Rio Grande Channel Analysis: Highway 380 to Elephant Butte Delta (RM 87 to RM 45)

Interior Region 7: Upper Colorado Basin

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Cover Photo: Aerial photo from River Mile 68 looking northeast showing the Black Mesa (Mesa de la Contadera) and AT&SF Railroad Bridge, 9/17/2013. (Reclamation)

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List of Acronyms and Abbreviations

1-D .... One-dimensional
AAO .... Albuquerque Area Office
ac .... acres
AT&SF .... Atchison, Topeka and Santa Fe Railway
BDA .... Bosque del Apache
cfs .... cubic feet per second
$D_{(\#\#)}$ .... median grain size
DEM .... digital elevation models
DOI .... Department of the Interior
EB .... Elephant Butte
ft .... feet
H&O .... Hink and Ohmart
HEC-RAS .... Hydraulic Engineering Center River Analysis System
Hwy .... highway
in .... inches
LiDAR .... Light Detection and Ranging
MRCOG .... Mid-Region Council of Governments
RG .... Rio Grande
RM .... River Mile
SO .... Socorro
USACE .... US Army Corps of Engineers
USBR .... Bureau of Reclamation

Executive Summary

This report provides a background assessment of the geomorphic, hydraulic, and vegetation trends to inform river maintenance and habitat restoration activities on the Rio Grande between the US Highway 380 Bridge at San Antonio and the Elephant Butte Reservoir (River Mile (RM) 87.1 – 45, Figure 1, Figure 2). The assessment includes analysis of the river and floodplain geomorphology using Reclamation cross section survey data, a hydraulic analysis using the 25% and 50% return flows of 2,300 cfs and 500 cfs respectively, a summary of bed material sample gradations from samples in the study reach, and an analysis of vegetation trends in the channel and floodplain from aerial imagery. These analyses are intended to identify spatial and temporal trends in bed stability, water conveyance capacity, and vegetation in the channel and floodplain. Analysis was performed for each year of available aerial imagery (2012, 2016, and 2018) and cross section survey data (2012-2019). Results are reported for the entire study reach and for each of the six subreaches identified.

Overall findings from the analysis are described in the points below.

Study Reach: Highway 380 Bridge to Elephant Butte Narrows (RM 87.1 – RM 45.3)

- Non-vegetated channel widths decreased along the reach, with few cross sections increasing in width. Non-vegetated channel widths in the area above River Mile 75.6 (SO-1613) decreased by 61 feet on average between 2012 and 2016. Non-vegetated widths between River Miles 75.6 and 45 decreased by 32 feet on average between 2012 and 2018.
- Reach-average thalweg elevations decreased overall by 0.3 ft (3.6 in of degradation) throughout the study reach between 2012 and 2019. The years 2012 – 2013 and 2014 – 2015 underwent increases in the average thalweg elevation. Areas where thalweg elevation increased between 2012 and 2019 are in the upper BDA area and between Silver Canyon and the Narrows. These are the same areas where sediment plugs formed in 2019.
- Reach-average mean bed elevations at the 50% and 25% exceedance flow rates decreased by 0.6 ft (7.2 in of degradation) overall along the study reach from 2012 to 2019, with increases (aggradation) from 2012 – 2013 and 2014 – 2015. Average bed slopes at the 500 cfs and 2,300 cfs flow rates fluctuated around 0.00061 ft/ft between 2012 and 2019.
- Average bed elevation of surveyed cross sections decreased by 0.7 ft (8.4 in of degradation) from 2012 to 2019, with only the 2012 – 2013 period undergoing an overall increase (aggradation). Notable areas of deposition were the upper BDA area and between Silver Canyon and the Narrows.
- Reach-average bank elevations of the active channel decreased by 0.7 ft (8.4 in of degradation) overall from 2012 – 2019, with increases (aggradation) between the years 2013 – 2014, 2015 – 2016, and 2018 – 2019. Banks downstream of the AT&SF Railroad Bridge underwent the most change year-to-year as the active channel occupied varying portions of the main channel. Channel banks in the upper BDA area aggraded between 2018 and 2019.
- Bank-to-bank active channel widths decreased by 25 ft on average throughout the reach from 2012 – 2019. Only the year 2015 – 2016 saw an average increase in channel widths throughout the reach. Channel widths changed the most downstream of the AT&SF Railroad Bridge as the active channel occupied varying portions of the main channel.

- Reach-average active channel depths increased and decreased in different parts of the channel. Channel depths increased in the degradational areas between the BDA sediment plug and Silver Canyon. Overall channel depths decreased in the upper BDA area and between Silver Canyon and the Narrows.
- Bed material sample data show that the wash load (D_{10}) and D_{16} grain sizes fell in the very fine sand (0.0625 – 0.125 mm) to fine sand (0.125 – 0.25 mm) ranges. Median grain sizes (D_{50}) fell in the fine to medium sand (0.25 – 0.5 mm) range. The D_{84} grain size fell mostly in the fine to medium sand ranges, with samples taken in 2019 falling in the coarse (0.5 – 1 mm) to very coarse sand (1 – 2 mm) range.
- Woody vegetation decreased slightly in the study area from 2012 to 2016, followed by burning of ~6,700 acres of wooded area in the 2017 Tiffany Fire. Areas of herbaceous vegetation decreased slightly from 2012 to 2016, with ~2500 acres of herbaceous vegetation burned during the Tiffany Fire. Areas with less than 25% cover decreased between 2016 and 2018 while herbaceous areas increased. The 2018 vegetation areas were estimated from aerial imagery, while the 2016 and 2012 H&O polygons were created from field data and aerial imagery

Subreach 1: Highway 380 Bridge to RM 78 (RM 87.1 – 78)

- Thalweg and mean bed elevations at the 500cfs and 2300 cfs flow rates elevations increased overall (aggradation). This subreach includes the BDA and the sediment plug that formed in 2019. In 2019 degradation occurred below the sediment plug, leading to an increased subreach slope.
- Channel banks were fairly stable from 2012 – 2017, then aggraded from 2017 – 2019. This is likely related to the channel aggradation from 2012 – 2019 and 2019 plug formation decreasing the flow threshold at which overbanking flows deposit sediments on the banks.
- Average bank-to-bank width decreased by 44 ft from 2012 – 2019, and average non-vegetated channel widths decreased by 62 ft from 2012 – 2016. The 2019 BDA plug area was narrower than the immediately upstream section.
- Aggradation in the channel above and along the sediment plug led to decreased channel depths, with increased channel depths below the sediment plug caused by degradation.
- Conveyance capacity of this reach decreased from 2850 cfs to 1750 cfs as a result of the overall aggradation from 2012 to 2019 and the sediment plug formation in 2019. Conveyance capacity of this reach is likely to change significantly as the realignment of the channel around the BDA sediment plug continues to adjust as flows are passed through it.
- Due to the aggradation typical of this subreach and its low water conveyance capacity, management strategies recommended for this reach include Reconstruct and Maintain Channel Capacity, Increase Available Area to the River, and Manage Sediment. The 2019 channel realignment project in the BDA area may fall under the both the strategies Increase Available Area to the River and Reconstruct and Maintain Channel Capacity since the channel was moved to a lower point in the valley using excavation and berm construction. The strategy Manage Sediment could be used to reduce the sediment load in this subreach through construction of sedimentation basins on the river or tributary arroyos.

Subreach 2: RM 78 to Tiffany Junction (RM 78 – 72.6)

- This subreach underwent aggradation from 2012 – 2015 then overall degradation from 2015 – 2019. Sediment was scoured from the bed from 2018 – 2019 as a result of the cutoff of upstream sediment supply by the 2019 BDA sediment plug. Thalweg elevations and mean bed elevations at the 500 cfs and 2300 cfs flow rates decreased in Subreach 2 the most out of all six subreaches.

- Bank elevations decreased overall, with bank elevations increasing from 2016 – 2017.
- Bank-to-bank channel width decreased by 18 ft overall from 2012 – 2019, and non-vegetated channel width decreased by 36 ft from 2012 – 2016.
- Channel depths increased the most along Subreach 2 out of all six subreaches. The 2019 sediment plug in Subreach 1 caused degradation and increased channel depth from 2018 – 2019.
- Conveyance capacity increased overall in this reach along with the increases in channel depth.
- Since Subreach 2 is downstream of an aggradational, plug-prone reach, the following effects can be expected based on observations in other reaches: incision or bed degradation, bank erosion, and coarsening of the bed material. Substantial degradation, channel narrowing, and increased depths have been already observed in this reach and may lead to bank erosion and lateral migration. Strategies to address these trends include Promote Elevation Stability to prevent further bed degradation leading to bank erosion and channel migration. The strategy Promote Alignment Stability could include bank stabilization to prevent channel migration which could affect the BDA Levee system. Rehabilitate Channel and Floodplain is a strategy that could be used to reduce sediment transport capacity to more closely match the sediment supply as well as promote RGSM and SWFL habitat.

Subreach 3: Tiffany Junction to Fort Craig Bend (RM 72.6 – RM 64)

- Subreach 3 underwent degradation from 2015 – 2019, with thalweg and mean bed elevations at the 500 cfs and 2300 cfs flows decreasing by 1.1 – 1.4 ft (degradation).
- Bank elevations decreased overall along Subreach 3, with most of the changes downstream of the AT&SF Railroad Bridge.
- Bank-to-bank channel widths decreased by 6.6 ft overall from 2012 – 2019, and non-vegetated channel widths decreased by 25 ft from 2012 – 2018.
- Channel depth increased by 0.8 ft overall along Subreach 3 from 2012 – 2019.
- The conveyance capacity of Subreach 3 fluctuated between 6600 cfs and 7850 cfs from 2012 – 2019.
- Like Subreach 2, Subreach 3 was overall degradational throughout the study period. Channel narrowing, increase in depths, and increase in capacity have been observed in this reach. Strategies to address these trends include Promote Elevation Stability, Promote Alignment Stability, and Rehabilitate Channel and Floodplain. Maintaining the river alignment around the AT&SF Railroad Bridge is particularly important in this subreach.

Subreach 4: Fort Craig Bend to Silver Canyon (RM 64 – RM 54.5)

- Thalweg and mean bed elevations at the 500 cfs and 2300 cfs flow rates decreased by 1.4 – 2 ft overall (degradation) from 2012 – 2019.
- Average bank elevations along Subreach 4 decreased overall by 1.5 ft from 2012 – 2019, with increases from 2015 – 2016 and 2018 – 2019.
- Bank-to-bank channel widths decreased by 20.7 ft overall from 2012 – 2019, and non-vegetated channel widths decreased by 35 ft overall from 2012 – 2018.
- Channel depth increased overall by 0.3 ft from 2012 – 2019.
- Subreach 4 had the highest conveyance capacity of all six subreaches with a flow capacity between 10,000 cfs and 14,000 cfs during the study period.

- Like Subreaches 2 and 3, Subreach 4 was overall degradational throughout the study period. Channel narrowing, increase in depths, and increase in capacity were observed. Strategies to address these trends include Promote Elevation Stability, Promote Alignment Stability, and Rehabilitate Channel and Floodplain.

Subreach 5: Silver Canyon to RM 51 (RM 54.5 – RM 51)

- Thalweg and mean bed elevations at the 500 cfs and 2300 cfs flow rates increased by 0.2 – 0.7 ft overall (aggradation) from 2012 – 2019, with the most aggradation occurring along this subreach from 2016 – 2017.
- Channel banks degraded by 0.7 ft overall, aggradation occurring only from 2012 – 2013 and 2015 – 2016.
- Bank-to-bank channel width decreased by 27.3 ft, and non-vegetated channel width decreased by 43 ft.
- Channel depths decreased by 0.9 ft overall.
- The conveyance capacity of Subreach 5 decreased overall from 6,650 to 4,050 cfs from 2012 – 2019.
- Subreach 5 underwent both aggradation and degradation during the study period, with decreased transport capacity following aggradation in 2019. Increase Available Area to the River may not be appropriate for this subreach since the channel is fairly wide and shallow in this subreach. The strategy Reconstruct and Maintain Channel Capacity may be appropriate to address the decreased conveyance capacity in this reach. Aggradation could be addressed using strategy Manage Sediment to reduce the sediment load in this subreach through construction of sedimentation basins on the upstream river channel or tributary arroyos.

Subreach 6: RM 51 to Elephant Butte Narrows (RM 51 – RM 45.3)

- Thalweg and mean bed elevations at the 500 cfs and 2300 cfs flow rates increased by 0.8 – 1.2 ft overall (aggradation) from 2012 – 2019, with the most aggradation occurring along this subreach from 2016 – 2017.
- Channel banks elevations decreased by 1.6 ft overall, aggradation occurring only from 2012 – 2013 and 2015 – 2016.
- Bank-to-bank channel width decreased by 28.8 ft, and non-vegetated channel width decreased by 46 ft between 2012 and 2018.
- Channel depth decreased by 2.2 ft overall from 2012 – 2019.
- The conveyance capacity of Subreach 6 decreased from 6400 to 3550 as a result of aggradation.
- Subreach 6 underwent both aggradation and degradation during the study period, with decreased channel depth and transport capacity following aggradation and sediment plug formation in 2019. The strategy “Reconstruct and Maintain Channel Capacity” may be appropriate to address the decreased conveyance capacity in this reach. Aggradation could be addressed using the strategy “Manage Sediment” to reduce the sediment load in this subreach through construction of sedimentation basins on the river or tributary arroyos, depending on the source of sediment to this reach. Any of these management strategies will be subject to the effects of base level change of the Elephant Butte Arroyo, with an increase in water level likely to decrease the reach slope and lead to aggradation in the Highway 380 – Elephant Butte Reach. A decrease in water level is likely to increase the reach slope and lead to further degradation.

Background

The purpose of this report is to provide a background assessment of the Rio Grande's geomorphic, hydraulic, and vegetation trends between cross-sections SO-1475.9 and EB-50 (River Miles (RM's) 87.1 to 45) from 2012 to 2019. This reach extends from the Highway 380 Bridge at San Antonio through the Bosque Del Apache (BDA) National Wildlife Refuge (NWR) to the Elephant Butte Reservoir (Figure 1). The study reach has historically been aggradational due to an overabundant sediment supply, relatively flat valley slope, and base level effects of the Elephant Butte Reservoir pool. The current river channel and Low Flow Conveyance Channel (LFCC) alignments were established in the early 1950's as part of historical channelization by Reclamation in the reach associated with extreme drought that occurred in the late 1940's and early 1950's. The BDA, Tiffany, and San Marcial Levees bound the river on the western side from Highway 380 to RM 58.5 (EB-26.3). Water and sediment delivery infrastructure in this reach include the main river channel and the LFCC, as well as various riverside drains and canals which collect seepage and irrigation return flows north of the Tiffany Junction. Other infrastructure include the AT&SF railroad line embankment and bridge crossing at San Marcial.

This study is intended to inform river maintenance and habitat restoration activities throughout the study reach. The elements of the study include assessment of geomorphic trends including vegetation in the channel and floodplain, channel bed stability, floodway and channel topography, and available bed material data, as well as a hydraulic assessment to determine changes related to conveyance capacity of the reach. Lastly, to better understand the relationship between hydrology and the observed changes in geomorphology in study reach, summary flow data were gathered for the USGS Gages at Highway 380, at San Marcial, and at the Elephant Butte Narrows for the study period.

The reach was divided into six subreaches for this analysis based on trends in aggradation and degradation, geologic controls, and variability in hydraulic parameters. The sections are described in Table 1 below and shown on Figure 2. Maps of the individual subreaches including river miles, rangelines, and pertinent landmarks are included in Figure 3 through Figure 8.

The reach from the Highway 380 Bridge to RM 78 (RM 87.1 – 78) includes the BDA area in which sediment plugs formed in 2008 and 2019 (Figure 3). This is followed by the reach from RM 78 to the Tiffany Junction, which underwent degradation from 2012 – 2019 (Figure 4). The reach from the Tiffany Junction to the Fort Craig Bend was generally stable and includes the A&SF Railroad Bridge where the river alignment is artificially held in place to accommodate the railroad alignment as well as the geologic control exerted by the Black Mesa (Figure 5). The reach from Fort Craig Bend to Silver Canyon had high year-to-year variability in simulated water surfaces and mean bed elevations, with variability in these parameters decreasing markedly at Silver Canyon (Figure 6). The reach from Silver Canyon to RM 51 had low year-to-year variability in simulated water surface elevations and mean bed elevations as well as a relatively low and wide channel (Figure 7). The reach from RM 51 to the Elephant Butte Narrows had greater variability in hydraulic parameters than the immediately upstream reach and underwent aggradation and sediment plug formation in 2019 (Figure 8). Subreaches 1, 5, and 6 stored sediment decreased in channel depth and conveyance capacity overall throughout the study period. Subreaches 2 – 4 evacuated sediment and increased in channel depth and conveyance capacity overall from 2012 – 2019.

Table 1: Subreaches in the analysis reach and their starting and ending River Miles (RM's) and lengths.

Subreach	Subreach Name	Upstream River Mile	Downstream River Mile	Length (mi)
1	Hwy 380 to RM 78	87.1	78	9.1
2	RM 78 to Tiffany Junction	78	72.6	5.4
3	Tiffany Junction to Fort Craig	72.6	64	8.6
4	Fort Craig to Silver Canyon	64	54.5	9.5
5	Silver Canyon to RM 51	54.5	51	3.5
6	RM 51 to Elephant Butte Narrows	51	45.3	5.7

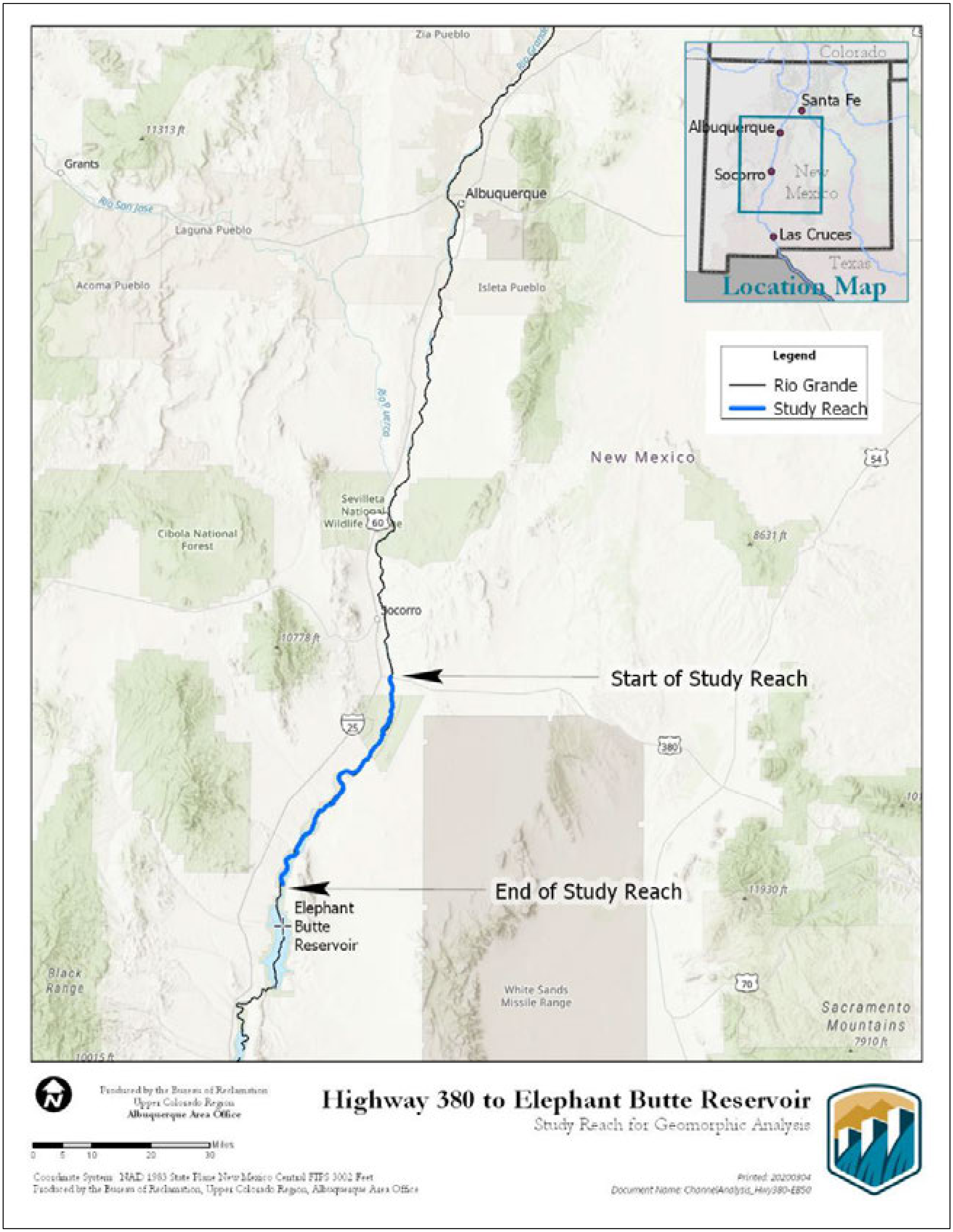

Figure 1: Vicinity map showing the study area along the Rio Grande within New Mexico.

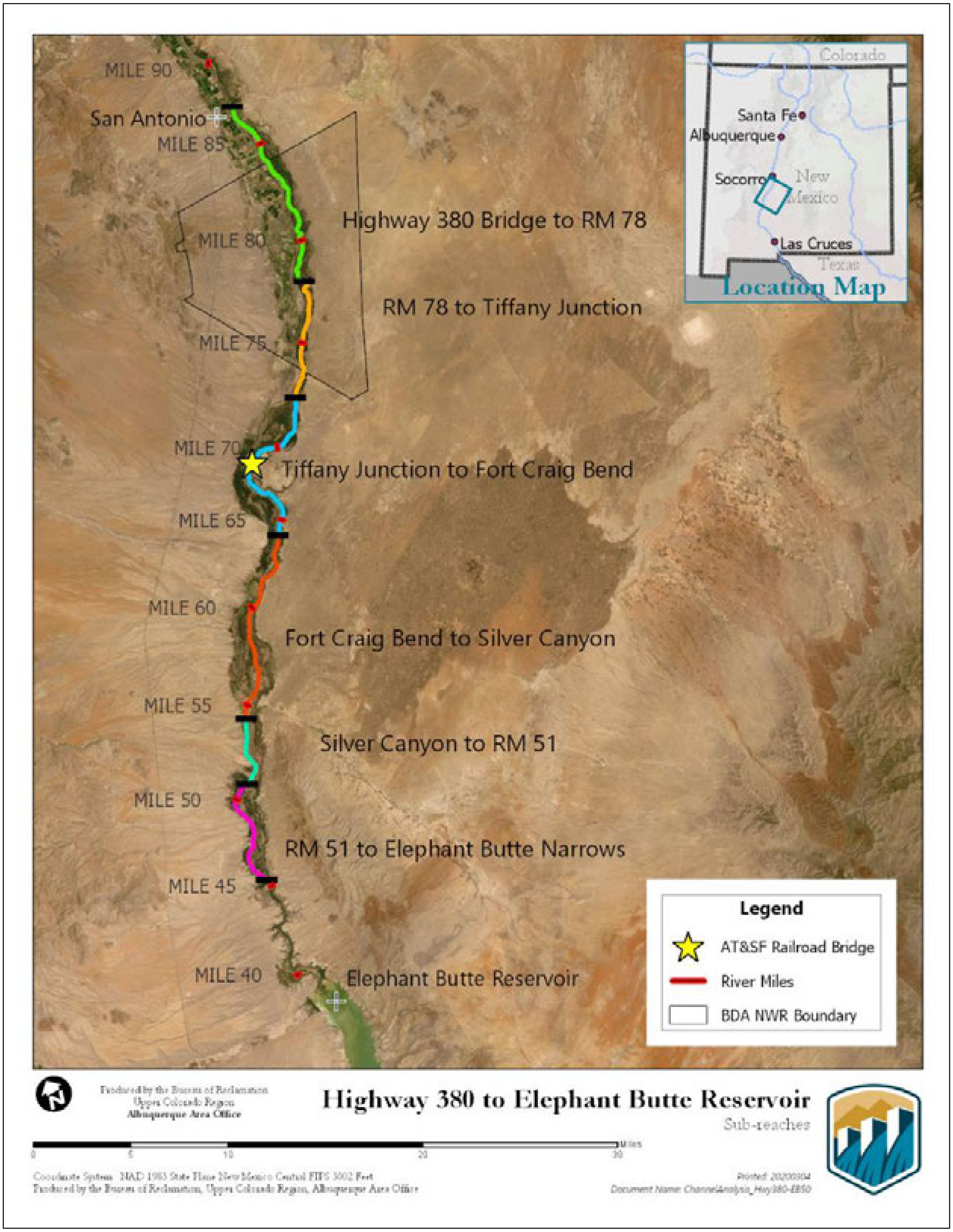

Figure 2: Map showing the subreaches and location of the AT&SF Railroad Bridge within the analysis reach.

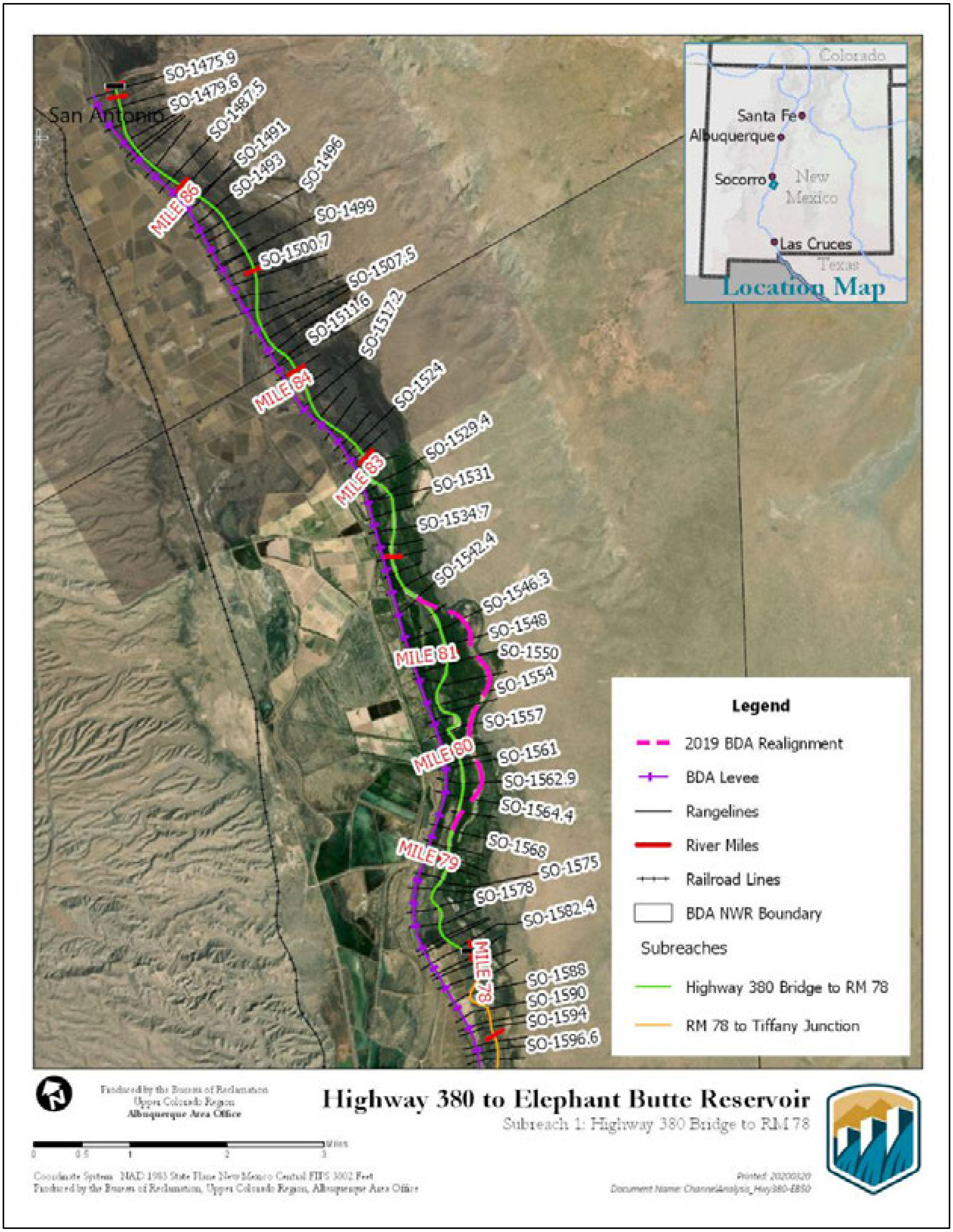

Figure 3: Map showing Subreach 1 including River Miles, Rangelines, the BDA Levee, and the 2019 BDA realignment.

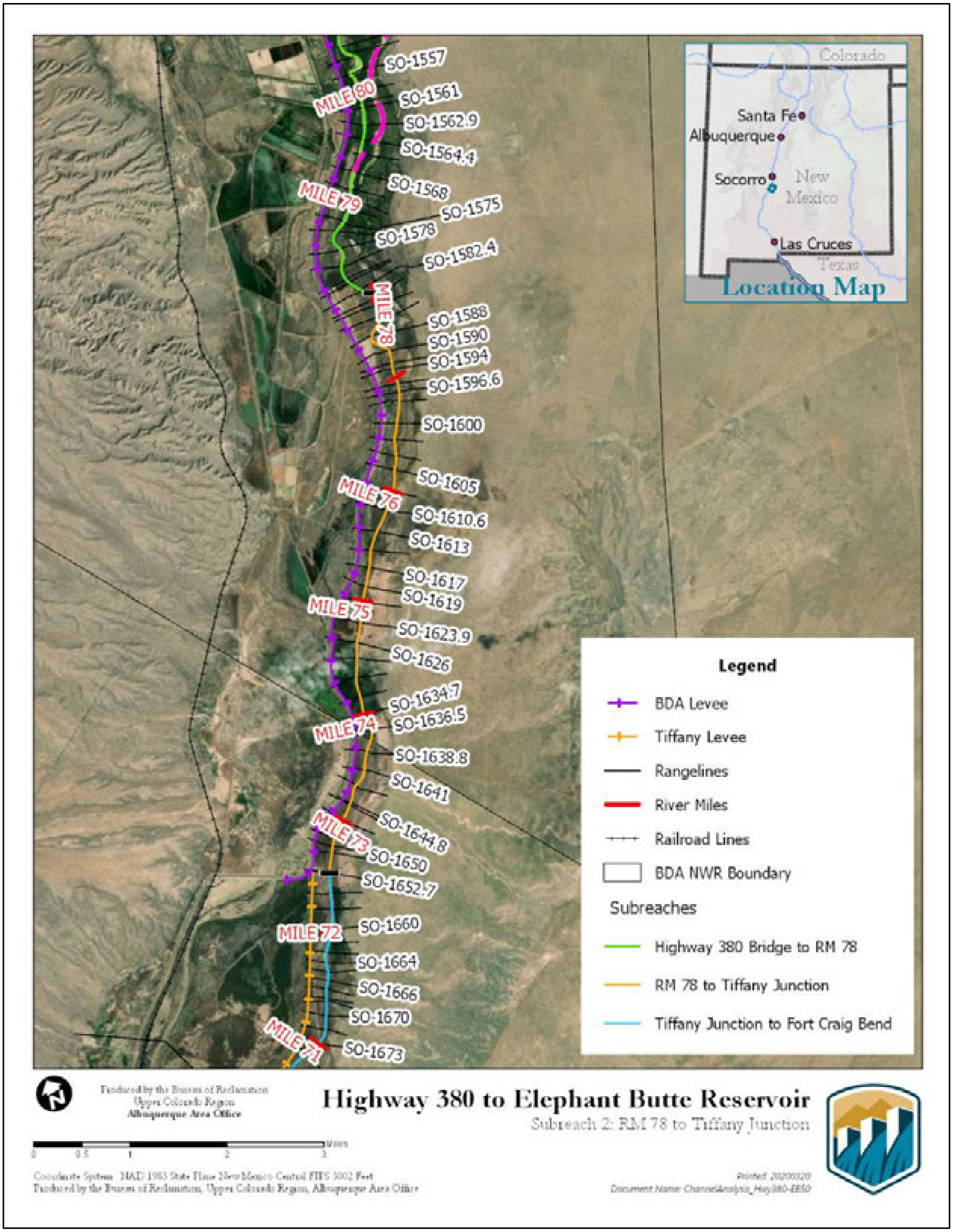

Figure 4: Map showing Subreach 2 including River Miles, Rangelines, and the BDA Levee.

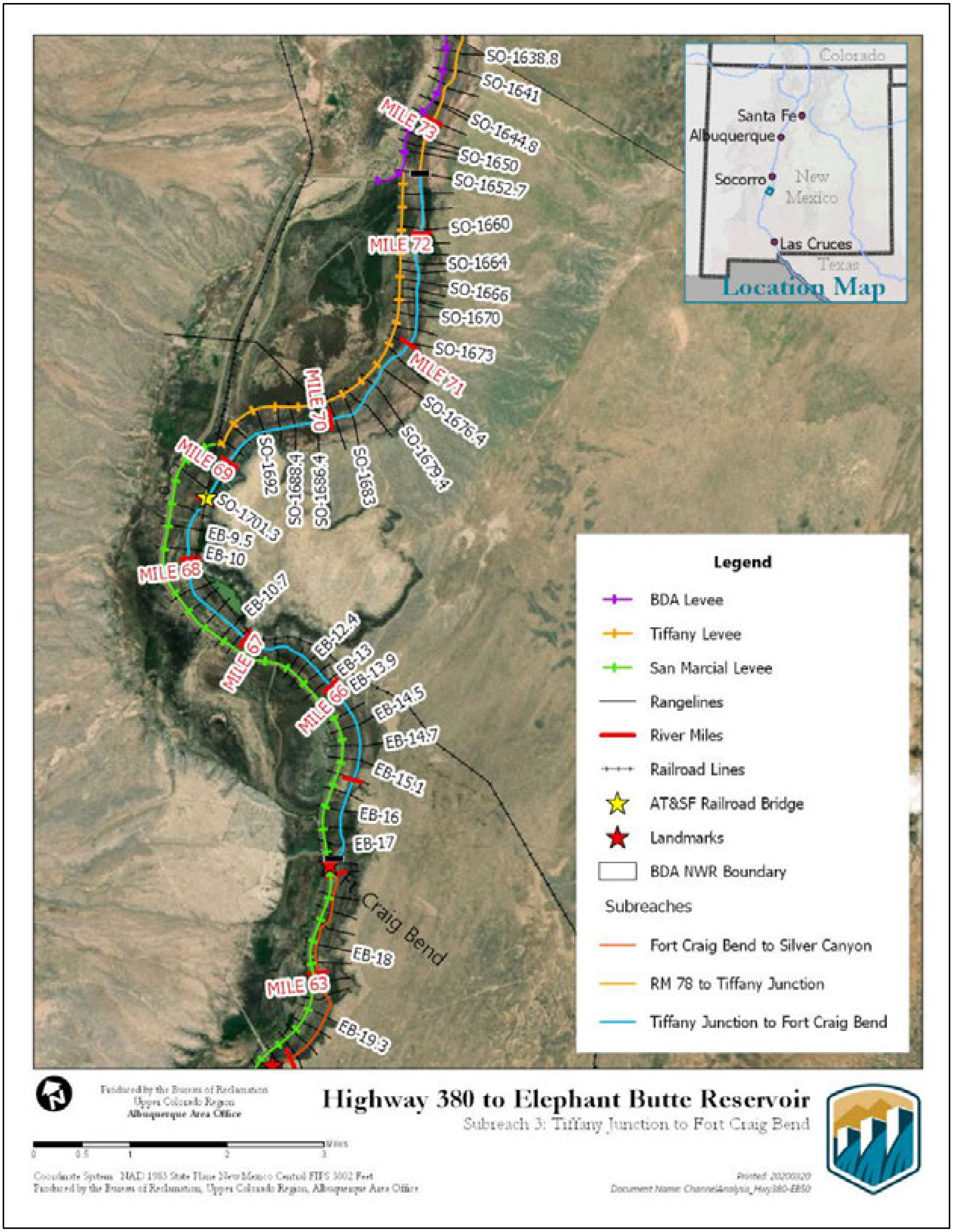

Figure 5: Map showing Subreach 3 including the AT&SF Railroad Bridge, Tiffany and San Marcial Levees, River Miles and Rangelines.

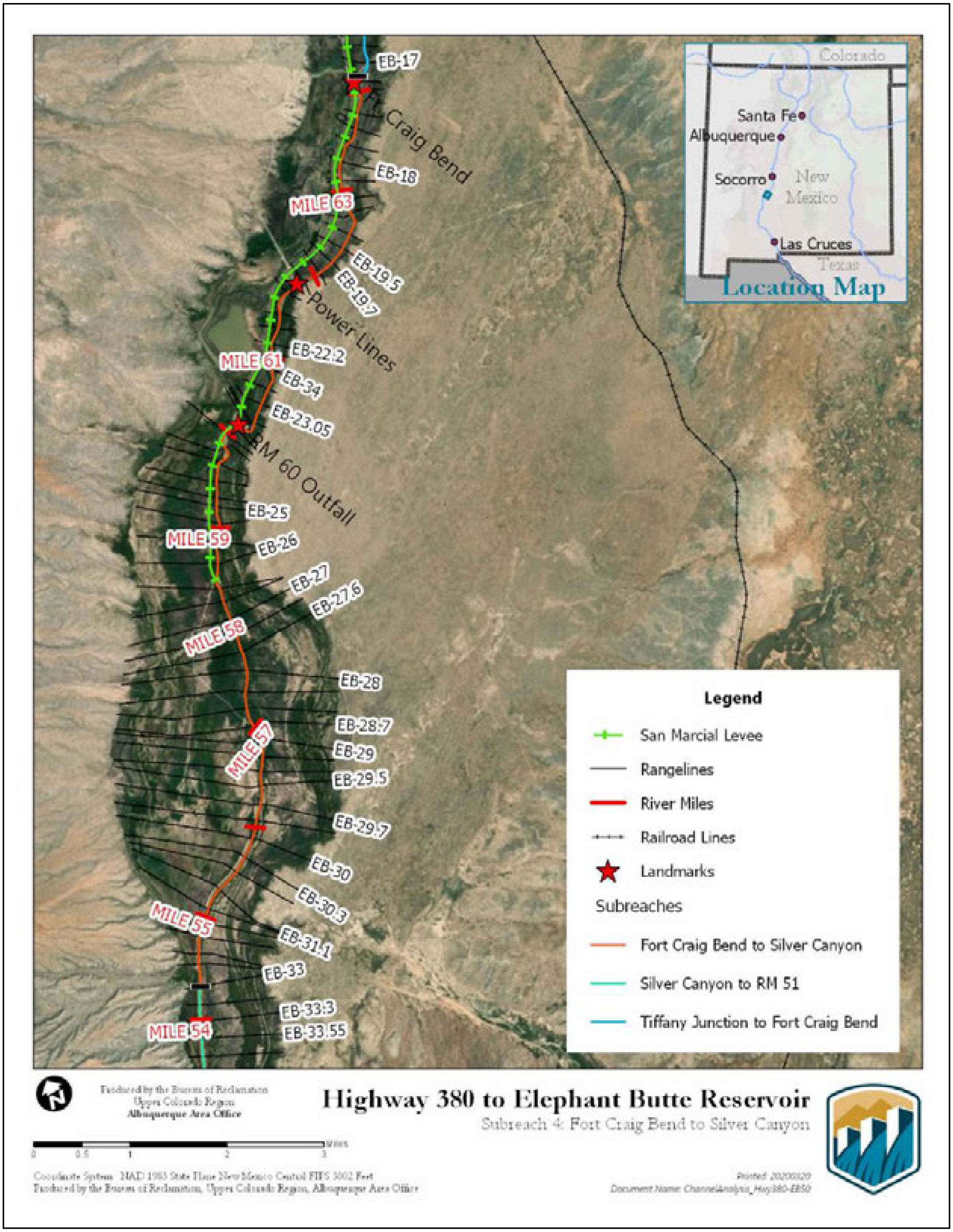

Figure 6: Map showing Subreach 4 including River Miles, Rangelines, and the San Marcial Levee.

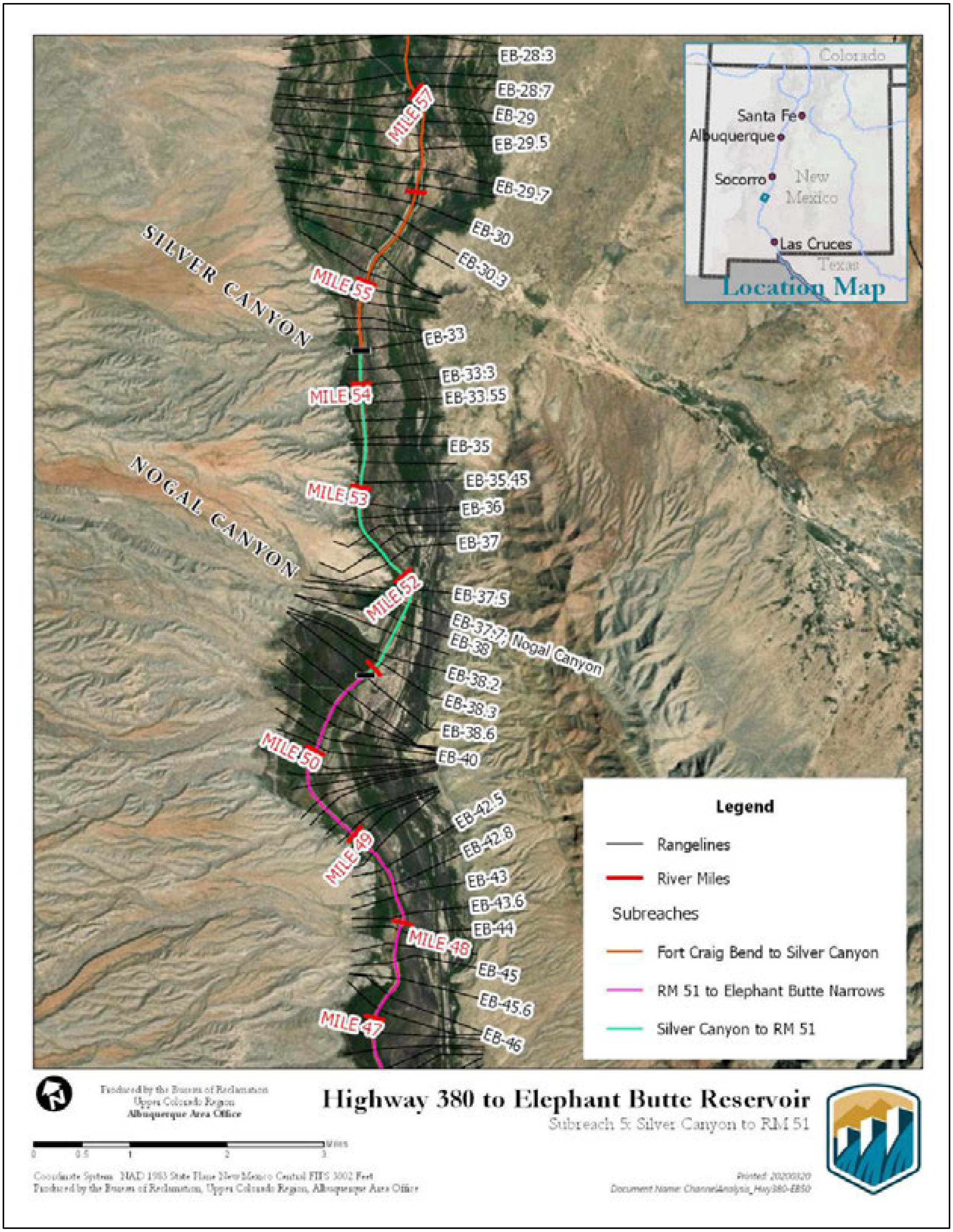

Figure 7: Map showing Subreach 5 including River Miles and Rangelines.

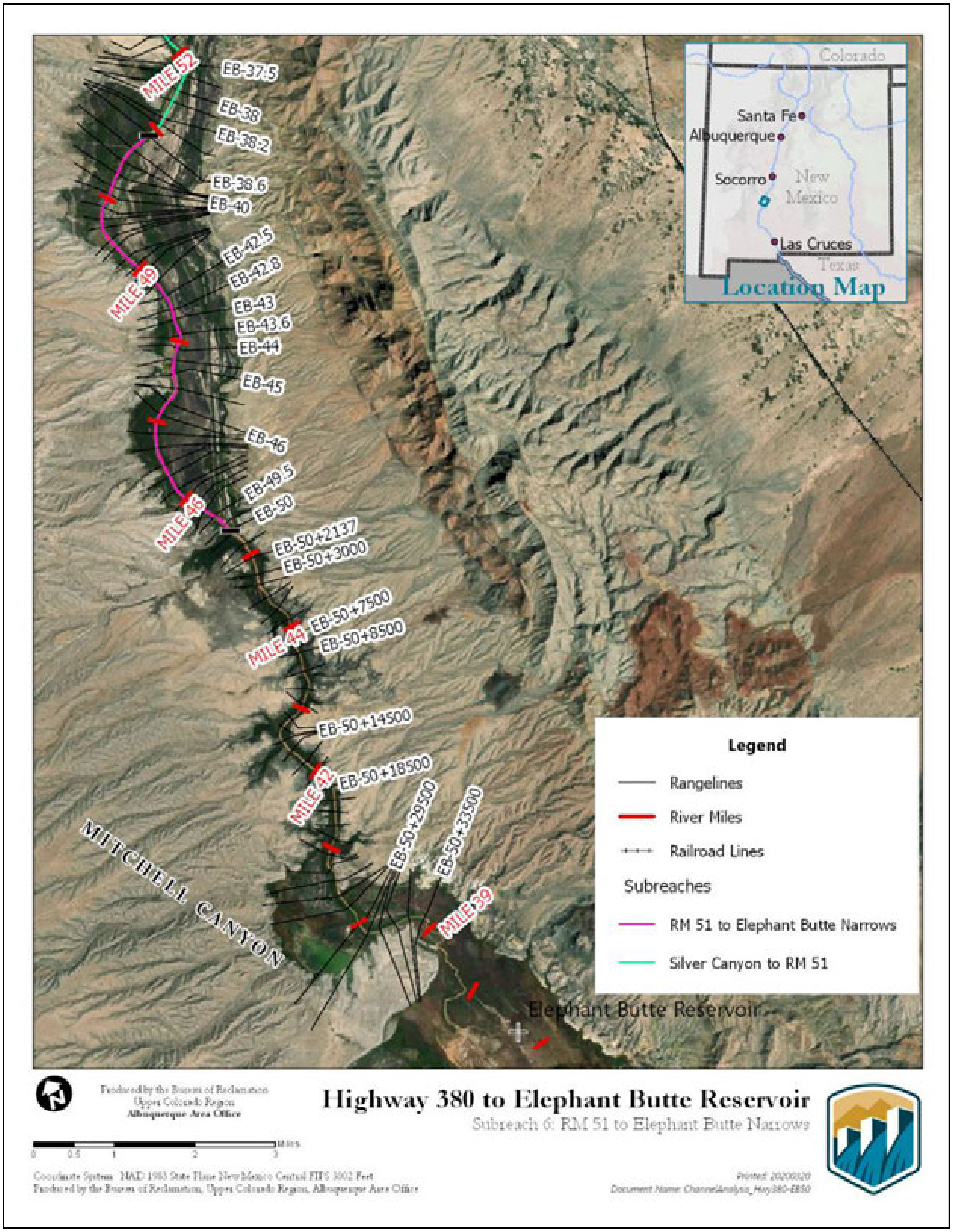

Figure 8: Map showing Subreach 6 and the extent of surveyed cross sections into the Elephant Butte pool area including River Miles and Rangelines.

Summary of Data

The data used in this analysis include yearly Reclamation cross section surveys, digital elevation models (DEM's) from Light Detection and Ranging (LiDAR) data acquisition flights, aerial imagery, Reclamation-generated Hink and Ohmart (H&O) vegetation polygons, river sediment sample gradations, and outputs from the US Army Corps of Engineers (USACE) Hydraulic Engineering Center River Analysis System (HEC-RAS) 1-Dimensional (1-D) hydraulic models. The Reclamation cross section surveys were taken at rangelines that are denoted as "SO" for those lines between Socorro and the AT&SF Railroad Bridge, and "EB" for those rangelines between the AT&SF Railroad Bridge and the Elephant Butte Reservoir. Vegetation in the channel and floodplain was assessed using aerial imagery and the H&O polygons. The bed stability and channel and floodplain topography were assessed using the yearly cross section surveys, sediment sample gradations, and outputs from the 1-D hydraulic models. The hydraulic analysis used the yearly cross section surveys and DEM's as inputs to produce the hydraulic simulations and numerical result outputs. The available cross section, LiDAR, and imagery data used in this analysis are described in Table 2 through Table 4 below. See the section "Bed Material Grain Size" for the list of available sediment samples in the study reach between 2012 and 2019.

Table 2: Available Reclamation cross section surveys for SO lines (above AT&SF Railroad Bridge) and EB lines (below AT&SF Railroad Bridge) from 2012 – 2019. See Appendix I for a complete list of cross sections surveyed by year.

Survey Year	SO Lines	EB Lines
2019	Dec 11, 2018 – Feb 6, 2019 (SO-1491-1572); Aug 1 – Aug 28, 2019	Sept 3 – Oct 17, 2019
2018	Jul 5 – Jul 25, 2018	Jul 11 – Sept 27, 2018
2017	Oct 11 – Dec 13, 2016	Mar 16 – Aug 2, 2017
2016	Mar – Apr, 2016	Feb 21 – Mar 26, 2016
2015	Mar 12 – May 20, 2015	Mar 28 – May 14, 2015
2014	Apr 16 – Jun 6, 2014	(no survey)
2013	Feb 4 – Jun 4, 2013	Feb 21 – Mar 13, 2013
2012	Feb 1, 2012 – Feb 16, 2012	Feb 16 – Mar 1, 2012

Table 3: Available Reclamation and Mid-Region Council of Governments (MRCOG) LiDAR datasets in the study area from 2012 – 2019.

Survey Year	Flight Date	LiDAR Elevation Data Extent
2019	Jan 17, 2019	BDA South Boundary to Elephant Butte
2018	Feb, 2018	MRCOG LiDAR tiles Highway 380 to BDA North Boundary
2016	Oct 1, 2016	BDA NWR Area
2012	Feb, 2012	Highway 380 Bridge to Elephant Butte

Table 4: Available Reclamation aerial imagery in the study area from 2012 – 2019.

Survey Year	Flight Date	Aerial Imagery Extent
2018	May 27, 2018	BDA South Boundary to Elephant Butte
2016	Oct 16, 2016	Highway 380 to Elephant Butte
2012	Feb 11 – 22, 2012	Highway 380 to Elephant Butte

Geomorphic Analysis

The geomorphic analysis includes evaluating changes in non-vegetated channel width, longitudinal profiles of the channel thalweg and mean bed elevations, thalweg and mean bed slopes, channel and floodway topography, and bed material sizes for the study reach between 2012 and 2019.

Non-vegetated Channel Width

Non-vegetated channel widths were estimated by taking the distance between vegetated areas as recorded on Reclamation cross section surveys and cross-checking this value with aerial imagery from 2012, 2016, and 2018. Aerial imagery taken in 2012 and 2016 was available for the entire study reach, and aerial imagery taken in 2018 was available for the section of the study reach south of River Mile 75.5 (SO-1615.1). Therefore, summary statistics of the non-vegetated channel width are presented for comparison only for cross sections within the image boundaries. Overall, the average non-vegetated width of the channel from SO-1615.1 to EB-50 decreased by about 32 feet between 2012 and 2018, with most of the change occurring between 2012 and 2016 (Table 5). For the section of the study reach between SO-1475.9 and SO-1613 where only 2012 and 2016 imagery were available, the average non-vegetated channel width decreased by 61 feet between 2012 and 2016 (Table 6). Non-vegetated channel width profile plots by subreach are included in Figure 9 through Figure 14, each followed by non-vegetated width summary statistics by subreach (Table 7 through Table 12).

Table 5: Summary of non-vegetated channel widths between SO-1615.1 and EB-50.

Channel Property	2012	2016	2018
Minimum Width (ft)	67	56	58
Maximum Width (ft)	506	553	578
Average Width (ft)	167	139	135
Standard Deviation (ft)	83	67	66

Table 6: Summary of non-vegetated channel widths between SO-1475.9 and SO-1613.

Channel Property	2012	2016
Minimum Width (ft)	100	69
Maximum Width (ft)	676	461
Average Width (ft)	214	153
Standard Deviation (ft)	92	65

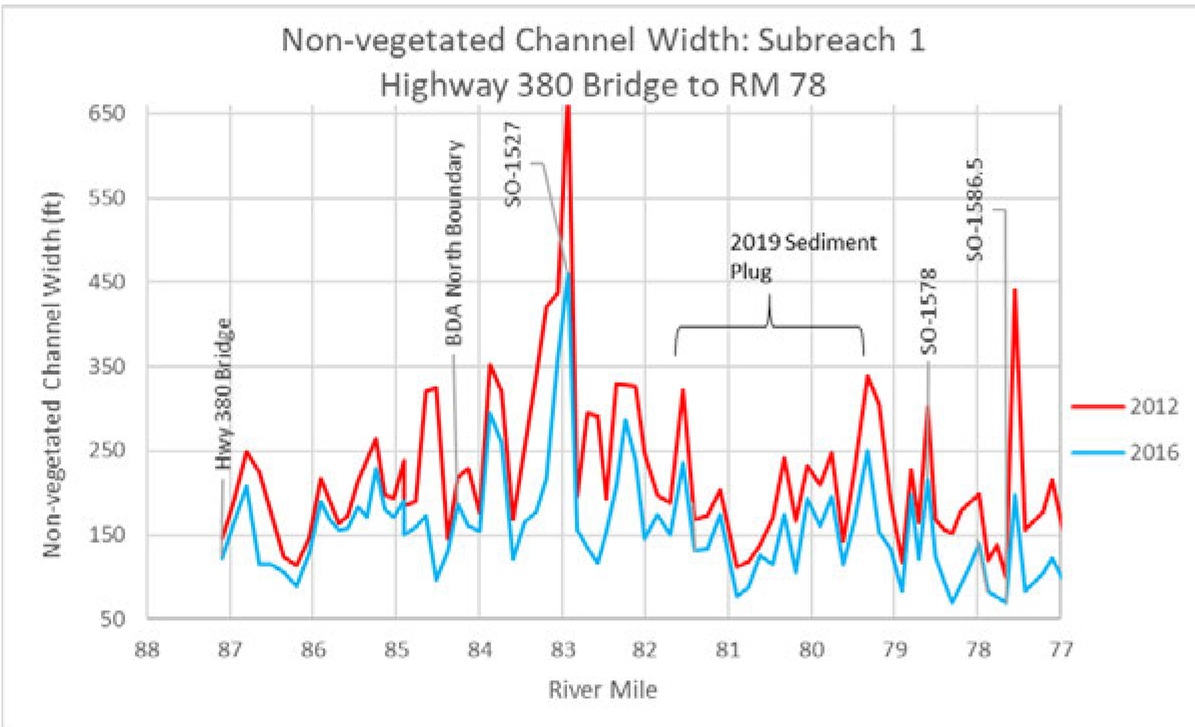

Figure 9: Non-vegetated channel width measurements from 2012 and 2016 aerial imagery for Subreach 1 (RM 87.1 – RM 78)

Table 7: Summary of non-vegetated channel widths along Subreach 1, Highway 380 Bridge to RM 78

Channel Property	2012	2016
Minimum Width (ft)	112	70
Maximum Width (ft)	676	461
Average Width (ft)	228	166
Standard Deviation (ft)	91	64

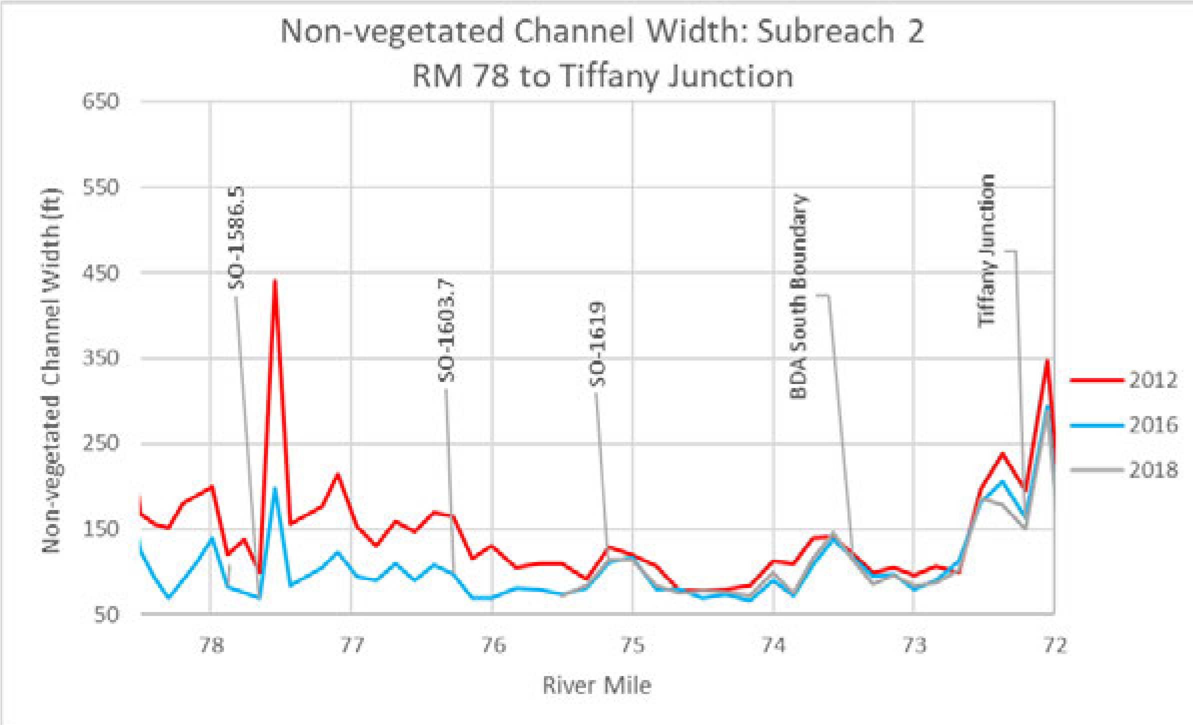

Figure 10: Non-vegetated channel width measurements from 2012, 2016, and 2018 aerial imagery for Subreach 2 (RM 78 – 72.6)

Table 8: Summary of non-vegetated channel widths along Subreach 2, RM 78 to Tiffany Junction

Channel Property	2012	2016
Minimum Width (ft)	78	67
Maximum Width (ft)	440	198
Average Width (ft)	133	97
Standard Deviation (ft)	60	28

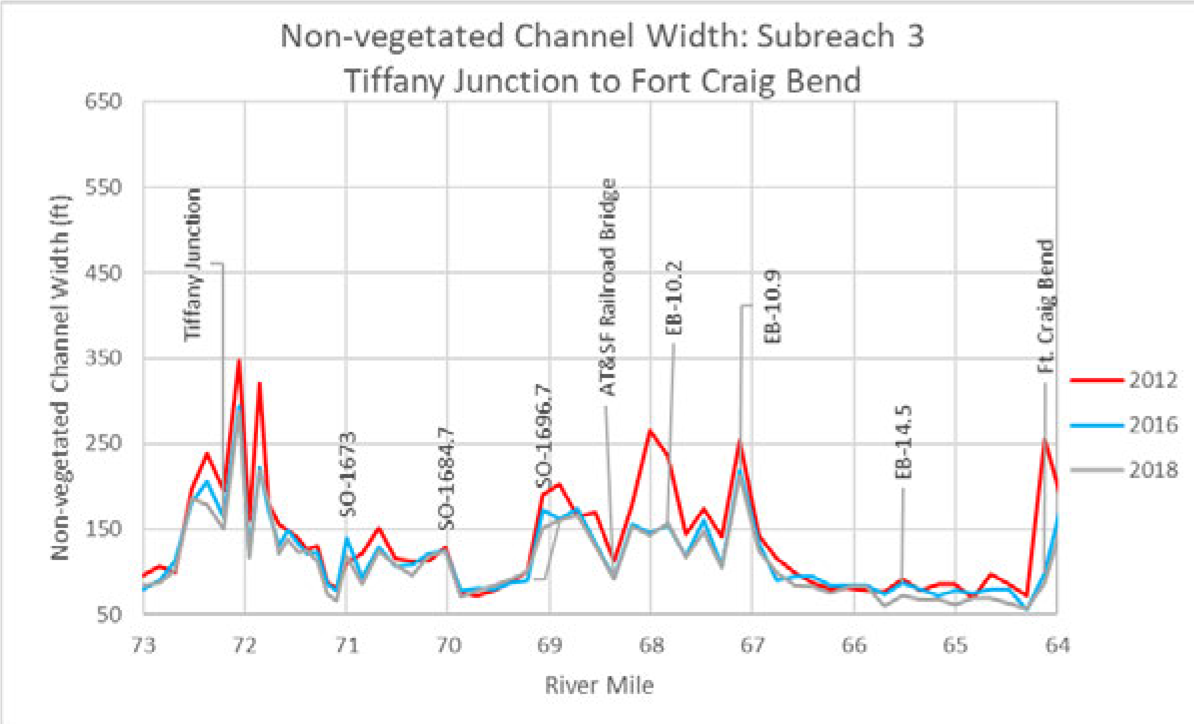

Figure 11: Non-vegetated channel width measurements from 2012, 2016, and 2018 aerial imagery for Subreach 3 (RM 72.6 – RM 64)

Table 9: Summary of non-vegetated channel widths along Subreach 3, Tiffany Junction to Fort Craig Bend

Channel Property	2012	2016	2018
Minimum Width (ft)	70	56	58
Maximum Width (ft)	348	294	287
Average Width (ft)	139	120	114
Standard Deviation (ft)	65	46	45

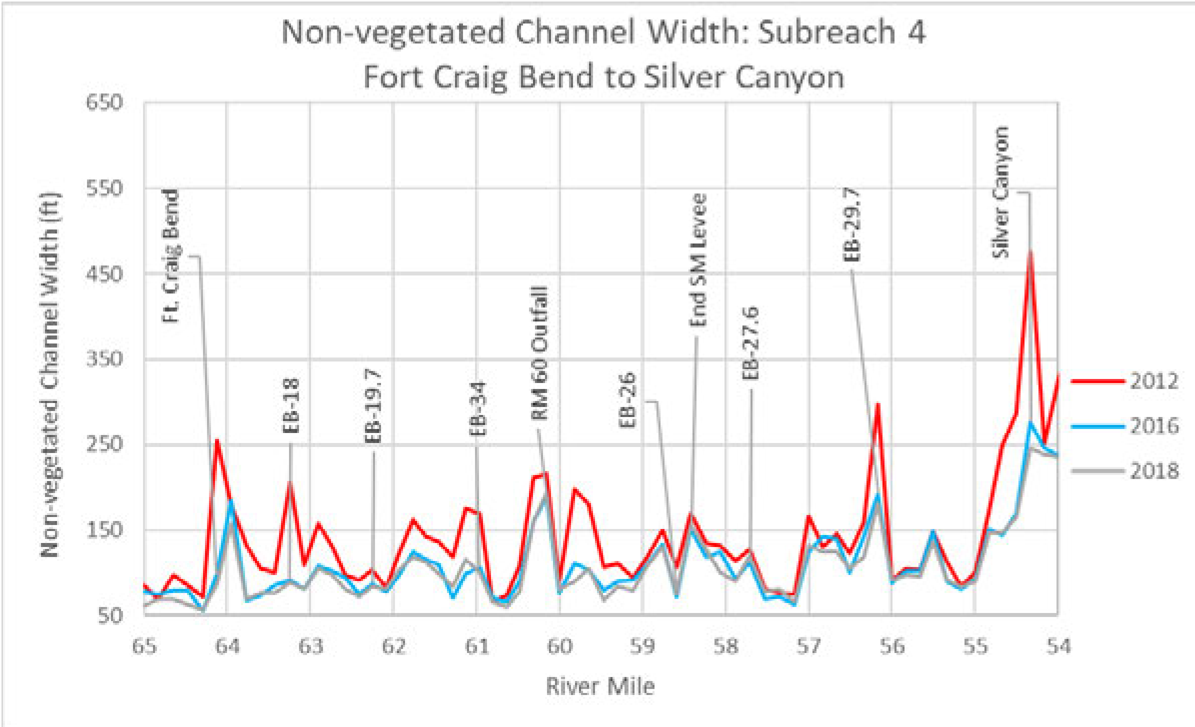

Figure 12: Non-vegetated channel width measurements from 2012, 2016, and 2018 aerial imagery for Subreach 4 (RM 64 – RM 54.5)

Table 10: Summary of non-vegetated channel widths along Subreach 4, Fort Craig Bend to Silver Canyon

Channel Property	2012	2016	2018
Minimum Width (ft)	67	63	61
Maximum Width (ft)	476	276	246
Average Width (ft)	142	110	107
Standard Deviation (ft)	66	39	35

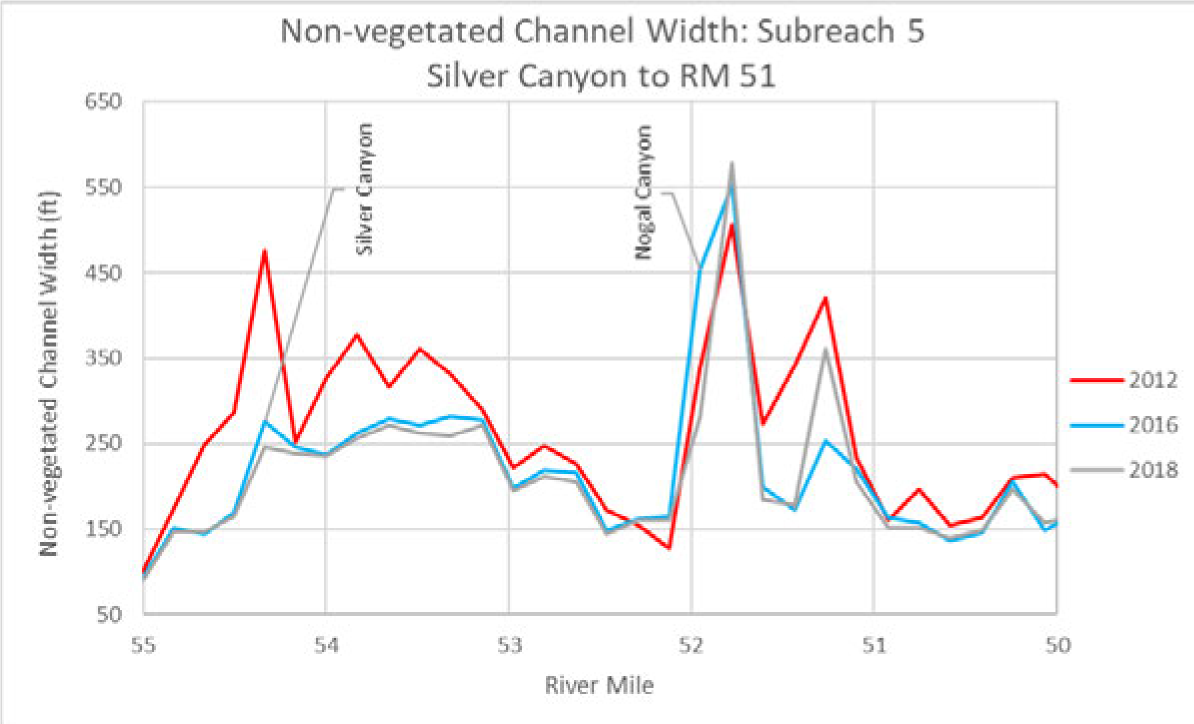

Figure 13: Non-vegetated channel width measurements from 2012, 2016, and 2018 aerial imagery for Subreach 5 (RM 54.5 – RM 51)

Table 11: Summary of non-vegetated channel widths along Subreach 5, Silver Canyon to RM 51

Channel Property	2012	2016	2018
Minimum Width (ft)	127	148	144
Maximum Width (ft)	506	553	578
Average Width (ft)	284	249	241
Standard Deviation (ft)	94	96	94

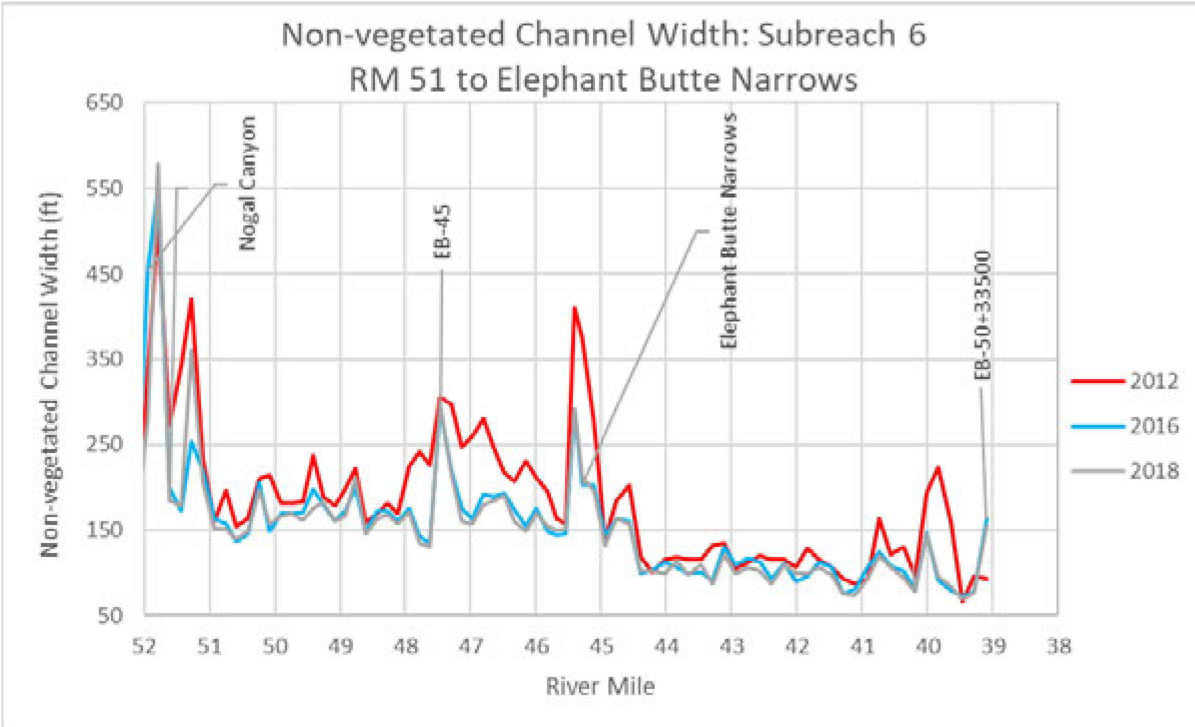

Figure 14: Non-vegetated channel width measurements from 2012, 2016, and 2018 aerial imagery for Subreach 6 (RM 51 – RM 45.3)

Table 12: Summary of non-vegetated channel widths along Subreach 6, RM 51 to Elephant Butte Narrows

Channel Property	2012	2016	2018
Minimum Width (ft)	155	135	130
Maximum Width (ft)	411	292	298
Average Width (ft)	220	177	174
Standard Deviation (ft)	57	35	36

The cross sections that underwent the greatest increase in non-vegetated channel width from 2012 to 2018 are shown in Table 13 below. Cross sections in the EB section of the reach (below AT&SF Railroad Bridge) widened the most overall and between each set of images. The cross sections that underwent the most narrowing are shown in Table 14.

Table 13: Greatest increases in non-vegetated channel width (ft) between 2012, 2016, and 2018, and corresponding rangelines

'12-'16	Rangeline	'16-'18	Rangeline	'12-'18	Rangeline
+115	EB-37.5	+108	EB-38.2	+72	EB-37.7
+47	EB-37.7	+26	EB-37.7	+34	EB-37
+38	EB-37	+15	EB-22.6	+8	SO-1673
+28	SO-1673	+13	EB-22.2	+6	SO-1688.4
+14	SO-1650	+11	EB-42	+5	SO-1683

Aerial images of the cross sections that underwent the greatest increase in non-vegetated channel width are shown below. The channel at EB-37 widened between 2012 and 2016 with the eastern bank moving away from the channel, then widened more between 2016 and 2018 as the vegetation grew sparse at the eastern channel bank (Figure 15). The cross sections EB-37.5 and EB-37.7 widened from 2012 to 2016 as the vegetated western bank became a partially submerged sand bar with less dense vegetation (Figure 16). From 2016 to 2018, EB-37.5 narrowed as vegetation became established on the western bank while EB-37.7 widened as vegetation on the western bank became sparser. The changes at EB-37.5 and 37.7 may be related to clearing by Reclamation rather than natural processes since these cross sections coincide with a staging area. EB-38.2 narrowed from 2012 to 2016 as vegetation became established on both banks, then widened between 2016 and 2018 as smaller vegetation on the east bank disappeared Figure 17.

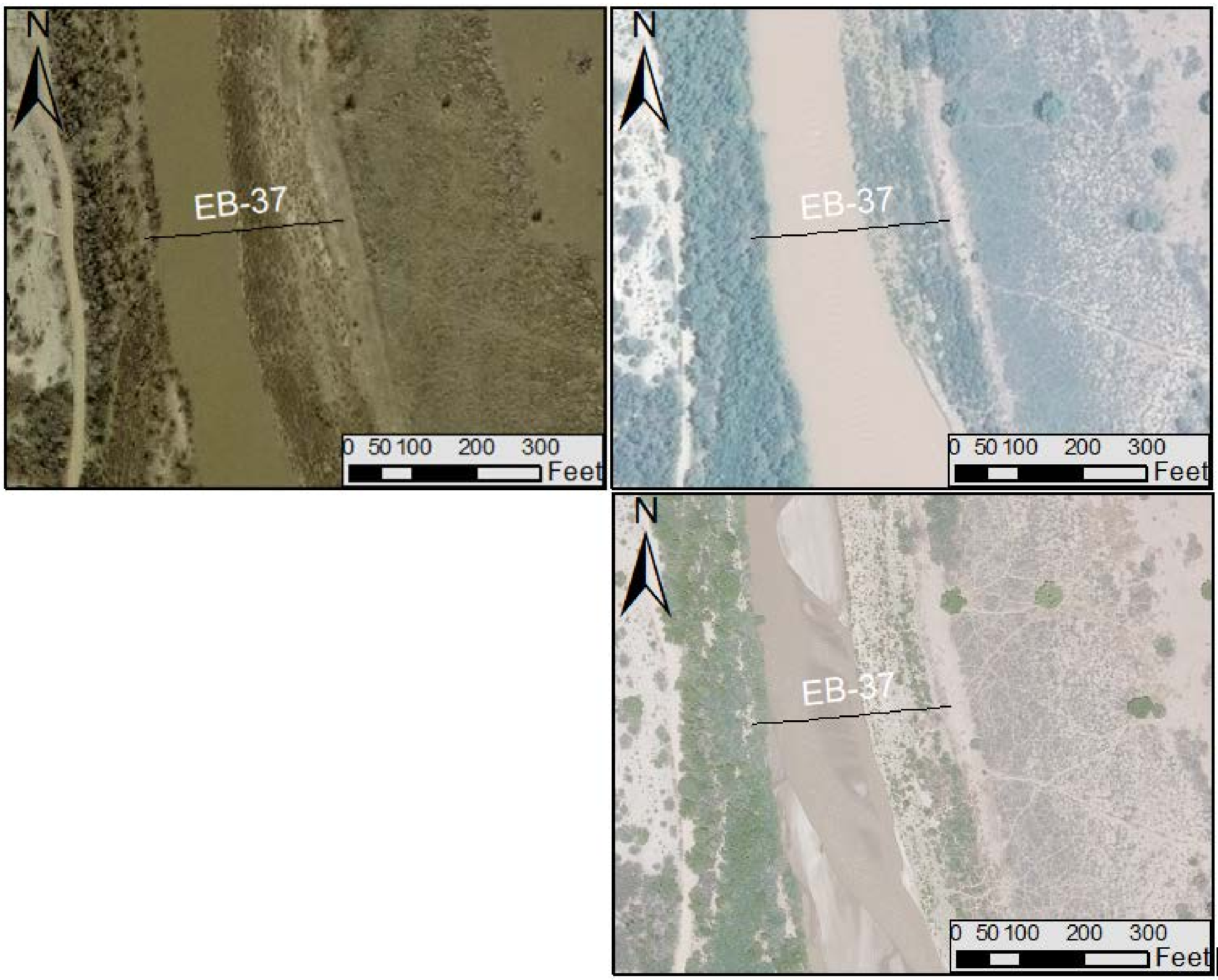

Figure 15: Widening of non-vegetated width at cross section EB-37 from 2012 (top left) to 2016 (top right) and widening slightly as vegetation on the eastern bank grew sparse between 2016 and 2018 (bottom right)

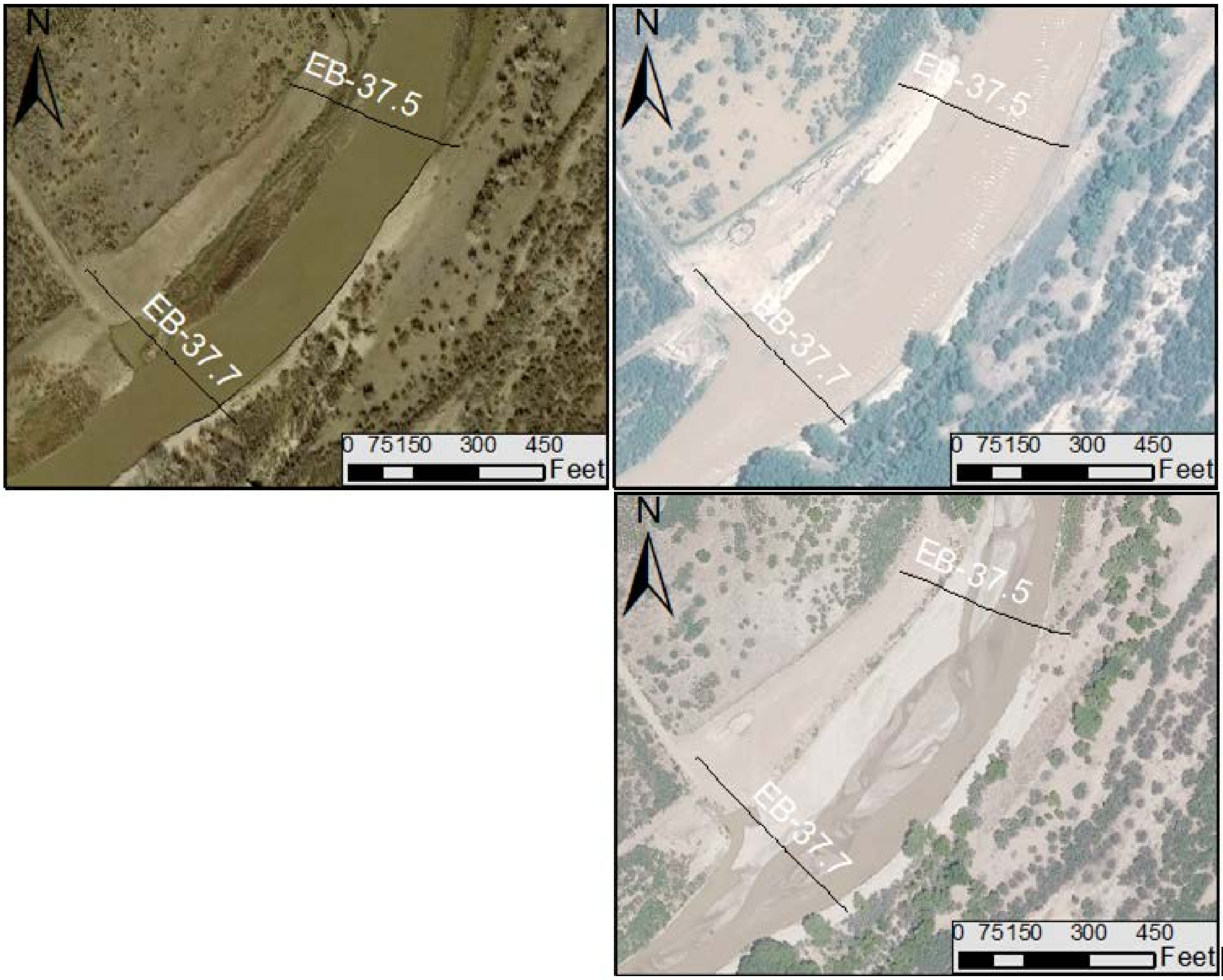

Figure 16: Widening of non-vegetated width at cross sections EB-37.5 and 37.7 from 2012 (top left) to 2016 (top right) as the vegetated sand bar on the western bank was cleared and submerged. From 2016 to 2018 (bottom right), EB-37.5 narrowed slightly as vegetation re-established on the western bank. EB-37.7 widened from 2016 to 2018 as vegetation on the western bank retreated.

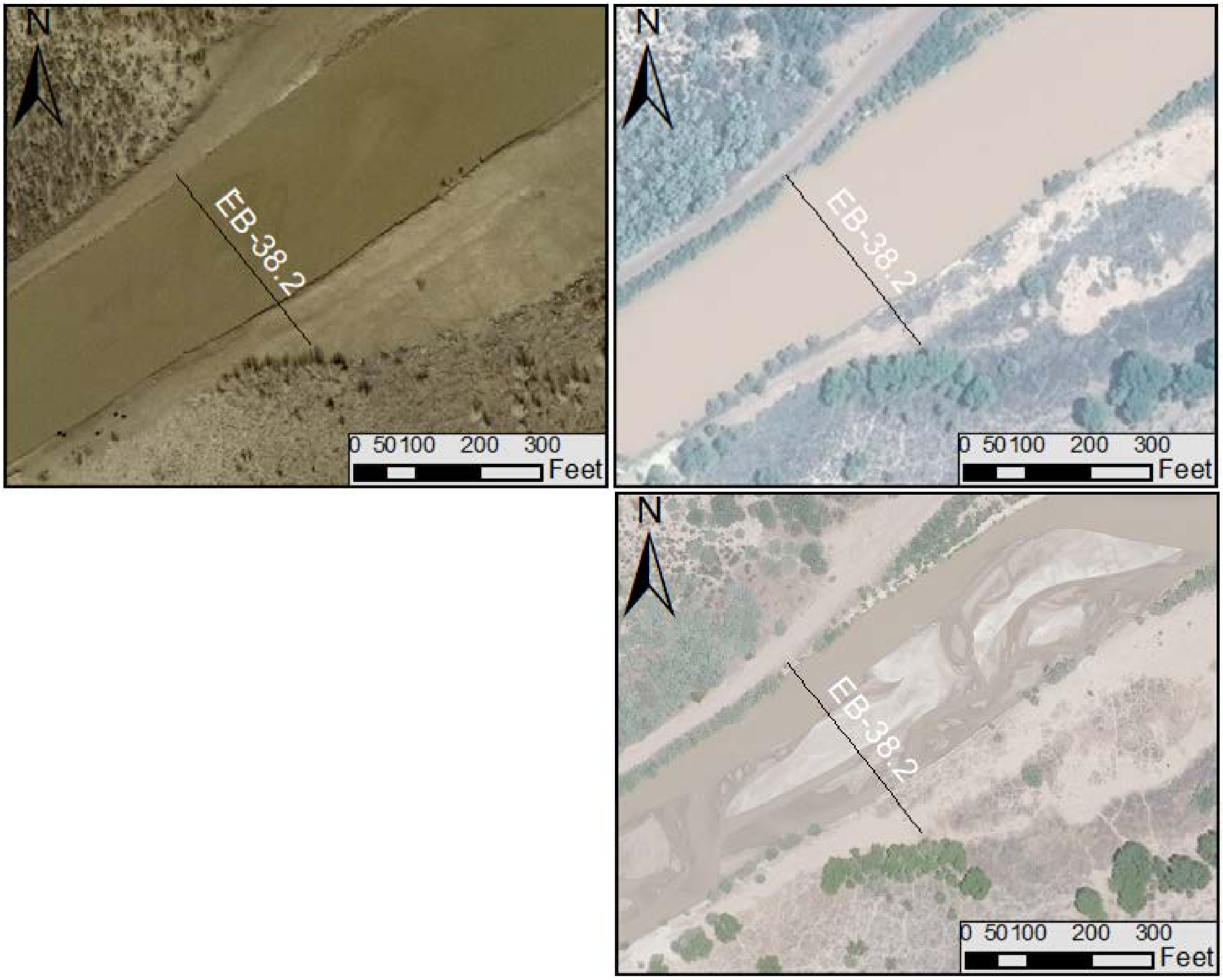

Figure 17: Narrowing of non-vegetated width at cross section EB-38.2 as vegetation became established on both banks from 2012 (top left) to 2016 (top right). The cross section widened from 2016 to 2018 (bottom right) as vegetation on the eastern bank disappeared.

Table 14: Greatest decreases in non-vegetated channel width (ft) between 2012, 2016, and 2018, and corresponding rangelines.

'12-'16	Rangeline	'16-'18	Rangeline	'12-'18	Rangeline
-242	SO-1588	-173	EB-37.5	-230	EB-33
-228	SO-1507.5	-30	EB-33	-167	EB-17.35
-215	SO-1527	-28	EB-17.7	-162	EB-50
-204	SO-1524	-27	SO-1656.1	-162	EB-38.1
-200	EB-33	-25	EB-29.5	-123	EB-10.1

The cross sections that narrowed the most from 2012 to 2016 were in the SO rangelines (above the AT&SF Railroad Bridge), while the cross sections that narrowed most from 2016 to 2018 and overall from 2012 to 2018 were in the EB section (below the AT&SF Railroad Bridge). Aerial images of the cross sections that narrowed the most are shown below. SO-1507.5 narrowed between 2012 and 2016 as a vegetated sand bar developed on the eastern bank (Figure 18). SO-1588 narrowed as vegetation grew on the eastern sand bar between 2012 and 2016 (Figure 19). The cross section at EB-17.35 (Fort Craig Bend) narrowed between 2012 and 2016 as vegetation established on both banks, then kept approximately the same non-vegetated width from 2016 to 2018 (Figure 20). EB-33 narrowed substantially from 2012 to 2016 as vegetation grew on both banks and the western bank migrated toward the channel, then narrowed further as the western bank continued to migrate toward the channel between 2016 and 2018 (Figure 21). Lastly, EB-50 narrowed from 2012 to 2016 as vegetation became established on the sand bar connected to the eastern bank (Figure 22). Vegetation retreated from the bank slightly on both sides of the channel from 2016 to 2018, widening the channel slightly.

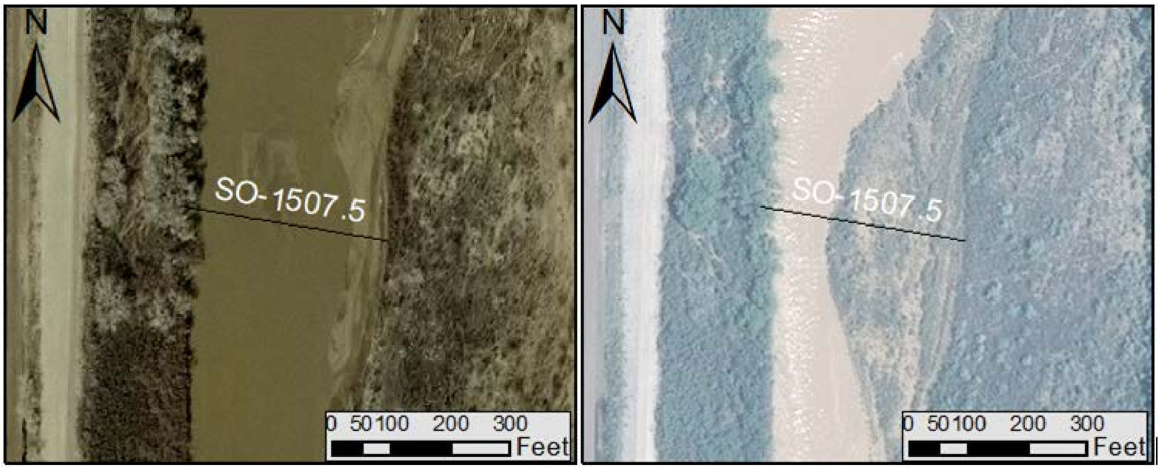

Figure 18: Narrowing of non-vegetated width at cross section SO-1507.5 from 2012 (left) to 2016 (right).

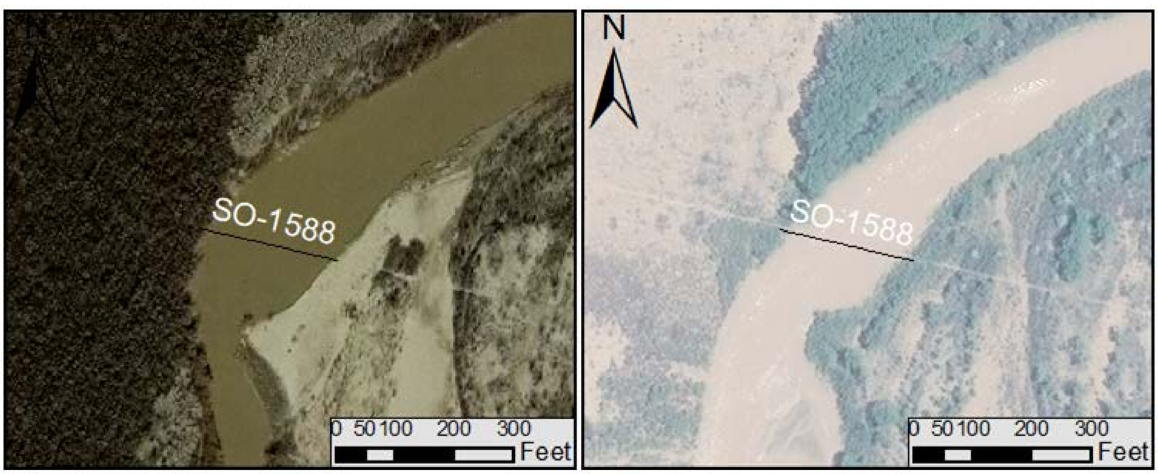

Figure 19: Narrowing of non-vegetated width at cross section SO-1588 from 2012 (left) to 2016 (right).

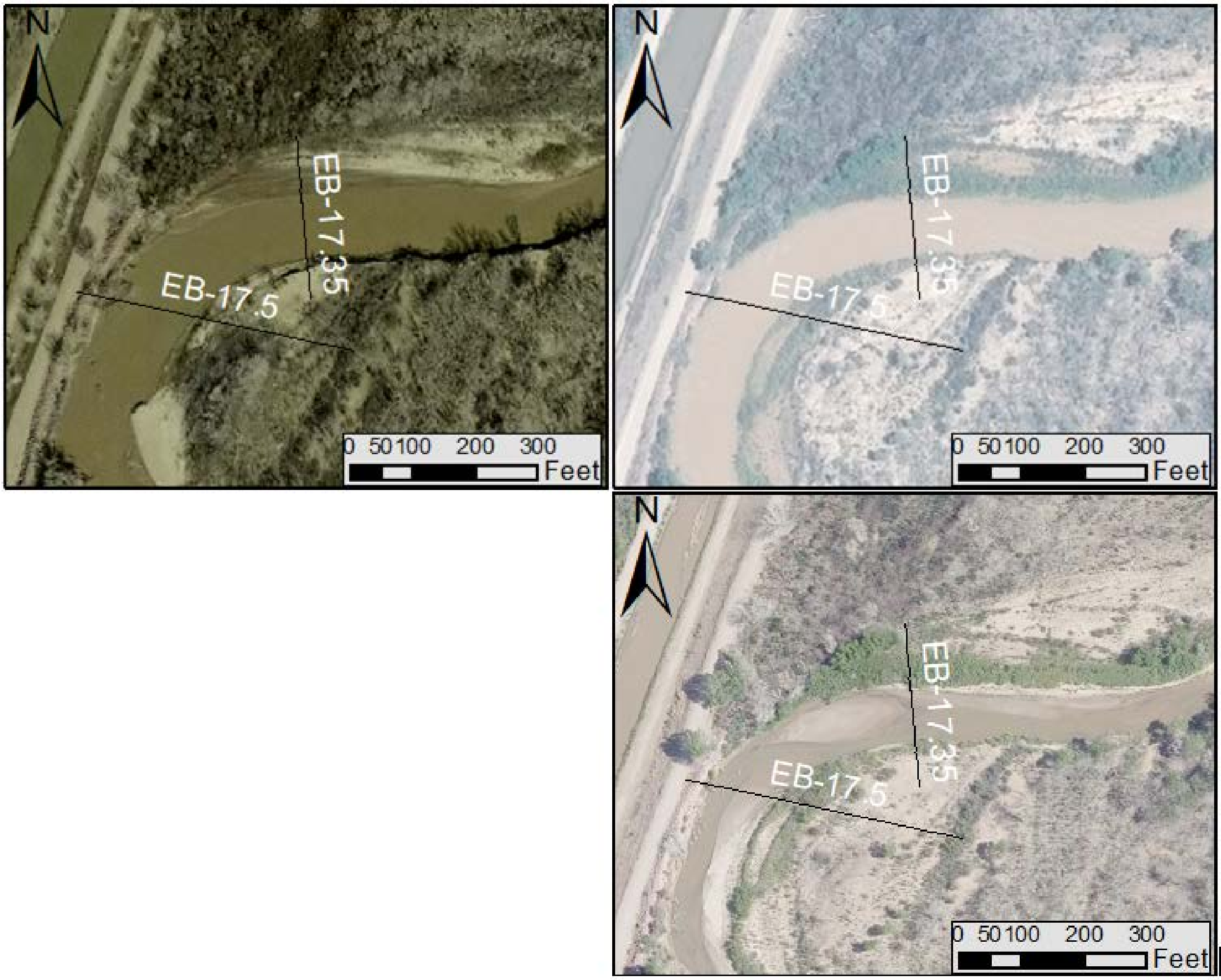

Figure 20: Narrowing of non-vegetated width at cross section EB-17.35 (Fort Craig Bend) from 2012 (top left) to 2016 (top right) as vegetation became established on the eastern bank. Non-vegetated width stayed approximately the same from 2016 to 2018 (bottom right).

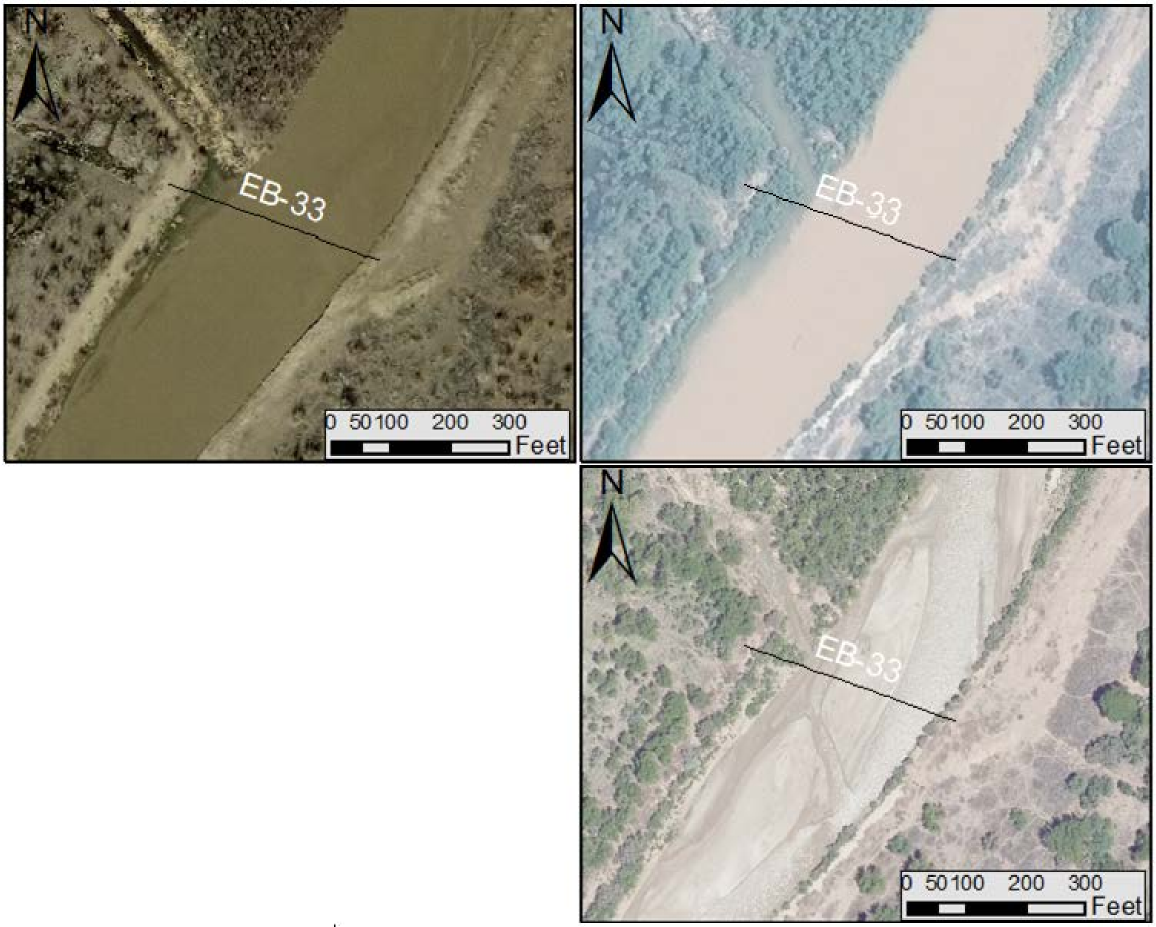

Figure 21: Narrowing of non-vegetated width at cross section EB-33 from 2012 (top left) to 2016 (top right) and 2018 (bottom right).

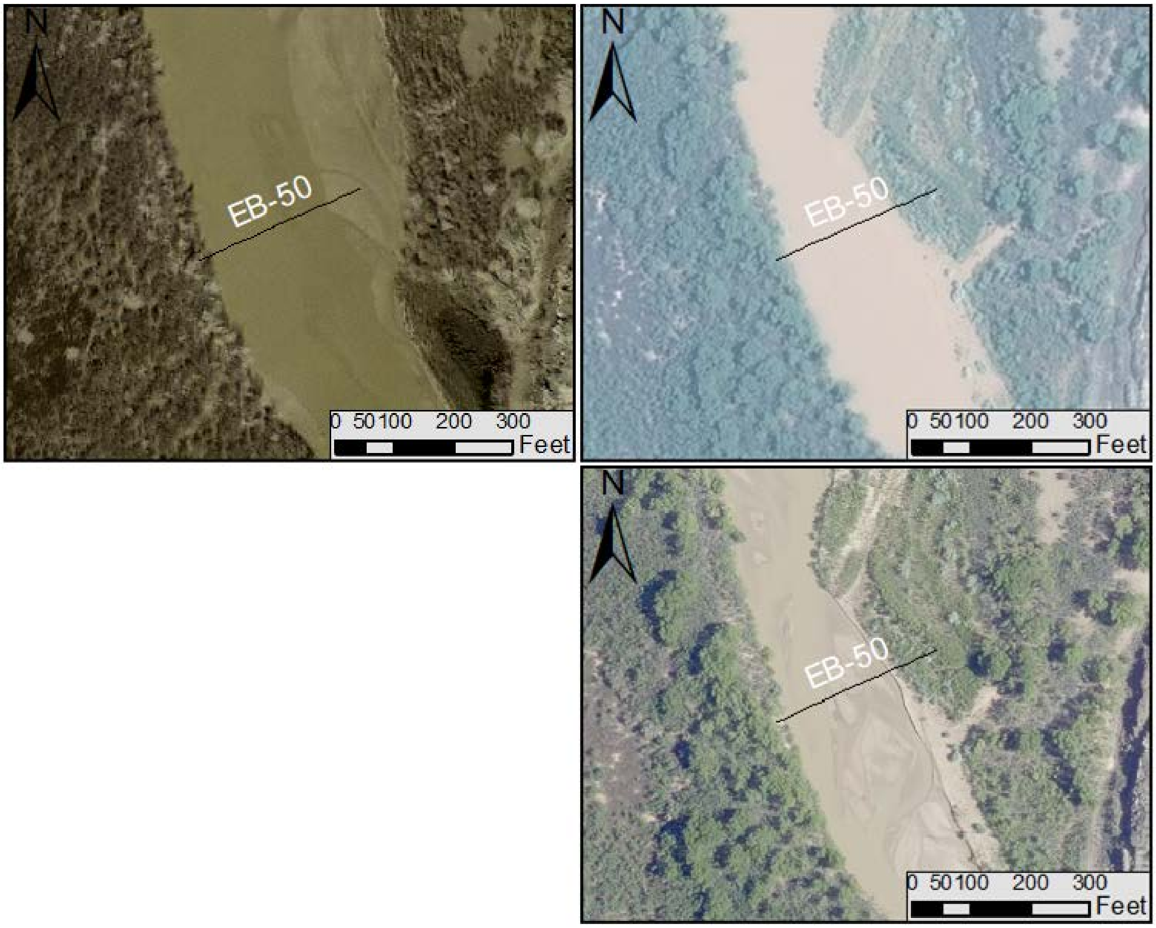

Figure 22: Narrowing of non-vegetated width at cross section EB-50 from 2012 (top left) to 2016 (top right) as vegetation grew on the sand bar connected to the eastern bank. The non-vegetated width increased very slightly from 2016 to 2018 (bottom right).

Bed Stability Assessment

The channel thalweg and mean bed elevations at the 50% and 25% exceedance flows of 500 cfs and 2,300 cfs (Bui, 2014) were used to assess bed stability in the reach. The mean bed elevation is equal to the calculated water surface elevation at a cross section minus the calculated hydraulic depth. Mean depth is used here to assess the bed stability because it averages the overall bed change along the entire active cross section width as compared to evaluating the thalweg elevation (deepest location in the cross section). The thalweg can have more variability associated with the flow regime and scour and fill occurring when the data was collected. The thalweg elevation is actively worked by all river flows including low flows while the mean bed is actively worked by the higher discharges.

Longitudinal Thalweg Profile

Overall, the longitudinal profile of the channel thalweg underwent a period of aggradation between 2012 and 2015, followed by a general period of degradation from 2015 to 2019. The years 2013 – 2014 and 2016 – 2017 saw the least change in thalweg elevation. The distance-weighted, reach-average thalweg elevation was lowered by 0.3 ft (3.6 in) between the 2012 and 2019 cross section surveys. Table 15 below summarizes average and maximum thalweg elevation changes from 2012 to

2019. Here positive values in row 1 indicate aggradation while negative values indicate degradation. Values reported for the maximum degradation (row 5 in Table 15) are reported as positive values and indicate a decrease in elevation. Note that these values were generated using the HEC-RAS output tables from each year of cross section data used in the model, including cross section geometries carried over from the previous year's model when newer data was not generated. Other than cross sections below the AT&SF Railroad Bridge (EB lines) in 2014, cross sections were surveyed in both the EB and SO sections of the reach once per year between 2012 and 2019. See Appendix I for a list of years each cross section was surveyed.

Table 15: Summary of thalweg elevation changes along the study reach from 2012 to 2019.

Unit	'12-'13	'13-'14	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Average Δ (ft)	0.2	0.0	0.3	-0.2	0.0	-0.2	-0.3	-0.3
Max. Aggradation (ft)	5.6	1.6	4.4	3.5	3.9	4.5	5.5	6.9
Location (Rangeline)	SO-1529.4	SO-1566	EB-43.6	EB-47	EB-35	EB-23.4	SO-1550	SO-1550
Max. Degradation (ft)	2.5	5.2	4.1	3.8	2.8	2.7	4.1	4.5
Location (Rangeline)	SO-1644.8	SO-1529.4	EB-47	EB-35	EB-25.3	EB-47.7	SO-1572.5	SO-1626

Changes in the thalweg elevations by subreach are tabulated in Table 16 below. Profile plots showing the thalweg elevations along the study reach are shown in Figure 23 through Figure 28 below.

Table 16: Year-to-year changes in subreach average thalweg elevations between 2012 and 2019 color coded by value.

Unit	'12-'13	'13-'14	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Subreach 1 Average Δ (ft)	0.2	0.0	0.7	-0.1	0.1	0.4	0.5	1.8
Subreach 2 Average Δ (ft)	0.2	-0.1	0.5	-0.1	-0.2	-1.1	-1.8	-2.6
Subreach 3 Average Δ (ft)	0.1	0.0	0.0	-0.2	-0.4	-0.3	-0.2	-1.1
Subreach 4 Average Δ (ft)	0.1	0.0	0.6	-0.5	-1.0	0.2	-0.7	-1.4
Subreach 5 Average Δ (ft)	0.6	0.0	0.6	-0.9	1.3	-0.5	-0.5	0.5
Subreach 6 Average Δ (ft)	0.4	0.0	-0.6	0.0	1.4	-0.4	0.5	1.2

Subreach 1 underwent mostly aggradation between 2012 and 2019, with net degradation occurring only over the 2015-2016 year (Figure 23). Regarding the 2019 sediment plug in the BDA area, the 2019 cross section survey was completed through August 2019. In September through December of 2019 the active river channel was realigned to the eastern part of the floodplain, with the plugged section of channel left in place. Therefore, the 2019 cross section survey does not reflect the current channel condition in the BDA realignment area.

The next downstream section (Subreach 2) underwent mostly degradation between 2012 and 2019, with aggradation only from 2012 – 2013 and 2014 – 2015 (Figure 24). The 2019 thalweg profile stands out since it is lower than profiles from the previous years. This is likely a result of the cutoff of sediment delivery from Subreach 1 by the sediment plug that formed in 2019, leading to excess sediment transport capacity and scouring in the channel downstream of the plug.

Thalweg elevations along Subreach 3 were fairly stable between 2012 and 2019, with overall degradation from 2015 – 2019 (Figure 25). Again, the 2019 profile stands out in this plot due to the degradation above the AT&SF Railroad Bridge. Subreach 3 straddles the volcanic escarpment known as Black Mesa (or Mesa de la Contadera) which acts as a geologic control on river bed elevations.

Subreach 4 underwent overall aggradation from 2012 – 2015 and degradation from 2015 – 2019. Aggradation was most evident between the RM 60 Outfall and the Silver Canyon (Figure 26).

Subreach 5 underwent net aggradation between 2012 and 2019, with the period from 2016 – 2017 contributing the most aggradation (Figure 27). This subreach includes the mouths of Silver and Nogal Canyons, and coincides with a section of valley narrowing from Silver Canyon to Nogal Canyon (Figure 7).

Thalweg elevations in Subreach 6 underwent net aggradation between 2012 and 2019, with a sediment plug forming at RM 46 – 47 in 2019 (Figure 28). The only years in which Subreach 6 underwent degradation were 2014 – 2015 and 2017 – 2018.

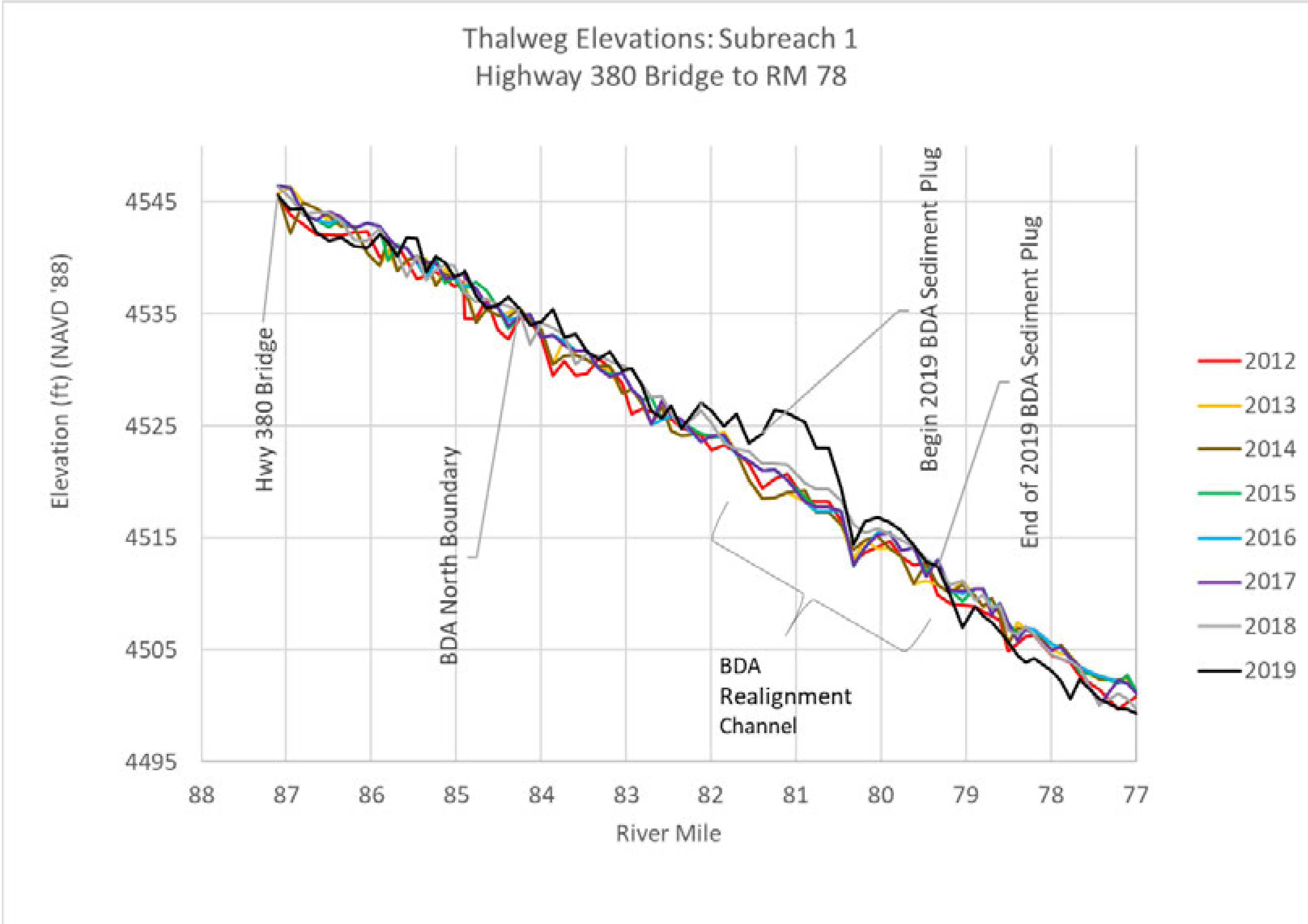

Figure 23: Thalweg elevations for Subreach 1 (RM 87.1 – RM 78)

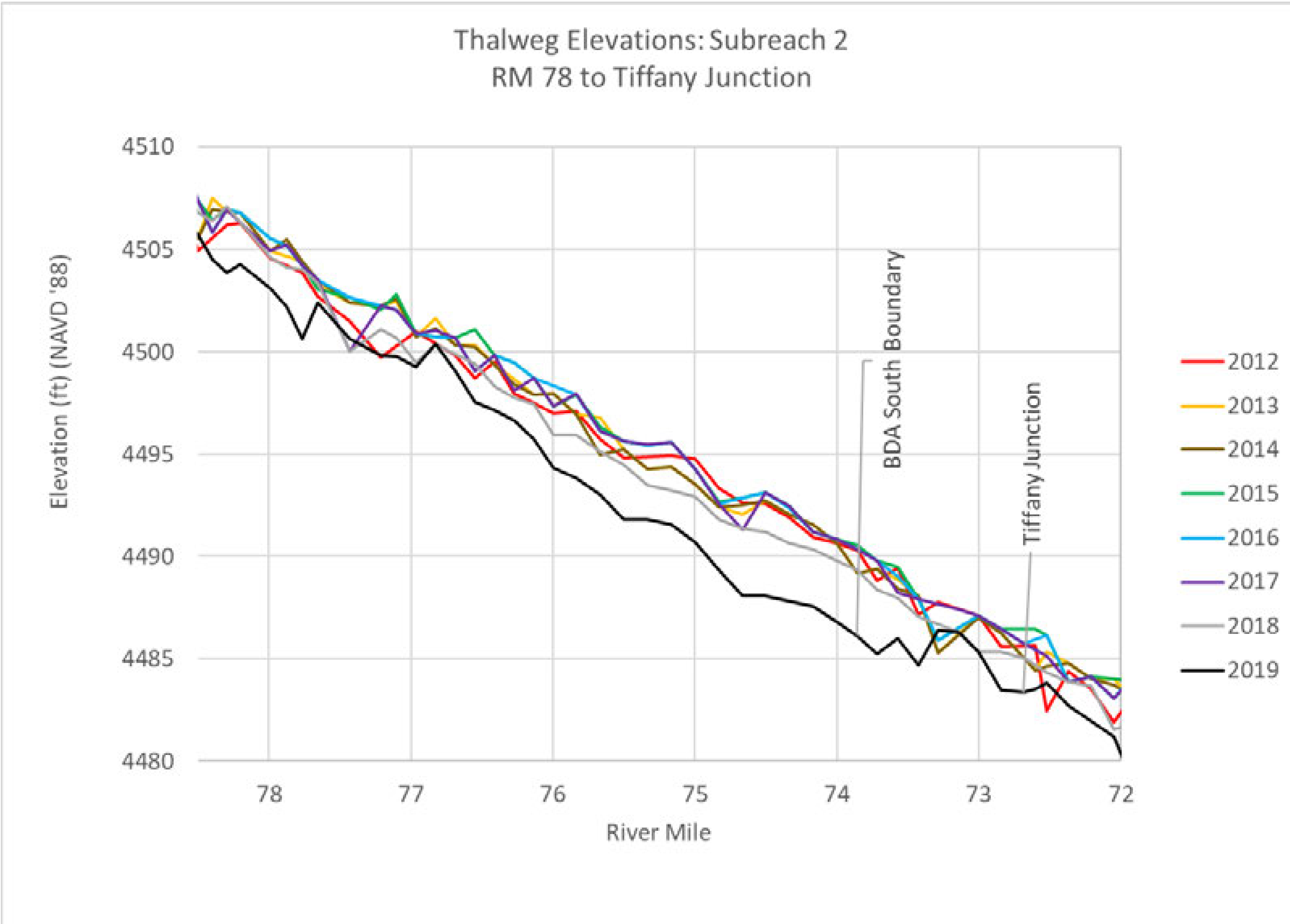

Figure 24: Thalweg elevations for Subreach 2 (RM 78 – RM 72.6)

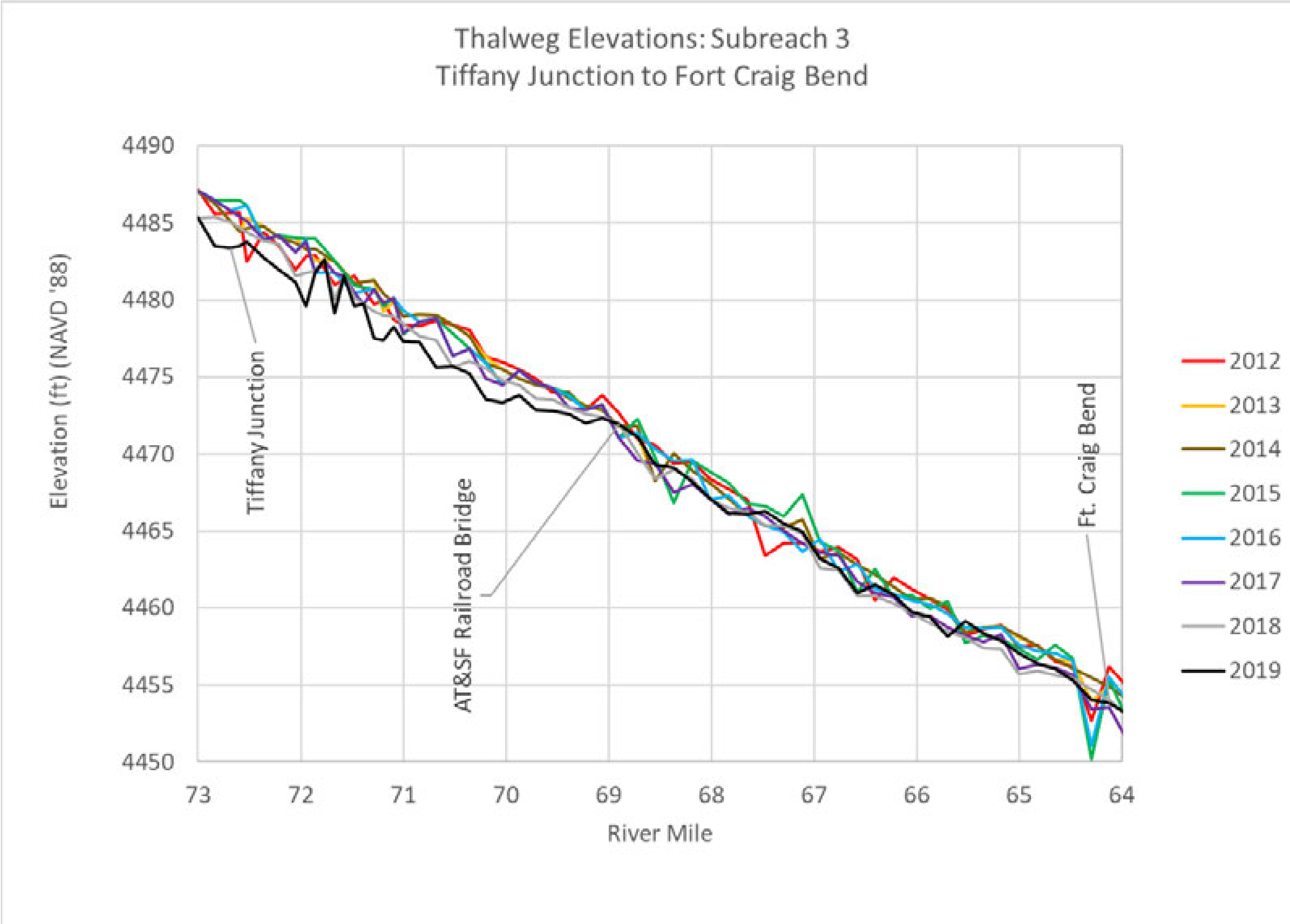

Figure 25: Thalweg elevations for Subreach 3 (RM 72.6 – RM 64)

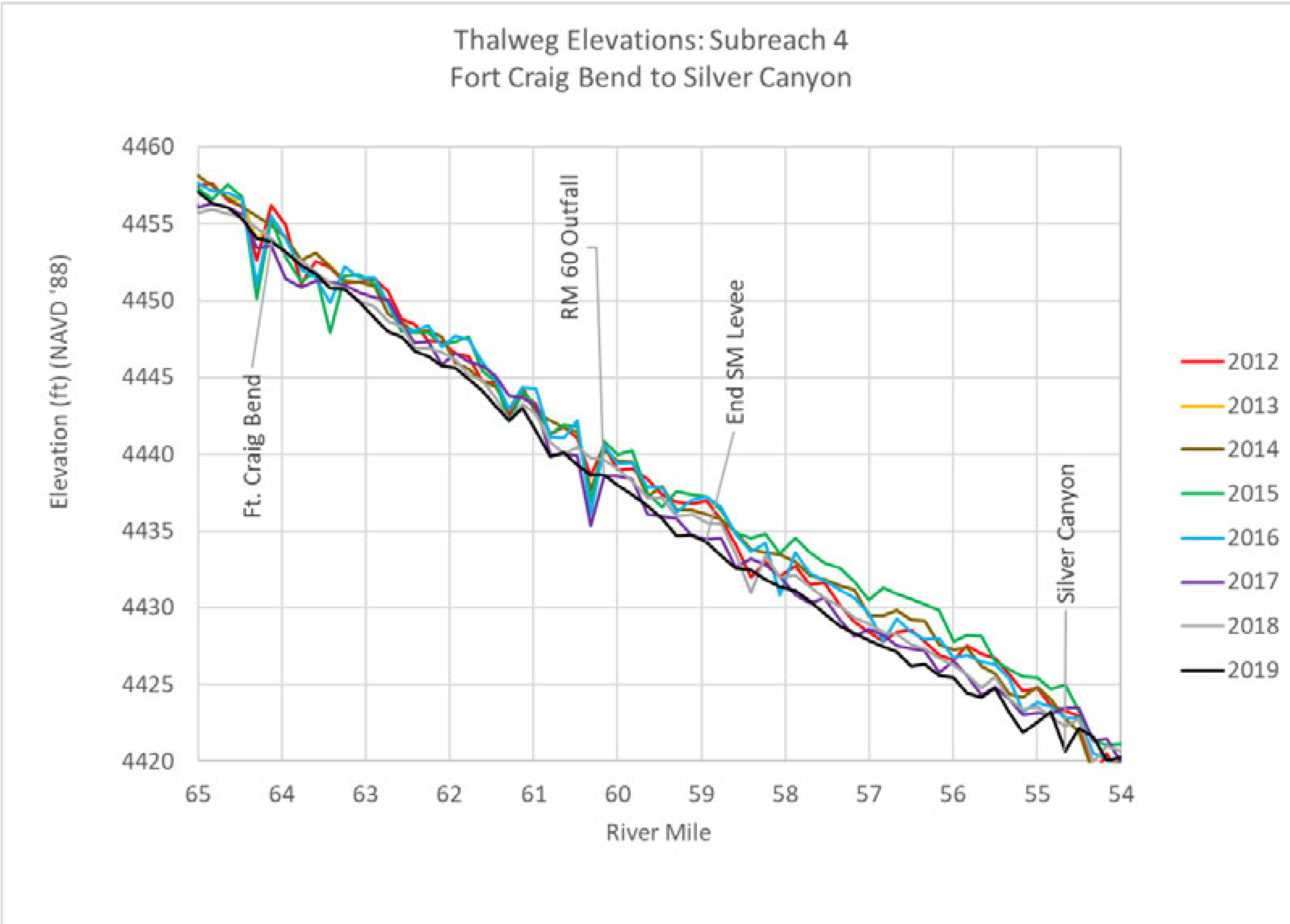

Figure 26: Thalweg elevations for Subreach 4 (RM 64 – RM 54.5)

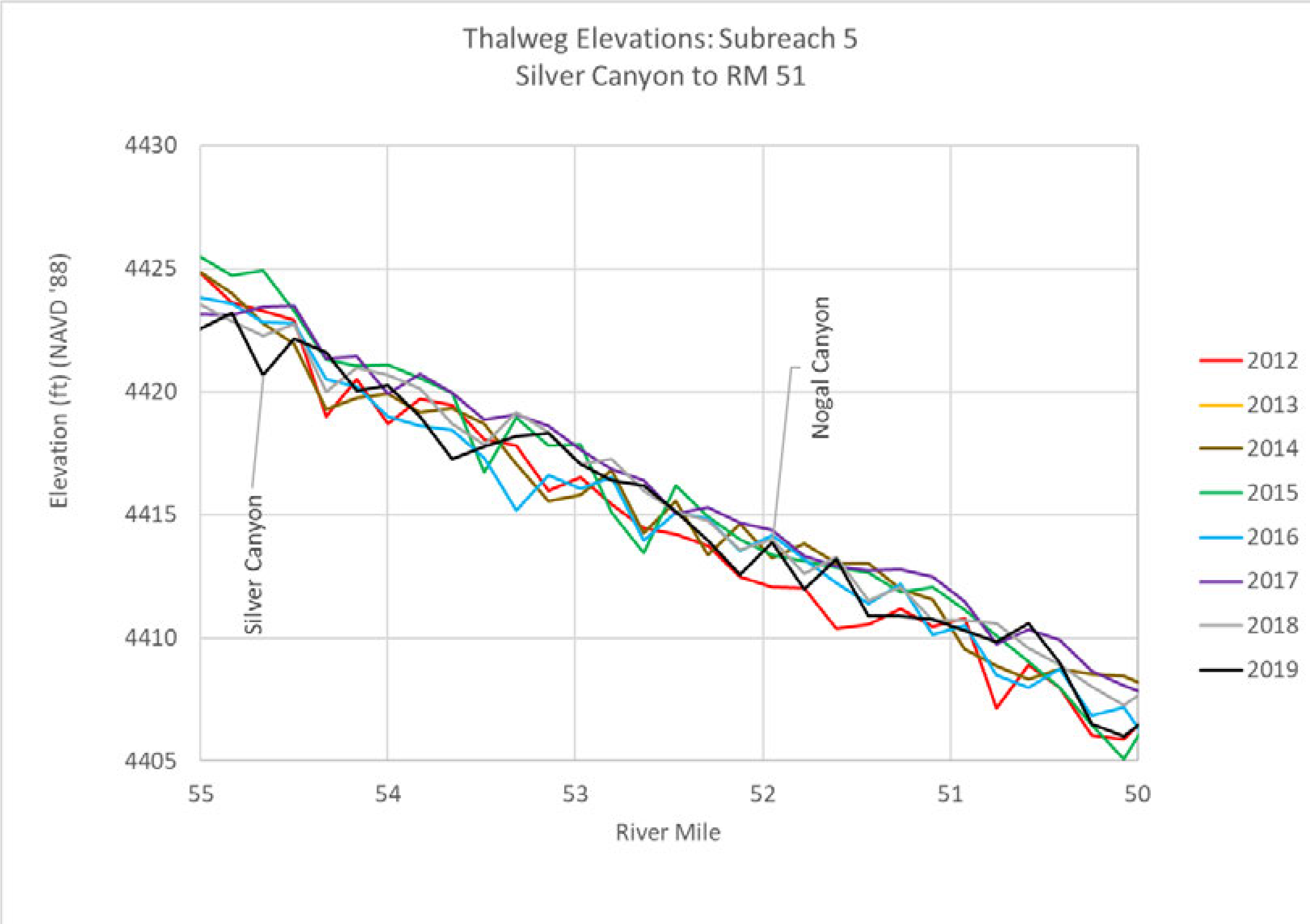

Figure 27: Thalweg elevations for Subreach 5 (RM 54.5 – RM 51)

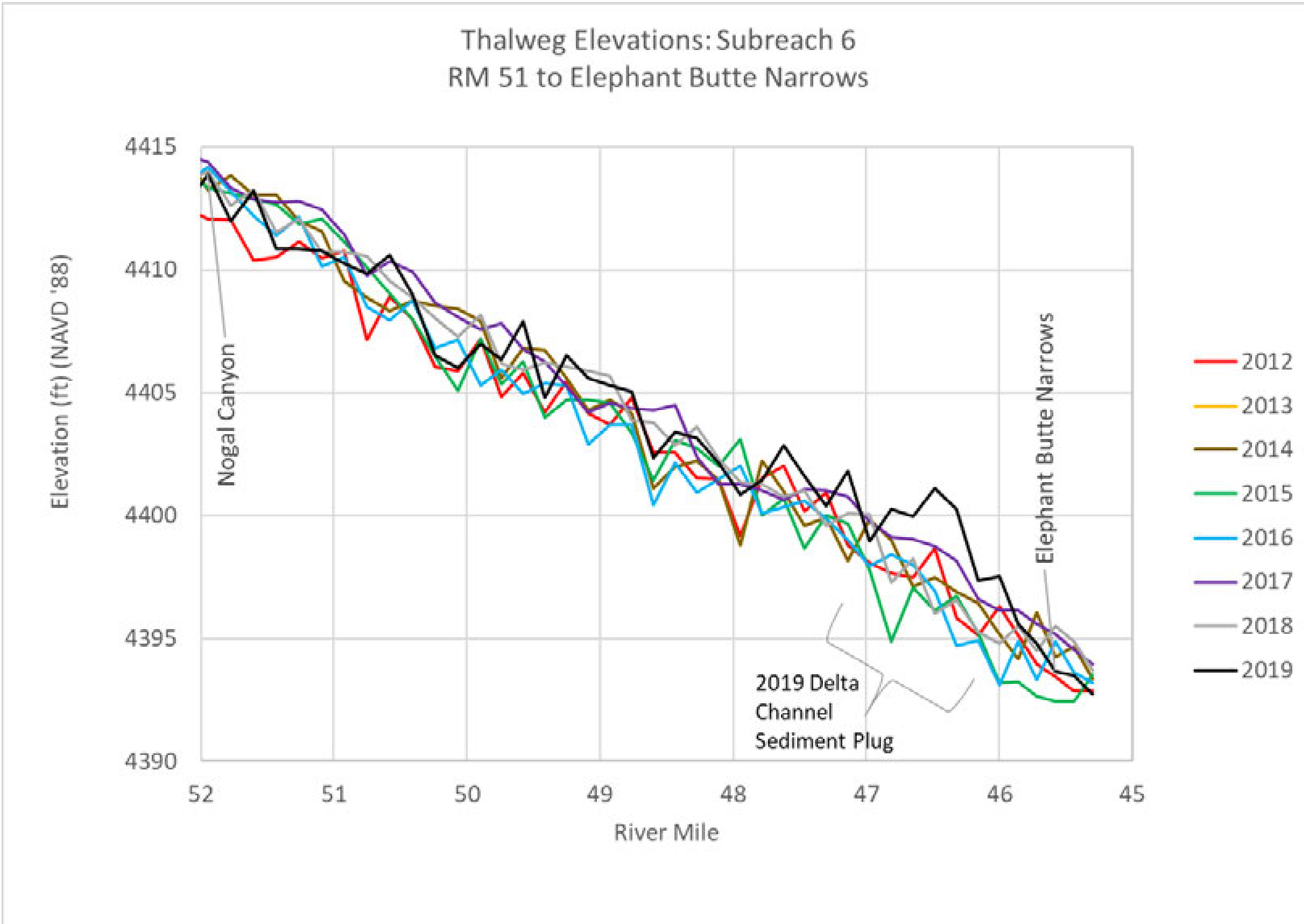

Figure 28: Thalweg elevations for Subreach 6 (RM 51 – RM 45.3)

To illustrate the overall change from year to year as well as the locations of thalweg elevation changes along the reach, cumulative change plots for each year-to-year period were generated (Figure 29). These plots represent the cumulation in the downstream direction of the magnitude of elevation change from year to year. A positive slope in the downstream direction represents an increase in values between the years being compared while a negative slope represents a decrease in values. Notably, the overall change in thalweg elevations from 2012 to 2019 is a decrease, indicating that the reach has on average experienced downcutting. However, the sections from the Highway 380 Bridge to SO-1579.5 and from Silver Canyon to the Elephant Butte Narrows were dominated by deposition. These areas include River Mile 81 on the BDA NWR and River Mile 46 upstream of the Narrows, the areas where sediment plugs formed in 2019 (for details see Wilco, 2019). The years 2012 – 2013 and 2014 – 2015 were dominated by deposition as shown by the overall positive slope in the downstream direction. The year 2013 – 2014 shows very little change in thalweg elevations along the reach, partly because rangelines in the EB section (below the AT&SF Railroad Bridge) were not surveyed in 2014. The overall negative slopes of the cumulative change plot for the years from 2015 to 2019 in the study area indicates that these years were dominated by degradation. Based on the shape of the cumulative change plot for 2012 – 2019, the aggradation in the section upstream of the AT&SF Railroad Bridge appears to have been contributed largely by the years 2017 – 2018 and 2018 – 2019 while the degradation followed by aggradation between the AT&SF Railroad Bridge and Elephant Butte Narrows appears to have been largely contributed by the 2016 – 2017 year.

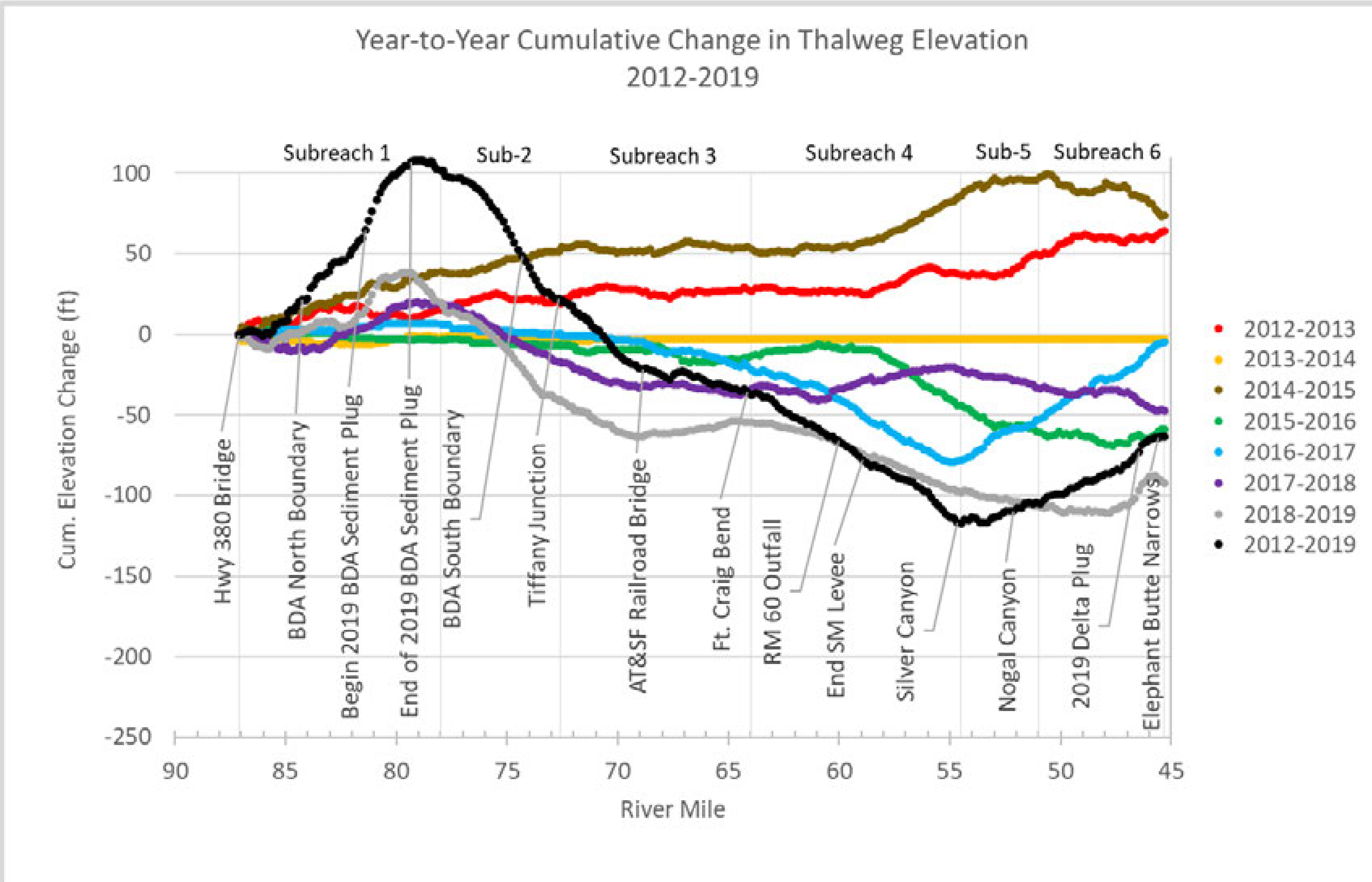

Figure 29: Year-to-year cumulative changes in thalweg elevations for the study reach (River Mile 87.1 – 39, SO-1475.9 – EB-50) from 2012 to 2019.

Mean Bed Elevation at the 25% Exceedance Flow Rate

The longitudinal profiles of the mean bed elevation calculated at the 500 cfs flow rate, corresponding to 50% exceedance flow rate (Bui, 2014), are summarized below. Here the mean bed elevation is defined as the difference between the calculated water surface elevation and the hydraulic depth at a cross section. Hydraulic depth is equal to the area of flow in the cross section divided by the top width of the calculated water surface at the cross section. At the 50% exceedance flow rate of 500 cfs, the greatest year-to-year change in the calculated reach-averaged mean bed elevation was a decrease of 0.3 ft (3.6 in) from 2017 to 2018 and from 2018 to 2019. Overall the reach-averaged mean bed elevation at the 500 cfs flow rate decreased by 0.6 ft (7.2 in) from 2012 to 2019. The only years that saw an increase in average mean bed elevation at the 500 cfs and 2,300 cfs flow rates were 2012 – 2013 and 2014 – 2015, which were also the only years in which thalweg elevations increased on average.

Table 17: Summary of reach-average changes in 500 cfs mean bed elevation profile.

Unit	'12-'13	'13-'14	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Average Δ (ft)	0.1	0.0	0.1	-0.2	-0.1	-0.3	-0.3	-0.6
Max. Aggradation (ft)	2.0	1.3	1.9	1.4	2.2	2.4	4.9	6.1
Max. Degradation (ft)	0.9	1.6	1.5	2.3	3.1	1.7	3.2	4.5

Mean bed elevations at the 500 cfs flow rate increased overall in Subreaches 1, 5, and 6 while mean bed elevations decreased overall in Subreaches 2 – 4 between 2012 and 2019 (Table 18). Plots of the mean bed profile calculated at the 500 cfs flow rate for each subreach are shown in Figure 30 through Figure 35 below.

Table 18: Summary of changes in 500 cfs Mean Bed Elevations between 2012 and 2019 by subreach color coded by value.

Unit	**'12-'13**	**'13-'14**	**'14-'15**	**'15-'16**	**'16-'17**	**'17-'18**	**'18-'19**	**'12-'19**
Subreach 1 Average Δ (ft)	0.1	0.1	0.4	0.0	0.1	0.2	0.7	1.5
Subreach 2 Average Δ (ft)	0.1	0.0	0.1	-0.1	0.0	-1.2	-2.0	-3.2
Subreach 3 Average Δ (ft)	0.1	-0.1	-0.2	-0.1	-0.3	-0.6	-0.1	-1.4
Subreach 4 Average Δ (ft)	0.3	0.0	0.4	-0.5	-0.9	0.1	-1.1	-1.8
Subreach 5 Average Δ (ft)	0.4	0.0	0.3	-0.3	0.5	-0.4	0.2	0.7
Subreach 6 Average Δ (ft)	-0.1	0.0	-0.3	-0.4	1.1	-0.3	0.9	0.8

Prominent features of the 500 cfs mean bed elevation profile include the increase in mean bed elevations of the 2019 model downstream of the BDA North Boundary associated with the 2019 BDA sediment plug (Figure 30). This area of elevated mean bed profile is followed by the decrease in mean bed elevations below the plug area, similar to the thalweg elevation profile. The 2019 mean bed profile remained low relative to the other survey years until just above Silver Canyon, where 2019 mean bed elevations increased until just above the Narrows (Figure 35).

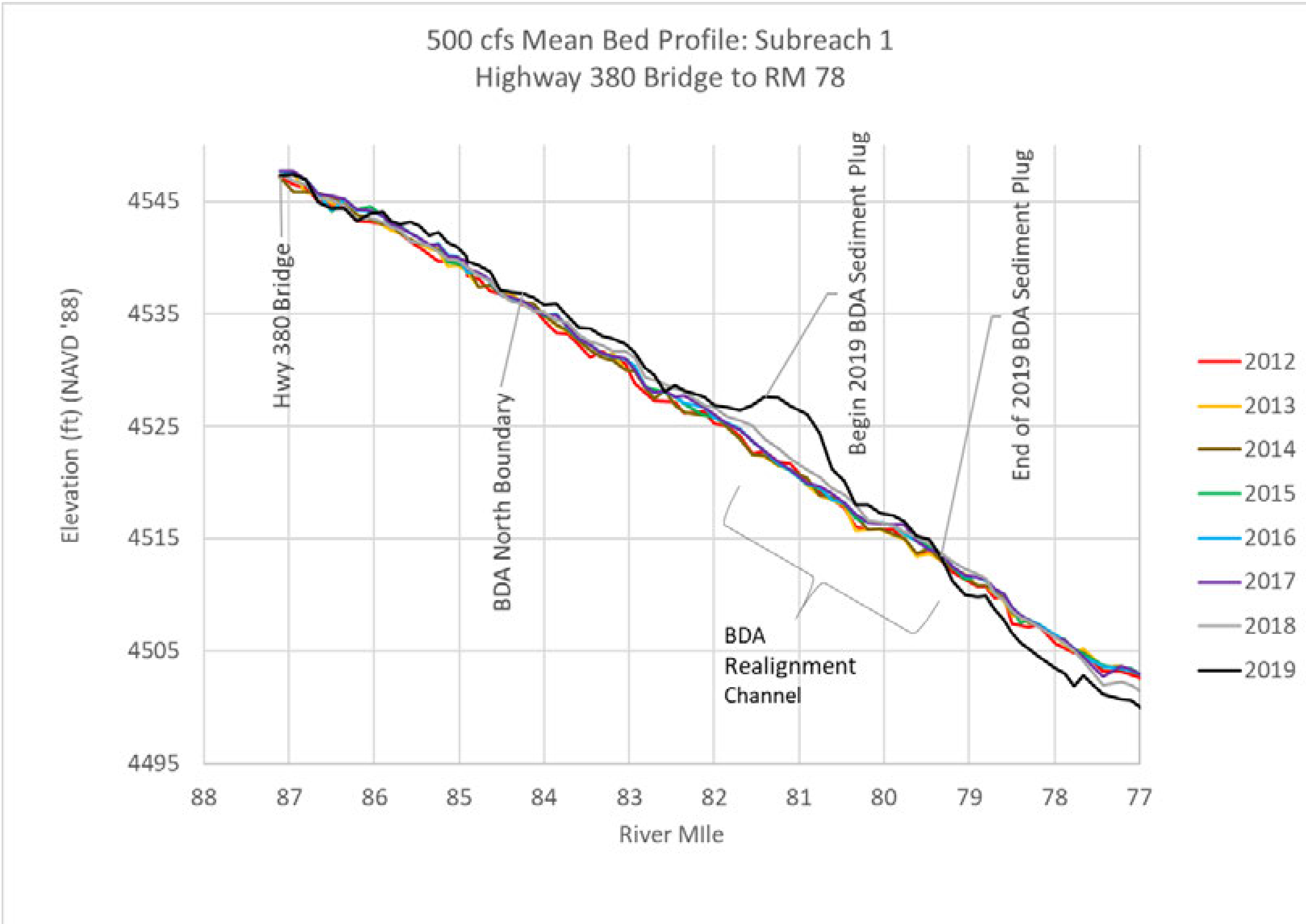

Figure 30: Calculated mean bed elevation profile at the 500 cfs flow rate for Subreach 1 (RM 87.1 – RM 78)

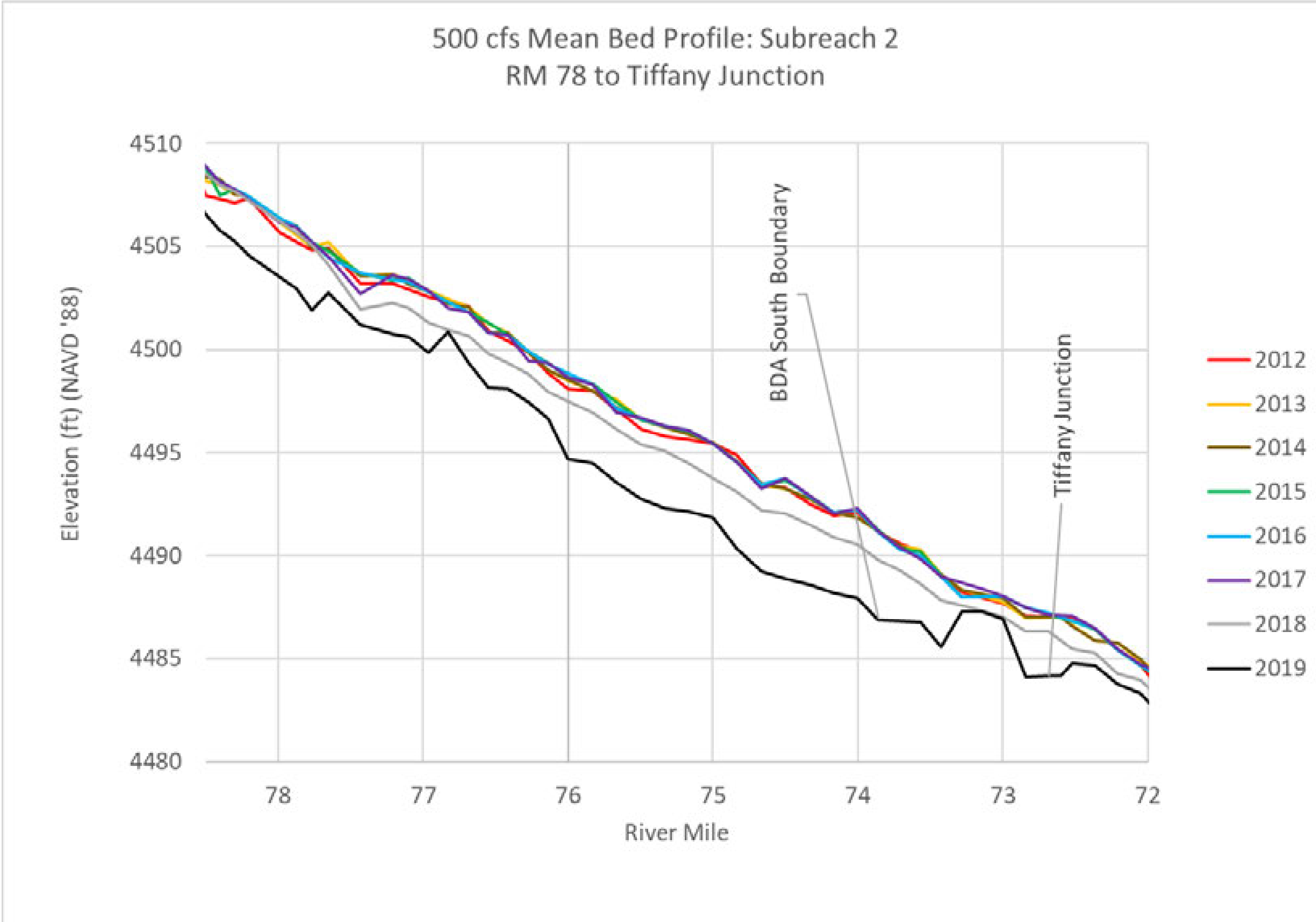

Figure 31: Calculated mean bed elevation profile at the 500 cfs flow rate for Subreach 2 (RM 78 – 72.6)

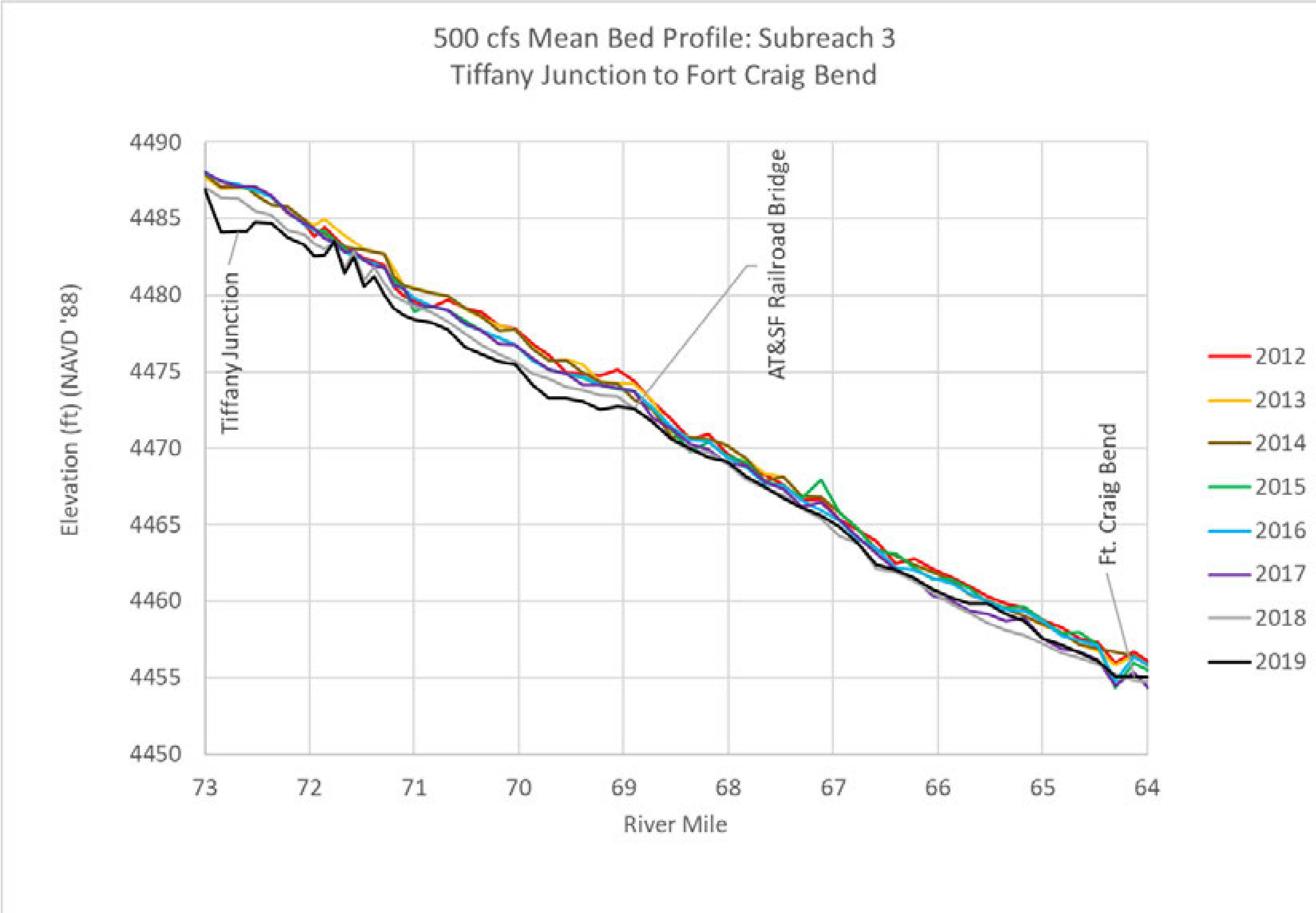

Figure 32: Calculated mean bed elevation profile at the 500 cfs flow rate for Subreach 3 (RM 72.6 – RM 64)

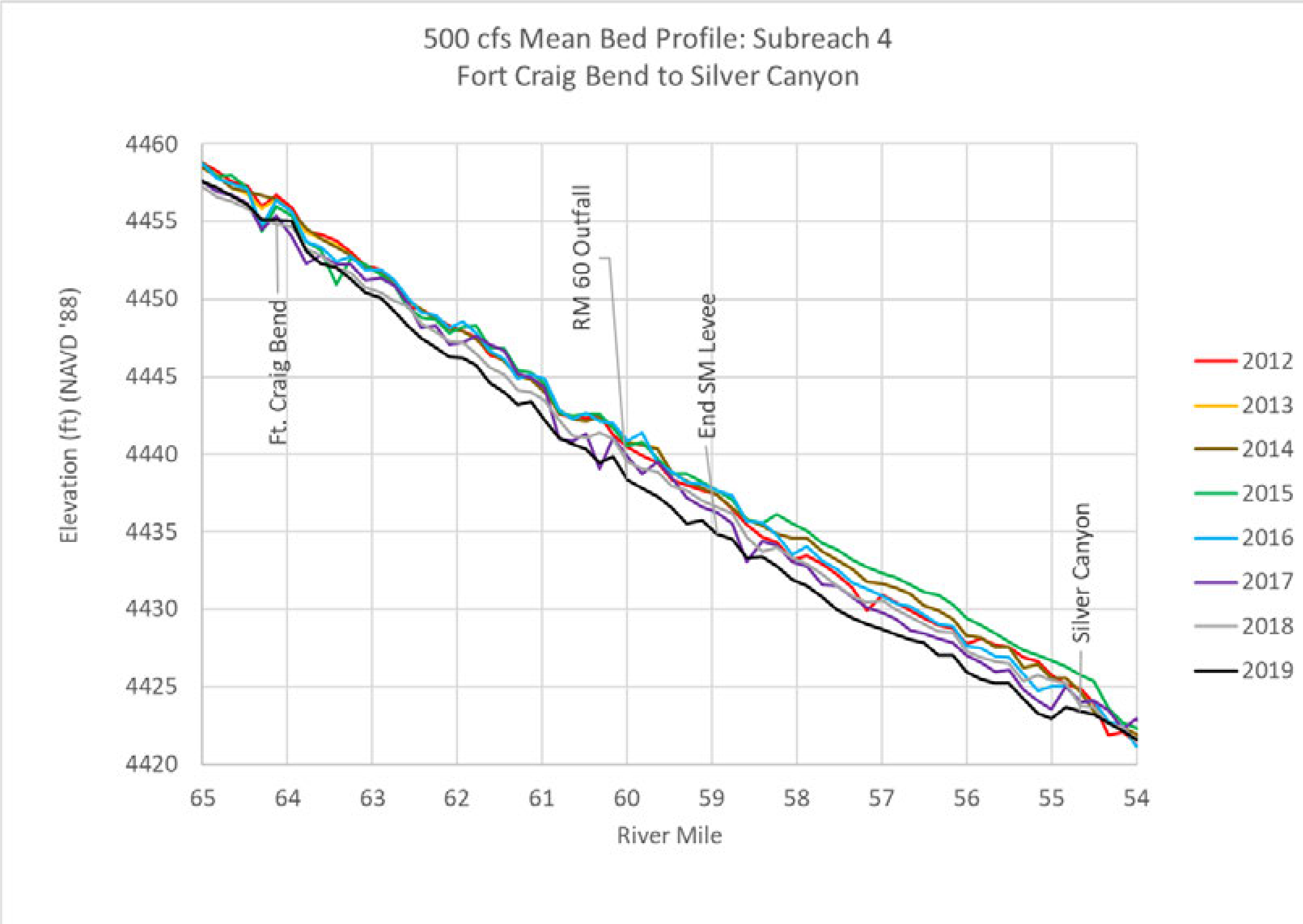

Figure 33: Calculated mean bed elevation profile at the 500 cfs flow rate for Subreach 4 (RM 64 – RM 54.5)

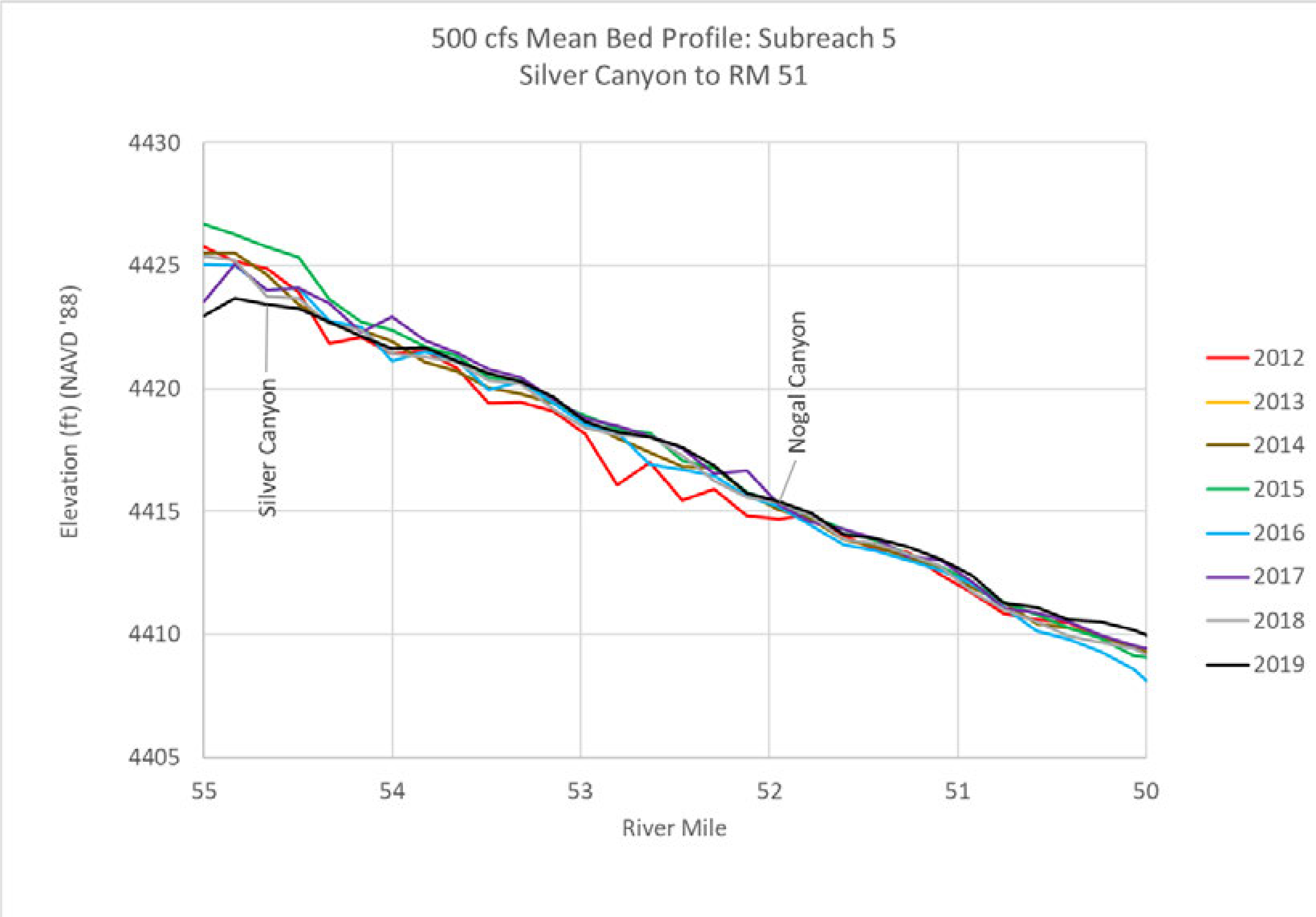

Figure 34: Calculated mean bed elevation profile at the 500 cfs flow rate for Subreach 5 (RM 54.5 – RM 51)

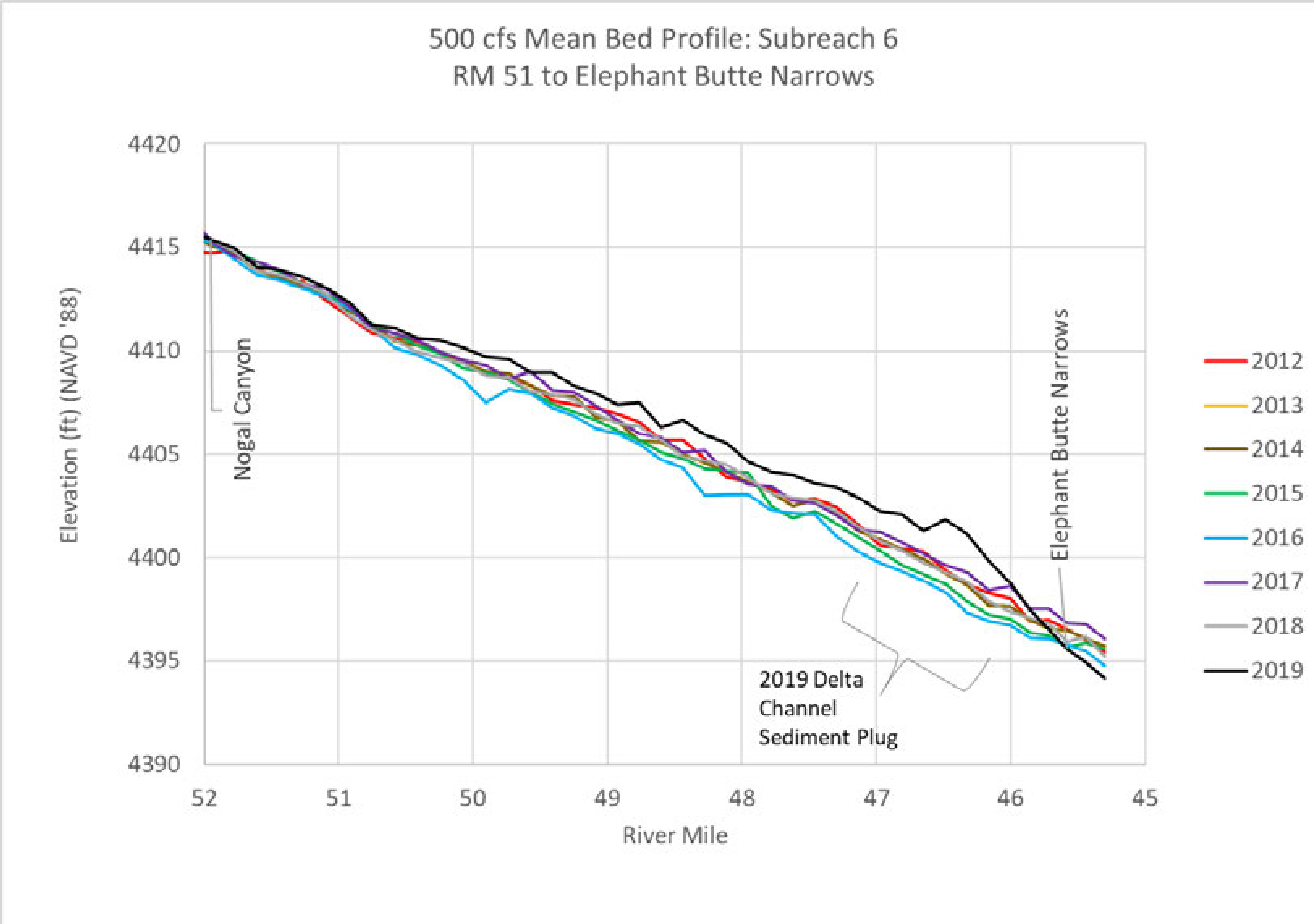

Figure 35: Calculated mean bed elevation profile at the 500 cfs flow rate for Subreach 6 (RM 51 – RM 45.3)

Mean Bed Elevation at the 50% Exceedance Flow Rate

At the 2,300 cfs flow rate the greatest year-to-year change in mean bed elevation was also from 2018 to 2019 (decrease of 0.5 ft, or 6 in), with an overall decrease of 0.6 ft (7.2 in) from 2012 to 2019 (Table 19). The only years that saw an increase in average mean bed elevation at the 2,300 cfs flow rates were 2012 – 2013 and 2014 – 2015, which were also the only years in which thalweg elevations increased on average. Mean bed elevations at the 2300 cfs flow rate increased overall in Subreaches 1, 5, and 6 while mean bed elevations decreased overall in Subreaches 2 – 4 between 2012 and 2019 (Table 20). Plots of the mean bed profile calculated at the 2,300 cfs flow rate are shown in Figure 36 through Figure 41 below. The 2019 mean bed profile is most prominent here since it differs most from the previous years. Compared to the 500 cfs flow rate, mean bed elevations at the 2,300 cfs flow rate are elevated above the previous years' mean bed elevations farther upstream from the BDA plug area.

Table 19: Summary of reach-average changes in 2,300 cfs mean bed elevation profile.

Unit	'12-'13	'13-'14	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Average Δ (ft)	0.1	-0.1	0.4	-0.3	0.0	-0.3	-0.5	-0.6
Max. Aggradation (ft)	3.4	3.4	4.7	3.6	3.5	4.0	3.9	5.6
Max. Degradation (ft)	3.3	2.9	2.9	3.5	2.9	4.8	7.5	5.3

Table 20: Summary of changes in 2300 cfs Mean Bed Elevations between 2012 and 2019 by subreach color coded by value.

Unit	'12-'13	'13-'14	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Subreach 1 Average Δ (ft)	0.2	0.0	0.6	0.2	0.0	0.5	0.7	1.9
Subreach 2 Average Δ (ft)	0.2	-0.2	0.9	-0.3	0.3	-1.3	-3.0	-3.6
Subreach 3 Average Δ (ft)	0.1	-0.1	-0.1	-0.1	-0.2	-0.7	-0.3	-1.4
Subreach 4 Average Δ (ft)	0.3	0.0	0.6	-0.6	-0.8	-0.1	-1.4	-2.0
Subreach 5 Average Δ (ft)	-0.2	0.0	0.5	-0.7	0.6	-0.3	0.2	0.2
Subreach 6 Average Δ (ft)	-0.2	0.0	-0.3	-0.4	1.1	-0.3	1.1	0.9

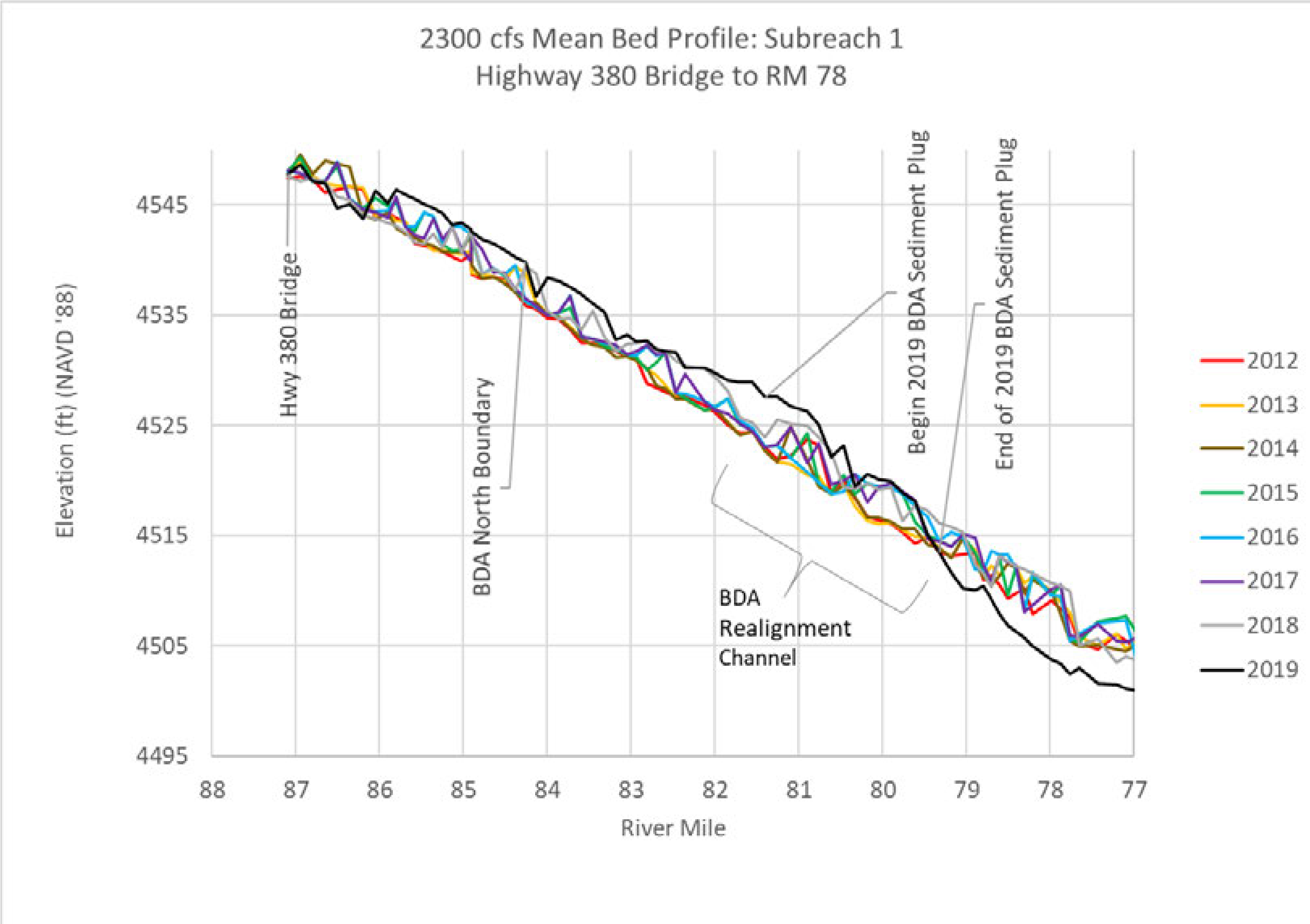

Figure 36: Calculated mean bed elevation profile at the 2,300 cfs flow rate for Subreach 1 (RM 87.1 – RM 78)

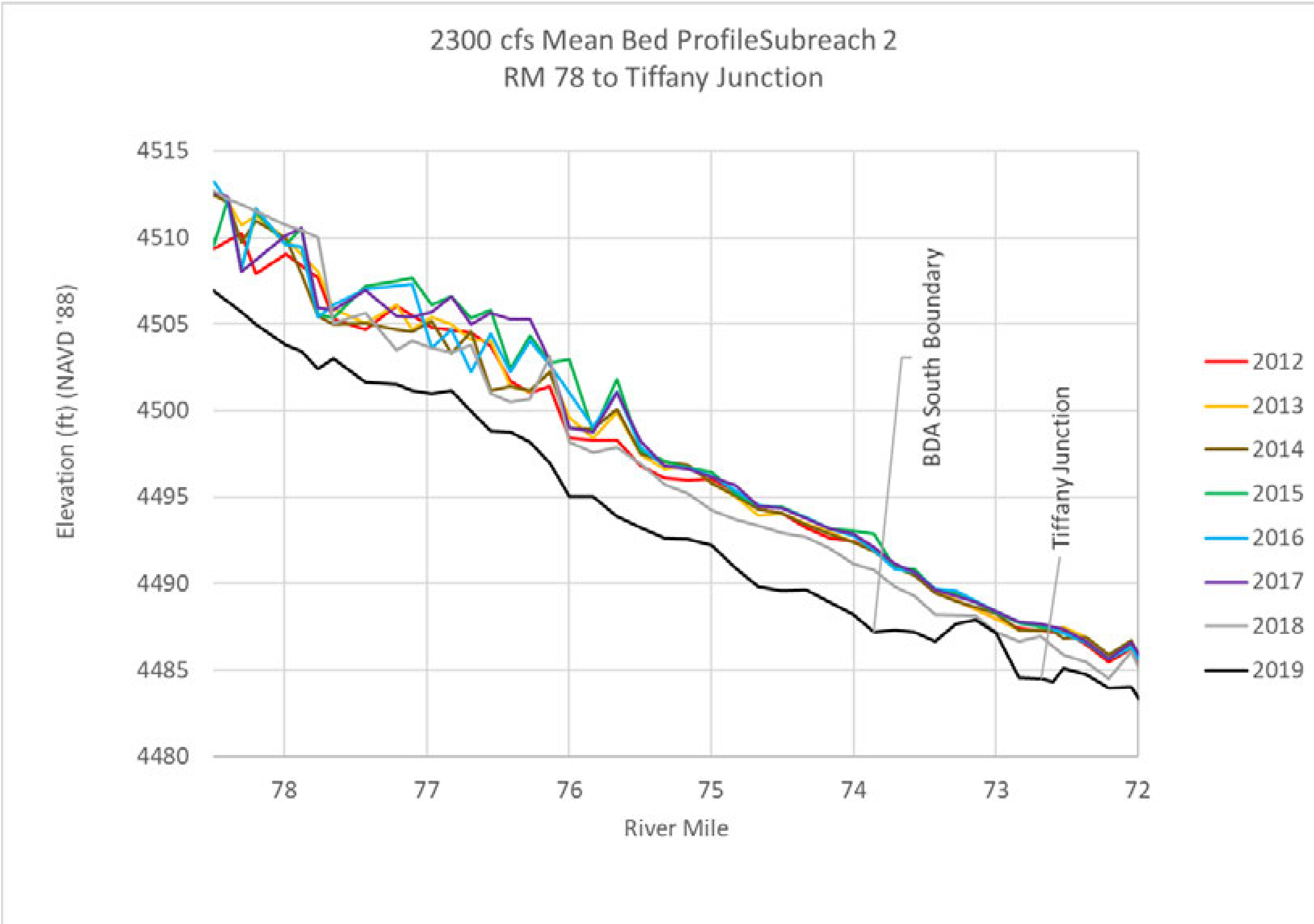

Figure 37: Calculated mean bed elevation profile at the 2,300 cfs flow rate for Subreach 2 (RM 78 – 72.6)

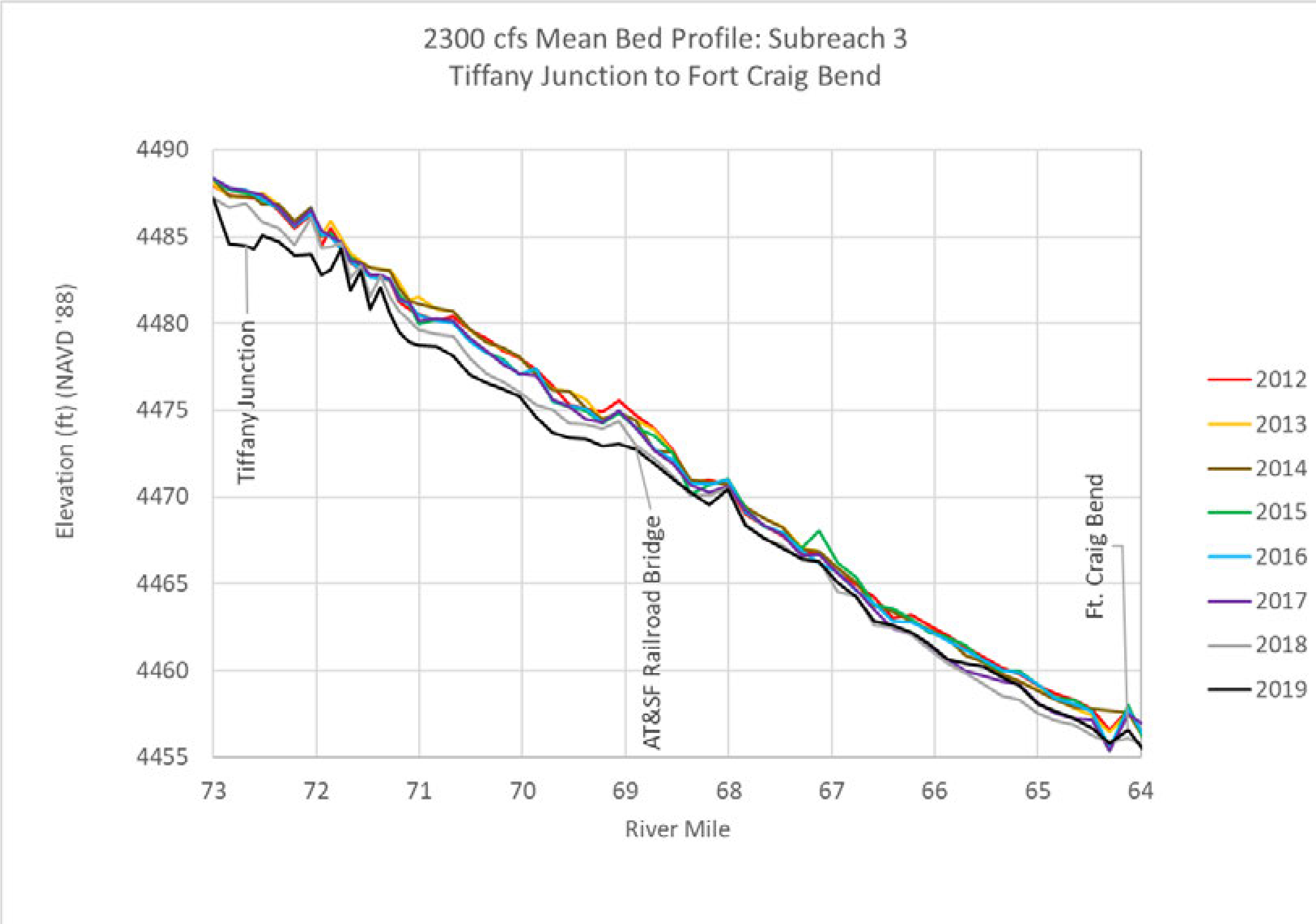

Figure 38: Calculated mean bed elevation profile at the 2,300 cfs flow rate for Subreach 3 (RM 72.6 – RM 64)

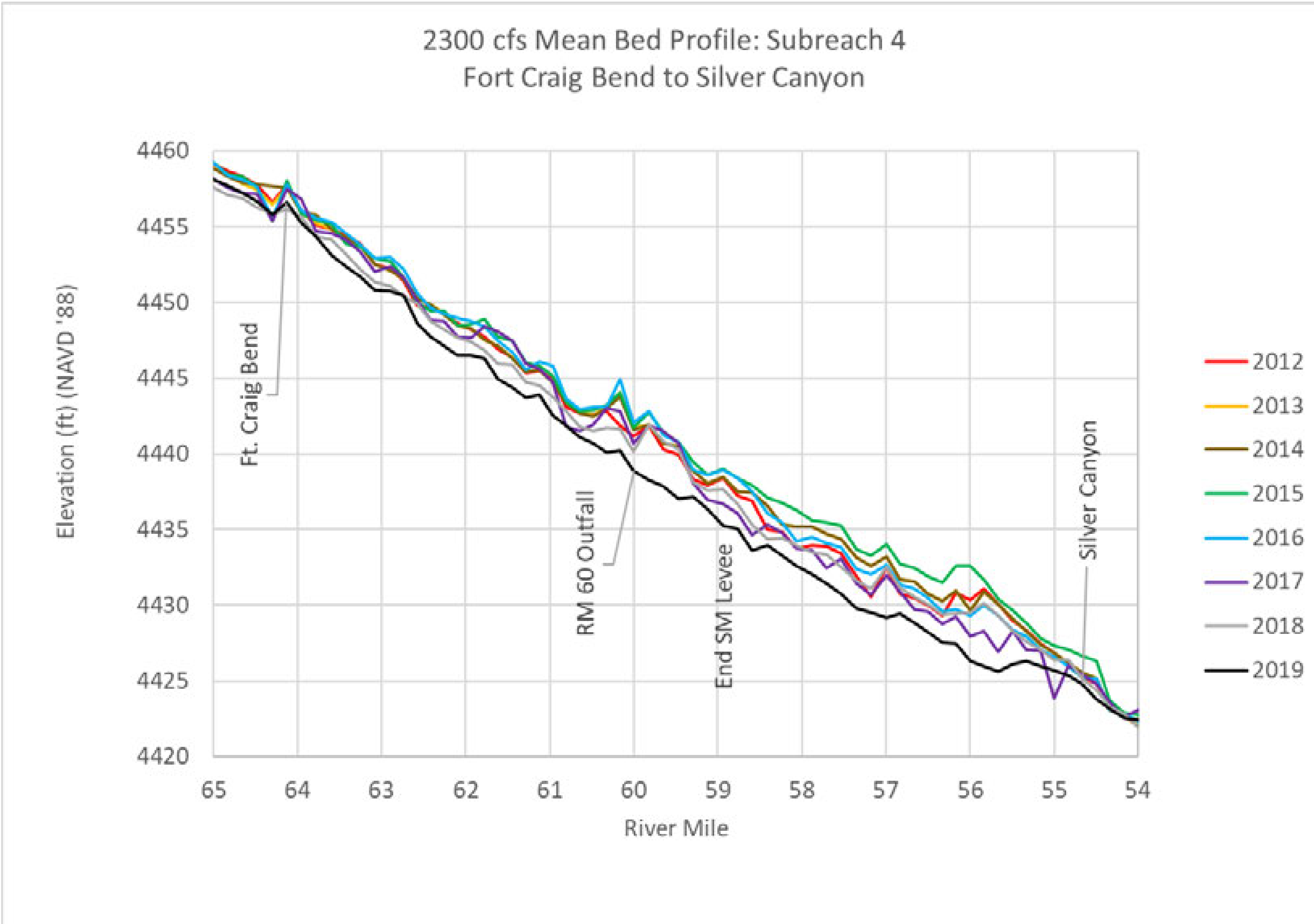

Figure 39: Calculated mean bed elevation profile at the 2,300 cfs flow rate for Subreach 4 (RM 64 – RM 54.5)

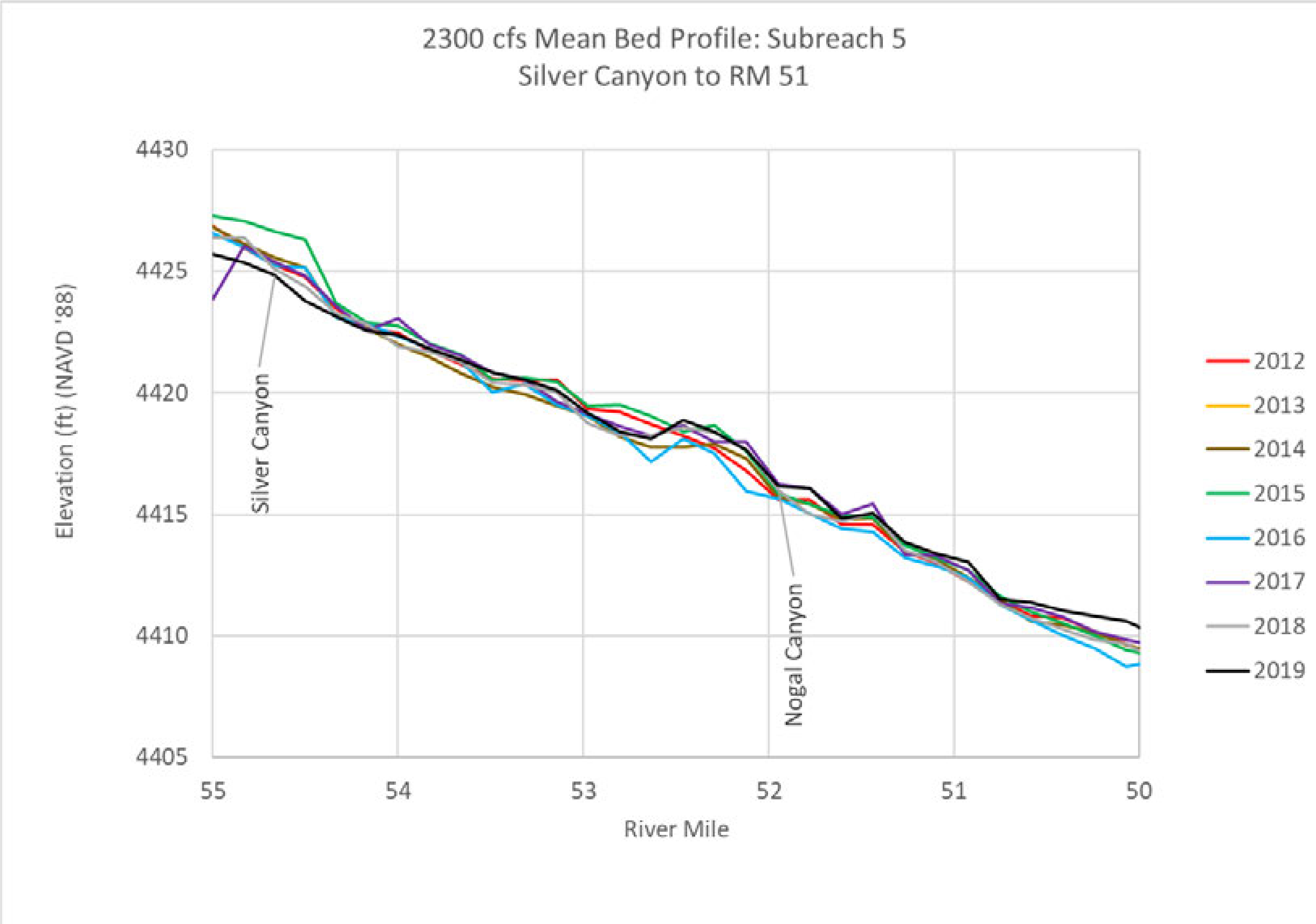

Figure 40: Calculated mean bed elevation profile at the 2,300 cfs flow rate for Subreach 5 (RM 54.5 – RM 51)

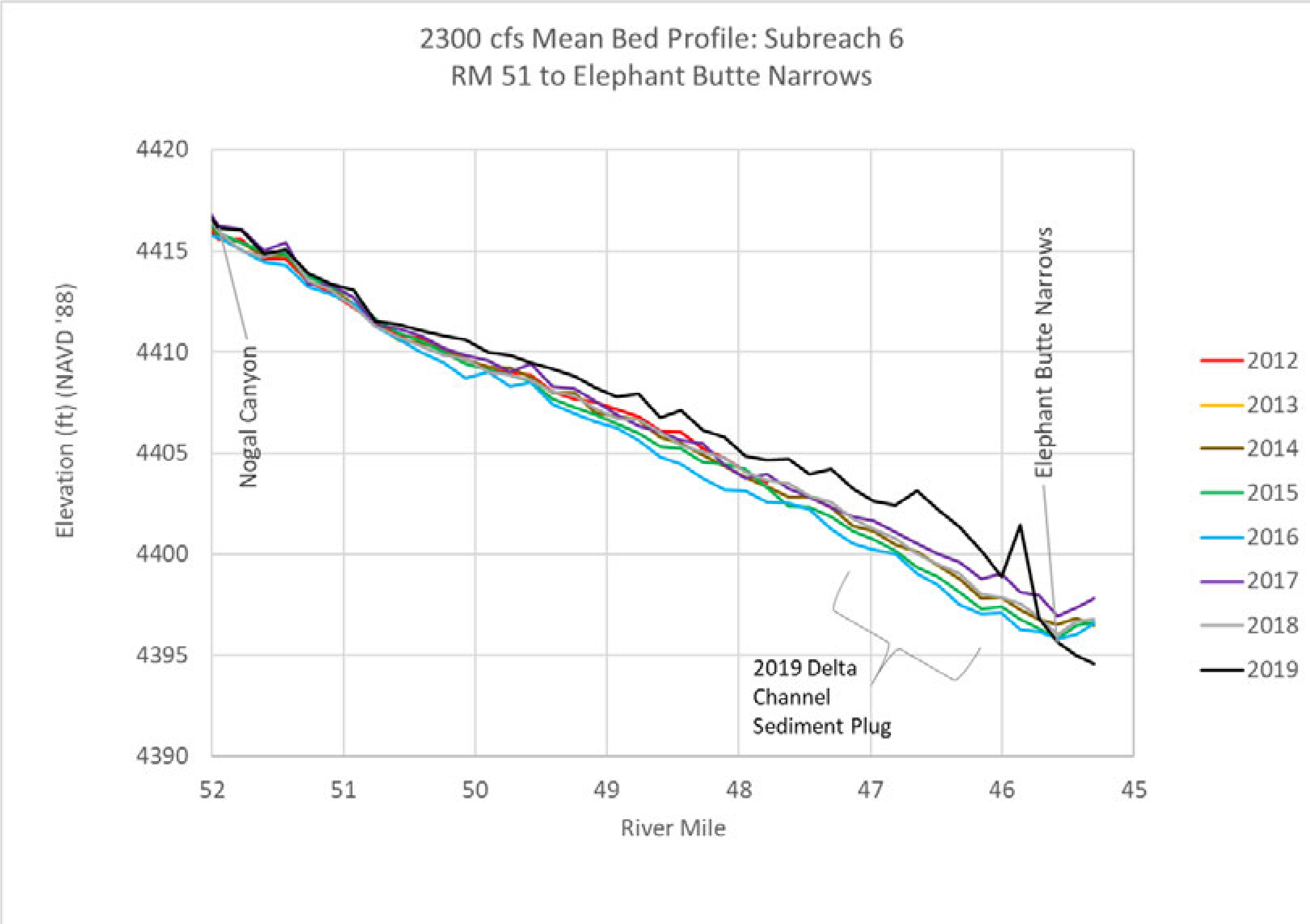

Figure 41: Calculated mean bed elevation profile at the 2,300 cfs flow rate for Subreach 6 (RM 51 – RM 45.3)

Thalweg and Mean Bed Slope

Overall the distance-weighted reach-average thalweg slope in the study reach maintained approximately the same value from 2012 to 2019 (Table 21). Average mean bed slopes at the 500 cfs and 2,300 cfs flow rates fluctuated similarly from 2012 to 2019, with 2017 having the least steep downstream slope of 0.00059 ft/ft (Table 22 and Table 23). Reach-average thalweg and mean bed slopes fluctuated around 0.00061 ft/ft from 2012 to 2019.

Table 21: Summary of thalweg slopes for the entire study reach from 2012 to 2019.

Unit	2012	2013	2014	2015	2016	2017	2018	2019
Average (ft/ft)	0.00062	0.00061	0.00061	0.00062	0.00062	0.00061	0.00061	0.00061
Maximum (ft/ft)	0.00470	0.01080	0.01250	0.00880	0.01110	0.00910	0.00500	0.01640
Minimum (ft/ft)	-0.00350	-0.00830	-0.00650	-0.00660	-0.00700	-0.00880	-0.00390	-0.00520

Table 22: Summary of 500 cfs mean bed elevation slopes in the analysis reach from 2012 to 2019.

Unit	2012	2013	2014	2015	2016	2017	2018	2019
Average (ft/ft)	0.00061	0.00061	0.00061	0.00061	0.00062	0.00059	0.00061	0.00062
Maximum (ft/ft)	0.00252	0.00218	0.00596	0.00306	0.00258	0.00455	0.00685	0.00740
Minimum (ft/ft)	-0.00106	-0.00322	-0.00295	-0.00347	-0.00340	-0.00334	-0.00233	-0.00230

Table 23: Summary of 2,300 cfs mean bed elevation slopes in the analysis reach from 2012 to 2019.

Unit	2012	2013	2014	2015	2016	2017	2018	2019
Average (ft/ft)	0.00062	0.00062	0.00061	0.00061	0.00063	0.00059	0.00061	0.00062
Maximum (ft/ft)	0.00340	0.00882	0.00992	0.01691	0.01657	0.02636	0.03086	0.00932
Minimum (ft/ft)	-0.00199	-0.00299	-0.00356	-0.00405	-0.00437	-0.00441	-0.00321	-0.00315

Looking at the thalweg and mean bed slopes by subreach (Figure 42 through Figure 44), Subreach 1 had the steepest thalweg slope of approximately 0.0007 ft/ft. This is partly the result of the endpoint of Subreach 1 being below the 2008 and 2019 sediment plug area; both aggradation in the upper part and degradation in the lower part of Subreach 1 contributed to the change in slope. Slopes in Subreach 2 fluctuated between 2012 and 2018, decreasing in 2019 as the degradation below the BDA sediment plug reduced the elevation drop along the subreach. Slopes in Subreaches 3 – 5 were fairly stable between 2012 and 2019. Although Subreach 6 underwent overall aggradation, subreach slopes increased overall from 2012 to 2019 as a result of the degradation below RM 46.

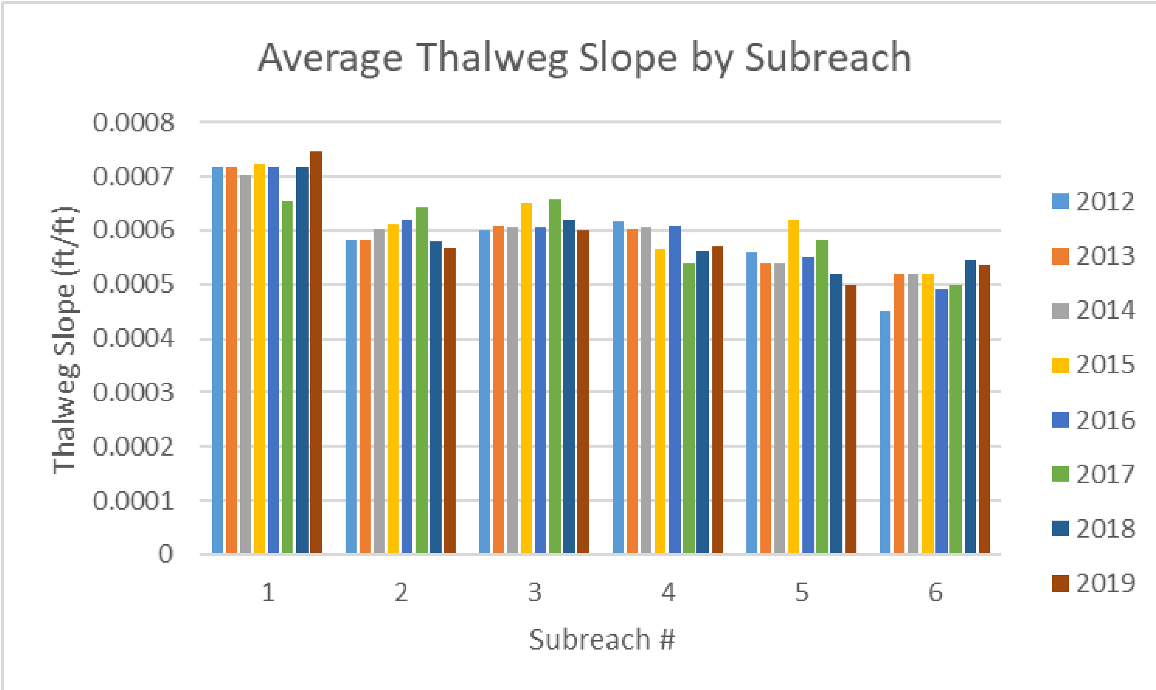

Figure 42: Distance weighted, subreach averaged thalweg slopes between 2012 and 2019.

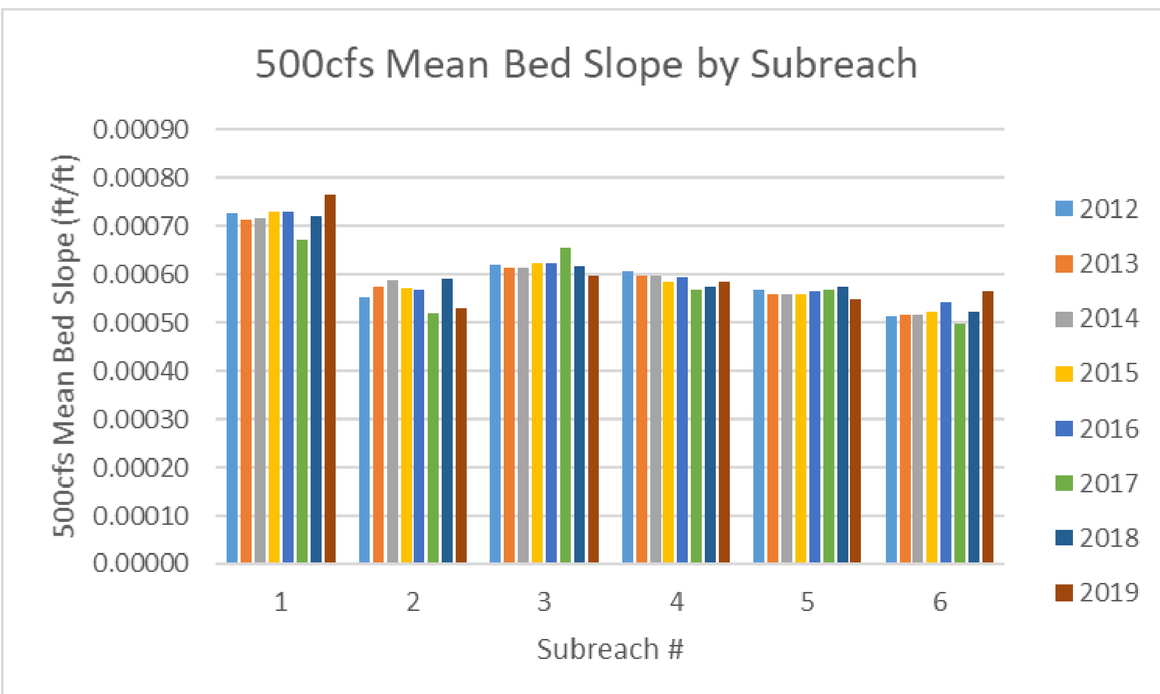

Figure 43: Distance weighted, subreach averaged 500 cfs mean bed slopes between 2012 and 2019

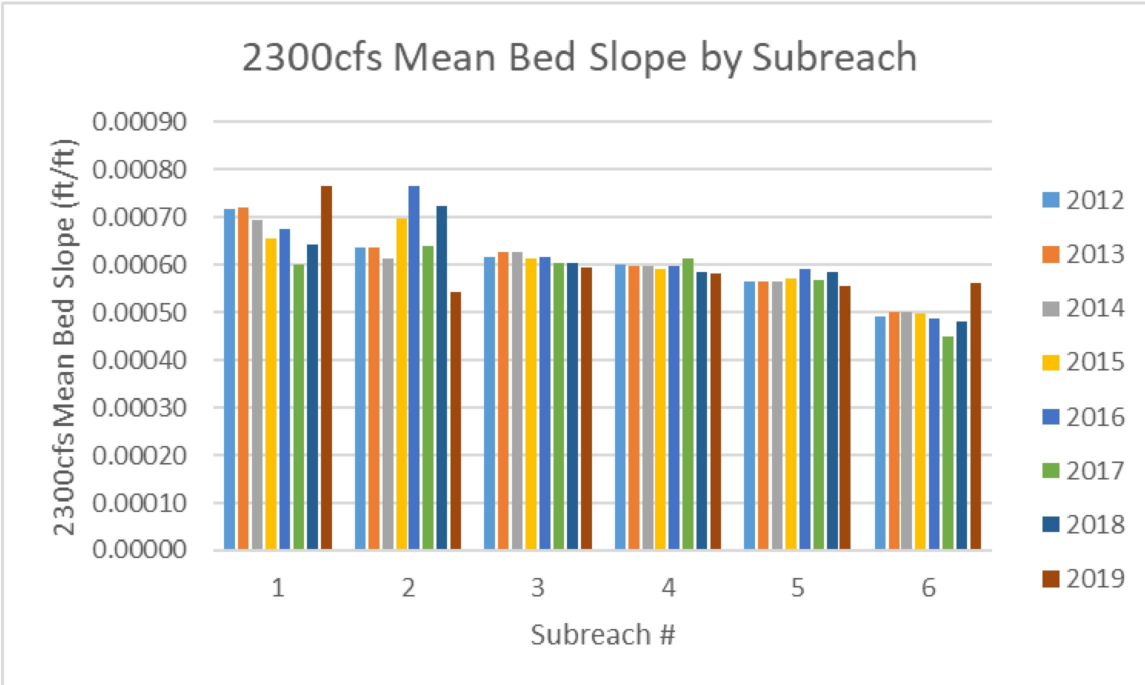

Figure 44: Distance weighted, subreach averaged 2300 cfs mean bed slopes between 2012 and 2019.

Channel and Floodway Topography

Changes in topography of the channel and floodway were assessed using the channel cross-section survey data collected by Reclamation contractors in station-elevation format. Deposition and erosion in the channel, mean channel depth, average bank elevations, and channel width measurements were generated from the cross section survey data. The results reported are for the 42-mile study reach (RM 87 – 45) although additional survey data below the study reach were collected in 2016 – 2019 and are included in the plots for display only. Note that information in this section was generated directly from the cross section survey data in station-elevation format using Microsoft Office Excel. Therefore, no cross section data in this section of the analysis are carried over from a previous year as with results from the HEC-RAS models. Only cross sections surveyed in both of the years being compared are used for analysis in this section. See the Appendix I for a complete list of the cross section survey dates being compared.

Erosion and Deposition

Erosion and deposition in the main channel and the channel banks were assessed using the distance-weighted average bed elevation and average elevation of the river banks (Figure 45). Left and right banks were taken as recorded in the Reclamation cross-section survey data (recorded as LTOB, RTOB, or TOB) except when a bank was not specifically recorded, when multiple bank points were recorded on either side of the channel, when the banks did not represent the transition from channel to floodplain, or when bank points were inconsistent between years. In these cases bank points were selected at a point where the channel and floodplain met that was consistent between survey years in order to have a meaningful comparison. Note that the 2014 survey included only SO rangelines (rangelines above the AT&SF Railroad Bridge).

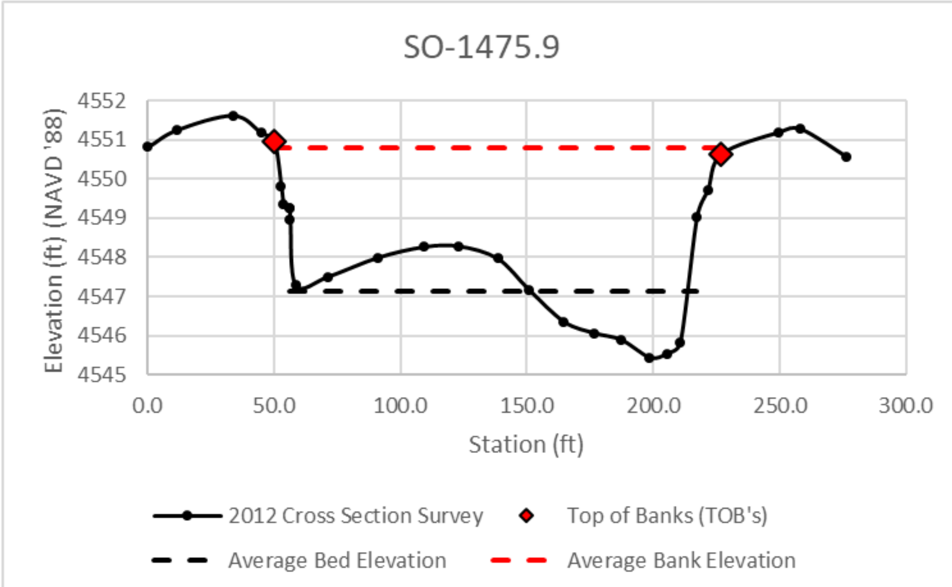

Figure 45: Example illustrating cross section station-elevation data, bank elevation points, and calculated distance-weighted average bed elevation and average bank elevation.

Year to year changes in average channel elevations of the surveyed cross sections in the study area are summarized in Table 24 and Table 25 below. On average, the bed elevation of surveyed cross sections decreased by 0.7 ft (8.4 in.) between 2012 and 2019. This overall decrease is greater than the observed reach-average decrease in thalweg elevations and closer to the reach-average decrease in mean bed elevations at the 500 cfs and 2,300 cfs flow rates. Most years saw a decrease in the bed elevation of the surveyed cross sections, except for 2012 – 2013, which saw an average increase of 0.1 ft (1.2 in.). These values for the mean bed elevation differ from those reported in the 500 and 2,300 cfs mean bed elevation tables since these values are based only on the measured channel geometry as opposed to the 500 and 2,300 cfs mean bed profile elevations, which are based on the simulated water surface elevation.

Table 24: Year-to-year changes in cross section average bed elevation of surveyed cross sections from SO-1475.9 to EB-50. *Cross sections in the EB area were not surveyed in 2014.

Unit	**'12-'13**	**'13-'14***	**'14*-'15**	**'15-'16**	**'16-'17**	**'17-'18**	**'18-'19**	**'12-'19**
Average Δ (ft)	0.1	-0.1	-0.2	-0.3	-0.2	-0.2	-0.2	-0.7
Max. Aggradation (ft)	3.4	2.1	0.7	2.0	1.9	2.2	4.7	5.9
Location (Rangeline)	SO-1600	SO-1557	SO-1583	EB-24A	EB-48	EB-17	SO-1550	SO-1550
Max. Degradation (ft)	3.3	3.5	2.0	2.1	4.3	3.3	3.1	4.7
Location (Rangeline)	EB-23.6A	SO-1600	SO-1660	EB-27	EB-24A	EB-23.6A	SO-1636.5	SO-1623.9

By subreach (Table 25), trends in cross section average bed elevation mirrored those in thalweg and mean bed elevations. Subreaches 2 – 4 had some aggradation before 2015 but overall degradation from 2012 – 2019. Subreaches 1, 5, and 6 underwent aggradation overall, with aggradation in the upper section occurring most years while aggradation in the lower section occurred mainly from 2016 – 2017 and 2018 – 2019.

Table 25: Summary of changes in cross section average bed elevation between 2012 and 2019 by subreach, color coded by value. *Cross sections in the EB area were not surveyed in 2014.

Unit	'12-'13	'13-'14*	'14*-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Subreach 1 Average Δ (ft)	0.2	0.2	-0.1	0.2	0.1	0.1	0.6	1.1
Subreach 2 Average Δ (ft)	0.3	-0.6	0.0	-0.3	-0.3	-0.9	-2.1	-3.3
Subreach 3 Average Δ (ft)	0.0	-0.3	-0.6	-0.1	-0.6	-0.3	-0.1	-1.4
Subreach 4 Average Δ (ft)	0.2	-	-	-0.6	-0.9	-0.1	-1.0	-1.8
Subreach 5 Average Δ (ft)	-0.1	-	-	-0.4	0.3	-0.2	0.2	0.2
Subreach 6 Average Δ (ft)	-0.2	-	-	-0.3	0.8	-0.3	0.9	0.6

To illustrate year-to-year changes along the reach, cumulative change plots for the mean bed elevation of the surveyed cross sections from year to year are included in Figure 46 below. From this plot it is clear that the average increase in cross section average bed elevation from 2012 – 2013 was distributed across the reach, similar to the increase in thalweg elevations observed from 2012 – 2013. In contrast, changes from 2015 – 2018 were mostly downstream of the AT&SF Railroad Bridge as shown by the flat slopes of these lines above the railroad bridge. A notable difference between the changes in thalweg elevations and the changes in cross section average bed elevation is that increases in the thalweg elevation were evident in the BDA area as early as 2017 – 2018. Looking at the cumulative change in cross section average elevations, increases in bed elevation in the BDA area were not evident until the 2018 – 2019 period. The period from 2018 – 2019 saw the greatest change both upstream and downstream of the AT&SF Railroad Bridge, with aggradation in the upper part of the Bosque Del Apache reach and between Silver Canyon and the Narrows. The years 2013 – 2014 and 2014 – 2015 are truncated in this plot because little change occurred in the upper part of the study reach and EB lines were not surveyed in 2014, so no comparison is made between 2013, 2014, and 2015 EB lines.

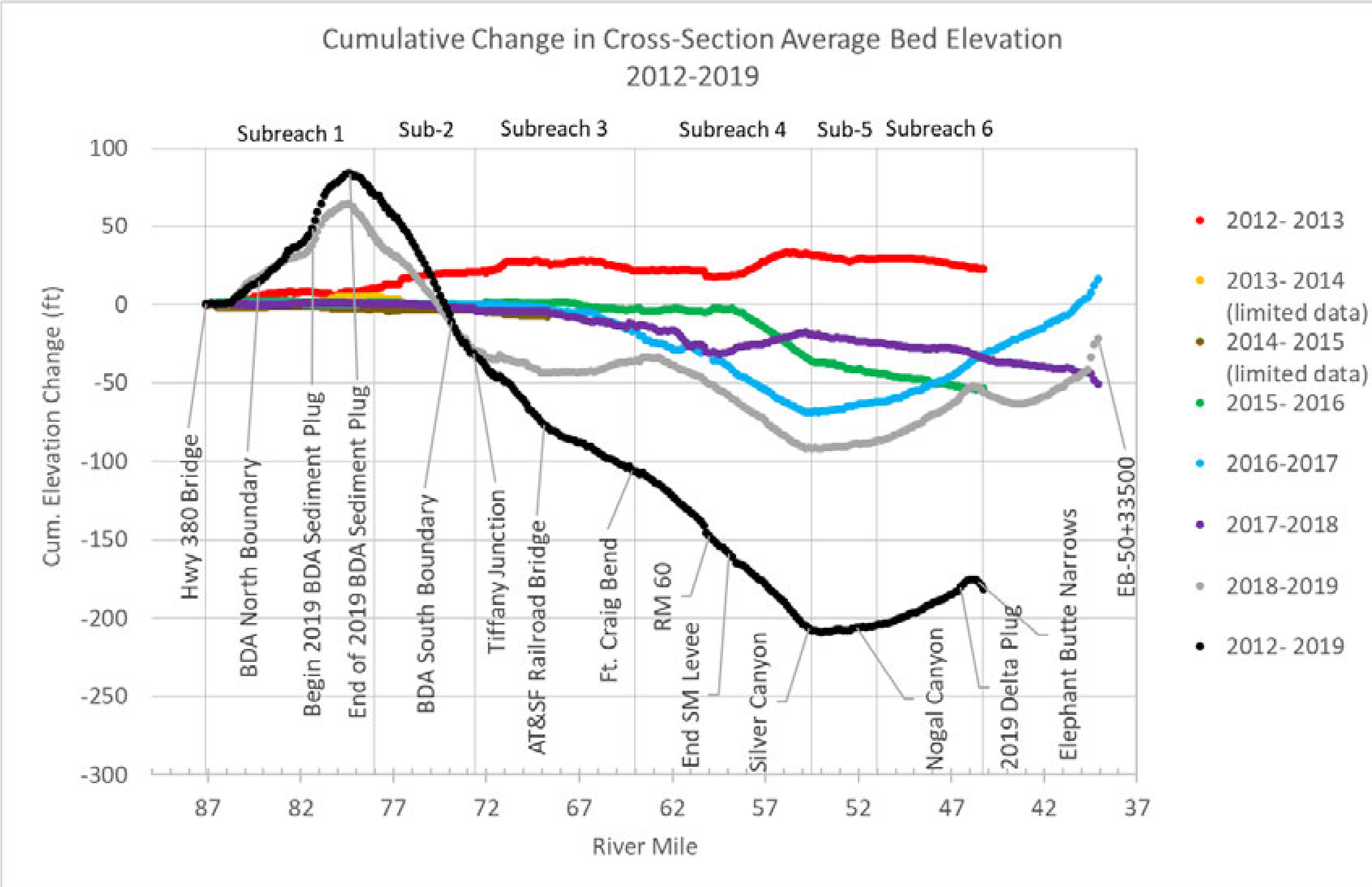

Figure 46: Year-to-year cumulative changes in cross section average bed elevations for the study reach (River Mile 87.1 – 45, SO-1475.9 – EB-50), and the section downstream of the Elephant Butte Narrows (EB-50 – EB-50+33500), from 2012 to 2019.

Bank elevation measurements are presented here with some nuance. Bank points were taken as recorded on Reclamation yearly cross section surveys, which carry some influence from the surveyor's perception of the bank location. Figure 47 showing the cross section at EB-9.4 (just below the AT&SF Railroad Bridge along the San Marcial Levee) helps to illustrate this point. At this location the main channel was confined between stations 75 and 300, points along the cross section that changed very little over the 7-year study period. However, recorded bank points changed when the active channel occupied less space than the larger available channel and sediment deposits on the left side of the cross section became the new banks and survey endpoints (on Figure 47 the 2017, 2018, and 2019 surveys stopped at the new, lower river left bank points). The water level at the time of surveying most likely also influenced perceptions of the bank points. This effect occurred most along the San Marcial Levee in Subreaches 3 and 4, where the channel capacity analysis (using more conservative bank points – see "Hydraulic Analysis" section) showed the least overtopping of the main channel banks. With these caveats in mind, the bank elevations from the Reclamation cross section surveys can be interpreted as the bank elevations of the active portion of the channel shaped by flows during the preceding year. The active portion of the channel was smaller than the larger main channel in sections of the channel that have high flow capacity. Therefore, increasing bank elevations here do not solely represent bank deposition of sediments induced by overbanking. Particularly for the sections of reach bounded by the San Marcial Levee, an increase in bank elevations over one year indicates that the flows during that year were high enough to increase the active channel area, and vice-versa. Overbanking is more likely the cause of changing bank elevations in the BDA and Delta Channel areas, where overbanking of the main channel occurred at lower flows. Bank elevations of the active channel decreased on average by 0.7 ft (8.4 in) from 2012 to 2019, with active channel bank elevations increasing from 2015 – 2016 and 2018 – 2019, and decreasing or changing little for all other year to year periods (Table 26).

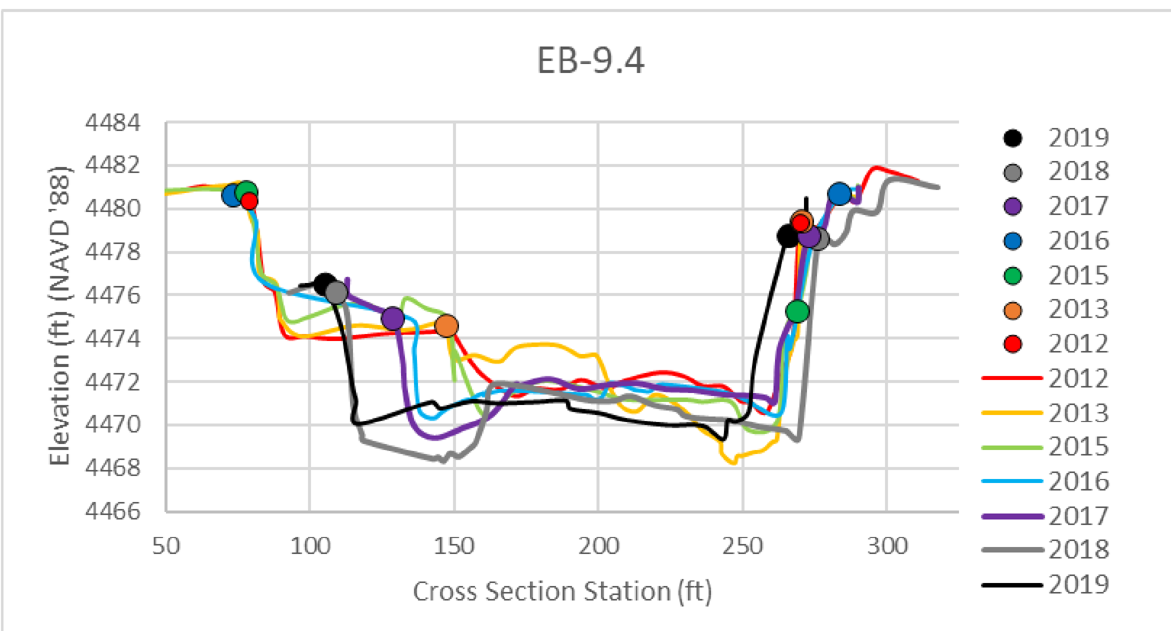

Figure 47: Available cross section surveys and bank points at EB-9.4 (RM 68.5) from 2012 to 2019.

Table 26: Year-to-year changes in average bank elevations of surveyed cross sections from SO-1475.9 to EB-50. *Cross sections in the EB area were not surveyed in 2014.

Unit	'12-'13	'13-'14*	'14*-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Average Δ (ft)	-0.1	0.0	-0.4	0.8	-0.9	-0.9	0.3	-0.7
Max. Increase (ft)	7.3	6.5	1.8	11.7	2.7	5.5	9.7	5.2
Location (Rangeline)	EB-39.3	SO-1596.6	SO-1572.5	EB-25.3	SO-1641	EB-30	EB-24.9	EB-25
Max. Decrease (ft)	7.0	2.8	6.0	3.9	7.8	13.4	5.4	9.6
Location (Rangeline)	EB-26.3	SO-1665	SO-1596.6	SO-1670	EB-27	EB-49.5	EB-30	EB-23.6A

Table 27: Year-to-year changes in cross section average bank elevations of surveyed cross sections by subreach, color coded by value. *Cross sections in the EB area were not surveyed in 2014.

Unit	'12-'13	'13-'14*	'14*-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Subreach 1 Average Δ (ft)	0.1	0.0	-0.1	-0.2	0.2	0.3	0.4	0.6
Subreach 2 Average Δ (ft)	-0.1	0.7	-1.1	0.4	2.0	-1.0	0.1	-0.8
Subreach 3 Average Δ (ft)	0.0	-0.7	-0.2	0.2	-0.5	0.1	-0.2	-0.7
Subreach 4 Average Δ (ft)	-0.9	-	-	1.3	-1.1	-2.0	1.2	-1.5
Subreach 5 Average Δ (ft)	0.1	-	-	1.4	-1.1	0.1	-0.6	-0.7
Subreach 6 Average Δ (ft)	0.4	-	-	0.6	-1.0	-0.7	-0.2	-1.6

Cumulative change plots of the active channel bank elevations show that the greatest change in active channel bank elevations occurred below the AT&SF Railroad Bridge (Figure 48). In particular, the section between the AT&SF Railroad Bridge and the end of the San Marcial Levee appears to be where the most dramatic changes in active channel bank elevations took place for most years. As mentioned above, this is due to the higher main channel capacity in this section of the study reach, resulting in small flows taking up less of the main channel and larger flows depositing sediments in the less used part of the main channel. In this section the bank points tended to move between the banks of the main channel and the banks of the smaller active channel within the main channel (Figure 48). In contrast, bank elevations in the BDA section of the reach changed in the 2018 – 2019 period when thalweg elevations increased. These increases in bank elevation were mainly in the upper BDA area, where the overall lower channel capacity and aggradation associated with the 2019 sediment plug increased overbanking. Overall from 2012 to 2019 average active channel bank elevations increased in the upper BDA area, which was influenced heavily by the 2018 – 2019 period. The overall decrease in active channel bank elevations downstream of the AT&SF Railroad

Bridge was most influenced by the 2012 – 2013 and 2016 – 2018 periods. In general, when the slope of the line in Figure 48 is positive proceeding in the downstream direction, the channel bank elevation is increasing and the channel is becoming more perched. When the slope is negative proceeding in the downstream direction, the channel bank elevation is decreasing and the channel is becoming more incised.

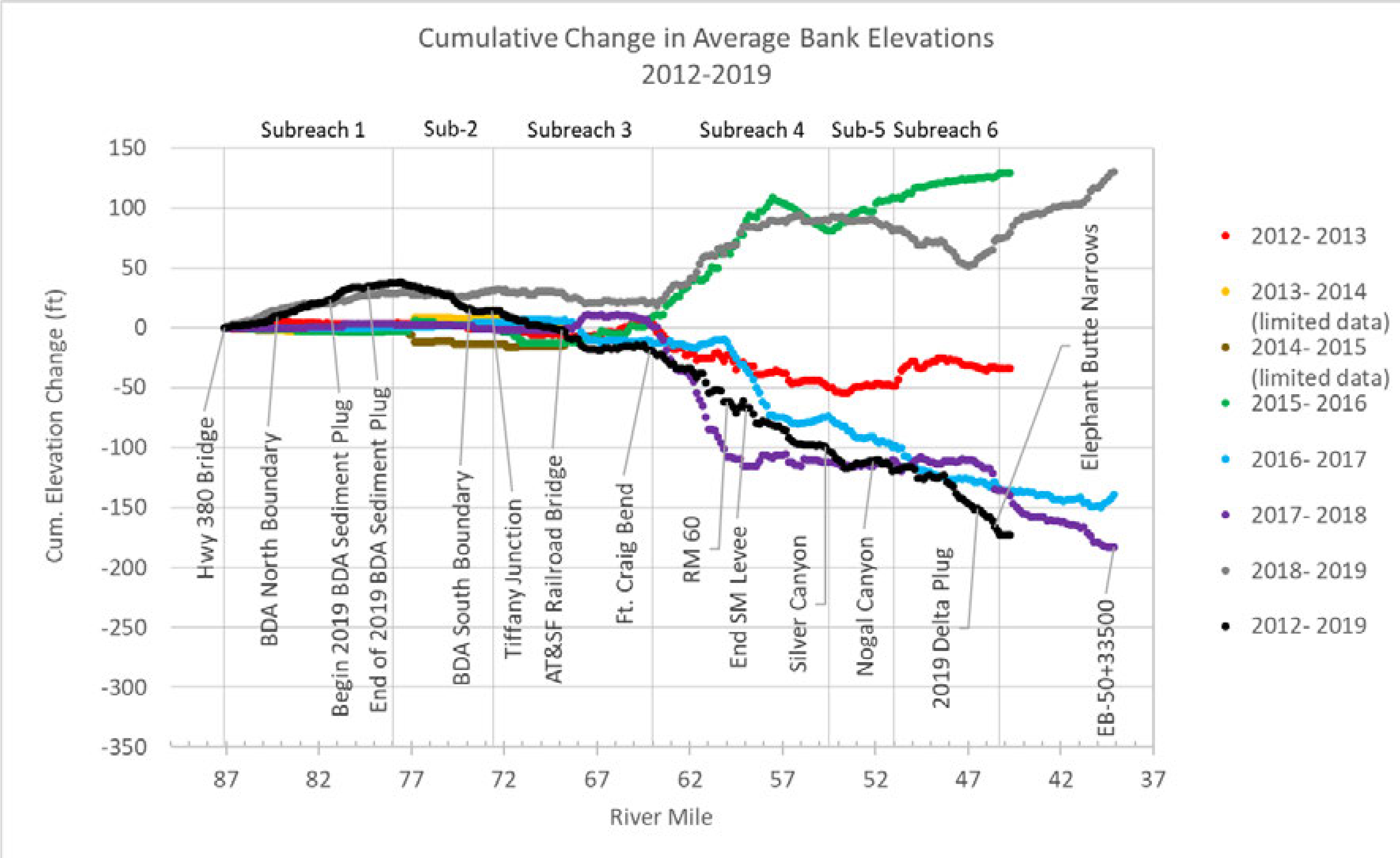

Figure 48: Year-to-year cumulative changes in average bank elevations for the study reach (River Mile 87.1 – 45, SO-1475.9 – EB-50), and the section downstream of the Elephant Butte Narrows (EB-50 – EB-50+33500), from 2012 to 2019.

Channel Width

Year to year changes in bank-to-bank channel widths of the surveyed cross sections are summarized in Table 28 below. Reach-average channel width decreased all years except from 2015 – 2016, with an overall reach-average decrease of 25 feet from 2012 to 2019 (Table 28). As with the bank elevations from the Reclamation cross section data, the channel widths reported here carry some bias and most accurately represent the active channel shaped by flows during the previous year. In the section bounded by the Tiffany and San Marcial Levees, channel widths decreased mainly because flows occupied a smaller area of the main channel, with sediment deposits within the main channel acting as a new bank point. Similarly to the bank elevations, the greatest changes in bank-to-bank channel width were between the AT&SF Railroad Bridge and the end of the San Marcial Levee (Figure 55). In this section banks mainly changed as different flows took up different portions of the main channel. The overall change from 2012 to 2019 was dominated by channel narrowing, with only 2015 – 2016 undergoing an average increase in channel width.

Table 28: Year-to-year changes in average bank-to-bank widths of surveyed cross sections from SO-1475.9 to EB-50. *Cross sections in the EB area were not surveyed in 2014.

Unit	**'12-'13**	**'13-'14***	**'14*-'15**	**'15-'16**	**'16-'17**	**'17-'18**	**'18-'19**	**'12-'19**
Average Δ (ft)	-4.9	-10.8	-5.1	9.1	-12.2	-6.0	-2.7	-25.0
Max. Increase (ft)	144.3	77.6	28.9	146.0	43.7	65.6	188.4	185.3
Location (Rangeline)	SO-1507.5	SO-1557	SO-1560.5	EB-50	SO-1641	EB-37.7	SO-1530.5	SO-1530.5
Max. Decrease (ft)	179.3	106.3	51.2	128.6	149.8	116.7	129.8	237.0
Location (Rangeline)	EB-23.6A	SO-1499	SO-1524	SO-1536	EB-50	EB-23.6A	SO-1660	EB-50

All of the Subreaches had decreasing width from 2012 – 2019, with the subreaches that underwent aggradation (Subreaches 1, 5, and 6) decreasing in width most while the Subreaches that underwent degradation (Subreaches 2, 3, and 4) had the least overall decrease in width. Plots of bank-to-bank channel width by subreach are included in Figure 49 to Figure 54. Cumulative change plots of the channel width from 2012 – 2019 are shown on Figure 55.

Table 29: Year-to-year changes in bank-to-bank widths of surveyed cross sections by subreach, color coded by value. *Cross sections in the EB area were not surveyed in 2014.

Unit	'12-'13	'13-'14*	'14*-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Subreach 1 Average Δ (ft)	-2.8	-17.0	-5.7	-2.8	-0.2	-11.0	0.4	-44.3
Subreach 2 Average Δ (ft)	-1.6	-5.4	-5.6	-11.9	28.0	-13.7	-3.3	-18.3
Subreach 3 Average Δ (ft)	-2.6	-3.3	-3.1	4.9	-5.5	1.6	-5.2	-6.6
Subreach 4 Average Δ (ft)	-14.3	-	-	15.1	-14.9	-15.5	8.5	-20.7
Subreach 5 Average Δ (ft)	-14.6	-	-	12.3	-17.0	7.0	-11.7	-27.3
Subreach 6 Average Δ (ft)	5.9	-	-	9.8	-13.7	-1.5	-18.3	-28.8

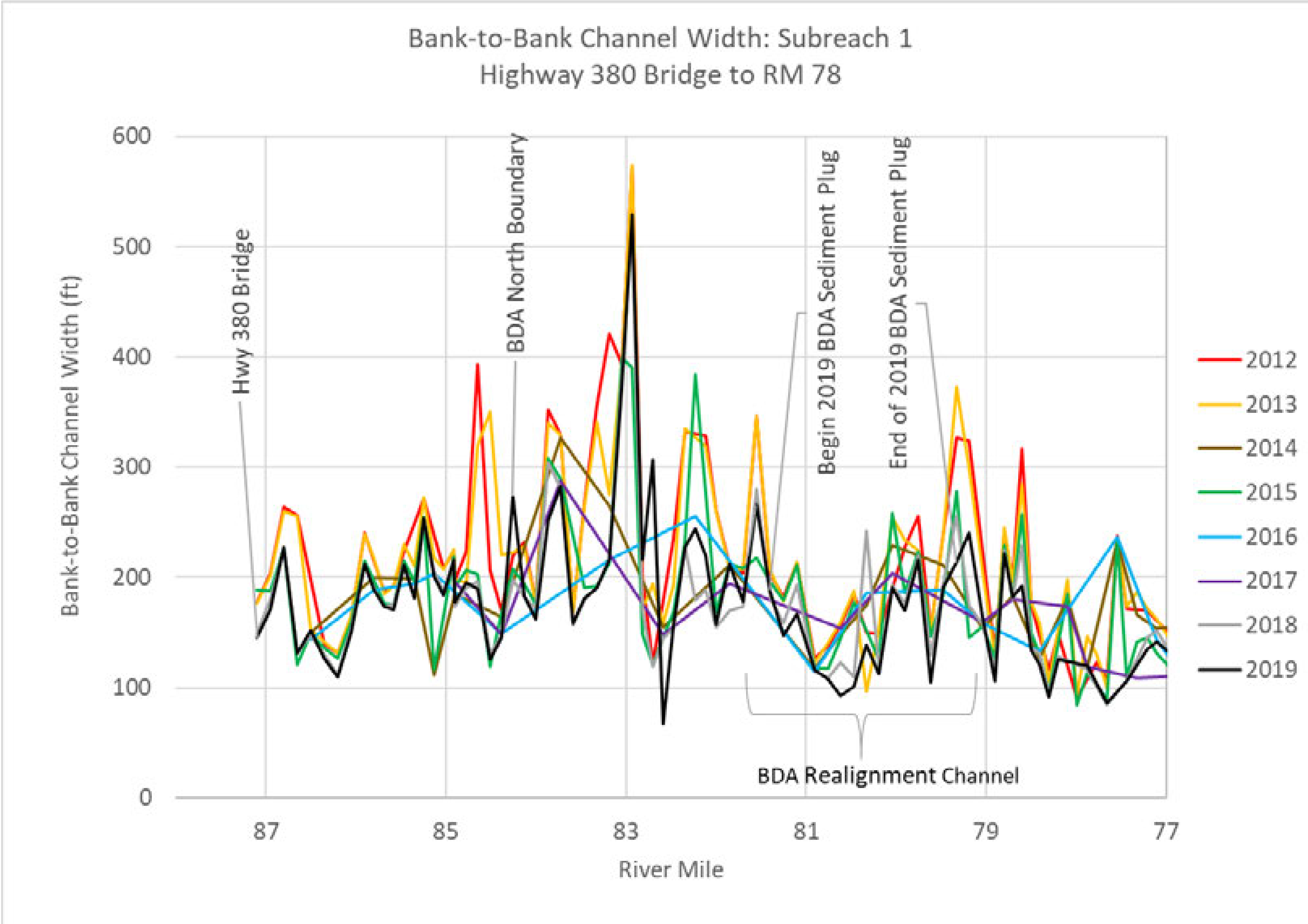

Figure 49: Bank-to-bank channel widths for Subreach 1 (RM 87.1 – RM 78).

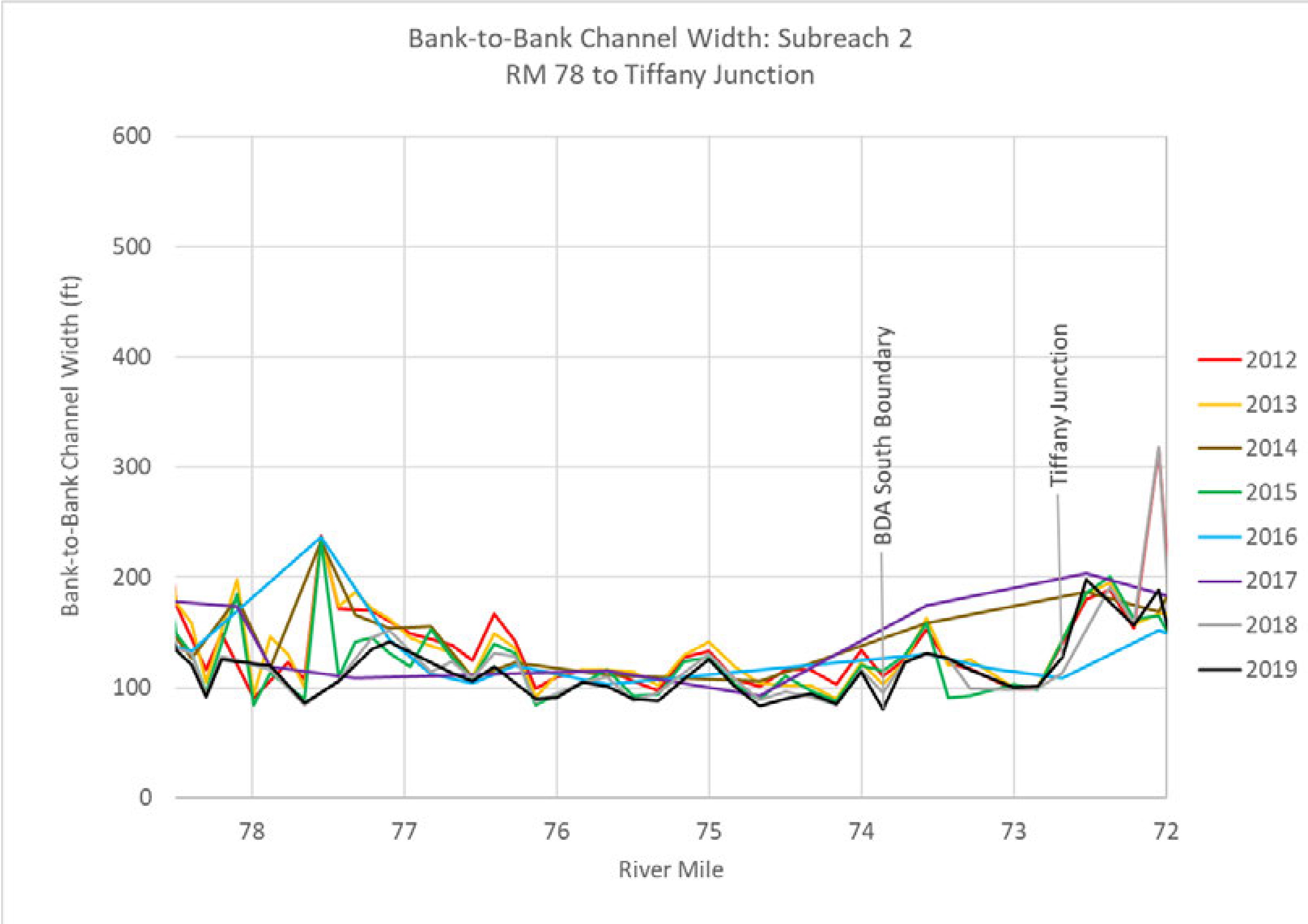

Figure 50: Bank-to-bank channel widths for Subreach 2 (RM 78 – 72.6).

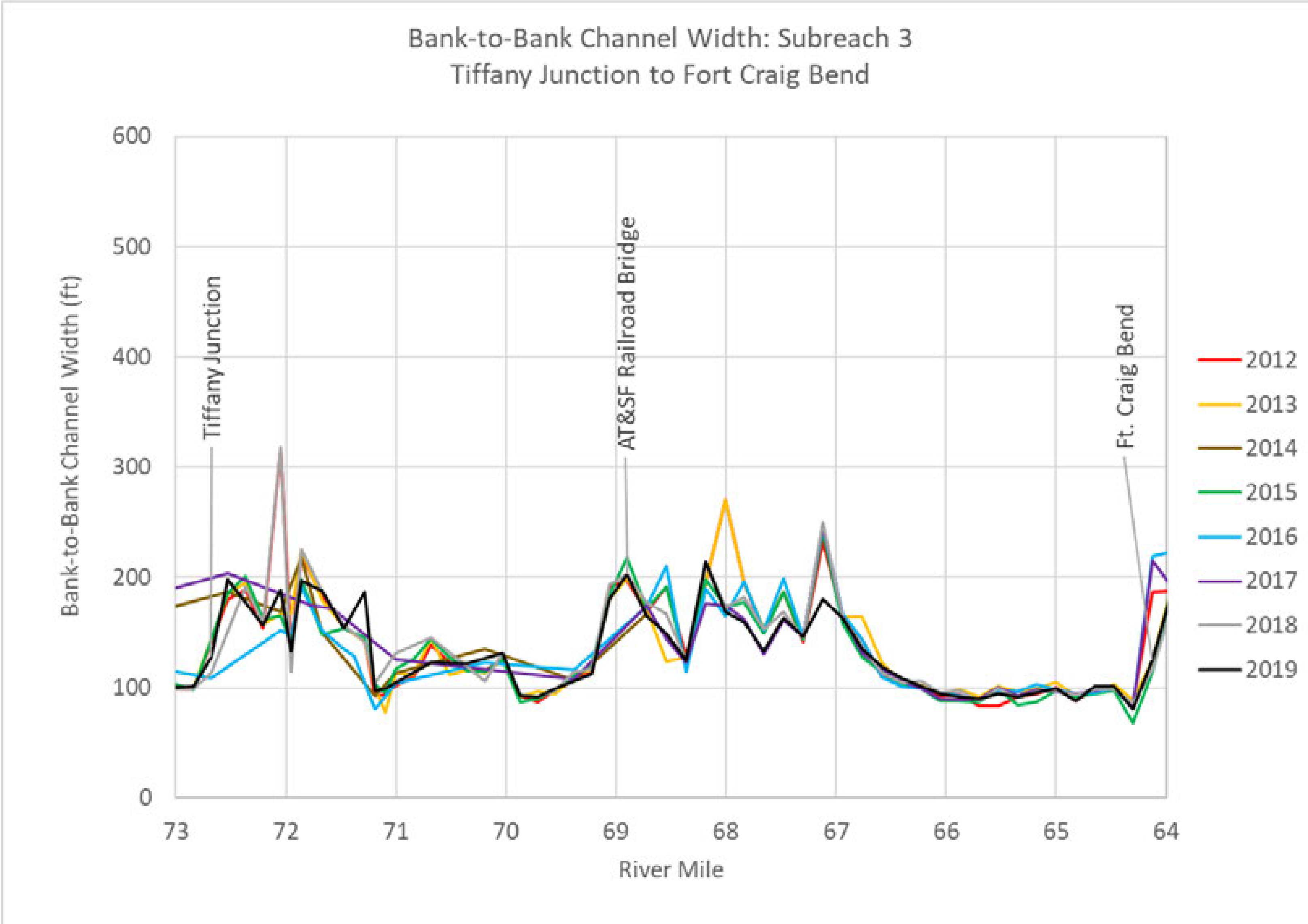

Figure 51: Bank-to-bank channel widths for Subreach 3 (RM 72.6 – RM 64).

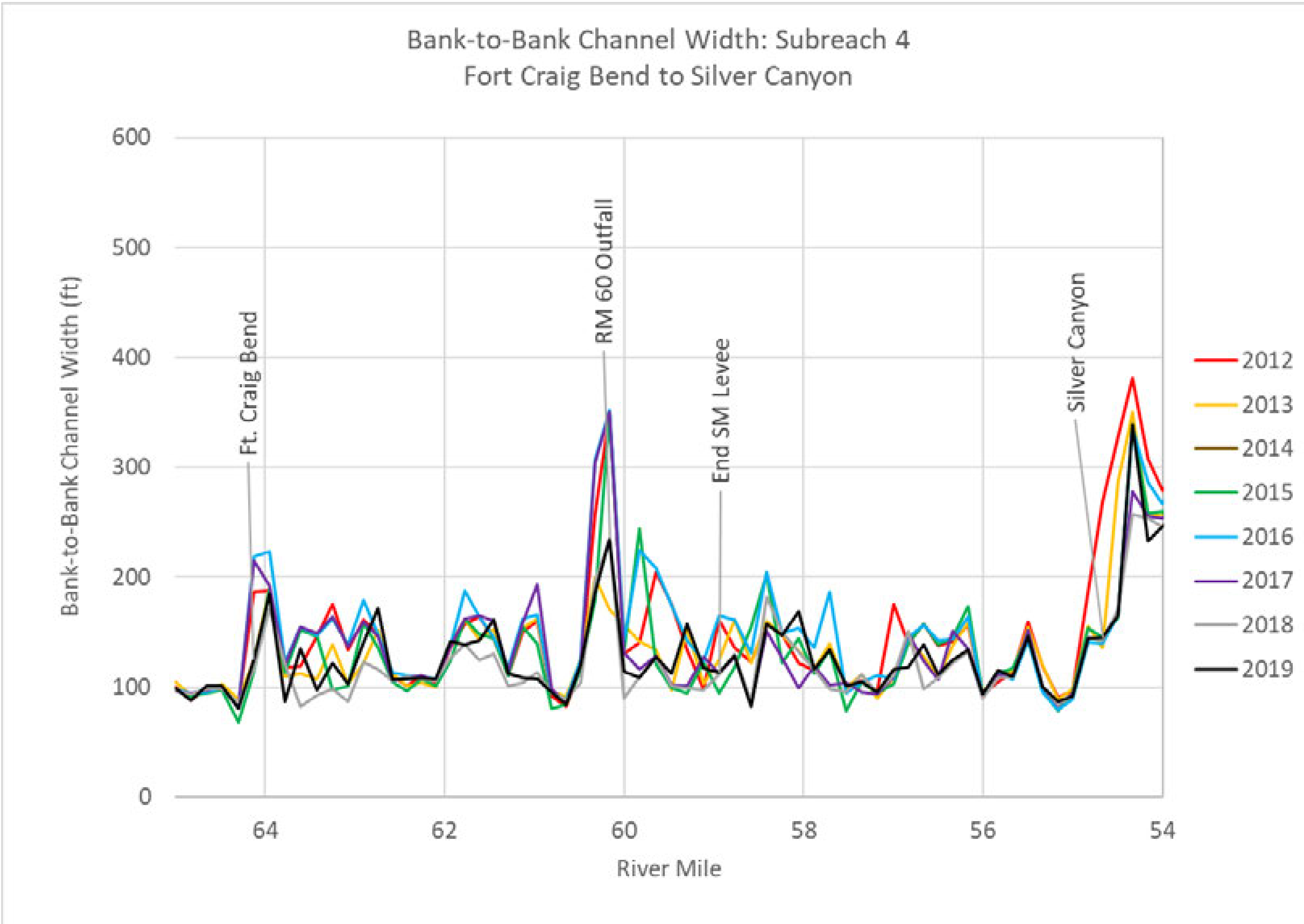

Figure 52: Bank-to-bank channel widths for Subreach 4 (RM 64 – RM 54.5).

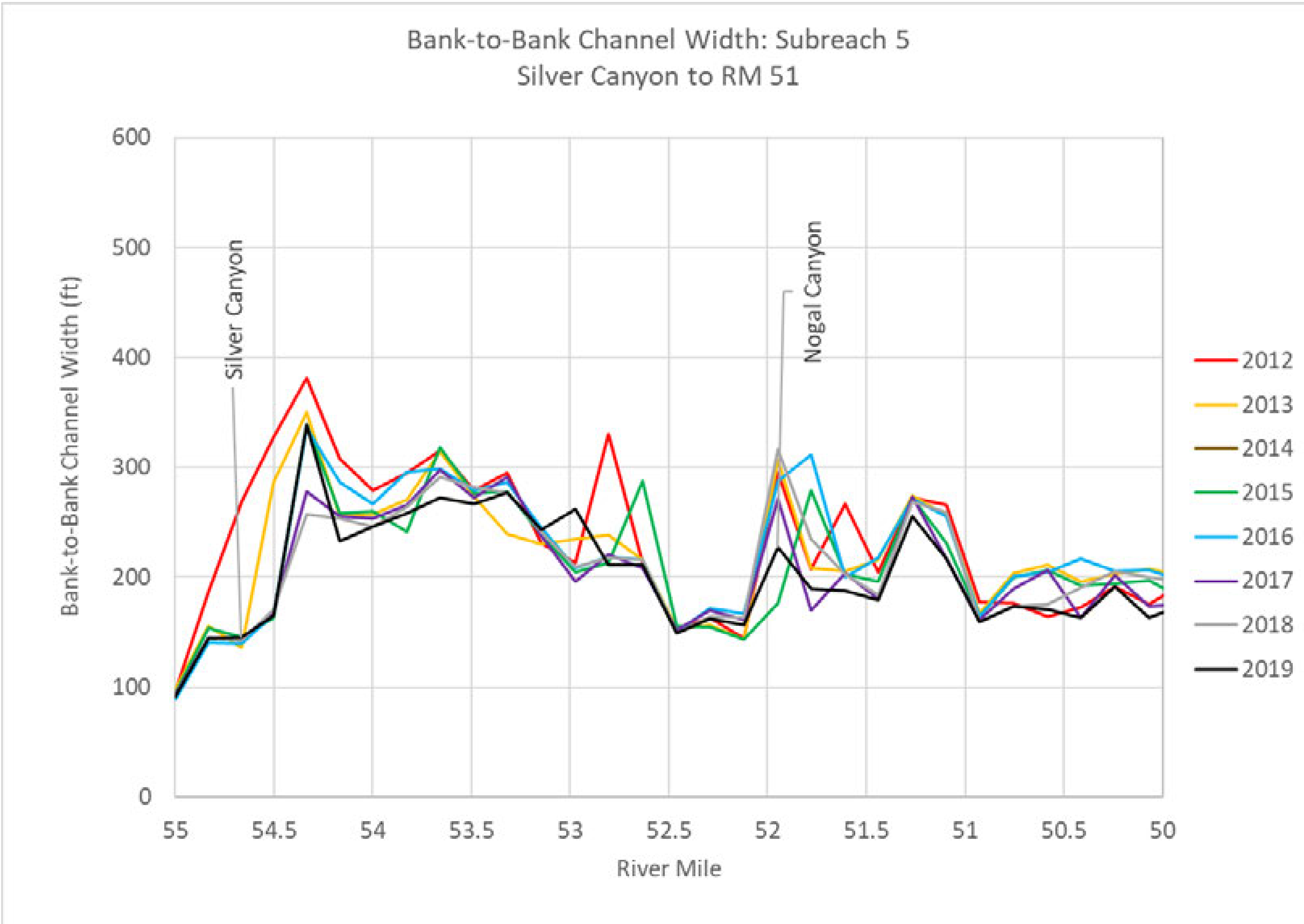

Figure 53: Bank-to-bank channel widths for Subreach 5 (RM 54.5 – RM 51).

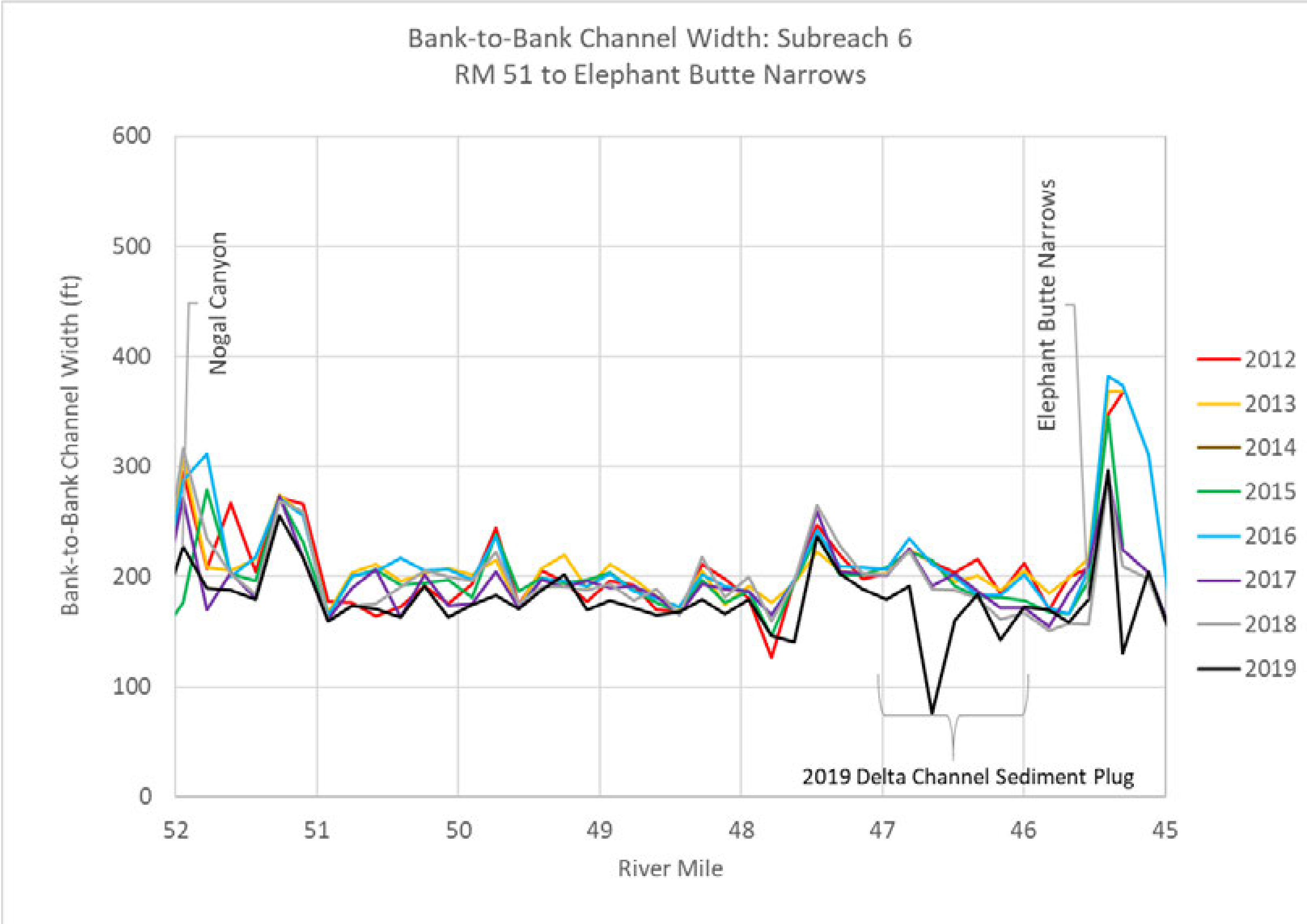

Figure 54: Bank-to-bank channel widths for Subreach 6 (RM 51 – RM 45.3).

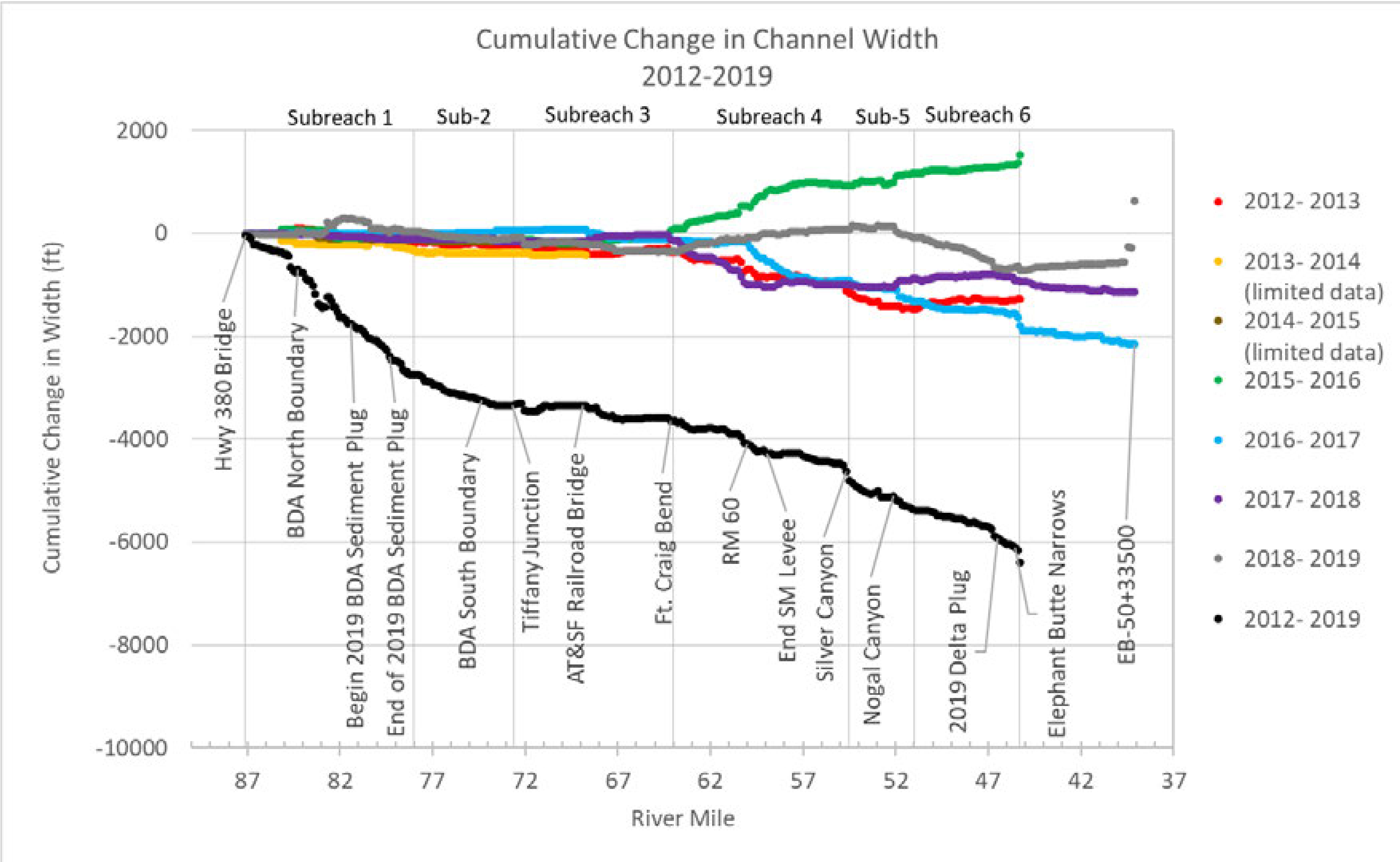

Figure 55: Year-to-year cumulative changes in average bank elevations for the study reach (River Mile 87.1 – 45, SO-1475.9 – EB-50), and the section downstream of the Elephant Butte Narrows (EB-50 – EB-50+33500), from 2012 to 2019.

Mean Channel Depth

Channel depth is defined here as the difference between the average elevation of the channel banks and the cross-section average bed elevation. Since these data are derived from Reclamation-generated survey data, they carry some bias and most accurately represent the active channel shaped by flows during the previous year. As described in the previous sections, bank changes in the reach bounded by the San Marcial Levee were predominantly due to changes of the active channel within the main channel. Bank changes above and below these sections were more related to overbanking. The change in reach-average mean channel depth from 2012 to 2019 was negligible although certain sections of the reach became deeper while others became shallower (Table 30). Reach-average channel depths of surveyed cross sections increased from 2013 – 2014, 2015 – 2016, and 2018 – 2019. These year-to-year periods coincide with the only year-to-year periods in which bank elevations increased or remained approximately the same.

Table 30: Year-to-year changes in average channel depth of surveyed cross sections from SO-1475.9 to EB-50. *Cross sections in the EB area were not surveyed in 2014.

Unit	'12-'13	'13-'14*	'14*-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Average Δ (ft)	-0.2	0.2	-0.2	1.1	-0.7	-0.6	0.5	0.0
Max. Increase (ft)	7.4	6.8	2.0	11.9	3.9	5.1	10.4	6.9
Location (Rangeline)	EB-39.3	SO-1596.6	SO-1572.5	EB-23.4	EB-17.8	EB-30	EB-24.9	EB-25
Max. Decrease (ft)	7.8	2.0	6.1	5.1	7.2	12.5	5.6	8.0
Location (Rangeline)	EB-26.3	SO-1665	SO-1596.6	SO-1660	EB-39.6	EB-49.5	EB-40.5	EB-40.5

Table 31: Year-to-year changes in mean channel depth of surveyed cross sections by subreach, color coded by value. *Cross sections in the EB area were not surveyed in 2014.

Unit	'12-'13	'13-'14*	'14*-'15	'15-'16	'16-'17	'17-'18	'18-'19	'12-'19
Subreach 1 Average Δ (ft)	-0.1	-0.2	0.0	-0.4	0.0	0.3	-0.2	-0.5
Subreach 2 Average Δ (ft)	-0.4	1.3	-1.0	0.7	2.3	0.0	2.2	2.6
Subreach 3 Average Δ (ft)	0.0	-0.4	0.4	0.3	0.0	0.4	-0.1	0.8
Subreach 4 Average Δ (ft)	-1.1	-	-	1.9	-0.2	-1.9	2.2	0.3
Subreach 5 Average Δ (ft)	0.2	-	-	1.7	-1.4	0.3	-0.8	-0.9
Subreach 6 Average Δ (ft)	0.6	-	-	0.9	-1.9	-0.4	-1.1	-2.2

Cumulative change plots show that channel depth decreased for all years except 2015 – 2016 and 2018 – 2019, with the 2018 – 2019 year heavily influencing the upper part of the study reach (Figure 62). The 2013 – 2014 year saw a slight increase in mean channel depths of the surveyed SO rangelines. From 2015 – 2016 average bed elevations decreased while bank elevations increased, leading to increases in depth closely mirroring the increase in bank elevations. From 2018 – 2019 average bank elevations increased overall while average bed elevations decreased through most of the reach, increasing mainly at the upstream and downstream ends (upper BDA area and Silver Canyon to the Narrows). Increases in bed elevation at the upstream and downstream ends outweighed the increase in bank elevations, leading to an overall decrease in channel depth from 2018 – 2019 in these areas of aggradation. The overall change in channel depths from 2012 – 2019 was heavily influenced by the 2018 – 2019 year, with channel aggradation in the upper and lower portions of the study reach causing decreases in channel depth.

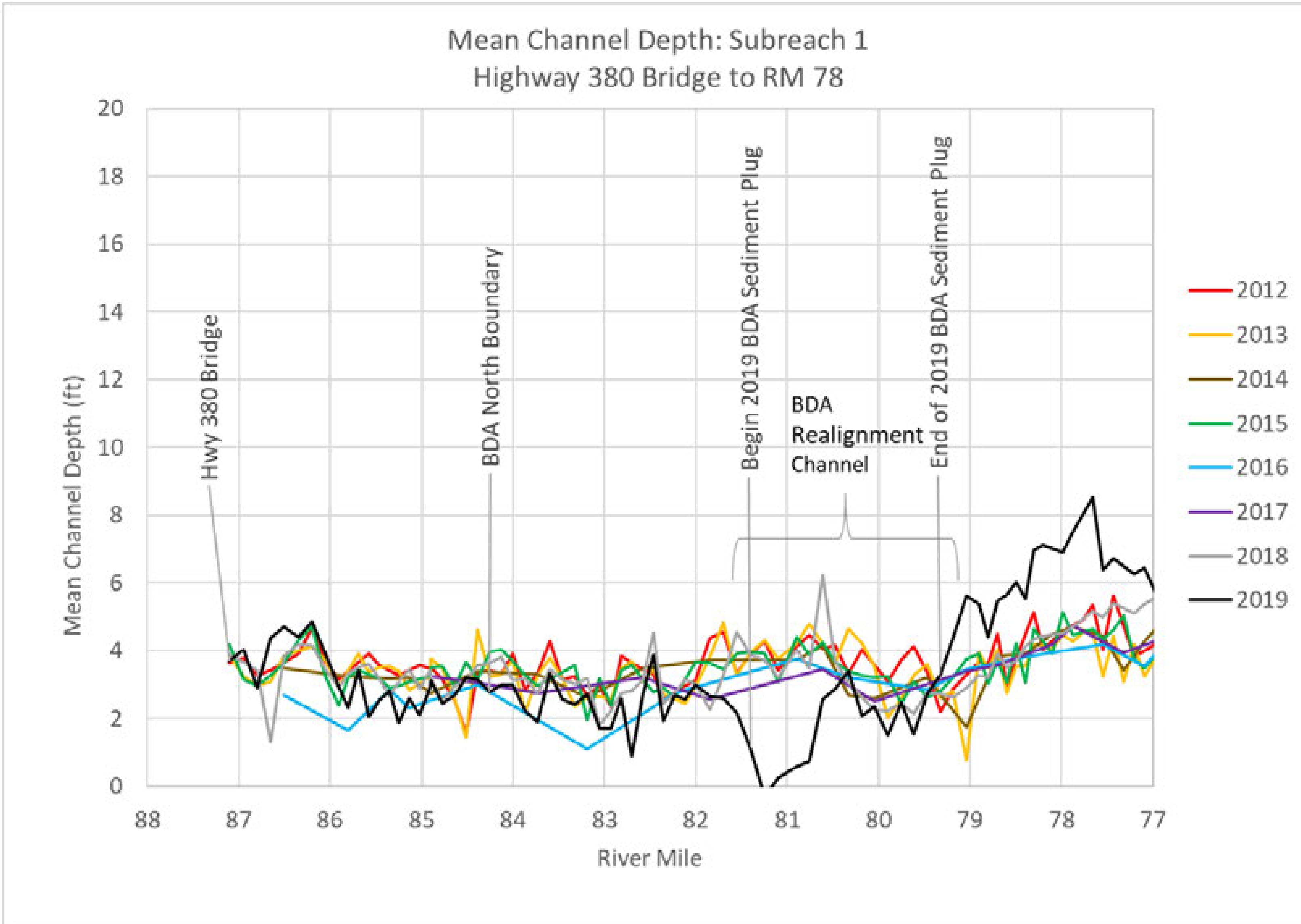

Figure 56: Mean channel depth for Subreach 1 (RM 87.1 – RM 78).

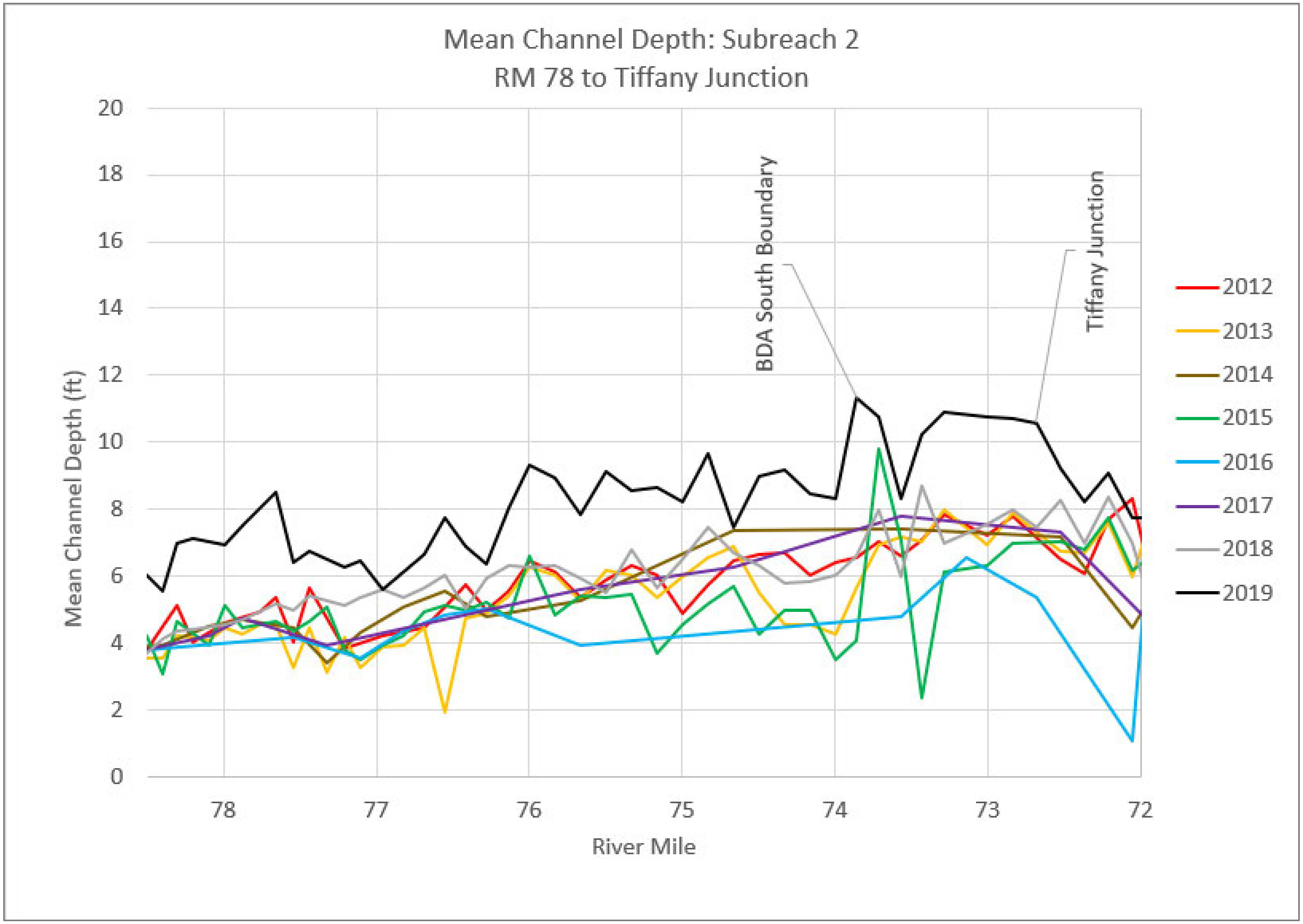

Figure 57: Mean channel depth for Subreach 2 (RM 78 – 72.6).

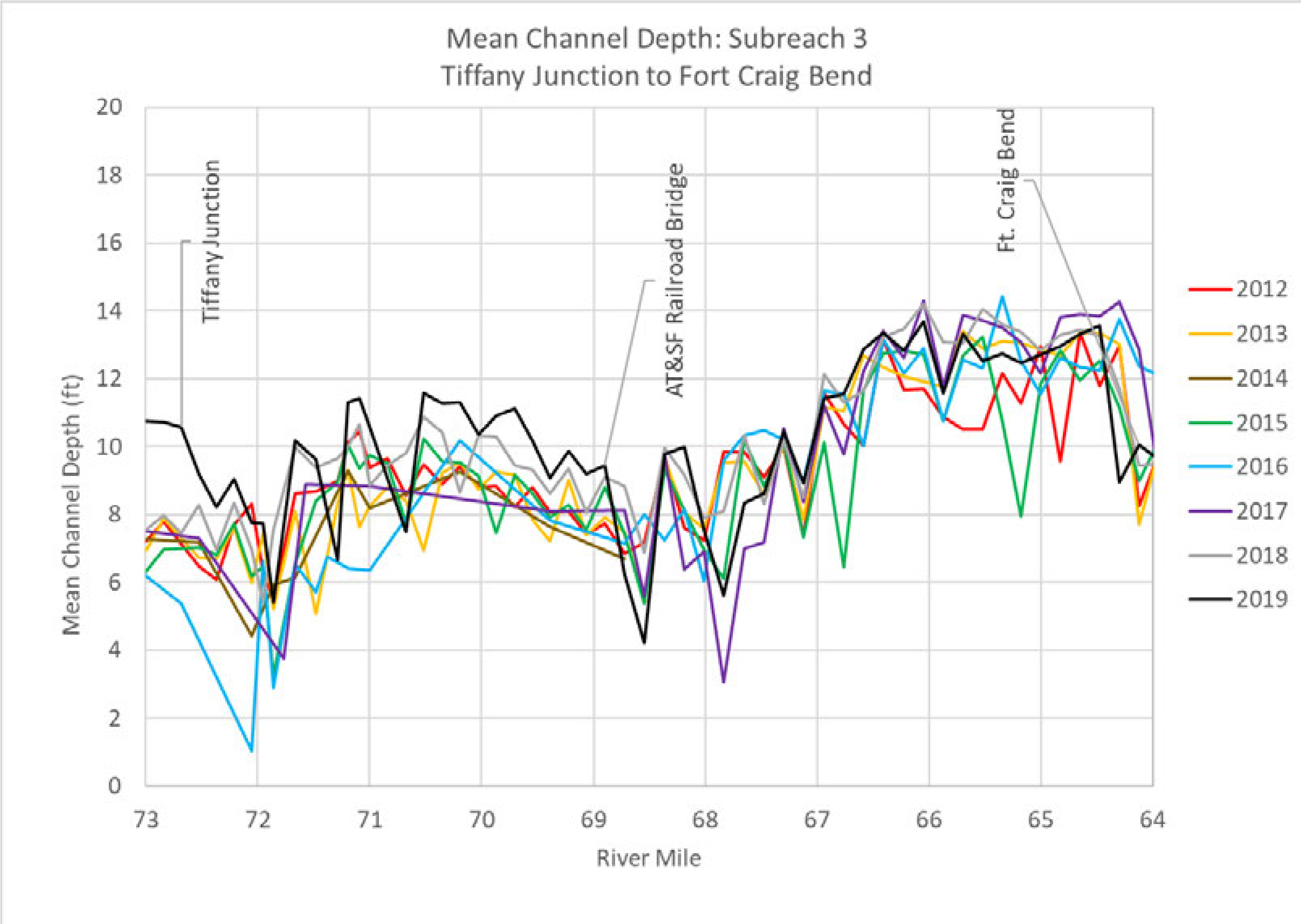

Figure 58: Mean channel depth for Subreach 3 (RM 72.6 – RM 64).

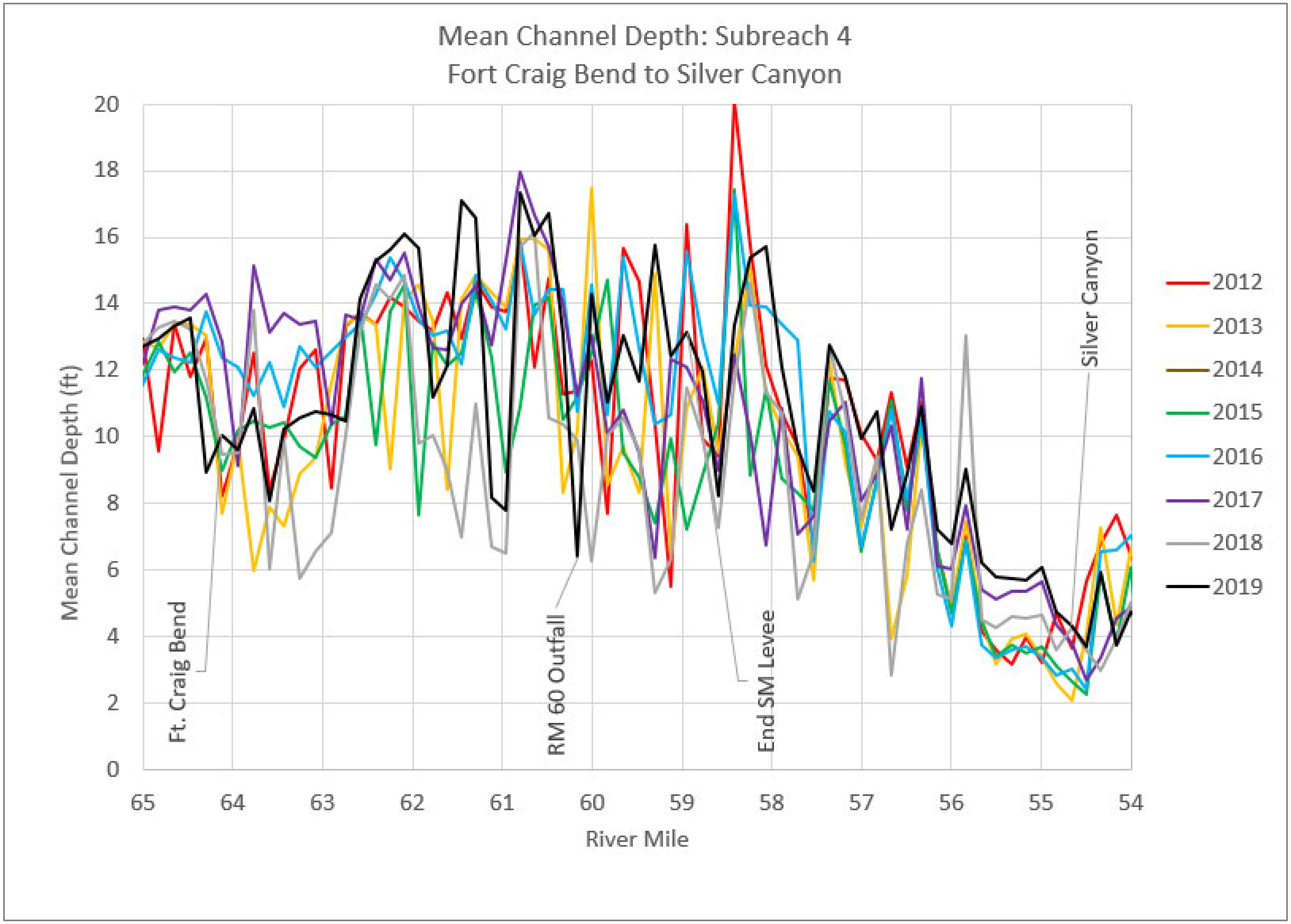

Figure 59: Mean channel depth for Subreach 4 (RM 64 – RM 54.5).

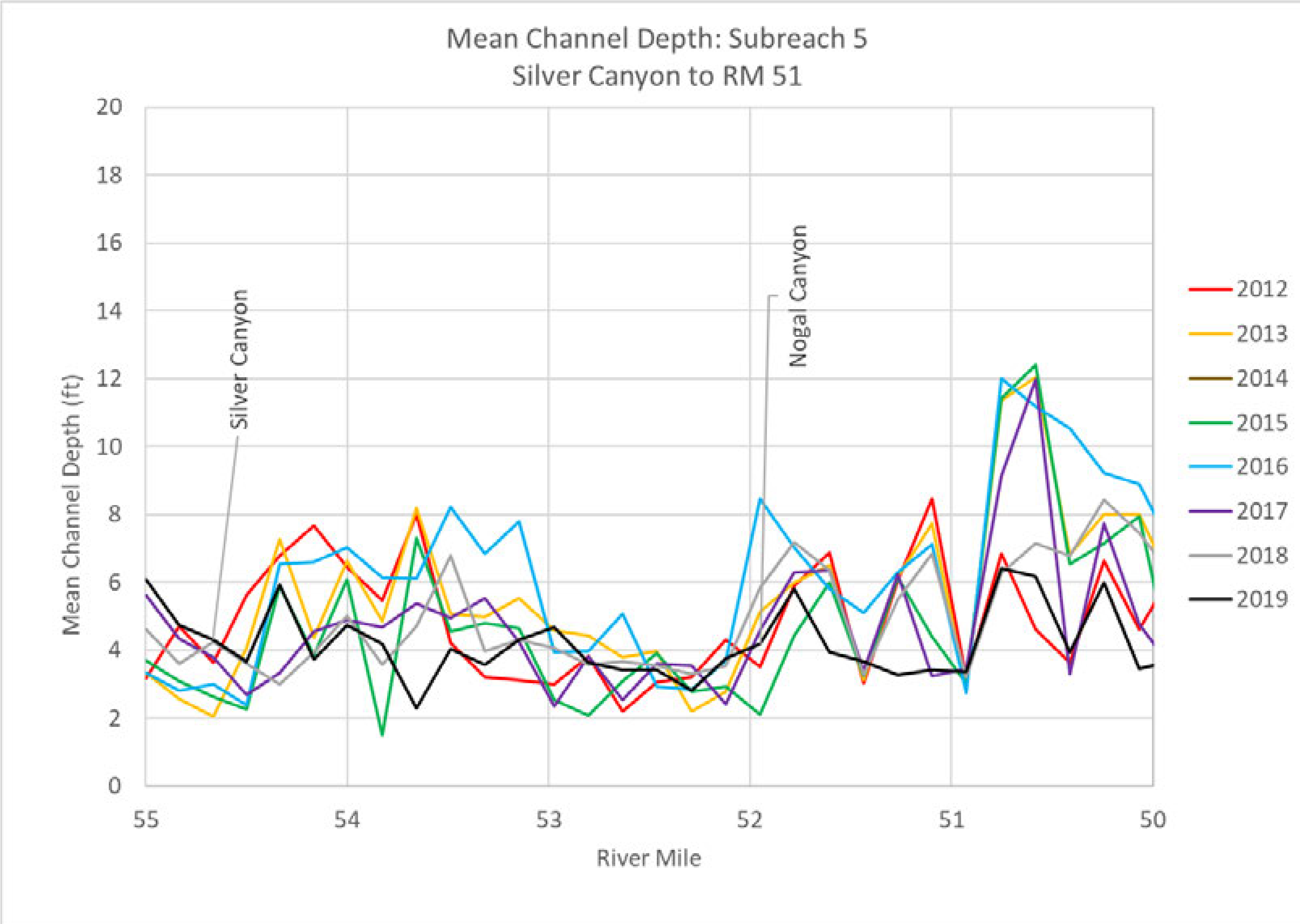

Figure 60: Mean channel depth for Subreach 5 (RM 54.5 – RM 51).

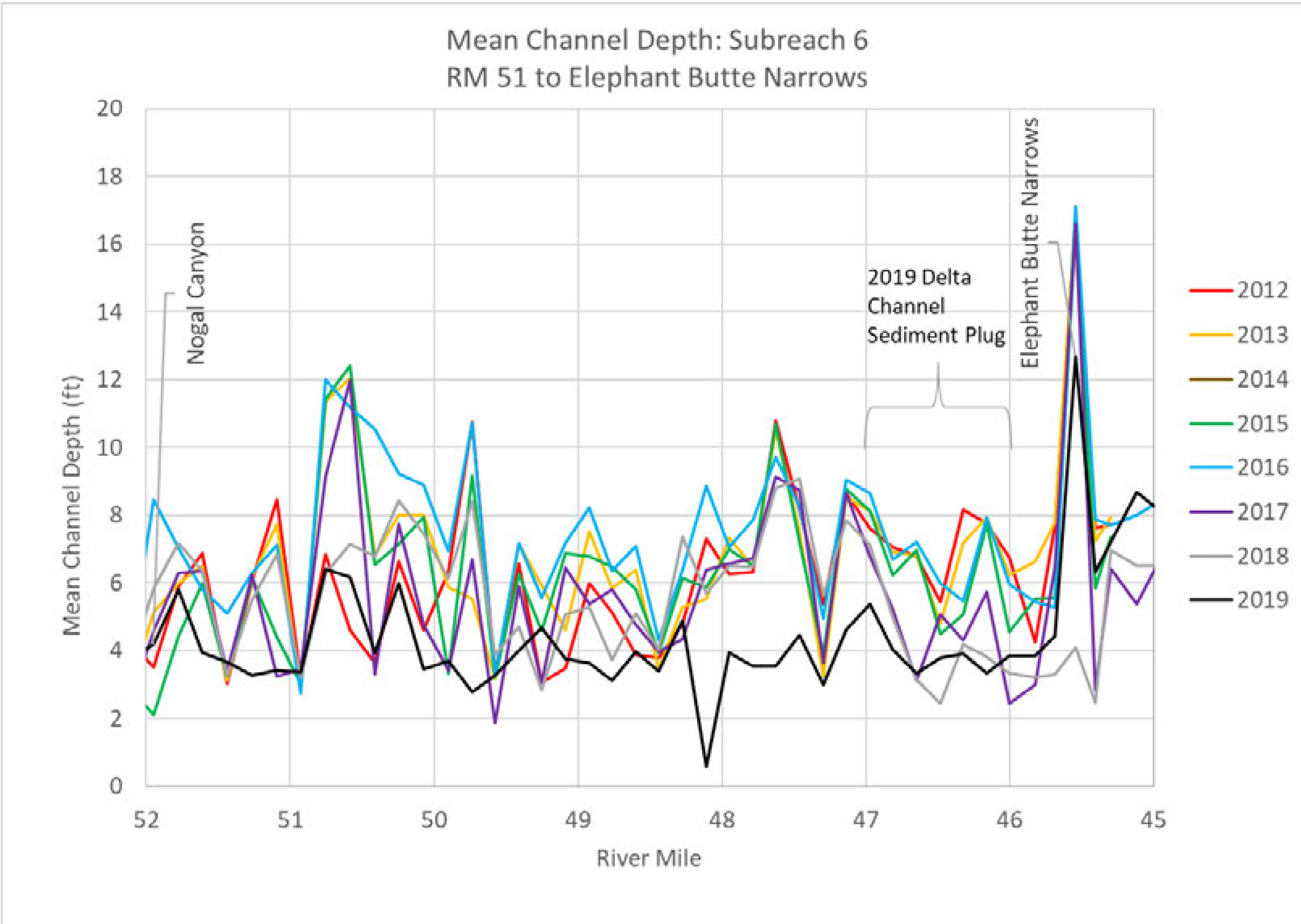

Figure 61: Mean channel depth for Subreach 6 (RM 51 – RM 45.3).

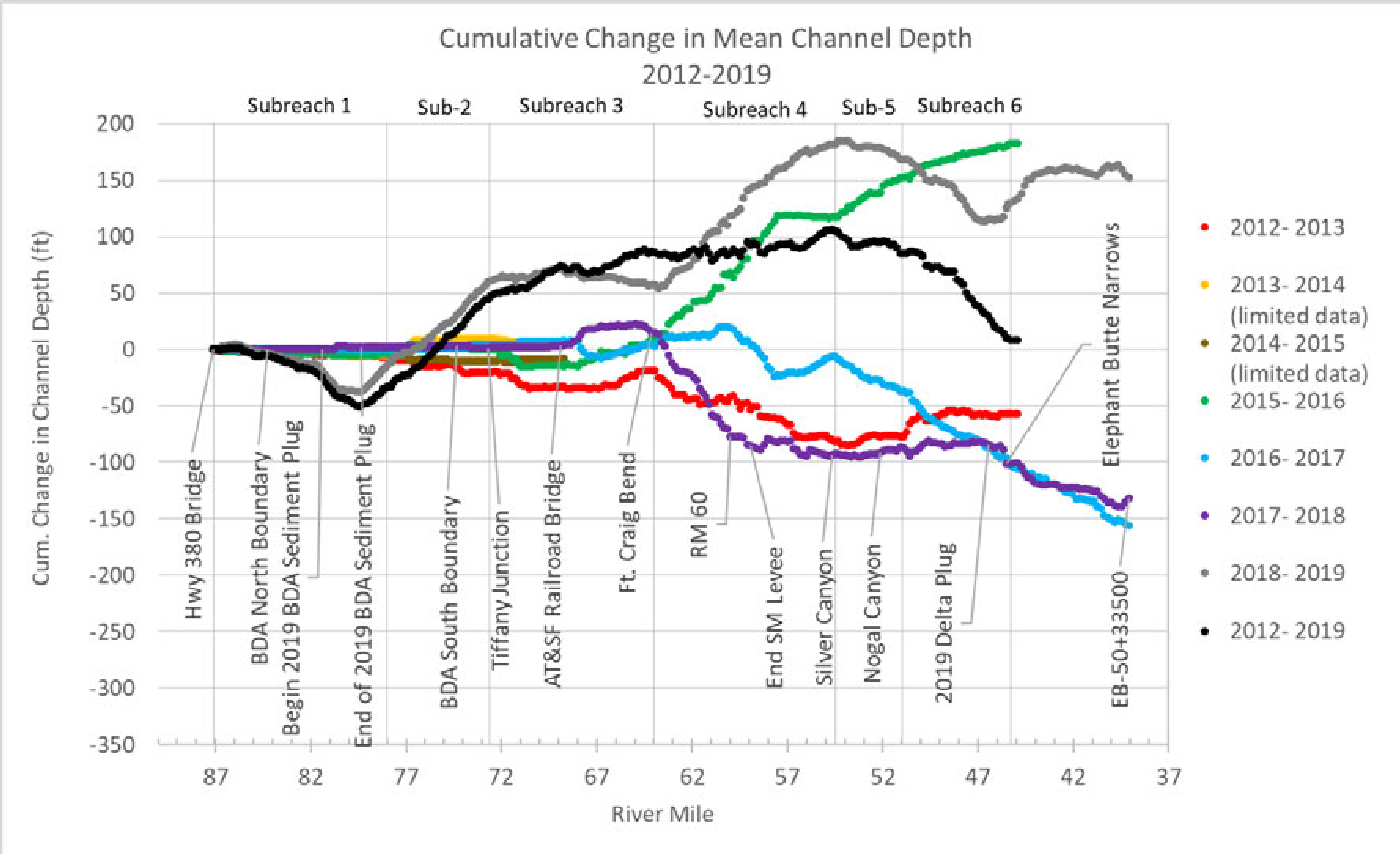

Figure 62: Year-to-year cumulative changes in mean channel depth for the study reach (River Mile 87.1 – 39, SO-1475.9 – EB-50), and the section downstream of the Elephant Butte Narrows (EB-50 – EB-50+33500), from 2012 to 2019.

Bed Material Grain Size

Bed material sample data available for the analysis reach are summarized in Table 32 below. An "X" indicates a bed sample was taken at the cross section in that year, and a number in parentheses indicates the number of samples taken at the cross section if more than 1.

Table 32: Summary of available bed material samples by year and number of samples taken at cross sections in the study reach from 2012 – 2019.

Rangeline	2019	2018	2017	2016	2014
SO-1482.6				X	
SO-1508.9	X (3)	X		X	
SO-1534					X
SO-1539	X (3)				X (4)
SO-1572.5	X (2)	X		X	X (5)
SO-1583					X (5)
SO-1596.6				X	
SO-1652.7				X	
SO-1665					X (5)
EB-10		X	X		
EB-18		X	X		
EB-20		X	X		
EB-22.7		X			
EB-24			X		
EB-24A		X			
EB-34.8			X		

Since bed material samples were sparse and a year-to-year comparison would include only a few samples distributed irregularly between years, the overall range of grain sizes are summarized below (Figure 63), followed by plots by rangeline of bed material grain sizes for the wash load grain size (D_{10}), median grain size (D_{50}), and grain sizes plus/minus one standard deviation from the median (D_{84} and D_{16}) (Figure 64). For comparison, the average was taken of sample grain sizes for years in which multiple samples were taken at a cross section. Values reported as less than 0.08 mm (<0.08 mm) are displayed here as 0.08 mm. The grain size distribution plots and grain sizes for all of the available sample data, including multiple samples at a cross section, are included in Appendix II.

The D_{84} grain size was mostly in the range of medium sand (0.25 – 0.5 mm), with a few samples having a D_{84} bordering on fine sand (0.125 – 0.25 mm) and the 3 samples taken in 2019 all falling above this range. The 2019 samples taken at SO-1508.9 and SO-1539 (3 samples at each cross section) had the highest D_{84} grain sizes on average, with SO-1508.9 and SO-1539 having D_{84} values in the very coarse sand (1.4 mm) and coarse sand (0.77 mm) ranges. The median grain size (D_{50}) fell in the fine to medium sand range. The D_{16} grain size was in the very fine (0.0625 – 0.125 mm) to fine sand range, and samples with the smallest D_{16} (<0.08 mm) were taken in the SO rangelines. Wash load grain sizes were in the very fine sand to fine sand range.

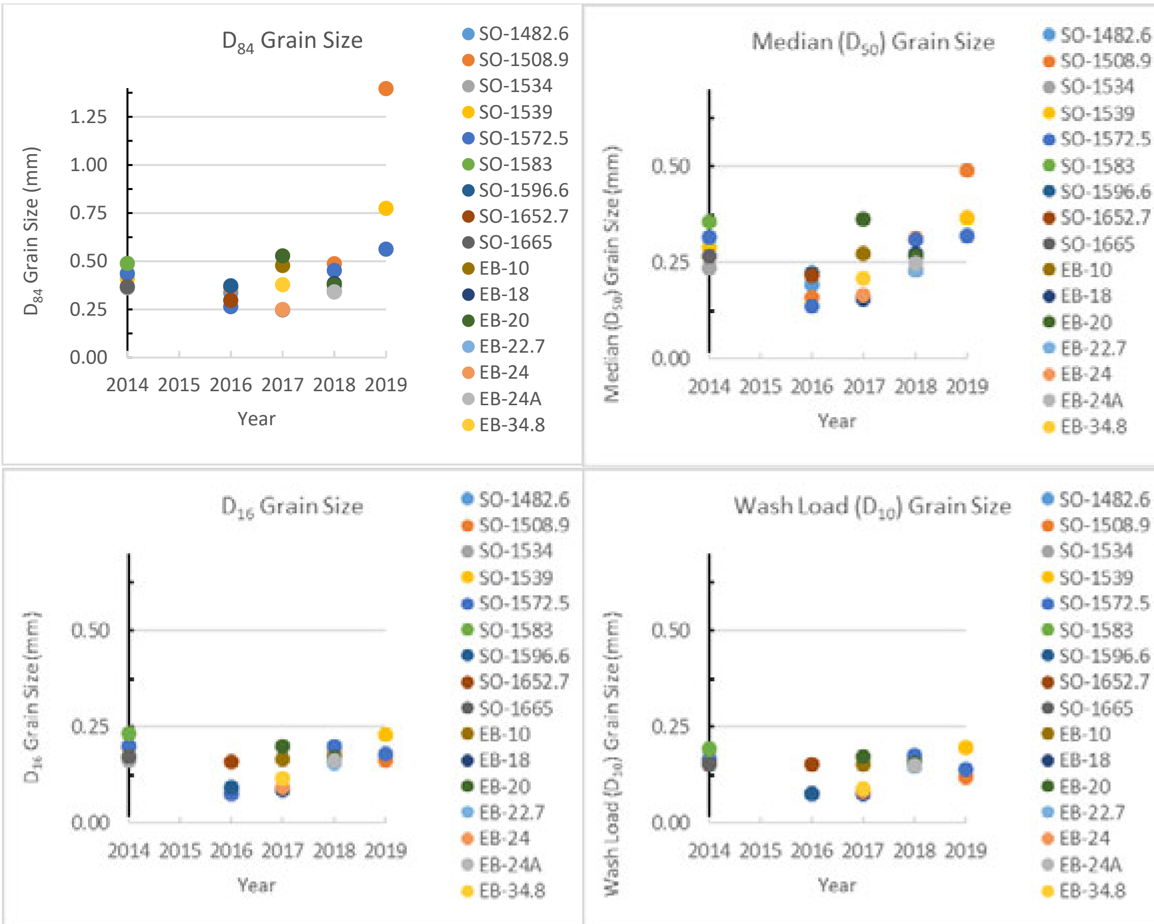

Figure 63: Range of median grain size, wash load grain size, and grain sizes plus/minus one standard deviation from the median from bed material samples taken in 2014, 2016, 2017, 2018, and 2019.

Plots of the bed material grain sizes by rangeline from upstream to downstream are shown in Figure 64 below.

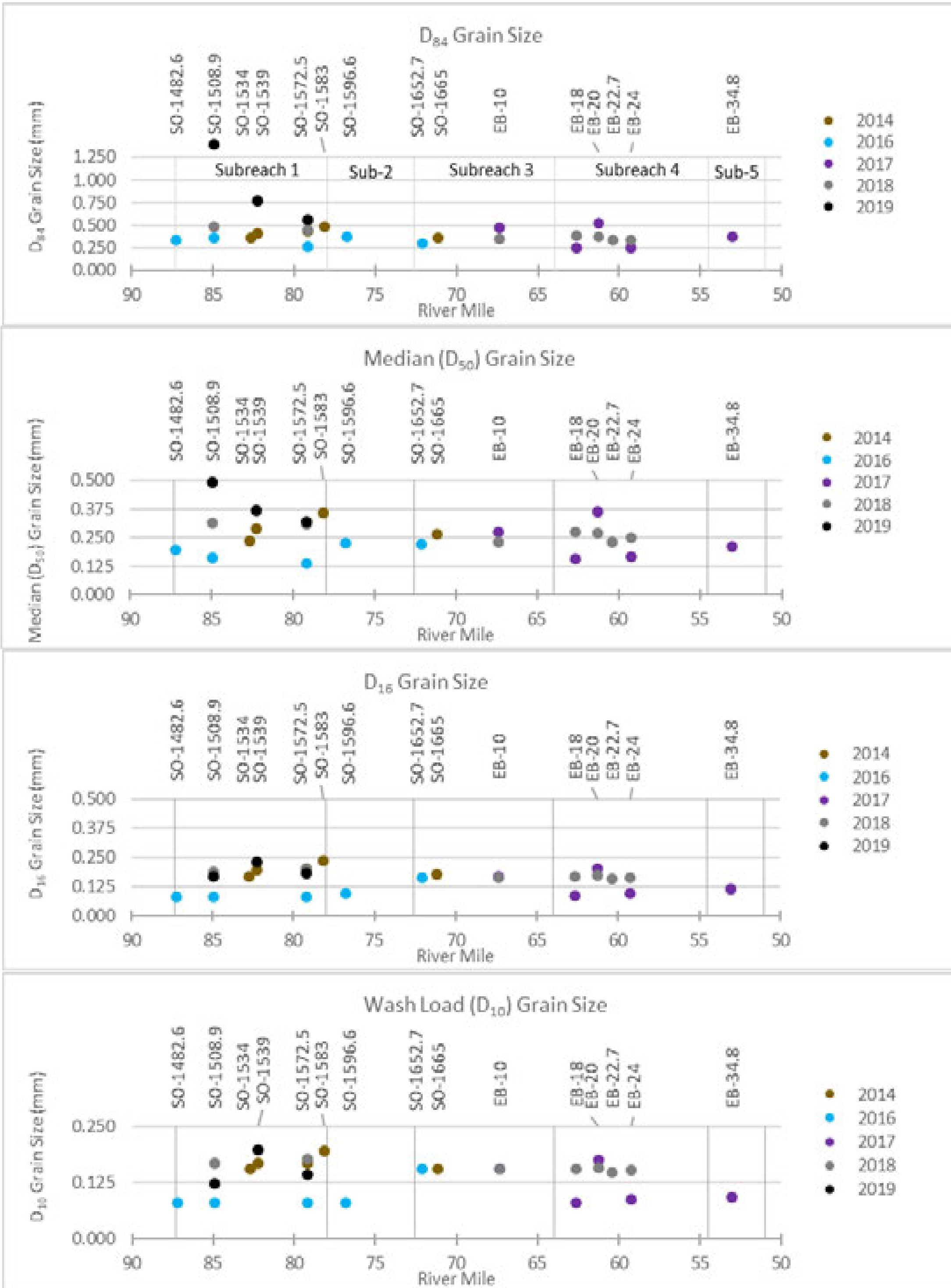

Figure 64: Bed material grain sizes from bed samples taken in 2014, 2016, 2017, 2018, and 2019 by river mile.

Vegetation Analysis

Vegetation polygon shapefiles generated by Reclamation were used to determine the amount of area covered by woody vegetation, wet and dry meadows, and open area in the analysis reach. Vegetation shapefiles using the Hink and Ohmart (H&O) classification system (Hink and Ohmart, 1984) were available for 2012 and 2016 and were used for this analysis (USBR Technical Service Center, 2012; 2016). The 2012 and 2016 H&O polygons were created from summer field surveys and aerial imagery by Reclamation staff from the Technical Service Center in Denver, Colorado. These shapefiles were clipped to cover approximately the same extent and do not include the Elephant Butte Reservoir Pool area. The area of each polygon was calculated using ESRI ArcMap v10.6.1. Areas of vegetation by general type (woody vegetation, herbaceous vegetation, and burned vegetation) for 2018 were generated using the 2018 aerial imagery which covers the area of the study reach south of River Mile 75.5 (SO-1615.1), including the burn area of the 2017 Tiffany Fire (BDA South Boundary to the Power Lines). The 2018 imagery was taken on May 27, 2018. The 2018 vegetation polygons were digitized in ESRI ArcMap at a scale of 1:5,000 (or 1 inch=0.08 miles) using a much simpler method than was used to create the H&O Polygons.

2012 and 2019 H&O Polygons

Based on the H&O polygon shapefiles, areas of woody vegetation in the study area decreased between 2012 and 2016 while open areas, grass meadows, and wet meadows increased (Table 33). Areas of woody vegetation decreased by 152 acres, and areas of total herbaceous vegetation (including wet and grass meadows) increased from 955 to 1152 acres. Open area (including roads, railroad lines, and areas with less than 25% cover) increased by 181 acres. Differences in the total areas of each H&O polygon set (63 acres) are accounted for by slight differences in the boundaries of the delineated vegetated areas and a larger area of open water where the channel meets the Elephant Butte pool in 2016 compared to 2012.

Table 33: Estimated areas of vegetation classification types from 2012 and 2016 Hink and Ohmart (H&O) classifications for the study area from Highway 380 to Elephant Butte.

Vegetation	2012 Acreage	2016 Acreage
Woody	24,567	24,770
Herbaceous	955	285
Wet Meadow	-	851
Grass Meadow	-	16
Open Area	4,501	4,682
Open Water	2,002	1,594

2018 Vegetation Polygon Delineation

For consistency in comparisons between the 2012, 2016, and 2018 years, the 2012 and 2016 H&O polygon shapefiles were clipped to cover the same area as the available imagery from 2018. Estimated areas of vegetation for the section of the study reach south of River Mile 75.5 are shown in Table 34 below. Vegetation polygons generated from the 2018 imagery carry some bias since they were created using a much simpler method than the H&O classification system, which were developed from both field data and aerial imagery. The time of year the data for the vegetation polygons were collected may also have influenced the delineated areas of each vegetation type. The 2012 and 2016 H&O surveys were conducted in May – September of 2012 and June – August of 2016 while the 2018 aerial imagery was collected on May 27, 2018. Differences in the total areas of each vegetation polygon set are accounted for by slight differences in the boundaries of the delineated vegetated areas as well as slight overlaps and gaps created from digitizing at the 1:5,000 scale. Vegetation polygons were taken from Braz, 2018 for the Tiffany Fire area and expanded to cover the available imagery extent.

The most noticeable change in vegetation between 2016 and 2018 was in the area of the Tiffany Levee, where the Tiffany Fire burned approximately 9,100 acres of Bureau of Reclamation and New Mexico State Forestry lands in 2017. Most of the burned area was woody, with a large burned area that was predominantly herbaceous brush and sparse woody vegetation. Open water replaced some areas that were classified as wet and dry meadows in the 2016 H&O polygons. The increased estimates of total woody and herbaceous areas in 2018 were likely influenced by differences in perception of open areas, areas of sparse woody vegetation, areas of herbaceous vegetation, and mixtures of these general types. Open areas with less than 25% cover decreased significantly in 2018, a result which is likely influenced by the different methods used to generate the vegetation polygons. Overall the 2017 Tiffany Fire accounts for the decrease in observed woody vegetation and the increase in open water.

Table 34: Estimated areas of general vegetation types from 2012 and 2016 H&O classification system and from 2018 aerial imagery for the study area south of River Mile 75.5 (SO-1615.1)

Vegetation	2012 Acreage	2016 Acreage	2018 Acreage
Woody	19,989	20,471	14,079
Burned Woody	-	-	6,658
Herbaceous	941	1,060	1,650
Burned Herbaceous	-	-	2,435
Open Area	5,405	5,402	1,559
Open Water	1,549	1,148	1,451

Hydraulic Analysis

For the hydraulic analysis of the study reach, outputs from 1-D HEC-RAS models developed for each year between 2012 and 2019 were compared at the 50% and 25% exceedance flow rates of 500 cfs and 2,300 cfs respectively. Additionally, the flow rate at which the computed water surface elevation overtopped the main channel river banks at a majority of the cross sections in the study reach as well as by subreach was determined and output variables were compared at this bankfull flow rate. For this analysis, existing levee capacity models for the reach from Highway 380 Bridge to River Mile 59.5 (EB-24.6) for the years 2012 – 2016 were used and expanded to cover the area from the Highway 380 Bridge (RM 87, SO-1475.9) to the Elephant Butte Narrows (RM 45, EB-50). Models for the 2017 – 2019 years extended from the Highway 380 Bridge to the Elephant Butte Narrows. Cross section geometries were checked against the original cross section survey data to ensure the most recent survey data for each year was used and cross sections that were not surveyed in a given year were carried forward from the previous year. See Appendix I for a complete list of cross section survey data used in the hydraulic models.

For all models, Manning's roughness values were set at 0.021 for the main channel and 0.077 for the floodplain for the channel along the levee system based on previous calibration studies (Holste, 2013). Normal depth was set as the downstream boundary condition with a slope determined from the average thalweg slope of the farthest downstream 15 cross sections in the study reach. Blocked obstructions were set at the top of the spoil levees when necessary to represent high points of the levee system. Internal HEC-RAS levee points were set at the top of banks to account for channel perching and riverside berms. Since one objective of the hydraulic analysis was to determine the reach-average channel flow capacity, channel banks were set to capture the main channel area outside of which flows would not be considered part of the main conveyance. In the HEC-RAS models bank points were selected at points outside of which the topography lowered or flattened. This was done to remove the effects of sand bars and terraces developing in the channel that were recorded as banks in the Reclamation cross section surveys as described in the "Channel and Floodway Topography" section. For cross sections below the San Marcial Levee where spoil berms bound the river closely (RM 57 to 45.5), banks were set at the point outside of which the topography became flat if the spoil berm was separated from the main channel. At cross sections where the spoil berm essentially sloped into the main channel, bank points were set as the top of the spoil berm. Areas of ineffective flow were set at locations along the cross sections where overbanking would cause weir-like lateral flow to avoid including these 2-D flow areas in the main channel conveyance when possible.

25% and 50% Exceedance Flows

The distance-weighted average and maximum hydraulic variables resulting from the 25% and 50% exceedance flows of 500 cfs and 2,300 cfs are summarized graphically in Figure 65 through Figure 70 below.

Subreach 1: Highway 380 Bridge to RM 78 (RM 87.1 – 78)

Simulated water surface elevations in Subreach 1 increased as a result of the overall aggradation that took place between 2012 and 2019. Top widths at the 2,300 cfs flow rate also increased as the aggradation in this subreach caused overbanking and floodplain inundation at lower flows. The energy grade slope of Subreach 1 changed as aggradation above the 2019 sediment plug affected elevations along the subreach, increasing in 2019 with the degradation below the sediment plug.

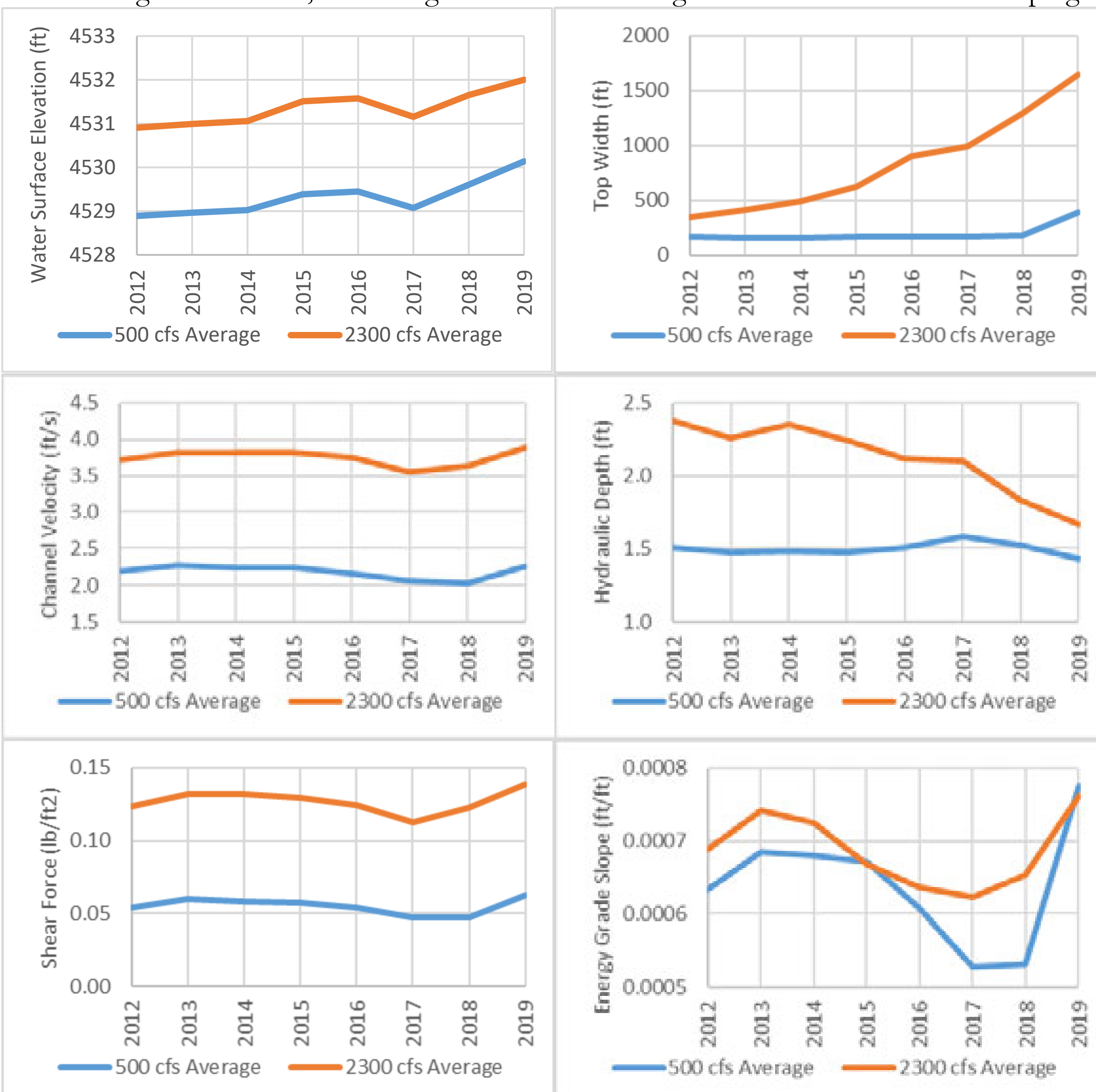

Figure 65: Subreach-average hydraulic parameters at the 500 cfs and 2300 cfs flow rates for Subreach 1.

Subreach 2: RM 78 to Tiffany Junction (RM 78 – 72.6)

Subreach 2 underwent overall degradation between 2012 and 2019, resulting in decreasing water surface elevations and increased hydraulic depth. The greatest changes along Subreach 2 occurred between 2017 and 2019 when degradation was most prevalent.

Figure 66: Subreach-average hydraulic parameters at the 500 cfs and 2300 cfs flow rates for Subreach 2.

Subreach 3: Tiffany Junction to Fort Craig Bend (RM 72.6 – RM 64)

Subreach 3 underwent overall degradation between 2012 and 2019, with most of the degradation occurring after 2015. Hydraulic depth at the 500 cfs flow rate depth increased similarly to Subreach 2, however hydraulic depth at the 2300 cfs flow rate increased more rapidly in Subreach 2 compared to Subreach 3, which underwent less degradation. Top widths were similar between the 500 cfs and 2300 cfs flow rates along Subreach 3 since the relatively high conveyance capacity of Subreach 3 results in little overbanking at these flows.

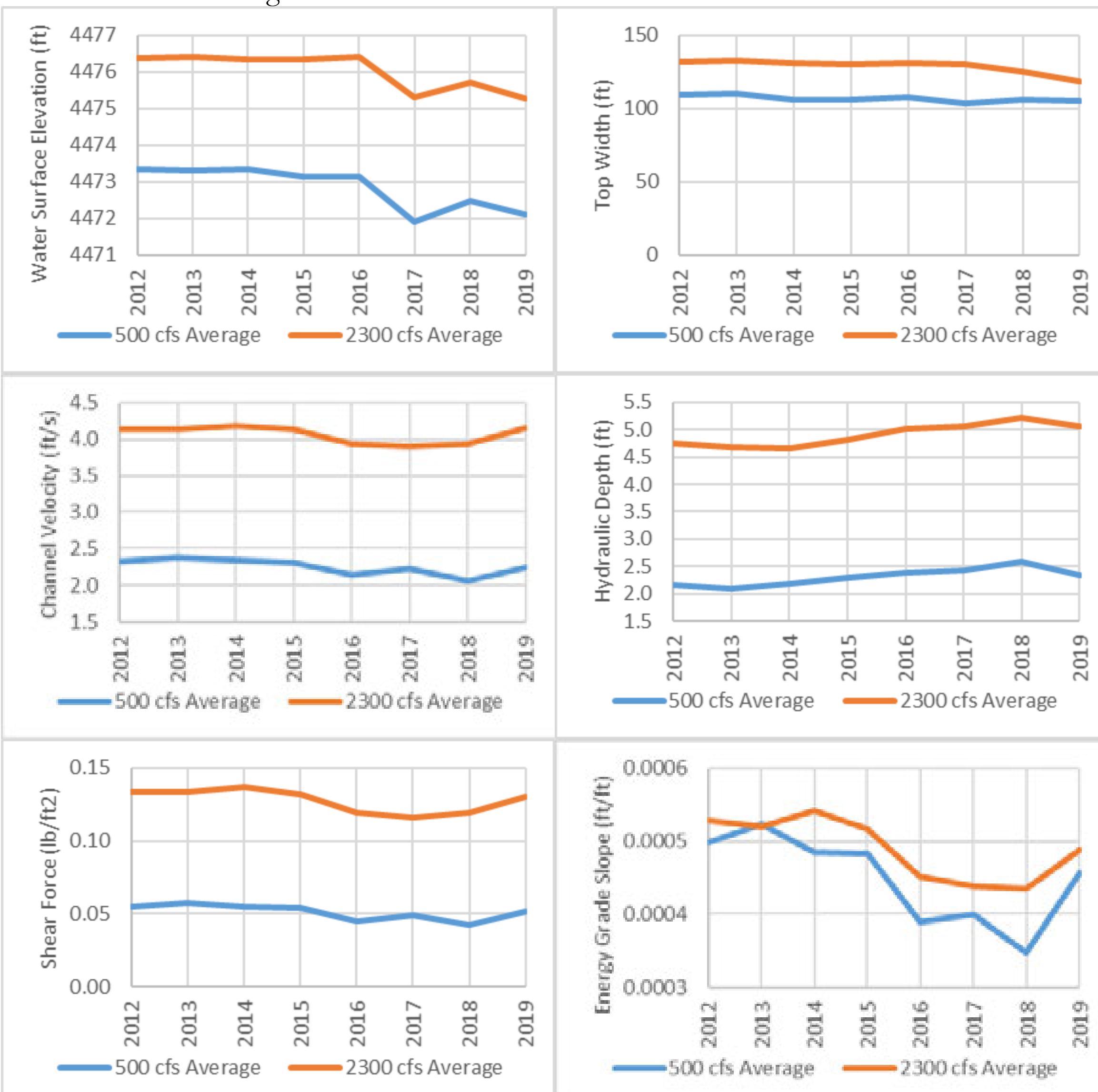

Figure 67: Subreach-average hydraulic parameters at the 500 cfs and 2300 cfs flow rates for Subreach 3.

Subreach 4: Fort Craig Bend to Silver Canyon (RM 64 – RM 54.5)

Similarly to Subreach 2 and 3, Subreach 4 underwent overall degradation between 2012 and 2019. This is reflected in the overall decreased water surface elevations at the 500 cfs and 2300 cfs flow rates. Other hydraulic parameters were relatively stable between 2012 and 2019, with channel velocity and energy grade slope increasing slightly.

Figure 68: Subreach-average hydraulic parameters at the 500 cfs and 2300 cfs flow rates for Subreach 4.

Subreach 5: Silver Canyon to RM 51 (RM 54.5 – RM 51)

Subreach 5 underwent overall aggradation between 2012 and 2019, with the greatest aggradation during the 2016 – 2017 year. The effects of this aggradation are reflected in the decreased energy grade slope and increased water surface elevations.

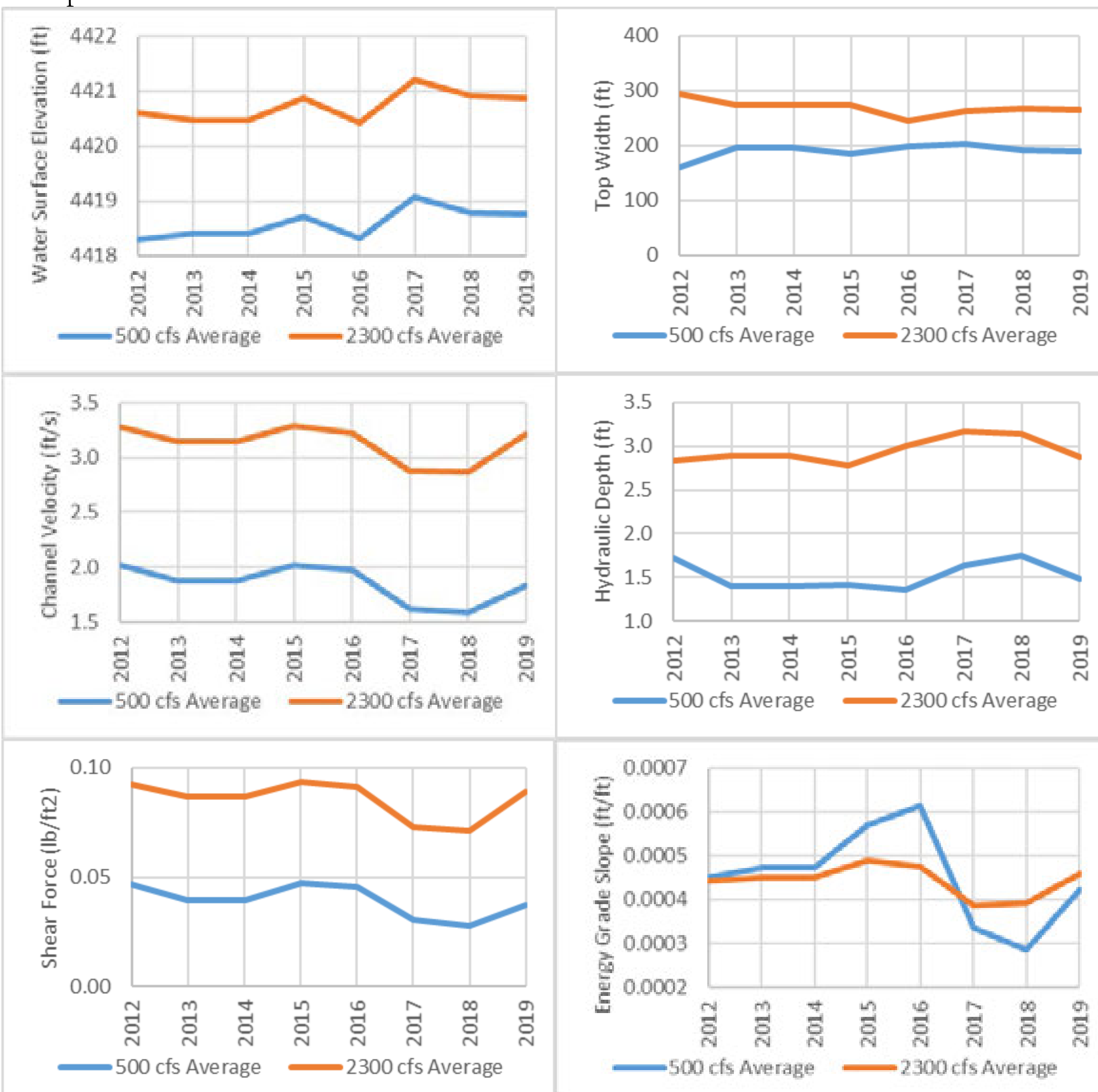

Figure 69: Subreach-average hydraulic parameters at the 500 cfs and 2300 cfs flow rates for Subreach 5.

Subreach 6: RM 51 to Elephant Butte Narrows (RM 51 – RM 45.3)

Subreach 6 underwent significant aggradation, much of which occurred between 2016 and 2017 as in Subreach 5, with similarly reduced energy grade slope and increased water surface elevations. A sediment plug formed along this subreach in 2019, leading to degradation below the plug and an increased energy grade slope in 2019.

Figure 70: Subreach-average hydraulic parameters at the 500 cfs and 2300 cfs flow rates for Subreach 6.

Main Channel Capacity

Channel capacity was estimated by varying the modelled flow in increments of 50 cfs until the water surface elevation overtopped at least one bank at a majority of the cross sections. Based on this analysis, the main channel capacity of the entire study reach decreased from 2012 – 2015 (overall aggradational period), followed by an increase from 2015 – 2018 (overall degradational period). Data from 2019 show that average channel capacity of the study reach based on this analysis method decreased back to nearly the 2015 level (Figure 71). For all models, Subreaches 1, 5, and 6 were predominantly where overbanking occurred first. Subreaches 3 and 4, which include the San Marcial Levee, had very little overbanking at the modelled capacity flows.

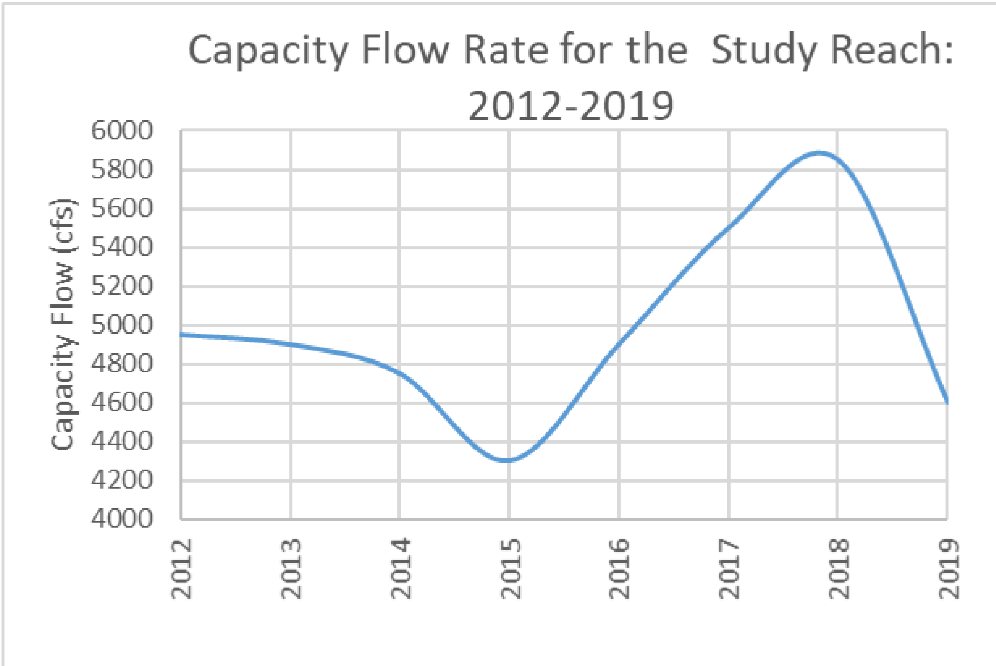

Figure 71: Main channel capacity for the entire study reach from 2012 to 2019. Channel capacity here is defined as the flow rate at which the water surface at a majority of the surveyed cross sections overtops the banks.

Table 35: Average hydraulic parameters from 1-D HEC-RAS models at the reach capacity flow rate for the entire study reach.

Average at Capacity	Water Surface Elevation (ft)	Flow Area (ft^2)	Top Width (ft)	Total Wetted Perimeter (ft)	Max. Channel Depth (ft)	Hydraulic Depth (ft)
2012	4474.16	1545.04	931.87	937.53	8.69	4.32
2013	4474.17	1578.45	921.48	927.12	8.52	4.34
2014	4473.99	1531.44	936.51	942.18	8.35	4.22
2015	4473.78	1479.36	945.94	951.19	8.18	4.19
2016	4474.15	1681.40	929.95	935.86	8.51	4.39
2017	4475.84	2120.84	1310.24	1315.65	9.15	4.08
2018	4474.65	2251.42	1243.13	1248.98	9.44	4.38
2019	4473.62	1585.07	905.38	911.12	8.90	4.62
Average at Capacity	**Hydraulic Radius (ft)**	**Energy Grade Slope (ft/ft)**	**Channel Velocity (ft/s)**	**Channel Froude #**	**Channel Shear Stress (lb./ft^2)**	**Capacity Flow Rate (cfs)**
2012	4.17	0.00053	4.98	0.37	0.182	4950
2013	4.19	0.00054	4.96	0.37	0.181	4900
2014	4.08	0.00056	4.99	0.37	0.184	4750
2015	4.04	0.00053	4.79	0.36	0.172	4300
2016	4.24	0.00055	5.00	0.37	0.186	4900
2017	3.94	0.00051	4.84	0.36	0.173	5500
2018	4.23	0.00051	5.02	0.36	0.184	5850
2019	4.43	0.00055	5.04	0.37	0.188	4600

Channel capacity flow rate was also calculated by subreach (Figure 72). Between 2012 and 2019, channel capacity decreased for Subreaches 1, 5, and 6, which are the subreaches that underwent overall aggradation between 2012 and 2019. Subreaches 2 and 4 gained capacity overall between 2012 and 2019, and Subreach 3 had little change in channel capacity. Subreach 1 had the lowest channel capacity in 2012 of 2850 cfs which decreased to 2200 cfs by 2018 and fell to 1750 cfs by 2019 as a result of the sediment plug in the BDA. Subreach 2, which underwent degradation overall as well as downstream effects from the 2019 BDA sediment plug, had increased flow capacity from 2016 to 2019. This is when most of the degradation along this subreach occurred. The channel capacity of Subreach 3 was relatively stable from 2012 to 2019, possibly due to the geologic control exerted by the Black Mesa keeping the channel from degrading as rapidly as Subreaches 2 and 4. Subreach 4, which includes the lower part of the San Marcial Levee and the current LFCC outfall, had the highest channel capacity for all years between 2012 and 2019. Subreach 4 also underwent overall degradation. Subreach 5 underwent some aggradation leading to decreased channel capacity. Subreach 6, where a sediment plug also formed in 2019, had aggradation and decreased channel capacity between 2018 and 2019.

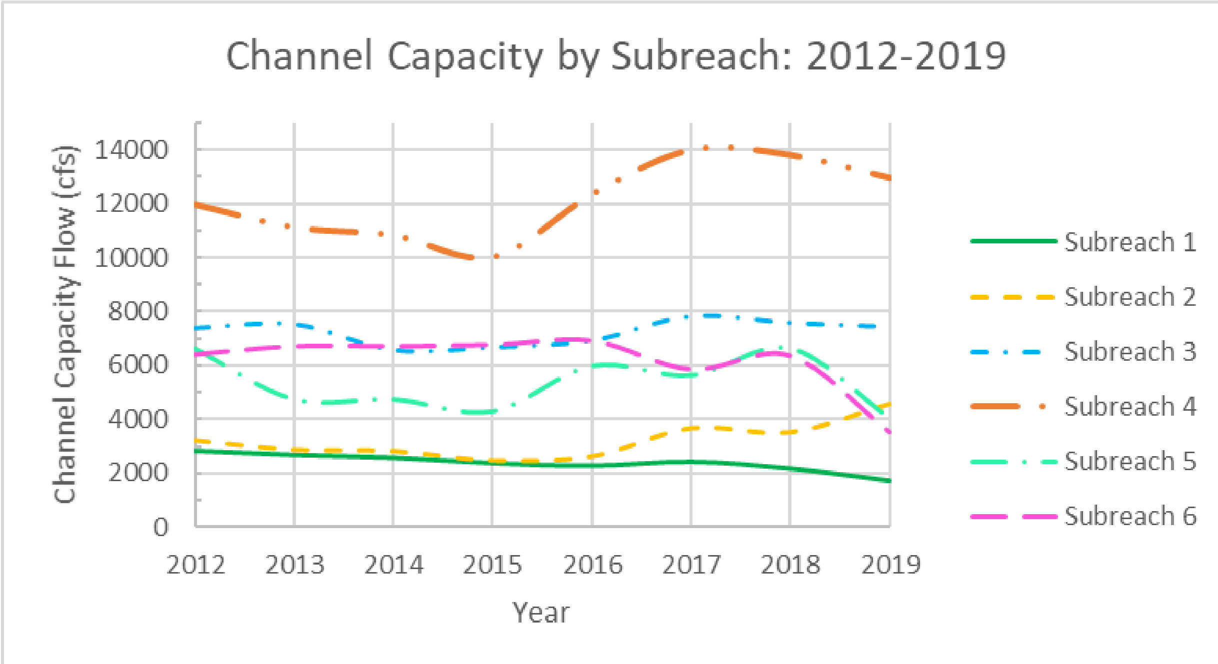

Figure 72: Main channel capacity by subreach from 2012 to 2019. Channel capacity here is defined as the flow rate at which the water surface at a majority of the surveyed cross sections in a subreach overtop the banks.

Table 36: Channel flow capacities by subreach from 2012 – 2019, with rows color coded by value. Channel capacity here is defined as the flow rate at which the water surface at a majority of the surveyed cross sections in a subreach overtop the banks.

Unit	2012	2013	2014	2015	2016	2017	2018	2019
Subreach 1 Channel Capacity (cfs)	2,850	2,700	2,600	2,400	2,300	2,450	2,200	1,750
Subreach 2 Channel Capacity (cfs)	3,200	2,850	2,800	2,450	2,600	3,650	3,500	4,550
Subreach 3 Channel Capacity (cfs)	7,400	7,550	6,600	6,700	6,950	7,850	7,600	7,450
Subreach 4 Channel Capacity (cfs)	11,950	11,100	10,800	10,000	12,350	14,000	13,800	12,950
Subreach 5 Channel Capacity (cfs)	6,650	4,750	4,750	4,300	6,000	5,650	6,650	4,050
Subreach 6 Channel Capacity (cfs)	6,400	6,700	6,700	6,750	6,900	5,850	6,350	3,550

Water Year Summary

To better understand how the hydrologic regime of each year affected the changes in the channel, daily mean flow data were gathered for the period from October 1, 2011 to September 30, 2019 for the USGS Gages at Highway 380 at San Antonio (Gage# 8355490, RM 87.7), at San Marcial (Gage#

8358400, RM 68.4), and at the Narrows (Gage# 8359500, RM 44.1). Flows for each water year were summarized using the mean daily flow, peak daily flow, total volume of water passing the gage, and the number of days above 500 cfs, 1000 cfs, and 2300 cfs in the water year. Data were gathered by water year here since the cross section surveys were conducted between October of the previous year and August of the same year, corresponding more closely to water years than calendar years. Provisional USGS data was used for April – September 2019 at the US Highway 380 Gage, February 2017 – September 2019 at the San Marcial Gage, and May – September 2019 at the Narrows Gage. No data were available at the Narrows Gage before May 2012 and at the San Marcial Gage from October 2016 – February 2017. All other data were approved by the USGS. For ease of interpretation, the daily flow data at the USGS Highway 380 Gage (most complete data set) were plotted along with the cross section survey dates and are shown below in Figure 73. The locations of the 3 USGS flow gages along the study reach are shown in Figure 74 below.

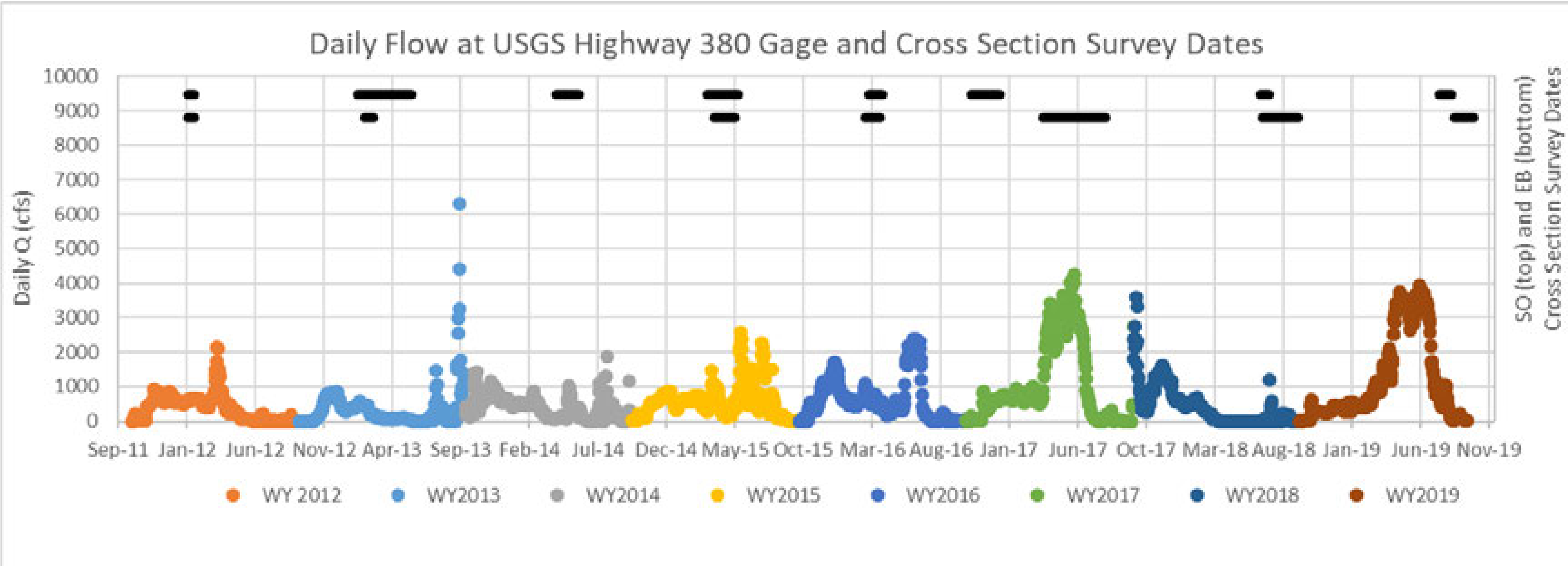

Figure 73: Hydrographs for the USGS Gage at Highway 380 plotted with cross section survey dates (black horizontal lines) for SO lines (top) and EB lines (bottom).

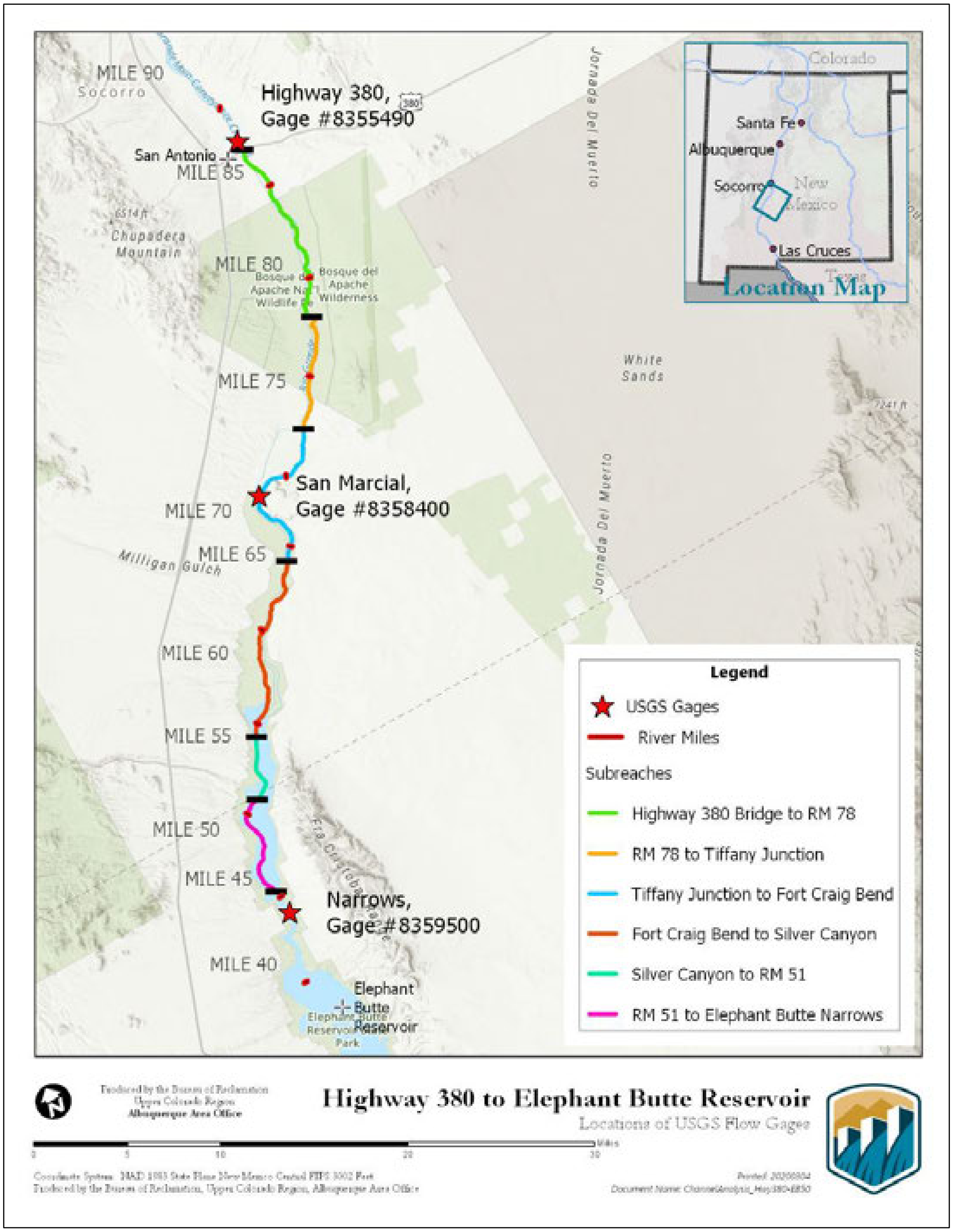

Figure 74: Locations of USGS Gages in the study reach.

The mean daily flow, peak daily flow, total volume of water passing the gage in the water year, and the number of days above flows of 500 cfs, 1000 cfs, and 2300 cfs are shown in Figure 75 below. Overall water volume and mean flow increased from 2012 – 2017, declined in 2018, and increased again in 2019. The plots of mean daily flow, total water volume, and number of days above 1000 cfs have similar shapes, with 2017 and 2019 standing out as the highest values. The number of days above 2300 cfs is also highest for the 2017 and 2019 water years.

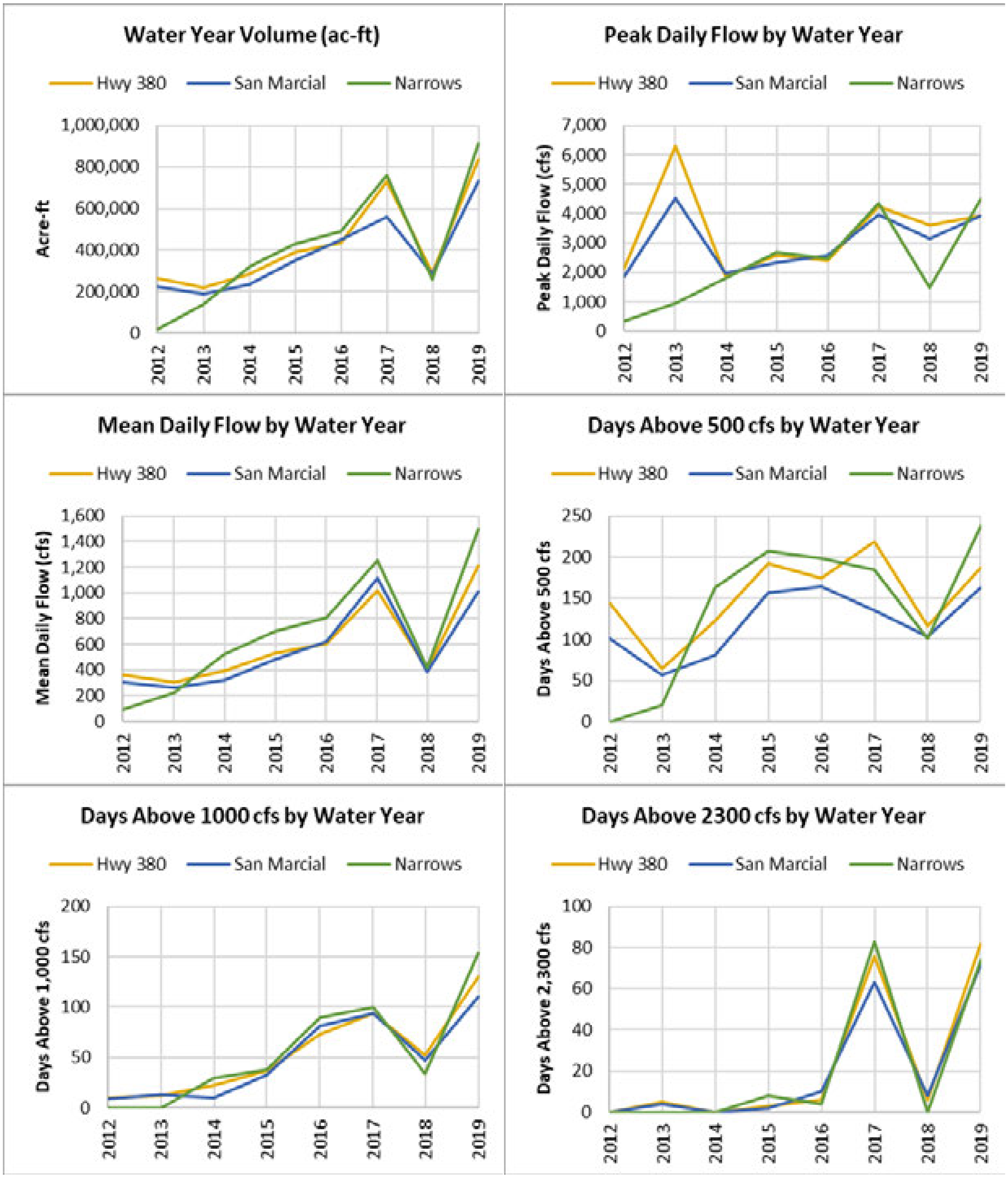

Figure 75: Daily flow data from USGS Gages at Highway 380 (8355490), San Marcial (8358400), and the Narrows (8359500) summarized by water year as volume passing the gage, annual mean of daily flows, peak daily flow, and number of days above 500 cfs, 1000 cfs, and 2300 cfs.

The overall greater flows from 2015 – 2019 correlate with the overall period of degradation in thalweg and mean bed elevations from 2015 – 2019. The years 2012 – 2014 had the lowest volumes of water, lowest mean daily flows, and lowest number of days above 1000 cfs. These low flow years correlate with the years in which the channel underwent overall aggradation (2012 – 2015).

The years in which bank elevations of the active channel increased (2013 – 2014, 2015 – 2016, and 2018 – 2019) can be expected to relate to years in which high flows caused overbanking and sediment deposition along the banks for the sections of the reach above and below the Tiffany and San Marcial Levees. The changes from 2013 – 2014 in the active channel may be related to the high peak flows passing the Highway 380 and San Marcial Gages in 2013. Other than an increased number of days above 500 cfs, the 2015 year did not seem to have drastically different flows from the 2014 and 2016 years that could account for the change in bank elevations that was observed from 2015 – 2016 but not in the 2014 – 2015 or 2016 – 2017 years. Based on the changes in the channel and floodplain topography, the 2015 – 2016 period was the only one in which active channel bank elevations, widths, and depths all increased. The increase in active channel bank elevations from 2018 to 2019 is very likely related to the unusually high flows conveyed through the reach in 2019. Notably, the relatively high flows in 2017 did not seem to result in increased bank elevations.

The increases in mean and total flow from 2016 – 2017 and 2018 – 2019 coincide with the aggradational zones in the BDA and Narrows areas. The 2016 – 2017 year is associated with a slight aggradation in the BDA area and aggradation above the Narrows. In 2017 – 2018 aggradation continued in the BDA area while overall degradation occurred in the same area above the Narrows that underwent aggradation from 2016 – 2017. Aggradation in the BDA area continued in the 2018 – 2019 year, with signs of aggradation again in the lower part of the reach. Sediment plugs developed in the BDA and Delta channel in response to the above average runoff flows exceeding 2300 cfs for an extended amount of time.

Conclusions

The overall conclusions of the study are described in the points below. Recommended management strategies from the 2012 Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide (USBR, 2012) are included for each subreach.

Study Reach: Highway 380 Bridge to Elephant Butte Narrows (RM 87.1 – RM 45.3)

- Non-vegetated channel widths decreased along the reach, with few cross sections increasing in width. Non-vegetated channel widths in the area above River Mile 75.6 (SO-1613) decreased by 61 feet on average between 2012 and 2016. Non-vegetated widths between River Miles 75.6 and 45 decreased by 32 feet on average between 2012 and 2018.
- Reach-average thalweg elevations decreased overall by 0.3 ft (3.6 in of degradation) throughout the study reach between 2012 and 2019. The years 2012 – 2013 and 2014 – 2015 underwent increases in the average thalweg elevation. Areas where thalweg elevation increased between 2012 and 2019 are in the upper BDA area and between Silver Canyon and the Narrows. These are the same areas where sediment plugs formed in 2019.
- Reach-average mean bed elevations at the 50% and 25% exceedance flow rates decreased by 0.6 ft (7.2 in of degradation) overall along the study reach from 2012 to 2019, with increases (aggradation) from 2012 – 2013 and 2014 – 2015. Average bed slopes at the 500 cfs and 2,300 cfs flow rates fluctuated around 0.00061 ft/ft between 2012 and 2019.

- Average bed elevation of surveyed cross sections decreased by 0.7 ft (8.4 in of degradation) from 2012 to 2019, with only the 2012 – 2013 period undergoing an overall increase (aggradation). Notable areas of deposition were the upper BDA area and between Silver Canyon and the Narrows.
- Reach-average bank elevations of the active channel decreased by 0.7 ft (8.4 in of degradation) overall from 2012 – 2019, with increases (aggradation) between the years 2013 – 2014, 2015 – 2016, and 2018 – 2019. Banks downstream of the AT&SF Railroad Bridge underwent the most change year-to-year as the active channel occupied varying portions of the main channel. Channel banks in the upper BDA area aggraded between 2018 and 2019.
- Bank-to-bank active channel widths decreased by 25 ft on average throughout the reach from 2012 to 2019. Only the year 2015 – 2016 saw an average increase in channel widths throughout the reach. Channel widths changed the most downstream of the AT&SF Railroad Bridge as the active channel occupied varying portions of the main channel.
- Reach-average active channel depths increased and decreased in different parts of the channel. Channel depths increased in the degradational areas between the BDA sediment plug and Silver Canyon. Overall channel depths decreased in the upper BDA area and between Silver Canyon and the Narrows.
- Bed material sample data show that the wash load (D_{10}) and D_{16} grain sizes fell in the very fine sand (0.0625 – 0.125 mm) to fine sand (0.125 – 0.25 mm) ranges. Median grain sizes (D_{50}) fell in the fine to medium sand (0.25 – 0.5 mm) range. The D_{84} grain size fell mostly in the fine to medium sand ranges, with samples taken in 2019 falling in the coarse (0.5 – 1 mm) to very coarse sand (1 – 2 mm) range.
- Woody vegetation decreased slightly in the study area from 2012 to 2016, followed by burning of ~6,700 acres of wooded area in the 2017 Tiffany Fire. Areas of herbaceous vegetation decreased slightly from 2012 to 2016, with ~2500 acres of herbaceous vegetation burned during the Tiffany Fire. Areas with less than 25% cover decreased between 2016 and 2018 while herbaceous areas increased. The 2018 vegetation areas were estimated from aerial imagery, while the 2016 and 2012 H&O polygons were created from field data and aerial imagery

Subreach 1: Highway 380 Bridge to RM 78 (RM 87.1 – 78)

- Thalweg and mean bed elevations at the 500cfs and 2300 cfs flow rates elevations increased overall (aggradation). This subreach includes the BDA and the sediment plug that formed in 2019. In 2019 degradation occurred below the sediment plug, leading to an increased subreach slope.
- Channel banks were fairly stable from 2012 – 2017, then aggraded from 2017 – 2019. This is likely related to the channel aggradation from 2012 – 2019 and 2019 plug formation decreasing the flow threshold at which overbanking flows deposit sediments on the banks.
- Average bank-to-bank width decreased by 44 ft from 2012 – 2019, and average non-vegetated channel widths decreased by 62 ft from 2012 – 2016. The 2019 BDA plug area was narrower than the immediately upstream section.
- Aggradation in the channel above and along the sediment plug led to decreased channel depths, with increased channel depths below the sediment plug caused by degradation.
- Conveyance capacity of this reach decreased from 2850 cfs to 1750 cfs as a result of the overall aggradation from 2012 to 2019 and the sediment plug formation in 2019. Conveyance capacity of this reach is likely to change significantly as the realignment of the channel around the BDA sediment plug continues to adjust as flows are passed through it.

- Due to the aggradation typical of this subreach and its low water conveyance capacity, management strategies recommended for this reach include Reconstruct and Maintain Channel Capacity, Increase Available Area to the River, and Manage Sediment. The 2019 channel realignment project in the BDA area may fall under the both strategies Increase Available Area to the River and Reconstruct and Maintain Channel Capacity since the channel was moved to a lower point in the valley using excavation and berm construction. The strategy Manage Sediment could be used to reduce the sediment load in this subreach through construction of sedimentation basins on the river or tributary arroyos.

Subreach 2: RM 78 to Tiffany Junction (RM 78 – 72.6)

- This subreach underwent aggradation from 2012 – 2015 then overall degradation from 2015 – 2019. Sediment was scoured from the bed from 2018 – 2019 as a result of the cutoff of upstream sediment supply by the 2019 BDA sediment plug. Thalweg elevations and mean bed elevations at the 500 cfs and 2300 cfs flow rates decreased in Subreach 2 the most out of all six subreaches.
- Bank elevations decreased overall, with bank elevations increasing from 2016 – 2017.
- Bank-to-bank channel width decreased by 18 ft overall from 2012 – 2019, and non-vegetated channel width decreased by 36 ft from 2012 – 2016.
- Channel depths increased the most along Subreach 2 out of all six subreaches. The 2019 sediment plug in Subreach 1 caused degradation and increased channel depth from 2018 – 2019.
- Conveyance capacity increased overall in this reach along with the increases in channel depth.
- Since Subreach 2 is downstream of an aggradational, plug-prone reach, the following effects can be expected based on observations in other reaches: incision or bed degradation, bank erosion, and coarsening of the bed material. Substantial degradation, channel narrowing, increase in depths, and increase in capacity have been already observed in this reach and may lead to bank erosion and lateral migration. Strategies to address these trends include Promote Elevation Stability to prevent further bed degradation leading to bank erosion and channel migration. The strategy Promote Alignment Stability could include bank stabilization to prevent channel migration which could affect the BDA Levee system. Rehabilitate Channel and Floodplain is a strategy that could be used to reduce sediment transport capacity to more closely match the sediment supply as well as promote RGSM and SWFL habitat.

Subreach 3: Tiffany Junction to Fort Craig Bend (RM 72.6 – RM 64)

- Subreach 3 underwent degradation from 2015 – 2019, with thalweg and mean bed elevations at the 500 cfs and 2300cfs flows decreasing by 1.1 – 1.4 ft (degradation).
- Bank elevations decreased overall along Subreach 3, with most of the changes downstream of the AT&SF Railroad Bridge.
- Bank-to-bank channel widths decreased by 6.6 ft overall from 2012 – 2019, and non-vegetated channel widths decreased by 25 ft from 2012 – 2018.
- Channel depth increased by 0.8 ft overall along Subreach 3 from 2012 – 2019.
- The conveyance capacity of Subreach 3 fluctuated between 6600 cfs and 7850 cfs from 2012 – 2019.
- Like Subreach 2, Subreach 3 was overall degradational throughout the study period. Channel narrowing, increase in depths, and increase in capacity have been observed in this reach. Strategies to address these trends include Promote Elevation Stability, Promote Alignment

Stability, and Rehabilitate Channel and Floodplain. Maintaining the river alignment around the AT&SF Railroad Bridge is particularly important in this subreach.

Subreach 4: Fort Craig Bend to Silver Canyon (RM 64 – RM 54.5)

- Thalweg and mean bed elevations at the 500 cfs and 2300 cfs flow rates decreased by 1.4 – 2 ft overall (degradation) from 2012 – 2019.
- Average bank elevations along Subreach 4 decreased overall by 1.5 ft from 2012 – 2019, with increases from 2015 – 2016 and 2018 – 2019.
- Bank-to-bank channel widths decreased by 20.7 ft overall from 2012 – 2019, and non-vegetated channel widths decreased by 35 ft overall from 2012 – 2018.
- Channel depth increased overall by 0.3 ft from 2012 – 2019.
- Subreach 4 had the highest conveyance capacity of all six subreaches with a flow capacity between 10,000 cfs and 14,000 cfs during the study period.
- Like Subreaches 2 and 3, Subreach 4 was overall degradational throughout the study period. Channel narrowing, increase in depths, and increase in capacity were observed. Strategies to address these trends include Promote Elevation Stability, Promote Alignment Stability, and Rehabilitate Channel and Floodplain.

Subreach 5: Silver Canyon to RM 51 (RM 54.5 – RM 51)

- Thalweg and mean bed elevations at the 500 cfs and 2300 cfs flow rates increased by 0.2 – 0.7 ft overall (aggradation) from 2012 – 2019, with the most aggradation occurring along this subreach from 2016 – 2017.
- Channel banks degraded by 0.7 ft overall, aggradation occurring only from 2012 – 2013 and 2015 – 2016.
- Bank-to-bank channel width decreased by 27.3 ft, and non-vegetated channel width decreased by 43 ft.
- Channel depths decreased by 0.9 ft overall.
- The conveyance capacity of Subreach 5 decreased overall from 6,650 to 4,050 cfs from 2012 – 2019.
- Subreach 5 underwent both aggradation and degradation during the study period, with decreased transport capacity following aggradation in 2019. Increase Available Area to the River may not be appropriate for this subreach since the channel is fairly wide and shallow in this subreach. The strategy Reconstruct and Maintain Channel Capacity may be appropriate to address the decreased conveyance capacity in this reach. Aggradation could be addressed using strategy Manage Sediment to reduce the sediment load in this subreach through construction of sedimentation basins on the upstream river channel or tributary arroyos.

Subreach 6: RM 51 to Elephant Butte Narrows (RM 51 – RM 45.3)

- Thalweg and mean bed elevations at the 500 cfs and 2300 cfs flow rates increased by 0.8 – 1.2 ft overall (aggradation) from 2012 – 2019, with the most aggradation occurring along this subreach from 2016 – 2017.
- Channel banks degraded by 1.6 ft overall, aggradation occurring only from 2012 – 3013 and 2015 – 2016.
- Bank-to-bank channel width decreased by 28.8 ft, and non-vegetated channel width decreased by 46 ft between 2012 and 2018.

- Channel depth decreased by 2.2 ft overall from 2012 – 2019.
- The conveyance capacity of Subreach 6 decreased from 6400 to 3550 as a result of aggradation.
- Subreach 6 underwent both aggradation and degradation during the study period, with decreased channel depth and transport capacity following aggradation and sediment plug formation in 2019. The strategy "Reconstruct and Maintain Channel Capacity" may be appropriate to address the decreased conveyance capacity in this reach. Aggradation could be addressed using the strategy "Manage Sediment" to reduce the sediment load in this subreach through construction of sedimentation basins on the river or tributary arroyos, depending on the source of sediments to this reach. Any of these management strategies will be subject to the effects of base level change of the Elephant Butte Arroyo, with an increase in water level likely to decrease the reach slope and lead to aggradation in the Highway 380 – Elephant Butte Reach. A decrease in water level is likely to increase the reach slope and lead to further degradation.

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Appendix I: Cross section survey dates

Table 37: Cross Section Survey Dates from 2012-2019 for cross sections between Highway 380 and the Elephant Butte Reservoir

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
SO-1475.9	X	X			X		X	X
SO-1477.9	X	X			X		X	X
SO-1479.6	X	X			X		X	X
SO-1481.4	X	X			X		X	X
SO-1482.6	X	X	X		X	X	X	
SO-1483.1	X	X			X		X	X
SO-1485.3	X	X			X		X	X
SO-1487.5	X	X					X	X
SO-1489.2	X	X					X	X
SO-1491	X	X		X	X	X	X	
SO-1491.4	X	X					X	X
SO-1493	X	X					X	X
SO-1494.9	X	X					X	X
SO-1496	X	X	X		X	X	X	
SO-1497.4	X	X					X	X
SO-1499	X	X		X	X	X	X	
SO-1499.1	X	X					X	X
SO-1500.7	X	X					X	X
SO-1502	X	X	X		X	X	X	X
SO-1503.9	X	X					X	X
SO-1505.6	X	X					X	X
SO-1507.5	X	X					X	X
SO-1508.9	X	X	X	X	X	X	X	X
SO-1510.1	X	X					X	X
SO-1511.6	X	X					X	X
SO-1513.5	X	X					X	X
SO-1515.2	X	X					X	X
SO-1517.2	X	X	X		X	X	X	X
SO-1518.9	X	X			X		X	X
SO-1520.8	X	X			X		X	X
SO-1522.9	X	X			X		X	X
SO-1524	X	X		X	X	X	X	X
SO-1525	X	X			X		X	X
SO-1527	X	X			X		X	X
SO-1529.4	X	X			X		X	X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
SO-1530.5	X	X			X		X	X
SO-1531	X	X	X		X	X	X	
SO-1532.9	X	X			X		X	X
SO-1534.7	X	X			X		X	X
SO-1536	X	X		X	X			
SO-1536.4	X	X					X	X
SO-1538.5	X	X			X		X	X
SO-1539	X	X	X		X	X	X	X
SO-1540.6	X	X			X		X	X
SO-1542.4	X	X			X		X	X
SO-1544	X	X			X		X	X
SO-1546.3	X	X			X		X	X
SO-1548	X	X			X		X	X
SO-1550	X	X		X	X	X	X	X
SO-1551.9	X	X			X		X	X
SO-1554	X	X	X		X	X	X	X
SO-1555.1	X	X			X		X	X
SO-1557	X	X		X	X	X	X	X
SO-1559.1	X	X			X		X	X
SO-1560.5	X	X	X		X	X	X	
SO-1561	X	X			X		X	X
SO-1562.9	X	X			X		X	X
SO-1564.4	X	X			X		X	X
SO-1566	X	X		X	X	X	X	X
SO-1568	X	X			X		X	X
SO-1570.3	X	X			X		X	X
SO-1572.5	X	X	X	X	X	X	X	
SO-1573.3	X	X			X		X	X
SO-1575	X	X			X		X	X
SO-1576	X	X	X		X	X	X	X
SO-1578	X	X			X		X	X
SO-1579.5	X	X			X		X	X
SO-1581	X	X		X	X	X	X	
SO-1581.4	X	X			X		X	X
SO-1582.4	X	X					X	X
SO-1583			X		X	X	X	
SO-1583.2	X	X			X		X	X
SO-1585	X	X	X		X	X	X	
SO-1585.1							X	X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
SO-1586.5	X	X			X		X	X
SO-1588	X	X		X	X	X	X	X
SO-1590	X	X			X		X	X
SO-1591		X	X		X	X	X	
SO-1593.3	X	X			X		X	X
SO-1594	X	X		X	X	X	X	
SO-1595.6	X	X			X		X	X
SO-1596.6		X	X		X	X	X	
SO-1597.6	X	X			X		X	X
SO-1600	X	X		X	X	X	X	X
SO-1601.8	X	X			X		X	X
SO-1603.7	X	X	X		X	X	X	X
SO-1605	X	X			X		X	X
SO-1607.5	X	X			X		X	X
SO-1610.6	X	X			X		X	X
SO-1613	X	X	X	X	X	X	X	X
SO-1615.1	X	X			X		X	X
SO-1617	X	X			X		X	X
SO-1619	X	X			X		X	X
SO-1621.8	X	X			X		X	X
SO-1623.9	X	X			X		X	X
SO-1626	X	X	X		X	X	X	X
SO-1627.9	X	X			X		X	X
SO-1630.5	X	X			X		X	X
SO-1632.6	X	X			X		X	X
SO-1634.7	X	X			X		X	X
SO-1636.5	X	X					X	X
SO-1638.8	X	X			X		X	X
SO-1641	X	X	X	X	X	X	X	X
SO-1643.1	X	X			X		X	X
SO-1644.8	X	X			X		X	X
SO-1645			X					
SO-1646.9		X			X		X	
SO-1649.1	X	X			X		X	X
SO-1650	X	X		X				
SO-1652.7	X	X	X		X	X	X	X
SO-1656.1	X	X			X		X	X
SO-1657.7	X	X			X		X	X
SO-1660	X	X		X	X	X	X	X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
SO-1662	X	X	X		X		X	X
SO-1663	X	X		X	X	X	X	X
SO-1664		X	X					
SO-1665	X	X		X	X	X	X	X
SO-1666		X	X					
SO-1667	X	X		X	X		X	X
SO-1668		X	X					
SO-1668.4	X	X			X		X	X
SO-1670	X	X		X	X	X	X	X
SO-1671.5	X	X			X		X	X
SO-1673	X	X	X	X	X	X	X	X
SO-1674.8		X			X		X	X
SO-1676.4	X	X			X		X	X
SO-1679.4	X	X			X		X	X
SO-1680.8	X	X			X		X	X
SO-1683	X	X	X		X	X	X	X
SO-1684.7	X	X			X		X	X
SO-1686.4	X	X			X		X	X
SO-1688.4	X	X			X		X	X
SO-1689.9	X	X			X		X	X
SO-1692	X	X	X	X	X	X	X	X
SO-1694.9	X				X		X	X
SO-1696.7	X				X		X	X
SO-1698.9	X				X		X	X
SO-1701.3	X		X	X	X	X	X	X
EB-9.4	X	X	X	X	X		X	X
EB-9.5	X	X	X	X	X		X	X
EB-10	X	X	X	X	X		X	X
EB-10.1	X	X	X	X	X		X	X
EB-10.2	X	X	X	X	X		X	X
EB-10.3	X	X	X	X	X		X	X
EB-10.45	X	X	X	X	X		X	X
EB-10.7	X	X	X	X	X		X	X
EB-10.9	X	X	X	X	X		X	X
EB-11.1	X	X	X	X	X		X	X
EB-11.5	X	X	X	X	X		X	X
EB-11.9	X	X	X	X	X		X	X
EB-12.4	X	X	X	X	X		X	X
EB-12.7	X	X	X	X	X		X	X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
EB-13	X	X	X	X	X		X	X
EB-13.9	X	X	X	X	X		X	X
EB-14.3	X	X	X	X	X		X	X
EB-14.5	X	X	X	X	X		X	X
EB-14.7	X	X	X	X	X		X	X
EB-15.1	X	X	X	X	X		X	X
EB-15.4	X	X	X	X	X		X	X
EB-15.7	X	X	X	X	X		X	X
EB-16	X	X	X	X	X		X	X
EB-16.5	X	X	X	X	X		X	X
EB-17	X	X	X	X	X		X	X
EB-17.35	X	X	X	X	X		X	X
EB-17.7	X	X	X	X	X		X	X
EB-17.8	X	X	X	X	X		X	X
EB-17.85	X	X	X	X	X		X	X
EB-17.9	X	X	X	X	X		X	X
EB-18	X	X	X	X	X		X	X
EB-18.5	X	X	X	X	X		X	X
EB-18.9	X	X	X	X	X		X	X
EB-19.1	X	X	X	X	X		X	X
EB-19.3	X	X	X	X	X		X	X
EB-19.5	X	X	X	X	X		X	X
EB-19.7	X	X	X	X	X		X	X
EB-19.8	X	X	X	X	X		X	X
EB-20	X	X	X	X	X		X	X
EB-20.3	X	X	X	X	X		X	X
EB-20.7	X	X	X	X	X		X	X
EB-21	X	X	X	X	X		X	X
EB-22.2	X	X	X	X	X		X	X
EB-22.6	X	X	X	X	X		X	X
EB-34		X					X	X
EB-34.5		X					X	X
EB-23.05	X	X	X	X	X		X	X
EB-23.2	X	X	X	X	X		X	X
EB-23.4	X	X	X	X	X		X	X
EB-23.6A		X			X		X	X
EB-23.8	X	X	X	X	X		X	X
EB-24A		X			X		X	X
EB-24.3	X	X	X	X	X		X	X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
EB-24.6	X	X	X	X	X		X	X
EB-24.9	X	X	X	X	X		X	X
EB-25	X	X	X	X	X		X	X
EB-25.3	X	X	X	X	X		X	X
EB-25.5	X	X	X	X	X		X	X
EB-26	X	X	X	X	X		X	X
EB-26.3	X	X	X	X	X		X	X
EB-26.8	X	X	X	X	X		X	X
EB-27	X	X	X	X	X		X	X
EB-27.3	X	X	X	X	X		X	X
EB-27.6	X	X	X	X	X		X	X
EB-28	X	X	X	X	X		X	X
EB-28.3	X	X	X	X	X		X	X
EB-28.5	X	X	X	X	X		X	X
EB-28.7	X	X	X	X	X		X	X
EB-29	X	X	X	X	X		X	X
EB-29.1	X	X	X	X	X		X	X
EB-29.3	X	X	X	X	X		X	X
EB-29.5	X	X	X	X	X		X	X
EB-29.7	X	X	X	X	X		X	X
EB-29.9	X	X	X	X	X		X	X
EB-30	X	X	X	X	X		X	X
EB-30.3	X	X	X	X	X		X	X
EB-30.6	X	X	X	X	X		X	X
EB-31.1	X	X	X	X	X		X	X
EB-32.1	X	X	X	X	X		X	X
EB-32.2	X	X	X	X	X		X	X
EB-32.3	X	X	X	X	X		X	X
EB-32.5	X	X	X	X	X		X	X
EB-32.65	X	X	X	X	X		X	X
EB-33	X	X	X	X	X		X	X
EB-33.2	X	X	X	X	X		X	X
EB-33.3	X	X	X	X	X		X	X
EB-33.55	X	X	X	X	X		X	X
EB-33.65	X	X	X	X	X		X	X
EB-34.8	X	X	X	X	X		X	X
EB-35	X	X	X	X	X		X	X
EB-35.2	X	X	X	X	X		X	X
EB-35.45	X	X	X	X	X			X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
EB-35.8	X	X	X	X	X		X	X
EB-36	X	X	X	X	X		X	X
EB-36.3	X	X	X	X	X		X	X
EB-36.6	X	X	X	X	X		X	X
EB-37	X	X	X	X	X		X	X
EB-37.5	X	X	X	X	X		X	X
EB-37.7	X	X	X	X	X		X	X
EB-38	X	X	X	X	X		X	X
EB-38.1	X	X	X	X	X		X	X
EB-38.2	X	X	X	X	X		X	X
EB-38.3	X	X	X	X	X		X	X
EB-38.6	X	X	X	X	X		X	X
EB-39.1	X	X	X	X	X		X	
EB-39.3	X	X	X	X	X		X	X
EB-39.6	X	X	X	X	X		X	X
EB-40	X	X	X	X	X		X	X
EB-40.2	X	X	X	X	X		X	X
EB-40.4	X	X	X	X	X		X	X
EB-40.5	X	X	X	X	X		X	X
EB-40.7	X	X	X	X	X		X	X
EB-40.9	X	X	X	X	X		X	X
EB-41	X	X	X	X	X		X	X
EB-41.4	X	X	X	X	X		X	X
EB-41.8	X	X	X	X	X		X	X
EB-42	X	X	X	X	X		X	X
EB-42.3	X	X	X	X	X		X	X
EB-42.5	X	X	X	X	X		X	X
EB-42.8	X	X	X	X	X		X	X
EB-43	X	X	X	X	X		X	X
EB-43.6	X	X	X	X	X		X	X
EB-44	X	X	X	X	X		X	X
EB-44.6	X	X	X	X	X		X	X
EB-45	X	X	X	X	X		X	X
EB-45.6	X	X	X	X	X		X	X
EB-46	X	X	X	X	X		X	X
EB-46.4	X	X	X	X	X		X	X
EB-47	X	X	X	X	X		X	X
EB-47.3	X	X	X	X	X		X	X
EB-47.7	X	X	X	X	X		X	X

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
EB-48	X	X	X	X	X		X	X
EB-48.3	X	X	X	X	X		X	X
EB-48.5	X	X	X	X	X		X	X
EB-48.7	X	X	X	X	X		X	X
EB-49	X	X	X	X	X		X	X
EB-49.5	X	X	X	X	X		X	X
EB-49.7	X	X	X	X	X		X	X
EB-50	X	X	X	X	X		X	X
EB-50+1090	X	X	X	X				
EB-50+2137	X	X	X	X				
EB-50+3000	X	X	X	X				
EB-50+3500	X	X	X	X				
EB-50+4500	X	X	X	X				
EB-50+5500	X	X	X	X				
EB-50+6500	X	X	X	X				
EB-50+7500	X	X	X	X				
EB-50+8500	X	X	X	X				
EB-50+9500	X	X	X	X				
EB-50+10500	X	X	X	X				
EB-50+11500	X	X	X	X				
EB-50+12500	X	X	X	X				
EB-50+13500	X	X	X	X				
EB-50+14500	X	X	X	X				
EB-50+15500	X	X	X	X				
EB-50+16500	X	X	X	X				
EB-50+17500	X	X	X	X				
EB-50+18500	X	X	X	X				
EB-50+19500	X	X	X	X				
EB-50+20500	X	X	X	X				
EB-50+21500	X	X	X	X				
EB-50+22500	X	X	X	X				
EB-50+23500	X	X	X	X				
EB-50+24500	X	X	X	X				
EB-50+25500	X	X	X	X				
EB-50+26500	X	X	X	X				
EB-50+27500	X	X	X	X				
EB-50+28500	X	X	X	X				
EB-50+29500	X	X	X	X				
EB-50+30500	X	X	X	X				

Rangeline	2019	2018	2017	2016	2015	2014	2013	2012
EB-50+31500	X	X	X	X				
EB-50+32500	X	X	X	X				
EB-50+33500	X	X	X	X				

Appendix II: Bed Material Samples

Grain Sizes by Sample

D_{84} Grain Size

Table 38: D84 Grain sizes (mm) by sediment sample for samples taken between 2012 and 2019 in the Rio Grande between Highway 380 and the Elephant Butte Reservoir.

Rangeline	2019	2018	2017	2016	2014
SO-1482.6				0.34	
(2019) SO-1508.9, Sta. 52+75-53+25	2.69				
(2019) SO-1508.9, Sta. 53+25-53+65	0.56				
(2019) SO-1508.9, Sta. 53+65-54+13	0.94				
SO-1508.9 Average	1.40	0.49		0.36	
SO-1534					0.36
(2014) SO-1539, 12+20					0.46
(2014) SO-1539, 12+00					0.49
(2014) SO-1539, 11+60					0.34
(2014) SO-1539, 10+60					0.39
(2019) SO-1539, Sta. 14+65 to STA 14+95	1.21				
(2019) SO-1539, STA 14+95 to STA 15+70	0.57				
(2019) SO-1539, STA 15+70 to STA 16+28	0.55				
SO-1539 Average	0.77				0.41
(2014) SO-1572.5, 2+30					0.40
(2014) SO-1572.5, 2+15					0.39
(2014) SO-1572.5, 1+80					0.46
(2014) SO-1572.5, 1+50					0.53
(2014) SO-1572.5, 1+25					0.41
(2019) SO-1572.5, STA 21+49 to STA 22+20	0.59				
(2019) SO-1572.5, STA 22+20 to STA 22+95	0.54				
SO-1572.5 Average	0.56	0.45		0.26	0.44

Rangeline	2019	2018	2017	2016	2014
(2014) SO-1583, 7+60					0.44
(2014) SO-1583, 7+40					0.52
(2014) SO-1583, 7+20					0.55
(2014) SO-1583, 7+00					0.48
(2014) SO-1583, 6+80					0.46
SO-1583 Average					0.49
SO-1596.6				0.37	
SO-1652.7				0.30	
(2014) SO-1665, 2+50					0.43
(2014) SO-1665, 2+10					0.42
(2014) SO-1665, #3					0.36
(2014) SO-1665, #4					0.36
(2014) SO-1665, #5					0.27
SO-1665 Average					0.37
EB-10		0.35	0.48		
EB-18		0.38	0.25		
EB-20		0.38	0.53		
EB-22.7		0.34			
EB-24			0.25		
EB-24A		0.34			
EB-34.8			0.38		

Median (D_{50}) Grain Size

Table 39: D50 Grain sizes (mm) by sediment sample for samples taken between 2012 and 2019 in the Rio Grande between Highway 380 and the Elephant Butte Reservoir.

Rangeline	2019	2018	2017	2016	2014
SO-1482.6				0.20	
(2019) SO-1508.9, Sta. 52+75-53+25	0.72				
(2019) SO-1508.9, Sta. 53+25-53+65	0.39				
(2019) SO-1508.9, Sta. 53+65-54+13	0.36				
SO-1508.9 Average	0.49	0.31		0.16	
SO-1534					0.24
(2014) SO-1539, 12+20					0.32
(2014) SO-1539, 12+00					0.37
(2014) SO-1539, 11+60					0.22
(2014) SO-1539, 10+60					0.31
(2019) SO-1539, Sta. 14+65 to STA 14+95	0.26				
(2019) SO-1539, STA 14+95 to STA 15+70	0.43				
(2019) SO-1539, STA 15+70 to STA 16+28	0.41				
SO-1539 Average	0.37				0.29
(2014) SO-1572.5, 2+30					0.30
(2014) SO-1572.5, 2+15					0.25
(2014) SO-1572.5, 1+80					0.34
(2014) SO-1572.5, 1+50					0.38
(2014) SO-1572.5, 1+25					0.31
(2019) SO-1572.5, STA 21+49 to STA 22+20	0.27				
(2019) SO-1572.5, STA 22+20 to STA 22+95	0.37				
SO-1572.5 Average	0.32	0.31		0.14	0.32
(2014) SO-1583, 7+60					0.33
(2014) SO-1583, 7+40					0.37
(2014) SO-1583, 7+20					0.39
(2014) SO-1583, 7+00					0.35
(2014) SO-1583, 6+80					0.35
SO-1583 Average					0.36
SO-1596.6				0.23	
SO-1652.7				0.22	
(2014) SO-1665, 2+50					0.33
(2014) SO-1665, 2+10					0.33
(2014) SO-1665, #3					0.24
(2014) SO-1665, #4					0.24
(2014) SO-1665, #5					0.20
SO-1665 Average					0.27

Rangeline	2019	2018	2017	2016	2014
EB-10		0.23	0.28		
EB-18		0.27	0.16		
EB-20		0.27	0.36		
EB-22.7		0.23			
EB-24			0.17		
EB-24A		0.25			
EB-34.8			0.21		

D_{16} Grain Size

Table 40: D16 Grain sizes (mm) by sediment sample for samples taken between 2012 and 2019 in the Rio Grande between Highway 380 and the Elephant Butte Reservoir.

Rangeline	2019	2018	2017	2016	2014
SO-1482.6				<0.08	
(2019) SO-1508.9, Sta. 52+75-53+25	0.12				
(2019) SO-1508.9, Sta. 53+25-53+65	0.21				
(2019) SO-1508.9, Sta. 53+65-54+13	0.17				
SO-1508.9 Average	0.17	0.19		<0.08	
SO-1534					0.17
(2014) SO-1539, 12+20					0.19
(2014) SO-1539, 12+00					0.29
(2014) SO-1539, 11+60					0.16
(2014) SO-1539, 10+60					0.19
(2019) SO-1539, Sta. 14+65 to STA 14+95	0.07				
(2019) SO-1539, STA 14+95 to STA 15+70	0.32				
(2019) SO-1539, STA 15+70 to STA 16+28	0.31				
SO-1539 Average	0.23				0.20
(2014) SO-1572.5, 2+30					0.19
(2014) SO-1572.5, 2+15					0.15
(2014) SO-1572.5, 1+80					0.21
(2014) SO-1572.5, 1+50					0.28
(2014) SO-1572.5, 1+25					0.19
(2019) SO-1572.5, STA 21+49 to STA 22+20	0.16				
(2019) SO-1572.5, STA 22+20 to STA 22+95	0.21				
SO-1572.5 Average	0.18	0.20		<0.08	0.20
(2014) SO-1583, 7+60					0.20
(2014) SO-1583, 7+40					0.26
(2014) SO-1583, 7+20					0.28
(2014) SO-1583, 7+00					0.21
(2014) SO-1583, 6+80					0.22
SO-1583 Average					0.24
SO-1596.6				0.09	
SO-1652.7				0.16	
(2014) SO-1665, 2+50					0.20
(2014) SO-1665, 2+10					0.20
(2014) SO-1665, #3					0.17
(2014) SO-1665, #4					0.17
(2014) SO-1665, #5					0.15
SO-1665 Average					0.18

Rangeline	2019	2018	2017	2016	2014
EB-10		0.16	0.17		
EB-18		0.17	0.09		
EB-20		0.17	0.20		
EB-22.7		0.16			
EB-24			0.10		
EB-24A		0.17			
EB-34.8			0.12		

Wash Load Grain Size (D_{10})

Table 41: D10 Grain sizes (mm) by sediment sample for samples taken between 2012 and 2019 in the Rio Grande between Highway 380 and the Elephant Butte Reservoir.

Rangeline	2019	2018	2017	2016	2014
SO-1482.6				<0.08	
(2019) SO-1508.9, Sta. 52+75-53+25	0.07				
(2019) SO-1508.9, Sta. 53+25-53+65	0.17				
(2019) SO-1508.9, Sta. 53+65-54+13	0.13				
SO-1508.9 Average	0.12	0.17		<0.08	
SO-1534					0.16
(2014) SO-1539, 12+20					0.17
(2014) SO-1539, 12+00					0.22
(2014) SO-1539, 11+60					0.12
(2014) SO-1539, 10+60					0.17
(2019) SO-1539, Sta. 14+65 to STA 14+95	0.04				
(2019) SO-1539, STA 14+95 to STA 15+70	0.31				
(2019) SO-1539, STA 15+70 to STA 16+28	0.25				
SO-1539 Average	0.20				0.17
(2014) SO-1572.5, 2+30					0.17
(2014) SO-1572.5, 2+15					0.10
(2014) SO-1572.5, 1+80					0.18
(2014) SO-1572.5, 1+50					0.22
(2014) SO-1572.5, 1+25					0.17
(2019) SO-1572.5, STA 21+49 to STA 22+20	0.10				
(2019) SO-1572.5, STA 22+20 to STA 22+95	0.18				
SO-1572.5 Average	0.14	0.18		<0.08	0.17
(2014) SO-1583, 7+60					0.18
(2014) SO-1583, 7+40					0.21
(2014) SO-1583, 7+20					0.22
(2014) SO-1583, 7+00					0.18
(2014) SO-1583, 6+80					0.19
SO-1583 Average					0.20
SO-1596.6				<0.08	
SO-1652.7				0.15	
(2014) SO-1665, 2+50					0.18
(2014) SO-1665, 2+10					0.18
(2014) SO-1665, #3					0.16
(2014) SO-1665, #4					0.16
(2014) SO-1665, #5					0.11
SO-1665 Average					0.16

Rangeline	2019	2018	2017	2016	2014
EB-10		0.15	0.15		
EB-18		0.16	0.08		
EB-20		0.16	0.17		
EB-22.7		0.15			
EB-24			0.09		
EB-24A		0.15			
EB-34.8			0.09		

Grain Size Distribution Plots

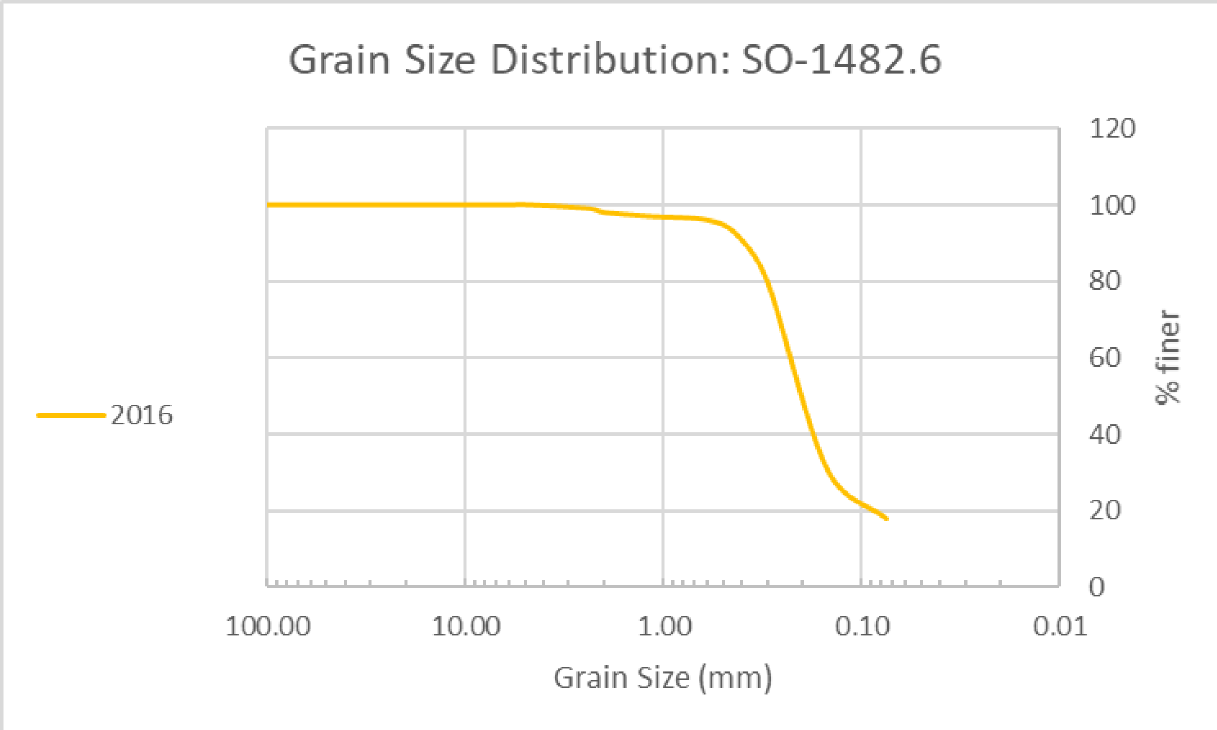

Figure 76: Grain size distribution plot for sediment samples taken at SO-1482.6 between 2012 and 2019.

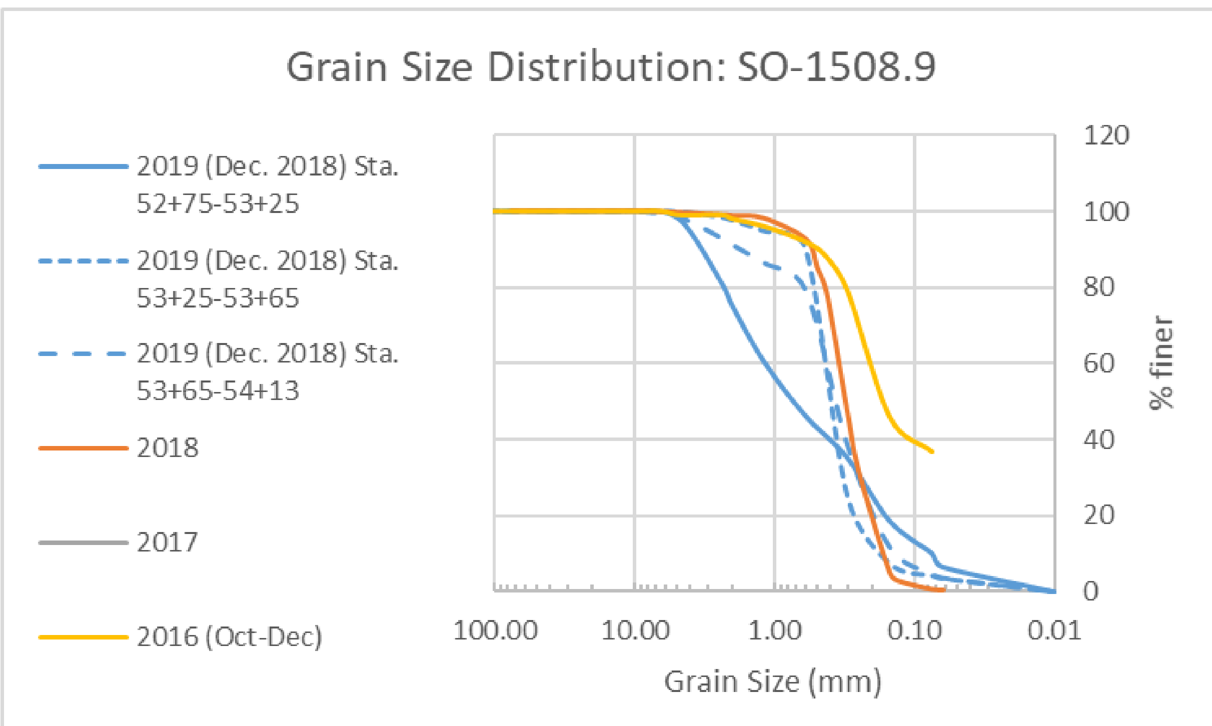

Figure 77: Grain size distribution plot for sediment samples taken at SO-1508.9 between 2012 and 2019.

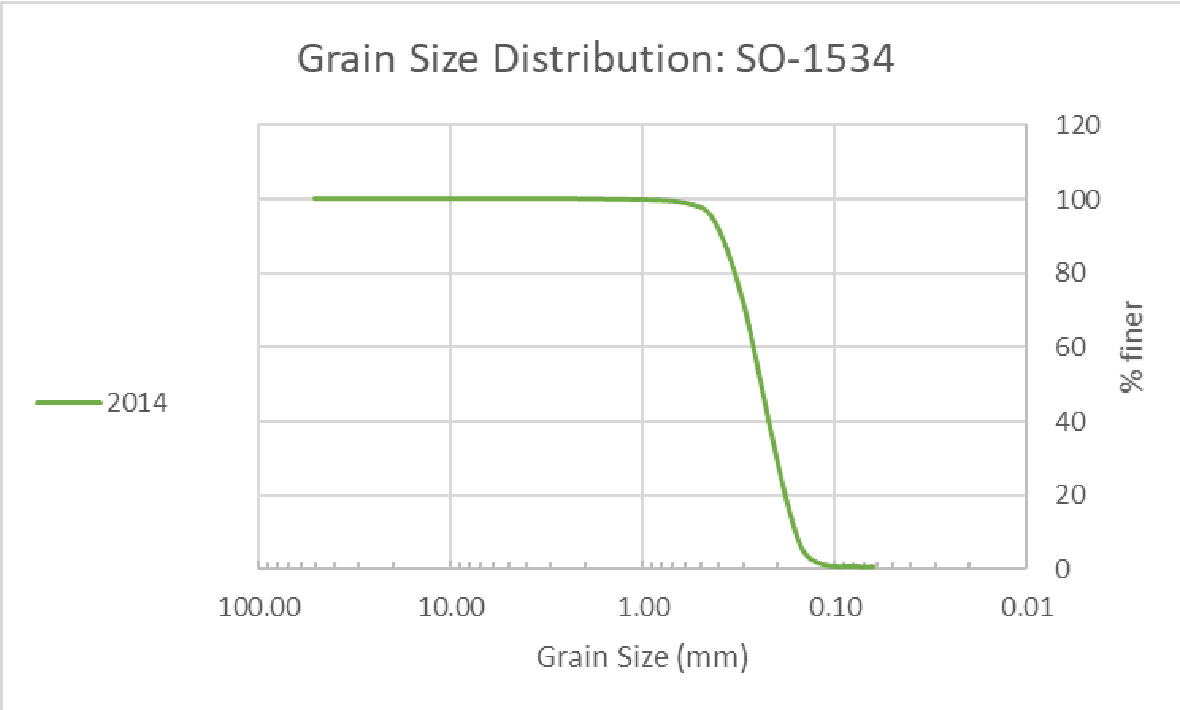

Figure 78: Grain size distribution plot for sediment samples taken at SO-1534 between 2012 and 2019.

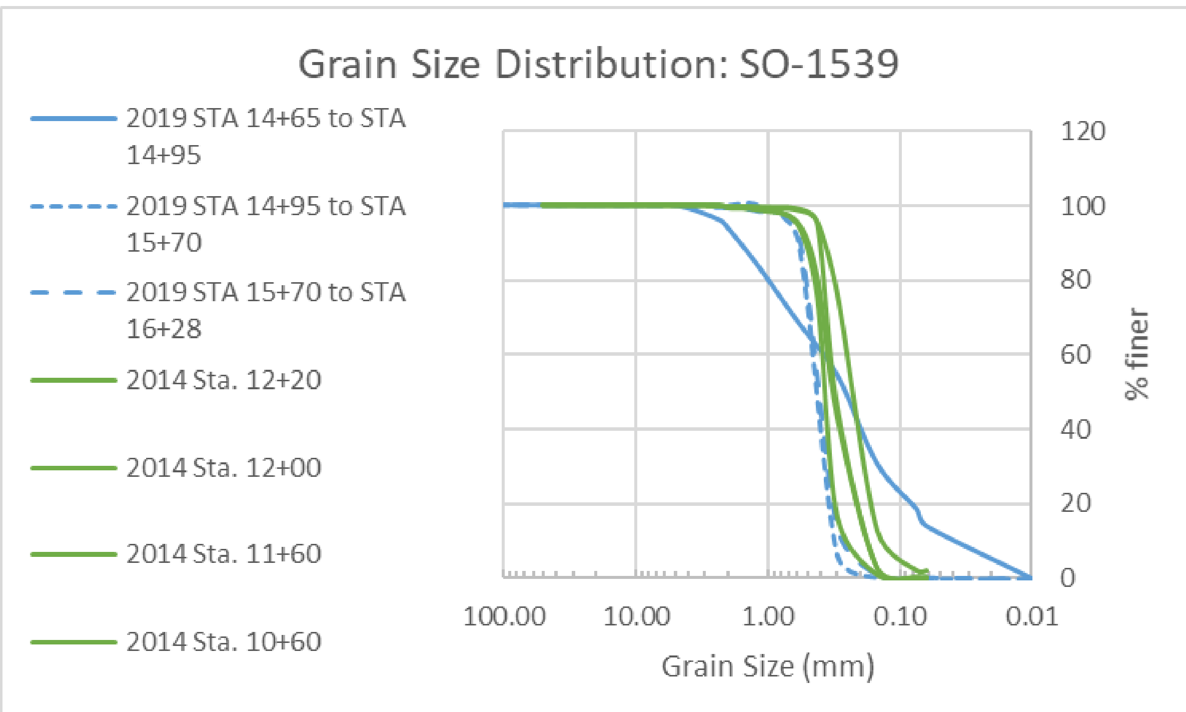

Figure 79: Grain size distribution plot for sediment samples taken at SO-1539 between 2012 and 2019.

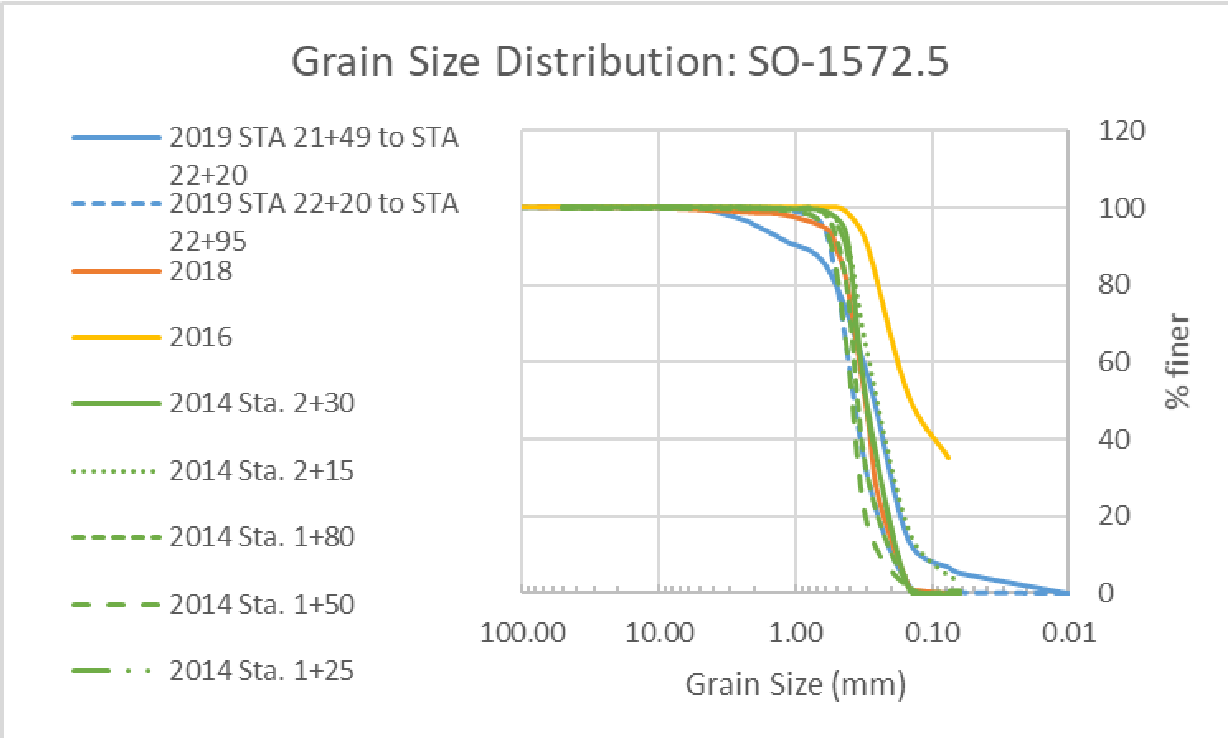

Figure 80: Grain size distribution plot for sediment samples taken at SO-1572.5 between 2012 and 2019.

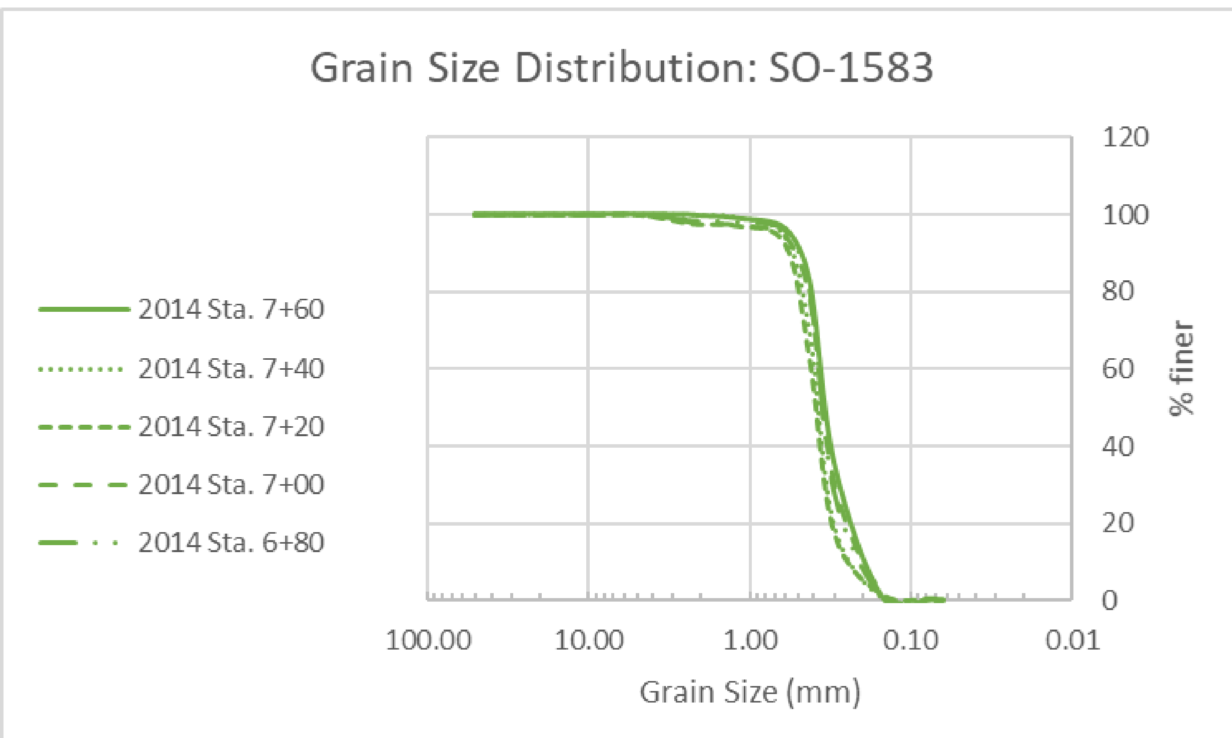

Figure 81: Grain size distribution plot for sediment samples taken at SO-1583 between 2012 and 2019.

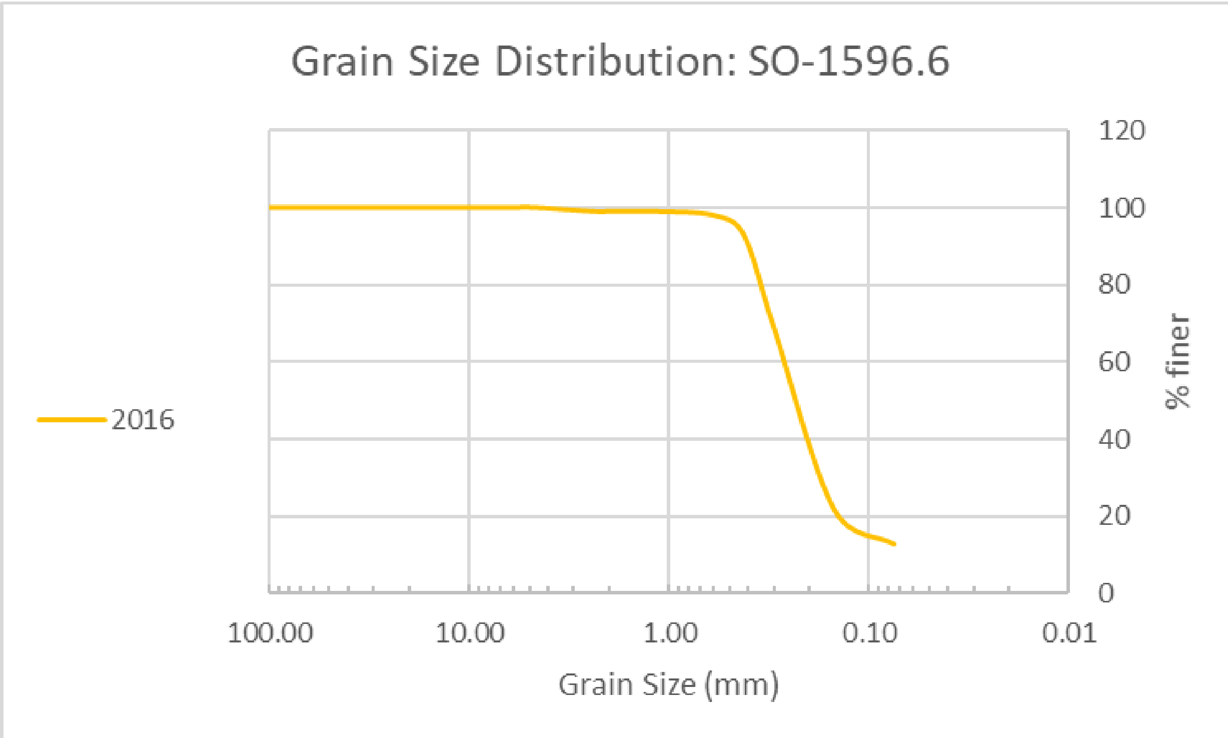

Figure 82: Grain size distribution plot for sediment samples taken at SO-1596.6 between 2012 and 2019.

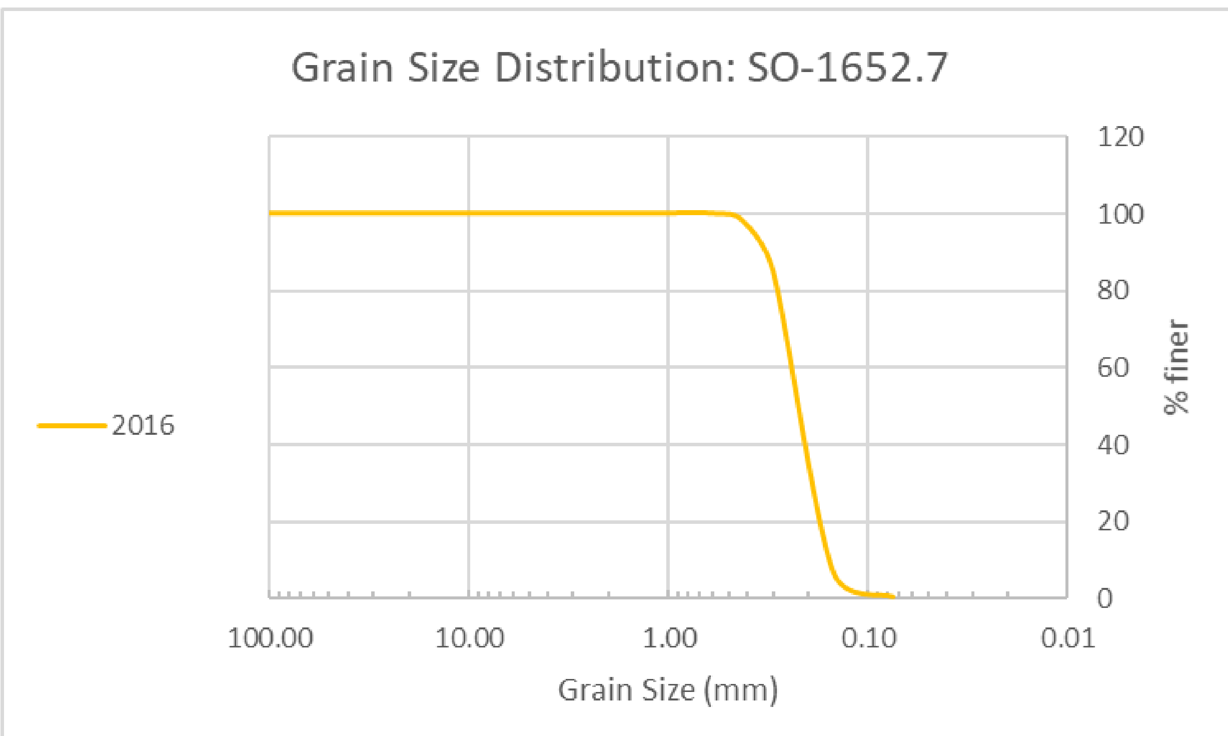

Figure 83: Grain size distribution plot for sediment samples taken at SO-1652.7 between 2012 and 2019.

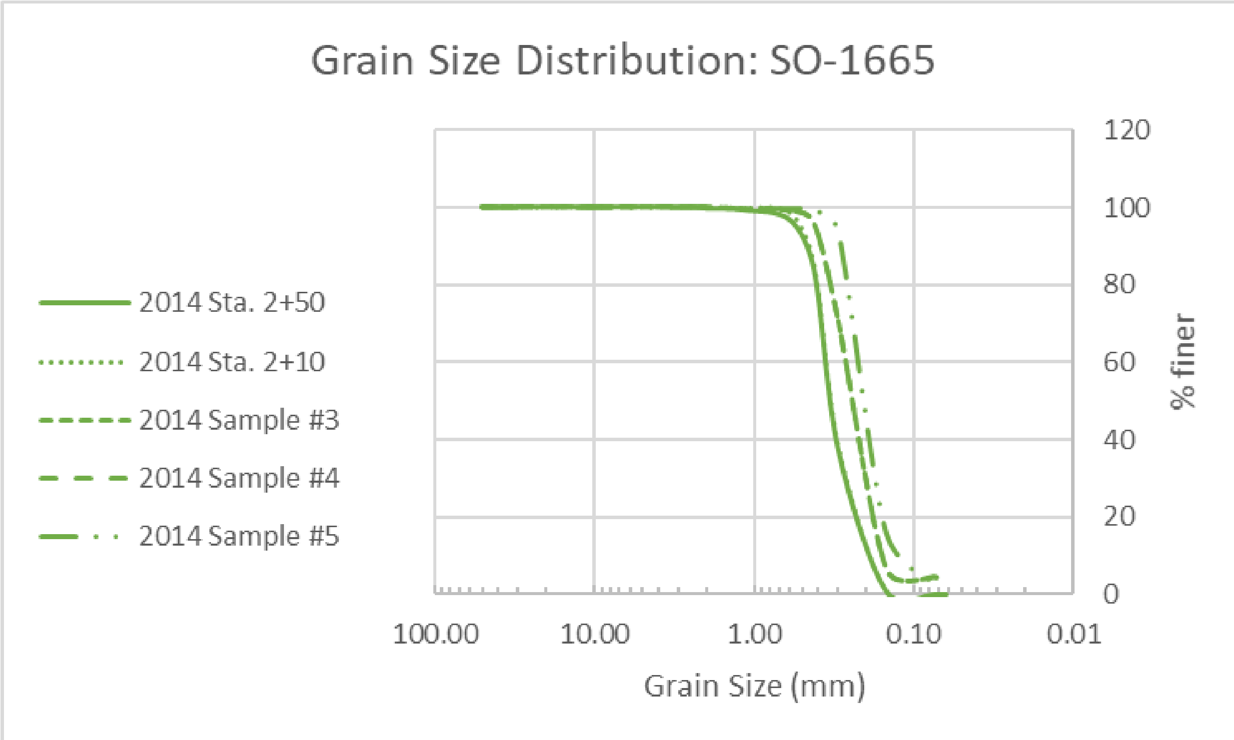

Figure 84: Grain size distribution plot for sediment samples taken at SO-1665 between 2012 and 2019.

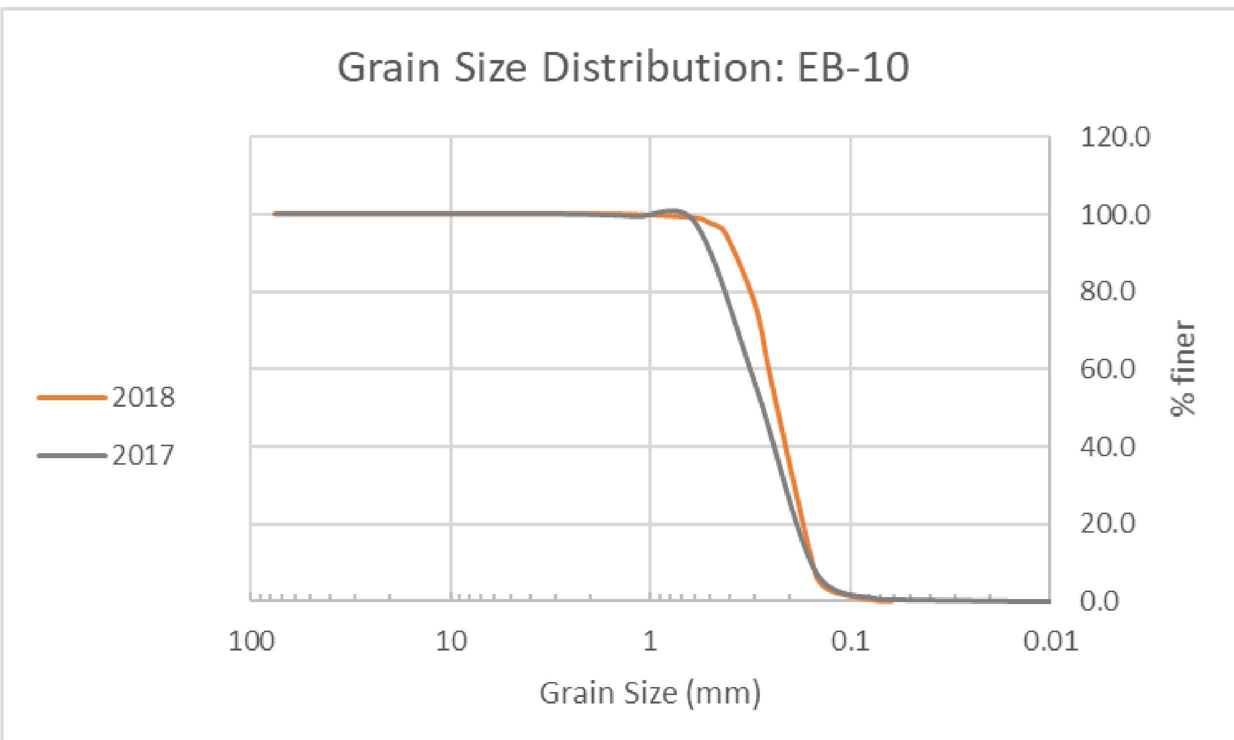

Figure 85: Grain size distribution plot for sediment samples taken at EB-10 between 2012 and 2019.

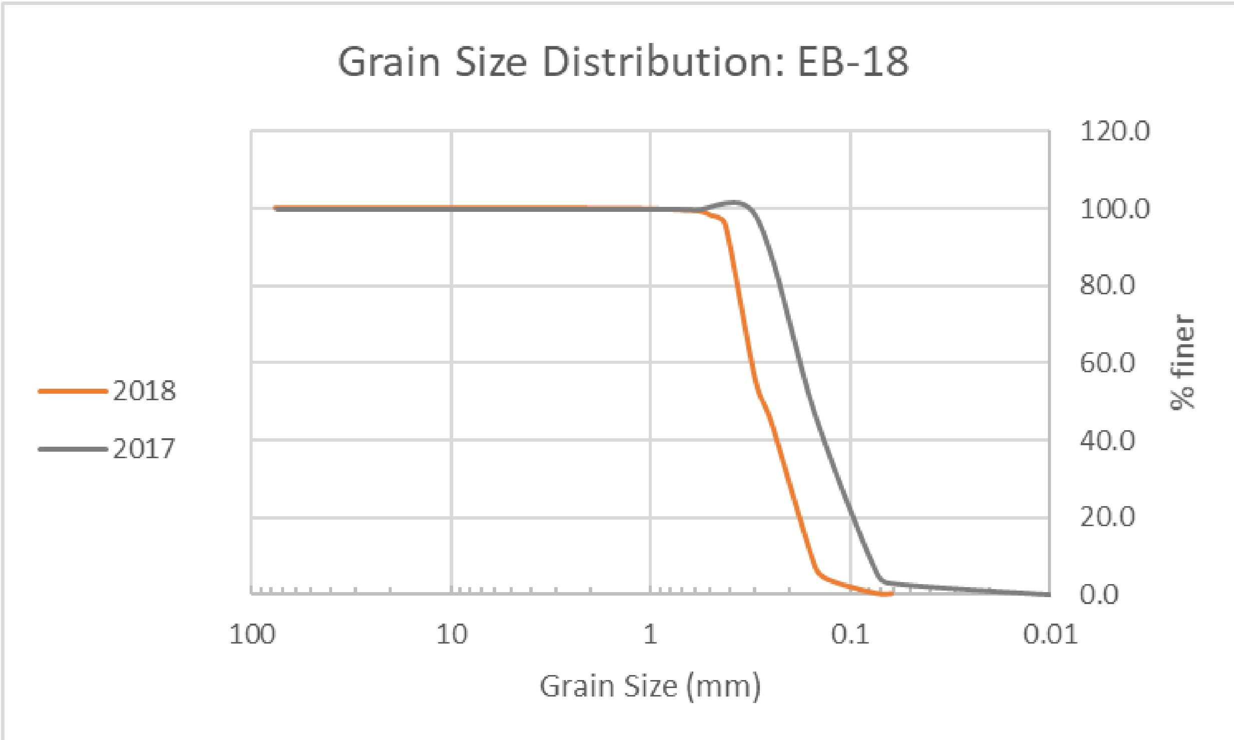

Figure 86: Grain size distribution plot for sediment samples taken at EB-18 between 2012 and 2019.

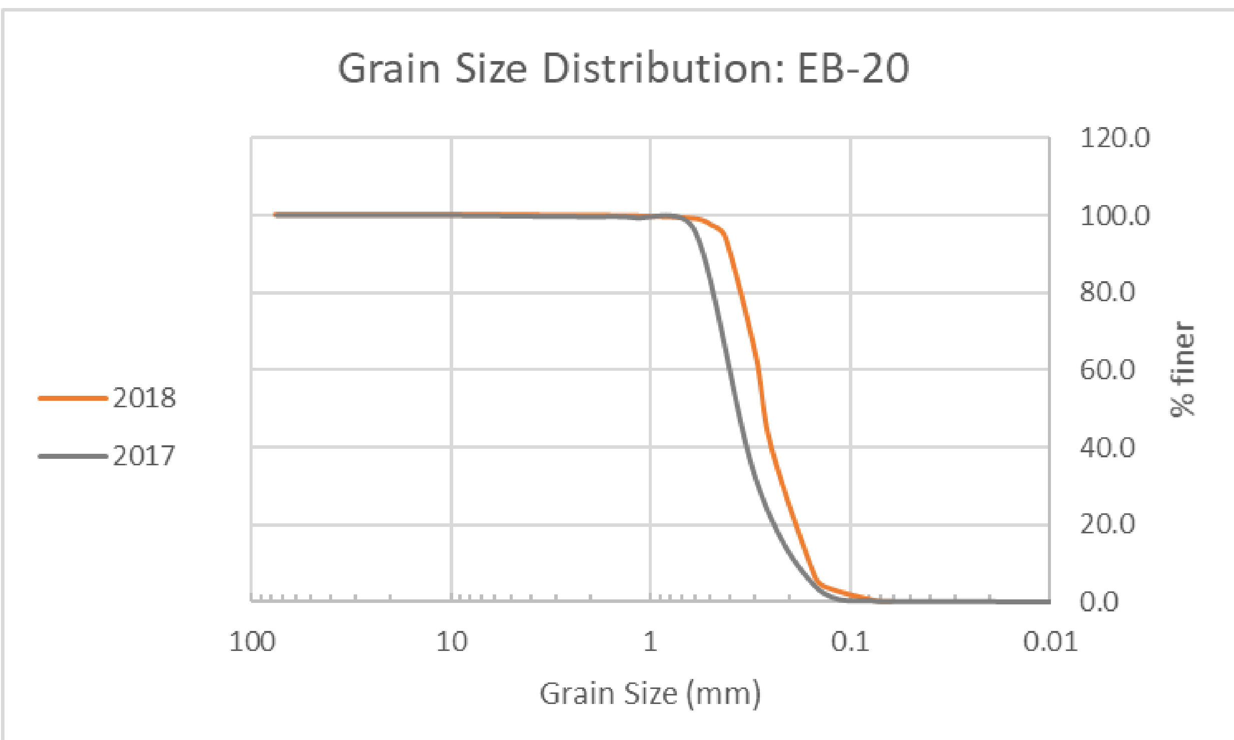

Figure 87: Grain size distribution plot for sediment samples taken at EB-20 between 2012 and 2019.

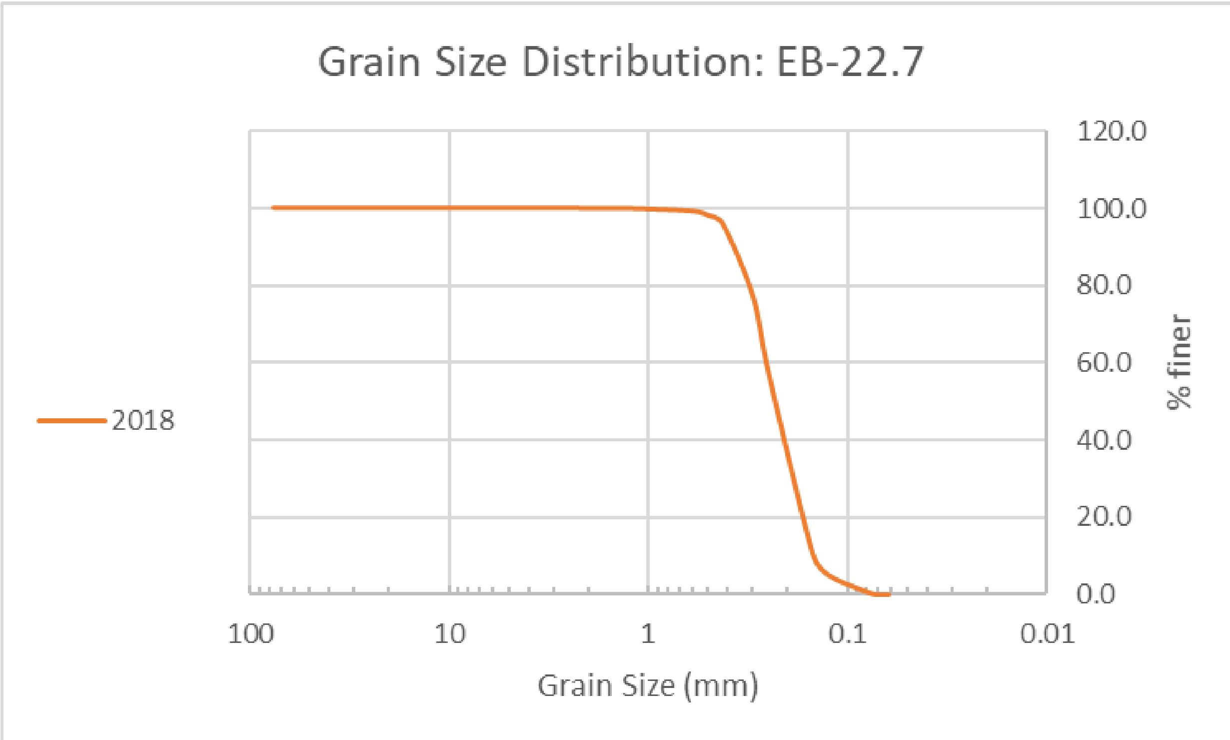

Figure 88: Grain size distribution plot for sediment samples taken at EB-22.7 between 2012 and 2019.

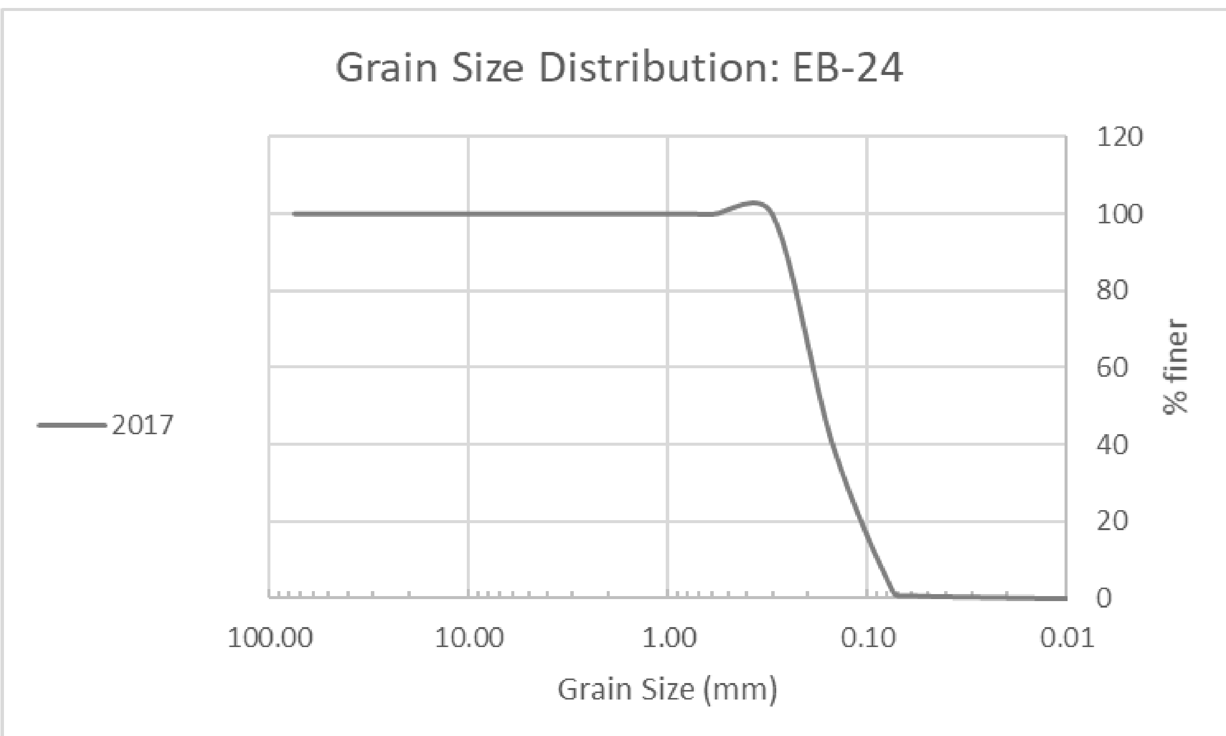

Figure 89: Grain size distribution plot for sediment samples taken at EB-24 between 2012 and 2019.

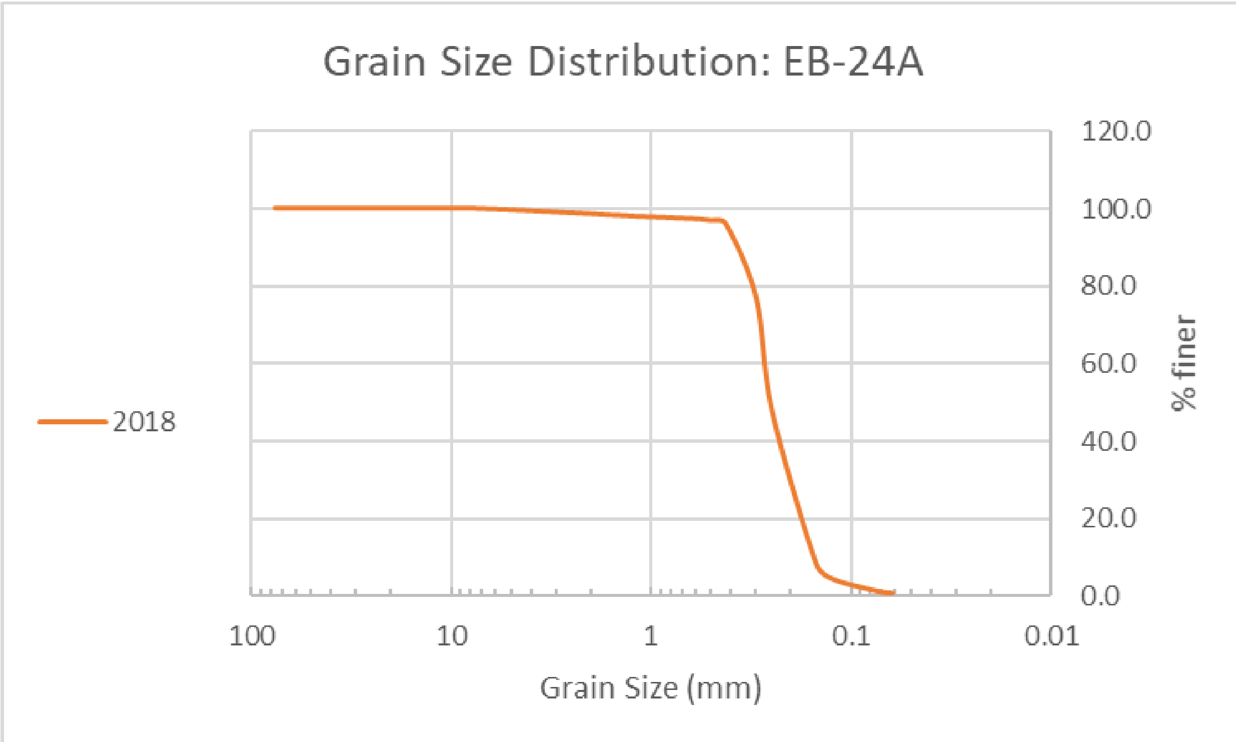

Figure 90: Grain size distribution plot for sediment samples taken at EB-24A between 2012 and 2019.

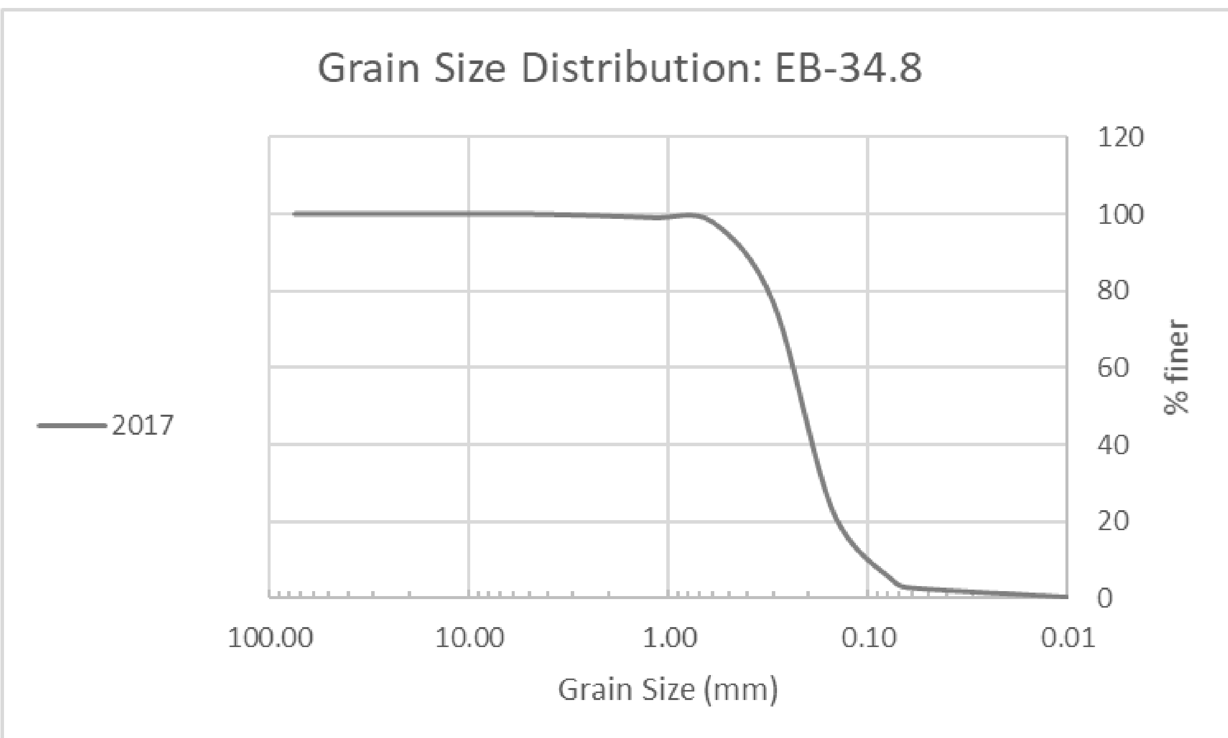

Figure 91: Grain size distribution plot for sediment samples taken at EB-34.8 between 2012 and 2019.

Appendix III: Longitudinal Profile Plots at the 500 cfs and 2,300 cfs Flow Rates

Water Surface Elevation at 500 cfs

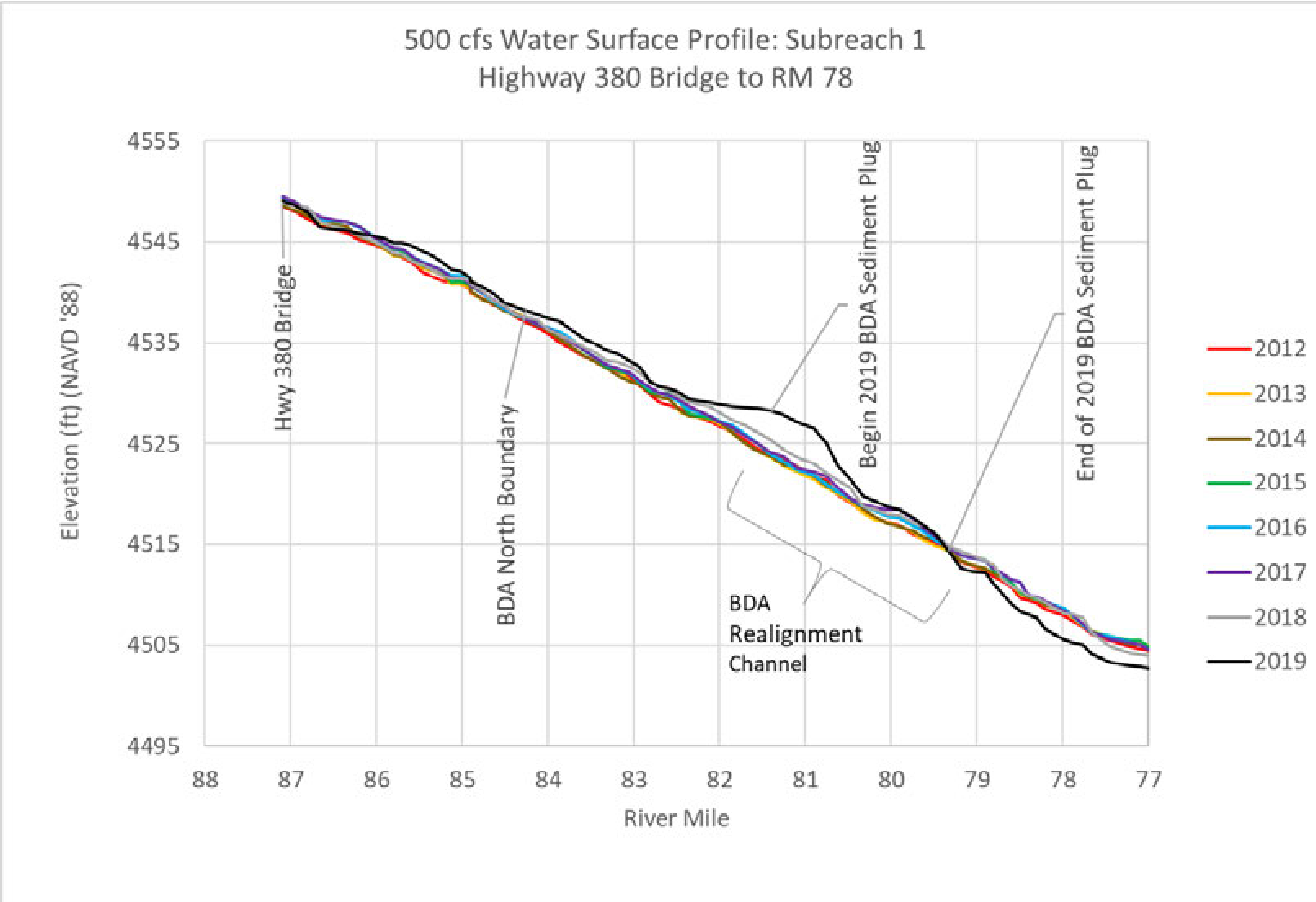

Figure 92: Simulated water surface profiles at the 500 cfs flow rate for Subreach 1 (RM 87.1 - RM 78).

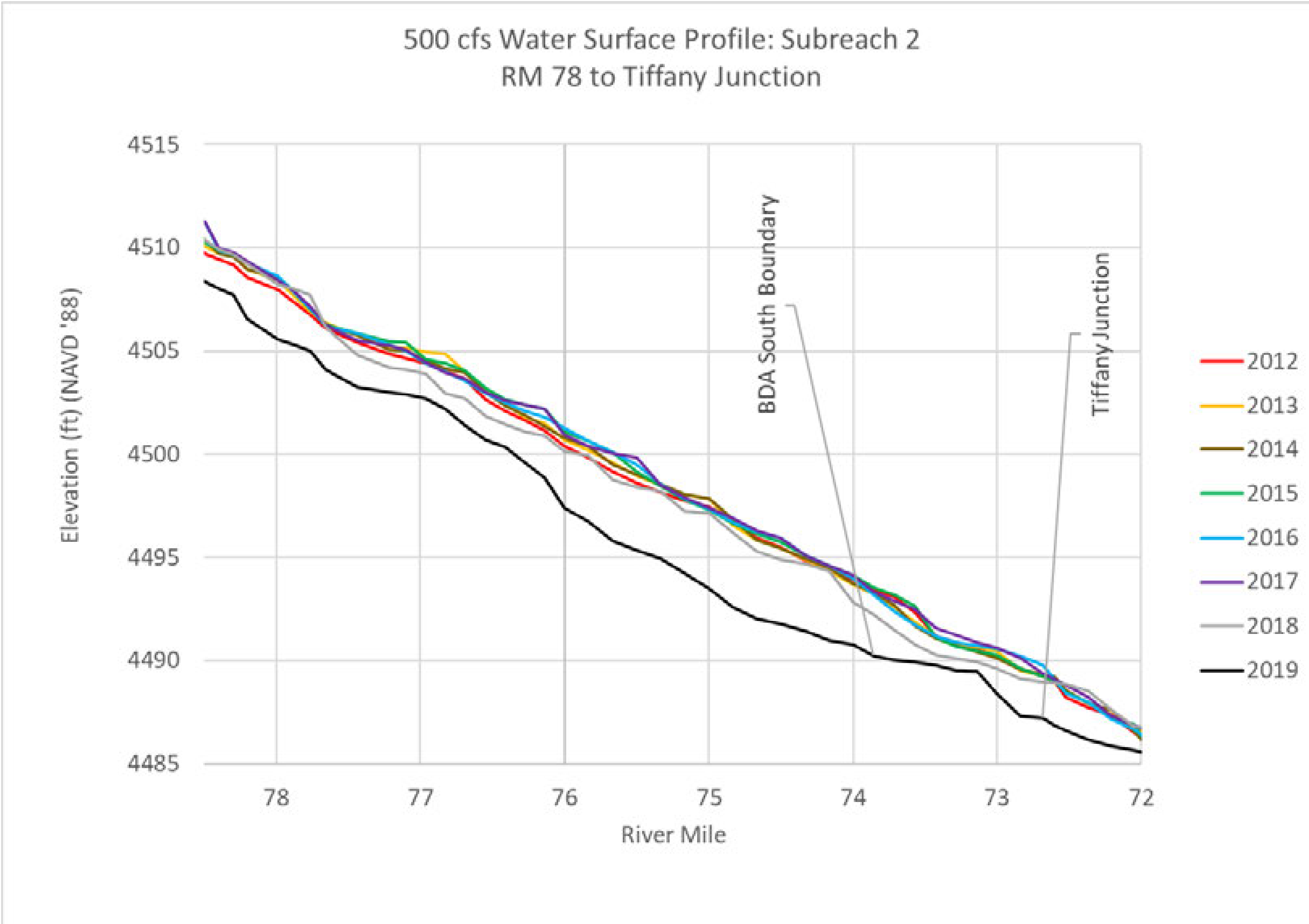

Figure 93: Simulated water surface profiles at the 500 cfs flow rate for Subreach 2 (RM 78 – 72.6).

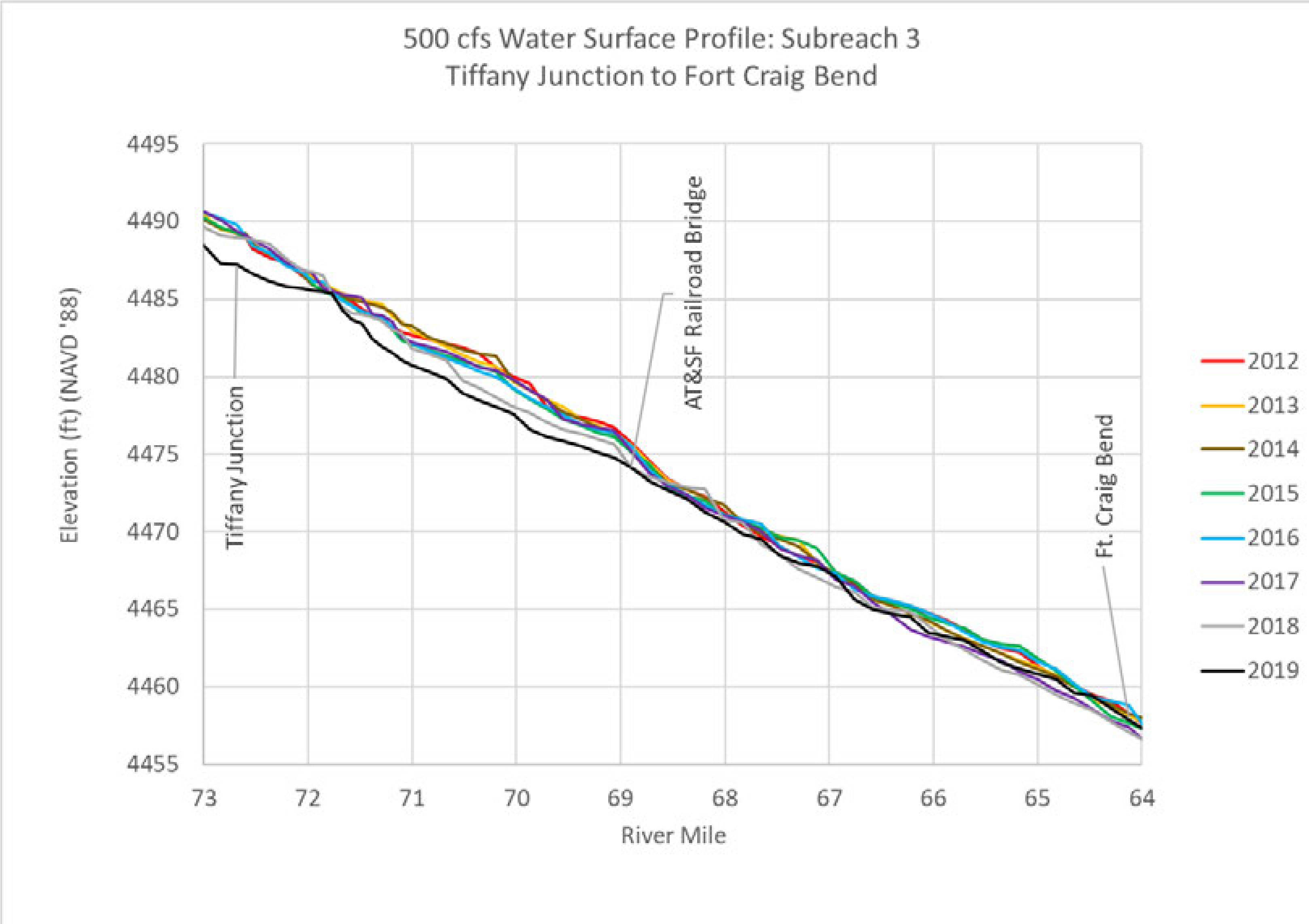

Figure 94: Simulated water surface profiles at the 500 cfs flow rate for Subreach 3 (RM 72.6 – RM 64).

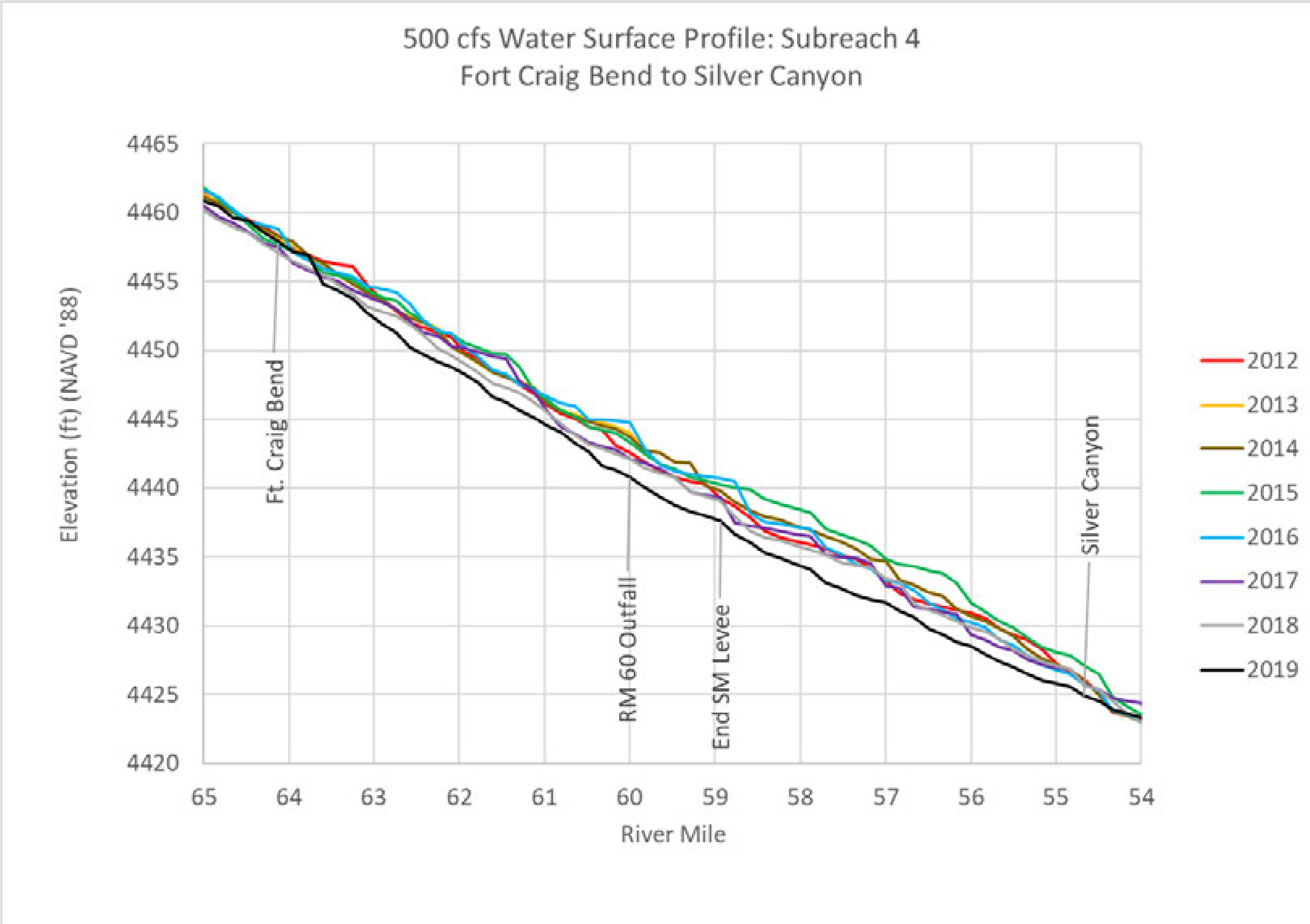

Figure 95: Simulated water surface profiles at the 500 cfs flow rate for Subreach 4 (RM 64 – RM 54.5).

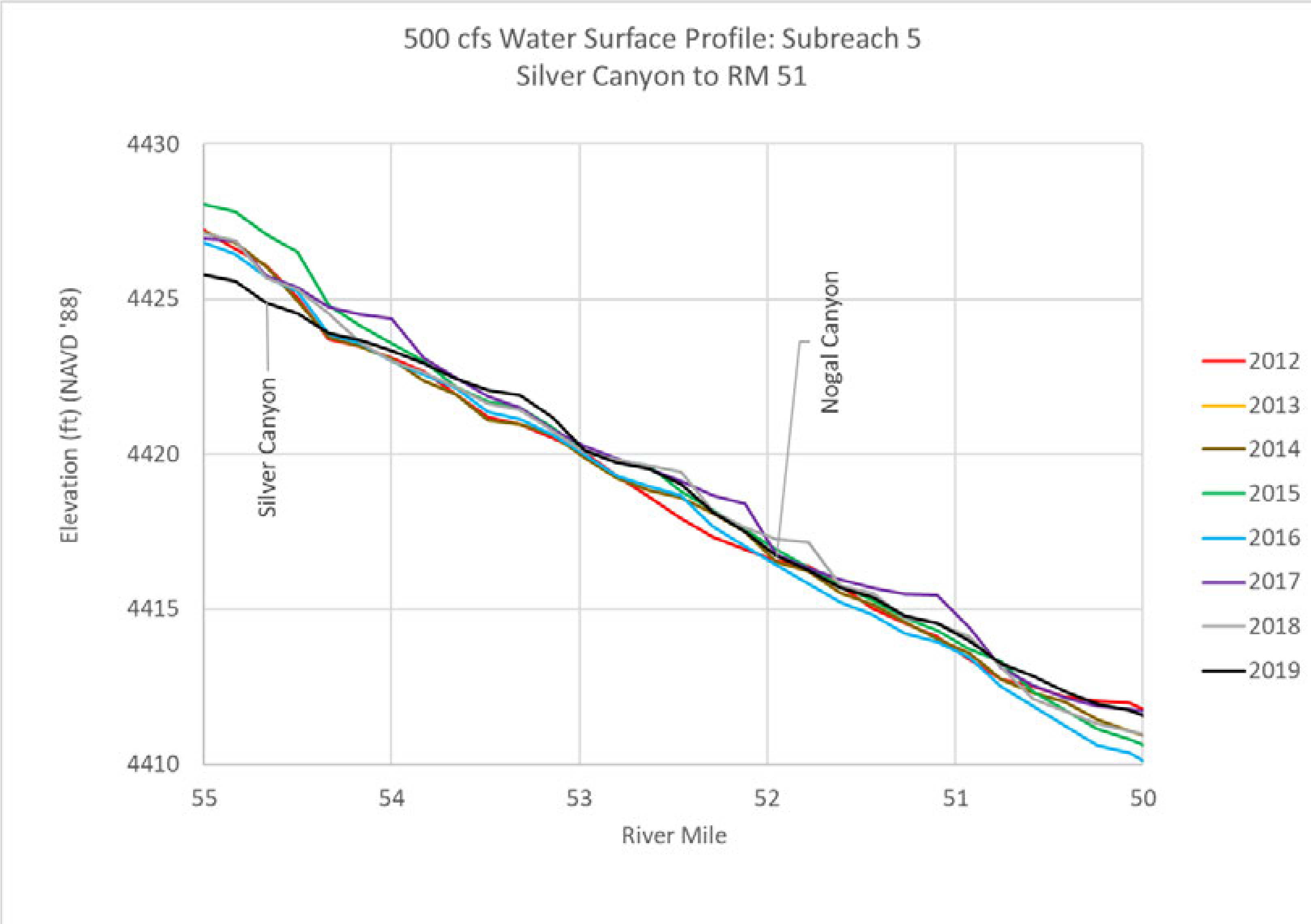

Figure 96: Simulated water surface profiles at the 500 cfs flow rate for Subreach 5 (RM 54.5 – RM 51)

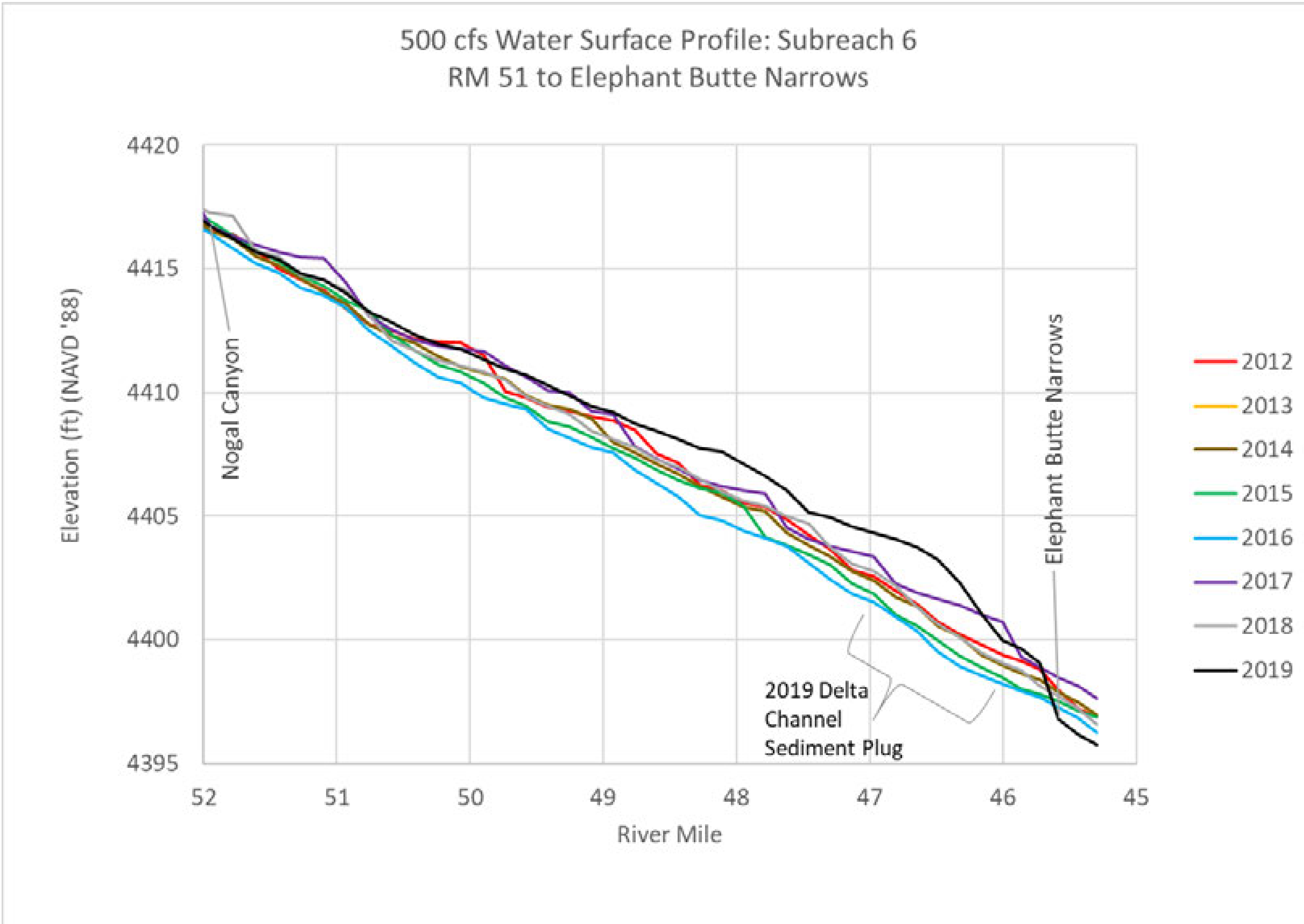

Figure 97: Simulated water surface profiles at the 500 cfs flow rate for Subreach 6 (RM 51 – RM 45.3)

Water Surface Elevation at 2,300 cfs

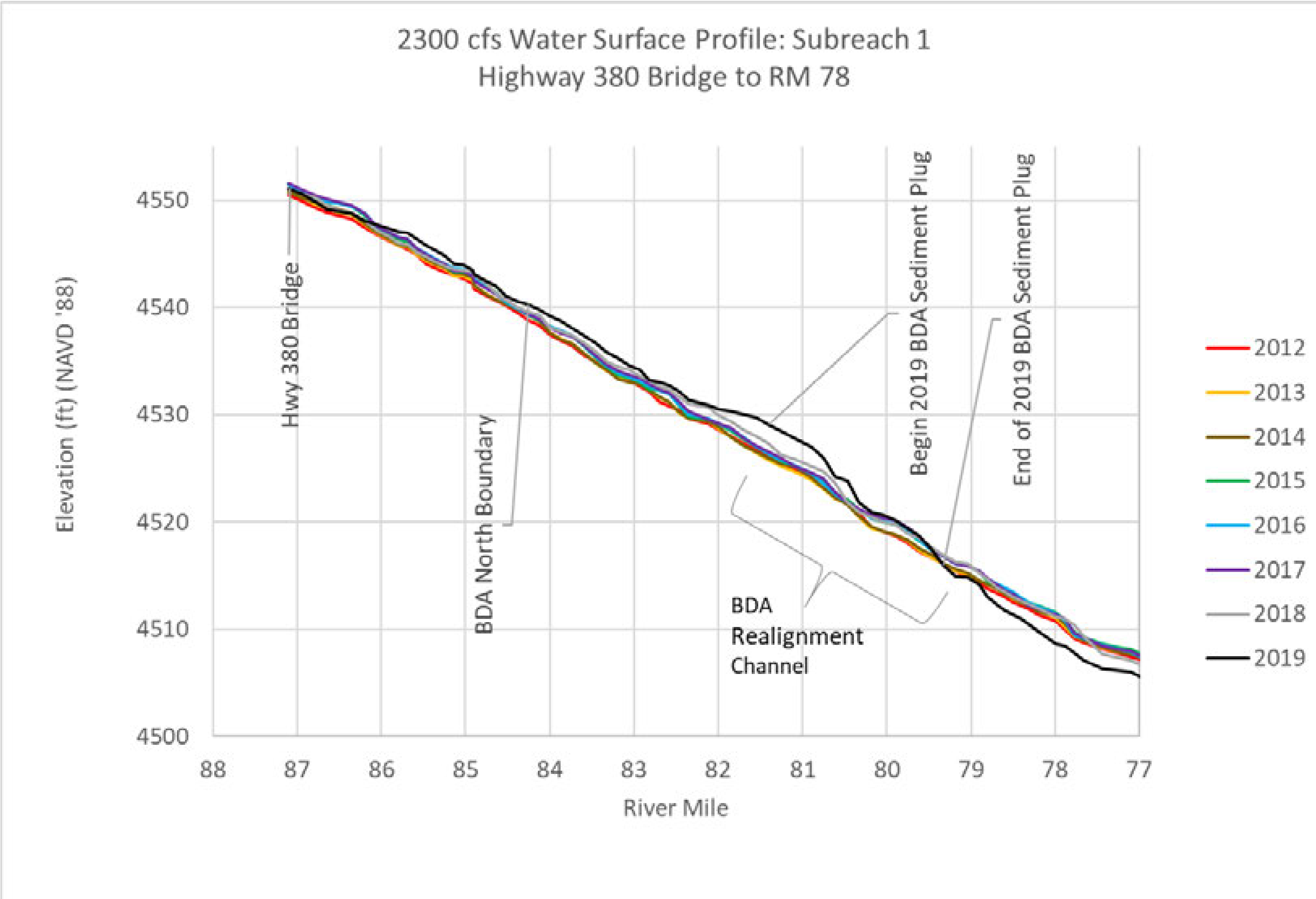

Figure 98: Simulated water surface profiles at the 2,300 cfs flow rate for Subreach 1 (RM 87.1 - RM 78).

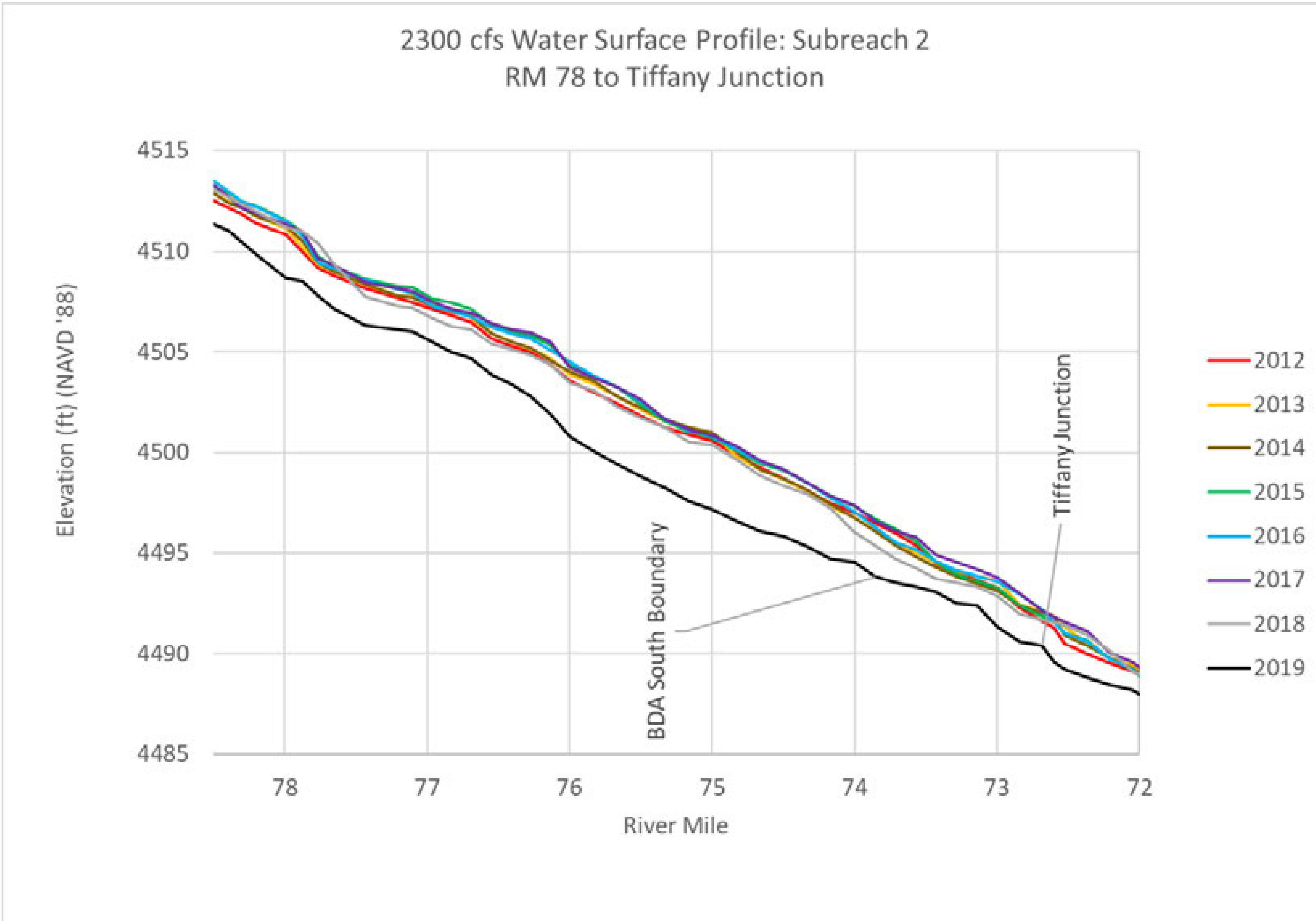

Figure 99: Simulated water surface profiles at the 2,300 cfs flow rate for Subreach 2 (RM 78 – 72.6).

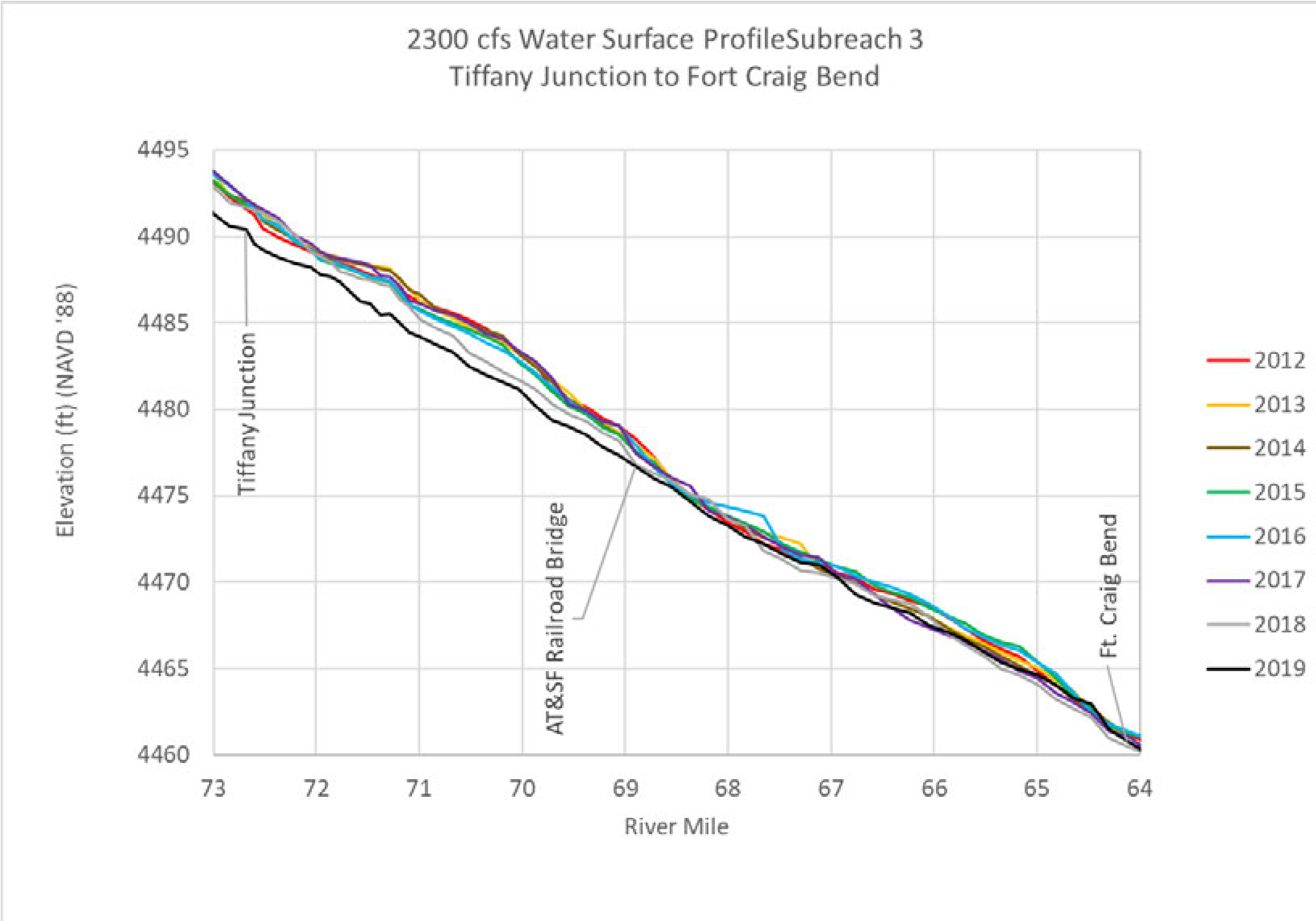

Figure 100: Simulated water surface profiles at the 2,300 cfs flow rate for Subreach 3 (RM 72.6 – RM 64).

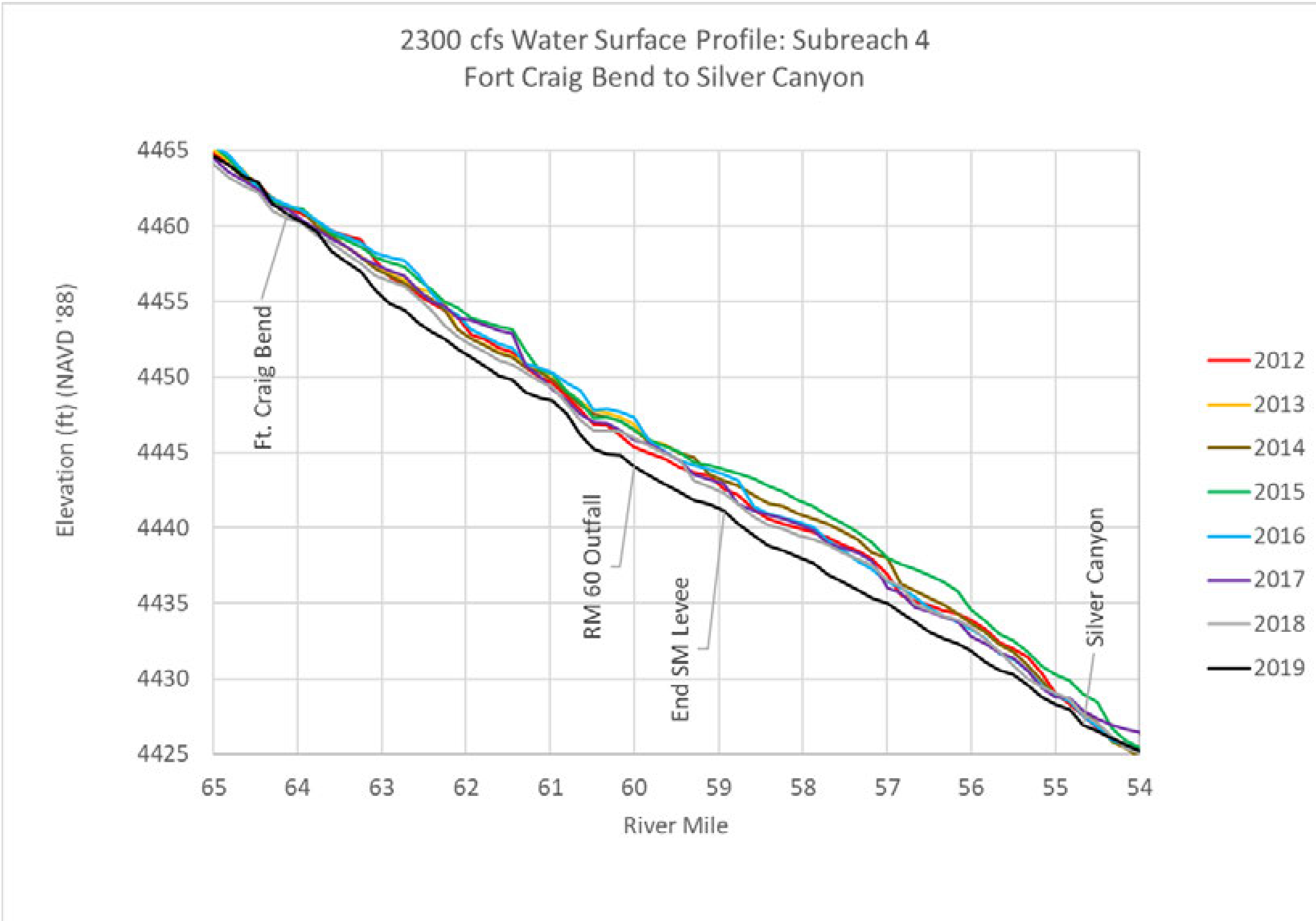

Figure 101: Simulated water surface profiles at the 2,300 cfs flow rate for Subreach 4 (RM 64 – RM 54.5).

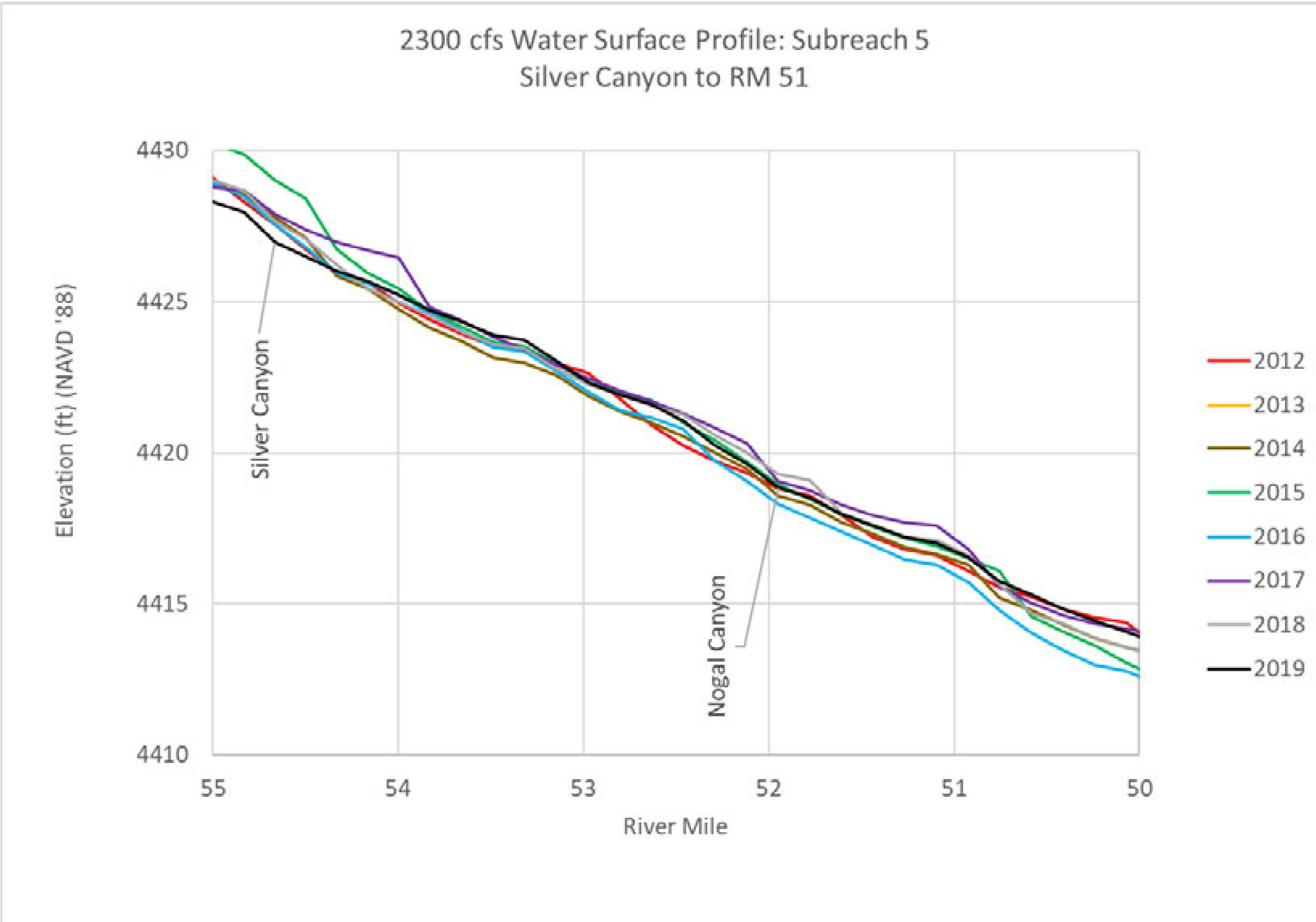

Figure 102: Simulated water surface profiles at the 2,300 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

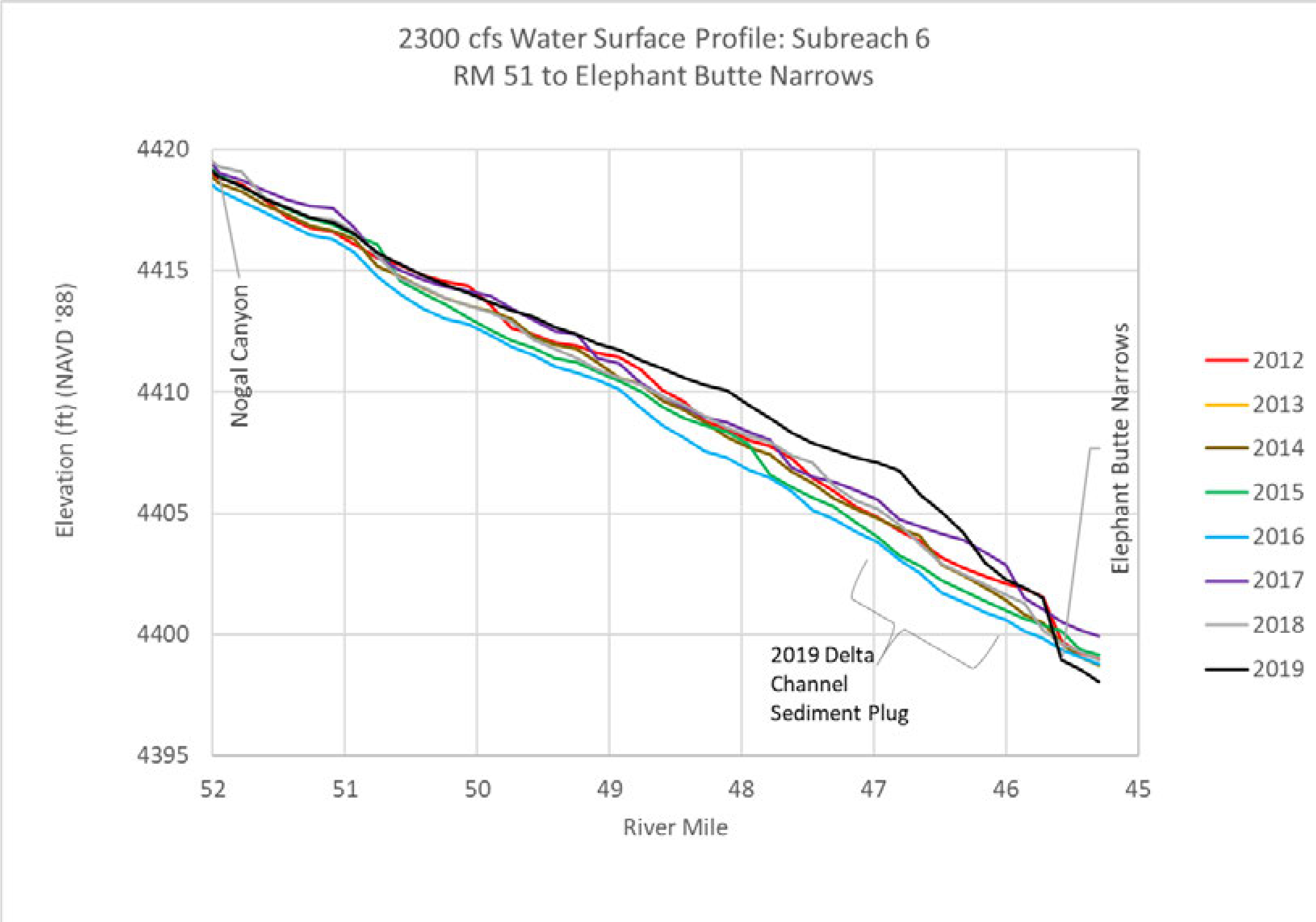

Figure 103: Simulated water surface profiles at the 2,300 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Energy Grade Elevation at 500 cfs

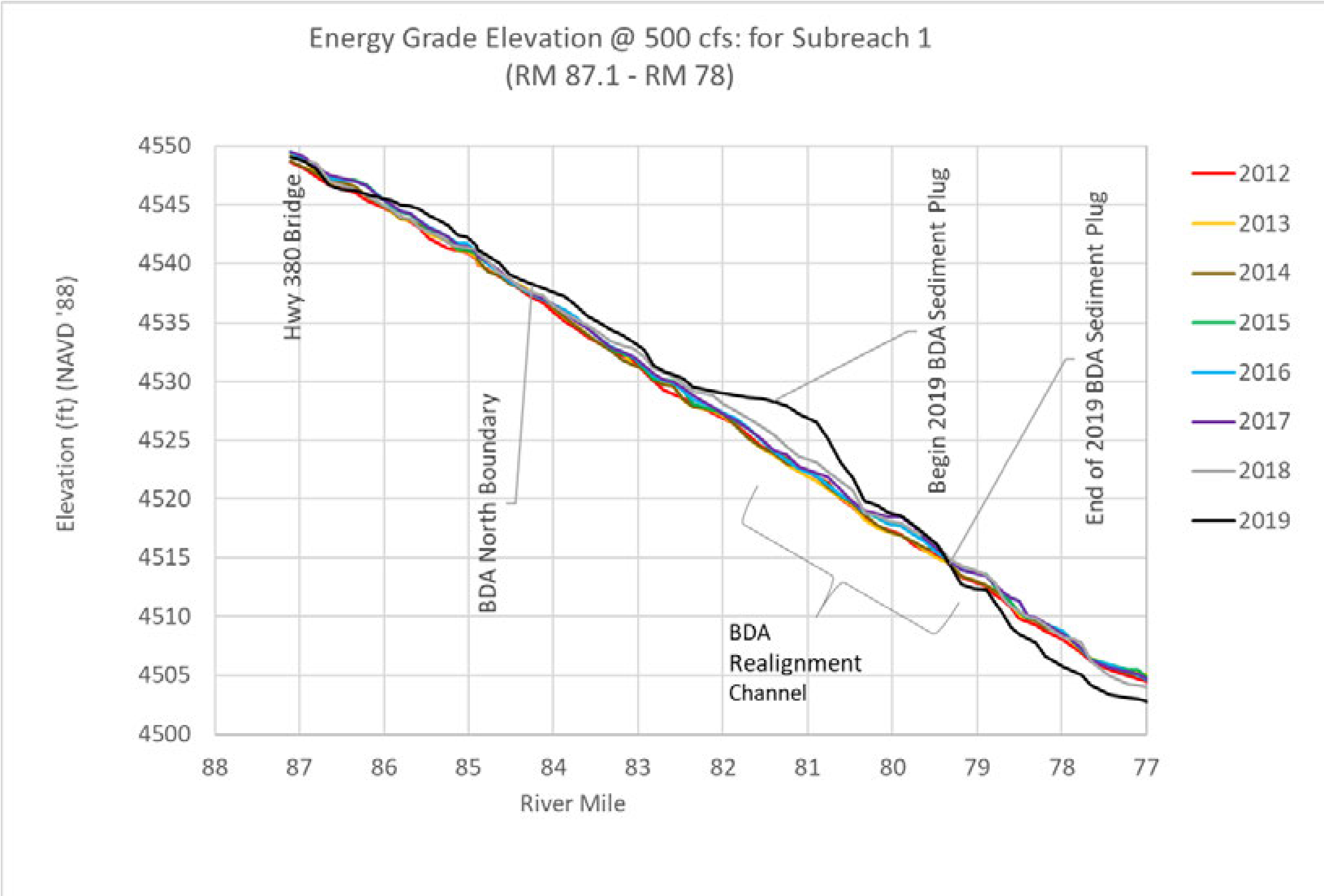

Figure 104: Simulated energy grade profiles at the 500 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

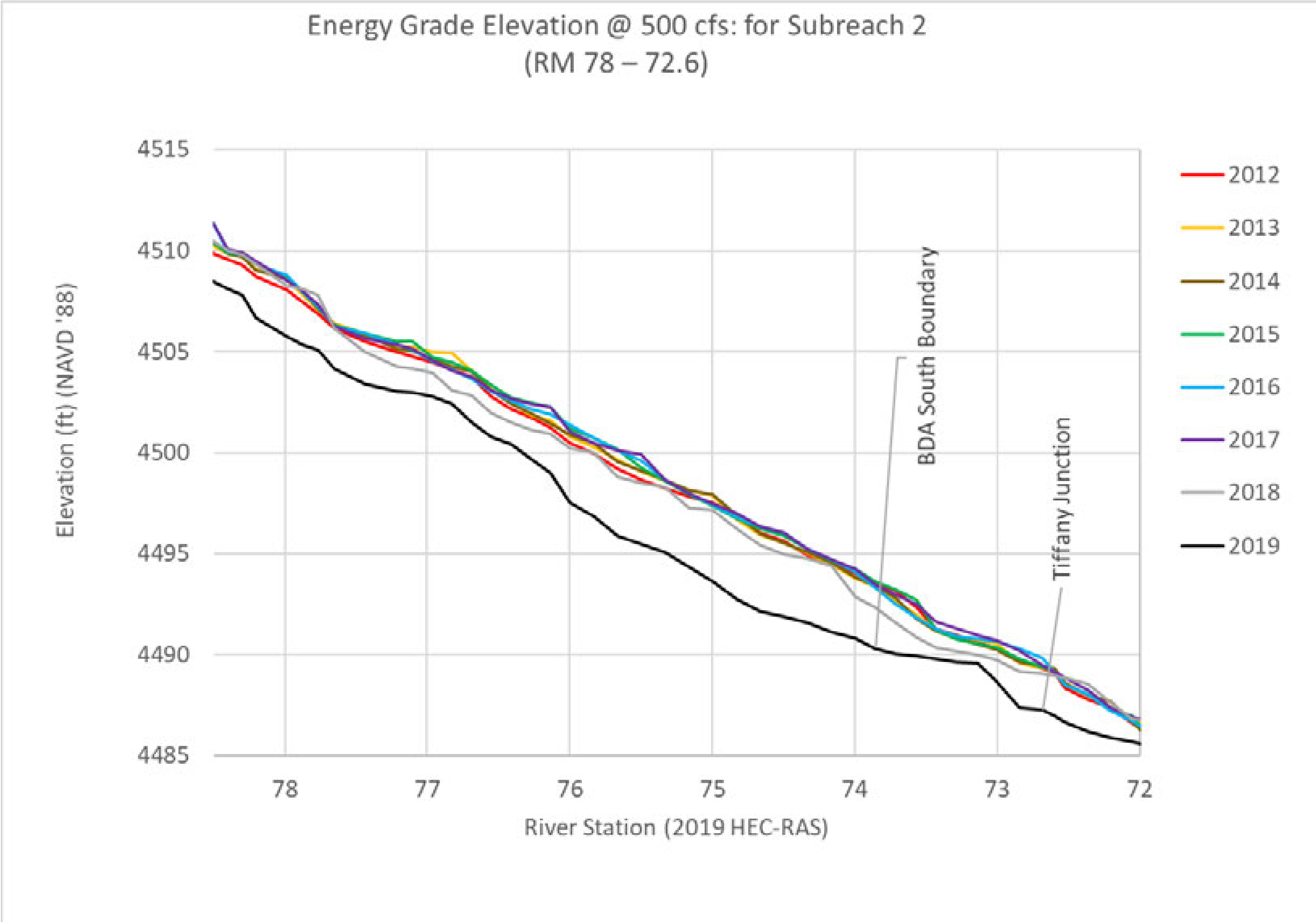

Figure 105: Simulated energy grade profiles at the 500 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

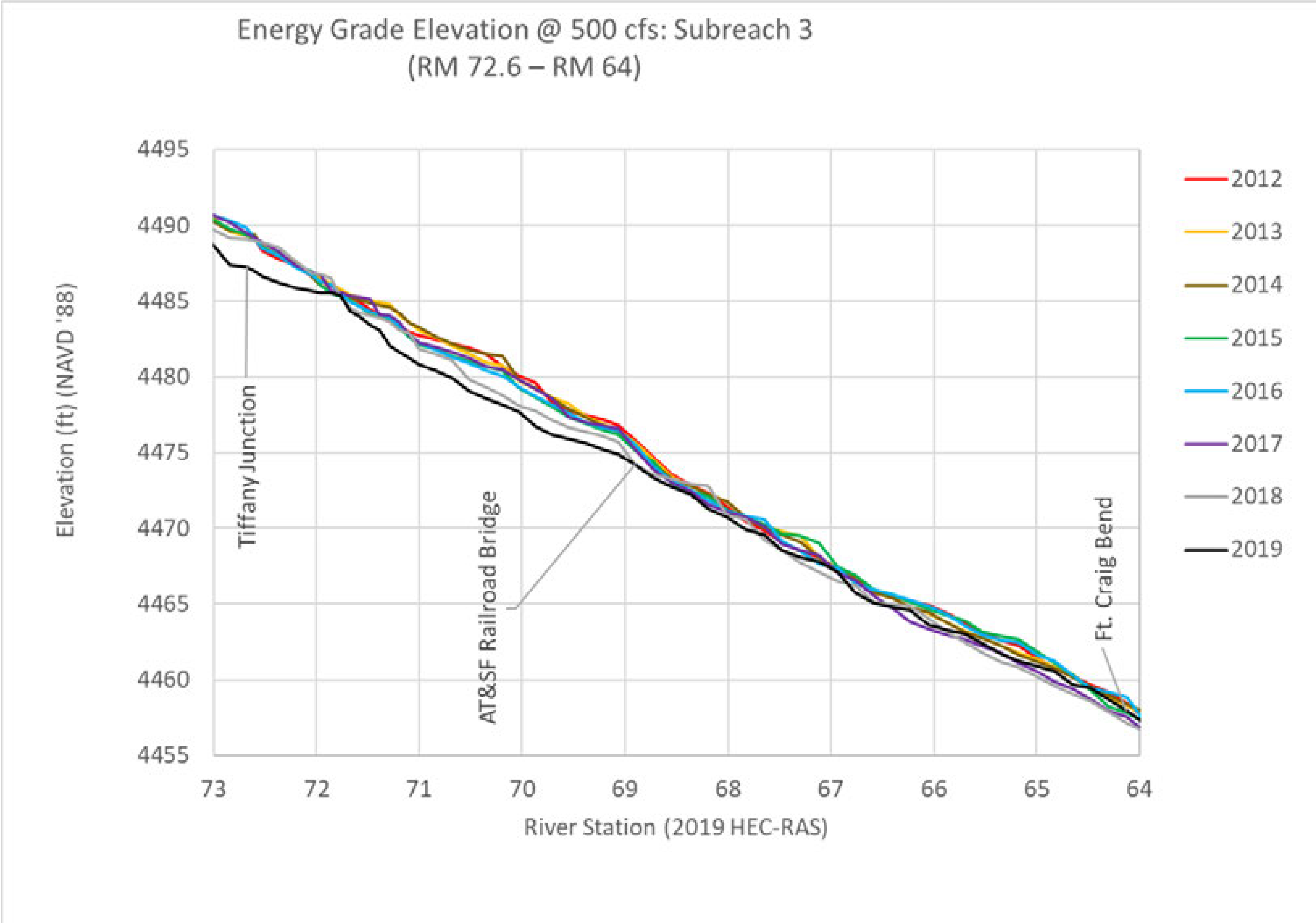

Figure 106: Simulated energy grade profiles at the 500 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

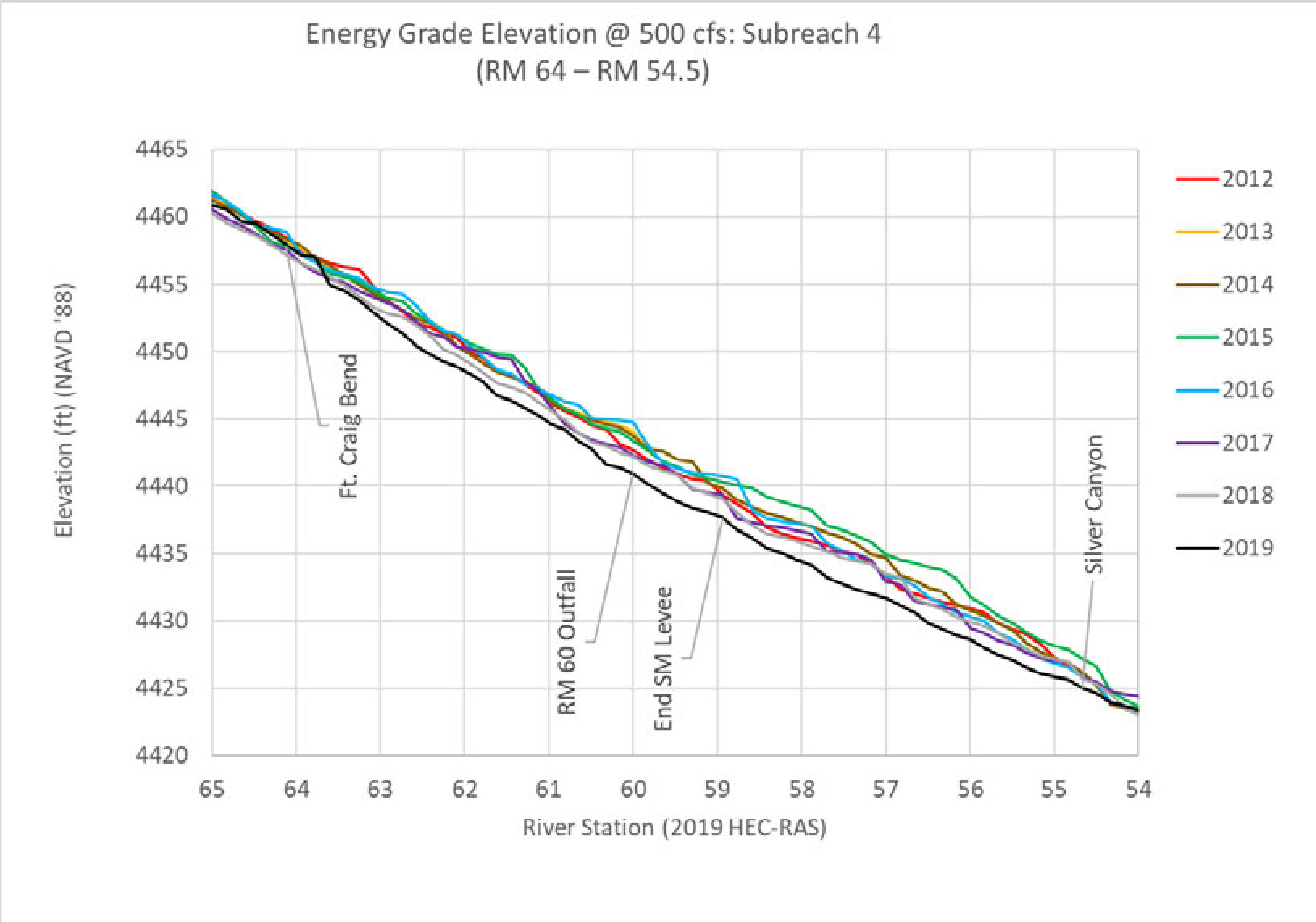

Figure 107: Simulated energy grade profiles at the 500 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

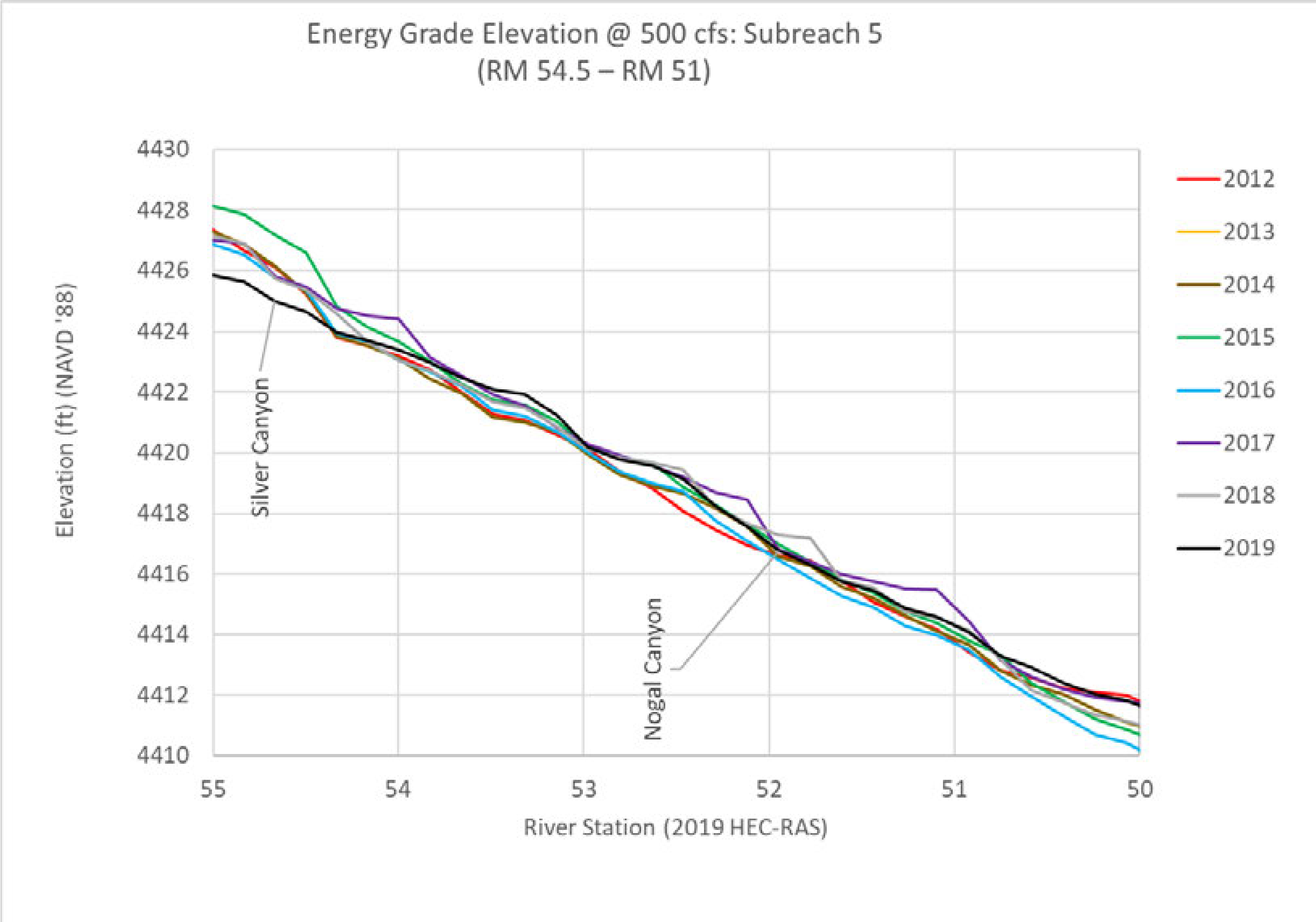

Figure 108: Simulated energy grade profiles at the 500 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

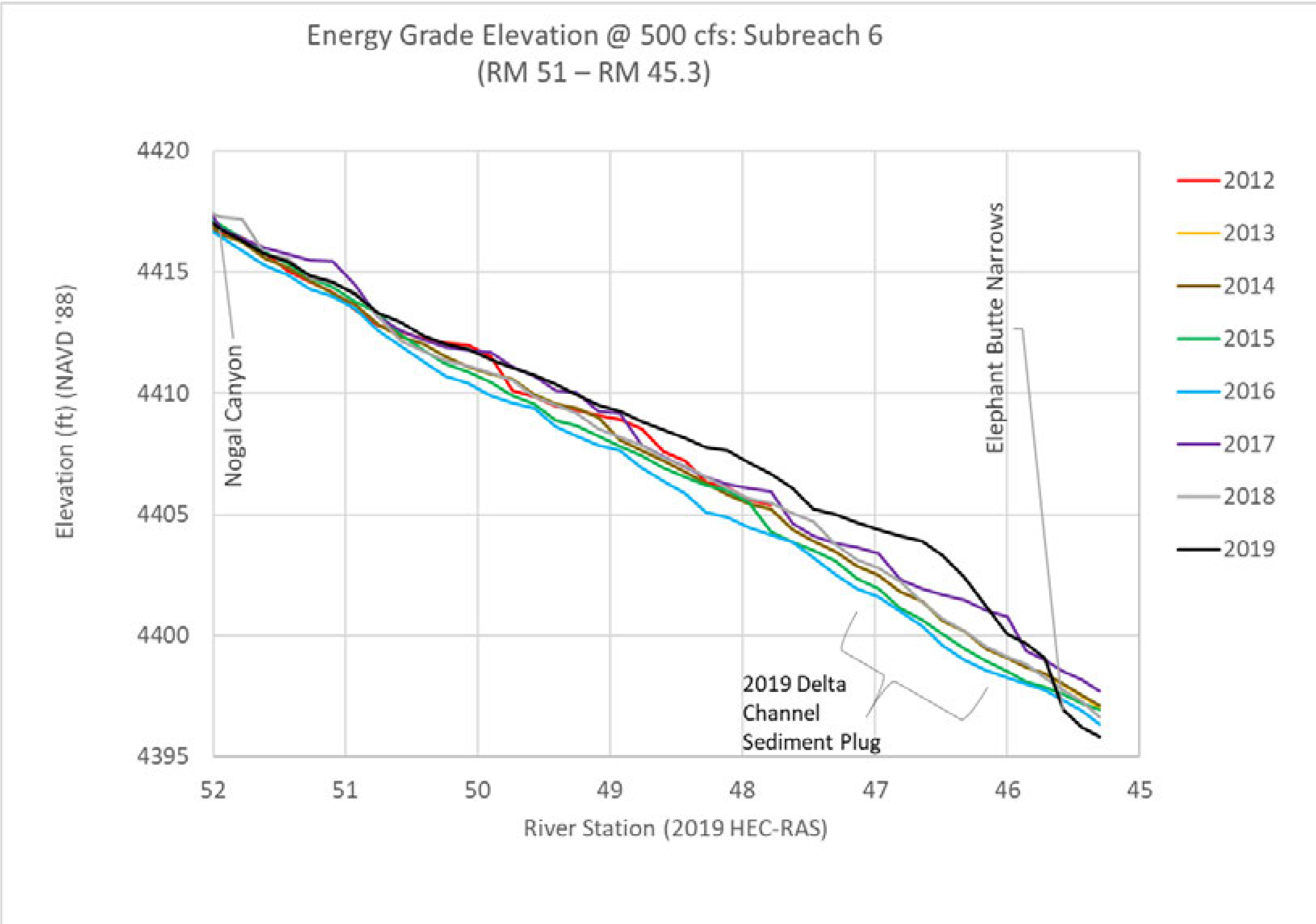

Figure 109: Simulated energy grade profiles at the 500 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Energy Grade Elevation at 2,300 cfs

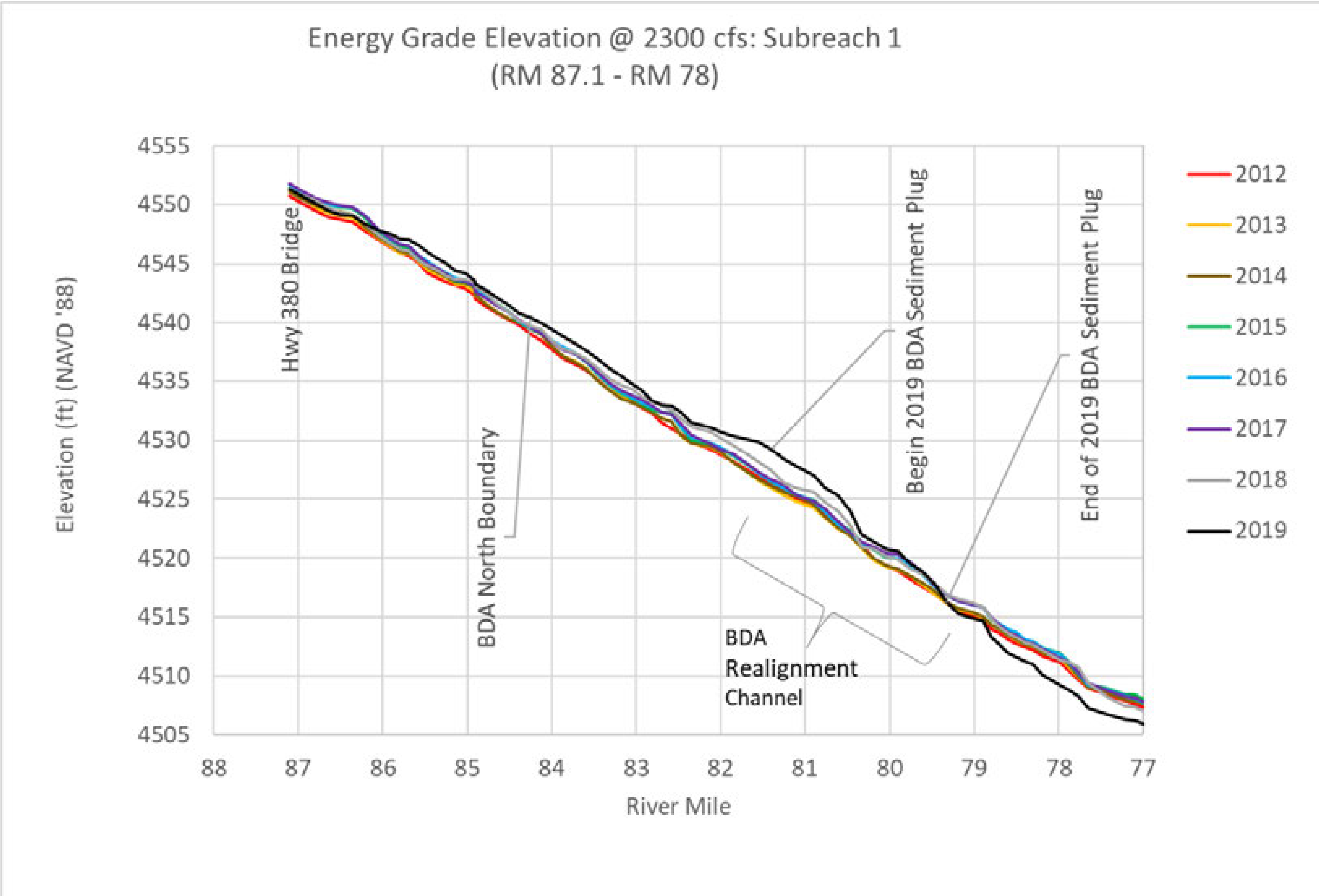

Figure 110: Simulated energy grade profiles at the 2,300 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

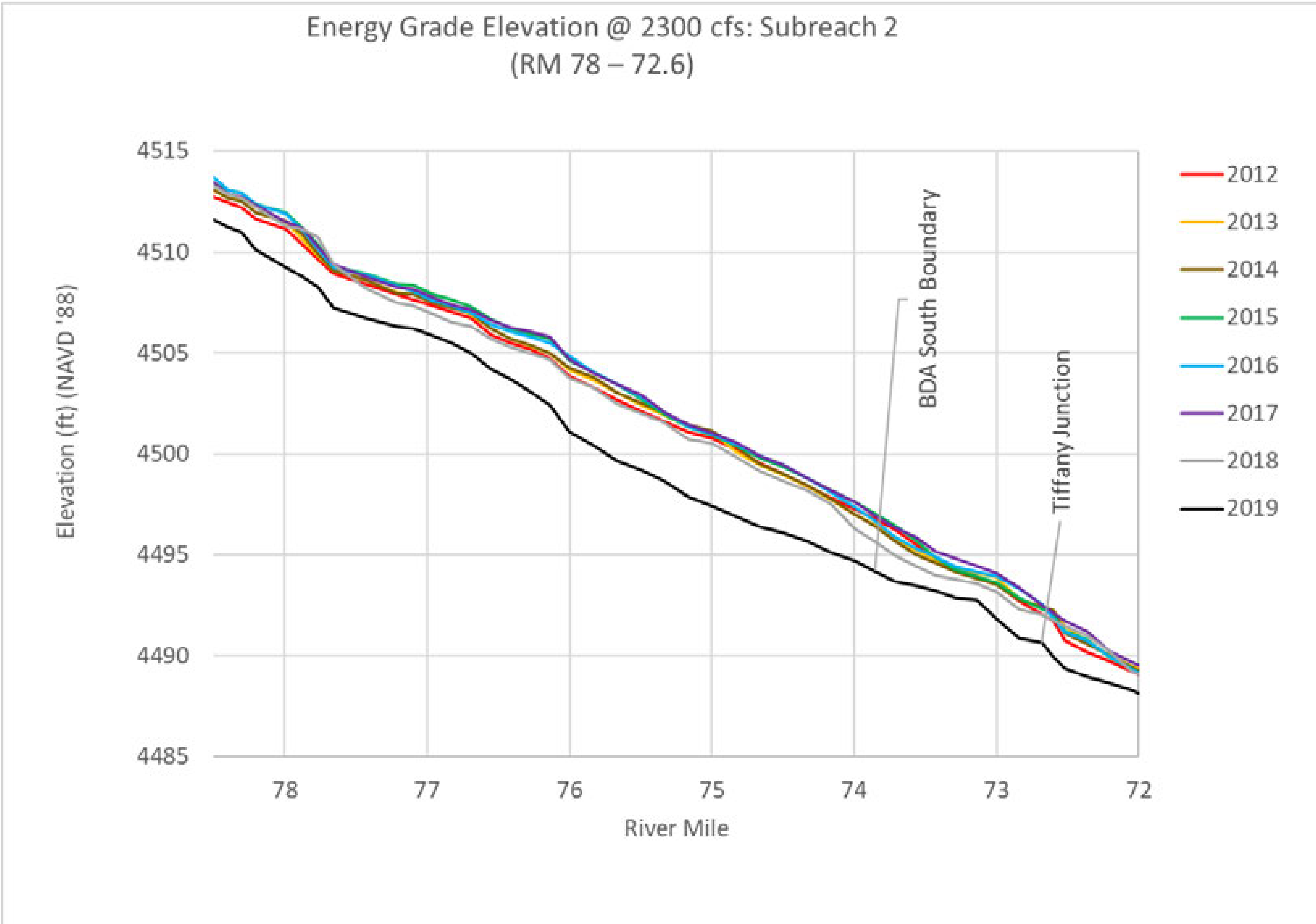

Figure 111: Simulated energy grade profiles at the 2,300 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

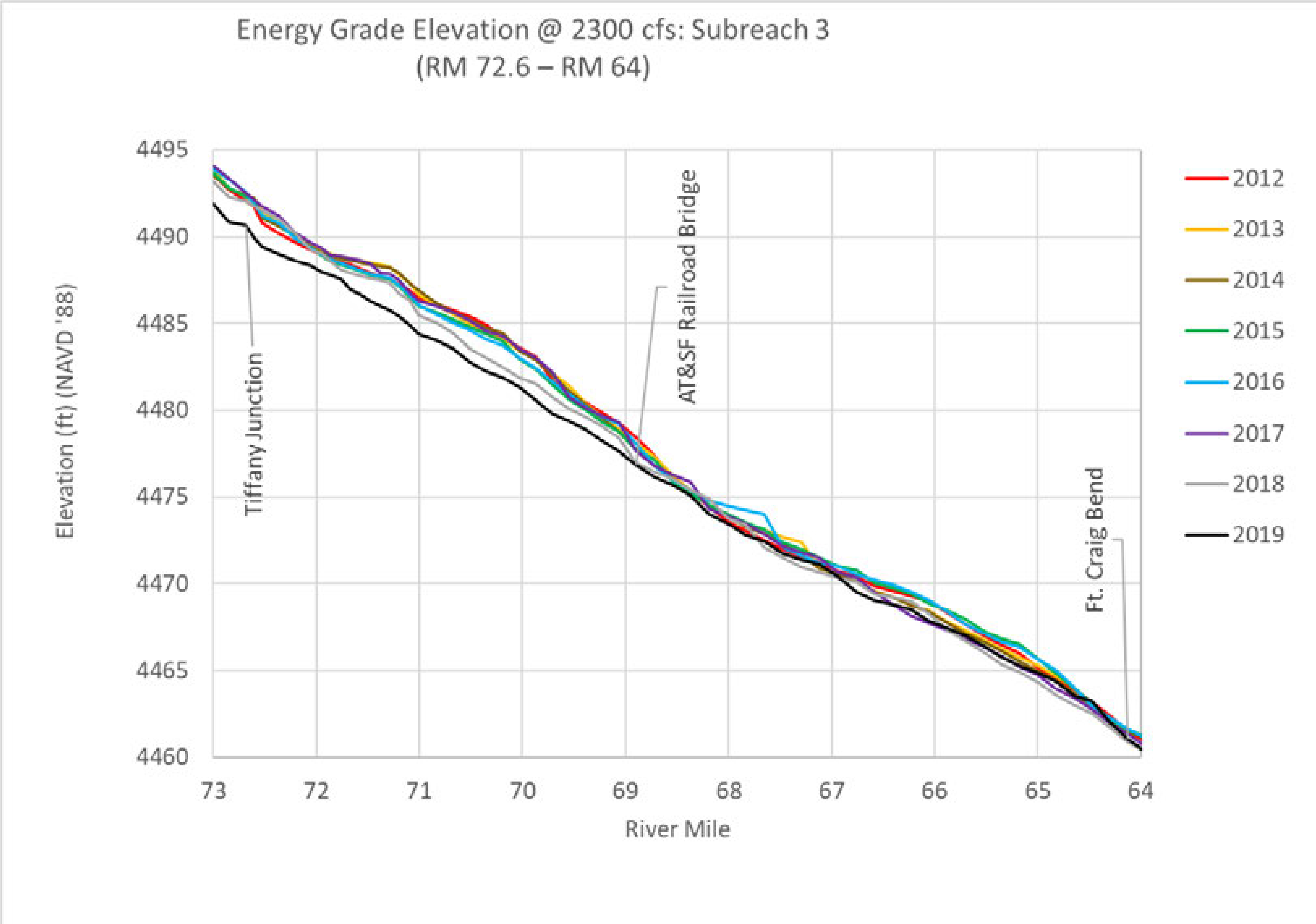

Figure 112: Simulated energy grade profiles at the 2,300 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

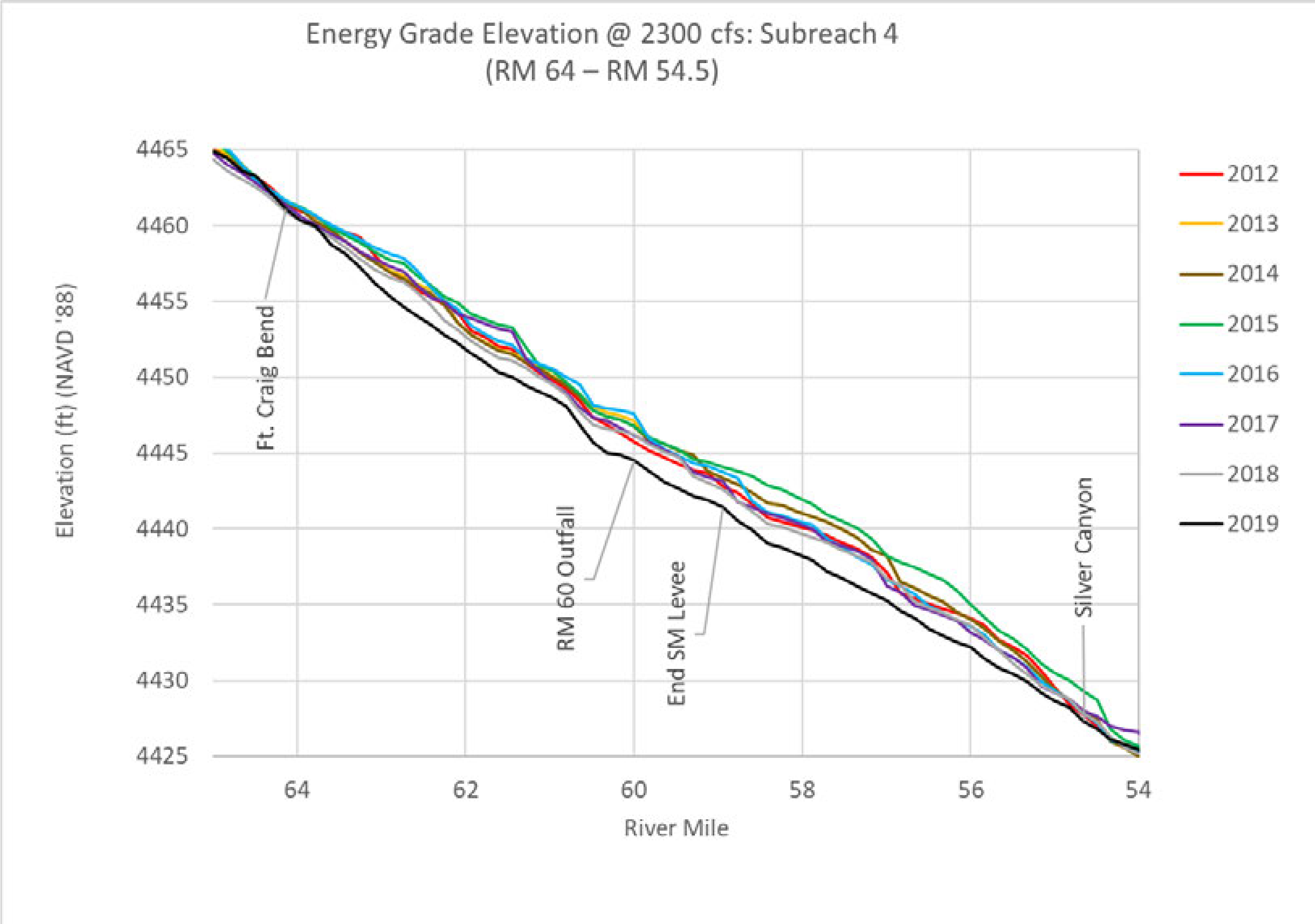

Figure 113: Simulated energy grade profiles at the 2,300 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

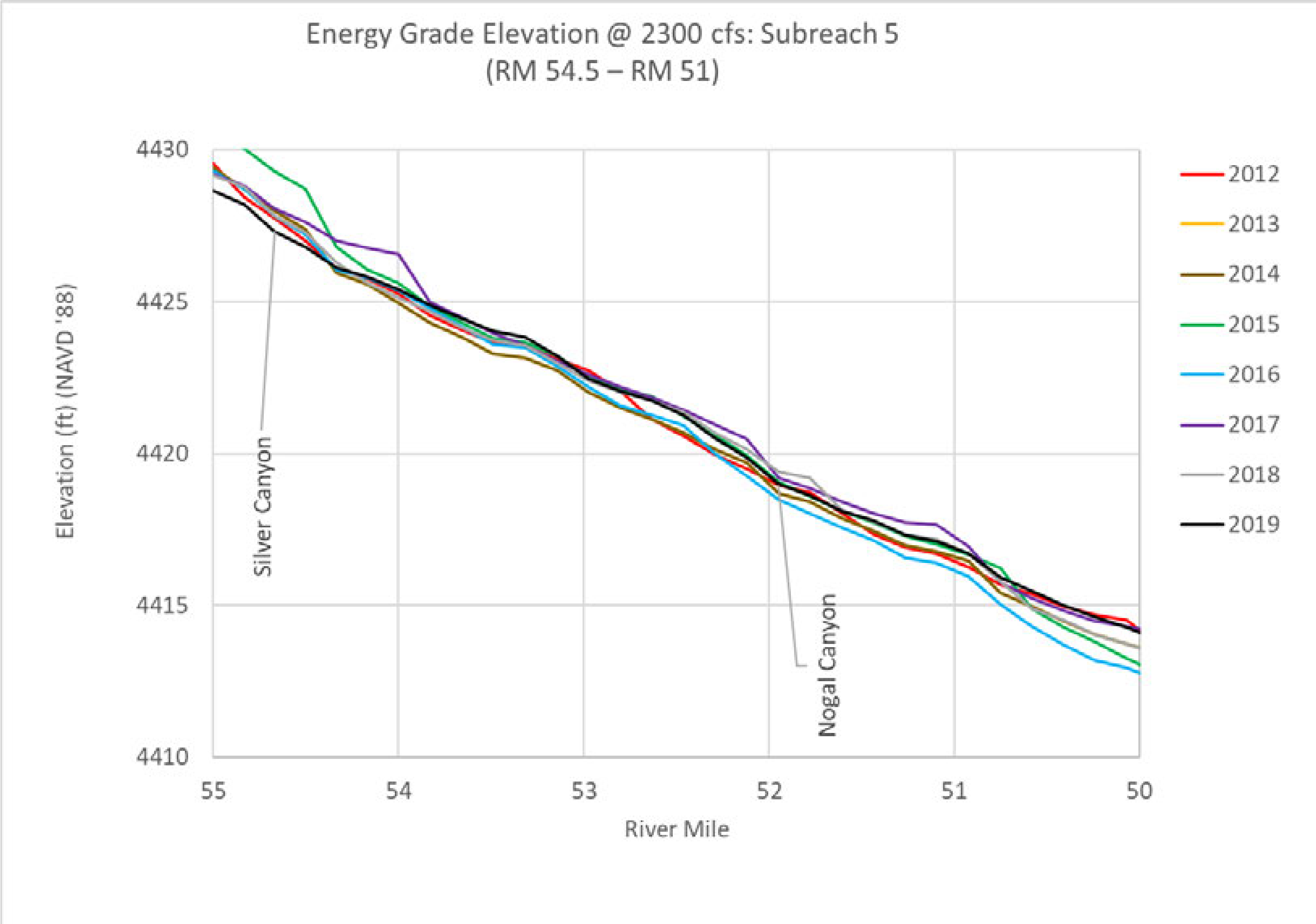

Figure 114: Simulated energy grade profiles at the 2,300 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

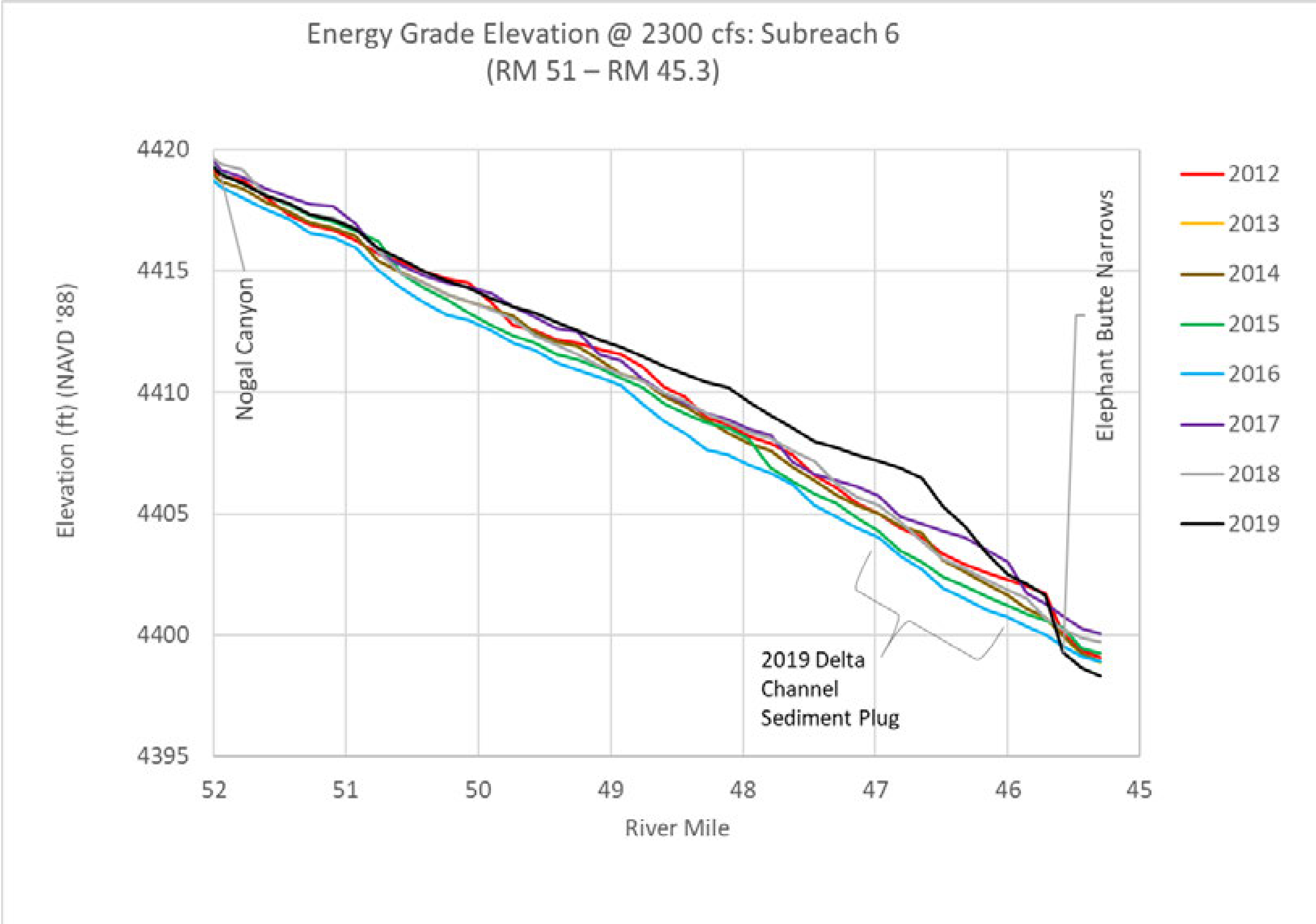

Figure 115: Simulated energy grade profiles at the 2,300 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Hydraulic Depth at 500 cfs

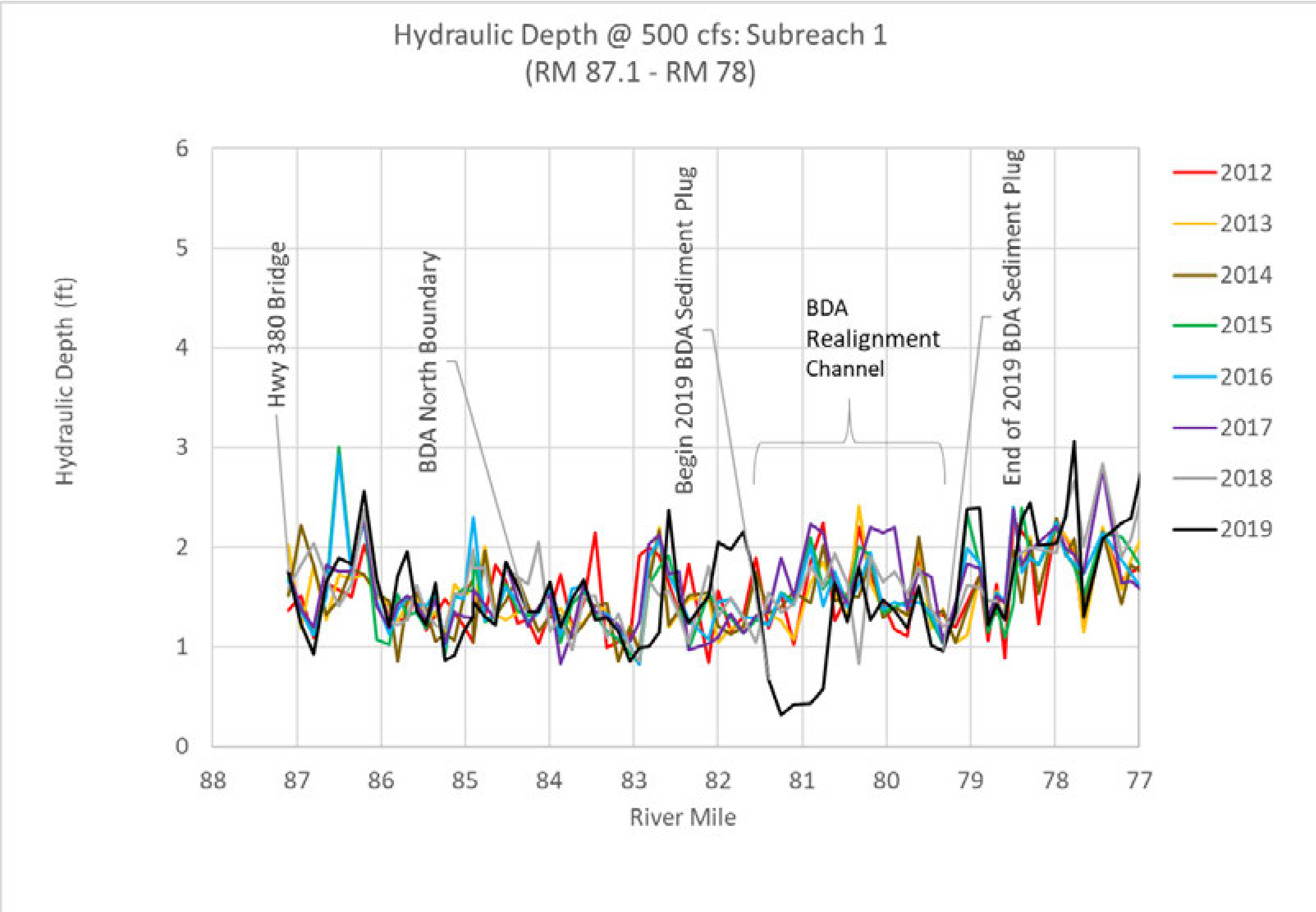

Figure 116: Simulated hydraulic depth profiles at the 500 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

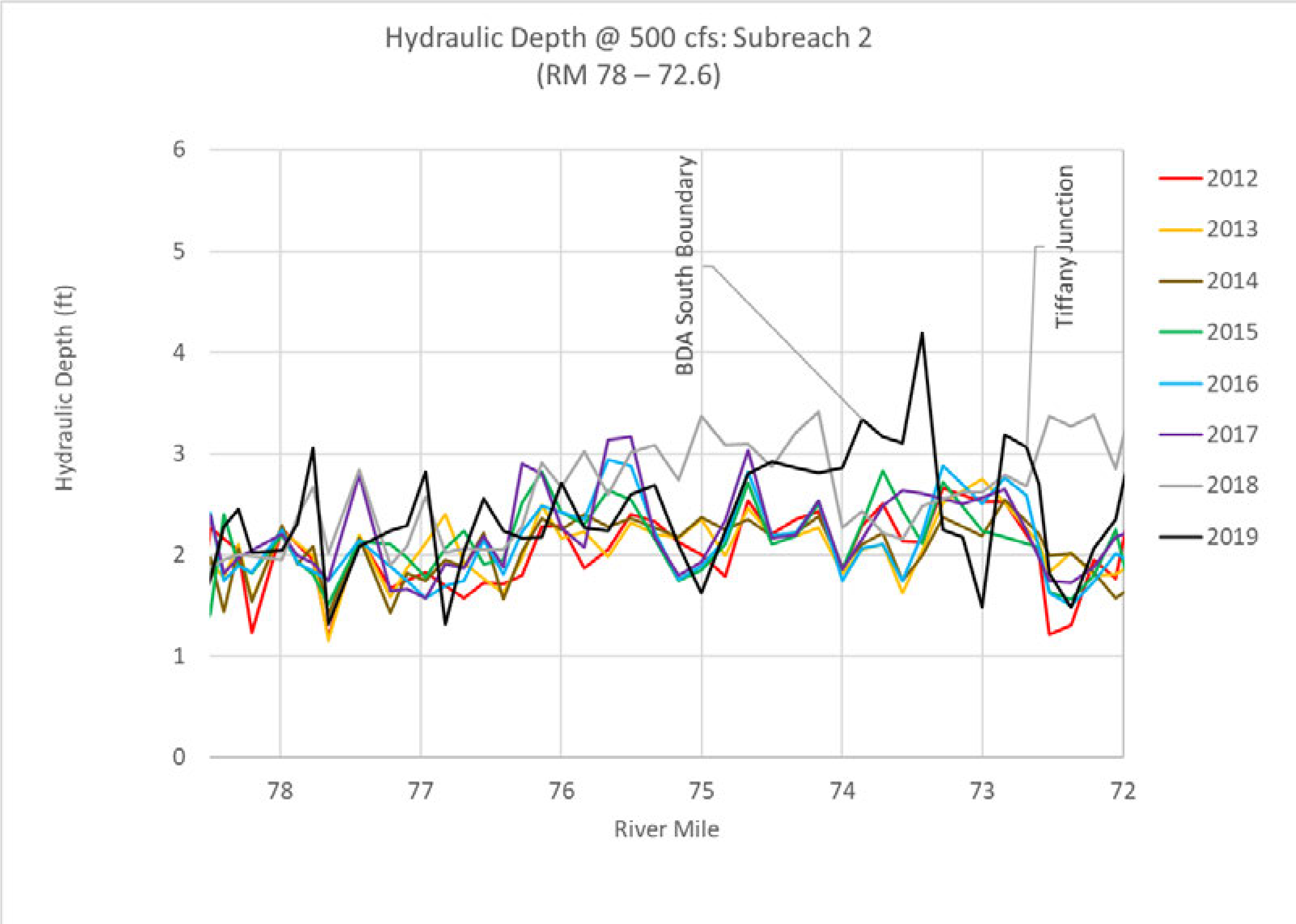

Figure 117: Simulated hydraulic depth profiles at the 500 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

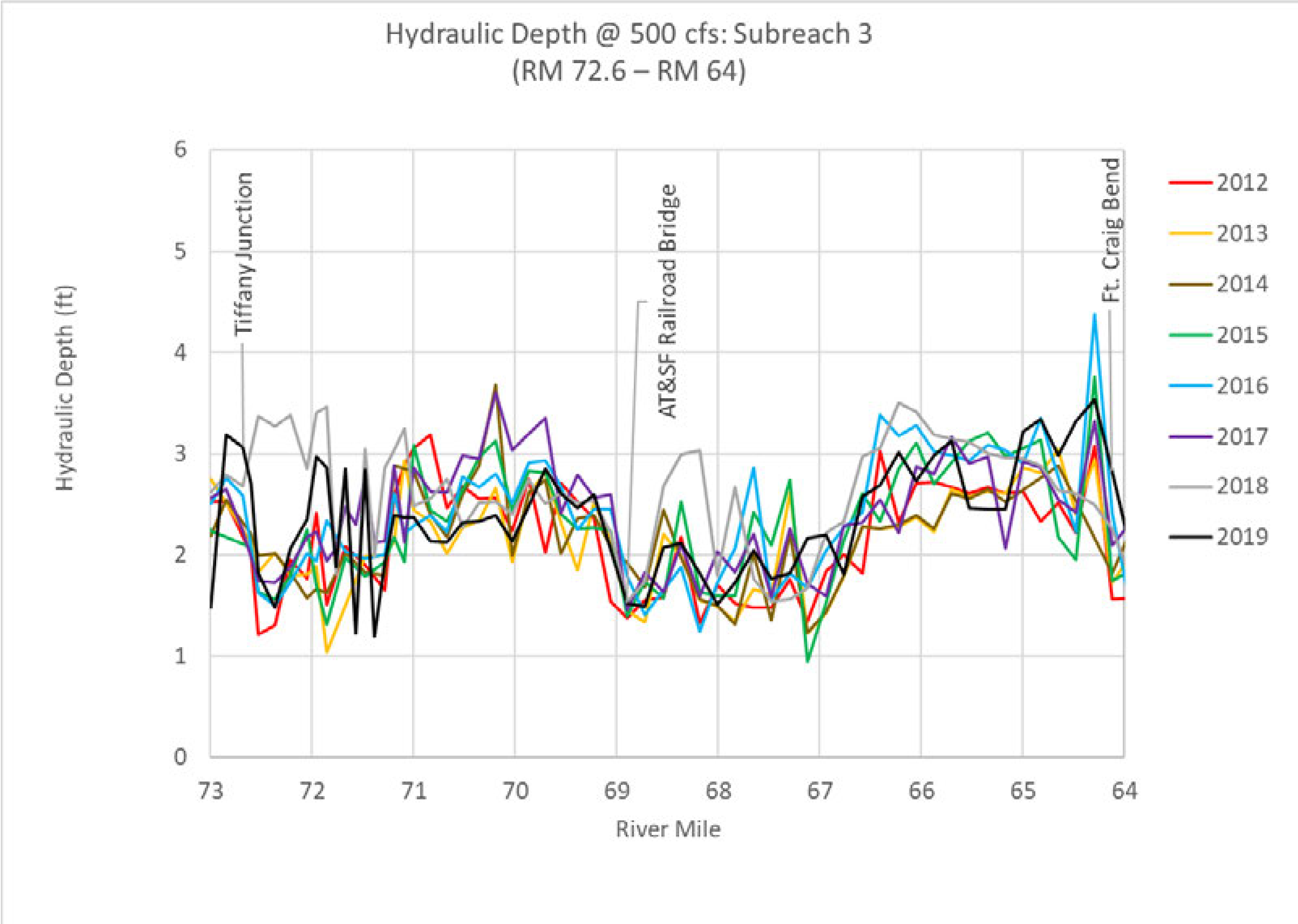

Figure 118: Simulated hydraulic depth profiles at the 500 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

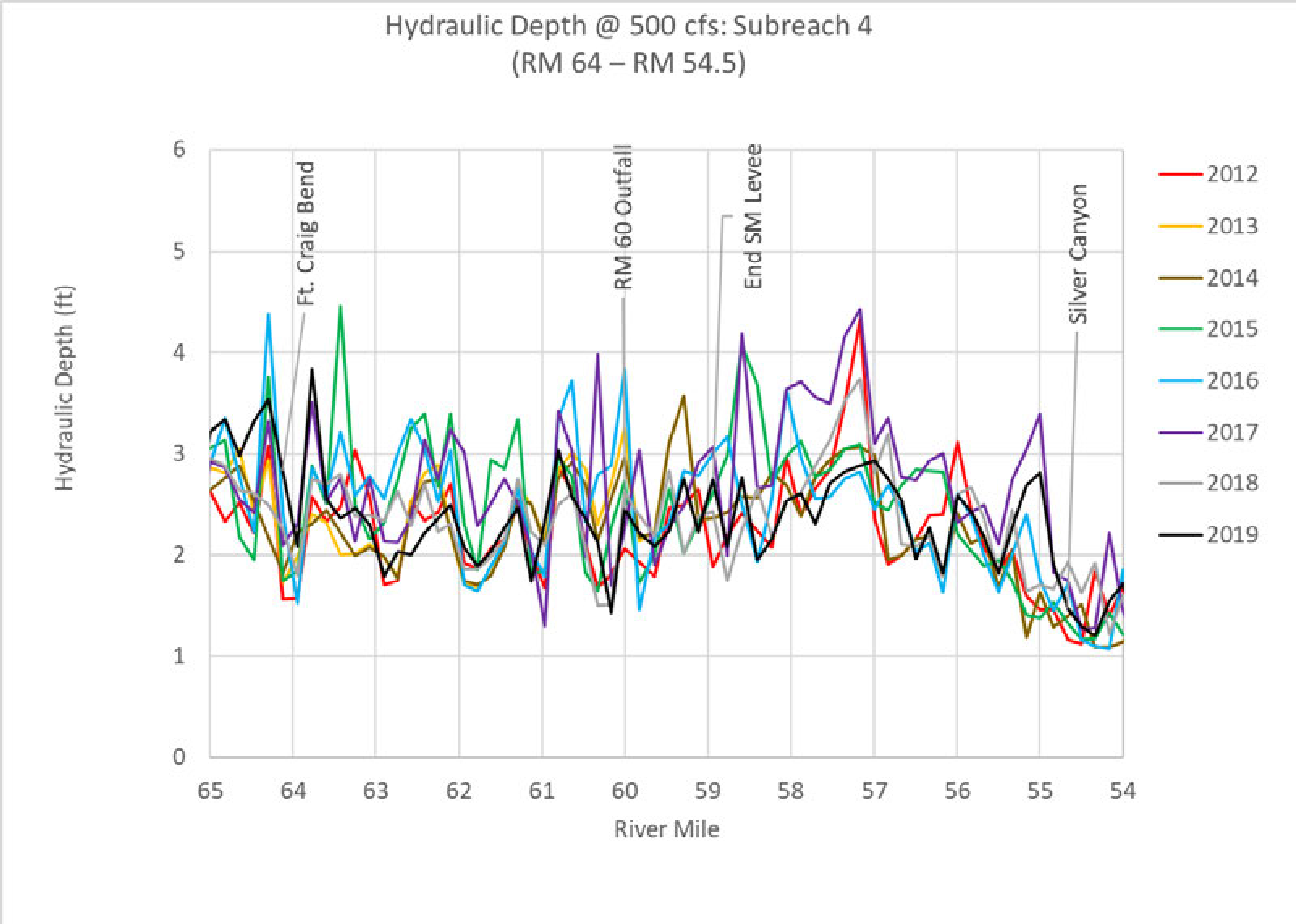

Figure 119: Simulated hydraulic depth profiles at the 500 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

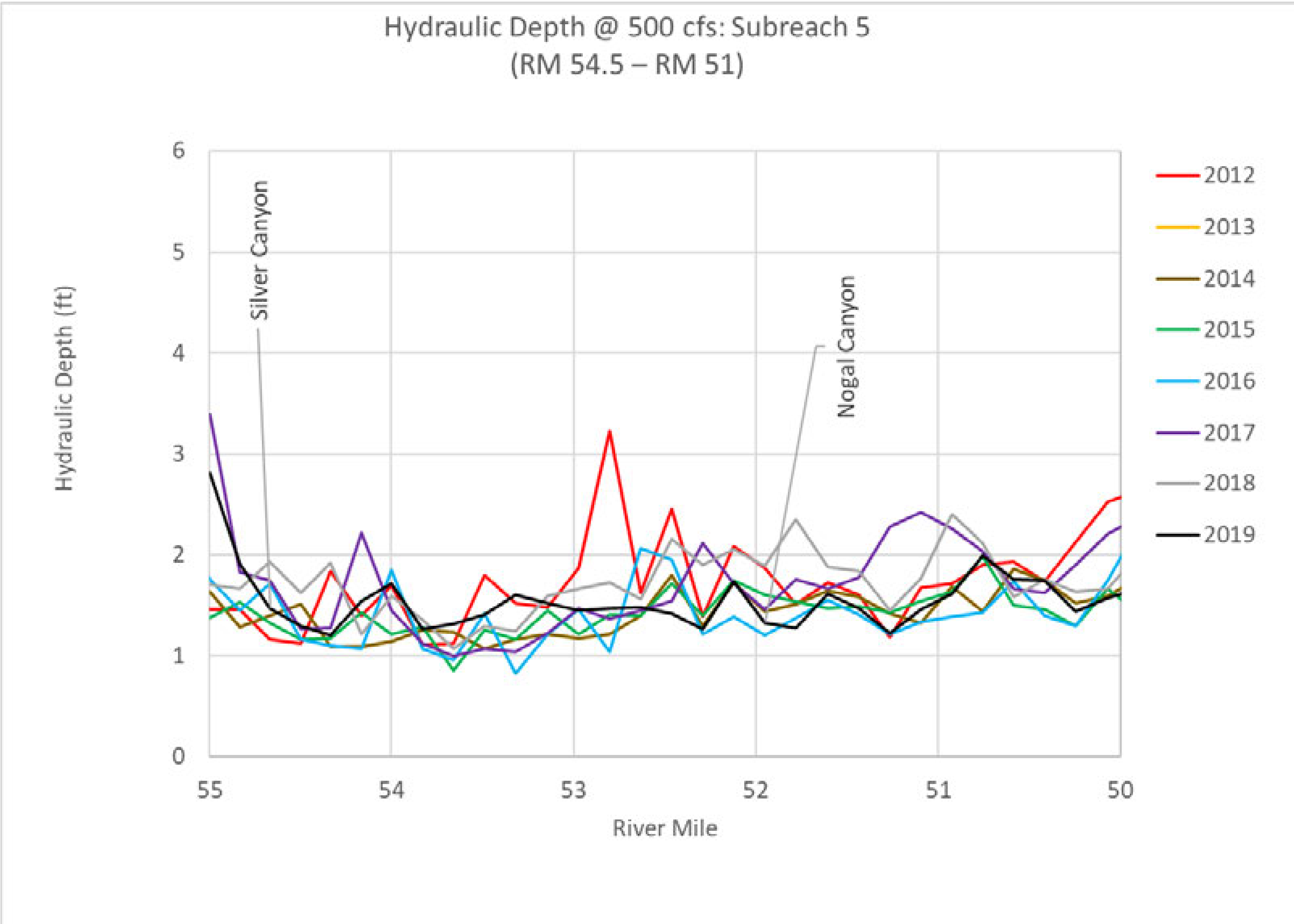

Figure 120: Simulated hydraulic depth profiles at the 500 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

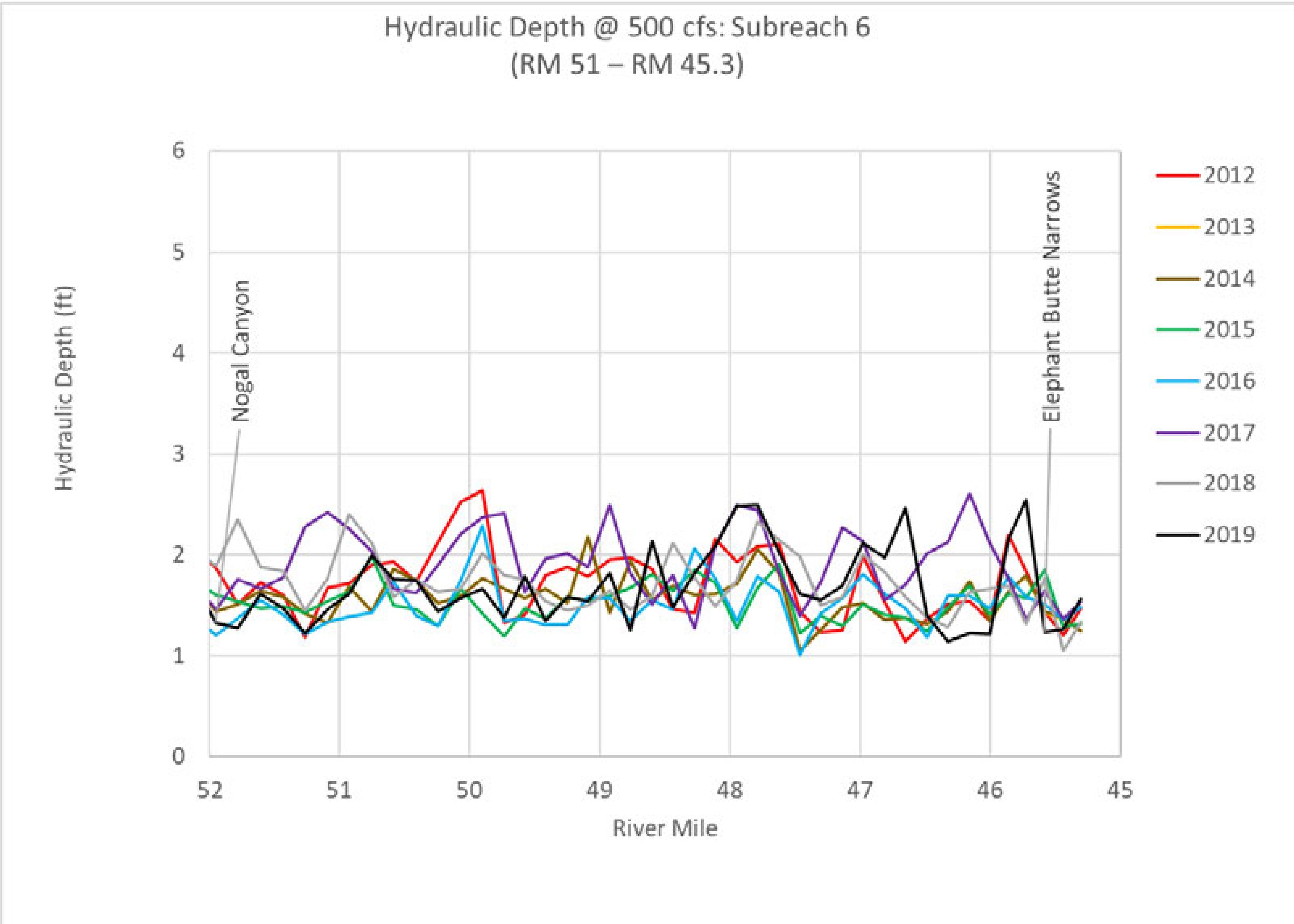

Figure 121: Simulated hydraulic depth profiles at the 500 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Hydraulic Depth at 2,300 cfs

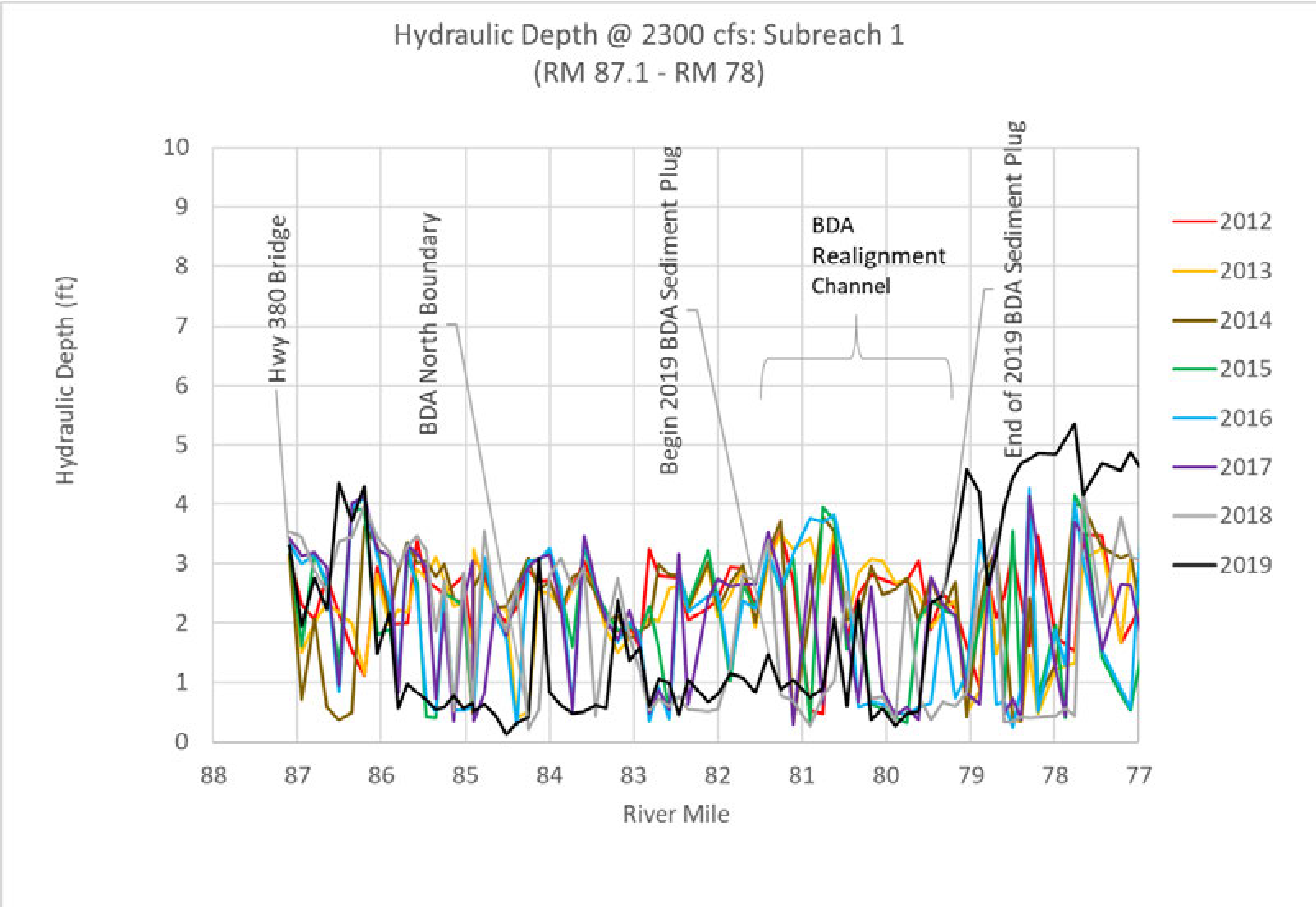

Figure 122: Simulated hydraulic depth profiles at the 2,300 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

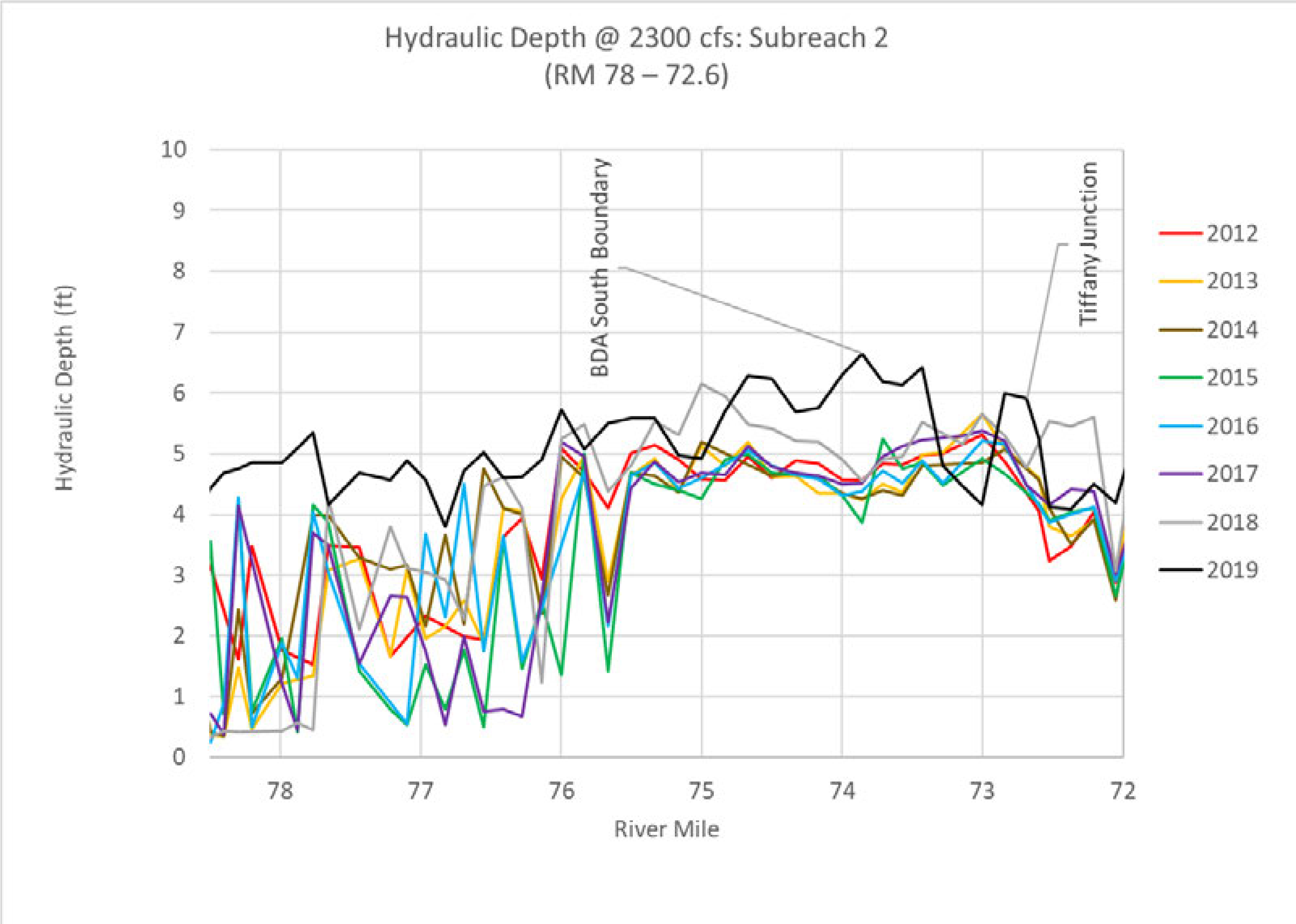

Figure 123: Simulated hydraulic depth profiles at the 2,300 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

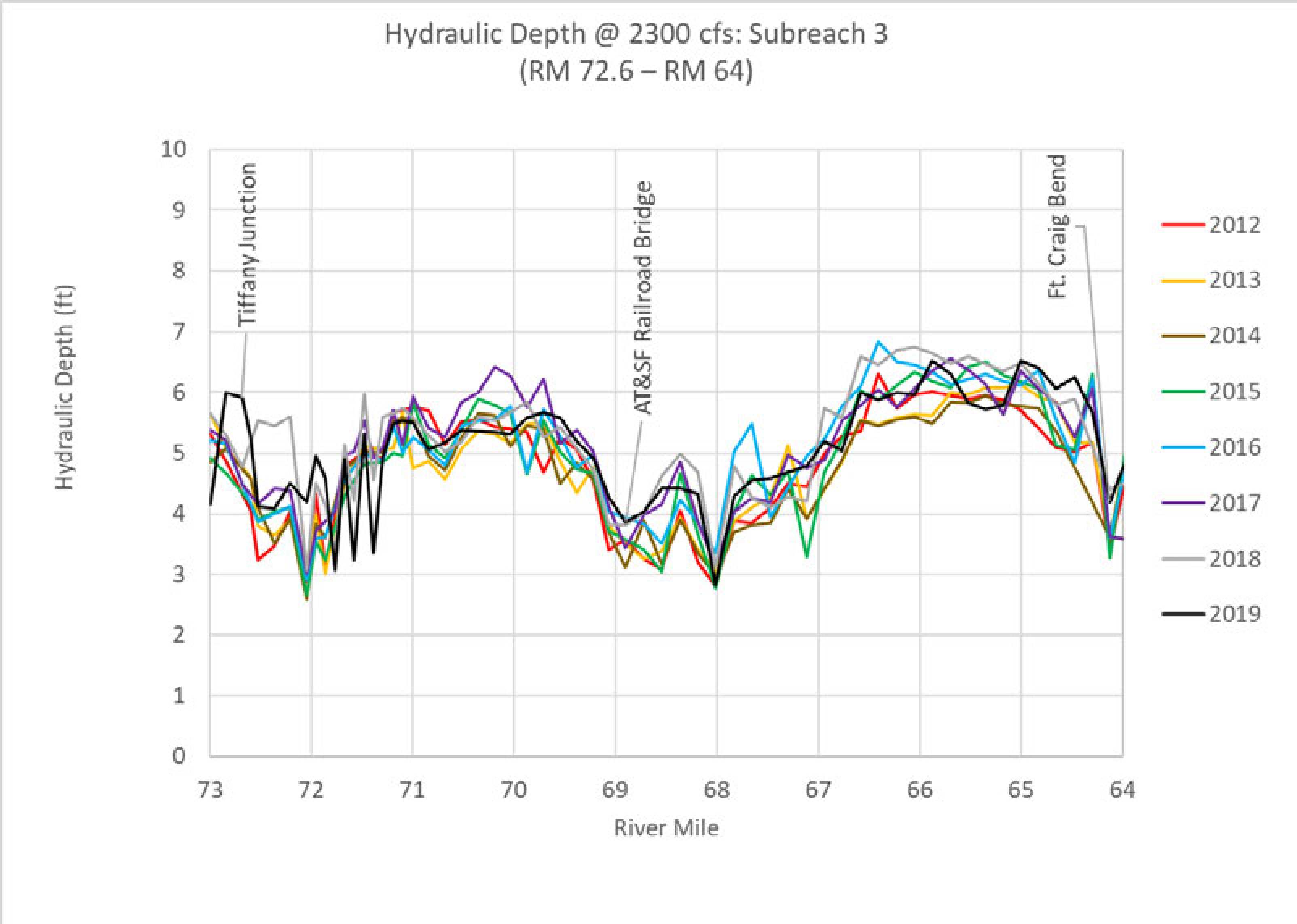

Figure 124: Simulated hydraulic depth profiles at the 2,300 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

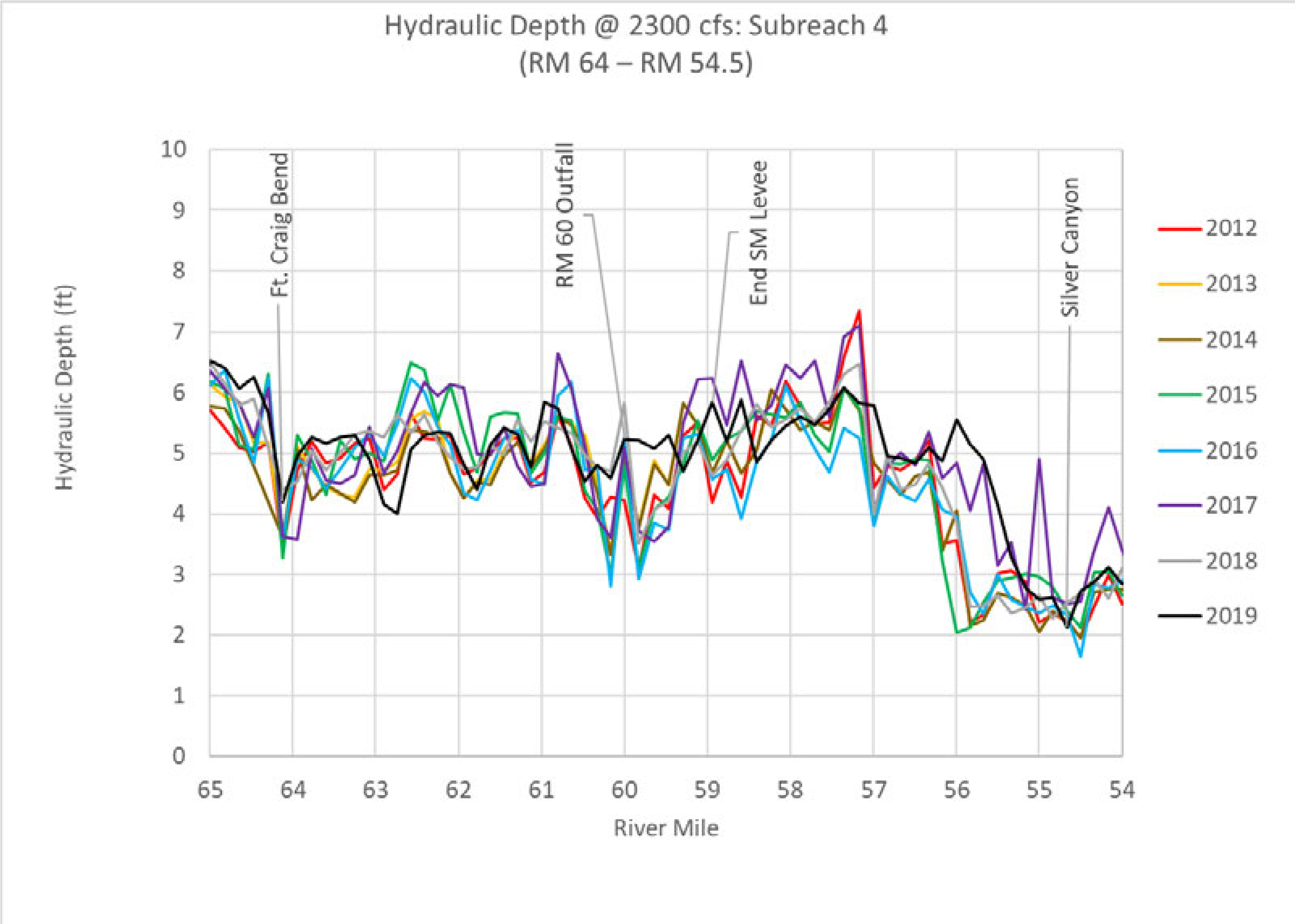

Figure 125: Simulated hydraulic depth profiles at the 2,300 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

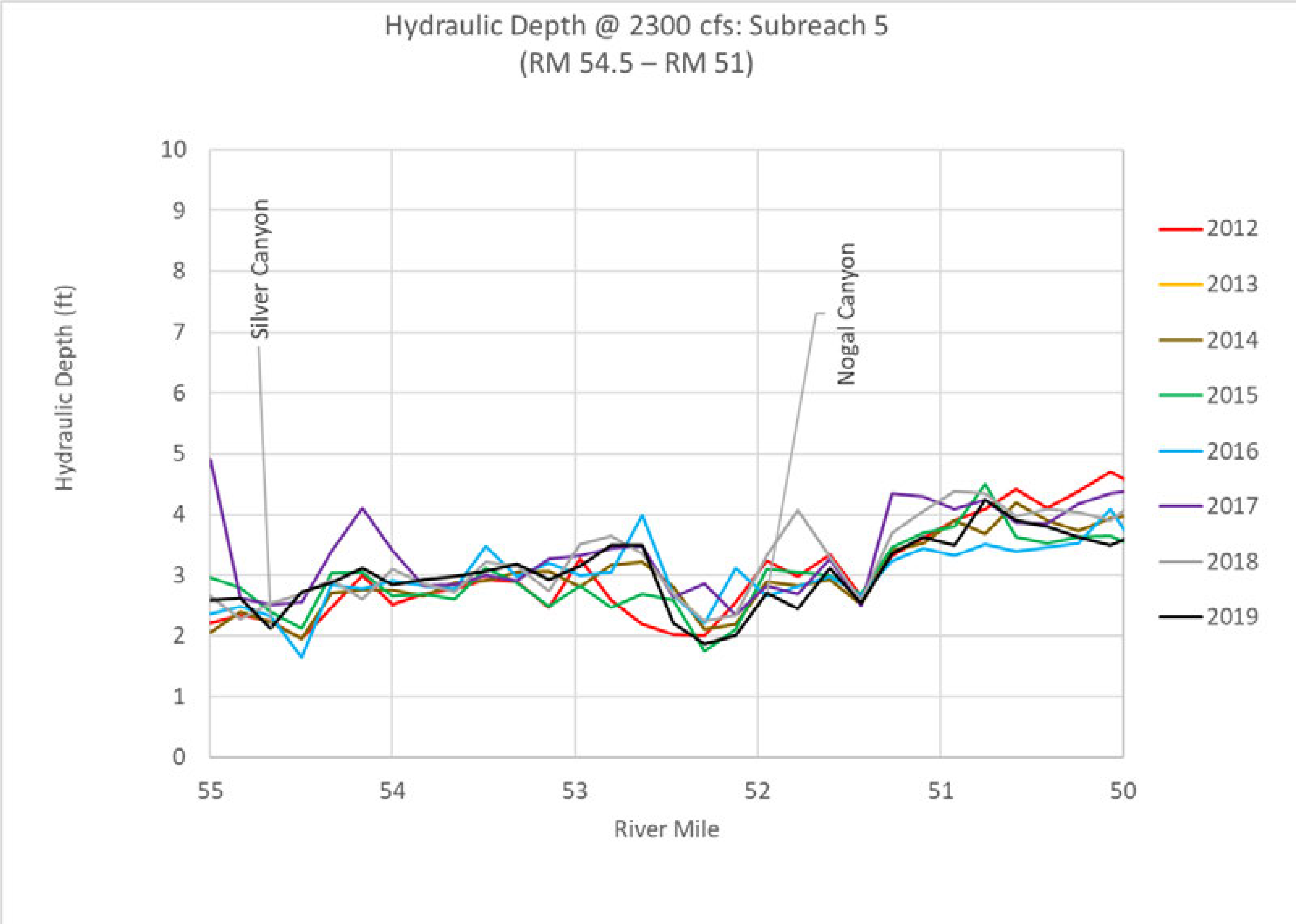

Figure 126: Simulated hydraulic depth profiles at the 2,300 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

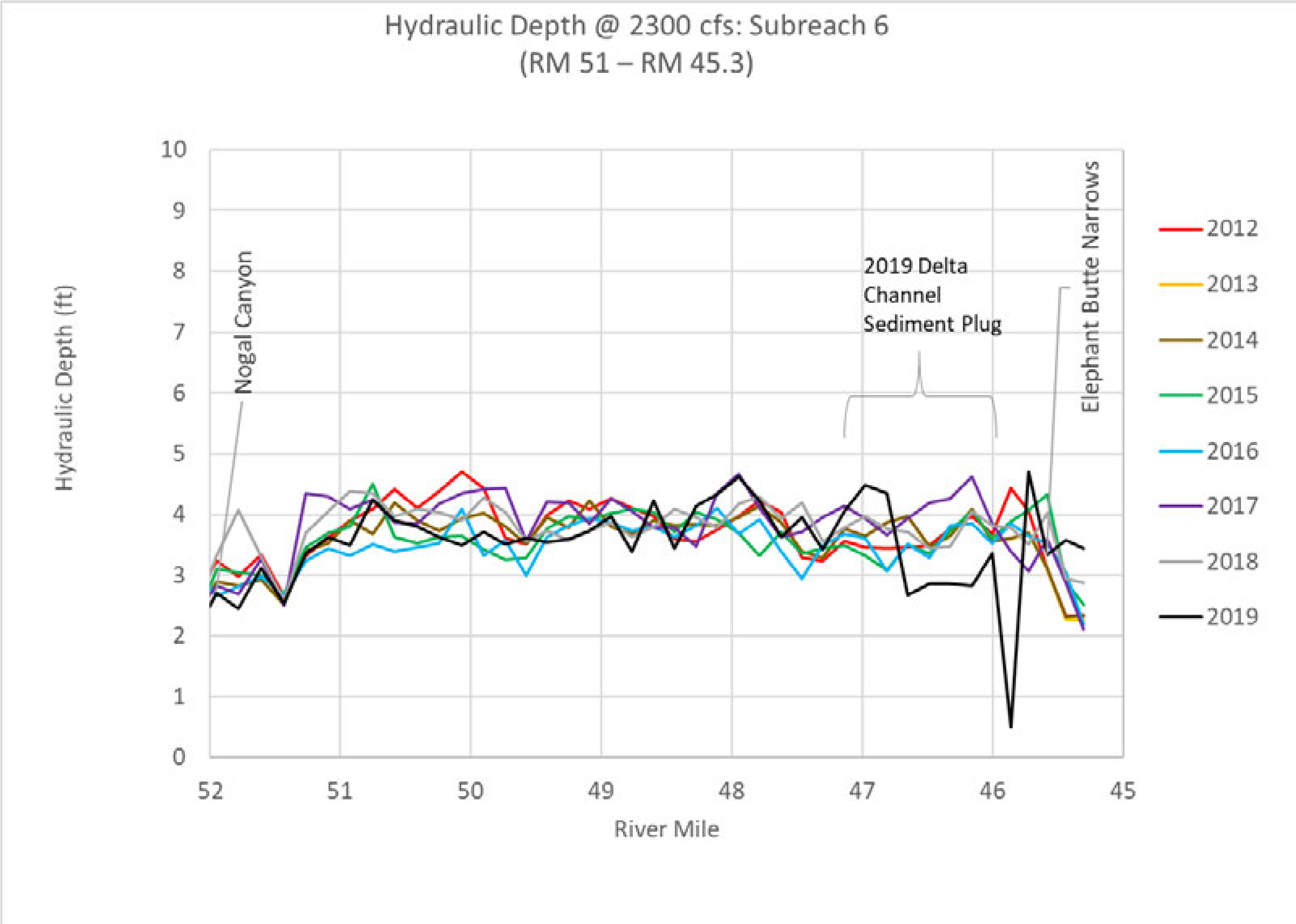

Figure 127: Simulated hydraulic depth profiles at the 2,300 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Channel Velocity at 500 cfs

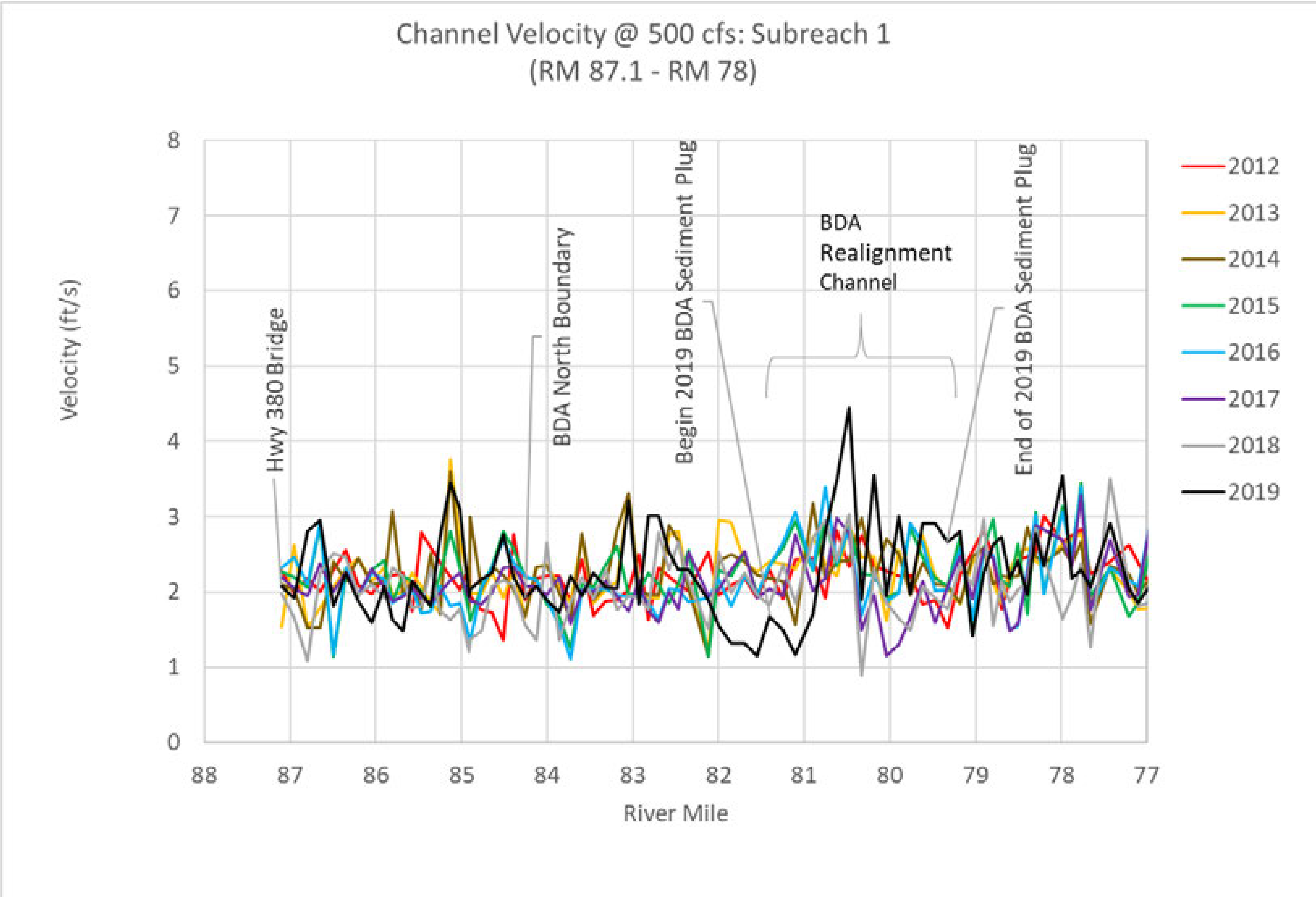

Figure 128: Simulated channel velocity profiles at the 500 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

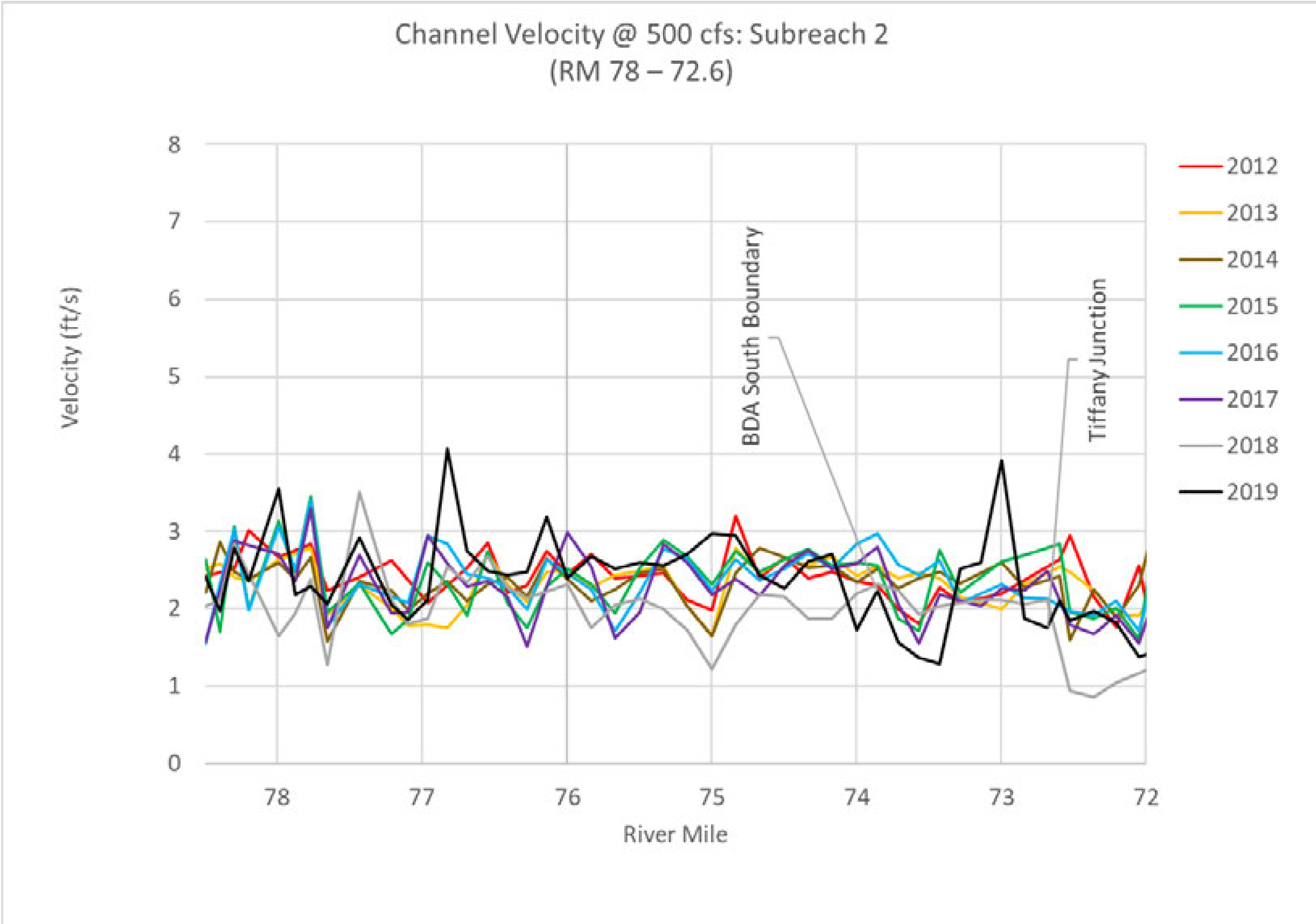

Figure 129: Simulated channel velocity profiles at the 500 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

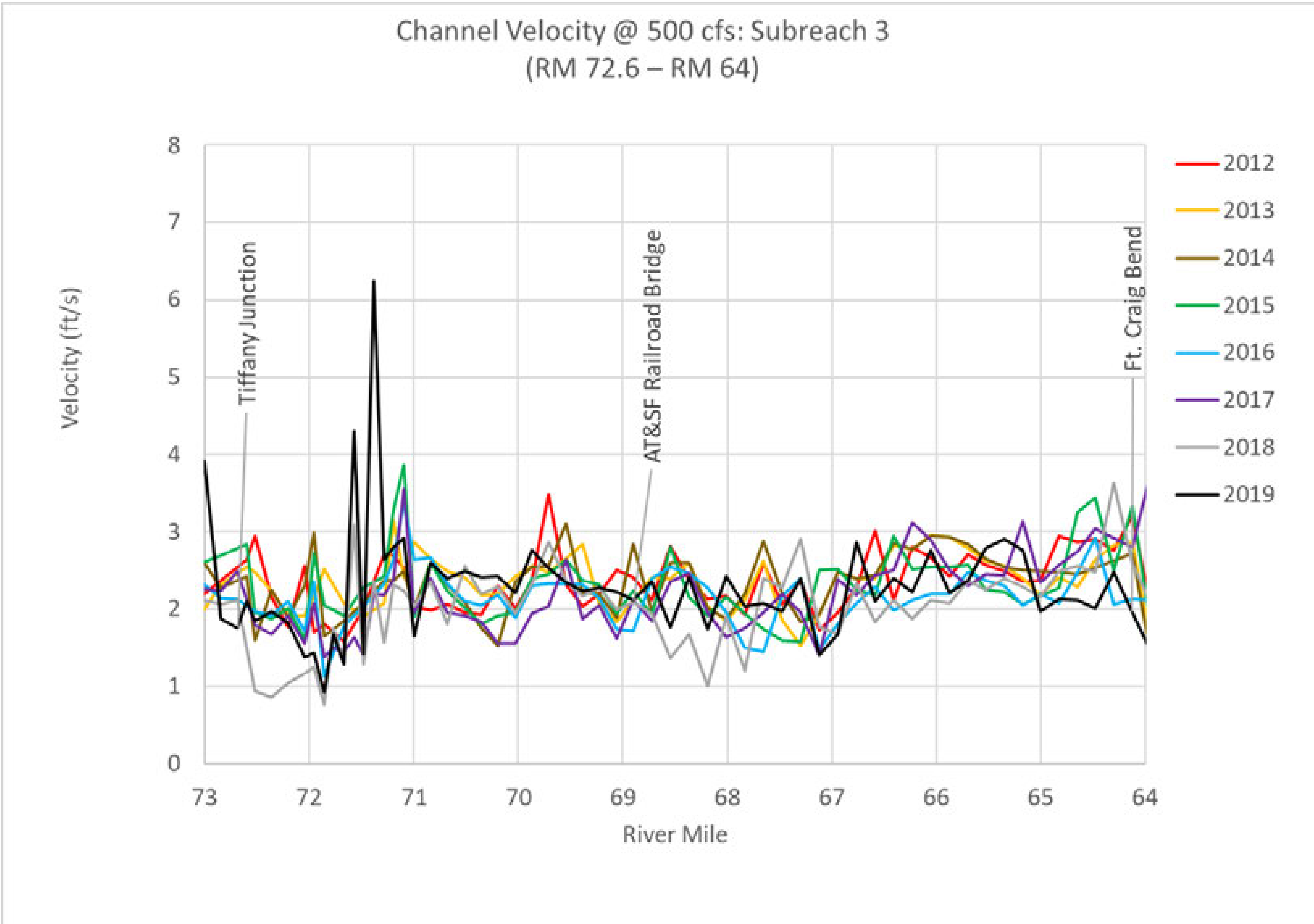

Figure 130: Simulated channel velocity profiles at the 500 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

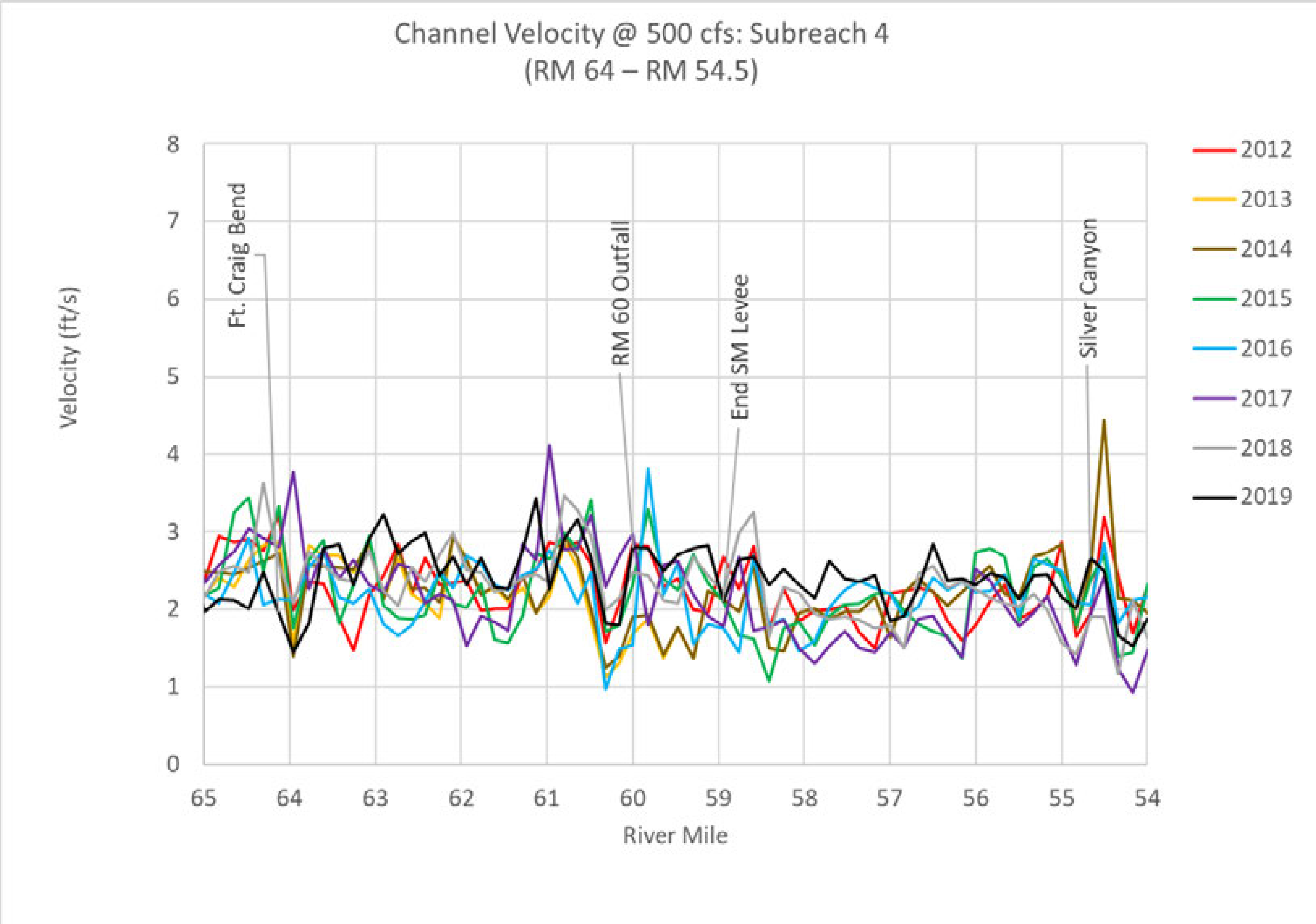

Figure 131: Simulated channel velocity profiles at the 500 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

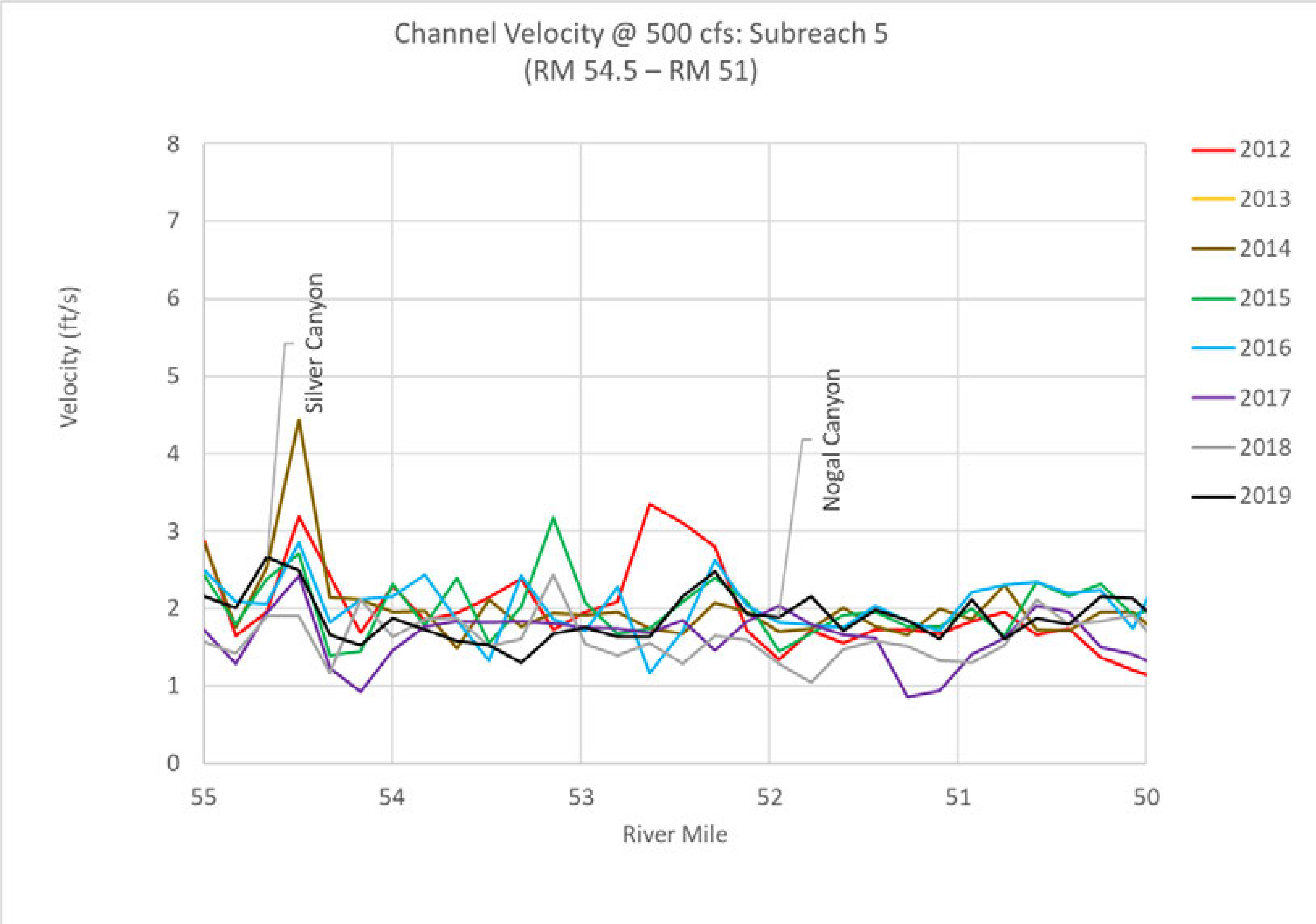

Figure 132: Simulated channel velocity profiles at the 500 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

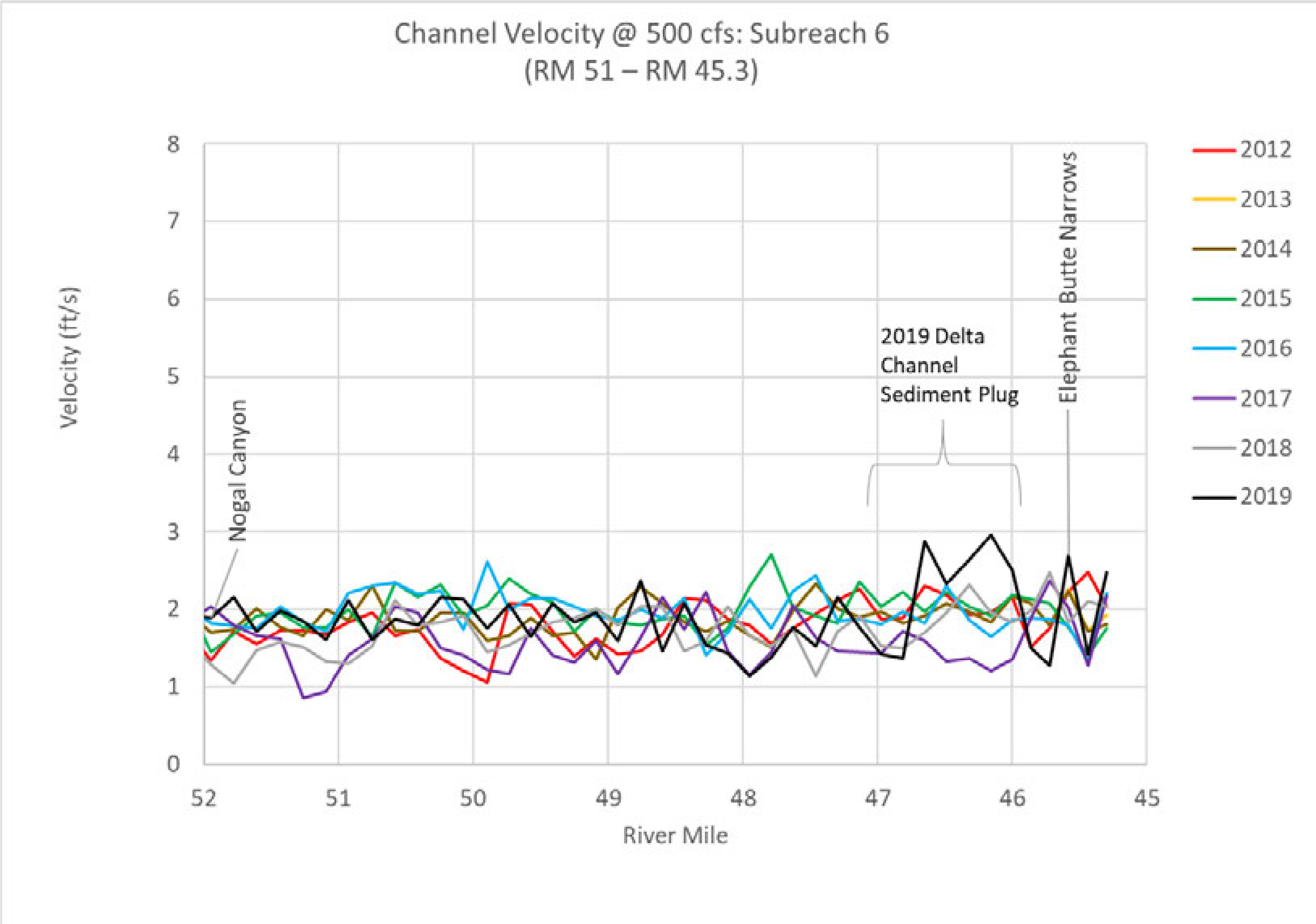

Figure 133: Simulated channel velocity profiles at the 500 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Channel Velocity at 2,300 cfs

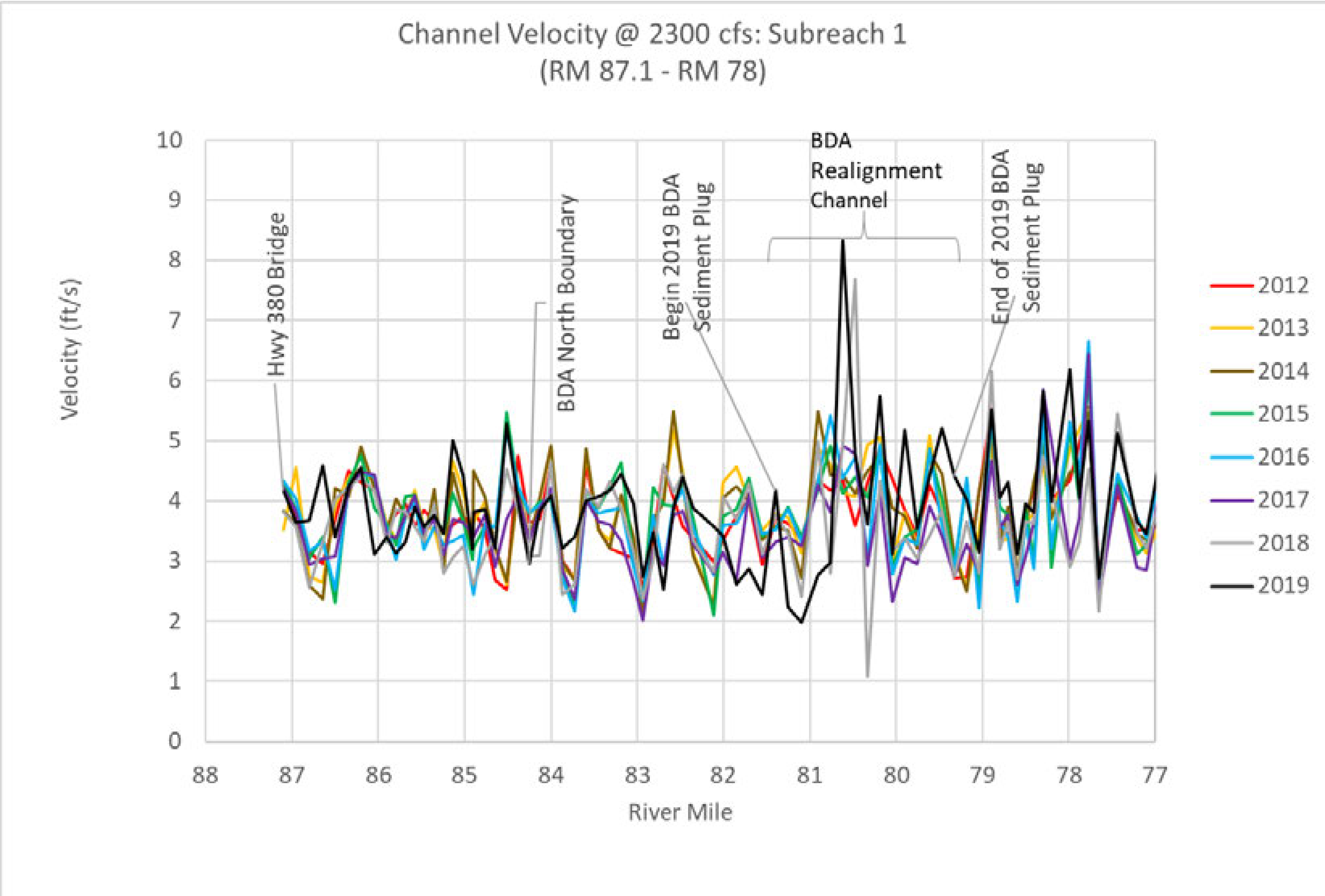

Figure 134: Simulated channel velocity profiles at the 2,300 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

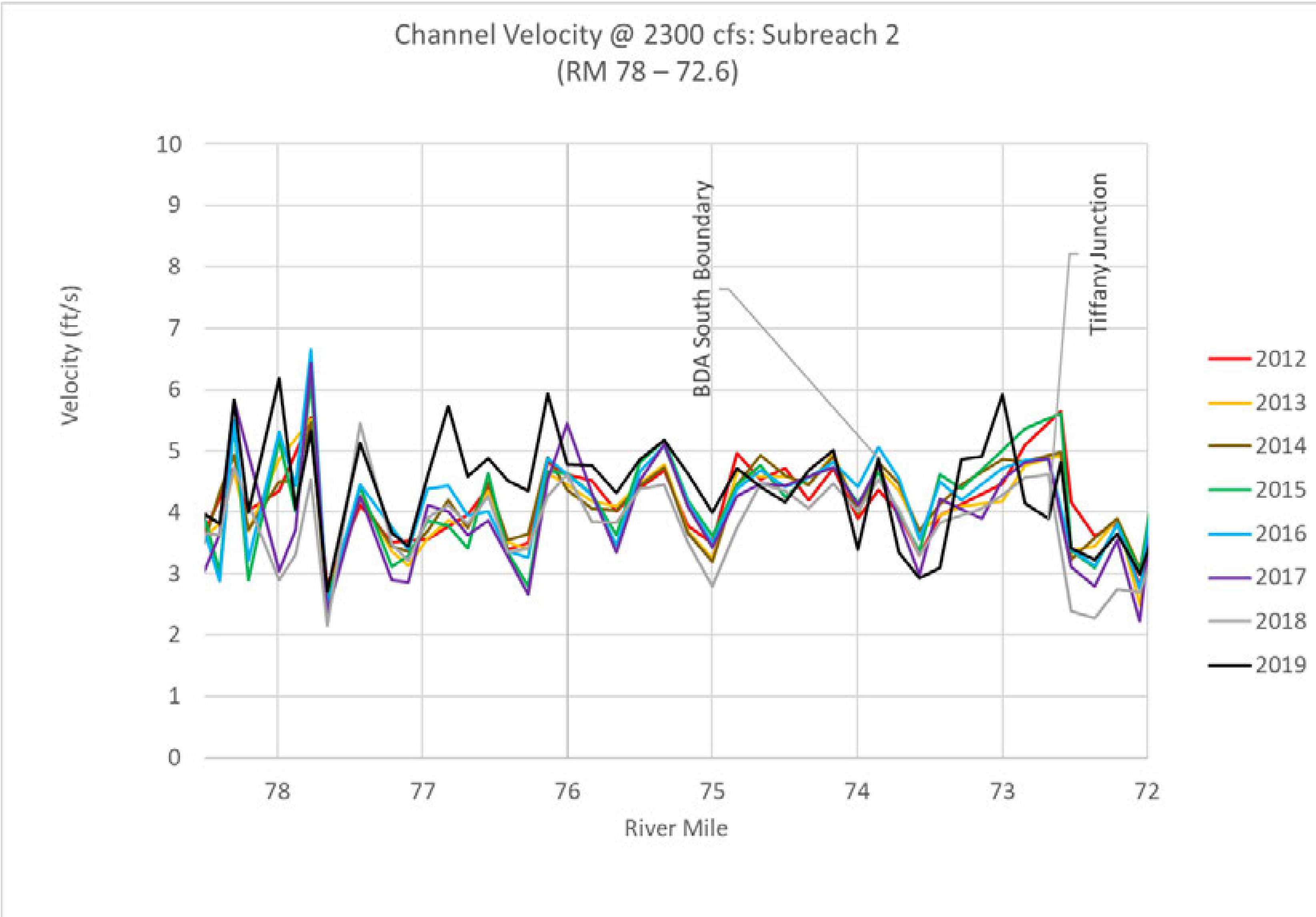

Figure 135: Simulated channel velocity profiles at the 2,300 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

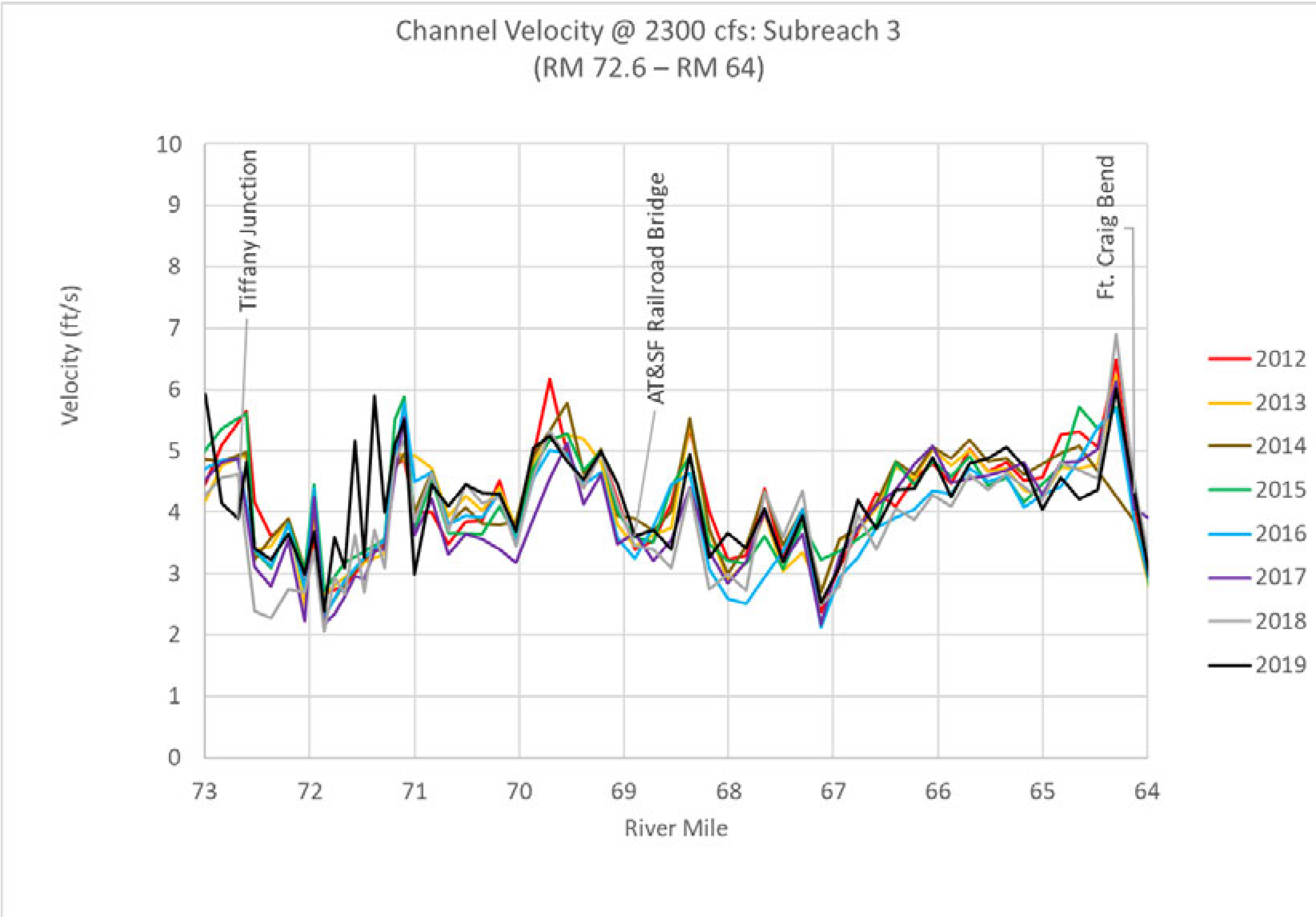

Figure 136: Simulated channel velocity profiles at the 2,300 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

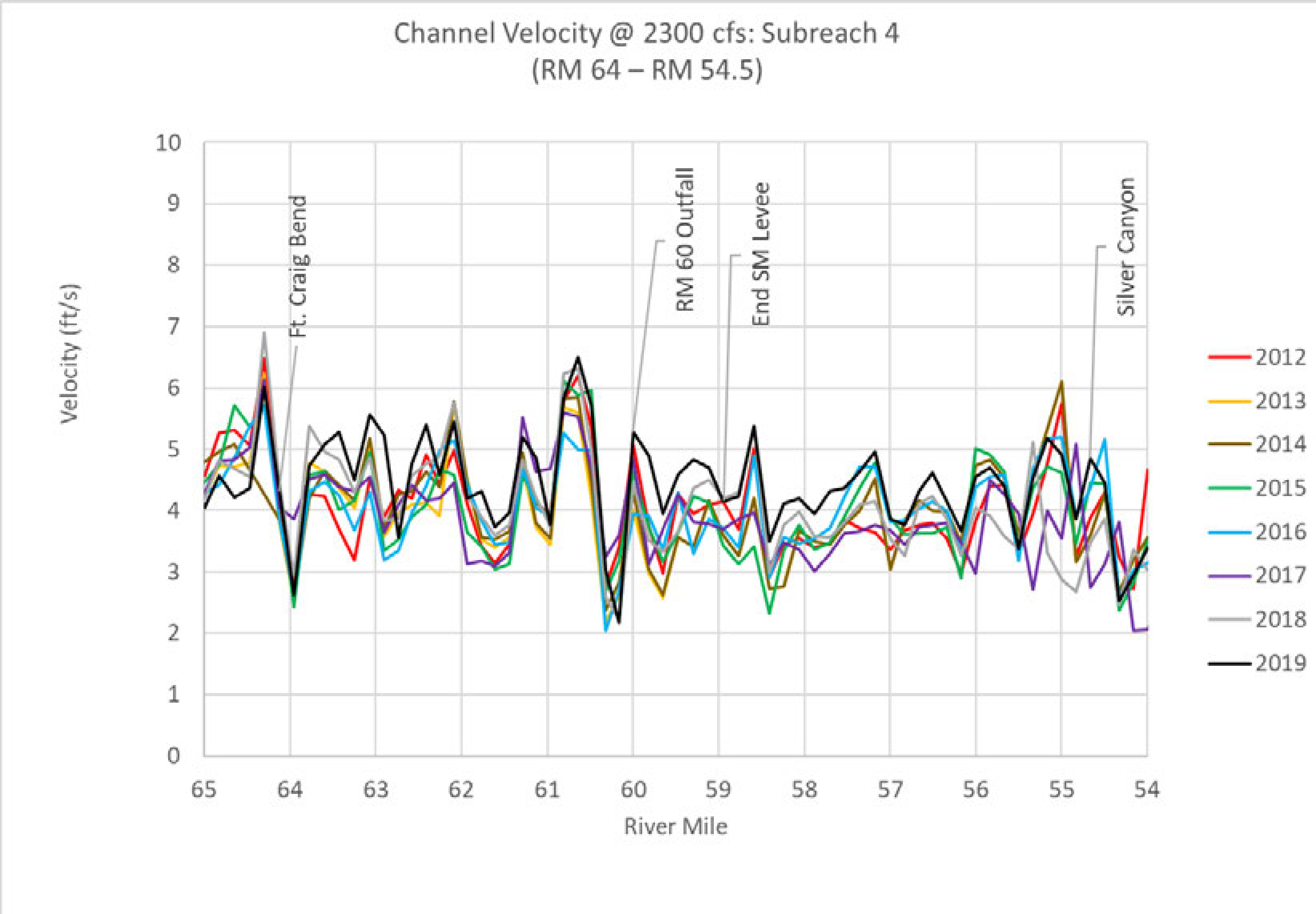

Figure 137: Simulated channel velocity profiles at the 2,300 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

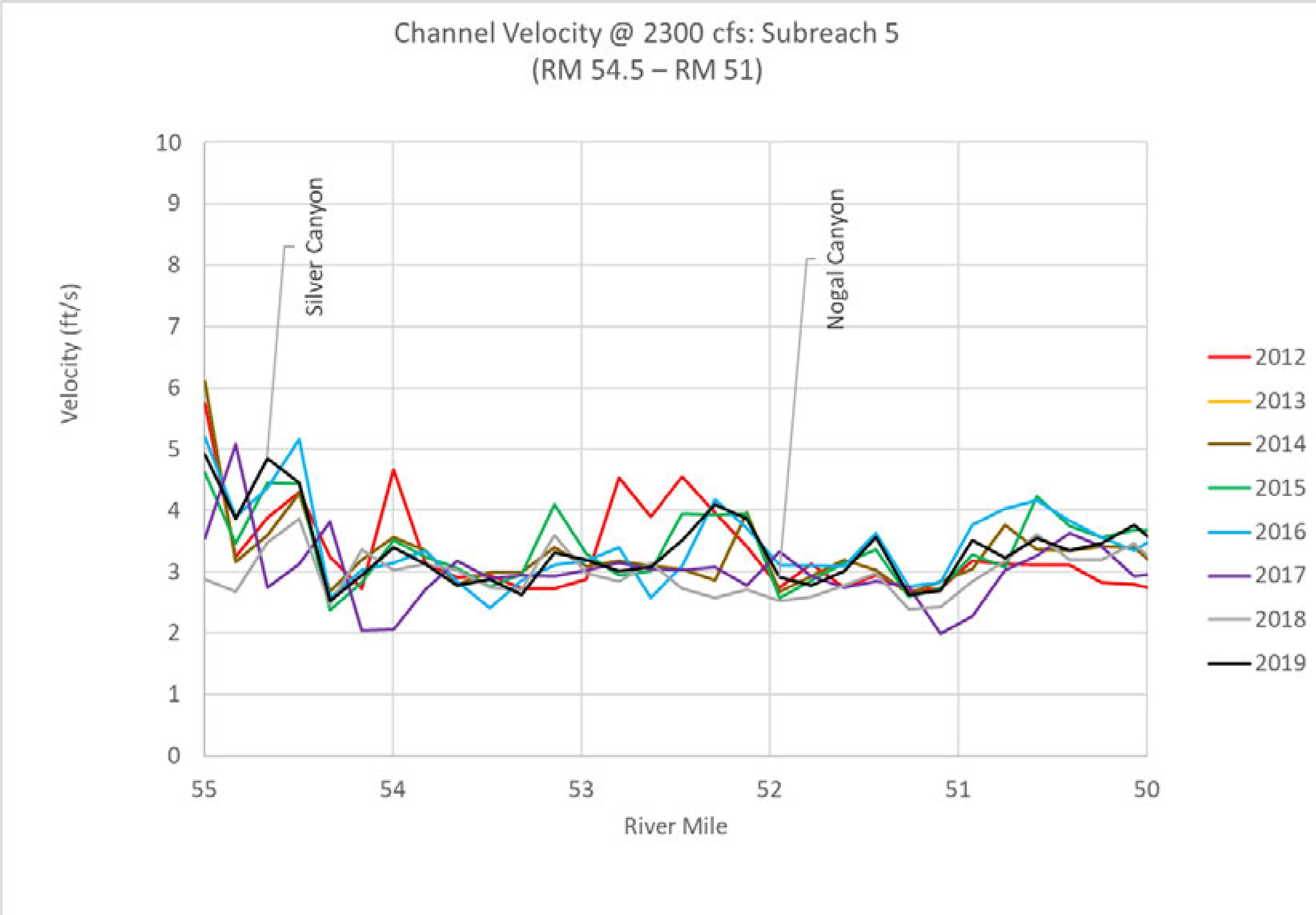

Figure 138: Simulated channel velocity profiles at the 2,300 cfs flow rate Subreach 5 (RM 54.5 – RM 51).

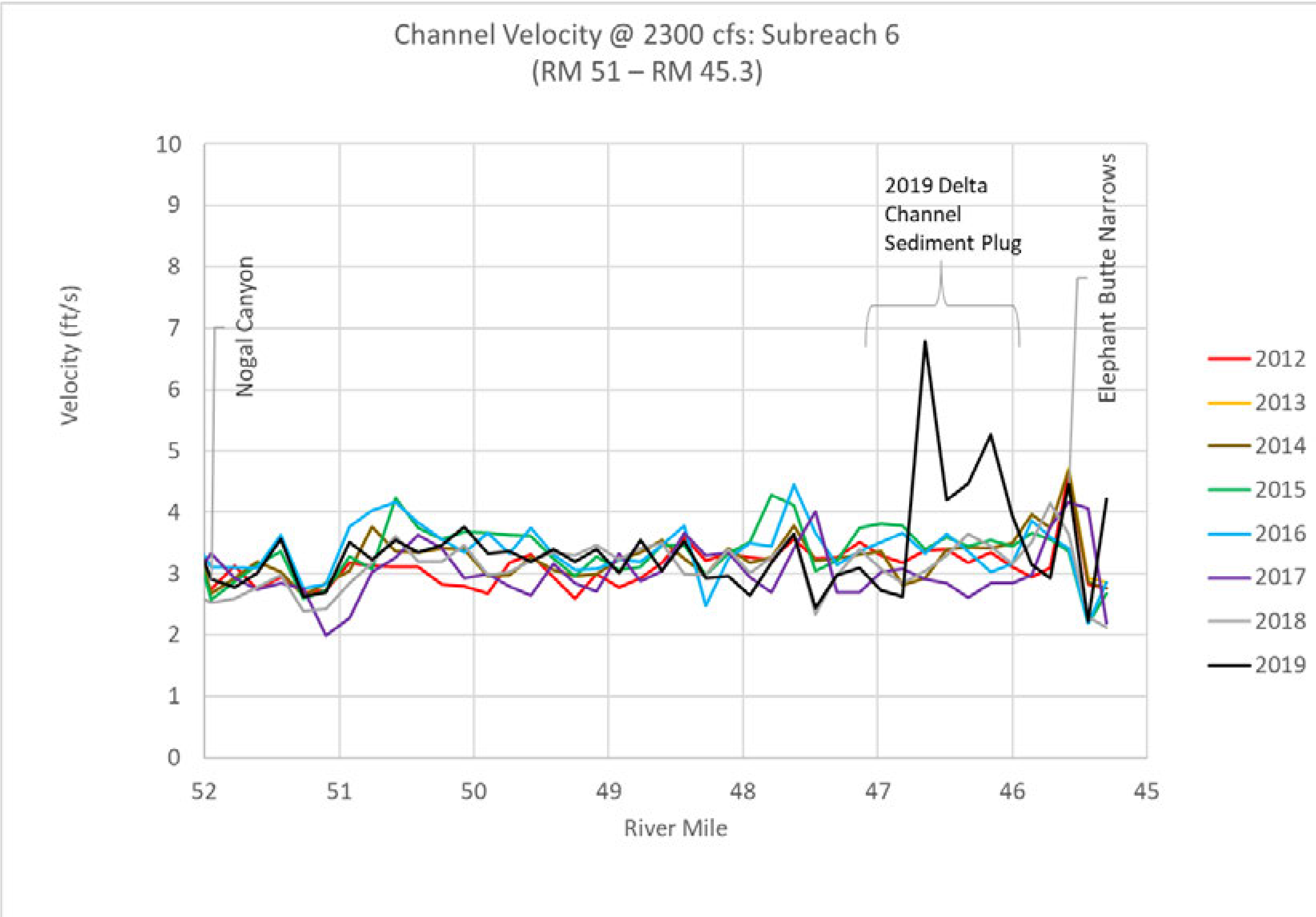

Figure 139: Simulated channel velocity profiles at the 2,300 cfs flow rate Subreach 6 (RM 51 – RM 45.3).

Channel Shear Force at 500 cfs

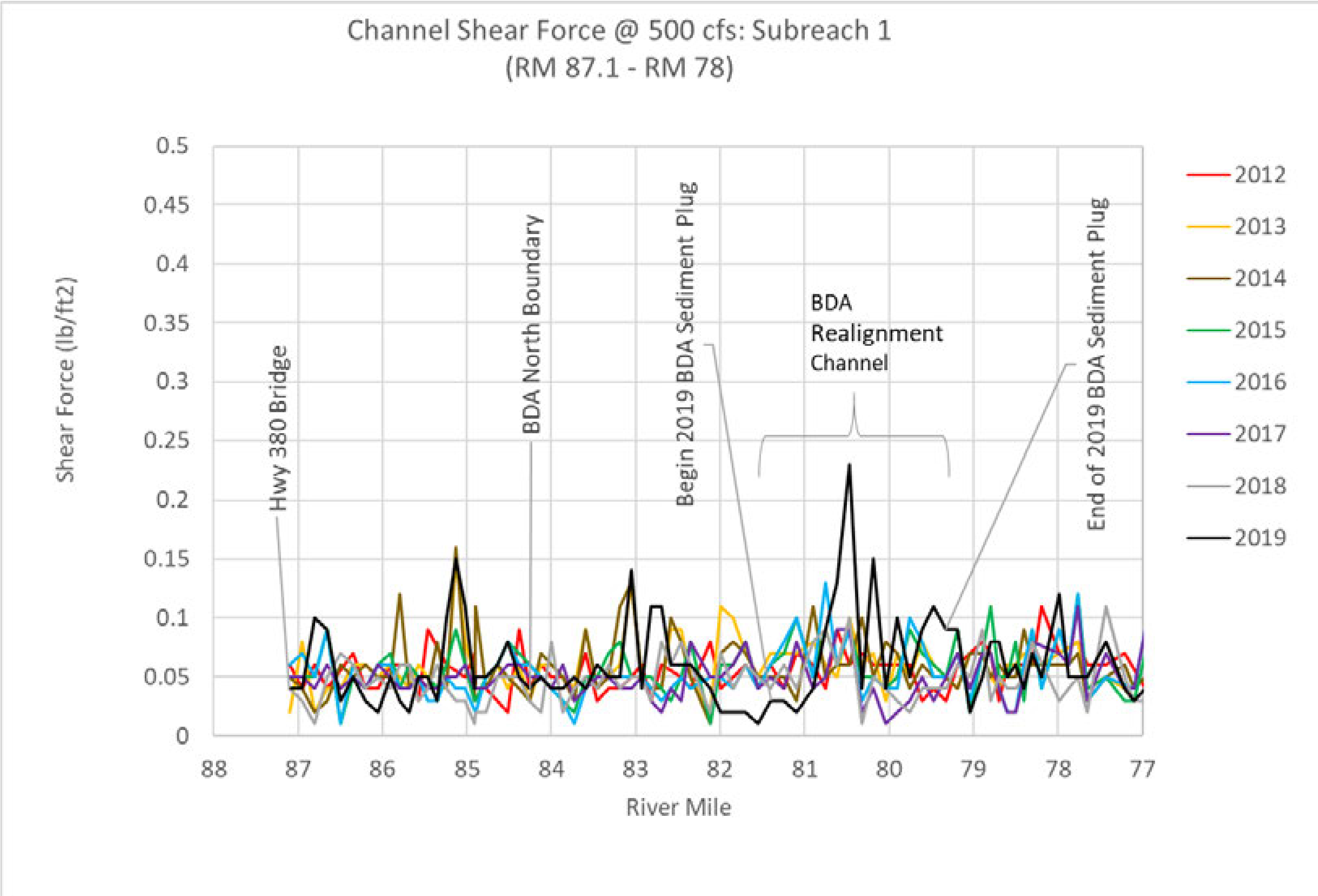

Figure 140: Simulated channel shear force profiles at the 500 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

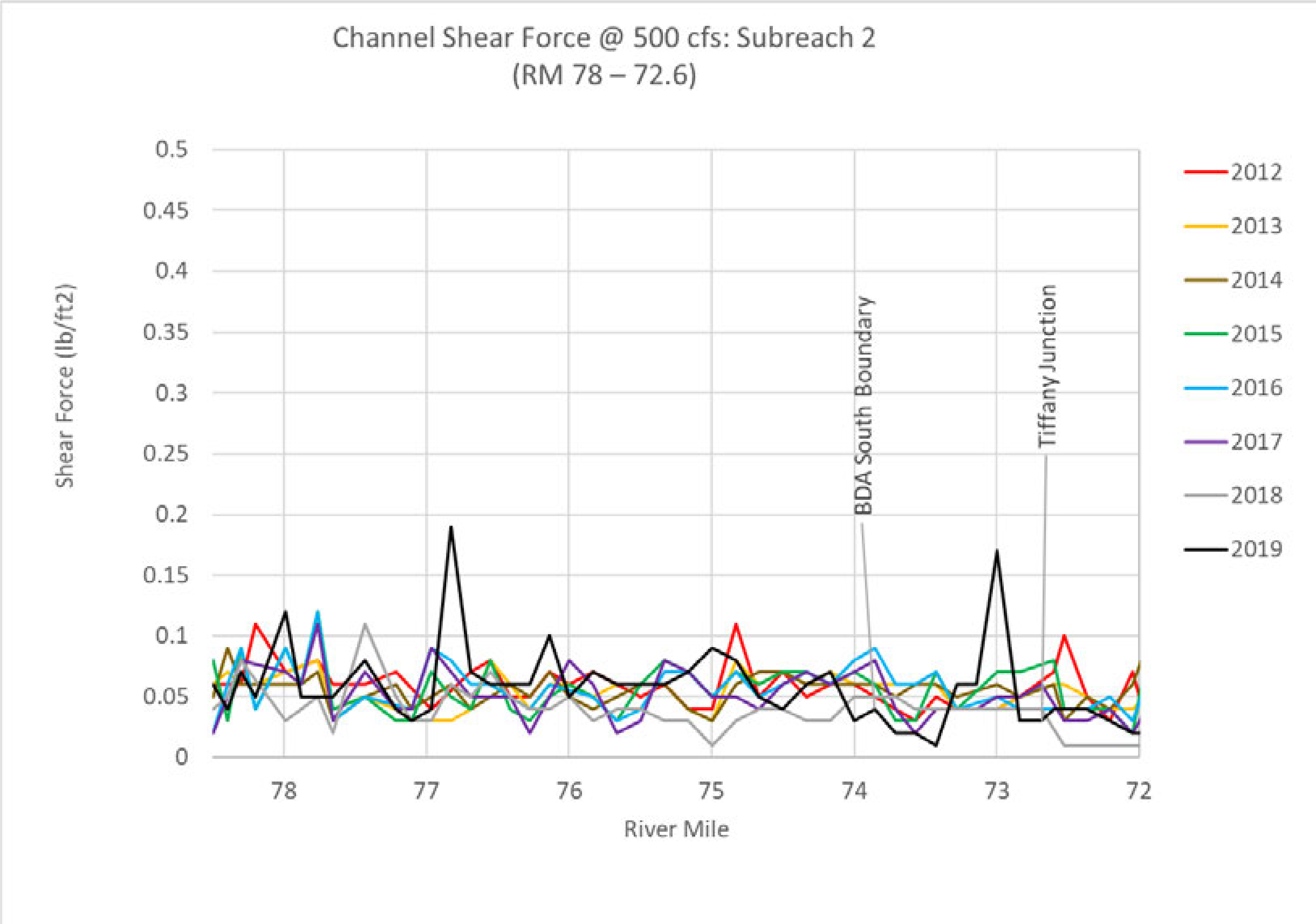

Figure 141: Simulated channel shear force profiles at the 500 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

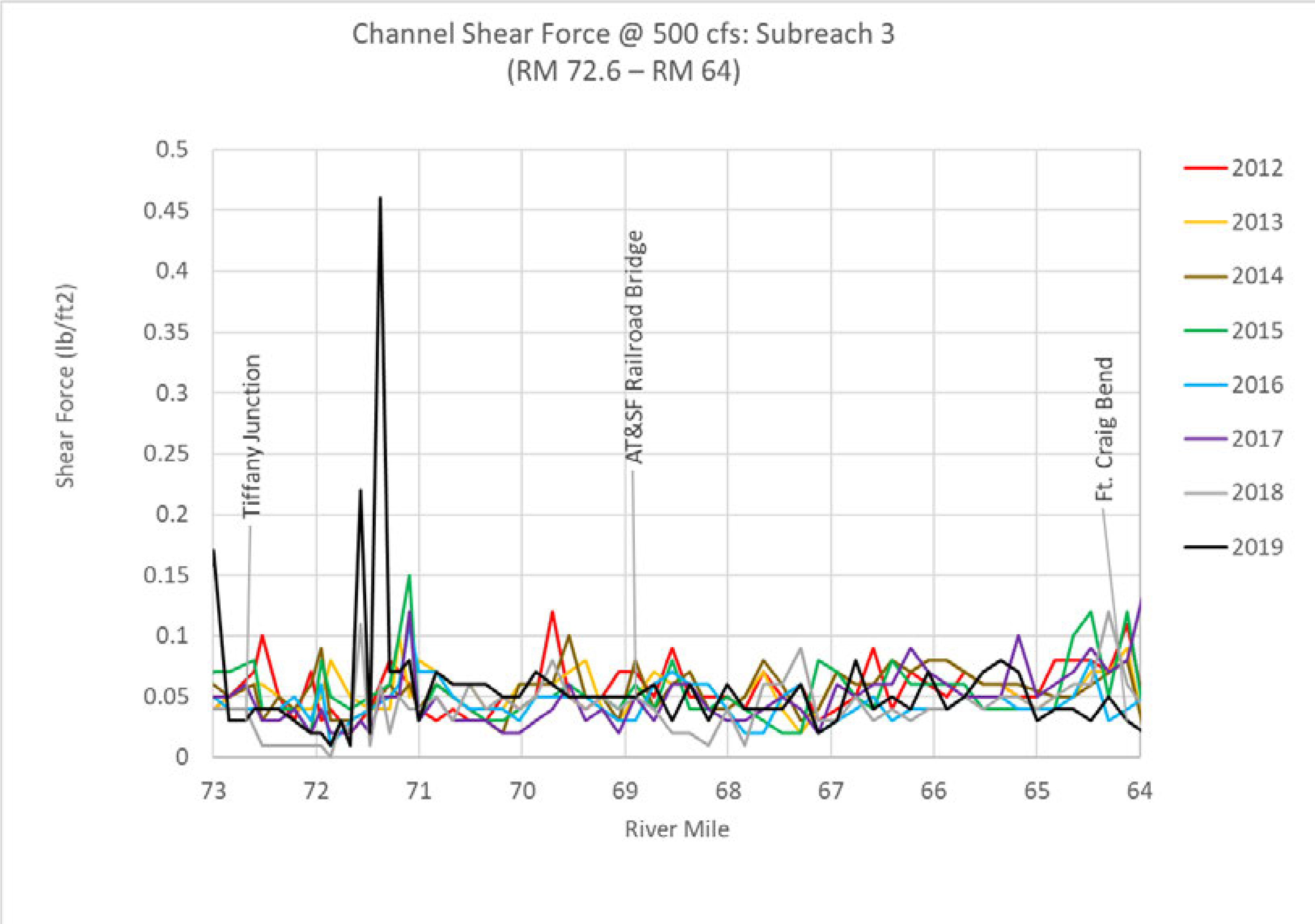

Figure 142: Simulated channel shear force profiles at the 500 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

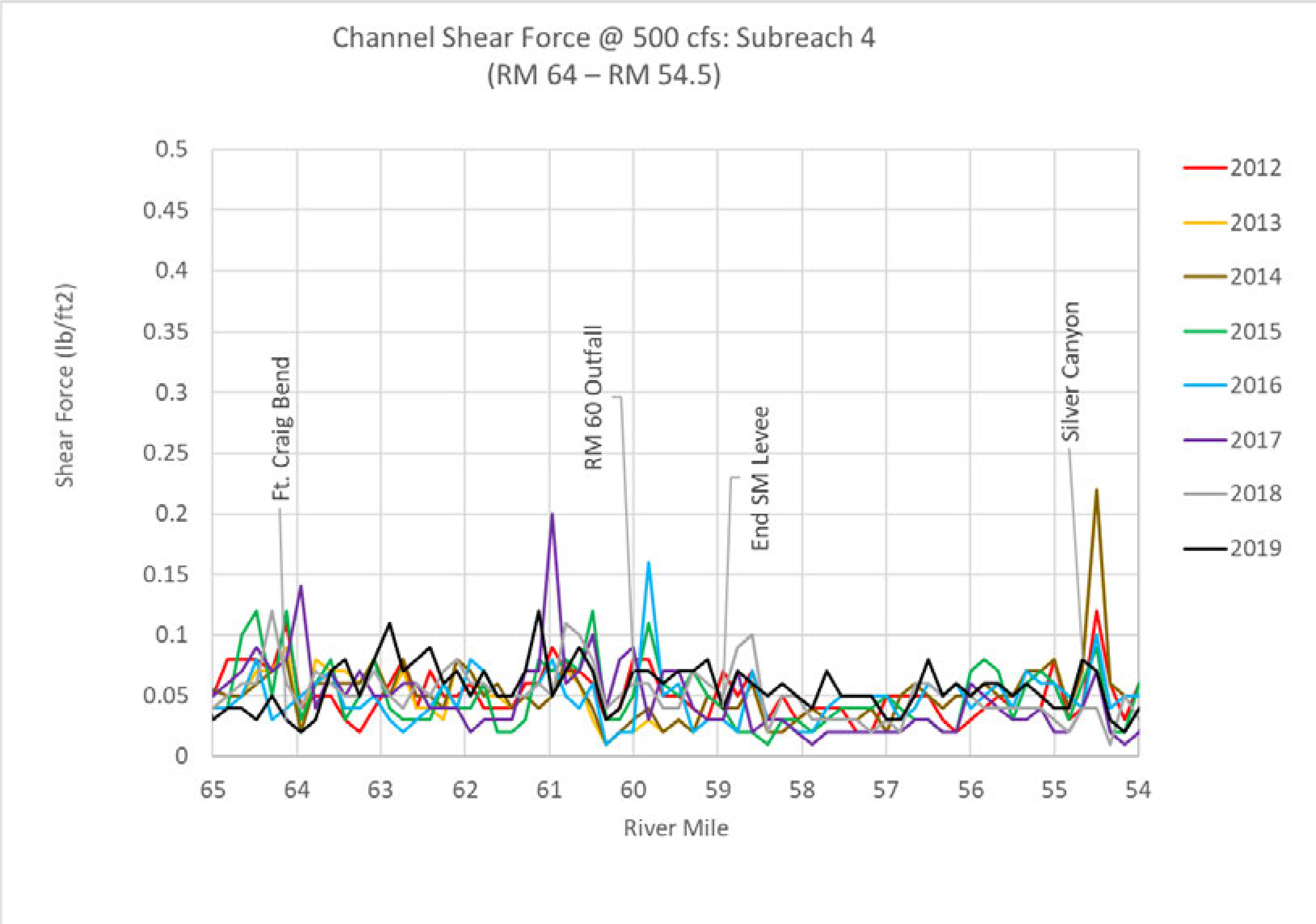

Figure 143: Simulated channel shear force profiles at the 500 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

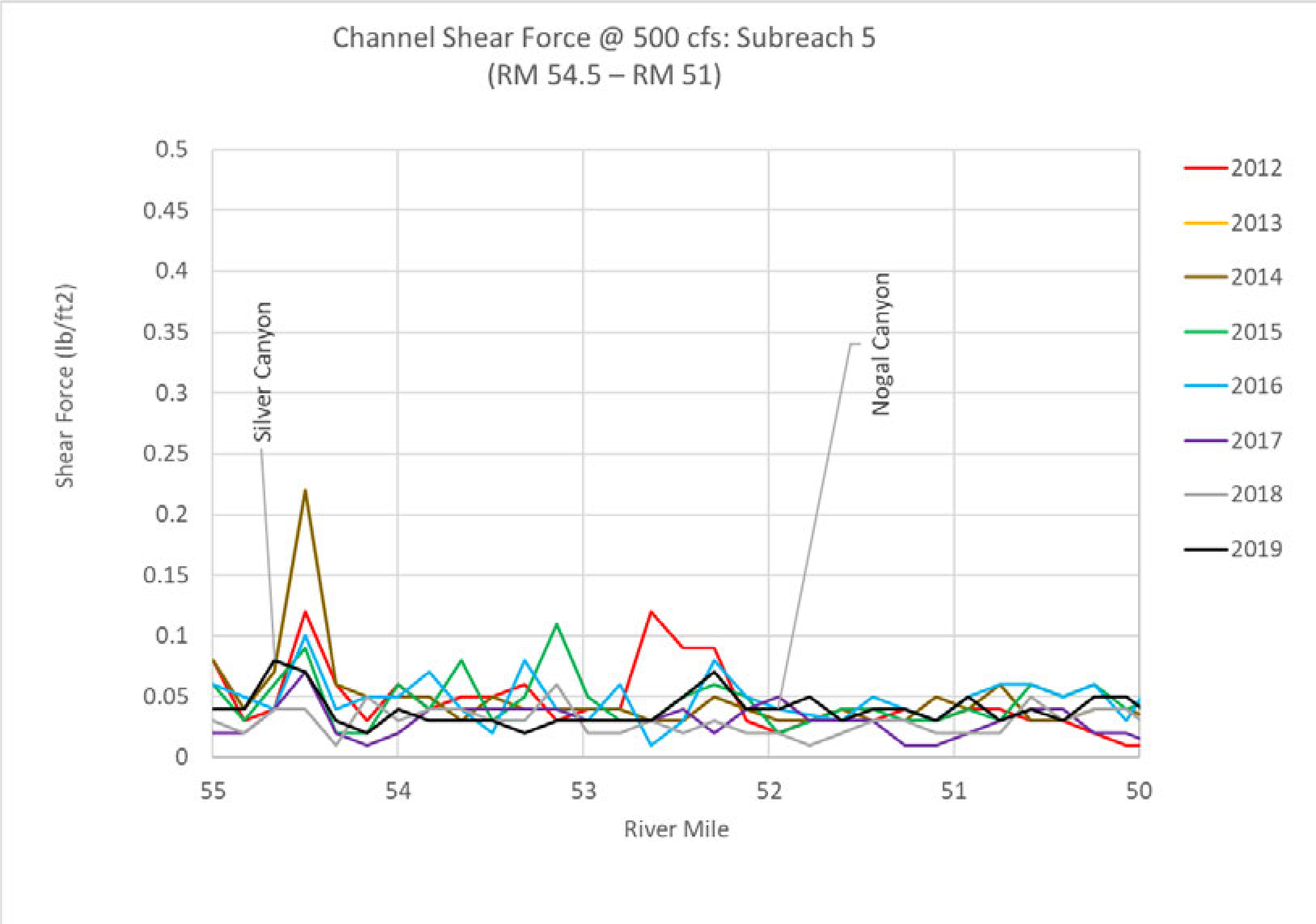

Figure 144: Simulated channel shear force profiles at the 500 cfs flow rate for Subreach 5 (RM 54.5 – RM 51).

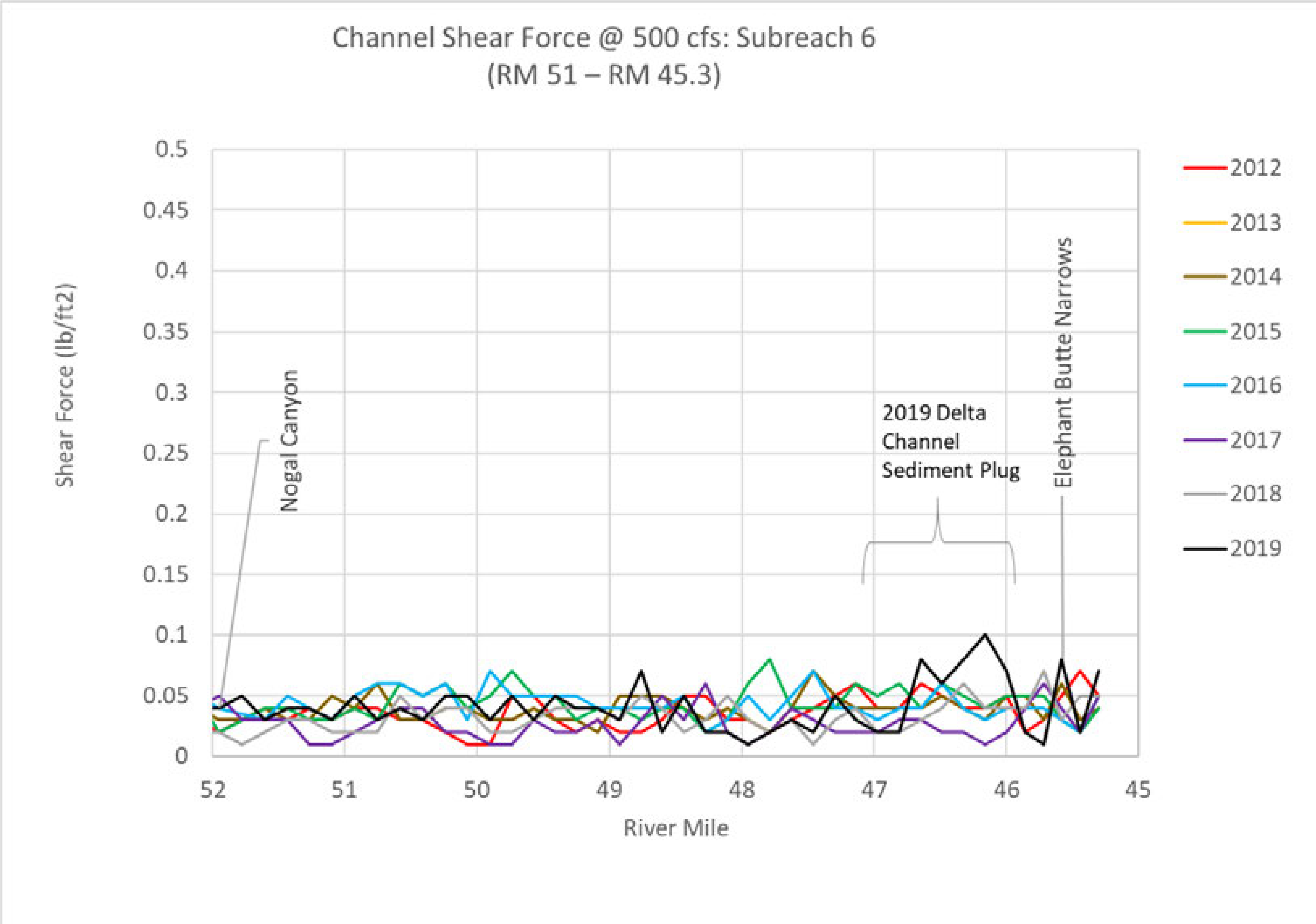

Figure 145: Simulated channel shear force profiles at the 500 cfs flow rate for Subreach 6 (RM 51 – RM 45.3).

Channel Shear Force at 2,300 cfs

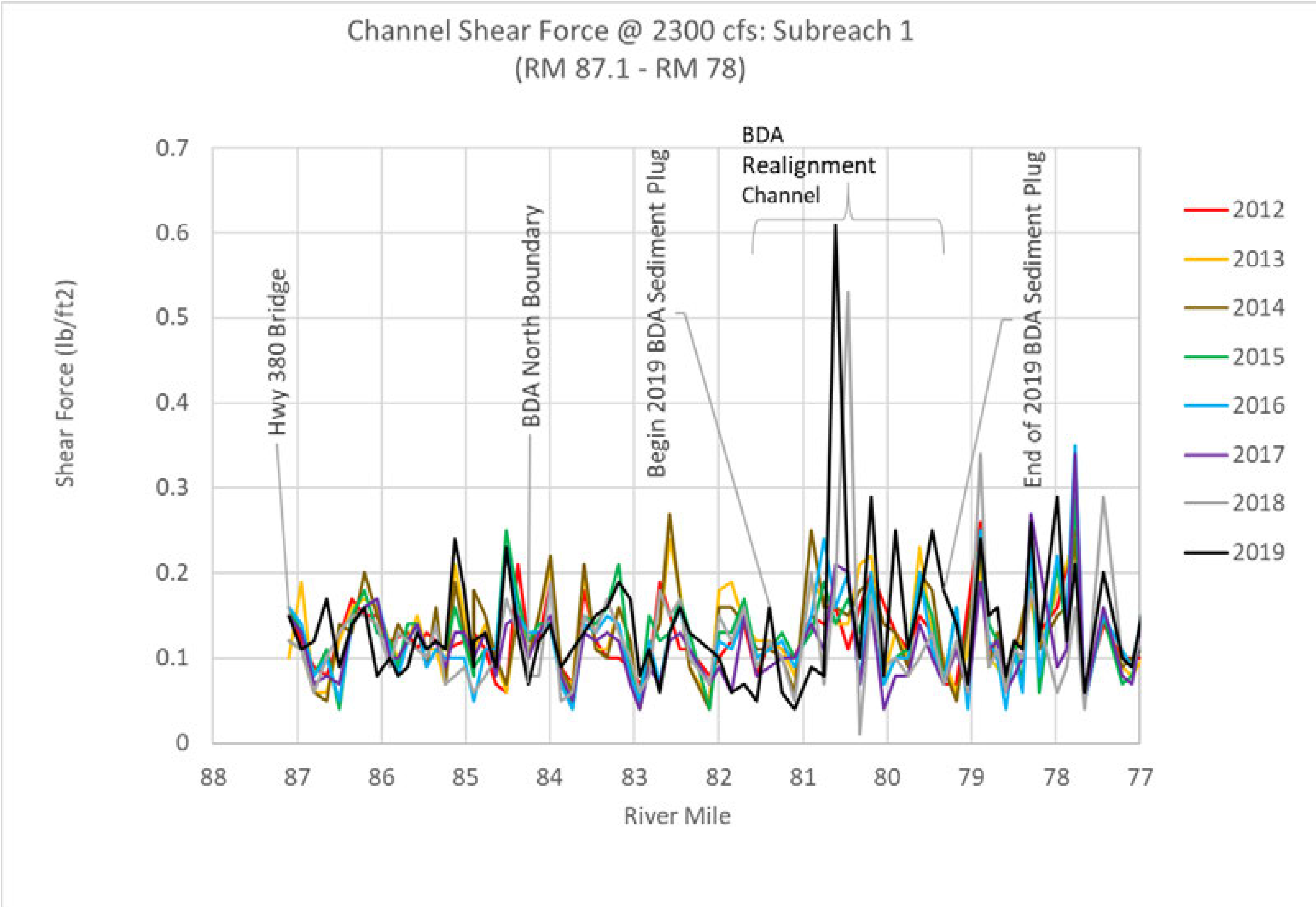

Figure 146: Simulated channel shear force profiles at the 2,300 cfs flow rate for Sub-reach 1 (RM 87.1 - RM 78).

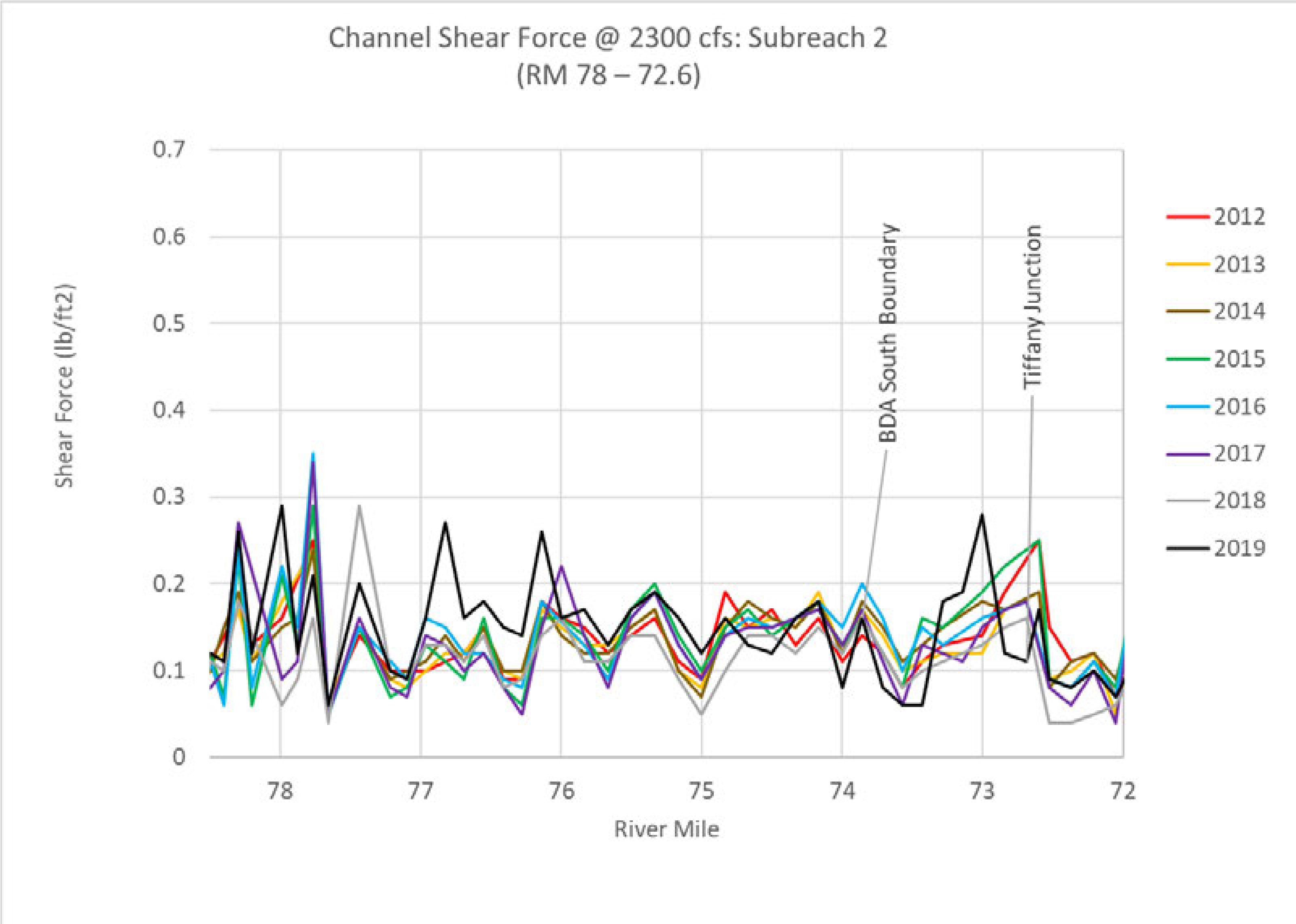

Figure 147: Simulated channel shear force profiles at the 2,300 cfs flow rate for Sub-reach 2 (RM 78 – 72.6).

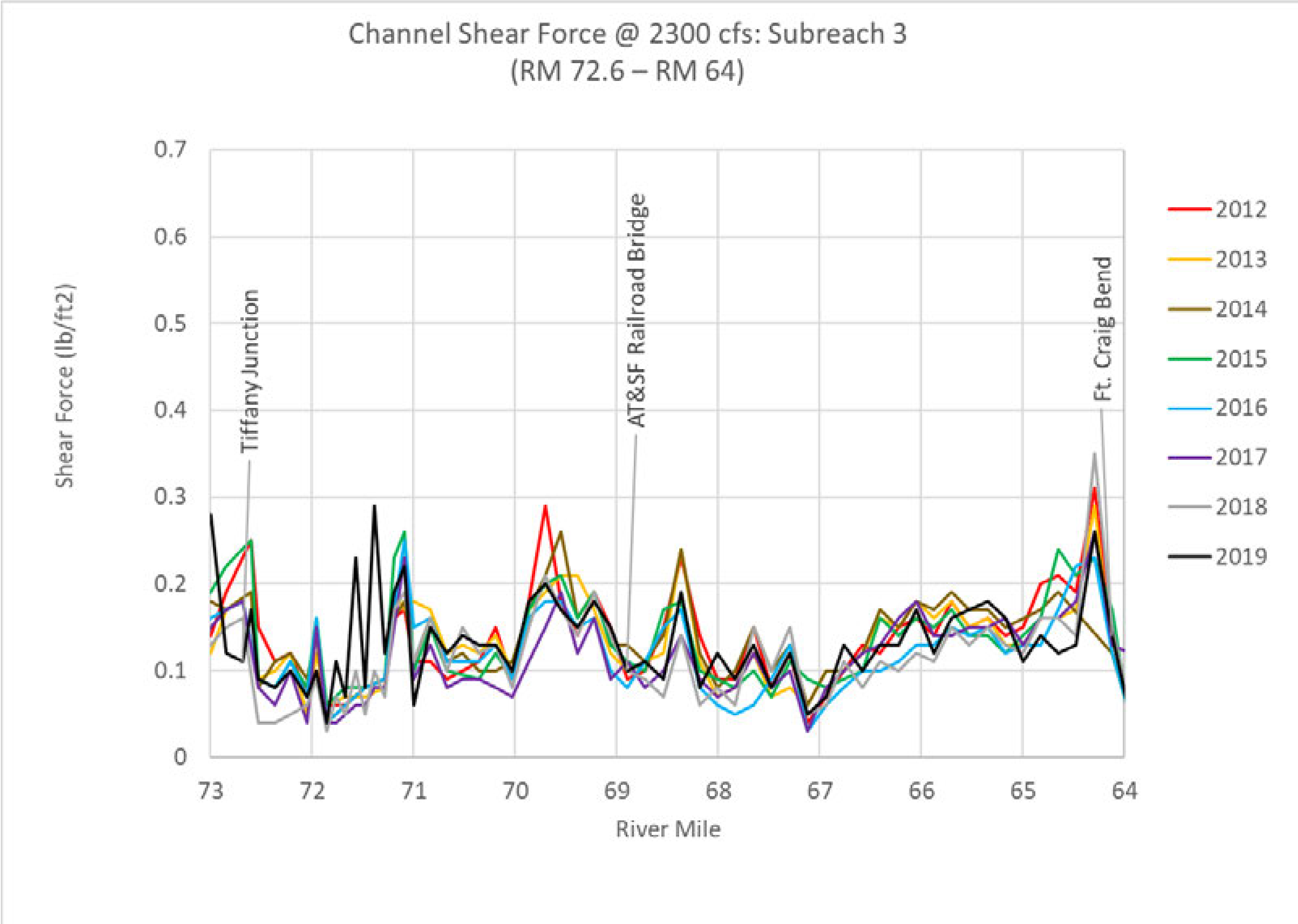

Figure 148: Simulated channel shear force profiles at the 2,300 cfs flow rate for Sub-reach 3 (RM 72.6 – RM 64).

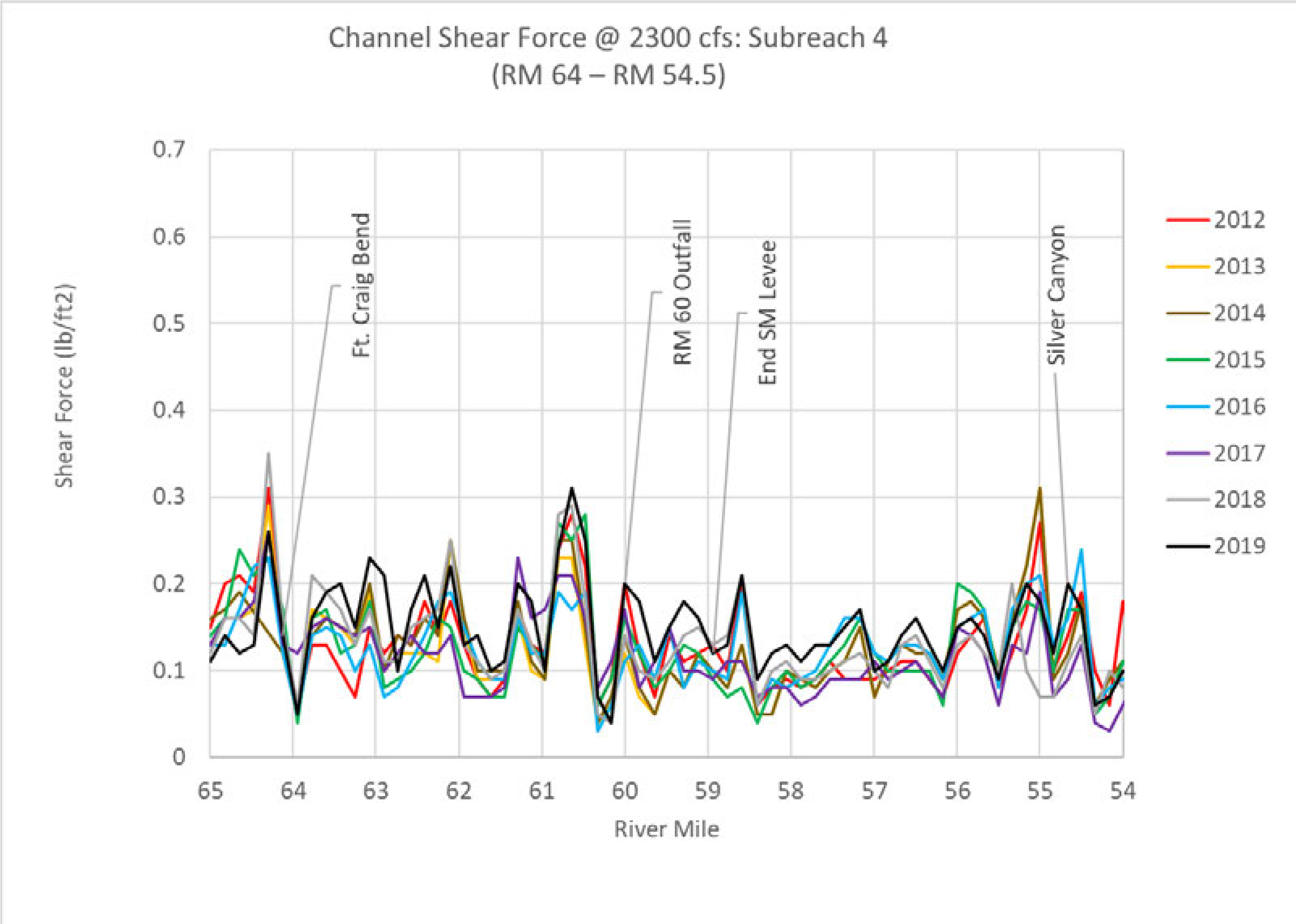

Figure 149: Simulated channel shear force profiles at the 2,300 cfs flow rate for Sub-reach 4 (RM 64 – RM 54.5).

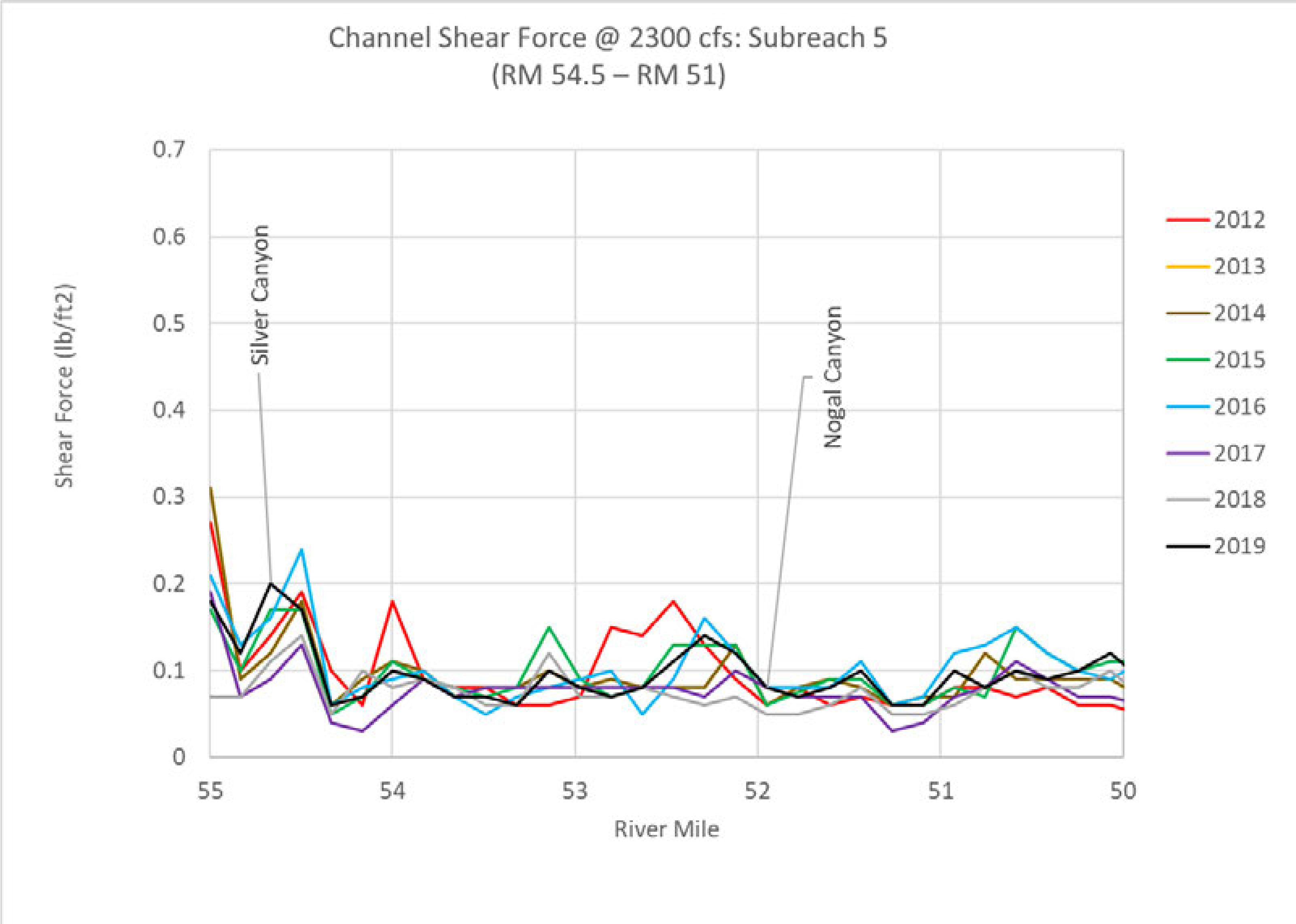

Figure 150: Simulated channel shear force profiles at the 2,300 cfs flow rate Subreach 5 (RM 54.5 – RM 51).

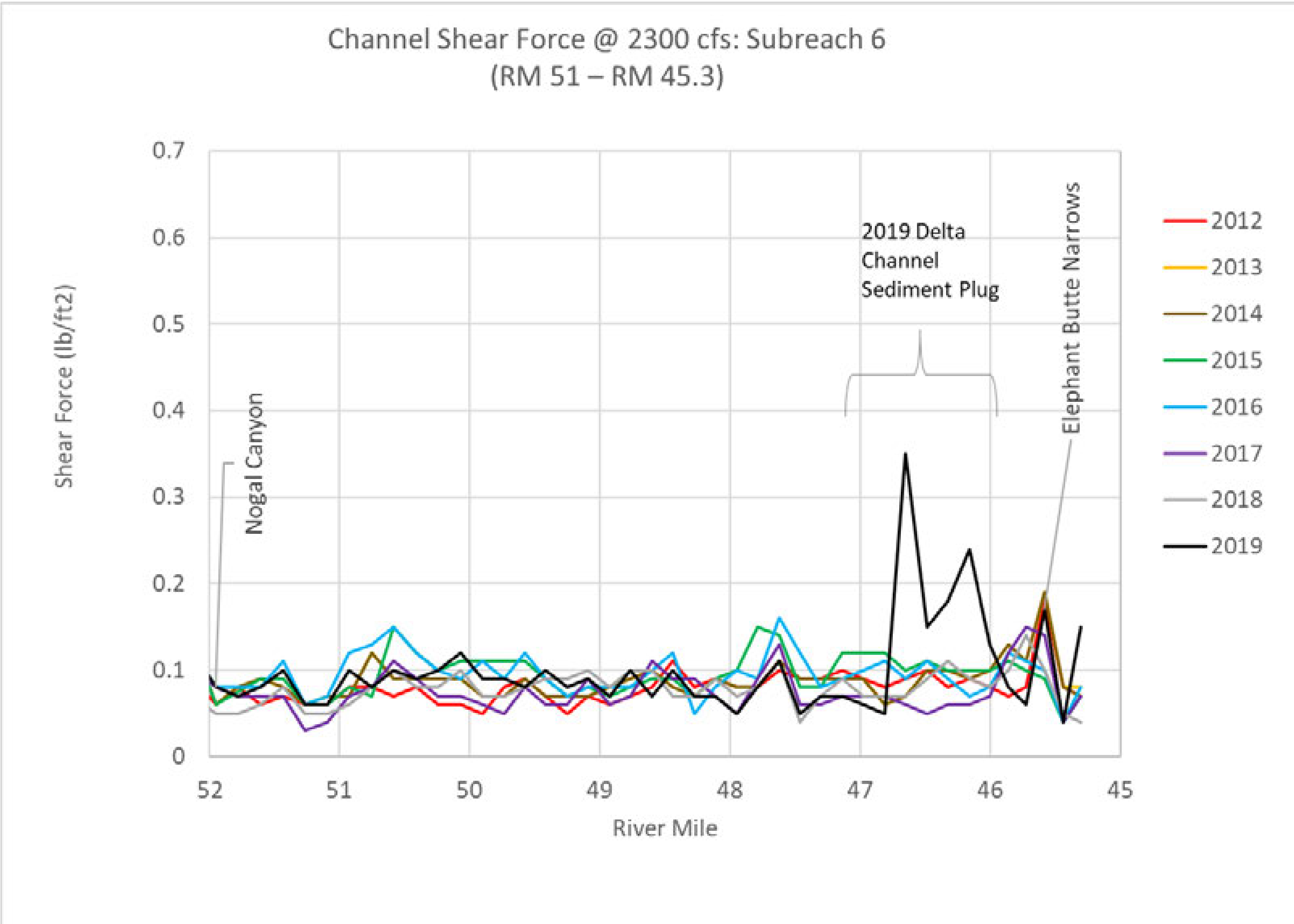

Figure 151: Simulated channel shear force profiles at the 2,300 cfs flow rate Subreach 6 (RM 51 – RM 45.3).