MEMORANDUM

Date: May 6, 2019
To: Andrea McNamara Doyle and Chrissy Bailey, Office of Chehalis Basin
From: Adam Hill, PE, Anchor QEA; Larry Karpack, PE, Watershed Science and Engineering
Cc: Heather Page, Anchor QEA
Re: Chehalis River Basin Climate Change Flows and Flooding Results

Purpose

This memorandum documents the preparation of streamflow and flooding estimates under future climate change conditions. The streamflow estimates use the information contained in the Chehalis River Basin Hydrologic Modeling (WSE 2019a) technical memorandum combined with U.S. Geological Survey (USGS) flow records to develop flows under future climate change conditions. The flows were input to the 2D model developed for the Chehalis River Basin Existing Conditions RiverFlow2D Model Development and Calibration (WSE 2019b) technical memorandum to estimate flooding conditions under future climate change conditions.

The results of these analyses will be used for other technical studies that require estimates of streamflow and resulting hydraulic conditions under climate change, providing baseline technical study information for the Chehalis Basin Strategy.

Streamflow Under Climate Change Conditions

Factor for Increasing Peak Flows

The factors applied to increasing peak flows were developed using results from the Chehalis River Basin Hydrologic Modeling technical memorandum (WSE 2019a). Table 1 provides the peak flow increases recommended by Watershed Science and Engineering (WSE) for climate change conditions for mid-century conditions (2016 to 2060) and late-century conditions (2055 to 2099).

Table 1
Peak Flow Increases Due to Climate Change

CLIMATE CHANGE SCENARIO	PEAK FLOW INCREASE	RATIONALE
Mid-century	12%	Average of RCP 4.5 and RCP 8.5 average peak flow mid-century increase (15 sites)
Late-century	26%	RCP 8.5 average peak flow late-century increase (15 sites)

Notes:
Source: WSE 2019a
RCP: Representative Concentration Pathway

Seasonal Flow Adjustment

Analyses performed for peak flows were also applied to streamflow outside of peak flow periods. Streamflows from the same 15 sites analyzed in Chehalis River Basin Hydrologic Modeling technical memorandum (WSE 2019a) were analyzed to determine the change in average monthly flows throughout the modeling period of record. It was projected that flows increase from November to April and decrease from May to October.

To simplify the development of flows under climate change conditions, a single flow increase or decrease was determined for those 6-month periods for mid-century and late-century flow conditions using the average of flow changes across the 15 sites. Table 2 lists the adjustments to flow determined using that method.

Table 2
Flow Adjustment Factors Due to Climate Change

CLIMATE CHANGE SCENARIO	PERIOD	FLOW CHANGE
Mid-century	November to April (Winter; high flow)	4%
	May to October (Summer; low flow)	-11%
Late-century	November to April (Winter; high flow)	5%
	May to October (Summer; low flow)	-16%

Flow Records Used to Develop Climate Change

Streamflow generated by hydrologic modeling was not used in this analysis because the hydrologic model, "does a good job of replicating flow frequency results at some locations and recurrence intervals, and it does poorly at other locations" (WSE 2019a). To avoid bias in estimating streamflow under climate change for particular locations or gages, the adjustments to streamflow basin-wide, as shown in Tables 1 and 2, were applied to historical flows from active USGS gages. Table 3 provides a list of USGS gages and the type of data available and used in the analysis.

Table 3
Gages and Data Used in Flow Record Development

GAGE NAME	GAGE NO.	DATA USED
Chehalis River near Doty (Doty gage)	12020000	Hourly flow; Daily flow
Chehalis River near Grand Mound (Grand Mound gage)	12027500	Hourly flow; Daily flow
Chehalis River near Porter (Porter gage)	12031000	Daily flow
South Fork Chehalis River near Wildwood (South Fork gage)	12020800	Daily flow
Newaukum River near Chehalis (Newaukum gage)	12025000	Daily flow
Skookumchuck River near Bucoda (Skookumchuck gage)	12026400	Daily flow
Satsop River near Satsop (Satsop gage)	12035000	Daily flow
Wynoochee River above Black Creek near Montesano (Wynoochee gage)	12037400	Daily flow

Source: USGS 2019

Development of Flows Under Climate Change Conditions

Both hourly and daily flows under future climate change conditions were developed, depending on the gage analyzed and the technical study requirements the flows are being used for. To maintain consistency through all flow data development, data from a single period of record were used in flow development, from October 1988 to September 2018 (Water Years 1989 to 2018). This 30-year period of record was chosen because it is the period of record available for the hourly data at Doty gage (the shortest hourly period of record of gages used).

The summer flow adjustments were applied directly to the gage data to develop climate change flows.

Because the winter flow adjustments also include peak flow events, the flow change outside of peak flow events was reduced to balance the total volume of flow for winter. To determine that factor, the period that peak flow increases (Table 1) would occur was first defined. The period was assumed to be when the flow was above the 1% flow exceedance value for the period of record used (water years 1989 to 2018). Table 4 lists the 1% exceedance flows for the gages used in the climate change analyses.

Table 4
One-Percent Exceedance Flows

GAGE NAME	1% EXCEEDANCE FLOW (CUBIC FEET PER SECOND)
Doty gage	4,830 (Hourly flow); 4,690 (Daily flow)
Grand Mound gage	20,500 (Hourly flow); 20,100 (Daily flow)
Porter gage	25,840
South Fork gage	1,570
Newaukum gage	3,660
Skookumchuck gage	2,520
Satsop gage	15,040
Wynoochee gage	8,950

During storms with flows exceeding the thresholds listed in Table 4, the flows were multiplied by the factors in Table 1. The volume of flow in those events was calculated and the remainder of winter flows multiplied by factors until the total volume of winter flow agreed with the factors in Table 2. This non-peak factor was found to be 3% in both mid-century and late-century climate change conditions.

Although different thresholds were used for hourly and daily data for Doty and Grand Mound gages to maintain consistency in the flow calculations, the difference was minor, and a single factor of 3% was used for all non-peak flow adjustments.

A streamflow record for mid-century and late-century conditions was prepared for each gage listed in Table 3 using the adjustments described above. Streamflow data are not included in this memorandum because of their size; the data was provided to Office of Chehalis Basin in spreadsheet format. To

illustrate the change in flow, streamflow under climate change conditions for each gage listed in Table 3 was plotted against the historical streamflow records for 1996, 2009, and 2011. Those years contain a range of flow conditions, and the climate change flows based upon those years were used in EDT modeling. The plots are provided in Appendix A. Also included in Appendix A are the estimated change in flow during 10-year and 100-year flood events. The development of 10-year and 100-year hydrographs for current conditions are described in the Statistical Hydrology technical memorandum (WSE 2014). Peak flow adjustments from Table 1 were made to those hydrographs to estimate climate change conditions for those events.

Hydraulic Analyses

Hydraulic Model Used

A RiverFlow2D model was developed to model the hydraulics of the Chehalis River from River Mile 108 to the Porter gage at River Mile 33. Full details of the work completed are described in the WSE technical memorandum (WSE 2019b).

Climate Change Conditions

To evaluate climate change conditions, flows in the RiverFlow2D model were updated using the 10-year and 100-year events for mid-century and late-century periods shown in Figures A-25 and A-26. Tables 5 (mid-century) and 6 (late-century) show the water surface elevations at 21 locations along the Chehalis River from the RiverFlow2D model results.

Comprehensive water level data are not included in this memorandum because of their size; the data along with GIS maps of floodplain boundaries and depth of flooding were provided to Office of Chehalis Basin.

Table 5
RiverFlow2D Modeled Water Surface Elevation Results, Mid-Century Conditions

LOCATION	10-YEAR ELEVATION (FEET)	100-YEAR ELEVATION (FEET)
Near Doty	312.9	321.1
Curtis Store (on South Fork Chehalis River)	229.9	233.0
Downstream of South Fork Chehalis River	215.3	221.3
Near Adna	195.8	198.5
Labree Road Bridge (on Newaukum River)	205.7	206.3
Newaukum Confluence	183.3	186.4
Dillenbaugh Creek at I-5	182.5	186.6
South End of Airport Riverward of Levee	178.5	182.5
South End of Airport Landward of Levee	Dry	181.6
North End of Airport Riverward of Levee	175.3	180.9
North End of Airport Landward of Levee	Dry	181.6
Mellen Street Bridge	172.6	177.8
Mellen Street East of I-5	173.0	177.5

LOCATION	10-YEAR ELEVATION (FEET)	100-YEAR ELEVATION (FEET)
Skookumchuck Confluence	171.0	176.3
Upstream of Galvin Road	163.9	168.5
Grand Mound (Prather Road Bridge)	144.5	147.1
Near Rochester	121.9	124.8
Anderson Road	108.9	111.1
Black River Confluence	91.6	95.2
Sickman Ford Bridge	79.8	83.5
Porter Creek Road Bridge	51.2	54.2

Table 6

RiverFlow2D Modeled Water Surface Elevation Results, Late-Century Conditions

LOCATION	10-YEAR ELEVATION (FEET)	100-YEAR ELEVATION (FEET)
Near Doty	314.3	323.0
Curtis Store (on South Fork Chehalis River)	230.3	234.4
Downstream of South Fork Chehalis River	216.3	222.7
Near Adna	196.4	198.9
Labree Road Bridge (on Newaukum River)	205.9	206.5
Newaukum Confluence	183.8	186.9
Dillenbaugh Creek at I-5	183.5	187.1
South End of Airport Riverward of Levee	179.3	183.4
South End of Airport Landward of Levee	Dry	183.2
North End of Airport Riverward of Levee	176.4	182.3
North End of Airport Landward of Levee	162.9	182.4
Mellen Street Bridge	173.9	178.9
Mellen Street East of I-5	173.8	179.3
Skookumchuck Confluence	172.3	177.6
Upstream of Galvin Road	164.9	169.7
Grand Mound (Prather Road Bridge)	145.0	147.9
Near Rochester	122.5	125.7
Anderson Road	109.4	111.7
Black River Confluence	92.3	96.2
Sickman Ford Bridge	80.5	84.6
Porter Creek Road Bridge	51.8	55.3

References

USGS (U.S. Geological Survey), 2019. *NWIS Site Information for Washington: Site Inventory*. Accessed March 14, 2019. Available at https://waterdata.usgs.gov/wa/nwis/inventory/.

WSE (Watershed Science and Engineering), 2019a. Memorandum to: Robert Montgomery, Anchor QEA, LLC. Regarding: Chehalis River Basin Hydrologic Modeling. February 28, 2019.

WSE, 2019b. Memorandum to: Robert Montgomery, Anchor QEA, LLC. Regarding: Chehalis River Basin Existing Conditions RiverFlow2D Model Development and Calibration. February 28, 2019.

WSE, 2014. Memorandum to: Robert Montgomery, Anchor QEA, LLC. Regarding: Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species – Re-Evaluation of Statistical Hydrology and Design Storm Selection for the Chehalis River Basin. January 31, 2014.

Appendix A
Climate Change Flow Data Plots

Figure A-1:
Climate Change Flow Comparison - Doty Gage (Water Year 1996)

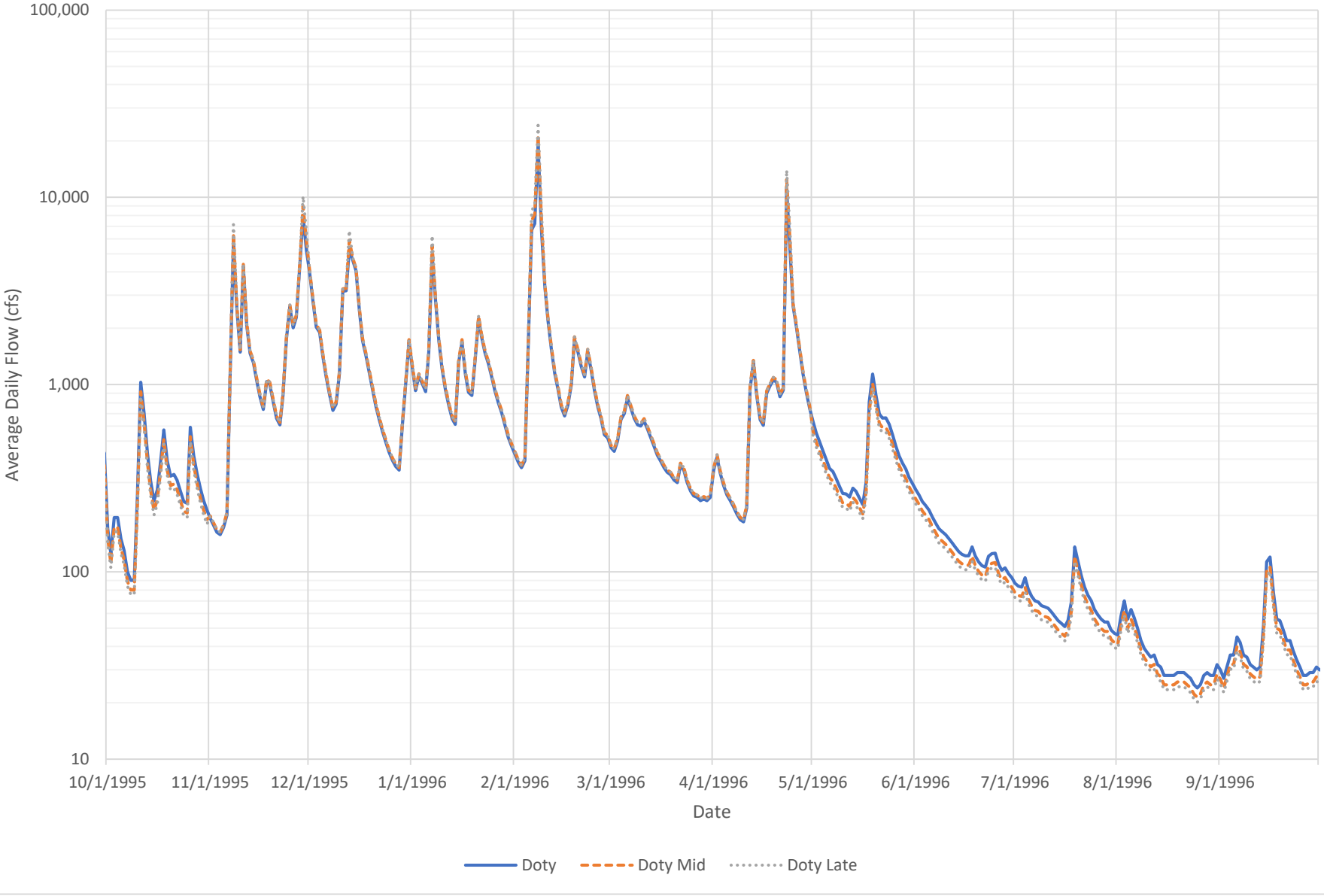

Figure A-2:
Climate Change Flow Comparison - Doty Gage (Water Year 2009)

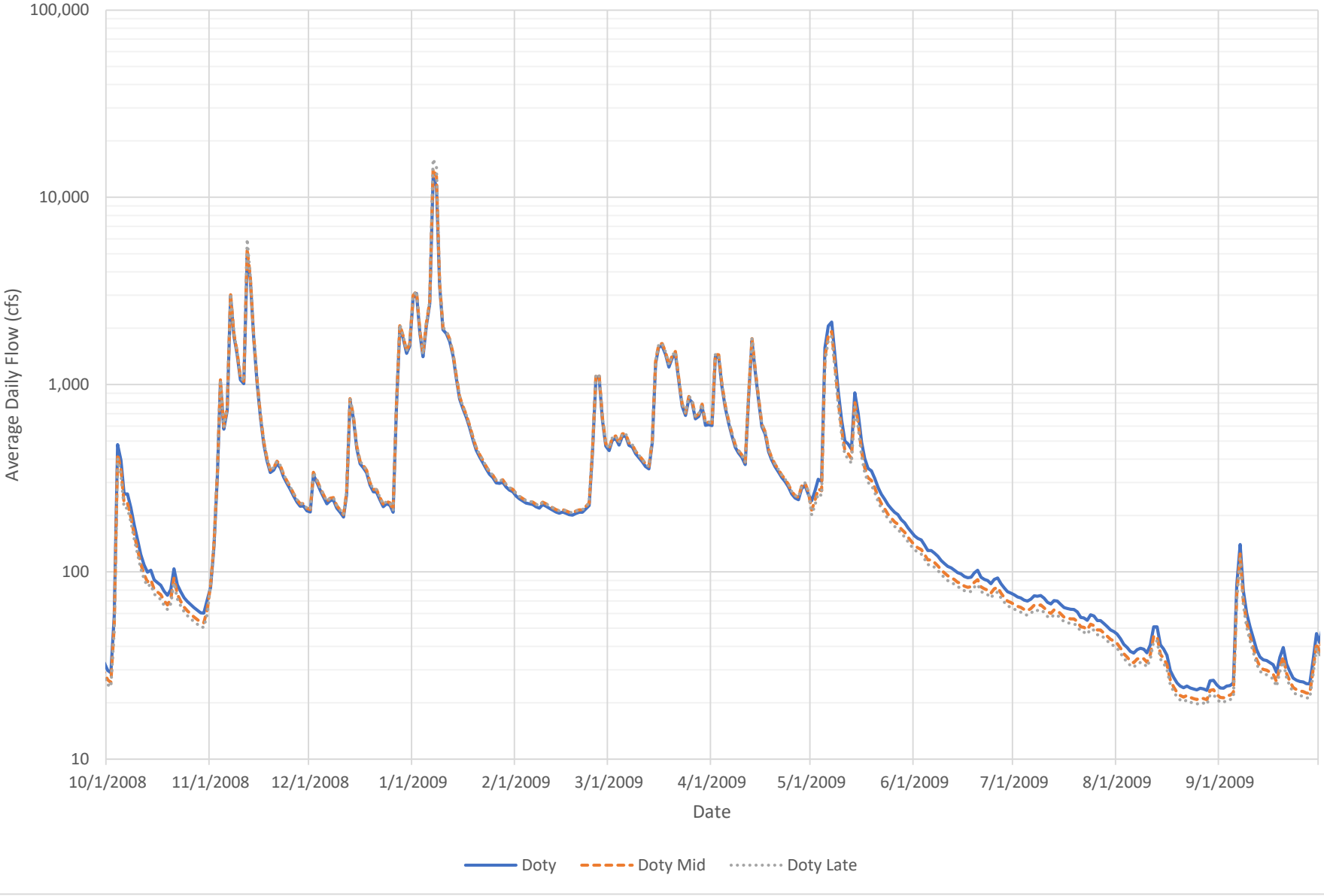

Figure A-3:
Climate Change Flow Comparison - Doty Gage (Water Year 2011)

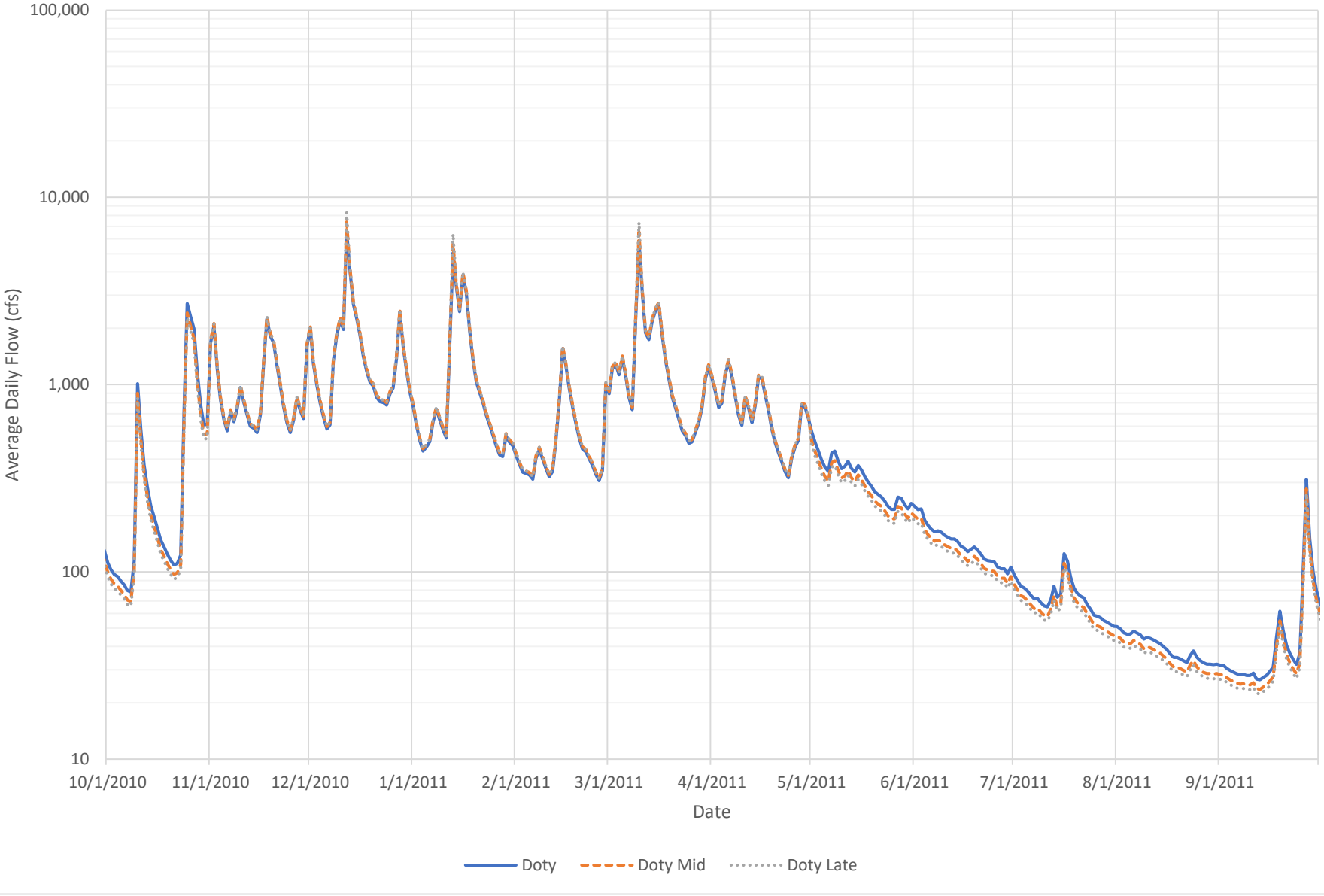

Figure A-4:
Climate Change Flow Comparison - Grand Mound Gage (Water Year 1996)

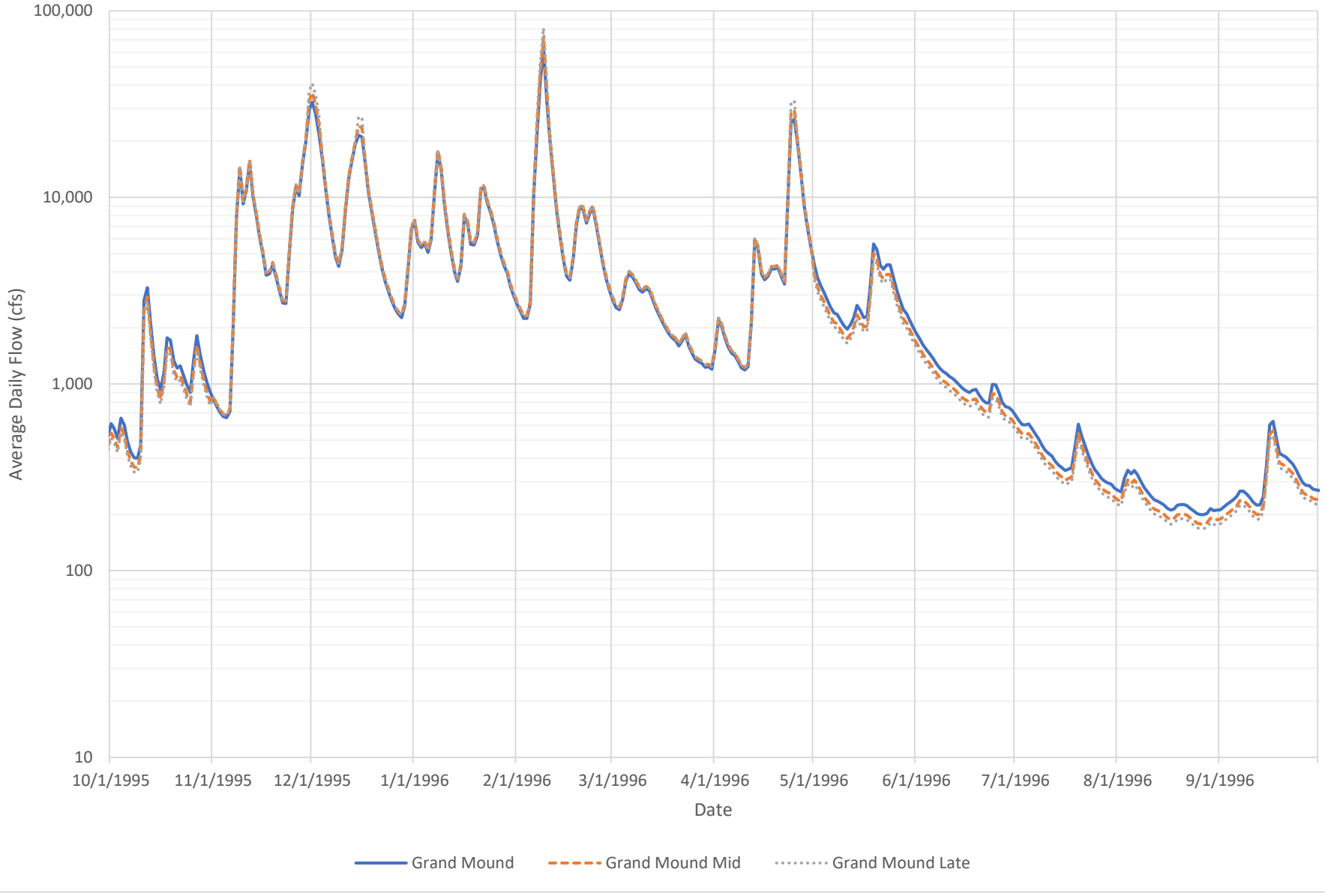

Figure A-5:
Climate Change Flow Comparison - Grand Mound Gage (Water Year 2009)

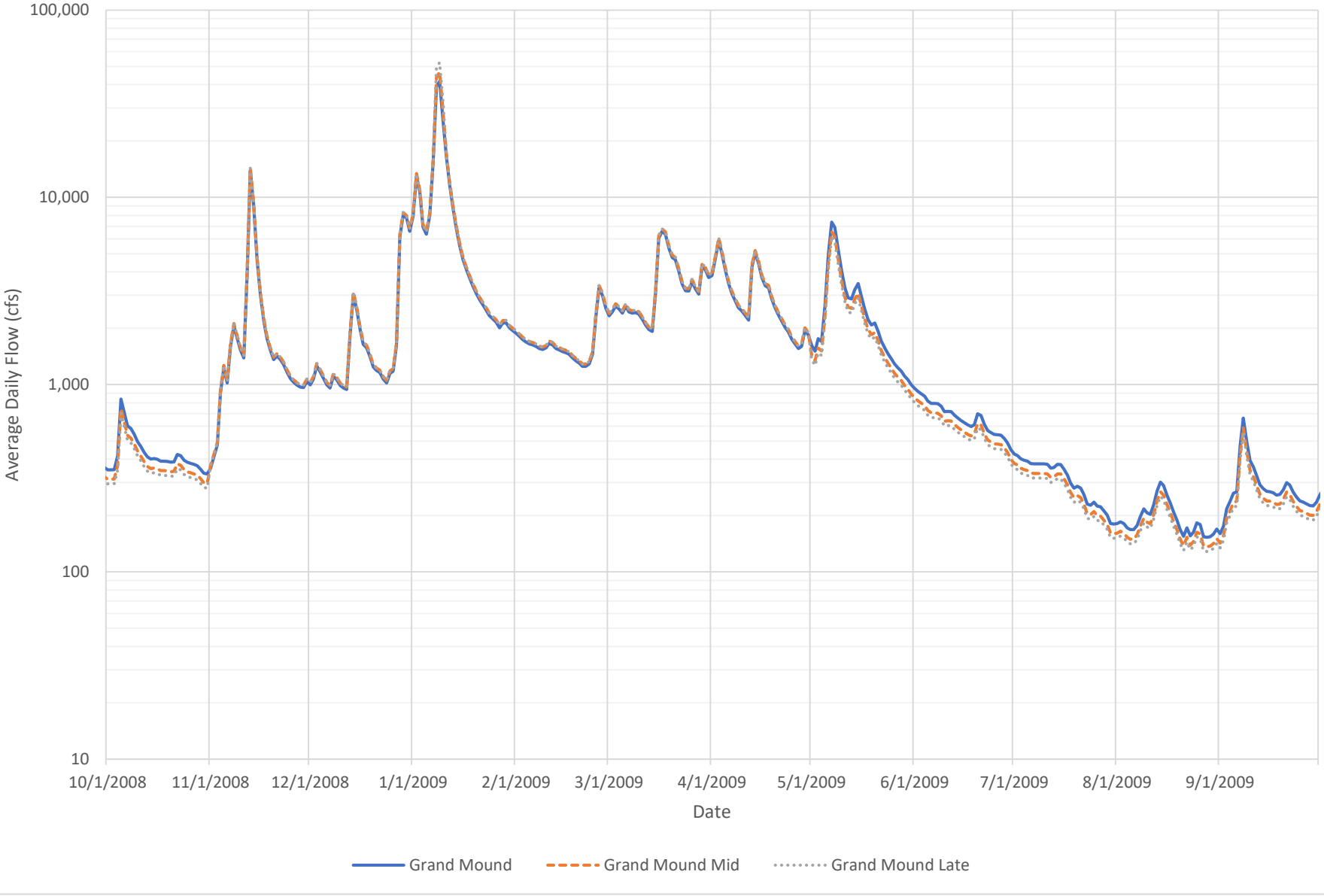

Figure A-6:
Climate Change Flow Comparison - Grand Mound Gage (Water Year 2011)

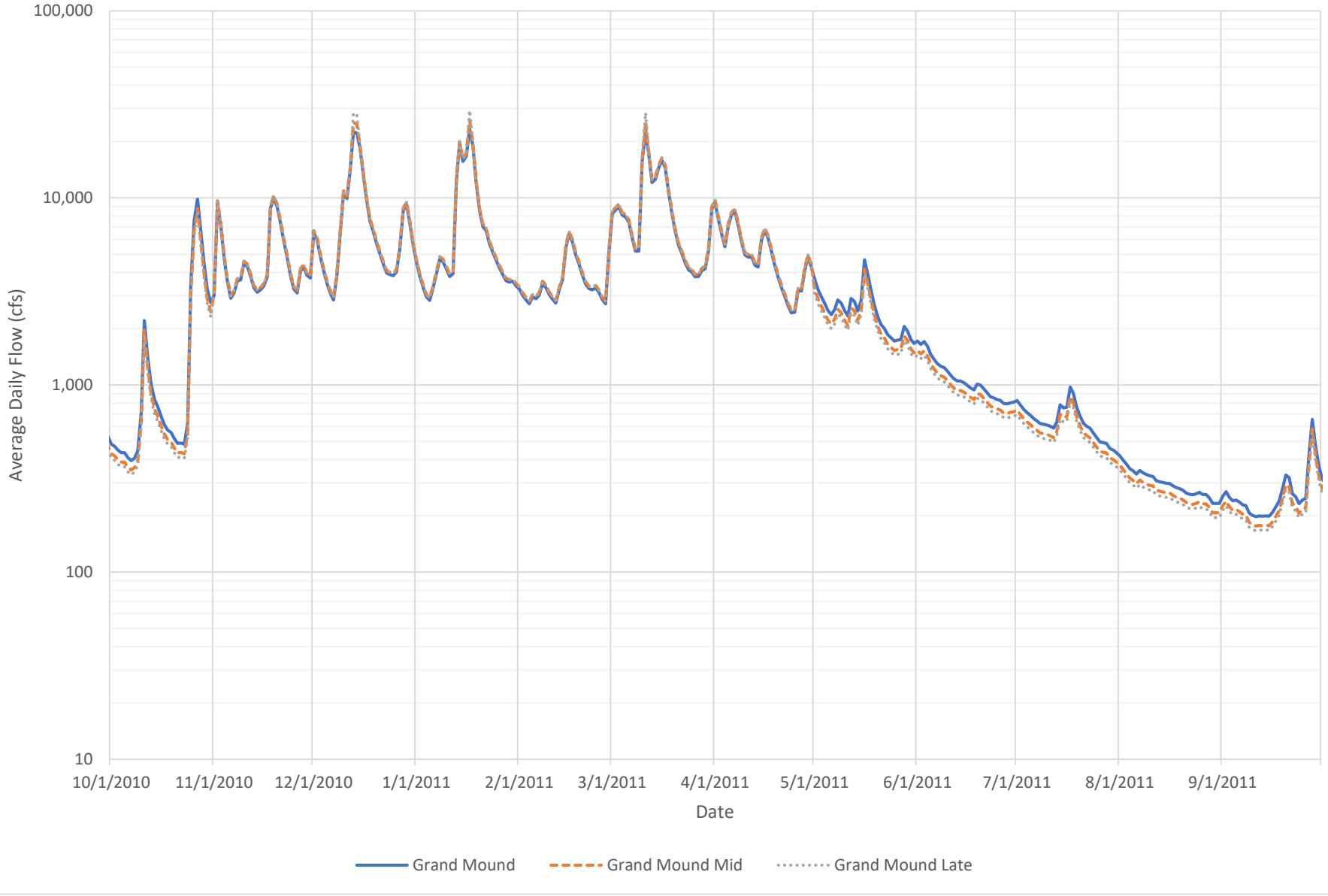

Figure A-7:
Climate Change Flow Comparison - Porter Gage (Water Year 1996)

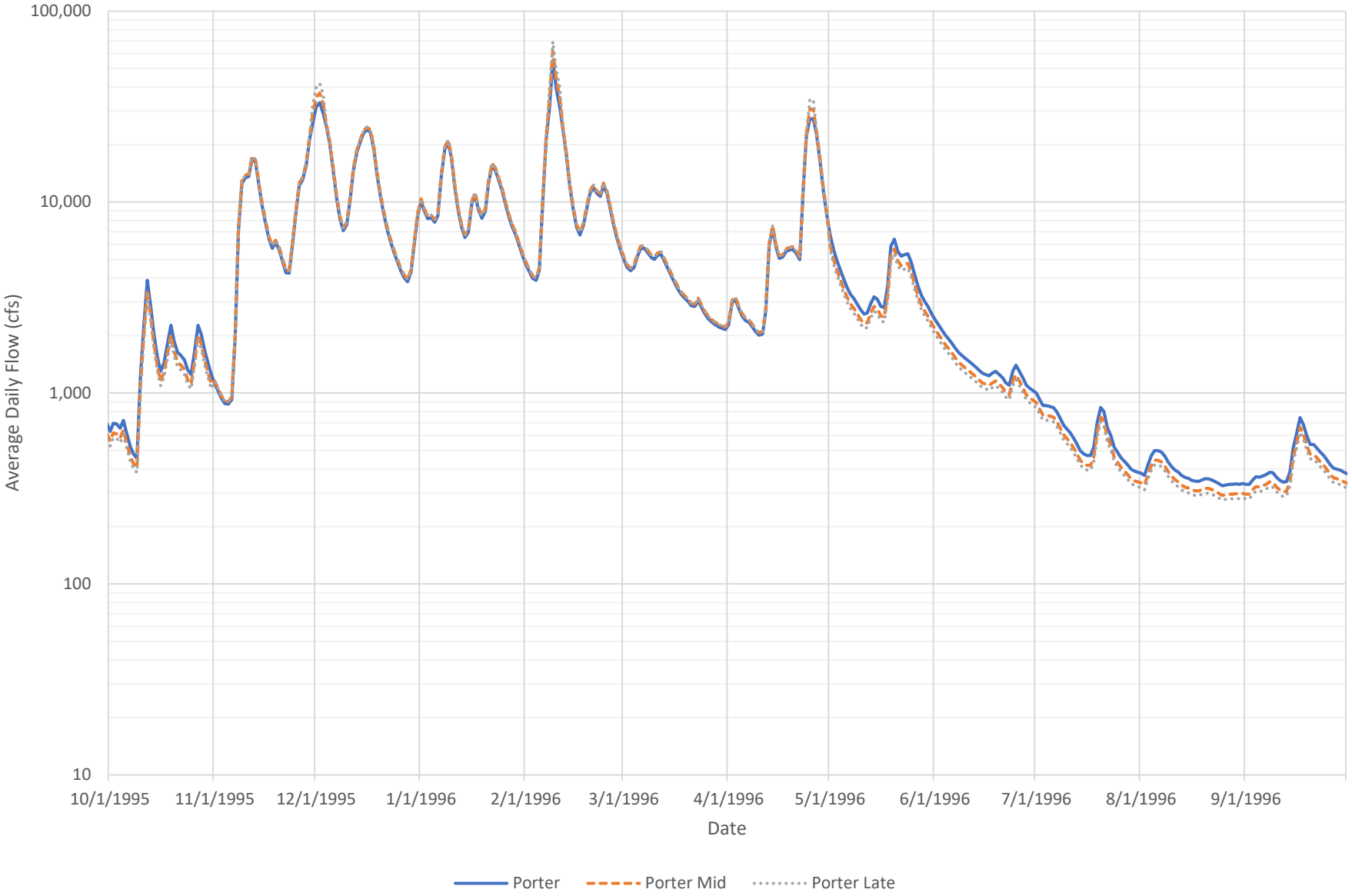

Figure A-8:
Climate Change Flow Comparison - Porter Gage (Water Year 2009)

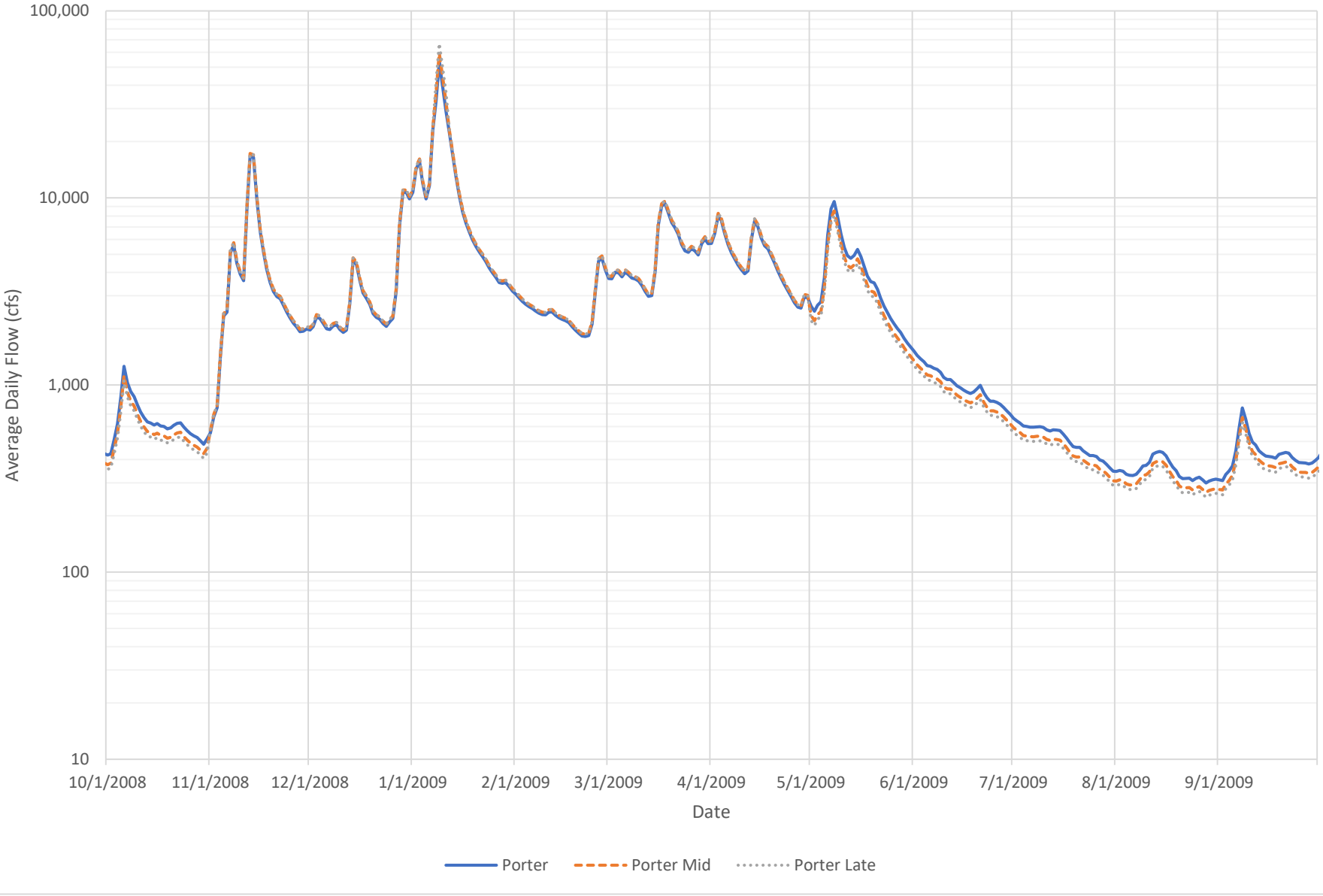

Figure A-9:
Climate Change Flow Comparison - Porter Gage (Water Year 2011)

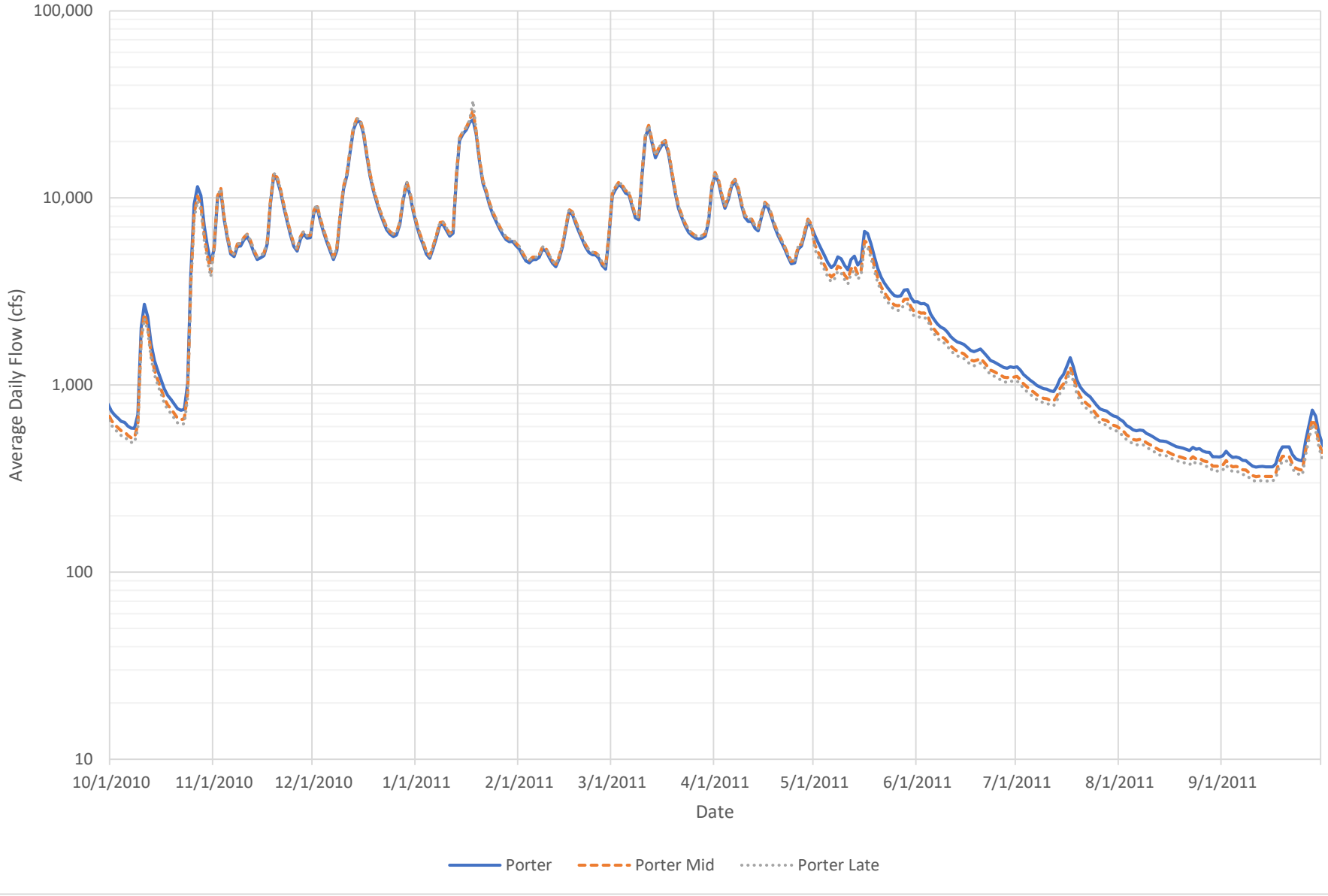

Figure A-10:
Climate Change Flow Comparison - South Fork Gage (Water Year 1996)

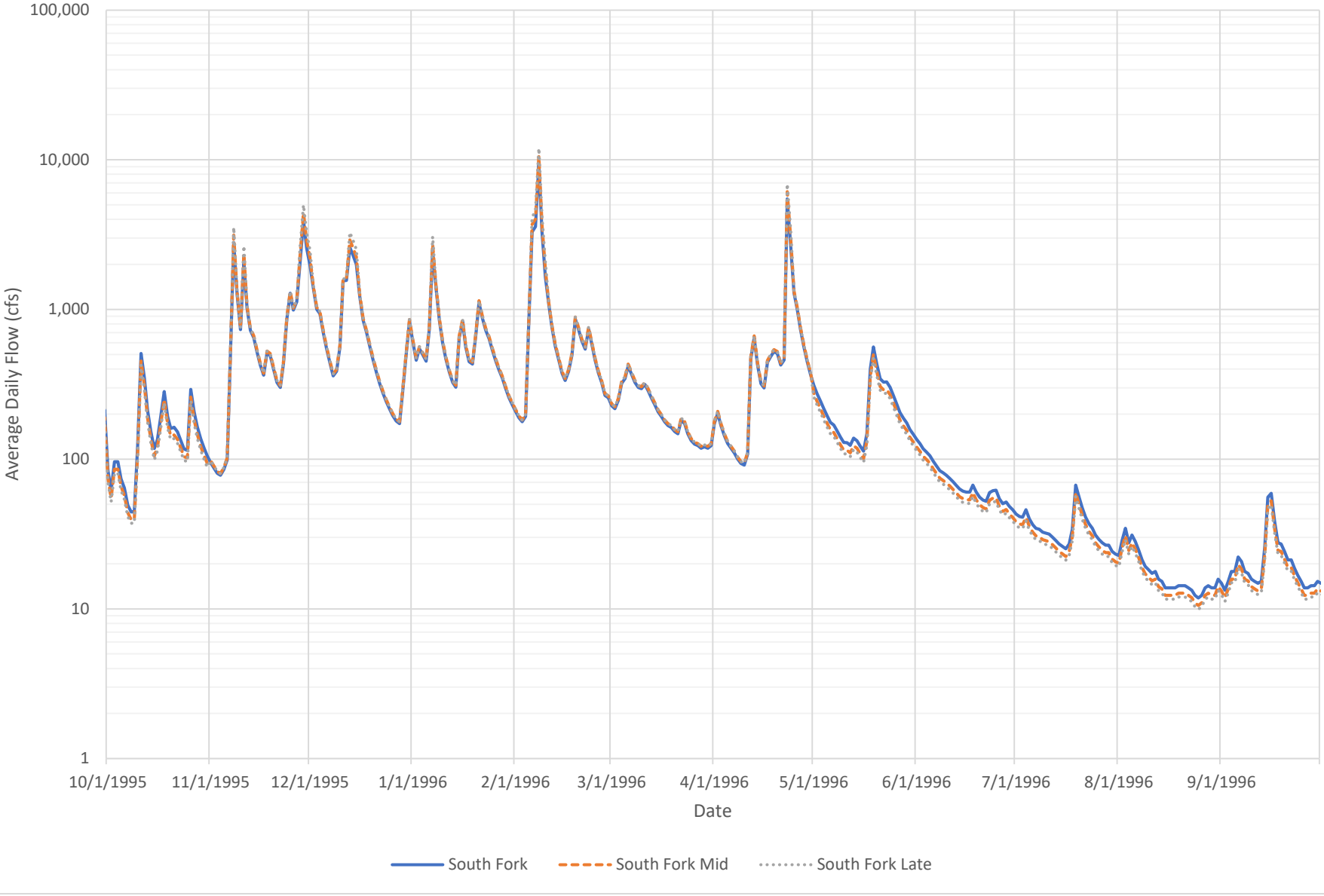

Figure A-11:
Climate Change Flow Comparison - South Fork Gage (Water Year 2009)

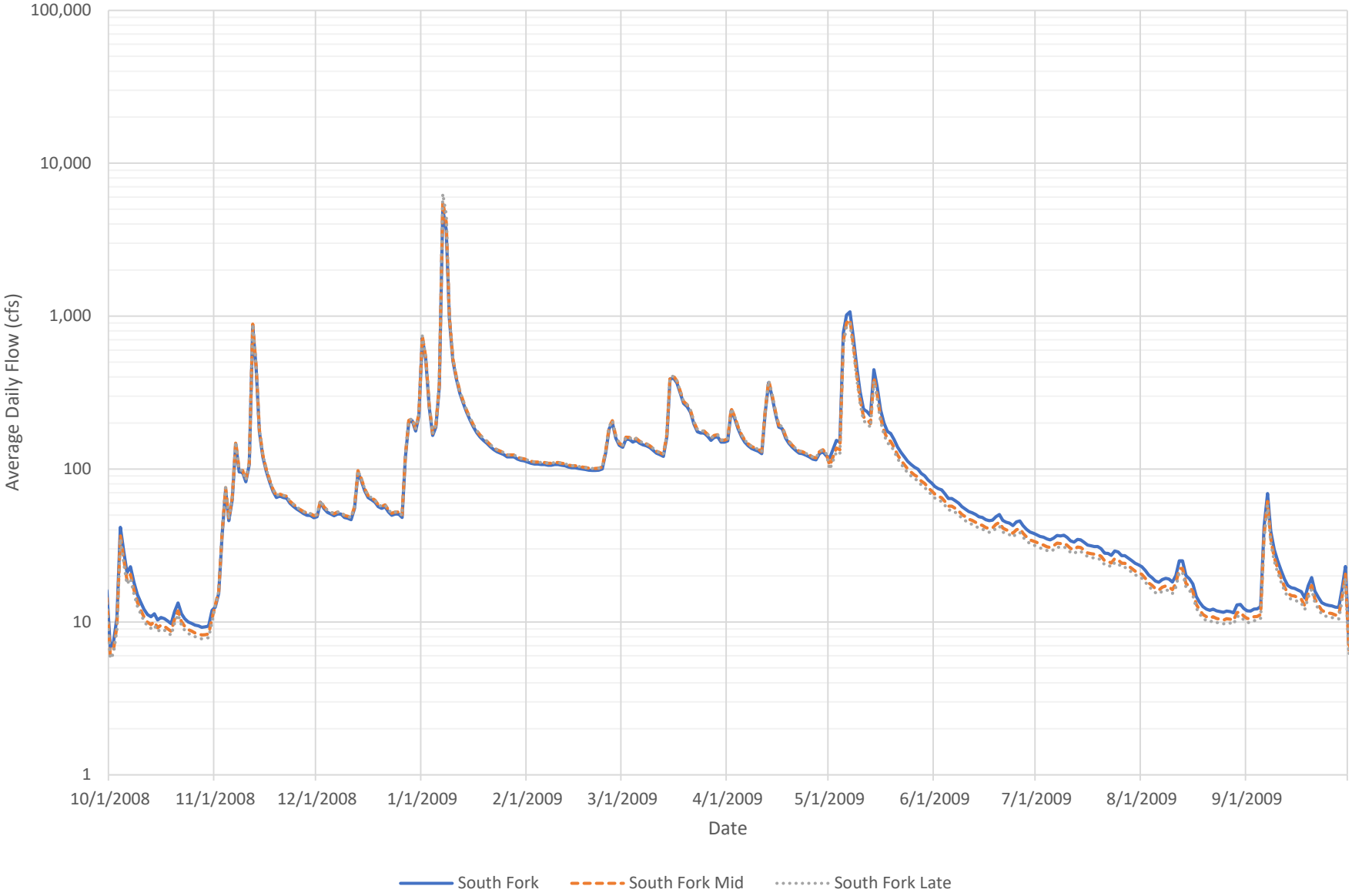

Figure A-12:
Climate Change Flow Comparison - South Fork Gage (Water Year 2011)

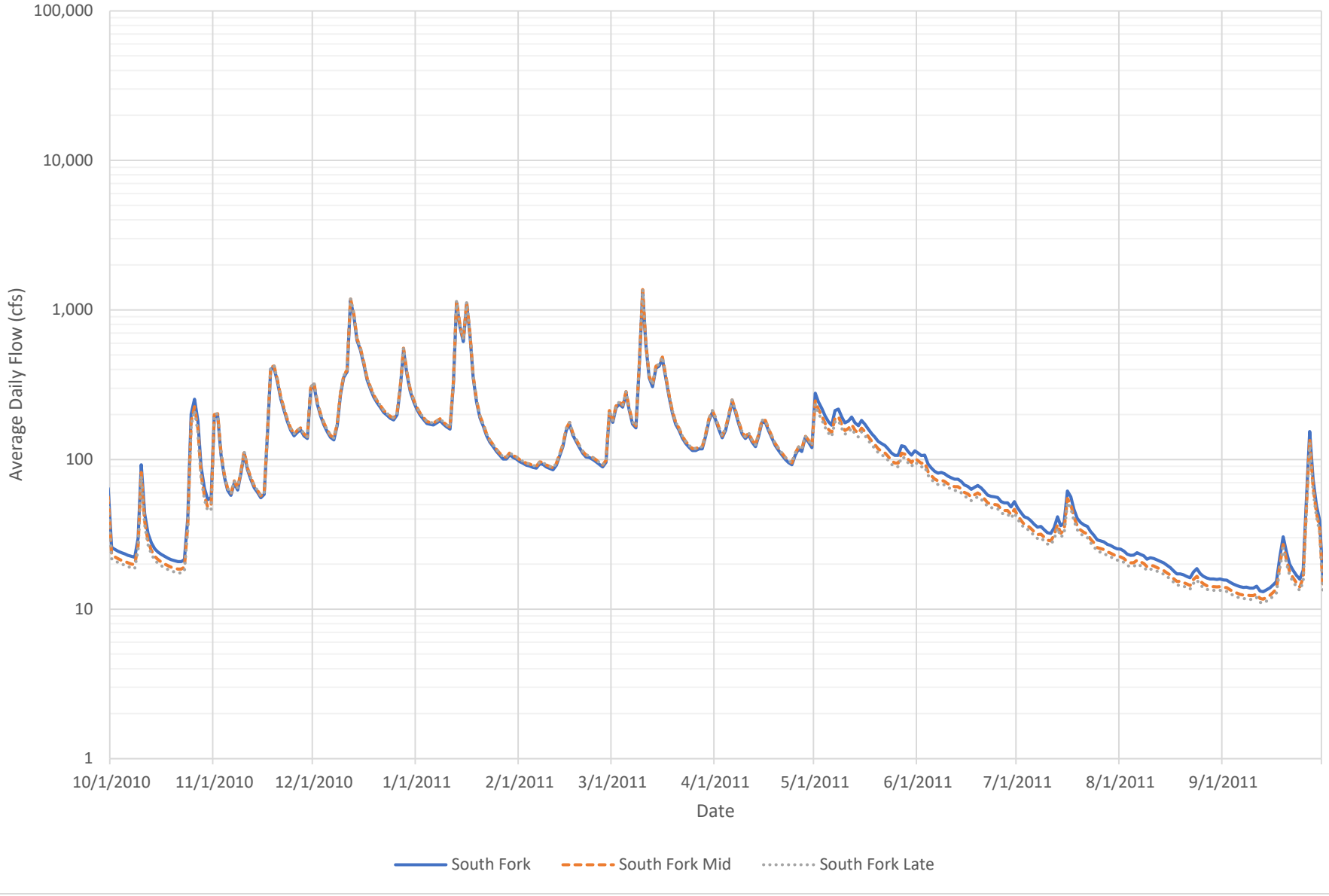

Figure A-13:
Climate Change Flow Comparison - Newaukum Gage (Water Year 1996)

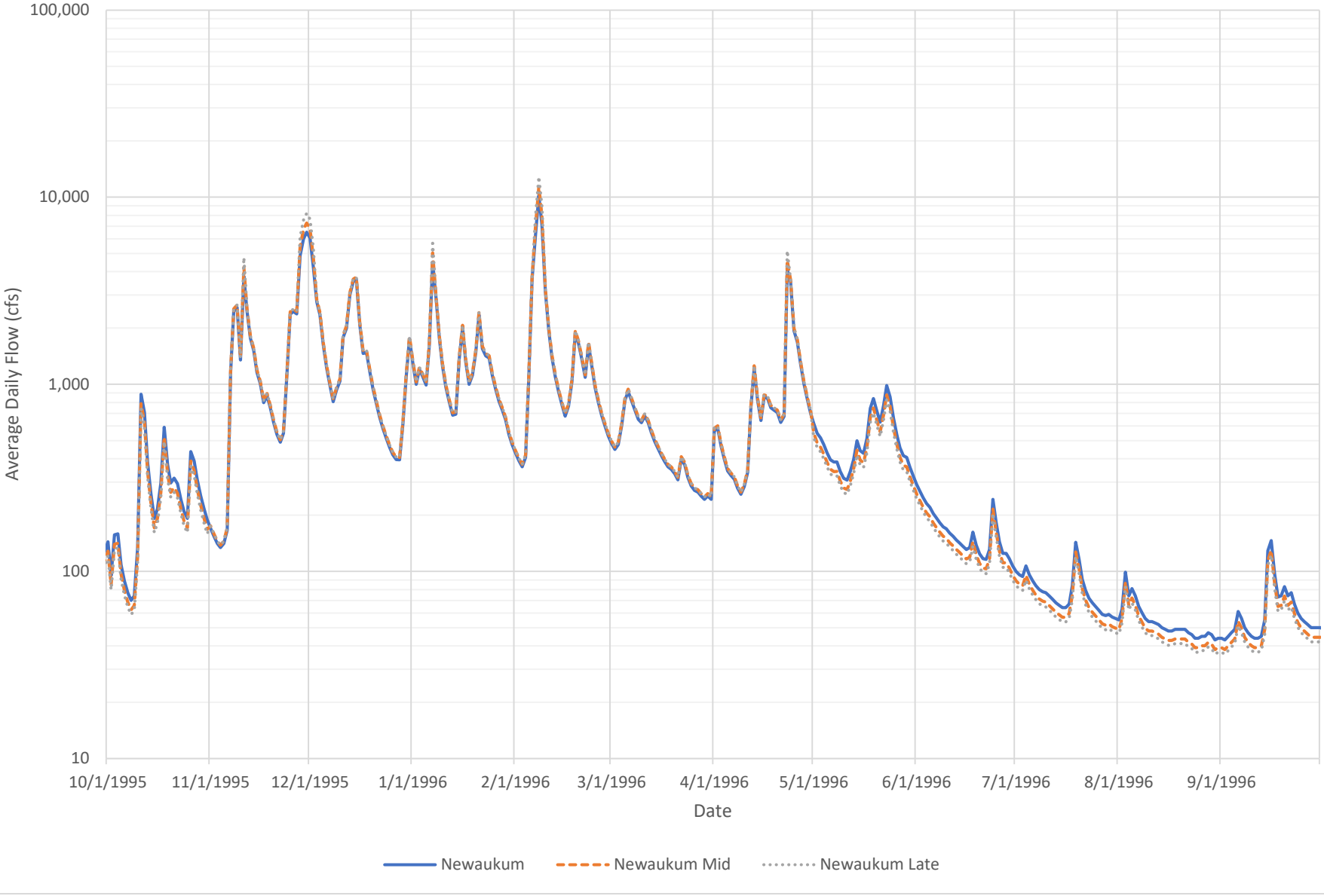

Figure A-14:
Climate Change Flow Comparison - Newaukum Gage (Water Year 2009)

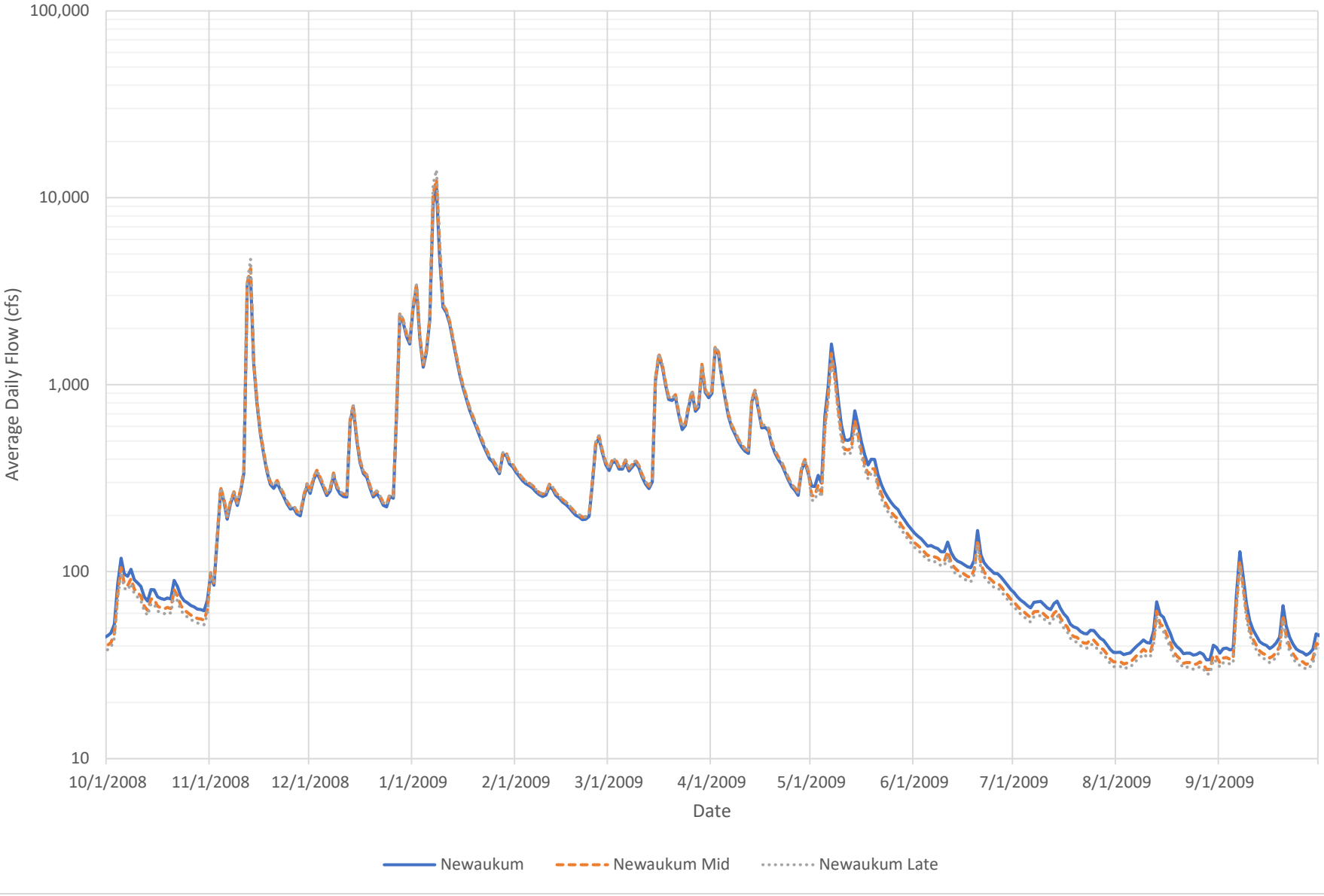

Figure A-15:
Climate Change Flow Comparison - Newaukum Gage (Water Year 2011)

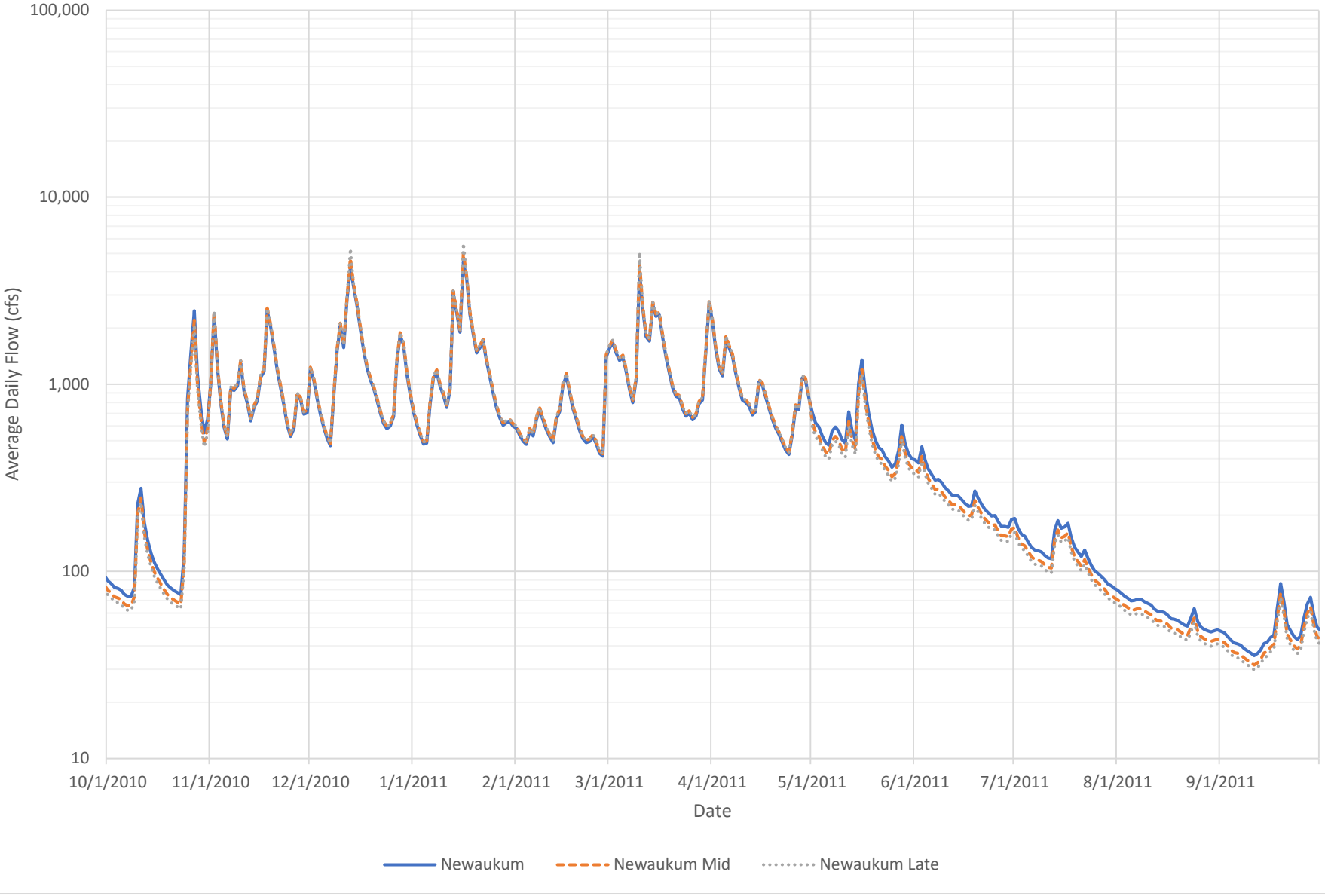

Figure A-16:
Climate Change Flow Comparison - Skookumchuck Gage (Water Year 1996)

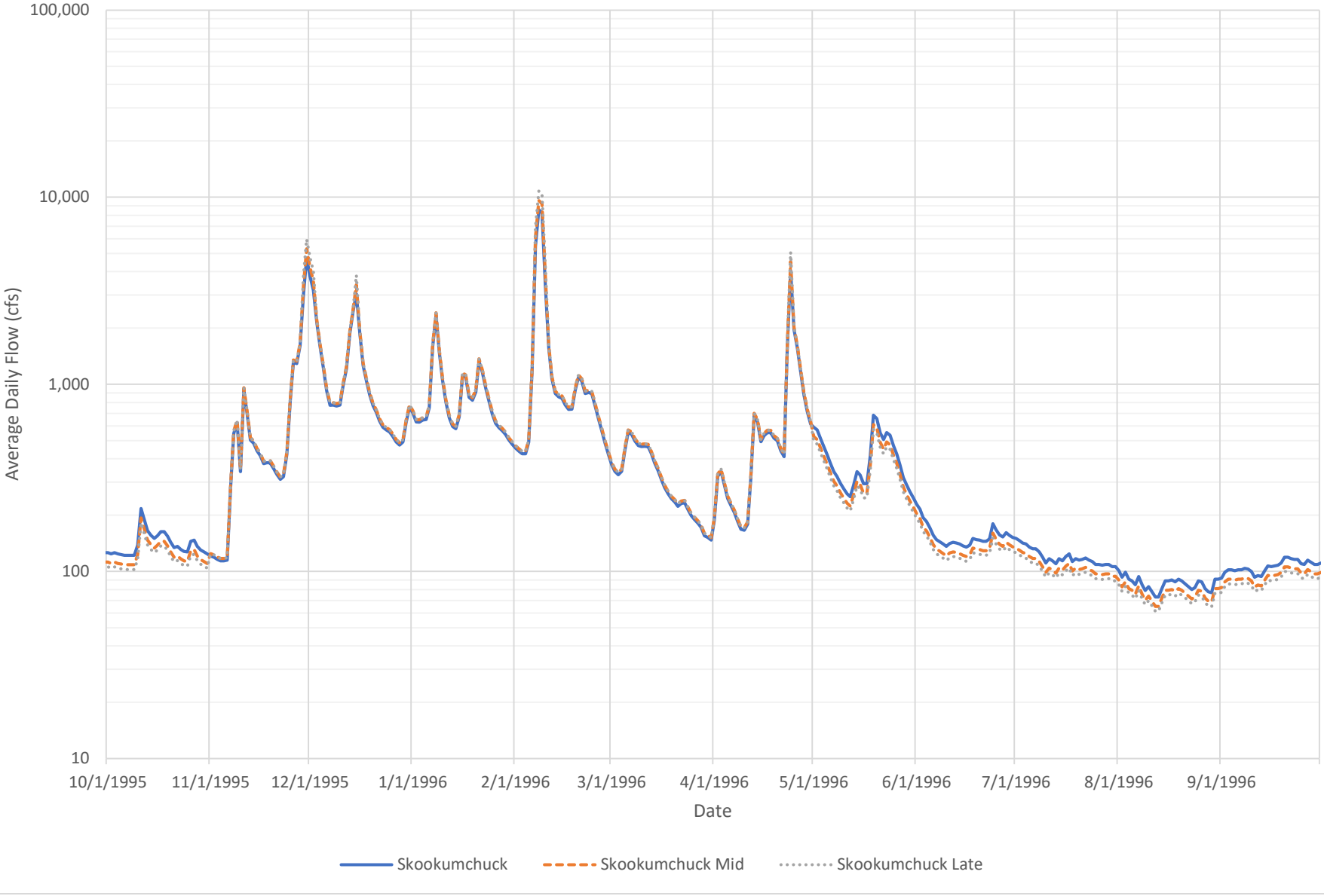

Figure A-17:
Climate Change Flow Comparison - Skookumchuck Gage (Water Year 2009)

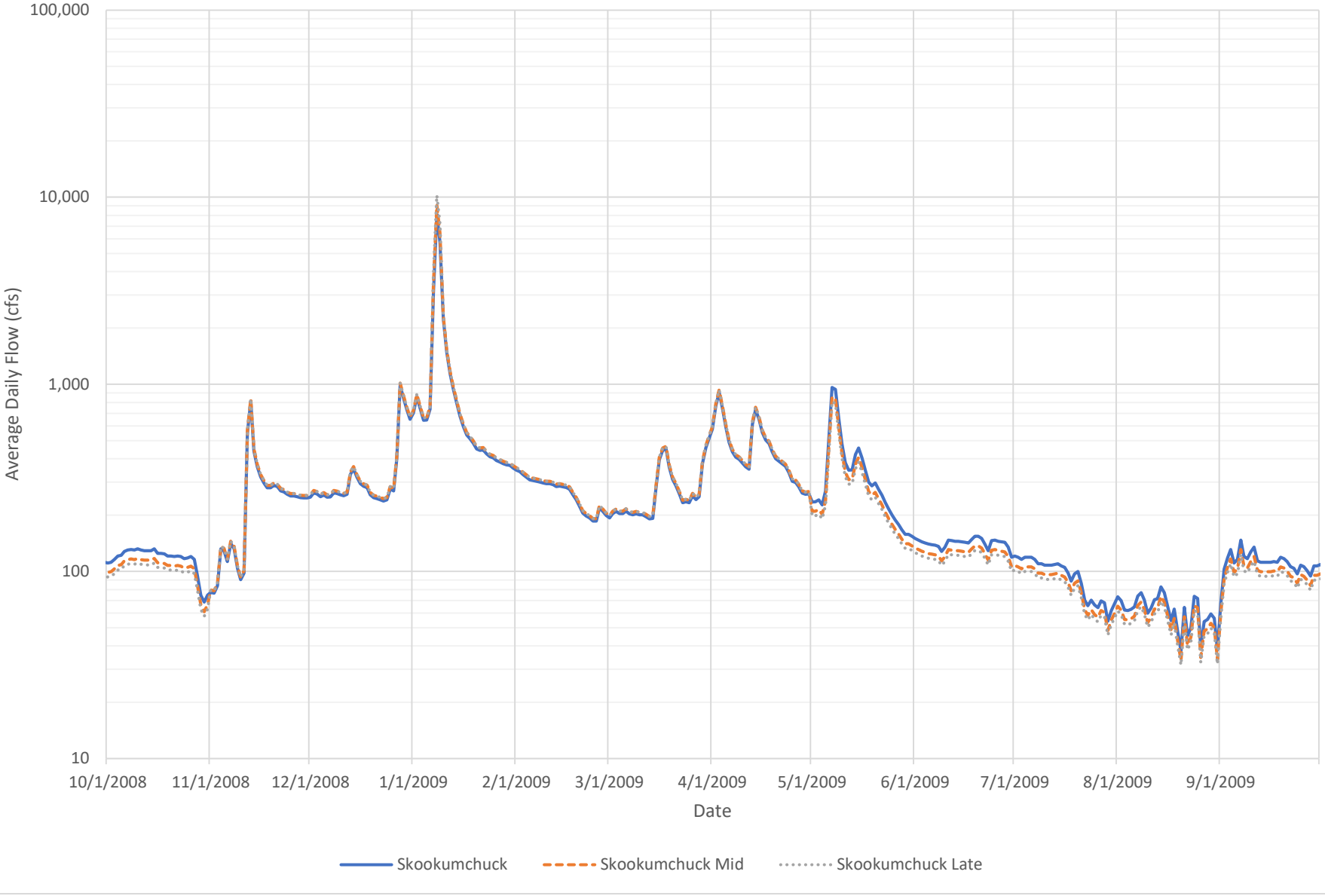

Figure A-18:
Climate Change Flow Comparison - Skookumchuck Gage (Water Year 2011)

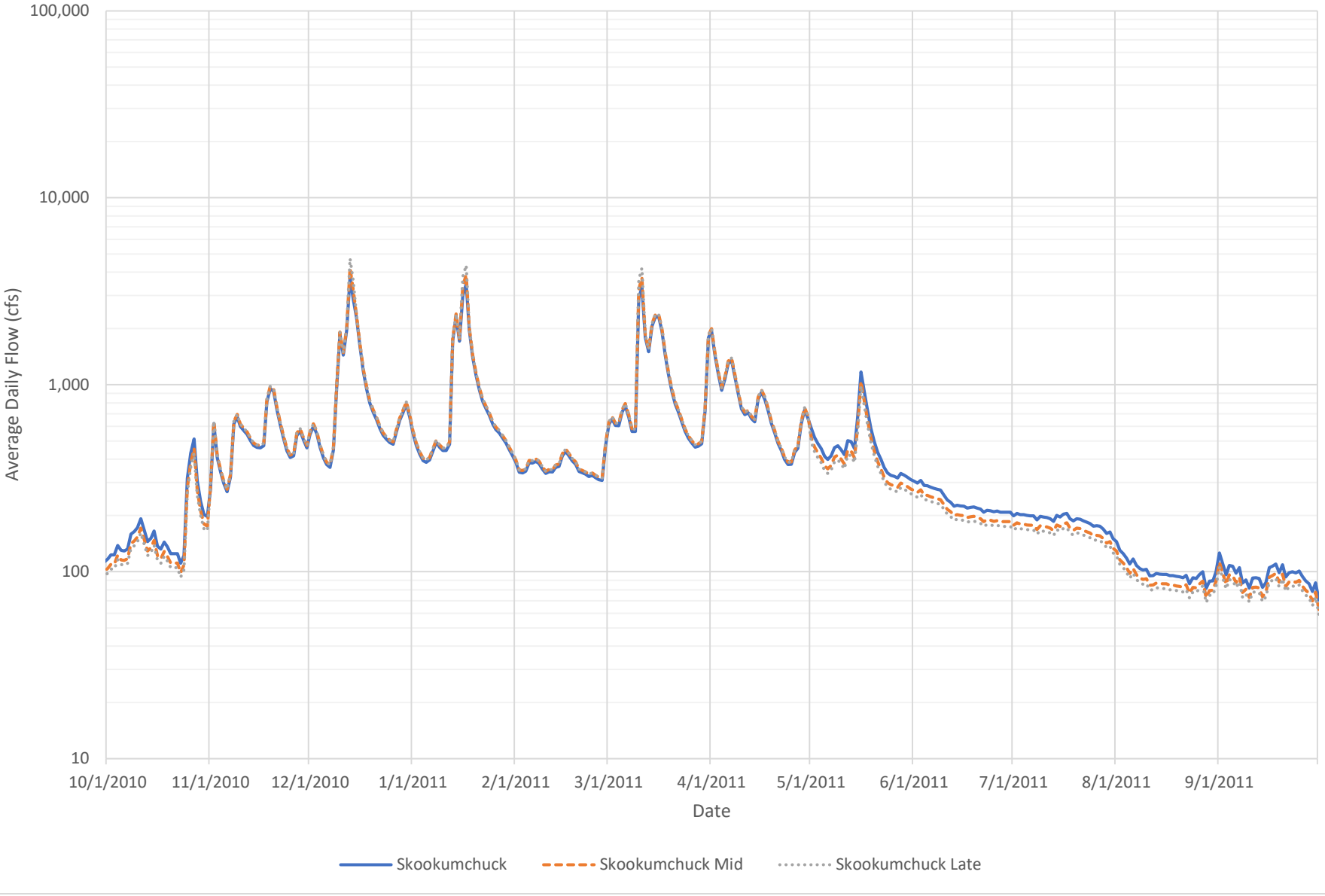

Figure A-19:
Climate Change Flow Comparison - Satsop Gage (Water Year 1996)

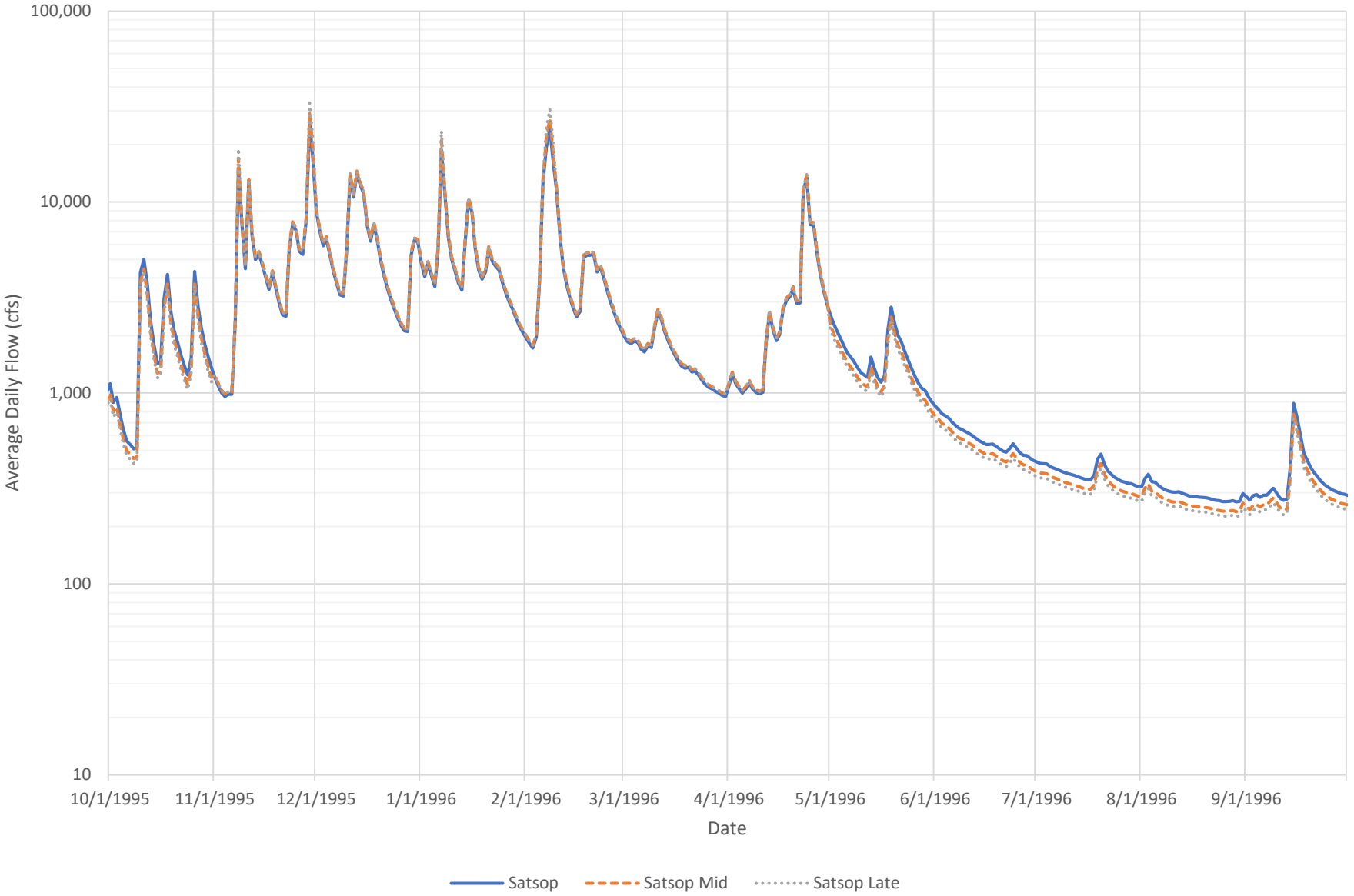

Figure A-20:
Climate Change Flow Comparison - Satsop Gage (Water Year 2009)

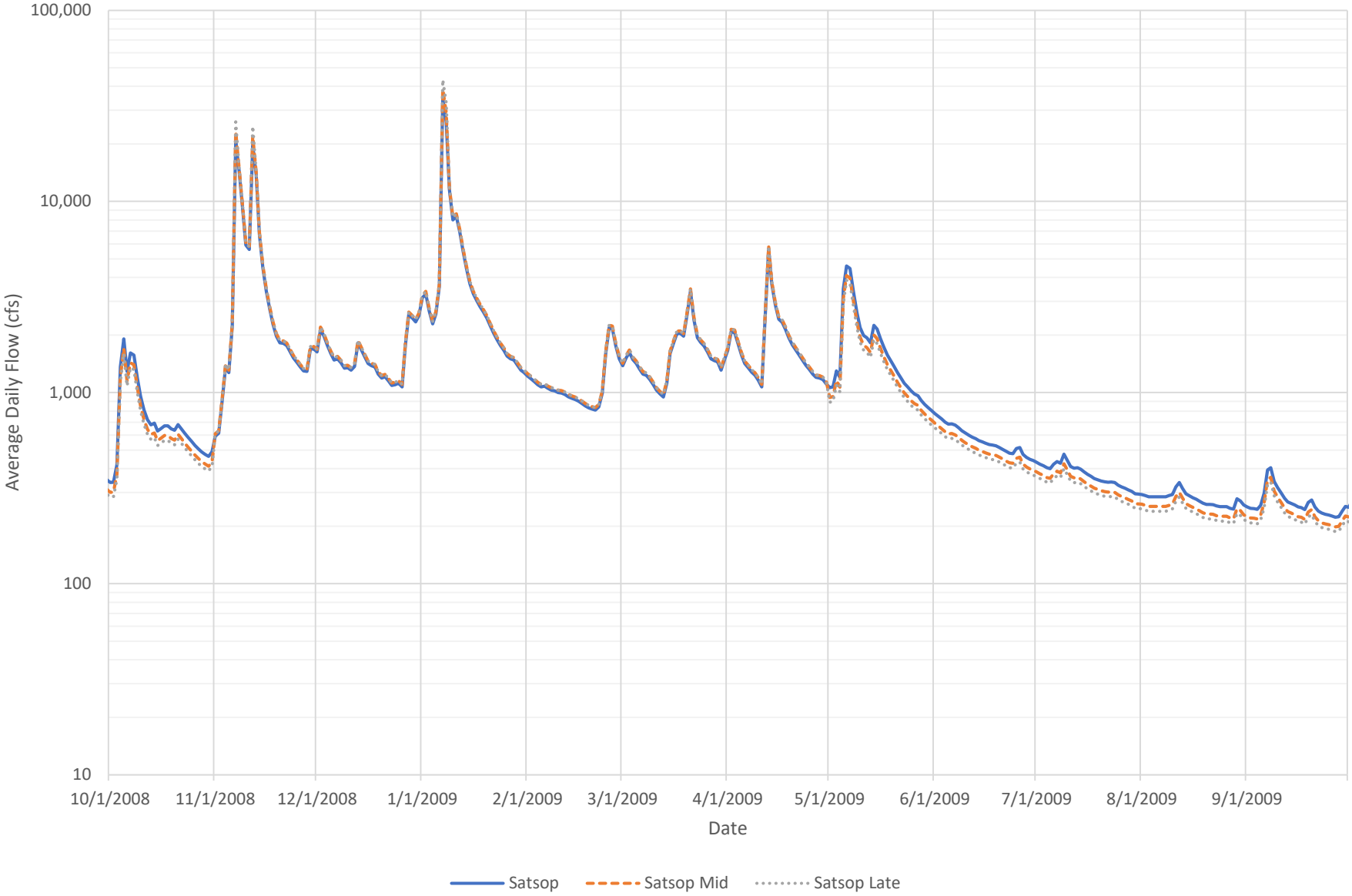

Figure A-21:
Climate Change Flow Comparison - Satsop Gage (Water Year 2011)

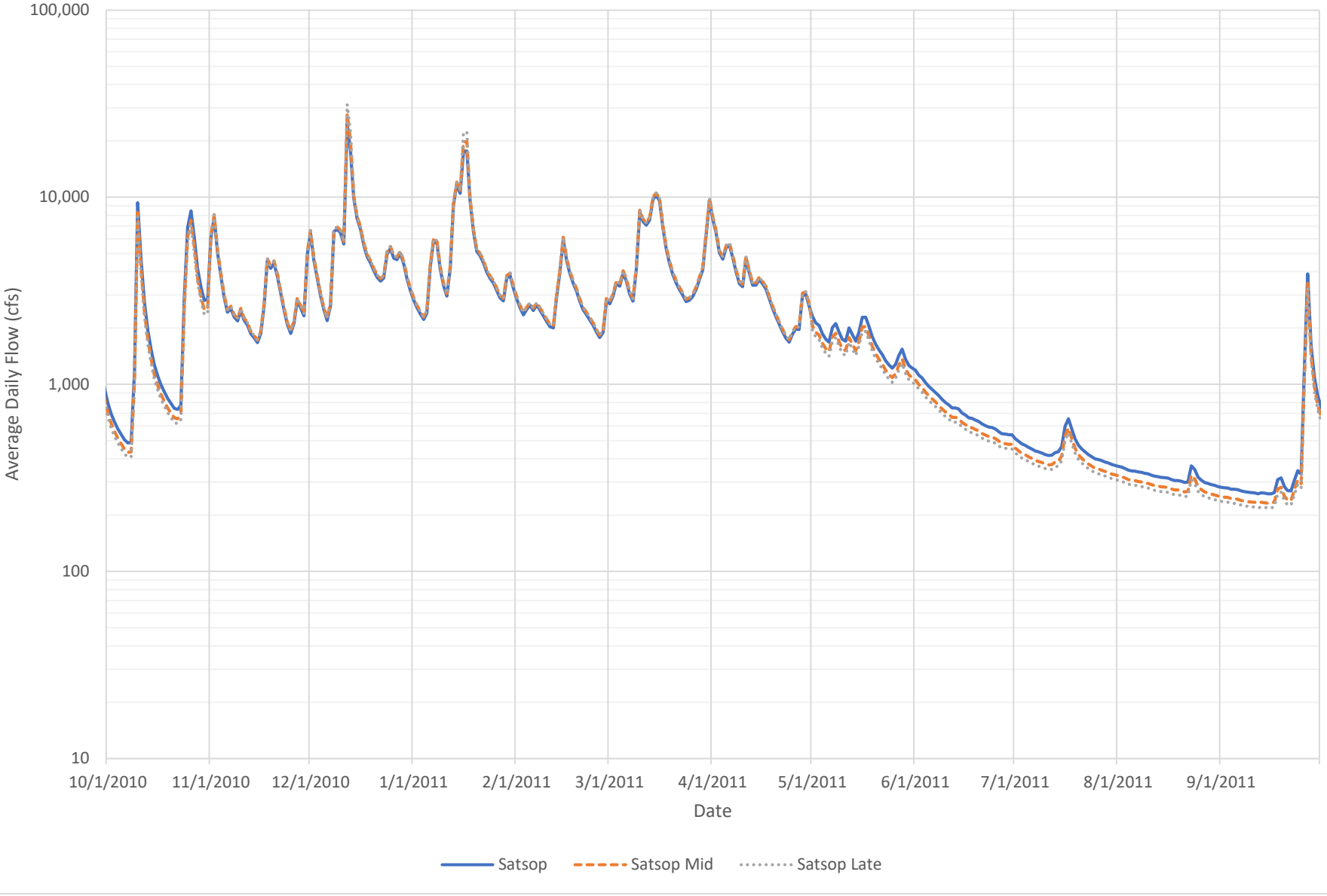

Figure A-22:
Climate Change Flow Comparison - Wynoochee Gage (Water Year 1996)

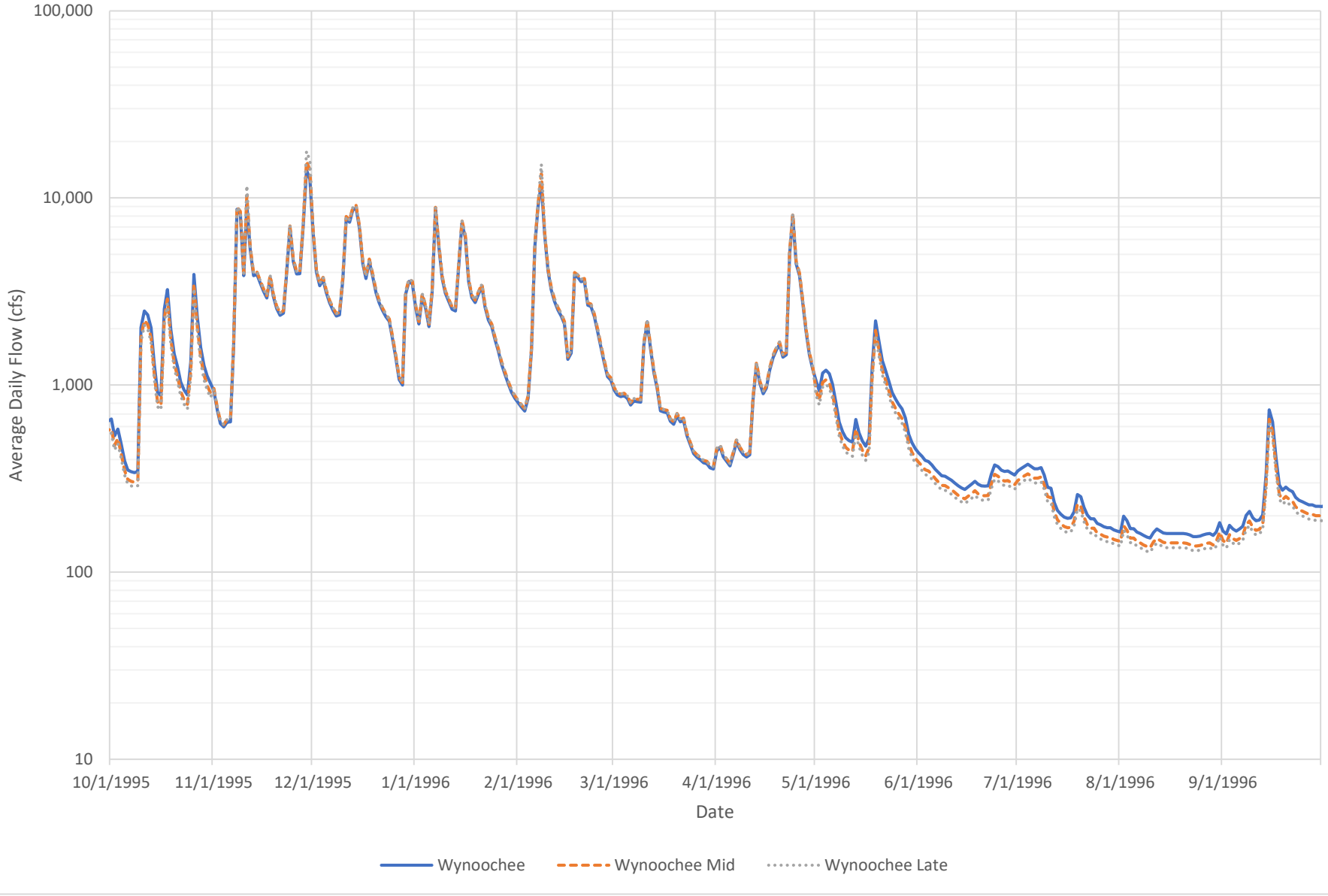

Figure A-23:
Climate Change Flow Comparison - Wynoochee Gage (Water Year 2009)

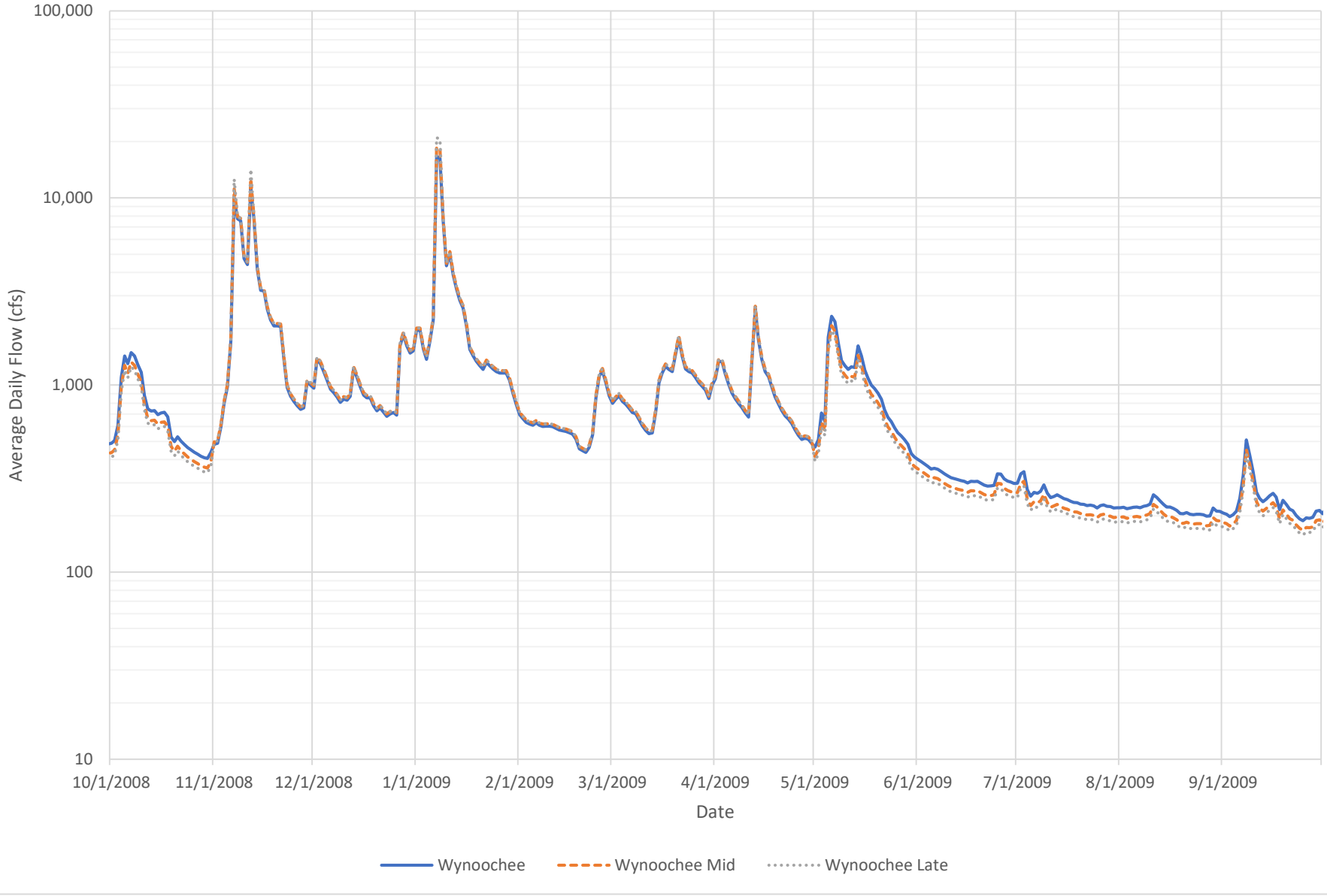

Figure A-24:
Climate Change Flow Comparison - Wynoochee Gage (Water Year 2011)

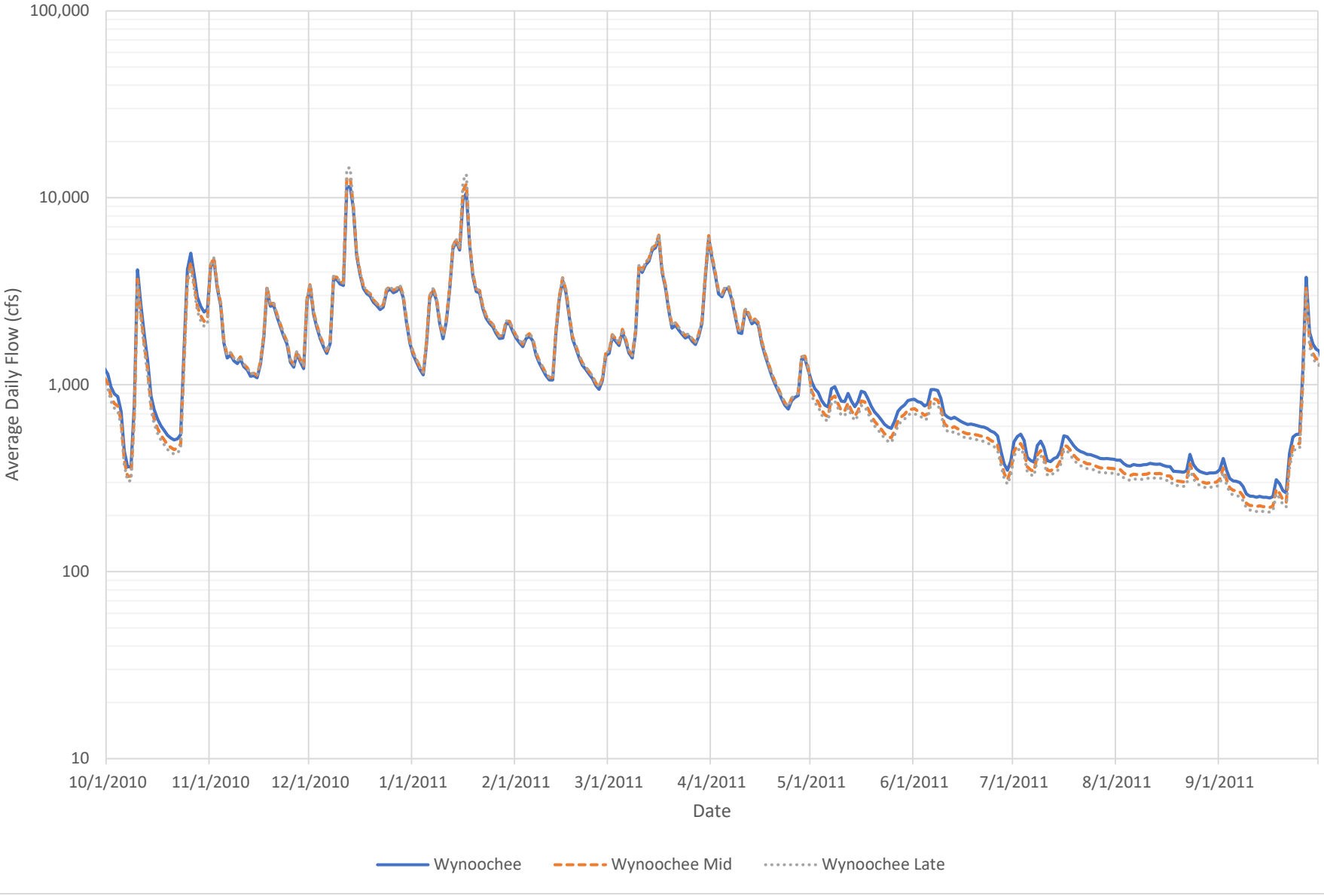

Figure A-25:
Climate Change Flow Comparison - Doty Gage (10-year)

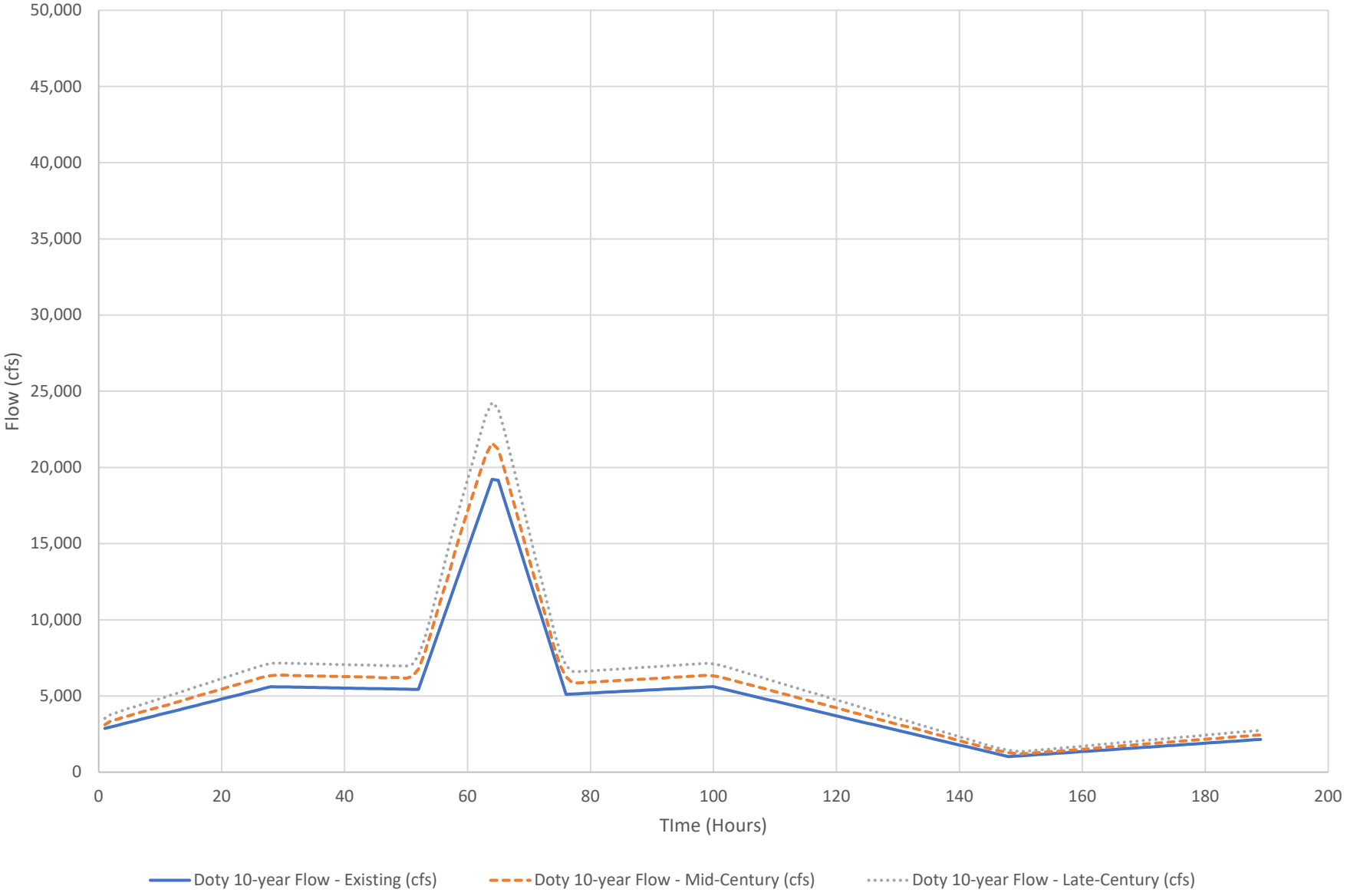

Figure A-26:
Climate Change Flow Comparison - Doty Gage (100-year)