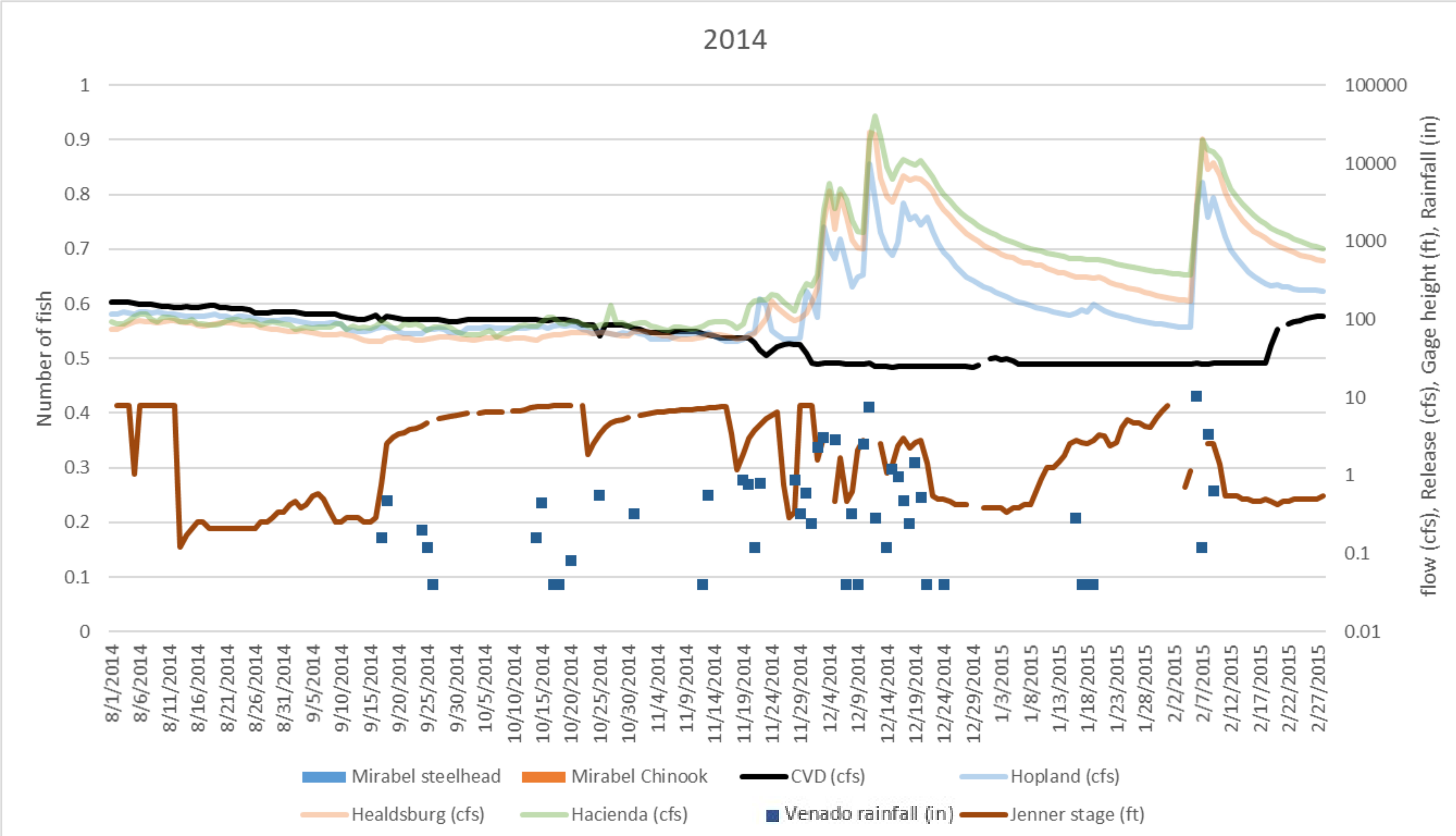

Figure 14. Daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor’s Center. Chinook Salmon counts at Mirabel were not collected in 2014.

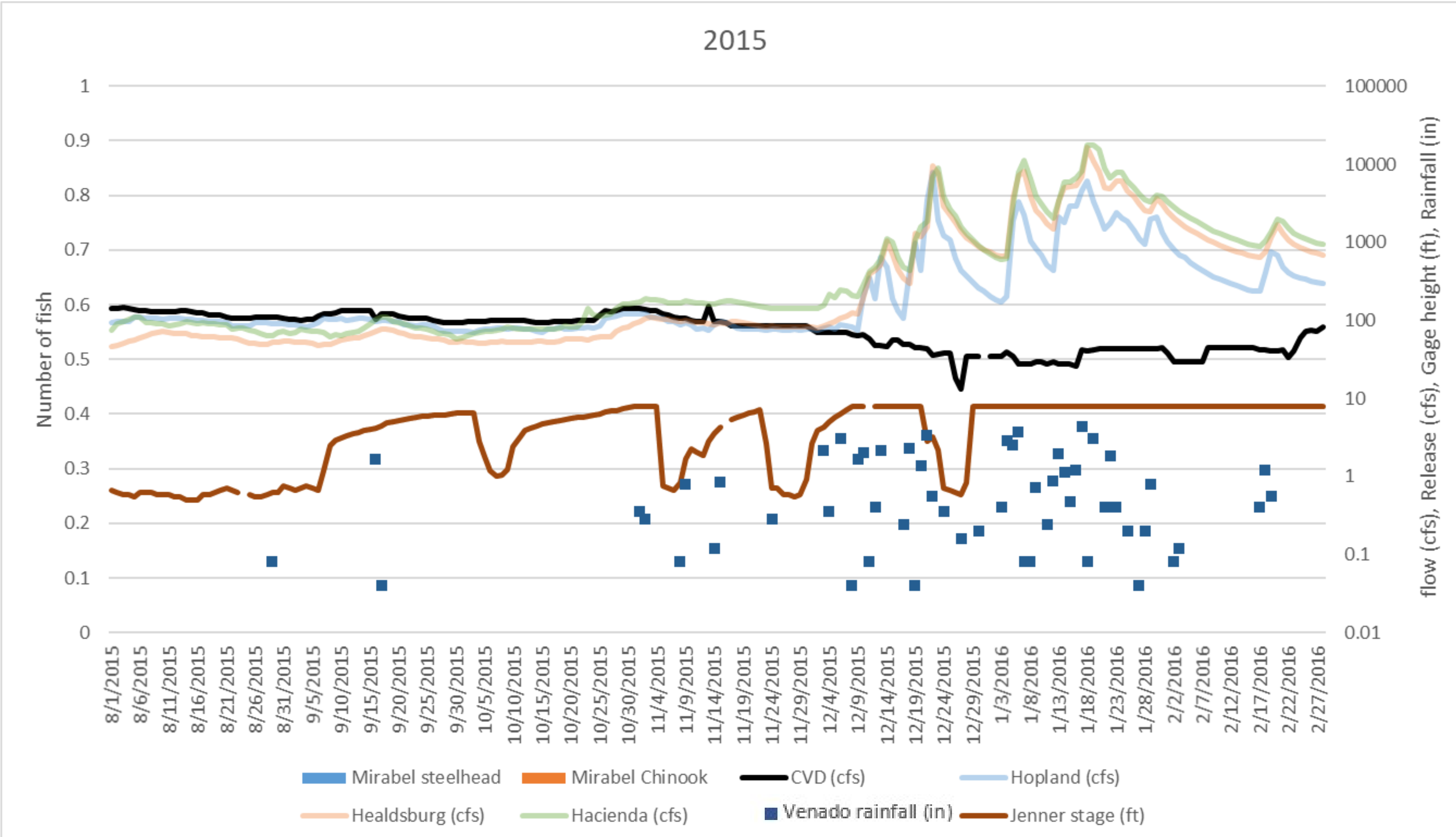

Figure 15. Daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center. Chinook counts were not collected at Mirabel in 2015.

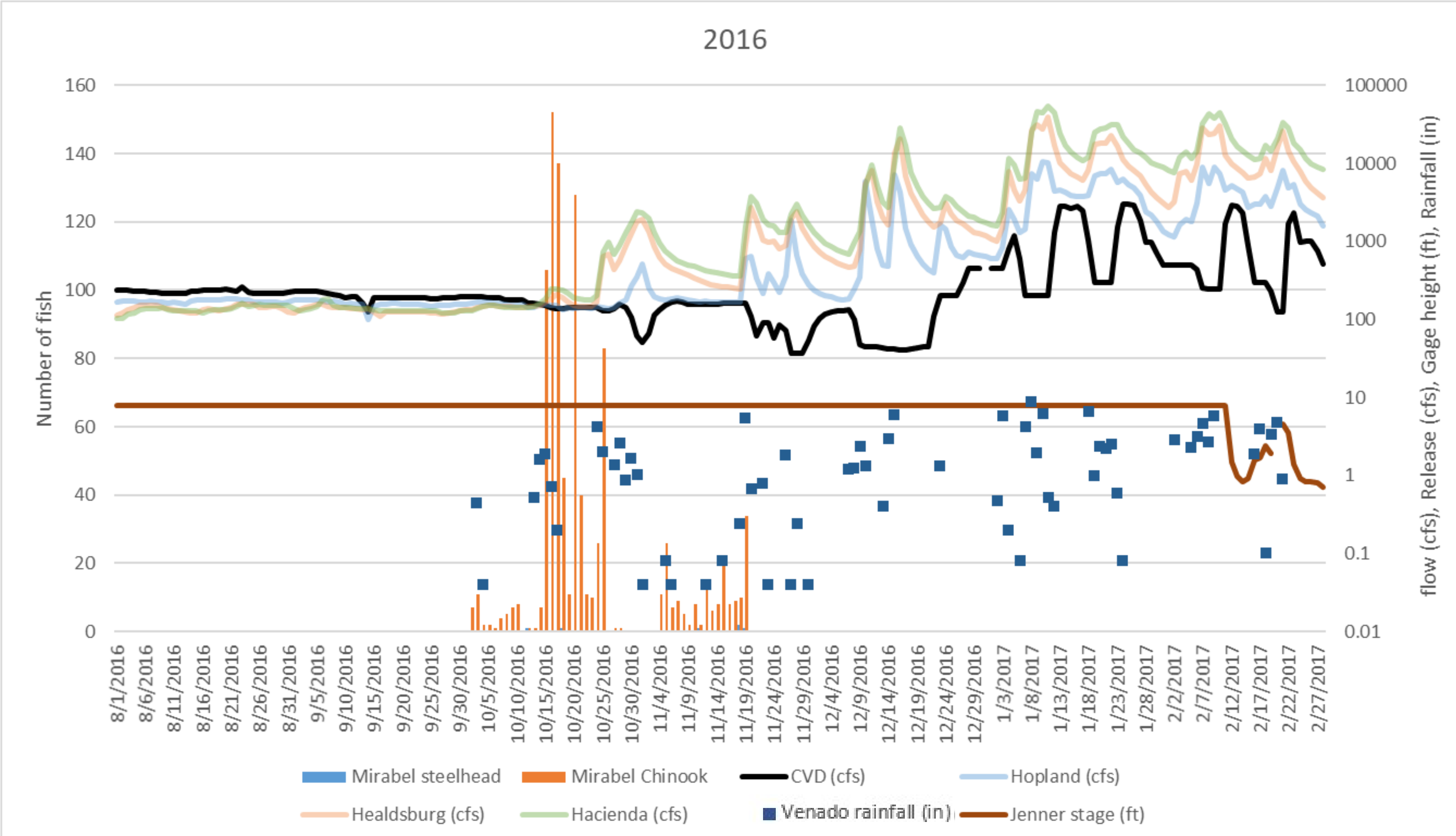

Figure 16. Chinook salmon counts from the underwater video cameras (return year 2016) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000),and rainfall (inches per day) at the Venado rainfall gage. Stage (ft) data from the gage at the Jenner Visitor's Center was unavailable for most of 2016.

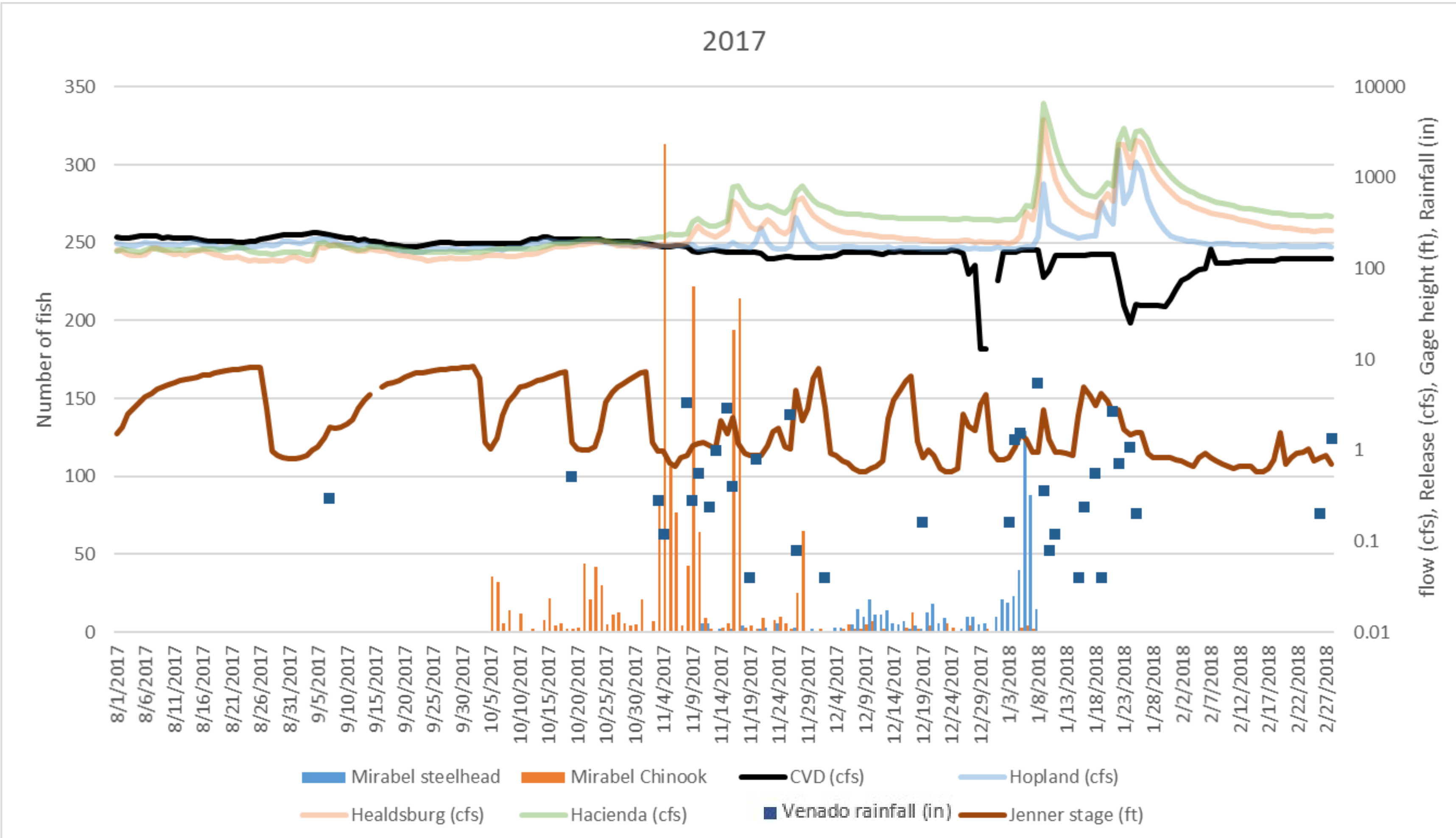

Figure 17. Chinook salmon counts from the underwater video cameras (return year 2017) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the gage at the Jenner Visitor's Center.

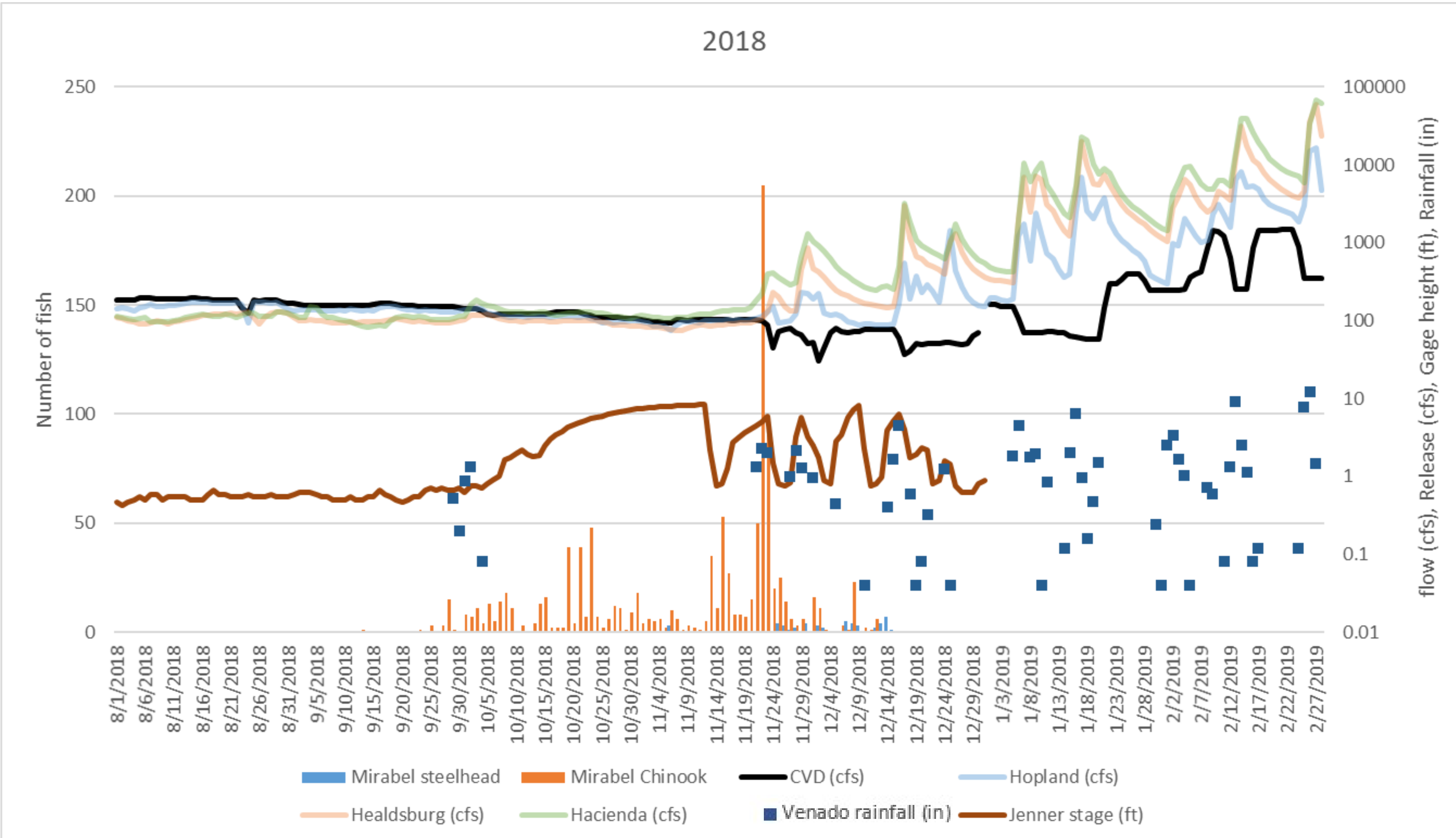

Figure 18. Chinook salmon counts from the underwater video cameras (return year 2018) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) the USGS stream gage at the Highway One Bridge near Jenner (USGS gage number 11467270).

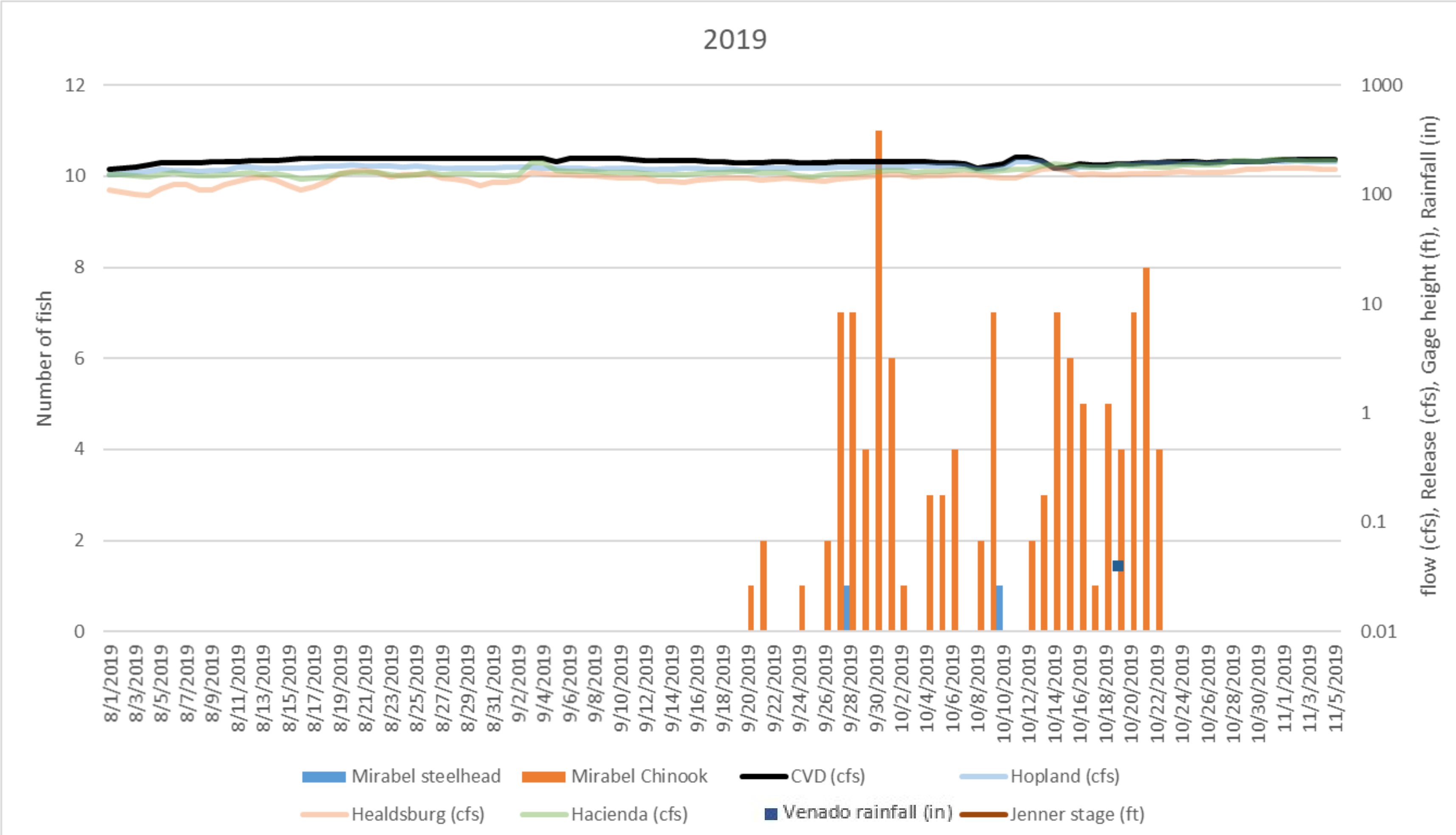

Figure 19. Chinook salmon counts from the underwater video cameras (return year 2019) shown with daily average flow (cfs) from Coyote Valley Dam releases, daily average flow (cfs) from the USGS stream gages at Hopland (USGS gage number 11462500), Healdsburg (USGS gage number 11464000), Hacienda (USGS gage number 11467000), rainfall (inches per day) at the Venado rainfall gage, and stage (ft) from the USGS stream gage at the Highway One Bridge near Jenner (USGS gage number 11467270).

During the months of September through November reservoir releases were typically between 100 and 300 cfs in 2001-2009, in 2012-2015, and in 2017-2018 (Figures 1-9, Figures 12-15, and Figures 17 and 18). In 2010 and 2011 releases from the flood control pool were made in mid-October. In late October 2016 releases dropped well below 100 cfs as operators responded to increases in unimpaired stream flow following a heavy rain event (Figure 16).

Stream flow in the Russian River was typically controlled by reservoir releases during the months of September through November except following heavy rain events. These heavy rain events and increased unimpaired flow occurred in: mid-November 2001 (Figure 1); early November 2002 (Figure 2); early November 2003 (Figure 3); mid-October through late November 2004 (Figure 4); mid and late November 2005 (Figure 5); mid to late November 2006 (Figure 6); early November 2008 (Figure 8); mid October 2009 (Figure 9); late October through November 2010 (Figure 10); early October and late November 2011 (Figure 11); late November 2012 (Figure 12); late November 2014 (Figure 14); late October 2016 (Figure 16); mid-November 2017 (Figure 2017); and late November 2018 (Figure 18). In nearly all years there were significant rain and unimpaired flow events in December (Figures 1 through 10, Figure 12, Figures 14 through 16, and Figures 18 and 19), with the exception of 2011, 2013, and 2017 (Figures 11, 13, and 17).

Brief river mouth closures and subsequent breaches occurred in most years from September through December (Figure 1 through Figure 19). In 2014 a persistent river mouth closure became established in mid-September, briefly opened in late October, and closed and remained closed through mid-November. This closure was closely followed by another closure that lasted until late November (Figure 14). In 2018 a long lasting river mouth closure began in early October, briefly opened (breached) in mid-November then closed and remained closed until late November (2018). Figure 20 displays river mouth closure dates for the Chinook migration period for years 2001 through 2018.

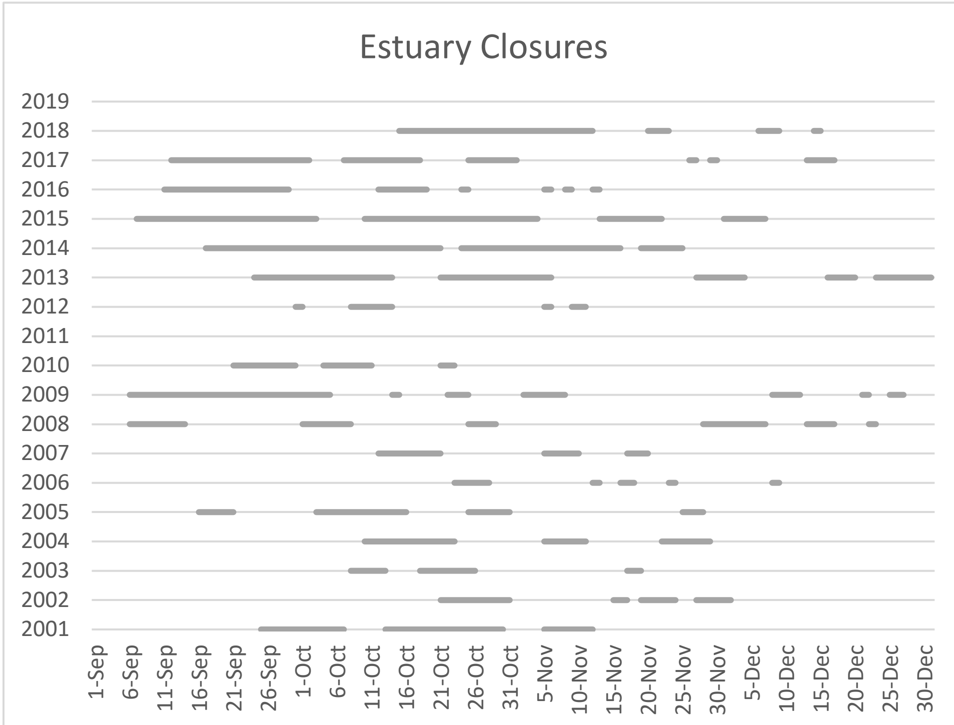

Figure 20. Dates the mouth of the Russian River was closed from 2001 through 2018 during the months of September through December.

Discussion

While the two Coyote Valley Dam fall flood control releases (Figure 10 and Figure 11) did appear to influence the migration of Russian River Chinook, releases are not the typical environmental cue that triggers upstream migrations. The typical environmental cues that trigger upstream migration appear to be seasonality (change in temperature or photoperiod), breaching of the barrier beach that periodically forms at the mouth of the river, river stage, and rain events.

Seasonality is likely one of the most significant environmental cues for upstream migration (Figure 21). The specific seasonal mechanisms that trigger migration may be shortening of photoperiod or a decrease in stream temperature (Figure 22). The run timing of Chinook salmon in the Russian River has likely adapted to the local Mediterranean climate where hot dry summers create inhospitable conditions for Chinook and wet cool winters provide suitable stream temperatures and ample flow. Year to year variability in the beginning and end of the run may be in part due to river mouth closures and the timing of the first rains.

The formation of a barrier beach at the river mouth that temporarily blocks Chinook from entering the Russian River appears to have a strong influence on daily Chinook counts. One example of the effect of river mouth closures on daily Chinook counts occurred in 2006 when a barrier beach formed in mid-October and breached in late-October (Figure 6). Chinook were detected at Sonoma Water's seasonal dam prior to closure of the mouth, declined during the closure, and counts increased significantly after a breach. If FIRO pre-releases occur during a fall closure they may increase stage in the estuary at a faster rate than would occur with more typical fall river flows. This could cause the estuary to reach flood stage sooner and may require a management action such as breaching the barrier beach in order to reduce flood risk.

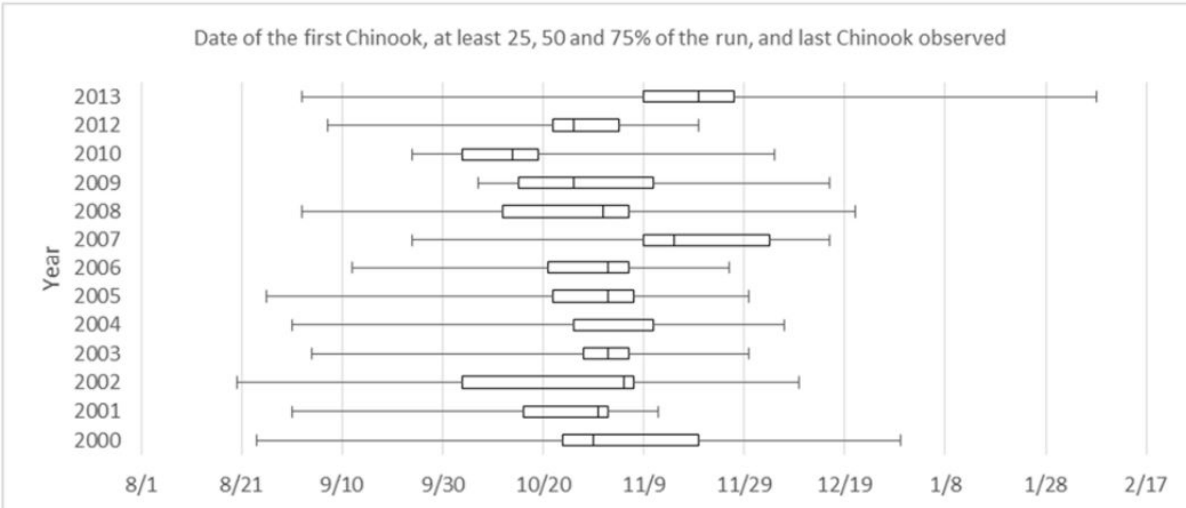

Figure 21. The date that the first and last Chinook were observed on video cameras at the Mirabel fish ladders shown as whiskers, and the date that at least 25%, 50%, and 75% of the run were observed shown as boxes. In most years the video cameras were installed on September 1. The video cameras were removed during the onset of the first major storm each year. This often coincides with the date the last fish was observed (SCWA 2016).

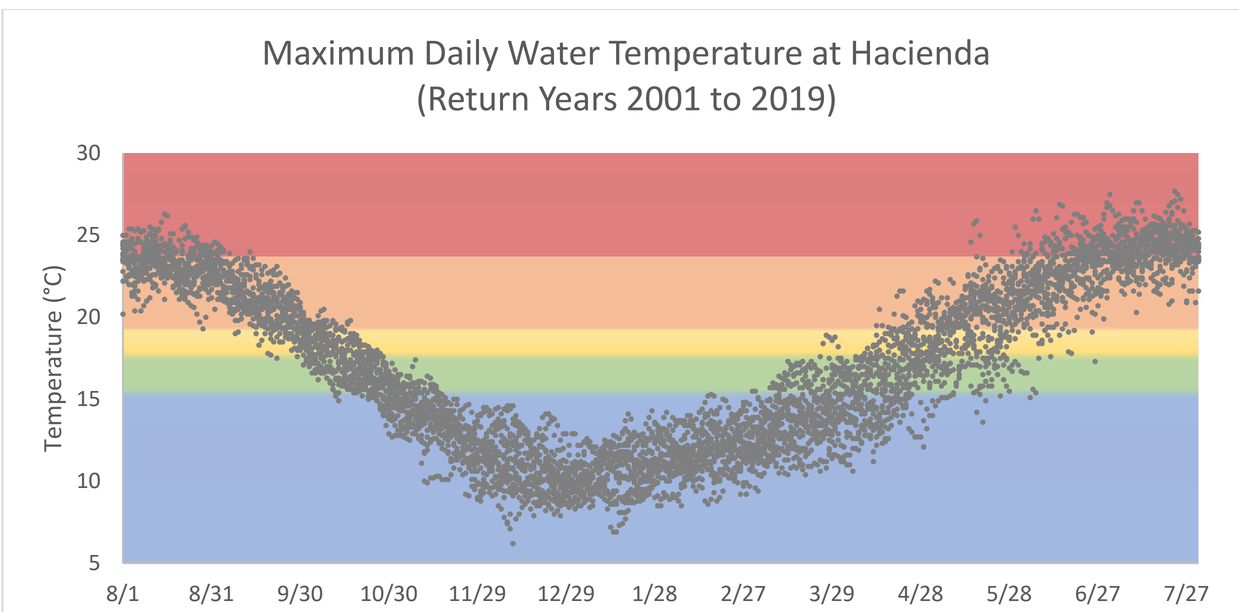

Figure 22. Maximum daily water temperature for Hacienda (USGS gage number 11467000) for return years 2001 through 2019 shown with temperature suitability criteria for adult Chinook salmon developed by Sonoma Water (2016). Blue, green, yellow, orange, and red represent optimal, suitable, tolerance, resistance, and lethal water temperatures, respectively.

Table 1. Adult salmonid temperature (°C) thresholds used for Chinook adult migration. Adapted from Sonoma Water (2016).

Description	Chinook
optimal upper limit	15.6
suitable upper limit	17.8
stressful upper limit	19.4
acutely stressful upper limit	23.8
lethal	23.9

Flow and water depth over shallow riffles in the lower Russian River is a factor that can affect Chinook run timing. Using flow as a proxy for stage, there is some evidence flows below 135 cfs may limit Chinook from moving through the lower Russian River (Sonoma Water 2016). However, flow in the lower Russian River is rarely below 135 cfs during the Chinook migration season.

Based on Chinook counts at the Mirabel dam, it appears that rain events are a strong environmental cue for Chinook migration. The specific environmental cues related to rain events may be changes in water temperature, water chemistry, turbidity, and low barometric pressure. Regardless of the specific mechanism, rain events (even small rain events which do not contribute significantly to flow) appear to have a strong effect on Chinook migration.

In conclusion it appears that Forecast Informed Reservoir Operations (FIRO) are unlikely to negatively affect the timing of upstream movement of Chinook salmon or the river conditions required for safe passage. Flood releases during the fall are uncommon and are not the typical environmental cue that triggers Chinook to migrate upstream in the Russian River. It is likely that seasonality, the absence of a barrier beach at the river mouth, and rain events are more typical environmental cues that encourage Chinook salmon to migrate upstream

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