ANALYSIS OF SEDIMENT PLUG HYPOTHESES

MIDDLE RIO GRANDE, NM

"PLAN B" TECHNICAL REPORT

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Abstract

A total of four sediment plugs have been documented within the Middle Rio Grande in recent history (Tiffany reach in 1991, 1995, and 2005; Bosque reach in 2008). Several hypotheses have been presented regarding the key processes behind sediment plug formation including: 1) fluctuations in the water surface elevation of Elephant Butte Reservoir; 2) flood and drought cycles; 3) backwater effects from bridges; 4) channel width; 5) channel depth and perching; 6) low overbank flow; 7) sediment concentration profile; and 8) local changes in grain size.

These hypotheses were evaluated to determine which were most valid. A review was conducted of various reports completed by the US Bureau of Reclamation, CSU affiliates, and others to examine site history as well as trends in channel properties. Additional analysis included examination of cross-section and channel geometry, flow records, suspended sediment records, reservoir time series, etc.

The factors identified as most likely to influence plug formation were backwater effects from bridges and bends, channel depth and perching, low overbank flow, and non-uniform sediment concentration. As flow with a non-uniform concentration profile goes overbank, relatively clear water is lost to the floodplain while the majority of sediment load remains in the channel, thereby reducing transport capacity and inducing plug formation. Secondary factors that likely influenced plug formation were reservoir levels, flood and drought cycles, and channel width. There were noticeable relationships among these factors associated with multiple sediment plugs, but not all of them. However, these factors are not independent and it is likely a combination of several factors that lead to sediment plug formation. It was determined that local changes in grain size did not have a significant influence on the location or timing of plug formation, although overall coarsening of the bed material influences the sediment concentration profile.

Acknowledgments

I would first like to the U.S. Bureau of Reclamation for funding this project. Many thanks to my advisor, Dr. Pierre Julien, for giving me this opportunity and for his guidance and many insights into the river's behavior. Thanks to Kiyoung Park for his ideas regarding sediment plug mechanics and his valuable analysis of the study reach. Thanks to Dr. Drew Baird for his contribution to plug hypotheses. Also, thanks to Ted Bender for his insight into the Bosque reach and overbank analysis.

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Section 1: Introduction

A total of four sediment plugs have been documented within the Middle Rio Grande in recent history (Tiffany area in 1991, 1995, and 2005; Bosque reach in 2008). While the exact mechanics remain uncertain, several hypotheses have been presented regarding the key processes behind sediment plug formation. This study was conducted to evaluate the validity of some of these hypotheses as well as identify the processes that are most likely to influence sediment plug formation and those that may be pure speculation. The intent of this report is to identify the most likely causes of plug formation in order to prioritize future investigations into sediment plug mechanics.

1.1 Definition of a Sediment Plug

Boroughs (2005) defined a sediment plug as "aggradation (that may include debris) in a river which completely blocks the original channel and grows upstream by accretion." The plugs that formed within the Middle Rio Grande occurred over a relatively short period of time (a matter of weeks), greatly reducing the conveyance capacity of the river and forcing flow overbank. The extent of upstream accretion associated with these sediment plugs has ranged from 1-5 miles (Boroughs, 2005).

Figure 1.1: View of Tiffany plug (2005) looking downstream (Owen et al., 2011)

Figure 1.2: View of Tiffany plug in 1991 looking downstream (Boroughs ,2005)

Figure 1.3: View of pilot channel dredged through Tiffany plug in 1991 (Boroughs, 2005)

Figure 1.4: Levee breach due to 1991 Tiffany plug (Boroughs, 2005)

Figure 1.5: View of Bosque plug in 2008 looking downstream

1.2 Problem Statement

Sediment plug formation presents several challenges in alluvial rivers. They greatly reduce the conveyance capacity of the river, thereby hindering water delivery to downstream areas. Overbank flows associated with sediment plugs increase the risk of flooding and exacerbate water losses due to evaporation and infiltration. This impacts not only human activities, but also adjacent wildlife and habitat. To deal with the plugs that formed on the Middle Rio Grande, the US Bureau of Reclamation (Reclamation) has utilized the practice of excavating a pilot channel through or around the plug, thereby restoring connectivity within the channel and allowing flow to re-channelize. However, this maintenance practice has proven to be time consuming and costly (Owens 2011). While some arguments have been made that sediment plugs may have some positive impacts, it is clear that a better understanding of how, why, when, and where sediment plugs are likely to occur is important for management of the Middle Rio Grande.

1.3 Potential Factors Influencing Plug Formation

Several hypotheses have been presented regarding likely factors influencing plug formation. Previous studies have examined the influence of factors such as temperature, resistance to flow, hyper-concentration, water losses, macroforms, etc. (Boroughs 2005). This report focuses on plug formation hypotheses related to the following:

1) Water surface elevation of Elephant Butte Reservoir
2) Flood and drought cycles
3) Backwater effects from bridges
4) Channel width
5) Channel depth and perching
6) Low overbank flow
7) Sediment concentration profile
8) Grain size

Many of these factors are interrelated and therefore unlikely to cause sediment plug formation by themselves. While each hypothesis was evaluated individually, it was necessary to keep in mind how other factors might contribute. In most cases, it is a likely combination of these factors that influence plug formation.

Section 2: Site Description

The Middle Rio Grande defined as the reach of the Rio Grande in New Mexico extending approximately 165 miles from Cochiti Dam to Elephant Butte Reservoir. Recently, sediment plugs have formed in the downstream portion of the Middle Rio Grande, just upstream of Elephant Butte Reservoir. For the purposes of this investigation, the study reach extends from the Highway 380 bridge located south of Socorro, New Mexico to Elephant Butte Reservoir, containing the two locations where sediment plugs have formed recently. This includes the Bosque reach which extends from Highway 380 to the south boundary of the Bosque del Apache National Wildlife Refuge (BDANWR) and the Elephant Butte reach which extends from the south boundary of BDANWR to Elephant Butte reservoir. The reach is approximately 55 river miles long.

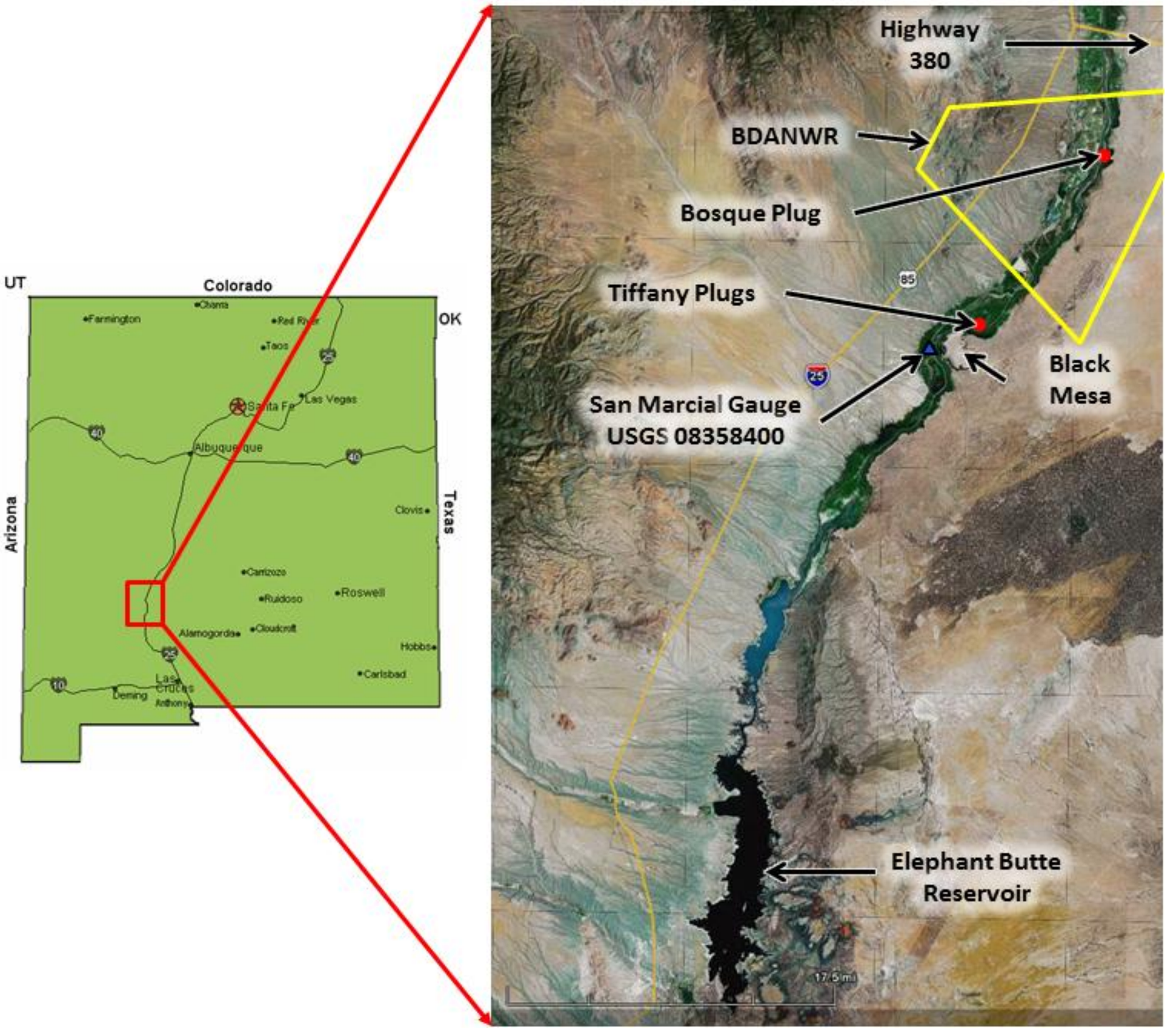

Figure 2.1: Location of study reach (Google Earth, 2012)

2.1 Precipitation

On average, this area of the Middle Rio Grande receives approximately 10 inches of rainfall annually. Figure 2.2 indicates that the majority of rainfall within the reach occurs during the summer months associated with the North American monsoon season (Paris et al., 2011).

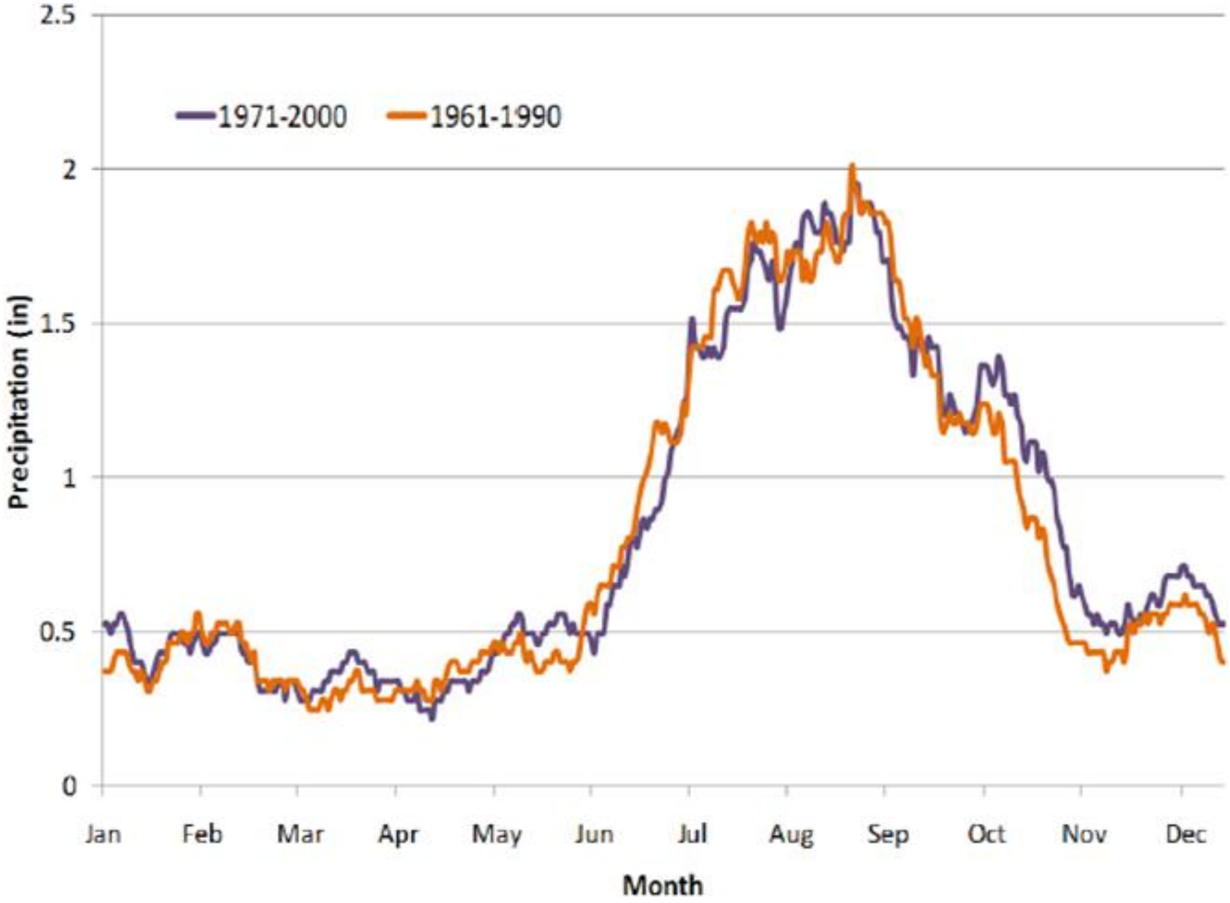

Figure 2.2: Mean monthly rainfall at Bosque del Apache (Paris et al., 2011)

2.2 Discharge

Discharge data was obtained from the San Marcial gaging station (USGS #0835840) located just downstream of where the sediment plugs formed (see Figure 2.1). Daily discharge was available from 1949-present, while peak discharge was available from 1965-present. The annual hydrograph in this reach typically experiences two peaks: a snowmelt peak between May and July associated with runoff from the Rocky Mountains in the north and; a thunderstorm peak between July and September associated with the monsoon season as mention above (see Figure 2.3).

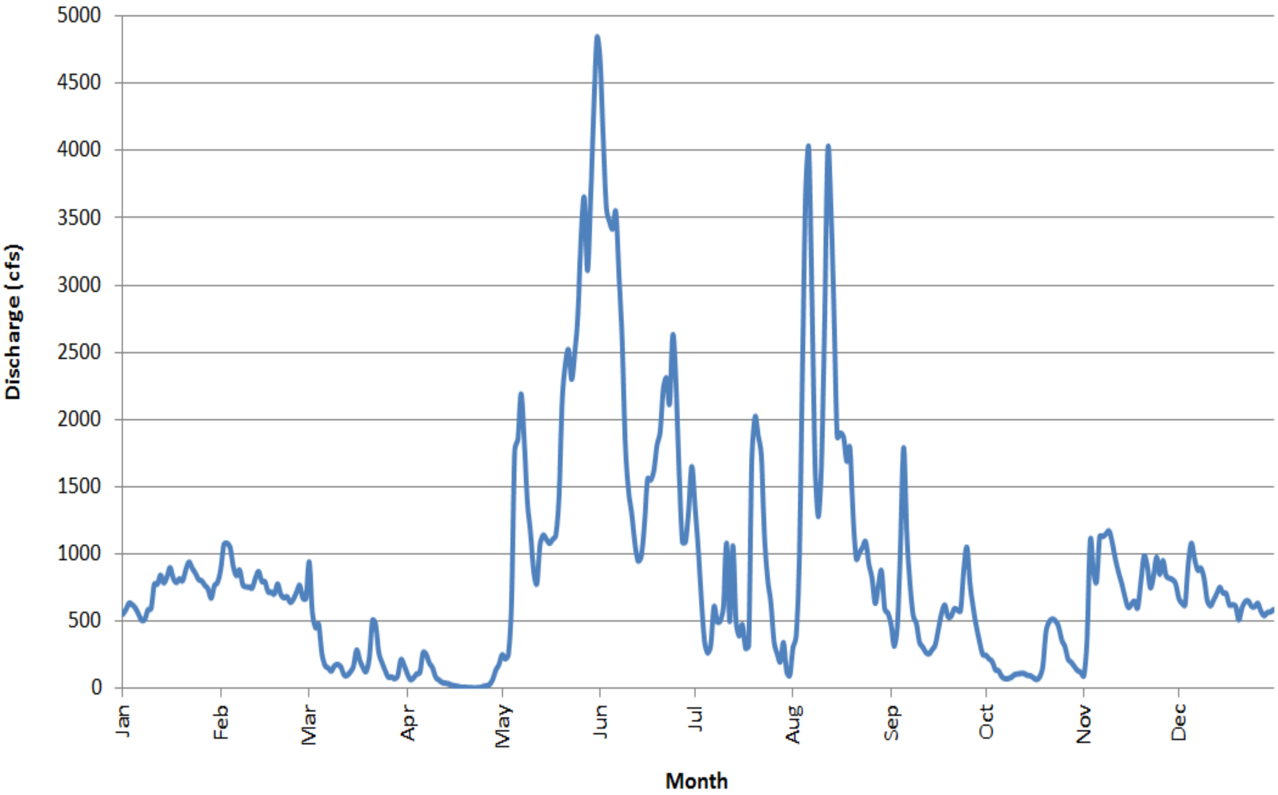

Figure 2.3: 1999 annual hydrograph at San Marcial gage (USGS #0835840)

Paris et al. estimated return intervals for the 1.5, 2, 2.5, 3, 4, 5, and 10 year discharges at the San Marcial gage as follows:

Table 2.1: Recurrence intervals at San Marcial gage (USGS #0835840)

Return Interval	***Probability***	***Discharge (cfs)***
10	0.1	6066
5	0.2	5452
4	0.25	5016
3	0.33	4547
2.5	0.4	4392
2	0.5	3405
1.5	0.67	2457

Reclamation has estimated a bankfull discharge of approximately 5000cfs in this reach, however, Bender and Julien (2012) state that the actual bankfull discharge may be significantly lower (see Section 3.6).

2.3 Elephant Butte Reservoir

Elephant Butte Dam was constructed in 1915 and the reservoir level has significant influence on upstream channel dynamics. Figure 2.4 is a time series of reservoir level fluctuations since 1915, including annual minimum and maximum levels.

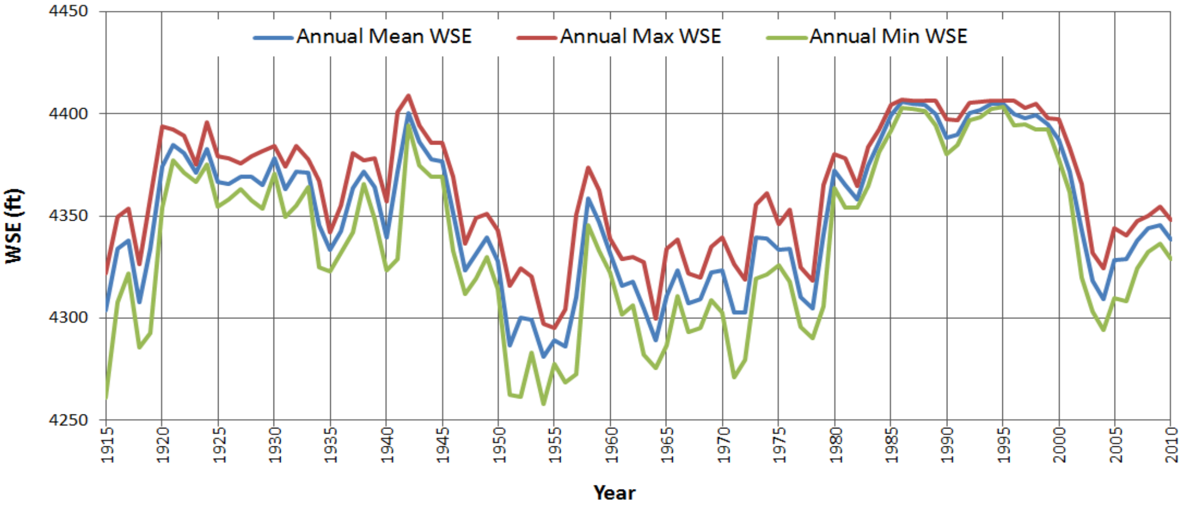

Figure 2.4: Elephant Butte Reservoir level time series

Figure 2.5 indicates the change longitudinal profile within Elephant Butte Reservoir and the range of water surface elevations. Reservoir elevations have fluctuated between approximately 4295ft and 4410ft, with an average water surface elevation of approximately 4355ft. The bed of the reservoir has aggraded as much as 50ft in some locations.

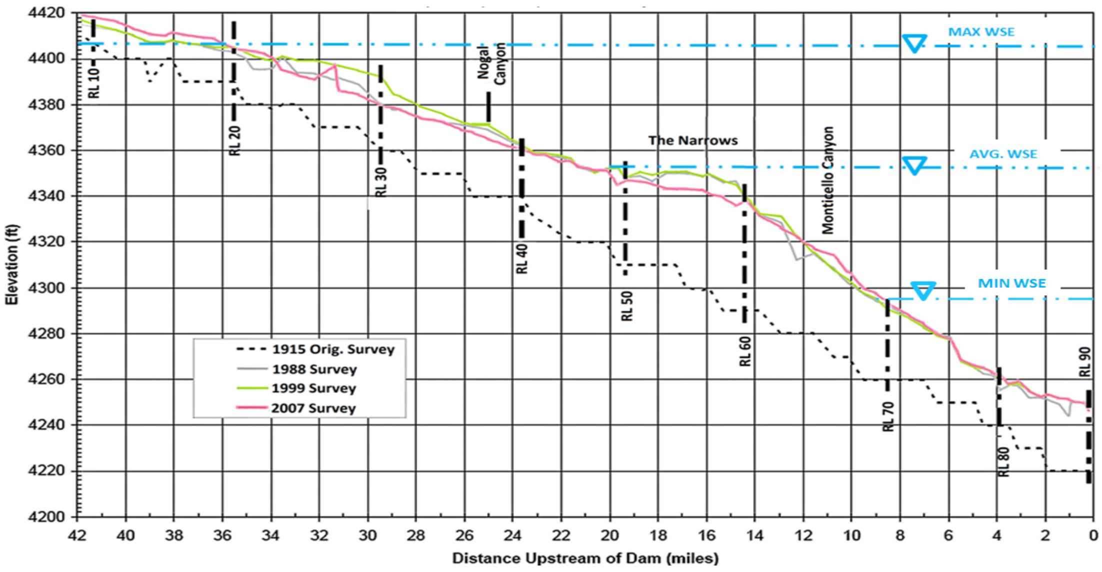

Figure 2.5: Elephant Butte Reservoir Historical Longitudinal Profile (Owen et al., 2011)

2.4 Bed Elevation and Slope

The bed slope throughout the reach ranges from approximately 0.00045 to 0.0008, generally decreasing in the downstream direction. The channel bed has aggraded as much as 50 feet in downstream locations since Elephant Butte Dam was constructed. The bed has aggraded approximately 15ft in the location (Agg/Deg #1683) of the 1991, 1995, and 2005 plugs, and approximately 10ft in the location (Agg/Deg #1550) of the 2008 plug (see Figure 2.6).

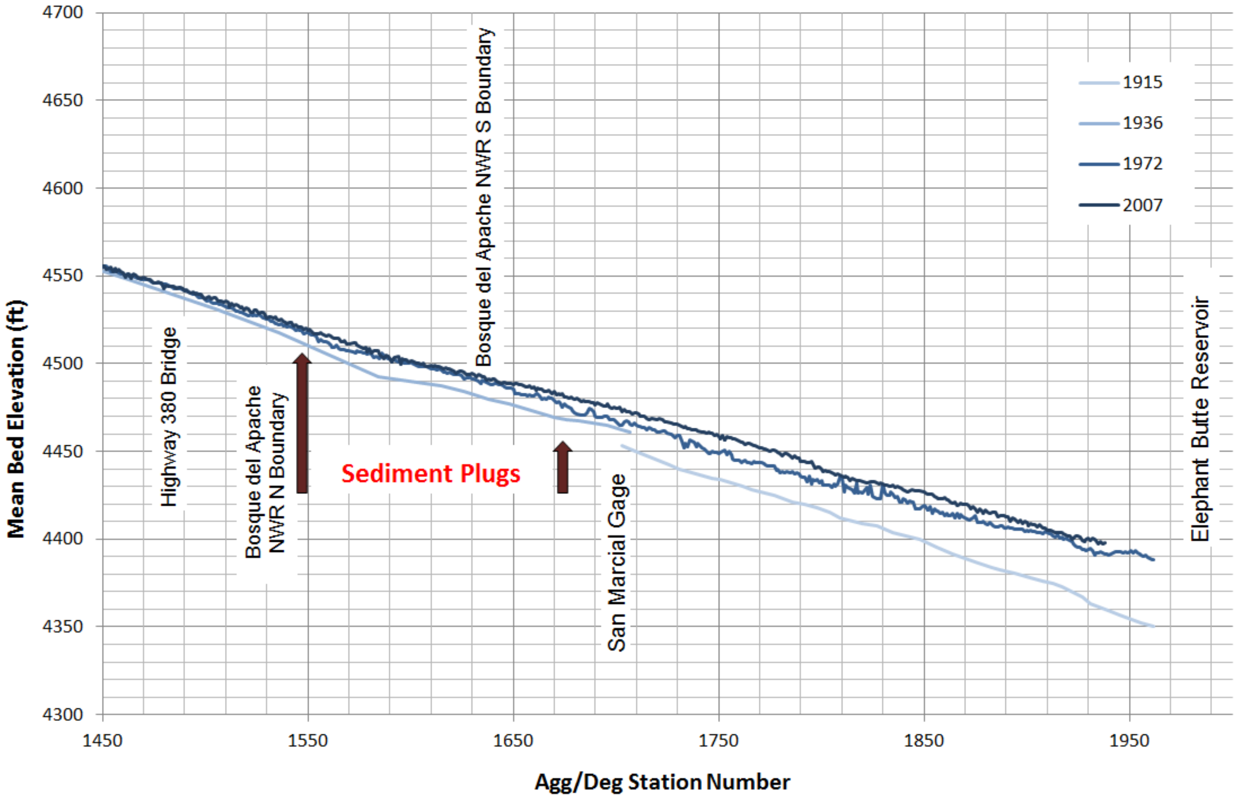

Figure 2.6: Mean bed elevation change

2.5 Planform

The historic planform of the Middle Rio Grande was very wide and highly braided. Reductions in flow and sediment supply have resulted in a much narrower that is typically single thread, especially at high flow. The channel width ranges from 80ft to 800ft, with an average width of approximately 250ft. The channel width tends to decrease in the downstream direction (see Figure 2.7).

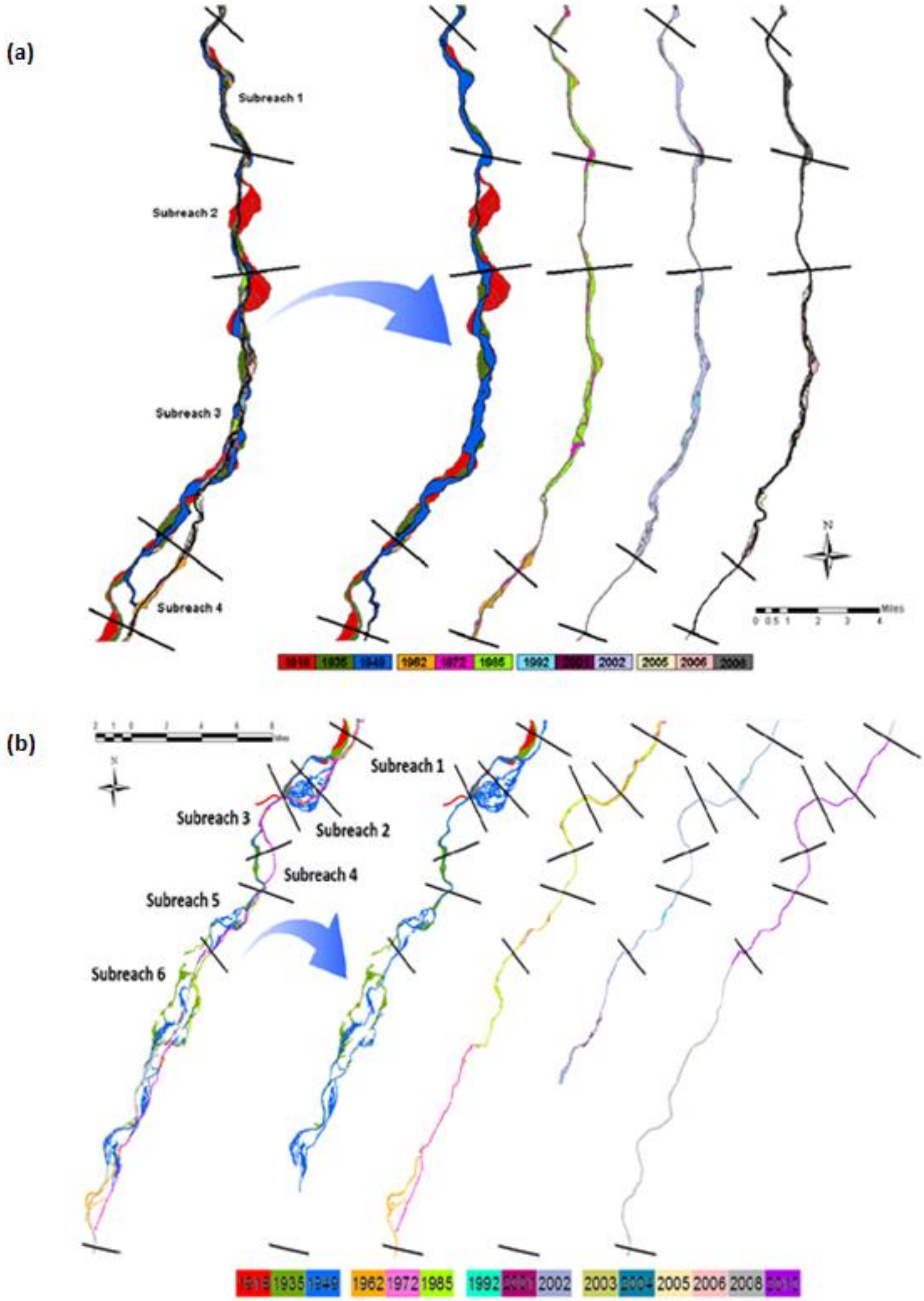

Figure 2.7: Planform changes from aerial photography for (a) Bosque Reach (Paris et al., 2011) and (b) Elephant Butte Reach (Owen et al., 2011)

2.6 Additional Data

Two existing HEC-RAS models containing geometric data for the Bosque and Elephant Butte reaches were used for this analysis. The models were developed using Aggradation/Degradation (Agg/Deg-line) surveys collected by Reclamation. The Agg/Deg-lines were derived using photogrammetry. They are spaced about 500 feet apart and were surveyed in 1962, 1972, 1992, and 2002.

Additional survey data were available including Socorro range line (SO-line), and Elephant Butte range line (EB-line) surveys, both within the Elephant Butte reach. SO and EB range lines were field surveyed by Reclamation beginning in 1980. These surveys are more detailed than the channel cross-sections that were developed from the aerial photographs (i.e. Agg/Deg lines). 18 SO-lines and 102 EB-lines are located in the reach. Figure 2.24 shows the location of the SO- and EB-lines and Table 2.11 shows the dates of available survey data at each SO- and EB-line.

Section 3: Analysis and Results

Each of the following factors was analyzed for its likelihood of having a significant influence on sediment plug formation. They were ranked as either highly likely, somewhat likely, or unlikely to influence sediment plug formation.

3.1 Reservoir Levels

One hypothesis is that plug formation is induced when Elephant Butte Reservoir is high such that the elevated base level reduces sediment transport capacity upstream. Figure 3.1 compares the reservoir level with the bed elevation at the San Marcial gage, just downstream of where the sediment plugs formed. The reservoir water surface elevation was high in 1991 (4,430ft) and 1995 (4,450ft) relative to the average reservoir water surface elevation (4,355ft) when sediment plugs formed. However, the reservoir level began to drop in 2000, and was low in both 2005 (4,300ft) and 2008 (4,340ft) when sediment plugs formed. The correlation between changes in reservoir level and the San Marcial bed elevation is also important to note. From 1980 to 1990, the reservoir level steadily increased as did the San Marcial bed elevation. However, after 1998, the reservoir level decreased sharply but there is only a slight downward trend in the San Marcial bed elevation. This indicates that high reservoir levels likely reduce sediment transport capacity at least as far upstream as the San Marcial gage. However, when the reservoir is low, this influence is reduced. Therefore, it is likely that the elevated base level played a role in the 1991 and 1995 sediment plugs. However, because the reservoir was low when the two most recent plugs formed, it can be concluded that level of Elephant Butte Reservoir is not a necessary factor in determining if and when a sediment plug might form.

It should also be noted that immediately following years in which sediment plugs formed, there is a sharp decline in the San Marcial bed elevation followed by a recovery to the pre-plug elevation. This is likely associated with a brief increase in sediment transport capacity due to pilot channel excavation.

Further investigation into effects of reservoir fluctuations would be useful. Understanding how far upstream and how long it takes for effects from these fluctuations to propagate upstream would provide a better estimate of the influence of reservoir levels on sediment plug formation.

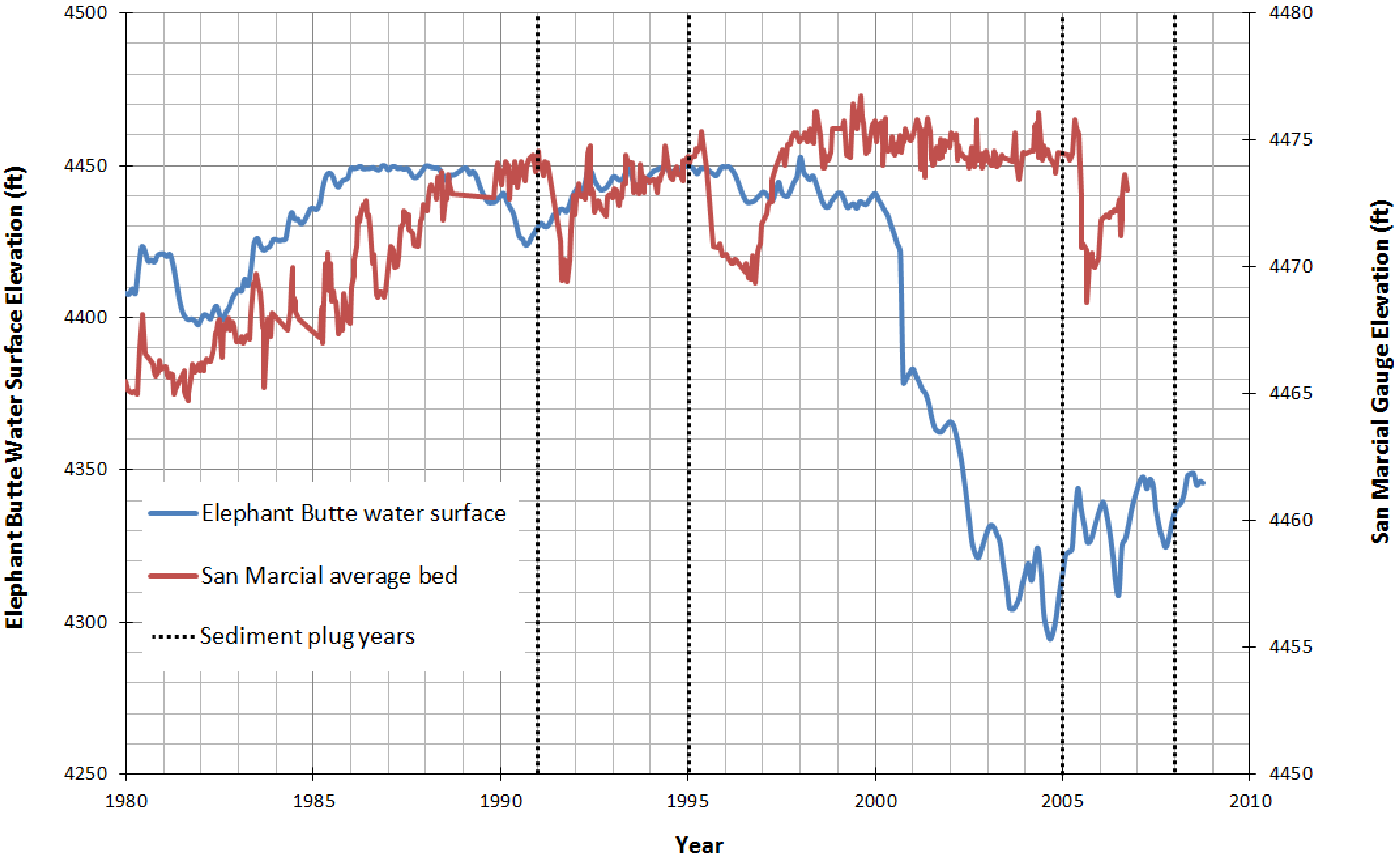

Figure 3.1: San Marcial bed elevation and Elephant Butte Reservoir level (modified from

3.2 Flood and Drought Cycles

Another hypothesis is that cycles of flooding and drought may influence the formation of sediment plugs. During a flood year in which no plugs develop, the flow is capable of carving out a deep, wide channel. If this is followed by several years of drought, the associated loss in sediment transport capacity may result in aggradation of the channel bed, producing a wide, shallow channel. This would reduce the capacity of the channel to convey a subsequent flood, resulting in increased overbank flow. This combined with channel perching and non-uniform vertical distribution of sediment load (see Section 3.6) may result in reduced sediment transport capacity, and potentially induce plug formation.

All four sediment plugs formed during the snowmelt peak of the annual hydrograph (see Figure 3.2-Figure 3.5 and Appendix A). It should be noted that the discharge at the upstream gage (San Acacia, USGS #08354900) is consistently greater than that at the downstream gage (San Marcial, USGS #0835840). The implications of this on plug formation were not investigated.

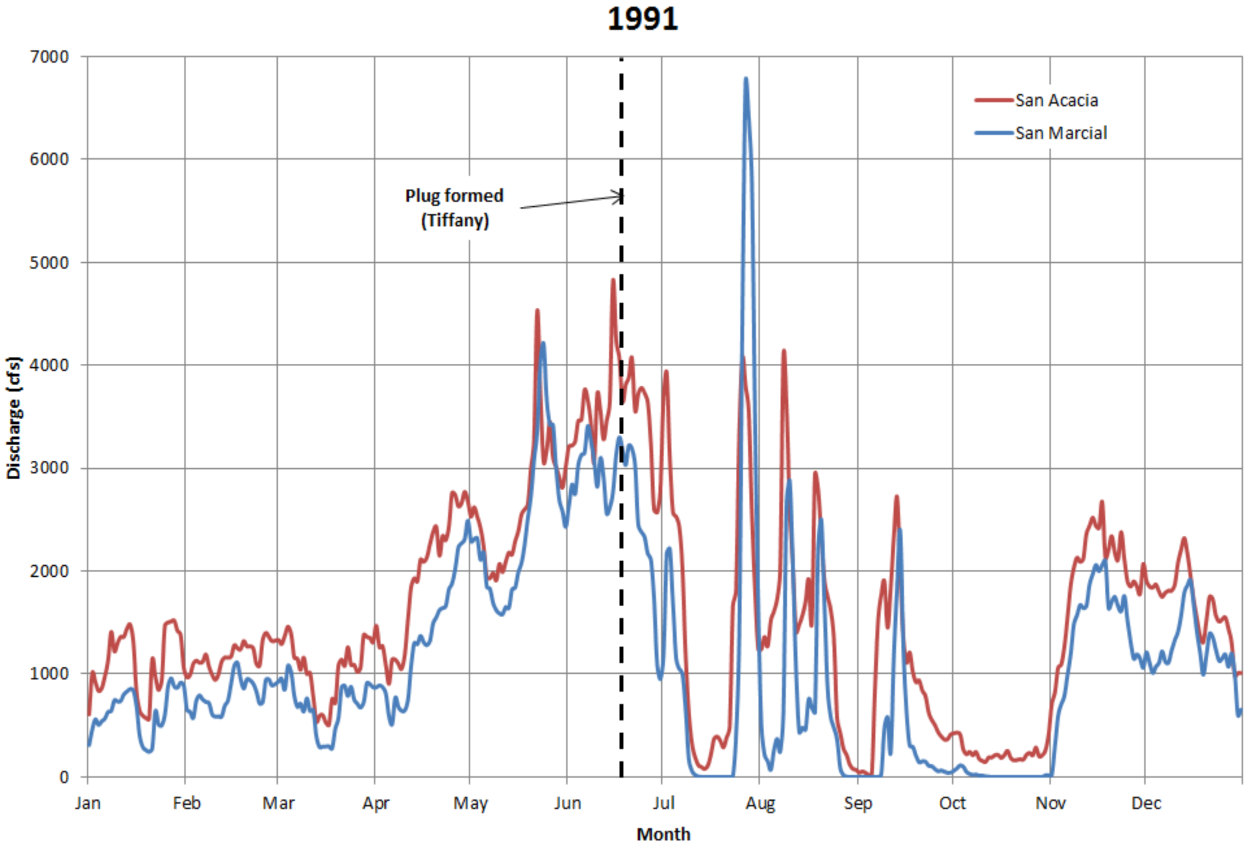

Figure 3.2: Annual hydrograph for 1991

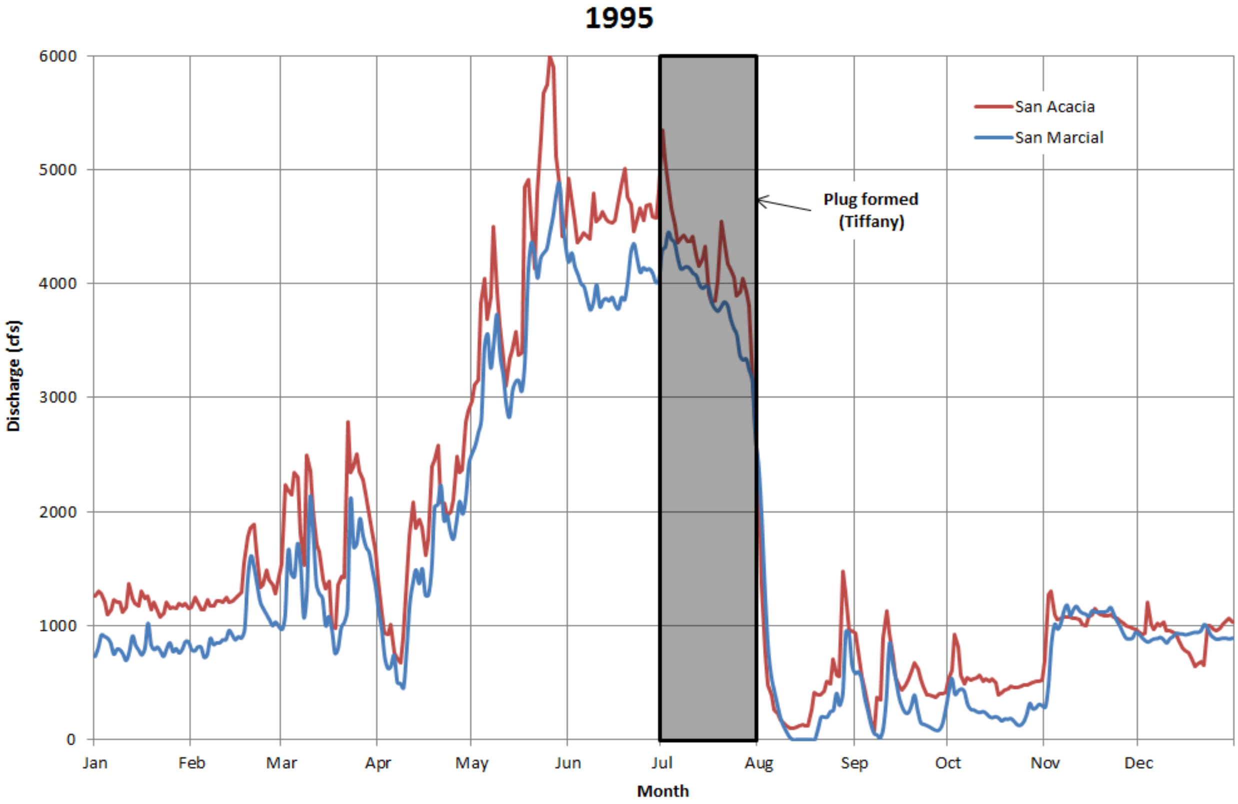

Figure 3.3: Annual hydrograph for 1995

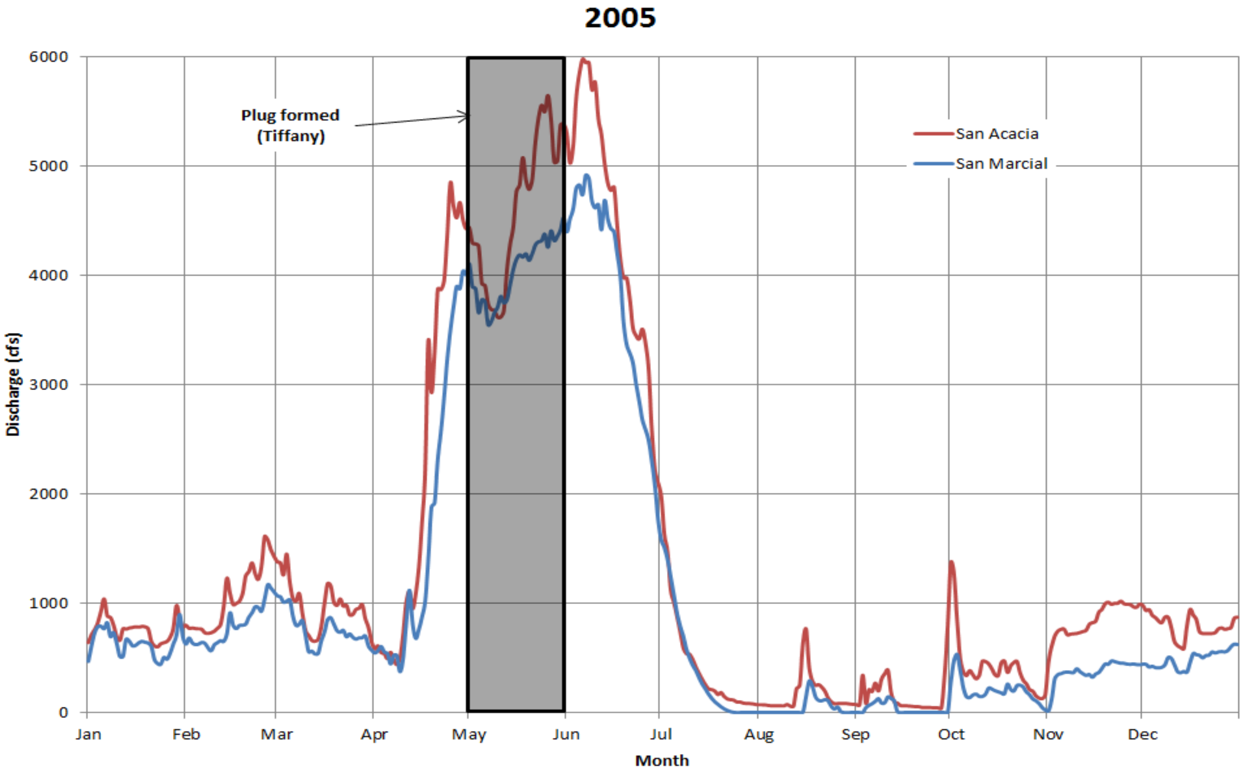

Figure 3.4: Annual hydrograph for 2005

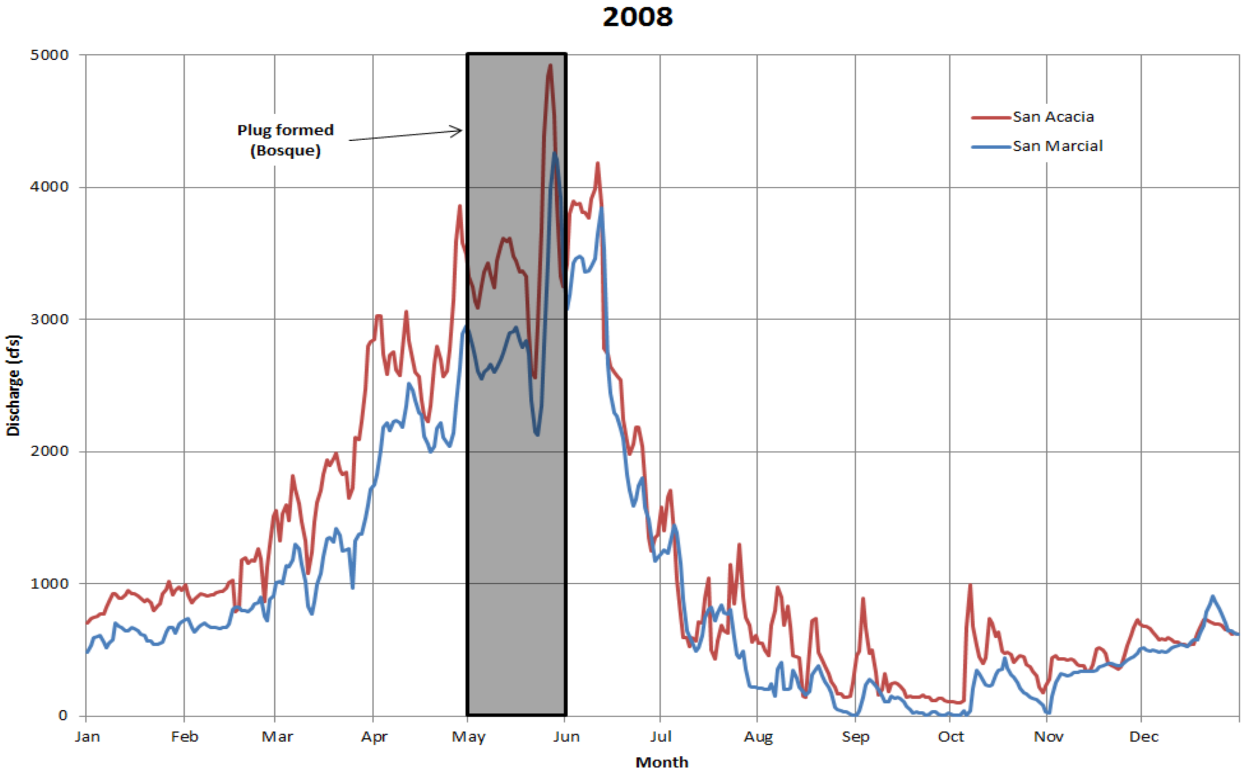

Figure 3.5: Annual hydrograph for 2008

Figure 3.6 shows the snowmelt-peak and average-annual flows at San Marcial gage from 1987 to 2011. The mean value of the peak-annual flows over this period was approximately 3,800cfs, while the mean value of the average-annual flows over this period was approximately 800cfs. The peak-annual flows in 1991, 1995, 2005, and 2008 (4,200cfs, 4,900cfs, 5,000cfs and 4,400cfs, respectively) were all significantly higher than average. Conversely, the two years prior to the 1991 plug experienced below-average average-annual and peak flows. Similarly, the five years prior to the 2005 year plug experienced significantly below-average peak-annual and average-annual flows. Also, while the 2006 peak flow was above-average, the average annual flow in the two years prior to the 2008 plug was below average. Therefore, it is reasonable to assume that a drought period leading up to floods in 1991, 2005, and 2008 may have contributed to sediment plug formation in each of those years. However, the four years leading up to the 1995 plug all experienced above-average average-annual flows and peak-annual flows that were higher than the 1995 peak flow. This indicates that there was not a significant drought period leading up to the 1995 plug. Therefore, it can be concluded that while flood and drought cycles likely contribute the formation of sediment plugs, they are not a necessary factors in determining if and when a sediment plug will form.

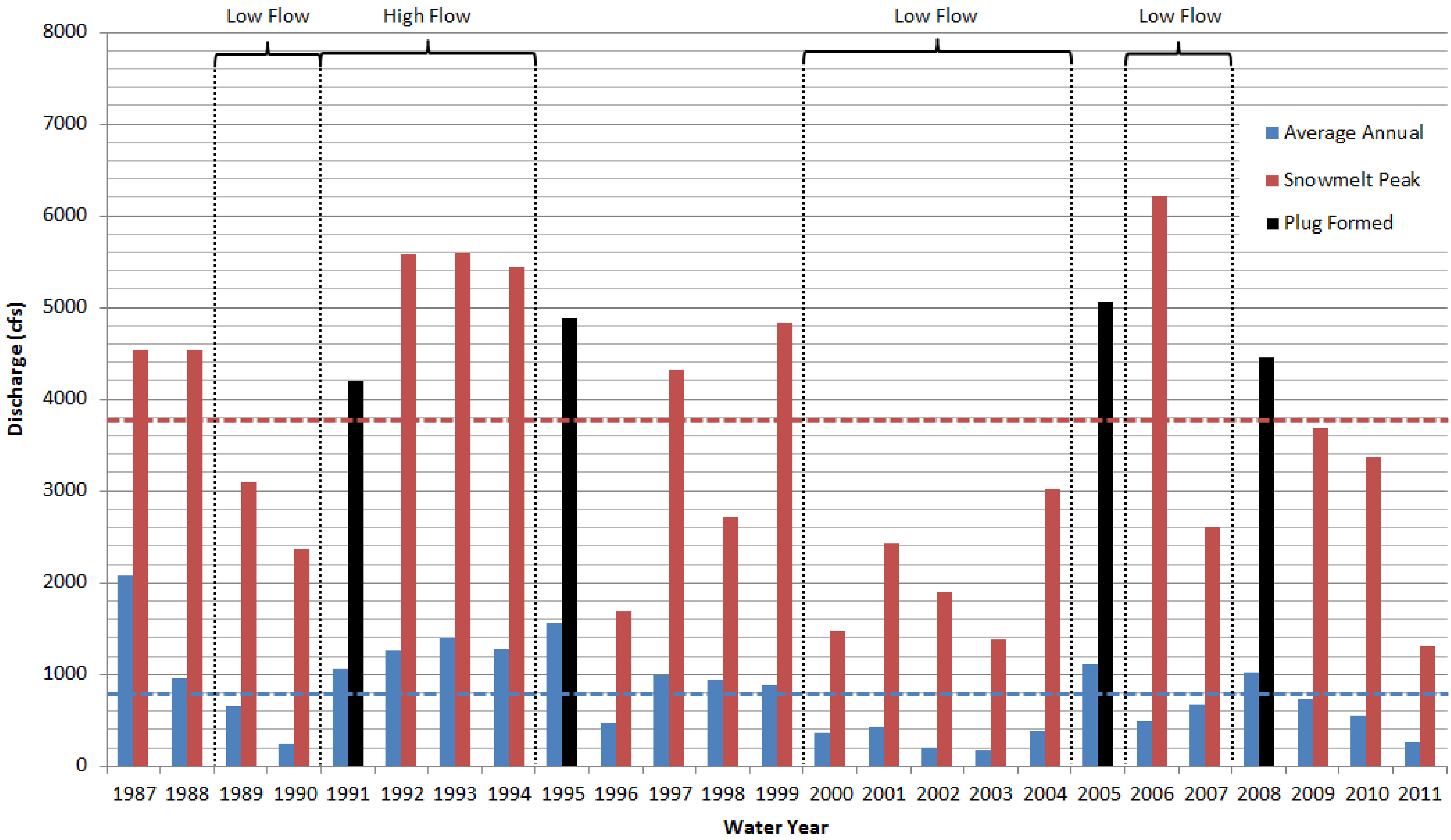

Figure 3.6: High and low flow periods relative to sediment plug formation (San Marcial gage USGS #0835840)

3.3 Backwater Effects

3.3.1 Bridges

During high flow, backwater effects from constrictions such as bridges can lead to reduced flow velocity upstream associated with increased flow area. A reducing in flow velocity can induce sedimentation and potentially lead to the formation of sediment plugs. Figure 3.7 indicates that the 1991, 1995, and 2005 (Tiffany) plugs formed approximately 1.5 river miles upstream of the San Marcial railroad bridge, while the 2008 (Bosque) plug formed approximately 15 river miles upstream of the bridge. The first three plugs are likely close enough to the bridge to experience significant backwater effects, although those effects are likely to diminish further upstream where the 2008 plug formed. Regardless, it is highly likely that backwater effects could have influenced the formation of sediment plugs, especially in 1991, 1995, and 2005.

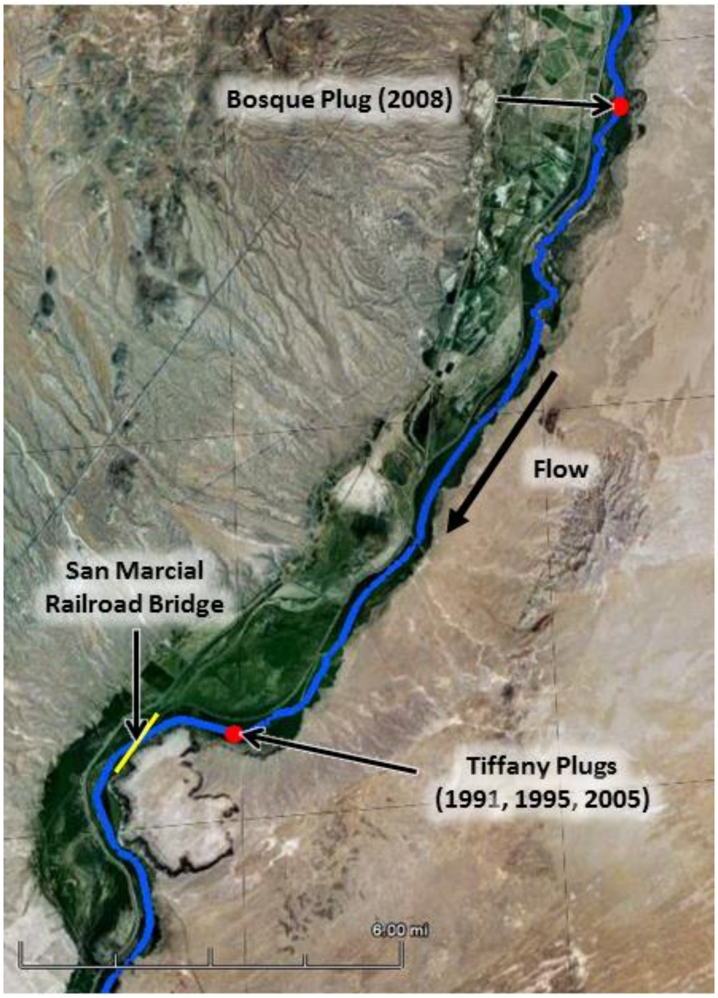

Figure 3.7: Location of sediment plugs relative to San Marcial railroad bridge

3.3.2 Bends

Another feature that might induce backwater effects upstream is a sharp bend in the channel. Figure 3.8 shows the location of the Tiffany and Bosque plugs relative to bends located just downstream. The bends in both locations are relatively sharp and likely significant enough to induce backwater effects that might induce plug formation. It may be useful to model backwater profiles and the associated sediment transport capacity in these reaches with and without bends to determine if their presence is significant.

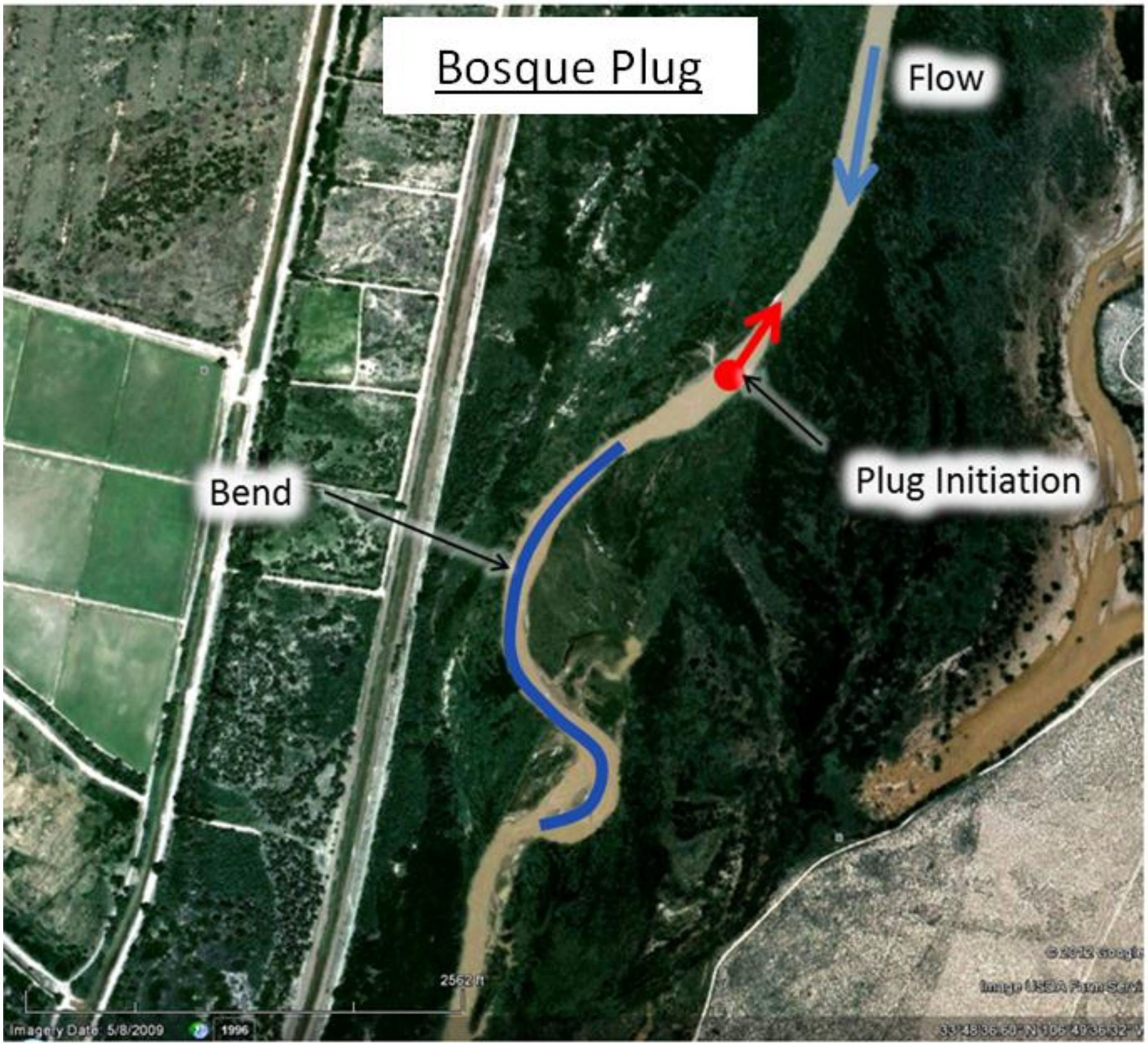

Figure 3.8: Bend located downstream of Bosque plug

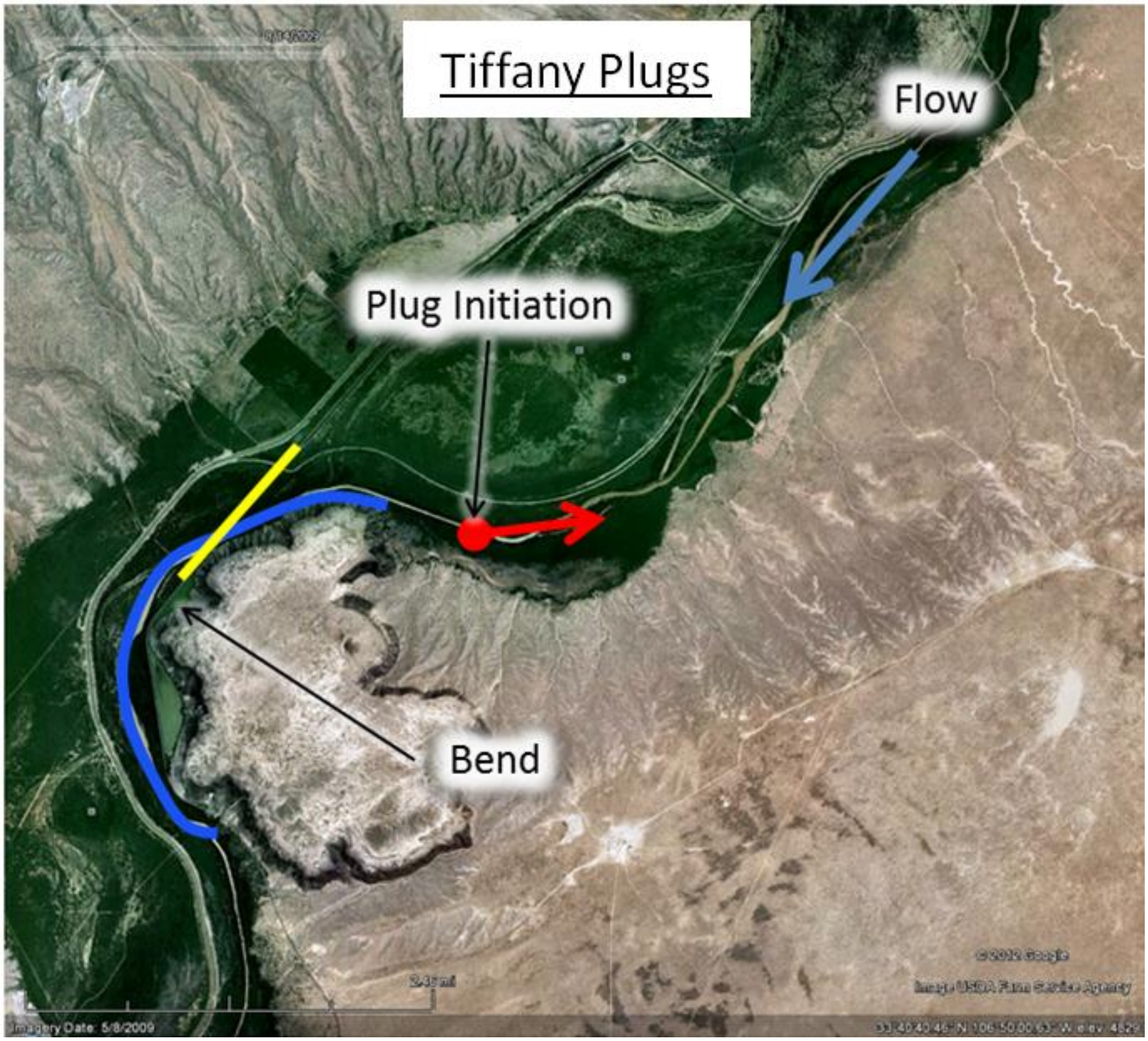

Figure 3.9: Bend located downstream of Tiffany plugs

3.4 Channel Width

Channel geometry has a significant impact on sediment transport capacity. A localized increase in channel width often results in decreased flow velocity when the width exceeds the optimum channel width (Park et al., 2012). The associated increase in wetted perimeter may also increase resistance to flow, further reducing flow velocity. The reduction in flow velocity reduces sediment transport capacity which can lead to aggradation that may induce sediment plug formation. A contraction downstream of a relatively wide region can generate energy loss that may also contribute to a reduction in sediment transport capacity. A contraction in the channel may also force the flow to go overbank at relatively low discharges. This may result in sediment plug formation if the vertical sediment concentration profile is non-uniform with sediment load concentrated near the bed (see Section 3.7)

Figure 3.11 indicates that the 1991, 1995, and the 2005 sediment plugs formed in a region (Agg/Deg 1683) just upstream of a contraction, where the river was much narrower (approx. 80 feet wide) than the average width (approx. 200ft wide) of the reach. Similarly, Figure 3.11 indicates that the 2008 plug appears to have formed in a wide section (approx. 800ft wide) of the reach just upstream of a contraction (approx. 300ft wide). However, this observation is based on data from 2002, and thus it is very possible that the reach characteristics may have changed significantly prior to the formation of the 2002 plug. Because each of the plugs initiated in relatively narrow sections of the reach, it is unlikely that excessive channel width was the sole cause of reduced sediment transport capacity. There are likely other factors at play, specifically the influence of non-uniform sediment concentration profile combined with overbank flow. It is possible that the contractions in channel width resulted in overbank flow, initiating sediment plugs that prograded upstream into wider sections of the channel.

Based on this cursory examination of the available data, it is difficult to determine if and how local variations in channel width influence sediment plug formation. Additional channel geometry immediately for years just before and after plugs formed would provide a better understanding of the influence of channel width.

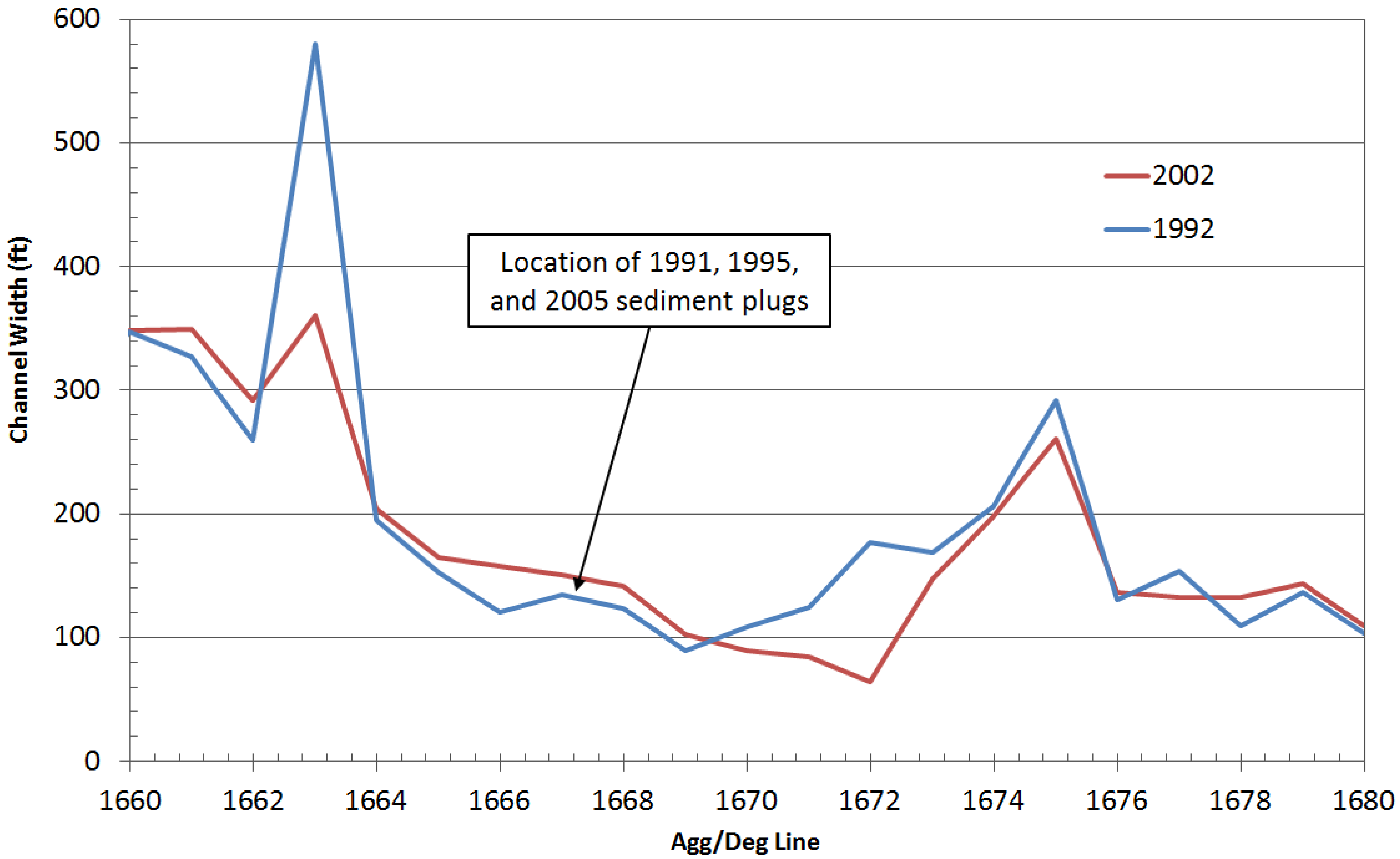

Figure 3.10: Plot of 1992 and 2002 channel widths at Agg/Deg Lines

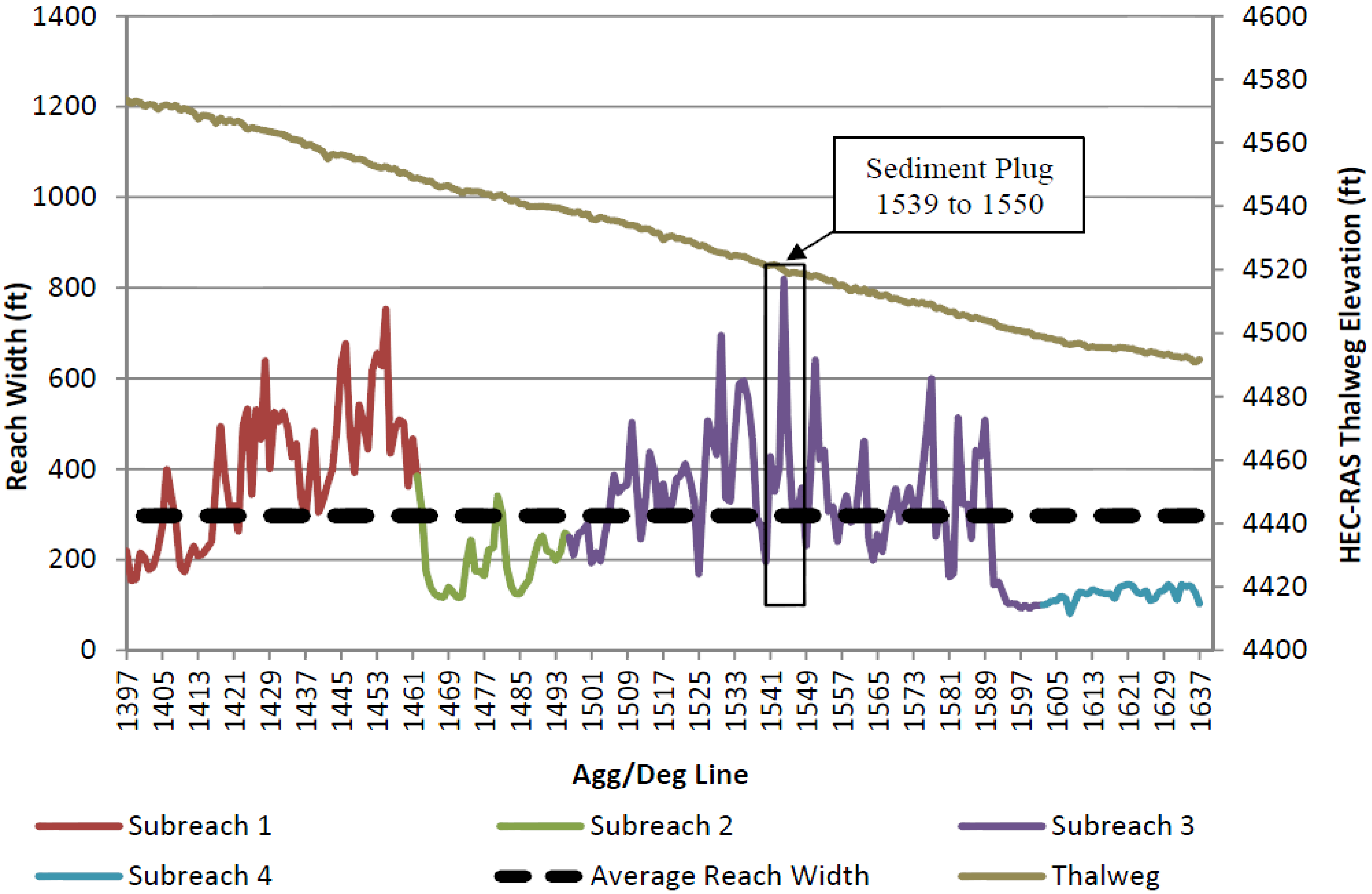

Figure 3.11: Plot of 2002 widths and thalweg at Agg/Deg Lines (Paris et al., 2011)

3.5 Channel Depth/Perching

A localized reduction in channel depth or bank height can cause flow to go overbank at relatively low discharge, especially in relatively narrow reaches. If the sediment load is concentrated near the channel bed, the fraction of flow lost overbank exceeds that of the sediment, thereby reducing the relative sediment transport capacity of the channel (see Section 3.7). This can lead to aggradation that might induce sediment plug formation.

Perching occurs as the channel bed aggrades and natural levees develop as overbank flows deposit sediment on the channel banks. This results in a channel that is elevated above the surrounding floodplain. When flow goes overbank during flood events, it becomes disconnected from the main channel and no longer contributes to the sediment transport capacity within the main channel.

Figure 3.12 displays the cross section geometry at the downstream end Tiffany plugs in 1992 and 2002 developed from photogrammetry. The perched nature of the channel is evident, with the floodplain elevation much lower than that of the channel banks. The channel was relatively deep in 1992 (approximately 7 feet), which was a high flow year following the sediment plug of 1991. There was significant aggradation from 1992 to 2002 as the channel depth decreased form 7 feet to approximately 4 feet. The decrease in channel depth results in decreased flow capacity in the main channel, causing flow to go overbank at low discharges. Combined with a non-uniform sediment concentration profile, the low overbank discharge may lead to sediment plug formation (see Section 3.7). While it is not known for certain, it is possible that depth of the channel in this location was also relatively shallow in 1991, 1995, and 2005 when sediment plugs formed in this location.

Figure 3.13 displays the same cross-section geometries at the downstream end of the Bosque plug. It is clear that this reach aggraded significantly (approximately 4 feet) from 1992 to 2002, becoming more perched as well. The channel depth was fairly shallow (approximately 2 feet deep) in 2002, which would likely result in a low overbanking discharge. While the channel geometry could have changed significantly from 2002 to 2008 when the plug formed, the trend of aggradation and further perching is likely. Modeling sediment transport capacity with varying channel depth and accounting for channel perching would be useful to better understand the influence of the factors on sediment plug formation.

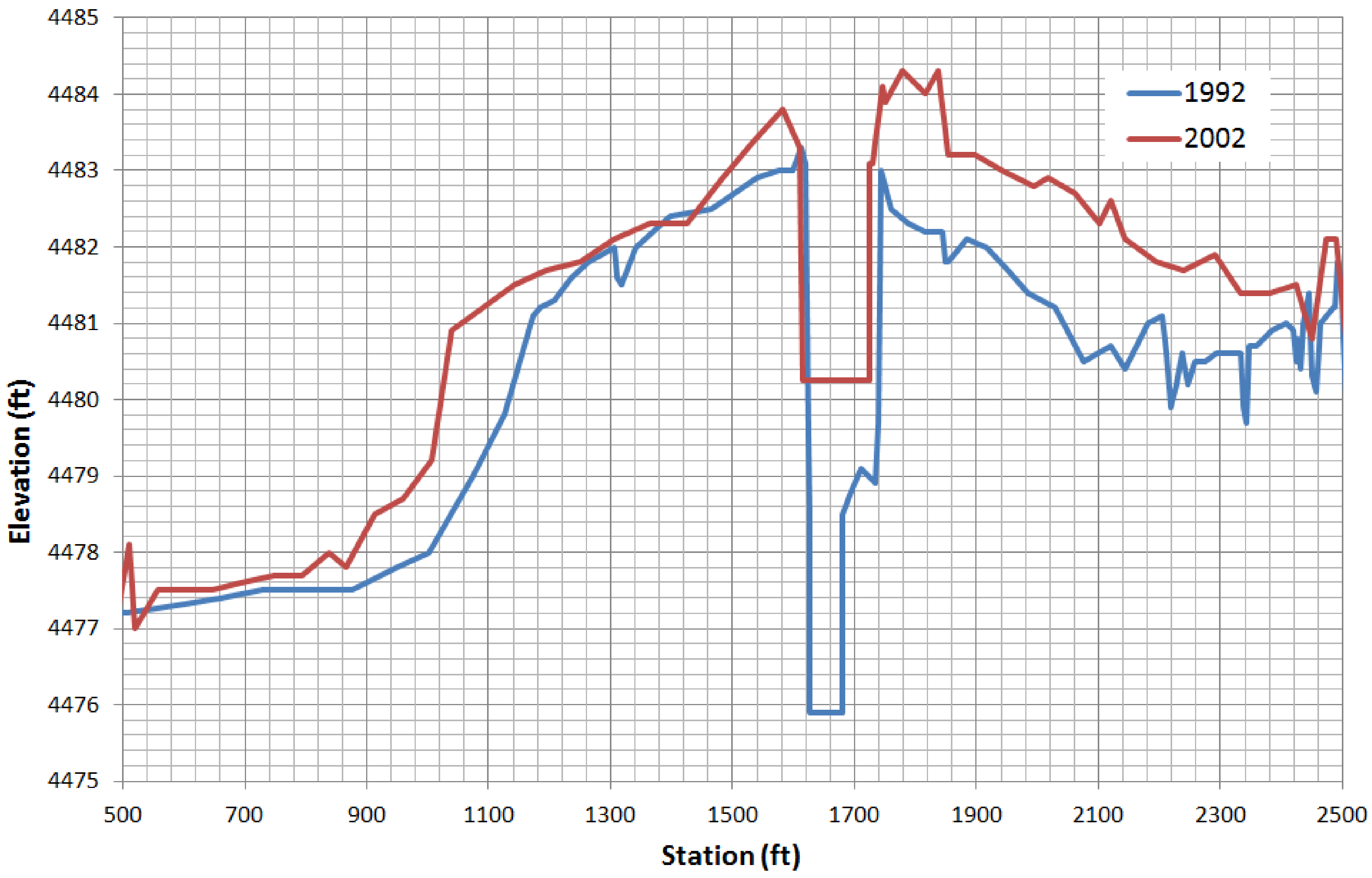

Figure 3.12: Cross-section at 1991, 1995, and 2005 plug location (Agg/Deg #1683)

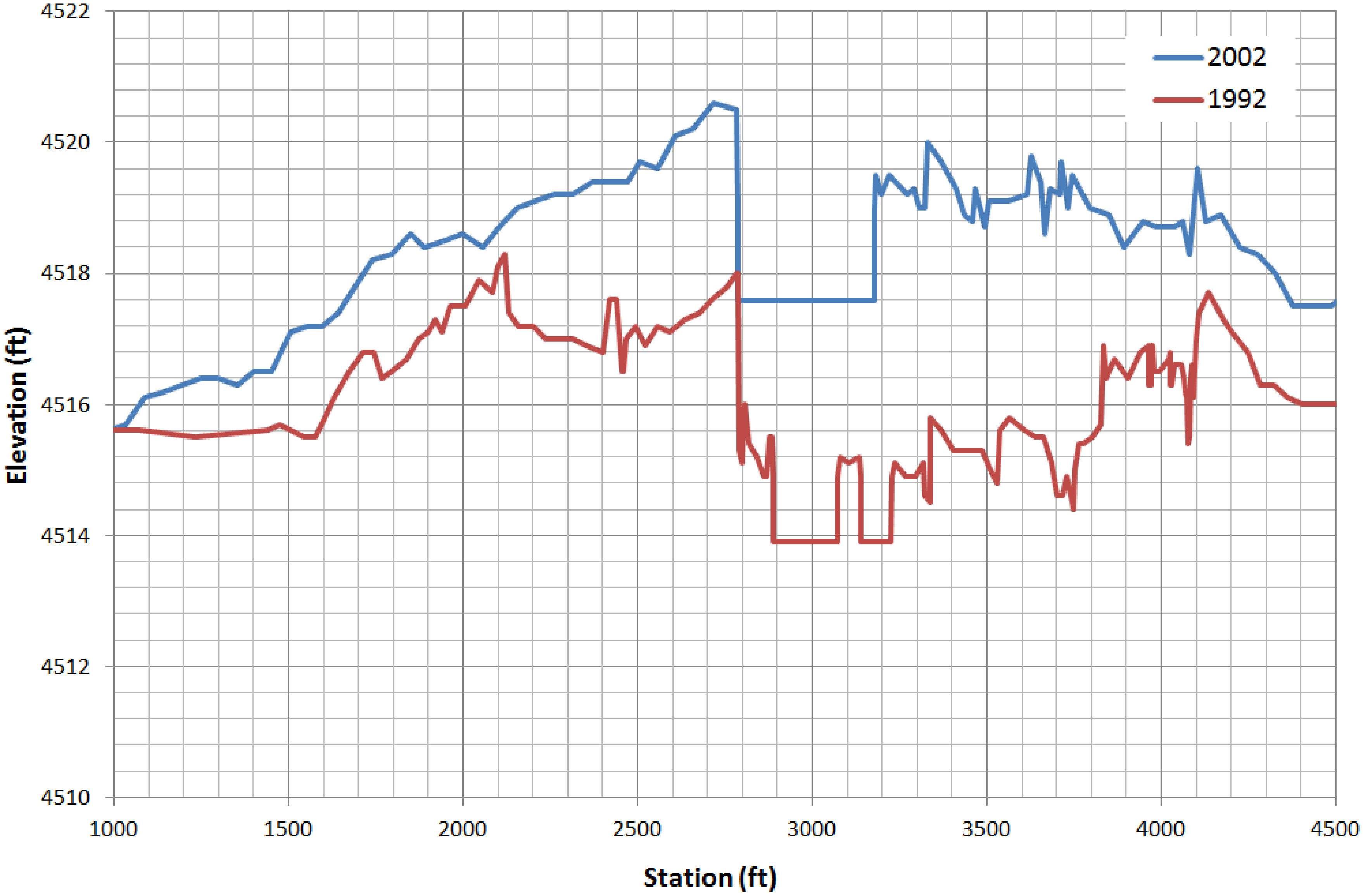

Figure 3.13: Cross-section at 2008 plug location (Agg/Deg #1550)

3.6 Low Overbank Flow

Another hypothesis is that sediment plugs are more likely to form in locations where flow goes overbank at low discharges relative to adjacent reaches. In these locations, significant flow is lost to the overbank, which reducing the sediment transport capacity in the reach assuming the sediment concentration profile is non-uniform (see Section 3.7). Bender and Julien (2012) conducted an overbank flow analysis within the Bosque reach to determine locations where flow went overbank at the lowest discharge. Figure 3.14 shows the five locations of lowest overbank discharge within the Bosque reach based on cross-section geometries from 1962, 1972, 1992, and 2002. It indicates that the five locations of lowest overbank discharge in 1992 all occurred within or just downstream of the location of the 2008 Bosque plug. Similarly, Figure 3.15 shows a moving average of 2002 overbanking discharges within the Bosque reach. The 2008 plug formed at the minimum of the curve. While it is possible that the channel geometry may have changed significantly between 2002 and 2008, it is reasonable to suggest that low overbank discharge may have contributed to plug formation. It would be useful to perform a similar analysis in the Elephant Butte reach to determine if similar trends occur there.

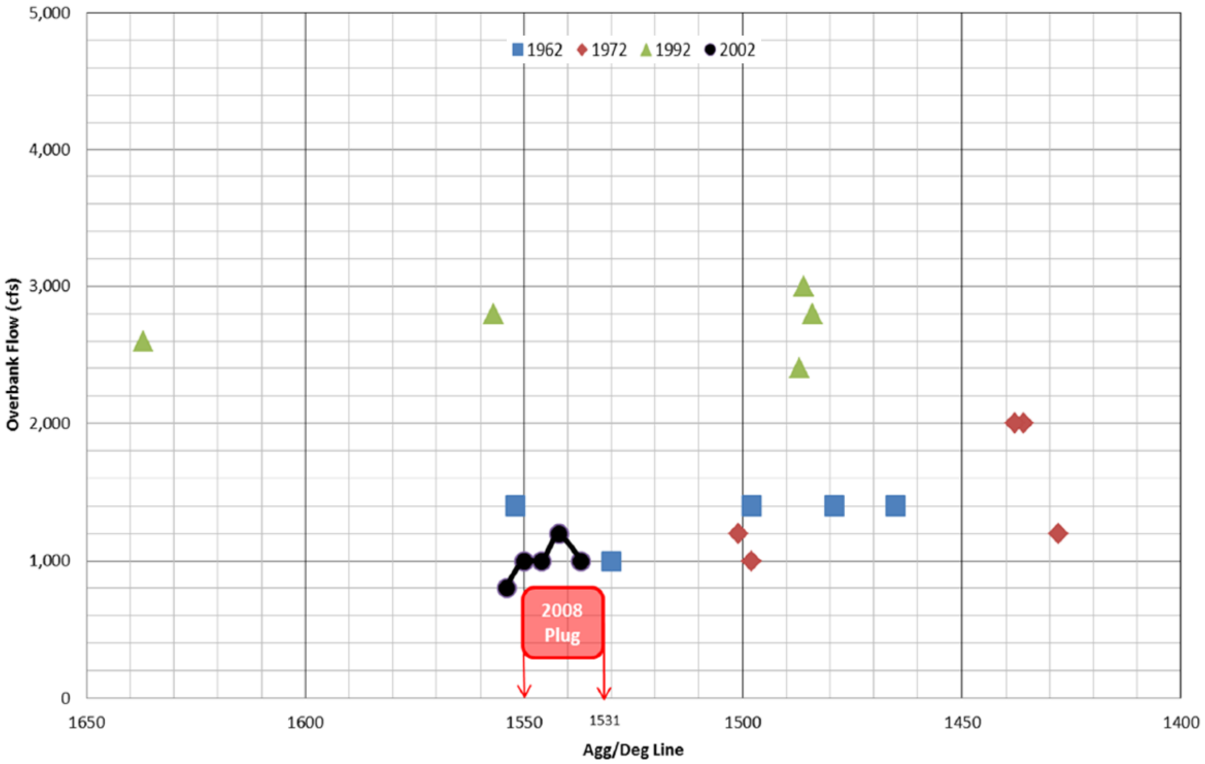

Figure 3.14: Top five overbank flows by year (from Bender and Julien, 2012)

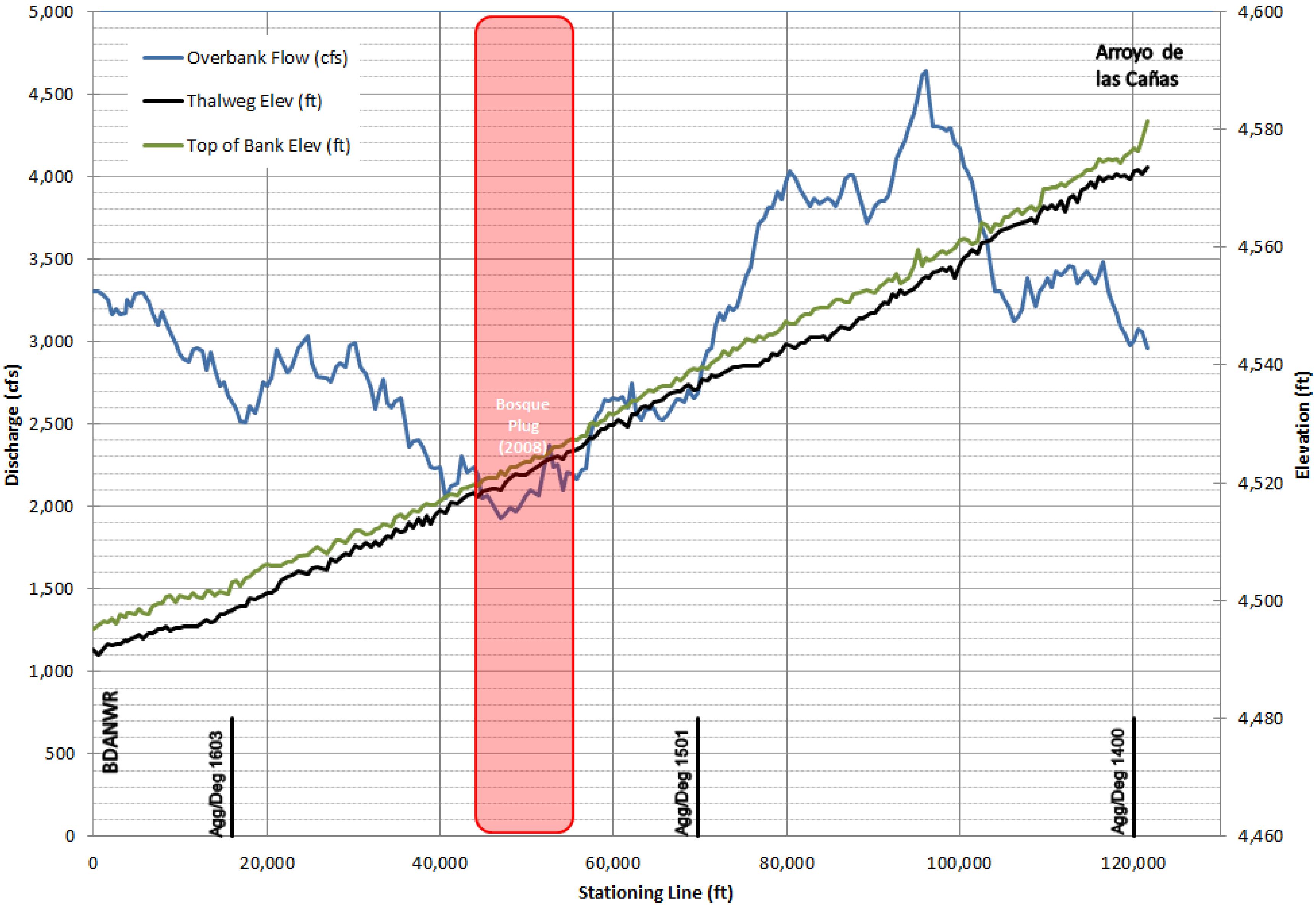

Figure 3.15: Moving average 2002 overbank discharge (from Bender and Julien, 2012)

3.7 Sediment Concentration Profile (Ro)

The shape of the sediment concentration profile within the water column has a significant impact on the transport of sediment. The Rouse number (Ro) describes the tendency of particles to remain in suspension and can be expressed as (Julien, 2010):

$$Ro = \frac{\omega}{\beta_s \kappa u_*} \qquad \text{(Equation 3.7)}$$

where ω is the particle fall velocity, $\beta_s = 1$, $\kappa = 0.4$, and u_* is the shear velocity. A high Rouse number indicates that the majority of sediment is in the form of bed-load, while a low Rouse number means the load is primarily mixed- or suspended-load. When flow goes overbank during high discharge, if the Rouse number is low and the concentration profile is relatively uniform, the amount of flow lost overbank is proportional to the loss of sediment. Therefore the transport capacity in within the channel remains relatively unchanged. However, in the case of a high Rouse number with sediment concentrated near the bed, there is essentially clear water near the surface. When flow goes overbank, clear water is lost to the overbank while the majority of the sediment remains within the channel. Therefore, the transport capacity with the channel is reduced, resulting in aggradation within the channel that could potentially form a sediment plug.

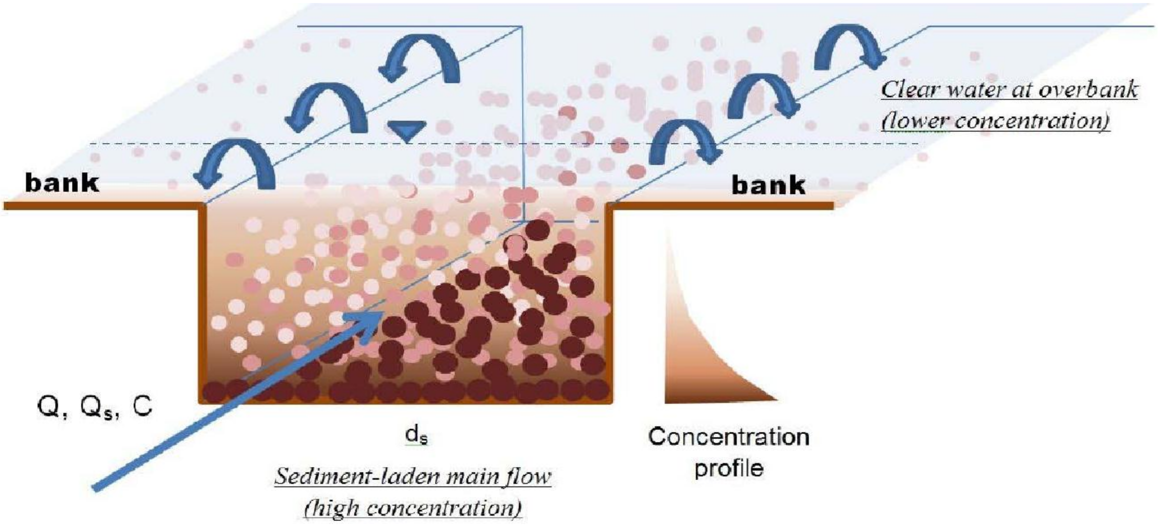

Figure 3.16: Vertical sediment concentration profile (Park and Julien, 2012)

Park and Julien (2012) modeled bed adjustments throughout the study reach incorporating the effects of overbank flow. The model was run at various discharges up to 5000cfs based on cross-section geometry from 1992 and 2002. The computed sediment concentration profiles indicated that in all instances, sediment load was concentrated primarily near the bed (see Figure 3.17)

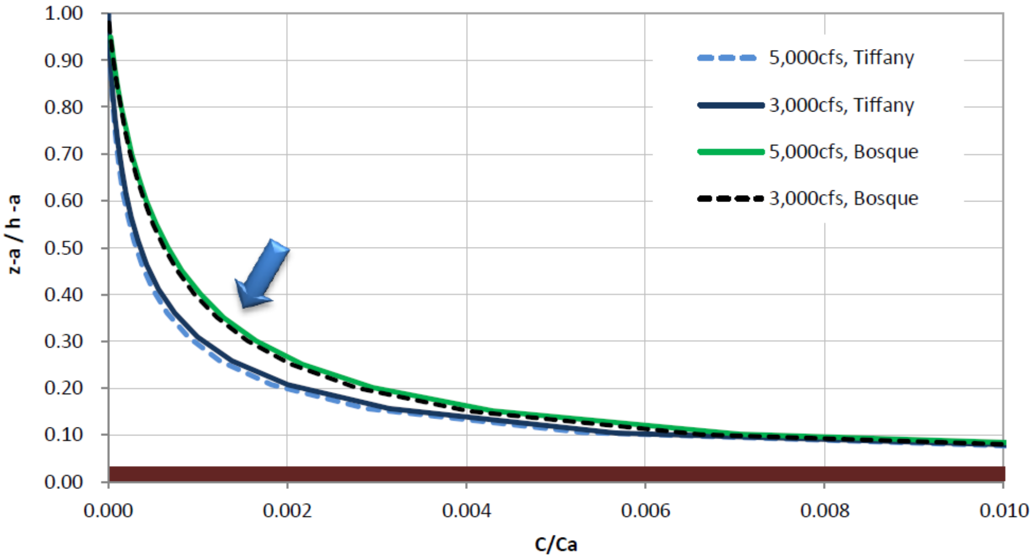

Figure 3.17: Sediment concentration profiles (from Park and Julien, 2012)

The Rouse number was computed at each cross section under the same conditions and values ranged from 0.6 to 1.7. It was determined that for > 1.2 , overbank flow accelerated aggradation of the bed. This suggests that the nature of the sediment concentration profile influences transport capacity in the case of overbank flow, and may influence plug formation.

3.8 Grain Size

The median grain size of the bed material bed material at San Marcial gage has coarsened slightly over the past several decades from approximately 0.125mm in 1968 to approximately 0.2mm in 2010 (see Figure 3.18). It is possible that the coarsening bed material may reduce the overall sediment transport capacity in these reaches, thereby increasing the likelihood of sediment plug formation. However, the overall coarsening of the reach does not explain why plugs formed at particular locations within the reach. Figure 3.19 shows the median grain size of samples taken at representative cross-sections in sub-reaches throughout the study area. The Bosque plug formed near the upstream end of Sub-reach 3 while the Tiffany plugs formed near the center of Sub-reach 6. The median grain size varied between 0.1mm at the most downstream end of the study reach and 0.3mm at the most upstream end in both 1992 and 2002. At both the locations of plug formation, the median grain size was close to the average median grain size of the reach (0.2mm). Thus, there is little evidence to suggest that local variations in grain size may have influenced plug formation, although a more detailed analysis of longitudinal variation in grain size may indicate otherwise.

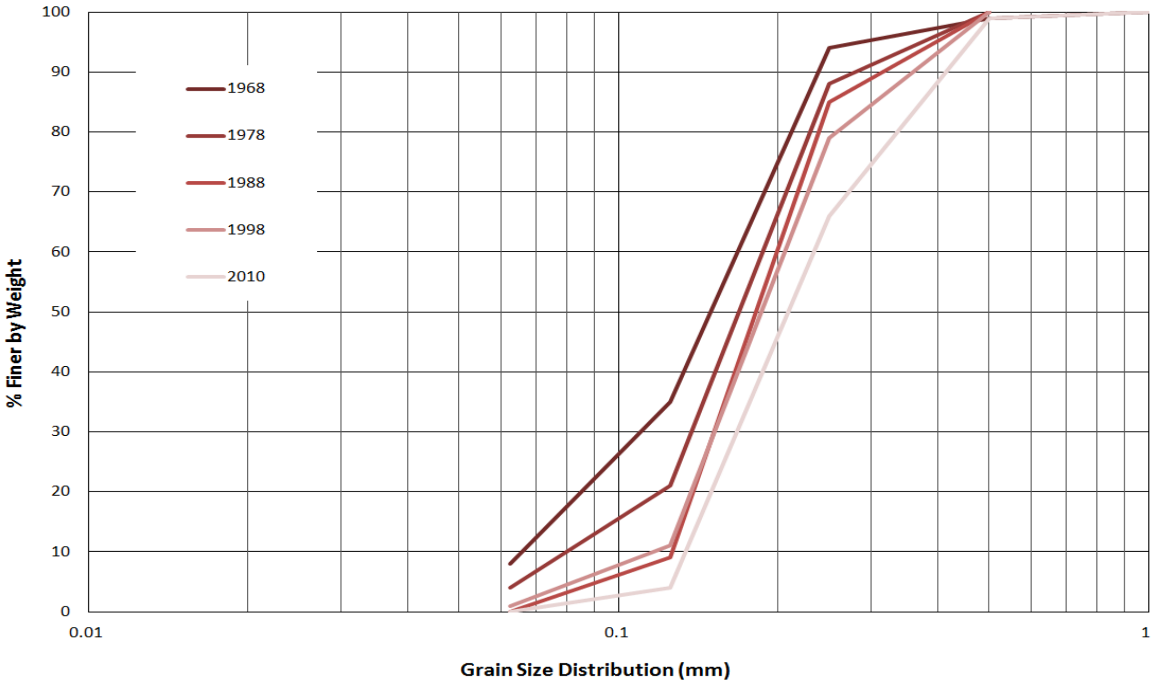

Figure 3.18: Annual bed material grain size distribution at San Marcial gage (Owen, 2012)

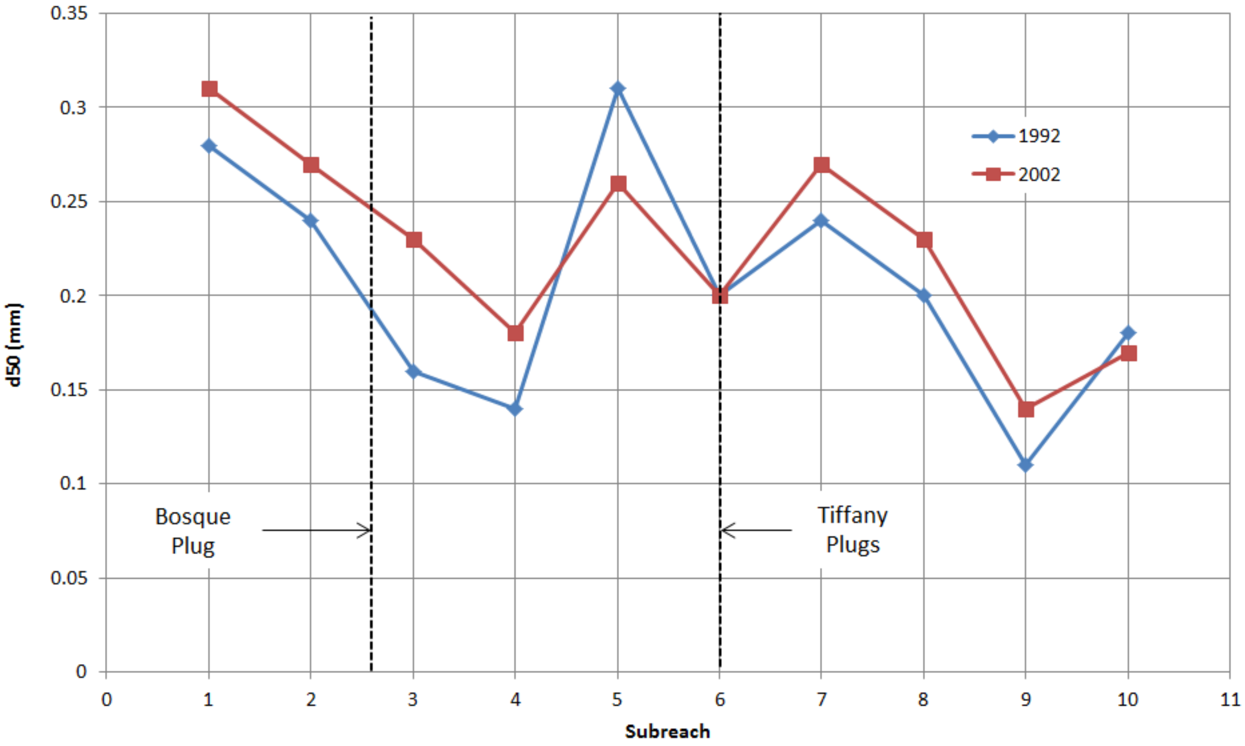

Figure 3.19: Grain size by sub-reach including locations of plugs

Section 4: Summary and Conclusions

Eight hypotheses were evaluated to determine their viability: 1) fluctuations in the water surface elevation of Elephant Butte Reservoir; 2) flood and drought cycles; 3) backwater effects from bridges; 4) channel width; 5) channel depth and perching; 6) low overbank flow; 7) sediment concentration profile; and 8) local changes in grain size. Many of these factors are interrelated and therefore unlikely to cause sediment plug formation by themselves. In most cases, it is a likely combination of these factors that influence plug formation. Analysis consisted of a review of reports produced by the US Bureau of Reclamation, CSU affiliates, and others as well as an examination of cross-section and channel geometry, flow records, suspended sediment records, reservoir time series, etc. The results are summarized as below:

1) Reservoir Levels

The reservoir water surface elevation was high in 1991 (4,430 ft) and 1995 (4,450 ft) relative to the average reservoir water surface elevation (4,355 feet) when sediment plugs formed. However, the reservoir level began to drop in 2000, and was low in both 2005 (4,300 ft) and 2008 (4,340 ft) when sediment plugs formed. Therefore, it is likely that the elevated base level played a role in the 1991 and 1995 sediment plugs. However, because the reservoir was low when the two most recent plugs formed, it can be concluded that level of Elephant Butte Reservoir is not a necessary factor in determining if and when a sediment plug might form.

2) Flood and Drought Cycles

All four sediment plugs formed during the snowmelt peak of the annual hydrograph. The mean value of the peak snowmelt flows from 1987 to 2011 was approximately 3,800 cfs, while the mean value of the average-annual flows over this period was approximately 800 cfs. The peak-annual flows in 1991, 1995, 2005, and 2008 were all significantly higher than average. The years leading up to the 1991, 2005, and 2008 plugs all experienced below average flow, indicating relative drought. However, the four years leading up to the 1995 plug all experienced above-average average-annual flows and peak snowmelt flows that were higher than the 1995 peak flow. Therefore, it can be concluded that while flood and drought cycles likely contribute the formation of sediment plugs, they are not a necessary factors in determining if and when a sediment plug will form.

3) Backwater Effects

The 1991, 1995, and 2005 plugs formed approximately 1.5 river miles upstream of the San Marcial railroad bridge, while the 2008 (Bosque) plug formed approximately 15 river miles upstream of the bridge. Therefore it is highly likely that backwater effects form the bridge could have influenced the formation of sediment plugs, especially in 1991, 1995, and 2005, although less likely for the 2008 plug. Also, the two locations where sediment plugs initiated are located just upstream of sharp bends in the channel. It is highly likely that backwater effects from these bends could have influenced plug formation.

4) Channel Width

Both locations of plug initiation are just upstream of contractions with the channel widening in the upstream direction. It is unlikely that an excessively wide channel was the sole result of decreased sediment transport capacity. It is likely that the contraction in the channel forced flow to go overbank at relatively low discharges. It is difficult to state for certain the influence of channel with on plug formation. Additional cross-section geometry for years just before and after plug formation, as well as numerical modeling of downstream variations of channel width would be useful to better understand the influence of channel width.

5) Channel Depth/Perching

The channels at both plug locations were perched in both 1992 and 2002. Both locations experienced significant aggradation form 1992 to 2002. The Tiffany plug location was much shallower in 2002 than in 1992, while the Bosque plug location was also relatively shallow in 2002. It is likely that the reduced channel capacity resulting from channel aggradation and the disconnectivity resulting from perching both influenced plug formation in each location.

6) Low Overbank Flow

The five locations of lowest overbank discharge in 1992 all occurred within or just downstream of the location of the 2008 Bosque plug. Also, the 2008 plug occurred at the minimum of the moving average curve of 2002 overbanking discharges within the Bosque reach. While it is possible that the channel geometry may have changed significantly between 2002 and 2008, it is reasonable to suggest that low overbank discharge may have contributed to plug formation. It would be useful to perform a similar analysis in the Elephant Butte reach to determine if similar trends occur there.

7) Sediment Concentration

One-dimensional hydraulic modeling has shown that Rouse numbers range from 0.6 to 1.7 within the study reach, with the majority of sediment load largely concentrated near the bed across a range of discharges. A potential threshold of $Ro = 1.2$ has been identified where values exceeding this threshold are likely to result in accelerated bed aggradation during overbank flow. The sediment concentration profile is highly likely to influence plug formation when combined with overbank flow.

8) Grain Size

The median grain size of the bed material bed material at San Marcial gage has coarsened slightly over the past several decades from approximately 0.125mm in 1968 to approximately 0.2mm in 2010. While it is possible that the coarsening bed material may reduce the overall sediment transport capacity in these reaches it does not explain why plugs formed at particular locations within the reach. At both the locations of plug formation, the median grain size was close to the average median grain size of the reach (0.2mm). Thus, there is little evidence to suggest that local variations in grain size may have influenced plug formation. Table 4.1 summarizes the results and identifies the factors most likely to influence sediment plug formation.

Table 4.1: Summary of potential factors influencing plug formation

Hypothesis	**Viable?**
1) Reservoir Level	Likely
2) Flood/Drought Cycles	Likely
3) Backwater Effects	**Highly Likely**
4) Channel Width	Likely
5) Depth/Perching	**Highly Likely**
6) Low Overbank Flow	**Highly Likely**
7) Concentration Profile (High Ro)	**Highly Likely**
8) Grain Size	Unlikely

Key areas requiring further investigation include:

1) Modeling the influence of reservoir fluctuations on upstream sediment transport capacity to determine extent and rate of propagation
2) Modeling backwater effects from bridges and bends to determine their influence on transport capacity
3) Modeling the influence of contractions on overbank flow and upstream transport capacity
4) Closer examination of local channel geometry in vicinity of plugs as well as changes with time
5) Overbank flow analysis for Elephant Butte reach
6) Further analysis of sediment concentration profiles and Rouse number thresholds in relation to overbank flow

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Appendix A – Annual Hydrographs

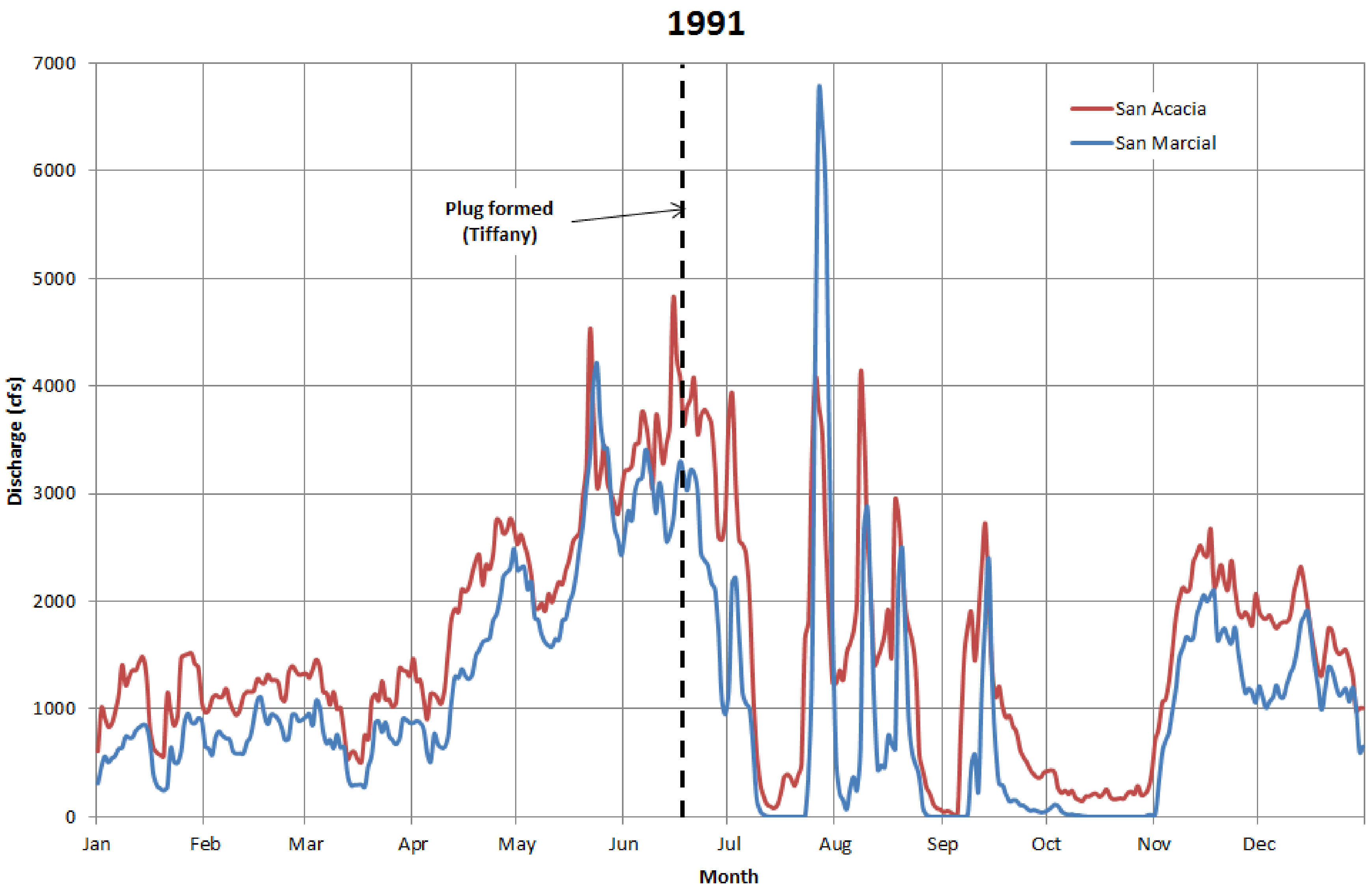

Figure A-1: Annual hydrograph for 1991

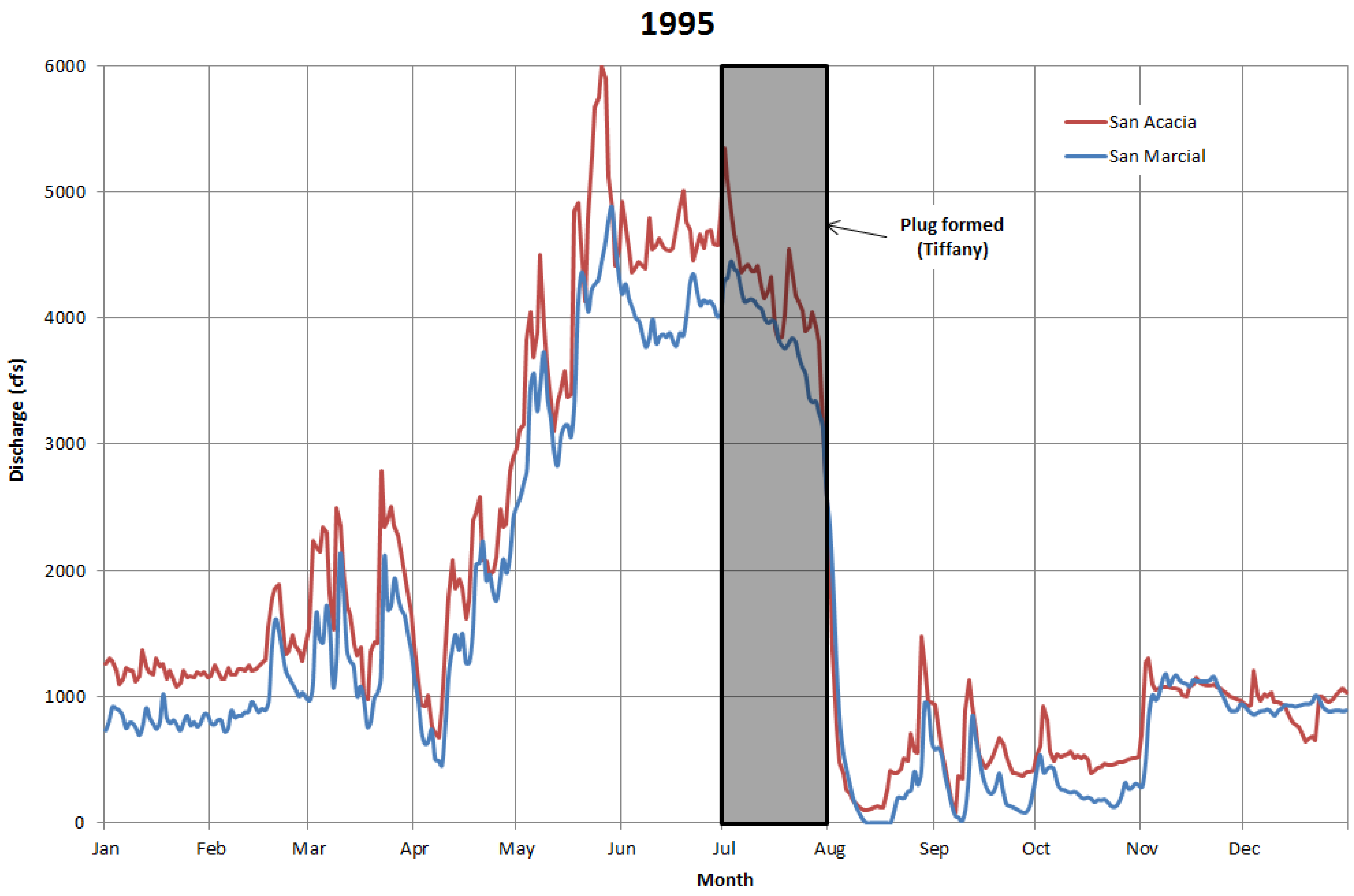

Figure A-2: Annual hydrograph for 1995

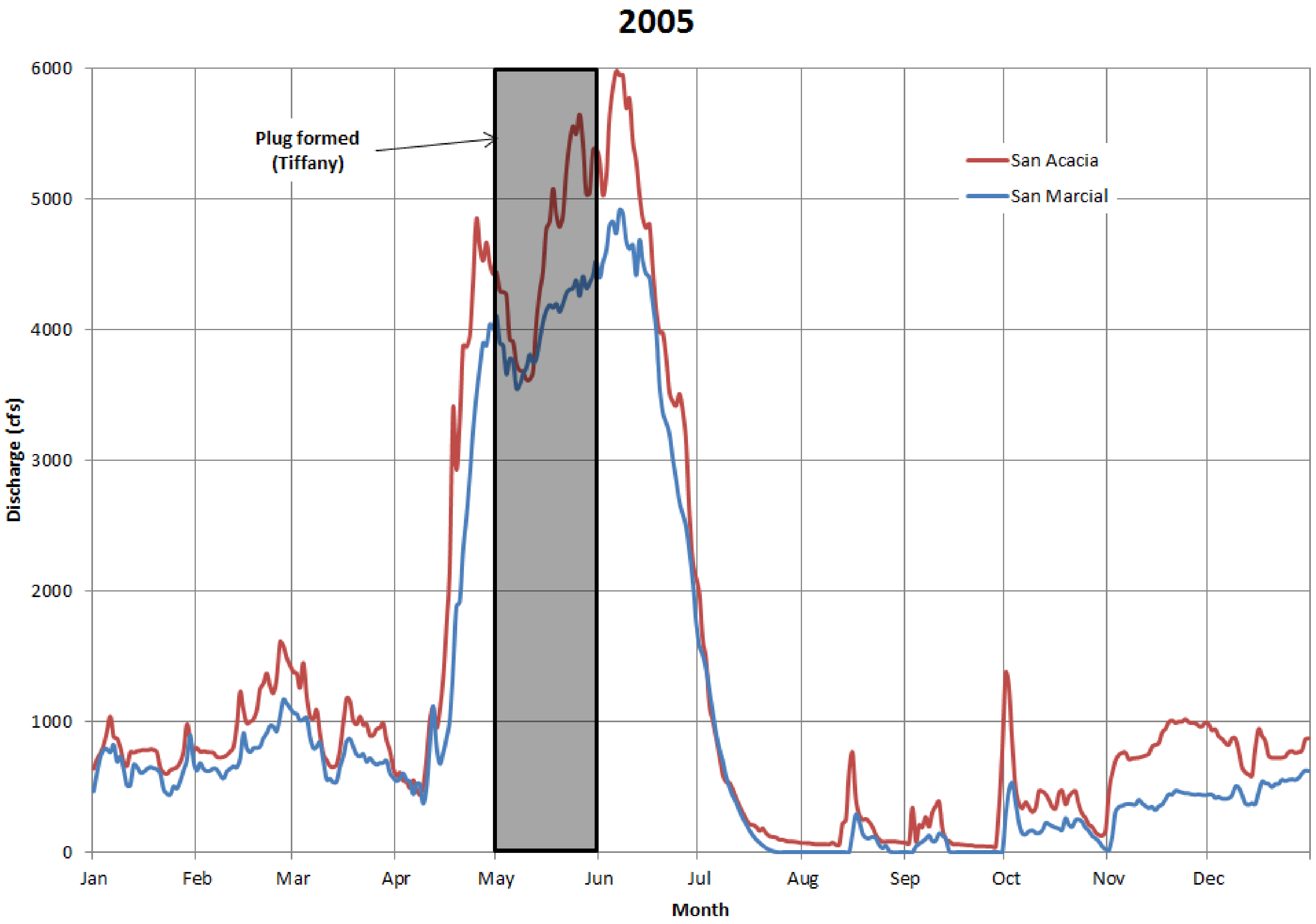

Figure A-3: Annual hydrograph for 2005

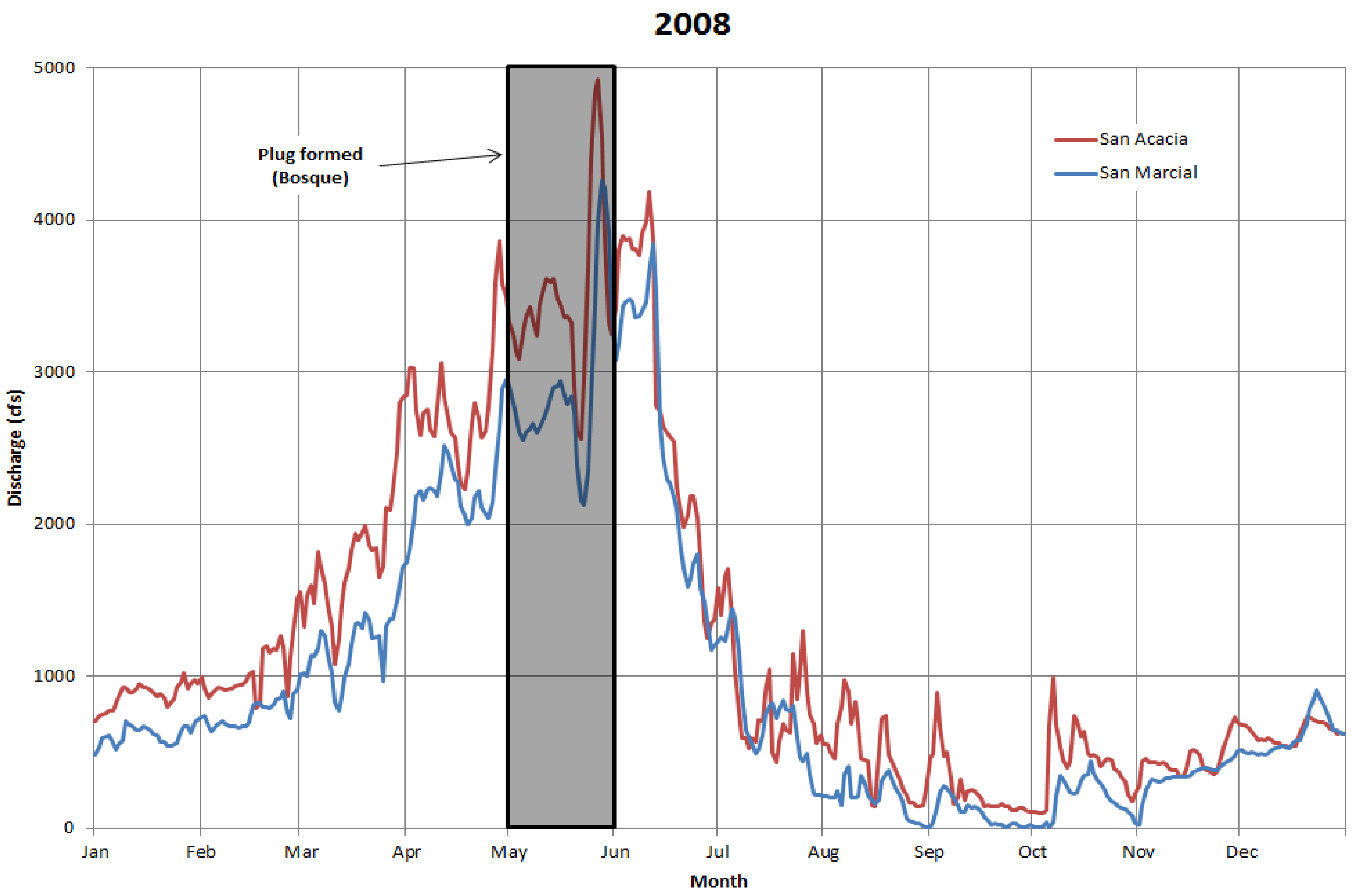

Figure A-4: Annual hydrograph for 2008

Appendix B – SO-Lines (from Owen, 2012)

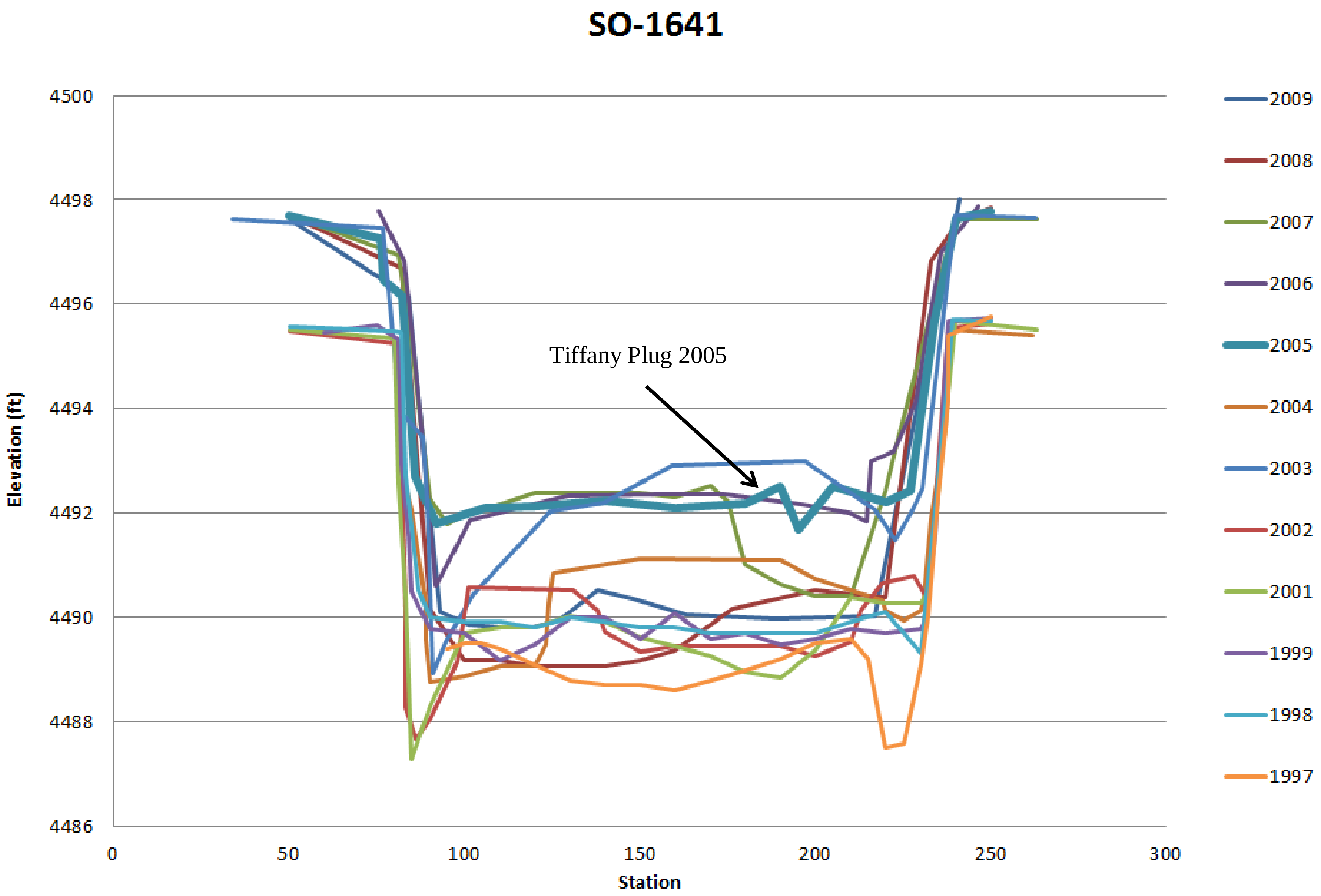

Figure B-1: SO-1641 Cross-section

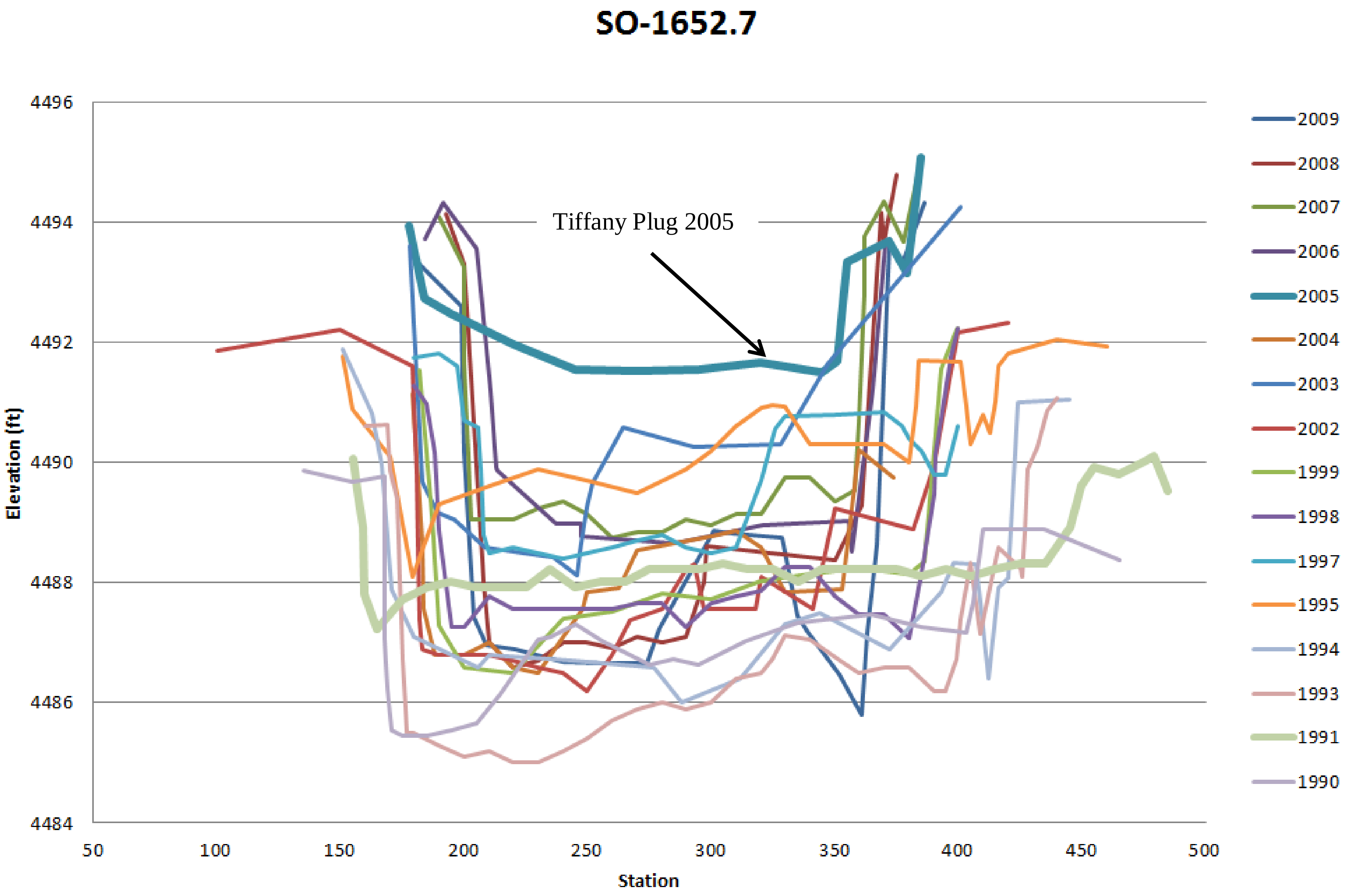

Figure B-2: SO-1652.7 Cross-section

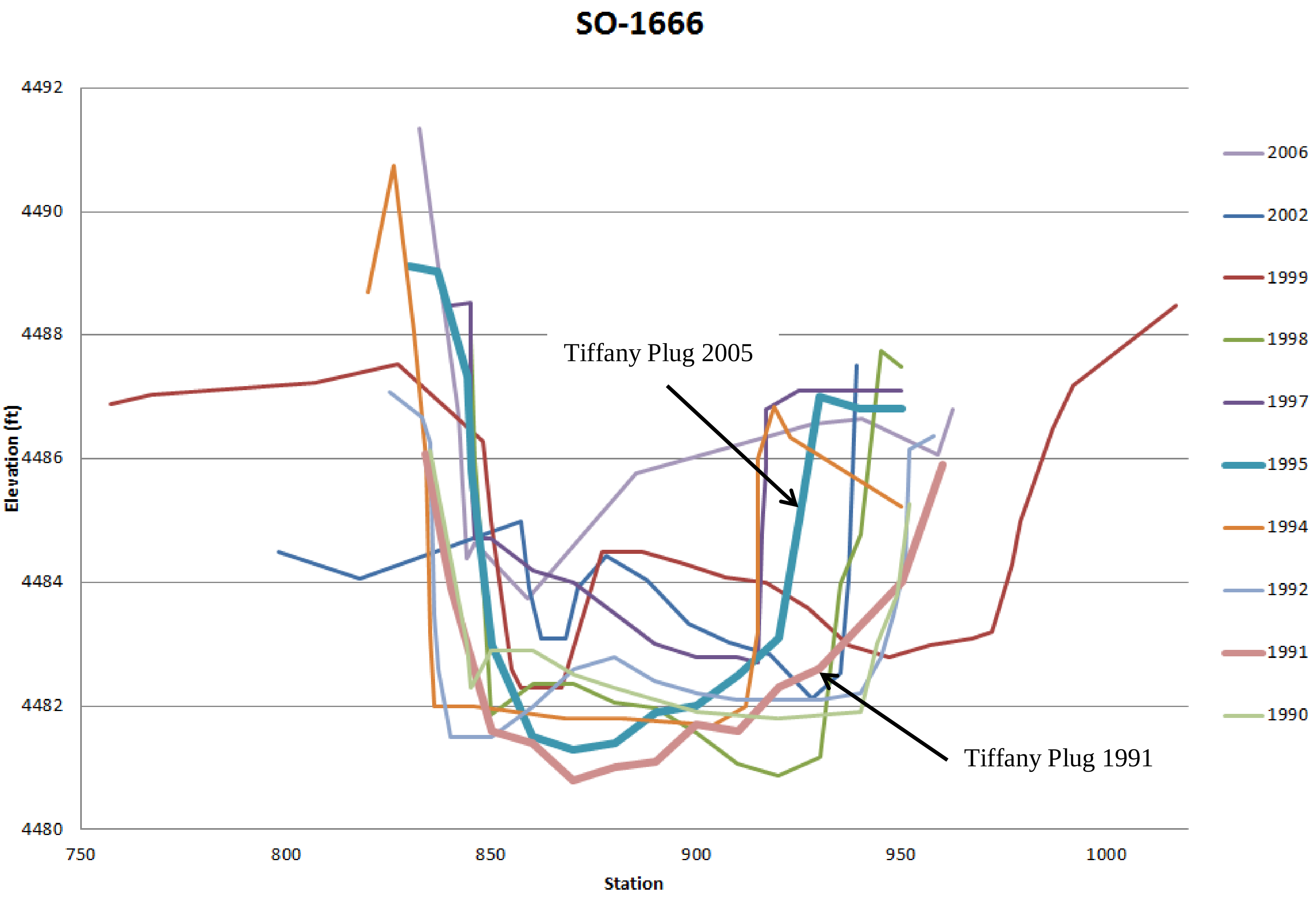

Figure B-3: SO-1666 Cross-section

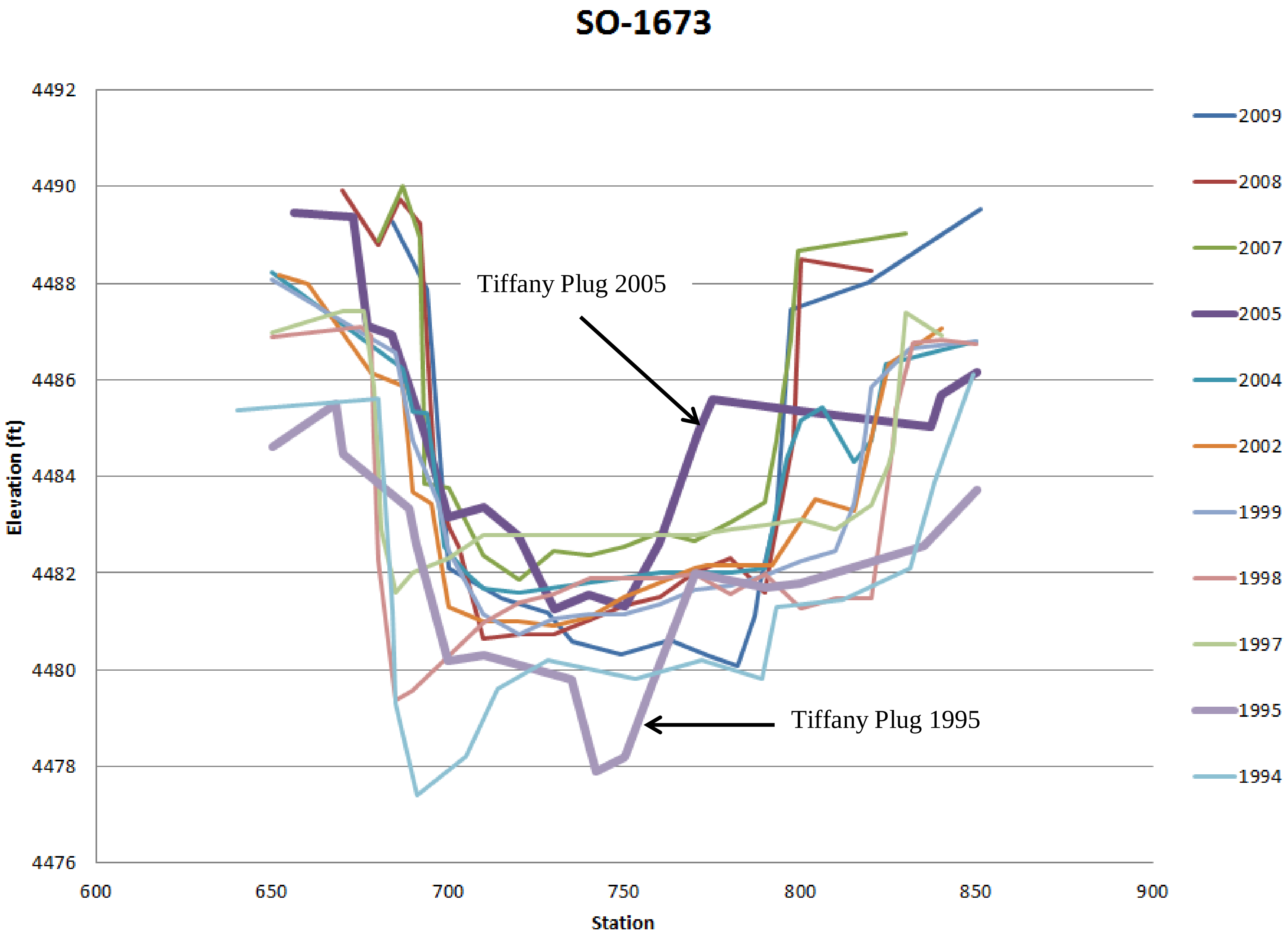

Figure B-4: SO-1673 Cross-section

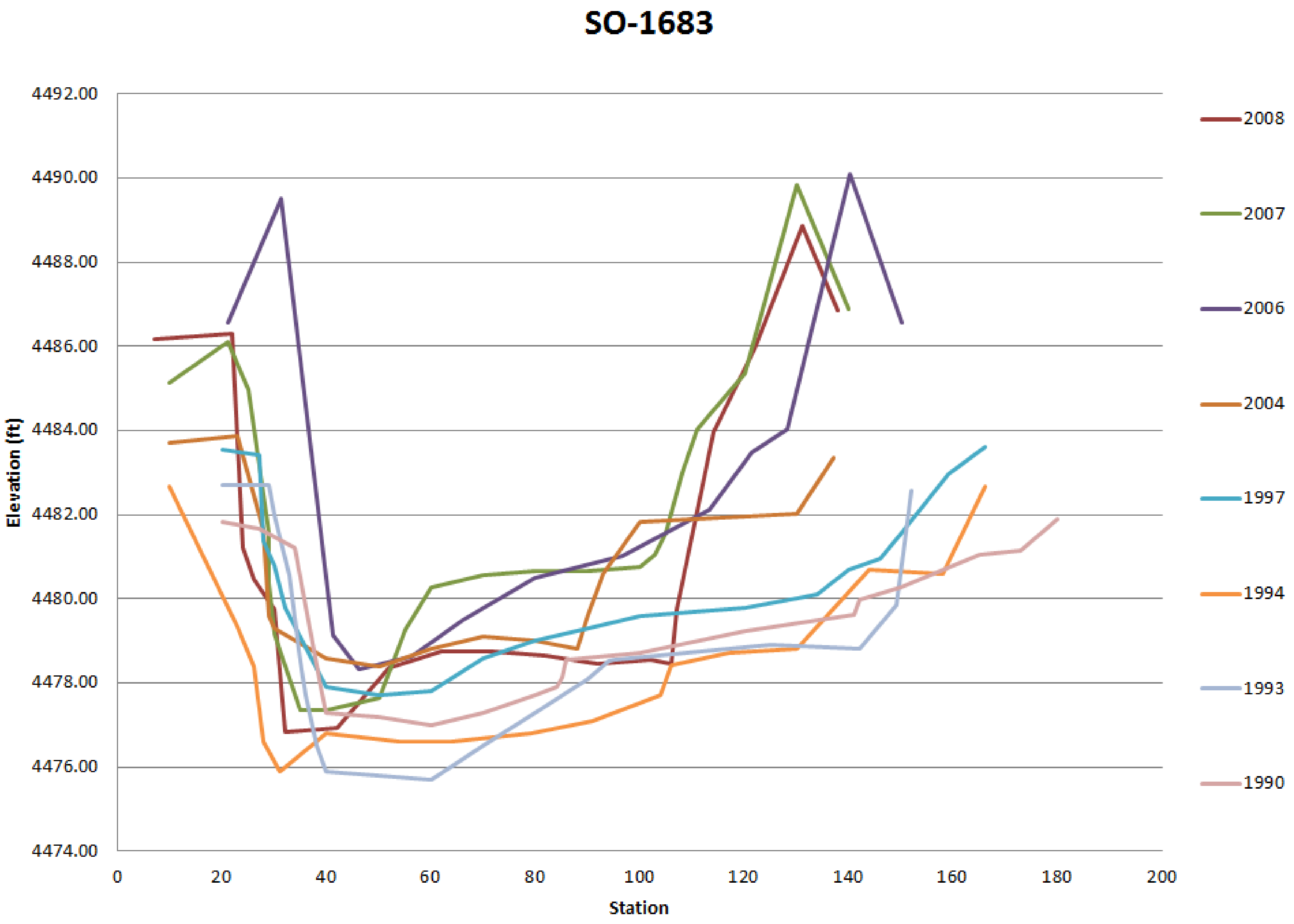

Figure B-5: SO-1683 Cross-section

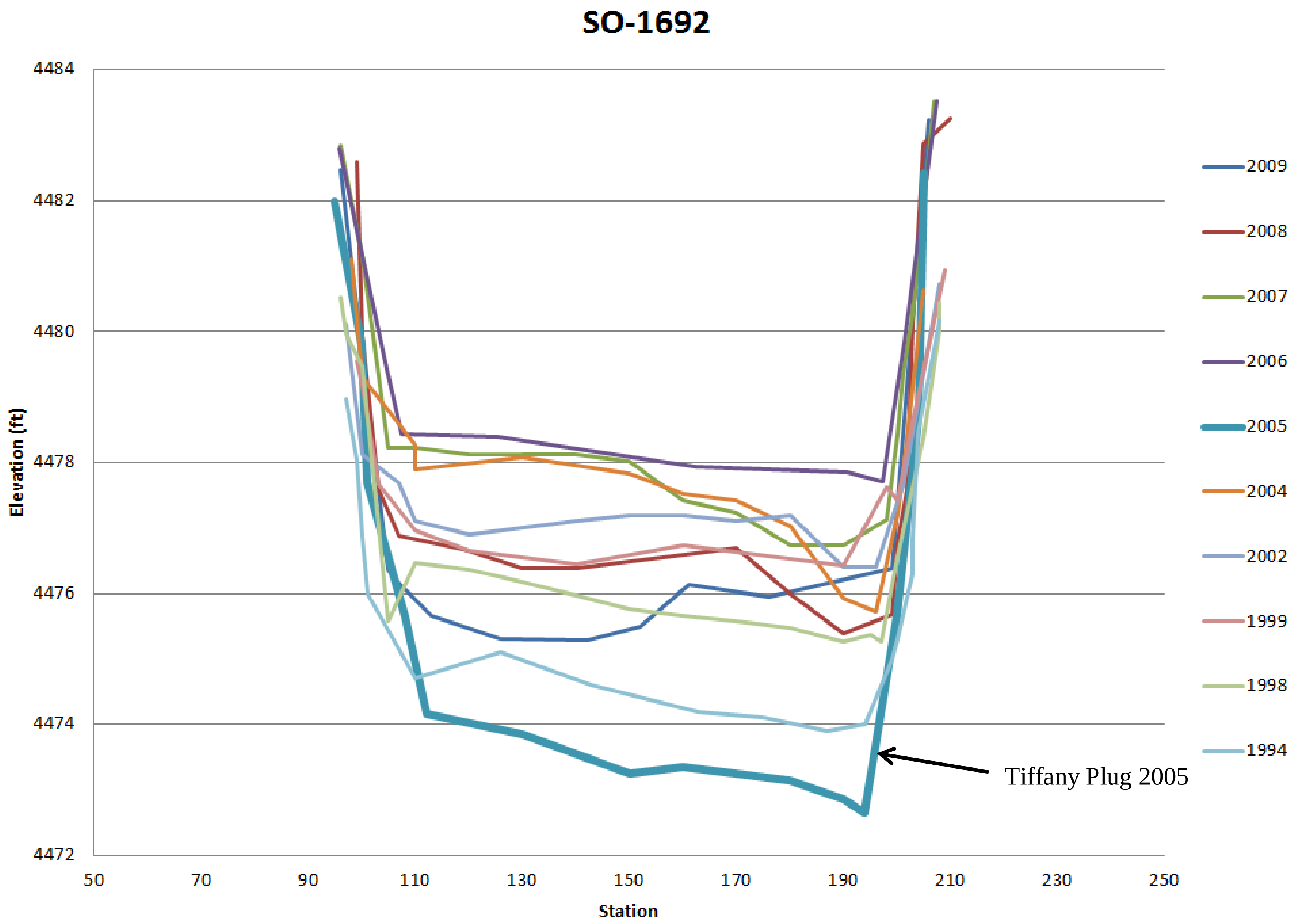

Figure B-6: SO-1692 Cross-section

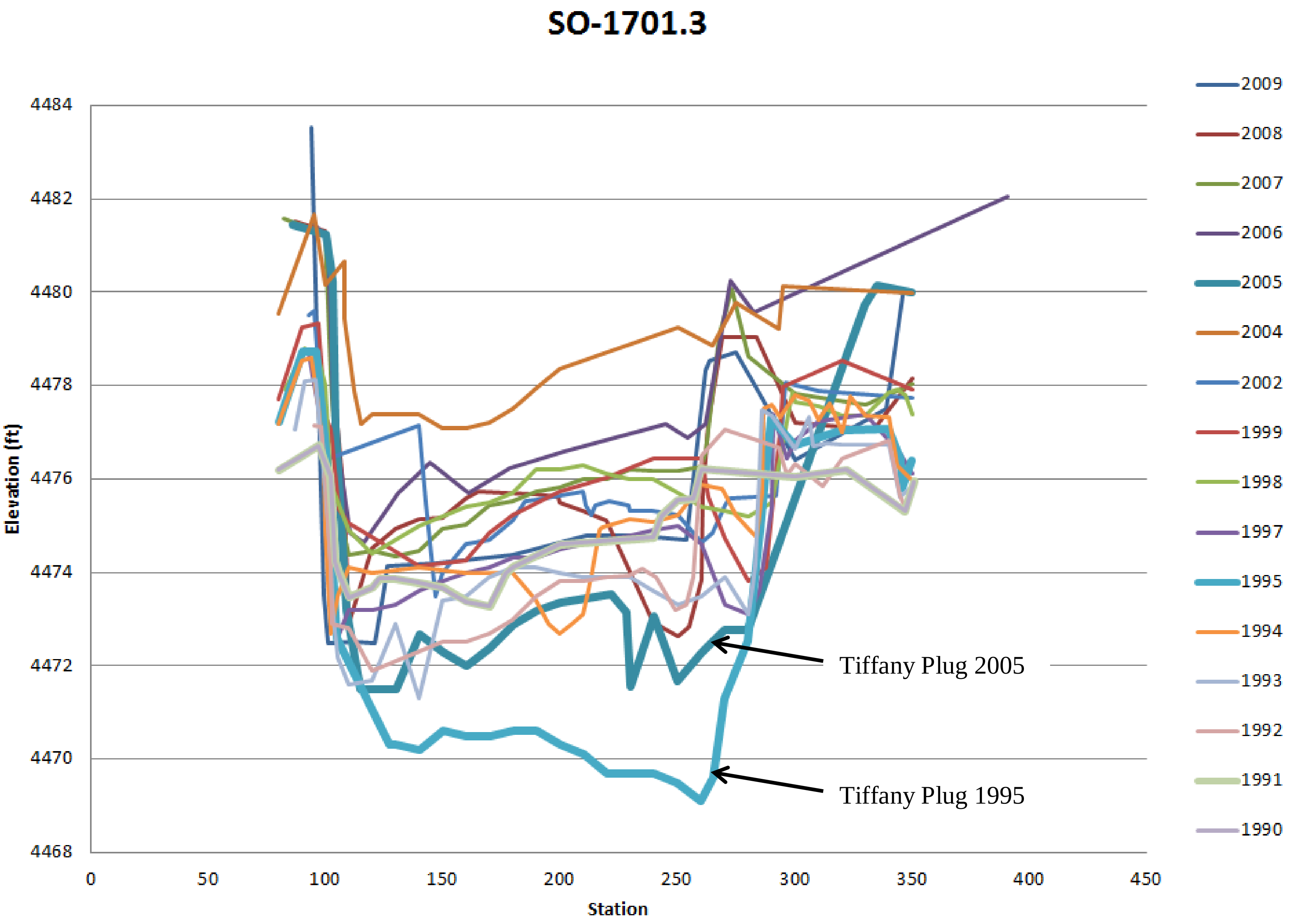

Figure B-7: SO-1701.3 Cross-section

Appendix C – Photographs

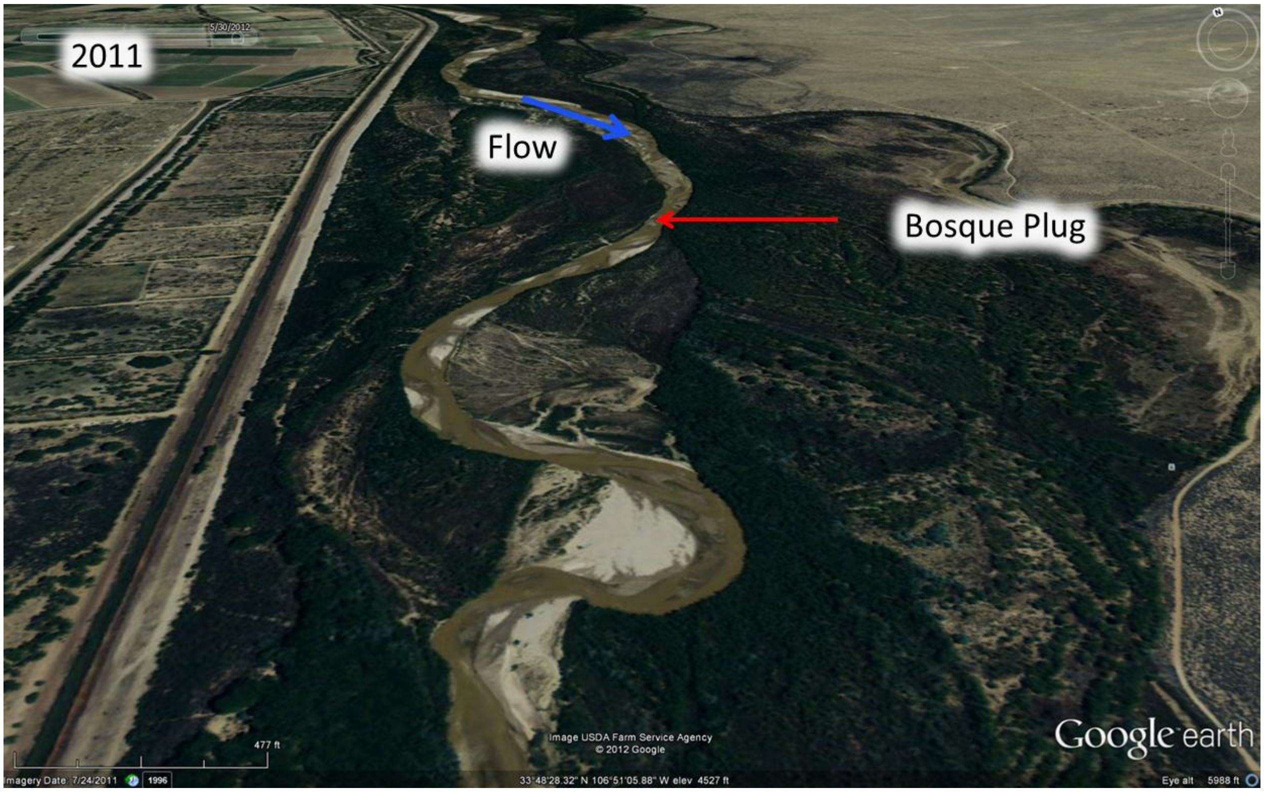

Figure B-1: Bosque plug location in August 2011 (Google Earth)

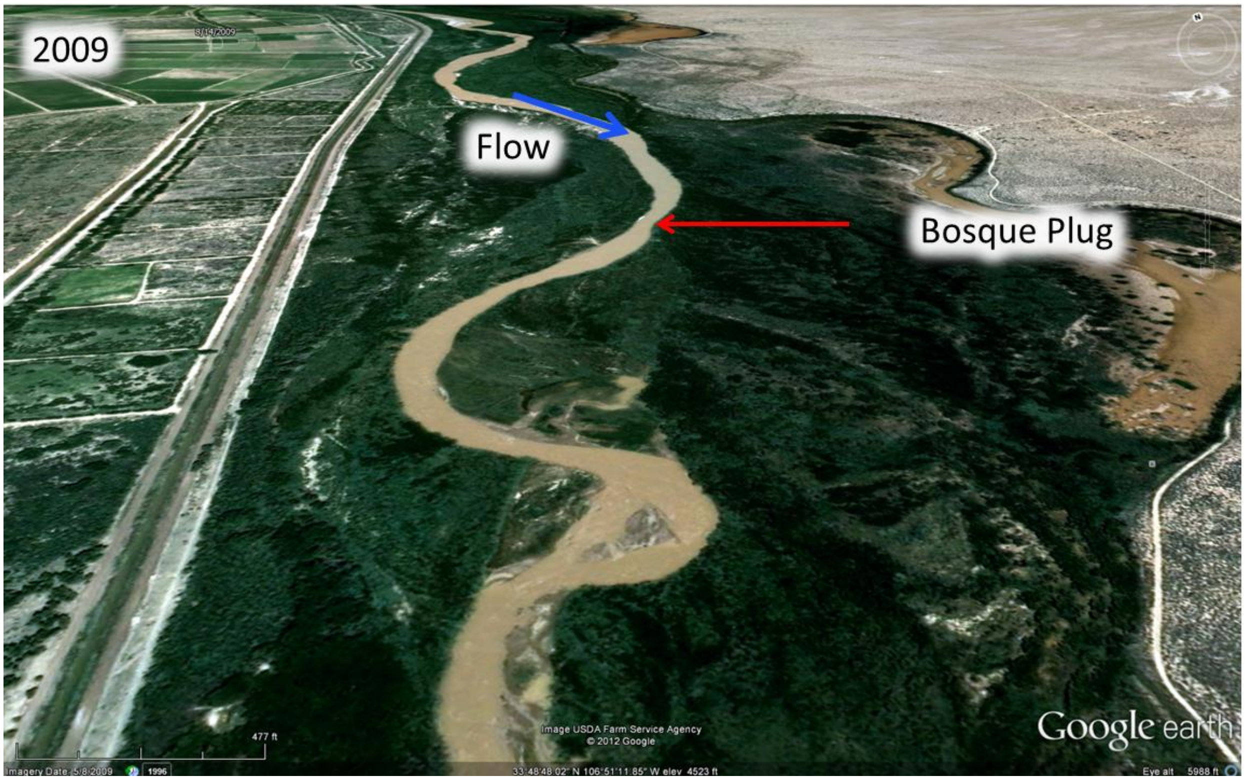

Figure B-2: Bosque plug location in August 2009 (Google Earth)

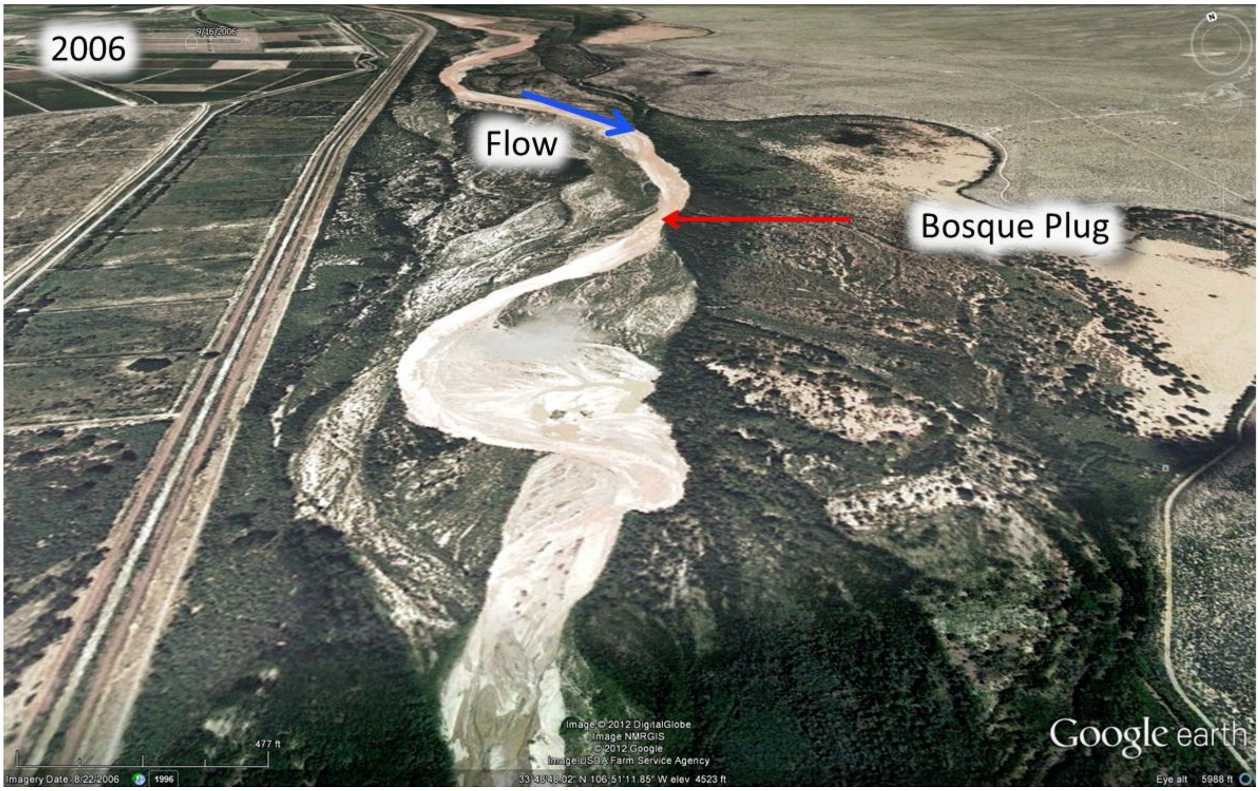

Figure B-3: Bosque plug location in September 2006 (Google Earth)

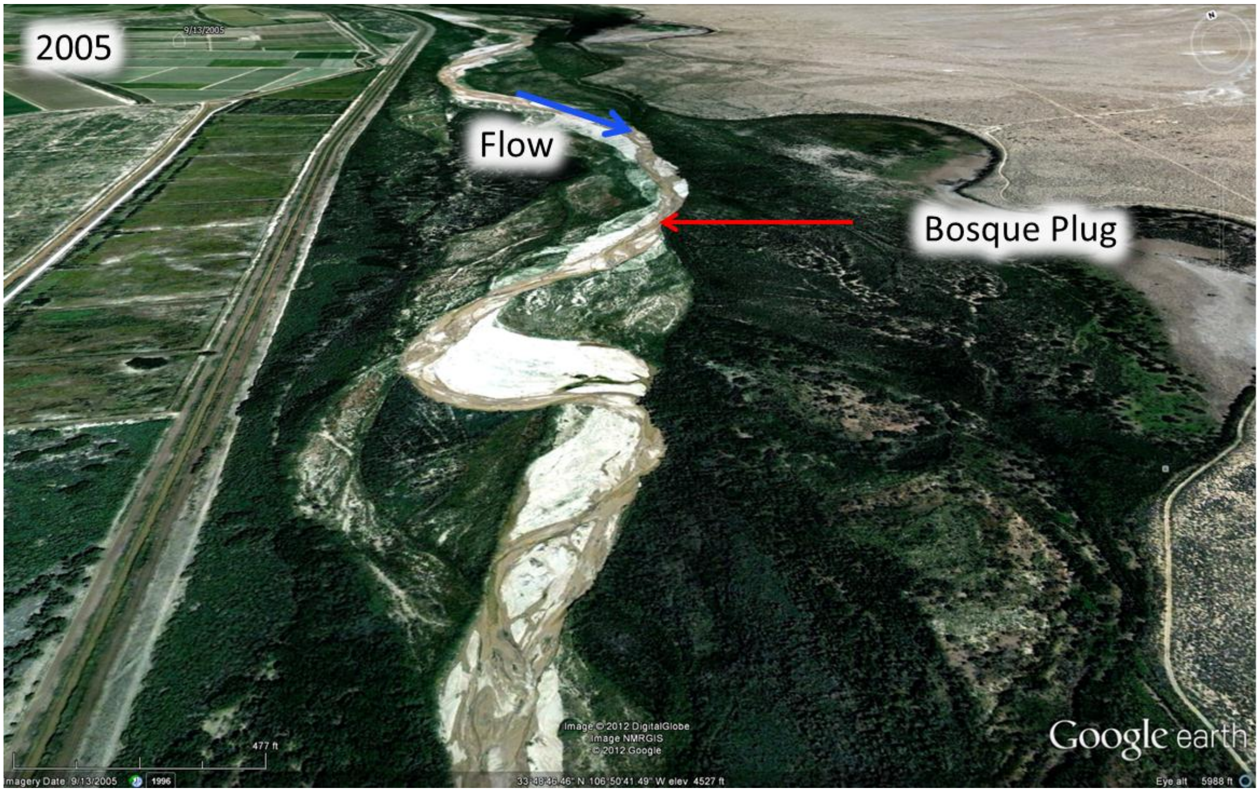

Figure B-4: Bosque plug location in September 2005 (Google Earth)

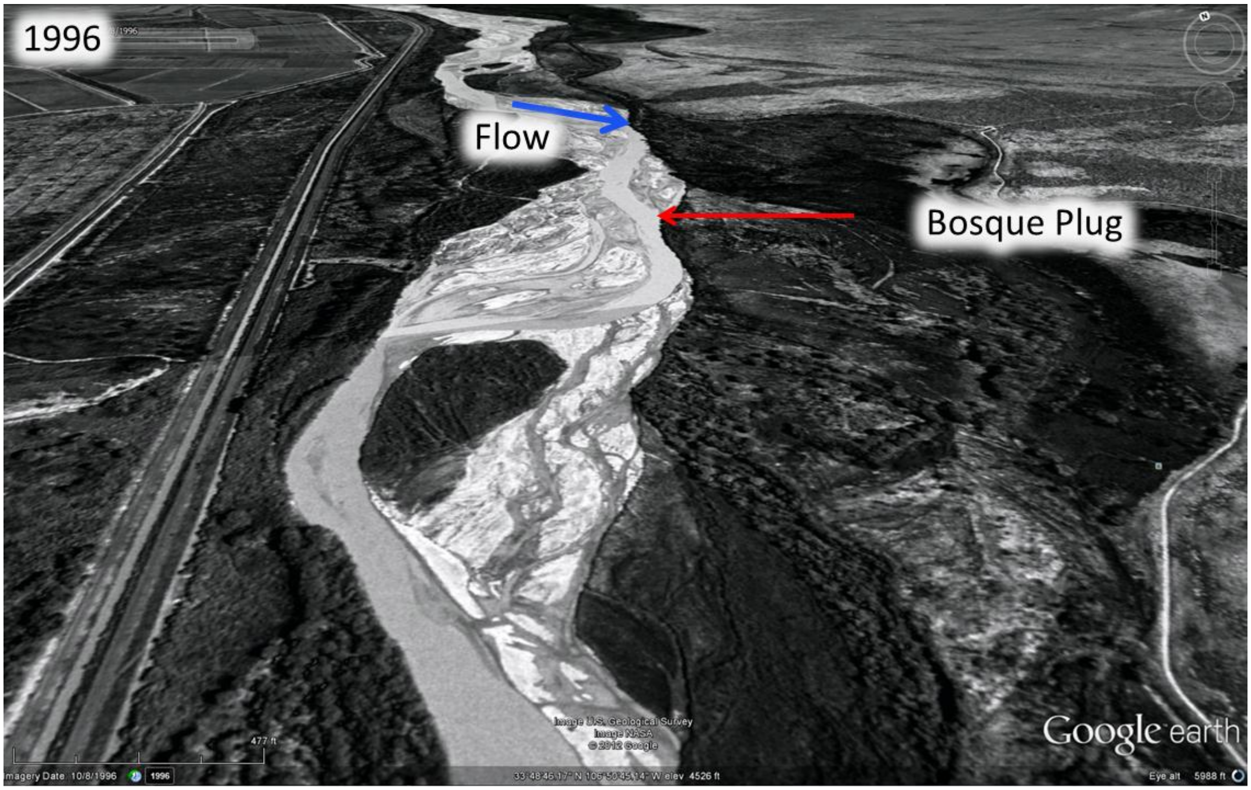

Figure B-5: Bosque plug location in October 1996 (Google Earth)

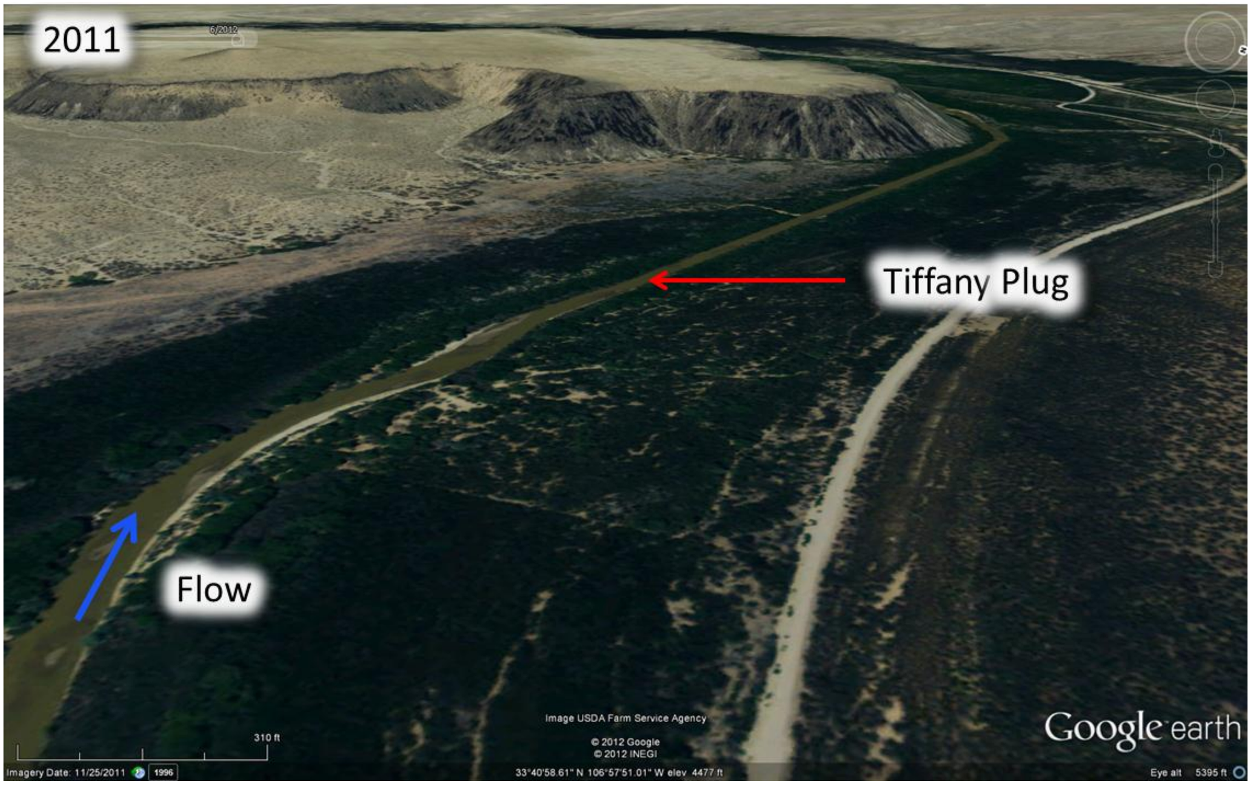

Figure B-6: Tiffany plug location in August 2011 (Google Earth)

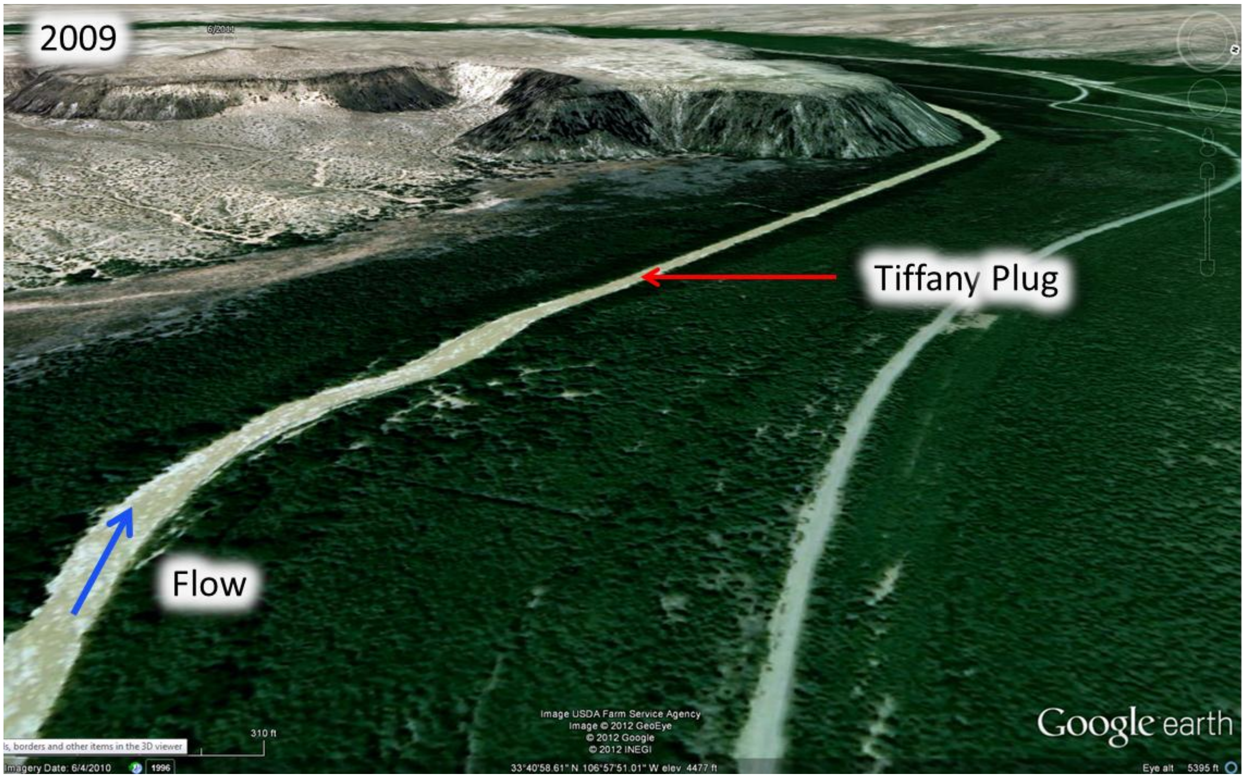

Figure B-7: Tiffany plug location in August 2009 (Google Earth)

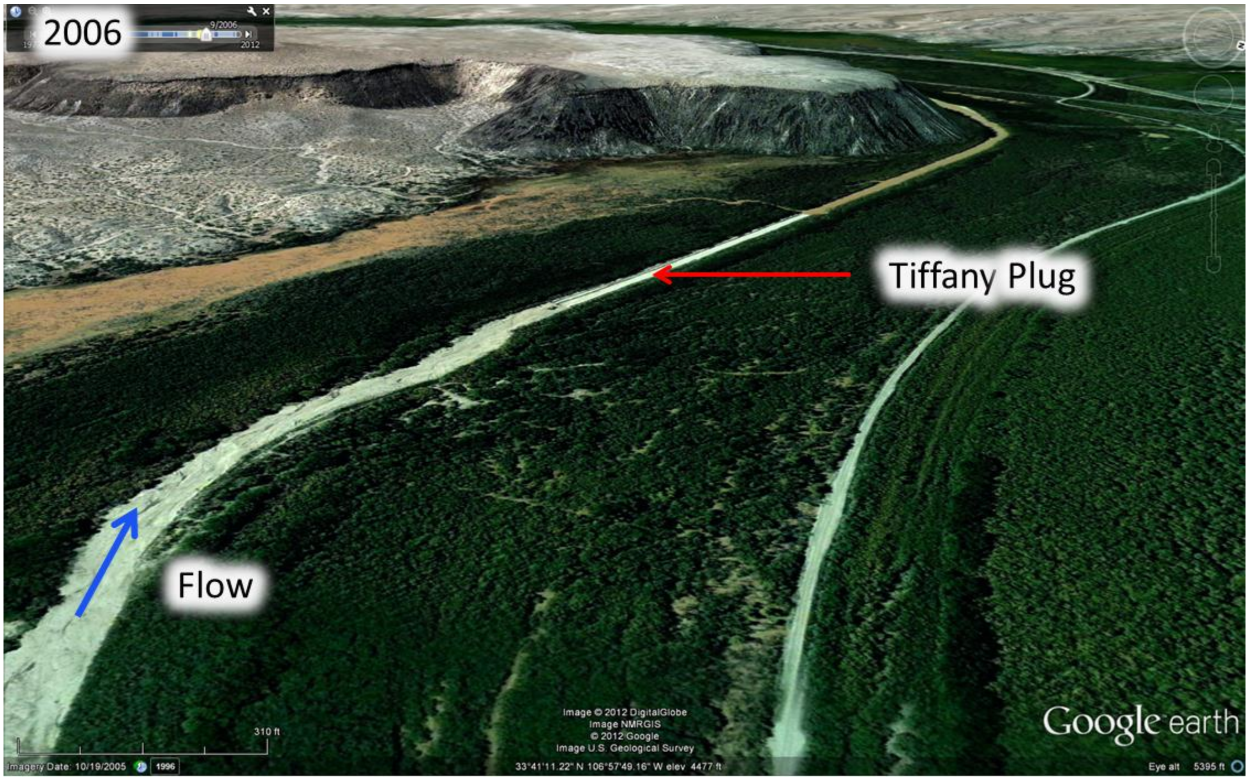

Figure B-8: Tiffany plug location in September 2006 (Google Earth)

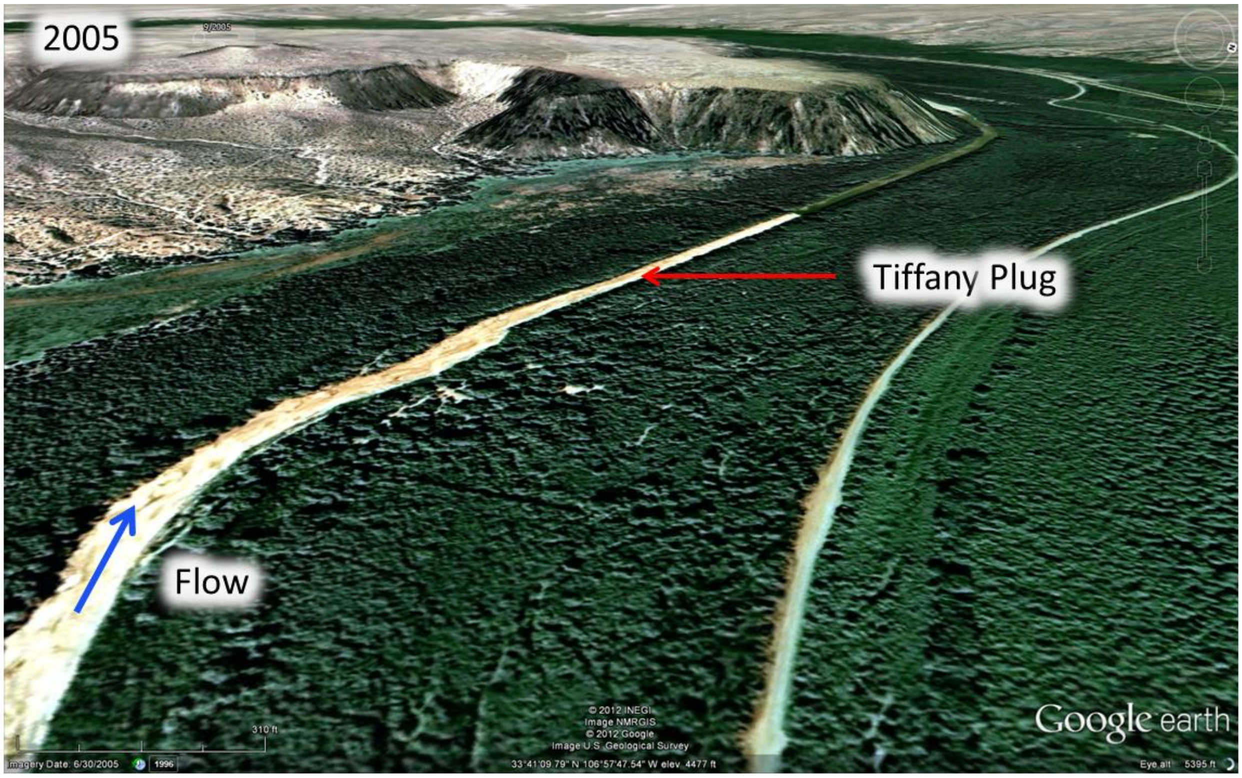

Figure B-9: Tiffany plug location in September 2005 (Google Earth)

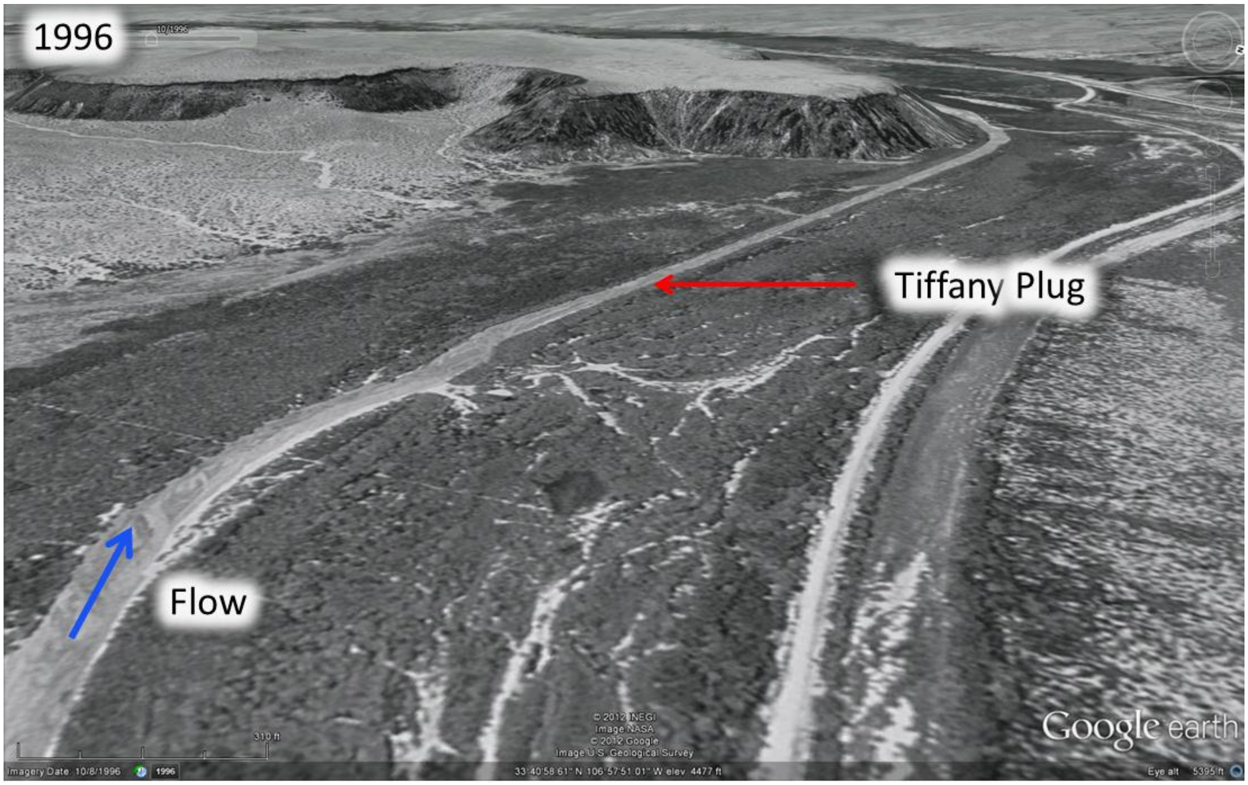

Figure B-10: Tiffany plug location in October 1996 (Google Earth)