DRAWDOWN MODEL REPORT
FOR THE KLAMATH RIVER RENEWAL PROJECT

100% DESIGN REPORT

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March 10, 2022

NHC Ref. No. 2004947

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1 INTRODUCTION

As part of the Klamath River Renewal Project (KRRP), a one-dimensional (1D) Hydraulic Engineering Center River Analysis System (HEC-RAS) hydraulic model (HEC, 2019) has been developed to assess the reservoir hydraulics during the drawdown of J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate Reservoirs on the Klamath River, located in Oregon and California. The model was developed using combined LiDAR, bathymetric surveys and a Digital Elevation Model (DEM) of the Klamath River (GMA, 2018). Inflows to the model are from the 2019 Biological Opinion (BiOp) flows (USBR, 2018).

Under contract to Knight Piésold (KP), Northwest Hydraulic Consultants Inc. (NHC) was tasked with developing a HEC-RAS model (HEC, 2019) (USACE, 2019).

1.1 Scope of Work

The primary purposes of the drawdown model and this report are to present simulated reservoir water surface elevations (WSEs) for the four reservoirs during the drawdown year as they relate to drawdown operations. These assessments were performed under a wide range of flow conditions to provide an assessment of the magnitude and timing of expected reservoir WSEs, inflows, and outflows. The proposed drawdown operations for each facility were evaluated using the HEC-RAS model for various flow conditions that could occur during the drawdown period. The entire 36-year record (October 1980 to September 2016) of daily average BiOp flows were used in the drawdown model.

The HEC-RAS model initiates drawdown for all the facilities on January 1 of the drawdown year. The HEC-RAS model simulates inflows, outflows and reservoir WSE through the drawdown period and for the post-drawdown period, prior to the final dam breach and establishment of the volitional fish channels. The pre-drawdown period, which is the period wherein temporary access, and dam and tunnel modifications are constructed, are not included in the HEC-RAS model.

1.2 Vertical Datum

All elevations in this report are relative to the National American Vertical Datum of 1988 (NAVD88) unless otherwise specified.

2 MODEL DEVELOPMENT

2.1 General

Three separate HEC-RAS models were used to simulate drawdown and operation of the reservoirs during drawdown for J.C. Boyle reservoir, Copco No. 1 and No. 2 reservoirs (the two Copco facilities are combined in one HEC-RAS model), and Iron Gate reservoir. The extent of each model domain and cross-section locations are shown on Figure 1. The outflow from the upstream facilities was used as the inflow into the next downstream reservoir (e.g. outflow from J.C. Boyle model is the inflow into Copco Lake).

HEC-RAS model cross-sections are based on the topobathymetric data (GMA, 2018) and reach lengths (i.e. the distance between HEC-RAS model cross-sections) were defined to represent, as best possible, a range of storage and conveyance conditions for both high reservoir stage and low-flow immediately after drawdown. Section 2.4 discusses checks of the reservoir volume between the HEC-RAS model (the hydraulic model volumes are based on reach length and cross-section area) and the bathymetric data. The low flow channel is estimated based on the 2018 bathymetric data and represents a very approximate riverine condition, though that is considered sufficient for this drawdown study work. As discussed in Section 2.3.1, the DEM was modified near the Copco No. 1 Historic Diversion Tunnel.

2.2 Hydraulic Model Inflows, Local Inflows, and Downstream Boundary Assumptions

Daily average 2019 BiOp flows, from October 1980 through September 2016, were provided at the USGS station Klamath River at Keno, Oregon (USGS 11509500), and at the USGS station Klamath River below Iron Gate Dam, California (USGS 11516530) (USBR, 2018). These flows were applied for the simulations discussed in this report. The Keno flow was specified as the HEC-RAS model inflow into the riverine reach upstream of the J.C. Boyle reservoir. Local inflow was determined based on the difference between the Keno and Iron Gate BiOp flows. These local inflows were applied to the HEC-RAS model, with each reach of the study area receiving a share of the inflows proportional to the approximate local drainage area within that reach. Based on this method, the difference between Keno and Iron Gate BiOp flows were applied as follows; 20 percent to the J.C. Boyle Dam reach, 30 percent to the Copco reach, and 40 percent to the Iron Gate Dam reach. The remaining 10 percent of the local inflow enters downstream of Iron Gate Dam. The time distribution of this local inflow volume was assumed to follow that at Keno. The downstream boundary for each model was assumed as the normal depth of the average downstream slope.

2.3 Digital Elevation Model and Structure Elevation Data

Table 1 lists elevations (El.) for key structure features used in the HEC-RAS model. Figure 2 through Figure 4 show profile views of the dam and reservoir portions of the HEC-RAS model for each of the dams with the elevations of relevant dam features.

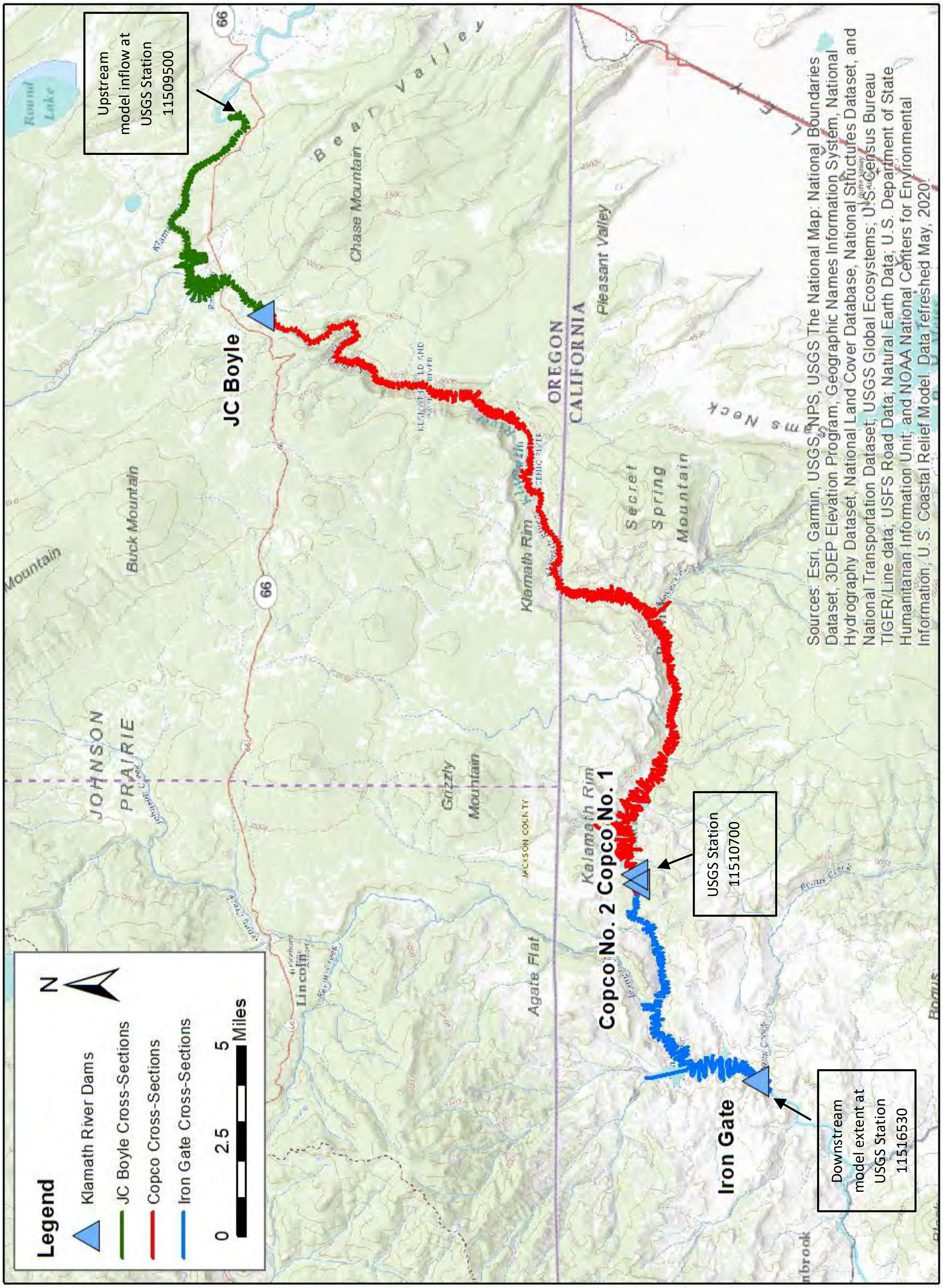


Figure 1. Vicinity Map.

Table 1. Dam feature elevations.

Dam	Dam Feature	Elevation (feet)
J.C. Boyle	Dam Crest	3803.7
	Spillway Crest	3785.2
	Power Intake Invert	3771.7
	Historic Cofferdam Crest	3770
	Diversion Culvert #1 Invert	3755.2
	Diversion Culvert #2 Invert	3755.2
Copco No. 1	Dam Crest	2616.5
	Spillway Crest	2597.1
	Historic Cofferdam Crest	2515
	Historic Diversion Tunnel Invert	2495
	Low-Level Outlet Invert (to be added prior to reservoir drawdown)*	2492.5 inlet 2477.3 outlet
Copco No. 2	Dam Crest	2496.5
	Spillway Crest	2476.5
	Spillway Bay No. 1 Invert (post dam removal elevation)*	2459.5
Iron Gate	Dam Sheet Pile	2351.3
	Dam Crest	2346.3
	Spillway Crest	2331.3
	Historic Cofferdam Crest	2212.0
	Historic Diversion Tunnel Outlet Invert	2178.3

**Notes a change from existing conditions*

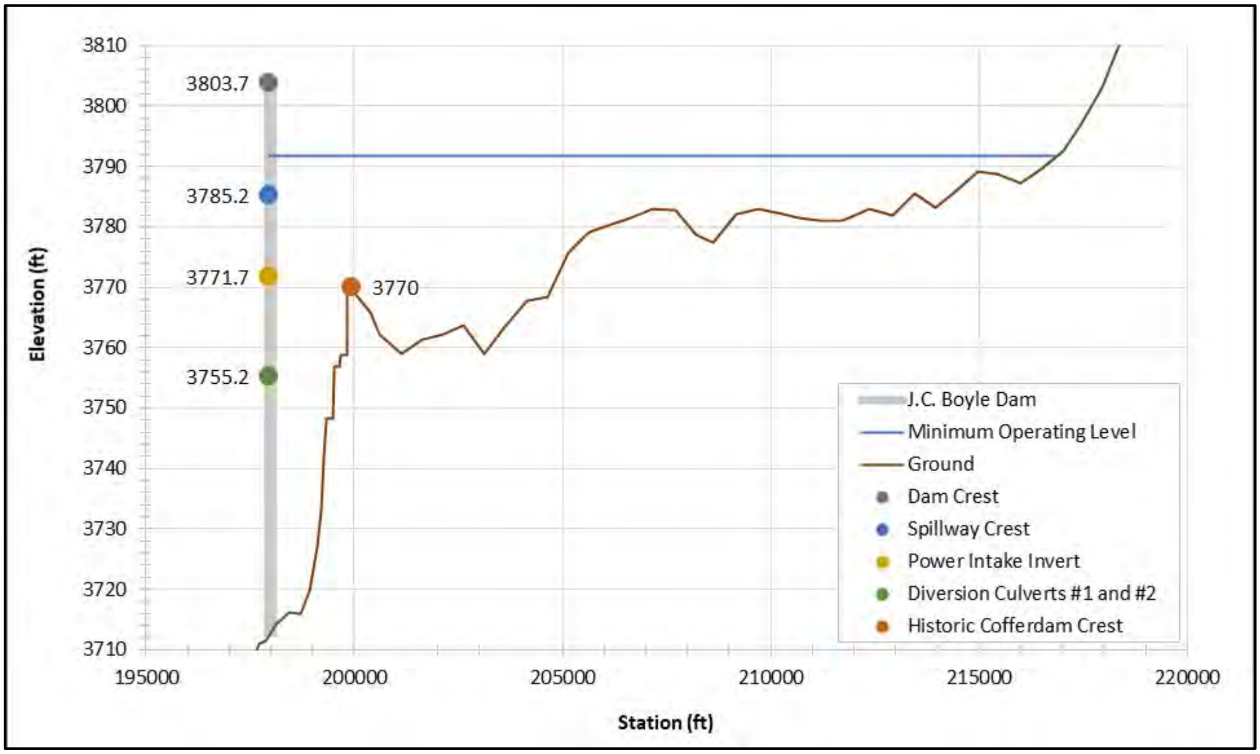


Figure 2. Profile of the dam and reservoir portion of J.C. Boyle HEC-RAS hydraulic model.

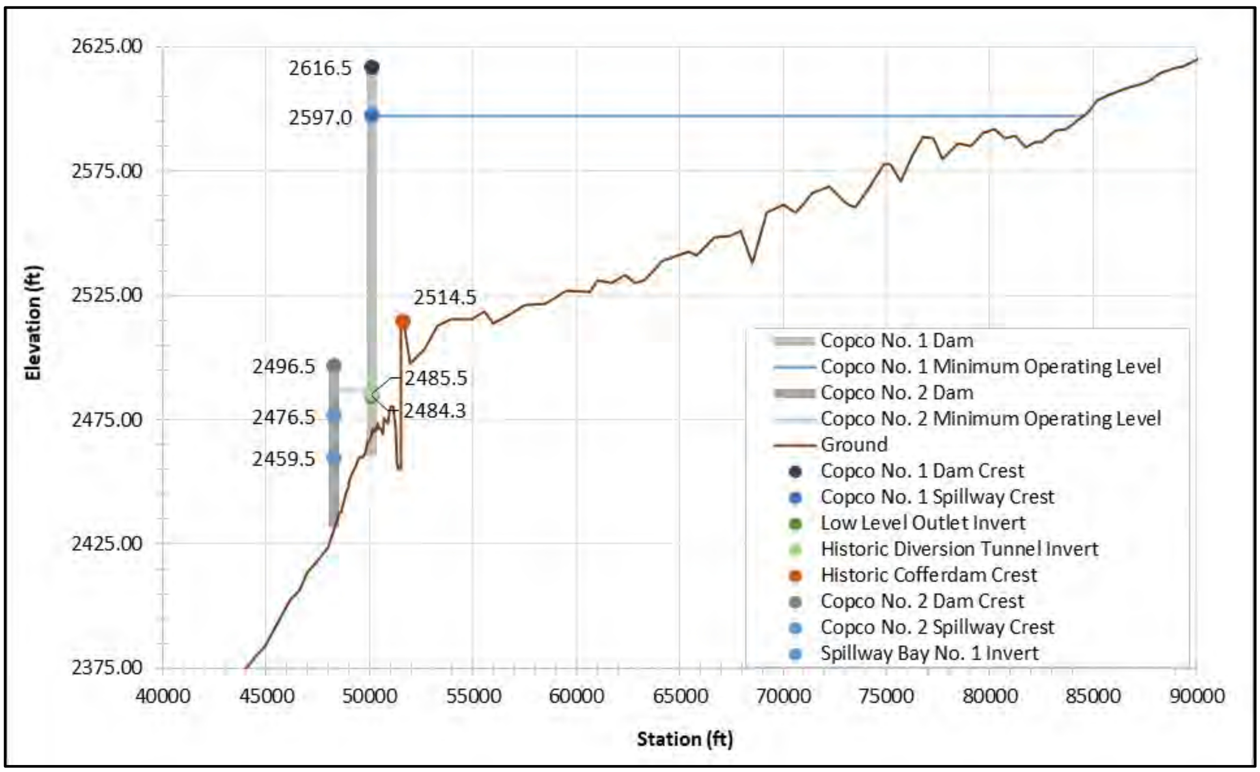


Figure 3. Profile of the dam and reservoir portion of Copco No. 1 and Copco No. 2 HEC-RAS hydraulic model.

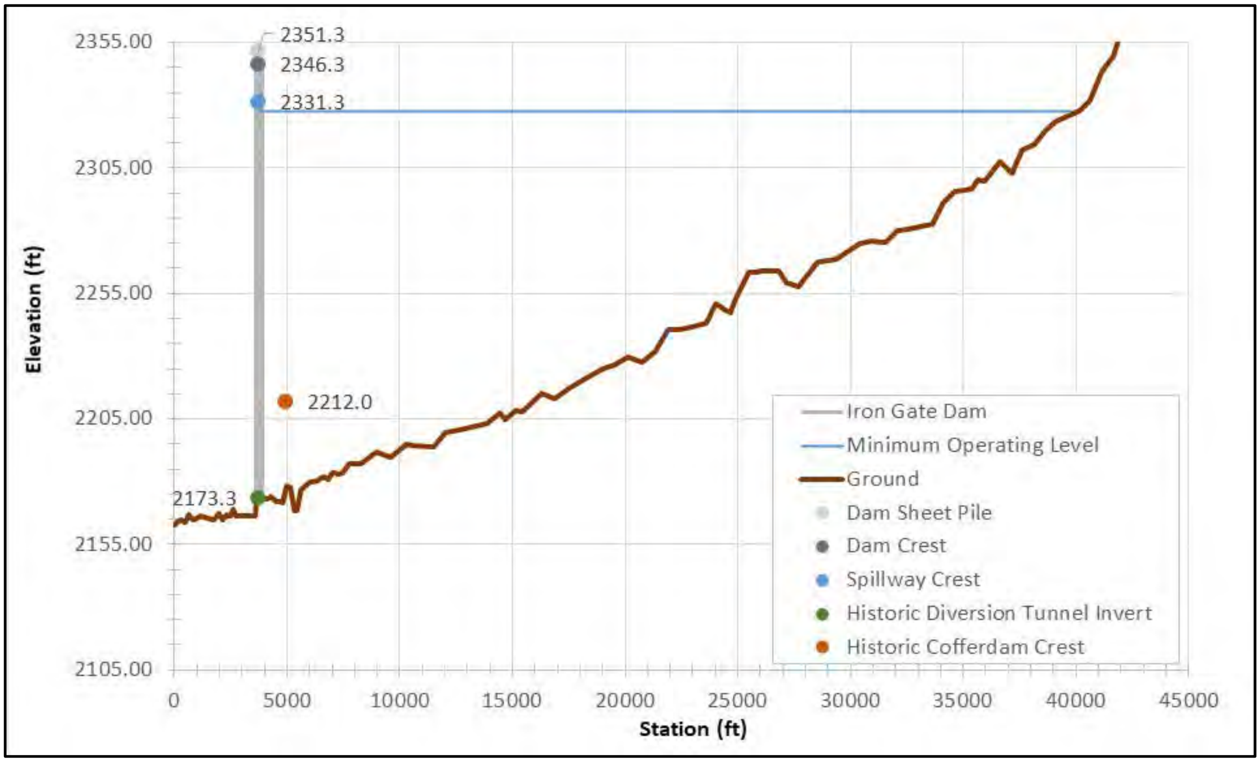


Figure 4. Profile of the dam and reservoir portion of Iron Gate HEC-RAS hydraulic model.

2.3.1 Digital Elevation Model Modifications

Sediment has accumulated near the entrance to the Copco No. 1 Historic Diversion Tunnel and the sediment will require excavation prior to the diversion tunnel opening. For the 100% design modeling, sediment was assumed to be removed to the Historic Diversion Tunnel intake, with approximately 1:1 side slopes. This represents a slight modification from the excavation plan as per KP Drawing C2120. However, this is not expected to impact the modeling results. No other modifications were made to the DEM.

2.4 Hydraulic Model Calibration and Validation

The model was validated to show that it can replicate observed reservoir stage. In a reservoir water balance, inflow plus change in reservoir storage equals outflow, and if these values are correct, then the hydraulic model should replicate observed stage.

Reservoir storage is a function of volume, and therefore the representation of the three main reservoirs within HEC-RAS (calculated up to the dam or spillway crest based on cross-section shape and the specified reach length between cross-sections) were compared to that of the topobathymetric data from approximately the spillway crest to at or near the historic coffer dam. Figure 5 shows this comparison (these plots are shown with the same volume scale for comparison purposes) and the values are generally within 10 percent when compared at 10-foot increments.

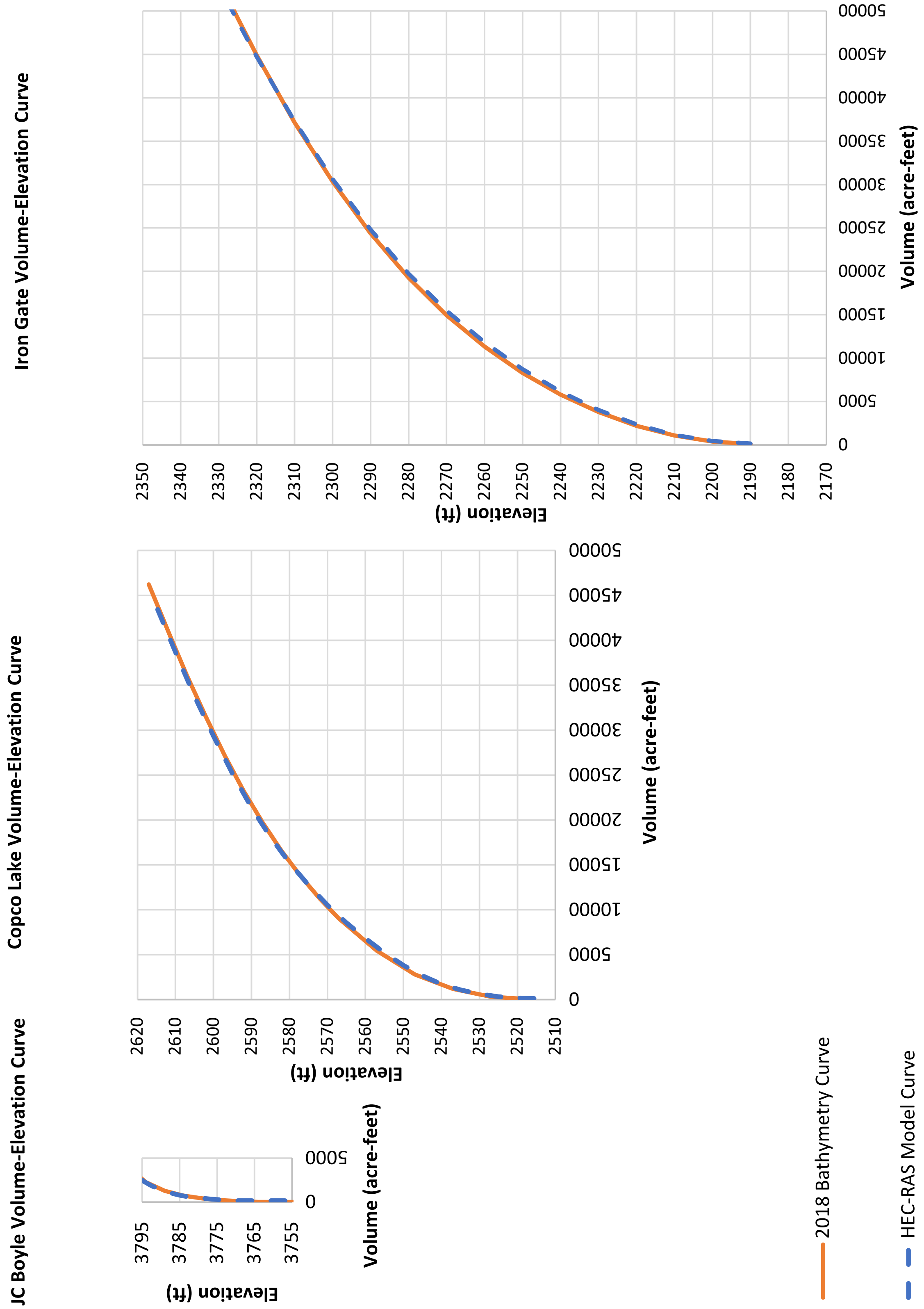


Figure 5. J.C. Boyle, Copco Lake and Iron Gate Reservoir HEC-RAS models volume (dashed blue) compared to topobathymetric data (solid orange).

In addition to storage, all inflows and outflows must be known or estimated to complete a water balance for the reservoirs. Gaged reservoir inflow and outflow data are available, however the local inflow between these points is also necessary to complete the water balance and evaluate the models' capability to replicate observed stage. As a proof of concept, the local inflows were roughly determined (Appendix A) to create an observed match between the simulated and observed stage within a portion of the normal operating pool range. Figure 6 to Figure 8 show for J.C. Boyle, Copco No. 1, and Iron Gate reservoirs, respectively, simulated stage with the estimated local inflow for a yearlong simulation at each reservoir. Root Mean Square Error for differences in simulated and gaged reservoir stage for these periods are 0.20, 0.16, and 0.18 for J.C. Boyle, Copco No.1, and Iron Gate reservoirs, respectively. Given the uncertainty of the local inflow, and that not knowing this accurately has a significant effect on the water balance, further evaluation was not conducted for this study.

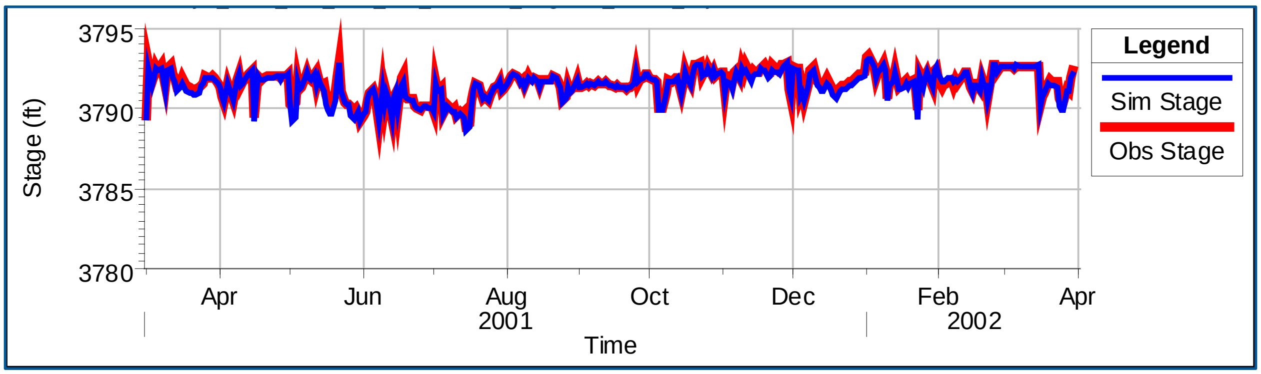


Figure 6. J.C. Boyle Reservoir Simulation Replicating Observed Stage with Estimated Ungaged Flow

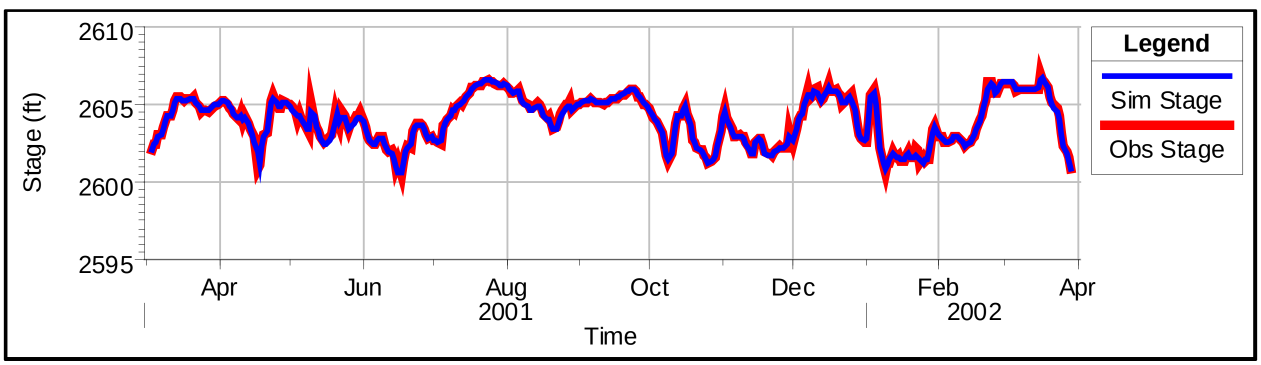


Figure 7. Copco No. 1 Reservoir Simulation Replicating Observed Stage with Estimated Ungaged Flow

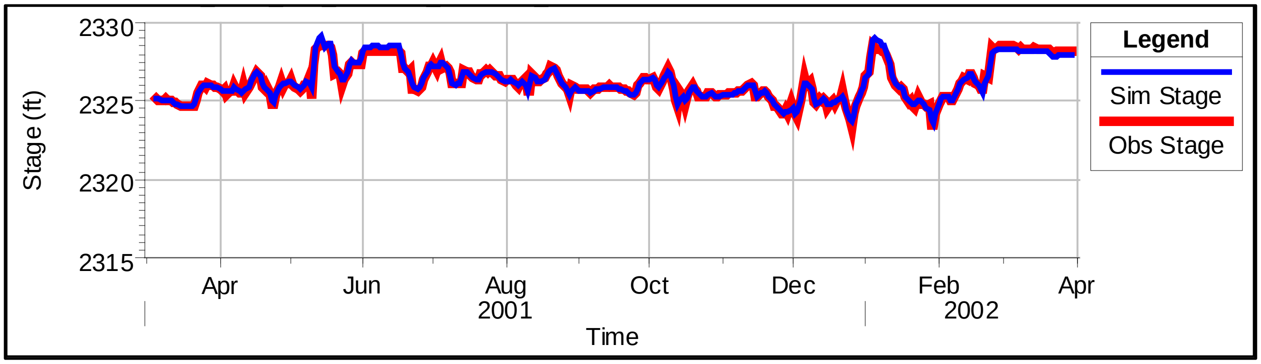


Figure 8. Iron Gate Reservoir Simulation Replicating Observed Stage with Estimated Ungaged Flow

The hydraulic model was calibrated to existing data for the riverine portions of the study area and also validated to show that it accurately simulates reservoir stage conditions within the range of normal pool operations. Figure 9 to Figure 11 show the different simulations run with Manning's roughness values of 0.04, 0.05, 0.06, and 0.07 to test model sensitivity for J.C. Boyle, Copco No.1, and Iron Gate, respectively. The local rating curve data from the three USGS gages were input as observed time series for each of the dams. The model became unstable for J.C. Boyle and Copco No. 1 simulations with a Manning's roughness value of 0.04. Manning's n was calibrated based on three USGS gaging stations within the study reach, and the value of n = 0.05 and n = 0.06 selected for the main channel and overbanks, respectively to match the best fit lines in Figure 9 to Figure 11 (Appendix A). Root Mean Square Error for differences in simulated and measured stage are 0.65, 0.35, and 0.40 for riverine sites upstream of J.C. Boyle, Copco No.1, and Iron Gate reservoirs, respectively. Simulated flows below 8,000 cfs are typically within one foot of measured USGS values. Figure 12 shows a time series example of simulated versus observed stage at USGS Station 11510700 upstream of the Copco No. 1 Reservoir for a range of flows. Sensitivity of model results to Manning's n is discussed in Section 2.5.

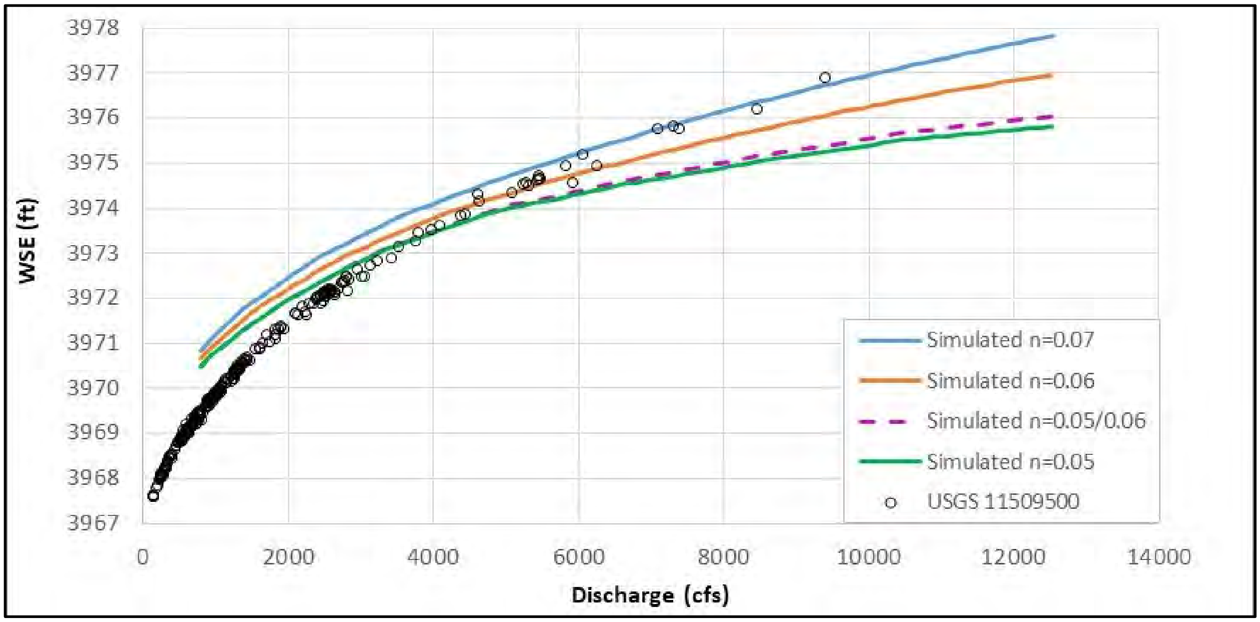


Figure 9. Simulated Stage Discharge Curves for a Range of Manning's n Values compared to Measured Values at a USGS Station 11509500 Upstream of the J.C. Boyle Reservoir

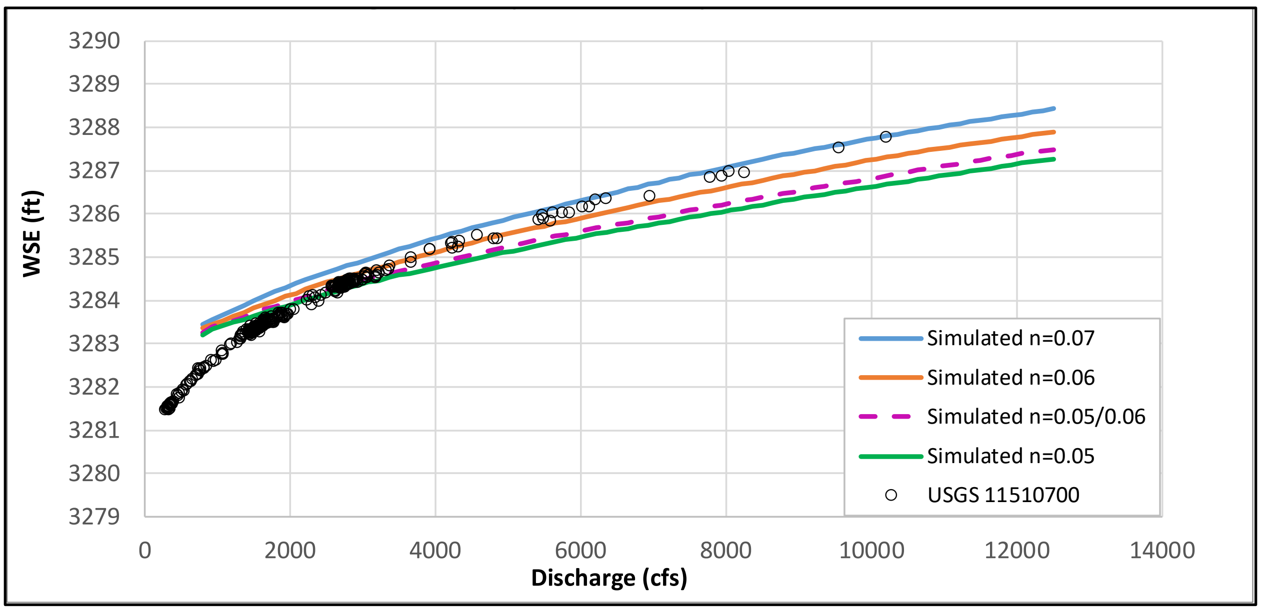


Figure 10. Simulated Stage Discharge Curves for a Range of Manning's n Values compared to Measured Values at a USGS Station 11510700 Upstream of the Copco No. 1 Reservoir

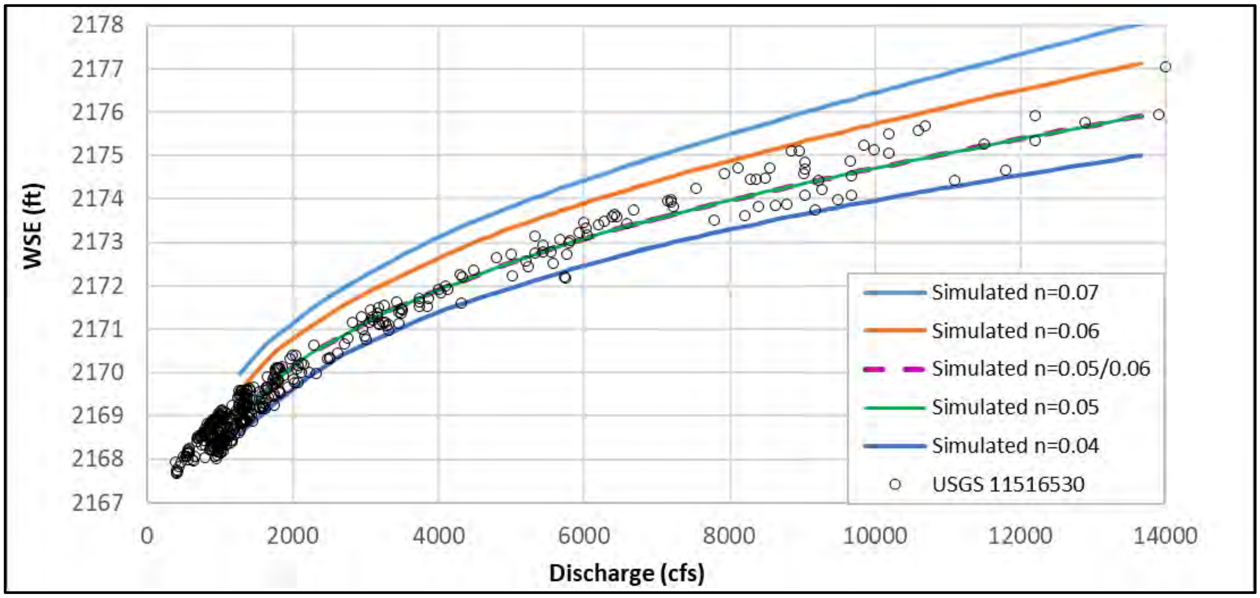


Figure 11. Simulated Stage Discharge Curves for a Range of Manning's n Values compared to Measured Values at a USGS Station 11516530 Downstream of the Iron Gate Reservoir

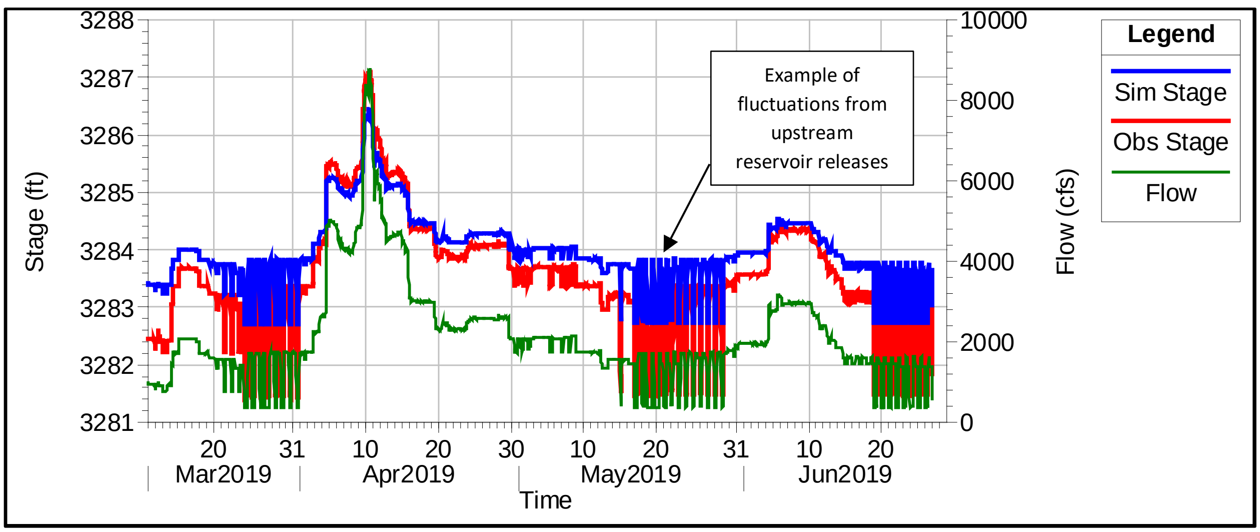


Figure 12. Example Simulated versus Observed Stage at a USGS Station 11510700 Upstream of the Copco No. 1 Reservoir

2.5 Sensitivity Analyses

Several sensitivity analyses were conducted to understand how adjustments to model parameters would affect the simulated results. When results show a high variability to modifying a specific model parameter, then additional attention should be made in selecting an appropriate value for that parameter. Sensitivity analyses evaluated varying Manning's n through the unregulated, riverine portions of the hydraulic model, and through the reservoirs, both with and without dams in place (the latter investigating sensitivity to the simulated drawdown condition) as well as varying the computational time step, and the effect of varying the output time step on downstream model results (where the upstream model output is used for input into the downstream model). Additional simulations have been conducted to evaluate different Manning's n values as well as other model parameters for all three reservoirs as discussed in the NHC technical memo on model sensitivity (Appendix A). These tests included:

- Removing the dams and testing the sensitivity of travel time, attenuation and stage to varying n (in 0.01 increments from 0.04 to 0.07) – to see how the Manning's n values affect simulation results during the drawdown condition.
- Through the riverine portion only (with dams in place) testing sensitivity of travel time, attenuation and stage to varying n (0.01 increments from 0.04 to 0.07).
- Through the reservoir portion only (with dams in place) testing sensitivity of travel time, attenuation and stage to varying n (n values of 0.03, 0.05 and 0.07).
- Varying the computational timestep (5, 15, 30 and 60 second timesteps).
- Varying reservoir volume by +/- 10%.

None of these had a significant effect on models results, with difference in water surface of typically less than a foot and time difference of less than an hour.

2.6 Hydraulic Modeling of Dam Structure Operations During Drawdown and Post-Drawdown

2.6.1 General

"Rules" are used in the hydraulic modeling to specify outflow from the dams through the various outlet structures. Computational fluid dynamics (CFD) methods were used to determine rating curves for the outlet structures at all four dams (NHC, 2020b; NHC, 2020c; NHC, 2020d; NHC, 2020e), and then the HEC-RAS rules were used to dictate when a specific outlet structure is active based on the specified drawdown operating criteria presented in the 90% Design Report (KP, 2020a). Further, at Iron Gate, the rating curve of the existing diversion tunnel was updated as per KP (2021) following a tunnel survey completed by Yurok Tribe between November 17 and November 20, 2020. For the simulations, all reservoirs are assumed lowered to their minimum operating levels and starting at that level when simulated drawdown begins on January 1 of each drawdown year.

2.6.2 J.C. Boyle

The drawdown of the J.C. Boyle reservoir will utilize the spillway, power intake, and two low-level diversion culverts. The drawdown operations specified in the HEC-RAS model for J.C. Boyle are as follows:

- Stage 1 – Drawdown using spillway gates:
    - Initial WSE is the minimum operating level (El. 3791.7 feet).

- Drawdown is initiated on January 1 and is regulated using the spillway gates at a target rate of 5 feet/day.

- Stage 2 – Drawdown using power intake to lower the reservoir levels to below the spillway crest:
  - The power intake opens on January 2. Flow through the power intake is not regulated.
- Stage 3 – Opening of Diversion Culvert #1:
  - Diversion Culvert #1 opens once the reservoir WSE is at or below El. 3783.2 feet (which is 2 feet below the spillway crest) for a period of 24 hours.
  - No operational controls exist for the culvert.
  - The power intake permanently closes when Diversion Culvert #1 is opened. Once the power intake is closed, it remains closed.
- Stage 4 – Opening of Diversion Culvert #2:
  - Diversion Culvert #2 is delayed until after the freshet.
  - Diversion Culvert #2 opens on or after June 10 and at a reservoir WSE at or below El. 3783.2 feet (which is 2.0 ft below the invert of the spillway crest) for a period of 24 hours.
  - No operational controls exist for the culvert.

The rating curves used in the HEC-RAS model for the J.C. Boyle facility are shown on Figure 13. The rating curve was developed using computational fluid dynamics (CFD) by NHC (2020b).

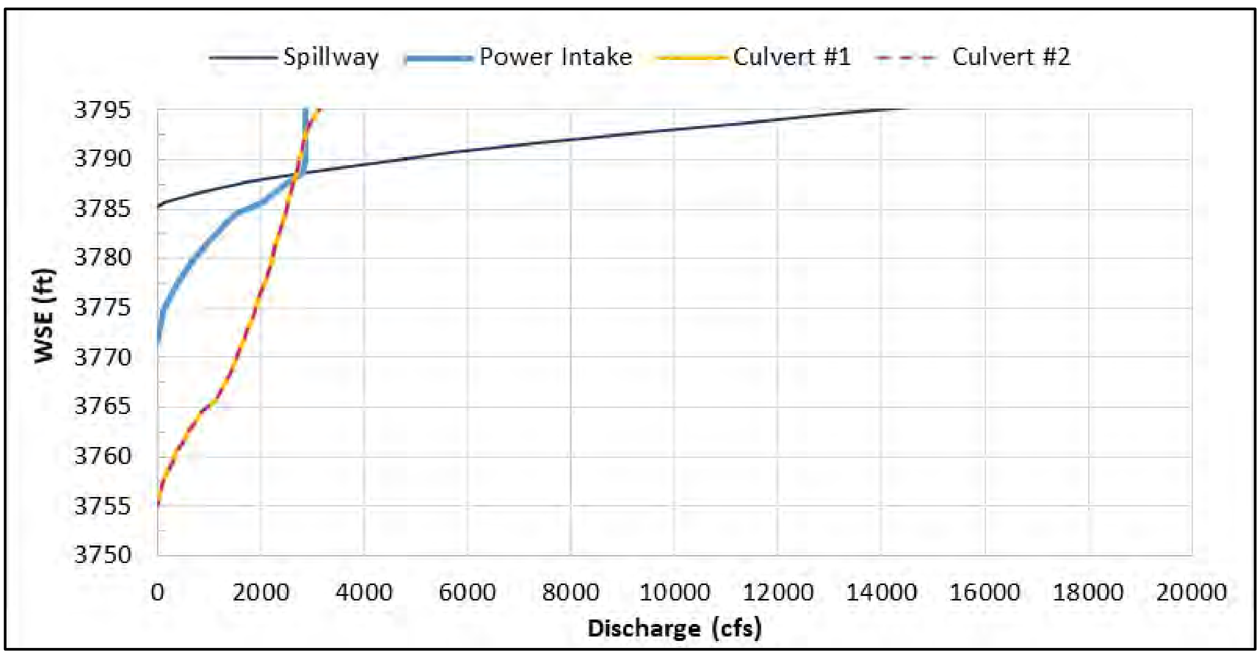


Figure 13. Stage versus flow relationships at J.C. Boyle Dam for simulating outflow at the dam.

2.6.3 Copco No. 1

The drawdown of the Copco No. 1 reservoir will be completed utilizing the spillway and by constructing a new low-level outlet with a 10.0 feet orifice inlet diameter and a 10.5 feet by 15 feet “D” shaped tunnel with a 10.5 feet diameter steel pipe at the outlet of the low-level outlet. The historic diversion tunnel will be used to further lower the water level in the reservoir after the majority of drawdown has occurred. The drawdown operations specified in the HEC-RAS model for Copco No.1 are as follows:

- Drawdown Phase – Opening of new low-level outlet:
  - Initial WSE is at the crest of the spillway (El. 2597 feet).
  - Drawdown is initiated on January 1 when the low-level outlet is opened.
  - The pre-drawdown phase is not included in the HEC-RAS model.
  - No powerhouse flows are included in the HEC-RAS model.
- Diversion Stage – Opening of historic diversion tunnel:
  - The historic diversion tunnel opens after June 15 of the drawdown year and once the reservoir WSE is at or below 2530 feet, which is approximately 20 feet above the top of the existing intake structure. Initially only a 5-foot opening is assumed, and once the water level drops below El. 2516 feet, then an 18 feet opening is assumed. The model assumes the historic diversion tunnel is opened instantaneously between these opening heights.

The rating curves used in the HEC-RAS model for the Copco No. 1 facility are shown on Figure 14. They were developed using computational fluid dynamics (CFD) by NHC (2020c).

Figure 14. Stage versus flow relationships at Copco No. 1 Dam.

2.6.4 Copco No. 2

The drawdown of the Copco No. 2 reservoir will be completed by opening the exiting spillway gates and removing the concrete plug at Spillway Bay No. 1. The drawdown operations specified in the HEC-RAS model for Copco No.2 are limited as follows:

- Drawdown Phase – Opening of the Spillway Bay No. 1:
  - Initial WSE is at the normal water level (El 2,486.5 ft).
  - Drawdown is initiated on January 1 when the concrete plug at Spillway Bay No. 1 is removed.
- Passing flow through the conveyance system to the powerhouse is not included in the HEC-RAS model.
- The pre-drawdown works, which involves fully opening the spillway gates to construct a temporary working platform downstream of the Spillway Bays No. 2 through No. 5 and the partial removal of the ogee for Spillway Bay No. 1, are not included in the HEC-RAS model. The lateral removal of the dam was not simulated for the post-drawdown and the same rating curve was applied for the entire simulation.

The rating curves used in the HEC-RAS model for the Copco No. 2 facility are shown on Figure 15. The rating curve was developed using computational fluid dynamics (CFD) by NHC (2020d).

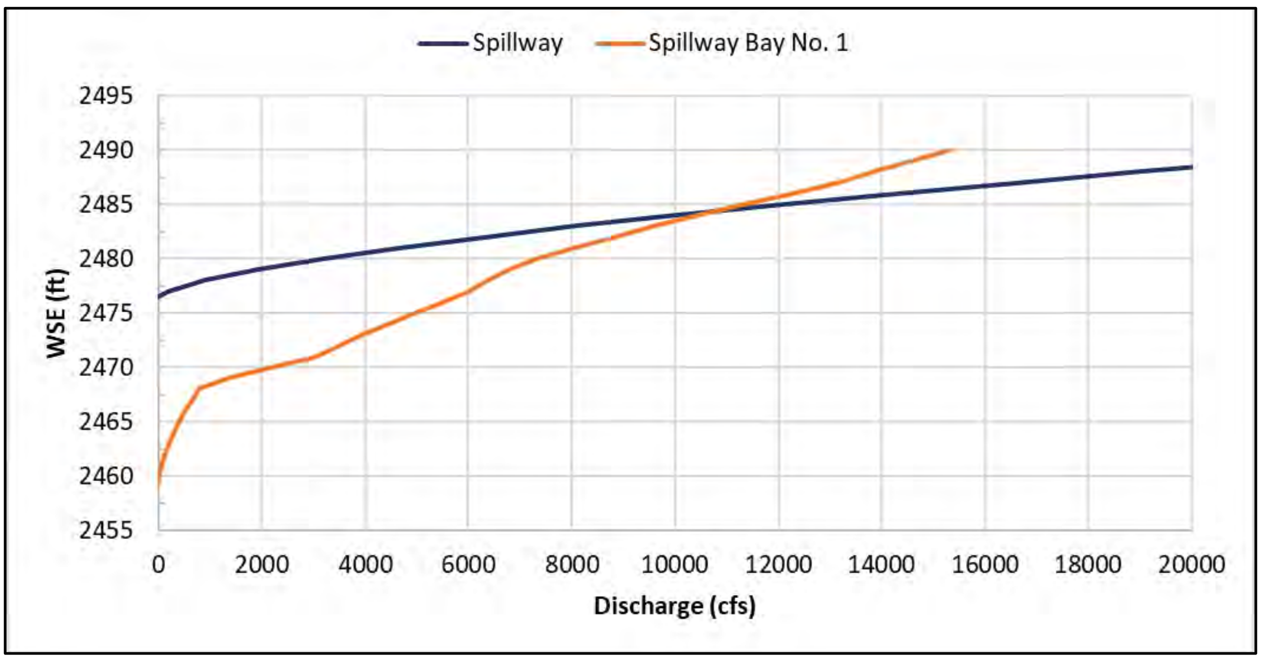


Figure 15. Stage versus flow relationships at Copco No. 2 Dam.

2.6.5 Iron Gate

The drawdown of the Iron Gate reservoir will utilize the spillway, power intake using hydraulic turbine or by-pass (Howell-Bunger valve), and existing diversion tunnel. The flow through the existing diversion tunnel will be controlled by the existing upper gate. The drawdown operations specified in the HEC-RAS model for Iron Gate are as follows:

- Drawdown Phase – Opening the existing upper gate in the diversion tunnel:
  - The initial WSE is at the minimum operating level (El. 2327.3 feet).
  - Drawdown is initiated on January 1 by fully opening the existing upper gate in the diversion tunnel (57 inches), and by opening the power intake and the bypass valve.

The rating curves used in the HEC-RAS model for the Iron Gate facility are shown on Figure 16. The rating curve was developed using computational fluid dynamics (CFD) by NHC (2020e) and KP (2021) following a tunnel survey completed by Yurok Tribe between November 17 and November 20, 2020.

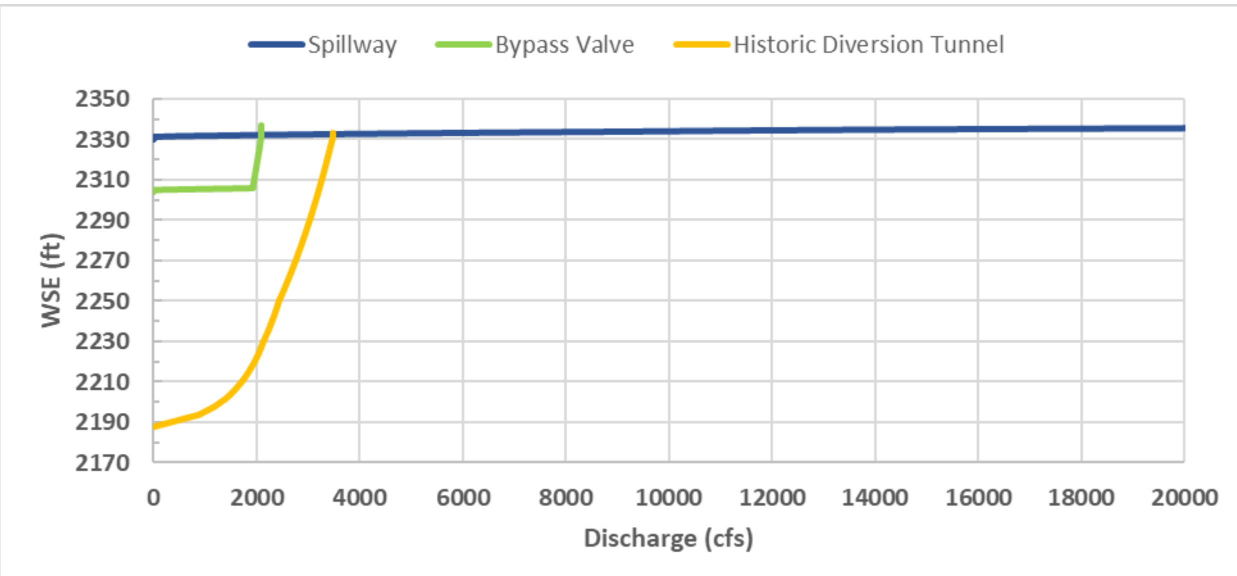


Figure 16. Stage versus flow relationships at Iron Gate Dam for simulating outflow at the dam.

3 SIMULATED RESERVOIR DRAWDOWN

The simulation results are described in detail in the following sections. The results highlight key elevation and time triggers for the hydraulic operational controls of the reservoirs for a variety of hydrologic conditions. All 36 simulation periods (1981 through 2016) were evaluated for each reservoir to ensure the efficacy and functionality of the proposed drawdown operations. Stage and flow plots for each simulation can be found in Appendices B through E. A drawdown plot for selected simulations is shown with text boxes helping to describe what is occurring in the simulation.

3.1 J.C. Boyle

3.1.1 Simulated Drawdown Results

Stage and flow results for select J.C. Boyle simulations are provided in Figure 17 to Figure 22 (these include simulation years 1987, 1993, 1997 and 2006 to show how the RAS “rules” operate under a range for flow conditions). The 1987 simulation is representative of typical hydrologic conditions based on BiOp flow volumes. The 1997 and 2006 simulations included extended periods of high flows and discharge, providing confirmation of certain proposed operational controls. The 1993 simulation provided a good example of peak flow attenuation between the four reservoirs. Both elevation controls (e.g. Culvert #1 will not open until the water surface elevation is below El. 3783.2 feet), and time controls (e.g. the power intake will not open until January 2) are utilized for this reservoir.

A stage and flow profile plot for the full 1987 simulation is provided in Figure 17. A finer resolution profile showing the key operational triggers at the beginning of the simulation is provided in Figure 18. The simulation begins at the minimum operating level of El. 3791.7 feet. The drawdown over the spillway is 2.7 feet, which is less than the target drawdown rate of 5 feet per day. The power intake opens on January 2, dropping the WSE 9.2 feet over the next 24 hours. The WSE drops below 3783.2 feet on January 2 and stays below this elevation for a minimum of 24 hours. This results in Culvert #1 opening on January 3. Once Culvert #1 is open, the power intake is closed permanently and cannot be reopened.

Tests were also completed to ensure that Culvert #2 was operating correctly under a variety of hydrologic and hydraulic conditions. Figure 19 and Figure 20 provide a weeklong snapshot of the 1987 and 2006 simulations, respectively, when Culvert #2 is activated. In Figure 19, Culvert #1 is activated at a previous time step (see Figure 18), and the WSE remains below 3783.2 for the 24 hours preceding June 11. On June 11, Culvert #2 is activated and remains open along with Culvert #1 for the remainder of the simulation. Another possible scenario is when Culvert #1 and #2 open at the same time. In the 2006 simulation (Figure 20), the WSE drops below El. 3783.2 feet on June 10, and stays below this elevation for 24 hours, causing both Culverts #1 and #2 to open on June 11. This confirms that both the elevation and time operational controls are functioning correctly.

Figure 21 is a stage and flow profile plot for the full 1997 simulation. Similar to the 2006 simulation, the 1997 simulation is an example of extended high headwater conditions, requiring the power intake to remain open until the middle of April. The WSE drops below El. 3783.2 feet for the first time on April 13 and stays under this elevation for 24 hours. Culvert #1 is opened on April 14, at which time the power intake is closed permanently for the remainder of the simulation. The WSE remains below El. 3783.2 feet for 24 hours prior to June 11, allowing Culvert #2 to open on June 11.

As previously mentioned, the HEC-RAS models represent a series of reservoirs by simulating the outflow from one reservoir into the next downstream reservoir. This means that rapid increases in flow within one reservoir should be observed within a close time frame in the immediate downstream reservoir. To confirm that the reservoirs are acting in series, the outflows from all four reservoirs were plotted during a storm in the 1993 simulation (Figure 22). The J.C. Boyle peak is on March 26 at 13:52. The Copco No. 1 and No. 2 peaks are on March 27 at 05:05, and the Iron Gate peak is on March 28 at 10:23. The peak flow from J.C. Boyle is attenuated approximately 16 hours before reaching Copco No. 1. The distance between Copco No. 1 and No. 2, along with the small capacity of Copco No. 2, resulted in no attenuation between the two Copco reservoirs. The peak discharge between Copco No. 2 and Iron Gate is attenuated approximately 29 hours. Longer attenuation between these two reservoirs was anticipated based on the distance between them, and the increased storage capacity of the Iron Gate reservoir. Figure 22 confirms that the reservoirs are acting in series, and Figure 17 through Figure 21 confirm that the operations controls are functioning as designed.

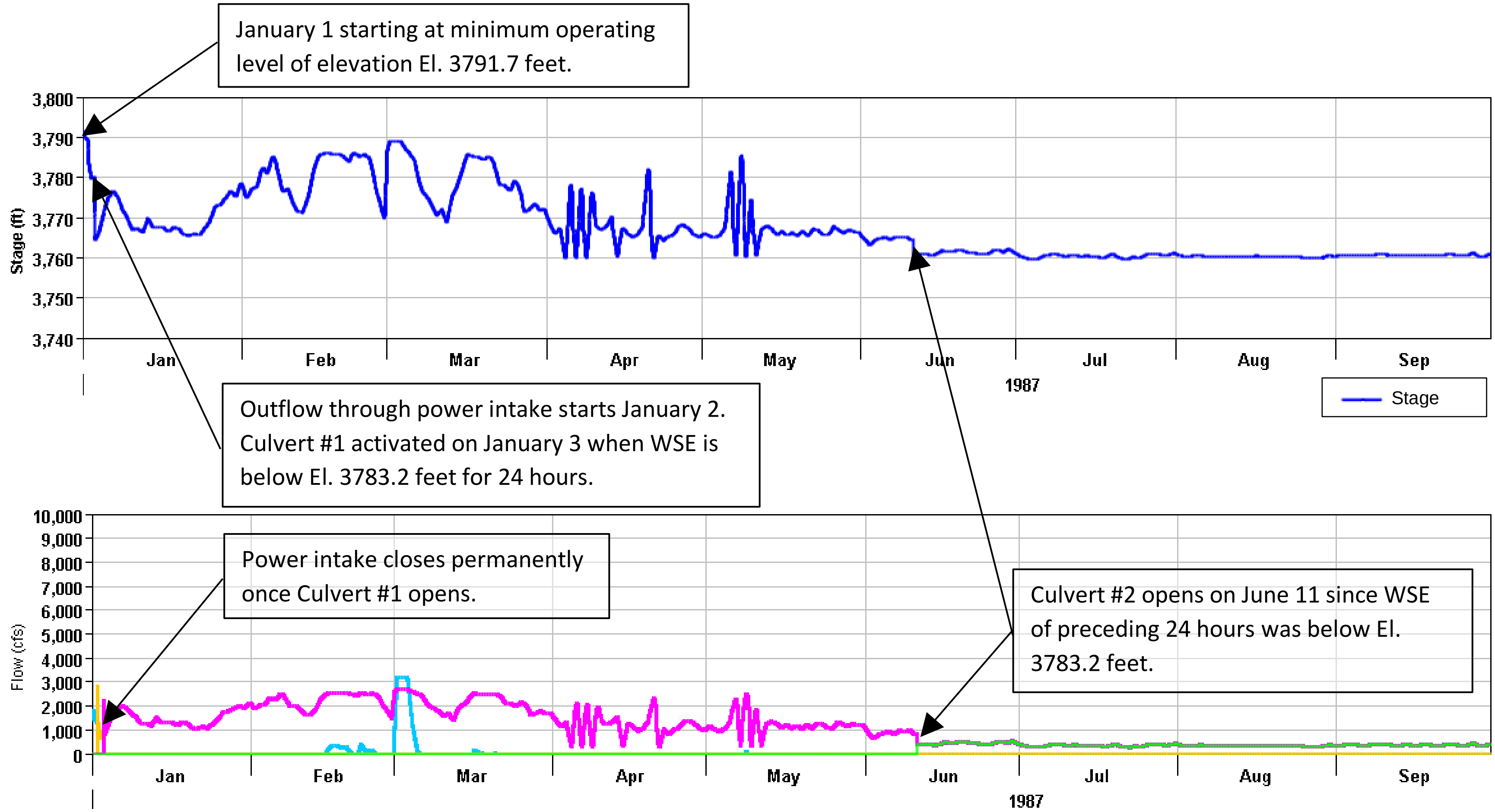
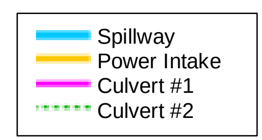


Figure 17. J.C. Boyle Project simulated drawdown and flow for full 1987 simulation



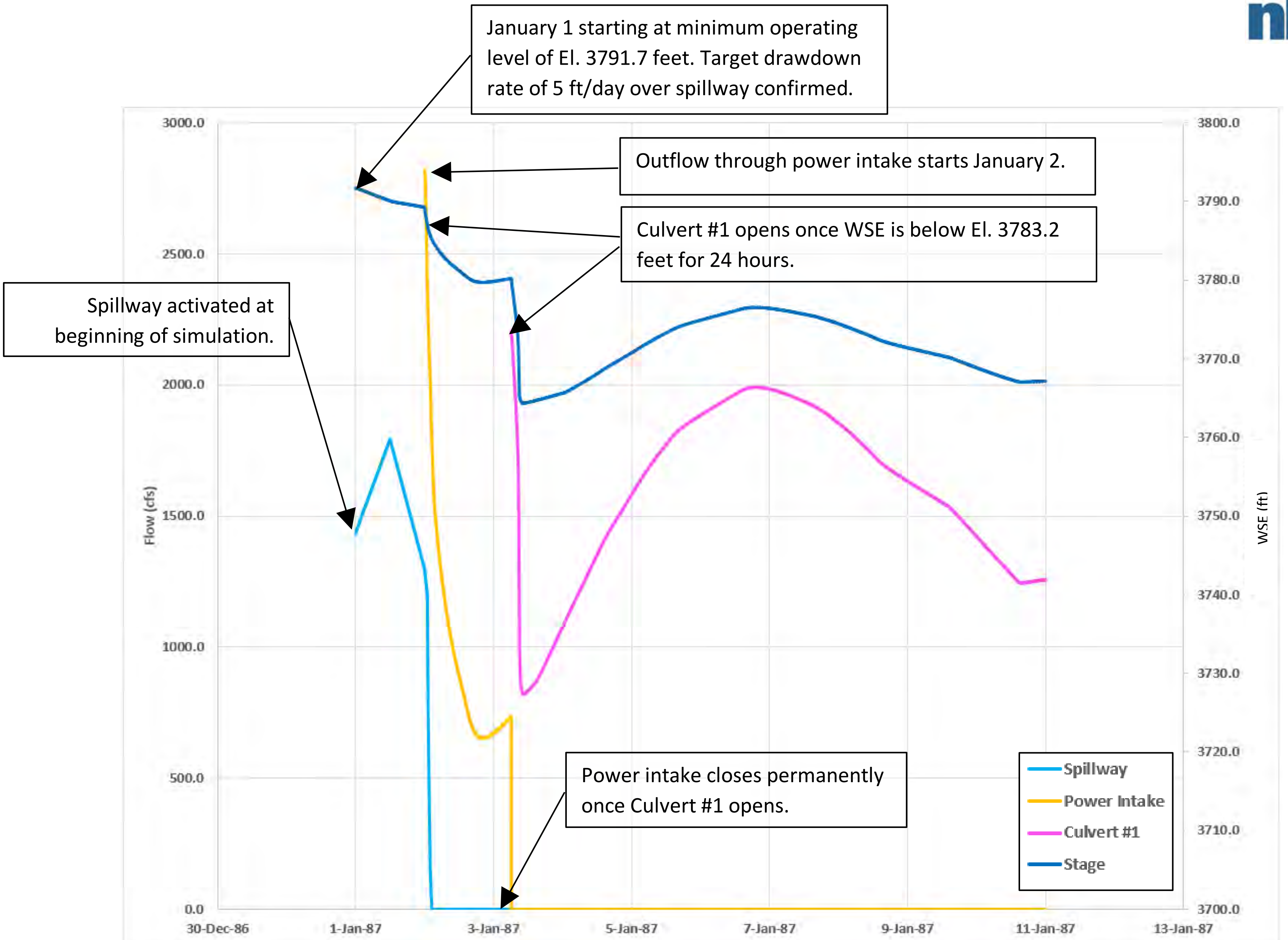


Figure 18. J.C. Boyle Project simulated drawdown and flow for finer resolution 1987 simulation.

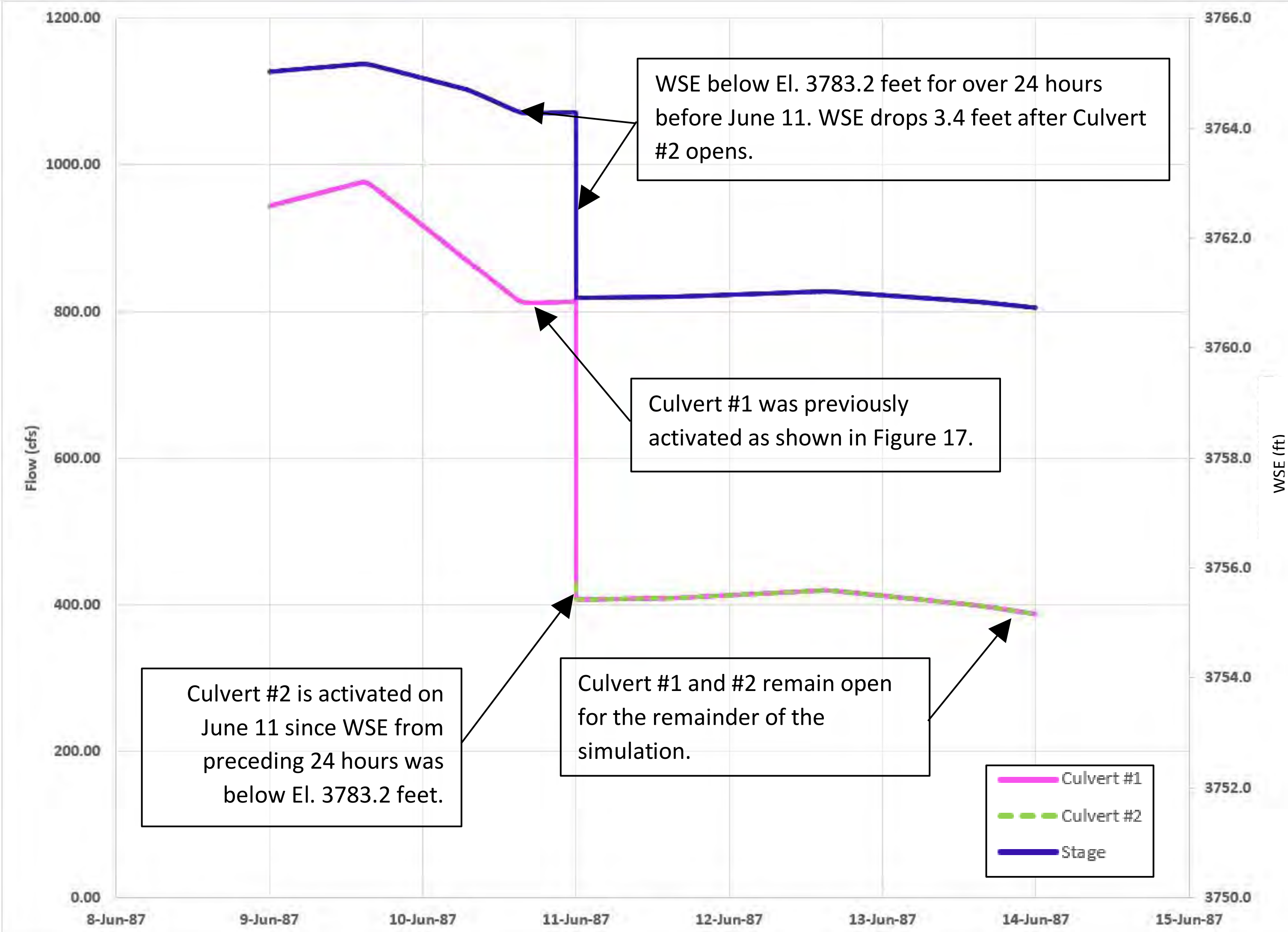


Figure 19. J.C. Boyle Project simulated drawdown and flow for Culvert #2 activation for 1987 simulation.

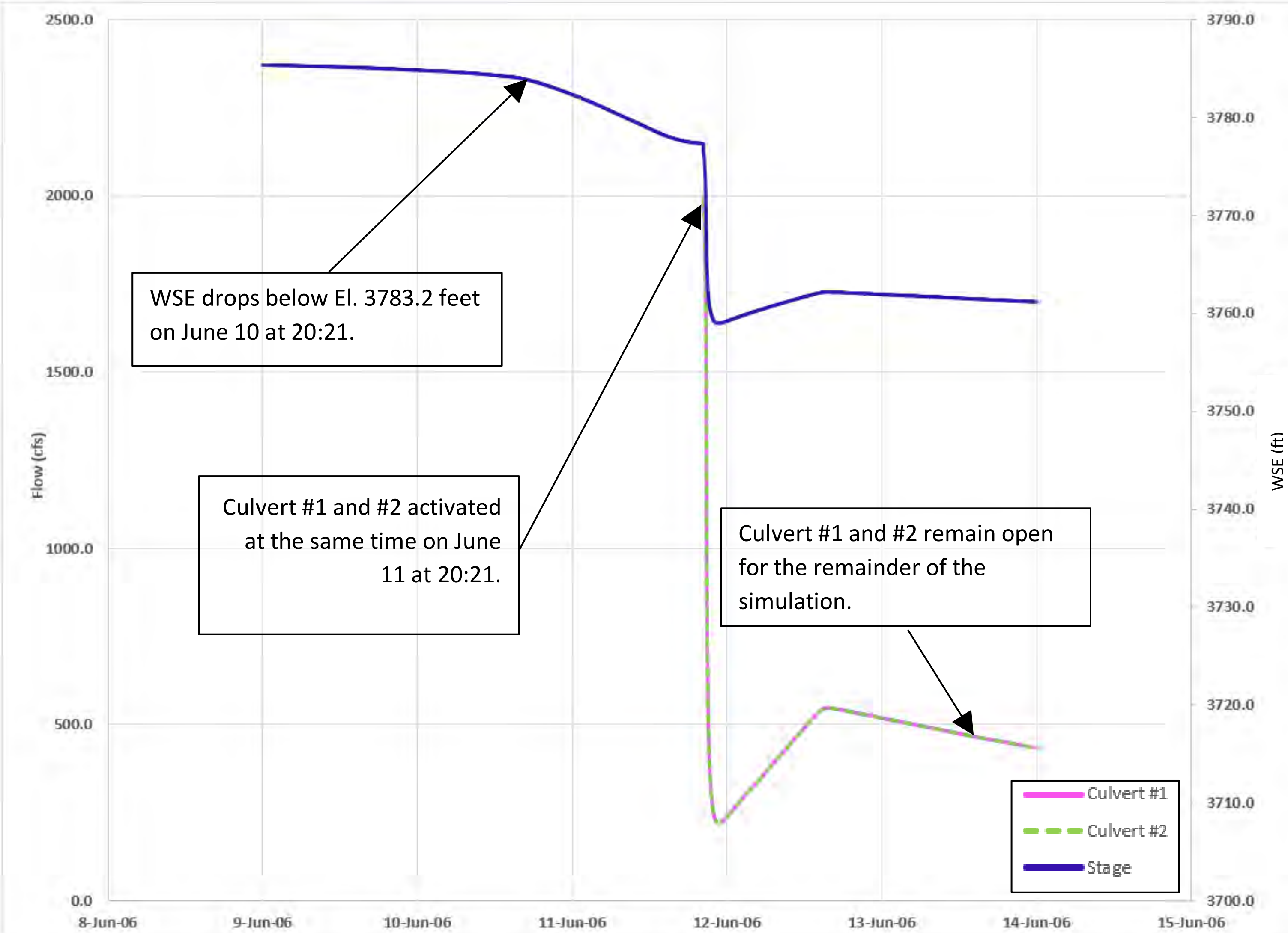


Figure 20. J.C. Boyle Project simulated drawdown and flow for Culvert #2 activation for 2006 simulation.

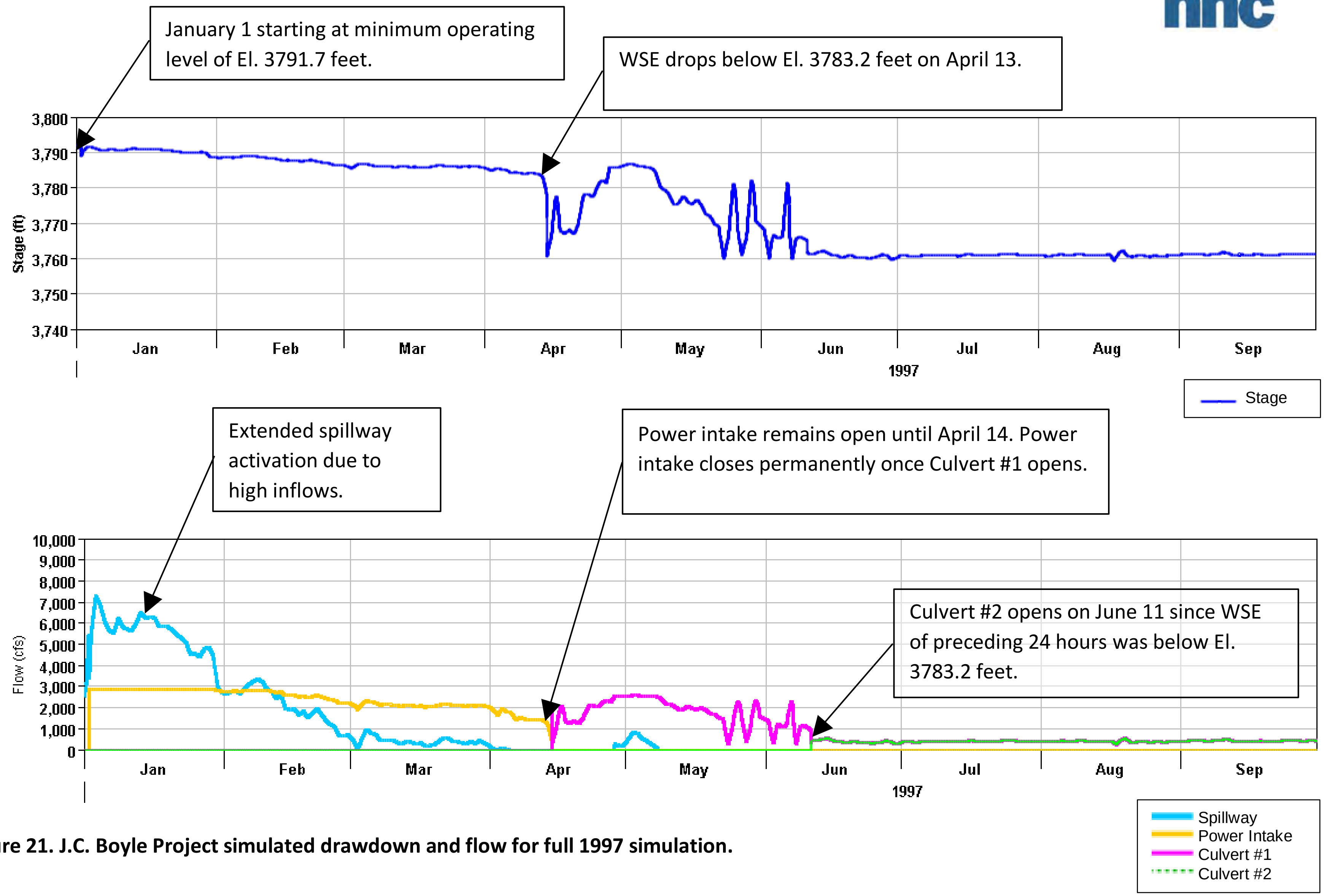


Figure 21. J.C. Boyle Project simulated drawdown and flow for full 1997 simulation.

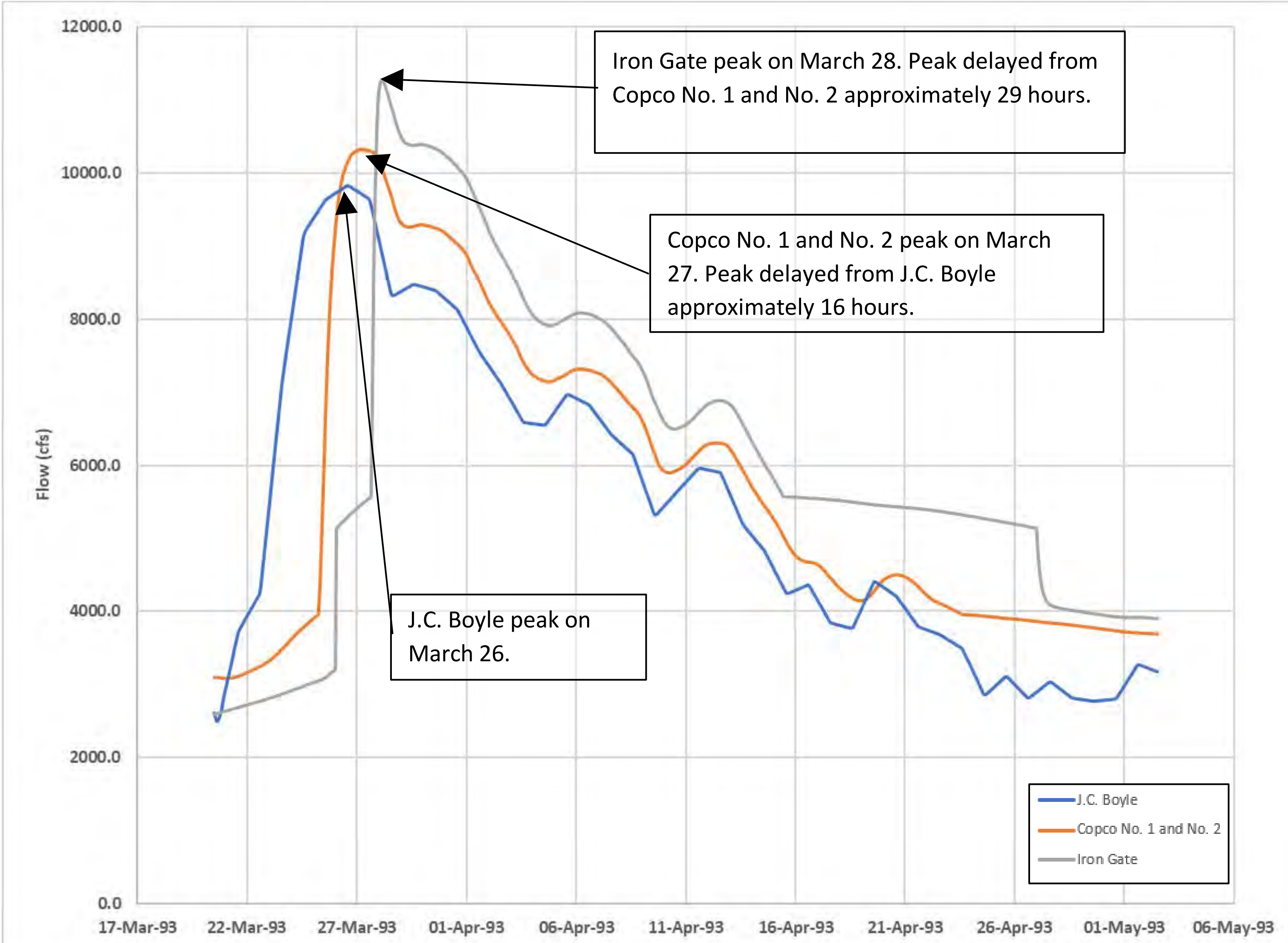


Figure 22. Comparison of inflows for the J.C. Boyle, Copco No. 1 and No.2 and Iron Gate reservoirs for the 1993 simulation.

3.2 Copco No. 1

3.2.1 Simulated Drawdown Results

Stage and flow results for selected Copco No. 1 simulations are provided in Figure 23 through Figure 26. These include simulation years 1984, 1993 and 1997. The 1984 simulation included an extended period of high inflows after the initial opening of the HDT, confirming the time and elevation controls for the HDT. The 1993 simulation displays the rapid drop in the WSE when the HDT is open to 18 feet, and the subsequent inactivation of the Low-Level Outlet. The 1997 simulation highlights the minimum operating level of the reservoir and confirms the proposed operational controls of the HDT due to fluctuating WSE at the beginning of the simulation. Both elevation controls (e.g. Historic Diversion Tunnel (HDT) will not open until WSE drops below El. 2530 feet), and time controls (e.g. HDT will not open until after June 15) are utilized for this reservoir.

A stage and flow profile plot for the full 1997 simulation is provided in Figure 23. A finer resolution profile showing the key operational triggers minimum operating levels is provided in Figure 24 through Figure 26. As show in Figure 23 and Figure 24, the simulation begins at the minimum operating level of El. 2597.0 feet. The Low-Level Outlet is open on January 1 and the spillway is also activated due to high inflows. Despite the WSE dropping below El. 2530.0 feet in April (Figure 23), the HDT will not open until after June 15.

Activation of the HDT is shown in Figure 25 and Figure 26. In Figure 25 (1993 simulation), the WSE is below El. 2530 feet allowing the HDT to open on June 16 to a height of 5 feet. Once the WSE drops below El. 2516 feet, the HDT opens to 18 feet on June 19, causing the WSE to drop 16 feet. This lowers the WSE below the crest of the cofferdam, inactivating the Low-Level Outlet (Figure 25).

Figure 26 (1984 simulation) confirms that both the elevation and time controls are working. The WSE drops below El. 2530 feet on June 21, causing the HDT to open to 5 feet. Opening of the HDT drops the WSE approximately 10 feet. The WSE drops below El. 2516 feet on June 27, causing the HDT to open to 18 feet. Since the HDT did not initially open until after the elevation (WSE below El. 2530) and time (after June 15) requirements, the efficacy of the proposed operational controls for Copco No. 1 are confirmed.

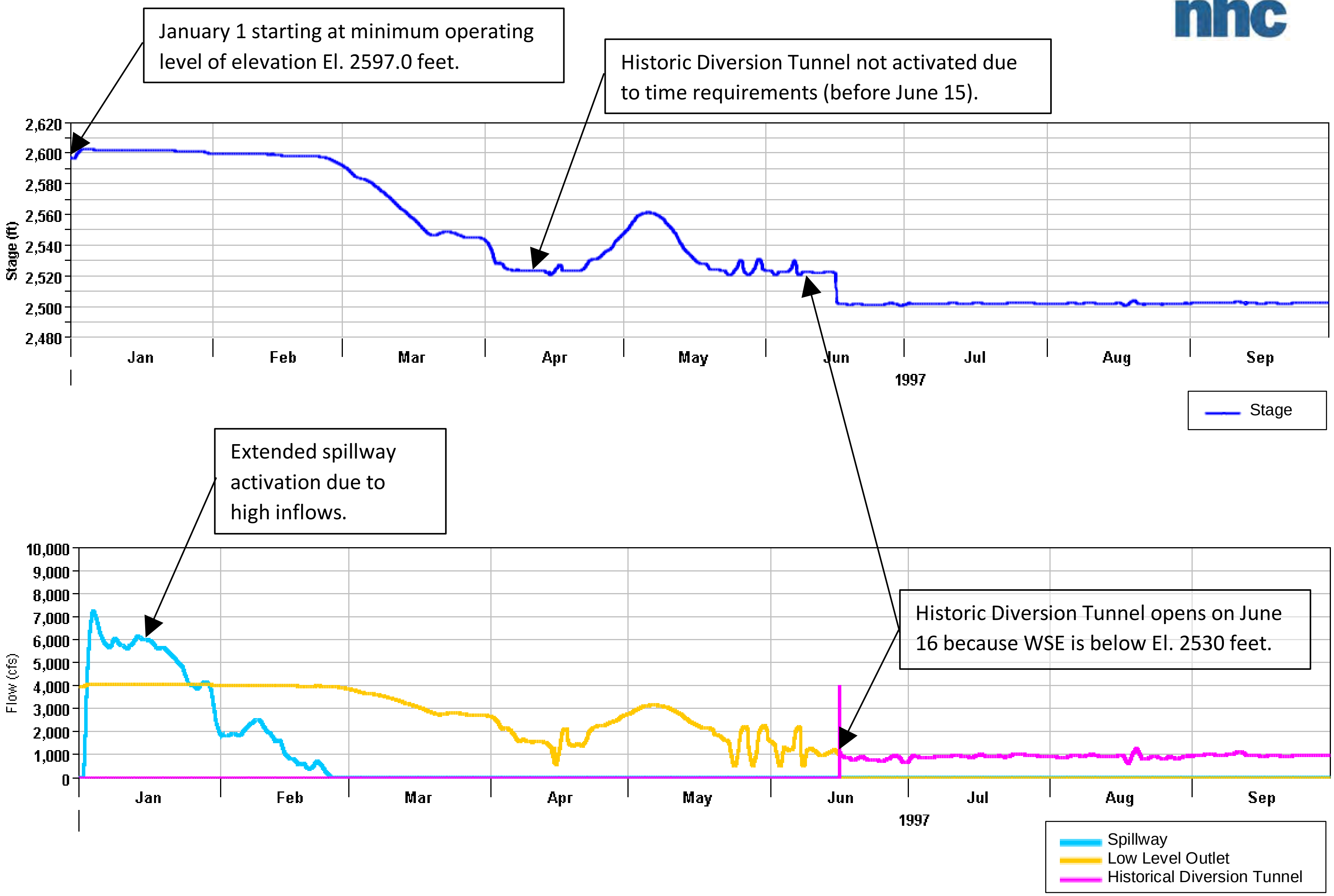


Figure 23. Copco No. 1 simulated drawdown and flow for full 1997 simulation.

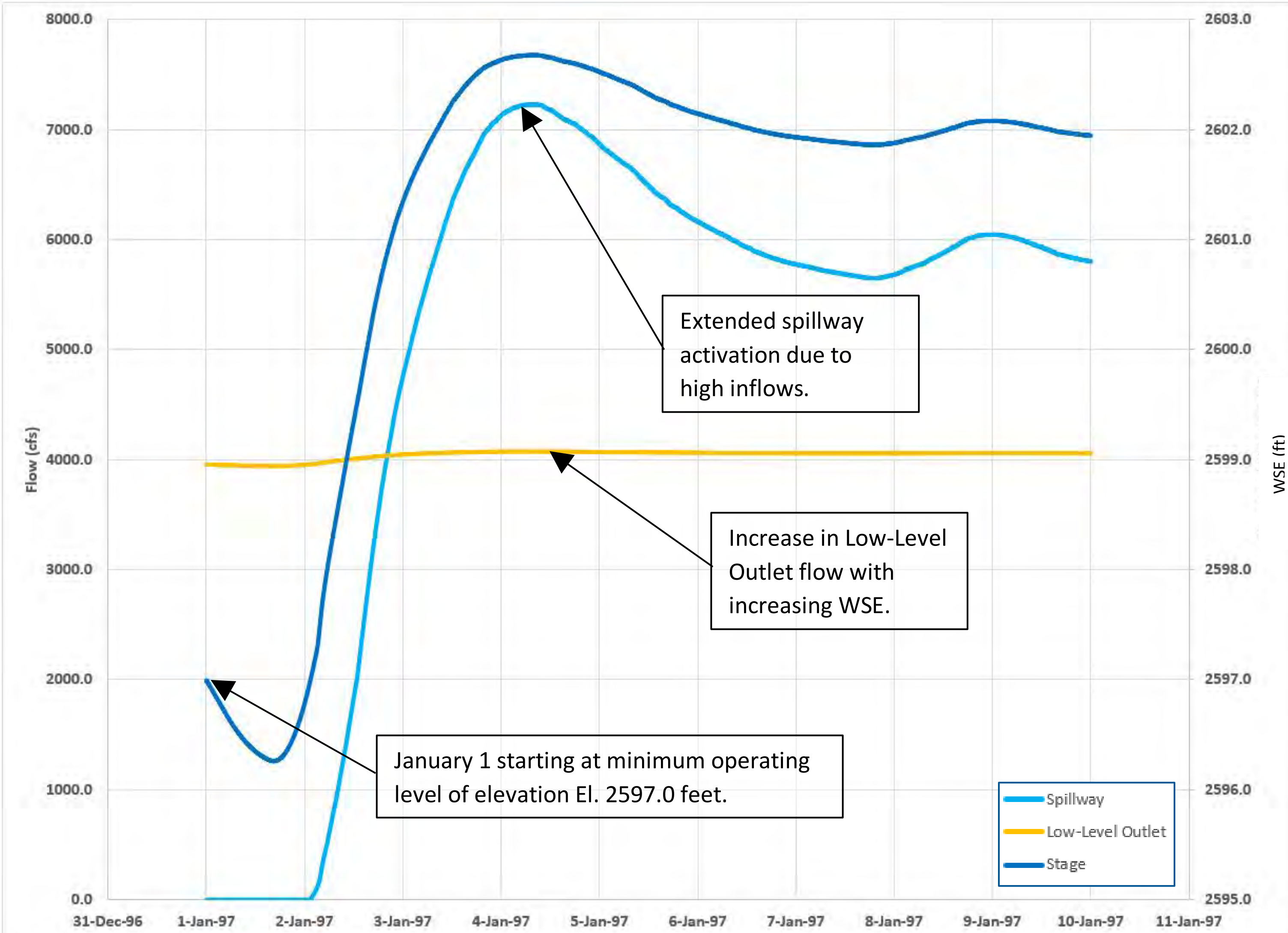


Figure 24. Copco No. 1 Project simulated drawdown and flow for spillway and new low-level outlet for 1997 simulation.

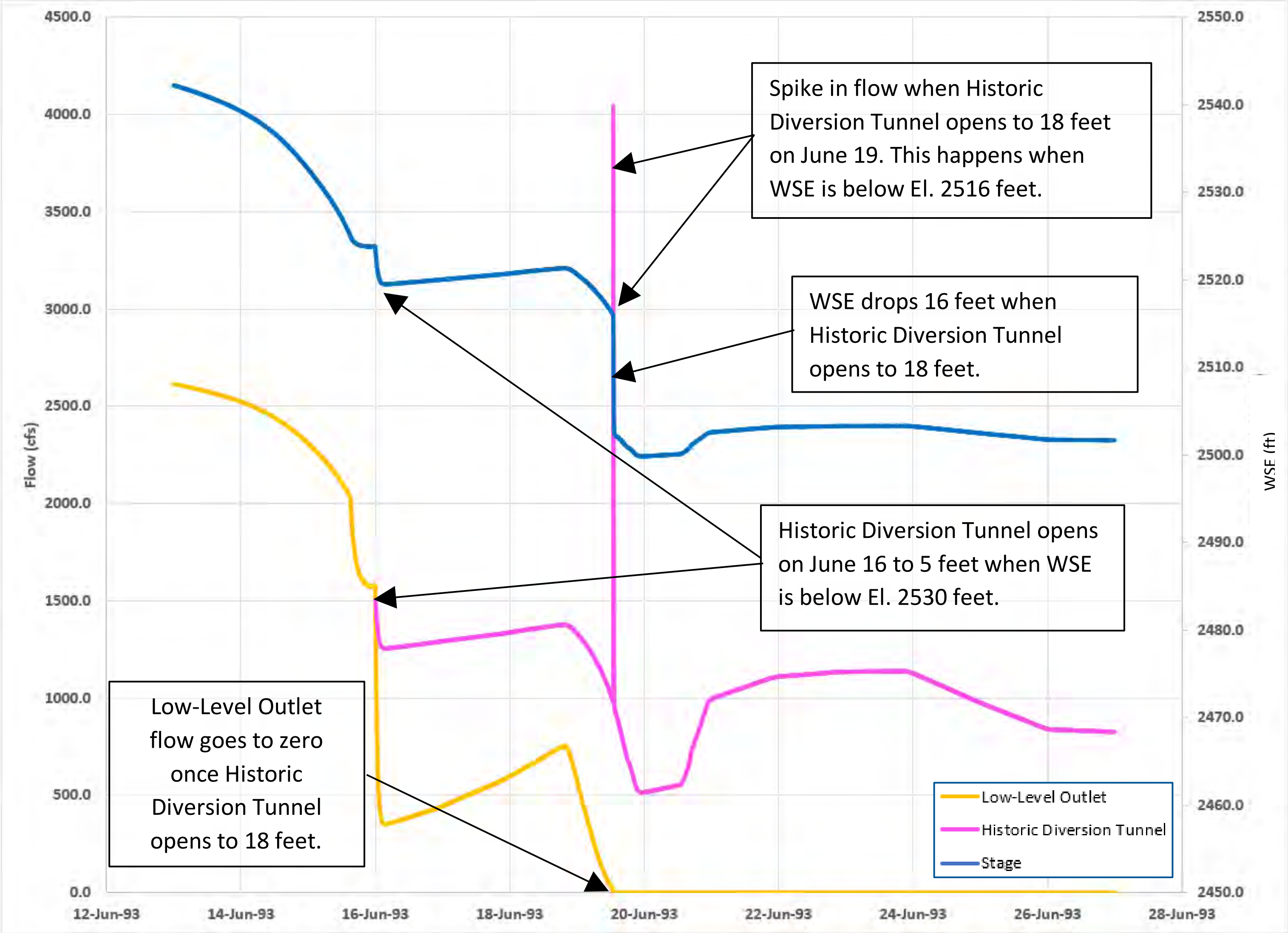


Figure 25. Copco No. 1 Project simulated drawdown and flow for new low-level outlet and HDT for 1993 simulation.

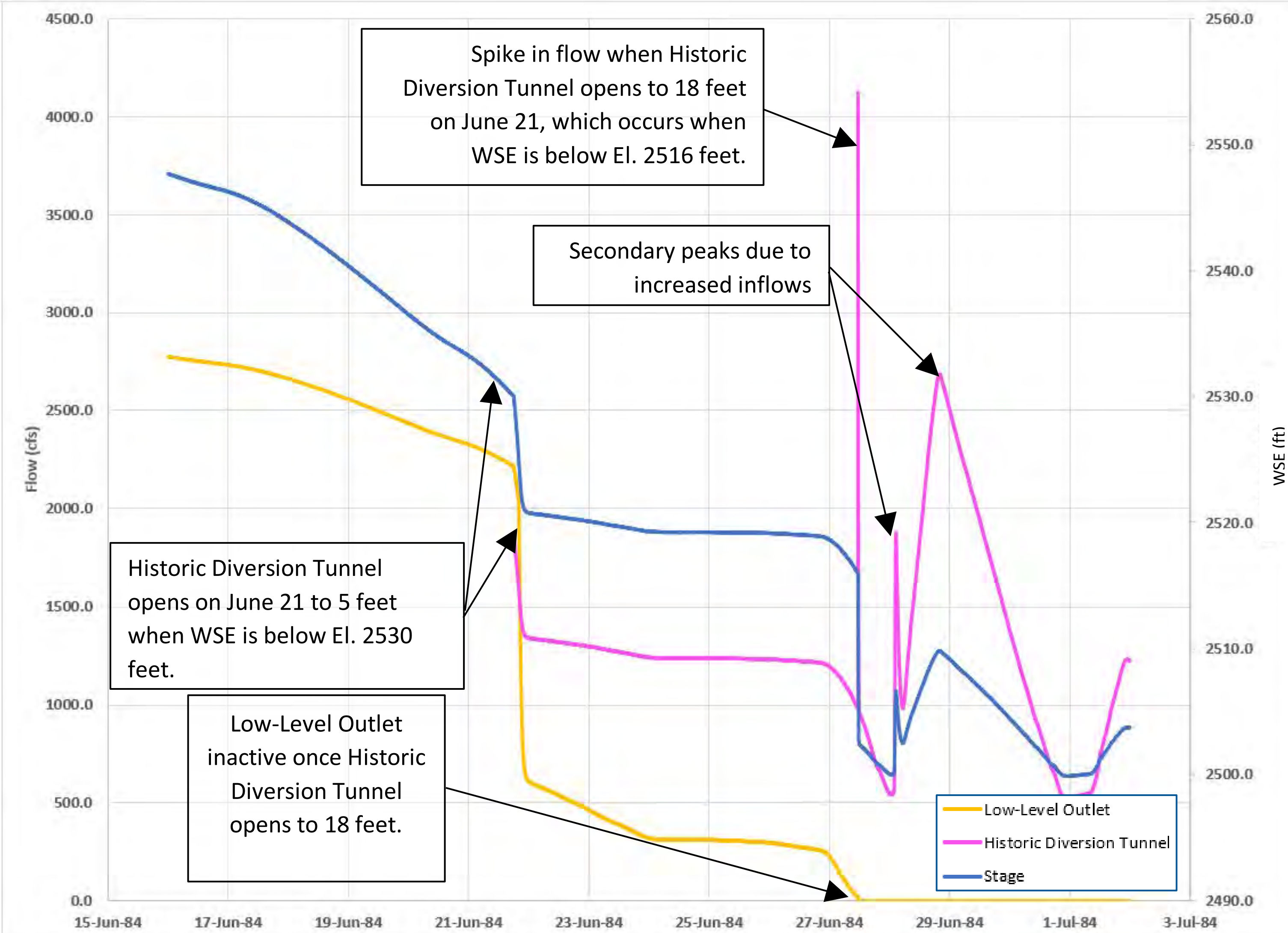


Figure 26. Copco No. 1 Project simulated drawdown and flow for new low-level outlet and HDT for 1984 simulation.

3.3 Copco No. 2

3.3.1 Simulated Drawdown Results

Stage and flow results for the 1997 Copco No. 2 simulation are provided in Figure 27 and Figure 28. The 1997 simulation highlights the connection between Copco No. 1 outflows, and Copco No. 2 inflows. The concrete plug at the spillway of Bay 1 is removed on January 1. No further openings or modifications are made throughout the simulation period at Copco No. 2, thus the outflows and stages in the reservoir are reflections of the rating curves for the remaining spillway gates and the concrete plug removal at Bay 1 only. Since Copco No. 2 functions as run-of-river, the behavior of the Copco No. 2 pond reflects upstream conditions, particularly the conditions at Copco No. 1. Figure 28 provides an example of how strongly correlated the peak flows are between Copco No. 1 and No. 2, typically with minimal attenuation. On June 16, the HDT opens to 5 feet high in Copco No. 1. Approximately 8 minutes later the peak flow reaches Copco No. 2. The HDT opens to 18 feet high at Copco No. 1 four hours after initially opening to 5 feet, and the peak flow reaches Copco No. 2 3 minutes later. The decrease in attenuation between the two peaks can be attributed to increased flow velocities from the rapid opening of the HDT from 5 to 18 feet.

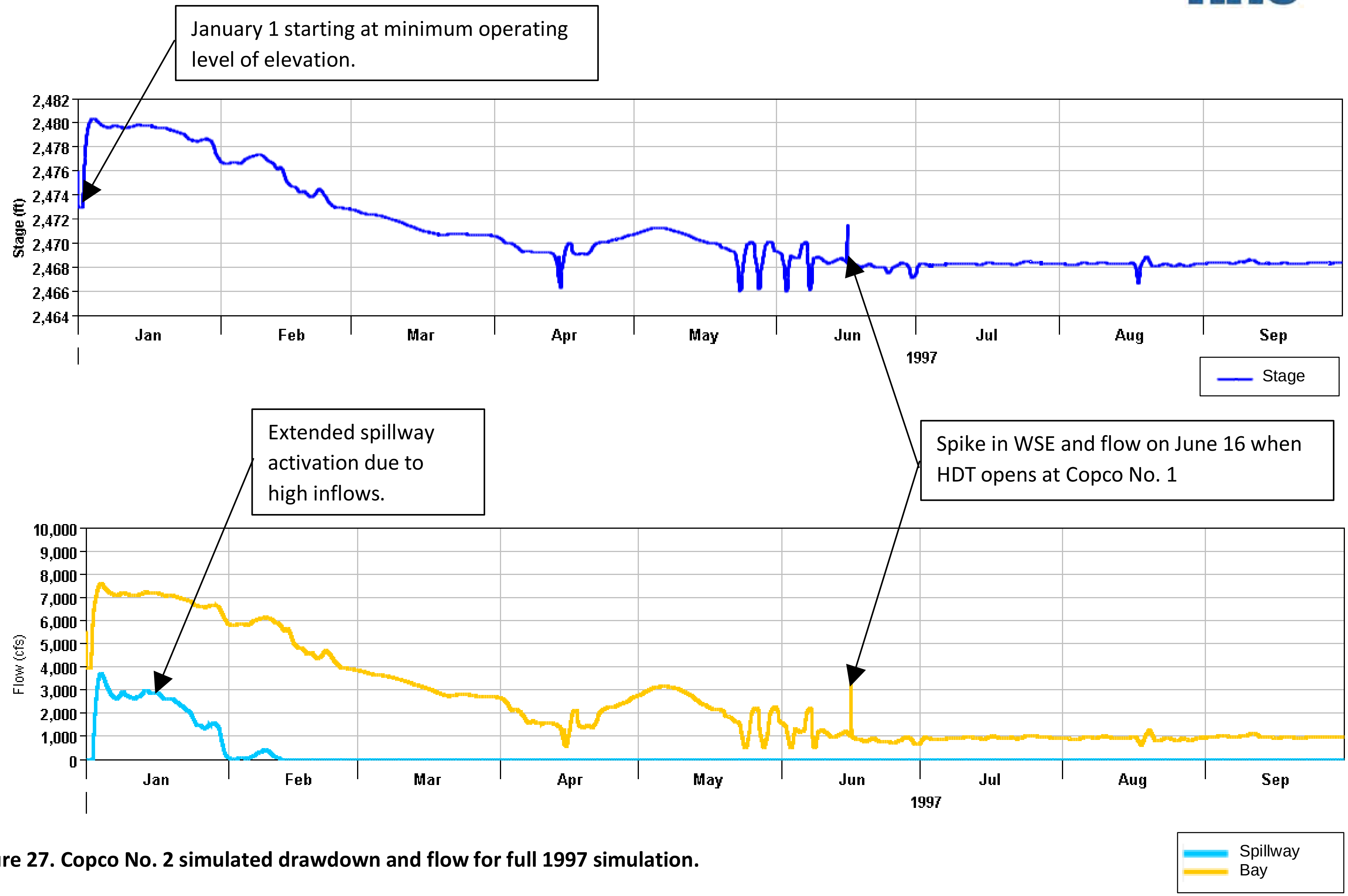


Figure 27. Copco No. 2 simulated drawdown and flow for full 1997 simulation.

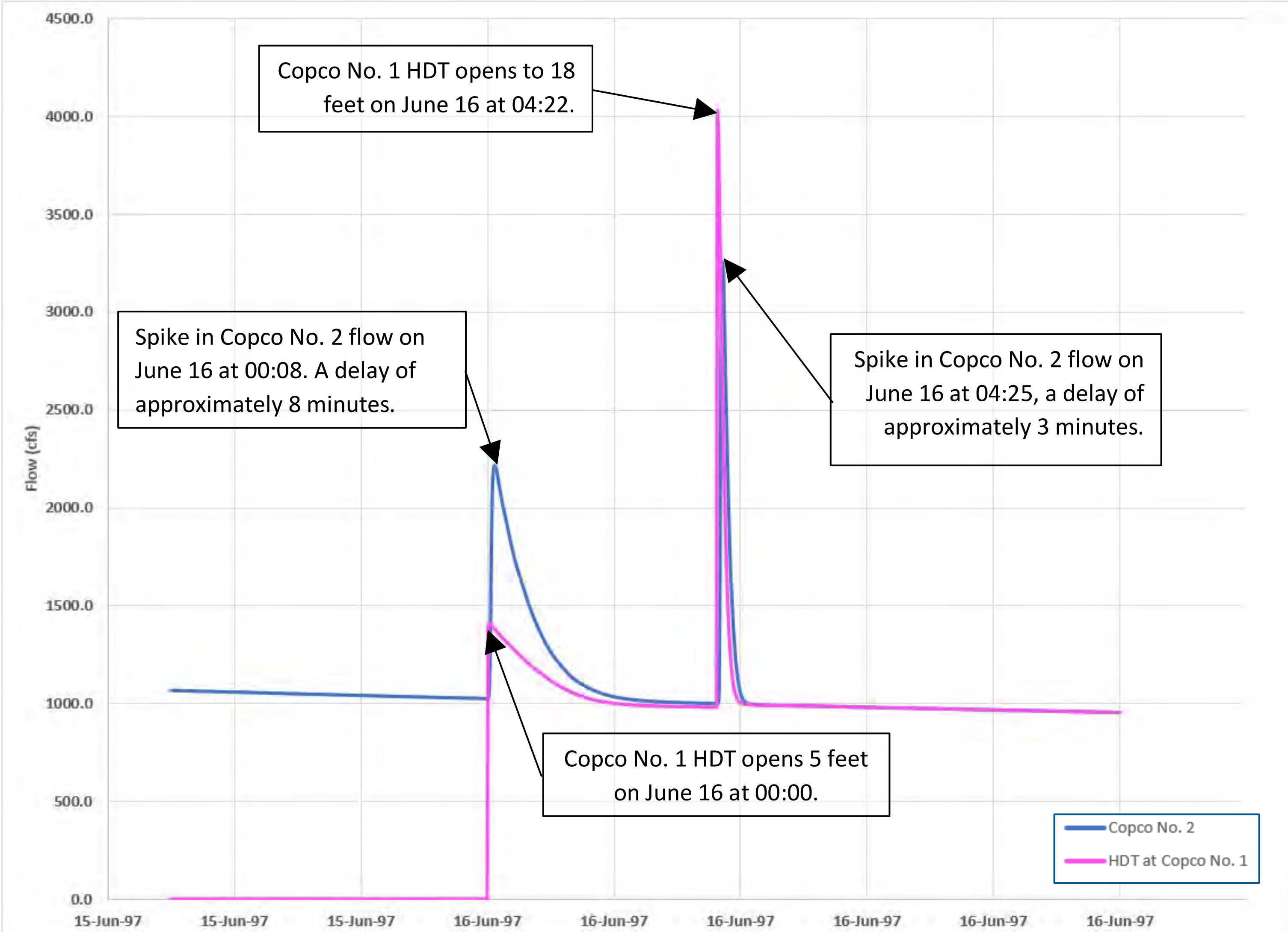


Figure 28. Comparison between Copco No. 1 and No. 2 flows for 1997 simulation.

3.4 Iron Gate

3.4.1 Simulated Drawdown Results

Stage and flow results for selected Iron Gate simulations are provided in Figure 29 through Figure 31. These include the 1997 and 2005 simulations. The 1997 simulation shows extended activation of the bypass valve due to high headwater conditions, and the 2005 simulation provides an example of dramatic stage increases due to spring storm events. Iron Gate is controlled by a spillway, bypass valve, and Historic Diversion Tunnel (HDT).

A stage and flow profile plot for the full 1997 simulation is provided in Figure 29. A finer resolution profile showing the minimum operating levels and initial hydraulic controls is provided in Figure 30. As shown in Figure 29 and Figure 30, the simulation begins at the minimum operating level of El. 2327.3 feet. The bypass valve and HDT are open on January 1 and the gate in the HDT will not be used to regulate flow. Due to high inflows, the bypass valve is utilized until March 17 (Figure 29), when the WSE drops below El. 2305 feet. This is in contrast to the 2005 simulation (Figure 31), where the WSE dropped below the bypass valve invert on January 6.

One notable result in the Iron Gate figures is the significant increase in stage seen in spring due to large inflows from Copco No. 2 and adjacent tributaries, as occurred in 2005 with a stage increase from 2200 to 2300 feet (Figure 31). In general, stage increases were between 40 to 100 feet in the reservoir during these inflows, with the larger increases in the drier years. Outflow from Iron Gate is hydraulically controlled by the regulating gate, which has a capacity of approximately 4000 cfs, providing some attenuation of large inflows within the Iron Gate reservoir. The magnitude of these surges is significant and should be carefully considered when developing plans for nearby work.

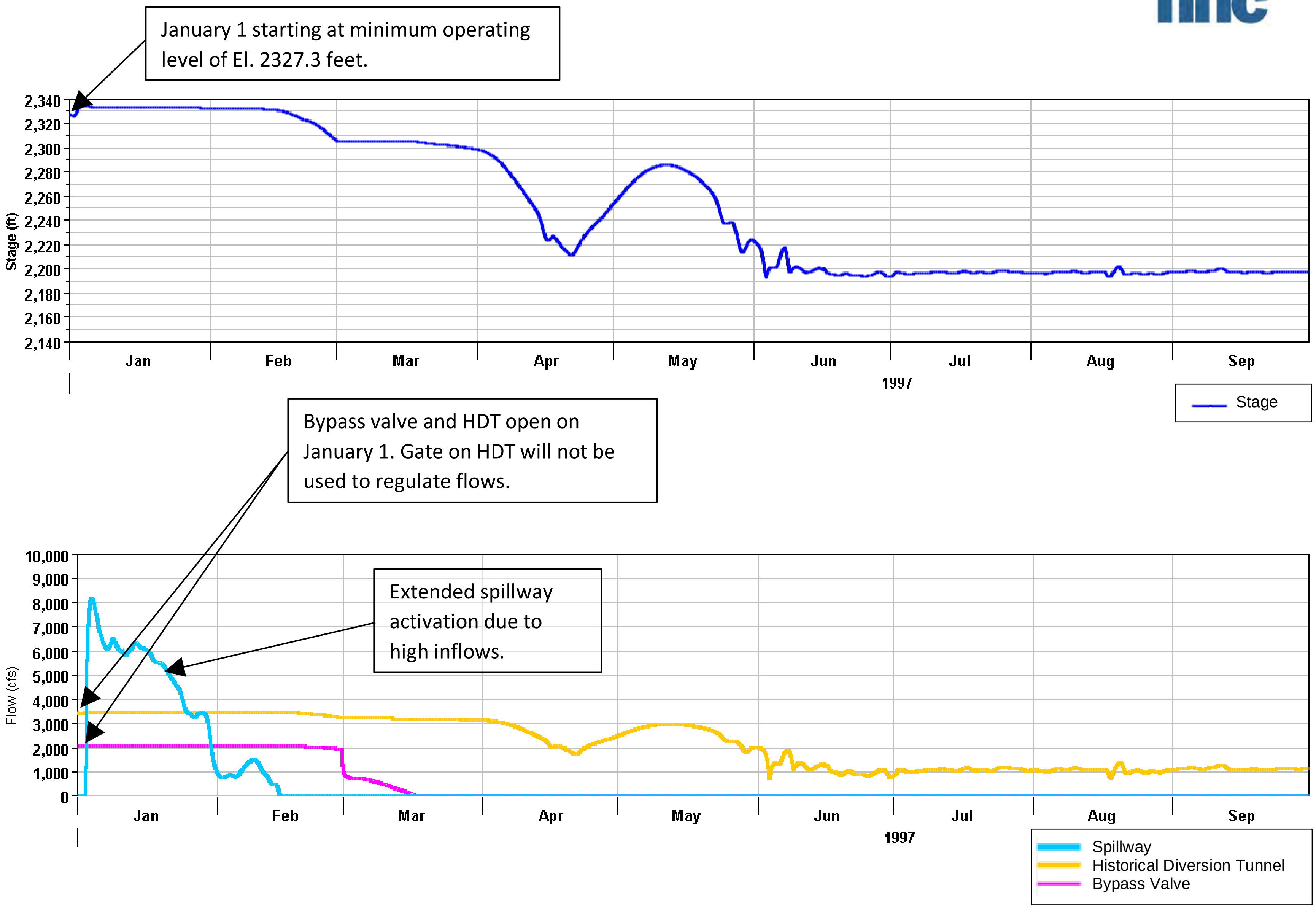


Figure 29. Iron Gate simulated drawdown and flow for full 1997 simulation.

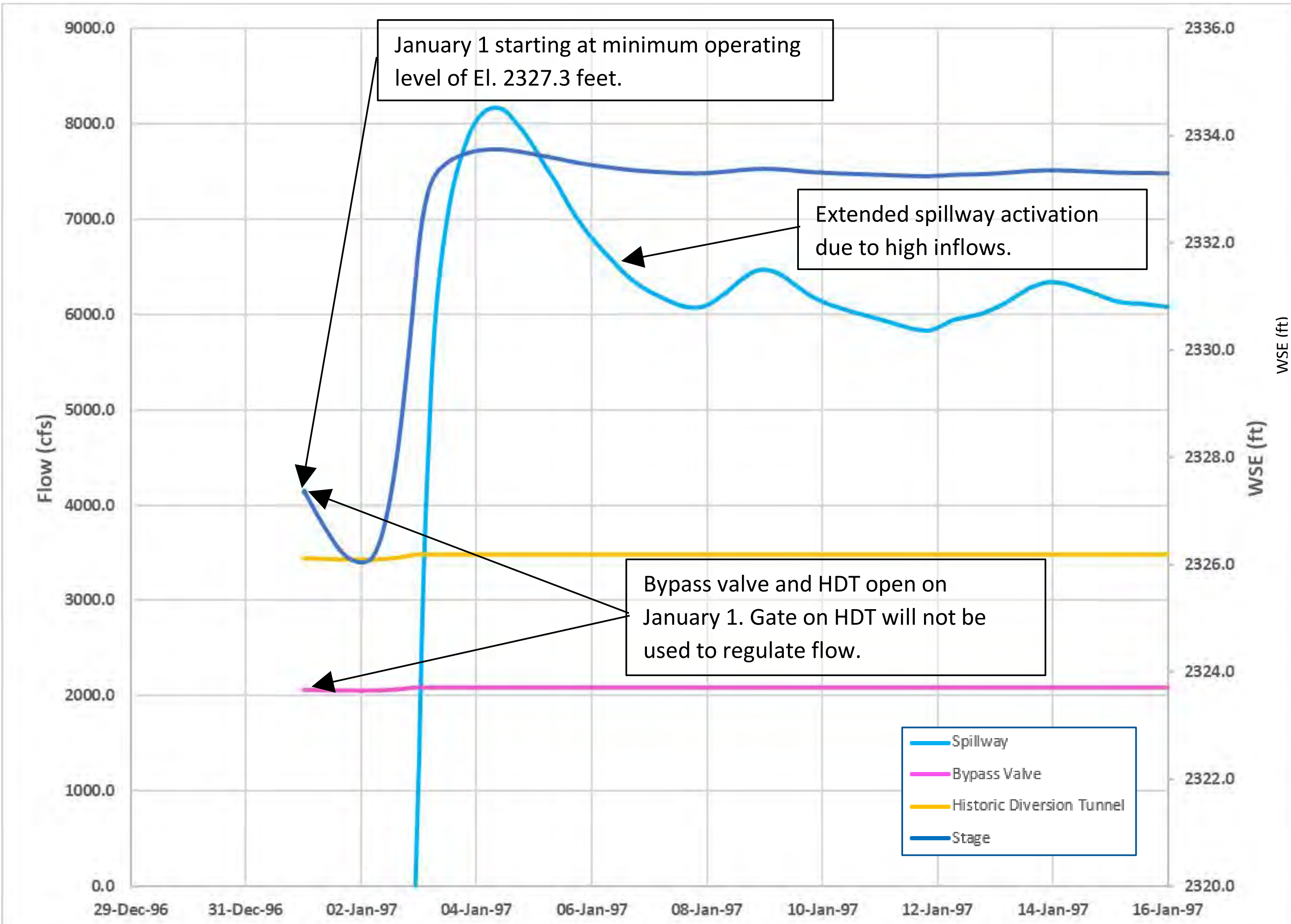


Figure 30. Iron Gate Project simulated drawdown and flow for spillway, HDT, and bypass valve for 1997 simulation.

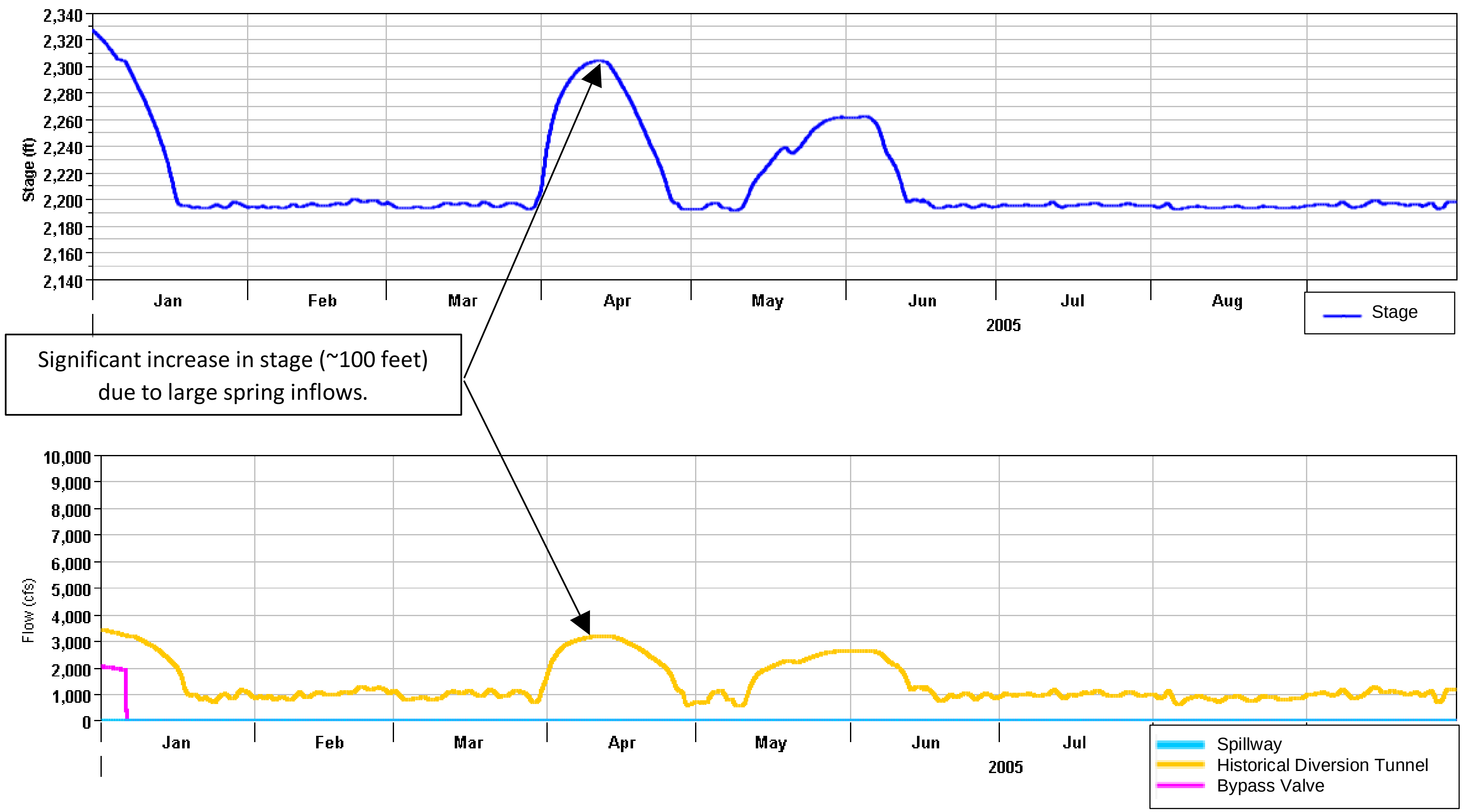


Figure 31. Iron Gate simulated drawdown and flow for full 2005 simulation.

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Appendix A:

Calibration and Sensitivity Analyses for Drawdown Modeling

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NHC Ref. No. 2004947 11.2

18 September 2020

Note to File: Klamath River Renewal Project
NHC Hydraulic Memo – 100% Design, Calibration and Sensitivity Analyses for Drawdown Modeling
Prepared by Kayla Kassa, NHC Junior Engineer, Jeremy Payne, NHC Engineer, and Todd Bennett, NHC Principal

Bullet point notes on calibration and sensitivity analyses as part of the 100% Design work for the reservoir drawdown analyses conducted by NHC:

General:

- USGS, PacifiCorp and Bureau of Land Management (BLM) data used for reservoir inflow, outflow and stage.
- Table 1 presents data sources for the reservoir simulations and riverine rating curve calibrations.
- HEC-RAS model developed by NHC used in the reservoir and riverine simulations.
- HEC-RAS model was for two applications:
    - Riverine calibration – to verify the selected Manning's n.
    - Reservoir routing – to verify model properly represented volumes and timing.

Riverine Calibration/Manning's n:

- USGS measured stage and discharge data used for riverine calibration (i.e., Manning's n values).
- For the riverine calibration, a sensitivity analysis was conducted using a range of Manning's n values and comparing the resulting stage/discharge relationships to measured values at the same location on the river. Manning's n values of 0.07 to 0.05 were simulated (using a uniform value for the entire channel width) as well as lower n values if the model numerical solution remained stable (e.g., the simulation became numerically unstable at n values of 0.04).
- A final n value of 0.05 was selected for the main channel based on representing all three conditions (the banks of estimated low flow river channel based on the 2018 bathymetric data was used to define the break between the main channel and the overbanks in the hydraulic model – see Figure 1). A final n value of 0.06 was selected for the overbanks. This yielded a rating curve that looked very similar to using 0.05 across the entire cross-section.
- In very steep sections of the hydraulic model, the n value was raised, and checked against Jarrett's equation (US Army Corps of Engineers Hydrologic Engineering Center, HEC-RAS River Analysis System Hydraulic Reference Manual Version 5, 2016) which substantiates high n values in steep streams.

Station Name	Data Type	Data Source	Period of Record	Time Step	Data Purpose
11509500 Klamath River at Keno, OR	Measured stage/discharge relationship	USGS	10/13/1970 to 06/09/2020	Sporadic Field Measurements	Comparing measured to simulated riverine stage/discharge relationships
	Discharge	USGS	10/01/1987 to Present	Daily	J.C. Boyle reservoir inflow
Historical Generation and Spillway Flow at J.C. Boyle Dam	Discharge	PacifiCorp	01/01/1979 to 12/31/2016	Daily	J.C. Boyle dam outflow Copco No. 1 reservoir inflow
Historical Reservoir Elevations at J.C. Boyle Dam	Stage	PacifiCorp	11/01/1978 to 12/31/2016	Daily	Comparing observed to simulated JC Boyle reservoir stage
11510700 Klamath River Below John C. Boyle PowerPlant, Near Keno, OR	Measured stage/discharge relationship	USGS	10/13/1970 to 06/10/2020	Sporadic Field Measurements	Comparing measured to simulated riverine stage/discharge relationships
Historical Generation and Spillway Flow at Copco No. 1 Dam	Generating and spillway discharge	PacifiCorp	01/01/1979 to 12/31/2016	Daily	Copco Dam No. 1 outflow Iron Gate reservoir inflow
Historical Reservoir Elevations at Copco Dam	Stage	PacifiCorp	11/01/1978 to 12/31/2016	Daily	Comparing observed to simulated Copco No. 1 reservoir stage
1156500 Jenny Creek, CA	Tributary Inflow	BLM	09/01/1998 to 10/01/2013	15-Minute	Tributary flow into Iron Gate reservoir
Historical Generation and Spillway Flow at Iron Gate Dam	Discharge	PacifiCorp	01/01/1979 to 12/31/2016	Daily	Iron Gate Dam outflow
Historical Reservoir Elevations at Iron Gate Dam	Stage	PacifiCorp	01/01/1979 to 12/31/2016	Daily	Comparing observed to simulated Iron Gate reservoir stage
11516530 Klamath River Below Iron Gate Dam, CA	Measured stage/discharge relationship	USGS	12/8/1960 to 06/01/2020	Sporadic Field Measurements	Comparing measured to simulated riverine stage/discharge relationships

Table 1. Data Sources.

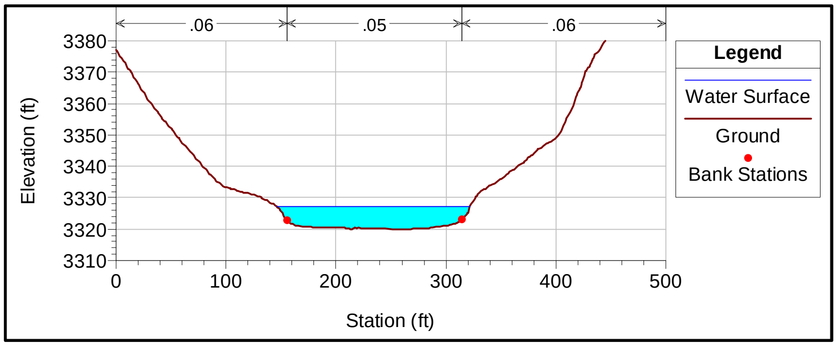

Figure 1. Example Riverine Cross-Section Derived from 2018 Bathymetric Data

Replicating Observed Reservoir Water Stage:

- The HEC-RAS models replicate observed reservoir stage using gaged inflow and outflow, and an estimation for ungaged flows.
- Adding "ungaged flows" in the model (i.e. a water balance calculation) accounts for contributing watershed runoff between the gaged inflow and outflow locations, "ungaged" sources such as groundwater and unreported outflow at the dam, and for potential inaccuracies in the gaged discharge data specified as inflow and outflow in the HEC-RAS model.
- Figure 2 shows an example from J.C. Boyle of reservoir simulations with no ungaged inflow. Using gaged inflow and gaged outflow the simulated reservoir runs dry indicating that additional inflow is needed. The simulation results are similar when ungaged inflows are not added at Copco No. 1 and Iron Gate reservoirs.
- Jenny Creek inflow (from the BLM) was added, in addition to the estimate for ungaged flows, into the Iron Gate reservoir.

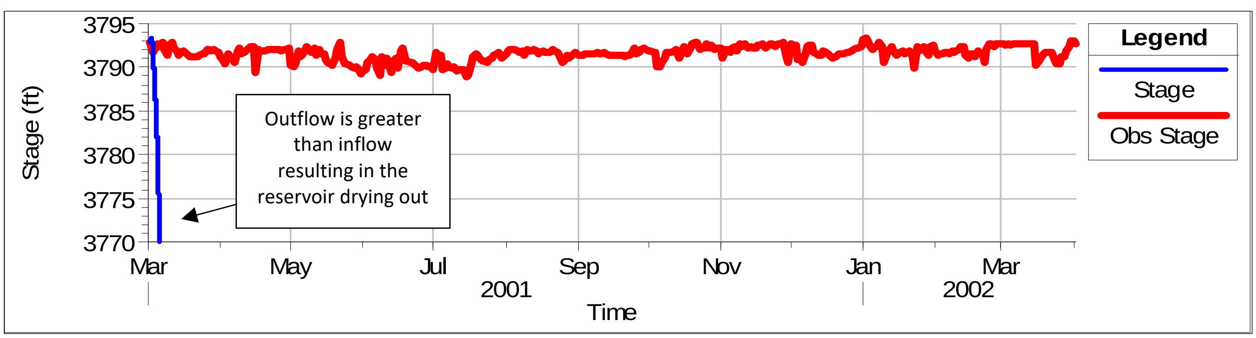

Figure 2. J.C. Boyle Reservoir Simulation Replicating Observed Stage Simulation Assuming No Estimated Ungaged Inflow

Results:

- The simulated to observed values were compared using the Root Mean Square Error (RMSE) method (Table 2 and Table 3). This method measures the differences between values predicted by a model and the values observed. The lower the value, the better performance of the model. The simulations replicating observed reservoir water stage have a RMSE less than 0.3 feet for all three reservoirs. For the simulations replicating the observed riverine condition, the closest to the USGS data uses a Manning's n equal to 0.05 in the channel and 0.06 in the overbanks for all three USGS gaging sites (RMSE less than 0.7 feet for rating curve values).
- Results of the reservoir simulations compared to observed stage, with added ungagged flows, for an example yearlong period are shown in Figure 3, Figure 4, and Figure 5.
- These results show the simulated reservoir stage matches the observed reservoir stage at all three reservoirs for the example year long period within a typical operating range. Given that this required extensive labor effort, and as much of the drawdown simulations for the 100% Design are at lower reservoir elevations, this was deemed a sufficient period for checking model results.
- Figure 6 shows the computed ungaged inflows for the three reservoirs compared to Jenny Creek. The drainage area for these areas are very roughly comparable to Jenny Creek and thus the magnitude of these flows, as expected, are roughly equivalent. For comparison, this figure also shows Klamath River at Keno gaged flow (these are the data used in simulation for gaged, riverine flow into the J.C. Boyle Reservoir) which is larger than the estimated ungaged inflows.
- In conducting this analysis, and evaluating gaged inflows, inconsistencies were noted in the recorded data, such as the reported daily outflow from a dam being greater than the reported outflow at a USGS gage immediately downstream, or changes in recorded reservoir stage not being consistent with changes in reservoir storage (e.g. stage increases but the net reservoir outflow decreases). These discrepancies required using negative ungaged inflow values in some cases (Figure 6).
- Figure 7, Figure 8, and Figure 9 show the results of the riverine simulations for a range of Manning's n values comparing simulated to measured stage/discharge relationships at three USGS station locations.
- Deviations between simulated and observed rating curves are the greatest at the lowest flows. To help explain why, approximate comparisons were made between the LiDAR and USGS measured values of channel width and area at the J.C. Boyle below Powerhouse USGS station. This showed the greatest difference in channel dimensions at the lowest elevations (in some cases the LiDAR data having roughly half the area but twice the width). This indicates poor representation of the channel by the LiDAR data at the lowest stage is limiting the ability to replicate observed water surface elevations at shallow depths (cross-section surveys throughout the entire study area would likely be necessary to ensure the bottom of the channel is accurately represented and improve calibration during the lowest flow).
- Figure 10 shows a time series example of simulated versus observed stage at USGS Station 11510700 upstream of the Copco No. 1 Reservoir for a range of flows

- Additional simulations have been conducted to evaluate different Manning's n values as well as other model parameters. These tests included:
    - Removing the dams and testing the sensitivity of travel time, attenuation and stage to varying n (in 0.01 increments from 0.04 to 0.07) – to see how the Manning's n values affects simulation results during the drawdown condition.
    - Through the riverine portion only (with dams in place) testing sensitivity of travel time, attenuation and stage to varying n (0.01 increments from 0.04 to 0.07).
    - Through the reservoir portion only (with dams in place) testing sensitivity of travel time, attenuation and stage to varying n (n values of 0.03, 0.05 and 0.07).
    - Varying the computational timestep (5, 15, 30 and 60 second timesteps).
    - Varying reservoir volume by +/- 10%.
- Sensitivity tests did not show any significant change in simulated stage, travel times or attenuation. These sensitivity tests were conducted for both high and low flows conditions.

Table 2. Root Mean Square Error for Differences in Simulated and Gaged Reservoir Stage

Station Name	RMSE (feet)
Historical Reservoir Elevations at J.C. Boyle Dam	0.20
Historical Reservoir Elevations at Copco No. 1 Dam	0.16
Historical Reservoir Elevations at Iron Gate Dam	0.18

Table 3. Root Mean Square Error, for Differences in Riverine Stage-Discharge Curves, Between USGS Field Measured and Simulated Data Using a Range of Manning's n Values

Station Name	RMSE (feet)			
	Manning's n = 0.05	Manning's n = 0.05/ 0.06	Manning's n = 0.06	Manning's n = 0.07
11509500 Klamath River at Keno, OR	0.72	0.65	0.87	1.08
11510700 Klamath River Below John C. Boyle PowerPlant, Near Keno, OR	0.35	0.35	0.41	0.57
11516530 Klamath River Below Iron Gate Dam, CA	0.40	0.40	0.51	0.83

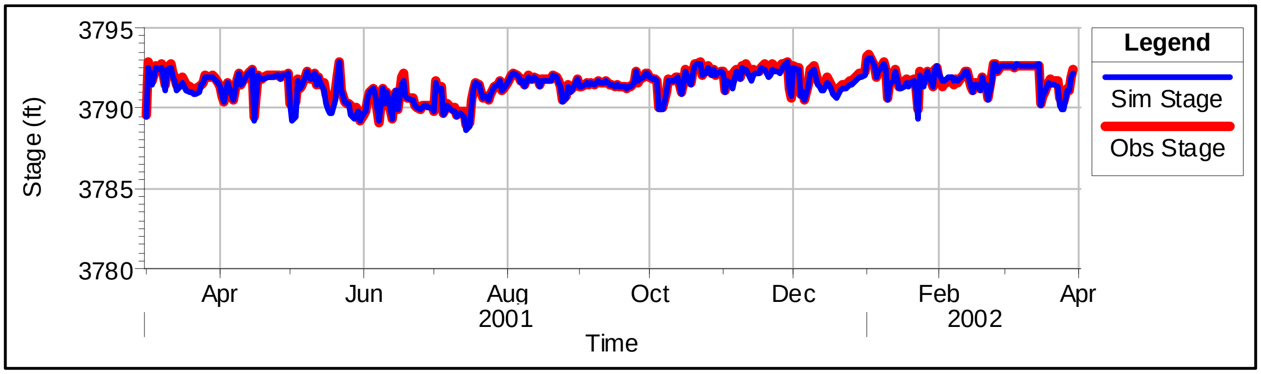

Figure 3. J.C. Boyle Reservoir Simulation Replicating Observed Stage with Estimated Ungaged Flow

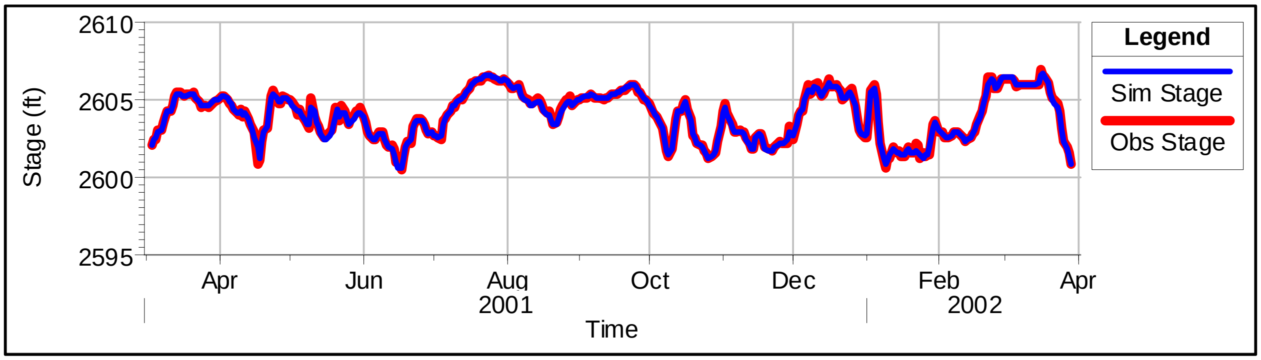

Figure 4. Copco No. 1 Reservoir Simulation Replicating Observed Stage with Estimated Ungaged Flow

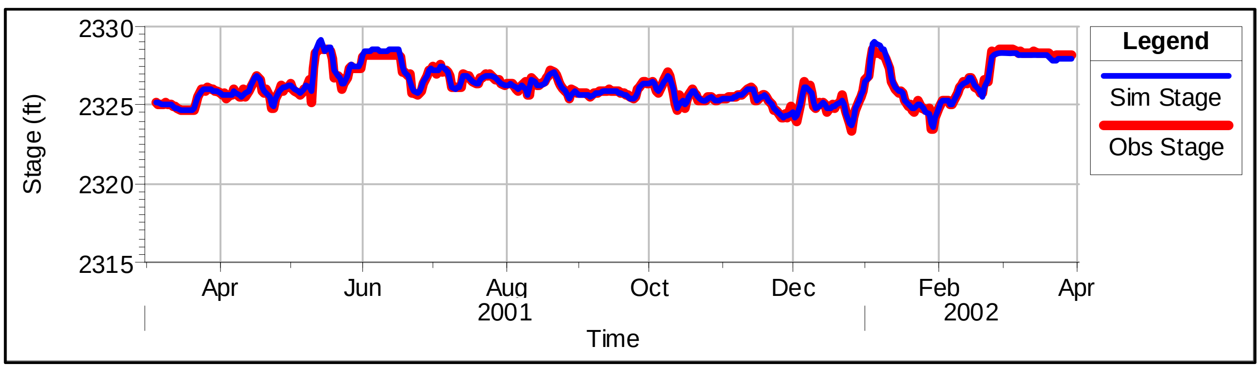

Figure 5. Iron Gate Reservoir Simulation Replicating Observed Stage with Estimated Ungaged Flow

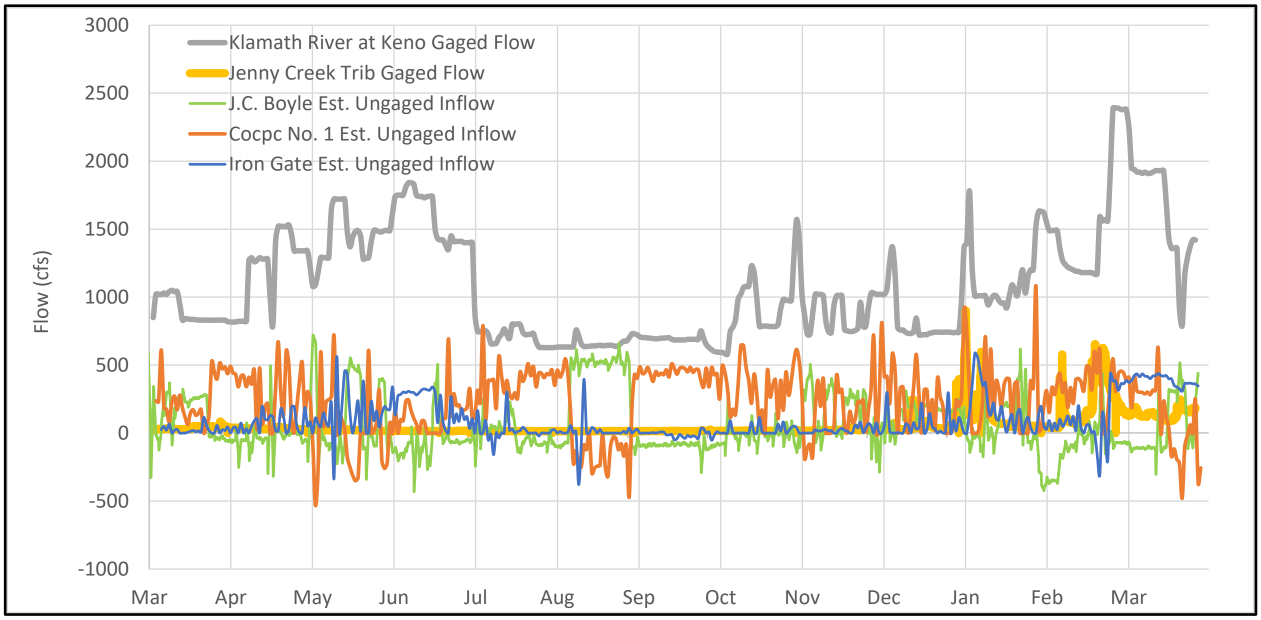

Figure 6. Estimated Ungaged Inflow for J.C. Boyle, Copco No. 1 and Iron Gate Reservoirs Compared to Jenny Creek and Klamath River at Keno Gaged Flows.

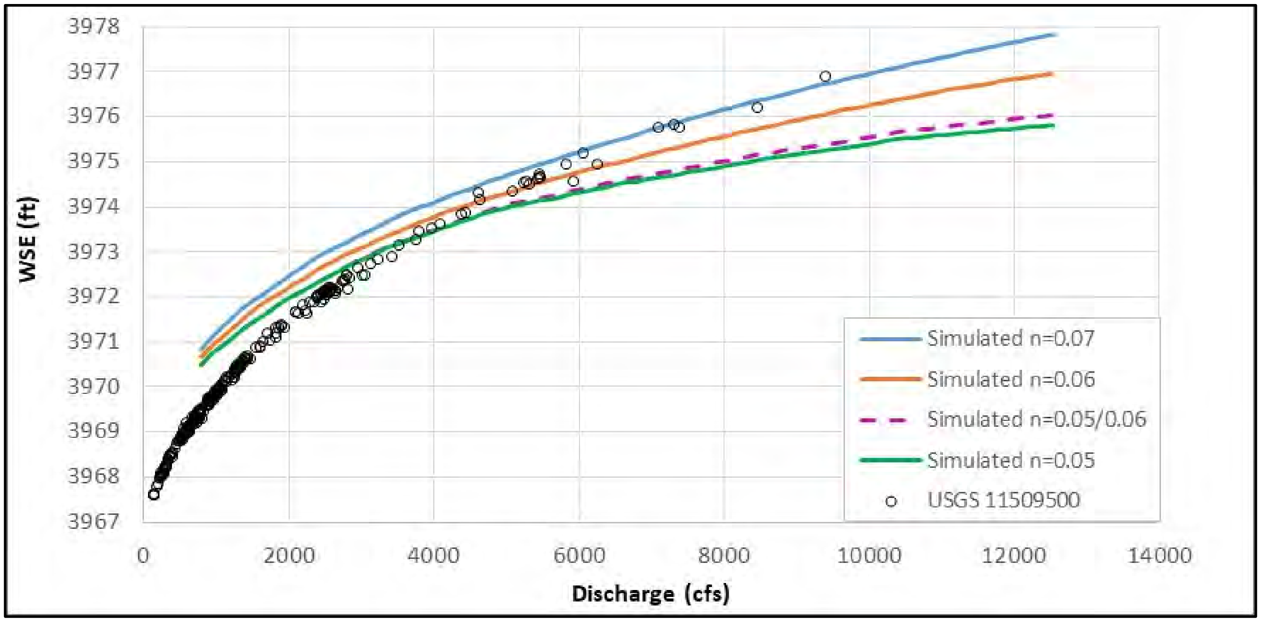

Figure 7. Simulated Stage Discharge Curves for a Range of Manning's n Values Compared to Measured Values at a USGS Station 11509500 Upstream of the J.C. Boyle Reservoir

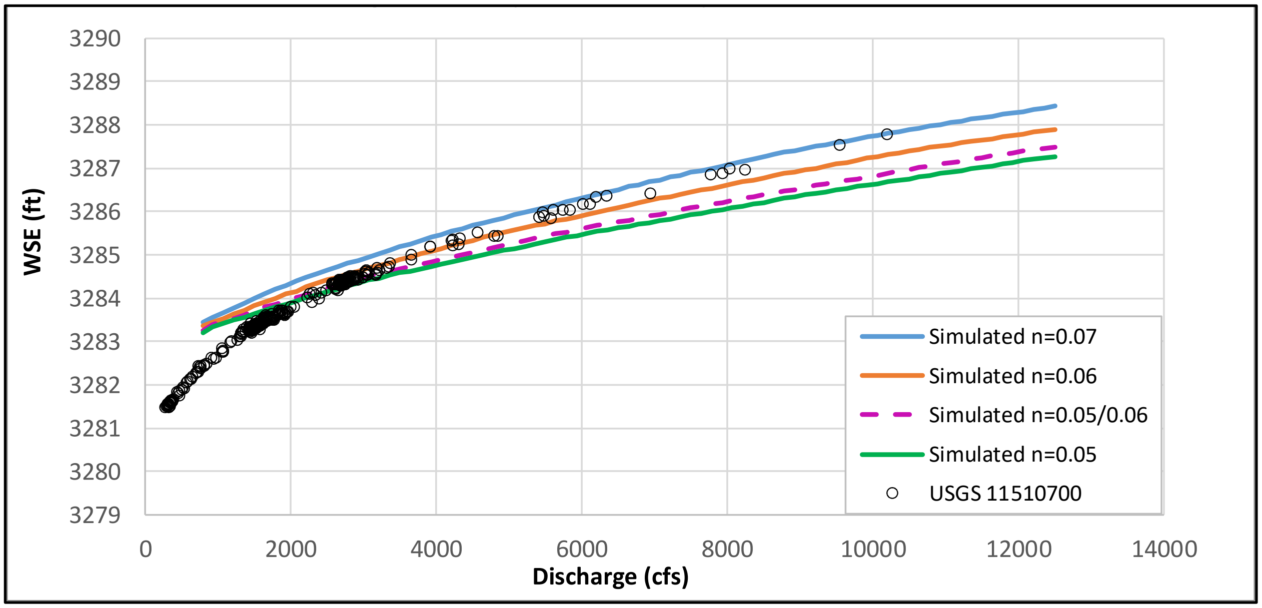

Figure 8. Simulated Stage Discharge Curves for a Range of Manning's n Values Compared to Measured Values at a USGS Station 11510700 Upstream of the Copco No. 1 Reservoir

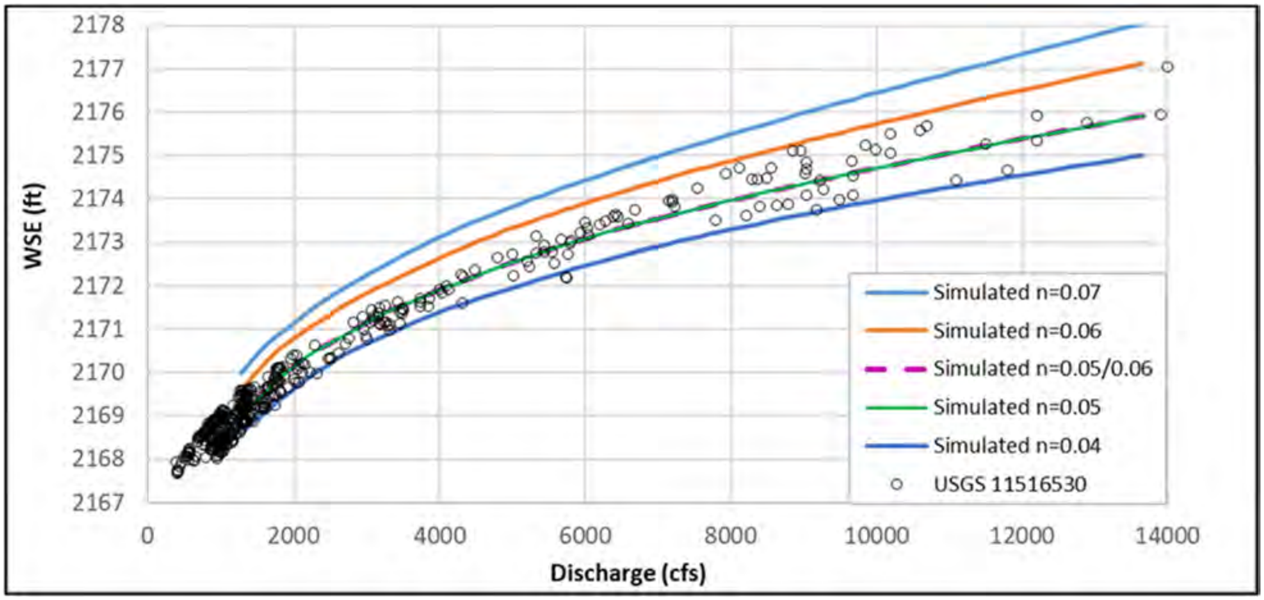

Figure 9. Simulated Stage Discharge Curves for a Range of Manning's n Values Compared to Measured Values at a USGS Station 11516530 Downstream of the Iron Gate Reservoir

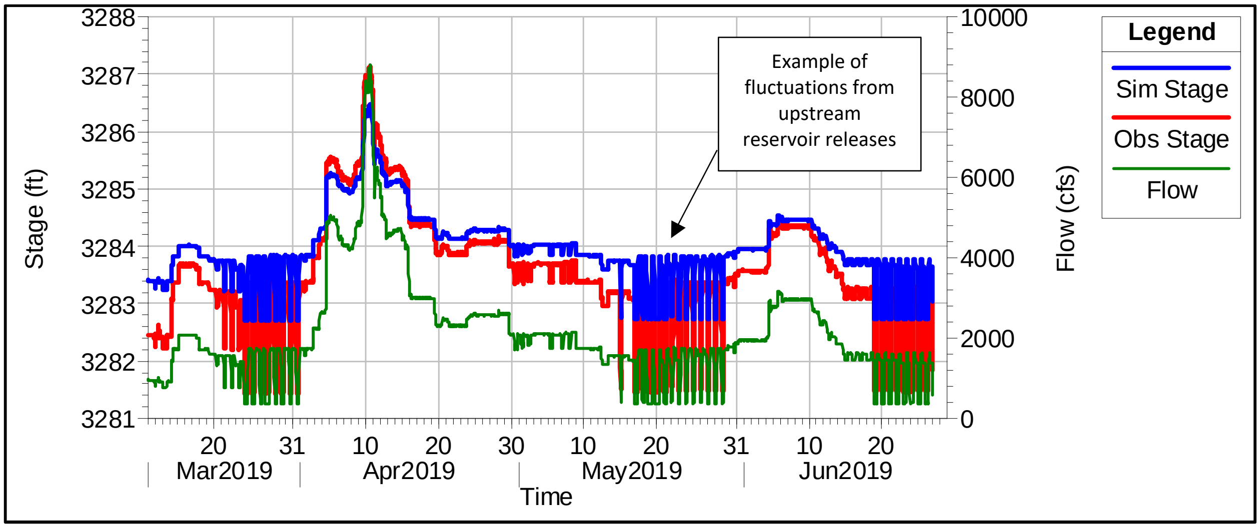

Figure 10. Simulated and Observed Stage for a Range of Flows at a USGS Station 11510700 Upstream of the Copco No. 1 Reservoir

Appendix B:

Drawdown Plots for J.C. Boyle Reservoir

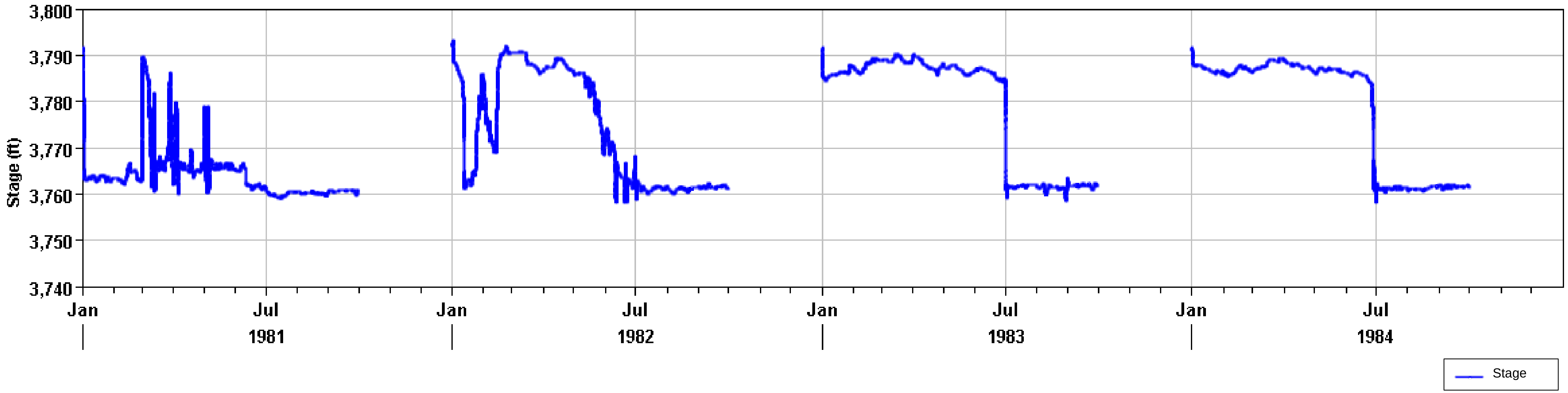

Figure 1: J.C. Boyle Drawdown Stage for years 1981 through 1984

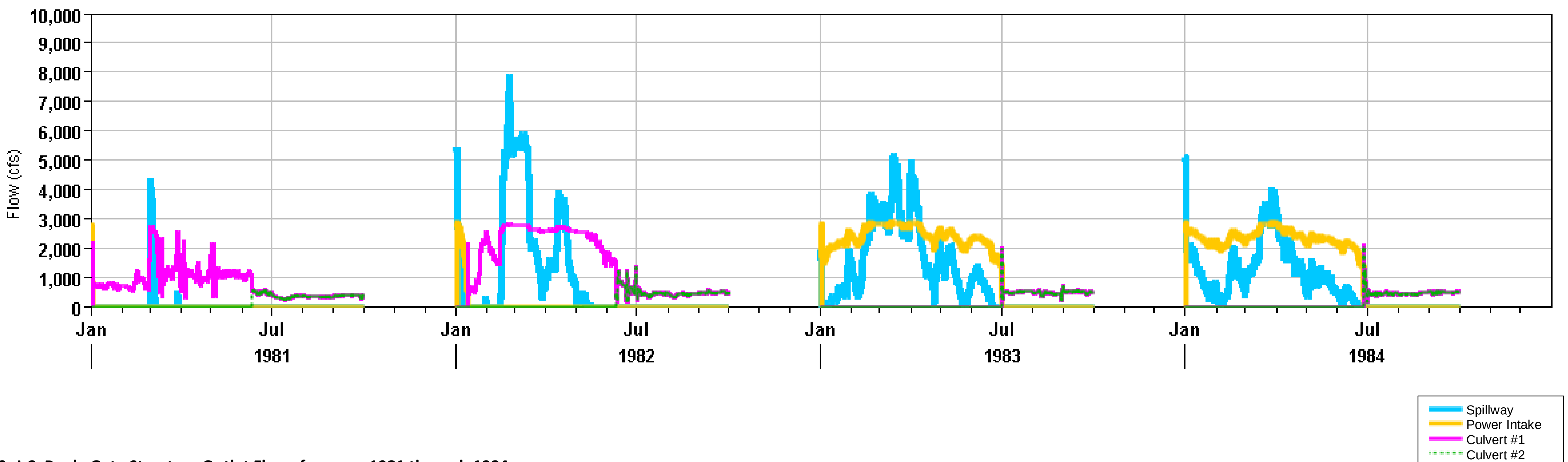

Figure 2: J.C. Boyle Gate Structure Outlet Flows for years 1981 through 1984

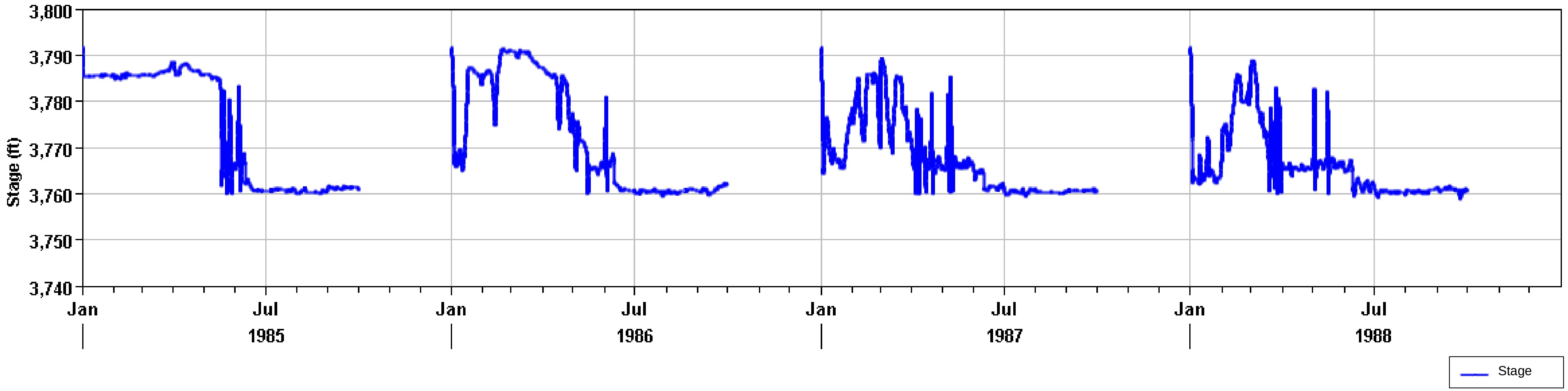

Figure 3: J.C. Boyle Drawdown Stage for years 1985 through 1988

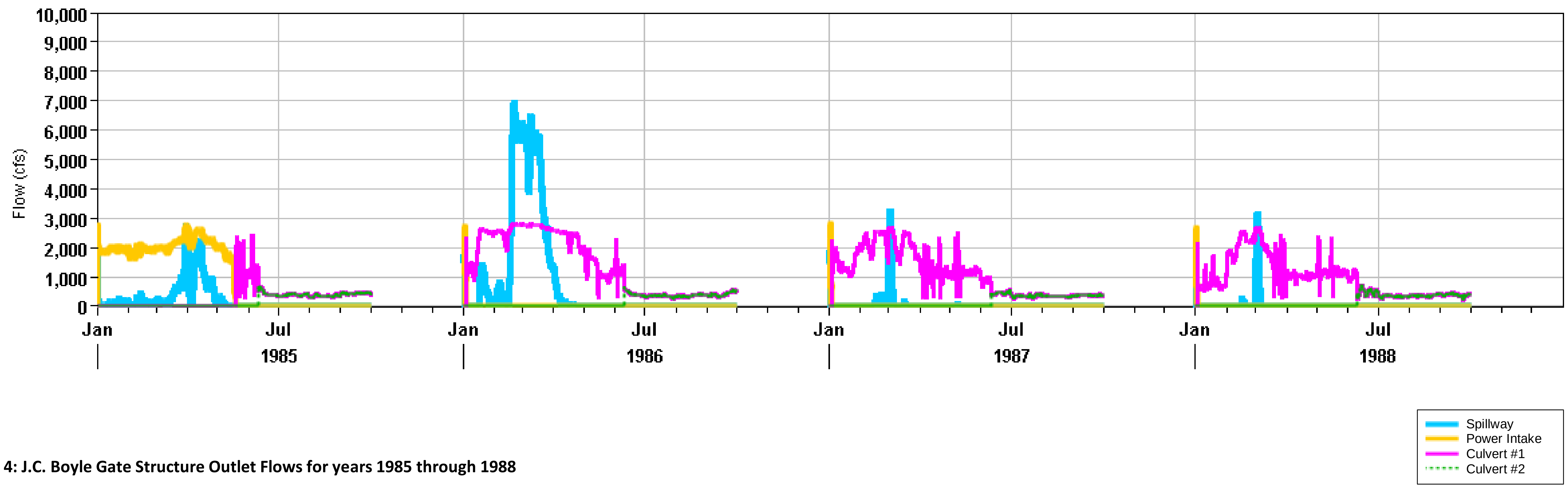

Figure 4: J.C. Boyle Gate Structure Outlet Flows for years 1985 through 1988

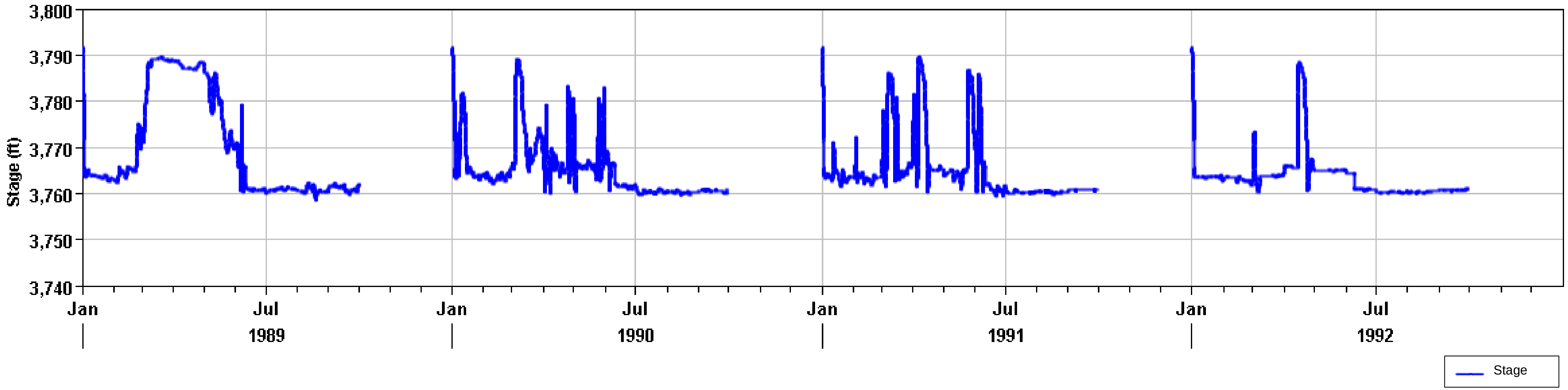

Figure 5: J.C. Boyle Drawdown Stage for years 1989 through 1992

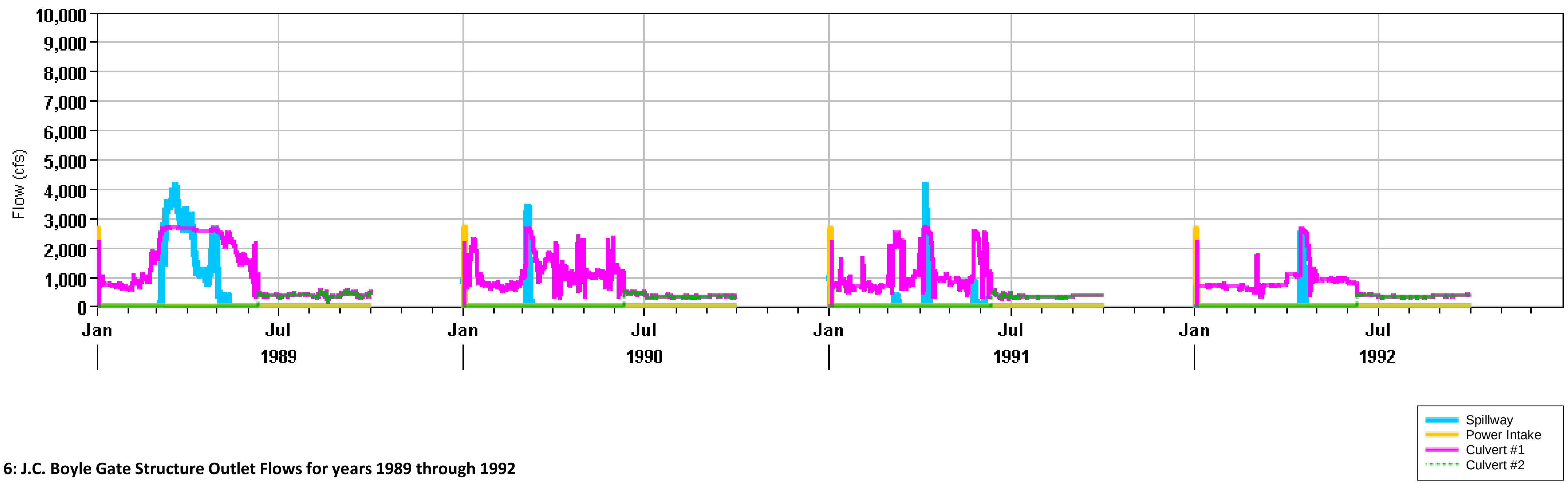

Figure 6: J.C. Boyle Gate Structure Outlet Flows for years 1989 through 1992

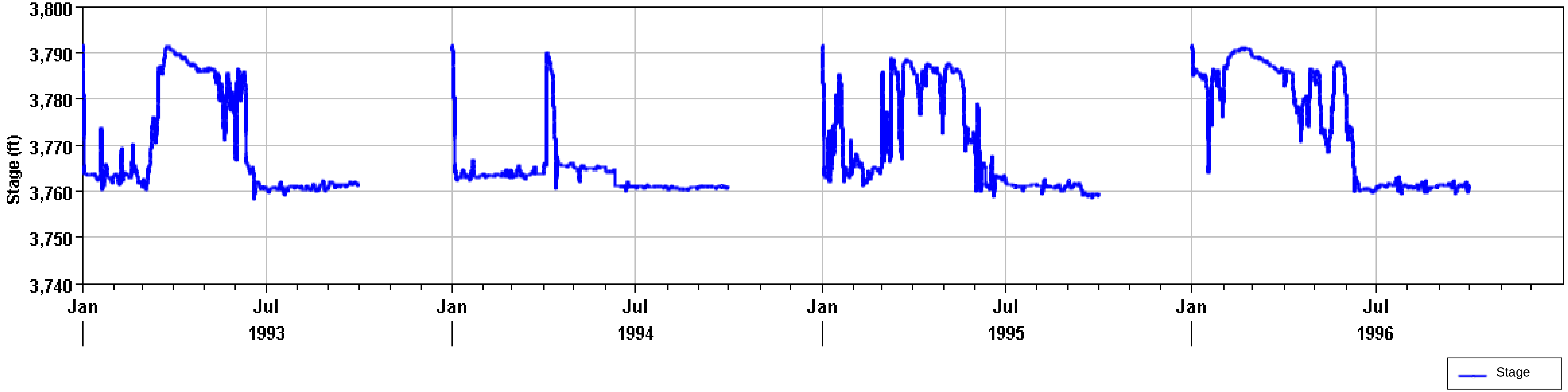

Figure 7: J.C. Boyle Drawdown Stage for years 1993 through 1996

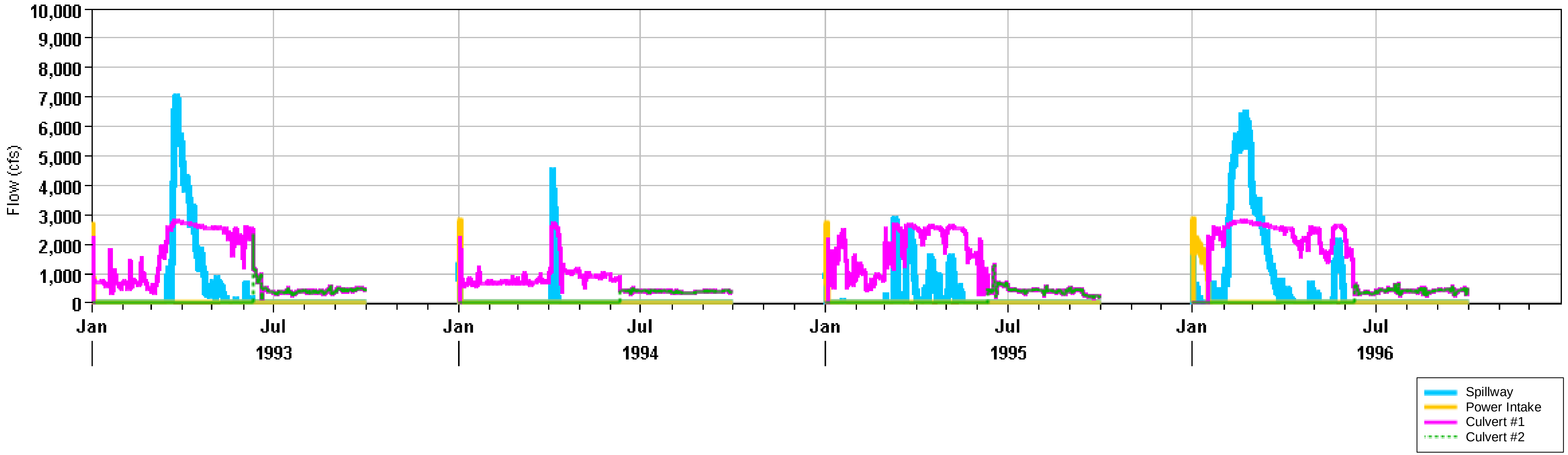

Figure 8: J.C. Boyle Gate Structure Outlet Flows for years 1993 through 1996

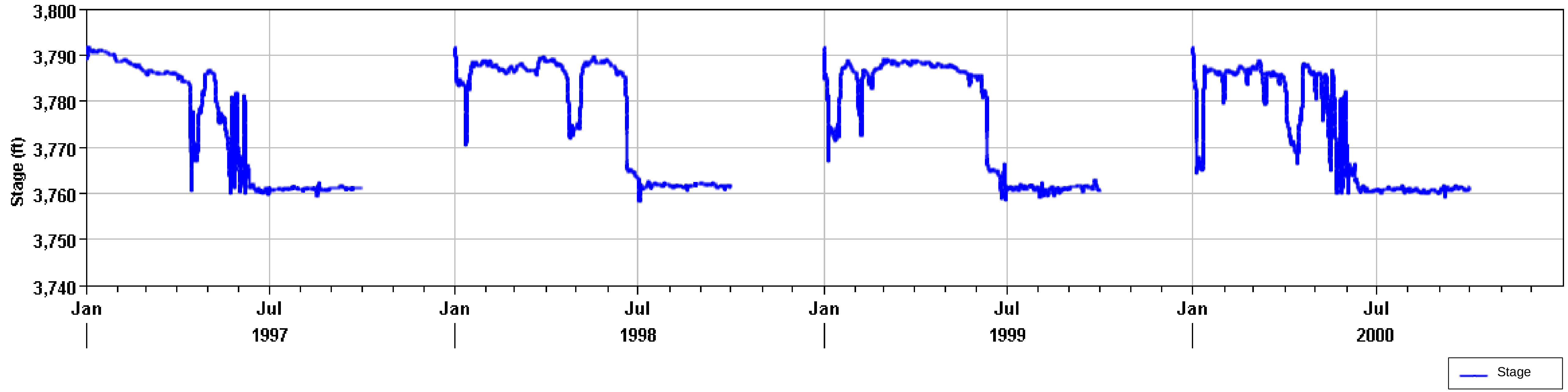

Figure 9: J.C. Boyle Drawdown Stage for years 1997 through 2000

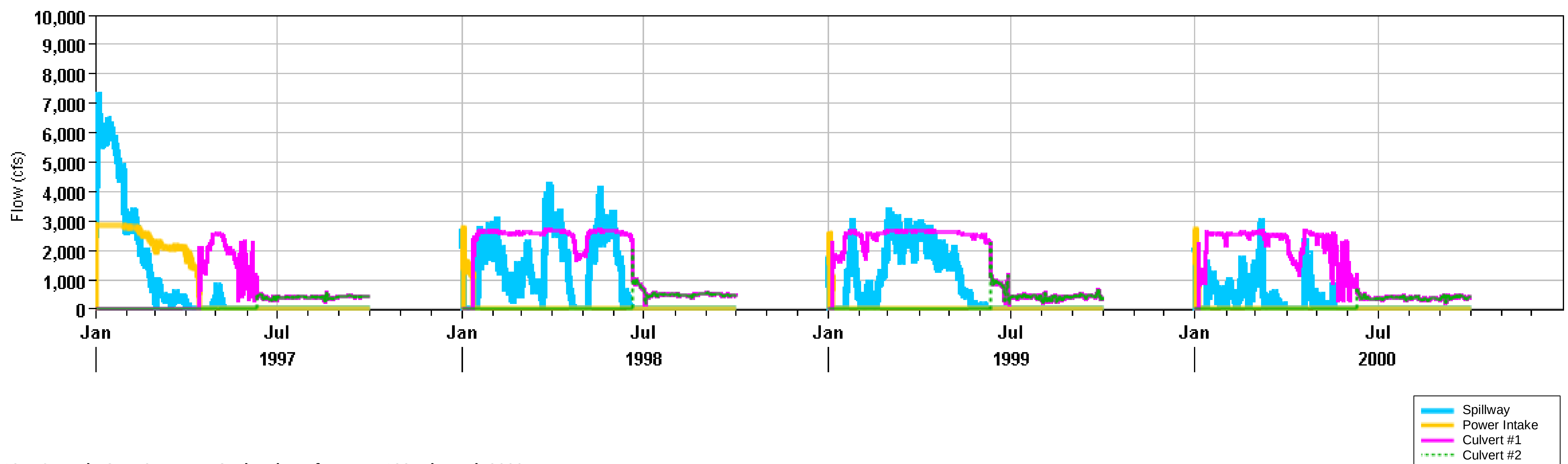

Figure 10: J.C. Boyle Gate Structure Outlet Flows for years 1997 through 2000

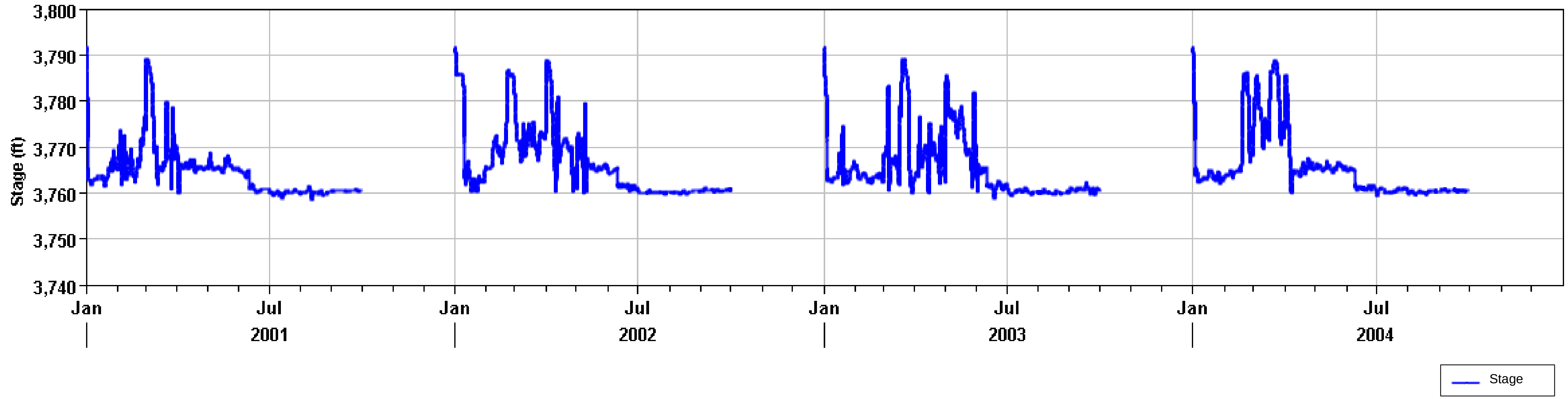

Figure 11: J.C. Boyle Drawdown Stage for years 2001 through 2004

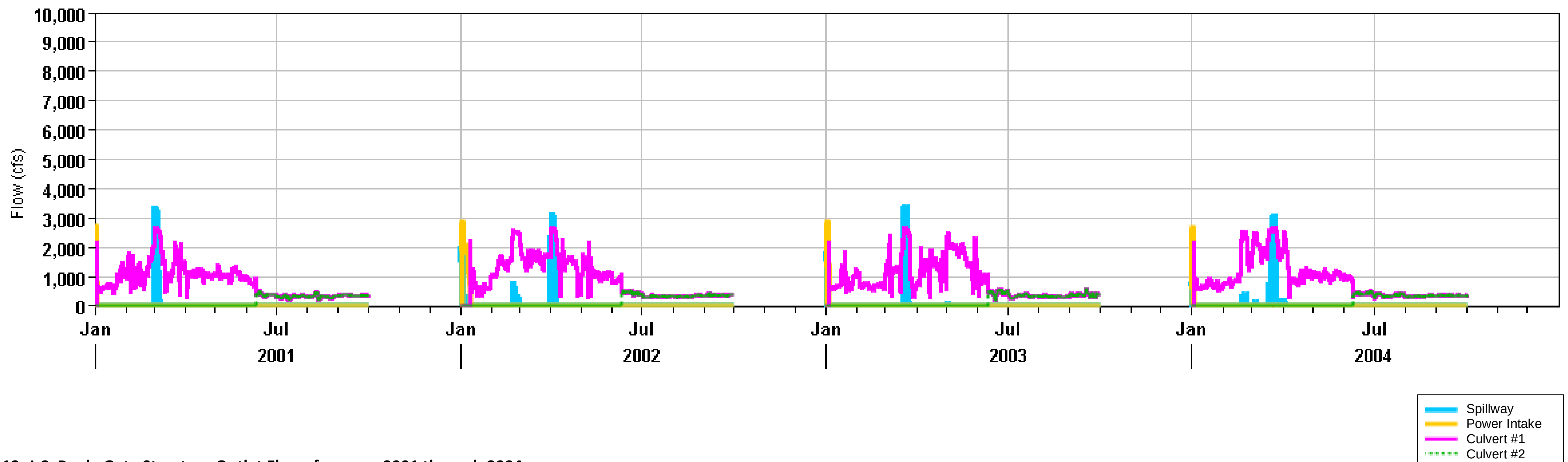

Figure 12: J.C. Boyle Gate Structure Outlet Flows for years 2001 through 2004

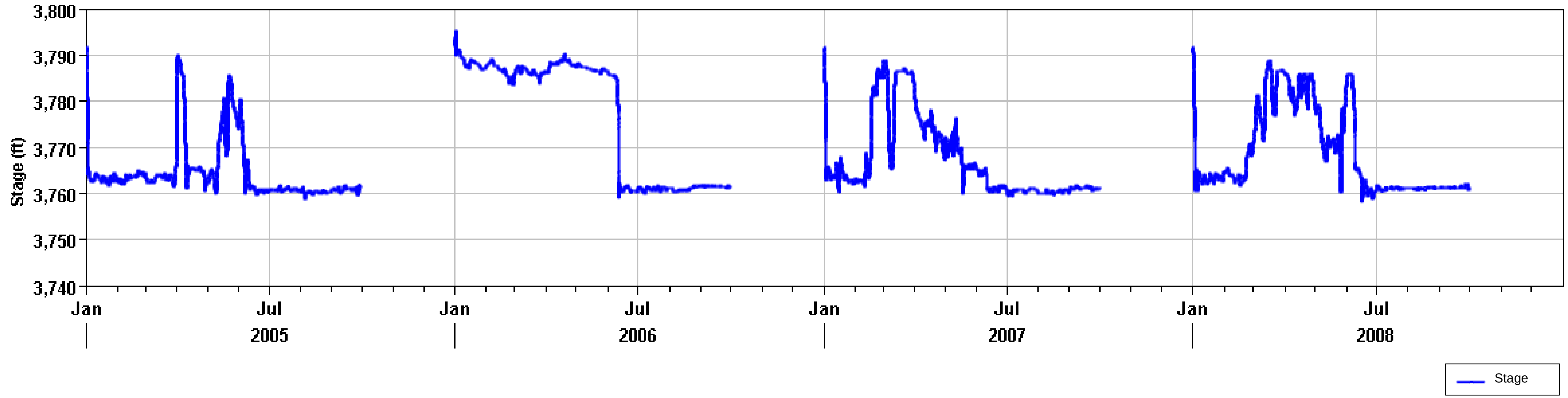

Figure 13: J.C. Boyle Drawdown Stage for years 2005 through 2008

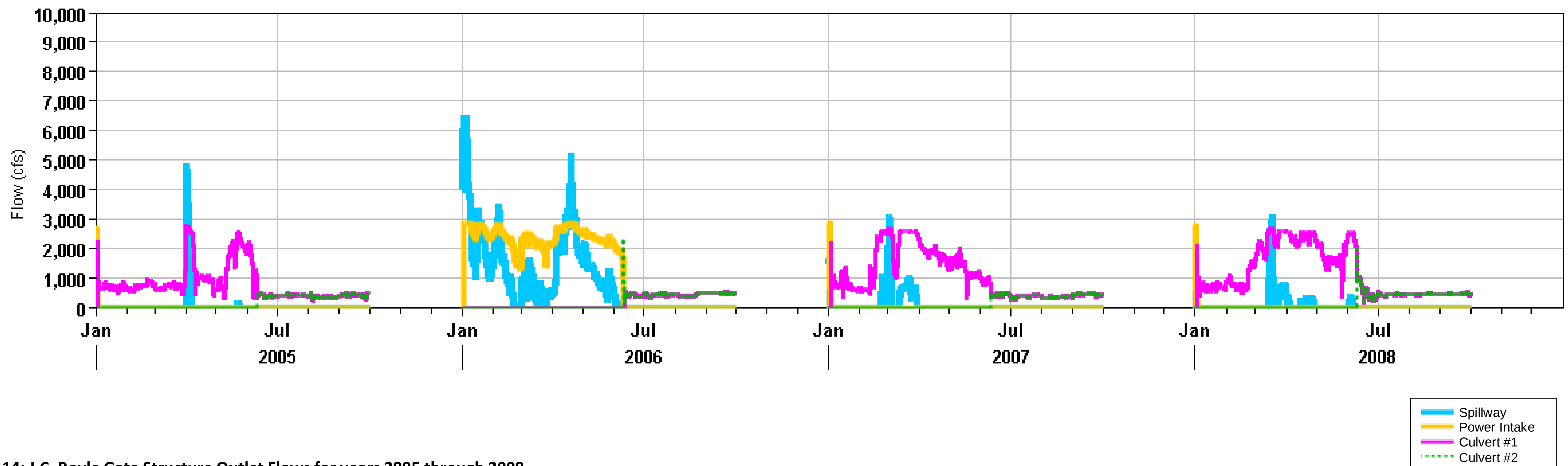

Figure 14: J.C. Boyle Gate Structure Outlet Flows for years 2005 through 2008

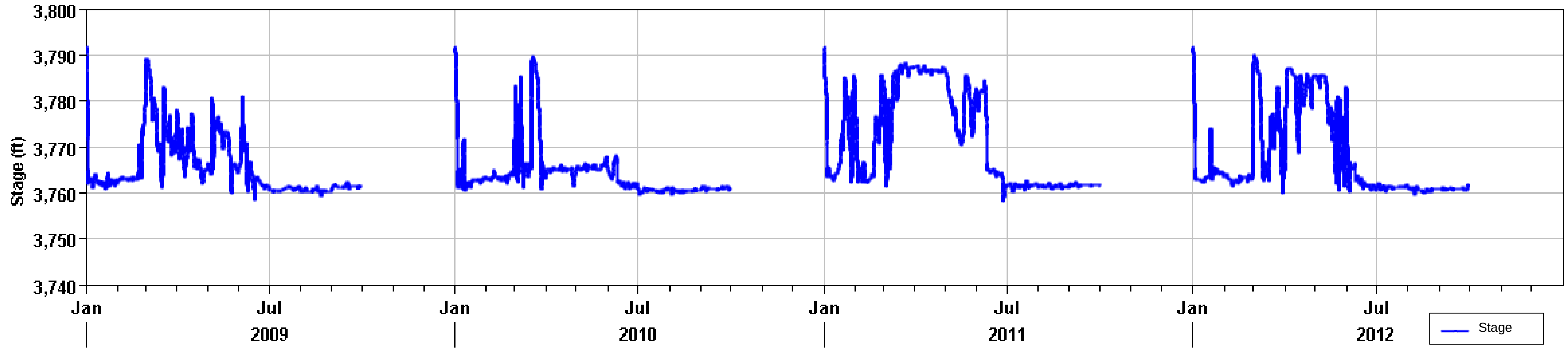

Figure 15: J.C. Boyle Drawdown Stage for years 2009 through 2012

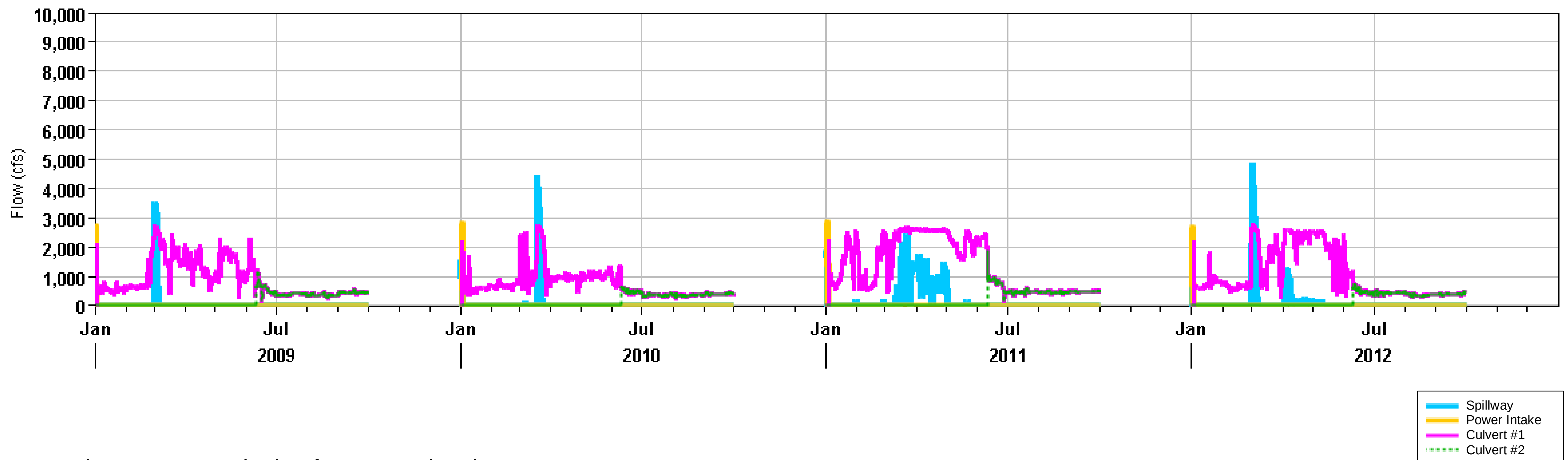

Figure 16: J.C. Boyle Gate Structure Outlet Flows for years 2009 through 2012

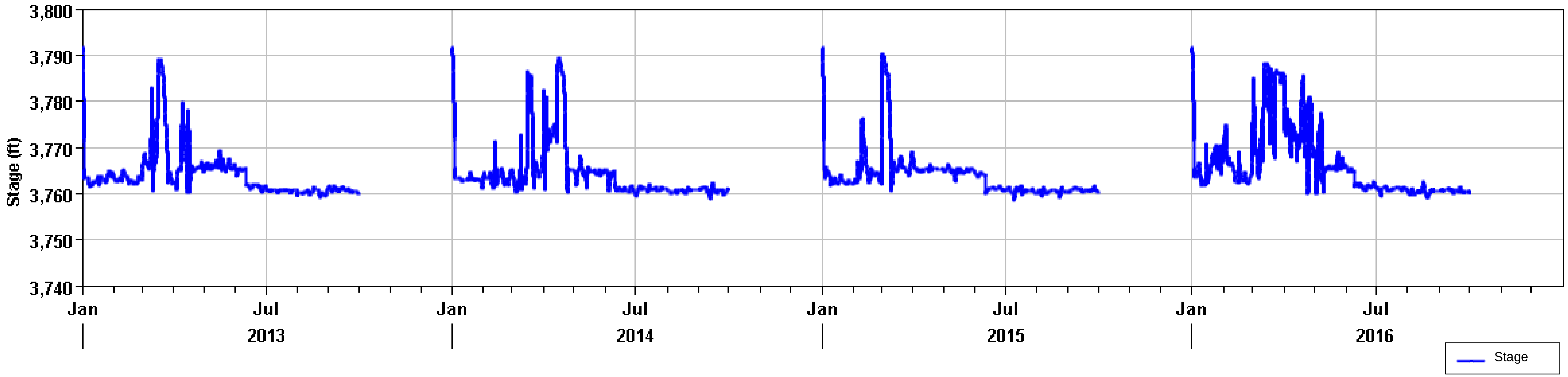

Figure 17: J.C. Boyle Drawdown Stage for years 2013 through 2016

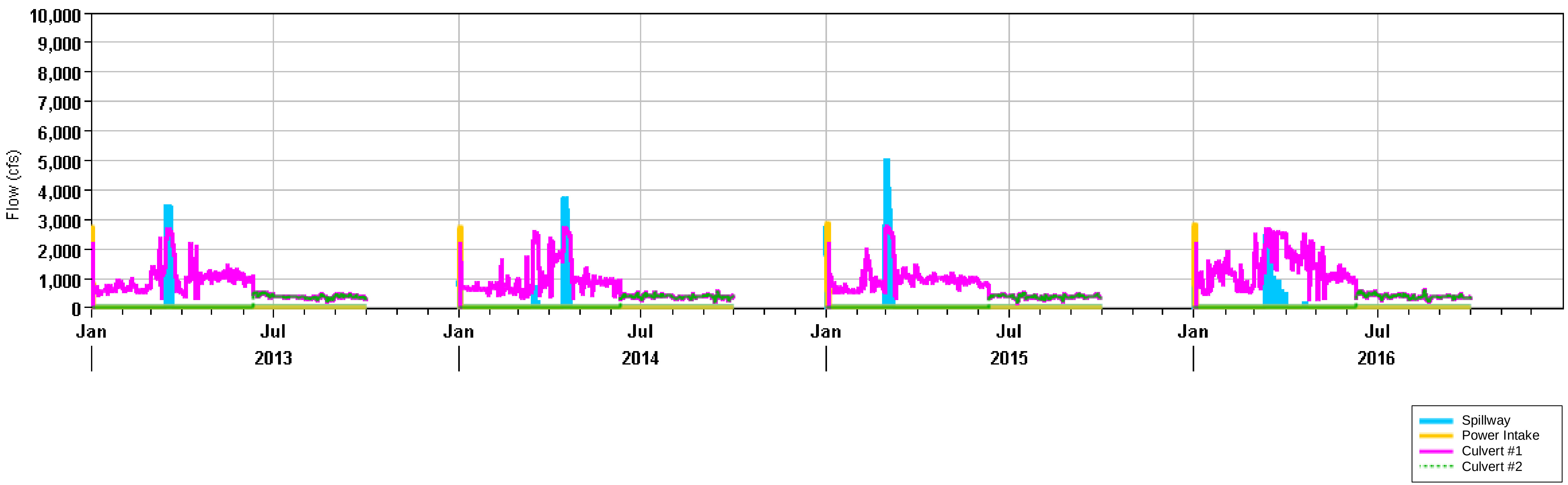

Figure 18: J.C. Boyle Gate Structure Outlet Flows for years 2013 through 2016

Appendix C:

Drawdown Plots for Copco No. 1 Reservoir

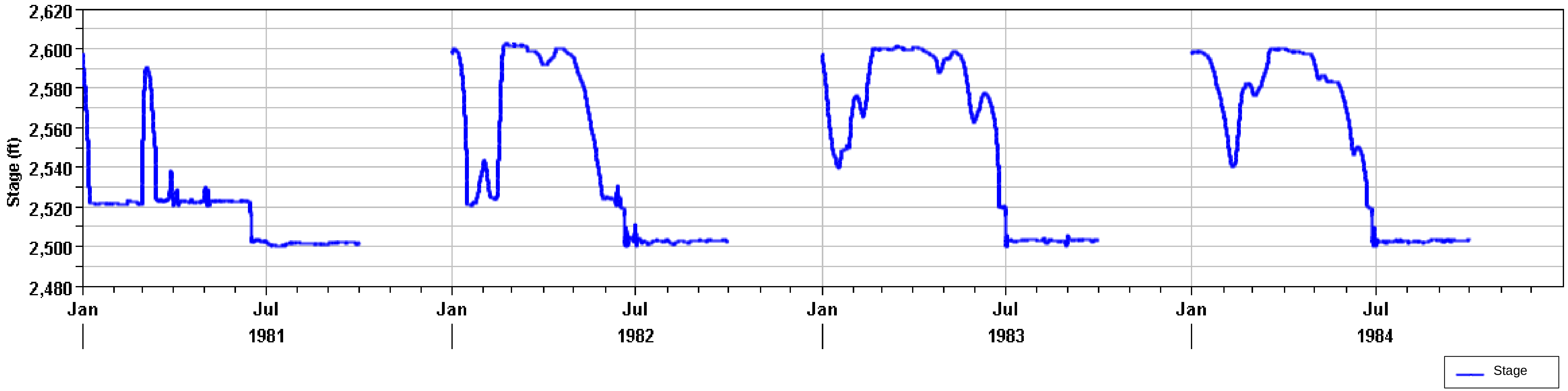

Figure 19: Copco No. 1 Drawdown Stage for years 1981 through 1984

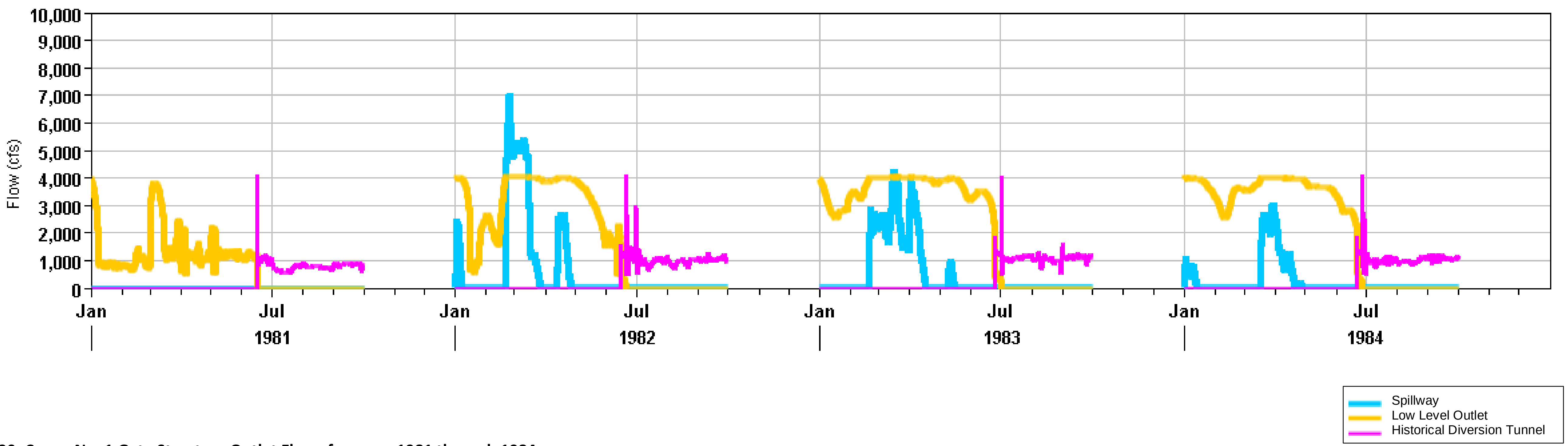

Figure 20: Copco No. 1 Gate Structure Outlet Flows for years 1981 through 1984

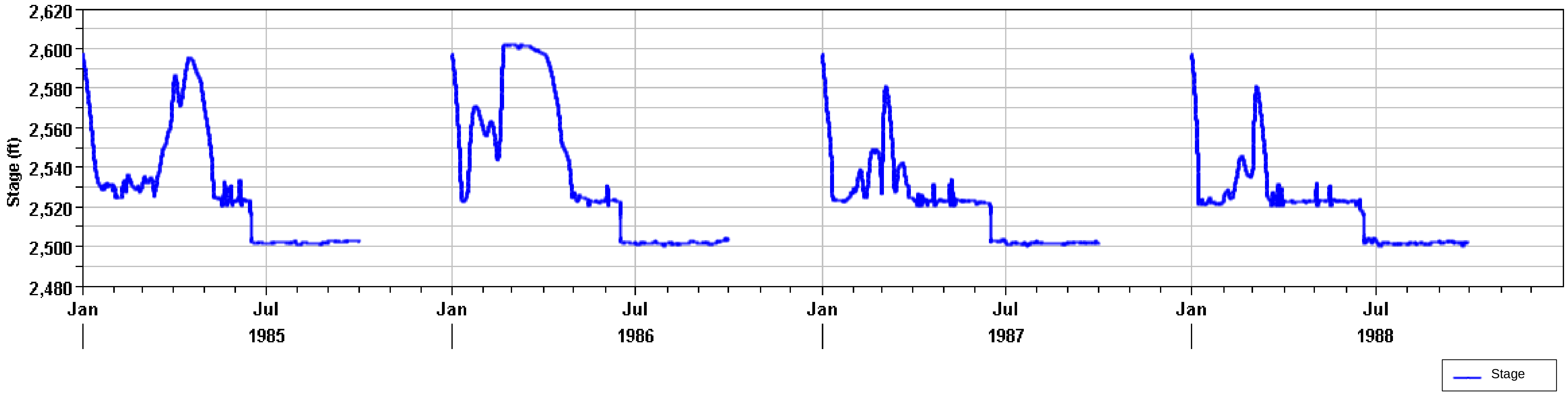

Figure 21: Copco No. 1 Drawdown Stage for years 1985 through 1988

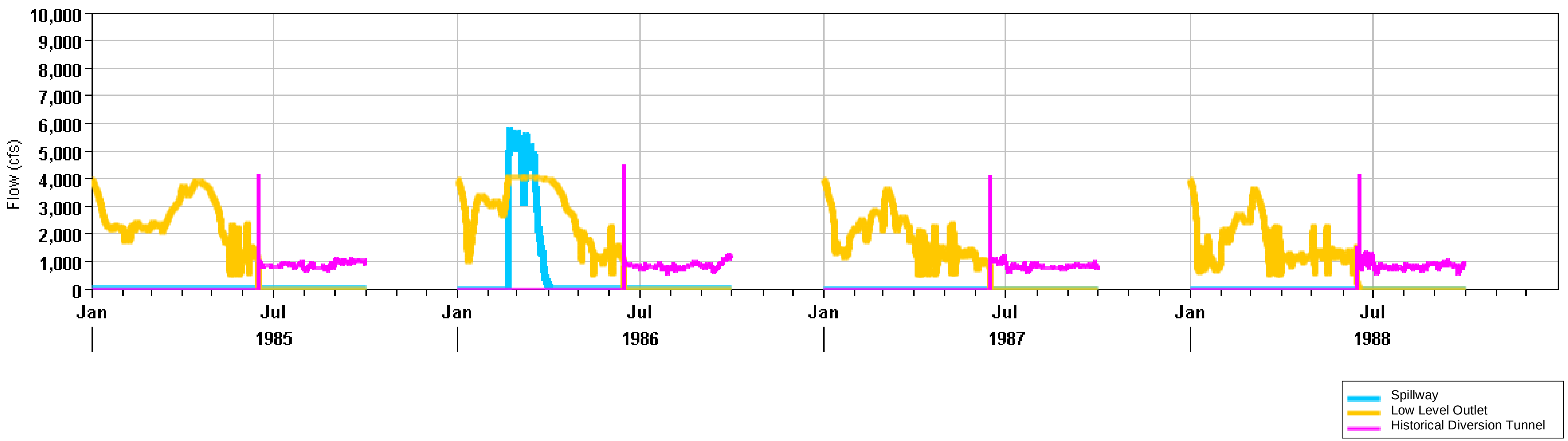

Figure 22: Copco No. 1 Gate Structure Outlet Flows for years 1985 through 1988

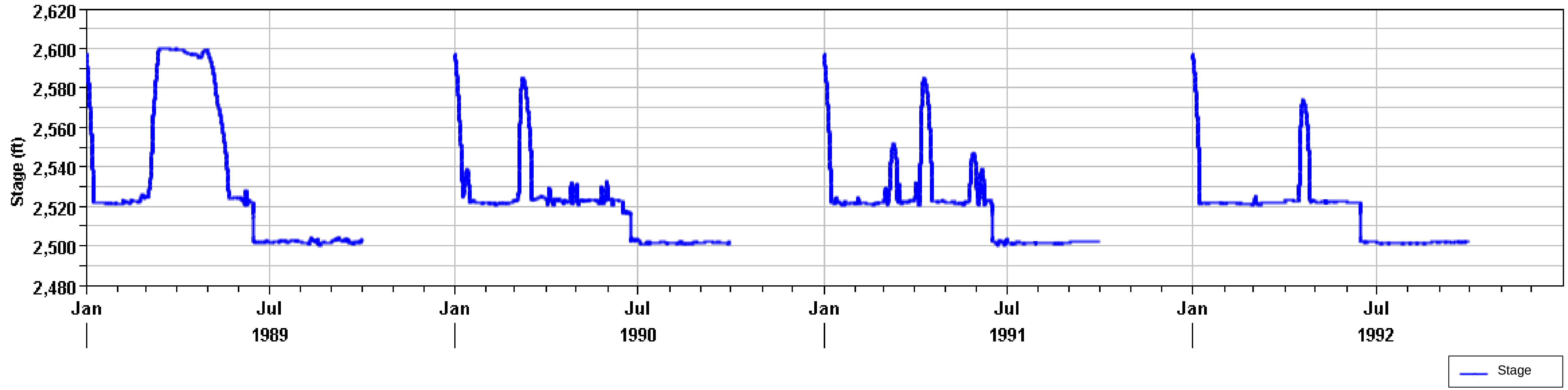

Figure 23: Copco No. 1 Drawdown Stage for years 1989 through 1992

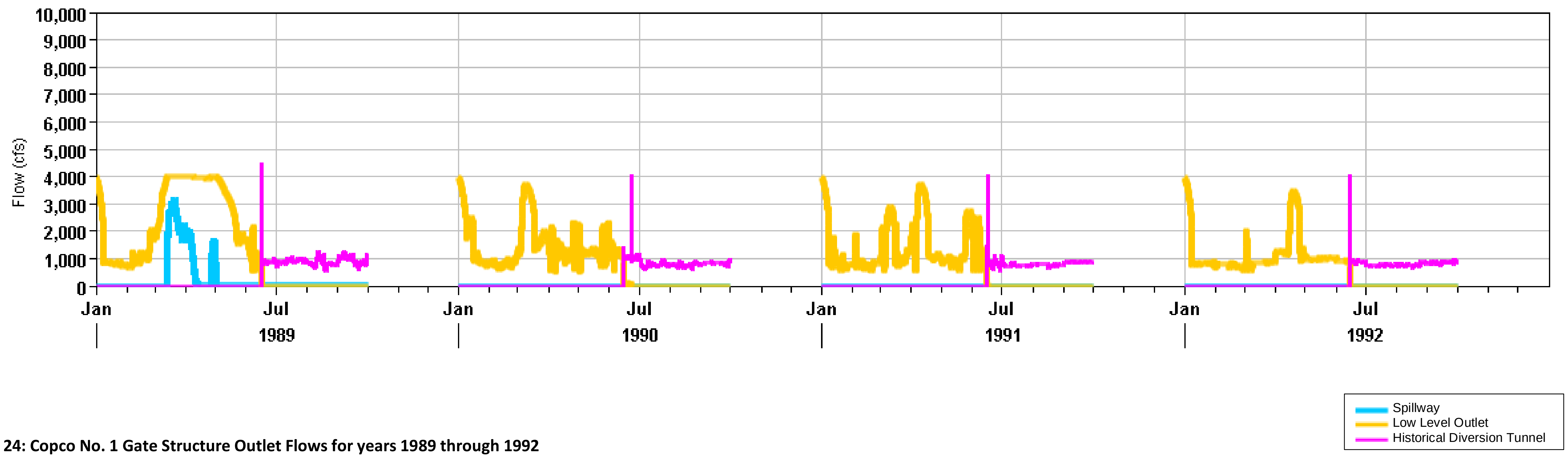

Figure 24: Copco No. 1 Gate Structure Outlet Flows for years 1989 through 1992

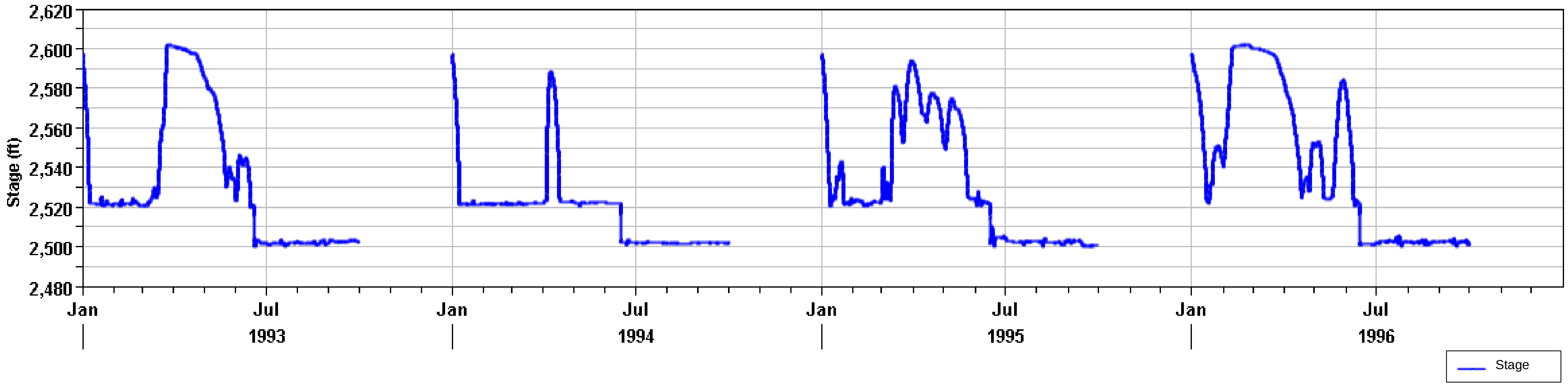

Figure 25: Copco No. 1 Drawdown Stage for years 1993 through 1996

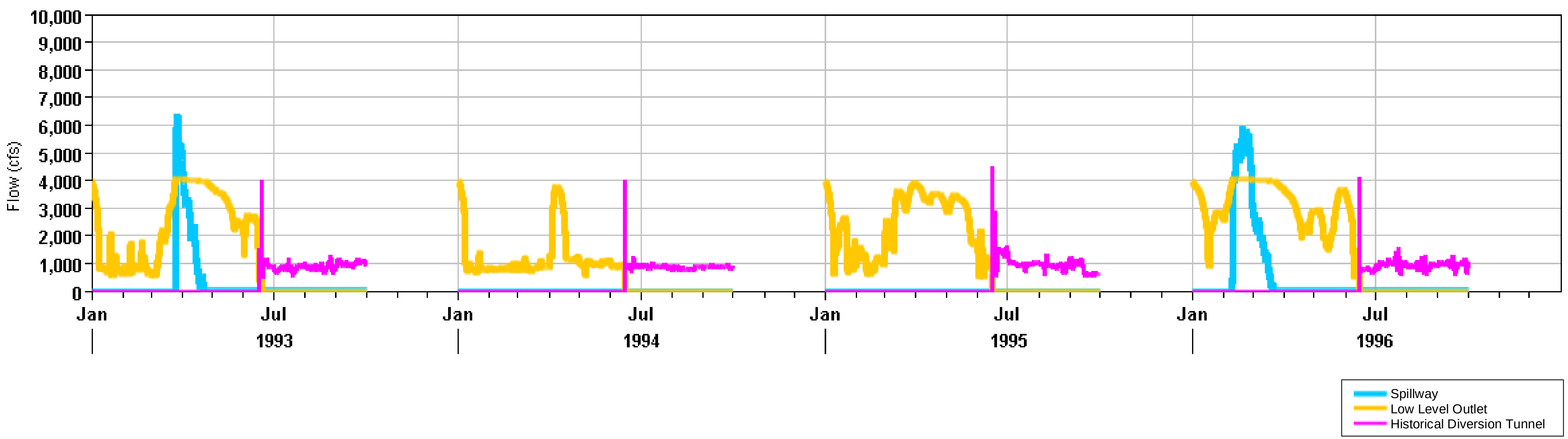

Figure 26: Copco No. 1 Gate Structure Outlet Flows for years 1993 through 1996

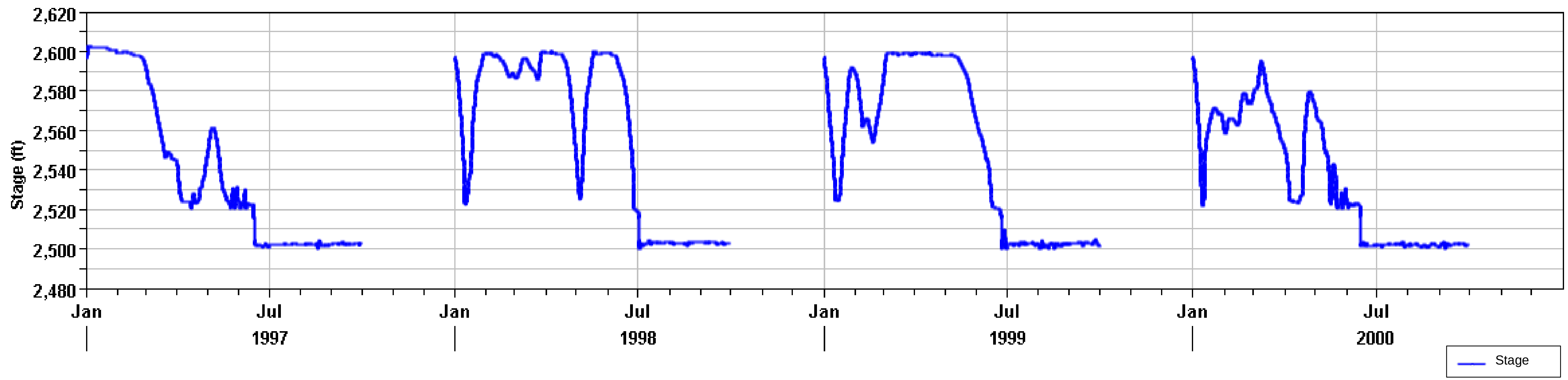

Figure 27: Copco No. 1 Drawdown Stage for years 1997 through 2000

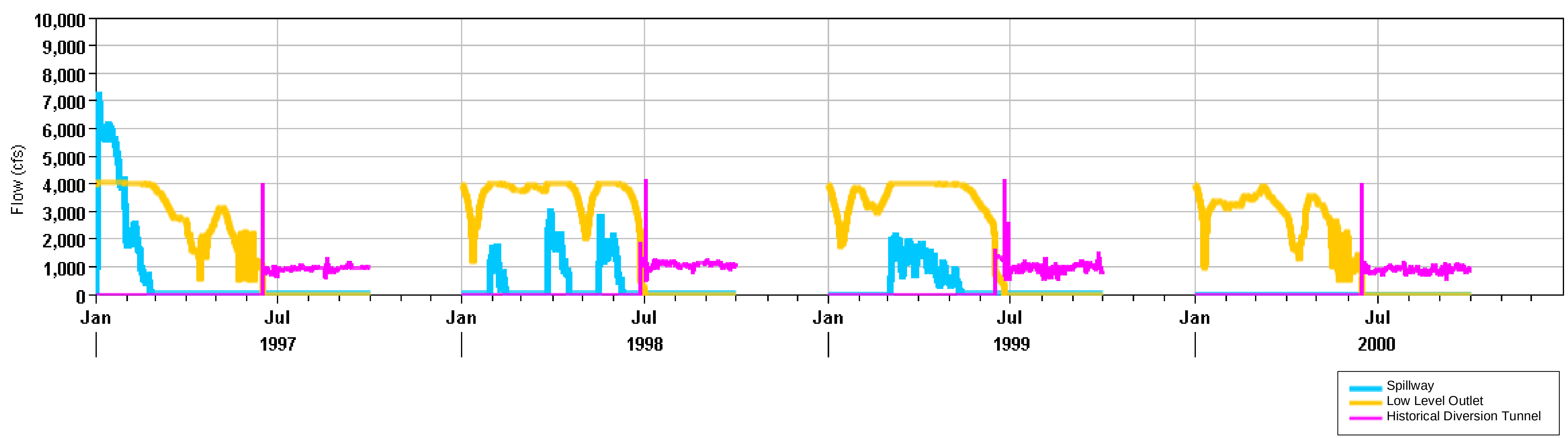

Figure 28: Copco No. 1 Gate Structure Outlet Flows for years 1997 through 2000

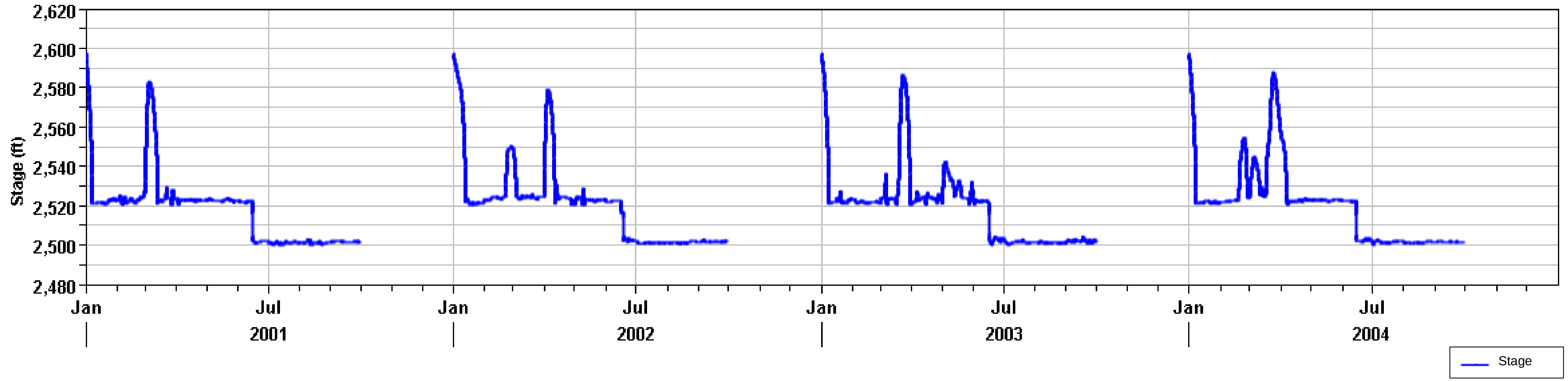

Figure 29: Copco No. 1 Drawdown Stage for years 2001 through 2004

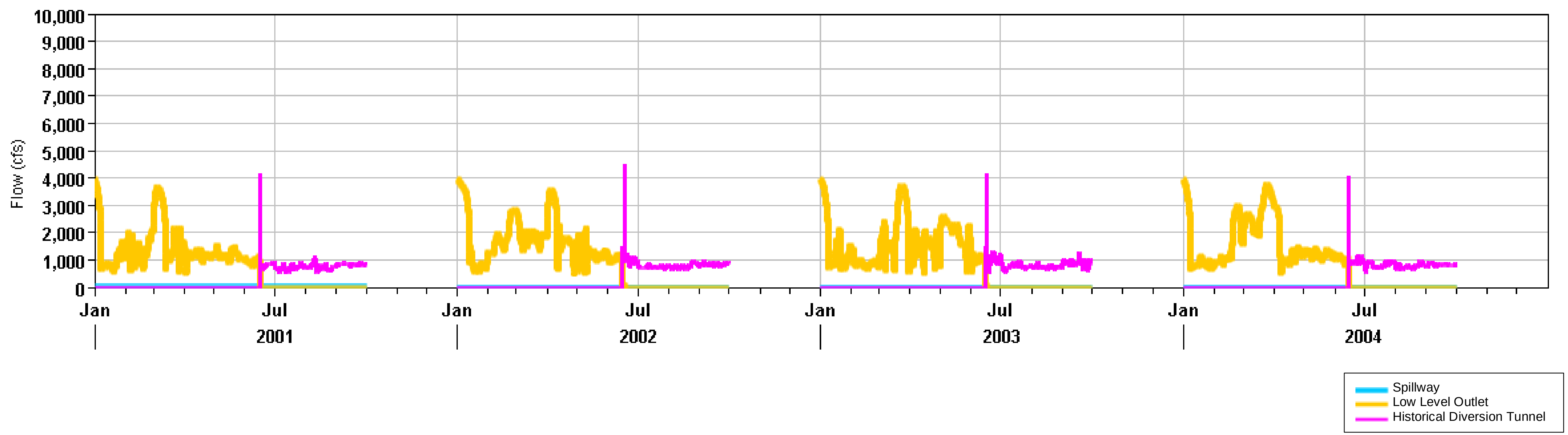

Figure 30: Copco No. 1 Gate Structure Outlet Flows for years 2001 through 2004

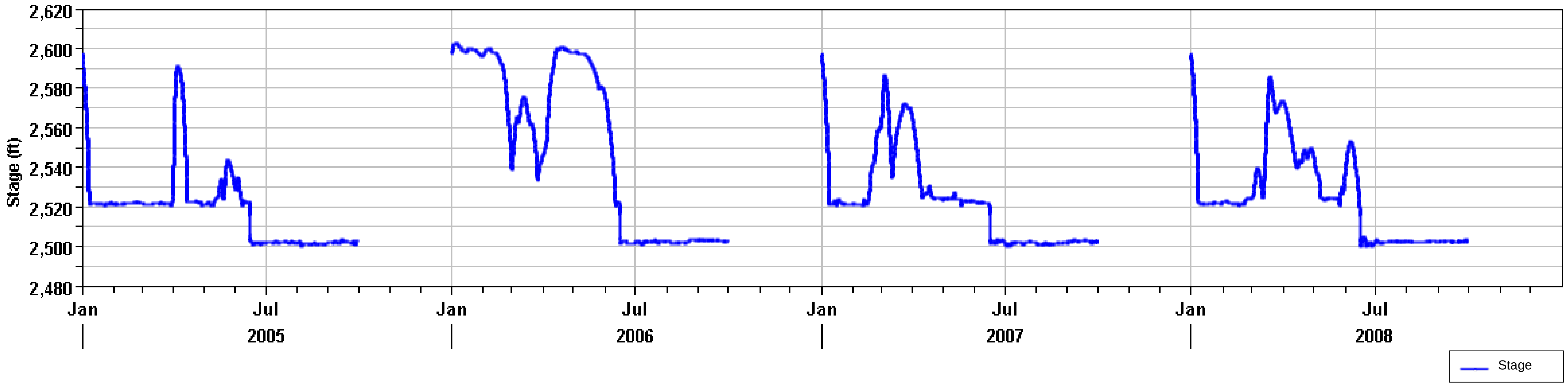

Figure 31: Copco No. 1 Drawdown Stage for years 2005 through 2008

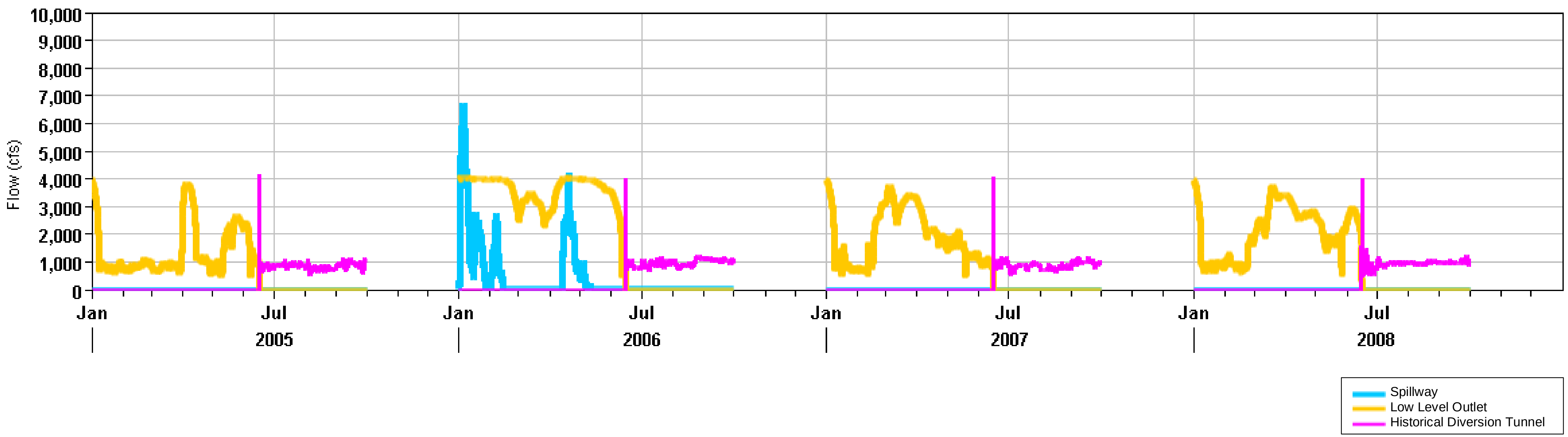

Figure 32: Copco No. 1 Gate Structure Outlet Flows for years 2005 through 2008

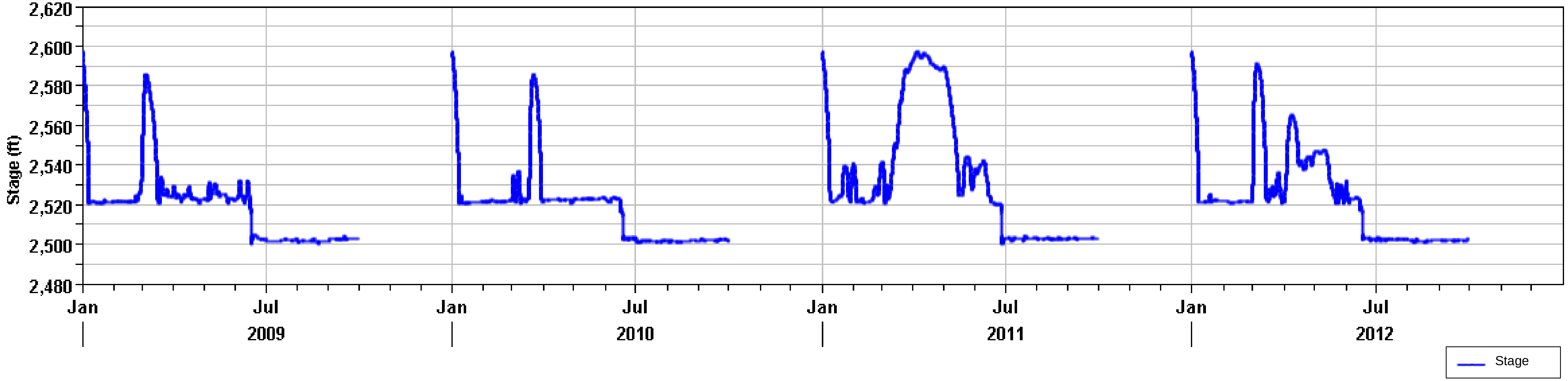

Figure 33: Copco No. 1 Drawdown Stage for years 2009 through 2012

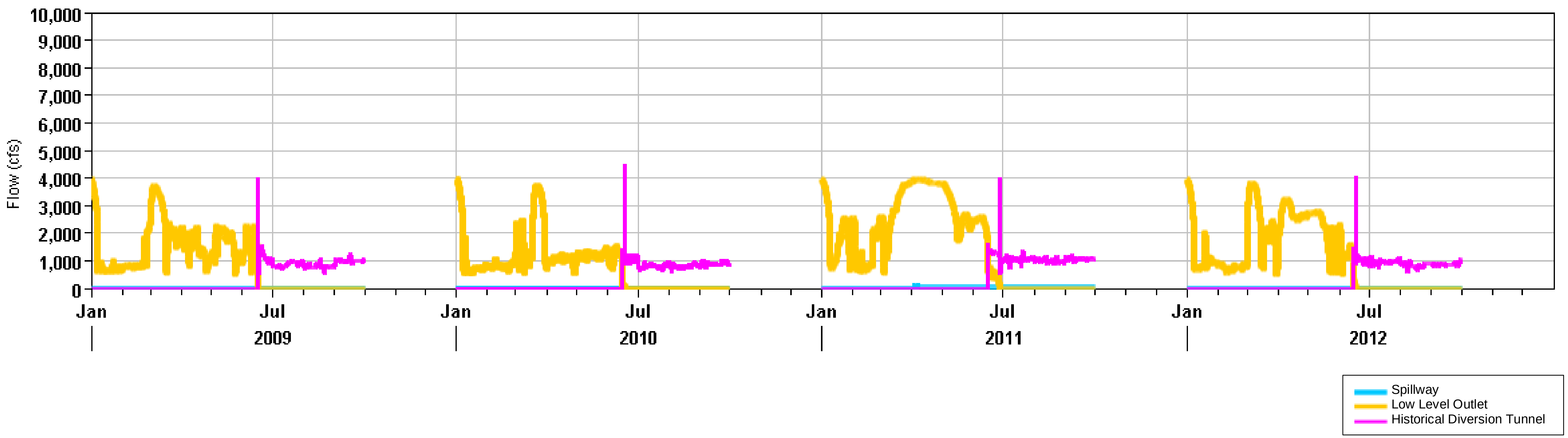

Figure 34: Copco No. 1 Gate Structure Outlet Flows for years 2009 through 2012

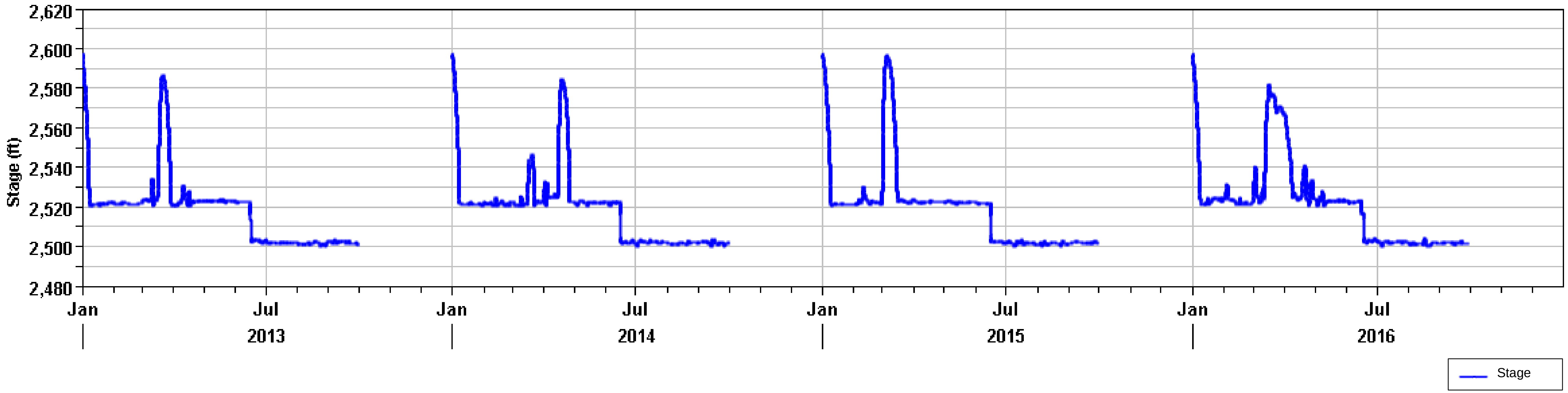

Figure 35: Copco No. 1 Drawdown Stage for years 2013 through 2016

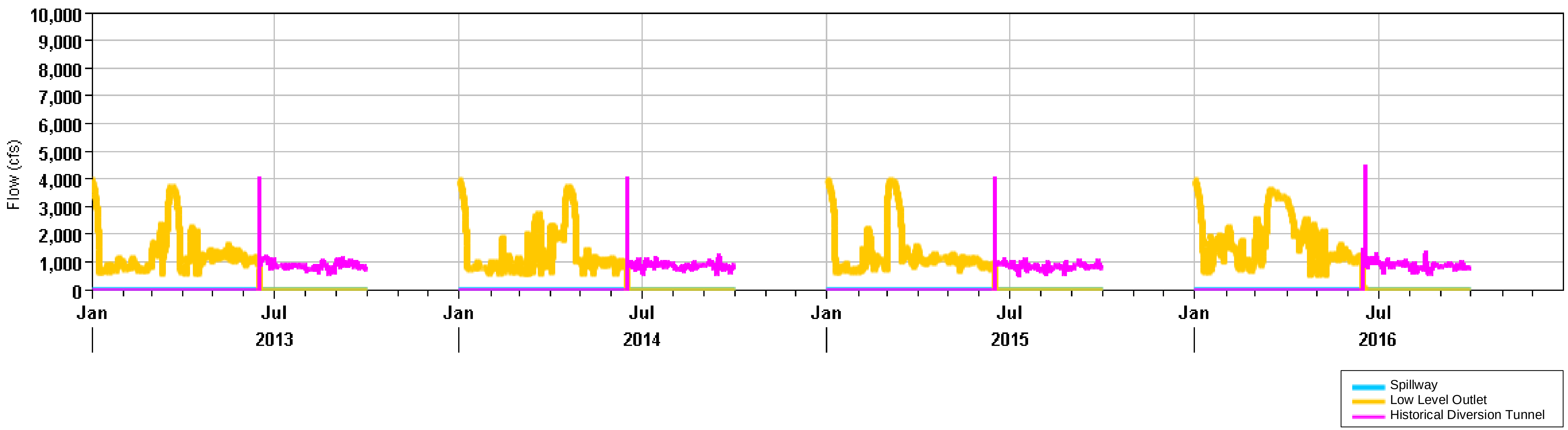

Figure 36: Copco No. 1 Gate Structure Outlet Flows for years 2013 through 2016

Appendix D.

Drawdown Plots for Copco No. 2 Reservoir

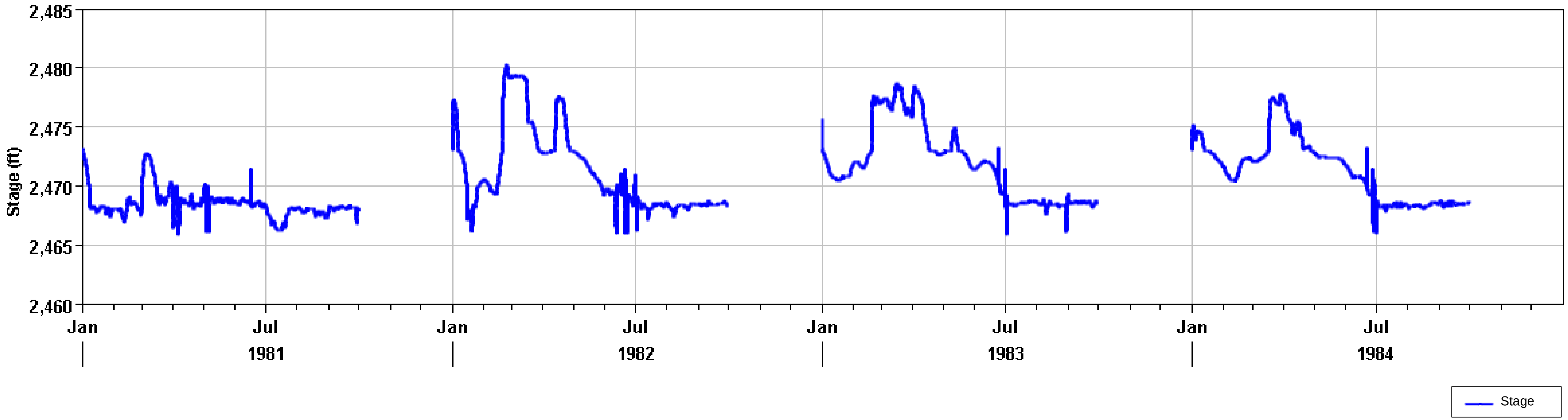

Figure 37: Copco No. 2 Drawdown Stage for years 1981 through 1984

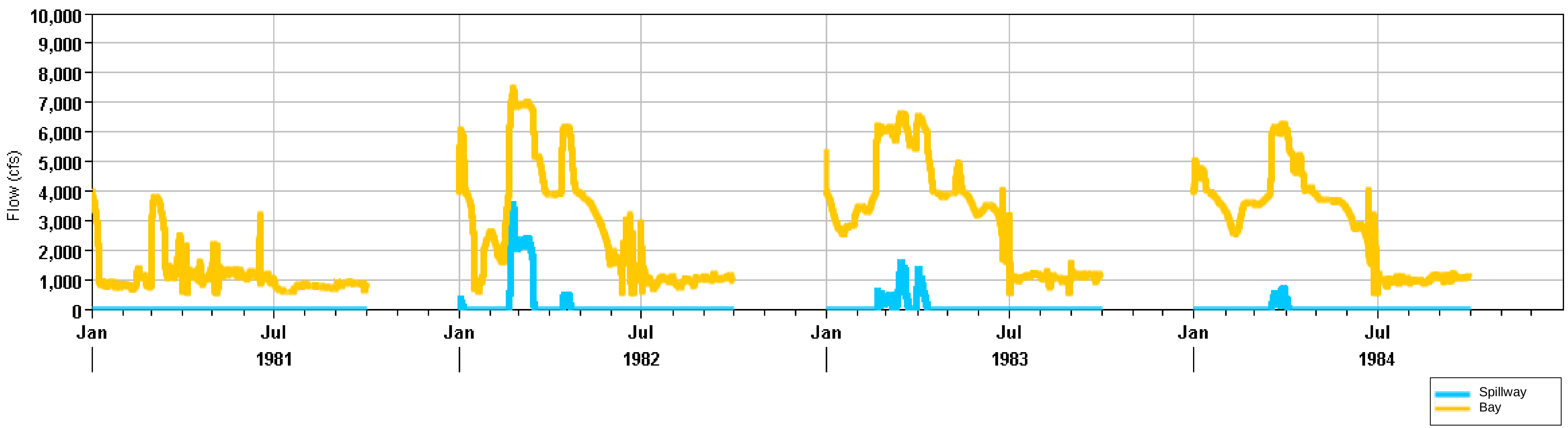

Figure 38: Copco No. 2 Gate Structure Outlet Flows for years 1981 through 1984

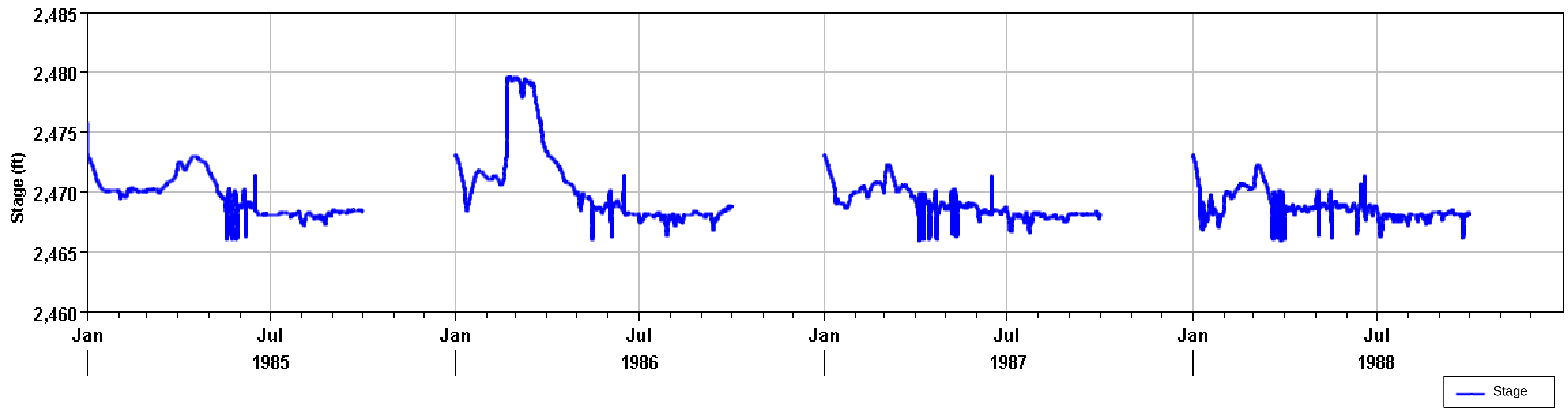

Figure 39: Copco No. 2 Drawdown Stage for years 1985 through 1988

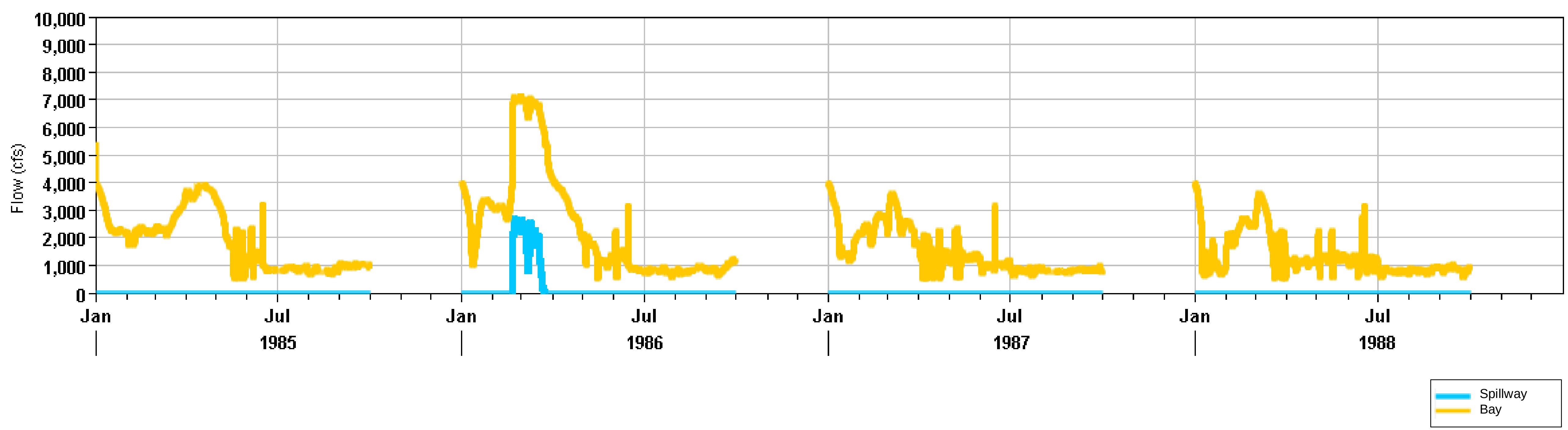

Figure 40: Copco No. 2 Gate Structure Outlet Flows for years 1985 through 1988

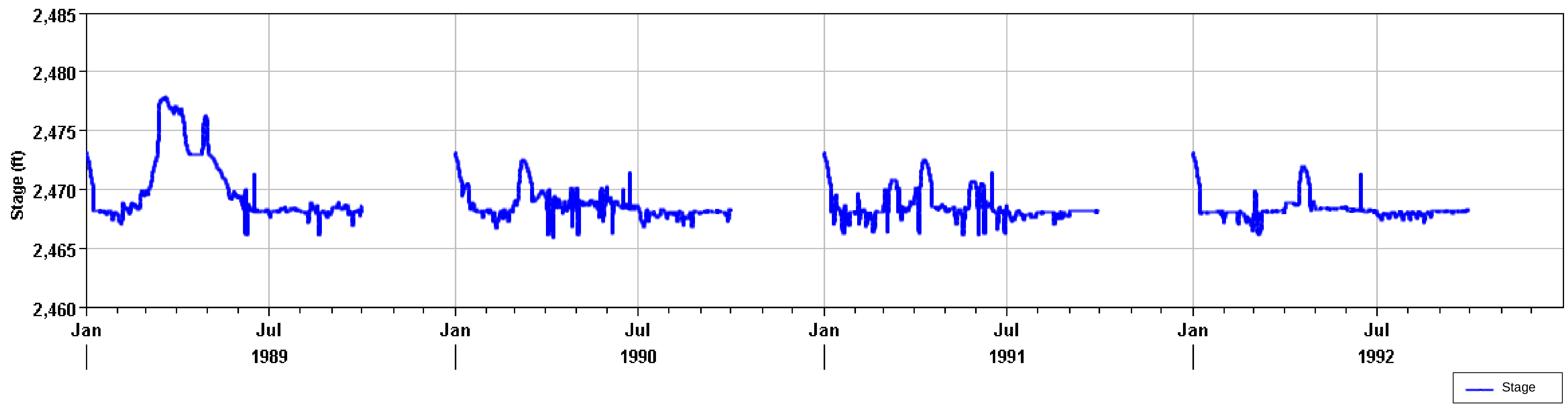

Figure 41: Copco No. 2 Drawdown Stage for years 1989 through 1992

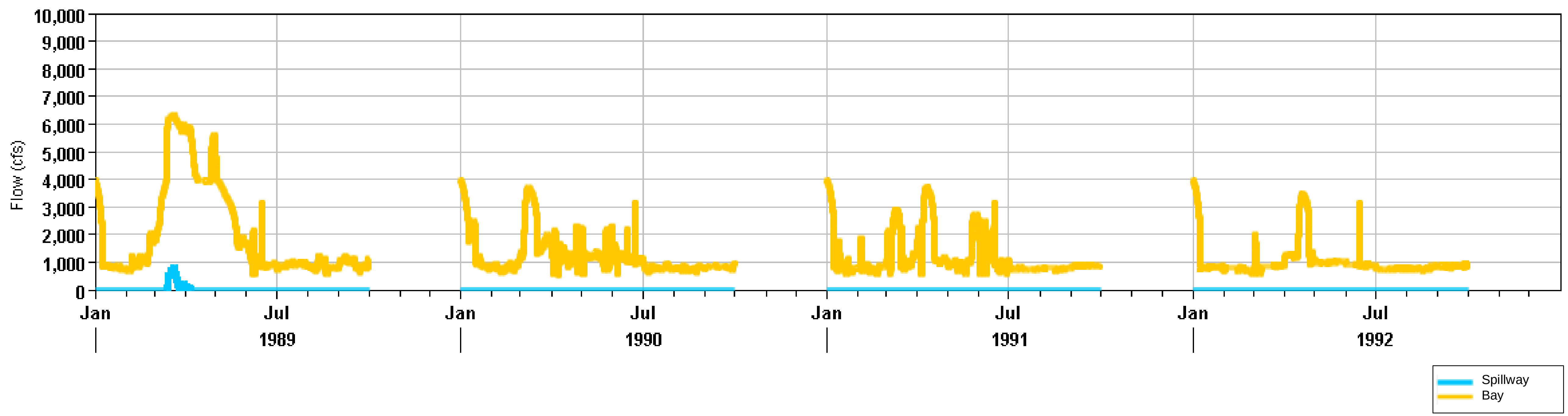

Figure 42: Copco No. 2 Gate Structure Outlet Flows for years 1989 through 1992

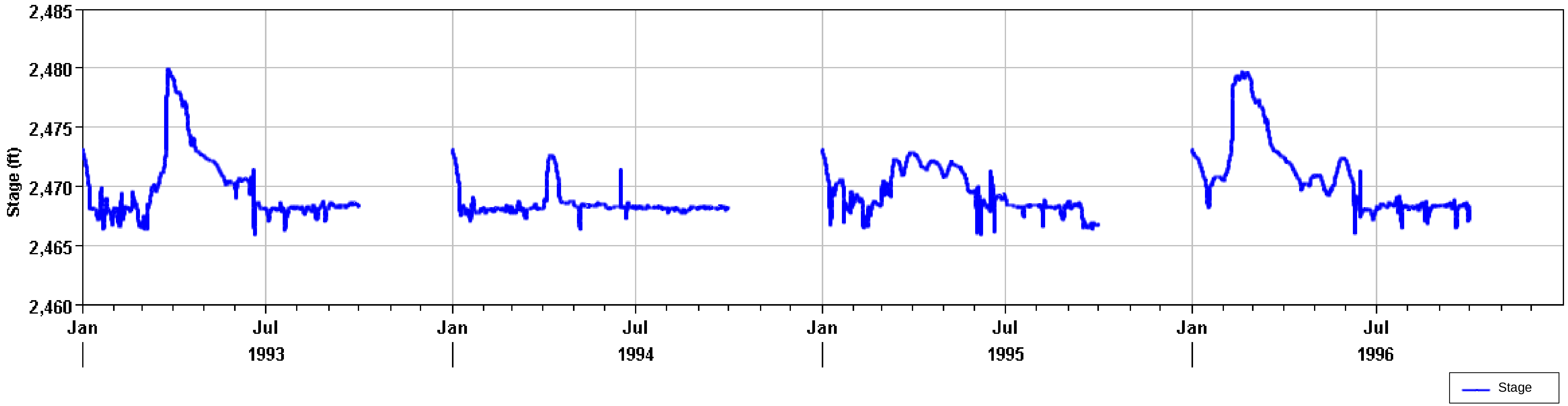

Figure 43: Copco No. 2 Drawdown Stage for years 1993 through 1996

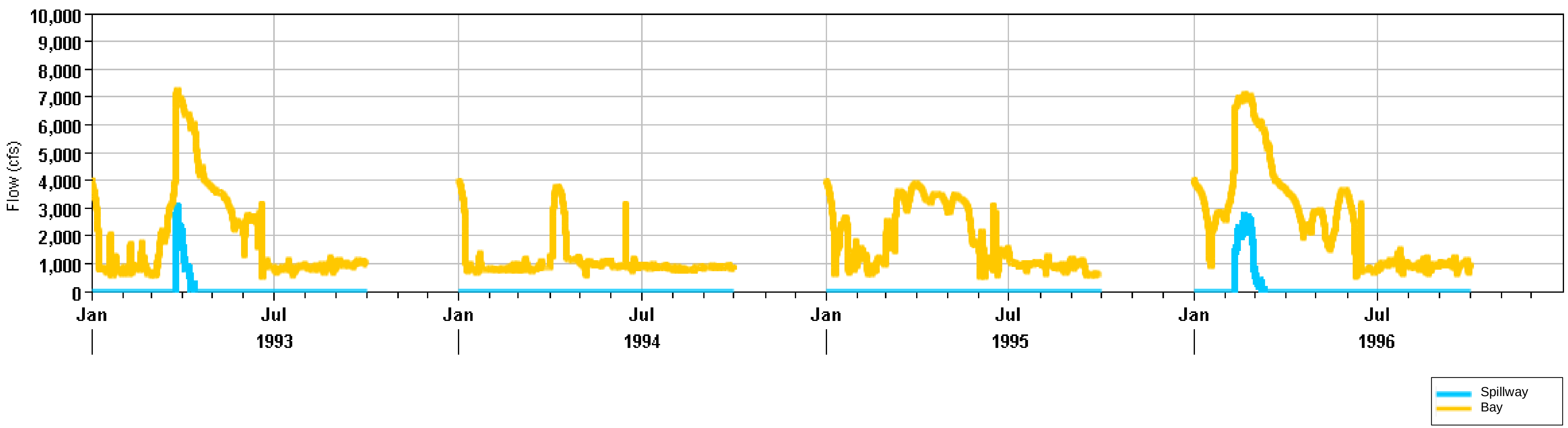

Figure 44: Copco No. 2 Gate Structure Outlet Flows for years 1993 through 1996

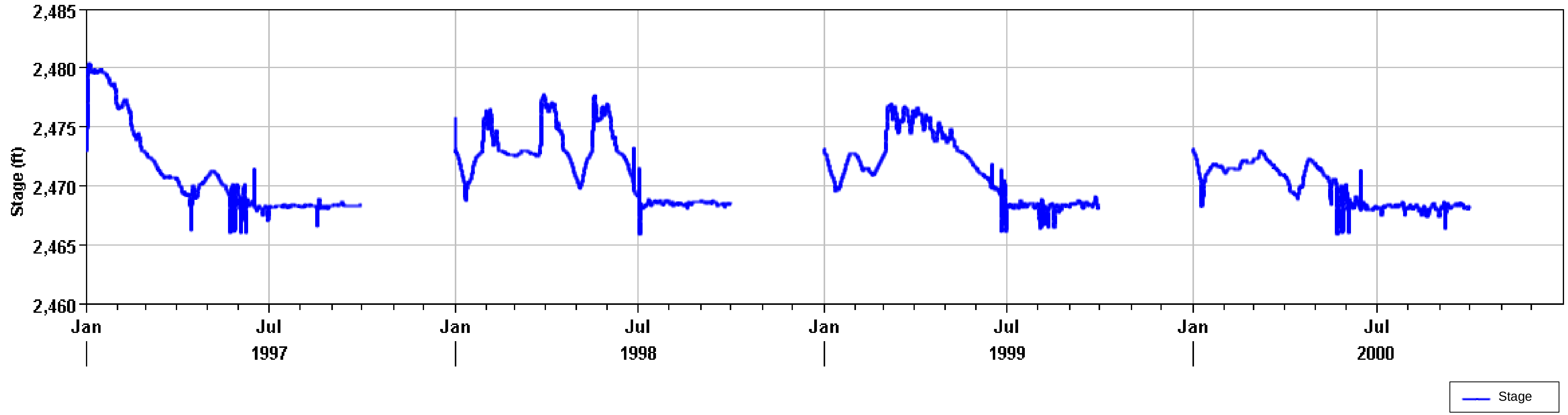

Figure 45: Copco No. 2 Drawdown Stage for years 1997 through 2000

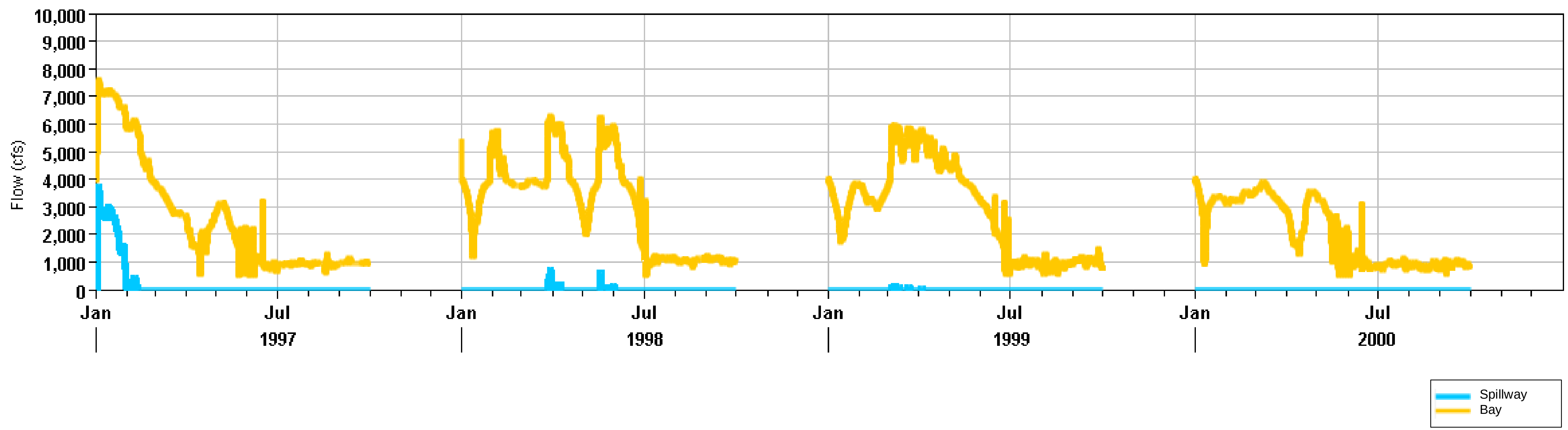

Figure 46: Copco No. 2 Gate Structure Outlet Flows for years 1997 through 2000

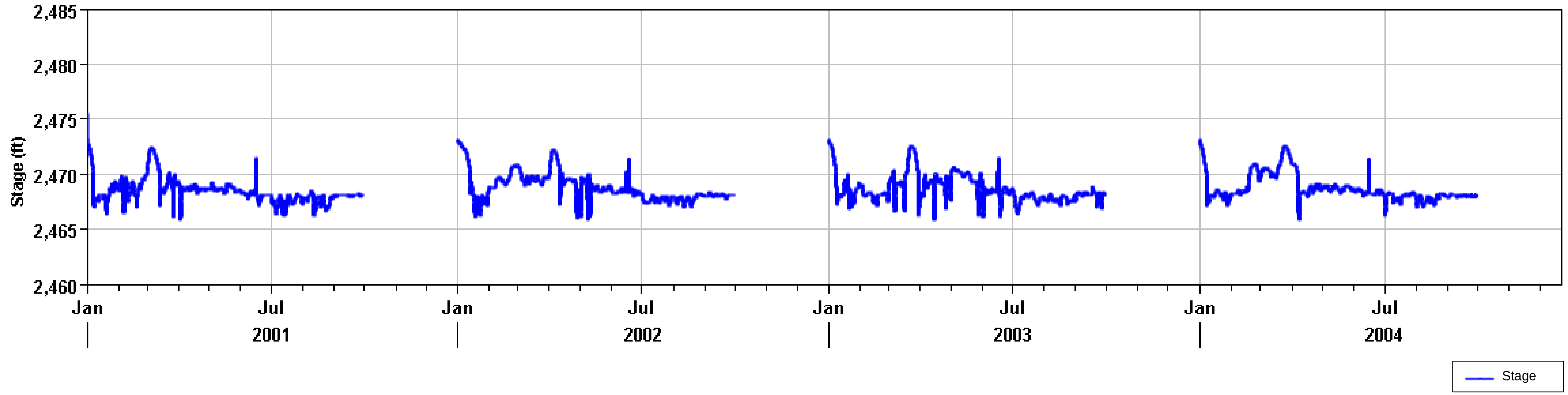

Figure 47: Copco No. 2 Drawdown Stage for years 2001 through 2004

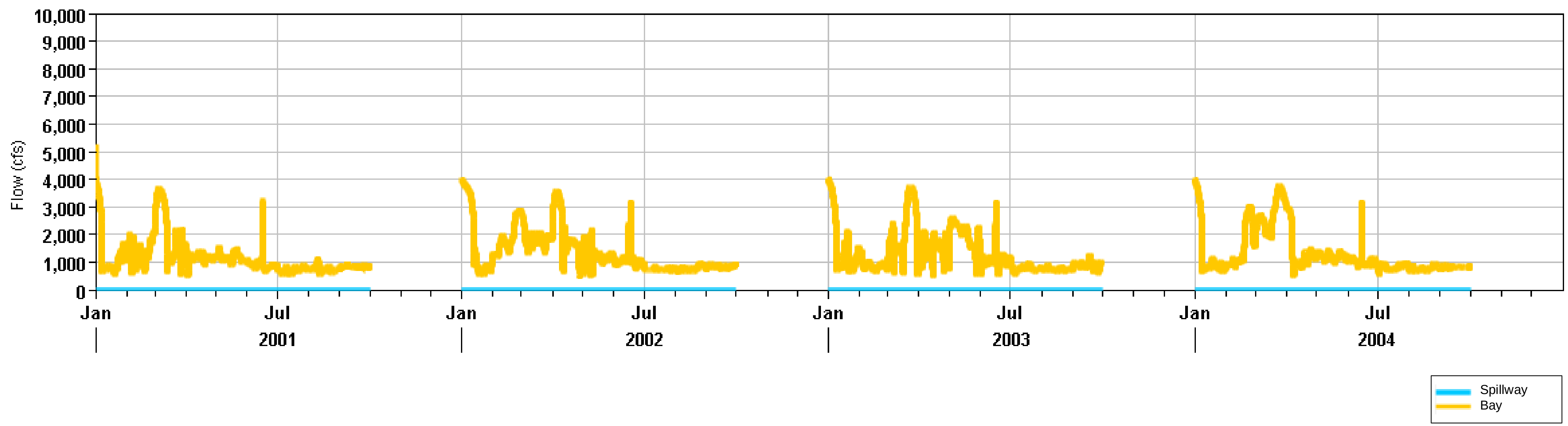

Figure 48: Copco No. 2 Gate Structure Outlet Flows for years 2001 through 2004

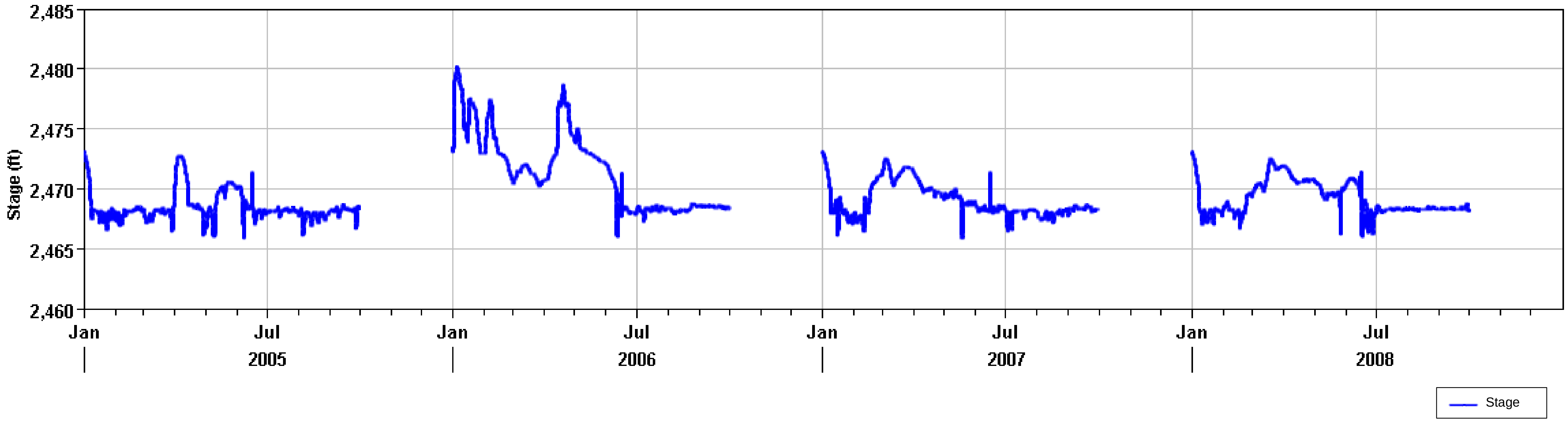

Figure 49: Copco No. 2 Drawdown Stage for years 2005 through 2008

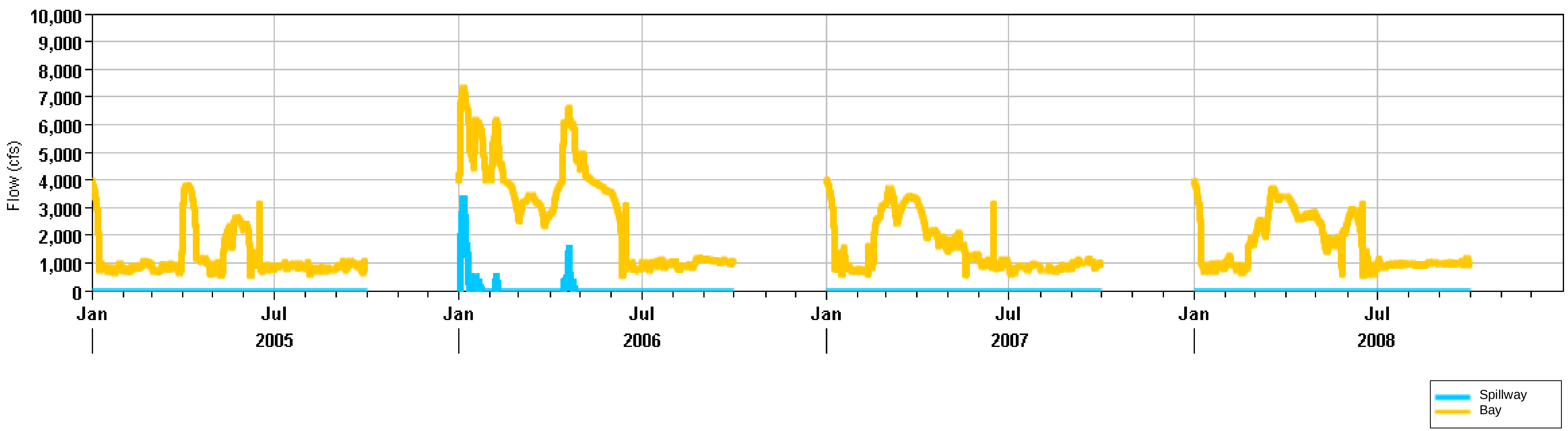

Figure 50: Copco No. 2 Gate Structure Outlet Flows for years 2005 through 2008

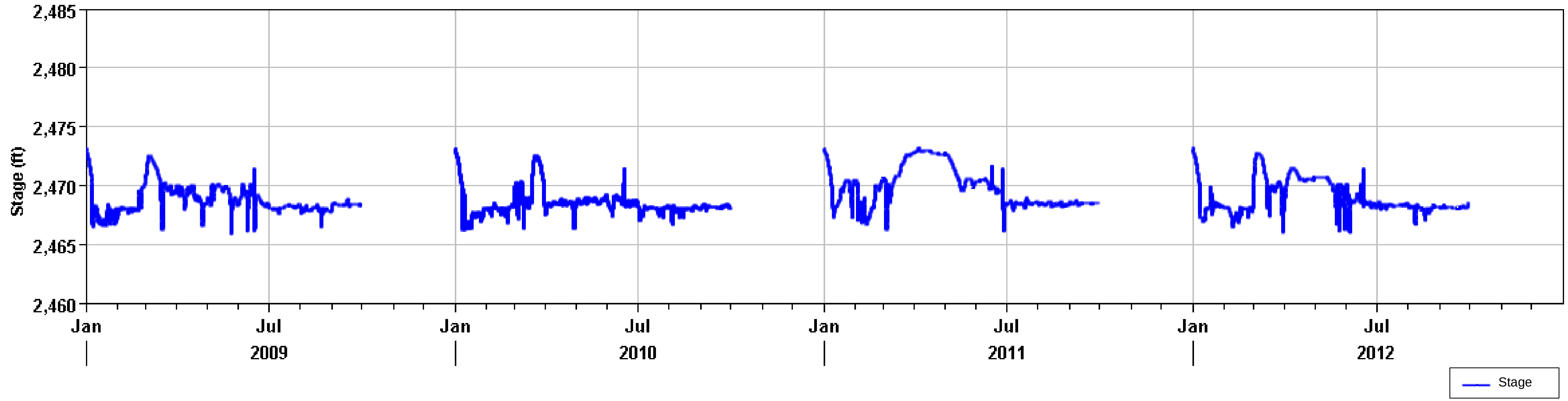

Figure 51: Copco No. 2 Drawdown Stage for years 2009 through 2012

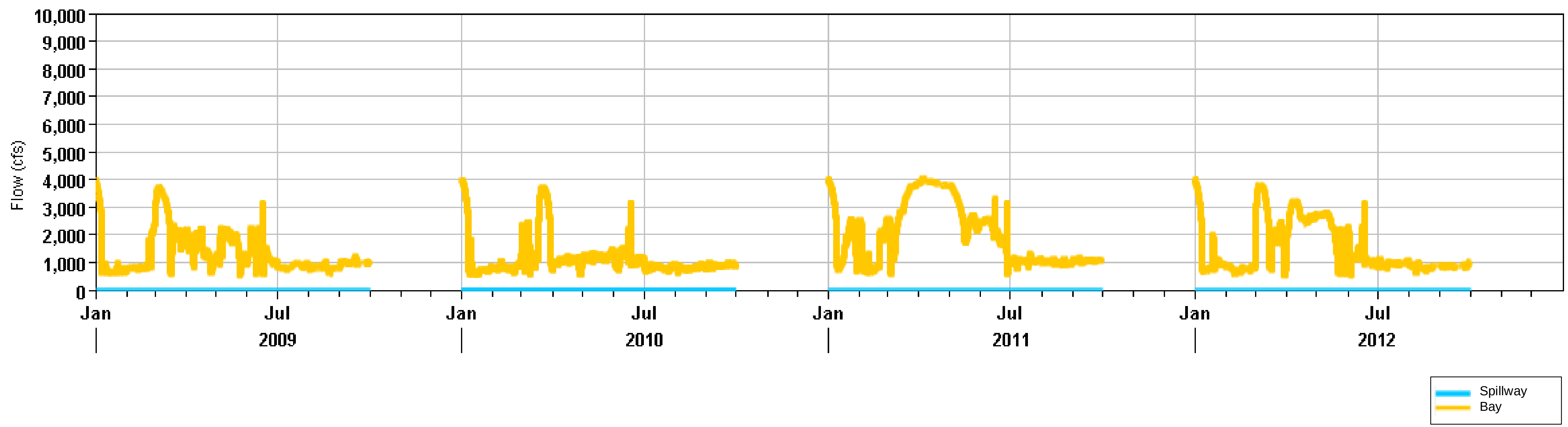

Figure 52: Copco No. 2 Gate Structure Outlet Flows for years 2009 through 2012

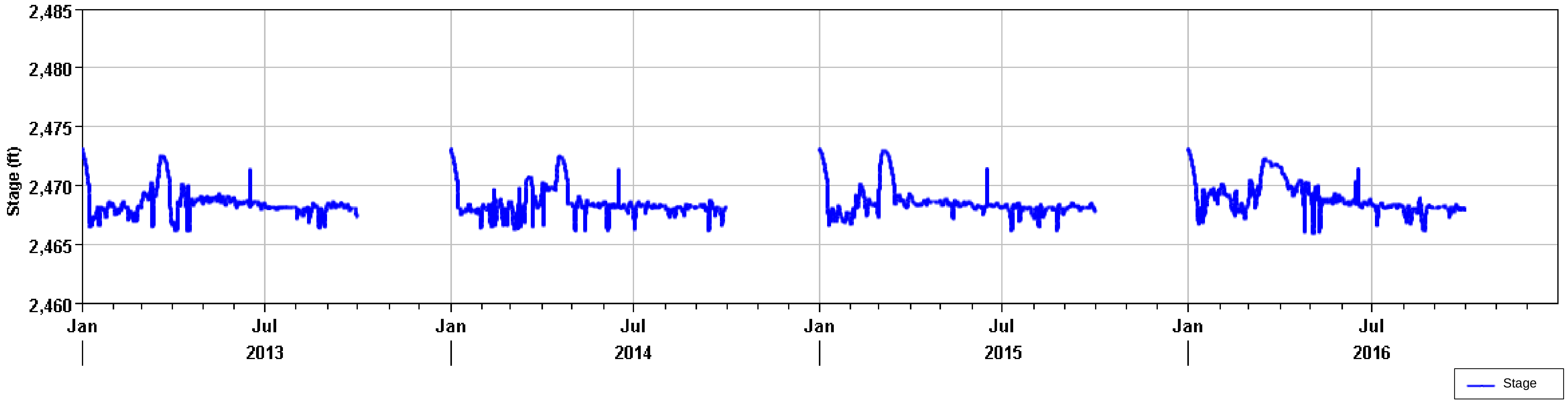

Figure 53: Copco No. 2 Drawdown Stage for years 2013 through 2016

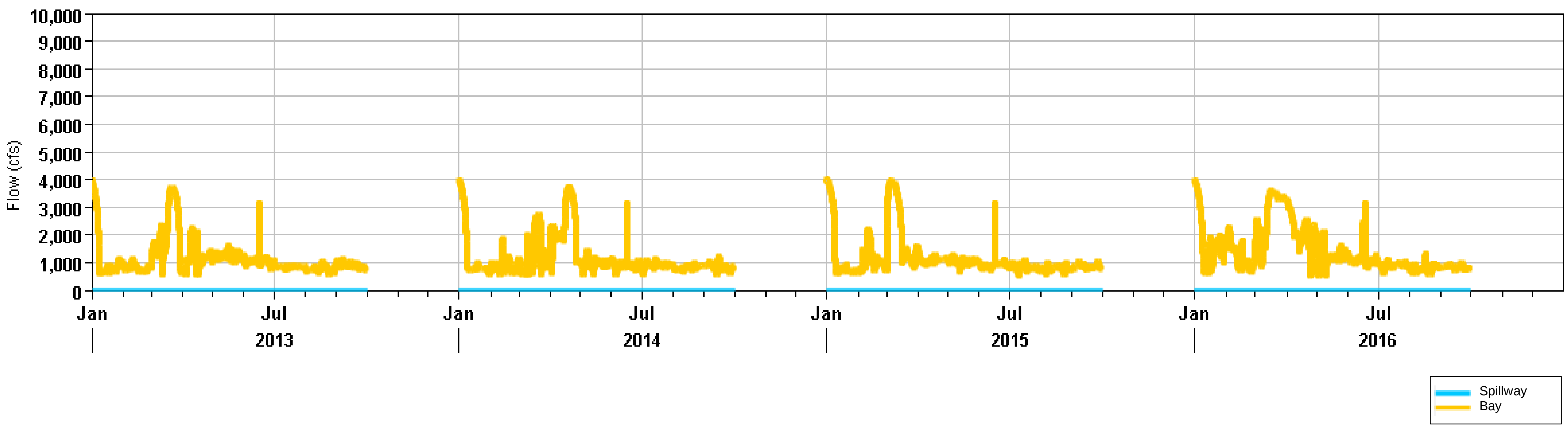

Figure 54: Copco No. 2 Gate Structure Outlet Flows for years 2013 through 2016

Appendix E:

Drawdown Plots for Iron Gate Reservoir

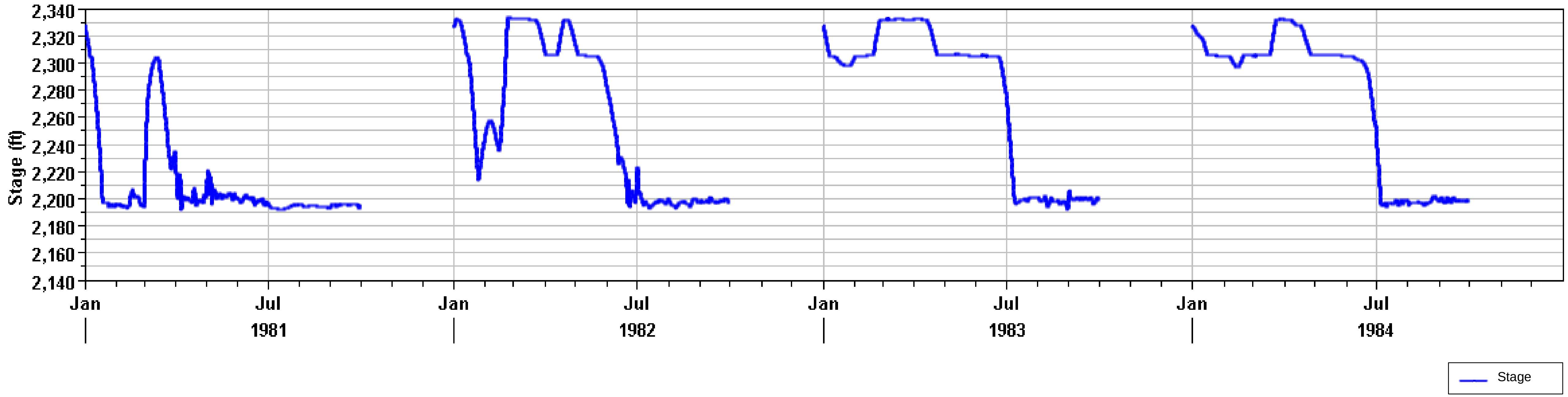

Figure 55: Iron Gate Drawdown Stage for years 1981 through 1984

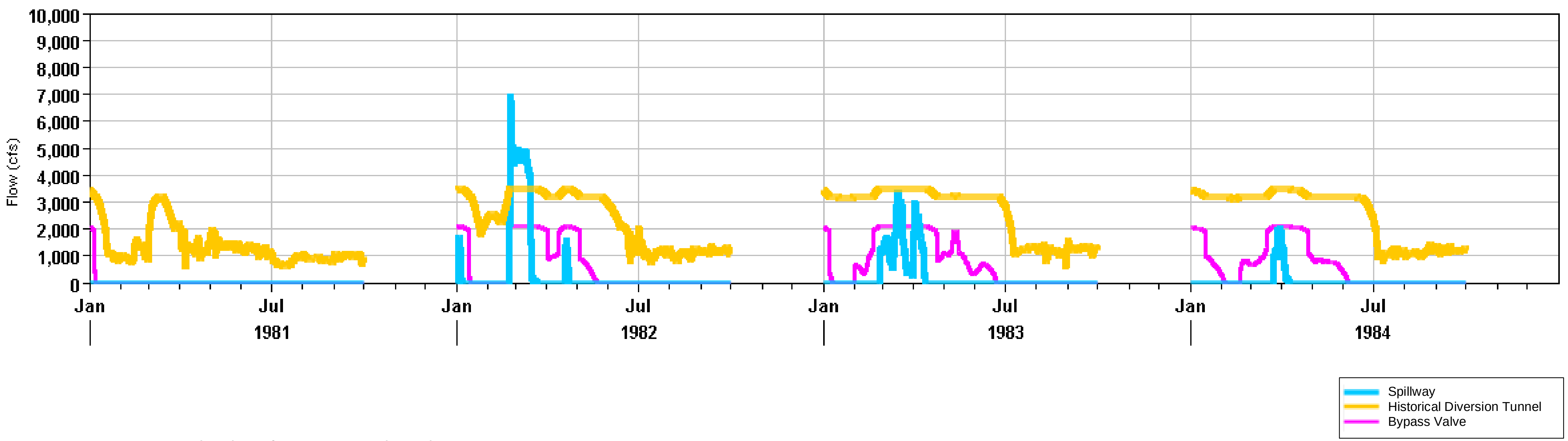

Figure 56: Iron Gate Structure Outlet Flows for years 1981 through 1984

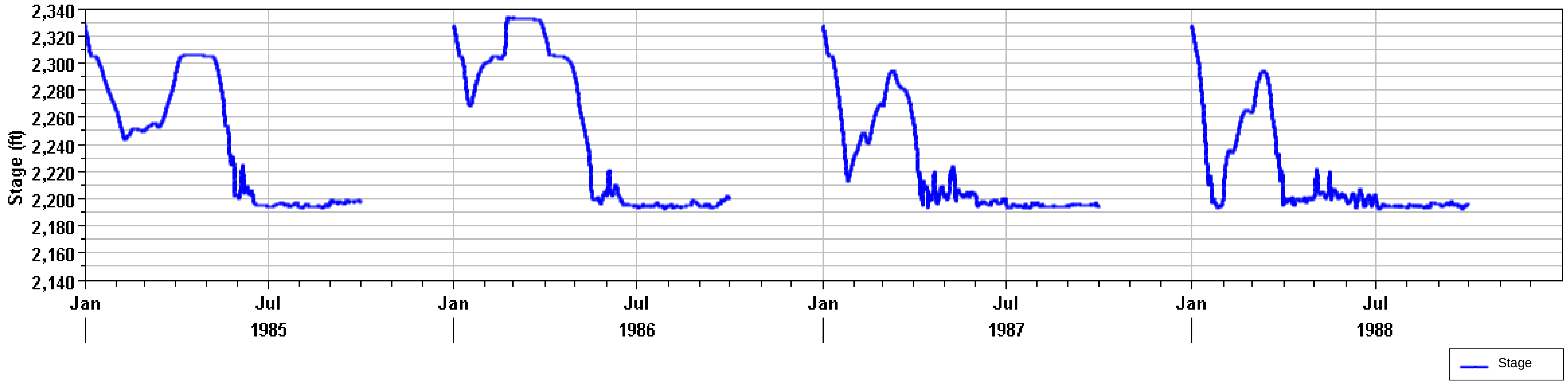

Figure 57: Iron Gate Drawdown Stage for years 1985 through 1988

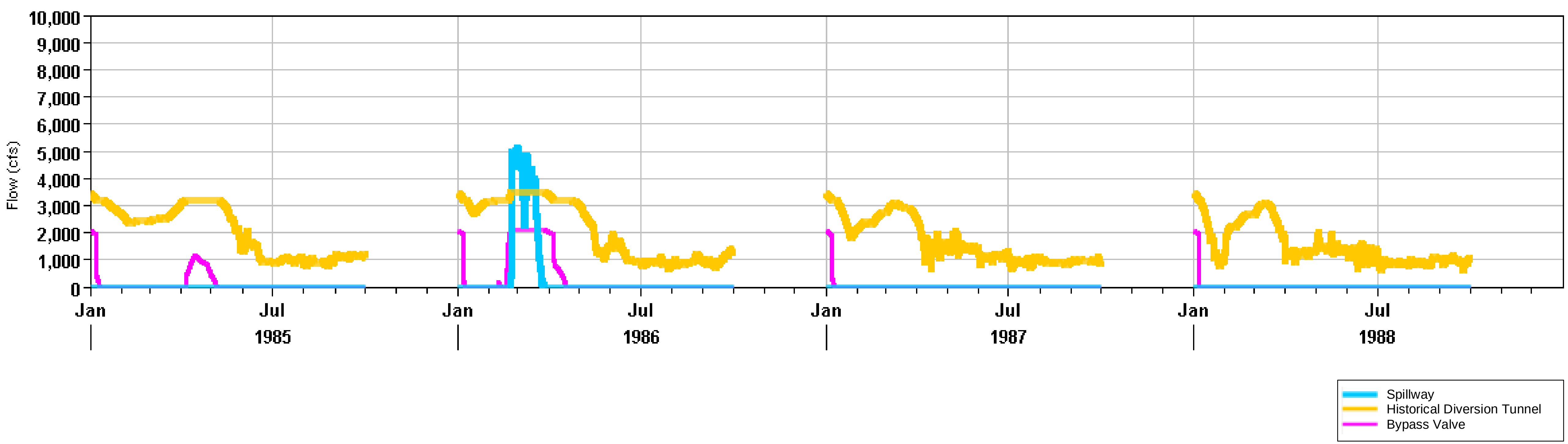

Figure 58: Iron Gate Structure Outlet Flows for years 1985 through 1988

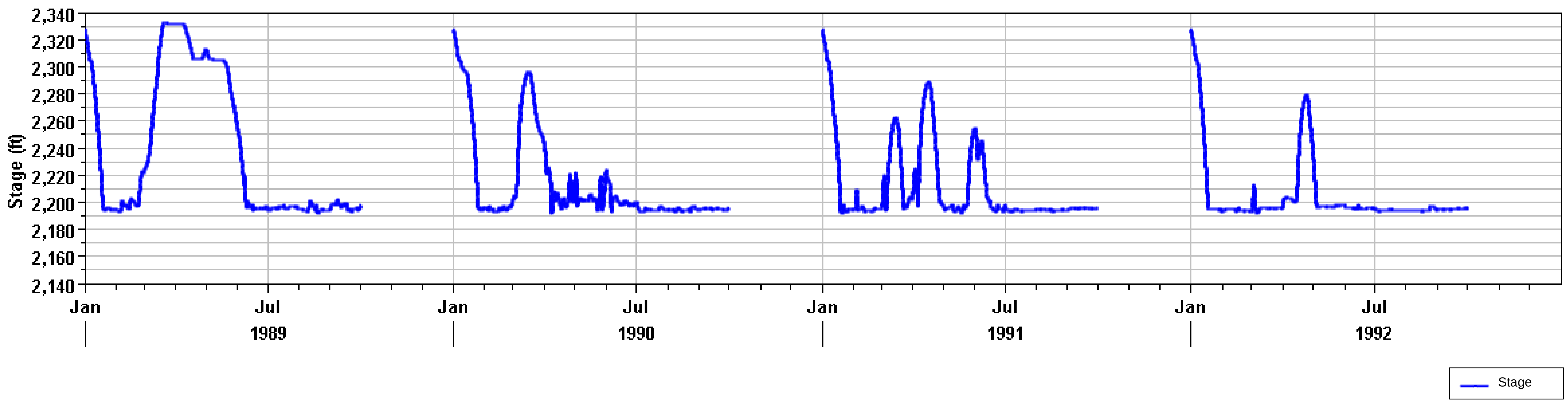

Figure 59: Iron Gate Drawdown Stage for years 1989 through 1992

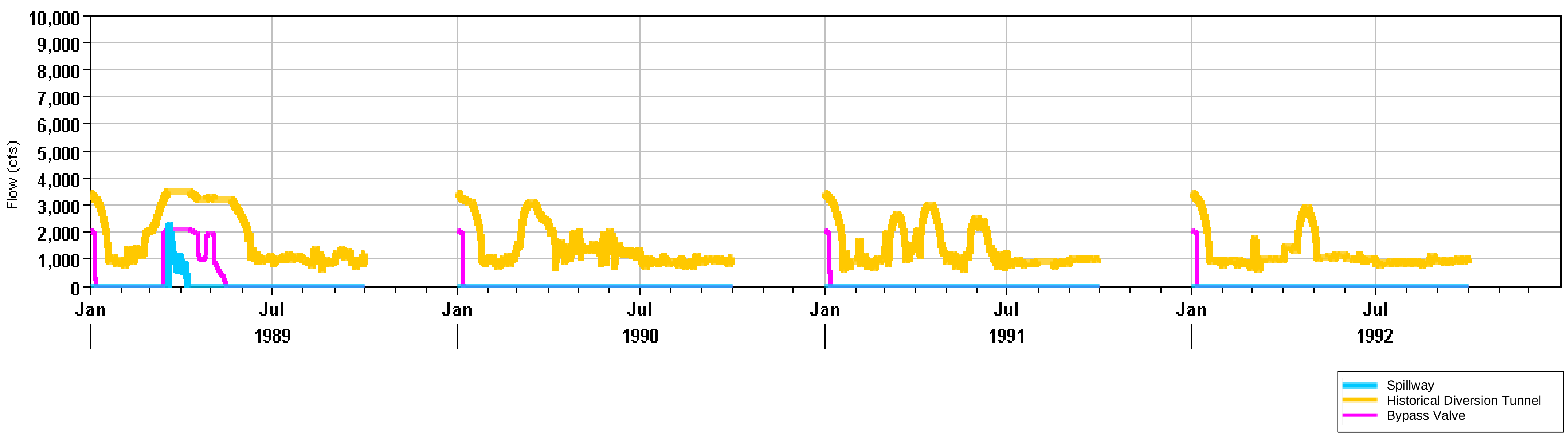

Figure 60 Iron Gate Structure Outlet Flows for years 1989 through 1992

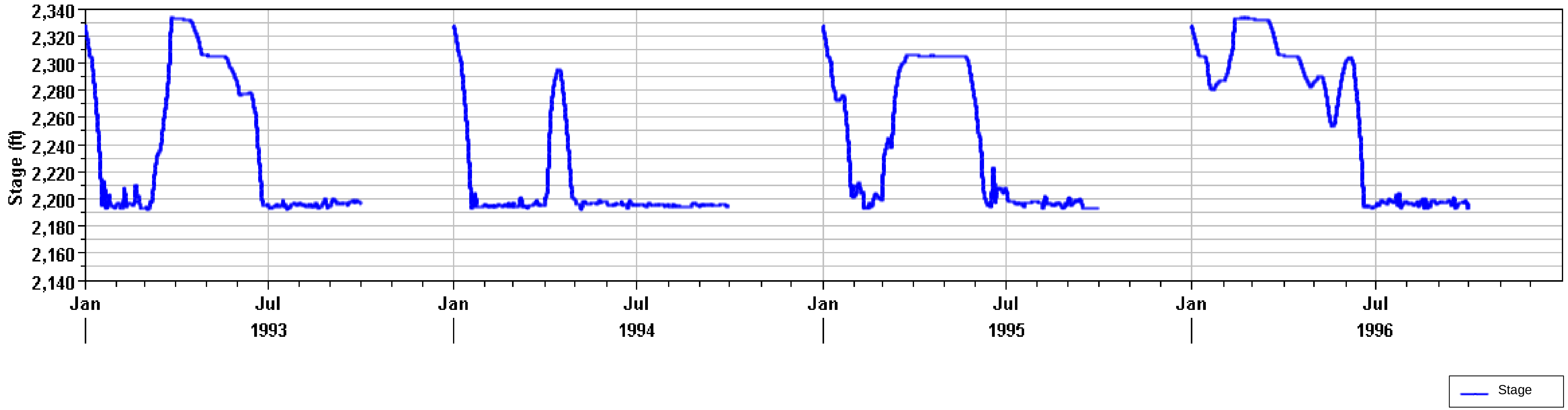

Figure 61: Iron Gate Drawdown Stage for years 1993 through 1996

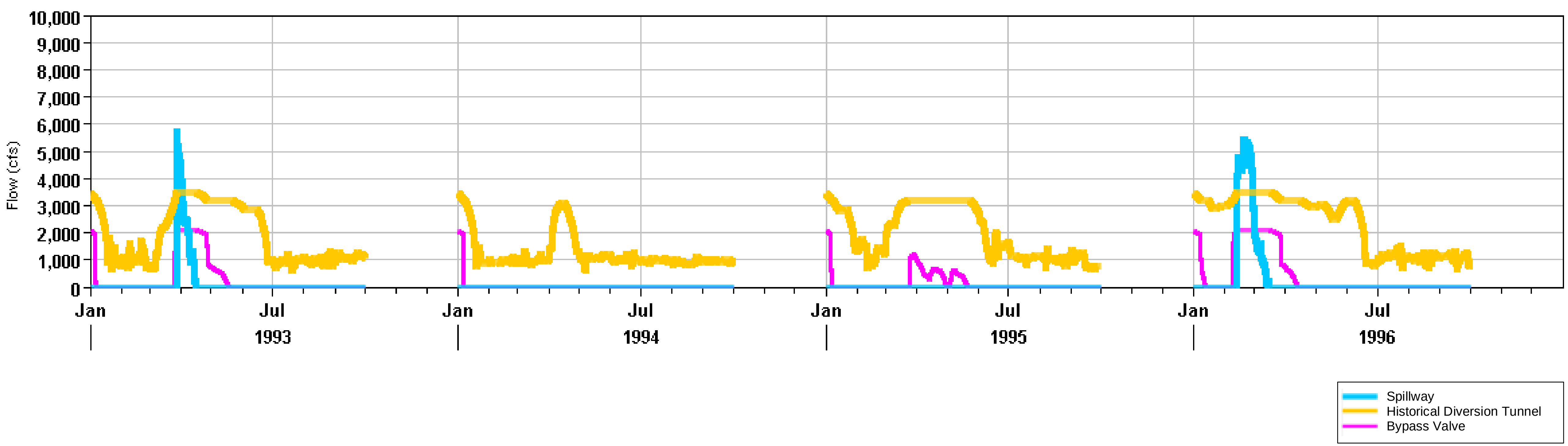

Figure 62: Iron Gate Structure Outlet Flows for years1993 through 1996

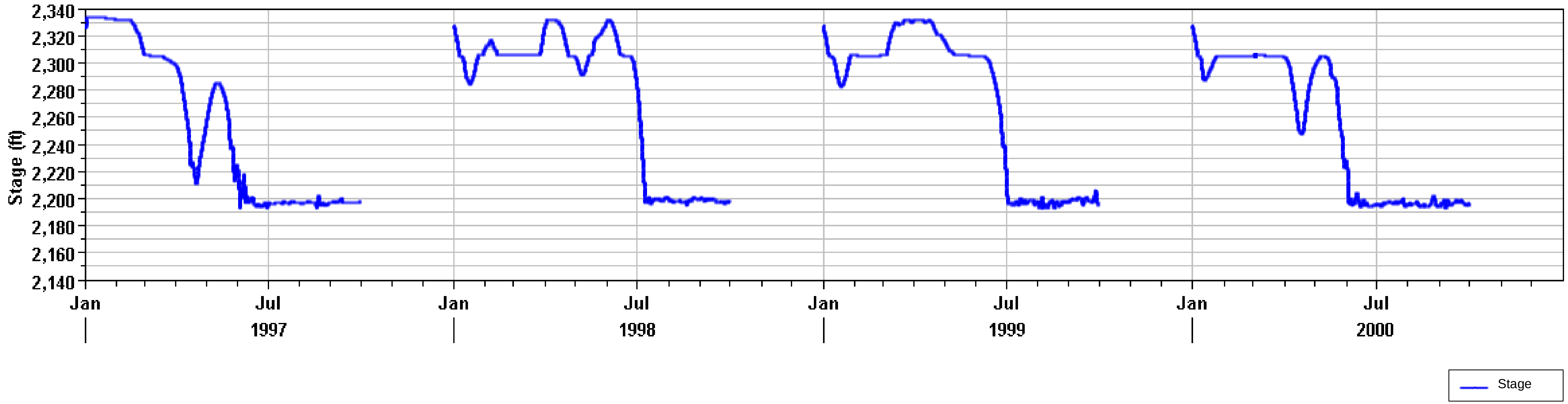

Figure 63: Iron Gate Drawdown Stage for years 1997 through 2000

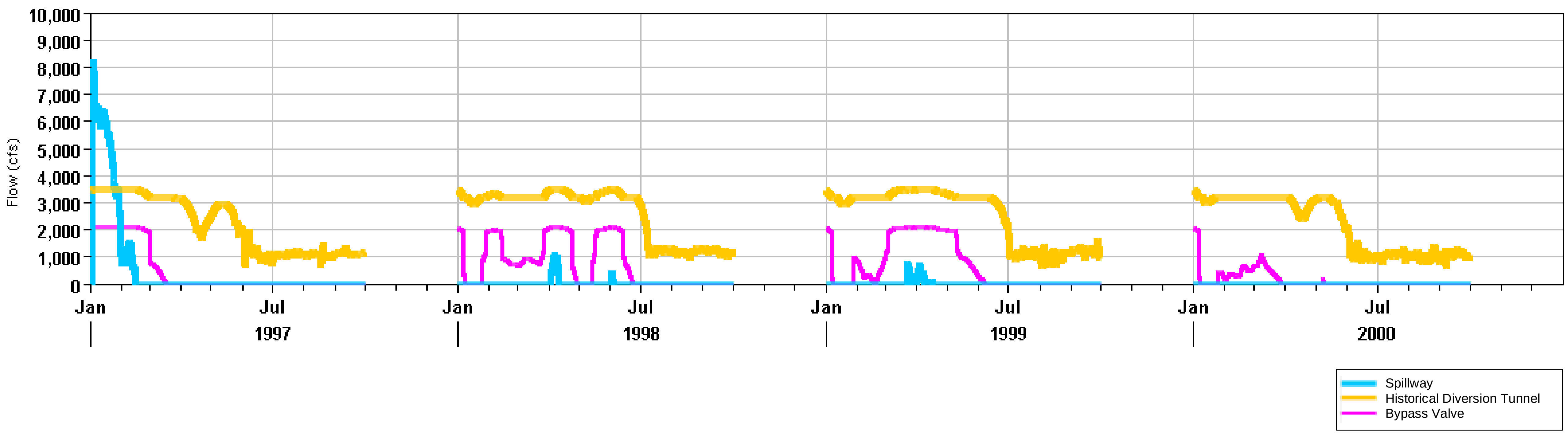

Figure 64: Iron Gate Structure Outlet Flows for years 1997 through 2000

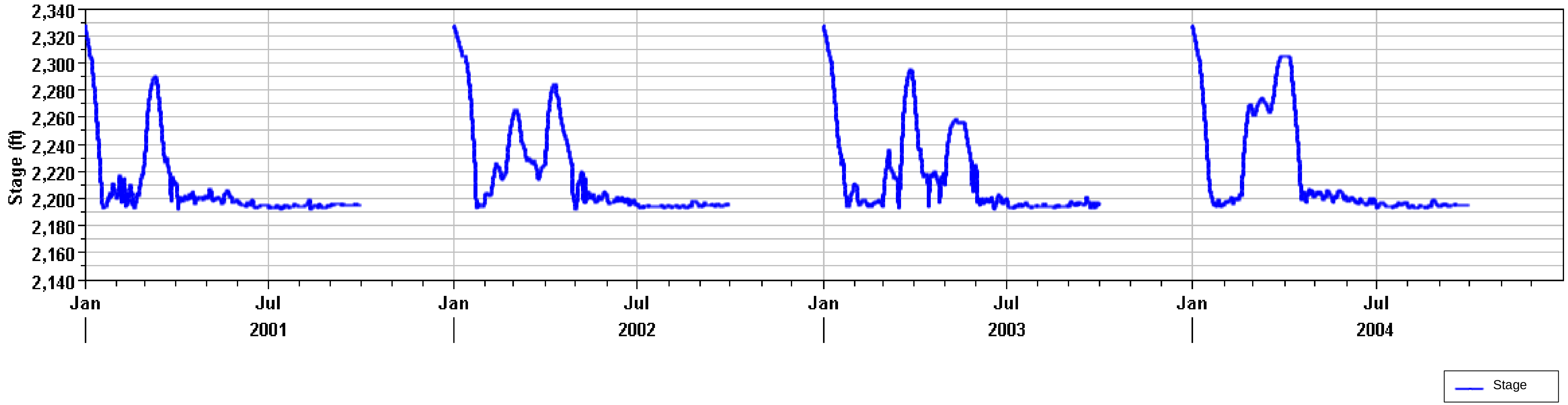

Figure 65: Iron Gate Drawdown Stage for years 2001 through 2004

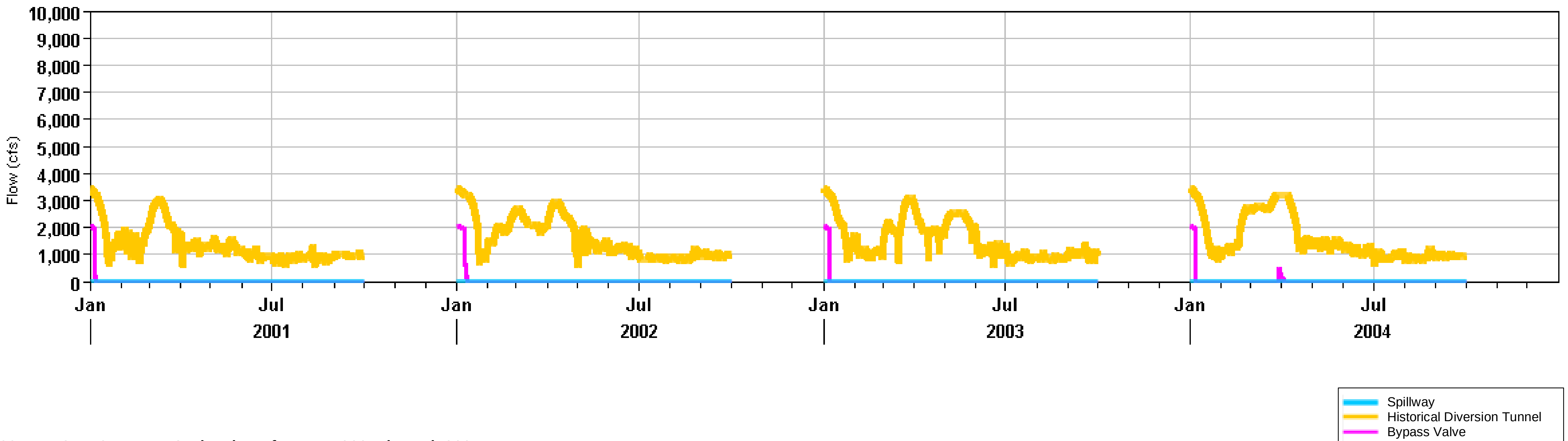

Figure 66: Iron Gate Structure Outlet Flows for years 2001 through 2004

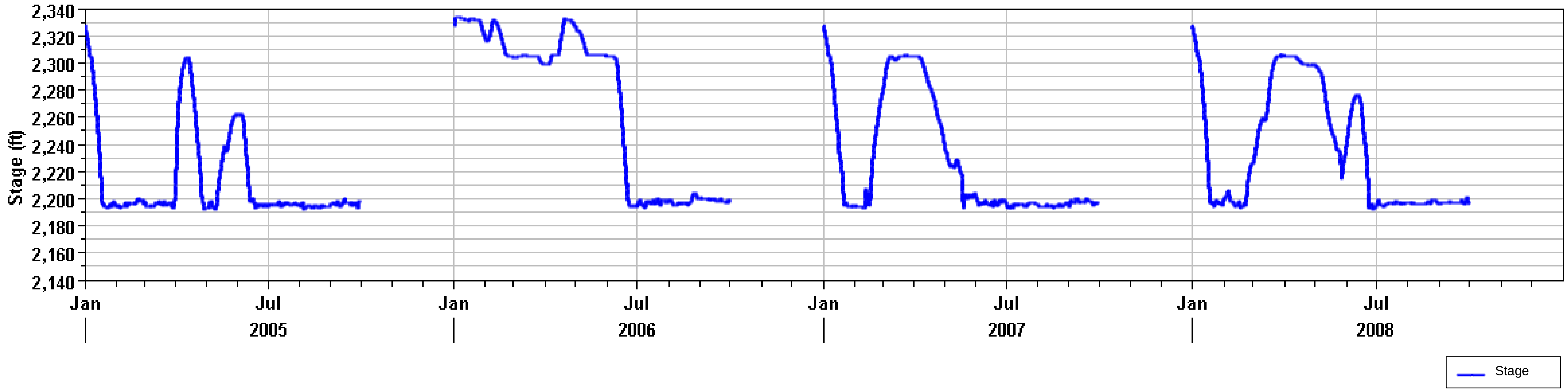

Figure 67: Iron Gate Drawdown Stage for years 2005 through 2008

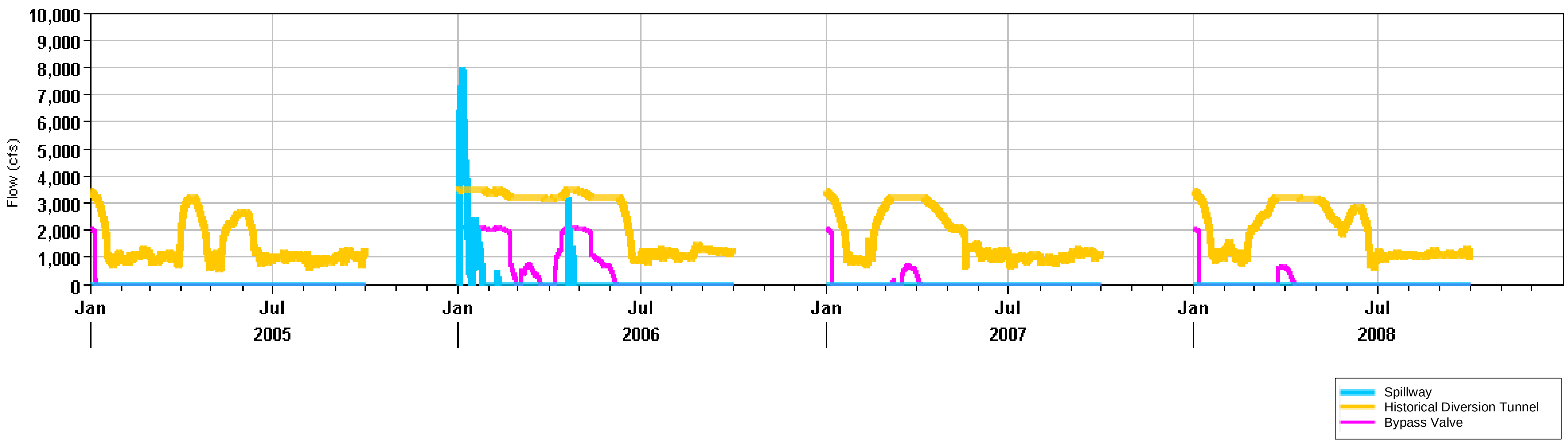

Figure 68: Iron Gate Structure Outlet Flows for years 2005 through 2008

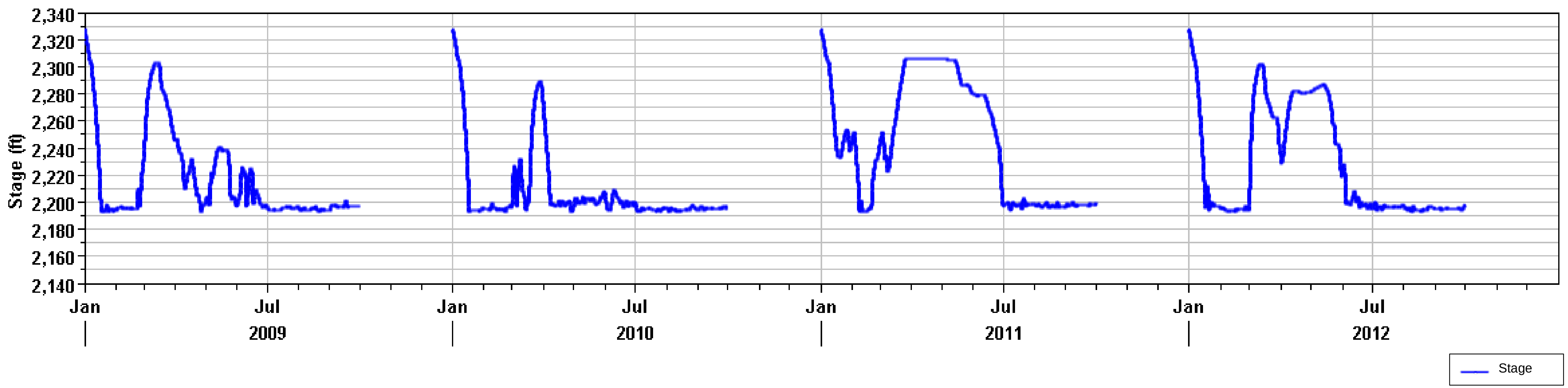

Figure 69: Iron Gate Drawdown Stage for years 2009 through 2012

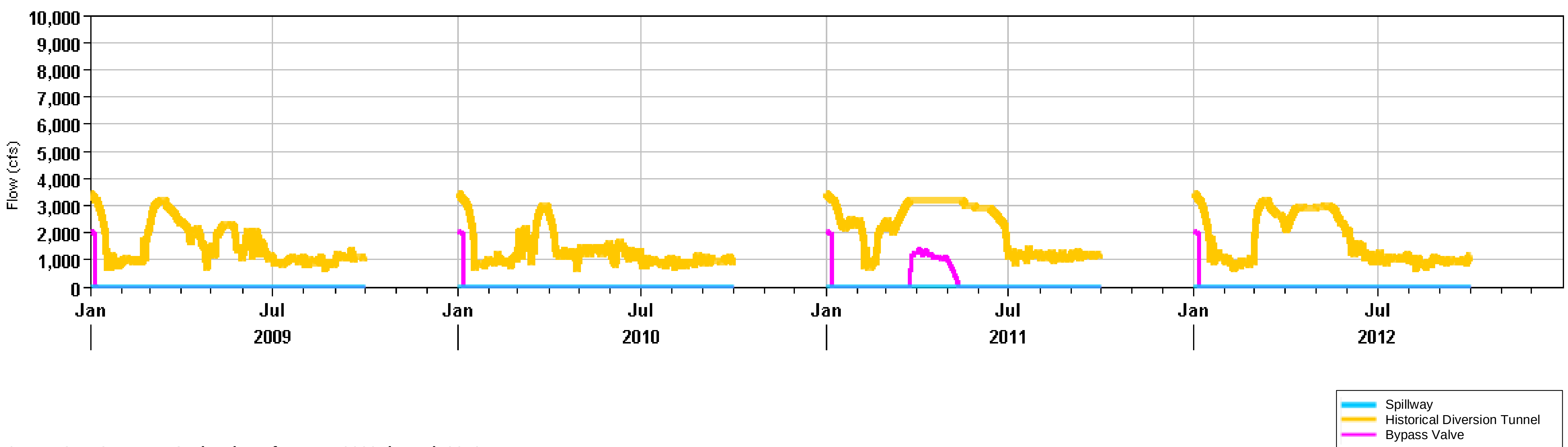

Figure 70: *Iron Gate* Structure Outlet Flows for years 2009 through 2012

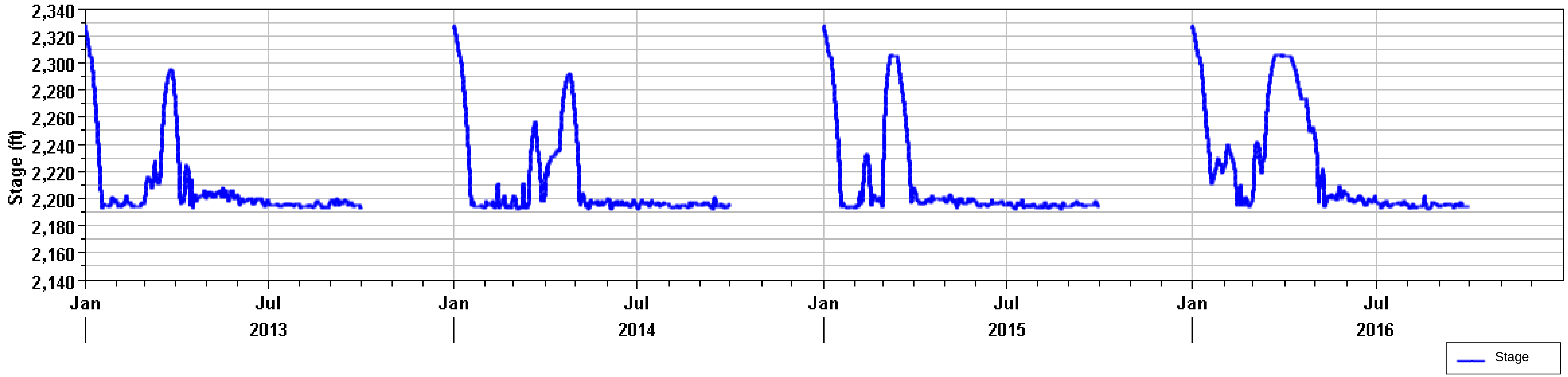

Figure 71: Iron Gate Drawdown Stage for years 2013 through 2016

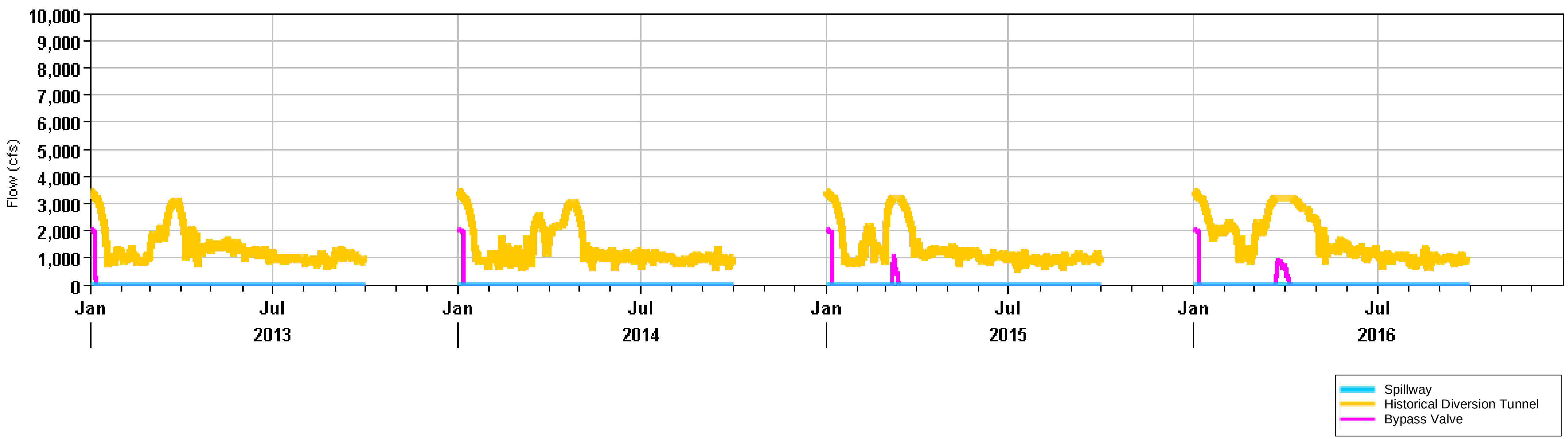

Figure 72: Iron Gate Structure Outlet Flows for years 2013 through 2016