APPENDIX K – Sediment Transport Capacity Analysis

Final
Detailed Sediment Transport Capacity Analysis for the Arroyo Seco Channel

Devils Gate Reservoir Sediment Removal and Management Project

January 7, 2013
Prepared for:
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Engineer's Certification

This report was prepared under the supervision of Charles S. Mohrlock, a Registered Civil Engineer in the State of California. The Registered Civil Engineer attests to the technical information contained herein and the engineering data upon which recommendations, conclusions, and decisions are based.

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Abbreviations

ac-ft – acre-feet

cfs – cubic feet per second

fps – feet per second

Acronyms

HEC-HMS – Hydrologic Engineering Center – Hydrologic Modeling System

HEC-RAS – Hydrologic Engineering Center River Analysis System

LACFCD - Los Angeles County Flood Control District

LIDAR – Light Detection and Ranging

WMS – Watershed Modeling System

Executive Summary

This Sediment Transport Capacity Analysis for the Arroyo Seco Channel has been prepared per the request of the Los Angeles County Flood Control District (LACFCD) in order to determine if natural storm flows anticipated to occur over a 3-5 year time period are capable of conveying accumulated sediment from behind the Devils Gate Dam, down the entire length of the Arroyo Seco Channel, to the Los Angeles River confluence.

Per direction from the LACFCD, three different sediment transport scenarios, referred to herein as Conditions 1, 2, and 3, have been analyzed within the scope of this report. All three of the conditions analyzed have been modeled with identical Sediment Transport Events which discharge stormwater outflows through one fully opened 5'x5' sluice gate and are comprised of 9.5 months of historical inflow data extending from January 1, 2006 through October 14, 2006; however, the subsequent Sediment Flushing Event, which discharges stormwater outflows through two fully opened 7'x10' slide gates, varies for each condition as described below.

The Condition 1 Sediment Flushing Event represents the anticipated long-term conditions that can be expected to occur if historically typical stormwater flows are utilized to flush sediment deposition from within the Channel under typical Dam operating conditions, which are comprised of 6 months of historical inflows extending from October 15, 2006 through, April 15, 2007. The results of this analysis indicate that the Condition 1 Sediment Flushing Event is not capable of flushing excess sediment down the length of the Channel.

The Condition 2 Sediment Flushing Event represents an idealized sediment flushing scenario that utilizes a constant flow rate of 4,900 cfs, which corresponds with the maximum possible controlled stormwater flow rate of that can be discharged through the Dam's two fully open 7'x10' slide gates. The results of this analysis indicate that the Condition 2 Sediment Flushing Event is capable of flushing excess sediment down the entire length of the Channel provided that this constant maximum flow rate of 4,900 cfs is maintained for a duration of 3 days; however, maintaining these flow characteristics requires unrealistic reservoir inflow rates and potentially hazardous Dam operating conditions.

The Condition 3 Sediment Flushing Event represents a theoretical sediment flushing scenario that utilizes a constant flow rate of 2,500 cfs, which corresponds with the minimum effective sediment flushing stormwater flow rate that was determined by this analysis. The results of this analysis indicate that a constant stormwater flow rate of no less than 2,500 cfs is capable of providing complete flushing of the Channel in approximately 6 days; however, maintaining these flow characteristics requires unrealistic reservoir inflow rates and potentially hazardous Dam operating conditions.

Overall, the sediment transport characteristics determined within the scope of this analysis indicate that historically typical stormwater flows available to this system are not capable of producing the conditions necessary to provide a complete and effective cycle of sediment transport and sediment flushing.

1 Introduction

1.1 Purpose

This Sediment Transport Capacity Analysis for the Arroyo Seco Channel has been prepared per the request of the Los Angeles County Flood Control District (LACFCD) in order to determine if natural storm flows anticipated to occur over a 3-5 year time period are capable of conveying accumulated sediment from behind the Devils Gate Dam, down the entire length of the Arroyo Seco Channel, to the Los Angeles River confluence.

Characteristics of sediment transport occurring upstream of the Dam outlet are not analyzed within the scope of this report; instead, per the direction of the LACFCD, the assumption that the Sediment Transport and Sediment Flushing Events contain sediment concentrations of 5% and 0% respectively has been made. The natural storm flows utilized for this analysis are comprised of 15.5 months of historical Devils Gate Dam inflow data that are categorized into two different events: the Sediment Transport Event, and the Sediment Flushing Event which are further discussed in Sections 2.1.1 and 2.1.2 of this report.

Analysis with respect to the determination of flow rates occurring at the Devils Gate Dam outlet as well as a general discussion of the models and methodologies utilized within this analysis are discussed herein. For a more detailed analysis of sediment transport characteristics of the Arroyo Seco Channel, including sediment deposition profile maps, plan view maps, and cross sections, reference the "Modeling of Sluicing and Flushing Conditions in the Arroyo Seco Channel Below the Devil's Gate Dam" report by Chang Consultants dated January 7, 2013 in Appendix B of this report.

This analysis utilizes information from several sources including: LACFCD provided historical Devils Gate Reservoir inflow data at hourly intervals for a 15.5 month period of time (January 1, 2006 through April 15, 2007); LACFCD provided Devils Gate Dam elevation-storage-discharge information for the sluice gate and slide gates; excerpts from LACFCD provided Devils Gate draft soils report by Leighton, dated October, 2011; excerpts from sediment gradation information obtained through NV5 soil samples performed on October 31, 2012; LACFCD provided LIDAR topographic information with a fly date of January 12, 2006; and the "Final Sediment Transport Capability Analysis For the Arroyo Seco Channel" report prepared by Bureau Veritas North America, Inc. dated August 3, 2012.

1.2 Project Description

The Devils Gate Dam (Dam) is located in the Los Angeles River Watershed in the City of Pasadena, CA. Situated immediately north of Interstate Highway 210, near the Rose Bowl Stadium, the Dam separates the upper and lower watersheds of the Arroyo Seco Channel and provides significant storage capacity for stormwater runoff originating north of the Dam in the San Gabriel Mountains.

Figure 1: Vicinity Map

The Dam was the first flood control facility built by the Los Angeles County Flood Control District and was completed in 1920 for flood control and groundwater recharge purposes. In 1971, the Dam was damaged by the Sylmar earthquake and was subsequently renovated and repaired in 1997 in order to perform its primary role of flood control for the downstream communities of Pasadena, South Pasadena, and Los Angeles. The Arroyo Seco Wash flows through the reservoir, now called Hahamongna Watershed Park, and proceeds through the outlet of the Dam.

In 2009, the Station fire burned through more than 160,000 acres of Los Angeles County. Approximately 68% of the 31.9 square mile Arroyo Seco Channel watershed tributary to the Devils Gate facility was burned during this event. Due to the denuding of this large natural tributary area, large sediment loads (in excess of 1 million cubic yards) were deposited within the reservoir area and adjacent Hahamongna Watershed Park.

Due to the volume of sediment deposited within the Dam reservoir, the Dam discharge structures are now under threat of becoming covered with sediment. These sediment deposits have also allowed for native and non-native vegetation to establish itself within the Dam reservoir.

The Devils Gate Dam directly discharges runoff to the Arroyo Seco Channel. The Channel is a natural creek for several hundred feet downstream of the Devils Gate Dam; however, this rapidly converts to an engineered concrete lined flood control Channel which was constructed in 1935. The Arroyo Seco Channel continues to flow in a southerly direction through Pasadena, meandering through Brookside Park and passed the Rose Bowl Stadium, ultimately draining to the Los Angeles River located approximately nine (9) miles downstream of Devils Gate Dam. The Arroyo Seco Channel lower watershed is approximately 95% urbanized with a large amount of developed areas located adjacent to the Arroyo Seco Channel.

In an effort to restore the flood control capacity of the Dam, while minimizing negative excavation and hauling related impacts to the Hahamongna Watershed Park, the LACFCD is interested in exploring the feasibility of sluicing excess sediment out of the reservoir and down the entire length of the Arroyo Seco Channel with natural storm flows occurring over a 3-5 year period.

A previous analysis performed by Bureau Veritas North America, Inc., dated August 3, 2012, utilized HEC-HMS, WMS, HEC-RAS, and FLUVIAL-12 models to explore one scenario which made the assumption that mechanical agitation of sediment near the Dam outlet would produce a 10% sediment concentration in natural stormwater flows leaving the Dam outlet. A combination of events including a typical storm event (150 cfs, 24 hr event) and a maximum storm event (2-year, 4-day storm) were utilized to transport then flush sediment down the length of the Arroyo Seco Channel. The results from the previous study indicated that the majority of the sediment introduced into stormwater flows would settle out and deposit along the Arroyo Seco Channel, particularly in the natural upstream reaches of the Channel, prior to reaching the Los Angeles River confluence.

In an effort to explore additional sediment transport methods that may be utilized to naturally remove excess sediment from behind the Dam, this analysis will create models for three different sluicing scenarios, as specified by the LACFCD and further described in Section 3 of this report, which analyze sediment transport characteristics over a much longer time period of 15.5 months and consider flows derived from historical data for the years of 2006 and 2007. This longer window of analysis will allow sediment transport trends to be analyzed more dynamically than was possible for the previously modeled 1-day and 4-day durations. Additionally, a lower sediment concentration of 5.0% will be assumed during the Sediment Transport Event, as the previously performed analysis indicated that a 10% concentration resulted in sediment deposition along the Channel.

2 Sediment Transport Capacity Methodology

2.1 Devils Gate Dam Characteristics

In its current impacted condition, the Devils Gate Dam is not providing the level of flood control that it was originally designed for. In an effort to restore the Dam's flood control capacity, the LACFCD is exploring the feasibility of sluicing accumulated sediment out of the Devils Gate Reservoir and down the Arroyo Seco Channel utilizing natural storm flows anticipated to occur over a period of 3-5 years.

LACFCD has provided the Consultant with historical Devils Gate Reservoir inflow data at hourly intervals for a 15.5 month period of time extending from January 1, 2006 through April 15, 2007. Figure 2 below represents this data graphically while extensive tabular format data is included in Appendix A.3 of this report. These flows are representative of a typical rainy season cycle and may commonly occur over the next 3-5 years. During this time period, the average and maximum observed reservoir inflow rates were 8.4 and 1,469 cfs respectively, and the total reservoir inflow volume was 8,600,000 cubic yards.

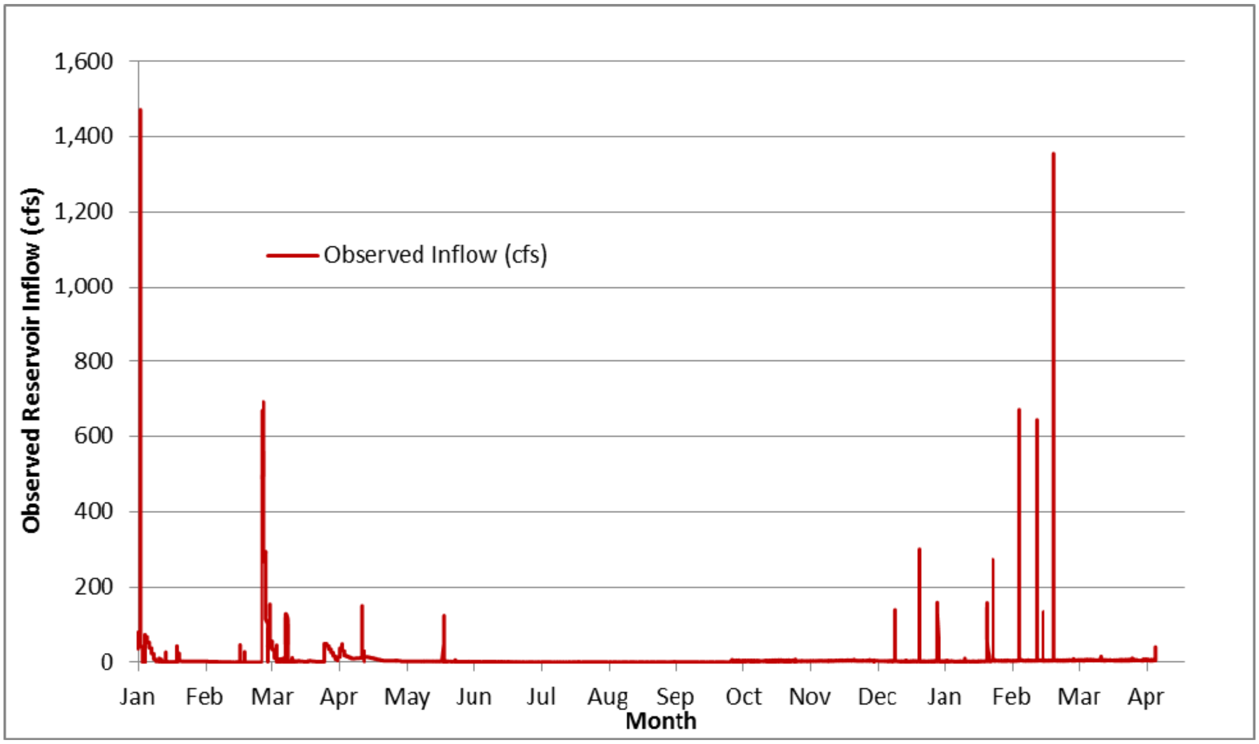


Figure 2: Graph of LACFCD Provided Reservoir Inflow Data from January 1, 2006 through April 15, 2007

This LACFCD provided inflow data and elevation-storage-discharge relationships for the Dam have been modeled in HEC-HMS software in order to produce hydrographs for three different scenarios as further described in Section 3 of this report. Regardless of the scenario being considered, all Dam outflows modeled in this analysis can be categorized as either Sediment Transport Event flows or Sediment Flushing Event flows as further described in Sections 2.1.1 and 2.1.2.

2.1.1 Sediment Transport Event

The Sediment Transport Event is used to sluice sediment deposits from within the Reservoir and is derived from observed Dam inflow rates that occurred over the 9.5 month time period extending from January 1, 2006 through October 14, 2006. These observed inflow rates have been routed through the Dam under the assumption that the Dam's sluice gate is fully opened to a width of 5' throughout the entire Sediment Transport Event. Figure 3 below illustrates the elevation-storage-discharge relationship for the Dam during the Sediment Transport Event as determined per LACFCD provided information included in Appendix A.1 of this report. During the Sediment Transport Event, it is assumed that the necessary Dam operations will occur to introduce a sediment concentration of 5.0% into stormwater flows discharging from the Dam outlet.

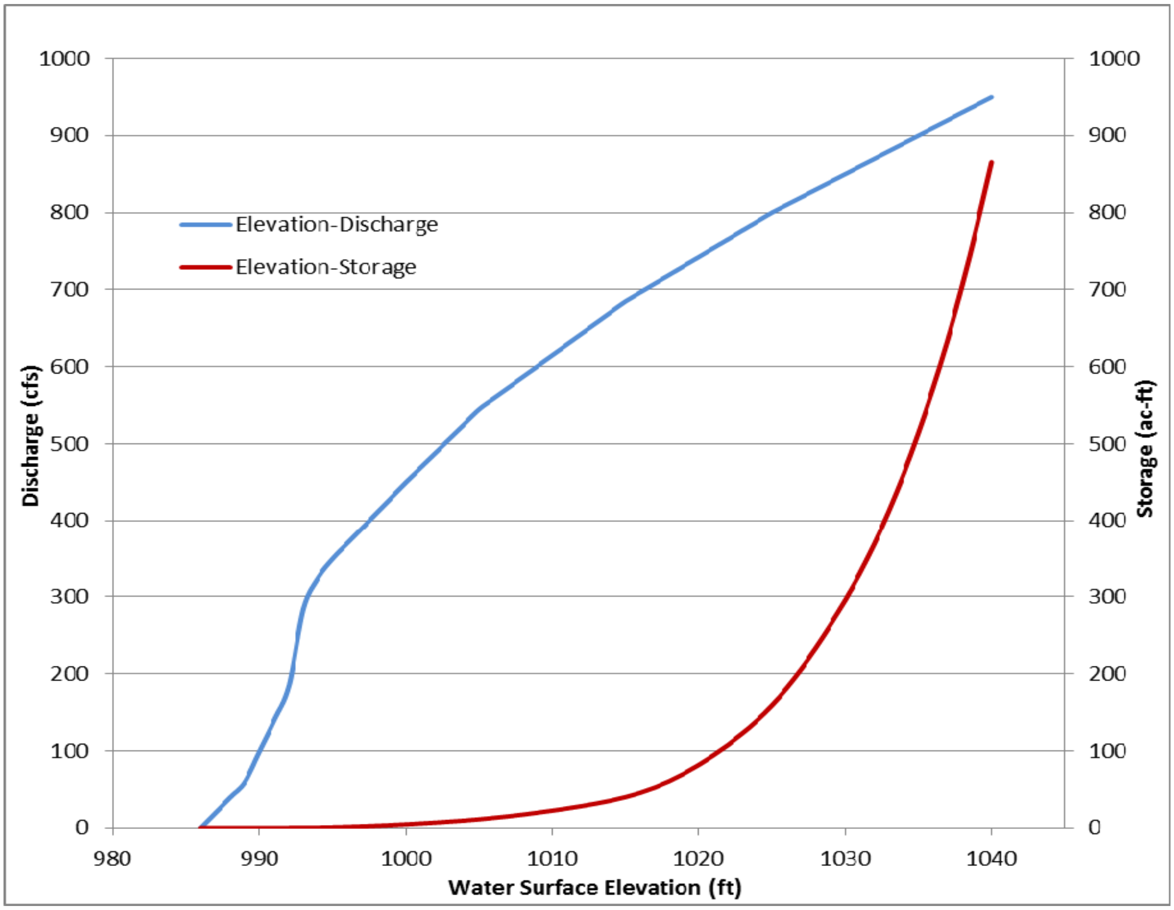
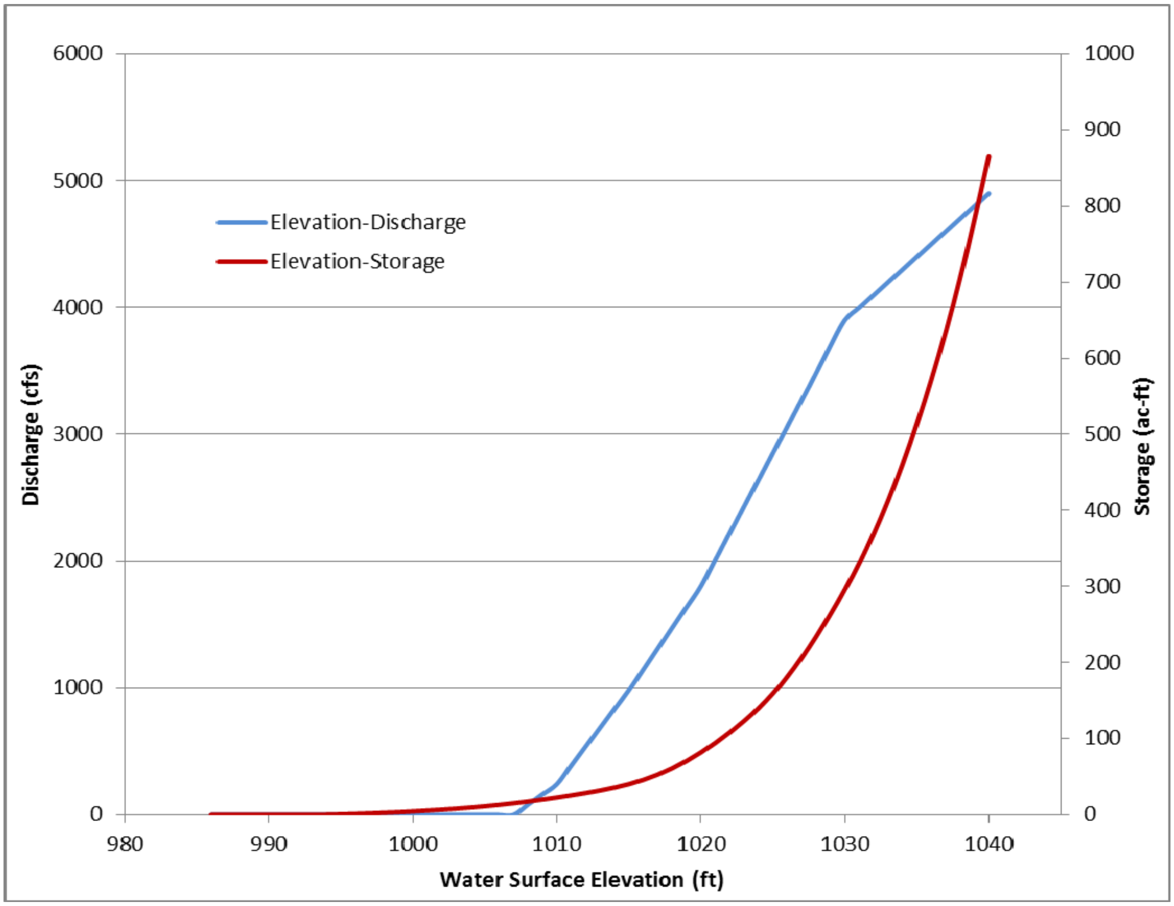


Figure 3: Elevation-Storage-Discharge Relationship for Sediment Transport Event – Fully Opened 5'x5' Devils Gate Dam Sluice Gate

2.1.2 Sediment Flushing Event

The Sediment Flushing Event is used to flush sediment deposits associated with the previously executed Sediment Transport Event down the entire length of the Channel. Per direction by the LACFCD, this analysis will consider three different Sediment Flushing Event scenarios as further described in Section 3 of this report. Depending on the scenario being analyzed, flows associated with the Sediment Flushing Event are derived from observed Dam inflow rates that occurred over the 6 month time period extending from October 15, 2006 through April 15, 2007, or are idealized flow rates developed to provide insight on what conditions may produce favorable Sediment Flushing characteristics. The observed inflow rates have been routed through the Dam under the assumption that the Dam's sluice gate is fully closed while two 7'x10' slide gates are fully opened throughout the duration of the Sediment Flushing Event. Figure 4 below illustrates the elevation-storage-discharge relationship for the Dam during the Sediment Flushing Event as determined per LACFCD provided information included in Appendix A.1. During the Sediment Flushing Event, it is assumed that the sediment concentration at the Dam outlet is 0.0%.



<u>Figure 4: Elevation-Storage-Discharge Relationship for Sediment Flushing Event – Two Fully Opened 7'x10' Slide Gates</u>

2.2 Sediment Gradation Characteristics

Sediment gradation characteristics for the sediment deposits located within the Reservoir have been determined per excerpts from the Draft Soils Report prepared by Leighton, dated October 2011. Sediment gradation characteristics for the native sediment located in the two natural downstream areas of the Arroyo Seco Channel have been determined per sediment gradation information obtained through soil sampling performed by NV5 Testing Engineers on October 31, 2012. The soil sampling information for these locations is included in Appendix A.2 of this report.

2.3 Arroyo Seco Channel Characteristics

Geometric characteristics of the Arroyo Seco Channel utilized in this analysis have been derived from the HEC-RAS model previously developed in the Final Arroyo Seco Channel Hydraulic Analysis, prepared by Bureau Veritas, dated April 25, 2012. However, the model reflected in the previous report omitted approximately 1,200’ of the most upstream natural portion of the Arroyo Seco Channel in order to allow large stormwater flows associated with the Capital Storm Event to normalize prior to entering the domain of the HEC-RAS model. As this natural portion of the Channel adjacent to the Dam now plays a key role in the sediment transport analysis performed within the scope of this report, the previous HEC-RAS model has been modified to include geometric data for this upstream portion of the Channel.

Cross sections for this portion of the Channel have been added to the HEC-RAS model through examination of LACFCD provided 2-foot contour LIDAR topographic information with a fly date of January 12, 2006. Per VERTCON software and conversion maps provided on the National Geodetic Survey website, the datum related elevation differences between the HEC-RAS model (NGVD29) and LIDAR (NAVD88) elevations range from 2.572 to 2.625 feet for the Arroyo Seco Channel project area. Therefore, all LIDAR elevations entered into the HEC-RAS model have been reduced by 2.6’ in order to reflect the conversion from NAVD88 to NGVD29.

This analysis has been performed under the assumption that the natural stormwater flows occurring in the Arroyo Seco Channel over the period of time being analyzed are governed entirely by the conditions at the outlet of the Devils Gate Dam. Due to the extremely long duration of analysis, and the subsequent amount of hourly flow data, conventional routing methods used to confluence the Dam outflows with additional downstream tributaries as the Channel extends downstream were not a feasible option for this analysis. Omitting the effects of additional downstream inflows into the Channel may reduce the sediment transport capacity of the Channel, particularly in the most downstream reaches of the Channel as the area of the additional tributaries increases. However, omitting these effects will have a negligible effect on the sediment transport capacity of the Channel in the most upstream reaches, such as in the most upstream natural reach of the Channel where additional tributary areas are negligible and stormwater flow rates are entirely governed by the Dam outflow. Given that the previously performed sediment transport capacity analysis indicated a large volume of sediment would settle out in this natural upstream portion of the Channel, the results presented herein are anticipated to produce an accurate model of the sediment transport characteristics of the Channel, particularly for the previously identified problem areas.

3 Sediment Transport Scenarios

Per direction from the LACFCD, three different sediment transport scenarios, referred to herein as Conditions 1, 2, and 3, have been analyzed within the scope of this report. All three of the conditions analyzed have been modeled with identical Sediment Transport Events (9.5 month duration of historical inflows from January 1, 2006 through October 14, 2006); however, the subsequent Sediment Flushing Event for each condition varies. A summary of these conditions is presented in Table 1 below and a more detailed discussion of the conditions is included in the sections that follow.

Condition Modeled	Sediment Transport Event			Sediment Flushing Event		
	Dates	Flow	Sediment Concentration	Dates	Flow	Sediment Concentration
Condition 1	January 1, 2006 through October 14, 2006	Historical	5.0%	October 15, 2006 through April 15, 2007	Historical	0.0%
Condition 2	January 1, 2006 through October 14, 2006	Historical	5.0%	October 15, 2006 through October 17, 2006	4,900 cfs	0.0%
Condition 3	January 1, 2006 through October 14, 2006	Historical	5.0%	October 15, 2006 through October 20, 2006	2,500 cfs	0.0%

Table 1: Summary of Dam Outflow Conditions Analyzed

3.1 Condition 1 – Historical Sediment Flushing Scenario: Typical Dam Outflow

The Condition 1 analysis ran the Sediment Transport Event (9.5 month duration from January 1, 2006 through October 14, 2006) assuming a 5.0% sediment concentration, and then ran the Sediment Flushing Event (6 month duration from October 15, 2006 through April 15, 2007) assuming a 0% sediment concentration subsequent to the Sediment Transport Event. All flow rates associated with the Sediment Transport and Sediment Flushing Events for Condition 1 have been generated by routing LACFCD provided historical inflow data through the Reservoir under the appropriate Dam operating conditions, as described in Sections 3.1.1 and 3.1.2, resulting in the Dam conditions illustrated in Figure 5 below.

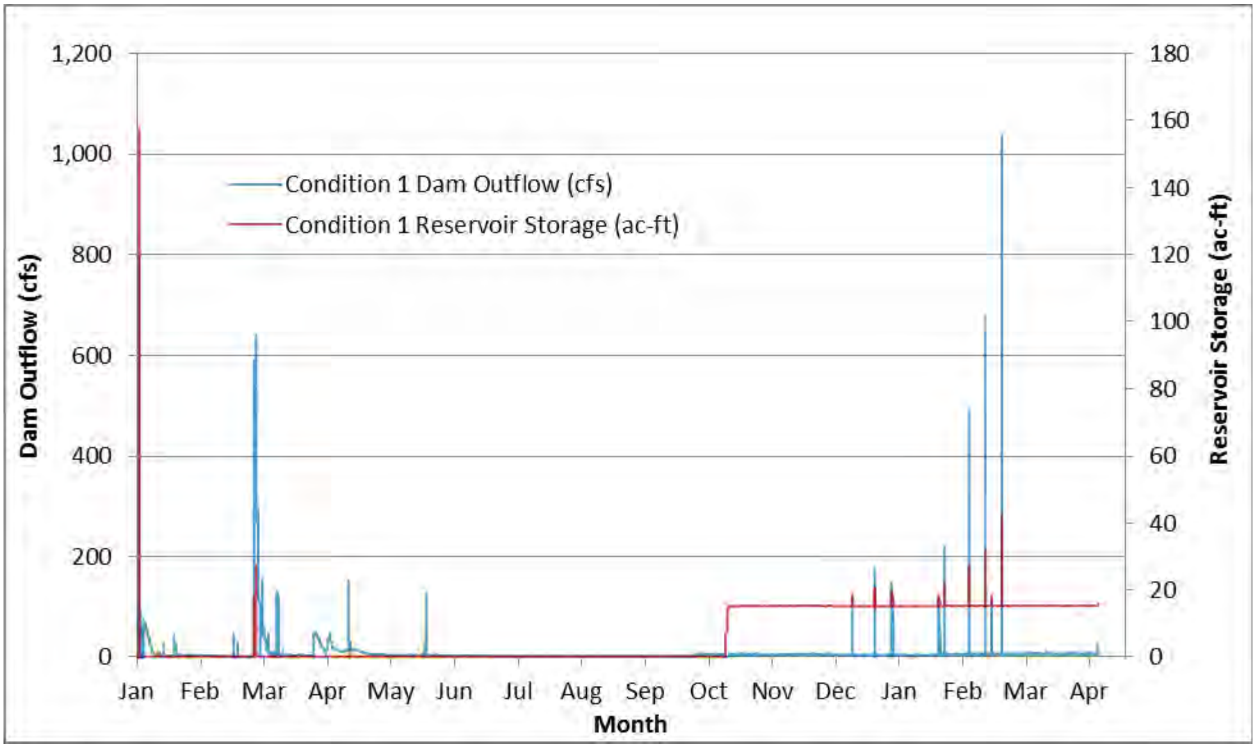


__Figure 5: Condition 1 Dam Outflow and Storage__

The Condition 1 analysis reflects the anticipated long-term conditions that can be expected to occur if historically typical stormwater flows are utilized to remove excess sediment deposition from within the reservoir and flush it down the length of the Channel under typical Dam operating conditions.

3.1.1 Condition 1 Sediment Transport Event

The Condition 1 Sediment Transport Event is used to sluice sediment deposits from behind the Dam through utilization of naturally occurring Dam inflow rates that were observed over the 9.5 month time period extending from January 1, 2006 through October 14, 2006. The corresponding Dam outflow rates have been determined by routing the historically observed inflows through the Dam utilizing the LACFCD provided elevation-storage-discharge relationship assuming that the sluice gate is fully opened to a width of 5'. During the Condition 1 Sediment Transport Event, it is assumed that the necessary Dam operations will occur to introduce a sediment concentration of 5.0% into stormwater flows discharging from the Dam outlet. Based on the historical stormwater inflow rates provided, a 5.0% sediment concentration in the Dam outflows results in a cumulative total of approximately 263,000 cubic yards of sediment that will be removed from the reservoir during the Sediment Transport Event.

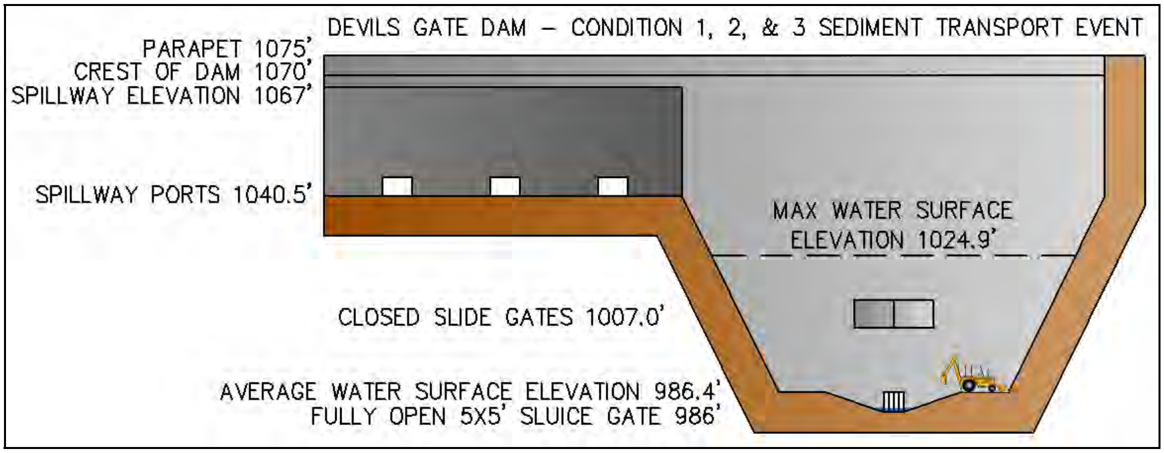


Figure 6: Condition 1 Sediment Transport Event

It should be noted that the average water surface elevation occurring behind the Dam during the Condition 2 Sediment Transport Event is a very shallow 986.4'. However, during the peak events from the 2006-2007 data, a much higher maximum water surface elevation of 1024.9' is anticipated. Any activities occurring within the reservoir area during these events, such as mechanical introduction of sediment into stormwater flows, should only be executed with appropriate caution.

3.1.2 Condition 1 Sediment Flushing Event

The Condition 1 Sediment Flushing Event is used to flush sediment deposits associated with the previously executed Sediment Transport Event down the entire length of the Channel through utilization of naturally occurring Dam inflow rates that were observed over the 6 month time period extending from October 15, 2006 through April 15, 2007. The corresponding Dam outflow rates have been determined by routing the historically observed flows through the Dam utilizing the LACFCD provided elevation-storage-discharge relationship for the two, fully opened 7’x10’ slide gates. The sluice gate will remain closed during this process and it is assumed that the sediment concentration at the Dam outlet is 0.0%.

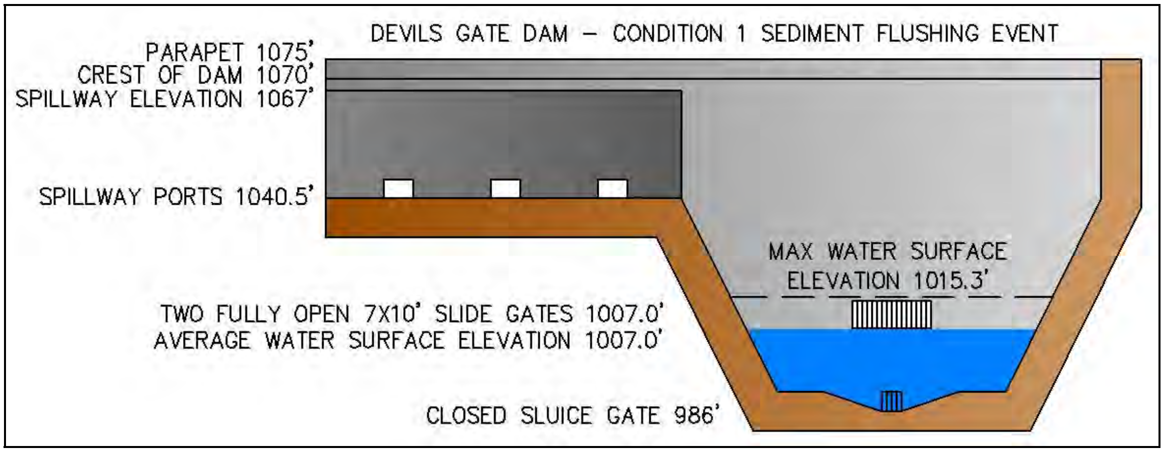


Figure 7: Condition 1 Sediment Flushing Event

It should be noted that the average and maximum water surface elevations occurring behind the Dam during the Condition 1 Sediment Flushing Event are 1007.0’ and 1015.3’ respectively. Based on the historical 2006-2007 inflow data utilized for the Condition 1 Sediment Flushing Event, approximately 4,000,000 cubic yards of stormwater inflow are anticipated during the 6 month Sediment Flushing period. Upon completion of the Condition 1 Sediment Transport and Sediment Flushing Events, approximately 20,000 cubic yards of sediment will be effectively transported down the length of the Channel and approximately 243,000 cubic yards will be deposited along the Channel.

A summary of results produced by the Condition 1 scenario is included in Section 3.4 of this report.

3.2 Condition 2 – Idealized Sediment Flushing Scenario: Maximum Dam Outflow

The Condition 2 analysis ran the Sediment Transport Event (9.5 month duration from January 1, 2006 through October 14, 2006) assuming a 5.0% sediment concentration, and then ran the Sediment Flushing Event with a constant flow rate of 4,900 cfs for a duration of 3 days assuming a 0% sediment concentration subsequent to the Sediment Transport Event. Flow rates associated with the Sediment Transport Event for Condition 2 have been generated by routing LACFCD provided historical inflow data through the Reservoir under the appropriate Dam operating conditions as described Section 3.2.1. Flow rates associated with the Sediment Flushing Event for Condition 2 have been generated by routing idealized flows through the Reservoir under the Dam operating conditions described in 3.3.2. A constant flow rate of 4,900 cfs is assumed throughout the entire duration of the Condition 2 Sediment Flushing Event which represents the maximum, idealized flow rate that can be discharged through the Dam's two fully opened slide gates. A duration of 3 days was selected for this analysis as it was found to correspond with the minimum amount of time necessary to provide complete flushing of the Channel at this flow rate. The resulting Condition 2 Dam conditions are illustrated in Figure 8 below

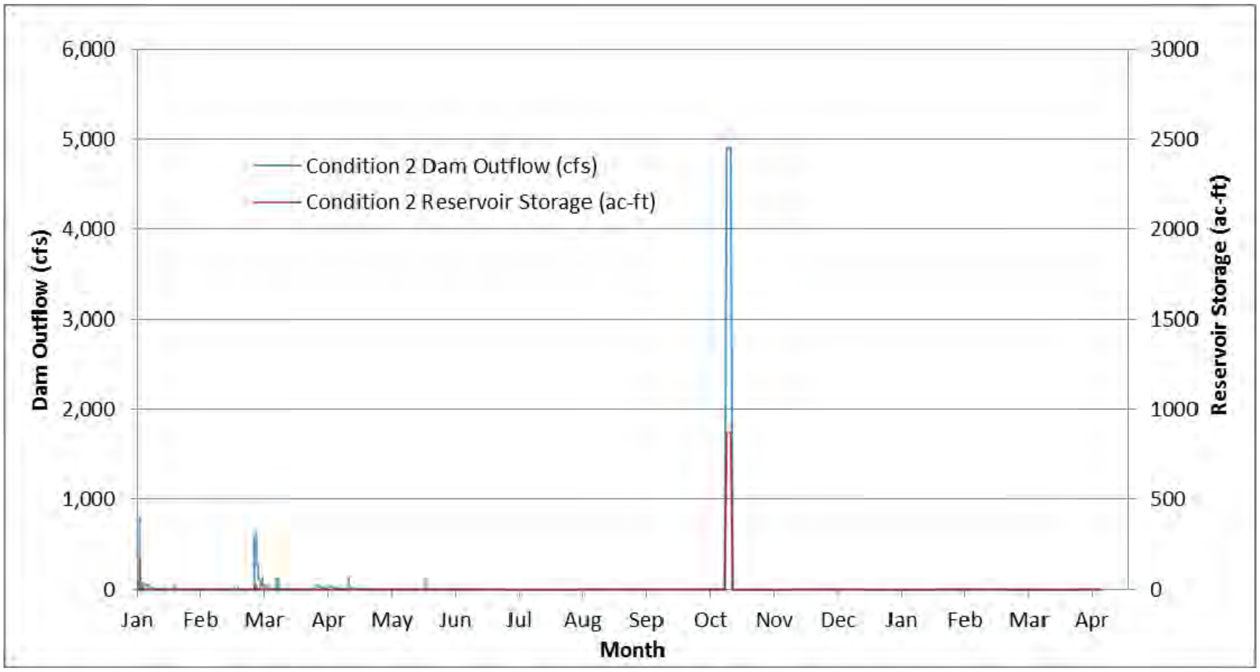


Figure 8: Condition 2 Dam Outflow and Storage

The Condition 2 analysis reflects the anticipated long-term conditions that can be expected to occur if historically typical stormwater flows are utilized to remove excess sediment deposition from within the reservoir and then a constant flow rate of 4,900 cfs occurring over a duration of 3 days is utilized to flush remaining sediment down the length of the Channel.

3.2.1 Condition 2 Sediment Transport Event

The Condition 2 Sediment Transport Event is used to sluice sediment deposits from behind the Dam through utilization of naturally occurring Dam inflow rates that were observed over the 9.5 month time period extending from January 1, 2006 through October 14, 2006. The corresponding Dam outflow rates have been determined by routing the historically observed inflows through the Dam utilizing the LACFCD provided elevation-storage-discharge relationship assuming that the sluice gate is fully opened to a width of 5’. During the Condition 2 Sediment Transport Event, it is assumed that the necessary Dam operations will occur to introduce a sediment concentration of 5.0% into stormwater flows discharging from the Dam outlet. Based on the historical stormwater inflow rates provided, a 5.0% sediment concentration in the Dam outflows results in a cumulative total of approximately 263,000 cubic yards of sediment that will be removed from the reservoir during the Sediment Transport Event.

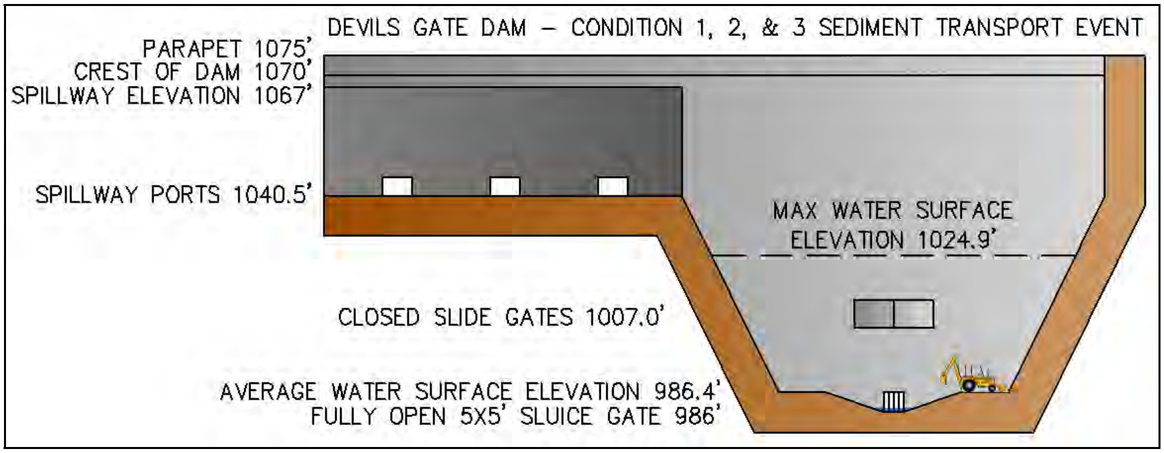


Figure 9: Condition 2 Sediment Transport Event

It should be noted that the average water surface elevation occurring behind the Dam during the Condition 2 Sediment Transport Event is a very shallow 986.4’. However, during the peak events from the 2006-2007 data, a much higher maximum water surface elevation of 1024.9’ is anticipated. Any activities occurring within the reservoir area during these events, such as mechanical introduction of sediment into stormwater flows, should only be executed with appropriate caution.

3.2.2 Condition 2 Sediment Flushing Event

The Condition 2 Sediment Flushing Event is used to flush sediment deposits associated with the previously executed Sediment Transport Event down the entire length of the Channel through utilization of an idealized Dam outflow condition that is not based on historical Dam inflow data. The idealized Dam outflow condition utilized for the Condition 2 Sediment Flushing Event represents the maximum discharge anticipated to discharge through two fully opened 7’x10’ slide gates. The sluice gate will remain closed during this process and it is assumed that the sediment concentration at the Dam outlet is 0.0%. The constant flow rate of 4,900 cfs associated with the Condition 2 Sediment Flushing Event represents the maximum, idealized flow rate that can be discharged through the Dam’s two fully opened slide gates as determined per LACFCD provided elevation-storage-discharge relationships located in Appendix A.1. A duration of 3 days was selected for this analysis as it was found to correspond with the minimum amount of time necessary to provide complete flushing of the Channel at this flow rate.

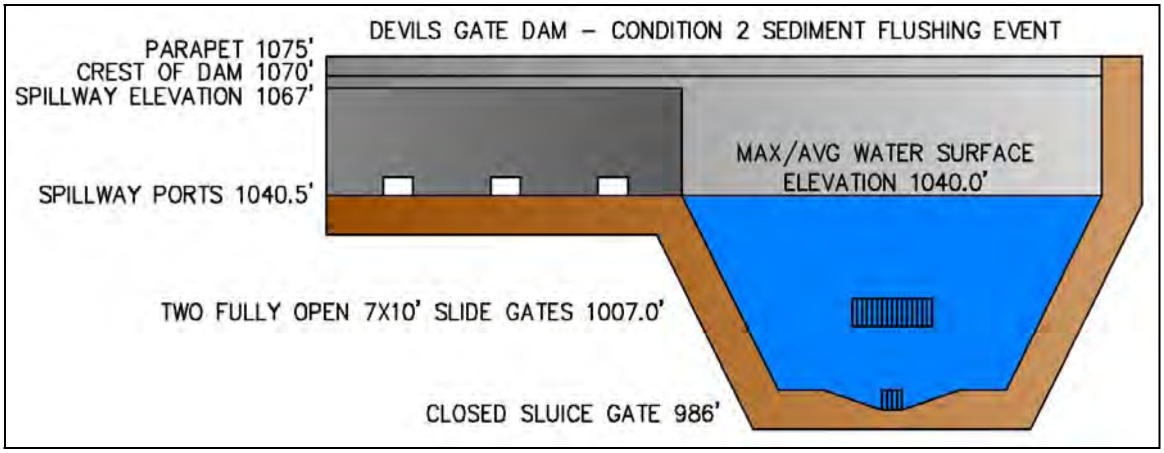


Figure 10: Condition 2 Sediment Flushing Event

It should be noted that, in order to produce a constant Dam outflow rate of 4,900 cfs, the water surface elevation behind the Dam must remain at 1040.0’ with the two 7’x10’ slide gates fully opened. With a constant Dam outflow of 4,900 cfs, it was determined that complete flushing of the Channel was feasible in 3 days. In order to produce an event of this magnitude, approximately 47,000,000 cubic yards of stormwater inflow would be required over the 6 month Sediment Flushing Event period, which is approximately 12 times greater than the stormwater volume indicated by the historical 2006-2007 inflow data.

A summary of results produced by the Condition 2 scenario is included in Section 3.4 of this report.

3.3 Condition 3 – Idealized Sediment Flushing Scenario: Minimum Effective Sediment Flushing Flow Rate

The Condition 3 analysis ran the Sediment Transport Event (9.5 month duration from January 1, 2006 through October 14, 2006) assuming a 5.0% sediment concentration, and then ran the Sediment Flushing Event with a constant flow rate of 2,500 cfs for a duration of 6 days assuming a 0% sediment concentration subsequent to the Sediment Transport Event. Flow rates associated with the Sediment Transport Event for Condition 3 have been generated by routing LACFCD provided historical inflow data through the Reservoir under the appropriate Dam operating conditions as described Section 3.3.1. Flow rates associated with the Sediment Flushing Event for Condition 3 have been generated by routing idealized flows through the Reservoir under the Dam operating conditions described in 3.3.2. A constant flow rate of 2,500 cfs is assumed throughout the entire duration of the Condition 3 Sediment Flushing Event which corresponds with the minimum effective sediment flushing stormwater flow rate that was determined by the analysis in Appendix B of this report. A duration of 6 days was selected for this analysis as it was found to correspond with the minimum amount of time necessary to provide complete flushing of the Channel at this flow rate. The resulting Condition 3 Dam conditions are illustrated in Figure 11 below.

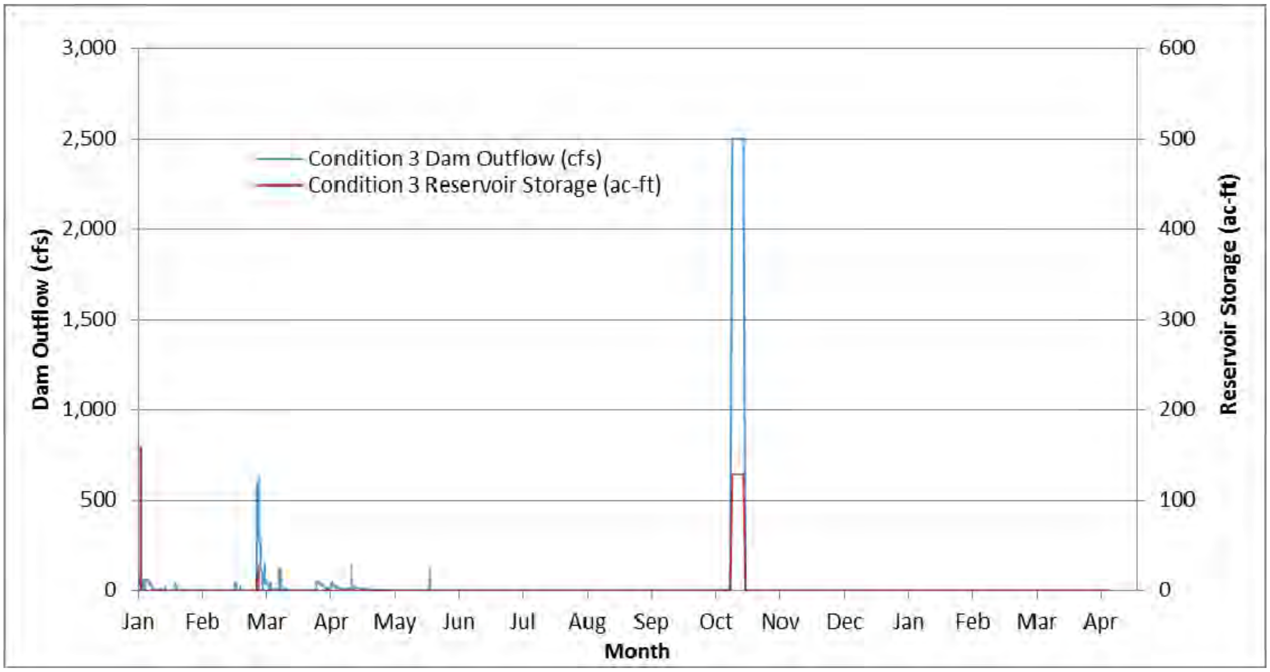


Figure 11: Condition 3 Dam Outflow and Storage

The Condition 3 analysis reflects the anticipated long-term conditions that can be expected to occur if historically typical stormwater flows are utilized to remove excess sediment deposition from within the reservoir and then a minimum recommended constant flushing rate of 2,500 cfs occurring over a duration of 6 days is utilized to flush remaining sediment down the length of the Channel.

3.3.1 Condition 3 Sediment Transport Event

The Condition 3 Sediment Transport Event is used to sluice sediment deposits from behind the Dam through utilization of naturally occurring Dam inflow rates that were observed over the 9.5 month time period extending from January 1, 2006 through October 14, 2006. The corresponding Dam outflow rates have been determined by routing the historically observed inflows through the Dam utilizing the LACFCD provided elevation-storage-discharge relationship assuming that the sluice gate is fully opened to a width of 5'. During the Condition 3 Sediment Transport Event, it is assumed that the necessary Dam operations will occur to introduce a sediment concentration of 5.0% into stormwater flows discharging from the Dam outlet. Based on the historical stormwater inflow rates provided, a 5.0% sediment concentration in the Dam outflows results in a cumulative total of approximately 263,000 cubic yards of sediment that will be removed from the reservoir during the Sediment Transport Event.

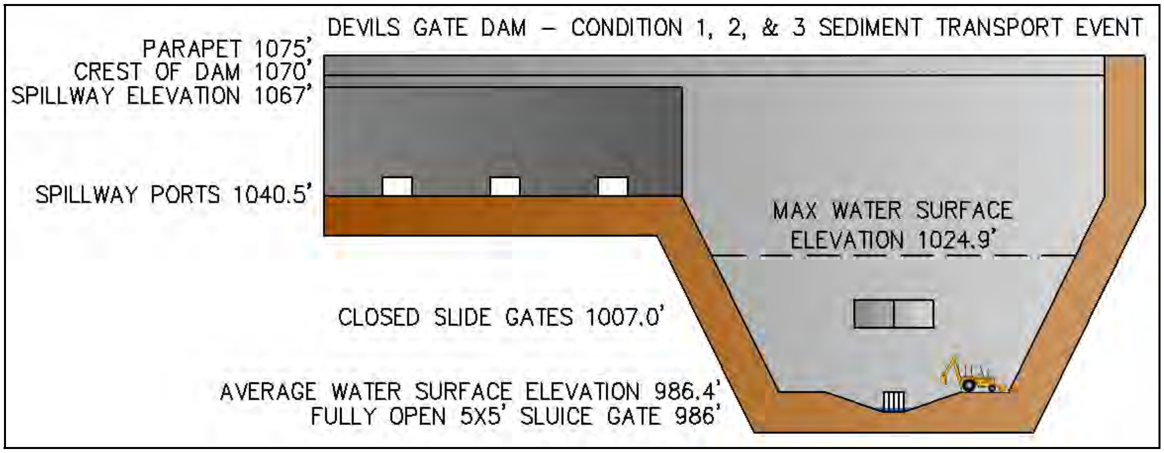


Figure 12: Condition 3 Sediment Transport Event

It should be noted that the average water surface elevation occurring behind the Dam during the Condition 2 Sediment Transport Event is a very shallow 986.4'. However, during the peak events from the 2006-2007 data, a much higher maximum water surface elevation of 1024.9' is anticipated. Any activities occurring within the reservoir area during these events, such as mechanical introduction of sediment into stormwater flows, should only be executed with appropriate caution.

3.3.2 Condition 3 Sediment Flushing Event

The Condition 3 Sediment Flushing Event is used to flush sediment deposits associated with the previously executed Sediment Transport Event down the entire length of the Channel through utilization of an idealized Dam outflow condition that is not based on historical Dam inflow data. The idealized Dam outflow condition utilized for the Condition 3 Sediment Flushing Event represents the minimum Dam outflow recommended for effective use of Channel flushing operations. Per the "Modeling of Sluicing and Flushing Conditions in the Arroyo Seco Channel Below the Devil's Gate Dam" report by Chang Consultants January 7, 2013, a minimum constant flow rate of 2,500 cfs occurring over a duration of 6 days may be capable of providing complete flushing of the Channel. This flow rate can be discharged through the Dam's two fully opened slide gates as determined per LACFCD provided elevation-storage-discharge relationships located in Appendix A.1.

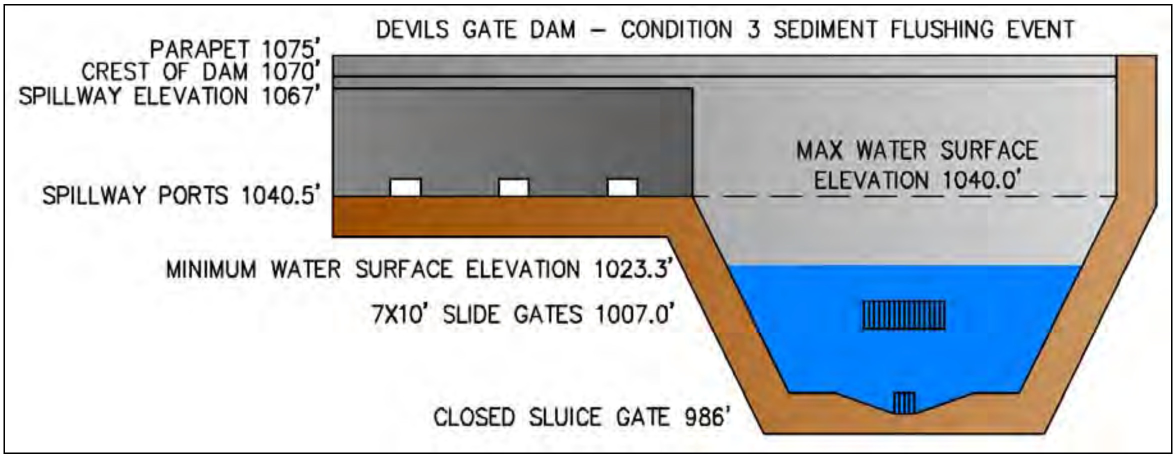


Figure 13: Condition 3 Sediment Flushing Event

It should be noted that, in order to produce a constant minimum Dam outflow rate of 2,500 cfs, water surface elevations behind the Dam will need to range from 1023.3' with the two 7'x10' slide gates fully opened, or will need to remain at an elevation of 1040.0' with the slide gates partially closed, for a total duration of 6 days. In order to produce an event of this magnitude, approximately 48,000,000 cubic yards of stormwater inflow would be required over the 6 month Sediment Flushing Event period, which is approximately 12 times greater than the stormwater volume indicated by the historical 2006-2007 inflow data.

A summary of results produced by the Condition 3 scenario is included in Section 3.4 of this report.

3.4 Conclusion

As indicated by the results included in Appendix B of this report, the accumulated sediment within the Devils Gate Reservoir cannot be effectively transported down the length of the Arroyo Seco Channel with natural storm flows anticipated to occur over a 3-5 year period under any of the 3 conditions that were modeled within the scope of this report.

The Condition 1 Sediment Flushing Event, which modeled the sediment transport characteristics of the Channel during historically typical flows and standard Dam operations, was found to be incapable of flushing excess sediment down the length of the Arroyo Seco Channel. After 9.5 months of historically typical sediment sluicing flows and 6 months of historically typical sediment flushing flows, approximately 20,000 cubic yards of sediment will be conveyed to the Los Angeles River, leaving approximately 243,000 cubic yards of sediment generated by the Sediment Transport Event in the Arroyo Seco Channel with deposits primarily occurring in and around the natural reaches. The Condition 1 Sediment Flushing Event experienced an average discharge rate of 6.7 cfs, a peak discharge rate of 1036.5 cfs, a total stormwater discharge volume of approximately 4,000,000 cubic yards, and Dam operating conditions that produced water surface elevations ranging from 1007.0’ to 1015.3’.

The Condition 2 Sediment Flushing Event, which modeled the sediment transport characteristics of the Channel during an idealized sediment flushing scenario producing a constant flow rate of 4,900 cfs, was found to be capable of flushing excess sediment down the length of the Arroyo Seco Channel but was also realistically infeasible. After 9.5 months of historically typical sediment sluicing flows and 3 days of idealized sediment flushing flows of 4,900 cfs, approximately 250,000 cubic yards of sediment will be conveyed to the Los Angeles River, leaving approximately 13,000 cubic yards of sediment generated by the Sediment Transport Event in the Arroyo Seco Channel with deposits primarily occurring in and around the natural reaches. The Condition 2 Sediment Flushing Event experienced an average/peak discharge rate of 4,900 cfs, a total stormwater discharge volume of approximately 47,000,000 cubic yards, and Dam operating conditions that produced a consistent water surface elevation of 1040.0’. This condition has been deemed infeasible because maintaining these flow characteristics would require unrealistic reservoir inflow rates that are approximately 12 times greater than historically typical data and would also require the Dam to operate in a potentially hazardous condition that provides limited flood control capabilities.

The Condition 3 Sediment Flushing Event, which modeled the sediment transport characteristics of the Channel during a theoretical sediment flushing scenario producing the minimum recommended constant flushing rate of 2,500 cfs, was found to be capable of flushing excess sediment down the length of the Arroyo Seco Channel but was also realistically infeasible. After 9.5 months of historically typical sediment sluicing flows and 6 days of idealized sediment flushing flows of 2,500 cfs, approximately 250,000 cubic yards of sediment will be conveyed to the Los Angeles River, leaving approximately 13,000 cubic yards of sediment generated by the Sediment Transport Event in the Arroyo Seco Channel with deposits primarily occurring in and around the natural reaches. The Condition 3 Sediment Flushing

Event experienced an average/peak discharge rate of 2,500 cfs, a total stormwater discharge volume of approximately 48,000,000 cubic yards, and Dam operating conditions that produced a consistent water surface elevation of 1023.3’. This condition has been deemed infeasible because maintaining these flow characteristics would require unrealistic reservoir inflow rates that are approximately 12 times greater than historically typical data and would also require the Dam to operate in a potentially hazardous condition that provides limited flood control capabilities.

For a more detailed analysis of sediment transport characteristics of the Arroyo Seco Channel, including sediment deposition profile maps, plan view maps, and cross sections, reference the “Modeling of Sluicing and Flushing Conditions in the Arroyo Seco Channel Below the Devil’s Gate Dam” report by Chang Consultants dated January 7, 2013 in Appendix B of this report. Should there be any discrepancies between the data and/or recommendations presented herein and in the data presented Appendix B, the information in Appendix B shall supersede. Additionally, all information presented in this report is intended to identify the potential feasibility of utilizing stormwater flows to convey accumulated sediment from behind the Devils Gate Dam, down the entire length of the Arroyo Seco Channel, to the Los Angeles River confluence, and this report is not intended to provide an operating procedure for such activities should they be executed. Additional implications including, but not limited to the maintenance stable cross sections within sensitive Channel reaches and the potential impacts of sediment transport activities on the level of Capital Flood protection provided by the Channel, are a few items that would require more study prior to implementation. However, because the results of this analysis do not identify any potentially feasible options for sediment sluicing, it is not likely that these items will be pursued any further.

3.5 References

Excerpts from LACFCD Provided Draft Soils Report, prepared by Leighton, dated October 2011.

Excerpts from Soil Sampling performed by NV5 Testing Engineers on October 31, 2012.

Final Sediment Transport Capability Analysis for the Arroyo Seco Channel, prepared by Bureau Veritas, dated August 3, 2012.

Final Arroyo Seco Channel Hydraulic Analysis, prepared by Bureau Veritas, dated April 25, 2012

Sediment Transport Analyses for the Arroyo Seco Channel, prepared by Chang Consultants, dated August 3, 2012

Los Angeles County Flood Control District – Devils Gate Dam Background/Reference Information.

Los Angeles County Flood Control District - Devils Gate Dam and Reservoir Post-Fire Sediment Removal - Short Term Solution Report for Sediment Accumulation Along the Face of the Dam, March 2011.

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4 Appendices

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Appendix A.1

Elevation-Storage-Discharge Relationship for Devils Gate Dam

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Elevation-Storage-Discharge Relationship for Sediment Transport Event
(Fully Opened 5'x5' Devils Gate Dam Sluice Gate)

Water Surface Elevation (ft)	LACFCD Storage (ac-ft) [1]	Discharge at Dam Outlet (cfs) [2]
Sill of Sluice Gate 986.0	0.00	0.0
987.0	0.01	20.0
988.0	0.02	40.0
989.0	0.03	60.0
990.0	0.04	100.0
Top of Sluice Gate 991.0	0.05	140.0
992.0	0.06	185.0
993.0	0.09	285.0
994.0	0.38	325.0
995.0	0.81	350.0
996.0	1.35	370.0
997.0	2.01	390.0
998.0	2.77	410.0
999.0	3.64	430.0
1000.0	4.61	450.0
1001.0	5.69	469.0
1002.0	6.87	488.0
1003.0	8.15	507.0
1004.0	9.58	526.0
1005.0	11.21	545.0
1006.0	13.06	559.0
1007.0	15.12	573.0
1008.0	17.39	587.0
1009.0	19.87	601.0
1010.0	22.53	615.0
1011.0	25.39	629.0
1012.0	28.44	643.0
1013.0	31.80	657.0
1014.0	35.63	671.0
1015.0	40.17	685.0
1016.0	45.72	696.5
1017.0	52.56	708.0
1018.0	60.84	719.5
1019.0	70.59	731.0
1020.0	81.76	742.5
1021.0	94.21	754.0
1022.0	107.92	765.5
1023.0	123.05	777.0
1024.0	139.87	788.5
1025.0	159.11	800.0
1026.0	181.23	810.0
1027.0	206.21	820.0
1028.0	233.87	830.0
1029.0	263.86	840.0
1030.0	295.56	850.0
1031.0	330.39	860.0
1032.0	369.49	870.0
1033.0	412.67	880.0
1034.0	460.75	890.0
1035.0	513.74	900.0
1036.0	571.57	910.0
1037.0	634.89	920.0
1038.0	705.16	930.0
1039.0	782.57	940.0
Port (1040.5) 1040.0	865.62	950.0
1041.0	*Sluice Gates Closed (Head limited to 50')**	

1. LACFCD provided storage volume values per LACFCD provided survey information dated March 8, 2012. Survey information was available for elevations of 993' and higher, volumes from 986'-992' were linearly interpolated.

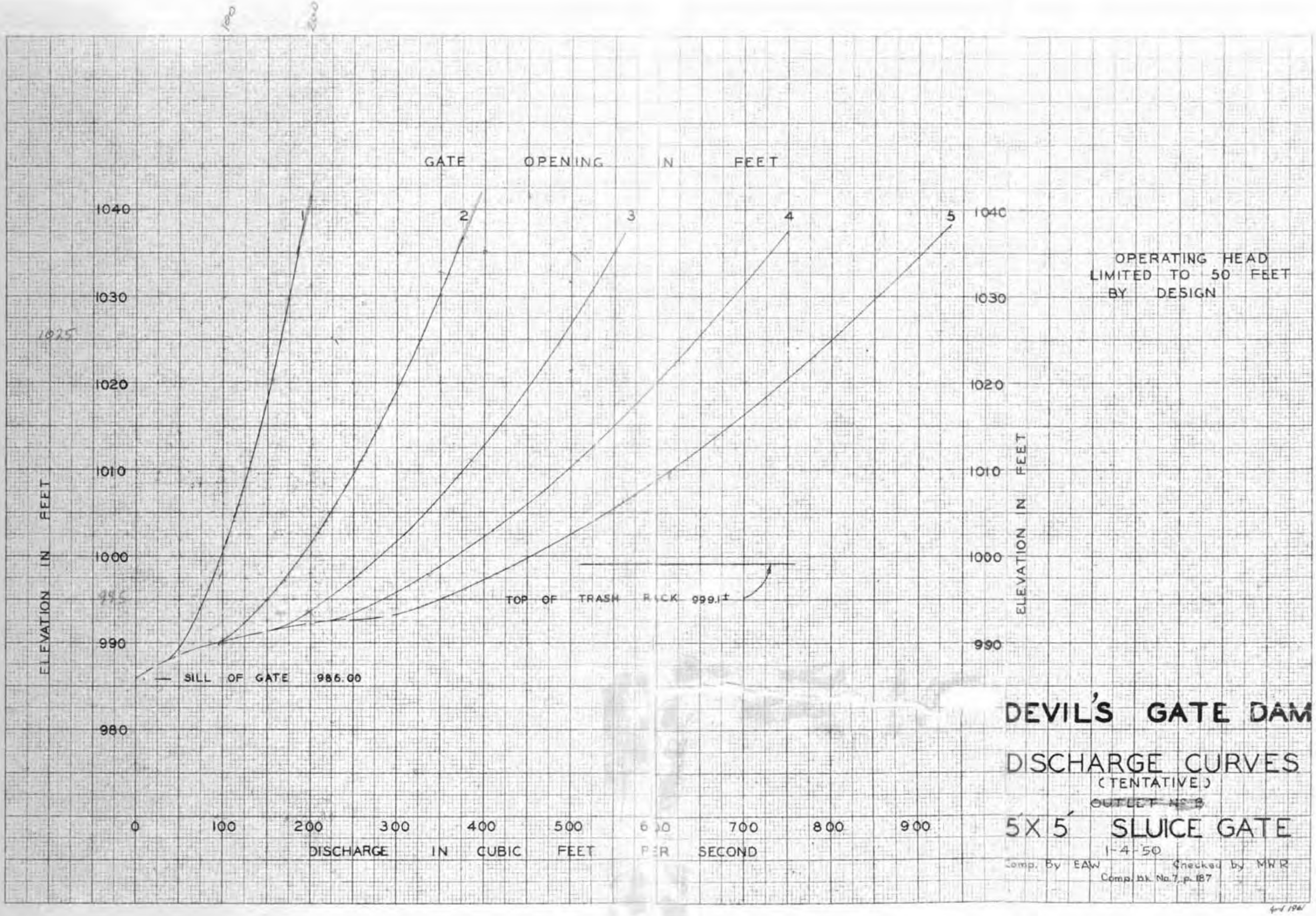
2. Discharge as interpreted from LACFCD provided discharge curve (see attached sluice gate curve). Sluice gate is assumed to be fully opened to for the entire storm duration and operating head is limited to 50'.

Elevation-Storage-Discharge Relationship for Sediment Flushing Event
(Two Fully Opened 7'x10' Slide Gates)

Water Surface Elevation (ft)		LACFCD Storage (ac-ft) [1]	Discharge at Dam Outlet (cfs) [2]
Sill of Sluice Gate	986.0	0.00	0.0
	987.0	0.01	0.0
	988.0	0.02	0.0
	989.0	0.03	0.0
	990.0	0.04	0.0
Top of Sluice Gate	991.0	0.05	0.0
	992.0	0.06	0.0
	993.0	0.09	0.0
	994.0	0.38	0.0
	995.0	0.81	0.0
	996.0	1.35	0.0
	997.0	2.01	0.0
	998.0	2.77	0.0
	999.0	3.64	0.0
	1000.0	4.61	0.0
	1001.0	5.69	0.0
	1002.0	6.87	0.0
	1003.0	8.15	0.0
	1004.0	9.58	0.0
	1005.0	11.21	0.0
	1006.0	13.06	0.0
Start Slide Gate	1007.0	15.12	0.0
	1008.0	17.39	80.0
	1009.0	19.87	160.0
	1010.0	22.53	240.0
	1011.0	25.39	388.0
	1012.0	28.44	536.0
	1013.0	31.80	684.0
	1014.0	35.63	832.0
	1015.0	40.17	980.0
	1016.0	45.72	1144.0
	1017.0	52.56	1308.0
	1018.0	60.84	1472.0
	1019.0	70.59	1636.0
	1020.0	81.76	1800.0
	1021.0	94.21	2010.0
	1022.0	107.92	2220.0
	1023.0	123.05	2430.0
	1024.0	139.87	2640.0
	1025.0	159.11	2850.0
	1026.0	181.23	3060.0
	1027.0	206.21	3270.0
	1028.0	233.87	3480.0
	1029.0	263.86	3700.0
	1030.0	295.56	3900.0
	1031.0	330.39	4000.0
	1032.0	369.49	4100.0
	1033.0	412.67	4200.0
	1034.0	460.75	4300.0
	1035.0	513.74	4400.0
	1036.0	571.57	4500.0
	1037.0	634.89	4600.0
	1038.0	705.16	4700.0
	1039.0	782.57	4800.0
Port (1040.5)	1040.0	865.62	4900.0

1. LACFCD provided storage volume values per LACFCD provided survey information dated March 8, 2012. Survey information was available for elevations of 993' and higher, volumes from 986'-992' were linearly interpolated.

2. Discharge as interpreted from LACFCD provided discharge curve (see slide gate curve). During the Sediment Flushing Event, the sluice gate will be closed and two 7'x10' slide gates will be fully opened.



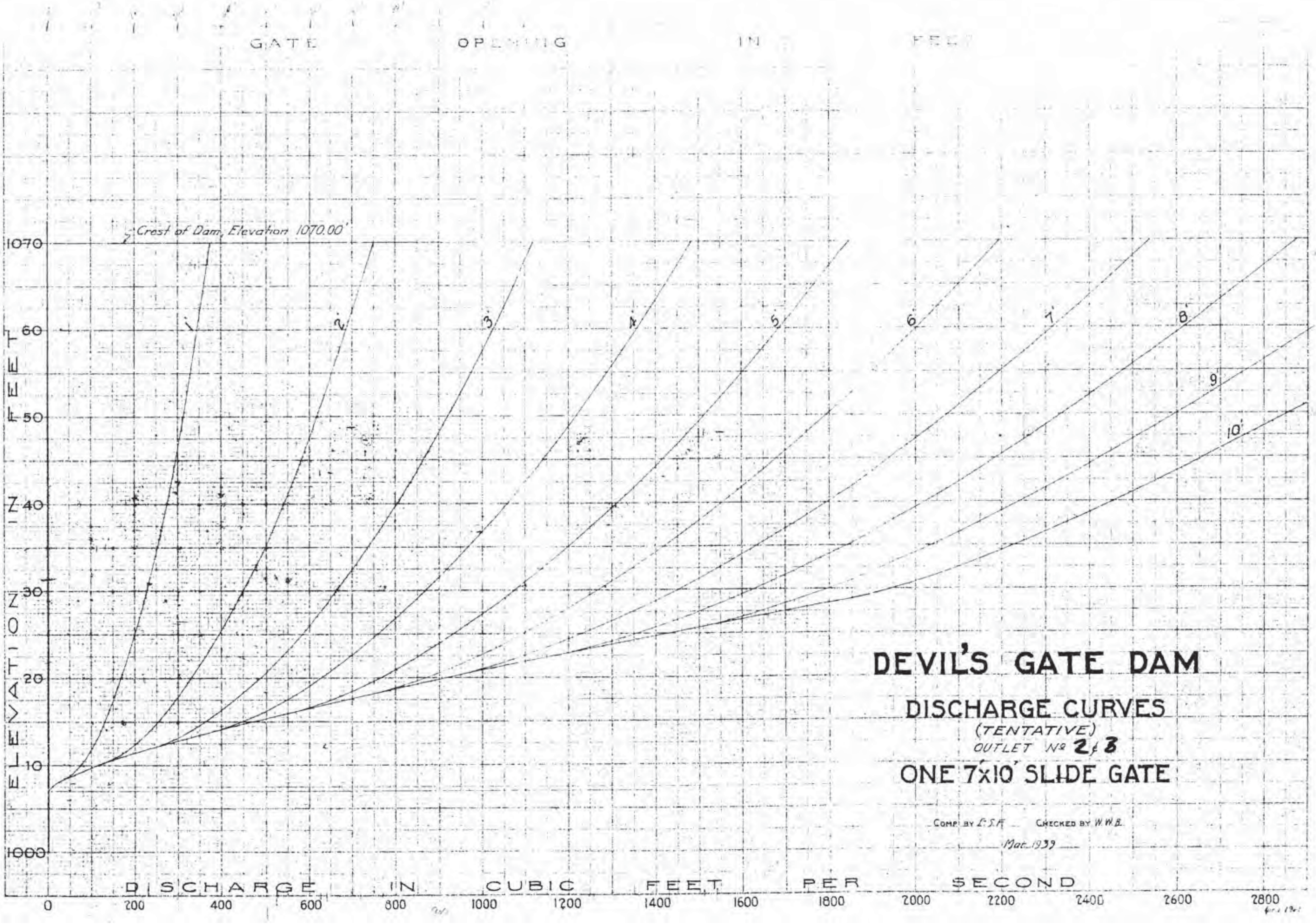
DEVIL'S GATE DAM

DISCHARGE CURVES
(TENTATIVE)
~~OUTLET No 8~~

5'X 5' SLUICE GATE
1-4-50

Comp. By EAW Checked by MWR
Comp. bk. No. 7, p. 187

4-1 1961



DEVIL'S GATE DAM

DISCHARGE CURVES

(TENTATIVE)

OUTLET Nº 2 & 3

ONE 7'x10' SLIDE GATE

COMP. BY E.S.R. CHECKED BY W.W.B.

Mar. 1939

Appendix A.2

Sediment Gradation Information

Excerpt from Draft Soils Report Upstream of Devils Gate Dam

Project: 603211-001	Eng/Geol: VPI/RML
Scale: 1 " = 1,000 '	Date: October, 2011

Base Map: ESRI Resource Center, 2010
Thematic Info: Leighton
Author: (mmurphy)

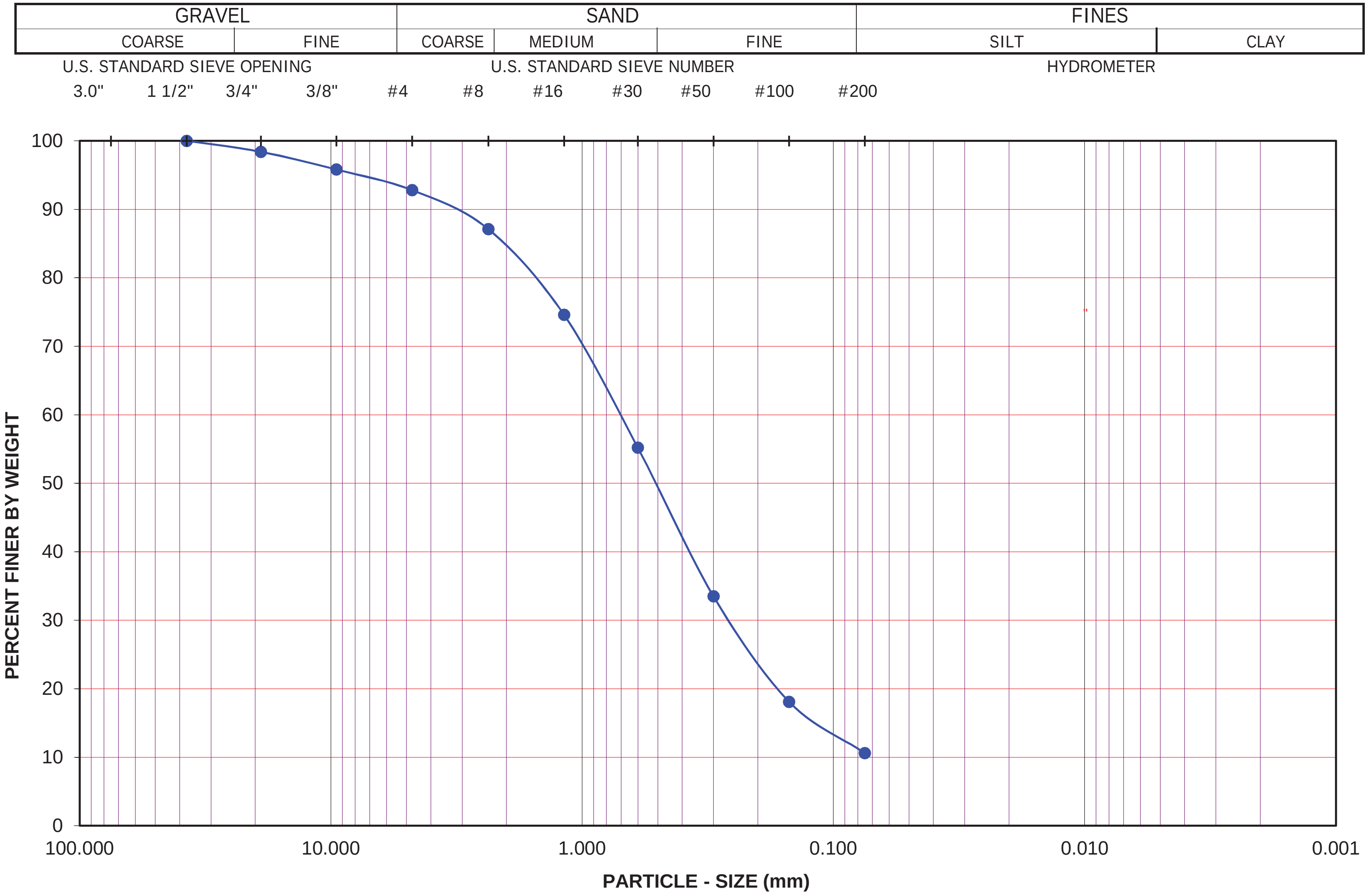
BORING LOCATION MAP

Devil's Gate Reservoir
Pasadena, California

Figure 2

Leighton

Map Saved as P:\drafting\603211\001\GIS\of_2011-10-27\Figure2.mxd on 10/27/2011 2:56:18 PM



Project Name: Devil's Gate

Project No.: 603211-001

Exploration No.: B-1

Sample No.: B3

Depth (feet): 15.0

Soil Type : SW-SM

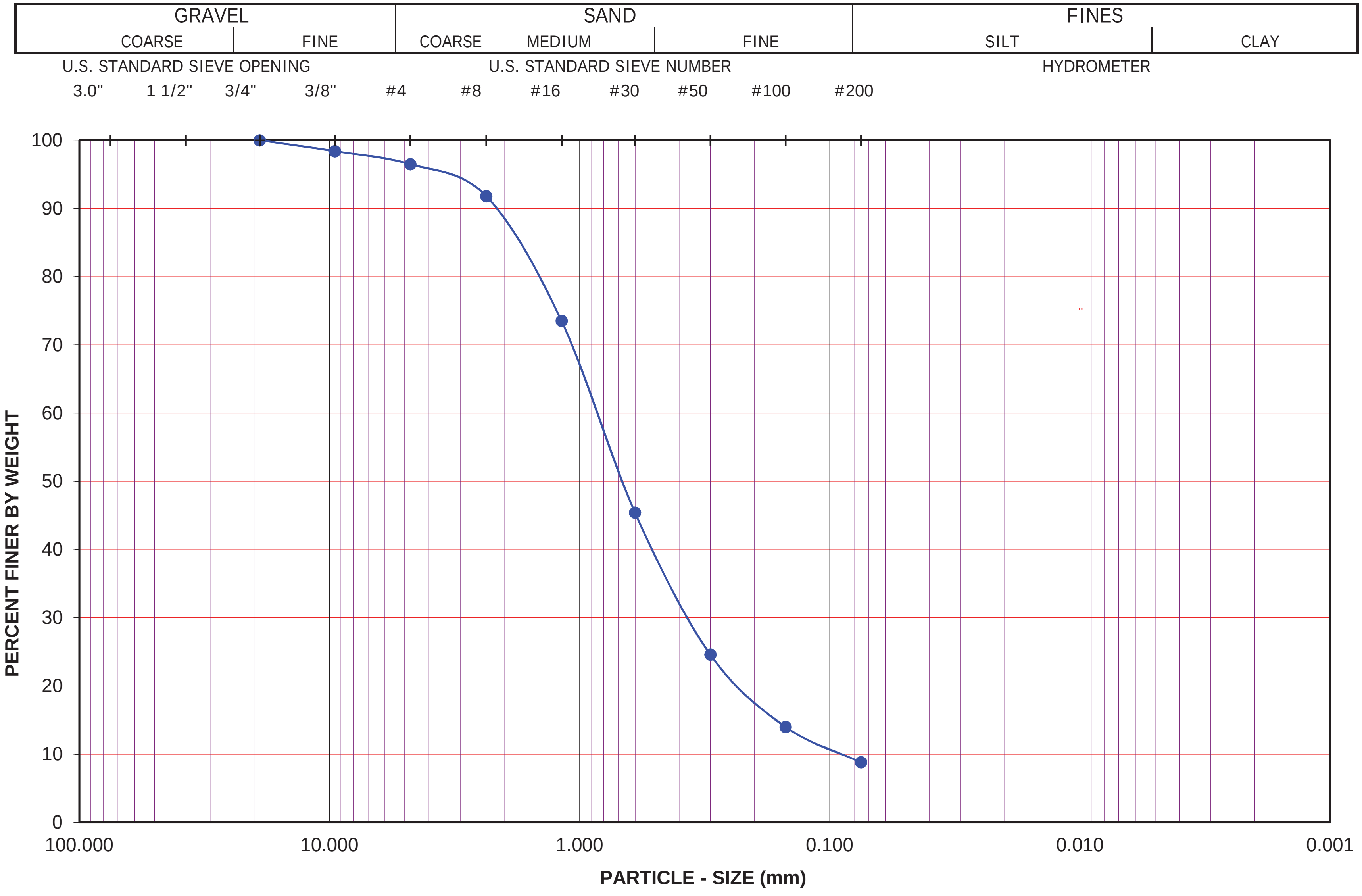
Soil Identification: Olive brown well-graded sand with silt (SW-SM)

GR:SA:FI : (%) 7 : 82 : 11

Leighton

PARTICLE - SIZE
DISTRIBUTION
ASTM D 6913

Oct-11



Project Name: Devil's Gate

Project No.: 603211-001

Exploration No.: B-3

Sample No.: B2

Depth (feet): 10.0

Soil Type : SW-SM

Soil Identification: Olive gray well-graded sand with silt (SW-SM)

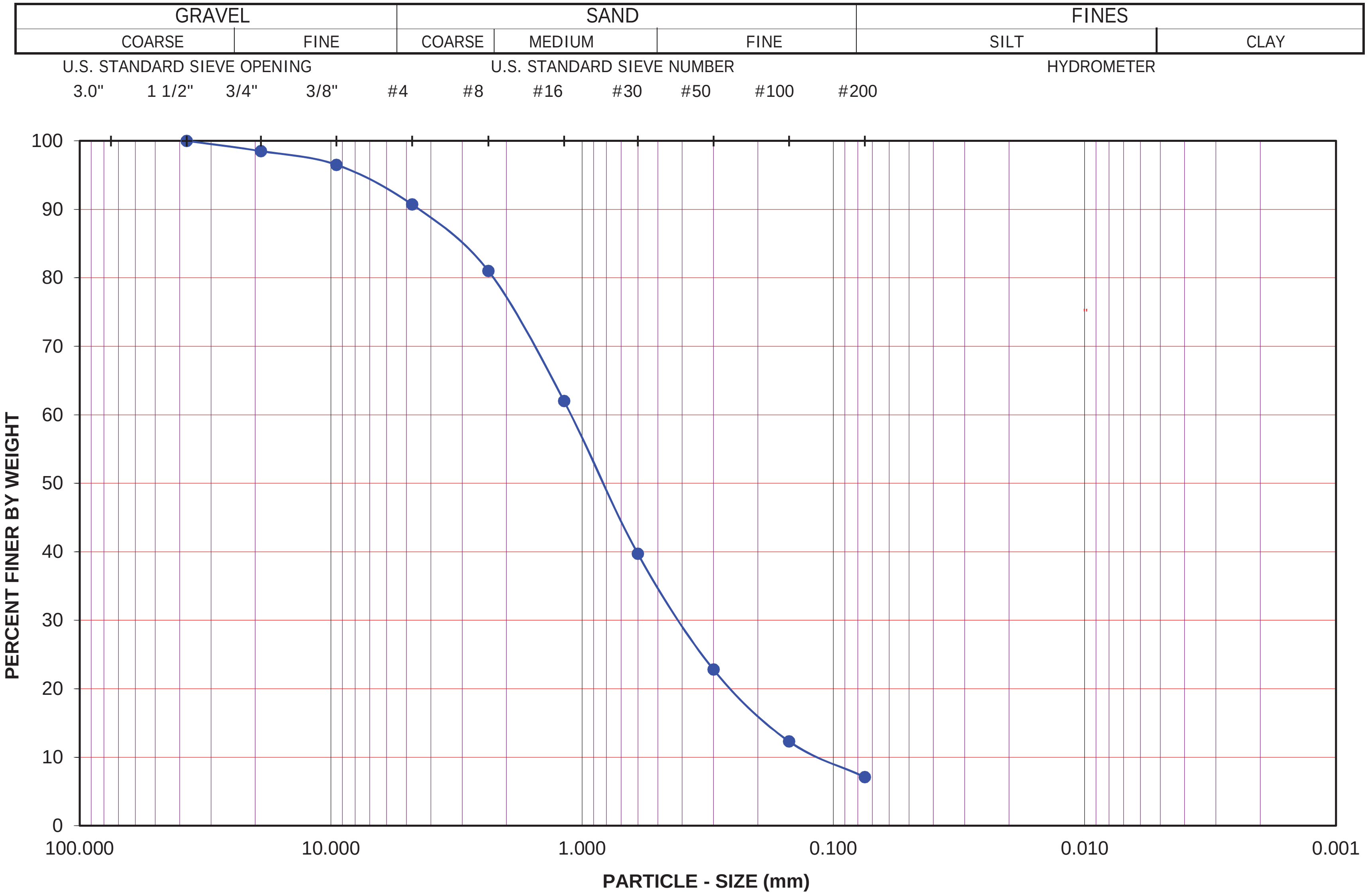
GR:SA:FI : (%) 4 : 87 : 9

Leighton

PARTICLE - SIZE
DISTRIBUTION
ASTM D 6913

Oct-11

SA B-3, B2 @ 10



Project Name: Devil's Gate

Project No.: 603211-001

Exploration No.: B-4

Sample No.: B2

Depth (feet): 10.0

Soil Type : SW-SM

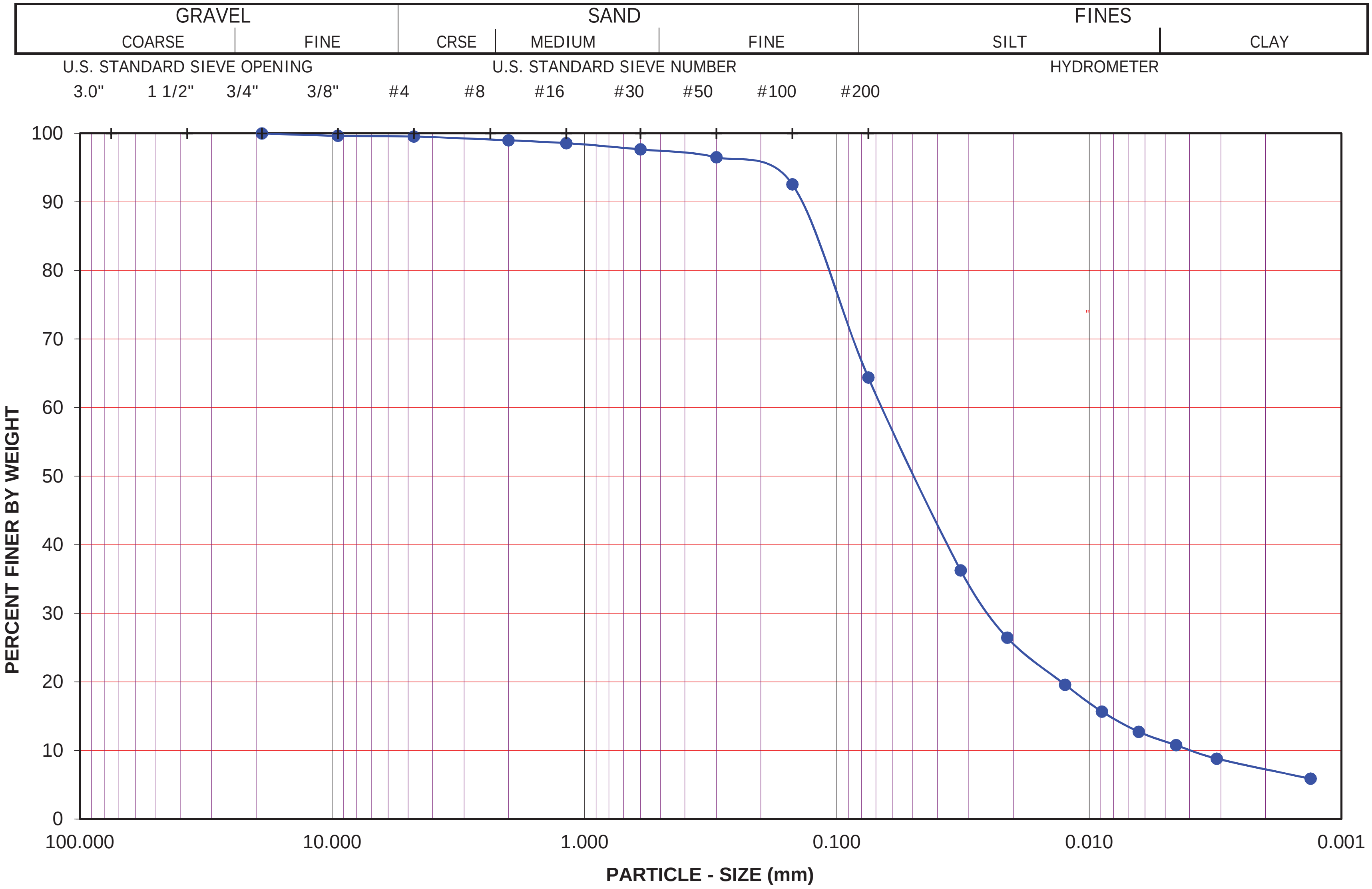
Soil Identification: Olive brown well-graded sand with silt (SW-SM)

GR:SA:FI : (%) 9 : 84 : 7

Leighton

PARTICLE - SIZE DISTRIBUTION ASTM D 6913

Oct-11



Project Name: Devil's Gate

Project No.: 603211-001

Leighton

PARTICLE - SIZE
DISTRIBUTION
ASTM D 422

Exploration No.: B-9

Sample No.: B2

Depth (feet) : 10.0

Soil Type : s(ML)

Soil Identification: Olive gray sandy silt s(ML); organic material noted

GR:SA:FI : (%) 0 : 36 : 64

Oct-11

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Gradations for Soil Sampling Downstream of the Devils Gate Dam

N|V|5

TESTING ENGINEERS VERTICALFIVE

Bureau Veritas North America
10620 Treena Street, Suite 200
San Diego, CA 92131

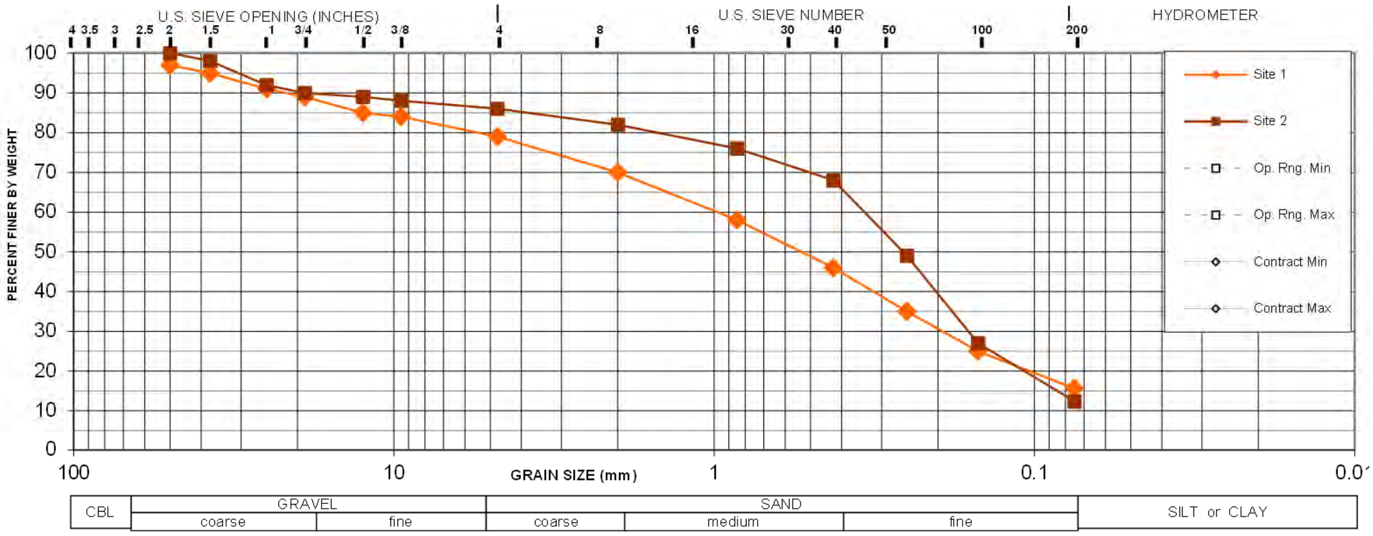
November 5, 2012
JOB No: **149466**
LAB No: 9350-51
Report No: 2646

Project: **Arroyo Seco Channel**

REPORT OF SIEVE ANALYSIS TEST

ASTM D422 - Soil

SAMPLE INFO:	**Site 1**	**Site 2**				
Description	Brown SAND with some organics	Gray brown SAND with organics				
Material	Native upper 2 feet	Native upper 2 feet				
Sample Location	Site 1: 10 ft north of creek	Site 2: 10 feet from creek				
Date Sampled	10/31/2012	10/31/2012				
Sampled By	M. Allen	M. Allen				
Date Tested	11/5/2012	11/5/2012				
Tested By	N. Regalado	N. Regalado				



Sample ID:	**Site 1**	**Site 2**				
Sieve Size	% Passing					
63mm (2 1/2")	100	100				
50mm (2")	97	100				
37.5mm (1 1/2")	**95**	**98**				
25mm (1")	**91**	**92**				
19mm (3/4")	**89**	**90**				
12.5mm (1/2")	**85**	**89**				
9.5mm (3/8")	**84**	**88**				
4.75mm (#4)	**79**	**86**				
2.36mm (#8)	**70**	**82**				
1.18mm (#16)	**58**	**76**				
600um (#30)	**46**	**68**				
300um (#50)	**35**	**49**				
150um (#100)	**25**	**27**				
75um (#200)	**15.7**	**12.4**				
Fineness Modulus	2.6	2.5				
Shape (sand & gravel)	N.R.	N.R.				
Hardness (sand & gravel)	N.R.	N.R.				
Specific Gravity	2.60	2.60				
Coef. of Curvature (C_C)	5.0	2.9				
Coef. of Uniformity (C_U)	194.1	21.5				
% Gravel	21	14				
% Sand	63	74				
% Fines	15.7	12.4				
USCS Class:	**???**	**???**				

Notes: *Hardness: H&D = Hard & Durable; W&F = Weathered & Friable*
N.R.: Not Recorded; N/A: Not Available.

Reviewed By:


Foothill Fwy Ovp
210
Sample Site 1
Linda Vista Ave


El Circulo Dr
El Portolo
159
N San Rafael Ave
Las Palmas Rd
134
Sample Site 2
Arroyo Dr
N Orange Grove Blvd
W Colorado Blvd
Westminster Dr
S Grand Ave
Del Rosa

Appendix A.3

Devils Gate Dam Outflow Hydrographs for Conditions 1, 2, and 3

Excerpt of Sediment Transport and Sediment Flushing Event Calculations - Refer to Excel Spreadsheet in Appendix A.4 for Complete Calculations

Date	Time (hrs)	Sediment Concentration (% By Weight)	Condition 1				Condition 2				Condition 3			
			Inflow (cfs)	Storage (Ac-ft)	Elevation (ft)	Outflow (cfs)	Inflow (cfs)	Storage (Ac-ft)	Elevation (ft)	Outflow (cfs)	Inflow (cfs)	Storage (Ac-ft)	Elevation (ft)	Outflow (cfs)
1-Jan-06	0:00	5.0%	39.3	0	988.0	39.3	39.3	0	988.0	39.3	39.3	0	988.0	39.3
1-Jan-06	1:00	5.0%	39.5	0	988.0	39.5	39.5	0	988.0	39.5	39.5	0	988.0	39.5
1-Jan-06	2:00	5.0%	39.7	0	988.0	39.7	39.7	0	988.0	39.7	39.7	0	988.0	39.7
1-Jan-06	3:00	5.0%	40.2	0	988.0	40.2	40.2	0	988.0	40.2	40.2	0	988.0	40.2
1-Jan-06	4:00	5.0%	40.7	0	988.0	40.7	40.7	0	988.0	40.7	40.7	0	988.0	40.7
1-Jan-06	5:00	5.0%	40.7	0	988.0	40.7	40.7	0	988.0	40.7	40.7	0	988.0	40.7
1-Jan-06	6:00	5.0%	41.2	0	988.1	41.2	41.2	0	988.1	41.2	41.2	0	988.1	41.2
1-Jan-06	7:00	5.0%	41.5	0	988.1	41.5	41.5	0	988.1	41.5	41.5	0	988.1	41.5
1-Jan-06	8:00	5.0%	41.7	0	988.1	41.7	41.7	0	988.1	41.7	41.7	0	988.1	41.7
1-Jan-06	9:00	5.0%	42.2	0	988.1	42.2	42.2	0	988.1	42.2	42.2	0	988.1	42.2
1-Jan-06	10:00	5.0%	42.5	0	988.1	42.5	42.5	0	988.1	42.5	42.5	0	988.1	42.5
1-Jan-06	11:00	5.0%	43.0	0	988.1	43.0	43.0	0	988.1	43.0	43.0	0	988.1	43.0
1-Jan-06	12:00	5.0%	43.3	0	988.2	43.3	43.3	0	988.2	43.3	43.3	0	988.2	43.3
1-Jan-06	13:00	5.0%	43.5	0	988.2	43.5	43.5	0	988.2	43.5	43.5	0	988.2	43.5
1-Jan-06	14:00	5.0%	43.8	0	988.2	43.8	43.8	0	988.2	43.8	43.8	0	988.2	43.8
1-Jan-06	15:00	5.0%	44.2	0	988.2	44.2	44.2	0	988.2	44.2	44.2	0	988.2	44.2
1-Jan-06	16:00	5.0%	79.8	0	989.5	79.5	79.8	0	989.5	79.5	79.8	0	989.5	79.5
1-Jan-06	17:00	5.0%	80.6	0	989.5	80.9	80.6	0	989.5	80.9	80.6	0	989.5	80.9
1-Jan-06	18:00	5.0%	37.0	0	987.9	37.1	37.0	0	987.9	37.1	37.0	0	987.9	37.1
1-Jan-06	19:00	5.0%	36.7	0	987.8	36.6	36.7	0	987.8	36.6	36.7	0	987.8	36.6
1-Jan-06	20:00	5.0%	48.9	0	988.4	48.9	48.9	0	988.4	48.9	48.9	0	988.4	48.9
1-Jan-06	21:00	5.0%	46.2	0	988.3	46.3	46.2	0	988.3	46.3	46.2	0	988.3	46.3
1-Jan-06	22:00	5.0%	42.6	0	988.1	42.6	42.6	0	988.1	42.6	42.6	0	988.1	42.6
1-Jan-06	23:00	5.0%	46.1	0	988.3	46.1	46.1	0	988.3	46.1	46.1	0	988.3	46.1
2-Jan-06	0:00	5.0%	47.5	0	988.4	47.5	47.5	0	988.4	47.5	47.5	0	988.4	47.5
2-Jan-06	1:00	5.0%	47.7	0	988.4	47.7	47.7	0	988.4	47.7	47.7	0	988.4	47.7
2-Jan-06	2:00	5.0%	102.0	0	990.0	101.6	102.0	0	990.0	101.6	102.0	0	990.0	101.6
2-Jan-06	3:00	5.0%	112.7	0	990.3	113.0	112.7	0	990.3	113.0	112.7	0	990.3	113.0
2-Jan-06	4:00	5.0%	76.6	0	989.4	76.5	76.6	0	989.4	76.5	76.6	0	989.4	76.5
2-Jan-06	5:00	5.0%	85.2	0	989.6	85.3	85.2	0	989.6	85.3	85.2	0	989.6	85.3
2-Jan-06	6:00	5.0%	80.3	0	989.5	80.3	80.3	0	989.5	80.3	80.3	0	989.5	80.3
2-Jan-06	7:00	5.0%	135.8	0	990.9	135.5	135.8	0	990.9	135.5	135.8	0	990.9	135.5
2-Jan-06	8:00	5.0%	185.5	0.1	992.0	185.5	185.5	0.1	992.0	185.5	185.5	0.1	992.0	185.5
2-Jan-06	9:00	5.0%	432.6	1.9	996.9	387.4	432.6	1.9	996.9	387.4	432.6	1.9	996.9	387.4
2-Jan-06	10:00	5.0%	815.7	14.1	1006.5	566.1	815.7	14.1	1006.5	566.1	815.7	14.1	1006.5	566.1
2-Jan-06	11:00	5.0%	1290.9	48.8	1016.4	701.6	1290.9	48.8	1016.4	701.6	1290.9	48.8	1016.4	701.6
2-Jan-06	12:00	5.0%	1469.7	102.4	1021.6	760.9	1469.7	102.4	1021.6	760.9	1469.7	102.4	1021.6	760.9
2-Jan-06	13:00	5.0%	1128.5	145.6	1024.3	791.9	1128.5	145.6	1024.3	791.9	1128.5	145.6	1024.3	791.9
2-Jan-06	14:00	5.0%	756.2	157.7	1024.9	799.2	756.2	157.7	1024.9	799.2	756.2	157.7	1024.9	799.2
2-Jan-06	15:00	5.0%	493.4	143.7	1024.2	790.8	493.4	143.7	1024.2	790.8	493.4	143.7	1024.2	790.8
2-Jan-06	16:00	5.0%	372.1	114.9	1022.5	770.8	372.1	114.9	1022.5	770.8	372.1	114.9	1022.5	770.8
2-Jan-06	17:00	5.0%	222.2	77.1	1019.6	737.7	222.2	77.1	1019.6	737.7	222.2	77.1	1019.6	737.7
2-Jan-06	18:00	5.0%	116.5	33.3	1013.4	662.4	116.5	33.3	1013.4	662.4	116.5	33.3	1013.4	662.4
2-Jan-06	19:00	5.0%	91.7	0.6	994.5	336.9	91.7	0.6	994.5	336.9	91.7	0.6	994.5	336.9
2-Jan-06	20:00	5.0%	85.0	0	986.0	0.0	85.0	0	986.0	0.0	85.0	0	986.0	0.0
2-Jan-06	21:00	5.0%	72.2	0.1	991.4	155.9	72.2	0.1	991.4	155.9	72.2	0.1	991.4	155.9
2-Jan-06	22:00	5.0%	53.7	0	986.0	0.0	53.7	0	986.0	0.0	53.7	0	986.0	0.0
2-Jan-06	23:00	5.0%	46.2	0	990.0	98.9	46.2	0	990.0	98.9	46.2	0	990.0	98.9
3-Jan-06	0:00	5.0%	38.6	0	986.0	0.0	38.6	0	986.0	0.0	38.6	0	986.0	0.0
3-Jan-06	1:00	5.0%	28.3	0	989.2	66.1	28.3	0	989.2	66.1	28.3	0	989.2	66.1
3-Jan-06	2:00	5.0%	23.6	0	986.0	0.0	23.6	0	986.0	0.0	23.6	0	986.0	0.0
3-Jan-06	3:00	5.0%	24.4	0	988.4	47.4	24.4	0	988.4	47.4	24.4	0	988.4	47.4
3-Jan-06	4:00	5.0%	20.0	0	986.0	0.0	20.0	0	986.0	0.0	20.0	0	986.0	0.0
3-Jan-06	5:00	5.0%	21.2	0	988.0	40.7	21.2	0	988.0	40.7	21.2	0	988.0	40.7
3-Jan-06	6:00	5.0%	25.3	0	986.3	6.2	25.3	0	986.3	6.2	25.3	0	986.3	6.2
3-Jan-06	7:00	5.0%	26.7	0	988.3	45.3	26.7	0	988.3	45.3	26.7	0	988.3	45.3
3-Jan-06	8:00	5.0%	33.5	0	986.8	15.2	33.5	0	986.8	15.2	33.5	0	986.8	15.2
3-Jan-06	9:00	5.0%	37.1	0	988.7	54.9	37.1	0	988.7	54.9	37.1	0	988.7	54.9

Excerpt of Sediment Transport and Sediment Flushing Event Calculations - Refer to Excel Spreadsheet in Appendix A.4 for Complete Calculations

Date	Time (hrs)	Sediment Concentration (% By Weight)	Condition 1				Condition 2				Condition 3			
			Inflow (cfs)	Storage (Ac-ft)	Elevation (ft)	Outflow (cfs)	Inflow (cfs)	Storage (Ac-ft)	Elevation (ft)	Outflow (cfs)	Inflow (cfs)	Storage (Ac-ft)	Elevation (ft)	Outflow (cfs)
14-Apr-07	20:00	0.0%	5.2	15.3	1007.1	5.5	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
14-Apr-07	21:00	0.0%	5.6	15.3	1007.1	5.4	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
14-Apr-07	22:00	0.0%	5.6	15.3	1007.1	5.6	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
14-Apr-07	23:00	0.0%	5.2	15.3	1007.1	5.4	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	0:00	0.0%	5.4	15.3	1007.1	5.3	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	1:00	0.0%	5.7	15.3	1007.1	5.6	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	2:00	0.0%	5.6	15.3	1007.1	5.7	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	3:00	0.0%	5.6	15.3	1007.1	5.6	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	4:00	0.0%	5.7	15.3	1007.1	5.7	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	5:00	0.0%	41.1	15.9	1007.3	26.7	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	6:00	0.0%	12.4	15.9	1007.3	26.8	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	7:00	0.0%	8.6	15.3	1007.1	7.5	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	8:00	0.0%	7.8	15.4	1007.1	8.3	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	9:00	0.0%	7.3	15.3	1007.1	7.4	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	10:00	0.0%	7.4	15.3	1007.1	7.3	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	11:00	0.0%	7.9	15.3	1007.1	7.7	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	12:00	0.0%	7.4	15.3	1007.1	7.6	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	13:00	0.0%	6.7	15.3	1007.1	6.9	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	14:00	0.0%	6.4	15.3	1007.1	6.5	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	15:00	0.0%	6.6	15.3	1007.1	6.5	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	16:00	0.0%	6.4	15.3	1007.1	6.5	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	17:00	0.0%	6.2	15.3	1007.1	6.3	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	18:00	0.0%	5.9	15.3	1007.1	6.0	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	19:00	0.0%	5.7	15.3	1007.1	5.8	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	20:00	0.0%	5.6	15.3	1007.1	5.6	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	21:00	0.0%	5.4	15.3	1007.1	5.5	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	22:00	0.0%	5.4	15.3	1007.1	5.4	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
15-Apr-07	23:00	0.0%	5.4	15.3	1007.1	5.4	*n/a*	*n/a*	*n/a*	*n/a*	n/a	n/a	n/a	n/a
Sediment Transport Event Characteristics		**Average**	**9.4**	**0.2**	**986.4**	**9.4**	**9.4**	**0.2**	**986.4**	**9.4**	**9.4**	**0.2**	**986.4**	**9.4**
		Maximum	**1469.7**	**157.7**	**1024.9**	**799.2**	**1469.7**	**157.7**	**1024.9**	**799.2**	**1469.7**	**157.7**	**1024.9**	**799.2**
		Minimum	**0.0**	**0.0**	**986.0**	**0.0**	**0.0**	**0.0**	**986.0**	**0.0**	**0.0**	**0.0**	**986.0**	**0.0**
Sediment Flushing Event Characteristics		**Average**	**6.8**	**15.2**	**1007.0**	**6.7**	**4900.0**	**865.6**	**1040.0**	**4900.0**	**2500.0**	**128.7**	**1023.3**	**2500.0**
		Maximum	**1353.7**	**42.1**	**1015.3**	**1036.5**	**4900.0**	**865.6**	**1040.0**	**4900.0**	**2500.0**	**128.7**	**1023.3**	**2500.0**
		Minimum	**0.0**	**0.0**	**986.0**	**0.0**	**4900.0**	**865.6**	**1040.0**	**4900.0**	**2500.0**	**128.7**	**1023.3**	**2500.0**
Total Sediment Transport Event Stormwater Volume (yd^3)			**8,642,480**				**8,642,480**				**8,642,480**			
Total Sediment Flushing Event Stormwater Volume (yd^3)			**3,947,773**				**47,040,000**				**48,000,000**			
Ratio: Historical Flushing Event Volume vs Modeled Flushing Event Volume			**1.00**				**11.92**				**12.16**			

Appendix A.4

Electronic Information

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Contact: County of Los Angeles Department of Public Works, 900 South Fremont Avenue, Alhambra

2nd floor public counter

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Appendix B

Modeling of Sluicing and Flushing Conditions in the Arroyo Seco Channel Below the Devils Gate Dam by Chang Consultants

APPENDIX B

“FINAL DRAFT”
MODELING OF SLUICING AND FLUSHING CONDITIONS IN THE ARROYO SECO CHANNEL BELOW THE DEVIL’S GATE DAM

January 7, 2013

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INTRODUCTION

Sediment transport analyses were previously performed for the Arroyo Seco Channel downstream of the Devil's Gate Dam (Dam). The analyses are included in the August 3, 2012, Chang Consultants report titled, *Sediment Transport Analyses for the Arroyo Seco Channel.* The Dam is located north of Interstate 210 (Foothill Freeway) and the Foothill Freeway overpass in the city of Pasadena (see Vicinity Map). Just below the Dam, the natural Arroyo Seco Channel passes under Interstate 210, then becomes an engineered, concrete-lined channel near the north end of the Brookside Golf Course. The channel below the dam extends over approximately 9 miles to its confluence with the Los Angeles River, and is concrete-lined except for the reach between the Dam and Brookside Golf Course (station 31+30 to 43+15) as well as a reach under Highway 134 (station 27+70 to 28+20). At the downstream end of each natural channel reach is a grade control structure used to stabilize the channel bed.

Vicinity Map

This report includes additional FLUVIAL-12 sediment transport modeling of the Arroyo Seco Channel in order to determine sediment transport processes in the predominately concrete-lined channel between the Devil's Gate Dam and the Los Angeles River confluence. The analyses were performed for three new conditions outlined by the Los Angeles County Flood Control District

(LACFCD). The conditions are described in detail below and are all based on sluicing sediment laden flow from the Dam over a 9.5 month duration. The conditions also model various sediment flushing events in which the sediment deposited by the sluicing is transported by subsequent flows. Furthermore, a fourth condition was added because it was determined during course of analyses that one of LACFCD's conditions should be altered. The fourth condition provides support for the alteration.

The following sections outline the four conditions that were analyzed, and then discuss the FLUVIAL-12 model and its results.

MODELING SCOPE

This study covers two types of water and sediment flows: sediment sluicing from the reservoir (natural sediment transport) followed by water flow to flush sediment from the channel (natural or idealized sediment flushing). For sluicing, water and sediment are released from the reservoir into the channel downstream based on flow records from January 1, 2006 to October 14, 2006 with a sediment concentration of 5 percent (by weight). This operation will result in sediment deposition along the Arroyo Seco Channel, mostly along the natural channel reach just below the dam.

The sluicing will be followed by flow events that flush the deposited sediment from the channel. The flushing is derived from either observed Dam inflow rates between October 15, 2006 to April 15, 2007 (natural flushing) or from simulated flow rates (idealized flushing). The flushing assumes zero percent sediment concentration at the Dam outlet. During the process of sediment flushing, the two natural channel reaches can undergo both erosion and deposition. The extended low flows can only deliver a small amount of sediment to the Los Angeles River. For the purpose of sediment management, three different options for sediment flushing requested by LACFCD are simulated that cover a variety of flow rates and durations. The purpose of the study is to determine the amount of sediment that can be flushed out of the Arroyo Seco Channel into the Los Angeles River under the options that were considered.

The study will determine sediment deposition and net capacity of the Arroyo Seco Channel to the Los Angeles River confluence. Specifically, the study shall provide the following items:

- Channel profiles illustrating the sediment deposition elevations with respect to the invert elevation of the channel

- Channel cross-sections depicting sediment deposition at key locations of the Channel.

The three LACFCD study conditions are as follows.

Condition 1. Natural Sediment Transport and Natural Sediment Flushing – This modeling run includes sediment sluicing and flushing phases simulating natural conditions as described below.

Phase 1. Sediment sluicing: Phase 1 is based on flow records from January 1, 2006 to October 14, 2006 for a total duration of about 9.5 months. A 5 percent sediment concentration by weight is assumed within the flow. The total amount of sediment flushed out of the reservoir is calculated from the total volume of the water flow during the same period.

As a first step, the total volume of water flow for the period of record is approximately 233,350,000 cubic feet. The total weight of water is determined by multiplying the volume by the unit weight of water (62.4 pounds per cubic feet). Based on this, the total weight was estimated at just over 7,280,000 tons. The sediment weight is 5 percent of the water weight or approximately 364,000 tons.

The weight of sediment is converted into a volume using the specific gravity of sediment of 2.65 and a void ratio of 0.62 for deposited sediment:

Weight of sediment per cubic foot = 62.4 × 2.65 × 0.62 = 102.52 pounds per cubic foot
Weight of sediment per cubic yard = 102.52 × 27 / 2,000 = 1.384 tons per cubic yard
Total volume of sediment released from reservoir by sluicing = 364,018 / 1.384
= 263,000 cubic yards

Phase 2. Sediment flushing: The subsequent flushing phase is based on flow records from October 15, 2006 through April 15, 2007 for a total duration of 6 months. A zero percent sediment concentration is assumed for the flow as it exits the Dam following the end of sluicing.

Condition 2: Natural Sediment Transport Followed by Three Days of Maximum Idealized Sediment Flushing at 4,900 cfs – This condition has two phases.

Phase 1. Sediment sluicing: The first phase of sediment sluicing is identical to that in Condition 1.

Phase 2. Sediment flushing: The second phase is a simulated sediment flushing event with a constant "idealized" flow rate of 4,900 cubic feet per second (cfs) for a duration that is necessary to completely clear the channel of sediment that was deposited during the Phase 1 sluicing of 263,000 cubic yards. FLUVIAL-12 was used to determine the minimum sediment flushing duration necessary to complete the flushing process. After several trial runs, the total duration of flushing was selected to be 3 days (the results for all of the conditions are discussed further in the next section).

Condition 3: Natural Sediment Transport and 6 Month Duration Idealized Sediment Flushing
The intent of this condition was to perform the same sluicing event as Conditions 1 and 2, and then determine the constant flow rate "idealized" flushing event that would remove the deposited sediment from Phase 1 over an approximately 6 month period. However, after performing trial runs, it was determined that flushing over a 6 month period was not a feasible condition. The sediment deposited by the sluicing requires a relatively high flow rate (determined to be 2,500 cfs) to adequately transport the sediment downstream. Under such a high flow rate, the sediment will be removed in a matter of days rather than months. A fourth condition (discussed next) was added to demonstrate that lower flow rates will not adequately transport the sediment. Based on this information, Condition 3 was modified as follows:

Phase 1. Sediment sluicing: The first phase of sediment sluicing is identical to that in Conditions 1 and 2.

Phase 2. Sediment flushing: The second phase is a simulated sediment flushing event to estimate the minimum constant "idealized" flow rate (2,500 cfs) needed to transport the deposited sediment and clear the channel. The required duration of flushing was determined to be 6 days.

Condition 4: Natural Sediment Transport Followed by Sediment Flushing at 1,000 cfs – This condition was added to demonstrate that lower flows will not adequately transport sediment and clear the channel. This finding led to the modification of Condition 3 as discussed above. Condition 4 includes the following:

Phase 1. Sediment sluicing: The first phase of sediment sluicing is identical to that in Conditions 1, 2, and 3.

Phase 2. Sediment flushing: The second phase is a simulated sediment flushing event under a constant "idealized" flow rate of 1,000 cfs. The duration of flushing was performed for up to 16 days.

MODELING INPUT

Stream hydraulics, sediment transport, and channel changes may be studied through physical modeling, mathematical modeling, or both. Physical modeling has been relied upon traditionally for stream projects, but mathematical modeling has become popular as this capability expands rapidly. The FLUVIAL-12 program is a mathematical model that has been formulated and developed in southern California since 1972 for water and sediment routing in natural and improved streams. The combined effects of flow hydraulics, sediment transport, and stream channel changes are simulated for given flow events and periods.

FLUVIAL-12 is applicable to ephemeral streams as well as streams with long-term, continuous flow. Because dynamic changes have transient behavior, ephemeral streams require more complicated model formulation techniques. Stream impacts simulated by the FLUVIAL-12 model include channel bed scour and fill (aggradation and degradation), width variation, and bed topography changes induced by channel curvature (i.e., bend scour associated with channel curvature). These inter-related changes are coupled at individual time steps over an entire flow event or series of flow events. While the model is applicable for erodible channels, physical constraints such as channel lining, bank protection or armoring, grade control structures, bedrock outcroppings, etc. may also be specified. Furthermore, the erodible material limits, bank erodibility, angle of repose, and channel roughness (e.g., channel bed and bank material, vegetation density, etc.) are included. Typical model applications include evaluations of sand and gravel mining, channelization, sediment delivery, etc.

This study provides FLUVIAL-12 modeling of the Arroyo Seco Channel in order to determine sediment transport processes in the predominately concrete-lined channel between the Dam and the Los Angeles River confluence. The FLUVIAL-12 model is based on cross-sectional data similar to the HEC-2 and HEC-RAS models. In addition, FLUVIAL-12 requires a sediment transport formula, flow hydrograph, bed material gradations, and sediment inflow. The following describes the basis of the model and the selected input parameters.

Analytical Basis of Model – FLUVIAL-12 is employed to simulate the hydraulics of flow, sediment transport and delivery, and stream channel changes of a stream channel for different cases. For a given flood hydrograph, the model simulates spatial and temporal variations in water surface elevation, sediment transport, and channel geometry. Scour and fill of the stream bed are coupled with width variation in the prediction of stream channel changes. Computations are based on finite difference approximations to energy and mass conservation that are representative of open channel flow.

The model simulates the inter-related changes in channel bed profile and channel width based upon a streams tendency to seek uniformities in sediment discharge and power expenditure. At each time step, scour and fill of the channel bed are computed based on the spatial variation in sediment discharge along the channel. Channel-bed corrections for scour and fill will reduce the non-uniformity in sediment discharge. Width changes are also made at each time step, resulting in a movement toward uniformity in power expenditure along the channel. Because the energy gradient is a measure of the power expenditure, uniformity in power expenditure also means a uniform energy gradient or linear water surface profile. A stream channel may not have a uniform power expenditure or linear water surface profile, but it is constantly adjusting itself toward that direction.

Engelund-Hansen Formula – A sediment transport formula is used in the FLUVIAL-12 model. The Engelund-Hansen (1967) formula was selected for this study. This formula applied Bagnold's stream power concept and the similarity principle to obtain their sediment transport equation:

$$f' \varphi = 0.1 \, (\tau_*)^{5/2} \qquad (1)$$

with

$$f' = \frac{2gRS}{U^2} \qquad (2)$$

$$\varphi = \frac{q_s}{\gamma_s \left[(s-1) g d^3\right]^{1/2}}, \qquad \tau_* = \frac{\tau_0}{(\gamma_s - \gamma) d} \qquad (3)$$

where f' is the friction factor, d is the median fall diameter of the bed material, φ is the dimensionless sediment discharge, s is the specific gravity of sediment, and τ_* is the dimensionless shear stress or the Shields stress. Substituting equations 2 and 3 into Eq. 1 yields

$$C_s = 0.05 \frac{s}{s-1} \frac{US}{\left[(s-1) g d\right]^{1/2}} \left[\frac{RS}{(s-1) d}\right]^{1/2} \qquad (4)$$

where C_s (= Q_s/Q) is the sediment concentration by weight. This equation relates sediment concentration to the *US* product (which is the rate of energy expenditure per unit weight of water) and the *RS* product (which is the shear stress).

The Engelund-Hansen formula was selected for the study for the following reasons:

1. An extensive evaluation of formulas was made by Brownlie in which the Engelund-Hansen formula had the best correlation with field data.

2. The Engelund-Hansen formula was used in many studies in this region. The results of these studies have verified by field data.

3. In a calibration study of the FLUVIAL-12 model, the results generated by the Engelund-Hansen formula were correlated with the measured channel changes in a southern California stream during a 1993 flood.

Additional Model Input – Basic data for the stream channel analyses was provided by Bureau Veritas, and include a HEC-RAS model of the Arroyo Seco Channel populated with hydraulic characteristics, sediment gradations for the natural channel sections, and dam outflow hydrographs for 15.5 months of historical reservoir inflow data. Furthermore, the sediment inflow was input based on the percentages described in the previous section. The given flow records for the study have a long duration extending over several months. This requires excessive simulation time for the FLUVIAL-12 model. In general, the smaller flow rates require more computing time. In order to reduce computer simulation time, flows smaller than 2.5 cfs were excluded from the simulation. These flow rates are so small as to have a minor impact on the results.

MODELING RESULTS

Sediment delivery is defined as the cumulative amount of sediment delivered past a certain channel section for a specified period of time:

$$Y = \int_T Q_s dt \tag{5}$$

where Y is sediment delivery (yield); Q_s is sediment discharge; t is time; and T is the duration. The sediment discharge Q_s pertains only to bed-material load of sand, gravel and cobble. Fine sediment such as clay and silt constitute the wash load, and are not computed by a sediment transport formula. Sediment delivery is widely employed by hydrologists for watershed management; it is used herein to keep track of sediment supply and removal along the channel reach.

Spatial variations in sediment delivery are manifested as channel storage or depletion of sediment associated stream channel changes since the sediment supply from upstream may be different from the removal. The spatial variation of sediment delivery depicts the erosion and deposition along a stream reach. A decreasing delivery in the downstream direction, i.e. negative gradient for the delivery-distance curve, signifies that sediment load is partially stored in the channel to result in a net deposition. On the other hand, an increasing delivery in the downstream direction (positive gradient for the delivery-distance curve) indicates sediment removal from the channel boundary or net scour. A uniform sediment delivery along the channel (horizontal curve) indicates sediment balance, i.e., zero storage or depletion. Channel reaches with net sediment storage or depletion may be designated in each figure on the basis of the gradient. From the engineering viewpoint, it is best to achieve a uniform delivery, the non-silt and non-scour condition, for dynamic equilibrium.

Figure 1 contains simulated time and spatial variations in sediment delivery for Condition 1. The delivery at the upstream channel entrance is the sediment released from the reservoir through the dam during the sediment sluicing phase of 287 days. Sluicing is followed by flushing over a long duration of low flows for 183 days. From the upstream channel entrance toward downstream, the delivery decreases rapidly indicating that the sediment settles rapidly in the natural channel below the dam. For the remaining channel reach, the delivery becomes limited indicating that only a small amount of sediment is transported along the channel to reach the Los Angeles River. The two curves for sluicing and flushing nearly overlap since only a small amount of sediment is transported during the low flows during flushing. The longitudinal profiles of the channel for Condition 1 are shown in Figure 2. The most noticeable physical changes (deposition) occur near the dam.

Figure 3 shows time and spatial variations of sediment delivery along the channel for Condition 2. The initial sluicing is followed by flushing over 3 days at a constant 4,900 cfs. The figure indicates major sediment deposition along the natural channel reach below the dam during the sluicing phase. The deposition is followed by gradual sediment removal by the constant flow. The removed sediment is transported downstream through the concrete-lined channel reaches without significant deposition. The delivery curves show some variations along the second natural channel reach near river mile 6.7. The top curve in the figure is the spatial variation of sediment delivery over a flushing duration of 3 days. This curve is more or less level along the channel from the dam to the Los Angeles River, indicating that a total amount of approximately 250,000 cubic yards of sediment can be delivered from the dam all the way to the Los Angeles River.

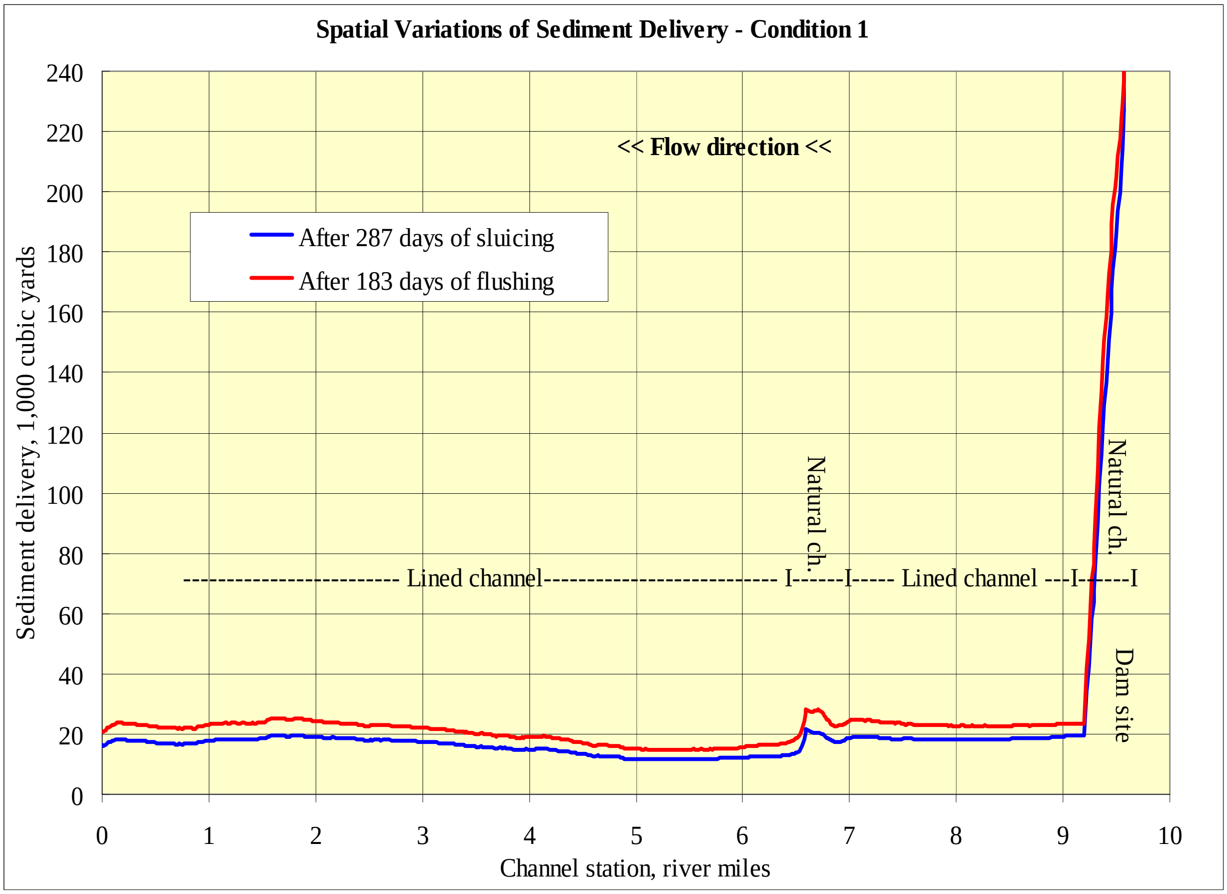
Longitudinal channel profiles of the channel for Condition 2 are shown in Figures 4 and 5. Sample cross-sectional changes are shown in Figures 6 through 10. These figures illustrate the pattern of channel changes in connection with sediment erosion and deposition along the channel.

Simulated results for sediment delivery, longitudinal channel profiles, and cross-sectional changes for Condition 3 are included in Figures 11 through 18. Condition 3 is based on a constant flushing discharge of 2,500 cfs for a total duration of up to 6 days. It can be seen that the effects from Condition 3 at 6 days are similar to those for Condition 2 at 3 days, i.e., a total amount of approximately 250,000 cubic yards of sediment can be delivered from the dam all the way to the Los Angeles River.

Condition 4 is based on a constant flushing discharge of 1,000 cfs for a total flushing duration of up to 16 days. Figures 19 through 26 illustrate the results for Condition 4. Over a 16 day duration, a total of approximately 200,000 cubic yards of sediment can be delivered to the Los Angeles River. However, a closer review of the results indicates that sediment will settle along the concrete-lined channel reaches just downstream of both natural areas. In addition, the sediment storage in the natural reach below the dam will only partially be removed by flushing. Therefore, the smaller flows will cause deposition and will not deliver all of the sediment downstream. Figures 27 and 28 contain the plan view locations where deposition is predicted to occur during this lower flow event.

CONCLUSION

The Los Angeles County Flood Control District requested three conditions be analyzed for sediment transport in the Arroyo Seco Channel between the Devil’s Gate Dam and Los Angeles River. All three conditions assumed the same initial long-term sluicing out of the Dam. The natural flushing assumed under Condition 1 will not transport all of the deposited sediment downstream. In fact, the sediment delivery is rather low. On the other hand, the constant flow rates under Conditions 2 and 3 can transport the deposited sediment downstream in a matter of 3 to 6 days. These conditions were based on idealized constant flow rates. It is unknown how feasible it is to generate constant flow rates over the multi-day periods. Finally, the lower range of flows represented by Condition 4 can transport sediment downstream, but the flows will allow some sediment to deposit and remain in the Arroyo Seco Channel.



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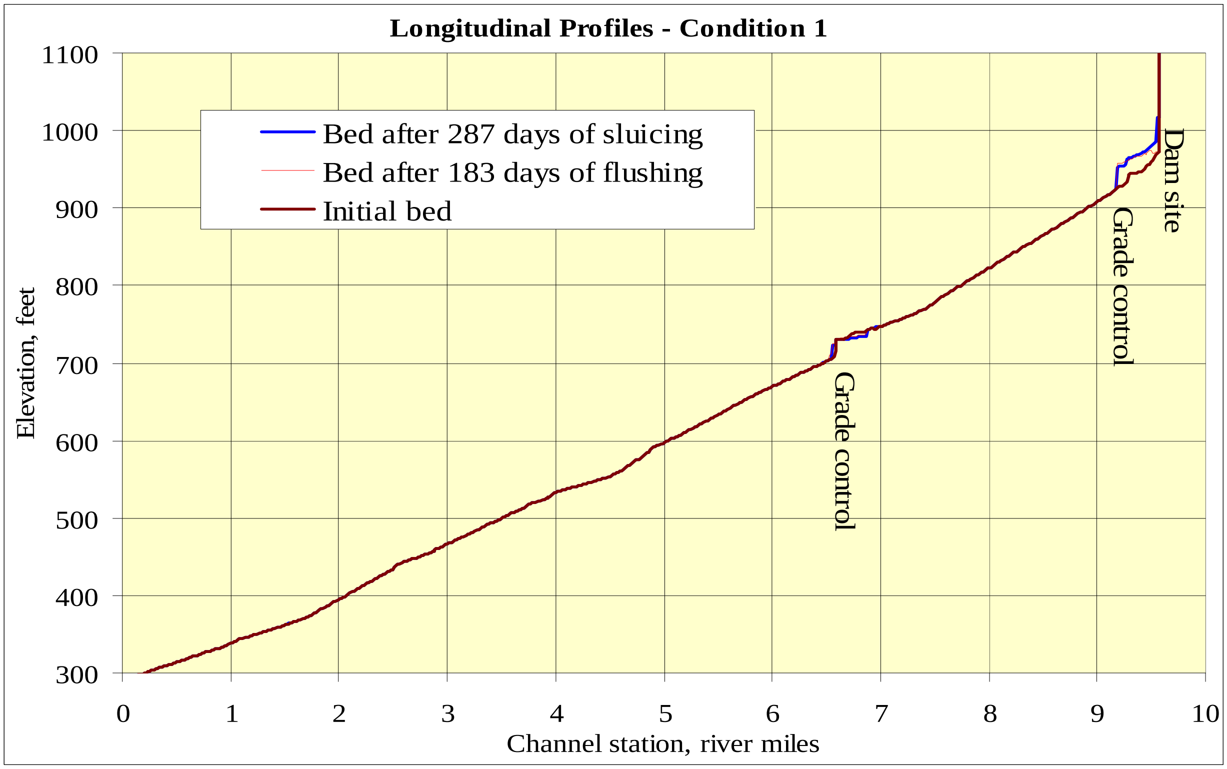
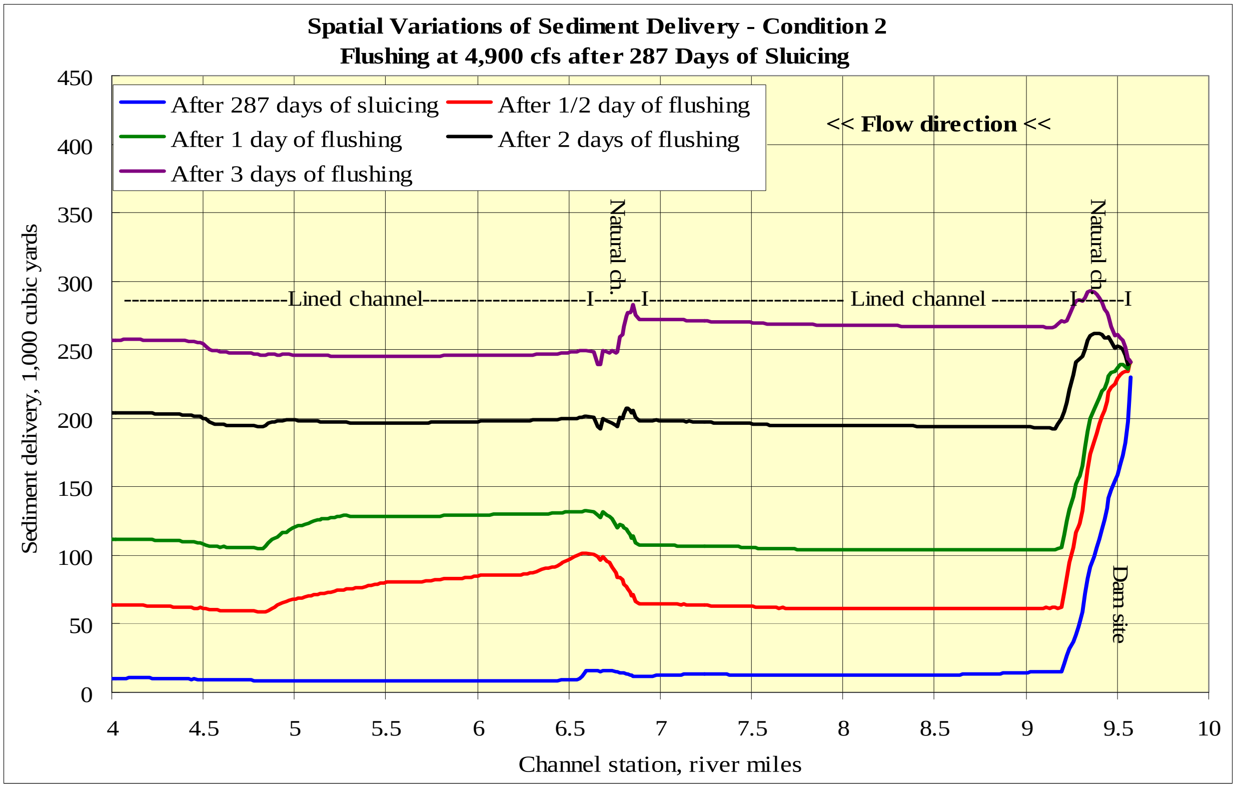


Figure 2



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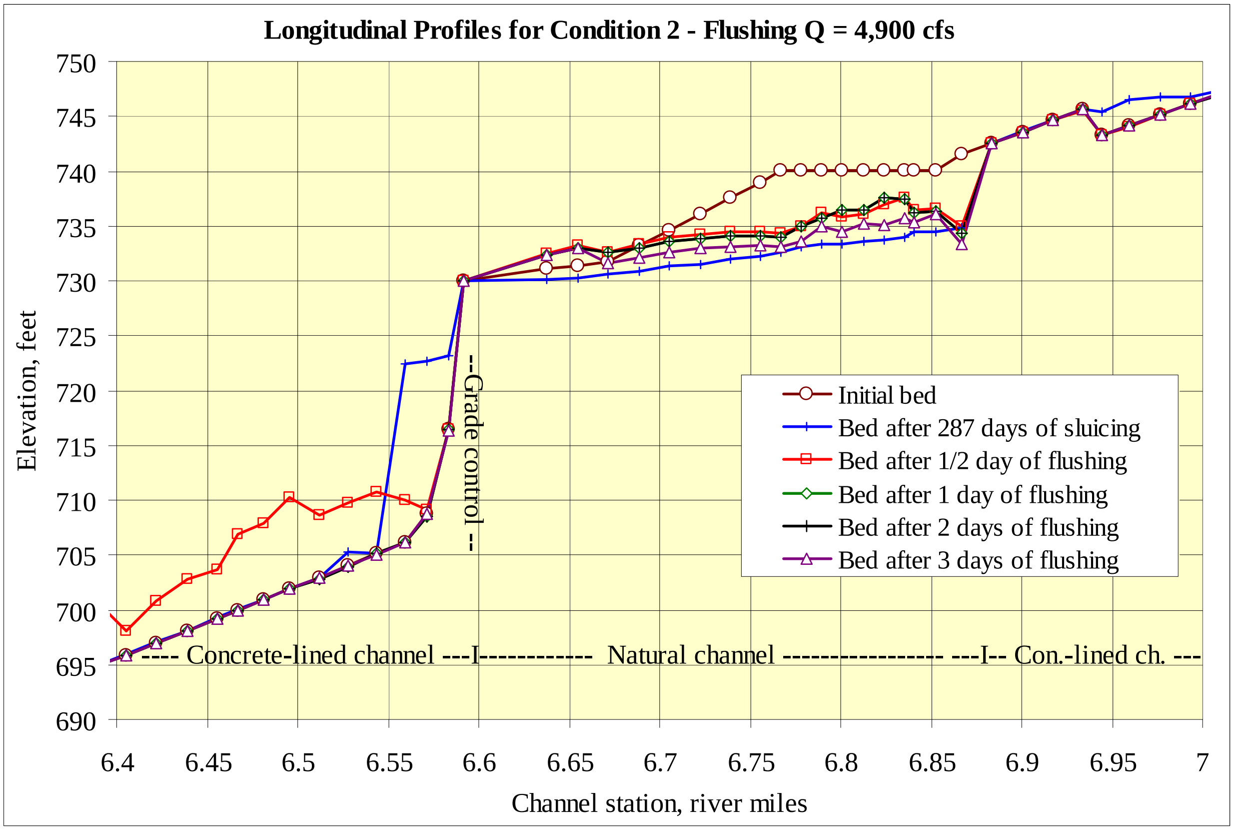

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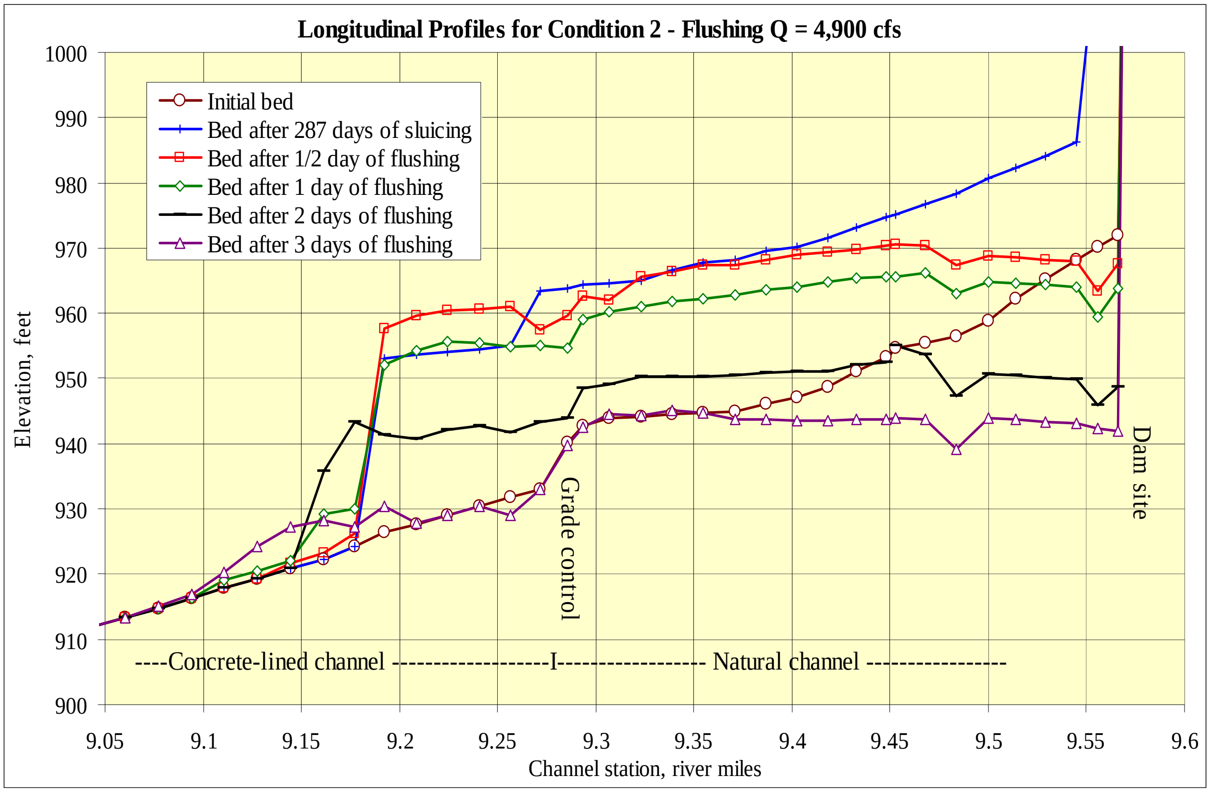

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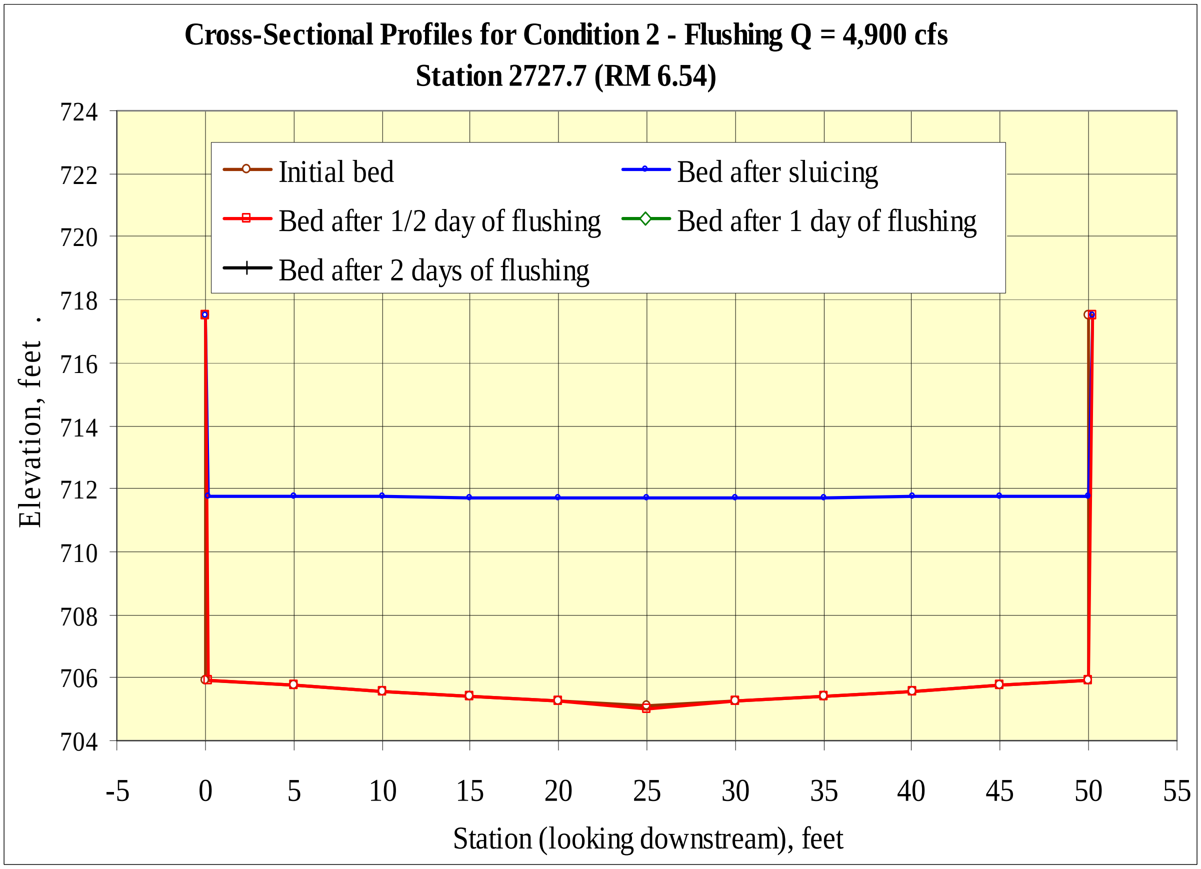

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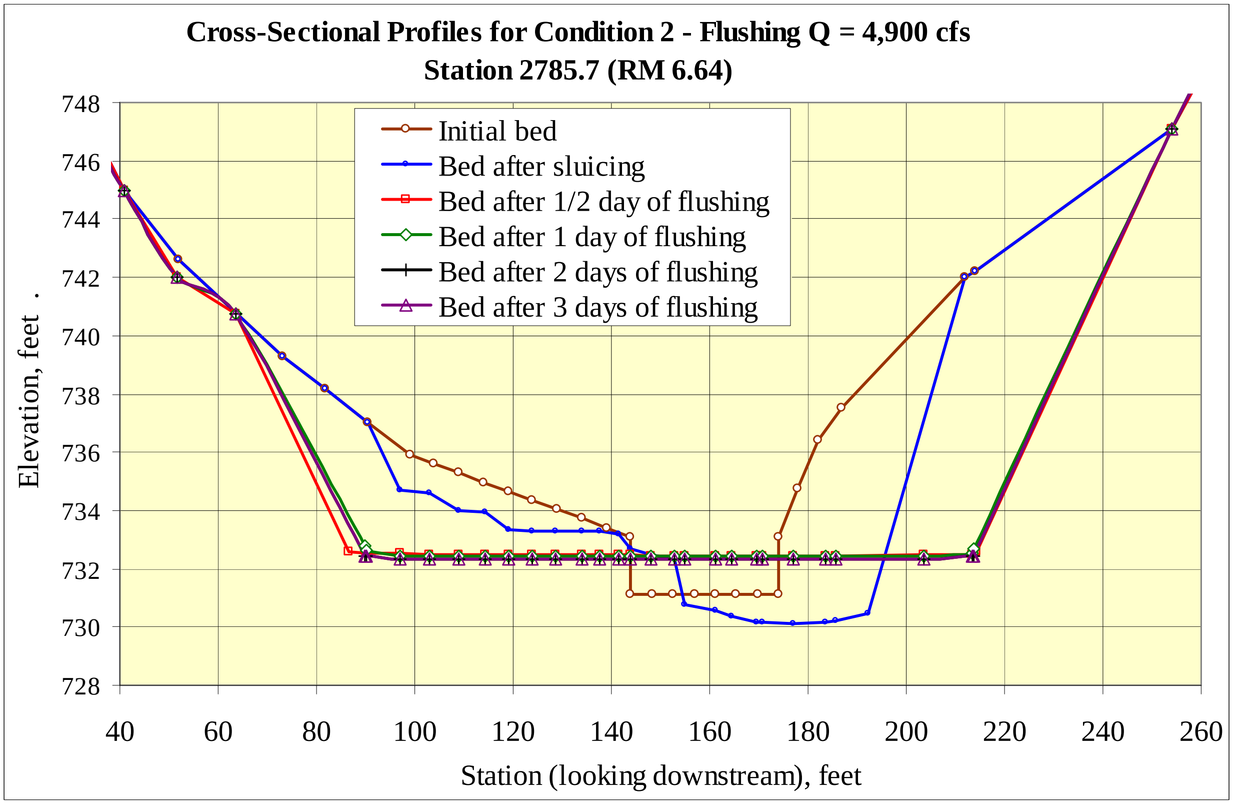

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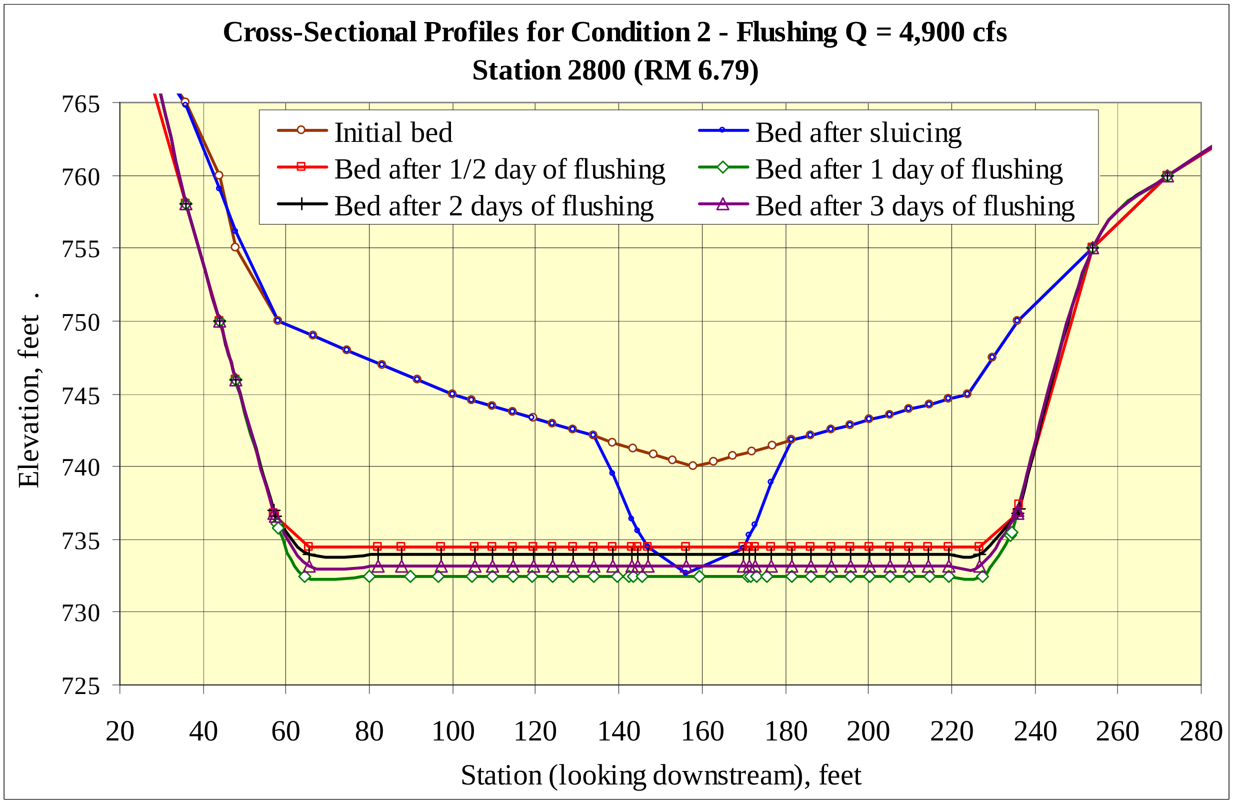

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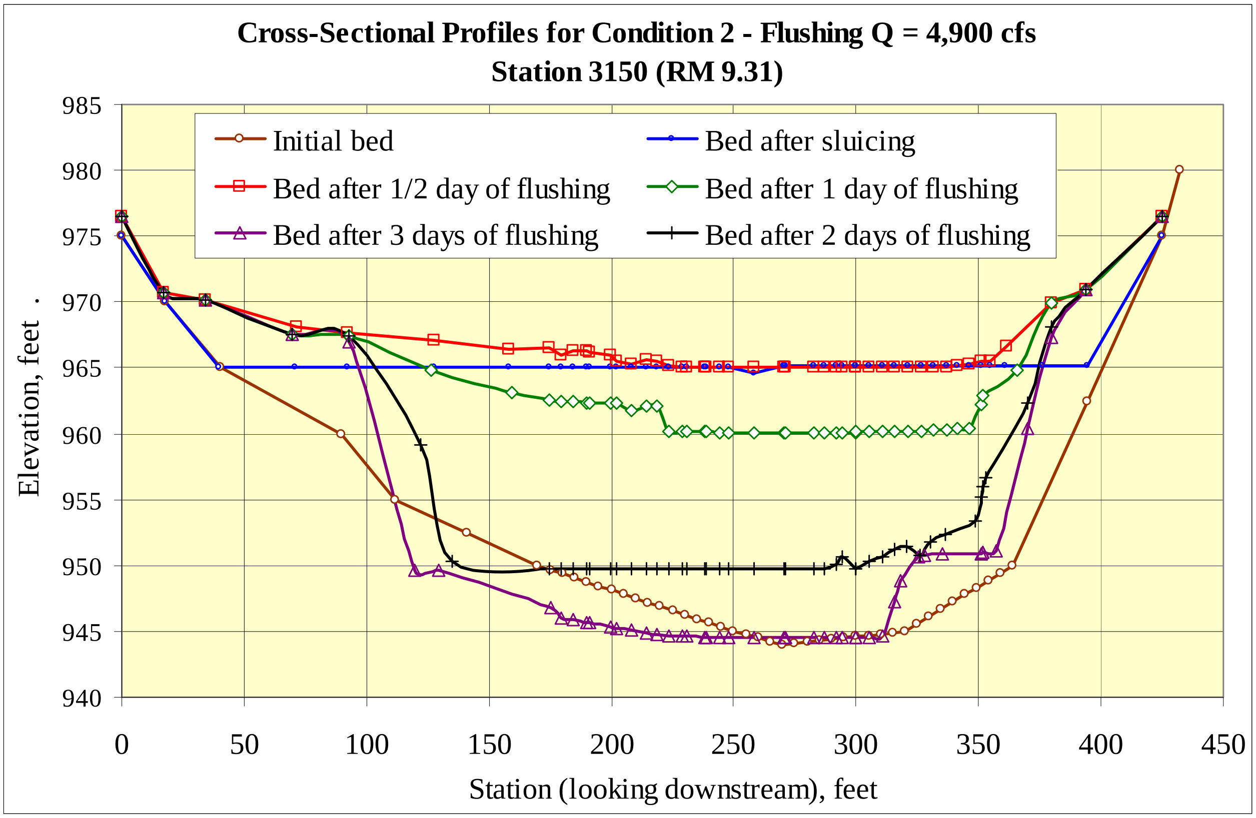

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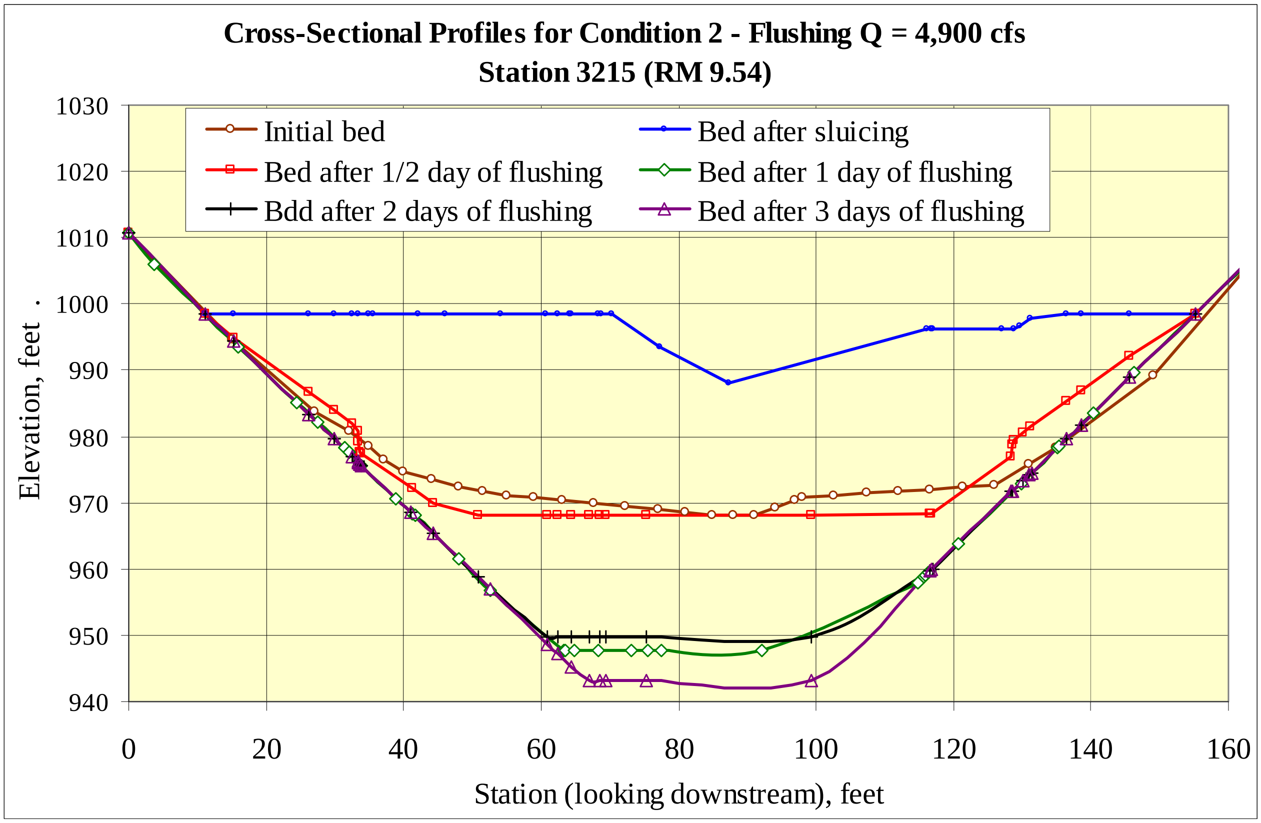

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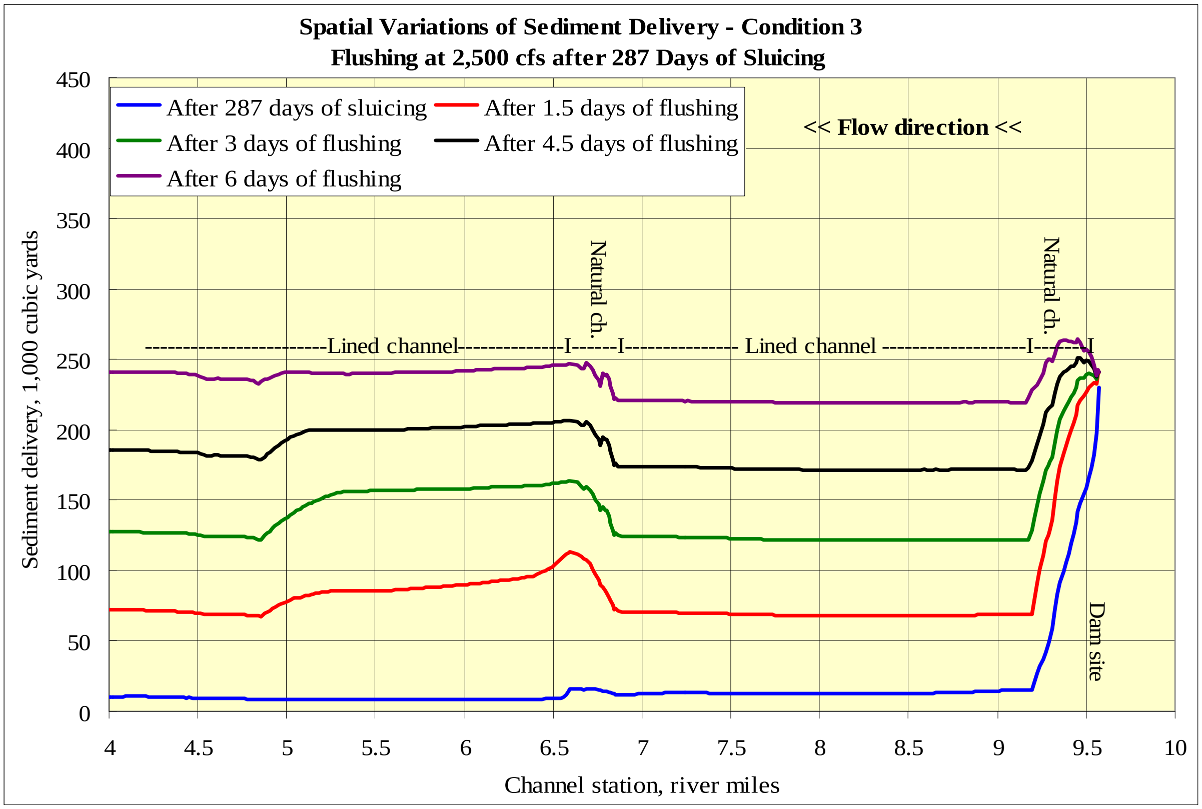

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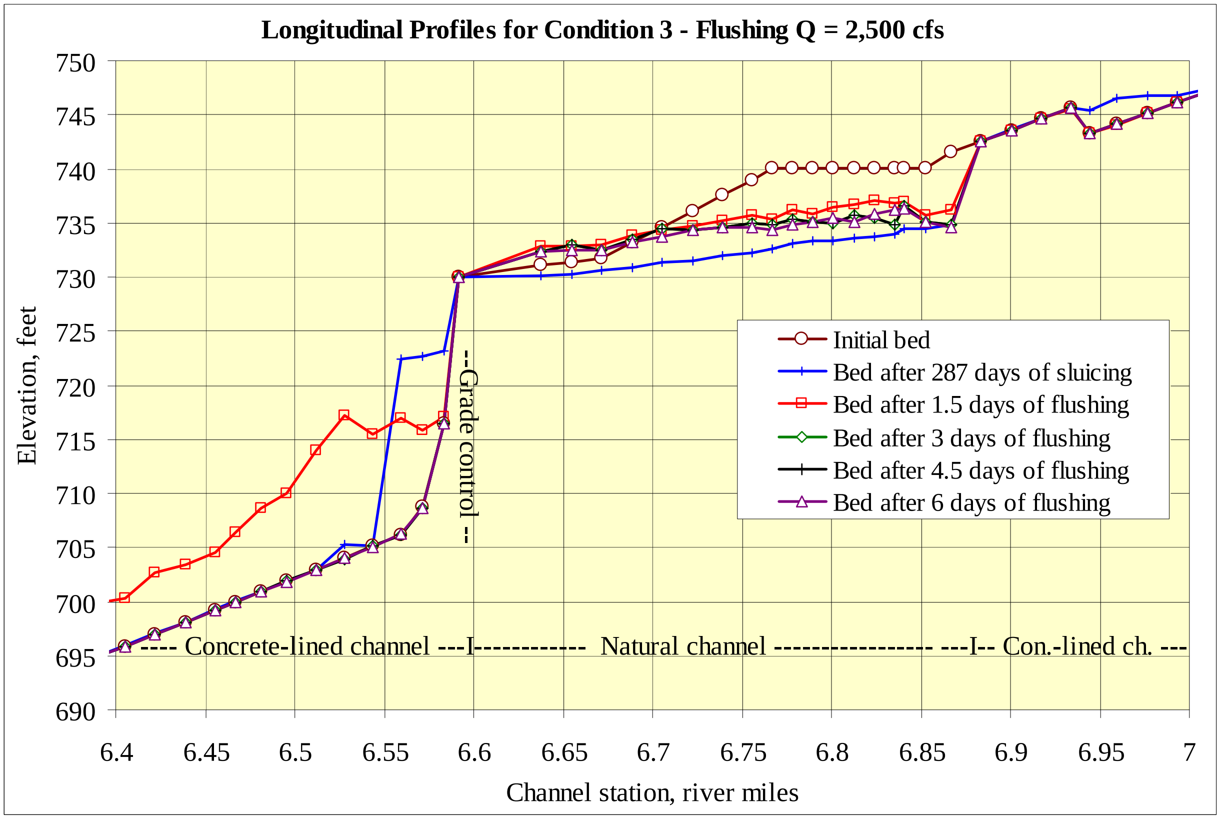

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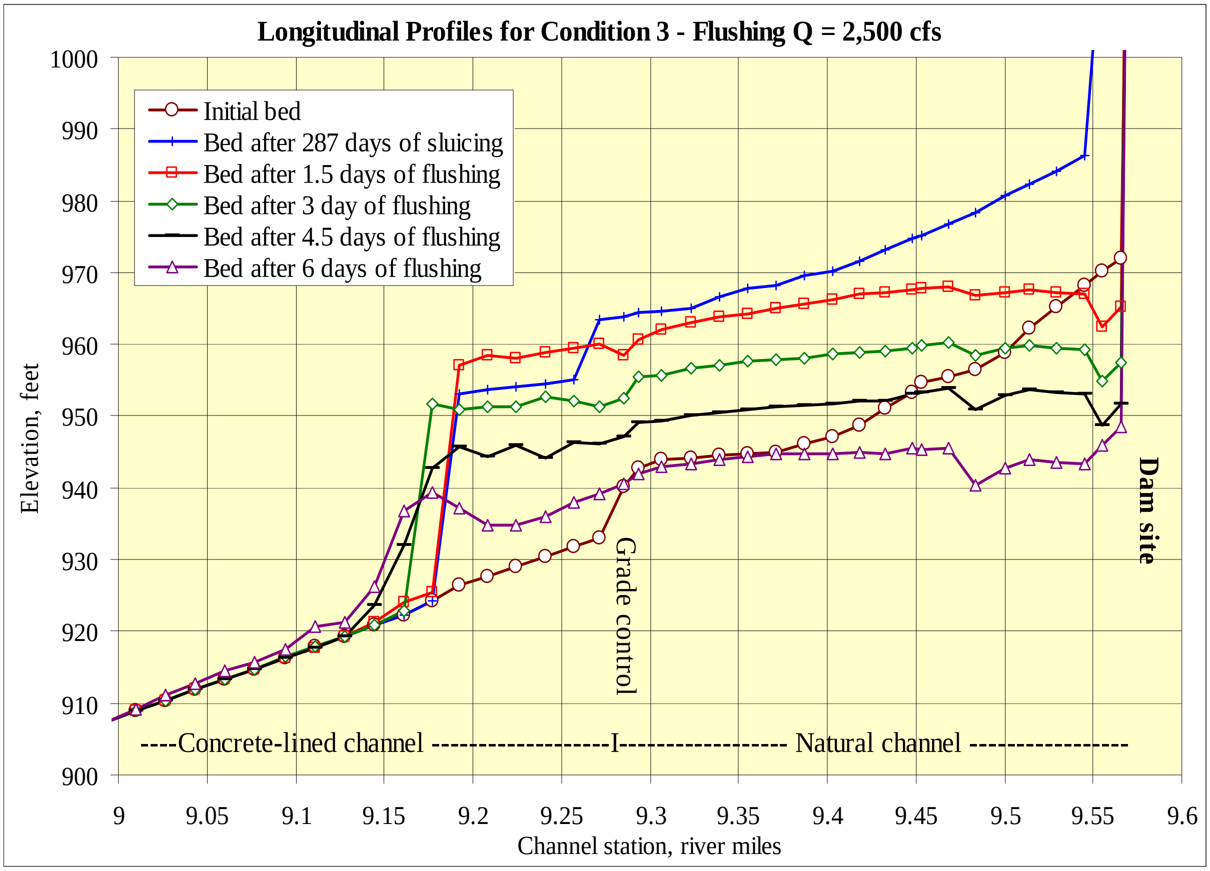

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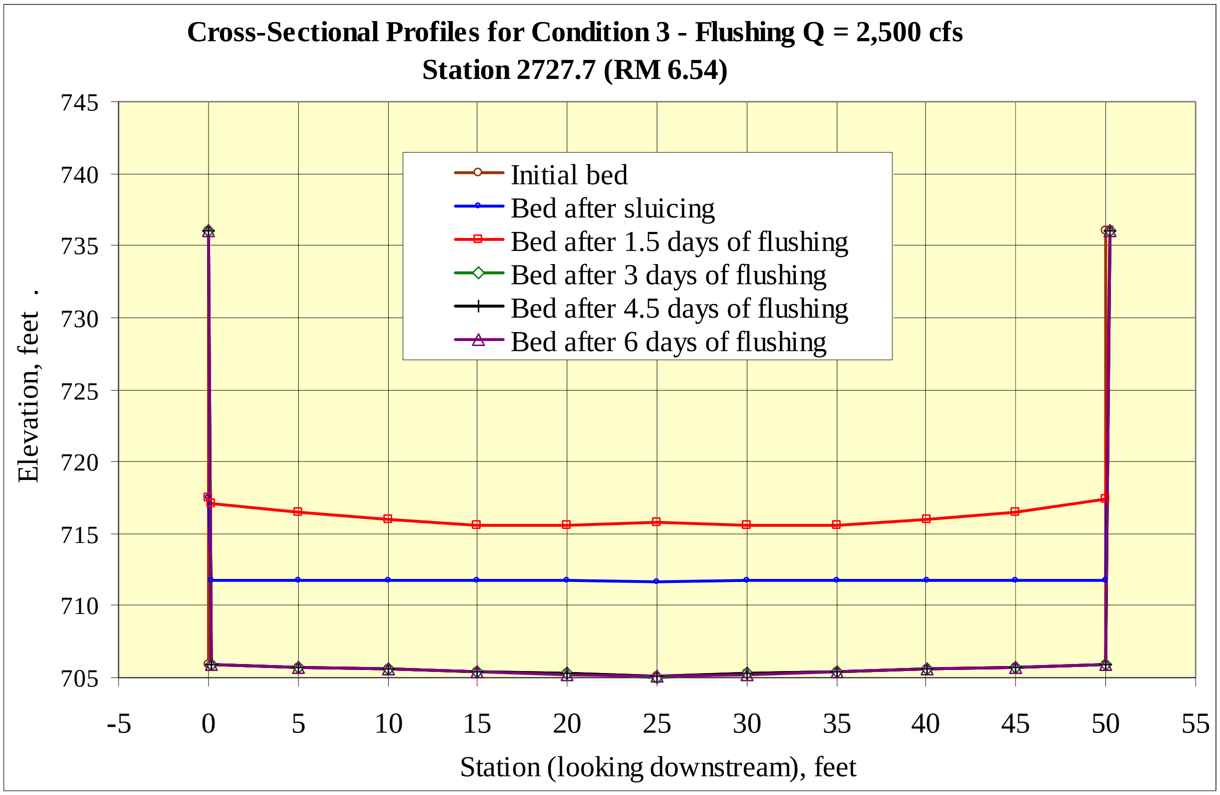

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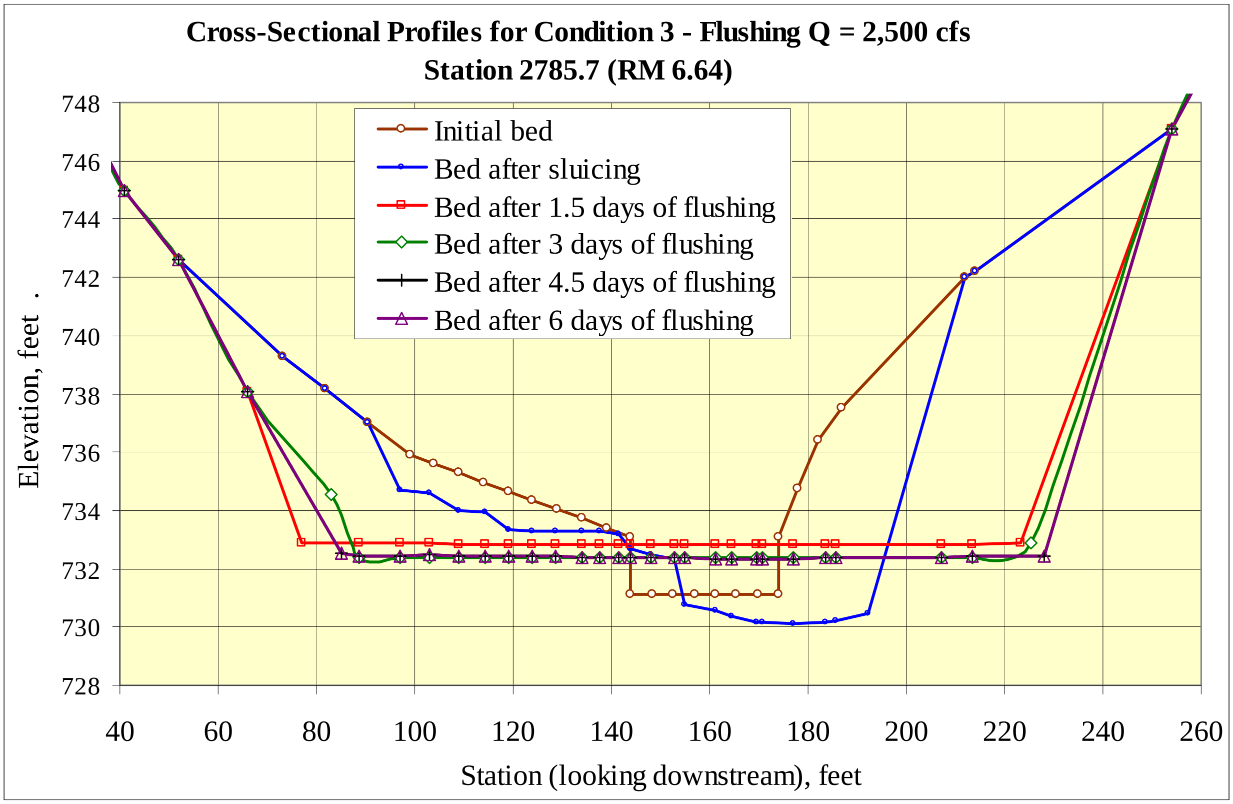

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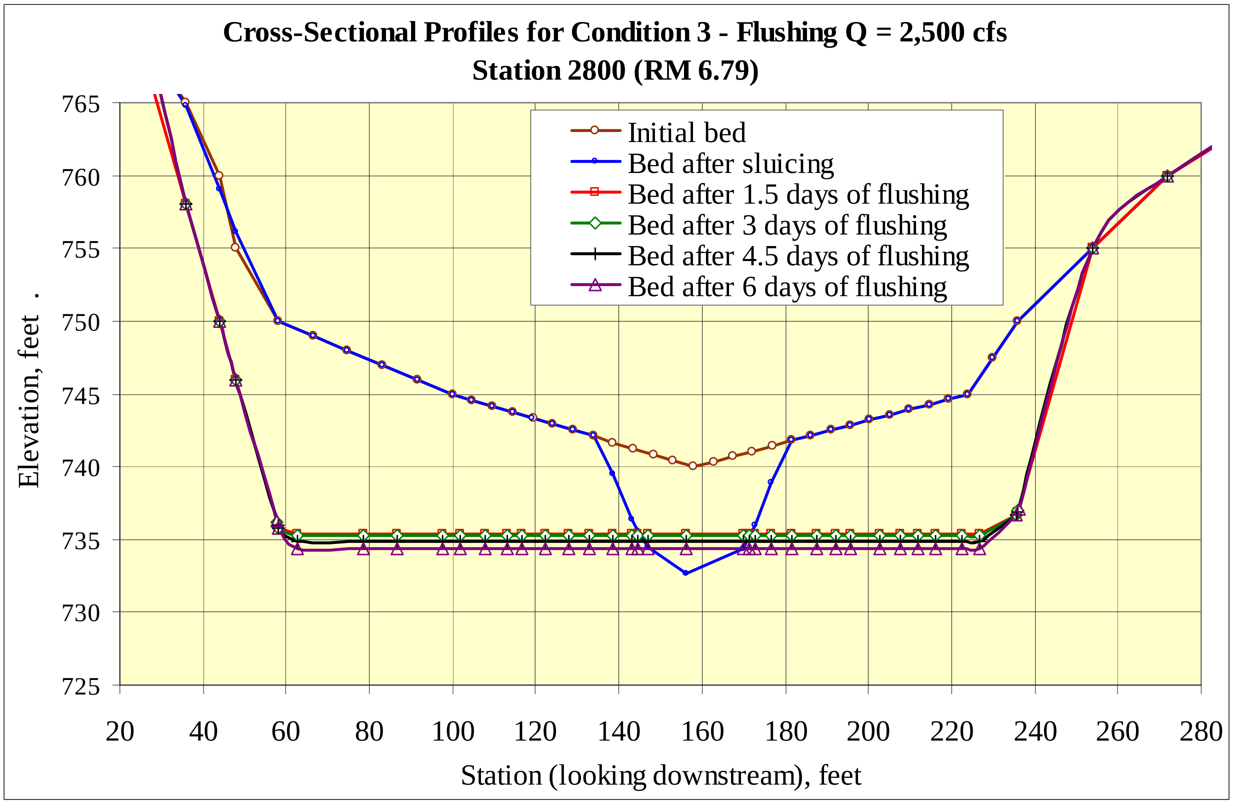

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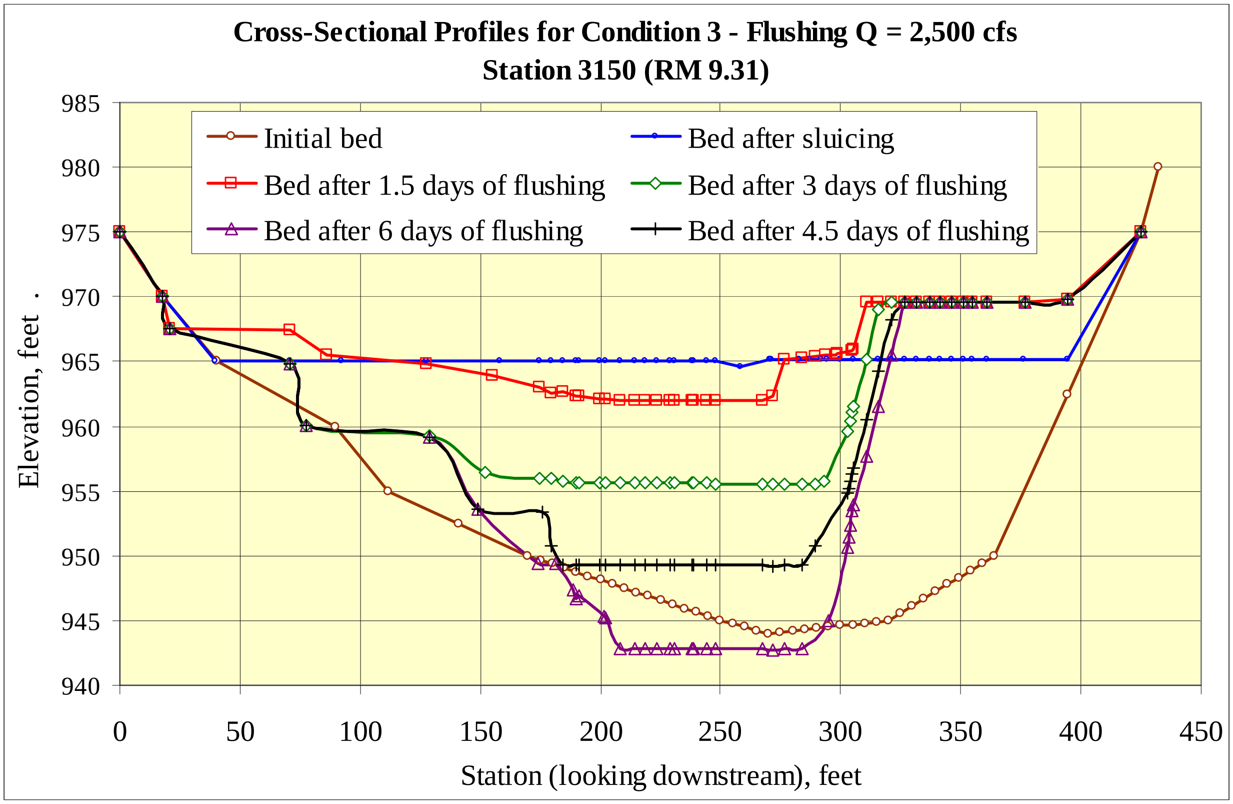

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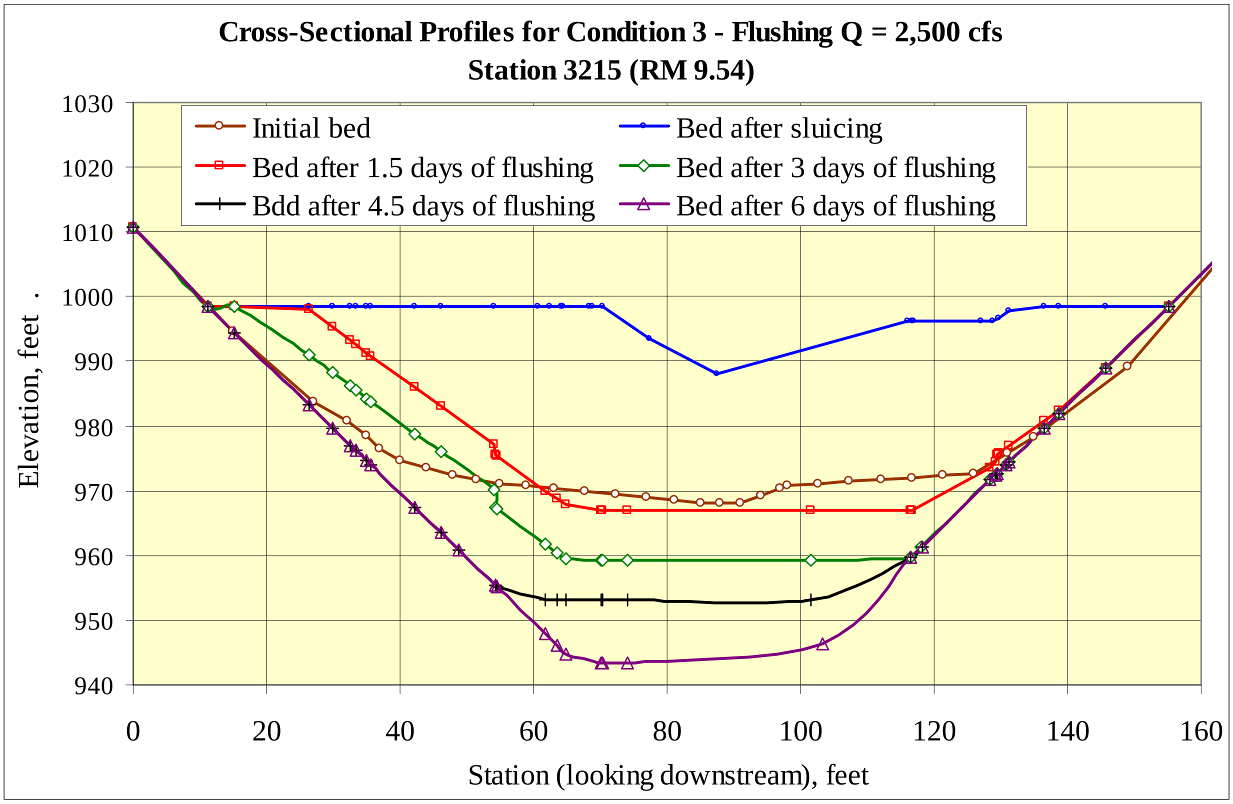

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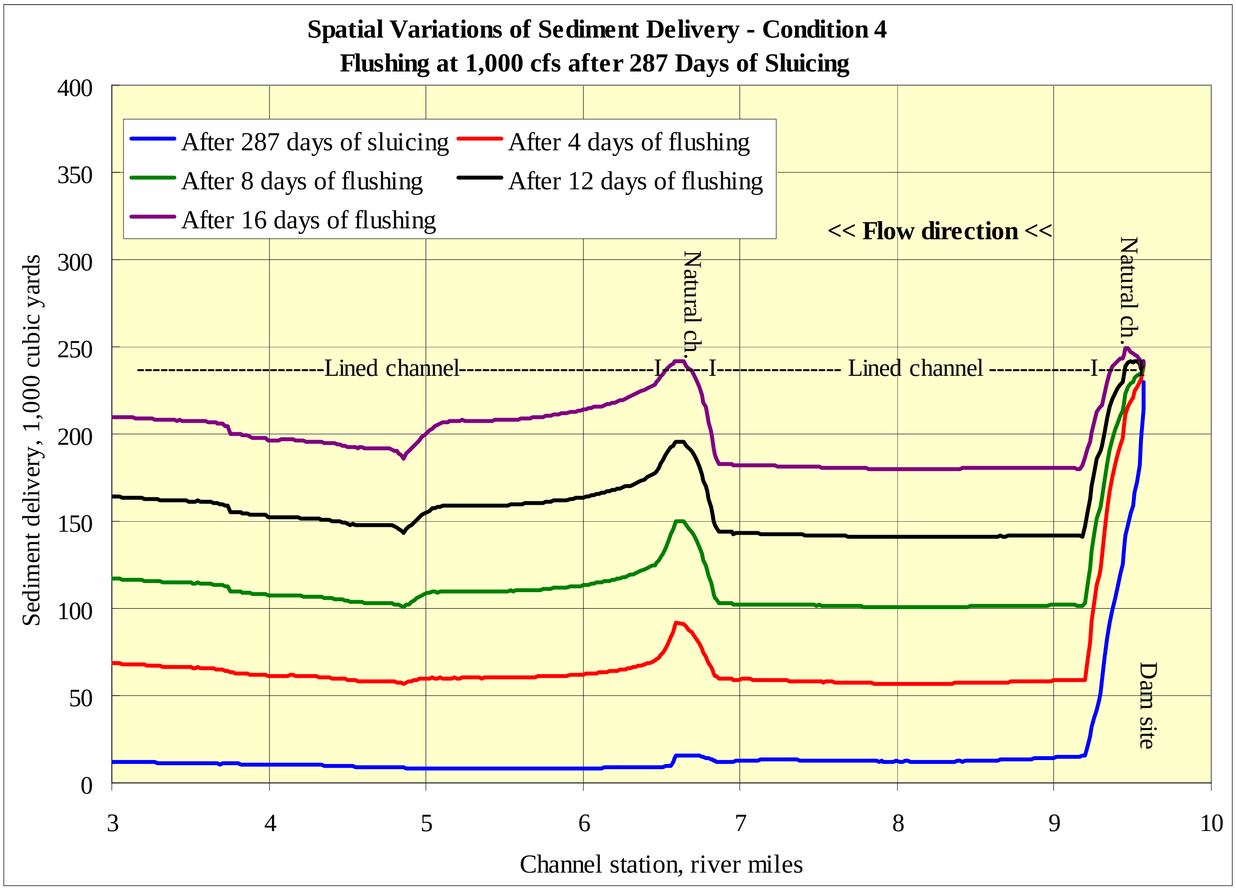

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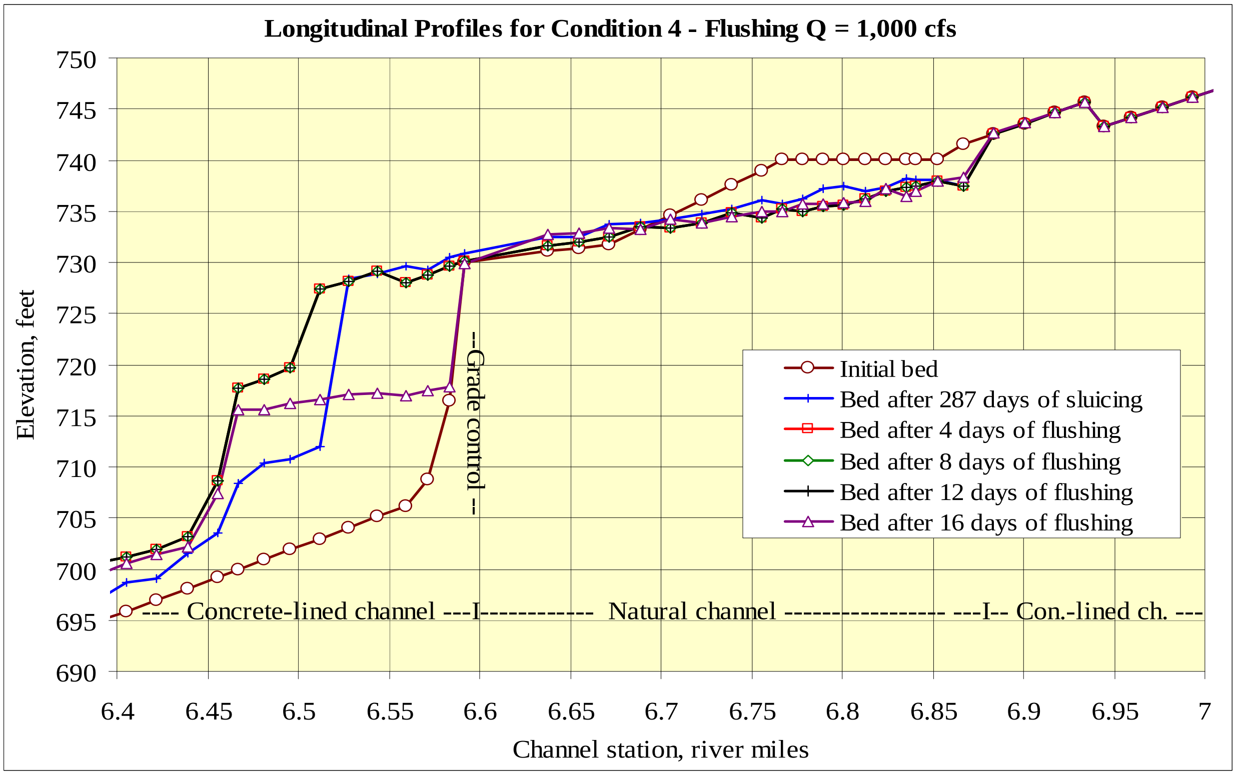

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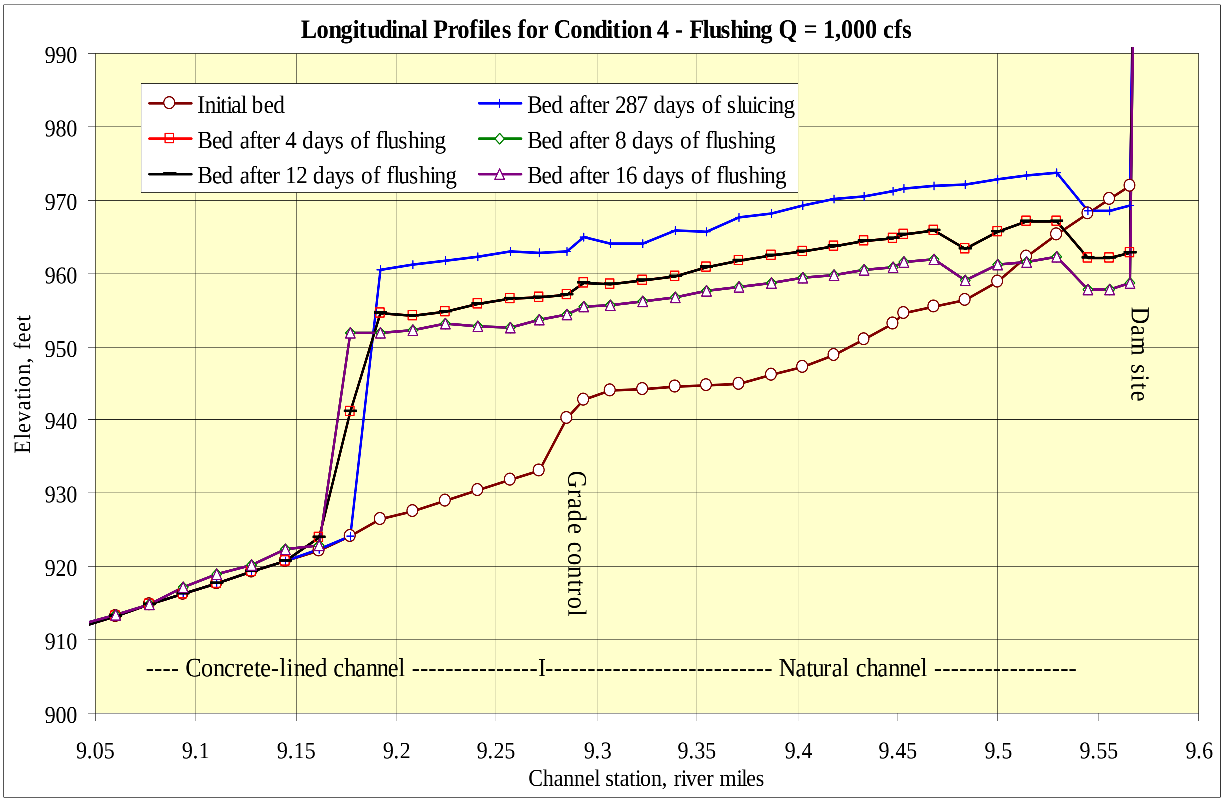

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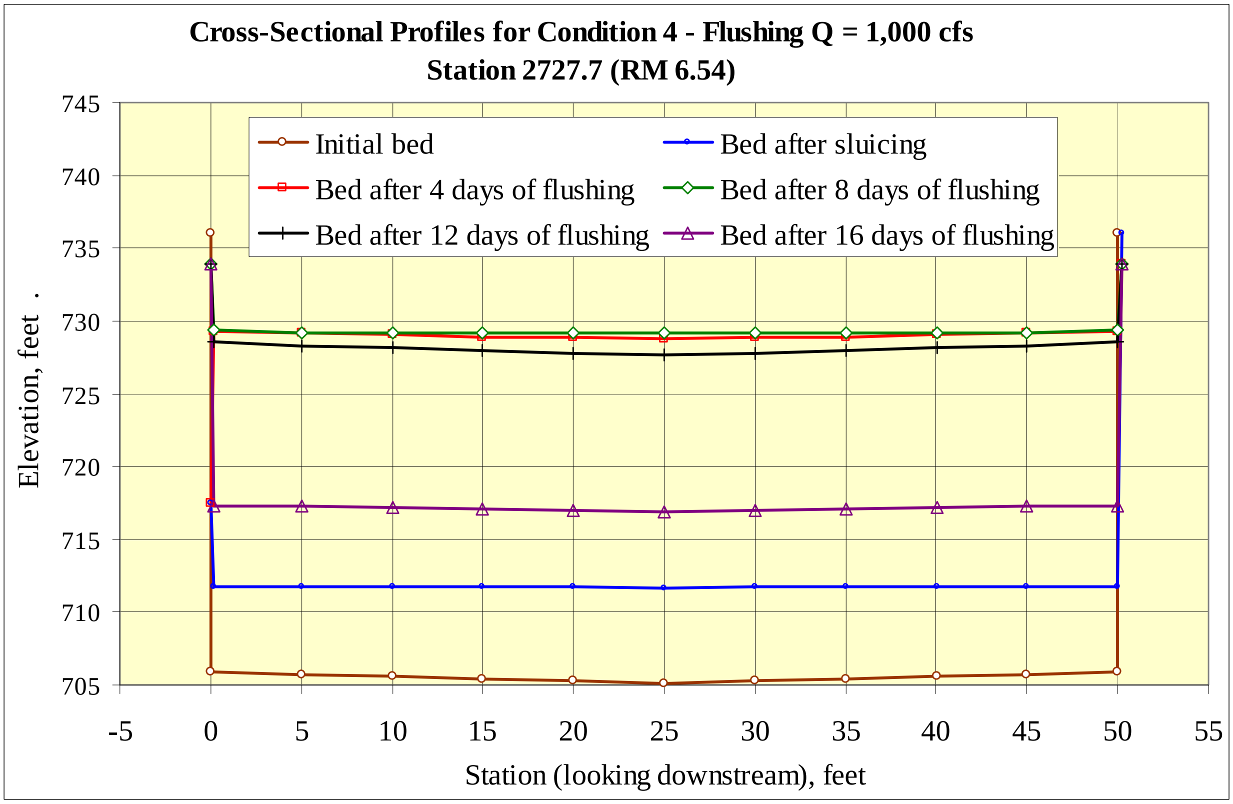

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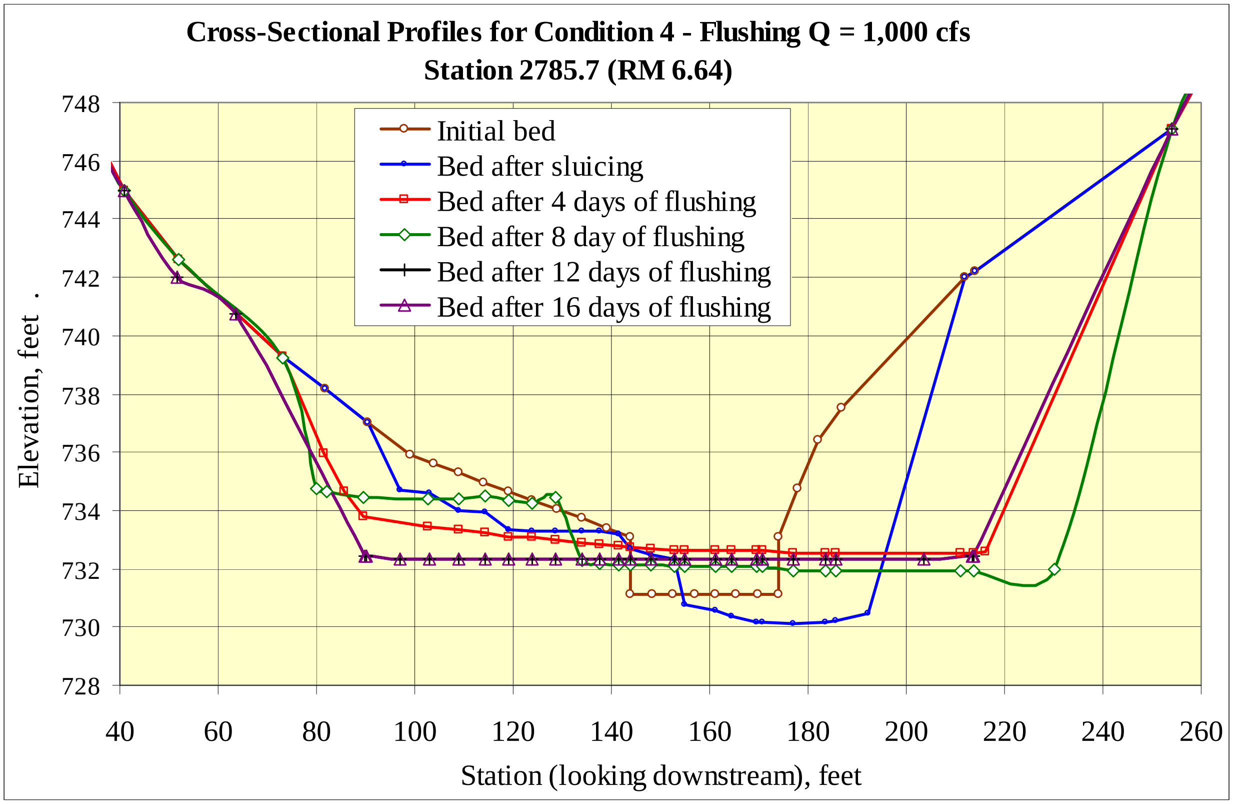

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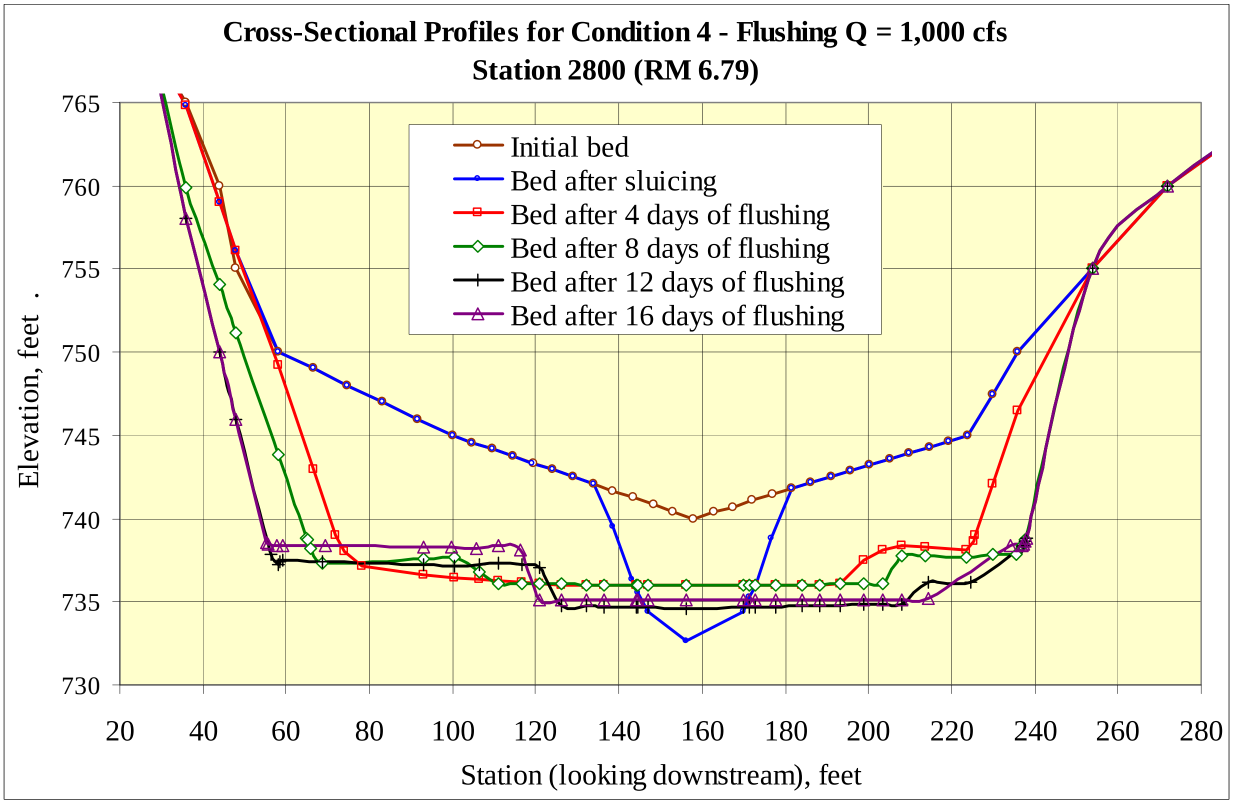

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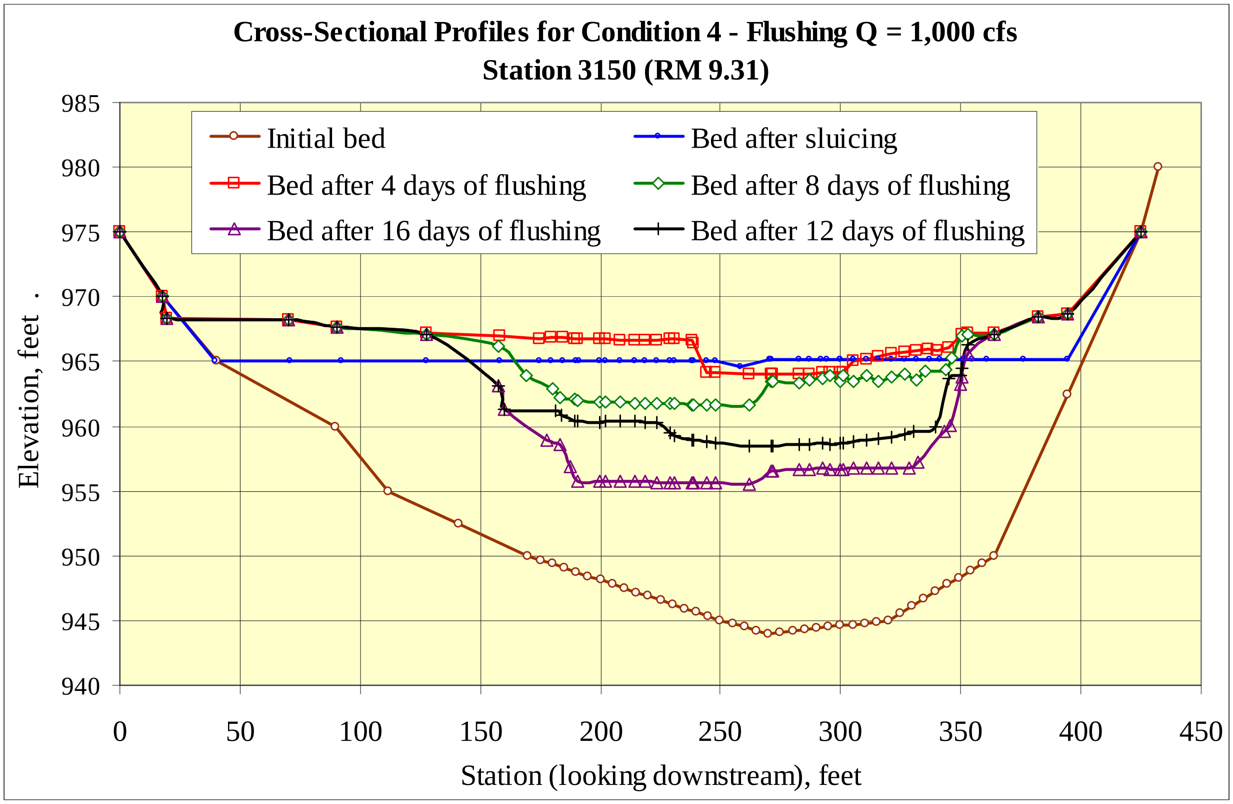

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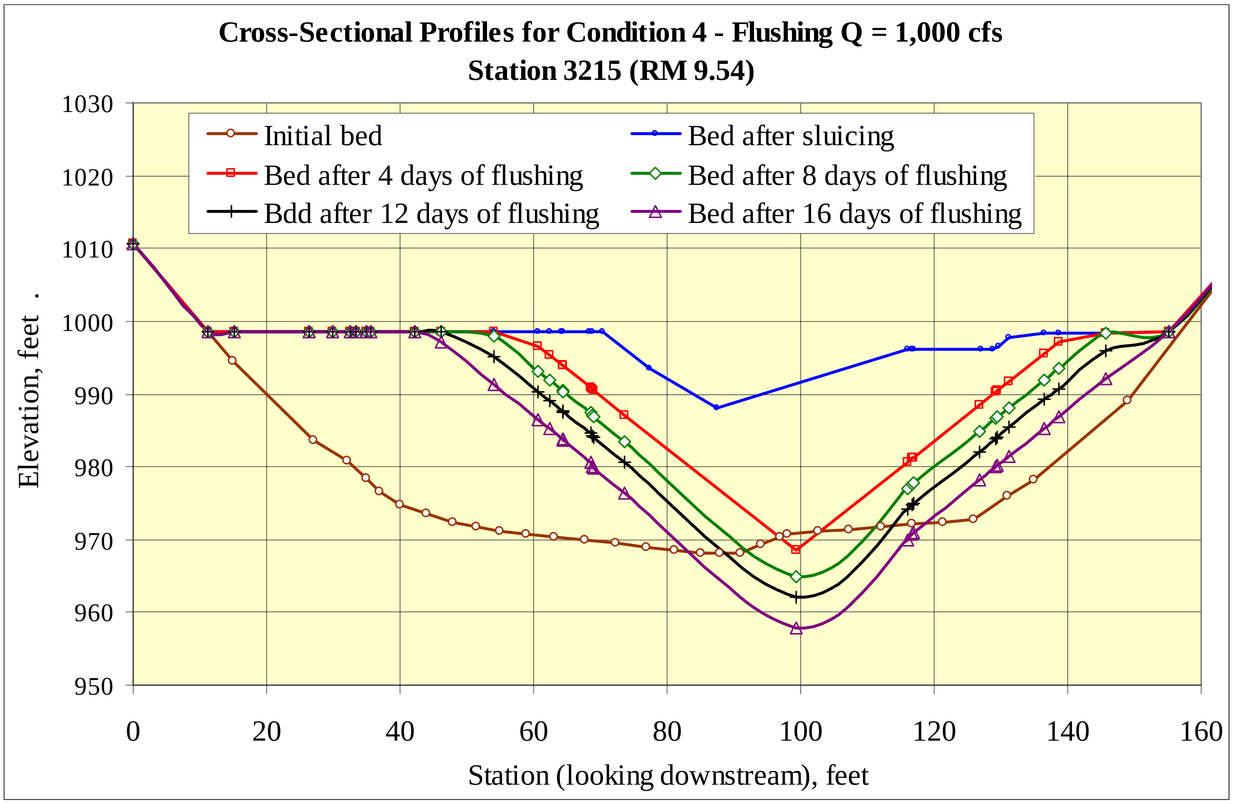

Figure 26

Figure 27. Deposition near Upper Grade Control under Condition 4

Figure 28. Deposition near Lower Grade Control Under Condition 4