

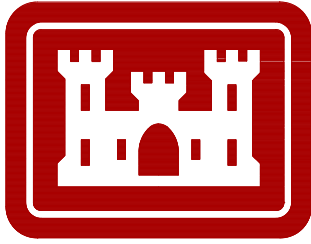


**US Army Corps
of Engineers®**
Los Angeles District

Los Angeles River Ecosystem Restoration Feasibility Study

DRAFT – APPENDIX E HYDROLOGY AND HYDRAULICS

September 2013



U.S. Army Corps
Of Engineers
Los Angeles District

LOS ANGELES COUNTY, CALIFORNIA



LOS ANGELES RIVER Ecosystem Restoration Feasibility Study

HYDROLOGY & HYDRAULICS F5 APPENDIX

-FINAL DRAFT-

Prepared By:

US Army Corps of Engineers, Los Angeles District
Engineering Division, Hydrology and Hydraulics Branch

August 2013

LOS ANGELES RIVER Ecosystem Restoration Study



HYDROLOGY & HYDRAULICS APPENDIX

For F5 Milestone

-FINAL DRAFT-

Prepared By:

US Army Corps of Engineers, Los Angeles District
Engineering Division, Hydrology and Hydraulics Branch

August 2013

ABBREVIATIONS AND ACRONYMS USED IN THIS APPENDIX

2-yr event	50% Annual Chance Exceedance Event
5-yr event	20% Annual Chance Exceedance Event
10-yr event	10% Annual Chance Exceedance Event
25-yr event	4% Annual Chance Exceedance Event
50-yr event	2% Annual Chance Exceedance Event
100-yr event	1% Annual Chance Exceedance Event
200-yr event	0.5% Annual Chance Exceedance Event
500-yr event	0.2% Annual Chance Exceedance Event
ACE	Annual Chance Exceedance
AFB	Alternatives Formulation Briefing
ARBOR	Alternative with Restoration Benefits and Opportunities for Restoration
CADWR	California Department of Water Resources
CE/ICA	Cost Estimate/Incremental Cost Analysis
CIMIS	California Irrigation Management Information System
COE	Corps of Engineers
EIS	Environmental Impact Statement
EM	Engineering Manual
ER	Engineering Regulation
ETo	Evapotranspiration
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HEC-RAS	River Analysis System computer program from HEC
LACDA	Los Angeles County Drainage Area
LACDPW	Los Angeles County Department of Public Works
MSL	Mean Sea Level
NAD	North American Datum
NAVD	North American Vertical Datum
NED	National Economic Development
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
RS	River Station
SPF	Standard Project Flood
SPS	Standard Project Storm
SWMP	Stormwater Management Plan
TIN	Triangulated Irregular Network
TSP	Tentatively Selected Plan
WRP	Water Reclamation Plant (Tillman)
WSE	Water Surface Elevation

UNITS USED IN THIS APPENDIX

ac	acres	ft/s	feet per second
af/yr	acre-feet per year	ft ³ /s	cubic feet per second
af	acre-feet	ft/mi	feet per mile
cy	cubic yards	in	inch
ft	feet	mi ²	square miles

DISCLAIMER:

This Hydrology and Hydraulics Appendix is intended to supplement the Main Report and associated Appendices for the Los Angeles River Ecosystem Restoration Feasibility Study. The Main Report and Appendices are considered DRAFTs until they have gone through all required levels of review and public comment.

Table of Contents

Section	Page
1. Introduction.....	1
2. Project Location.....	1
3. General Description of the Drainage Area.....	2
4. Soils.....	3
5. Vegetation.....	3
6. Structures Affecting Runoff.....	3
6.1. Hansen Dam.....	4
6.2. Sepulveda Dam.....	4
7. Runoff Characteristics.....	5
8. Climate.....	6
8.1. Temperature.....	6
8.2. Precipitation.....	6
8.3. General Winter Storms.....	7
8.4. Local Thunderstorms.....	7
8.5. General Summer Storms.....	8
9. Climate Change.....	8
10. Water Budget.....	9
10.1. Streamflow.....	9
10.2. Stream Gages.....	9
10.3. Local Runoff.....	10
10.4. Recycled Water.....	10
10.5. Imported Water.....	10
10.6. Precipitation.....	11
10.7. Infiltration.....	11
10.8. Evaporation.....	12
10.9. Evapotranspiration.....	12
11. Existing Conditions Discharges.....	13
12. Future Conditions Discharges.....	13
13. LACDA Design Storm.....	14
14. Channel Hydraulics.....	14
15. Hydraulic Modeling.....	15
15.1. Mapping.....	16
15.2. Numeric Models.....	16
15.3. River Stationing.....	17
15.4. Model Reach Assignments.....	18
15.5. Manning's N-Values.....	18
15.5.1. Design Conditions Model.....	18
15.5.2. Existing Conditions Model.....	19
15.6. Bridges.....	19
15.7. Boundary Conditions.....	20
15.8. Flow Regime.....	20
15.9. Flow Data.....	20

16. Adequacy of the Hydraulic Models	21
17. Floodplain Analyses.	21
18. With-Project Conditions.	22
18.1. Alternative Descriptions	22
18.2. Model Adjustments.	28
18.2.1. Manning's N-Values.	28
18.2.2. Contraction/expansion.....	29
18.2.3. Ineffective Flow Areas.....	29
19. Storm Drain Daylighting.	29
20. Evaluation of Alternatives.....	31
20.1. Water Surface Elevation.	31
20.2. Target Velocity.....	32
21. Results.	34
22. Flood Risks.	38
22.1. Authorization of the Existing Flood Risk Management Project.	38
22.2. LACDA 1992 Review.	38
22.3. Design Conditions.....	39
22.4. Existing Conditions.	39
22.5. Other Important Points.....	40
22.6. Recommendations.	41
23. Summary and Conclusions.	41
24. References.....	43

List of Tables

Table	Page
1. Hansen Dam Pertinent Data	47
2. Hansen Dam Hydrologic Data	48
3. Sepulveda Dam Pertinent Data	49
4. Sepulveda Dam Hydrologic Data	50
5. Monthly Temperatures	51
6. Monthly Precipitation	51
7. Precipitation Frequency Estimates (Point Estimates).....	52
8. Water Budget for Selected Alternatives.....	53
9. Average Daily Flows for ARBOR Reach of Los Angeles River	54
10. Infiltration Rate Criteria for SCS Hydrologic Soil Groups.....	54
11. Monthly Summary of Evaporation Rates	55
12. Monthly Evapotranspiration Rates.....	56
13. Vegetation Evapotranspiration Values	56
14. Frequency Peak Discharges Used in HEC-RAS Models.....	57
15. Bridges	58
16. Boundary Conditions For HEC-RAS Models	59

List of Tables (cont.)

Table	Page
17. Revised Channel Capacity and Bankfull Discharges.....	60
18. Alternative 10 Water Surface Elevation.....	61
19. Alternative 10 Velocities	62
20. Alternative 13 Water Surface Elevation.....	63
21. Alternative 13 Velocities	64
22. Alternative 16 Water Surface Elevation.....	65
23. Alternative 16 Velocities	66
24. Alternative 20 Water Surface Elevation.....	67
25. Alternative 20 Velocities	68

List of Plates

1. Los Angeles River ARBOR Reach Location Map
2. Los Angeles County Drainage Area (LACDA) Watershed Map
3. Los Angeles County ARBOR Area and Vicinity Soils
4. Los Angeles River Leveed Areas within ARBOR reach
5. Los Angeles River at Tujunga Ave. Period of Record Peak Flows
6. Los Angeles River above Arroyo Seco Period of Record Peak Flows
7. Los Angeles River below Firestone Blvd. Period of Record Peak Flows
8. Los Angeles River Design Discharges
9. Los Angeles River Design Velocities
10. Los Angeles River Unlined Sections
11. Los Angeles River ARBOR Project Reaches
12. Los Angeles River Cross Sections Reach 1
13. Los Angeles River Cross Sections Reach 2
14. Los Angeles River Cross Sections Reach 3
15. Los Angeles River Cross Sections Reach 4
16. Los Angeles River Cross Sections Reach 5
17. Los Angeles River Cross Sections Reach 6
18. Los Angeles River Cross Sections Reach 7
19. Los Angeles River Cross Sections Reach 8
- 20a. Los Angeles River Invert Profile with Bridge Locations (ARBOR upstream)
- 20b. Los Angeles River Invert Profile with Bridge Locations (ARBOR downstream)
- 21a. Los Angeles River 4% ACE Event Floodplains (ARBOR upstream)
- 21b. Los Angeles River 4% ACE Event Floodplains (ARBOR downstream)
- 22a. Los Angeles River 2% ACE Event Floodplains (ARBOR upstream)
- 22b. Los Angeles River 2% ACE Event Floodplains (ARBOR downstream)

List of Plates (cont.)

- 23a. Los Angeles River 1% ACE Event Floodplains (ARBOR upstream)
- 23b. Los Angeles River 1% ACE Event Floodplains (ARBOR downstream)
- 24a. Los Angeles River 0.2% ACE Event Floodplains (ARBOR upstream)
- 24b. Los Angeles River 0.2% ACE Event Floodplains (ARBOR downstream)
- 25. Los Angeles River 100-yr & 500-yr Floodplains from 1992 LACDA Review Study

- 26. Los Angeles River Alternative 20 Reach 2 Typical Cross Section
- 27. Los Angeles River Alternative 20 Reach 5 Typical Cross Section
- 28a. Los Angeles River Alternative 10 Reach 6 Typical Cross Section
- 28b. Los Angeles River Alternative 20 Reach 6 Typical Cross Section
- 29. Los Angeles River Alternative 20 Reach 7 Typical Cross Section

- 30a. Los Angeles River Alternative 13 Reach 8 Typical Cross Section
- 30b. Los Angeles River Alternative 20 Reach 8 Typical Cross Section
- 31. Los Angeles River Alternative 16 Reach 6 Cross Sections
- 32. Los Angeles River Alternative 13 Reach 6 Cross Sections
- 33. Los Angeles River Alternative 16 Reach 5 Cross Sections

- 34. Los Angeles River Alternative 16 Reach 6 Cross Sections
- 35. Los Angeles River Alternative 16 Reach 8 Cross Sections
- 36. Los Angeles River Alternative 20 Reach 5 Cross Sections
- 37. Los Angeles River Alternative 20 Reach 6 Cross Sections
- 38. Los Angeles River Alternative 20 Reach 8 Cross Sections

- 39. Los Angeles River Alternative 13 Reach 6 Water Surface Profiles
- 40. Los Angeles River Alternative 16 Reach 6 Water Surface Profiles
- 41. Los Angeles River Alternative 16 Reach 5 Water Surface Profiles
- 42. Los Angeles River Alternative 16 Reach 6 Water Surface Profiles
- 43. Los Angeles River Alternative 16 Reach 8 Water Surface Profiles

- 44. Los Angeles River Alternative 20 Reach 5 Water Surface Profiles
- 45. Los Angeles River Alternative 20 Reach 6 Water Surface Profiles
- 46. Los Angeles River Alternative 20 Reach 8 Water Surface Profiles

LOS ANGELES RIVER ECOSYSTEM RESTORATION STUDY

1. Introduction.

The purpose of this study is to investigate alternatives to improve the ecosystem function of the Los Angeles River specifically within the Los Angeles city limits. The Hydrology and Hydraulic Appendix contains a description of the existing and future hydrologic conditions and a description of the existing channel and appurtenant features. In addition, this appendix covers the modeling inputs and results for the with-project conditions for four selected alternatives. All elevations are based on the 1929 National Geodetic Vertical Datum (NGVD), unless otherwise noted.

The Corps of Engineers (COE) completed a feasibility level flood control review for the Los Angeles County Drainage Area (LACDA) in 1992 and summarized the results in a Main Report and Appendices. The main report and EIS for the Los Angeles County Drainage Area Review Final Feasibility Report was dated Dec. 1991, with revisions in Feb. 1992. There are separate Hydrology and Hydraulics Appendices, each dated Dec. 1991 (along with appendices for Economics, Recreation Inventory, Real Estate, Geotech, and Design). These documents went through extensive technical and independent review and were approved and certified prior to the final report date. The proposed project resulting from the Feasibility Study was completed in the late 1990s. The level of detail and adequacy of results is still sufficient for use in the current ecosystem restoration study. This document includes pertinent sections from the previous documents.

Currently, there is considerable public interest in the “revitalization” of the Los Angeles River. This Ecosystem Restoration study is running concurrently with several efforts from private and public interests, including the city of Los Angeles. It is important to note up front that the primary premise from the hydrology and hydraulics perspective is that any ecosystem project evaluated in this study must not negatively impact the flood risk management function of the system. This means any effort to alter the existing Los Angeles River channel must provide mitigation to offset any loss of conveyance.

The Los Angeles River Channel, for the most part, is a prismatic concrete channel. There are two stretches within the project extent that have natural inverts. These areas currently have a significant amount of vegetation growing along the invert. Funding for removal of vegetation has always been uncertain. In addition there are negative environmental impacts with removal. Thus, it was decided for this ecosystem restoration study the Existing Condition will include the vegetation and would be the condition against which all alternatives are compared. This decision does not imply there is any effort to change the design discharges for the channel.

2. Project Location.

A series of preliminary studies and decisions led to establishment of the project location for this study. Initially, the project covered the entire 32 mile stretch of the river within

the city of Los Angeles. The portion of the Los Angeles River ultimately decided to focus on is called the ARBOR reach, which stands for the Alternative with Restoration Benefits and Opportunities for Restoration. The reasons for this decision are addressed in the main report. The location of the ARBOR reach is shown on Plate 1.

The modeling limits for the project extend approximately 11 miles from the western side of Forest Lawn Cemetery at Barham Blvd. downstream to the 1st St. bridge in downtown Los Angeles. The Los Angeles River channel configuration is primarily trapezoidal or rectangular prismatic reaches with concrete side slopes and concrete invert. However, some reaches within the study area are trapezoidal channels with grouted riprap side slopes and an earthen invert, or “soft” bottom, with vegetation. The soft bottom reaches include a 0.9 mile reach that begins about 500 feet downstream of the Burbank Western confluence and ends approximately 1,000 feet downstream of the 5 Freeway crossing, and an approximately 5.9 mile reach that begins 2,000 feet downstream of the Verdugo Wash confluence and ends at the 5 Freeway’s second crossing over the Los Angeles River.

3. General Description of the Drainage Area.

The LACDA watershed lies mostly in Los Angeles County, California, although portions lie in San Bernardino and Orange Counties. See Plate 2 for location of ARBOR in relation to LACDA. The watershed is abutted on the east by the Santa Ana River Watershed, on the north by the Antelope Valley and Santa Clara River Watersheds, and on the west by the Calleguas Creek Watershed. The project area is located along the mainstem Los Angeles River within the Los Angeles city limits.

Elevations in the San Gabriel and Santa Susana Mountains, which form the northern boundary of the watershed, vary from 3,000 feet in the west to over 9,000 feet in the east. The Santa Monica Mountains, Montebello Hills, and Puente Hills separate the San Fernando and San Gabriel valleys from the coastal plain, and range from 500 to 1,500 feet in height.

Principal streams in LACDA are the Los Angeles River which has a drainage area of 824 mi² at the mouth (including the Rio Hondo above Whittier Narrows Dam and its tributaries), and the San Gabriel River which has a drainage area of 635 mi² at the mouth. The Rio Hondo Diversion Channel brings water from the San Gabriel River system to the lower Los Angeles River by way of Whittier Narrows Dam and may effectively increase the drainage area of the Los Angeles River during periods of high runoff. The principal tributaries of the Los Angeles River include: Pacoima and Tujunga Washes, both of which drain portions of the Santa Susana Mountains and the San Fernando Valley, Verdugo Wash, which drains portions of the Verdugo Hills; and the Arroyo Seco, which starts in the San Gabriel Mountains and then heads south to the Los Angeles River. The main channel of the Los Angeles River is approximately 51 miles long and its tributaries have an aggregate length of about 225 miles. Operations and maintenance for specific channel reaches is divided between the COE and Los Angeles County Department of Public Works (LACDPW).

4. Soils.

Soils in the LACDA watershed can be generally classified as either mountain or valley. Mountain soils consist of a relatively thin mantle of residual soils, which are coarse, porous, and rocky. The valley soils, classified as recent alluvium and older alluvium, vary from coarse sand and gravel at canyon mouths to silty clay, and clay in the lower areas. The soils underlying the project location fall primarily into Hydrologic Soil Group D (see Plate 3).

5. Vegetation.

Well-developed growths of ponderosa pine, incense cedar, juniper, and oak occur along the summits and in the higher ravines of the mountains. Cottonwoods, box elders, sycamores, oaks, willows, and alders grow along the watercourses at lower mountain elevations. In general, the remainder of the mountains is covered with chaparral, consisting of California lilac, scrub oak, mountain mahogany, sumac, laurel, sage, and manzanita. The chaparral is extremely susceptible to fires during the long, dry summers, and large areas of mountain watersheds are frequently denuded by fire. This causes a dramatic increase in the runoff and debris production potential in these areas. Few areas of native vegetation exist in the highly developed valleys. The pervious areas that remain are mostly landscaped.

6. Structures Affecting Runoff.

Most streams in the valleys and coastal plain are improved, while most mountain streams are natural. Channel improvements have significantly affected runoff: straightening and lining have reduced the amount of flood peak attenuation due to routing and have shortened flood flow travel time. Before manmade improvements, most of the water courses were poorly defined upon leaving the mouths of the mountain canyons. Stream alignments on the alluvial fans and coastal plain shifted with appreciable lateral movement in response to floods. Progressive stabilization has defined many of the present day stream alignments.

The water resources in LACDA are very intensely managed. Numerous multipurpose and special purpose dams and diversion structures, debris basins, channel improvements, and levees exist in the watershed. Leveed areas from the National Levee Database within the ARBOR reach are shown on Plate 4. The functions of major structures include flood control, water supply, water conservation, recreation, and debris control. There is an elaborate stormwater collection system in place that delivers interior runoff to the channels. Flood and debris flows are regulated at existing dams and debris basins. Debris pools exist at several reservoirs in the system.

Seven dams within LACDA are owned and operated by the Corps of Engineers. All were originally authorized as single purpose flood control projects. None have a permanent pool. Of the seven, only Whittier Narrows Dam currently has approved water conservation activities. Hansen, Lopez, and Santa Fe Dams at one time had water

conservation activities, but difficulties with excessive reservoir sedimentation, along with funding from local agencies, have caused suspension of the programs. The remainder, Sepulveda, Brea, and Fullerton Dams are strictly flood control and have no water conservation activities. Lopez Dam is relatively small and currently the reservoir is almost filled with sediment. It offers little in the way of peak flow attenuation. Recently, there has been renewed interest in re-evaluating water conservation at several of these dams. There are 15 non-Federal dams within LACDA which are operated by LACDPW. All are multipurpose, most having both water conservation and some flood control functions. Hansen and Sepulveda Dams are operated by the Corps of Engineers and have the biggest impact on flows reaching the project area. Pertinent information for these two dams are listed below.

6.1. Hansen Dam.

Pertinent Information. The Hansen Dam (see Plate 2 for location) drainage area is 151.9 mi², and is formed by the San Gabriel Mountains on the north and west, and by the Verdugo Mountains and a secondary range of the San Gabriel Mountains on the south and east. The watershed above Hansen Dam is about 24 miles in length, is irregular in shape, and varies from 5.5 to 9 miles in width. Elevations in the watershed range from about 6,000 ft at the upper edge of the watershed to 980 ft at the dam site. Big Tujunga Creek originates on the southern slope of the San Gabriel Mountains; it flows in a winding course through canyons to the base of the mountains, then joins with Little Tujunga Creek to form Tujunga Wash. Tujunga Wash flows through Hansen Dam, then southward to the Los Angeles River. The Los Angeles River flows into the Pacific Ocean about 38 miles downstream of its confluence with Tujunga Wash.

Hansen Dam was completed in September 1940 as a single purpose flood control structure. It is an earth fill dam, 97 feet high with a top elevation of 1087.0 ft. The spillway is an ogee type with a crest elevation of 1060.0 ft and a net crest length of 284 feet. The outlet works consist of eight 5' x 8' gated conduits, 265 feet in length, with an entrance invert elevation of 990.0 ft and two 8' x 6' uncontrolled conduits, 265 feet in length, with an entrance invert elevation of 1011.0 ft. The capacity of the improved channel downstream is 21,000 ft³/s. The original allocation for sedimentation at Hansen Dam was estimated at 5,000 af over a period of 50 years. This amount has already been exceeded (10,000 af of sediment had been deposited by 1977) and a revised 50-year sediment allowance of 10,500 af has been determined. Pertinent data for Hansen Dam is shown in Table 1. Hydrologic routing information is presented in Table 2.

6.2. Sepulveda Dam.

Pertinent Information. The Sepulveda Dam (see Plate 2 for location) drainage area is 152.0 mi², which is highly urbanized and responds quickly to rainfall. Sepulveda Dam is located across the Los Angeles River, 44 miles above the mouth of the river, and 6 miles above the confluence of Tujunga Wash and the

Los Angeles River. The dam is in the south-central portion of the San Fernando Valley, just northwest of the junction of the Ventura Freeway (U.S. Highway 101) and the San Diego Freeway (Interstate Highway 405).

The drainage area boundary on the south is formed by the Santa Monica Mountains; on the west, by the Simi Hills; on the north, by the Santa Susana Mountains; and on the east by a line extending approximately north and south across the valley and generally along the San Diego Freeway.

The headwaters of the Los Angeles River are in the Simi Hills on the west, formed by Chatsworth Creek, Dayton Canyon Wash, Bell Creek, and Arroyo Calabasas. Other major tributaries above Sepulveda Dam include Devil Canyon, Brown's Canyon, Limekiln Canyon, Wilbur, and Aliso Canyon Washes; and Caballero and Bull Creeks. The longest watercourse above the dam is Devil Canyon-Brown's Canyon-Los Angeles River. This watercourse is about 19 miles long with an average slope of 143 ft/mi.

Approximately 85 mi² of the watershed above Sepulveda Dam is of relatively steep, mountainous terrain, and about 67 mi² is of comparatively flat valley floor. Elevations in the valley vary from 668 feet at the base of the dam to about 1,200 feet at the base of the foothills. The average elevation of the Santa Monica Mountains is about 1,700 feet; that of the Simi Hills is about 1,800 feet; and that of the Santa Susana Mountains is about 2,000 feet. The highest point in the drainage area is San Fernando Peak, in the Santa Susana Mountains, having an elevation of 3,741 feet.

Sepulveda Dam was completed in September 1941 as a single purpose flood control structure. It is an earth fill dam, 57 feet high, with a top elevation of 725.0 ft. The spillway is an ogee type with spillway gates. The elevation with the gates raised is 710.0 ft. The outlet works consist of four 6 ft W x 6.5 ft H ungated outlets, with an invert elevation at 668.0 ft and four 6 ft W x 9 ft H gated outlets, also with an invert elevation of 668.0 ft. The capacity of the improved channel downstream is 17,000 ft³/s. There is no allocation for sedimentation at Sepulveda Dam. Pertinent data for Sepulveda Dam is shown in Table 3. Hydrologic routing information is presented in Table 4.

7. Runoff Characteristics.

In the mountains, runoff concentrates quickly from the steep slopes; hydrographs show that the stream flow increases rapidly in response to effective rainfall. High rainfall rates, in combination with the effects of shallow surface soils, impervious bedrock, fan-shaped stream systems, steep gradients, and occasional denudation of the area by fire, result in intense debris-laden floods. However, flood and debris flows are regulated at existing dams and debris basins.

Runoff from urban watersheds is characterized by high flood peaks of short duration that result from high-intensity rainfall on watersheds that have a high percentage of impervious cover. Flood hydrographs from single storm events are typically of less than 12 hours duration and are almost always less than 48 hours duration.

8. Climate.

The climate of LACDA varies considerably with elevation and distance from the coast. The entire region is Mediterranean, with dry summers and mildly wet winters. The coastal zone is subtropical, with cool summers and mild winters. The intermediate valleys and foothills are temperate, with warm summers and mild winters. The climate in the mountains ranges from temperate, with warm summers and cool winters at the resort levels (5,000 - 6,000 ft), to alpine, with cool summers, and cold winters over the highest peaks (9,000 - 10,000 ft).

8.1. Temperature.

In Los Angeles County, the average daily minimum/maximum temperatures range from about 48/64 (degrees Fahrenheit) in winter to 65/75 in summer along the coast. In the intermediate valleys, the range is from about 42/66 in winter to about 62/95 in summer. Over the higher mountains, the respective seasonal values are about 22/40 and 50/70. All-time low/high extremes of temperature are about 26/113 along the coast, 22/118 in the valleys and foothills, 5/105 at mountain resort levels, and -10/85 over the highest peaks. The coastal area does not experience significant frosts, but freezing temperatures are common in the higher mountains from November through March and occur on occasion during the winter in the intermediate valleys.

At the city of Burbank, located near the upstream limit of the ARBOR reach at an elevation of 655 feet above sea level, the average temperature is about 65° F, with extremes of 22° F and 113° F on record. Pertinent daily data and monthly average temperature for the Burbank weather station are shown in Table 5.

8.2. Precipitation.

Precipitation characteristically occurs in the form of rainfall, although in the higher elevations, some falls as snow. In general, the quantity of precipitation increases with elevation. Normal annual precipitation in LACDA ranges from about 12 inches along the coast in Long Beach to more than 44 inches over Mt. Baden-Powell and Mt. San Antonio (Old Baldy) in the East Fork drainage of the San Gabriel River. About 90 percent of the season's total precipitation normally falls from November through April, with December-March as the wettest months. Extreme monthly precipitation totals in the drainage range from zero at every location to more than 50 inches atop the wettest mountain peaks. As can be seen by these extremes, and as can be computed from NOAA Atlas 14 for any duration up to 24 hours or for any return period (out to well beyond 100 years),

the rainfall depth over the higher mountains is considerably greater than the corresponding depth on the coastal plains. The mountain/coastline ratios can be as high as 3 to 1 for durations of 6 hours and as high as 4 to 1 for 24 hours.

The mean seasonal precipitation at the project location is about 17.5 inches. The Burbank weather station recorded a maximum daily precipitation of 7.76 in. in Jan 1943. Nearly all precipitation occurs during the months of November through April. Rainless periods of several months during the summer are common. Pertinent data and monthly average precipitation values for the weather station are shown in Table 6.

Frequency point precipitation estimates for selected frequencies are available from NOAA Atlas 14. Specific estimates for the project location are presented in Table 7. Note: For comparison, the 100-year 24-hour point precipitation for the entire LACDA area from the 1992 LACDA Review Study was 9.78 inches.

8.3. General Winter Storms.

Most precipitation in southern California coastal drainages occurs during the cool season, primarily from November through early April, as mid-latitude cyclones from the north Pacific Ocean occasionally move across the West Coast of the United States to bring precipitation to southern California. Most of these storms are of the general winter type, with hours of light to moderate steady precipitation, but with occasionally heavy showers or thunderstorms embedded. These storms frequently produce significant snow above 6,000 feet, with snow falling below 2,000 feet on rare occasions. Snowmelt can at times contribute to runoff in LACDA streams, but the amount of high-elevation area which receives snowfall is not sufficient to generate large peak flows on the upper San Gabriel or Los Angeles Rivers; snowmelt is not a factor in the low-elevation Rio Hondo drainage.

8.4. Local Thunderstorms.

Local thunderstorms can occur in southern California at any time of the year, but are least common and least intense during the late spring. These types of storms occur fairly frequently in the coastal areas during or just after general winter storms. They can also occur between early July and early October, when desert thunderstorms occasionally drift westward across the mountains into coastal areas, sometimes enhanced by moisture drifting northward from tropical storms off the west coast of Mexico. Local thunderstorms can also occur throughout the fall, as upper-level low-pressure centers sometimes trigger left-over summer moisture. These local thunderstorms can at times result in very heavy rain for short periods of time over small areas, causing very rapid runoff from small drainages. Some of the smaller watersheds within LACDA are especially vulnerable to this type of storm.

8.5. General Summer Storms

General summer storms in southern California are quite rare; but on occasion a tropical storm from off the west coast of Mexico can drift far enough northward to bring rain, occasionally heavy, to southern California, sometimes with very heavy thunderstorms embedded. The season in which these storms are the most likely to significantly affect southern California is mid-August through early October, although there have been some effects in southern California from tropical storms as early as late June and as late as early November.

On rare occasions, southern California has received light rain from non-tropical general summer storms, some of which have exhibited characteristics of general winter storms.

8.6. Wind.

The prevailing wind in LACDA is the sea breeze. This gentle onshore wind is normally strongest during late spring and summer afternoons, with speeds of 10 to 15 miles per hour. The Santa Ana is a dry desert wind that blows from out of the northeast, most frequently during late fall and winter. It can be especially strong below mountain canyons, with peak gusts to more than 80 miles per hour at times. This type of wind can create very high fire hazards, but can also be instrumental in drying a saturated watershed, thus reducing the flood potential.

Rainstorm-related winds are the next most common type in southern California. Winds from the southeast ahead of an approaching storm average 20-30 mph, with occasional gusts to more than 40 mph. West to northwest winds behind storms can sometimes exceed 35 mph, with higher gusts.

9. Climate Change.

Climate change is a global-scale concern, but can be particularly important in the western United States where potential impacts on water resources can be significant to supplies for water agencies. The city of Los Angeles Department of Water and Power (LADWP) is considering impacts of climate change during development of its long-term water supply plan. LADWP prepared a report entitled "Draft 2010 Urban Water Management Plan" in January 2011. Chapter 12 of the report presents a discussion of the impact of climate change to the LADWP service area.

Scientists predict future climate change scenarios using highly complex computer global climate models to simulate climate systems. Although most of the scientific community agrees that climate change is occurring and, as a result, mean temperatures for the planet will increase, the specific degree of this temperature increase cannot be accurately predicted. Predictions of changes in precipitation are even more speculative, with some scenarios showing precipitation increasing in the future and others showing the opposite. No adjustments due to climate change were made to Future Condition

discharges for this analysis. The project area is located far enough upstream that potential sea level changes are not a factor; thus no changes were made for downstream boundary conditions in the hydraulic models..

10. Water Budget.

The factors influencing the water budget for the selected alternatives are the streamflow in the Los Angeles River, precipitation, infiltration, evaporation, and evapotranspiration. The water budget for the selected alternatives is presented in Table 8.

10.1. Streamflow.

Streamflow in the Los Angeles River at the project location is perennial due to upstream urban runoff and treatment plant releases. During storm events, runoff concentrates quickly from the steep slopes in the mountains and rushes through the improved Los Angeles River channel. Flood hydrographs from single storm events are typically of less than 12-hours duration and are almost always less than 48-hours duration. High rainfall rates, in combination with the effects of shallow surface soils, impervious bedrock, fan-shaped stream systems, steep gradients, and occasional denudation of the area by fire, result in intense debris-laden floods. However, flood and debris flows are regulated at existing dams and debris basins. The downstream area is almost entirely developed and relatively little sediment enters the channel downstream from the dams aside from the fine material carried in suspension. At the project location, a large portion of the contributing drainage lies downstream from dams.

10.2. Stream Gages.

There are four stream gages located along the Los Angeles River. These gages used to be maintained by the USGS, but now are now under the operation of LACDPW. There is also a gage just downstream from Sepulveda Dam that measures outflow from the dam. The Los Angeles River gages from upstream to downstream are:

Los Angeles River at Tujunga Ave., Station no. F300-R
Los Angeles River above Arroyo Seco, Station no. F57C-R
Los Angeles River below Firestone Blvd., Station no. F34D-R
Los Angeles River below Wardlow Rd., Station no. F319

The Los Angeles River above Arroyo Seco stream gage is closest to the project location and best represents the flow conditions for the project. The gage is located 800 feet above the confluence with the Arroyo Seco. The location has changed 3 times during period of record with no significant impact on recorded flows. The drainage area at the gage is 511 mi². The period of record is from 1929 to present. Flow is partially regulated by Sepulveda, Pacoima, Big Tujunga, and Hansen Dams. Flow data for this stream gage is presented in Table 9.

For the period of record, the average annual daily flow at this location is 164 ft³/s. During the summer months the average daily flow is 61 ft³/s, but can be less than 10 and has been as low as 1-2 ft³/s during some summer months. Subsequent to the Donald C. Tillman Water Reclamation Plant (WRP) coming online in 1985, the average daily flow at the project area has increased to 291 ft³/s annually and 134 ft³/s during the non-flood season.

Graphs of average daily flows for stream gages F300-R, F57C-R, and F34D-R are shown on Plates 5 to 7.

10.3. Local Runoff

The drainage area of the Los Angeles River at the upstream end of the project location is about 465 mi². At the downstream end, the drainage area of the Los Angeles River is approximately 580 mi². The total controlled drainage area for Hansen and Sepulveda dams is 304 mi². Therefore, there is about 276 mi² of uncontrolled area contributing flow to the project location (about half). Surface runoff from uncontrolled area enters the local drainage system and flows at relatively high velocities towards the Los Angeles River. The local storm drain system is operated and maintained primarily by LACDPW and some individual cities and is very efficient.

10.4. Recycled Water.

The Bureau of Sanitation under the Los Angeles County Department of Public Works operates the Donald C. Tillman WRP located in the Sepulveda Flood Control Reservoir in Van Nuys, California. After leaving homes and businesses, most San Fernando Valley wastewater travels along some of the sanitation system's 6,400 miles of sewers on its way to the Donald C. Tillman WRP. The plant carries out tertiary treatment on much of the liquid sewage and sends the solid as a slurry to Hyperion Treatment Plant near Dockweiler Beach. After approximately 11 hours of treatment at the Tillman WRP, the water is ready to be reused. This water is used to fill Lake Balboa, water a golf course and Japanese gardens, and used by a company to grow lawns; excess water is released through Sepulveda Dam down the Los Angeles River. Before completion of Lake Balboa, most of the treated wastewater ended up flowing down the Los Angeles River to the harbor. The plant, which opened in 1985, operates around the clock and processes 65 million to 70 million gallons of raw sewage daily.

10.5. Imported Water.

There is currently no imported water passing the project site. There is a turnout located on Tujunga Wash that may potentially be used to offset or supplement Los Angeles River flows at the project location.

10.6. Precipitation.

General precipitation for the project location is summarized above in the Climate section. The mean seasonal precipitation at the project location is about 17.5 inches as recorded at the Burbank weather station.

10.7. Infiltration.

The infiltration capacity is the maximum or potential rate at which water can enter the soil at any point in time. Water losses due to infiltration can be a significant factor in the water budget, especially if ponded areas are to be included in the proposed project. Normally, you can expect channel infiltration to be about 0.3 – 2.0 feet per day in Southern California streams. If the soil is not saturated, moisture will infiltrate into the ground at a rate controlled by the soil texture, vegetal cover, and degree of saturation. Infiltration rates are variable with time. Rates are highest when the soil is dry and lower after it is wetted. Infiltration rates decrease with time during a rainstorm and finally assume a uniform and minimum value. A large amount of rainfall on silt or clay surface will usually have limited infiltration. The presence of organic matter (loam) and vegetation will generally increase infiltration.

Soils are classified by the Natural Resource Conservation Service into four Hydrologic Soil Groups based on the soil's runoff potential. The four Hydrologic Soils Groups are A, B, C and D, where group A generally has the highest infiltration rate and smallest runoff potential while group D has the lowest infiltration rate and greatest runoff potential. Details of this classification can be found in 'Urban Hydrology for Small Watersheds' published by the Engineering Division of the Natural Resource Conservation Service, United States Department of Agriculture, Technical Release 55 (TR-55).

Group A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential,

soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

The soils underlying the project location fall primarily into Hydrologic Soil Group D (see Plate 3). The minimum infiltration rates for Hydrologic Soil Group D are shown in Table 10. For the project site, an average infiltration loss of 0.3 feet per day was used in the water budget.

10.8. Evaporation.

Evaporation, as used here, represents that portion of the water balance that evaporates from open water sources. Few formal studies of evaporation have been made in Los Angeles County; and, since most Corps of Engineers reservoirs are normally dry, with impoundments generally lasting only a few hours to a few days, evaporation is not typically measured. Studies from around the area indicate that mean daily evaporation ranges from about one-quarter inch in winter to more than one-half inch in summer. On days of very strong, dry Santa Ana winds, evaporation can be considerably greater than one inch.

For alternatives that incorporate ponding of water, evaporation may be an important factor. Evaporation rates were obtained in previous studies for nearby reservoirs, lakes, and spreading grounds in the region where measurements have been taken. Calculations for evaporation were made by LACDPW for the 2011 water year and published in their 2010-2011 Hydrologic Report. The average monthly evaporation rates for the Los Angeles area are shown in Table 11. As shown in the table, the rates are more significant during the non-flood season than during the flood season. Descanso Gardens are located closest to the project location. The average annual evaporation rate of 2.31 feet per year was used for this study.

10.9. Evapotranspiration.

The water demand of vegetation varies depending on the individual and combination of plant species within a habitat unit. The Department of Water Resources for California (CADWR) provides evapotranspiration data through the California Irrigation Management Information System (CIMIS). Reference evapotranspiration (ET_o) is a term used to describe the evapotranspiration rate of a reference crop expressed in inches. The reference crop used for the CIMIS program is grass, which is closely clipped, actively growing, completely shading the soil, and well watered. ET_o varies by location, time, and weather conditions. The main factors that influence ET_o include incoming radiation (energy from the sun), outgoing radiation (sensible energy leaving the earth), and the amount of moisture in the air, air temperature, and wind speed. ET_o can be estimated quite accurately through the use of a "model" (a series of complex mathematical equations). Evapotranspiration rates were computed using the Glendale, Los Angeles Basin dataset as shown in Table 12.

The Corps of Engineers previously undertook a study for the Rio Salado (Salt River) in Arizona. During that study, the State Arizona Game and Fish Department provide plant consumption values for riparian vegetation. These estimates can be used for planning purposes to develop the final water budget for the proposed project. The original data sources are listed in Table 13.

For the project site, average evapotranspiration rates for Sycamores of 3.6 feet per year, for Valley Oak Woodland of 5.0 feet per year, and for Cottonwood-Willow of 8 feet per year were used.

11. Existing Conditions Discharges.

The Corps of Engineers, Los Angeles District completed a hydrologic analysis of the entire Los Angeles River watershed as part of the Los Angeles County Drainage Area (LACDA) Feasibility Study. A report was published in 1992 and included detailed Hydrology and Hydraulics Appendices. Hydrologic models were set up using the HEC-1 and HEC-5 computer programs.

Frequency discharges were adopted from the 1992 LACDA Review Study. As noted in that report and in the Future Conditions Hydrology section below, the Los Angeles River drainage area is essentially “built-out”; thus discharges from that report are still applicable. Frequency discharges at selected locations, including main tributaries, are included in Table 14. The design discharges are also included in Table 14.

12. Future Conditions Discharges.

The discharges presented in Table 14 are applicable for Future Conditions. Most new development occurring within the city limits is re-development. The few remaining developable properties are small and far enough away as to have an insignificant impact on mainstem flows (low flows or high flows). The undeveloped areas outside the city limits, but within the drainage area, are primarily public lands consisting of national forest and state or local parks. These areas will not be developed.

As presented in the 1992 LACDA Review Study, the impact of expected future development was addressed by estimating the likely urbanization and the associated increase in impervious area, and second, by determining the change in system runoff attributed to that development. Future condition discharges were computed in an identical manner to present condition discharges, using estimated future impervious cover in determining subarea hydrographs. Future condition effective impervious cover was determined for all areas from land use planning maps for the year 2030 and then converting the total impervious cover using the relationship developed between total and effective impervious cover. The discharge-frequency determinations made for future conditions in the 1992 LACDA Review Study indicated no appreciable increase in peak runoff through the major reaches including the mainstem of the Los Angeles River.

13. LACDA Design Storm.

In general, the LACDA system was designed on a component basis (a flood control dam with an accompanying downstream channel) using 50-year frequency rainfall in older portions of the upper Los Angeles River, and a Standard Project Storm (SPS) based on the January 1943 SPS for San Gabriel components, including the Rio Hondo Diversion Channel and lower Los Angeles River. The rainfall depths from the SPS centered over the watershed are very similar to 24-hour, 50-year frequency rainfall determined during the 1992 LACDA Review Study. No evaluation of discharge-frequency was made during those early design phases because of short streamflow records upon which to base a statistical analysis and confidence that a high degree of protection would result from using the frequency-based design storm concept. The objective was to produce a Standard Project Flood (SPF; a large flood, one that is the largest event reasonably characteristic of the drainage area). However, the rainfall from the SPS, as indicated above, was not severe enough when measured during the 1992 hydrologic frequency analysis of the resulting runoff based on today's development. Design discharges for the Los Angeles River and Tujunga Wash within the project extent are shown on Plate 8. Velocities associated with the design discharges are shown on Plate 9.

14. Channel Hydraulics.

The main channel of the Los Angeles River is approximately 51 miles long and its tributaries have an aggregate length of about 225 miles. Most of the runoff from precipitation originates in the San Gabriel Mountains. The river flows through industrial and commercial areas and is bordered by railyards, freeways, and major commercial, industrial, and government buildings. The Los Angeles River, which once flowed freely over the coastal plain, was channelized between 1914 and 1970 to control the runoff and reduce the impacts of major flood events in the region. Construction on the stretch of the Los Angeles River within the ARBOR reach was started in the late 1930s and completed in the mid 1950s. The Corps of Engineers is responsible for operations and maintenance within the ARBOR reach. Today, the Los Angeles River is lined for most of its length. There are several stretches where the channel invert is not lined with concrete reinforcement: within the Sepulveda Flood Control Basin, through the Glendale Narrows, and south of Willow Street in Long Beach.

The Corps of Engineers, Los Angeles District completed a review of the entire LACDA system and published a Feasibility Report in 1992. Included with this was a Hydraulics Appendix (dated Dec. 1991) which documented the hydraulic analyses which were performed in support of the LACDA Review Study. The analyses included with- and without-project overflow analyses, preliminary alternative formulation and design, analyses to support the selection of the NED plan, and the final feasibility level design of the project. The HEC-2 computer program was used to calculate the water surface elevations under steady flow conditions for the channels and overbank areas. Cross sections were generated using 1:24,000 scale USGS quad maps.

Essentially all of the upper Los Angeles River and most of Tujunga Wash have contiguous overflow conditions. For these watercourses, when flows exceed the channel capacity, flooding is confined relatively close to the channel by fairly narrow floodplains with significant cross slope back towards the channel, resulting in a water surface elevation that can be assumed constant across the channel and both overbanks.

The proposed project (now completed) from the 1992 LACDA study consisted of improvements to the lower Los Angeles River and the Rio Hondo Diversion Channel. These improvements do not impact the flood protection along the Los Angeles River within the current ARBOR ecosystem project extents; the ecosystem project limits are upstream from the LACDA improvements. It is important to note there are several locations within the ARBOR reach where the probability of flows breaking out from the channel within the ecosystem project area is greater than 1% in any given year (equivalent to the 100-yr flood), i.e., the channel has less than 100-yr level of protection in some locations.

There are two main stretches of the Los Angeles River within the ARBOR reach that do not have concrete inverts. These locations are shown on Plate 10 (they are interrupted briefly with concrete sections under some of the bridges). The two main sections without concrete inverts have mostly grouted riprap side slopes with some grouted rock paving and some concrete slab side walls. There are several rock stabilizers within the channel and along the outside curves of the channel, but the integrity of these structures is unknown since they are covered with a significant amount of vegetation.

15. Hydraulic Modeling.

Subsequent to the 1992 LACDA Review Study, the Corps of Engineers, Los Angeles District generated design models using HEC-RAS and prepared a report in July 2005 to present the updated hydraulic analyses. This report is referred to as the Stormwater Management Plan (SWMP). The 2005 LACDA Upper Los Angeles River HEC-RAS Hydraulic Models used as-built construction plans to develop the HEC-RAS model geometry. The geometries for these models only covered the channel area. An initial attempt at georeferencing the models was made at that time. The effort was to create HEC-RAS models for the channels and determine the water surface elevations for the design discharges. These are referred to in this report as the Design Conditions models. In addition, the 2005 report establishes the regulatory water surface elevations that are used as the basis against which all hydraulic impacts to the Upper Los Angeles River and Tujunga Wash are evaluated. These models include the Los Angeles River ARBOR reach.

In 2008, as part of an initial phase of the ecosystem restoration study, the Corps of Engineers used updated geospatial techniques and re-georeferenced a portion of the design models within the city of Los Angeles limits. The cross sections were extended to cover a portion of the overbank area which ultimately covered the 0.2% ACE event (500-yr) floodplain.

This study encompasses the development of hydraulic models for the portion of the Upper Los Angeles River called the ARBOR reach. The hydraulic models encompass the reach from Barham Blvd. to First St., as well as the downstream reaches of Burbank Western Channel, Verdugo Wash, and the Arroyo Seco.

For the current analyses, the first step in the hydraulic modeling was to generate models and floodplains for the Design Conditions and the Existing Conditions to understand the impact of the vegetation within the channel. This required two different model geometries; for the Design Conditions and the Existing Conditions (which includes vegetation). Both were analyzed under a steady, mixed flow regime. The Existing Conditions geometric data only varied from the Design Conditions geometry within the channel. This was due to increased roughness from vegetation growth in "soft" bottom stretches along the Los Angeles River as well the channel invert conditions based on the 2005 survey described below.

15.1. Mapping.

The Los Angeles District Corps of Engineers, through contract services, developed digital terrain models (DTMs and TINs) and ortho-rectified photographs for the project area are based on a 2005 aerial survey flight. The 2005 survey is based on the 1983 NAD horizontal datum, State Plane Zone 5 for California; units are in feet. Elevations are also in feet and based on the 1988 NAVD. The scale of the survey data was 1" = 200' with a 2-foot contour interval.

The hydraulic models are based on topographic data obtained from the 2005 survey by the COE supplemented with 2008 topographic data from the city of Los Angeles. The city of Los Angeles' 2008 data was of similar accuracy and resolution. The additional 2008 data was required to cover the floodplain for the 0.2% ACE event.

15.2. Numeric Models.

The U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) version 4.2 beta was used for the hydraulic modeling. The current HEC-RAS version, 4.2 beta, allows the user to perform one-dimensional steady and unsteady flow river hydraulics calculations to determine water surface profiles and velocities. The system is comprised of graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities as well as graphic output capabilities.

HEC-GeoRAS, is an ArcGIS v. 10 extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into the HEC-RAS and generation of GIS data from RAS output. The user can also export HEC-RAS results back to ArcGIS using HECGeoRAS to develop spatial datasets of the results.

15.3. River Stationing.

The Los Angeles River Channel was constructed in non-contiguous sections at different periods in time. As a result, river stations (RS) were not consecutive from Pacific Ocean all the way to the upstream end of the Los Angeles River channel. During development of the 2005 SWMP design models, the LACDA project was broken into separate sections and river stations were assigned to closely match the design as-builts drawings. In 2008, an attempt was made to update the stationing, but the models still broke the channel into three sections (there were still some computer memory limitations working with such large terrain files) within the city of Los Angeles limits and carried over the inconsistent river stationing from the earlier models.

The 2008 HEC-RAS model entitled 'Reach 1' detailed the portion of the Los Angeles River from 250 feet upstream of the Glendale Freeway at RS 1420+55.6 to just downstream of 26th St. at RS 1026+39.5. RS 1420+55.6 indicates that it is located 142055.6 feet above the outlet. For this reach of the Los Angeles River the 2008 model river stations match the 2005 models and correspond to the pertinent data tables.

The 2008 HEC-RAS model entitled 'Reach 2' extends from 607.06 feet downstream of Fletcher Dr. at RS 00+00 to Sepulveda Dam. RS 00+00 is the point where the 'Reach 1' model ends and the 'Reach 2' model begins. At this point, the river stationing no longer matches the 2005 SWMP models or the pertinent data tables.

The ARBOR reach of the Los Angeles River includes a portion of 'Reach 1' and a portion of "Reach 2". These portions were extracted from the 2008 models and combined to form models covering the ARBOR reach. To update the models, river stations were initially copied from the 2008 HEC-RAS models. The 2008 models could not be used for this feasibility study because the cross sections did not extend far enough to capture the terrain required to cover the 0.2% ACE floodplain. However, it was ideal to initially use the same river station locations as the 2008 models so the bridge and cross section data could be copied to the current ARBOR HEC-RAS model.

River stations for the ARBOR models were developed independently of the 2005 and the 2008 models. It was decided that the ARBOR reach river stations would be numbered according to cumulative stream length within the project area. RS 692+94 upstream of Barham Blvd. is the upstream cross section and RS 10+31 at First St. is the downstream cross section. Interpolated cross sections were added where needed to remove instabilities in the hydraulic calculations. The ARBOR project reaches are shown on Plate 11. The river stations corresponding to the ARBOR study reaches are as follows:

Reach 1: Pollywog Park/Headworks (RS 625+77)) to midpoint of Bette Davis Park (RS 547+45). See Plate 12.

Reach 2: Midpoint of Bette Davis Park (RS 546+45) to upstream edge of Ferraro Fields (RS 510+05). See Plate 13.

Reach 3: Ferraro Fields (RS 504+93) to Brazil Street (RS 452+58). See Plate 14.

Reach 4: Brazil Street (RS 432+16) to Los Feliz Boulevard (RS 359+75). See Plate 15.

Reach 5: Los Feliz Boulevard (RS 358+63) to Glendale (2) Freeway (RS 271+89). See Plate 16.

Reach 6: Glendale (2) Freeway (RS 270+28) to I-5 Freeway (RS 144+23). See Plate 17.

Reach 7: I-5 Freeway (RS 142+91) to Main Street (RS 86+81). See Plate 18.

Reach 8: Main Street (RS 86+07) to 1st Street (RS 10+31). See Plate 19.

15.4. Model Reach Assignments.

The feasibility study ARBOR reach is approximately 11 miles in length, however the hydraulic models cover a distance of about 13 miles along the Los Angeles River to ensure smooth numeric transition into and out of the ARBOR reach. The models are divided into hydraulic reaches 1, 2, 3, and 4 according to the location of confluences with Burbank Western, Verdugo Wash, and the Arroyo Seco. These reach designations are for HEC-RAS model purposes only and do not correspond to the eight ARBOR study reaches. Model reach 4 is at the upstream end of the study area and reach 1 is at the downstream end of the study area. Burbank Western, Verdugo Wash, and Arroyo Seco are included as tributaries in the models.

15.5. Manning's N-Values.

15.5.1. Design Conditions Model.

The Manning's n-values for the main channel in the Design Conditions model were derived from the pertinent data tables for the Los Angeles River. The concrete portions of the channel were assigned a Manning's roughness coefficient of 0.014 (per the original design). The Manning's roughness coefficient for the soft bottom, grouted riprap side slope reaches was 0.03 (combined single n-value for the channel). There is a

short reach with grouted riprap sides and concrete bottom where the channel n-value is 0.02. The Manning's n-values for the left and right overbanks in the Design Conditions models were set at 0.04 along the entire ARBOR reach. This value was estimated based on the topographic mapping, aerial photos and field reconnaissance. The overbanks of the Los Angeles River in the ARBOR reach are primarily urban, highly impervious areas and have dramatically varying horizontal n-values so it was ideal to simplify and group the n-values into a single value for the left- and right- overbank. The focus of the study was to ensure there is no increase in flood risk; i.e., no increase in water surface elevation. Therefore, the choice of Manning's n-value for the overbank is not important and does not affect the choice of the Tentatively Select Plan (TSP).

15.5.2. Existing Conditions Model.

The Existing Conditions models use horizontally varying K values across the main channel. The geometry for these models were developed during a hydraulic analysis for Operations and Maintenance and documented in a memorandum entitled "Vegetation Clearing in Los Angeles River – Burbank Western Channel to Arroyo Seco", for COE Operations Branch, dated 17 March 2004. The hydraulic model was verified using high-water marks from a real-time event. The Existing Conditions models utilize the 2004 vegetation geometry as a reference for K values within the soft-bottom portions of the channel. The vegetation model had K values for the channel portion, but not the overbanks.

As noted above, the Design Conditions models, used an overbank Manning's n-value of 0.040 along the entire span of the ARBOR reach. The n-value of 0.040 was converted into a K value for a sample of cross-sections along the LA River by manipulating Manning's Equation for roughness. The conversion yielded K values that ranged from approximately 1.5 to 2.5. A sensitivity analysis was performed using the Existing Conditions model where overbank K values of 1.5 and 2.5 were used. A 100-yr floodplain was created for the 1.5 value and then compared to a 100-yr floodplain generated for an overbank K value of 2.5. It was concluded that there was very little difference between the floodplains delimited for the two K values (only at RS 515+13, RS 388+25, and RS 418+25), so an average K value of 2.0 for the overbanks was selected.

15.6. Bridges.

All input parameters for bridges and culverts were based on the 2008 models. The parameters were determined from plan and profile drawings as well as from field measurements. See Table 15 for a list of the bridges, by reach, which cross

the Los Angeles River within the ARBOR reach. Two feet of floating debris was added to each side of all piers that measure 6 feet or less in width (transverse direction). For piers with sloping noses, the debris depth was set to 6 feet below the water surface elevation. Floating debris was not added to piers greater than 6 feet in width. This complies with Hydrology & Hydraulics Policy Memorandum No. 4, dated August 2004. This practice is based on experience from past floods and physical model studies that indicate sloping pier extensions in high velocity flows are quite effective in moving debris up the slope out of the water and thereby preventing significant debris accumulation.

The bridge modeling approach for bridges without piers was set to the Energy Only (Standard Step) computational method. For bridges with piers, the highest energy solution between: (Energy Only (Standard Step), (2) Momentum, and (3) Yarnell (Class A only) was selected. Bridge locations are shown on the invert profiles presented on Plates 20 a & b.

15.7. Boundary Conditions.

Boundary conditions are necessary to establish the starting water surface at the ends of the river system (upstream and downstream). Table 16 summarizes the boundary conditions (starting water surface at upstream and downstream ends of the river reach) for the ARBOR reach. On both the upstream and downstream ends of the ARBOR reach, known water surface elevations with associated flows were used as boundary conditions. Numerous side drains enter the Los Angeles River within the ARBOR reach. Detailed design for side drains will be provided in the design phase. Pertinent data for all drains will be included at that time. Water surface elevations in the Los Angeles River may impact storm drain hydraulics.

15.8. Flow Regime.

With the exception of some isolated sections near some bridges and transitions, the profiles on the Los Angeles River are supercritical. The HEC-RAS output, which was used to define the flood profiles and the overflow boundaries, reflects a mixed flow regime with both supercritical and subcritical flow.

15.9. Flow Data.

Since the vegetation analysis described in the 2004 memorandum identified flows with an ACE of 10% or greater exceeding the channel capacity under Existing Conditions, the HEC-RAS models were set up to include discharges for the 10%, 4%, 2%, 1%, 0.5%, and 0.2% ACE events. These correspond to events from the 10-yr up to the 500-yr frequency. Discharges for the HEC-RAS models are included in Table 14.

16. Adequacy of the Hydraulic Models.

In applying the HEC-RAS numeric models, the flow is in a one-dimensional, uniform, steady state. The one-dimensional assumption is applicable for Without-Project Conditions since during high flows most of the flow travels downstream along the channel, allowing the model to analyze the flow in one direction. The uniform flow assumption is reasonable since in most instances flow is gradually changing. Steady flow assumes the change in depth is constant as a function of time.

Preliminary analyses of the alternatives using the one-dimensional HEC-RAS models to determine relative impacts and feasibility of a TSP was also determined to be justifiable. However, detailed numeric model evaluation of the TSP will require two-dimensional, and possibly, an unsteady flow model to more accurately simulate the proposed alterations in and adjacent to the channel. This can be done during a later phase of this study. For areas with significant modifications, physical modeling approach is highly recommended.

17. Floodplain Analyses.

Inundation maps were generated for the 4%, 2%, 1%, and 0.2% ACE events for both Existing and Design Conditions. The model results were exported from HEC-RAS into ESRI's ArcMap to automate the process of delineating the inundation boundaries using HEC-GeoRAS. The resulting inundation boundaries were then inspected and edited to remove spurious polygons and to ensure that all polygons contained other polygons with more frequent return periods. Floodplain delineations for Design and Existing Conditions are shown on Plates 21 a & b to 24 a & b. The Existing Conditions 100-year floodplain has two major breakout areas within the ARBOR reach. These correspond to the vegetated reaches of the Los Angeles River. The upstream area with extensive overbank flooding is between Barham Blvd. and the confluence with Verdugo Wash and has an average floodwater depth of 5.2 feet in the overbank areas. The downstream area with extensive overbank flooding is from the Verdugo Wash confluence to the Golden State Freeway, where the in-channel vegetation ends, and has an average floodwater depth of 3.9 feet in the overbank areas.

The 100-yr and 500-yr floodplains from the 1992 LACDA Review Study are shown on Plate 25 for comparison. The most noticeable difference is the large inundation area that has been removed in the current 1% ACE event (100-yr) in the downtown area from North Broadway to 1st St. The hydraulic model results were closely scrutinized and it was determined the volume and duration for flow exceeding the channel capacity was not sufficient to generate the relatively large inundation areas. The flow exceeding channel capacity was determined to cause street flooding close to the channel and be non-damaging. It should also be obvious the areas impacted due to vegetation within the channel. The current FEMA flood maps by contrast, show that all flow for the 100-yr event stays within the channel through the project reach. Portions of the FEMA maps have not been updated since the early 1980's and were determined to not represent current conditions.

18. With-Project Conditions.

The CE/ICA process documented in the Main Report and Economics Appendix, utilized environmental and preliminary cost information to identify the top four alternatives for further analysis. The features in the alternatives were developed by a multidisciplinary team with consideration for riparian, floodplain, and fisheries values and needs. The four selected alternatives are identified as comprehensive alternatives 10, 13, 16, and 20 and denoted as such in this appendix.

18.1. Alternative Descriptions. These alternatives are described in detail in the Main Report, but are summarized as they pertain to the hydraulic modeling process below:

Alternative 10.

Reach 1 - Restore riparian habitat corridors outside of the channel along the tops of both banks. There are no modifications to the hydraulic models within this reach.

Reach 2 - Restore riparian habitat corridors outside of the channel along the top of both banks. There are no modifications to the hydraulic models within this reach.

Reach 3 - Daylight large storm drain just downstream of Ferraro Fields on right bank in the Zoo Drive Area; freshwater marsh will be located in the daylighted area outside of the channel. Daylight two small storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance.

Reach 4 - Restore riparian habitat corridor outside of the channel along the top of left bank. Implement a side channel along right bank. Daylight one storm drain on right bank. Daylight six storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance.

Reach 5 - Restore riparian habitat corridor outside of the channel along the top of left bank. Daylight one storm drain on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance.

Reach 6 - Restore riparian habitat corridor outside of the channel along the top of left bank. Include a small terraced area along the left bank with vegetation from RS 261+80 to RS 256+00. The Los Angeles River channel is re-configured to take advantage of the Taylor Yard 'bowtie' parcel. At RS 243+17, the channel invert starts to widen into the left bank. The invert width increases to more than

100 feet before it contracts back to the original channel size at RS 201+76. The eastern edge of the widened invert is sloped back up at a 4:1 slope to the original ground elevation. Restore riparian habitat along the sloped channel wall of the widened channel.

Reach 7 - Daylight two storm drains on right bank. Daylight one storm drain on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance.

Reach 8 - Restore riparian habitat at Piggyback Yard outside of the channel. There are no modifications to the hydraulic models within this reach.

Alternative 13.

Reach 1 - Restore riparian habitat corridors outside of the channel along the top of both banks. There are no modifications to the hydraulic models within this reach.

Reach 2 - Restore riparian habitat corridors outside of the channel along the top of both banks. There are no modifications to the hydraulic models within this reach.

Reach 3 - Restore riparian habitat corridors outside of the channel along the top of right bank. Implements a side channel along the right bank behind Ferraro Fields. Connect side channel to daylighted storm drain just downstream of Ferraro Fields on the right bank in the Zoo Drive Area; freshwater marsh will be located in the daylighted area outside of the channel. Daylight three small storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Water sources for the side channel will be determined and evaluated during the design phase.

Reach 4 - Restore riparian habitat corridor outside of the channel along the top of left bank. Implement a side channel along right bank. Daylight one storm drain on right bank. Daylight six storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Water sources for the side channel are evaluated separately.

Reach 5 - Restore riparian habitat corridor outside of the channel along the top of left bank. Daylight one storm drain on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance.

Reach 6 - Allow vegetation on right channel wall through entire reach. Allow vegetation on left channel wall from RS 270+28 to RS 262+72 and from RS 191+61 to RS 144+23. The Manning's roughness coefficients in the hydraulic models were adjusted to account for vegetation on the walls within the channel. Include a small area of widening up to 150 feet to accommodate in-channel geomorphology and vegetation along the left bank from RS 265+38 to RS 251+78. The Los Angeles River channel is re-configured to take advantage of the Taylor Yard 'bowtie' parcel. At RS 243+17, the channel invert starts to widen into the left bank. The invert width increases to more than 620 feet before it contracts back to the original channel size at RS 201+76. The eastern edge of the widened invert is sloped back at a 3:1 slope to the original ground elevation approximately 15 feet from the railroad tracks. Restore riparian habitat along the sloped channel wall of the widened channel.

Reach 7 - Allow vegetation on channel wall along right bank through entire reach and on left bank from RS 128+71 to downstream end of reach. Restore riparian habitat outside of the channel at the Arroyo Seco confluence along the top of both banks. The hydraulic model channel geometry was not changed, but the Manning's roughness coefficients were adjusted to account for vegetation on the walls within the channel. Restore riparian habitat along the Arroyo Seco Channel by removing concrete and re-configuring the channel cross section.

Reach 8 - Restore riparian habitat at Piggyback Yard outside of the channel. There are no modifications to the hydraulic models within this reach.

Alternative 16.

Reach 1 - Restore riparian habitat corridors outside of the channel along the top of both banks. There are no modifications to the hydraulic models within this reach.

Reach 2 - Restore riparian habitat corridors outside of the channel along the top of both banks. There are no modifications to the hydraulic models within this reach.

Reach 3 - Restore riparian habitat corridors outside of the channel along the top of right bank. Implements a side channel along the right bank behind Ferraro Fields. Connect side channel to daylighted large storm drain just downstream of Ferraro Fields on the right bank in the Zoo Drive Area; freshwater marsh will be located in the daylighted area outside of the channel. Daylight two small storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Water sources for the side channel are evaluated separately.

Reach 4 - Restore riparian habitat corridors outside of the channel along the top of bank. Implement a side channel along right bank. Daylight one storm drain on right bank. Daylight six storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Water sources for the side channel are evaluated separately.

Reach 5 - Restore riparian habitat corridor outside of the channel along the top of left bank. Daylight one storm drain on left bank. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. The right bank of the channel changes from trapezoidal to vertical configuration for entire reach. A 2-foot by 2-foot notch along the top of right channel wall is added for hanging vines. The left bank of the channel transitions from trapezoidal to vegetated terraces from RS 356+22 to RS 286+05. The five terraces are 12-feet wide by 4-feet deep and tie into the existing ground elevation at a 3:1 slope. The left bank then transitions from terraces to a vertical configuration from RS 286+05 to RS 271+89 and then transitions back into the design channel configuration starting at RS 274+78.29, before the channel passes under the Glendale Freeway.

Reach 6 - Allow vegetation on right channel wall through entire reach. Allow vegetation on left channel wall from RS 270+28 to RS 262+72 and from RS 191+61 to RS 144+23. The Manning's roughness coefficients in the hydraulic models were adjusted to account for vegetation on the walls within the channel. Include a small area of widening up to 150 feet to accommodate in-channel geomorphology and vegetation along the left bank from RS 265+38 to RS 251+78. The Los Angeles River channel is re-configured to take advantage of the Taylor Yard 'bowtie' parcel. At RS 243+17, the channel invert starts to widen into the left bank. The invert width increases to more than 620 feet before it contracts back to the original channel size at RS 201+76. The eastern edge of the widened invert is sloped back at a 3:1 slope to the original ground elevation approximately 15 feet from the railroad tracks. Restore riparian habitat along the sloped channel wall of the widened channel.

Reach 7 - Allow vegetation on channel wall along right bank through entire reach and on left bank from RS 128+71 to downstream end of reach. Restore riparian habitat outside of the channel at the Arroyo Seco confluence along the top of both banks. The hydraulic model channel geometry was not changed, but the Manning's roughness coefficients were adjusted to account for vegetation on the walls within the channel. Restore riparian habitat along the Arroyo Seco Channel by removing concrete and re-configuring the channel cross section.

Reach 8 - Include 3-foot deep terraces along the right bank within the extent of the LADWP parking lot and tie into the existing ground with a 3:1 slope. The terraced area begins with one 3-foot deep terrace at RS 83+61 and ends with seven 3-foot deep terraces at RS 68+38. The Los Angeles River channel is re-

configured to take advantage of the Piggyback Yard parcel. At RS 69+93, the channel invert starts to widen into the left bank. The invert width increases to more than 500 feet before it contracts back to the original channel size at RS 38+47. Within the Piggyback Yard extent, a bench up to 1000-feet wide extends from RS 64+92 to RS 50+15. The bench is established at approximately the 2-year water surface elevation and includes marsh vegetation. The eastern edge of the bench is sloped back up to the original ground elevation to a point about 1800 feet from the channel. The hydraulic models include "dummy bridges" to represent the railroad trestles over the 'widened' channel from RS 68+38 to RS 40+13.

Alternative 20.

Reach 1 - Restore riparian habitat corridors outside of the channel along the top of both banks. There are no modifications to the hydraulic models within this reach.

Reach 2 - Restore riparian habitat corridors outside of the channel along the top of both banks. From RS 542+40 to RS 509+00, the right bank of the channel changes from trapezoidal to vertical configuration and includes a 2-foot by 2-foot notch along the top of the channel for hanging vines. Along the left bank, from RS 542+40 to RS 525+56, a 2-foot by 2-foot notch along the top of the channel is added to allow for hanging vines. The vegetation on both sides was assumed to have minimal hydraulic impacts and no adjustments were made to the Manning's roughness coefficients in the hydraulic models.

Reach 3 - Restore riparian habitat corridors outside of the channel along the top of bank. Implements a side channel along the right bank behind Ferraro Fields. Connect side channel to daylighted large storm drain just downstream of Ferraro Fields on the right bank in the Zoo Drive Area; freshwater marsh will be located in the daylighted area outside of the channel. Daylight two small storm drains on left bank. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Verdugo Wash is changed to soft-bottom channel from the confluence of Verdugo Wash and the Los Angeles River to approximately 1,200 feet upstream. Verdugo Wash is also widened to allow for marsh vegetation. Vegetation is included in the hydraulic models by a change in Manning's roughness coefficients. Water sources for the side channel are evaluated separately.

Reach 4 - Restore riparian habitat corridors outside of the channel along the top of bank. Implement a side channel along right bank. Daylight one storm drain on right bank. Daylight six storm drains on left bank. There are no modifications to the hydraulic models within this reach. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Water sources for the side channel are evaluated separately.

Reach 5 - Restore riparian habitat corridor outside of the channel along the top of left bank. Daylight one storm drain on left bank. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. The right bank of the channel changes from trapezoidal to vertical configuration for entire reach. A 2-foot by 2-foot notch along the top of right channel wall is added for hanging vines. The left bank of the channel transitions from trapezoidal to vegetated terraces from RS 356+22 to RS 286+05. The five terraces are 12 feet wide by 4 feet deep and tie into the existing ground elevation at along a 3:1 slope. The left bank then transitions from terraces to a vertical configuration from RS 286+05 to RS 271+89 and then transitions back into the design channel configuration starting at RS 274+78.29, before the channel passes under the Glendale Freeway.

Reach 6 - Allow vegetation on right channel wall through entire reach. Allow vegetation on left channel wall from RS 270+28 to RS 262+72 and from RS 191+61 to RS 144+23. The Manning's roughness coefficients in the hydraulic models were adjusted to account for vegetation on the walls within the channel. Include a small area of widening up to 150 feet to accommodate in-channel geomorphology and vegetation along the left bank from RS 265+38 to RS 251+78. The Los Angeles River channel is re-configured to take advantage of the Taylor Yard 'bowtie' parcel. At RS 243+17, the channel invert starts to widen into the left bank. The invert width increases to more than 620 feet before it contracts back to the original channel size at RS 201+76. The eastern edge of the widened invert is sloped back at a 3:1 slope to the original ground elevation approximately 15 feet from the railroad tracks. Restore riparian habitat along the sloped channel wall of the widened channel.

Reach 7 - Daylight one storm drain on right bank. Daylighted storm drains will be evaluated separately to ensure they meet all appropriate Corps regulations and guidance. Four 4-foot deep terraces on the right bank from RS 102+15 to 97+99 are added adjacent to the Cornfields site. At Cornfields, the western edge of the terrace is sloped back up to the original ground elevation. The hydraulic models include "dummy bridges" to represent the railroad trestles from RS 102+15 to 98+98. Restore riparian habitat outside of the channel at the Arroyo Seco confluence along the top of both banks. Restore riparian habitat along the Arroyo Seco Channel by removing concrete and re-configuring the channel cross section.

Reach 8 - Includes 3-foot deep terraces along the right bank within the extent of the LADWP parking lot and ties into the existing ground with a 3:1 slope. The terraced area begins with one 3-foot deep terrace at RS 83+61 and ends with seven 3-foot deep terraces at RS 68+38. The Los Angeles River channel is re-configured to take advantage of the Piggyback Yard parcel. At RS 69+93, the channel invert starts to widen into the left bank. The invert width increases to more than 500 feet before it contracts back to the original channel size at RS 38+47. Within the Piggyback Yard extent, a bench up to 1000-feet wide extends

from RS 64+92 to RS 50+15. The bench is established at approximately the 2-year water surface elevation and includes marsh vegetation. The eastern edge of the bench is sloped back up to the original ground elevation to a point about 1800 feet from the channel. The hydraulic models include "dummy bridges" to represent the railroad trestles over the 'widened' channel from RS 68+38 to RS 40+13.

18.2. Model Adjustments.

For With-Project Conditions, the geometry files for the HEC-RAS model were adjusted to best represent the selected alternatives. The geospatial files representing the selected alternatives were overlain on the cross sections in Arc-GIS. The cross sections impacted were then modified in HEC-RAS to account for any channel re-configurations and vegetated areas. Typical cross sections for selected reaches that include channel re-configuration are shown on Plates 26 to 30.

18.2.1. Manning's N-Values.

After the cross sections were adjusted spatially to account for any channel re-configurations, four scenarios of HEC-RAS model geometries were created with different Manning's n-values to reflect a range of vegetation densities and sizes. Manning's n-values representing 'heavy' ($n=0.08$), "moderate" ($n=0.06$), and "minimal" ($n=0.045$) vegetation were used. Manning's n-values were varied horizontally across the cross sections to reflect the proposed alternatives. The scenarios are described as follows:

Scenario I consists of moderate vegetation along the channel invert with moderate vegetation on channel side slopes and heavy vegetation in expanded channel areas.

Scenario II consists of minimal vegetation along the channel invert with moderate vegetation on channel side slopes and heavy vegetation in expanded areas.

Scenario III consists of moderate vegetation along the channel invert with minimal vegetation on channel side slopes and minimal vegetation in expanded channel areas.

Scenario IV consists of heavy vegetation along the channel invert with heavy vegetation on channel side slopes and heavy vegetation in expanded channel areas.

18.2.2. Contraction/expansion.

Contraction/expansion loss coefficients were set to 0.3 and 0.5, respectively in the cross sections near the bridges

18.2.3. Ineffective Flow Areas.

Ineffective flow areas were used in the models to account for non-conveying flow areas. These locations were determined to be areas where the flow has zero velocity. Ineffective areas were modeled due to backwater behind bridges, abrupt changes in channel geometry, tributaries, and in locations that experienced sudden contraction or expansion of flow. Such areas were determined using the alternative conceptual geospatial layouts, aerial photography, contours files, and site visits. Each cross section for the hydraulic models was meticulously reviewed and coded to include the necessary ineffective areas to ensure proper conveyance and water surface results.

19. Storm Drain Daylighting.

Storm drain "daylighting", as used herein, is the intentional re-exposing of storm drains that connect to the Los Angeles River Channel within the ARBOR reach. Several locations were pre-selected and included in the selected alternatives.

In urban design and urban planning, daylighting is the redirection of a stream into an above-ground channel. Typically, the goal is to restore a stream to a more natural state. Daylighting is intended to improve the riparian environment for a stream which had been previously diverted into a culvert, pipe, or a drainage system. Daylighting sections of storm drains allows for an increase in habitat, increased infiltration, and cleaning of flows by bioremediation processes. An example of a 'daylighted' storm drain is shown on Figures 1 and 2.

No adjustments to the hydraulic models were made at this time for daylighted storm drains. Detailed hydraulic design for daylighted storm drains will be performed during a future phase of this study. It is assumed any adverse impacts on the mainstem flows will be alleviated. This may include a 'hard' connection to the channel and/or flapgates. The hydraulic design will ensure the storm drain connection still meets the height above the invert, submergence, and angle of entry criteria as described in the "Hydrology and Hydraulics Policy Memorandum Number 1, Side Drain Connections into Flood Control Channels", dated 29 Dec. 1998. Opportunities to "daylight" sections of the storm drain system will be evaluated on a drain by drain basis.



Figure 1: Atwater Park - 'daylighted' storm drain, just after construction, Nov. 2011



Figure 2: Atwater Park - 'daylighted' storm drain, one year later, Oct. 2012

20. Evaluation of Alternatives.

One of the critical constraints for this ecosystem restoration study was that the proposed alternatives would have no impact on the flood control functions of the Los Angeles River Channel. In addition to the impacts on flood control, it is imperative the proposed alternatives do not create any adverse conditions related to high velocities. Since the proposed alternatives are quite elaborate and extensive, the COE needed an efficient process for determining impacts and feasibility for each of the proposed alternatives. To evaluate the hydraulic impacts, it was decided to base the impacts on two factors; the change in maximum water surface elevation and the maximum velocity.

20.1. Water Surface Elevation.

The primary focus was to compare the changes to the maximum water surface elevation during the design event for each reach. A major portion of the ARBOR reach has an unlined invert. These sections of the channel include significant amounts of vegetation. Although the COE has made several attempts to remove non-native vegetation, the amount of native riparian vegetation remaining has a significant impact on the channel capacity. Since, it was decided to use the current channel configuration, with vegetation, as the Existing Condition, revised channel capacities needed to be determined. This decision was so the impacts of alternatives could be determined and does not imply there is any effort to change the design discharges for the channel.

Channel capacities were evaluated for two cases that include vegetation: (1) using an appropriate value of minimum freeboard according to present-day design standards, and (2) with no freeboard. The discharges corresponding to the two cases are referred to in this report as the "revised channel capacity" and the "bankfull discharge", respectively. The freeboard standards used are as follows: 2 feet for rectangular channels, 2.5 feet for trapezoidal channels, and 3 feet for levees. These values are provided in EM 1110-2-1601, "Hydraulic Design of Flood Control Channels". In some limited reaches the revised channel capacity increased from the original design discharge because of more than adequate freeboard. The revised channel capacities and bankfull discharges were computed because the carrying capacity of the channel is significantly impacted by the amount of vegetation. The bankfull discharge, along with the revised channel capacity and equivalent return period of the bankfull discharge based on results from the 1992 LACDA Feasibility Study for each reach, are shown in Table 17.

The channel geometry files were modified to reflect the selected alternatives. In addition, Manning's n-values were adjusted to correspond to the vegetation within the channel. Each reach of each alternative was evaluated for a range of vegetation densities and sizes represented by Manning's n-values in the hydraulic models. Although the alternative descriptions may state "riparian" or "marsh", etc, these terms do not equate to a specific n-value and it is important to

understand the hydraulic effects of unrestricted growth within the channel sections. Manning's n-values representing 'heavy', 'moderate', and 'minimal' vegetation were selected based on guidelines in Chow's Open Channel Hydraulics, Open Channel Flow by Henderson, Roughness Characteristics of Natural Channels from the USGS, and engineering judgment. A Manning's n-value of 0.08 was assigned for 'heavy' vegetation. For 'moderate' vegetation, a Manning's n-value of 0.06 was used, and a Manning's n-value of 0.045 was used to represent 'minimal' vegetation within a reach. Factors such as vegetation bending over or breaking or washing out were taken into consideration when selecting these values. Representative cross sections showing Manning' n-values and maximum water surface elevation for selected reaches are shown on Plates 31 to 38. Water surface profiles for the selected reaches and the selected alternatives are displayed on Plates 39 to 46.

20.2. Target Velocity.

The existing Los Angeles River is for the most part, a high-velocity, prismatic concrete-lined channel. Velocities in the unlined invert sections are also relatively high. Restoration projects must be designed to ensure that the vegetation placed within the channel or on the banks will be stable for the full range of conditions expected during the design life of the project. It can be acceptable if during the natural cycle of flows some of the vegetation washes out as long as the integrity of the channel is maintained. Traditionally, shear stress and/or velocity have been used to evaluate the erosion potential for various channel lining materials including vegetation. Theoretical and empirical data on shear stress and velocities are limited as related to differing types of vegetation. In order to evaluate the selected alternatives on their impact on vegetation within the channel, a 'maximum permissible' velocity, or 'target' velocity, was selected. The target velocity for the ARBOR reach used was based on COE engineering regulations and guidance, supplemented by other available information.

A cursory review of the available publications showed the range of permissible velocities depending on the source intents and goals as well as the channel lining material. Table 2-5 from EM 1110-2-1601 (Hydraulic Design of Flood Control Channels, U.S. Army Corps of Engineers, 1 July 1991), gives a set of permissible velocities that can be used as a guide to design non-scouring flood control channels.

EM 1110-2-1205 (Environmental Engineering for Flood Control Channels, U.S. Army Corps of Engineers, Nov. 1989) states that herbaceous or woody vegetation may be used to protect channel side slope areas (depending on the frequency of inundation, velocity, and geotechnical constraints to infrequent flooding) and other bank areas where velocities are not expected to exceed 6 to 8 ft/s.

Hoag (1993) suggested that maximum flow velocities should not exceed 3 ft/s for herbaceous plantings, 3-5 ft/s for woody and herbaceous mixed plantings, 5-8 ft/s for woody plantings alone, and that maximum flows above 8 ft/s require soil-bioengineering approaches.

Lane (1955) presents curves showing permissible channel shear stress to be used for design, and the Soil Conservation Service (1954) presents similar information on grass-lined channels.

The designer should consider the maximum allowable velocity based on site specific conditions such as duration of flow, soils, temperature, debris load, plant species, as well as channel shape and planform (Streambank Soil Bioengineering Field Guide, NRCS, Dec. 2002).

Table 2-5 Suggested Maximum Permissible Mean Channel Velocities	
Channel Material	Mean Channel Velocity, fps
Fine Sand	2.0
Coarse Sand	4.0
Fine Gravel ¹	6.0
Earth	
Sandy Silt	2.0
Silt Clay	3.5
Clay	6.0
Grass-lined Earth (slopes less than 5%) ²	
Bermuda Grass	
Sandy Silt	6.0
Silt Clay	8.0
Kentucky Blue Grass	
Sandy Silt	5.0
Silt Clay	7.0
Poor Rock (usually sedimentary)	10.0
Soft Sandstone	8.0
Soft Shale	3.5
Good Rock (usually igneous or hard metamorphic)	20.0
Notes:	
1. For particles larger than fine gravel (about 20 millimetres (mm) = 3/4 in.), see Plates 29 and 30.	
2. Keep velocities less than 5.0 fps unless good cover and proper maintenance can be obtained.	

The 2007 LARRMP from the city of Los Angeles suggested reducing flow velocities to less than 12 ft/s. This velocity was determined as a threshold necessary to maintain a vegetated channel (LARRMP, Hydraulics Appendix, Dec. 2006). Velocities of 12 ft/s are still very fast and it is unclear whether

vegetation could actually establish and/or remain for an extended period. Soils conducive to growing vegetation would definitely be erodible at such a velocity. If the vegetation could get established, it would contribute to slowing the flows at the tradeoff of a higher water surface elevation. Impacts from vegetation on terraces or sited above a water surface corresponding to an infrequent frequency event can be estimated using quasi-2D in HEC-RAS, but some areas may require a true 2-dimensional model to evaluate the velocities.

After the event of January 2001 along the Los Angeles River, COE personnel went out and measured high water marks. Using a peak flow of 37,000 ft³/s (since updated to 37,500 ft³/s from LACDPW data), roughness coefficients were back-calculated (Memorandum for CESPL-ED, Subject: Vegetation in Los Angeles River Channel, April 2001). From the HEC-RAS runs, the peak flow corresponded to an average velocity of about 8-9 ft/s through the Taylor Yard reach. Photographs showed significant portions of the smaller to moderate size vegetation had been completely bent over or washed away. However, many moderate to large-size trees still remained in the channel. Vegetation tends to bend over and may recover if flow duration is not too long or if the velocity is slow enough.

The permissible values of velocity should be determined so that damage exceeding normal maintenance will not result from any event that could be reasonably expected to occur during the service life of the channel (EM1110-2-1601, Hydraulic Design of Flood Control Channels, U.S. Army Corps of Engineers, 1 July 1991). Based on this information, it was decided to use 8 ft/s as the maximum permissible velocity for the unlined portions of the project reach without supplemental protection measures. Departures from suggested permissible velocity values should be based on reliable field experience or laboratory tests. Channels whose velocities exceed permissible values will require some kind of channel and/or bank protection. Both rigid and flexible armor systems can be used in or adjacent to the channel to protect the channel bed and/or banks from erosion and to stabilize side slopes. A wide array of different armor materials is available. Reaches where velocities exceed 12 ft/s are not recommended for planting. In areas where vegetated walls (planter boxes) are considered, any proposed vegetation should be sized appropriately to not affect the integrity of the channel walls and assumed to wash out at regular intervals. Areas with high velocities will need more detailed analyses for scour and deposition to ensure sufficient protective measures are incorporated into the design. The original design for the existing soft-bottom stretches of the Los Angeles River within the ARBOR reach included grade stabilizers and large quantities of dumped derrick stone in areas susceptible to scour.

21. Results.

The results of applying the above criteria for water surface elevation and target velocities on the proposed alternatives are as follows:

Alternative 10

In Reach 1, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 feet per second (ft/s). The water surface elevation results are shown in Table 18. The velocities can be found in Table 19.

In Reach 2, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 12 ft/s.

In Reach 3, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 8 ft/s.

In Reach 4, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 8 ft/s.

In Reach 5, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 8 ft/s.

In Reach 6, there is adverse effect to the water surface elevation at the downstream section of Taylor Yard as it transitions back to the existing channel configuration (see Plate 39). This adverse effect can be attributed to the contraction of the river. The velocities in this reach are typically less than 12 ft/s.

In Reach 7, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 ft/s because the reach has a concrete invert.

In Reach 8, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 ft/s because the reach has a concrete invert.

Alternative 13

In Reach 1, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 feet per second (ft/s). The water surface elevation results are shown in Table 20. The velocities can be found in Table 21.

In Reach 2, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 12 ft/s.

In Reach 3, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 8 ft/s.

In Reach 4, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 8 ft/s.

In Reach 5, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 8 ft/s.

In Reach 6, there is adverse effect to the water surface elevation at the downstream section of Taylor Yard as it transitions back to the existing channel configuration (see Plate 40). This adverse effect can be attributed to the contraction of the river. The velocities in this reach are typically less than 12 ft/s.

In Reach 7, there is adverse effect to the water surface elevation due to the vegetation on the channel walls. The velocities in this reach are typically greater than 12 ft/s because the reach has a concrete invert.

In Reach 8, there is no adverse effect to the water surface elevation.. The velocities in this reach are typically greater than 12 ft/s because the reach has a concrete invert.

Alternative 16

In Reach 1, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 feet per second. The water surface elevation results are shown in Table 22. The velocities can be found in Table 23.

In Reach 2, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 12 ft/s.

In Reach 3, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 8 ft/s.

In Reach 4, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 8 ft/s.

In Reach 5, there is adverse effect to the water surface elevation in the upstream end of the reach (see Plate 41). The velocities in this reach are typically between 8 to 12 ft/s.

In Reach 6, there is adverse effect to the water surface elevation at the downstream section of Taylor Yard as it transitions back to the existing channel configuration (see Plate 42). This adverse effect can be attributed to the contraction of the river. The velocities in this reach are typically less than 12 ft/s.

In Reach 7, there is adverse effect to the water surface elevation due to the vegetation on the channel walls. The velocities in this reach are typically greater than 12 ft/s because the reach has a concrete invert.

In Reach 8, there is no adverse effect to the water surface elevation except in Scenario IV (see Plate 43). From River Station 83+61 to River Station 76+68, the velocities are typically greater than 12 ft/s because of the concrete invert. Whereas, the velocities are typically between 8 and 12 ft/s for the soft bottom invert from River Station 74+43 to 40+13. Downstream of River Station 40+13 to the project limits, the velocities are greater than 12 ft/s because of the concrete invert.

Alternative 20

In Reach 1, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 feet per second. The water surface elevation results are shown in Table 24. The velocities can be found in Table 25.

In Reach 2, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically between 8 to 12 ft/s.

In Reach 3, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 8 ft/s.

In Reach 4, there is no adverse effect to the water surface elevation except in Scenario IV. The velocities in this reach are typically greater than 8 ft/s.

In Reach 5, there is adverse effect to the water surface elevation in the upstream end of the reach (see Plate 44). The velocities in this reach are typically between 8 to 12 ft/s.

In Reach 6, there is adverse effect to the water surface elevation at the downstream section of Taylor Yard as it transitions back to the existing channel configuration (see Plate 45). This adverse effect can be attributed to the contraction of the river. The velocities in this reach are typically less than 12 ft/s.

In Reach 7, there is no adverse effect to the water surface elevation. The velocities in this reach are typically greater than 12 ft/s because the reach has a concrete invert.

In Reach 8, there is no adverse effect to the water surface elevation except in Scenario IV (see Plate 46). From River Station 83+61 to River Station 76+68, the velocities are typically greater than 12 ft/s because of the concrete invert. Whereas, the velocities are typically between 8 and 12 ft/s for the soft bottom invert from River Station 74+43 to 40+13. Downstream of River Station 40+13 to

the project limits, the velocities are greater than 12 ft/s because of the concrete invert.

22. Flood Risks.

Existing vegetation within the channel has a significant impact on conveyance of the design flood within the ARBOR reach. If allowed to grow unchecked under either the Without- or With-Project Conditions, such vegetation could eventually create an adverse condition with respect to flood risk. The District plans to adopt a course of action that allows for ecosystem restoration while not significantly altering conveyance of the previously authorized design flood within the Los Angeles River. Under this approach, Los Angeles District would modify the existing Operation, Maintenance, Rehabilitation, Repair and Replacement (OMRRR) Plan for the Los Angeles County Drainage Area (LACDA) project within the study area to accommodate the restoration features of the proposed project and to allow some vegetation to remain in the Los Angeles River channel within the study area to the extent that there are only minor effects on the channel's ability to convey the design flood.

22.1. Authorization of the Existing Flood Risk Management Project.

The Los Angeles River is a central component in the LACDA project, a flood risk management project constructed through a massive undertaking by the Corps and the Los Angeles County Flood Control District (now the Los Angeles County Department of Public Works - LACDPW). Federal construction efforts occurred from the 1930s through the 1950s. Construction of the Los Angeles River portion of LACDA was authorized and amended under several laws. The reach of the Los Angeles River being studied in this Feasibility Study, was first authorized for construction under Emergency Relief Acts, then authorized by the Flood Control Act of June 1936, as amended by the Flood Control Acts of 1937 and 1938. Modifications to the Los Angeles River channel have been addressed in later Flood Control Acts. Design discharges of the Los Angeles River for the authorized project range from 40,000 ft³/s to 104,000 ft³/s within the study area.

22.2. LACDA 1992 Review.

The Los Angeles River as originally constructed within the study area from the 1930s to the 1950s was designed to convey a design flood, not a specific frequency event such as the 1% ACE event. The Corps studied improvements to flood risk management conveyance capacity along the Los Angeles River in the 1992 LACDA Review. The 1992 LACDA Review Feasibility Study showed that the LACDA channel and dam flood control system had a relatively low level of flood protection for a metropolitan area. This low level of protection was and is attributable to the following factors: (1) the original design storm, which was based upon the Capital Flood/Standard Project Flood concept in use in the 1930s, generated floods with a magnitude that has an approximately 50-year return period for portions of Los Angeles River when compared to the 1992

frequency curves; (2) modern day freeboard requirements for flood control channel design means that the safe conveyance capacity of a portion of the Los Angeles River is significantly lower than the original design capacity with a lesser freeboard; and (3) the increased runoff response of the watershed due to intensive urbanization produces a higher peak discharge for the same rainfall event. As a consequence of the 1992 LACDA Review Study, the Corps was eventually authorized to upgrade flood risk management features for the Los Angeles River downstream of the Rio Hondo confluence to provide 133-year level of protection (0.8% ACE), but no upgrades were authorized for the upper Los Angeles River including the ARBOR reach. Flood risk management upgrades within the study area were not found to be economically justified in the 1992 review.

22.3. Design Conditions.

Two scenarios of the Los Angeles River were evaluated as part of the ongoing ecosystem restoration feasibility study. The first, referred to as the original authorized project or "Design" Conditions, represents a clean channel with no vegetation within the river channel. The original design was developed to address specific conveyance capacities, in other words, a specific design discharge for a designated reach within the ARBOR, and was not intended to specifically provide protection for a probability-based event such as the 1% ACE event. Based on the updated frequency analysis, the minimum level of protection for the ARBOR reach under Design Conditions is about a 4% ACE event (25-yr). This lowest level of flood conveyance occurs in an entrenched section of the Los Angeles River upstream from the Verdugo Wash confluence.

22.4. Existing Conditions.

The second scenario, referred to as the present or "Existing" Conditions, represents the current channel including the existing amount of vegetation growing within the soft-bottom reaches of the Los Angeles River. The original design did not contemplate allowing any sediment and vegetation to establish in the channel, and the existing vegetation and the sediment held in place by the vegetation has reduced the conveyance capacity of the originally authorized project. Lack of OMRRR funding for many years to remove this vegetation and eventually the environmental issues associated with removing the well-established vegetation have resulted in this reduced conveyance capacity becoming the current Existing Condition. The minimum level of protection for the ARBOR reach under Existing Conditions is about an 11% ACE event (9-yr), which occurs in the soft-bottom section downstream from the Verdugo Wash confluence. At the same time, and despite its degraded condition, the existing vegetation in the channel provides important habitat and connections for wildlife, provides connections between proposed restoration features, and is favored by many in the community. The environmental baseline for the Study assumes that existing vegetation remains in the river because of the Corps' lack of funding for

regular channel maintenance and the environmental considerations involved with vegetation removal.

22.5. Other Important Points.

The conditions described above raise a number of issues regarding flood risks and the relationship to proposed ecosystem restoration along the Los Angeles River. Several related points were considered during the feasibility study. These points are included for consideration:

Point 1. Flood risk management is not within the scope of the current Ecosystem Restoration Feasibility Study. The Corps is not studying flood risk management options under the current study, as there is no interested sponsor.

Point 2. Under Design Conditions, the 1% ACE event cannot be contained within the channel in the ARBOR reach, but current FEMA mapping does not accurately represent these conditions. This generates a responsibility to alert FEMA and the public by way of a Letter of Map Revision (LOMR). The current FEMA mapping of the 100-yr (1% ACE event) floodplain indicates that the 100-yr event can be totally contained within the channel for the entire ARBOR reach. These 'old' FEMA floodplains are based on data from the early 1980s, which we have not been able to obtain. Although the Corps presented floodplain maps for the 1% ACE event as part of the 1992 study (which are very similar to those which we have produced more recently for use in the current Feasibility Study) FEMA did not update its maps for the upper Los Angeles River including the ARBOR reach. FEMA only elected to use the Corps' floodplain mapping for the lower Los Angeles River and the Rio Hondo Diversion Channel. This is a long-standing issue because FEMA has not remapped with current data. In summary, the Corps indicated over 20 years ago that the 1% ACE event cannot be contained within the channel in the ARBOR reach and is different than shown on FEMA maps, but FEMA mapping has not been updated.

Point 3. The vegetation growing within the channel in the ARBOR reach under Existing Conditions represents a significant decrease in flood protection compared to Design Conditions. Within the ARBOR reach, the level of protection is decreased from a little over a 4% ACE event (25-yr) to about an 11% ACE event (9-yr) by the present level of vegetation and sediment. The area of inundation from the 1% ACE event increases significantly, compared to the Design Conditions, at specific locations. That is, the depth of flooding and the area of flooding under the 1% ACE event are both changed by the existing vegetation and sediment in the channel compared to Design Conditions.

Point 4. Although the current Feasibility Study focuses on ecosystem restoration and has no flood risk management purpose, the impact on flood risk management from a recommendation to modify the OMRRR plan to authorize existing sediment and vegetation to remain consistent with Existing Conditions

could trigger FEMA mitigation requirements. A memorandum dated June 2012 between FEMA and USACE entitled "Federal Emergency Management Agency (FEMA)/U.S. Army Corps of Engineers (USACE), Joint Actions on Planning for Flood Risk Management Projects" addresses the requirement to perform mitigation when proposed USACE flood risk reduction projects increase the Base (1-percent-annual-chance) Flood Elevation (BFE). An original constraint of the Feasibility Study is that the recommended project will have no negative impacts on the flood risk reduction capability of the Los Angeles River as compared to the Existing Conditions scenario. The proposed restoration features (new structures and vegetation put in place under the proposed project) will be designed to minimize impacts to conveyance capacity. The H&H analyses in the next phase will allow the District to assess whether and how the new features may result in minor differences to channel conveyance compared to Design Conditions and existing vegetation and sediment not associated with the restoration features will also be considered.

22.6. Recommendations.

Based on the above and although the restoration project and a modified OMRRR plan for flood risk management to leave vegetation in the channel would not induce flooding compared with Existing Conditions, the Los Angeles District proposes to adopt a course of action that would not significantly alter the ability to achieve conveyance of the original design flood. That is, the District would adopt a plan that will minimize any uncertainty about the need to mitigate for induced flooding. The proposed restoration features included in the TSP would be designed to avoid any negative impacts on the conveyance capacity compared to the original Design Conditions. In addition, the OMRRR plan would be modified to allow some vegetation in the channel where existing vegetation grows as well as part of new features, but only to the extent that such vegetation would have no more than minor impacts upon Design Conditions.

23. Summary and Conclusions.

This appendix documents the hydrologic and hydraulic analyses that were performed in support of the Ecosystem Restoration Feasibility Study for the Los Angeles River. The focus of the study is the ARBOR reach which extends from Barham Blvd. upstream to 1st St. in downtown Los Angeles. Since there is no flood risk management component to this study, no risk and uncertainty analyses were performed. During the design phase, the TSP will be designed in more detail and risk and uncertainty will be documented to ensure there is no adverse impacts to existing conditions and also to quantify any incidental benefits that may possibly occur.

The Without-Project Condition is defined as the Existing Conditions, which incorporates the vegetation currently growing within the channel. The hydraulic impact of the vegetation in the channel causes a substantial reduction in channel capacity. Photographic evidence suggests that most of the grasses, reeds, shrubs, and smaller

trees either bent over or washed out during moderate size events but many moderate to large-sized trees still remained in the channel. The smaller vegetation, including non-native plants, grew back rather quickly. The main governing criteria for conveyance is vegetation size and density and ability to bend with water flow. Even if the trees were to wash out, they could become lodged on bridge piers downstream and could create an obstruction greater than was allowed in that portion of the channel.

The Los Angeles River Channel was originally designed to convey a design flood, not a specific frequency event such as the 1% ACE event, with no vegetation within the channel. Even without vegetation in the channel, there are several locations within the ARBOR reach where the probability of flows breaking out from the channel within the ecosystem project area is greater than 1% in any given year (equivalent to the 100-yr flood), i.e., the channel has less than 100-yr level of protection in some locations. This is due to several factors including: the original design event was too small, the amount of urbanization was not anticipated to be so vast, and updated hydrologic and hydraulic criteria.

The four selected alternatives that were analyzed are compared to the Existing Conditions to determine their impacts on the flood control function of the channel. Any of the four alternatives can work hydraulically given the constraint on maintaining vegetation to acceptable limits. Since the proposed alternatives are quite elaborate and extensive, the Corps of Engineers needed a expeditious method for determining impacts and decided to evaluate the impacts on two factors; the change in maximum water surface elevation and the maximum velocity.

For the most part, the reaches that showed an increase in water surface elevation for the design event were at transition areas, either geometric (trapezoidal to rectangular or from a widened section to a narrow section) or construction material (soft-bottom to concrete or vice-versa). These areas can be mitigated by including language in the OMRRR plan to prevent vegetation from getting established in these transition areas and to remove it as soon as possible. The LACDA OMRRR Plan will be revised to accommodate the restoration features of the proposed project and to allow some vegetation to remain in the Los Angeles River channel within the study area to the extent that there are only minor effects on the channel's ability to convey the design flood.

Another option may be to include open water areas within the transition zones. Open water would reduce the amount of vegetation, but brings up other concerns such as vector control and water quality. Studies for the Tres Rios project in AZ show that if the open water area is long enough, wind fetch keeps enough circulation to prevent mosquito proliferation. Also, if the open water area is deep enough vegetation does not get established. Open water areas could be designed with circulation pumps to prevent adverse water quality impacts and mosquito control. Detailed modeling and design for the TSP to include the n-value limitations based on vegetation for these transition areas will be included in next Phase of this study.

Several reaches exhibited average velocities in excess of 12 ft/s. It is not recommended that any alternative that requires planting be allowed in these areas. Reaches with maximum velocities greater than 8 ft/s need to include supplemental protection measures to ensure no adverse impacts to the channel itself or appurtenant features such as bridge piers. The current soft-bottom stretches of the Los Angeles River include invert protection features. These stretches have exhibited a strong disposition for vegetation to get established on its own and also vegetation recovers very quickly after a flood event. These areas of high velocity need to be evaluated more thoroughly for scour erosion to ensure the structural integrity of the channel and appurtenant features are not compromised. Scour and erosion are very important parts of the hydraulic analyses. The study team determined these detailed calculations can be done later in the planning process for the TSP. Revised channel design discharges, including tributaries and side drains will be provided in the design phase.

It should be clearly understood, the results in this Hydrology & Hydraulics Appendix are based on one-dimensional, steady flow HEC-RAS models and that the TSP will require two-dimensional, and possibly, unsteady flow models to more accurately simulate the proposed alterations in and adjacent to the channel. For areas with significant modifications, a physical modeling approach is highly recommended.

24. References.

Los Angeles District, U.S. Army Corps of Engineers, Flood Control in the Los Angeles County Drainage Area. Los Angeles, CA, May 1938.

Los Angeles District, U.S. Army Corps of Engineers, Hydrology in the Los Angeles County Drainage Area, Los Angeles, CA, 1939.

Los Angeles District, U.S. Army Corps of Engineers, Dec. 1946. Restudy.

Open Channel Hydraulics, Chow, 1959.

Open Channel Flow, Henderson, 1966.

Roughness Characteristics of Natural Channels, USGS, 1967.

EM1110-2-1601, *Hydraulic Design of Flood Control Channels*, U.S. Army Corps of Engineers, 1 July 1991.

U.S. Army Corps of Engineers, Los Angeles District: Los Angeles County Drainage Area Final Feasibility Final Report, December 1991.

U.S. Army Corps of Engineers, Los Angeles District: Los Angeles County Drainage Area Final Feasibility Final Report, Appendix A Part I & II Hydrology, December 1991.

U.S. Army Corps of Engineers, Los Angeles District: Los Angeles County Drainage Area Final Feasibility Final Report, Appendix B Hydraulics, December 1991.

Slope Stabilization & Erosion Control, A Bioengineering Approach, Morgan & Rickson, 1995.

Bioengineering for Streambank Erosion Control, May 1997.

Verification of Roughness Coefficients for Selected Natural and Constructed Stream Channels in Arizona, USGS, PP 1584, 1998.

Operations, Maintenance, Repair, Replacement, and Rehabilitation Manual, Los Angeles County Drainage Area, California, December 1999.

Stability Thresholds for Stream Restoration Materials, Fischenich, USACE Research and Development Center, Environmental Laboratory, ERDC TN-EMRRP-SR-29, May 2001.

Streambank Soil Bioengineering Field Guide for Low Precipitation Areas, NRCS, Dec. 2002.

Los Angeles River Revitalization Master Plan, City of Los Angeles. April 2007.

Design of Roadside Channels with Flexible Linings, FHWA, DOT, HEC-1502, 2005.

U.S. Army Corps of Engineers, Hydrologic Engineering Center: HEC-RAS, River Analysis System, User's Manual, version 4.1, January 2010.

U.S. Army Corps of Engineers, Hydrologic Engineering Center: Hydrologic Modeling System, HEC-HMS, User's Manual, version 3.5, August 2010.

U.S. Army Corps of Engineers, Hydrologic Engineering Center: HEC-GeoHMS, Geospatial Hydrologic Modeling Extension, User's Manual, version 5.0, October 2010.

City of Los Angeles, Department of Water and Power: Draft 2010 Urban Water Management Plan, January 2011.

U.S. Army Corps of Engineers, Hydrologic Engineering Center: HEC-GeoRAS, GIS Tools for Support of HEC-RAS using ArcGIS, User's Manual, version 4.3.93, February 2011.

Table 1: Hansen Dam Pertinent Data

Drainage Area	151.9 mi ²
Reservoir Elevation	
Debris Pool	1,010.5 ft
Flood Control Pool (spillway crest)	1,060.0 ft
100-yr Flood Event	1,043.7 ft
Top of Dam	1,087.0 ft
Reservoir Area	
Debris Pool	372 ac
Spillway Crest	826 ac
Top of Dam	1,154 ac
Reservoir Gross Capacity	
Debris Pool	3,756 af
Spillway Crest	33,348 af
Top of Dam	59,299 af
Allowance for Sediment (100-yr)	21,000 af
Dam: - Type	Earthfill
Height above Original Streambed	97 ft
Top Length	15,440 ft
Top Width	30 ft
Outlets:	
Uncontrolled	
Number and Size of Gates	2 - 8 ft W x 6 ft H
Gate Sill Elevation	1,011.0 ft
Controlled	
Type of Gates	Vertical Lift
Number and Size of Gates	8 - 5 ft W x 8 ft H
Gate Sill Elevation	990.0 ft
Maximum Capacity at Spillway Crest	22,000 ft ³ /s
Regulated Capacity at Spillway Crest	21,000 ft ³ /s
Spillway:	
Type	Concrete Ogee
Crest Length	284 ft
Design Discharge	99,700 ft ³ /s
Sources: Water Conservation and Supply Feasibility Study, Hansen Dam, dated April 1999, Hansen Dam Water Control Manual dated November 1990, LACDA Feasibility Study and appendices dated 1992, and updated survey dated Nov. 2004.	

Table 2: Hansen Dam Hydrologic Data

Standard Project Flood	
Duration (inflow)	4 days
Total Inflow Volume (excl. base flow)	57,200 af
Inflow Peak	53,000 ft ³ /s
Max. Storage	19,560 af
Max. Elevation	1065.50 ft
Probable Maximum Flood	
Duration (inflow)	5 days
Total Inflow Volume	246,000 af
Inflow Peak	105,000 ft ³ /s
Peak. Outflow	99,700 ft ³ /s
Max. Elevation	1081.22 ft
100-yr Flood	
Duration (inflow)	1 day
Inflow Peak	47,900 ft ³ /s
Outflow Peak	18,900 ft ³ /s
Max Storage	15,500 af
Max. Elevation	1043.7 ft
Sources: Hansen Dam Analysis of Design dated June 1940, H&H Review of Hansen Dam dated June 1978, Hansen Dam Water Control Manual dated November 1990, and LACDA Feasibility Study and appendices dated 1992.	

Table 3: Sepulveda Dam Pertinent Data

Drainage Area	152.0 mi ²
Reservoir Elevation	
Spillway Crest (gates lowered)	700.0 ft
Flood Control Pool (spillway gates raised)	710.0 ft
100-yr Flood Event	712.1 ft
Top of Dam	725.0 ft
Reservoir Area	
Spillway Crest (gates lowered)	794 ac
Top of Spillway Gates (raised position)	1,348 ac
Top of Dam	2,591 ac
Reservoir Gross Capacity	
Spillway Crest (gates lowered)	7,280 af
Top of Spillway Gates (raised position)	18,129 af
Top of Dam	46,764 af
Allowance for Sediment	0 af
Dam: - Type	Earthfill
Height above Original Streambed	57 ft
Top Length	15,440 ft
Outlets:	
Uncontrolled	
Number and Size of Gates	4 - 6 ft W x 6.5 ft H
Gate Sill Elevation	668 ft
Controlled	
Type of Gates	Vertical Lift
Number and Size of Gates	4 - 6 ft W x 9 ft H
Gate Sill Elevation	668 ft
Maximum Capacity at Spillway Crest	16,500 ft ³ /s
Regulated Capacity at Spillway Crest	16,500 ft ³ /s
Spillway:	
Type	Concrete Ogee
Crest Length	399 ft
Design Discharge	99,540 ft ³ /s
Sources: Sepulveda Dam Water Control Manual dated May 1989, LACDA Feasibility Study and appendices dated 1992, and updated survey dated Nov. 2004.	

Table 4: Sepulveda Dam Hydrologic Data

Standard Project Flood	
Duration (inflow)	3 days
Total Inflow Volume	68,200 af
Inflow Peak	50,000 ft ³ /s
Max. Storage	22,493 af
Max. Area	1,529 ac
Max. Elevation	713.52 ft
Probable Maximum Flood	
Duration (inflow)	4 days
Total Inflow Volume	163,200 af
Inflow Peak	114,000 ft ³ /s
Peak Outflow	99,300 ft ³ /s
Max. Storage	27,563 af
Max. Area	1,710 ac
Max. Elevation	716.66 ft
100-yr Flood	
Duration (inflow)	1 day
Total Rainfall	8.84 in
Rainfall Loss	3.77 in
Rainfall Excess	5.07 in
Inflow Peak	82,500 ft ³ /s
Inflow Volume	41,100 af
Outflow Peak	17,000 ft ³ /s
Max Storage	20,300 af
Max. Elevation	712.1 ft
Sources: Sepulveda Dam Analysis of Design dated August 1939, H&H Review of Sepulveda Dam dated June 1978, Sepulveda Dam Water Control Manual dated May 1989, and LACDA Feasibility Study and appendices dated 1992.	

Table 5: Monthly Temperatures

Station Name: Burbank Valley Pump Plant								Station Number: 41194					
Period of Record: 1939 to 2001								Latitude: 34:11:00					
Elevation: 655 feet								Longitude: 118:20:00					
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max.	67.5	69.5	70.6	74.9	77.5	83.2	88.9	89.9	87.1	81.5	73.5	67.9	77.7
Min.	42.0	44.3	46.2	49.5	54.2	58.3	62.1	62.4	59.9	53.6	45.4	41.3	51.6
Avg.	54.8	56.9	58.4	62.2	65.9	70.8	75.5	76.2	73.5	67.6	59.5	54.6	64.7
Mean daily temperatures in degrees Fahrenheit (F)													
Data from Monthly Station Climate Summaries, 1971-2000, NWS, National Climatic Data Center (NCDC), Western Regional Climate Center.													

Table 6: Monthly Precipitation

Station Name: Burbank Valley Pump Plant									Station Number: 41194				
Period of Record: 1939 to 2001									Latitude: 34:11:00				
Elevation: 655 feet									Longitude: 118:20:00				
Average Total Precipitation													
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	
3.56	4.29	3.88	1.02	0.37	0.12	0.02	0.18	0.30	0.55	1.05	2.15	17.49	
Mean precipitation in inches													
Data from Monthly Station Climate Summaries, 1971-2000, NWS, National Climatic Data Center (NCDC), Western Regional Climate Center													

Table 7: Precipitation Frequency Estimates (Point Estimates)

Duration	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr	1000-yr
5-min:	0.14	0.20	0.27	0.33	0.41	0.48	0.56	0.64	0.75	0.84
10-min:	0.21	0.28	0.38	0.47	0.59	0.69	0.80	0.92	1.08	1.21
15-min:	0.25	0.34	0.46	0.57	0.72	0.84	0.97	1.11	1.30	1.46
30-min:	0.34	0.46	0.63	0.77	0.97	1.14	1.31	1.50	1.76	1.97
60-min:	0.48	0.66	0.90	1.11	1.40	1.64	1.89	2.15	2.53	2.84
2-hr:	0.71	0.96	1.31	1.61	2.03	2.37	2.73	3.12	3.67	4.11
3-hr:	0.89	1.20	1.64	2.00	2.52	2.95	3.39	3.87	4.55	5.10
6-hr:	1.26	1.71	2.31	2.83	3.56	4.15	4.78	5.45	6.41	7.19
12-hr:	1.68	2.27	3.08	3.77	4.76	5.56	6.40	7.31	8.60	9.66
24-hr:	2.19	2.99	4.09	5.02	6.37	7.45	8.61	9.86	11.63	13.08
2-day:	2.75	3.79	5.24	6.49	8.29	9.75	11.31	13.00	15.43	17.43
3-day:	3.13	4.37	6.09	7.58	9.74	11.50	13.39	15.45	18.41	20.86
4-day:	3.39	4.77	6.70	8.37	10.80	12.79	14.93	17.26	20.63	23.42
7-day:	3.88	5.53	7.86	9.88	12.84	15.28	17.91	20.79	24.98	28.46
10-day:	4.16	5.98	8.55	10.79	14.07	16.80	19.74	22.97	27.70	31.64
20-day:	4.90	7.07	10.17	12.89	16.92	20.27	23.94	27.99	33.96	38.99
30-day:	5.78	8.27	11.85	15.02	19.71	23.66	27.98	32.79	39.91	45.94
45-day:	6.89	9.69	13.71	17.29	22.64	27.16	32.15	37.71	46.00	53.08
60-day:	8.01	11.02	15.38	19.27	25.11	30.07	35.56	41.72	50.93	58.82
Point precipitation frequency estimates (inches) NOAA Atlas 14, Volume 6, Version 2 Data type: Precipitation depth Time series type: Partial duration Project area: Southwest Latitude (decimal degrees): 34.1091 Longitude (decimal degrees): -118.2497										

Table 8: Water Budget for Selected Alternatives

Alternative	Channel Streamflow		Precip (af/yr)	Water Sources	
	Annual (af/yr)	Summer (af/yr)		Annual (af/yr)	Summer (af/yr)
10	210,479	96,852	590	211,069	97,442
13	210,479	96,852	717	211,196	97,569
16	210,479	96,852	825	211,303	97,677
20	210,479	96,852	900	211,379	97,753
Summer = Apr thru Sep					

Alternative	Infiltration (af/yr)	Evaporation (af/yr)	ETo (af/yr)	Water Demand (af/yr)	Flow Out	
					Annual (af/yr)	Summer (af/yr)
10	44,271	40.8	2,558	46,870	164,199	50,572
13	53,809	50.9	2,974	56,835	154,361	40,734
16	61,905	88.6	3,365	65,359	146,944	32,318
20	67,593	88.6	3,707	71,389	139,991	26,364
ETo - evapotranspiration Flow Out = Water Source - Water Demand						

Table 9: Average Daily Flows for ARBOR Reach of Los Angeles River

Period of Record (WY1932-2012)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
162	120	780	271	65	44	42	32	33	73	64	74
Average daily flow Jan - Dec = 164 ft ³ /s Average daily flow Apr - Sep = 61 ft ³ /s											
Record Post - W.C. Tillman Treatment Plant (WY1985-2012)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
156	128	187	208	103	97	101	78	77	86	130	121
Average daily flow Jan - Dec = 291 ft ³ /s Average daily flow Apr - Sep = 134 ft ³ /s Flows in ft ³ /s Daily flows from LACDPW stream gage F57C-R; Los Angeles River at Figueroa St. Bridge											

Table 10: Infiltration Rate Criteria for SCS Hydrologic Soil Groups

Group	Minimum Infiltration	
	(in/hr)	(ft/day)
A	0.30 – 0.45	0.6 – 0.9
B	0.15 – 0.30	0.3 – 0.6
C	0.05 – 0.15	0.1 – 0.3
D	0.0 – 0.15	0.0 – 0.3
Source: McCuen, R. H., <i>Hydrologic Analysis and Design</i> , 2 nd ed., Prentice Hall, Upper Saddle River, New Jersey, 07458, 1998		

Table 11: Monthly Summary of Evaporation Rates

ID	Station Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
33-A	Pacoima Dam	6.83	[7.59]	5.80	8.06	5.31	[5.38]	7.56	8.03	5.98	9.25	[9.68]	8.72	[88.19]
46-D	Big Tujunga Dam	[]	[]	[]	[]	[]	[]	[]	6.63	8.24	[11.60]	[13.26]	[9.70]	[49.43]
63-C	Santa Anita Dam	2.96	3.96	2.30	3.25	2.48	2.53	3.20	[2.64]	[0.48]	[0.58]	[0.88]	[0.69]	[25.95]
89-B	San Dimas Dam	[2.74]	[1.96]	[2.67]	[1.52]	[1.59]	[2.64]	4.00	6.08	5.93	9.20	[8.11]	6.55	[52.98]
96-C	Puddingstone Dam	3.25	2.70	[0.99]	1.67	1.62	2.22	3.86	5.24	5.28	[7.64]	7.48	5.81	[47.76]
223-C	Big Dalton Dam	3.03	2.41	[0.95]	1.52	[1.77]	[2.53]	3.62	4.48	5.16	7.47	7.46	5.97	[46.37]
252-C*	Castaic Dam	8.20	3.98	2.57	3.81	3.26	5.34	11.03	10.35	7.83	11.02	11.81	8.85	88.05
334-B	Cogswell Dam	3.64	2.67	[1.94]	1.64	[1.96]	2.54	3.21	4.94	6.16	7.76	7.66	6.01	[50.10]
390-B	Morris Dam	4.86	4.83	3.22	4.62	4.10	5.42	6.85	[7.75]	8.69	11.03	10.67	8.58	[80.62]
409-B*	Pyramid Reservoir	[6.69]	4.29	3.50	[4.77]	4.01	6.02	[5.98]	11.39	10.53	18.15	14.96	[5.72]	[96.01]
425-B	San Gabriel Dam	5.05	4.92	[2.58]	3.60	[3.26]	3.74	5.14	6.95	6.86	9.22	9.77	8.41	[69.48]
598-D*	Check 43	[8.08]	[5.50]	[4.19]	[3.67]	5.22	[6.81]	[8.55]	[13.79]	[2.84]	[]	[]	[]	[58.65]
1058-B	Pamdale	3.25	2.72	1.47	1.67	1.62	3.30	3.86	5.24	10.65	13.20	12.85	7.70	[58.65]
1071-b	Descanso Gardens	[1.77]	[1.65]	[0.47]	[1.17]	[0.77]	[1.03]	[2.24]	[2.88]	[3.80]	[4.72]	4.24	2.92	67.53
1240*	Pearblosson	[7.49]	12.68	10.92	5.44	[6.85]	9.02	[11.00]	13.94	[14.67]	17.77	[11.57]	12.68	[134.03]

Source: LACDPW Hydrologic Report 2010 - 2011

Evaporation in inches

[] Records Incomplete

* CA Department of Water Resources

Table 12: Monthly Evapotranspiration Rates

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
3.95	2.73	2.31	2.20	2.45	3.64	4.74	5.31	6.06	6.75	6.66	5.01	51.81
Monthly evapotranspiration rates in inches Data from CADWR, CIMIS database Data for Glendale, Los Angeles Basin												

Table 13. Vegetation Evapotranspiration Values

Vegetation Type	Evapotranspiration Range (feet/year)	Evapotranspiration Average (feet/year)
Cottonwood Willow	4.1 – 8.5	8*
Salt Cedar	3 – 9.2	6.1
Honey Mesquite	3	3
Marsh	7.5 – 16	9*
Quailbush-Saltbush	3.2	3.2
Desert	2	2
Desert Wash (Xericriparian)	2	2
Source: Greeley and Hansen, 1998, Tres Rios, Arizona Feasibility Study Salt/Gila Groundwater Analysis. * Re-published in Rio Salado Oeste Feasibility Report and adjusted by COE, Mar. 2005.		

Table 14: Frequency Discharges Used in HEC-RAS Models

ARBOR Reach	RS	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr	Design
Reach 1	692+94	16,200	27,200	31,800	42,000	54,300	71,400	81,200	96,800	55,000
Reach 1	691+24	17,500	30,200	35,600	47,500	59,700	76,800	87,600	103,000	57,000
Reach 1	639+73	18,400	32,700	38,600	51,800	63,900	81,000	92,700	109,000	40,000
Reach 2	546+45	20,300	37,200	44,200	59,900	71,800	88,900	102,000	118,000	40,000
Reach 3a	475+68	20,300	37,200	44,200	59,900	71,800	88,900	102,000	118,000	40,000
Reach 3b	474+07	21,600	40,500	48,200	65,800	77,500	94,600	109,000	125,000	78,000
Reach 4	432+16	21,600	40,500	48,200	65,800	77,500	94,600	109,000	125,000	78,000
Reach 5	358+63	21,600	40,500	48,200	65,800	77,500	94,600	109,000	125,000	78,000
Reach 6a	270+28	21,600	40,500	48,200	65,800	77,500	94,600	109,000	125,000	78,000
Reach 6b	257+85	21,400	41,000	49,400	69,600	82,000	93,800	106,000	118,000	83,700
Reach 7a	142+91	21,400	41,000	49,400	69,600	82,000	93,800	106,000	118,000	83,700
Reach 7b	128+71	22,900	44,200	53,600	79,800	94,400	109,000	124,000	141,000	104,000
Reach 8	86+07	22,900	44,200	53,600	79,800	94,400	109,000	124,000	141,000	104,000
Burbank Western	18+04	2,150	4,320	4,990	7,040	8,360	12,400	14,200	16,900	15,000
Verdugo Wash	12+62	3,790	7,550	8,720	12,700	15,100	23,200	26,500	30,300	42,900
Arroyo Seco	9+26	1,500	3,200	4,190	10,200	12,500	17,700	22,200	26,400	43,000
River, Reach, and River Station (RS) from HEC-RAS Models There are 3 discharge locations for Reach 1 because the HEC-RAS models extended upstream from the ARBOR reach. Discharges in ft³/s from 1992 LACDA Feasibility Study Hydrology Appendix										

Table 15: Bridges

River Station	Bridge
682+24	Barham Boulevard
661+97	Warner Brothers Studio Gate
596+22	Ventura Freeway (State Route 134)
529+43	Victory Boulevard
515+90	Golden State Freeway (Interstate Highway 5)
431+85	Colorado Boulevard
359+31	Los Feliz Boulevard
336+95	Sunnynook Drive (Pedestrian bridge)
283+78	Fletcher Drive
271+11	Glendale Freeway (State Route 2)
143+64	Golden State Freeway (Interstate Highway 5)
136+76	Riverside Drive
134+04	UPPR u/s of State Route 110
131+38	Pasadena Freeway (State Route 110)
110+96	MTA Bridge
102+52	N. Broadway
97+78	Spring Street
86+42	Main Street
65+75	UPPR d/s of Main Street
63+38	UPPR u/s of Cesar Chavez Avenue
38+15	Cesar Chavez Avenue
30+13	Santa Ana Freeway (U.S. 101)
10+69	First Street

**Table 16: Boundary Conditions
For HEC-RAS Models**

Location	River Station	Flow Regime	Discharge (ft ³ /s)	WSE (ft)
Upstream End of ARBOR Reach	692+94	Mixed	54,300	525.94
			71,400	528.50
			81,200	529.71
			96,800	531.71
			55,000	526.04
Downstream End of ARBOR Reach	10+31	Mixed	94,400	254.01
			109,000	255.38
			124,000	256.51
			141,000	257.83
			104,000	254.85

Table 17: Revised Channel Capacity and Bankfull Discharge

Reach ^(a)	River Stations	Design ^(b) Discharge ft ³ /s	Bankfull ^(c) Discharge ft ³ /s	Freeboard ^(d) ft	Revised ^(e) Channel Capacity ft ³ /s	Return Period ^(f) (yrs)
Reach 1	625+77 to 547+45	40,000	NA	3	29,300	10
Reach 2	546+45 to 510+05	40,000	35,100	3	25,800	5
Reach 3a	504+93 to 477+85	40,000	NA	3	40,000	10
Reach 3b	475+68 to 452+58	78,000	NA	3	78,000	30
Reach 4	432+16 to 359+75	78,000	45,200	3	34,700	5
Reach 5	358+63 to 271+89	78,000	48,200	3	34,000	5
Reach 6a	270+28 to 262+73	78,000	78,000	2.5	64,500	15
Reach 6b	257+85 to 144+23	83,700	66,800	2.5	50,500	10
Reach 7a	142+91 to 131+22	83,700	NA	2.5	83,700	30
Reach 7b	128+71 to 86+61	104,000	98,900	3	83,700	30
Reach 8	86+07 to 10+31	104,000	89,700	3	89,600	30

Notes:

(a) letters a & b in Reach names denote a break due to a confluence or flow change.

(b) Original design discharge for clean prismatic channel.

(c) Bankfull discharge with vegetation and sedimentation. The values shown are the minimum discharge within the reach.

Bankfull discharges were only calculated for soft-bottom sections; NA denotes not applicable in all-concrete sections.

(d) Freeboard from EM 1110-2-1601; 3 feet for leveed sections and 2.5 feet for trapezoidal entrenched sections.

(e) Channel capacity with vegetation and sedimentation and freeboard. The values shown are the minimum within the reach.

(f) Return period for Revised Channel Capacity based on discharge frequency results from 1992 LACDA Feasibility Study.

Table 18: Alternative 10 Water Surface Elevation

Reach	River Station	Scenario I	Scenario II	Scenario III	Scenario IV
Reach 1	625+77 to 547+45				
Reach 2	546+45 to 510+05				
Reach 3a	504+93 to 477+85				
Reach 3b	475+68 to 452+58				
Reach 4	432+16 to 359+75				
Reach 5	358+63 to 271+89				
Reach 6a	270+28 to 262+73				
Reach 6b	257+85 to 144+23				
Reach 7a	142+91 to 131+22				
Reach 7b	128+71 to 86+81				
Reach 8	86+07 to 10+31				

Note: letters a & b in Reach name denote a break in the reach due to a confluence or flow change.

Color Codes:

Does not increase the water surface elevation

Increases the water surface elevation

No change from design conditions

Table 19: Alternative 10 Velocities

Reach	River Station	Scenario I						Scenario II						Scenario III					
		Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr
Reach 2	546+45 to 510+05																		
Reach 3a	504+93 to 477+85																		
Reach 3b	475+68 to 452+58																		
Reach 4	432+16 to 359+75																		
Reach 5	358+63 to 271+89																		
Reach 6a	270+28 to 262+73																		
Reach 6b	257+85 to 144+23																		
Reach 7a	142+91 to 131+22																		
Reach 7b	128+71 to 86+61																		
Reach 8	86+07 to 10+31																		
Arroyo Seco	n/a																		

Note: Letters a & b in Reach name denote a break in the reach due to a confluence or flow change.
n/a = not applicable

Color Codes:

0-8 ft/s
8 to 12 ft/s
> 12 ft/s

Table 20: Alternative 13 Water Surface Elevation

Reach	River Station	Scenario I	Scenario II	Scenario III	Scenario IV
Reach 1	625+77 to 547+45				
Reach 2	546+45 to 510+05				
Reach 3a	504+93 to 477+85				
Reach 3b	475+68 to 452+58				
Reach 4	432+16 to 359+75				
Reach 5	358+63 to 271+89				
Reach 6a	270+28 to 262+73				
Reach 6b	257+85 to 144+23				
Reach 7a	142+91 to 131+22				
Reach 7b	128+71 to 86+81				
Reach 8	86+07 to 10+31				

Note: letters a & b in Reach name denote a break in the reach due to a confluence or flow change.

Color Codes:

Does not increase the water surface elevation

Increases the water surface elevation

No change from design conditions

Table 21: Alternative 13 Velocities

Reach	River Station	Scenario I						Scenario II						Scenario III					
		Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr
Reach 2	546+45 to 510+05																		
Reach 3a	504+93 to 477+85																		
Reach 3b	475+68 to 452+58																		
Reach 4	432+16 to 359+75																		
Reach 5	358+63 to 271+89																		
Reach 6a	270+28 to 262+73																		
Reach 6b	257+85 to 144+23																		
Reach 7a	142+91 to 131+22																		
Reach 7b	128+71 to 86+61																		
Reach 8	86+07 to 10+31																		
Arroyo Seco	n/a																		

Note: Letters a & b in Reach name denote a break in the reach due to a confluence or flow change.
n/a = not applicable

Color Codes:

0-8 ft/s
8 to 12 ft/s
> 12 ft/s

Table 22: Alternative 16 Water Surface Elevation

Reach	River Station	Scenario I	Scenario II	Scenario III	Scenario IV
Reach 1	625+77 to 547+45				
Reach 2	546+45 to 510+05				
Reach 3a	504+93 to 477+85				
Reach 3b	475+68 to 452+58				
Reach 4	432+16 to 359+75				
Reach 5	358+63 to 271+89				
Reach 6a	270+28 to 262+73				
Reach 6b	257+85 to 144+23				
Reach 7a	142+91 to 131+22				
Reach 7b	128+71 to 86+81				
Reach 8	86+07 to 10+31				

Note: letters a & b in Reach name denote a break in the reach due to a confluence or flow change.

Color Codes:

Does not increase the water surface elevation

Increases the water surface elevation

No change from design conditions

Table 23: Alternative 16 Velocities

Reach	River Station	Scenario I						Scenario II						Scenario III					
		Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr
Reach 2	546+45 to 510+05																		
Reach 3a	504+93 to 477+85																		
Reach 3b	475+68 to 452+58																		
Reach 4	432+16 to 359+75																		
Reach 5	358+63 to 271+89																		
Reach 6a	270+28 to 262+73																		
Reach 6b	257+85 to 144+23																		
Reach 7a	142+91 to 131+22																		
Reach 7b	128+71 to 86+61																		
Reach 8	86+07 to 10+31																		
Arroyo Seco	n/a																		

Note: Letters a & b in Reach name denote a break in the reach due to a confluence or flow change.
n/a = not applicable

Color Codes:

0-8 ft/s
8 to 12 ft/s
> 12 ft/s

Table 24: Alternative 20 Water Surface Elevation

Reach	River Station	Scenario I	Scenario II	Scenario III	Scenario IV
Reach 1	625+77 to 547+45				
Reach 2	546+45 to 510+05				
Reach 3a	504+93 to 477+85				
Reach 3b	475+68 to 452+58				
Reach 4	432+16 to 359+75				
Reach 5	358+63 to 271+89				
Reach 6a	270+28 to 262+73				
Reach 6b	257+85 to 144+23				
Reach 7a	142+91 to 131+22				
Reach 7b	128+71 to 86+81				
Reach 8	86+07 to 10+31				

Note: letters a & b in Reach name denote a break in the reach due to a confluence or flow change.

Color Codes:

Does not increase the water surface elevation

Increases the water surface elevation

No change from design conditions

Table 25: Alternative 20 Velocities

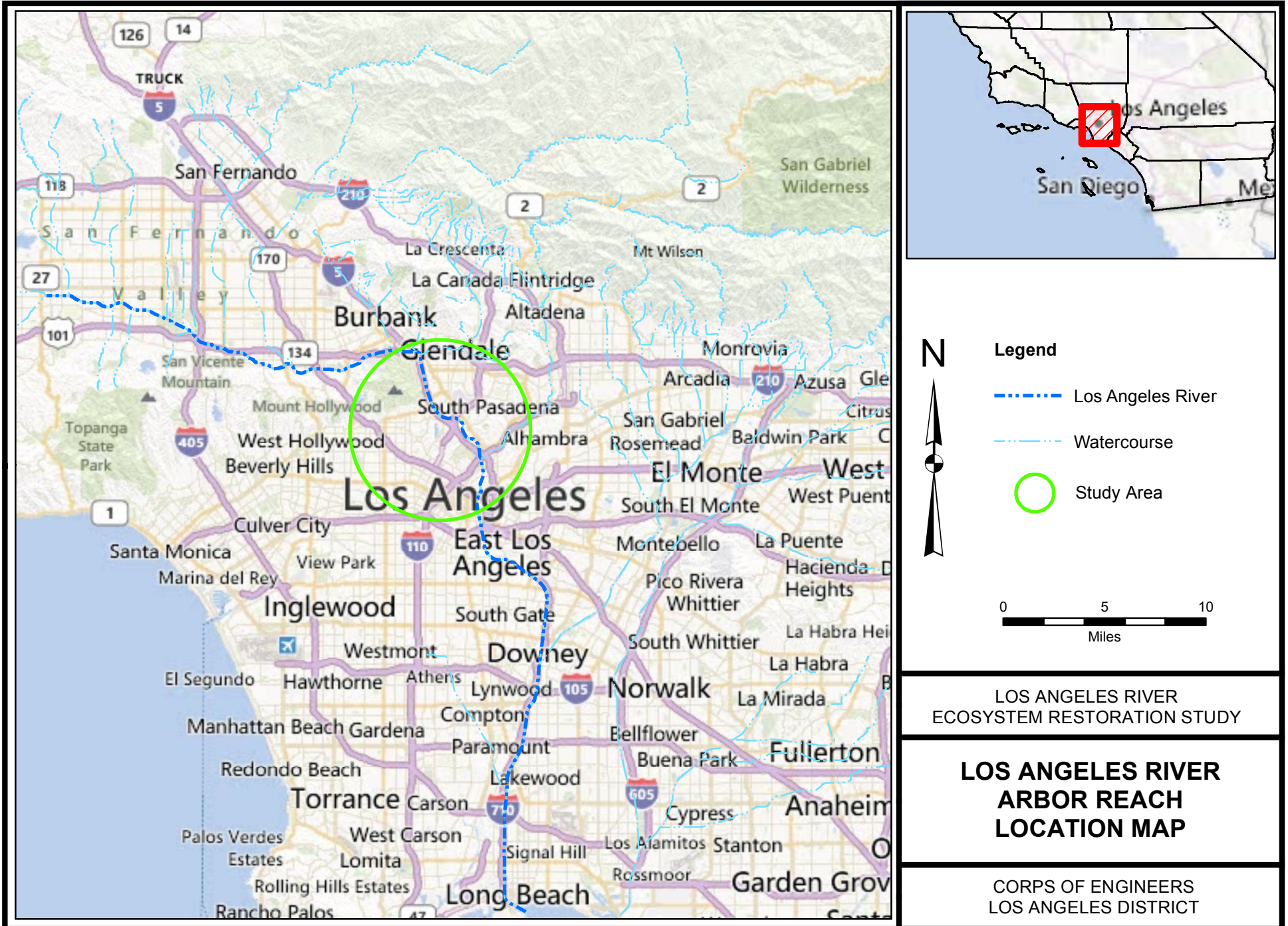
Reach	River Station	Scenario I						Scenario II						Scenario III					
		Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr	Bank full	2-yr	5-yr	10-yr	25-yr	50-yr
Reach 2	546+45 to 510+05																		
Reach 3a	504+93 to 477+85																		
Reach 3b	475+68 to 452+58																		
Reach 4	432+16 to 359+75																		
Reach 5	358+63 to 271+89																		
Reach 6a	270+28 to 262+73																		
Reach 6b	257+85 to 144+23																		
Reach 7a	142+91 to 131+22																		
Reach 7b	128+71 to 86+61																		
Reach 8	86+07 to 10+31																		
Arroyo Seco	n/a																		
Verdugo Wash	n/a																		

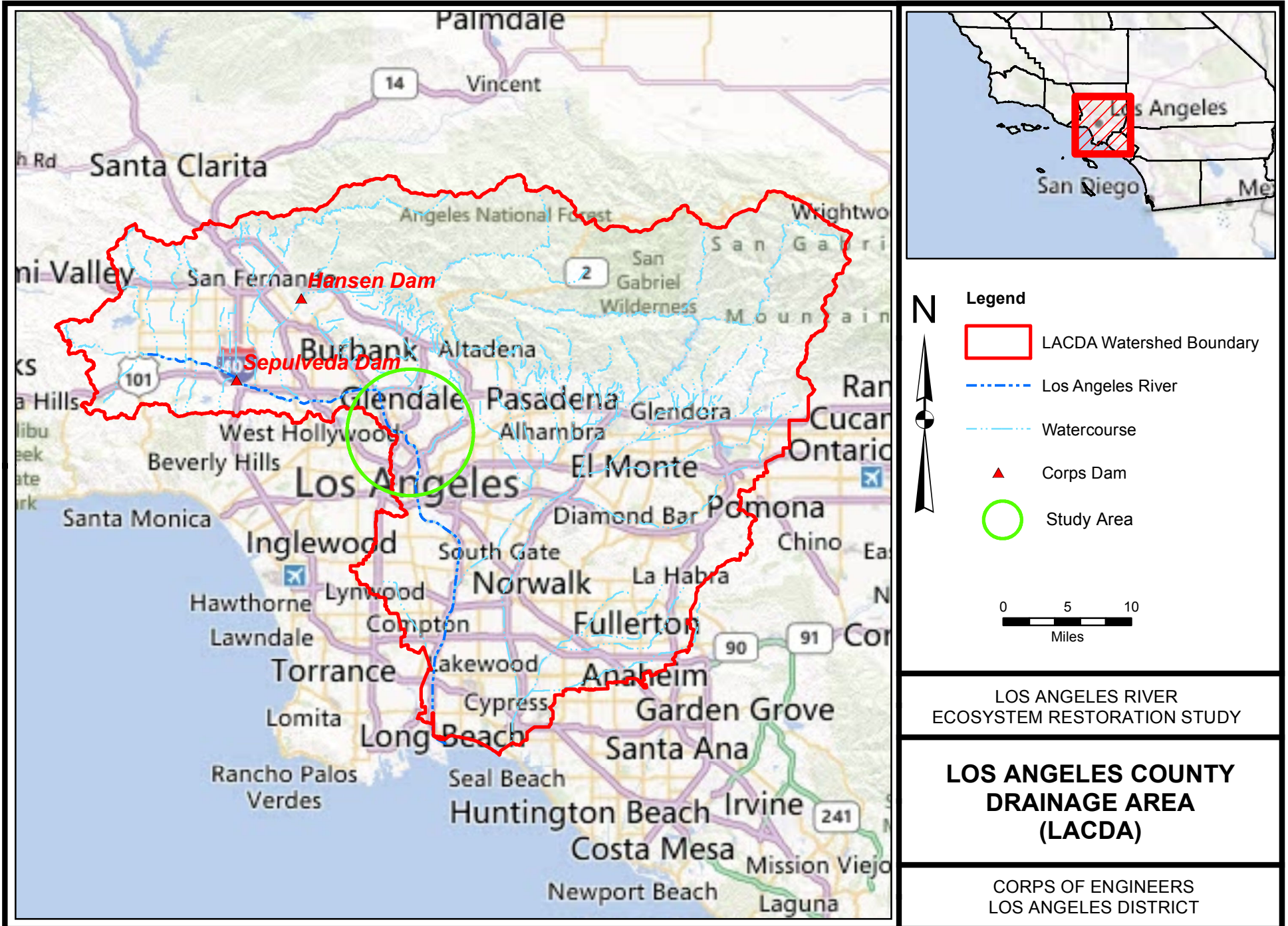
Note: Letters a & b in Reach name denote a break in the reach due to a confluence or flow change.

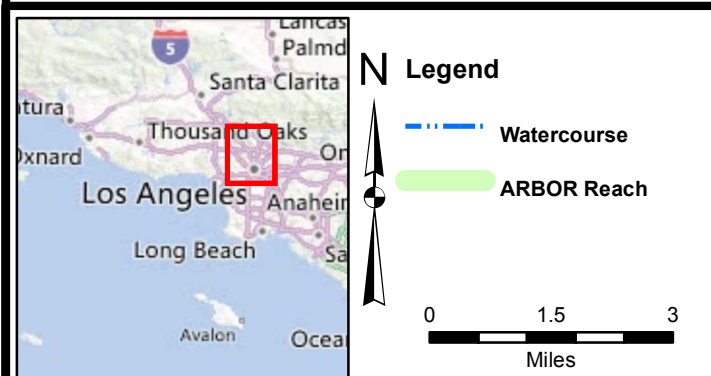
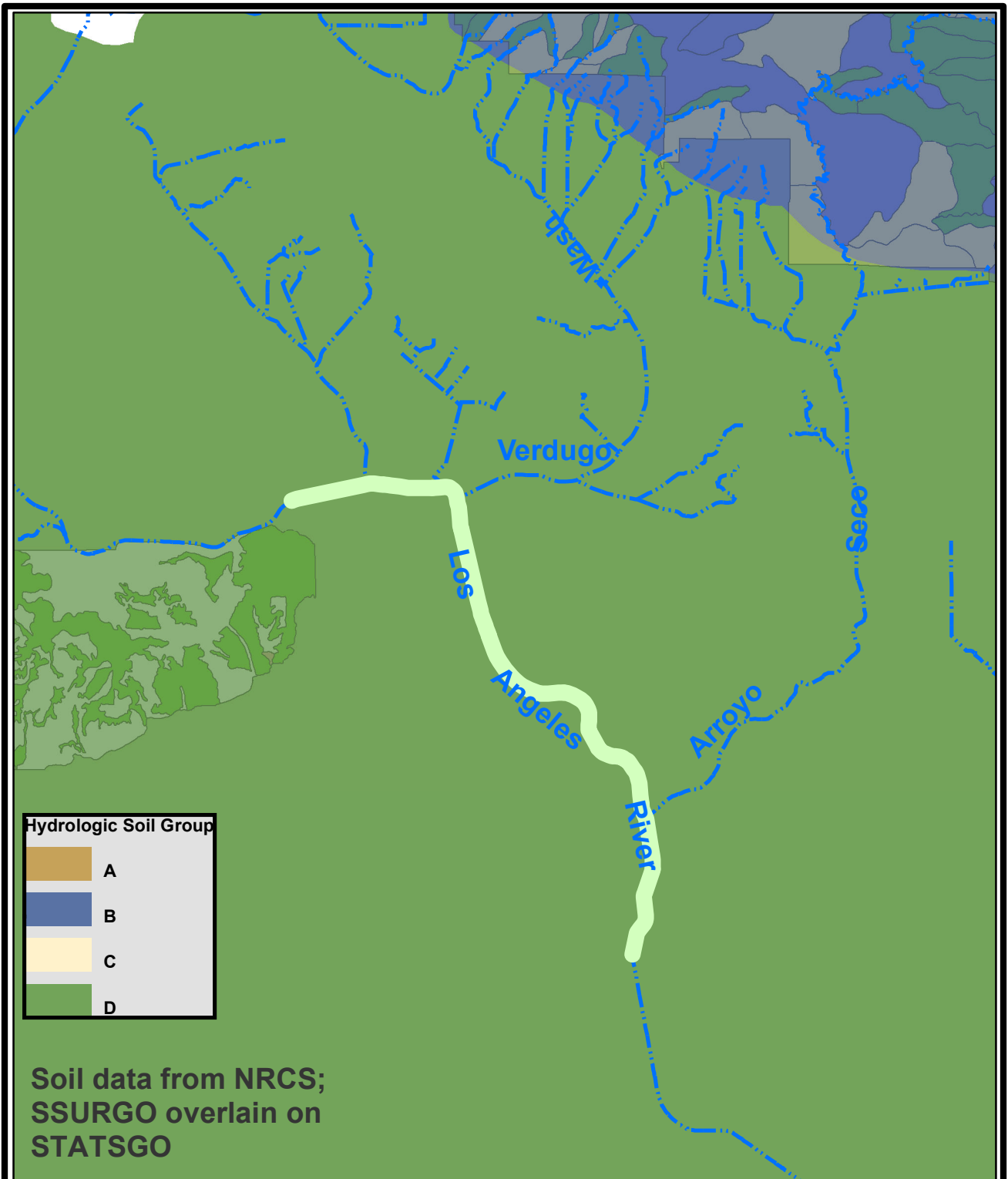
n/a = not applicable

Color Codes:

0-8 ft/s
8 to 12 ft/s
> 12 ft/s



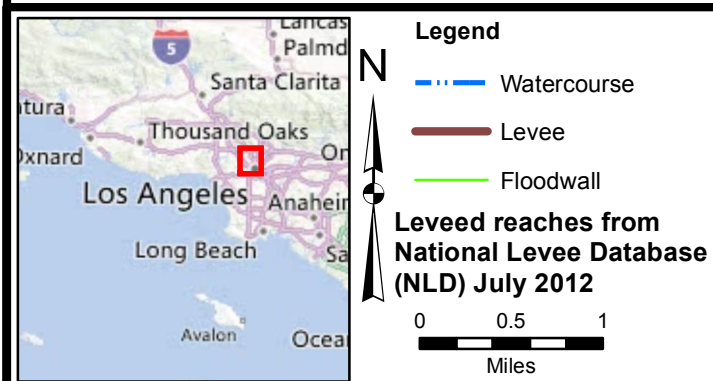
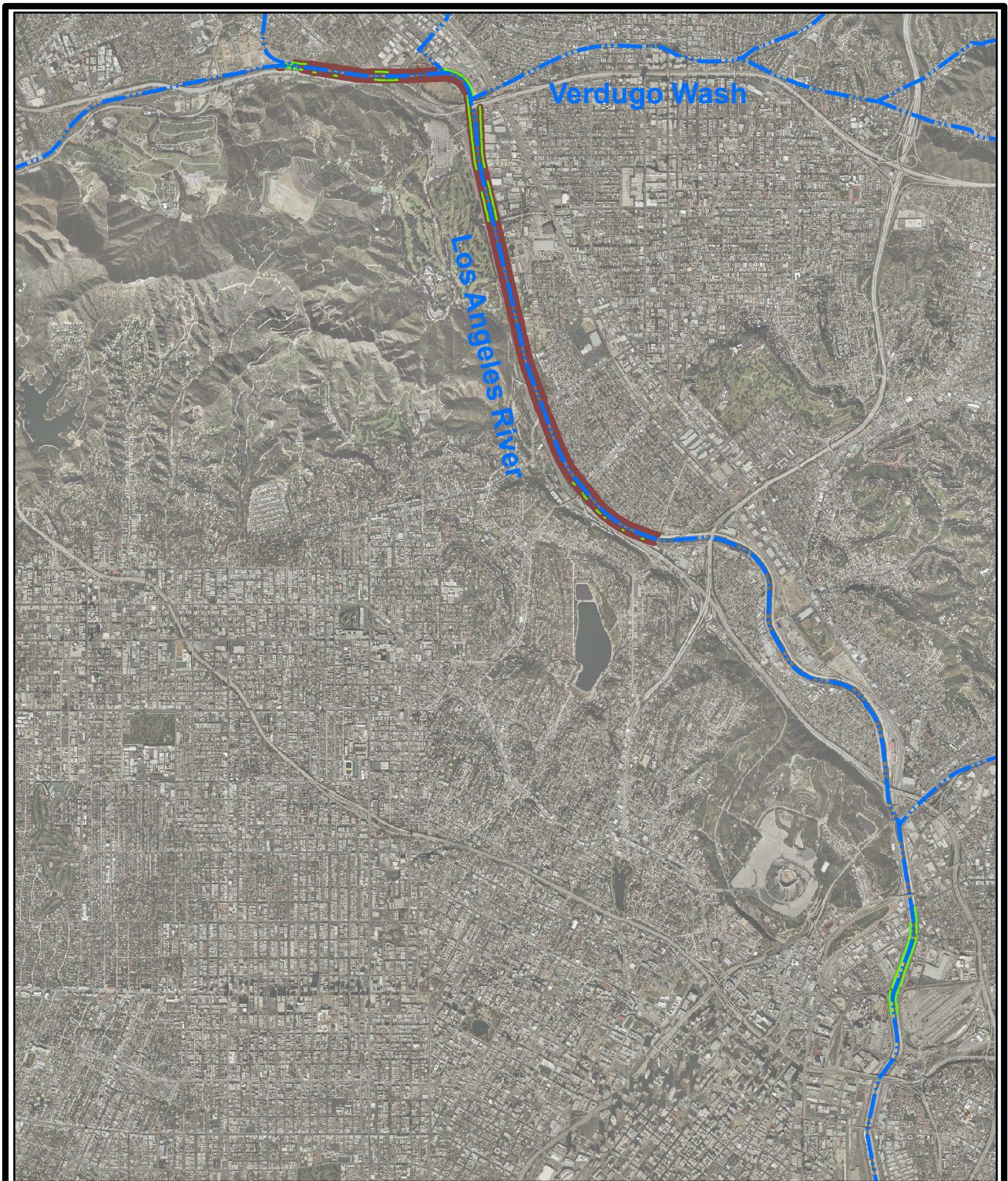




LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ARBOR AREA
AND VICINITY
HYDROLOGIC SOIL GROUPS**

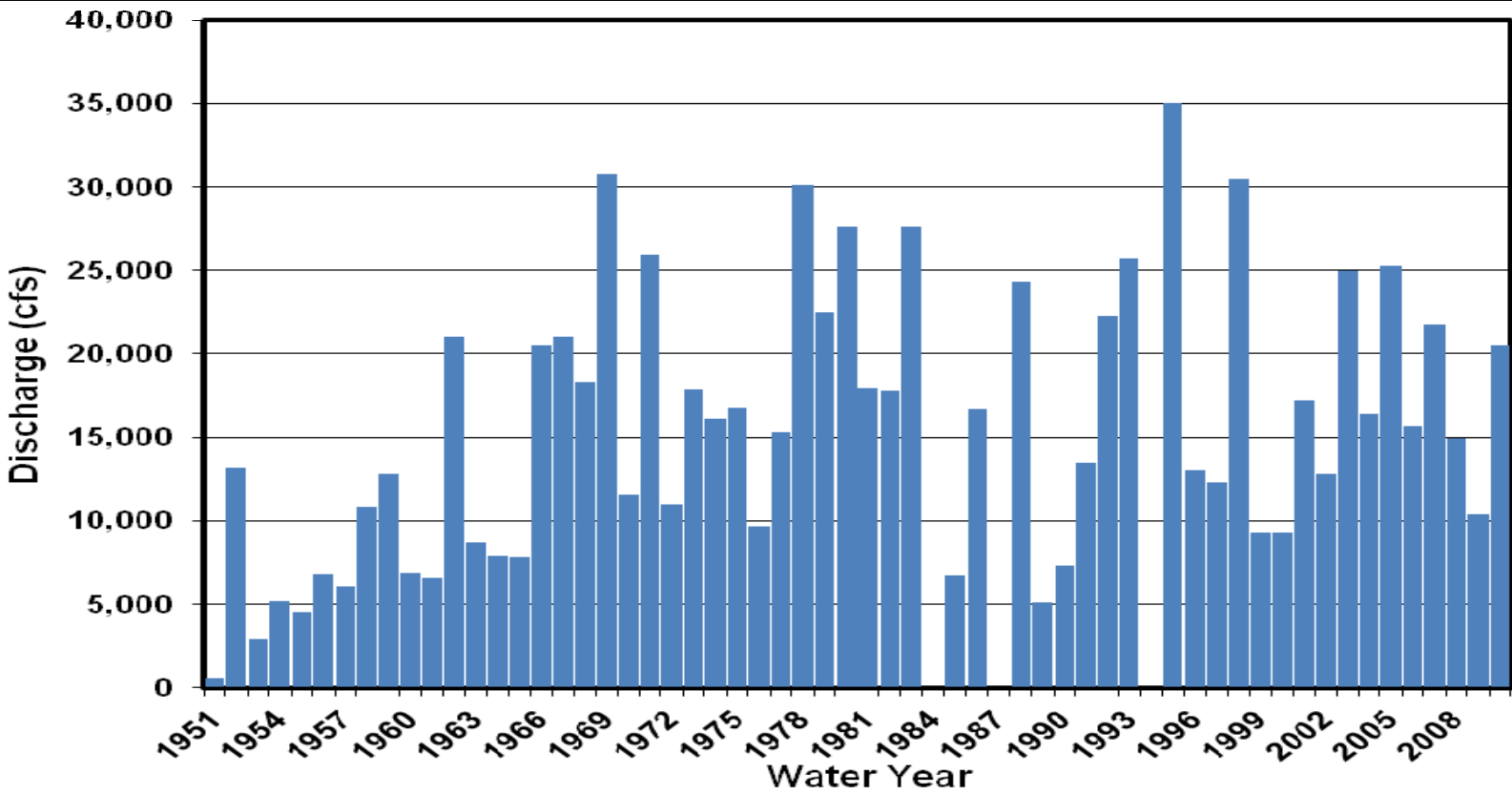
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER LEVEED REACHES ARBOR AREA

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



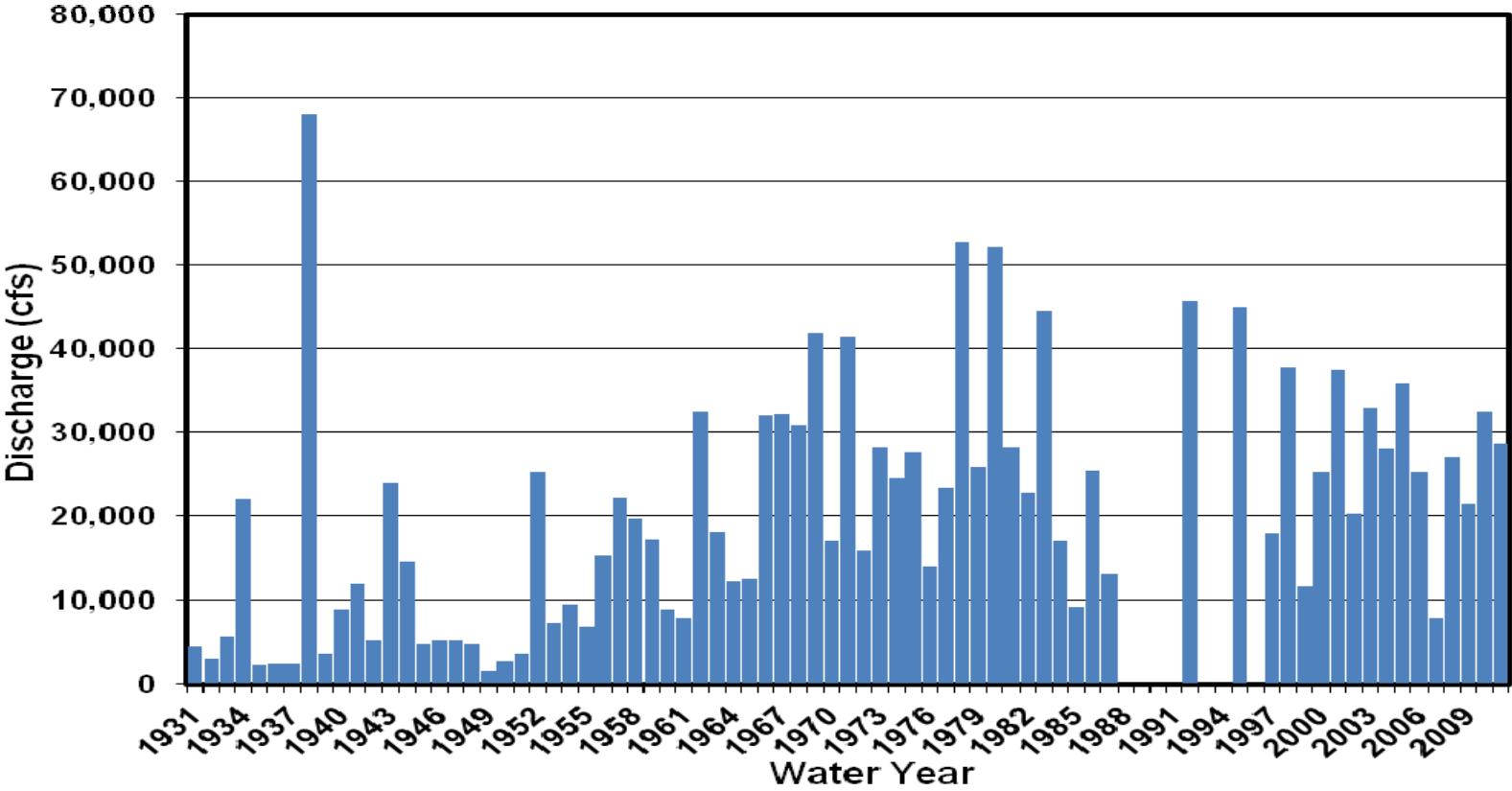
Peak annual flows for period of record.

Ref: Los Angeles County Department of Public Works (LACDPW) Gage F300-R; Los Angeles River at Tujunga Ave.

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
AT TUJUNGA AVE.
PERIOD OF RECORD FLOWS**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



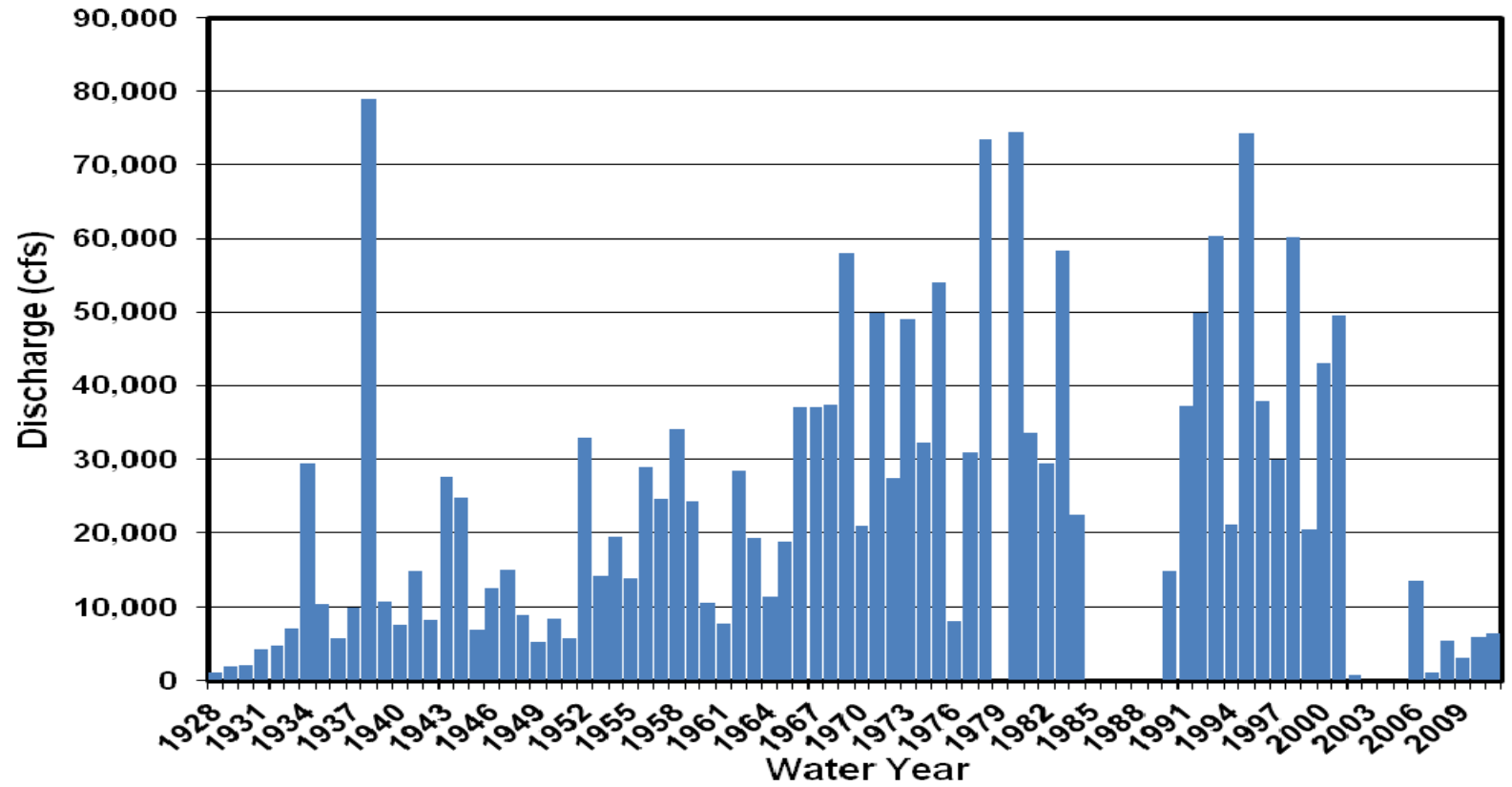
Peak annual flows for period of record.

Ref: Los Angeles County Department of Public Works (LACDPW) Gage F57C-R; Los Angeles River above Arroyo Seco.

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
ABOVE ARROYO SECO
PERIOD OF RECORD FLOWS**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



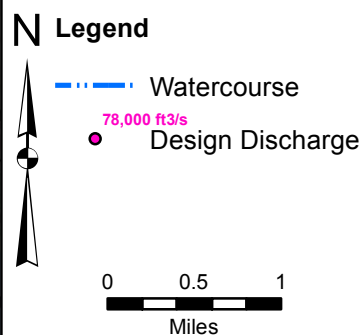
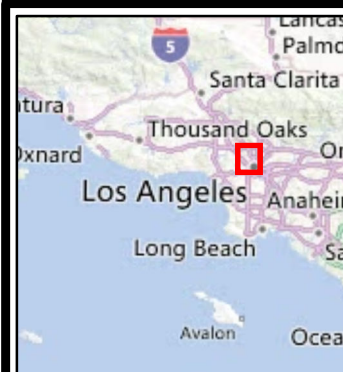
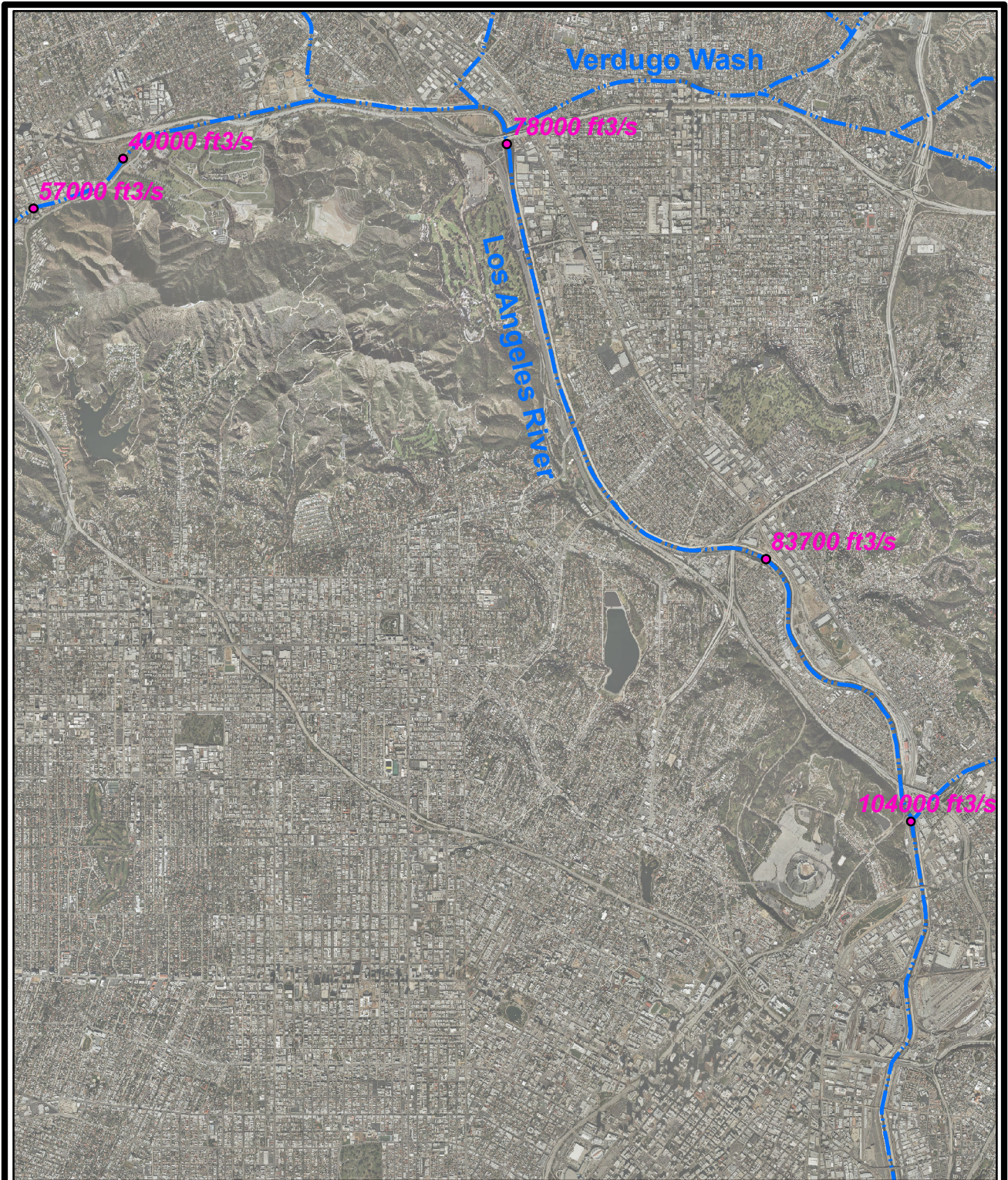
Peak annual flows for period of record.

Ref: Los Angeles County Department of Public Works (LACDPW) Gage F34D-R; Los Angeles River below Firestone Blvd.

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
BELOW FIRESTONE BLVD.
PERIOD OF RECORD FLOWS**

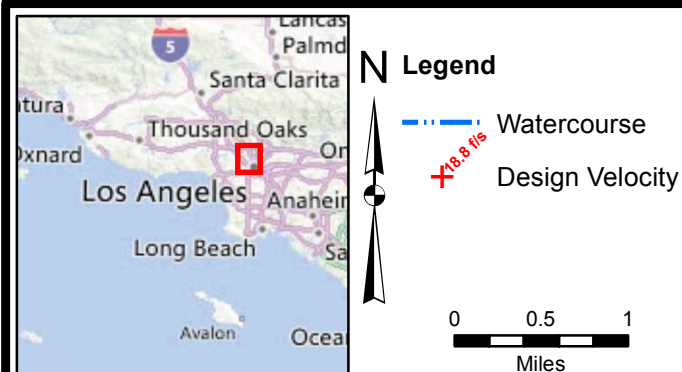
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER DESIGN DISCHARGE ARBOR AREA

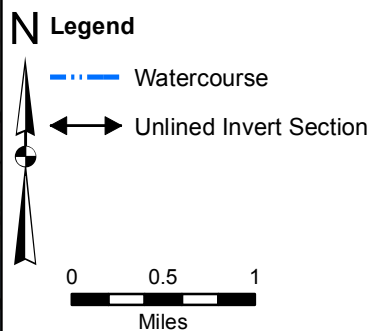
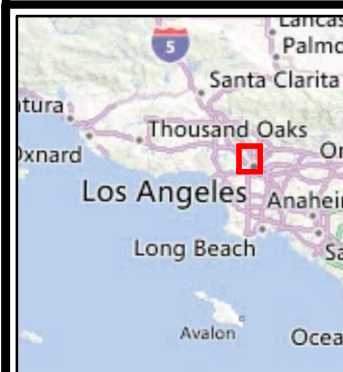
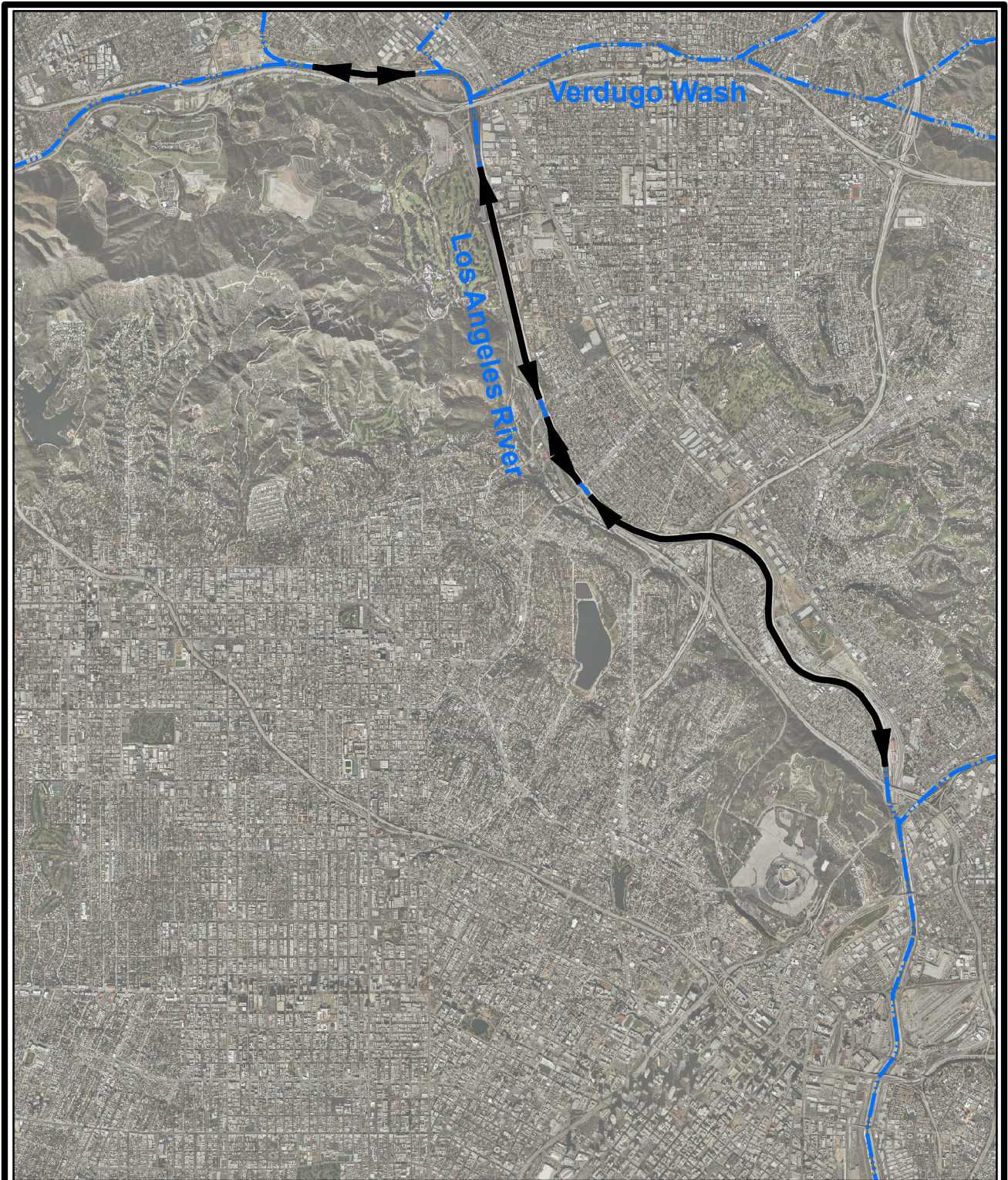
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER DESIGN VELOCITY ARBOR AREA

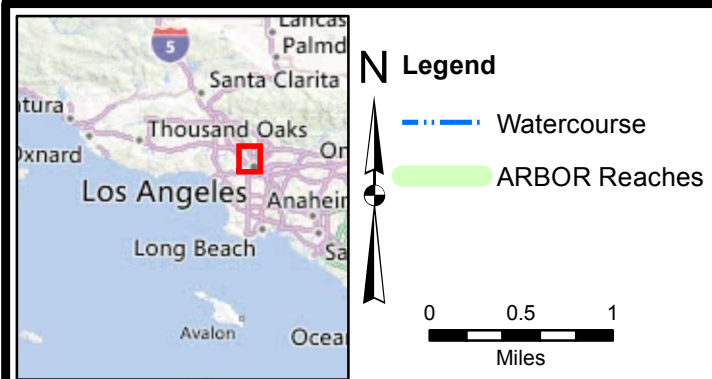
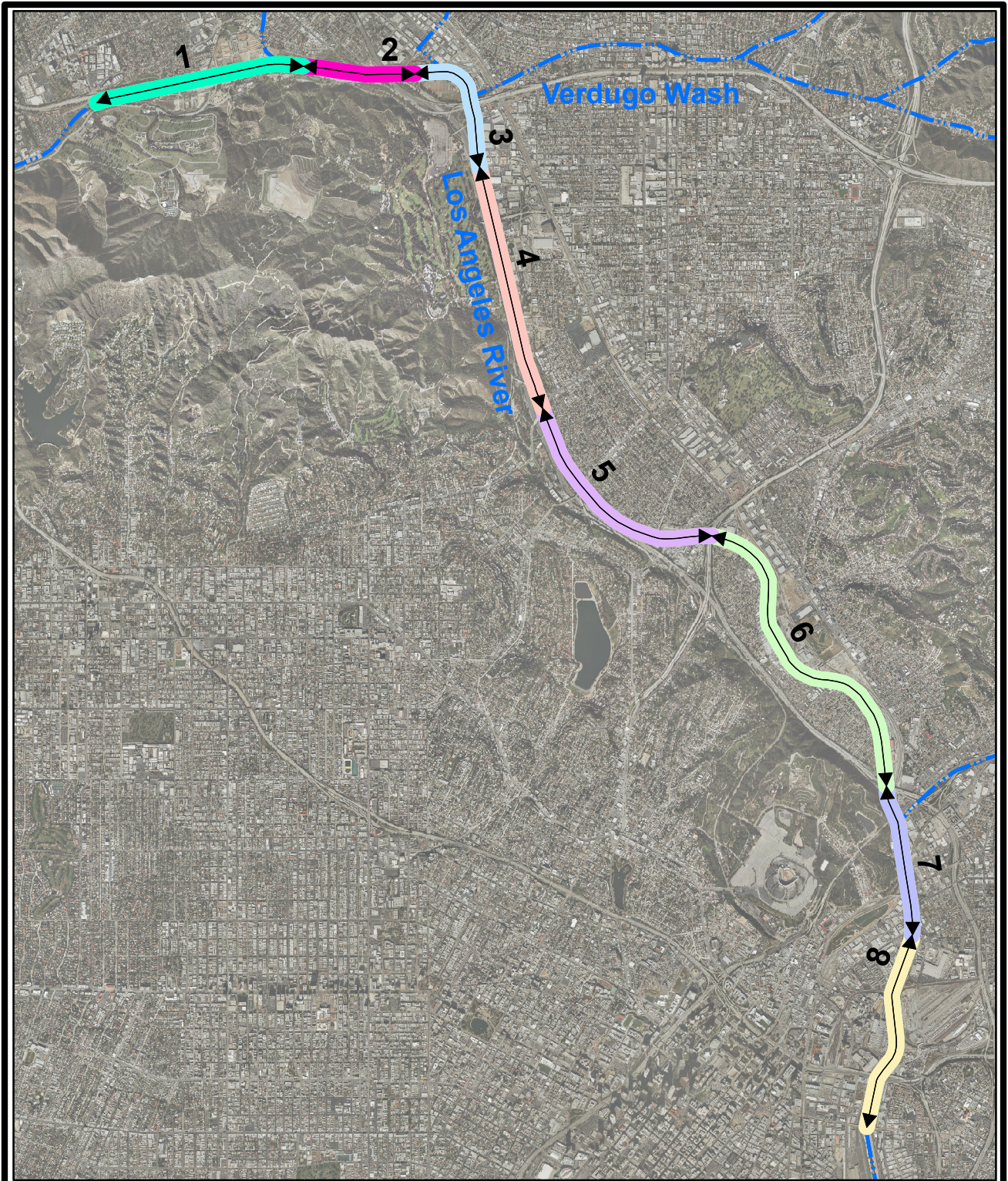
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
UNLINED INVERT SECTIONS
ARBOR AREA**

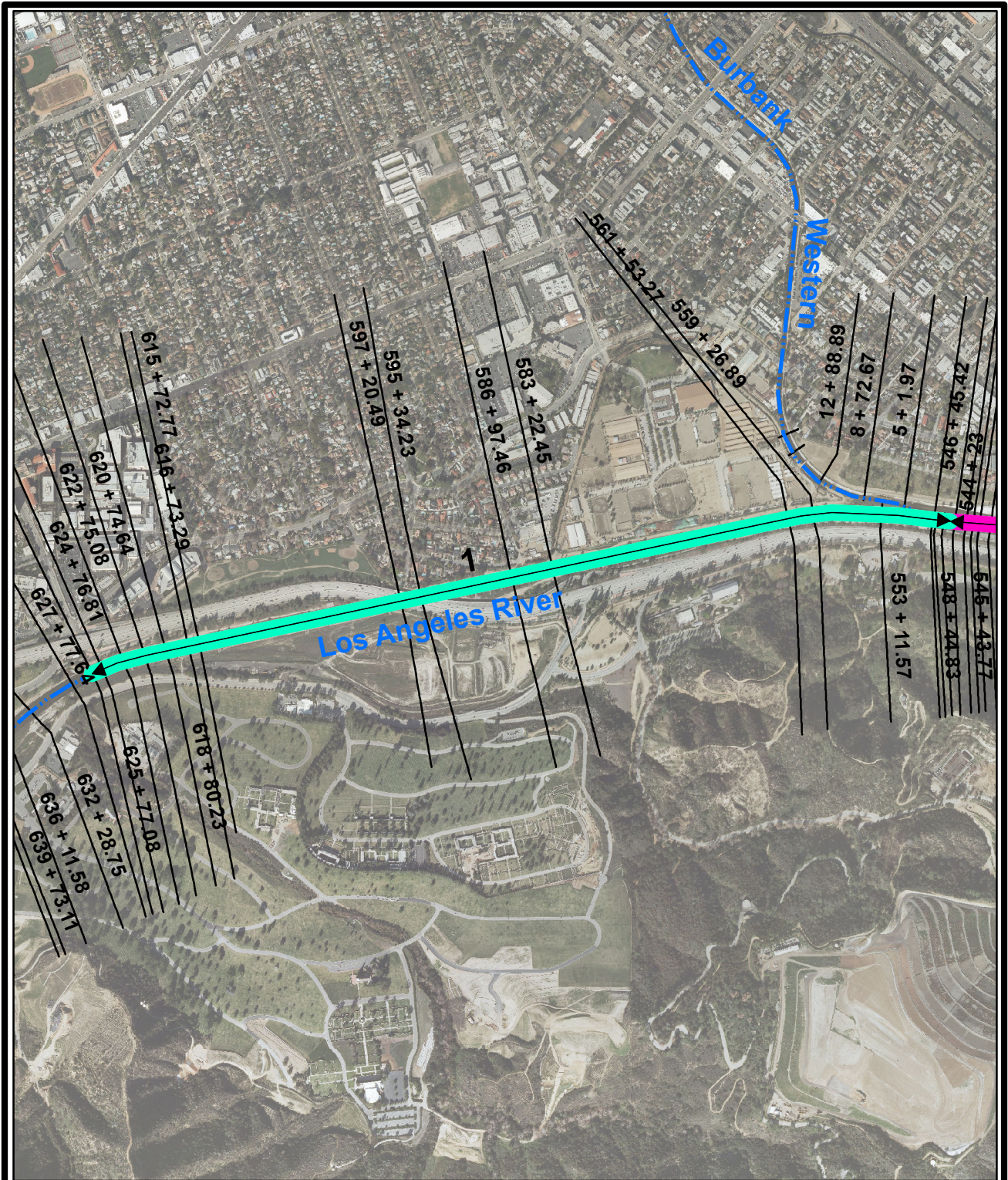
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER ARBOR REACHES

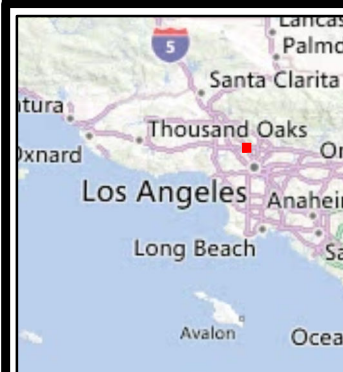
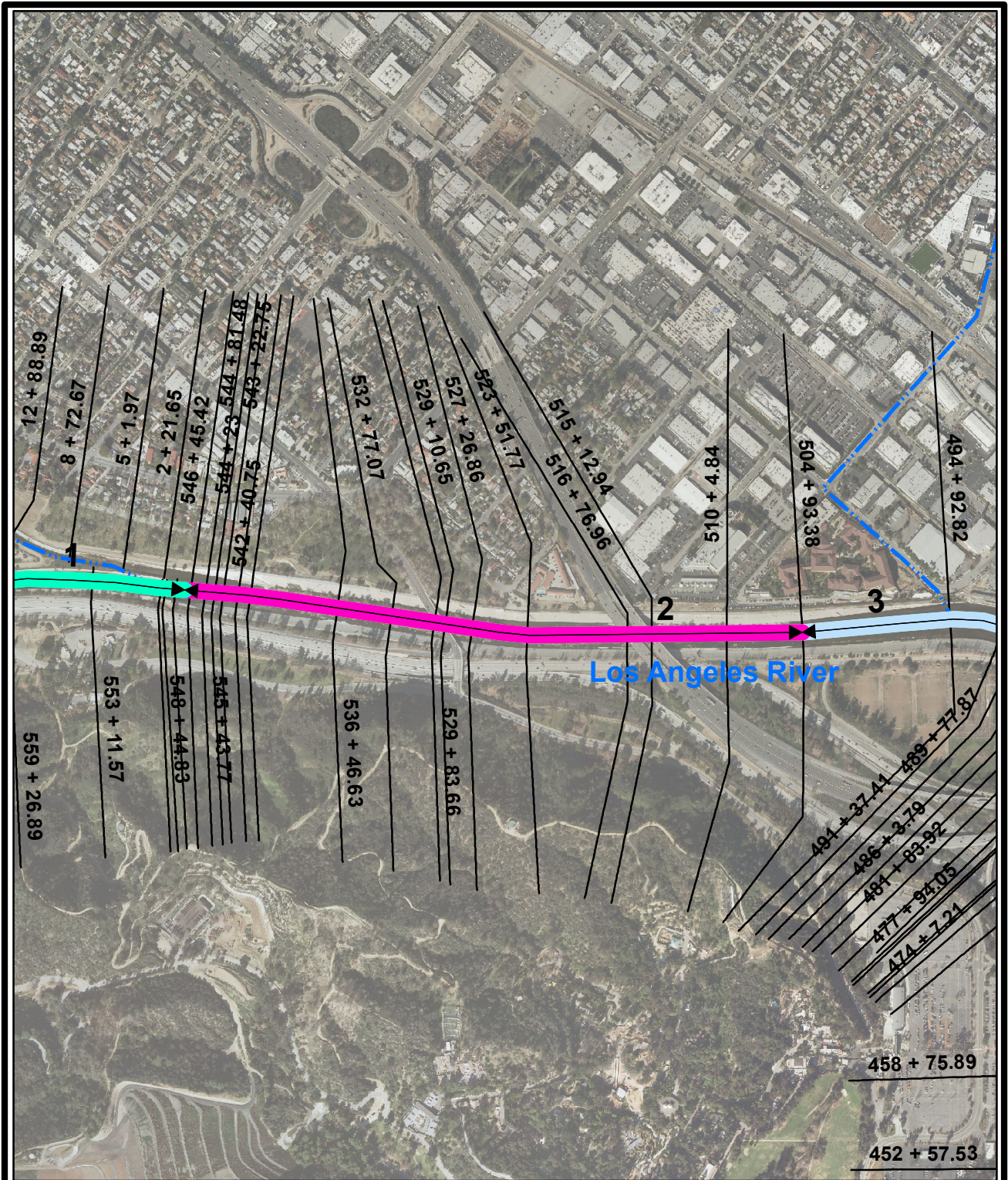
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER CROSS SECTIONS REACH 1

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

**Legend**

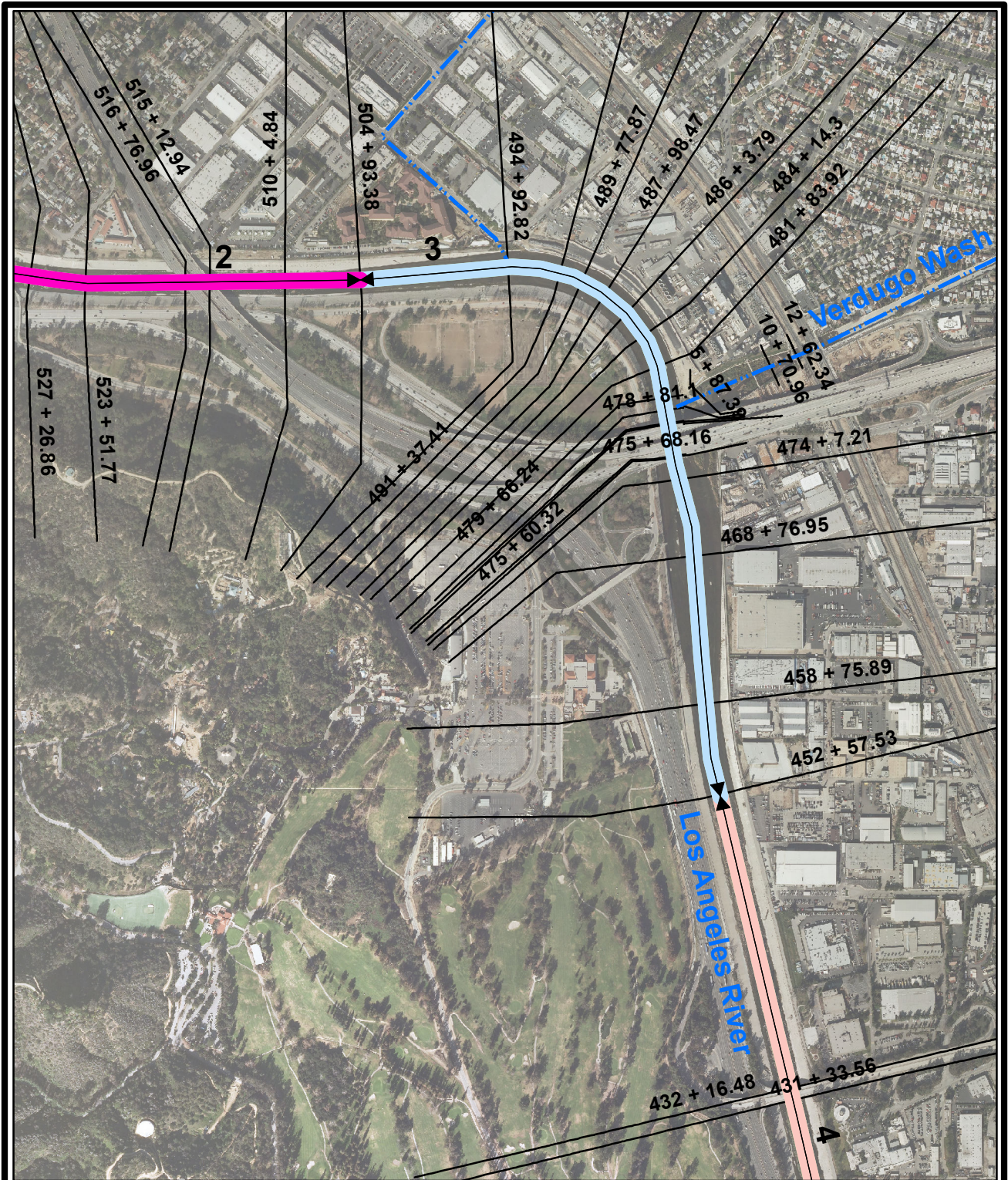
-  Watercourse
-  ARBOR Reaches
-  Cross Section



0 750 1,500
Feet

**LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY****LOS ANGELES RIVER
CROSS SECTIONS
REACH 2**

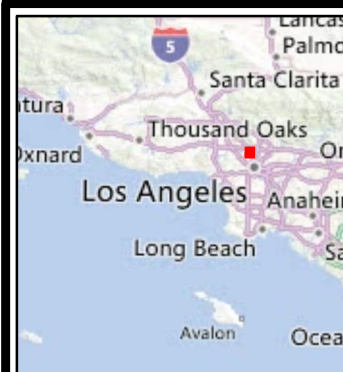
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER CROSS SECTIONS REACH 3

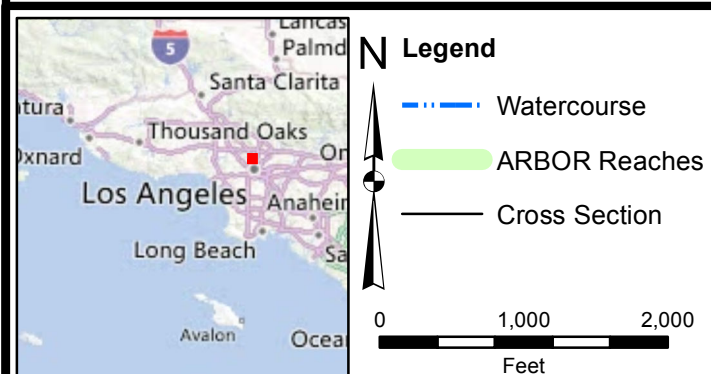
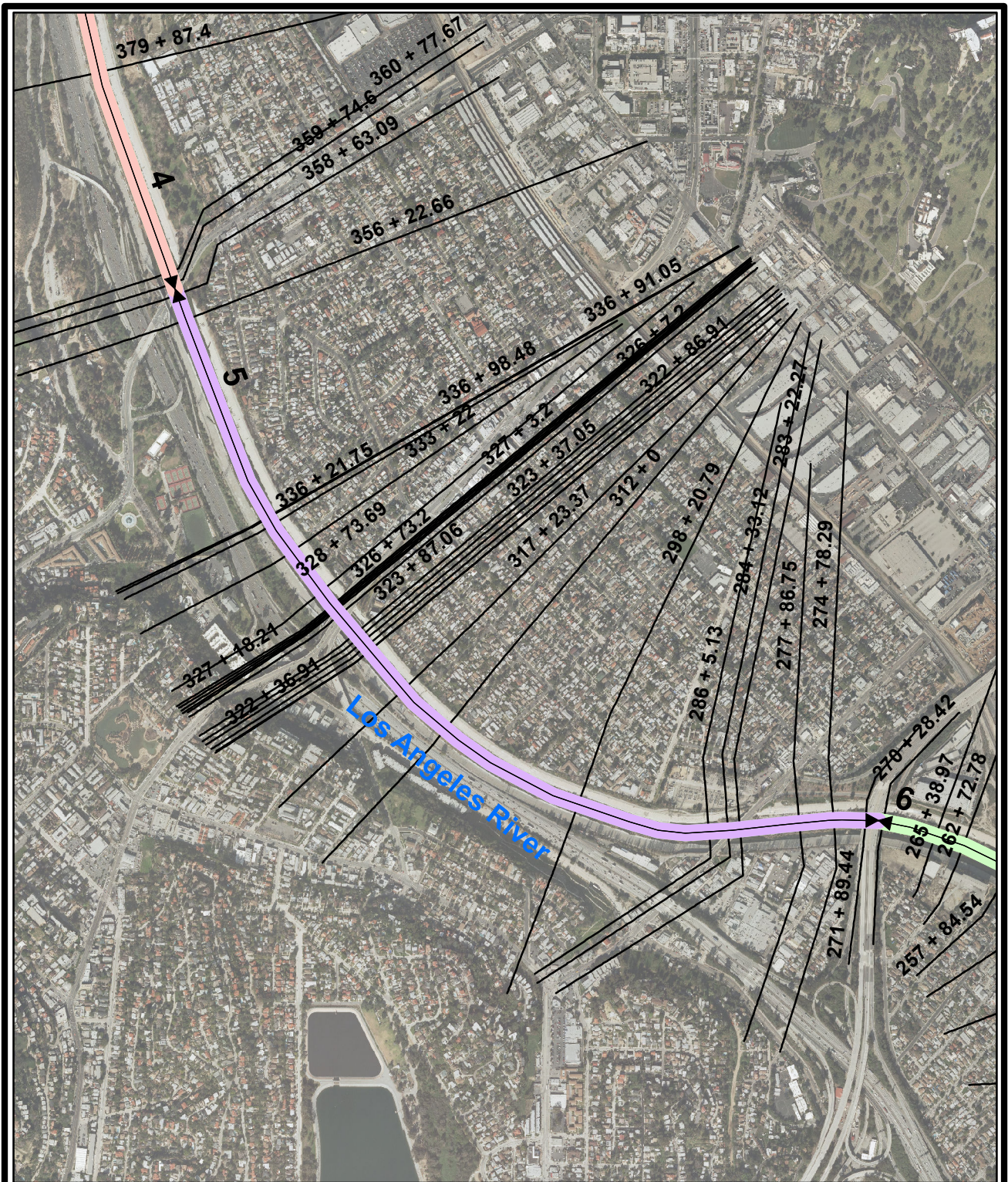
CORPS OF ENGINEERS
LOS ANGELES DISTRICT

**Legend**

-  Watercourse
 -  ARBOR Reaches
 -  Cross Section
- 0 1,000 2,000
Feet

**LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY****LOS ANGELES RIVER
CROSS SECTIONS
REACH 4**

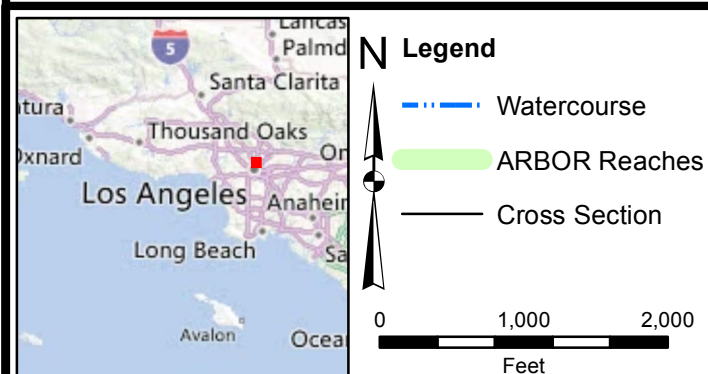
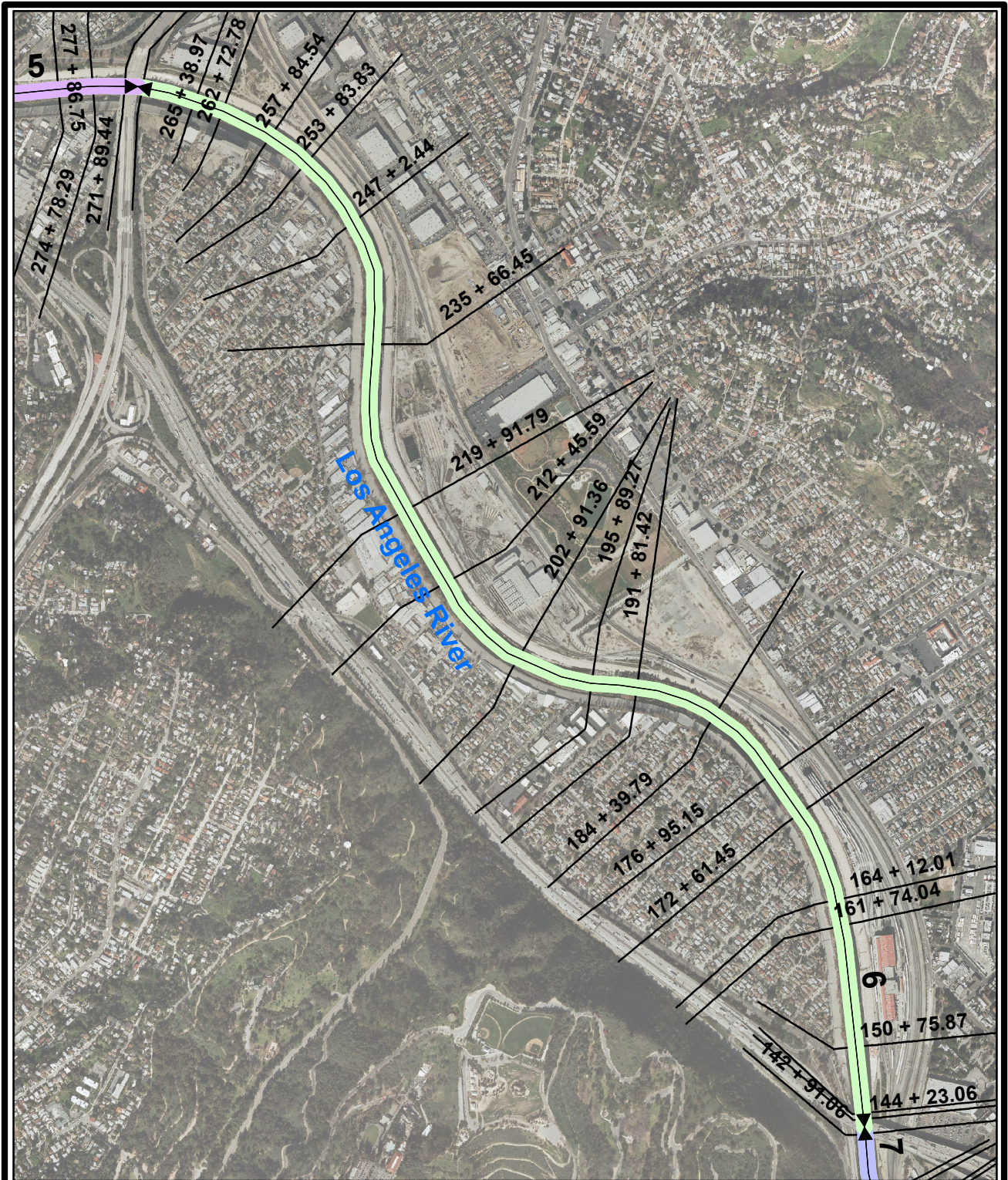
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER CROSS SECTIONS REACH 5

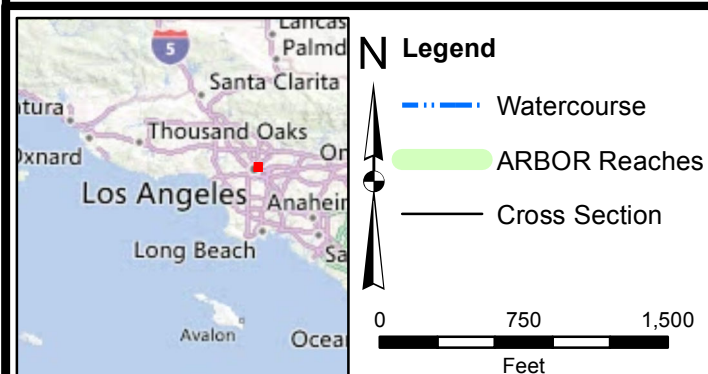
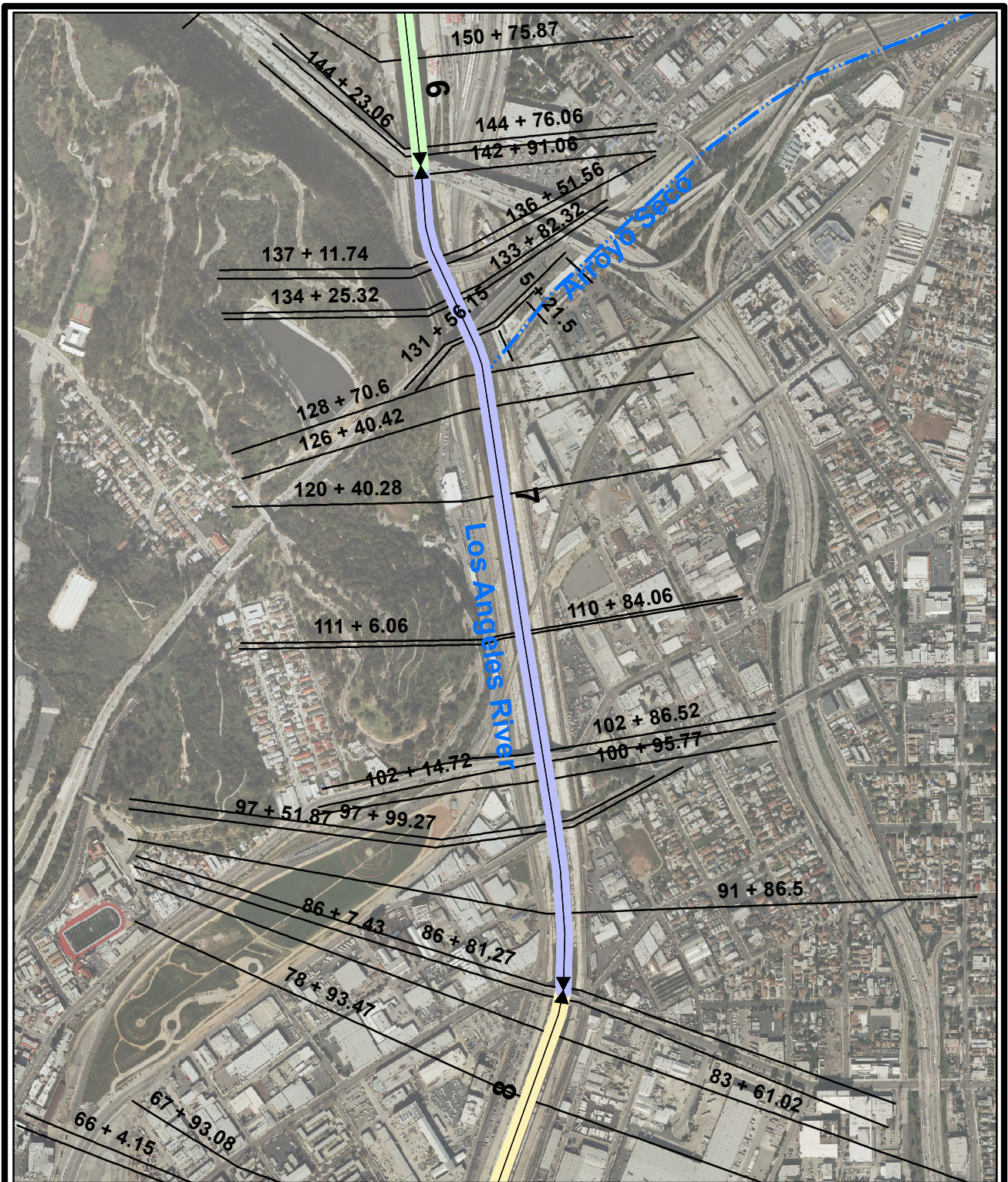
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER CROSS SECTIONS REACH 6

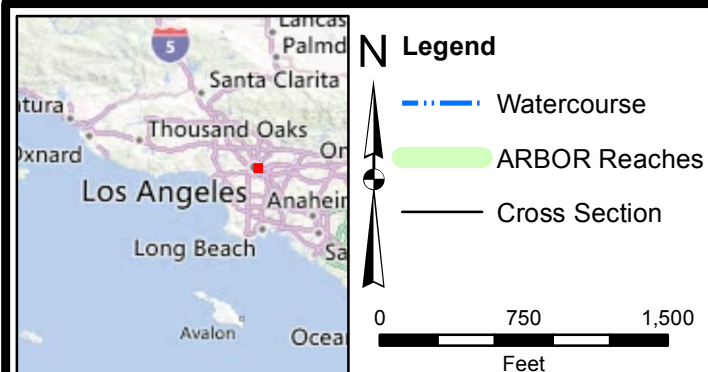
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER CROSS SECTIONS REACH 7

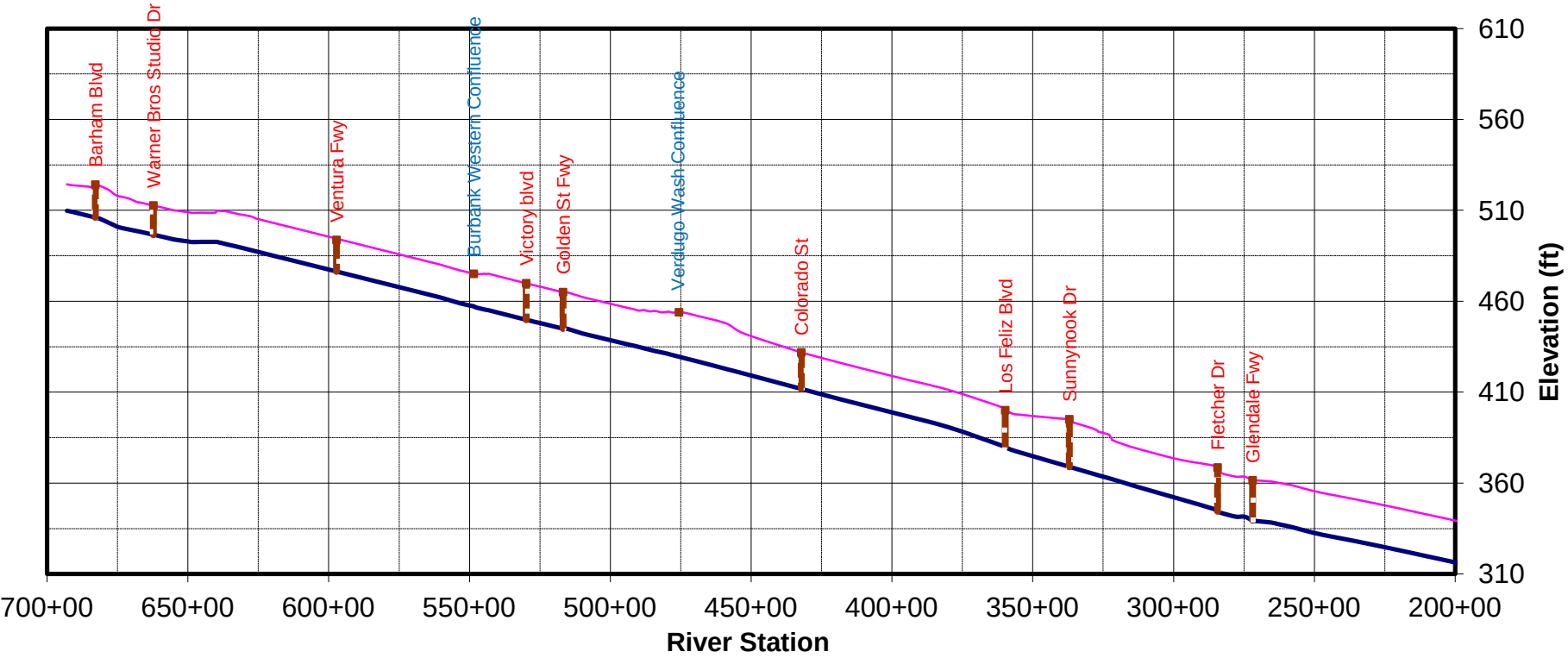
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER CROSS SECTIONS REACH 8

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



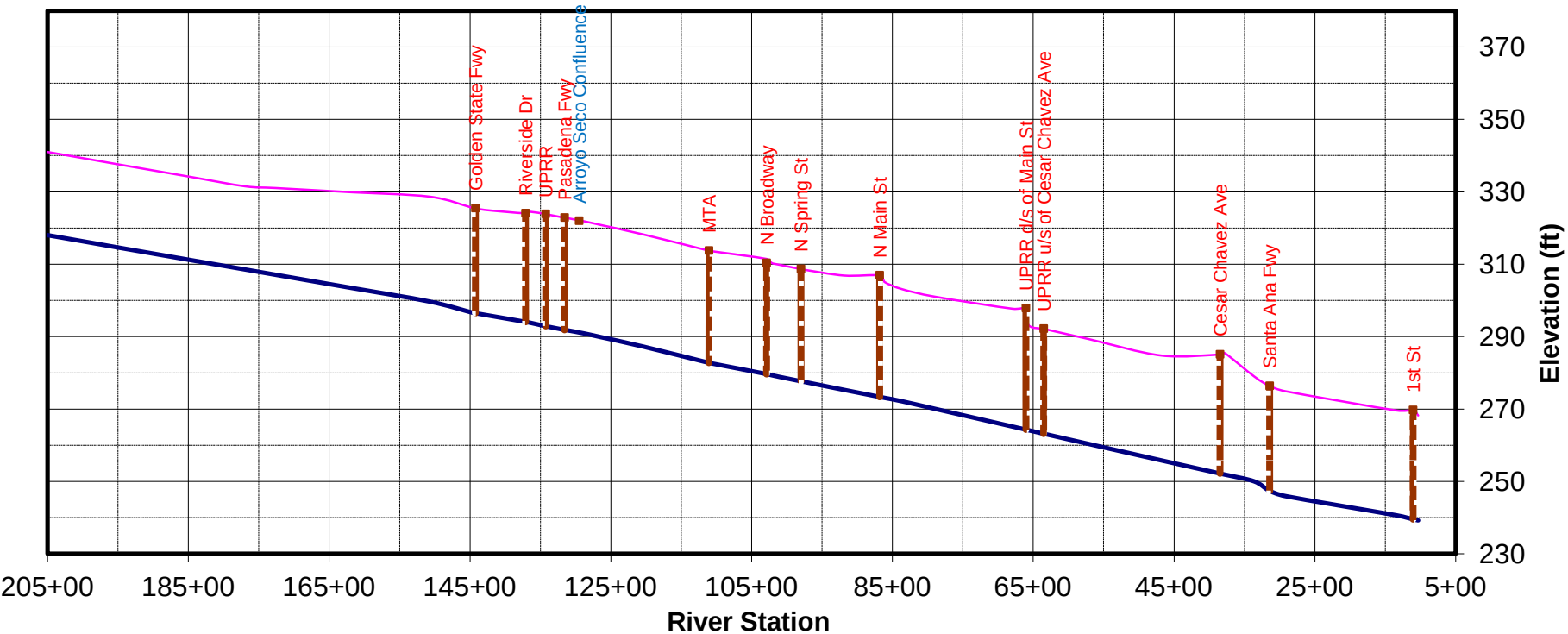
Streambed elevations based on lowest elevation in cross section from HEC-RAS models for the existing conditions.

—LAR Invert —Top of Channel Bridge

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER
INVERT PROFILE WITH
BRIDGE LOCATIONS

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



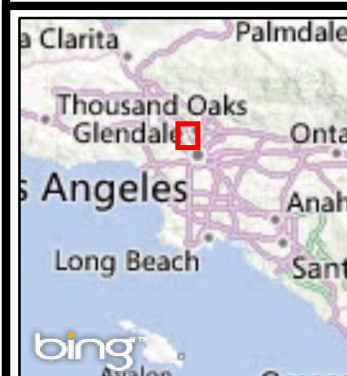
Streambed elevations based on lowest elevation in cross section from HEC-RAS models for the existing conditions.

—LAR Invert —Top of Channel - - - - - Bridge

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER
INVERT PROFILE WITH
BRIDGE LOCATIONS

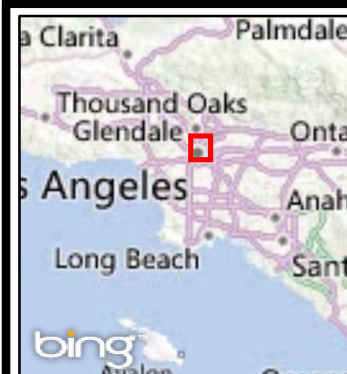
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



 Watercourse
 25-yr w/o vegetation
 25-yr w/ vegetation

LOS ANGELES RIVER 4% ACE EVENT FLOODPLAINS

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

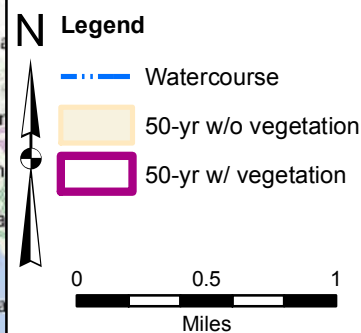
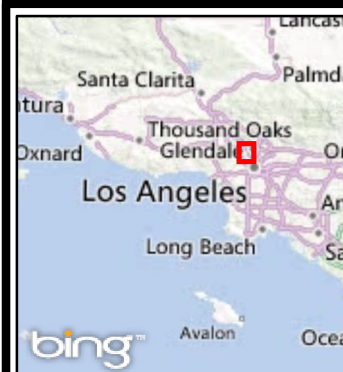
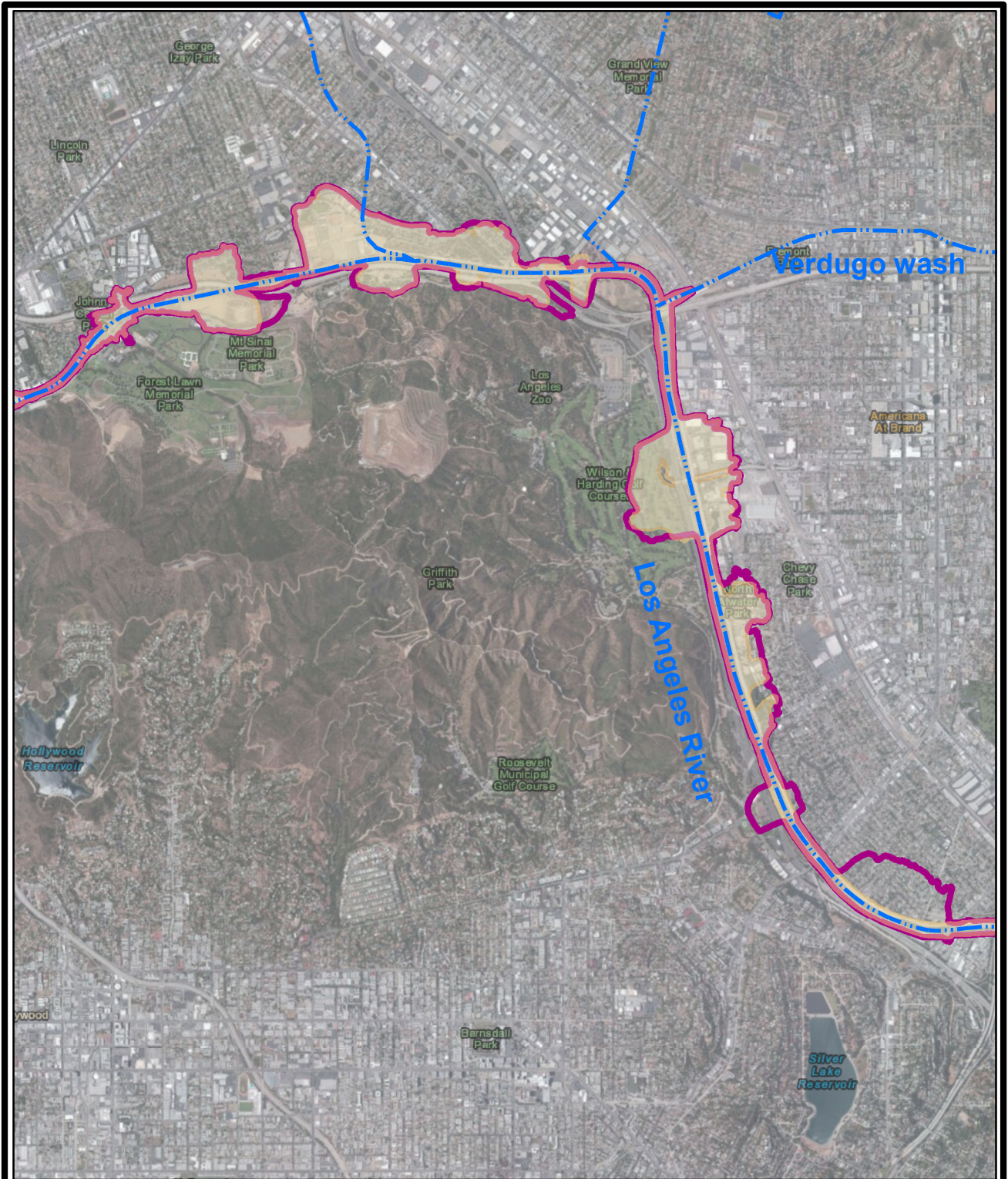
**Legend**

- Watercourse
- 25-yr w/o vegetation
- 25-yr w/ vegetation

0 0.5 1
Miles

**LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY****LOS ANGELES RIVER
4% ACE EVENT
FLOODPLAINS**

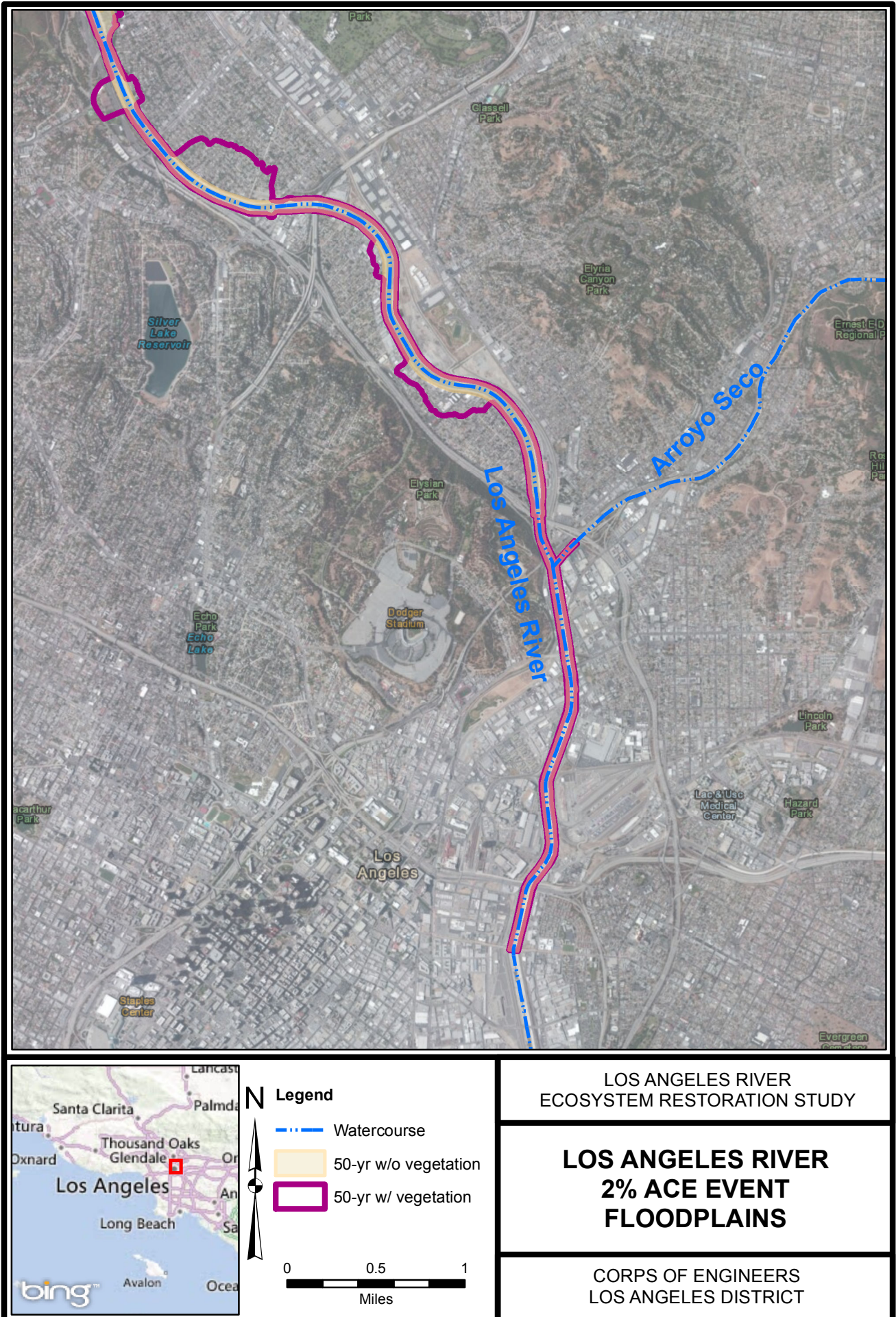
CORPS OF ENGINEERS
LOS ANGELES DISTRICT

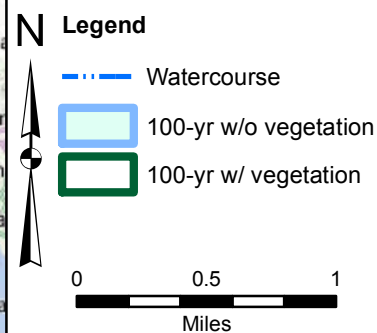
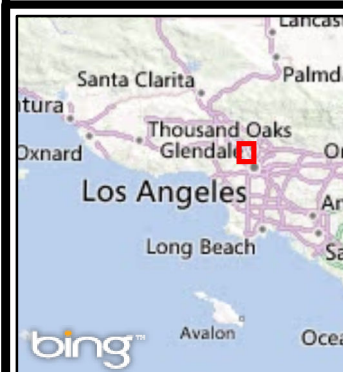
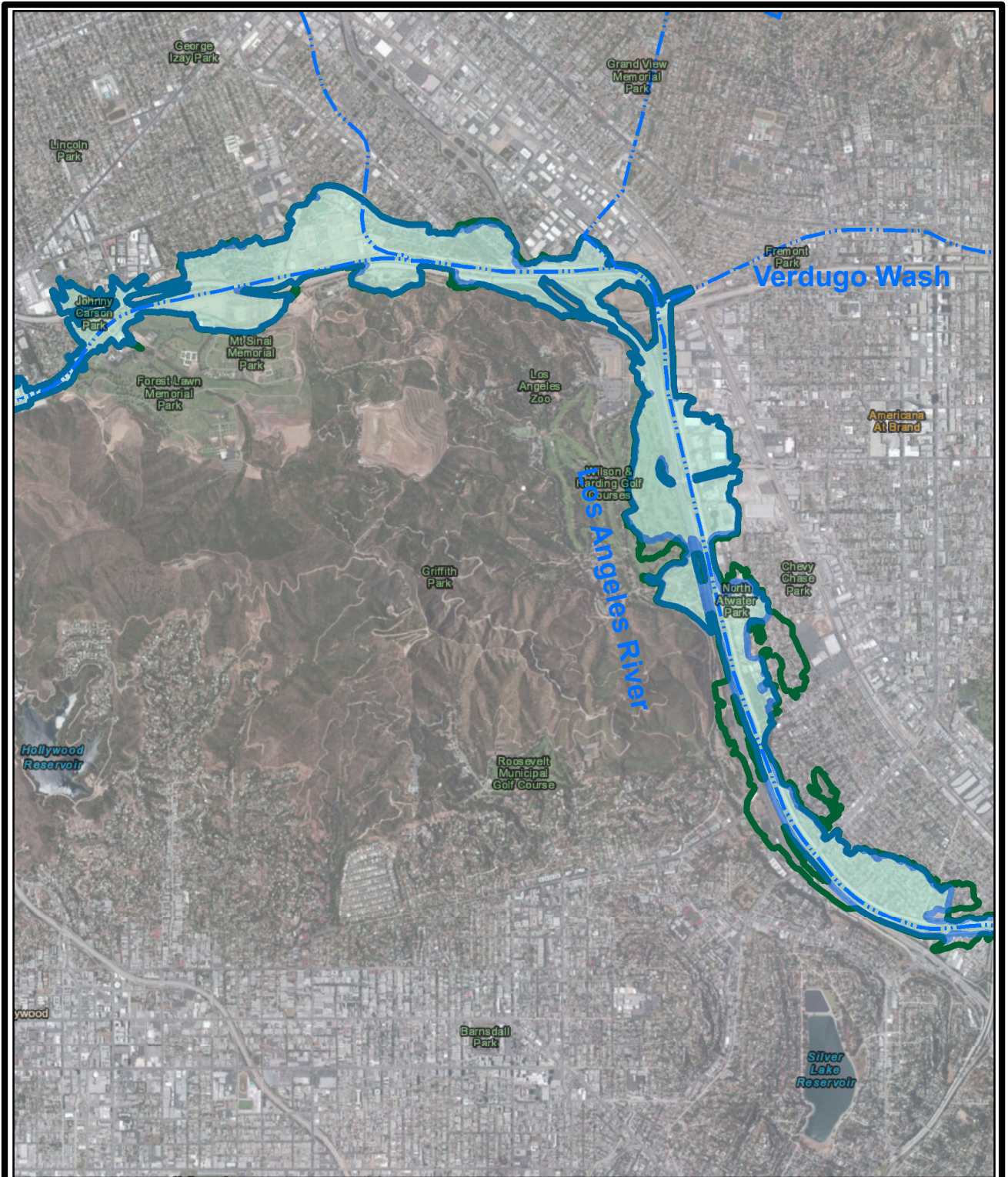


LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
2% ACE EVENT
FLOODPLAINS**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

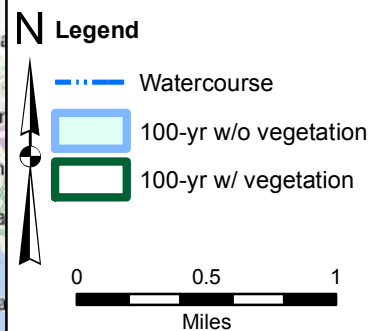
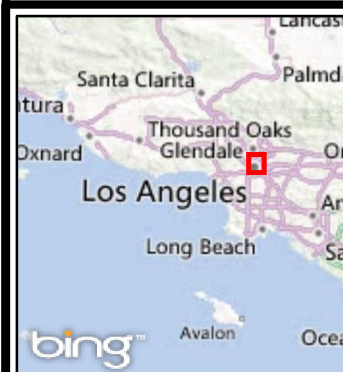




LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
1% ACE EVENT
FLOODPLAINS**

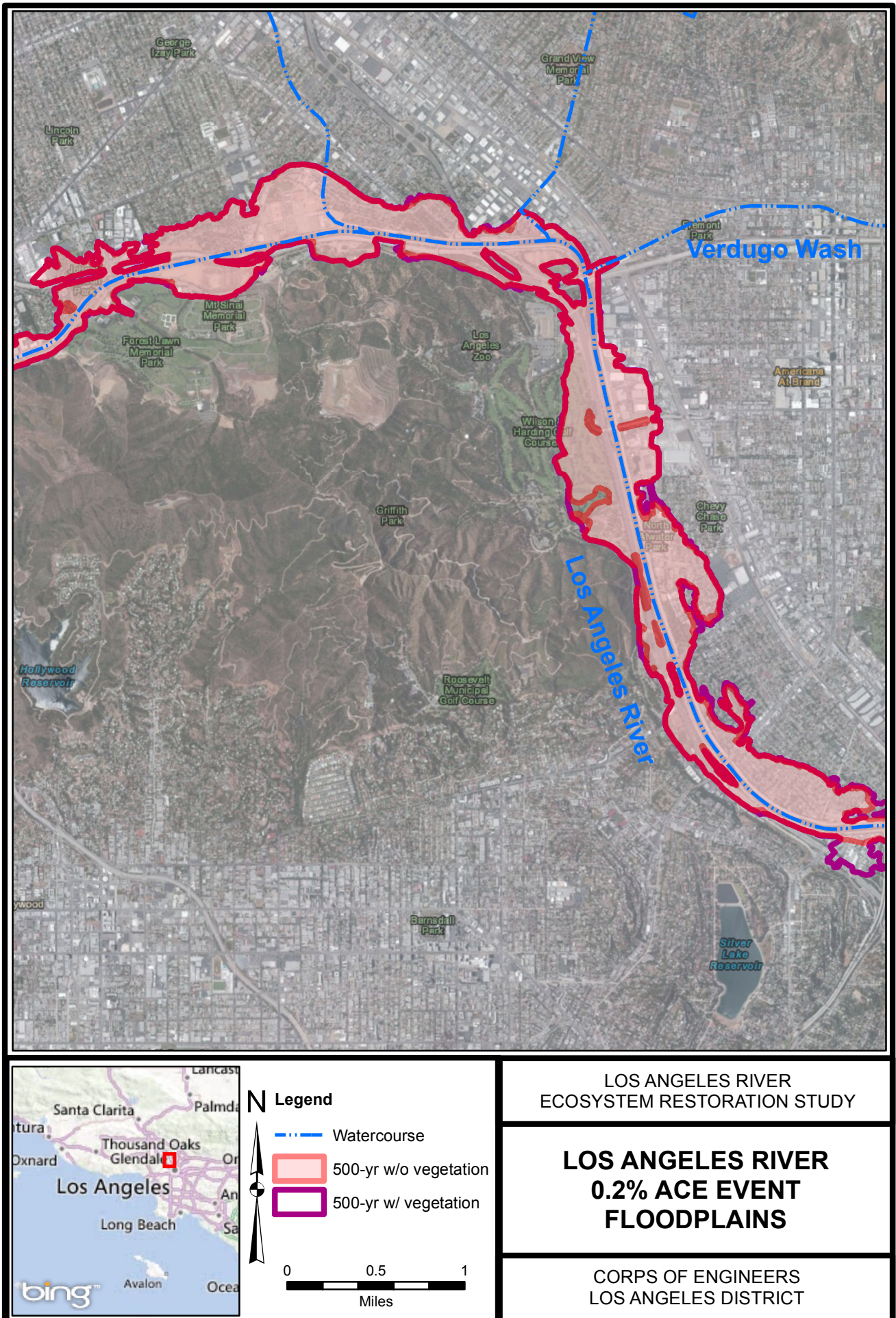
CORPS OF ENGINEERS
LOS ANGELES DISTRICT

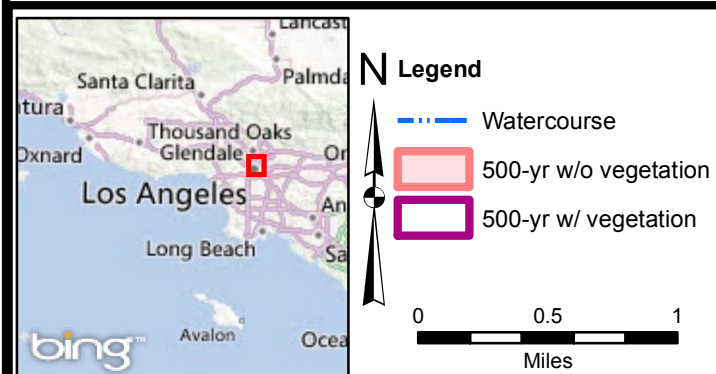


LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

LOS ANGELES RIVER 1% ACE EVENT FLOODPLAINS

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

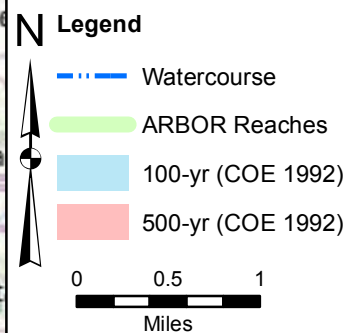
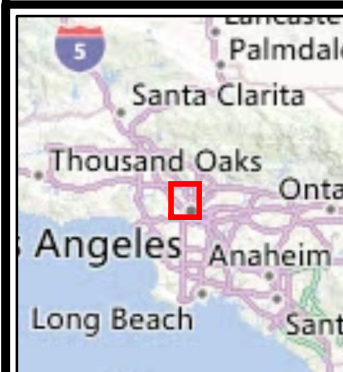
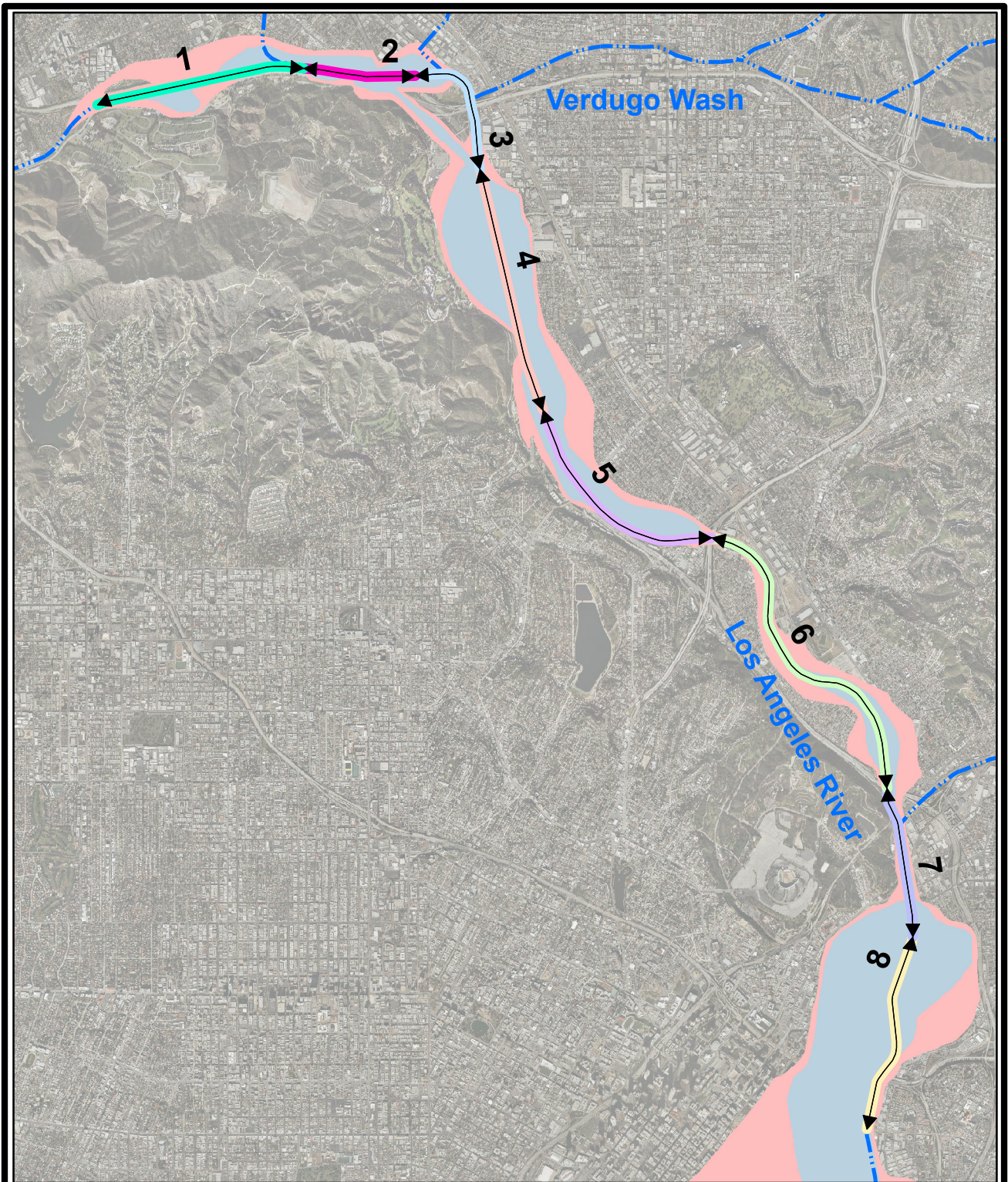




LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
0.2% ACE EVENT
FLOODPLAINS**

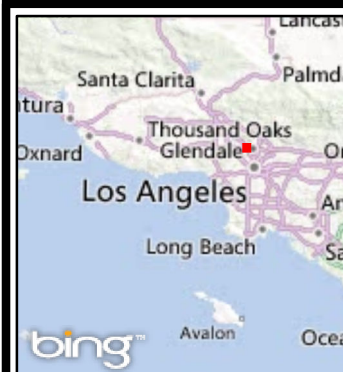
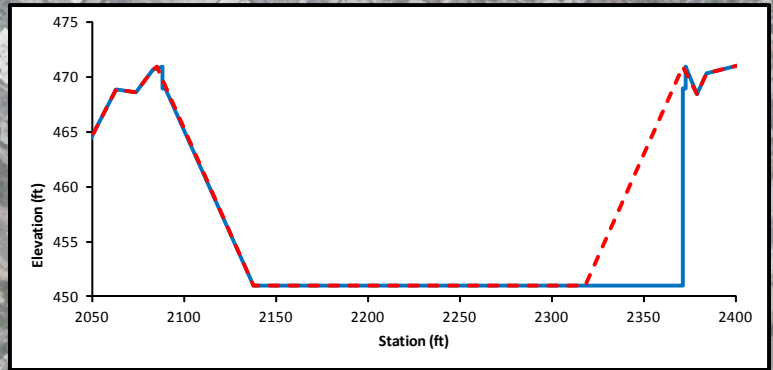
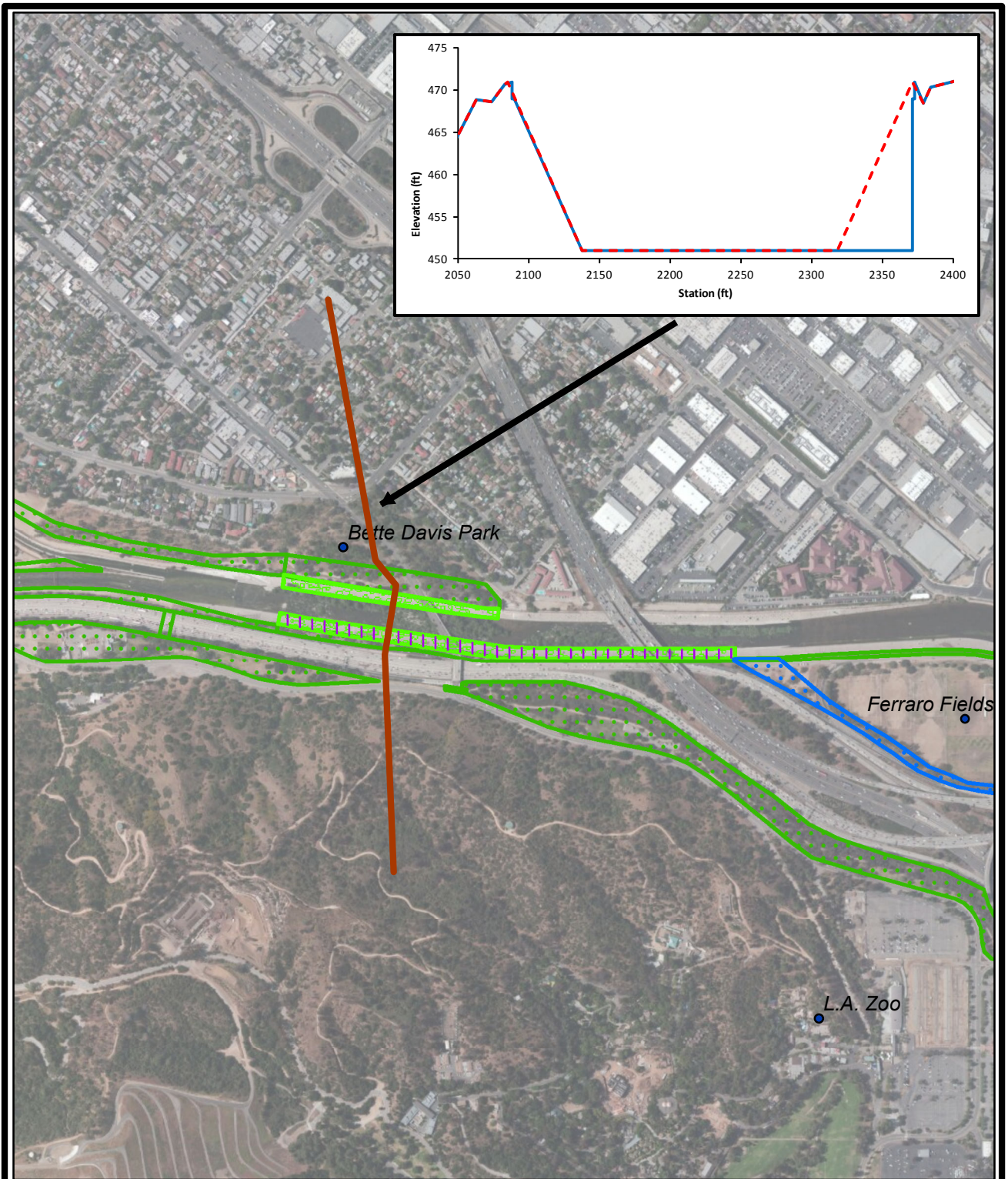
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**LOS ANGELES RIVER
1% & 0.2% AEC EVENTS
FLOODPLAINS
(from 1992 LACDA Study)**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



Legend

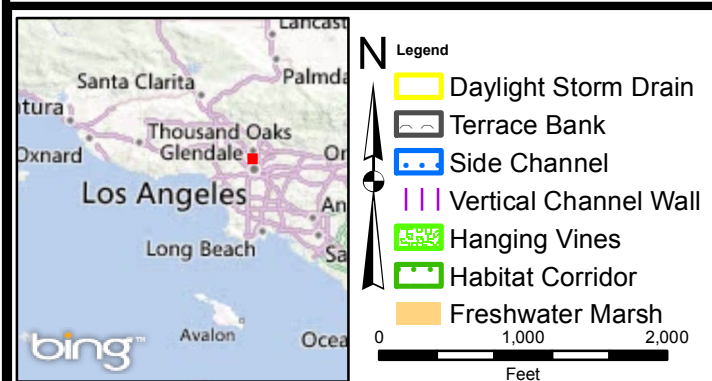
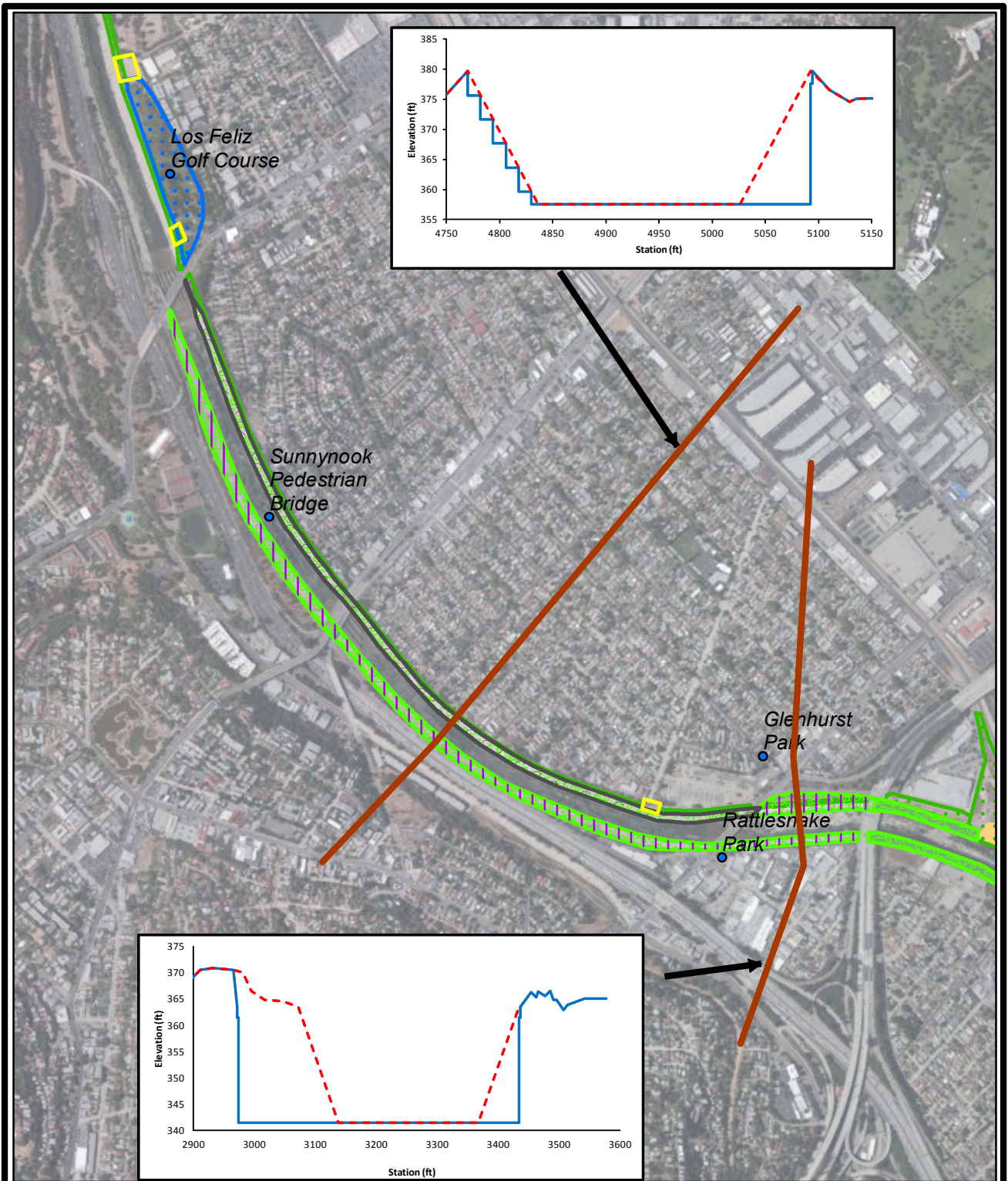
- Side Channel
- Vertical Side Walls
- Hanging Vines
- Habitat Corridor

0 750 1,500
Feet

**LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY**

**ALT. 20 REACH 2
TYPICAL CROSS
SECTION**

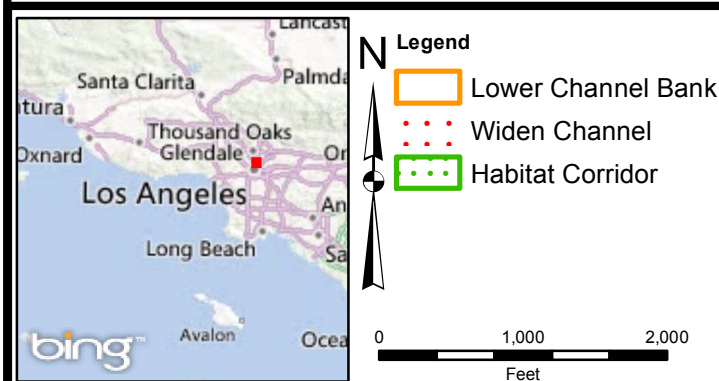
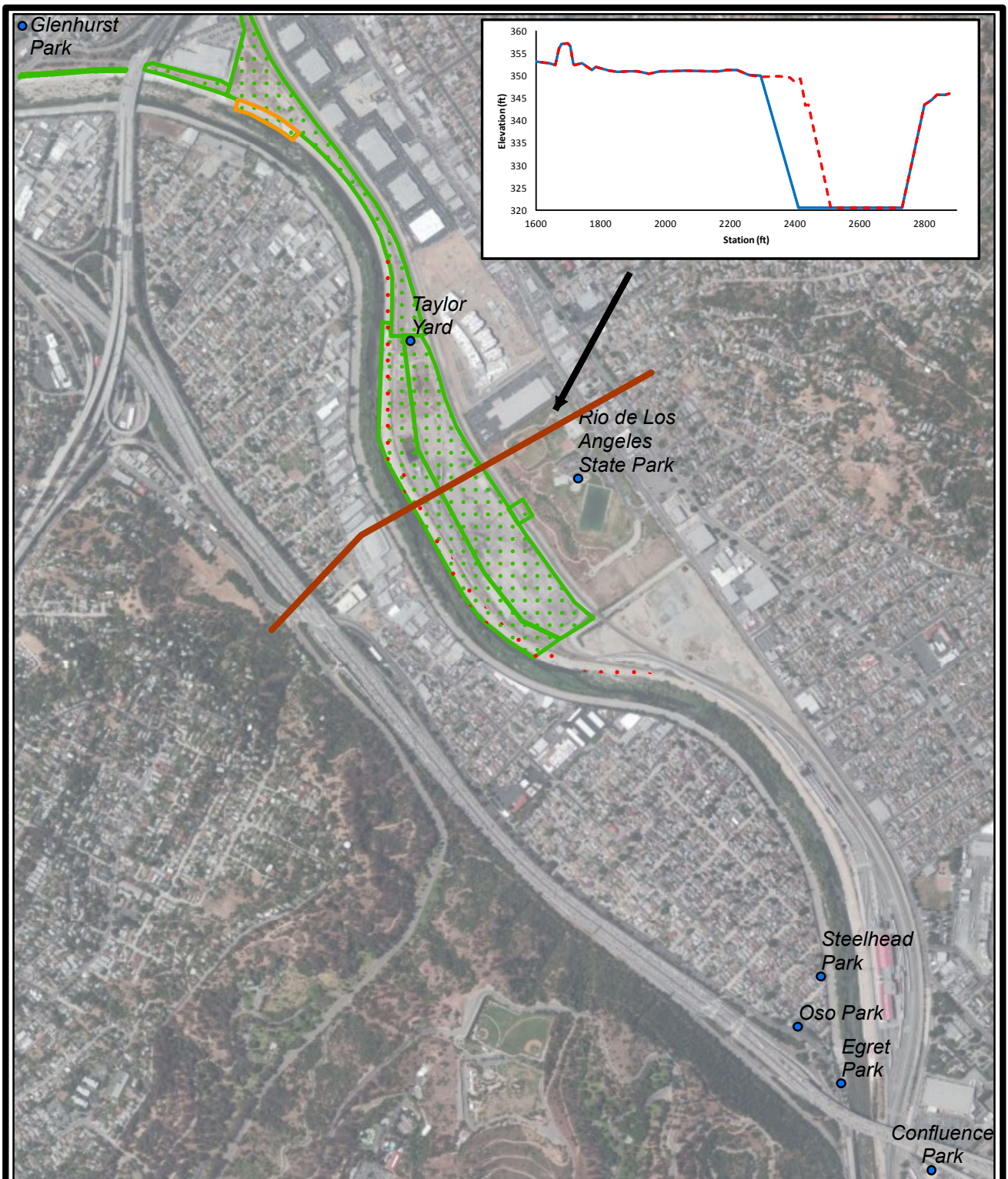
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 20 REACH 5
TYPICAL CROSS
SECTIONS**

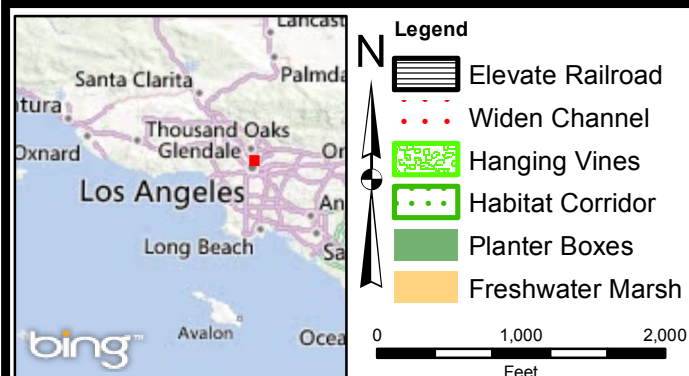
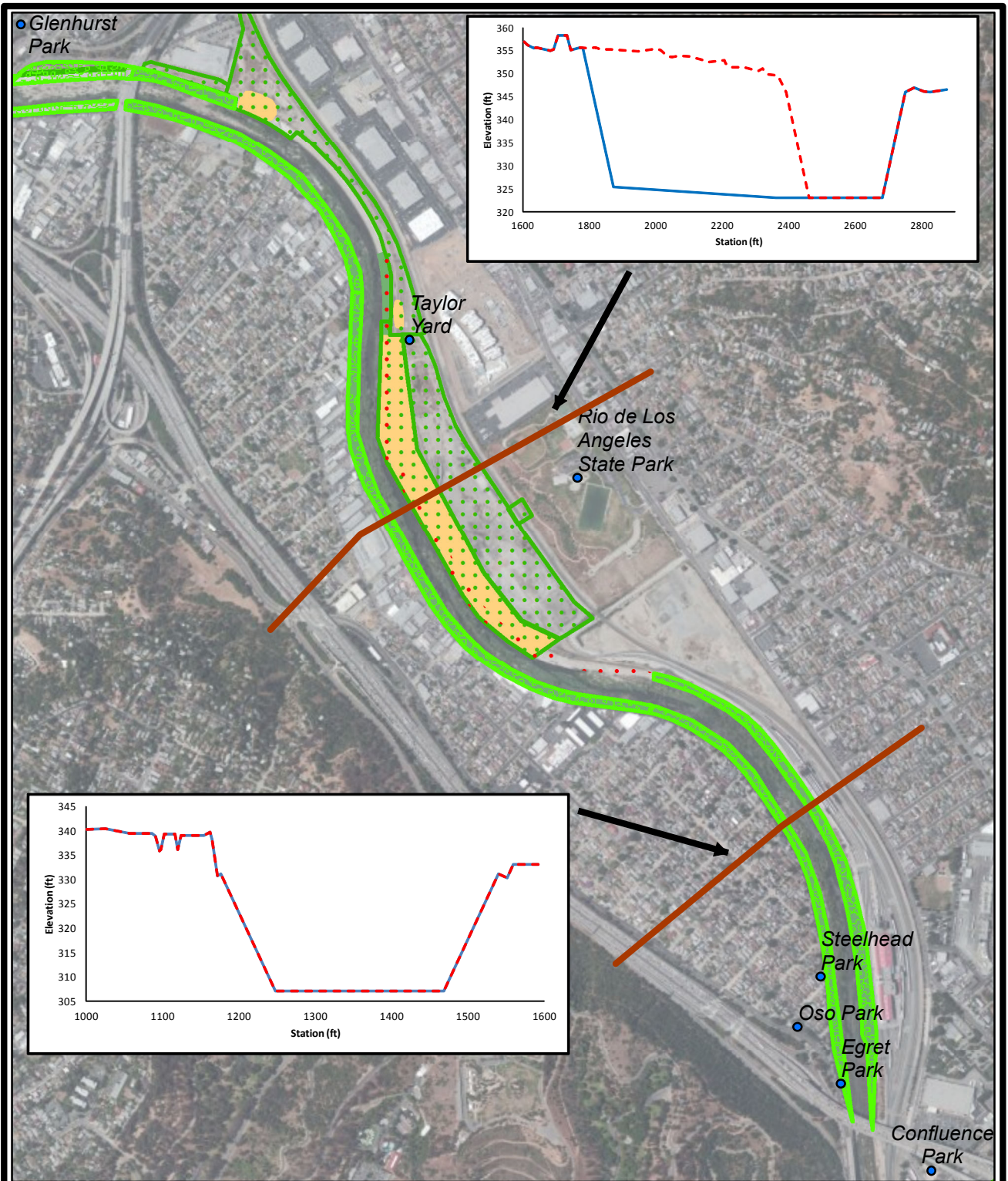
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER ECOSYSTEM RESTORATION STUDY

ALT. 10 REACH 6 TYPICAL CROSS SECTIONS

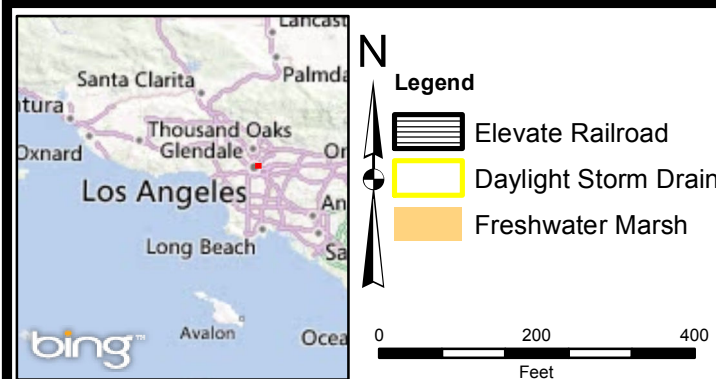
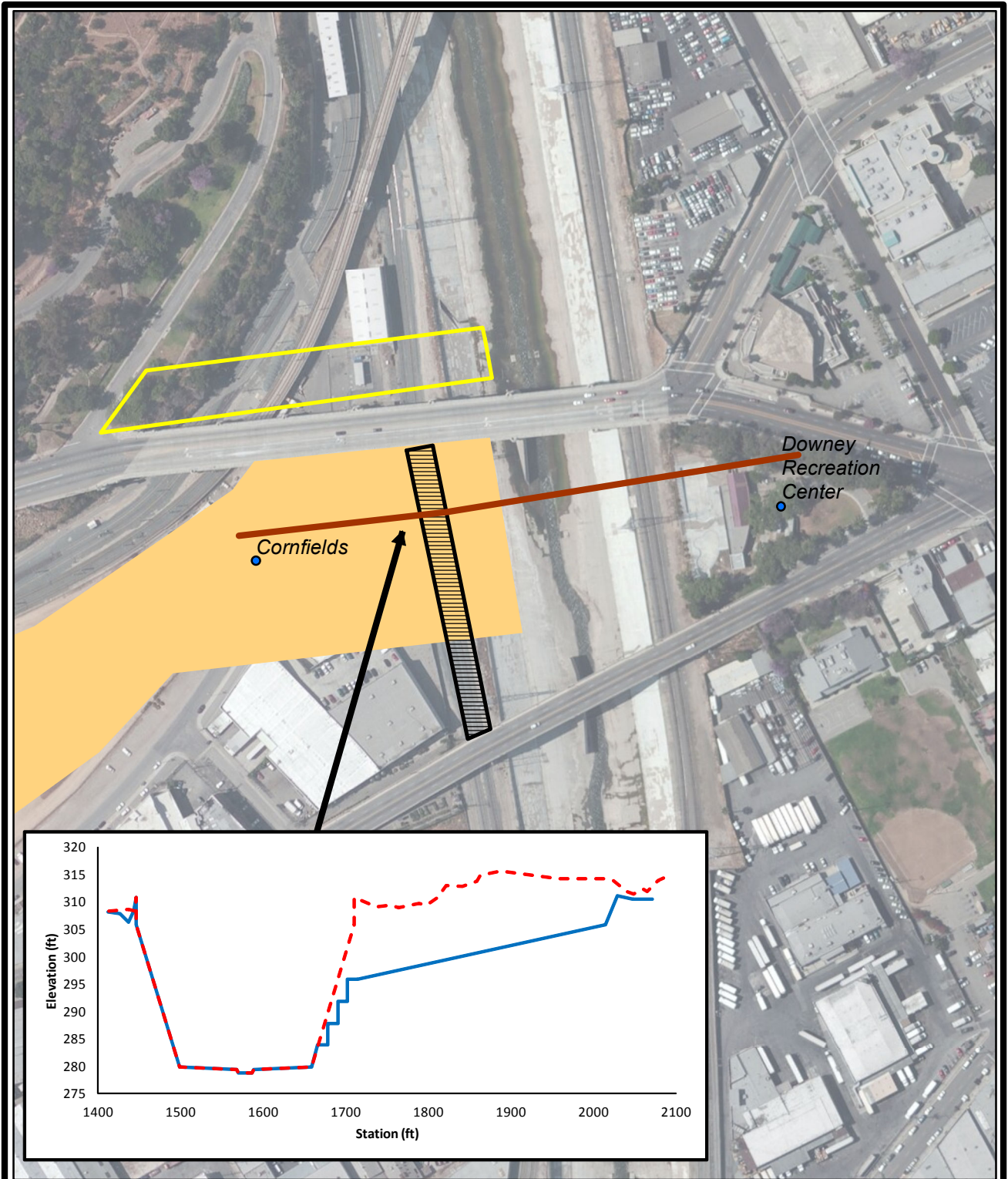
CORPS OF ENGINEERS
LOS ANGELES DISTRICT

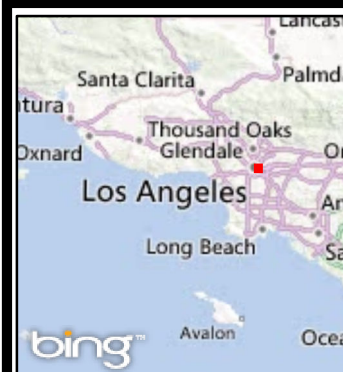
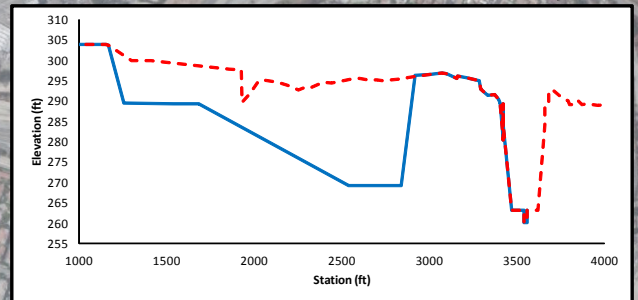
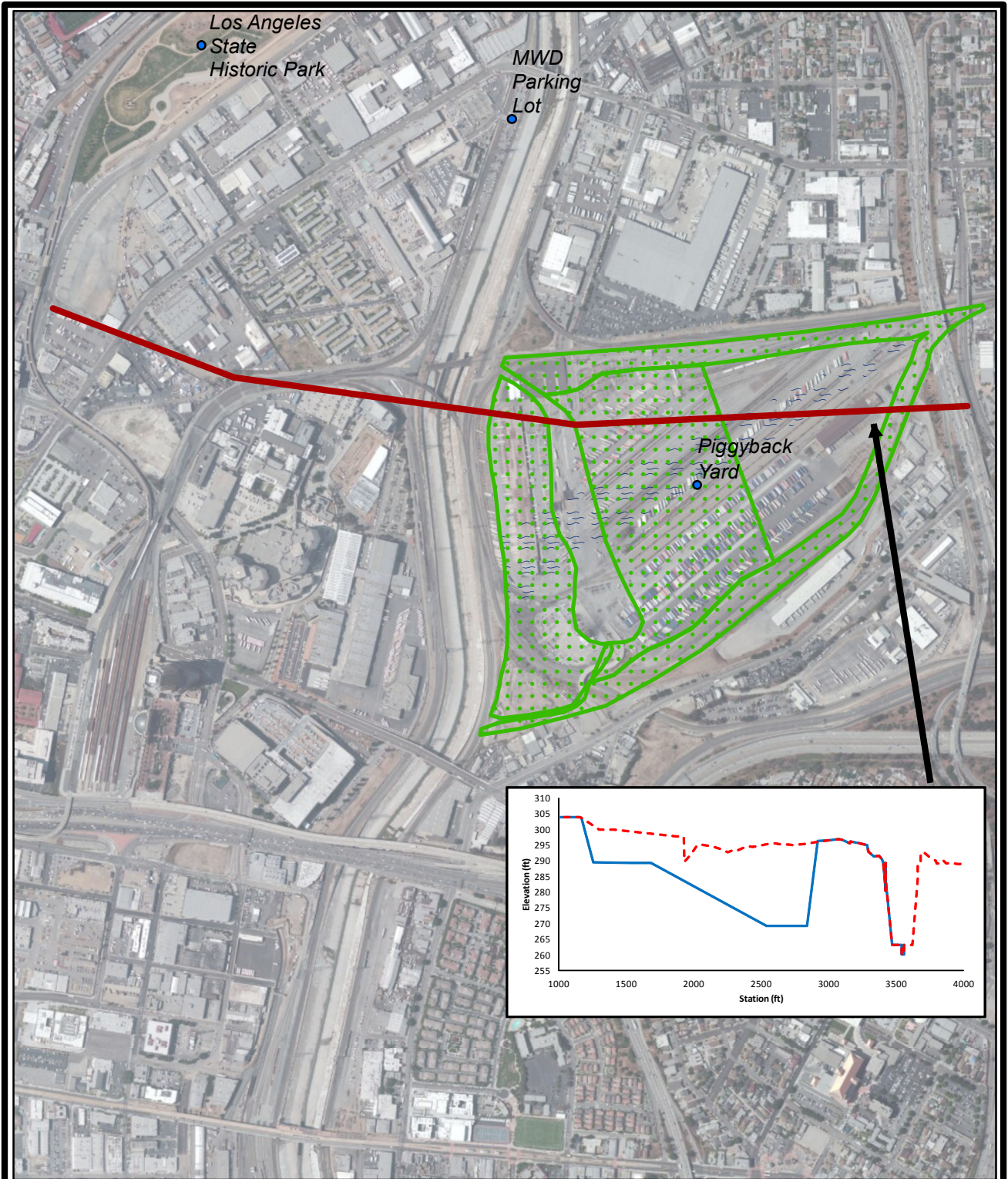


LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 20 REACH 6
TYPICAL CROSS
SECTIONS**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT





Legend

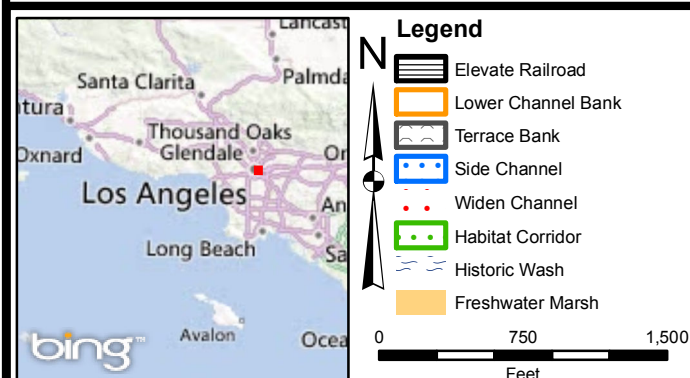
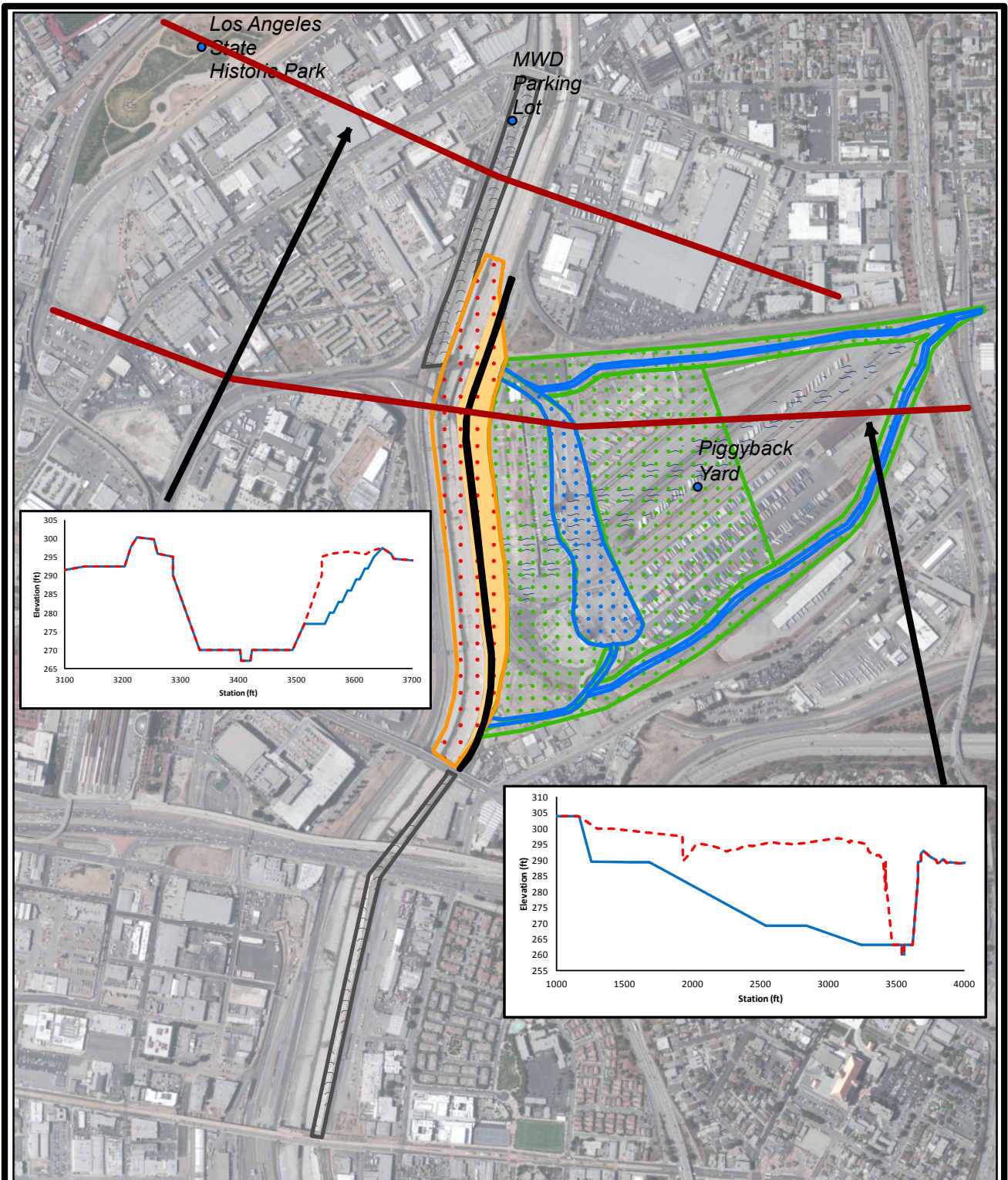
- Habitat Corridor
- Historic Wash

0 750 1,500
Feet

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

ALT. 13 REACH 8 TYPICAL CROSS SECTIONS

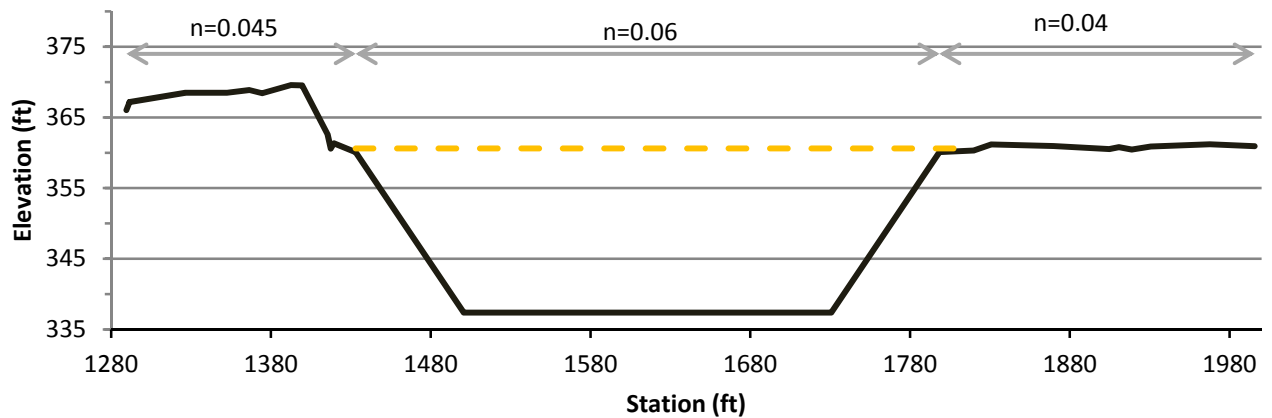
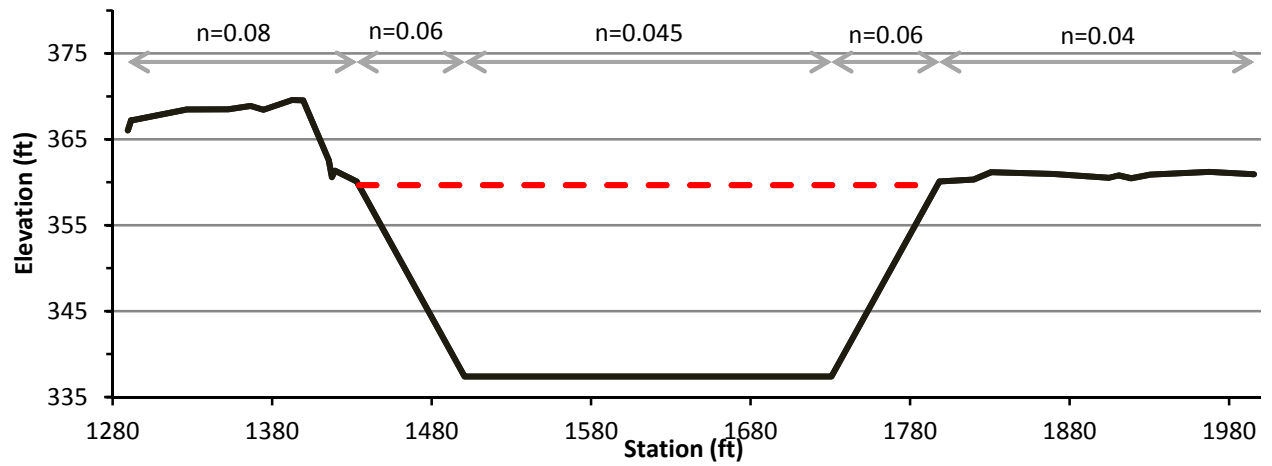
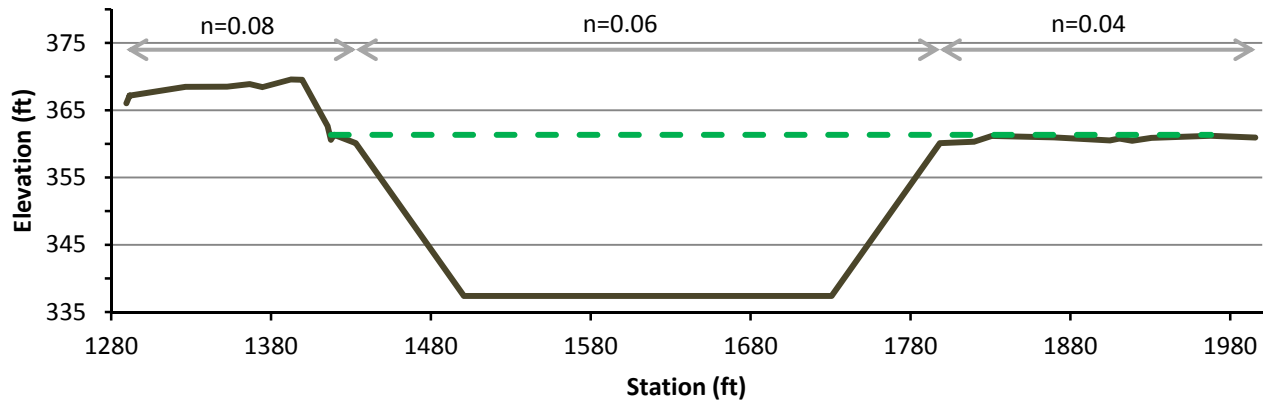
CORPS OF ENGINEERS
LOS ANGELES DISTRICT



LOS ANGELES RIVER ECOSYSTEM RESTORATION STUDY

ALT. 20 REACH 8 TYPICAL CROSS SECTIONS

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

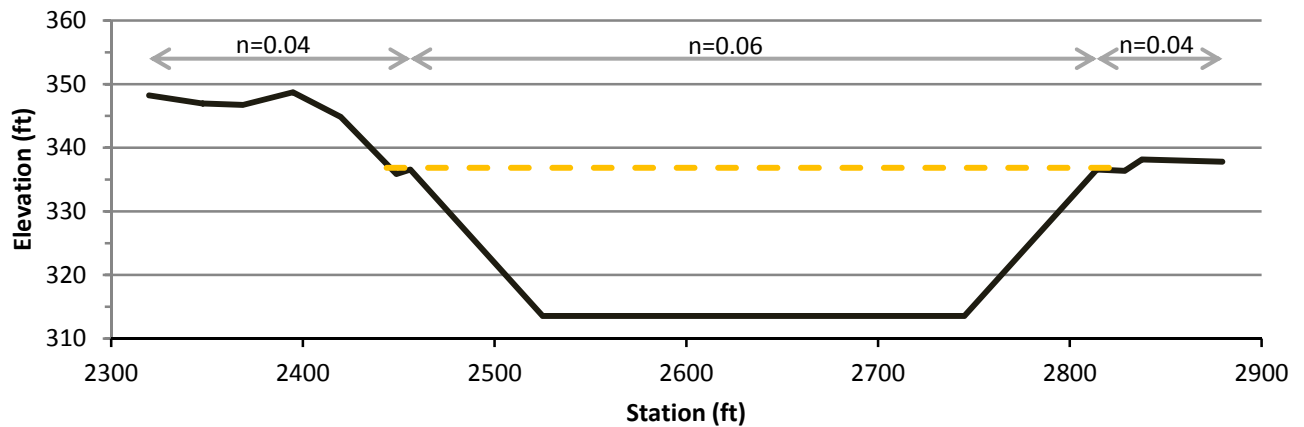
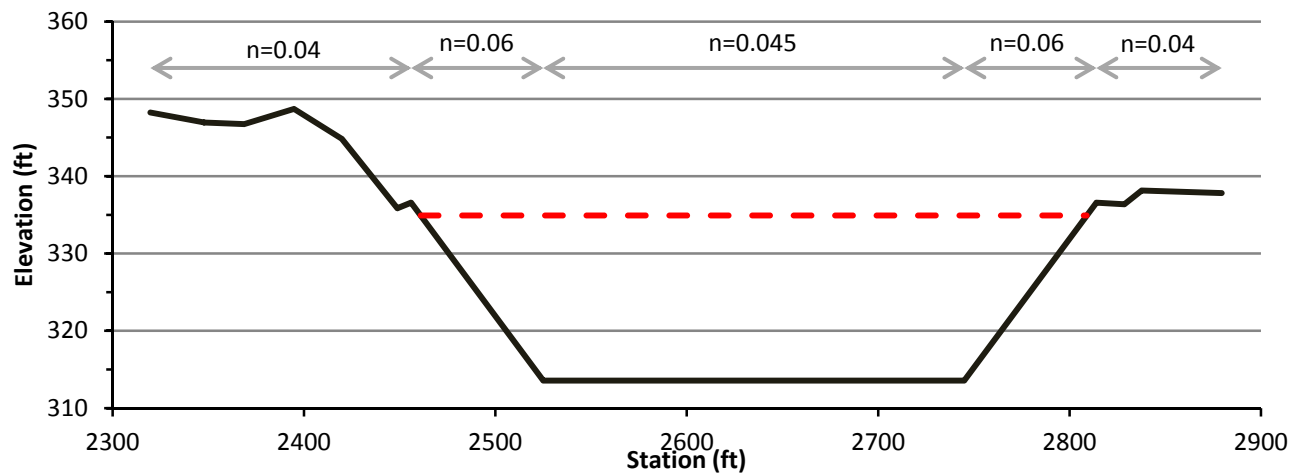
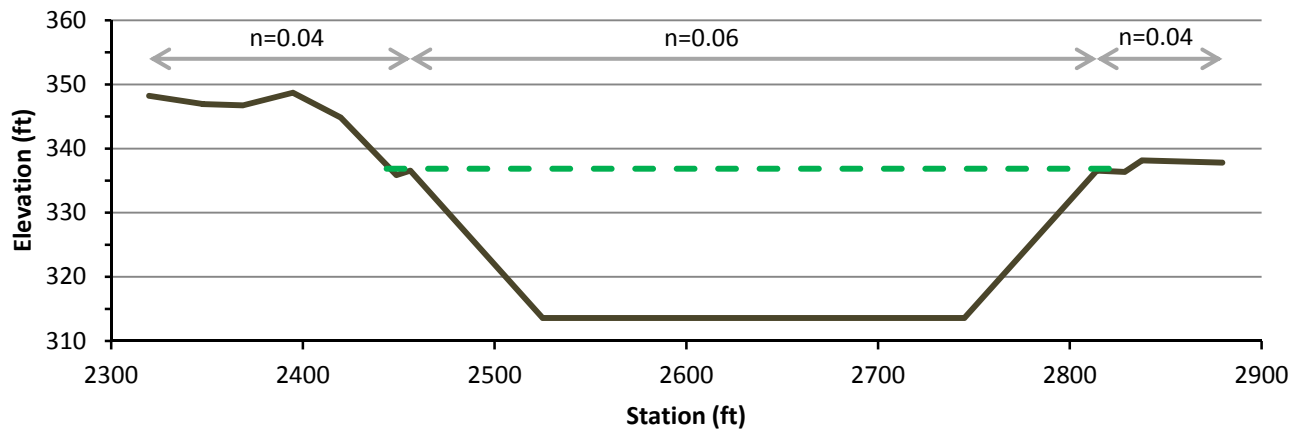


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 10 REACH 6
WSE COMPARISON
CROSS SECTION 262+72**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

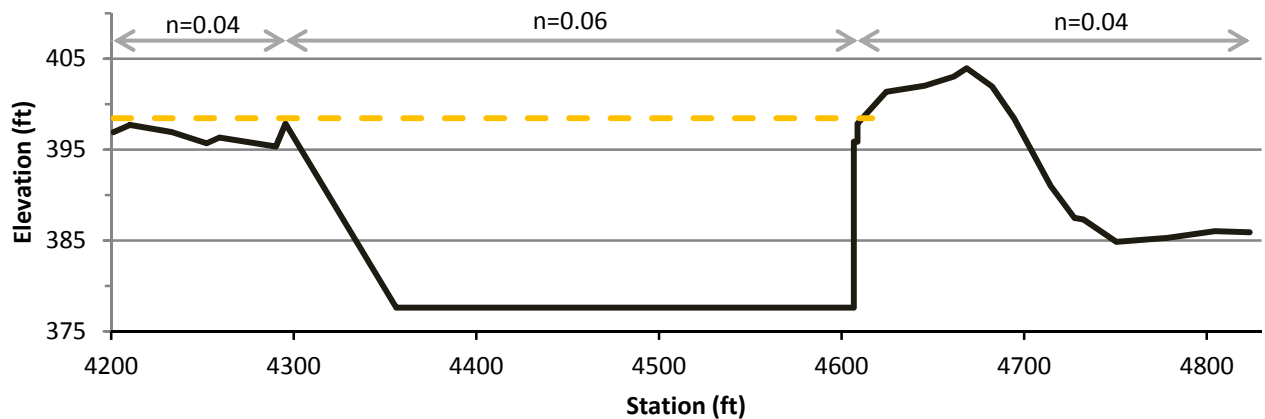
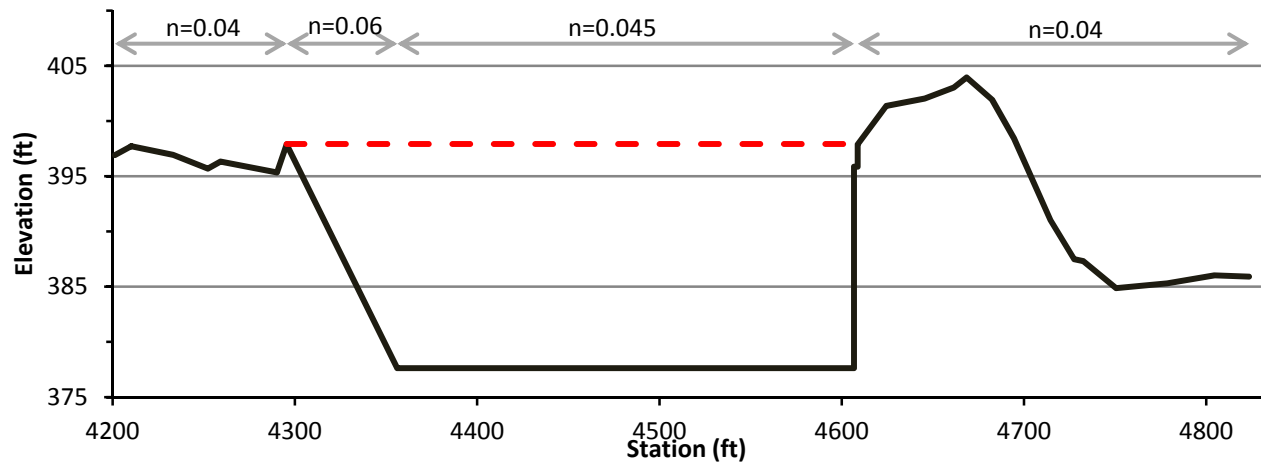
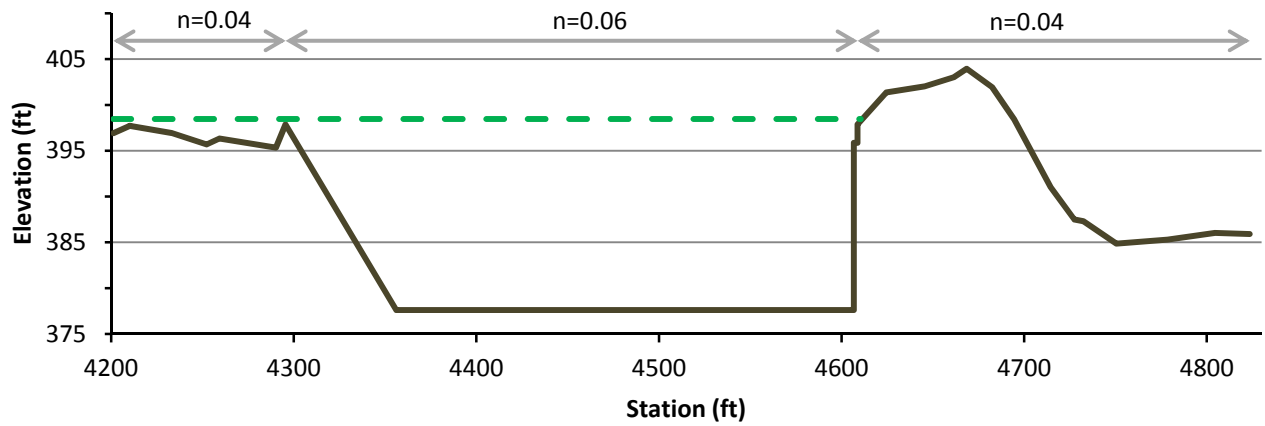


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 13 REACH 6
WSE COMPARISON
CROSS SECTION 191+81**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

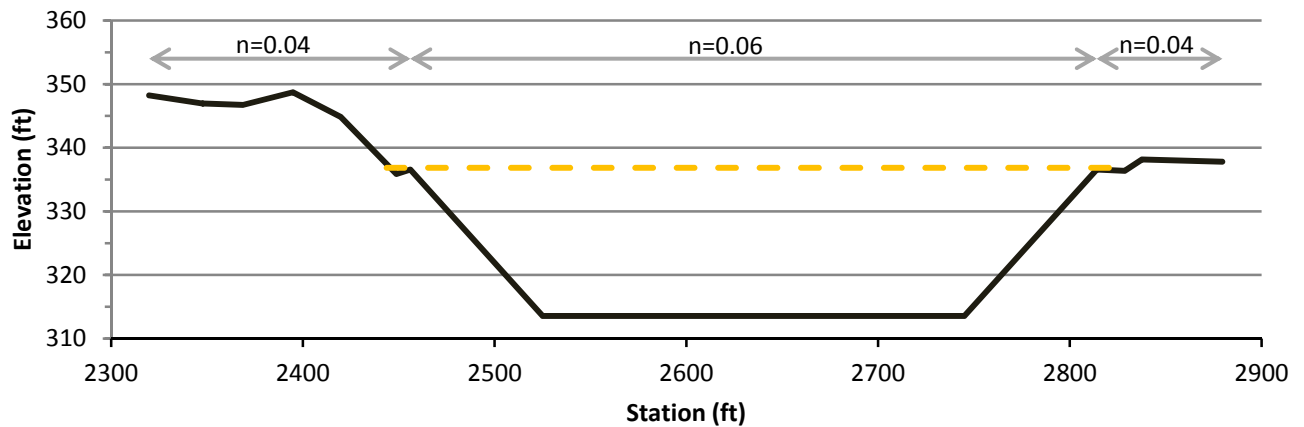
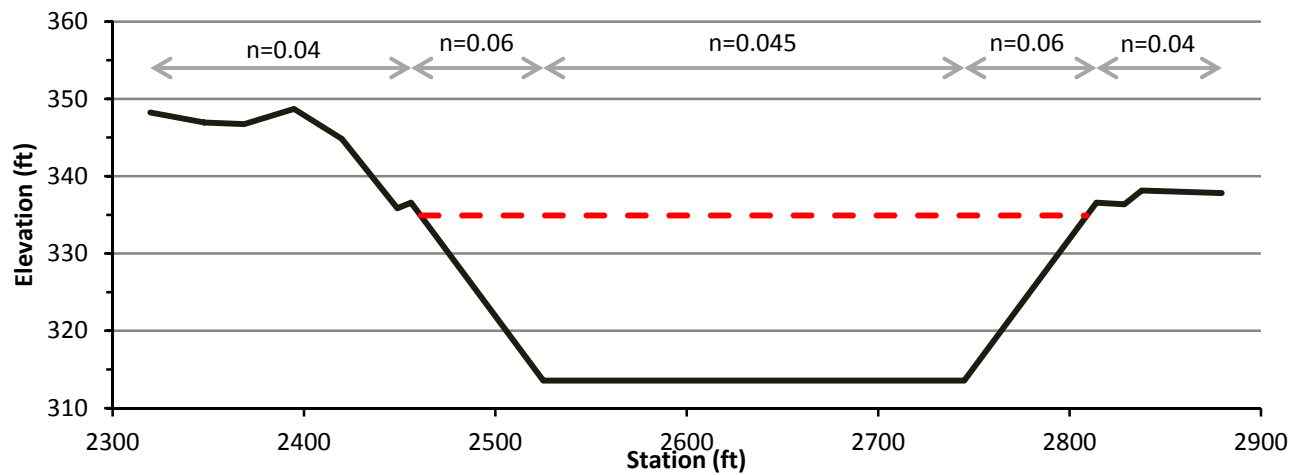
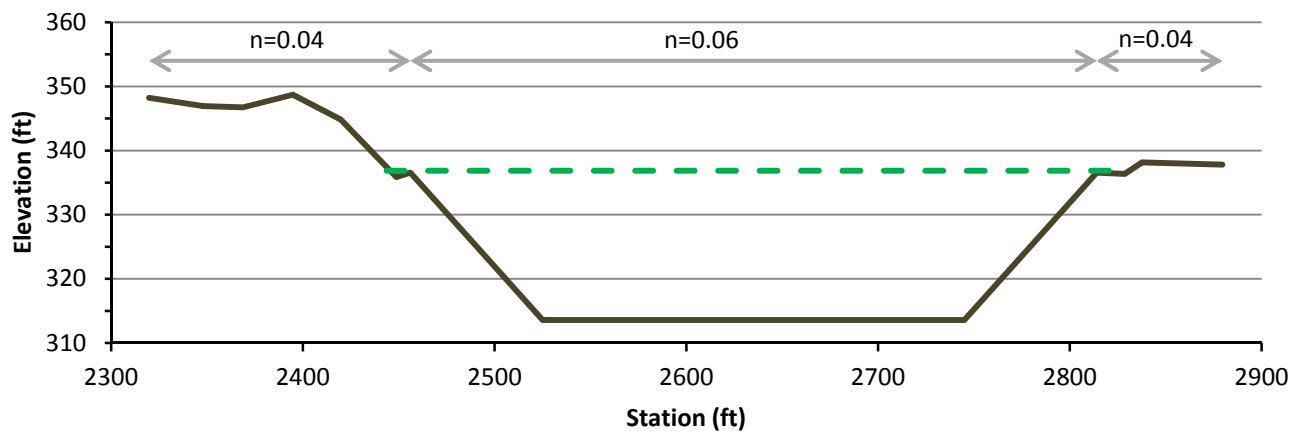


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 16 REACH 5
WSE COMPARISON
CROSS SECTION 356+22**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

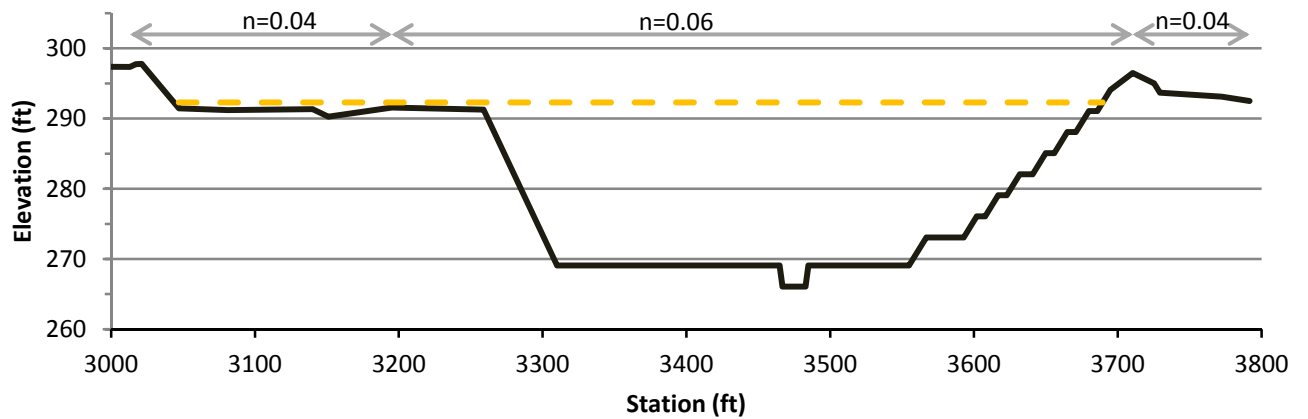
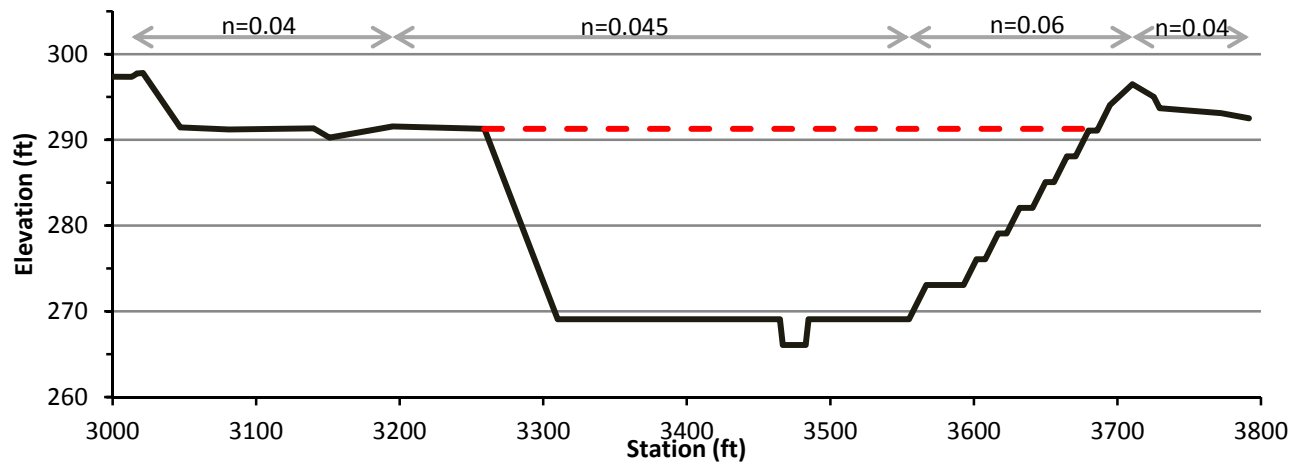
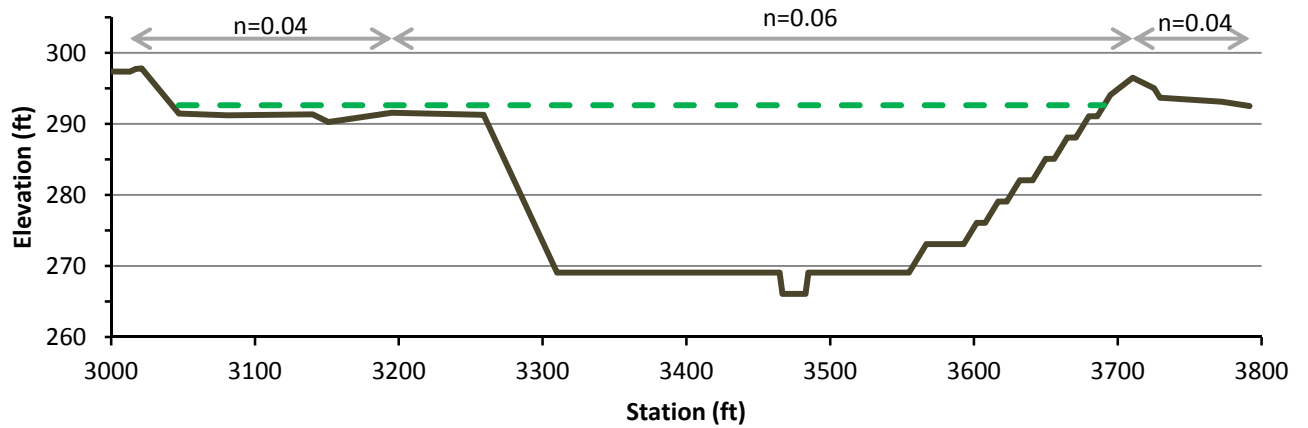


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

**LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY**

**ALT. 16 REACH 6
WSE COMPARISON
CROSS SECTION 191+81**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

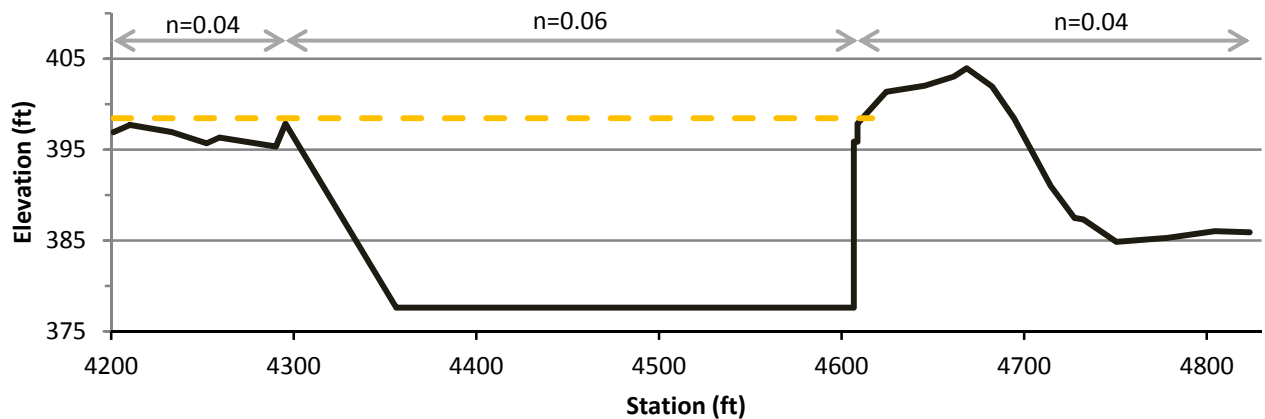
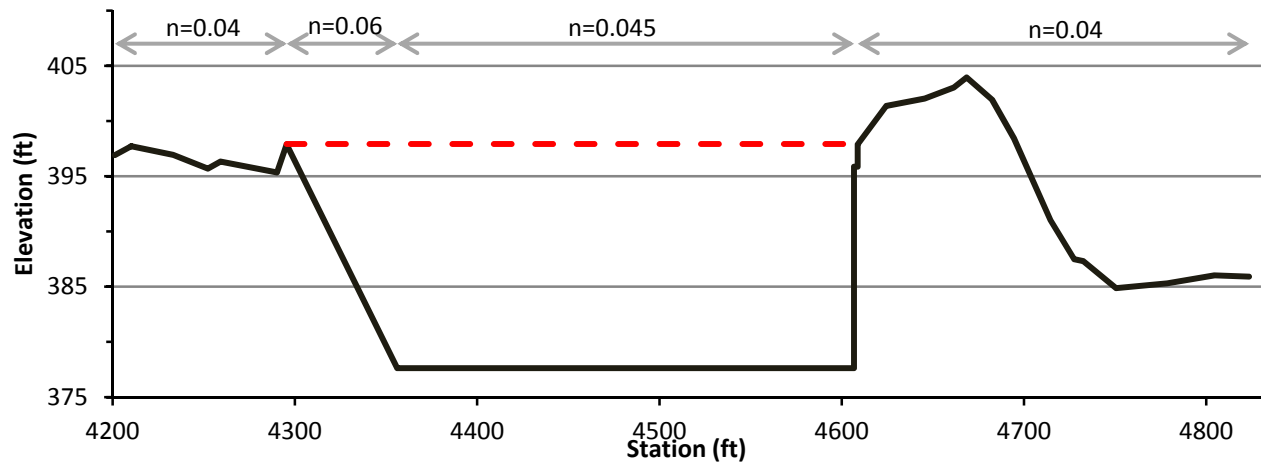
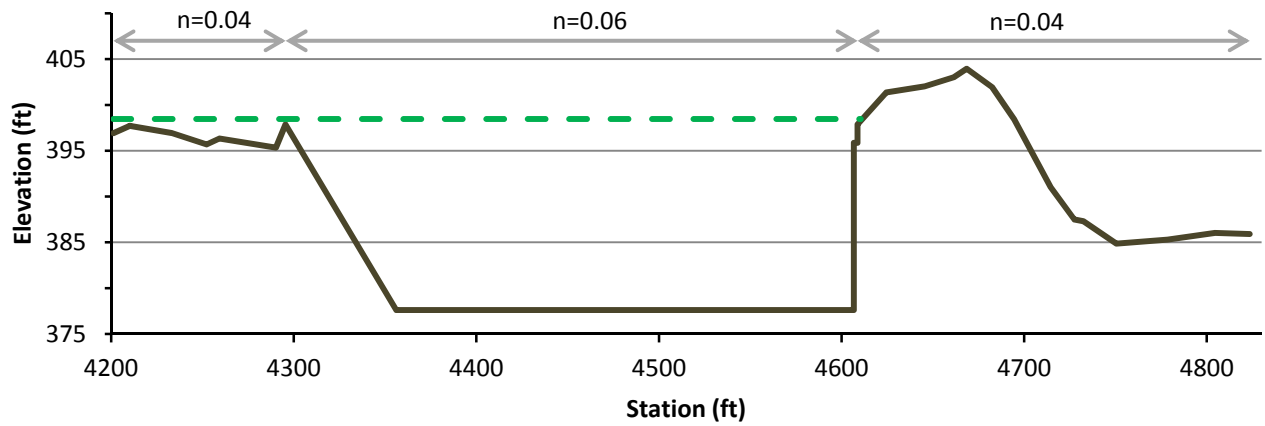


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 16 REACH 8
WSE COMPARISON
CROSS SECTION 69+93**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

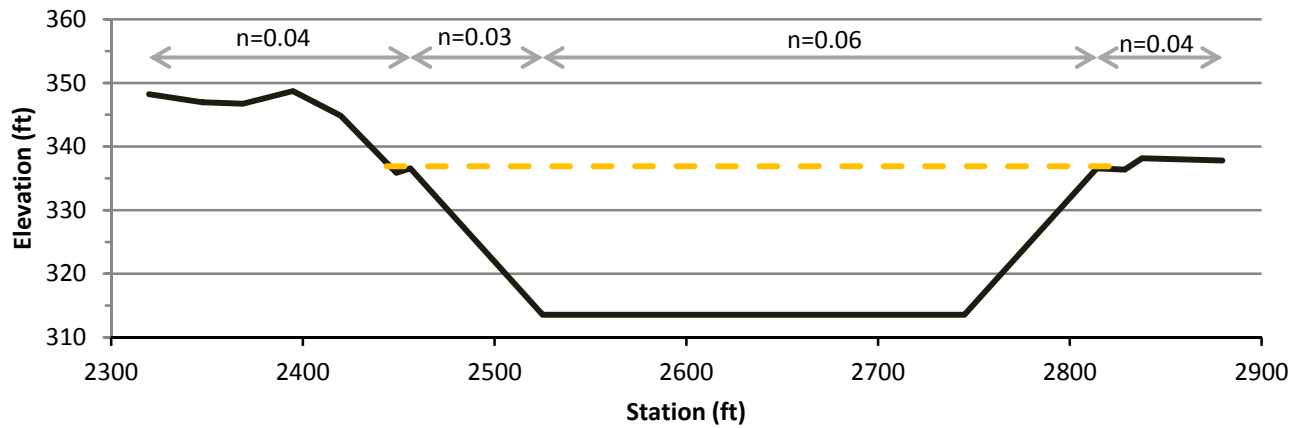
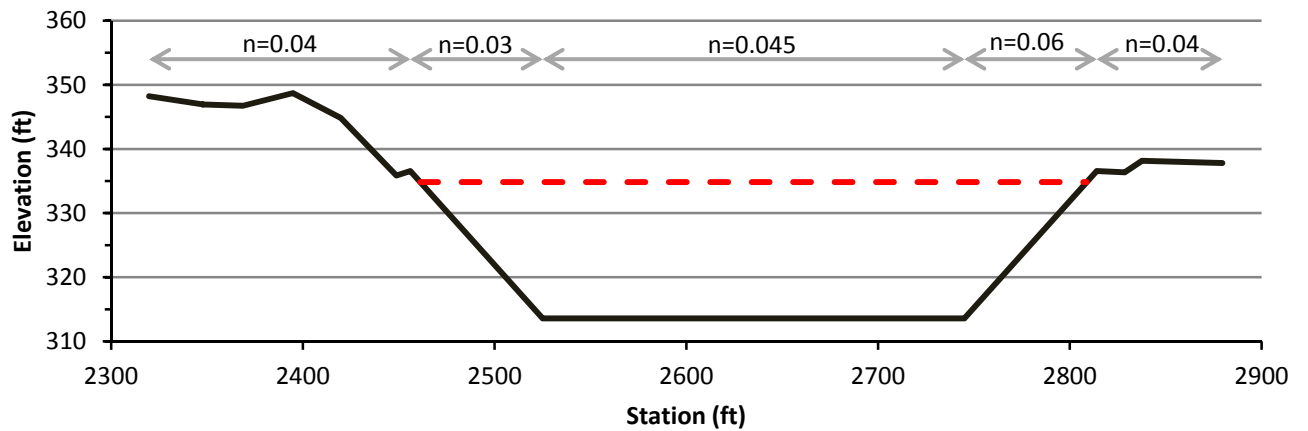
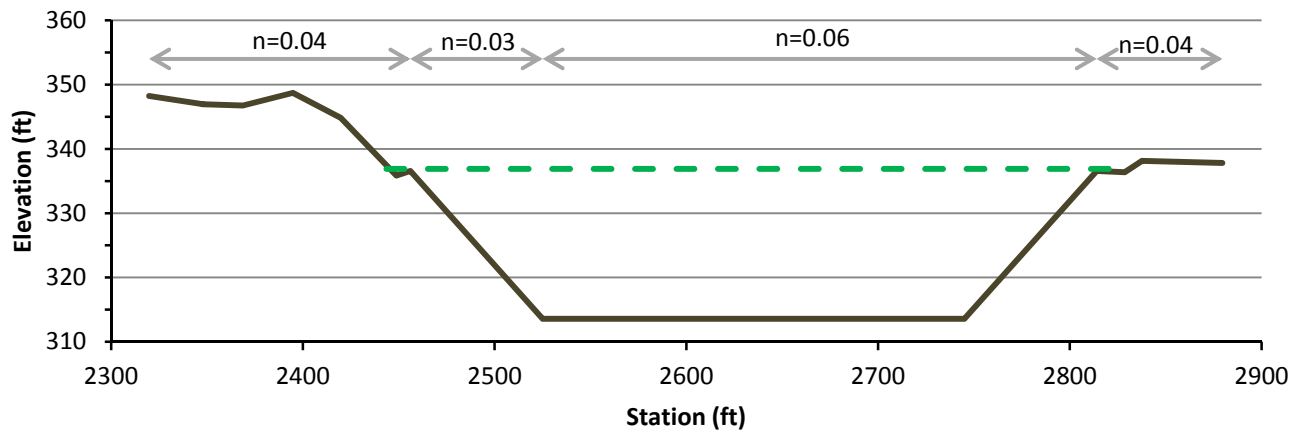


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

ALT. 20 REACH 5
WSE COMPARISON
CROSS SECTION 356+22

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

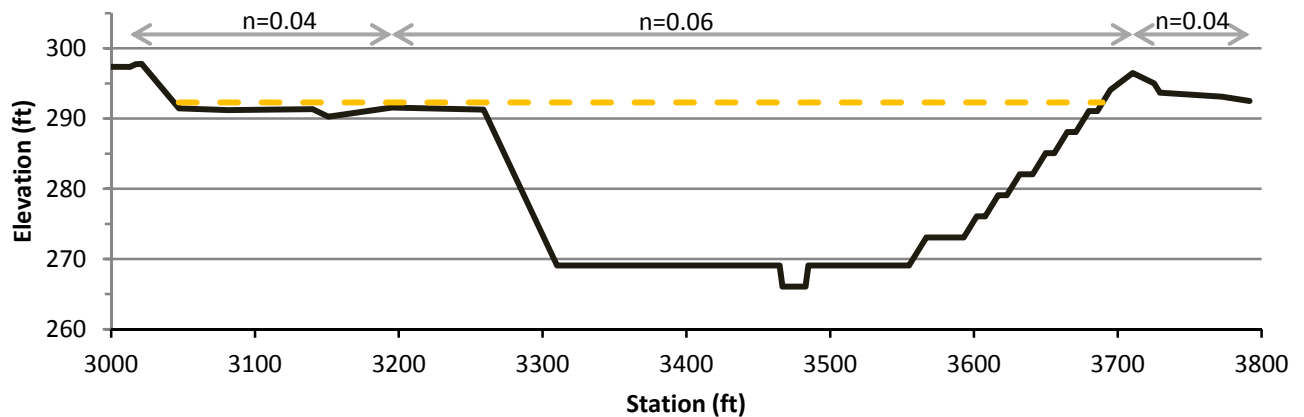
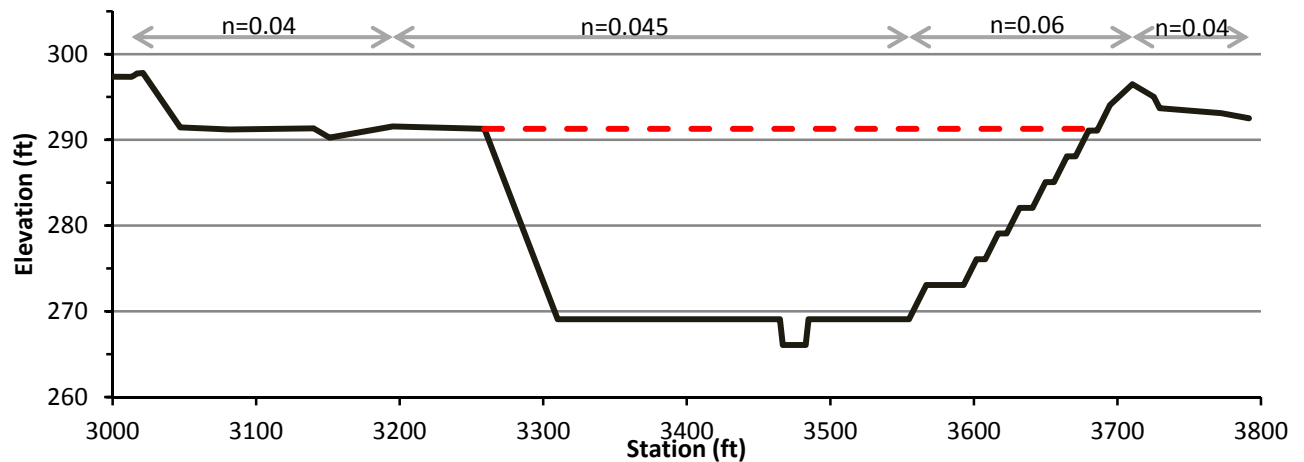
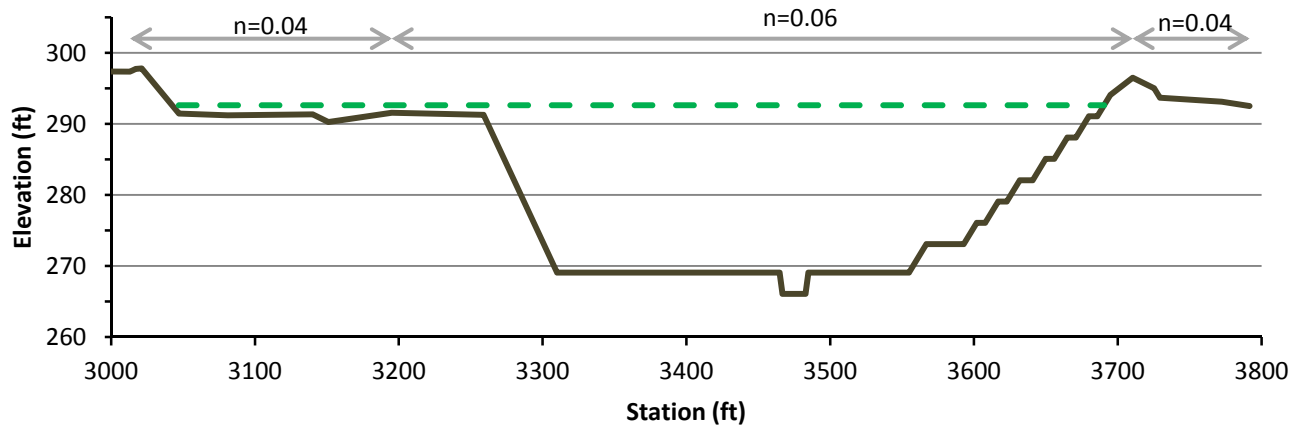


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT.20 REACH 6
WSE COMPARISON
CROSS SECTION 191+81**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

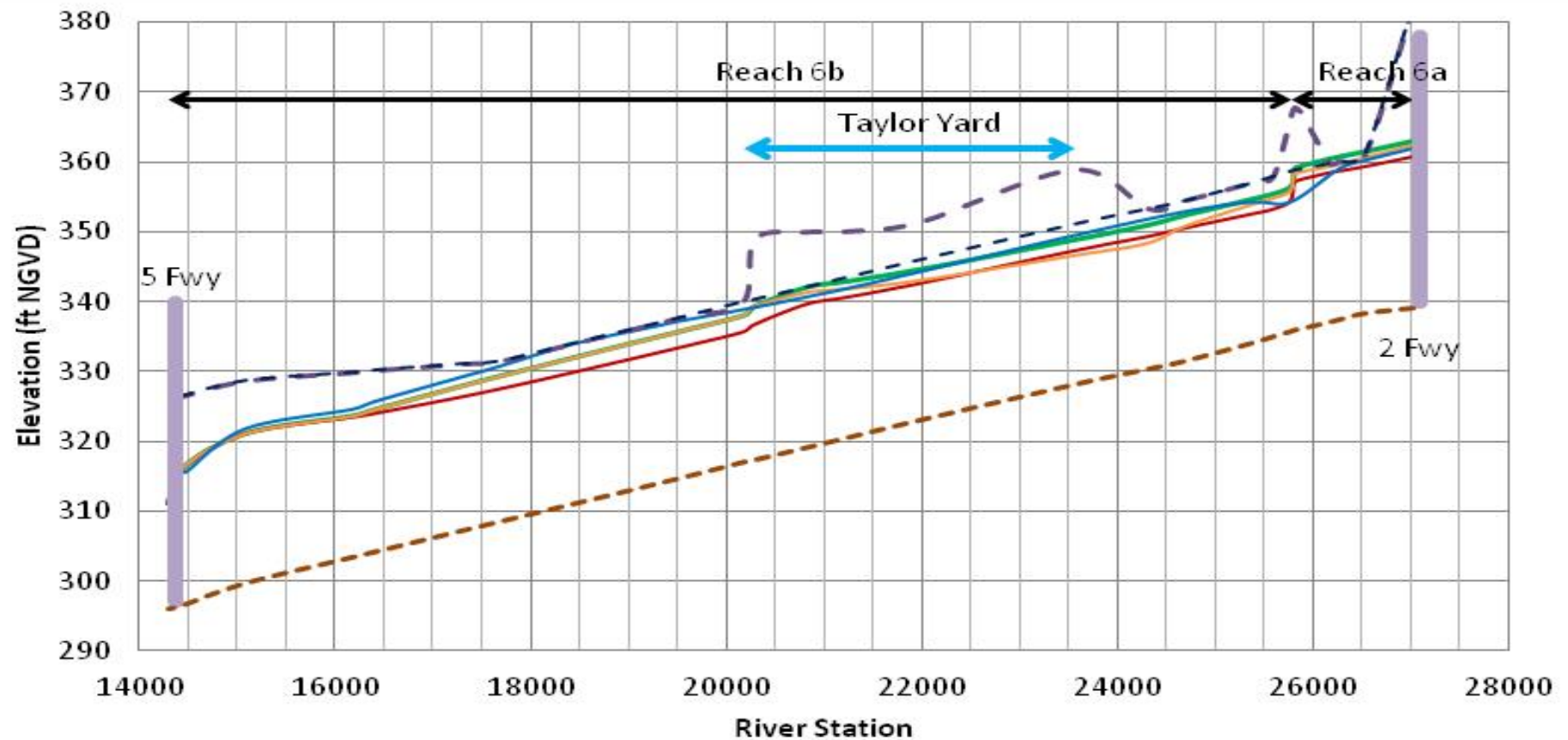


- Heavy Overbank Vegetation, Moderate Channel Vegetation
- Heavy Overbank Vegetation, Minimal Channel Vegetation
- Minimal Overbank Vegetation, Moderate Channel Vegetation

**LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY**

**ALT. 20 REACH 8
WSE COMPARISON
CROSS SECTION 69+93**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



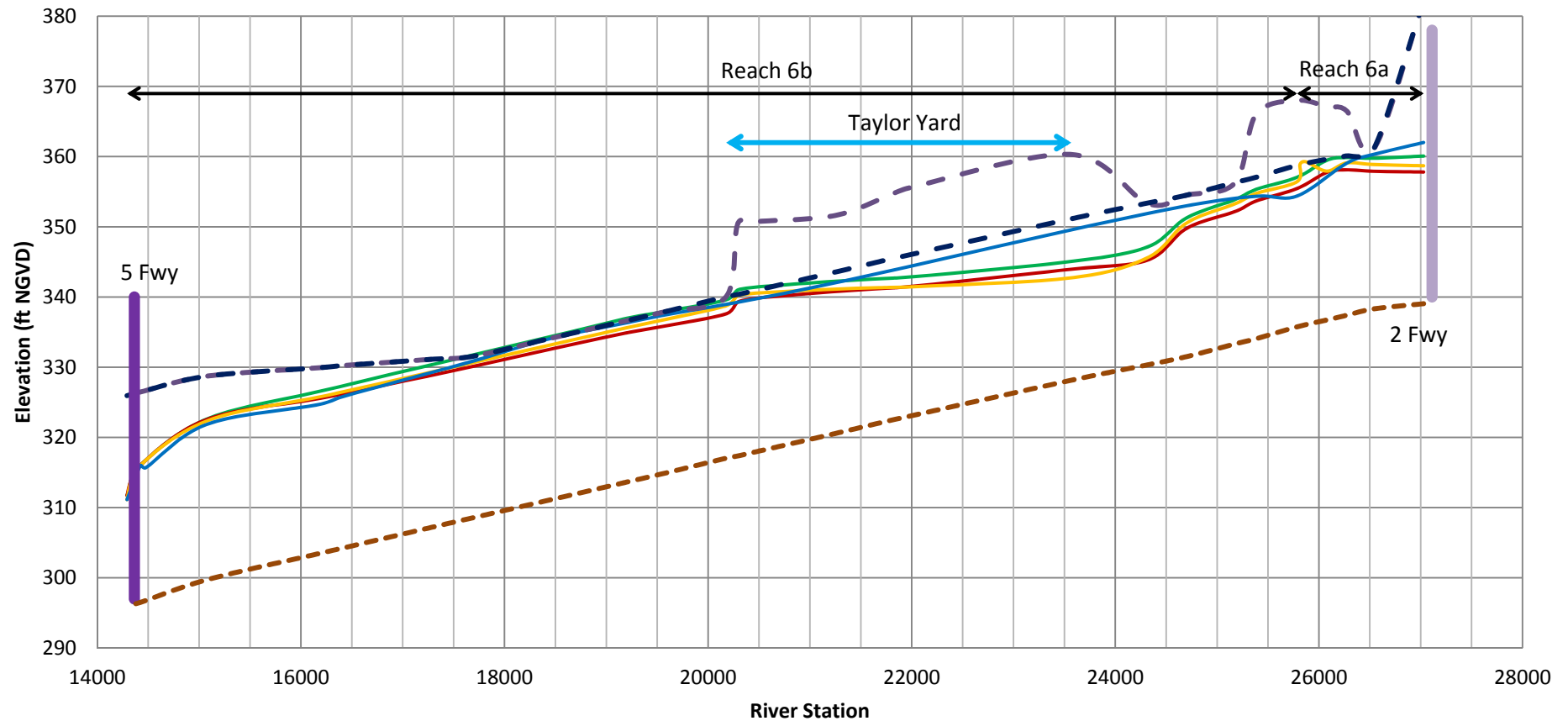
Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

- Moderate Vegetation Channel, Heavy Vegetation Overbank
- Moderate Vegetation Channel, Minimum Vegetation Overbank
- Left Bank
- Channel Invert
- Minimum Vegetation Channel, Heavy Vegetation Overbank
- Existing Conditions With Vegetation
- Right Bank

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

ALT. 10 REACH 6 LOS ANGELES RIVER WATER SURFACE PROFILES

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

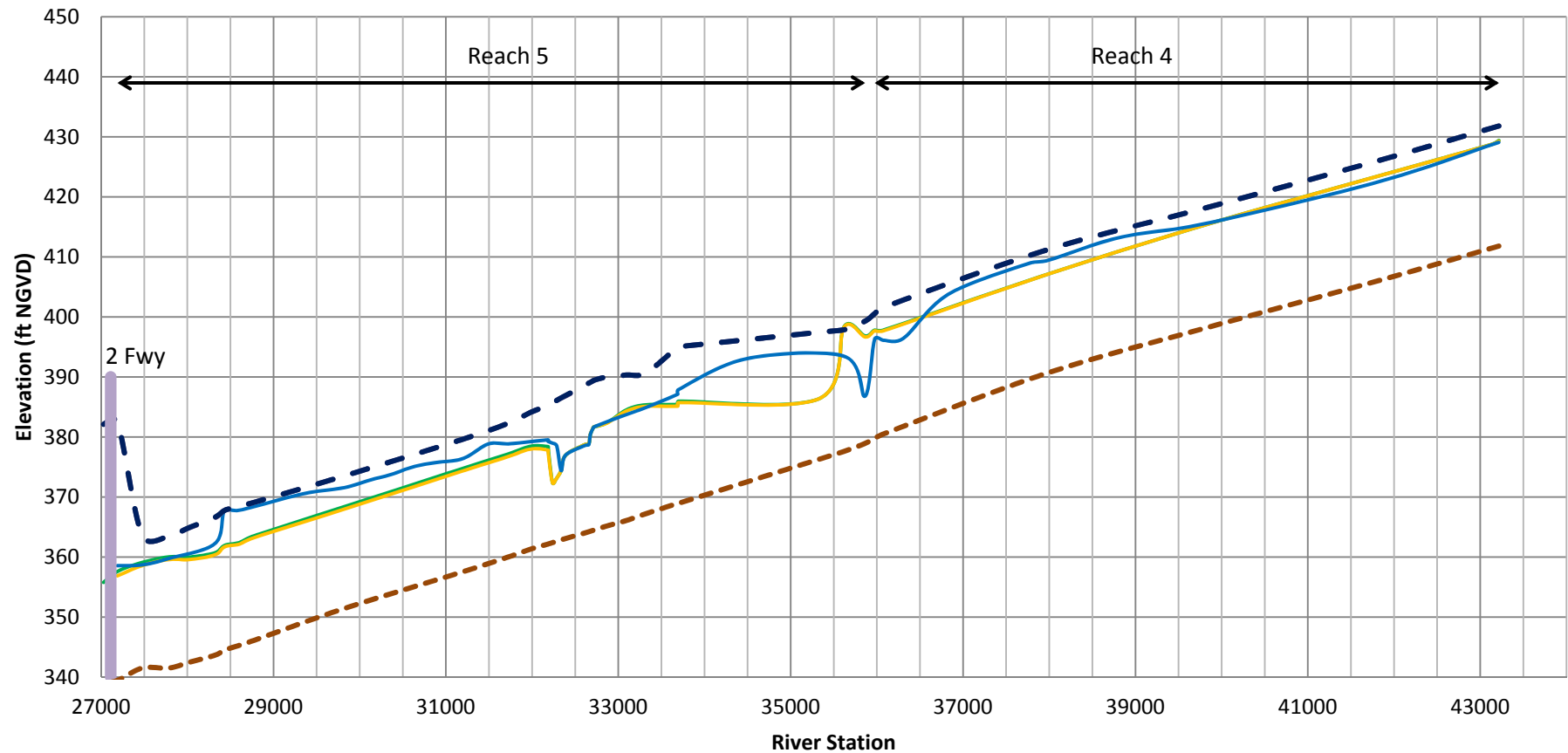


Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 13 REACH 6
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



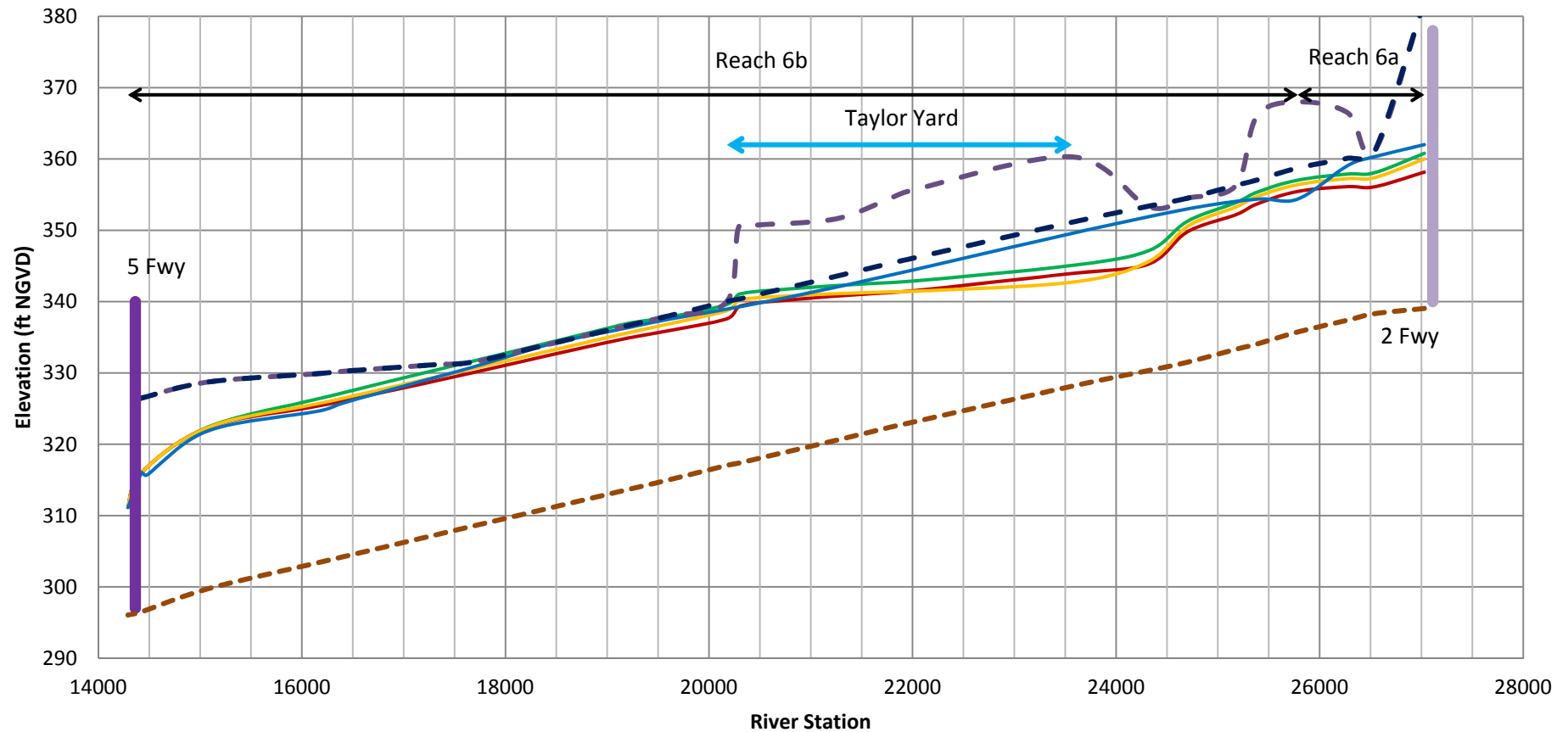
Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

- Moderate Vegetation Channel, Heavy Vegetation Overbank
- Moderate Vegetation Channel, Minimum Vegetation Overbank
- Left Bank
- Channel Invert
- Minimum Vegetation Channel, Heavy Vegetation Overbank
- Existing Conditions With Vegetation
- Right Bank

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 16 REACH 5
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

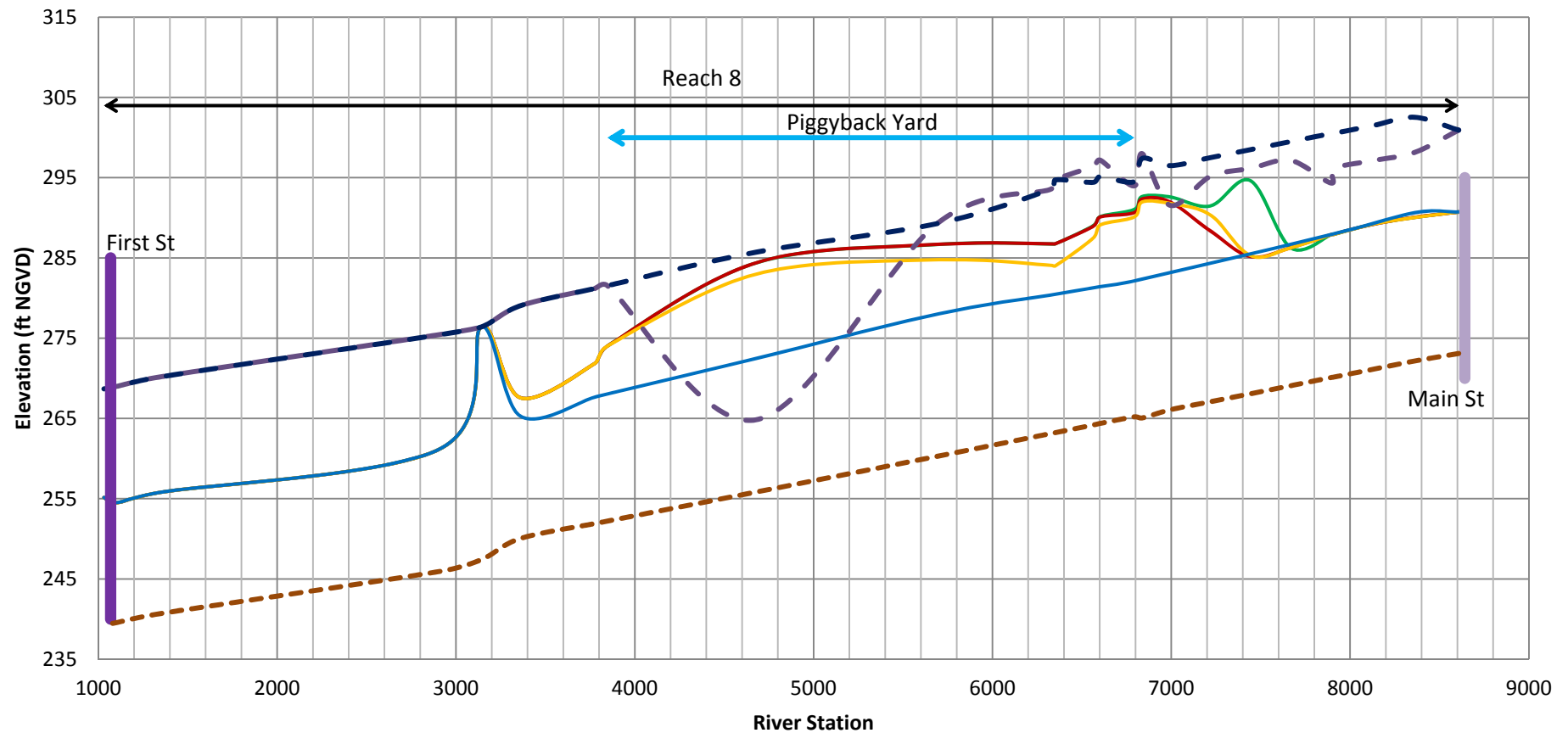


Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 16 REACH 6
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



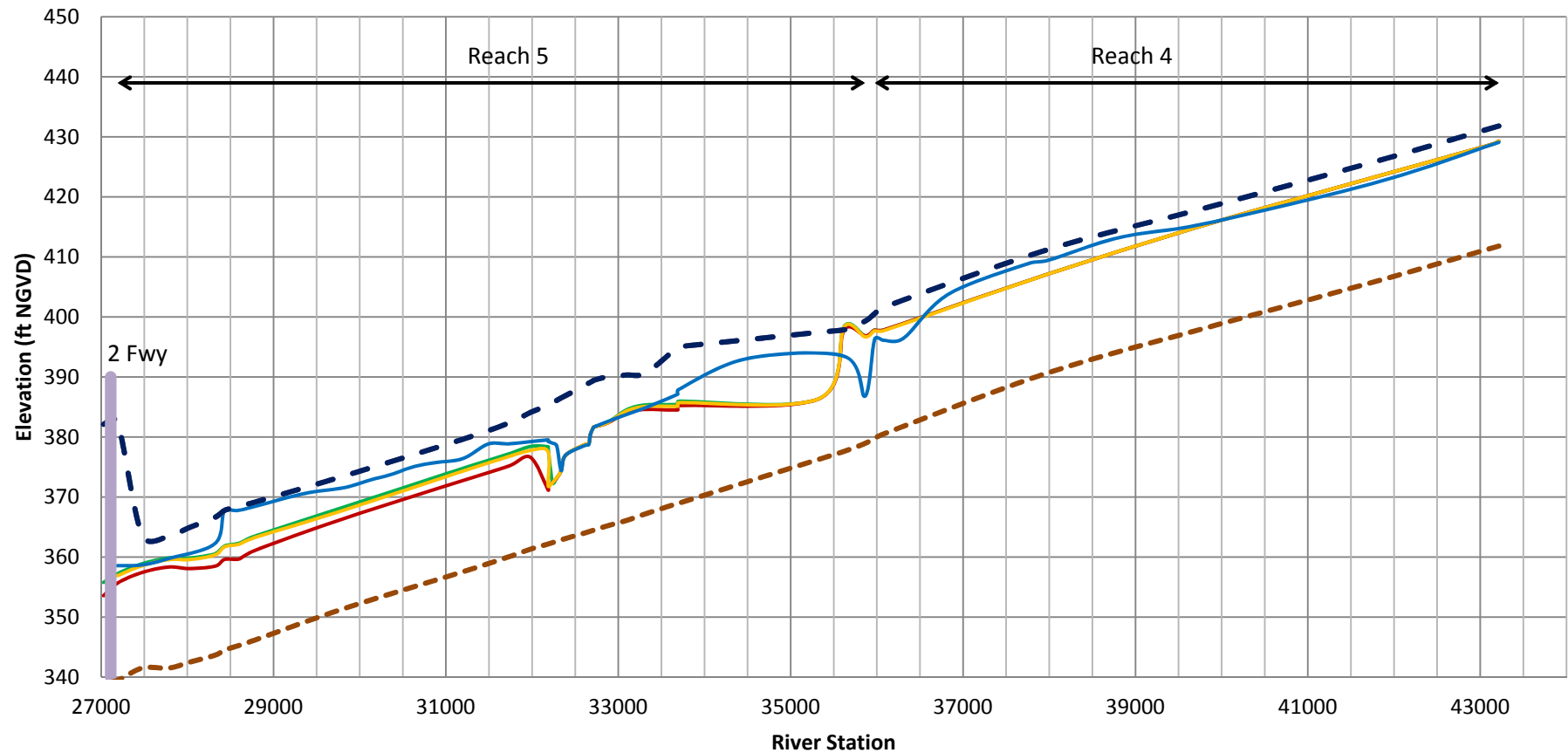
Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

- Moderate Vegetation Channel, Heavy Vegetation Overbank
- Moderate Vegetation Channel, Minimum Vegetation Overbank
- Left Bank
- Channel Invert
- Minimum Vegetation Channel, Heavy Vegetation Overbank
- Existing Conditions With Vegetation
- Right Bank

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 16 REACH 8
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



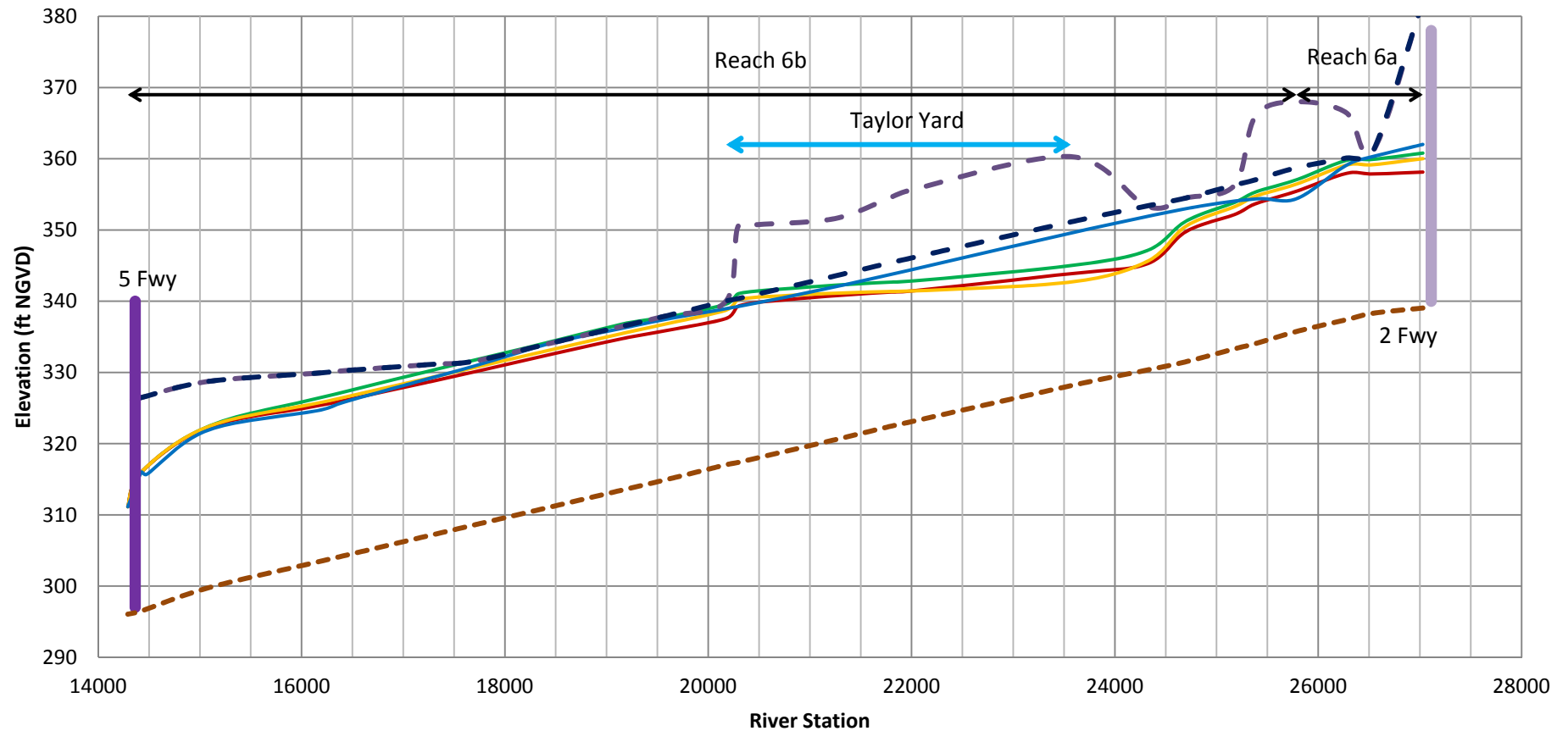
Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

- Moderate Vegetation Channel, Heavy Vegetation Overbank
- Moderate Vegetation Channel, Minimum Vegetation Overbank
- Left Bank
- Channel Invert
- Minimum Vegetation Channel, Heavy Vegetation Overbank
- Existing Conditions With Vegetation
- Right Bank

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 20 REACH 5
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT

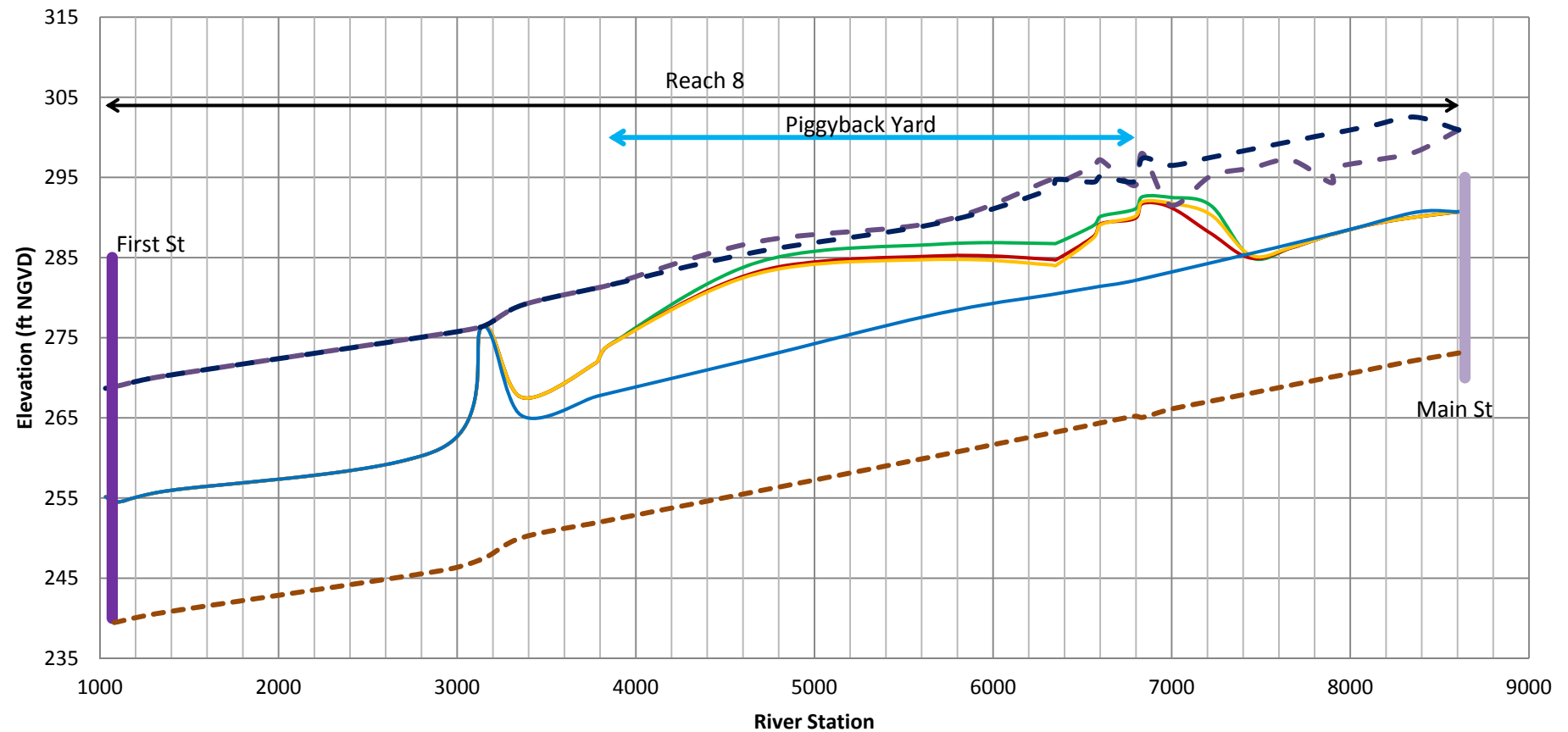


Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 20 REACH 6
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT



Streambed elevations based on lowest elevation in cross section from HEC-RAS models for shown alternative.

- Moderate Vegetation Channel, Heavy Vegetation Overbank
- Moderate Vegetation Channel, Minimum Vegetation Overbank
- Left Bank
- Channel Invert
- Minimum Vegetation Channel, Heavy Vegetation Overbank
- Existing Conditions With Vegetation
- Right Bank

LOS ANGELES RIVER
ECOSYSTEM RESTORATION STUDY

**ALT. 20 REACH 8
LOS ANGELES RIVER
WATER SURFACE
PROFILES**

CORPS OF ENGINEERS
LOS ANGELES DISTRICT