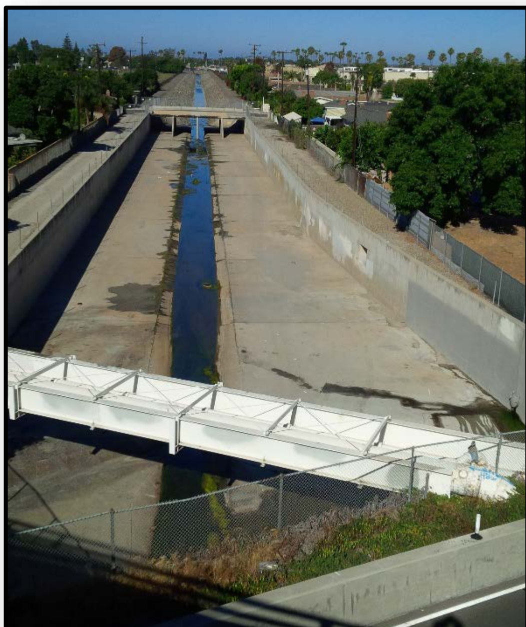
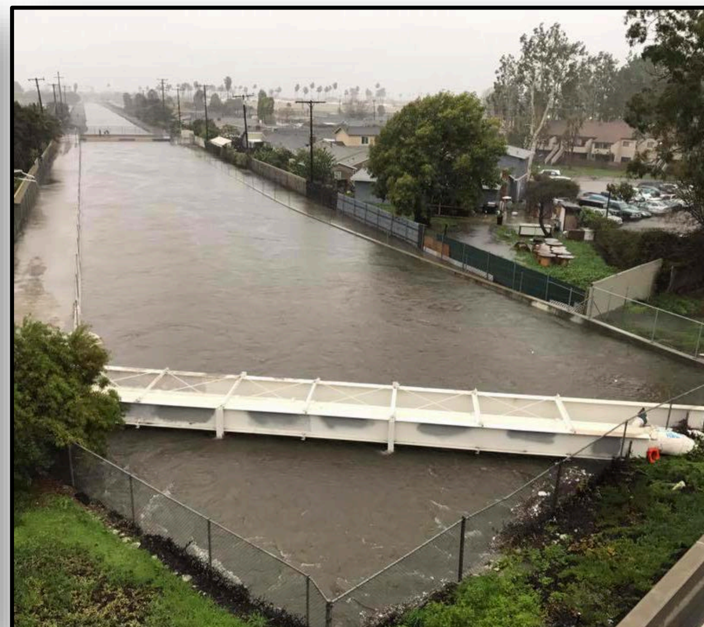
APPENDIX A – HYDROLOGY AND HYDRAULICS

For

WESTMINSTER, EAST GARDEN GROVE FLOOD RISK MANAGEMENT STUDY





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US Army Corps of Engineers
Chicago District

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APPENDIX A: HYDROLOGY AND HYDRAULICS

For

WESTMINSTER, EAST GARDEN GROVE

FLOOD RISK MANAGEMENT STUDY

1.0 Introduction

The U.S. Army Corps of Engineers, Chicago District (USACE), is currently conducting the Flood Risk Management Feasibility Phase of the Westminster East Garden Grove Study, a cost shared effort between the U.S. Army Corps of Engineers and the County of Orange and OCFCD.

The purpose of the Westminster Feasibility Study is to develop and evaluate potential non-structural and engineered solutions to address flooding issues for the two main drainage systems: the Bolsa Chica (C02)/Westminster (C04) Channels and the East Garden Grove – Wintersburg (C05)/Ocean View (C06) Channels within and near the in the cities of Anaheim, Stanton, Cypress, Garden Grove, Westminster, Fountain Valley, Los Alamitos, Seal Beach, and Huntington Beach within Orange County, California.

Hydraulic analysis for the Westminster channels was conducted using Hydrologic Engineering Center River Analysis System (HEC-RAS), HEC-GeoRAS, Water surface profiles were produced for existing conditions and alternative conditions. Alternatives included minimum channel improvements, maximum channel improvements, and moderate channel improvements. Water surface profiles and inundation maps were produced for the 1-,5-,10-,25-, 50-, 100-, 200-, and 500-year (99%, 20%, 10%, 4%, 2%, 1%, 0.5 and 0.2% Annual Chance Exceedance {ACE}) events for both Existing Conditions and alternative conditions. The existing condition's 10%, 4%, 2%, 1%, and 0.2% ACE floodplains display flooding in the both overbank sincluding comingling flooding between channel systems. Flooding begins at approximately the 10% ACE flood event throughout the project area and is caused by overtopping of the channels as well as failure of the levees in the downstream reaches of the C05 channel systems. Overtopping and failure of the levees the downstream reach of C04 occurs at approximately the 2% ACE flood event.

2.0 General Description of Study

The U.S. Army Corps of Engineers, Chicago District is currently conducting the Flood Risk Management Feasibility Phase of the Westminster Study, a cost shared effort between the U.S. Army Corps of Engineers (USACE) and the Orange County Flood Control District. The purpose of the Westminster Feasibility Study is to develop and evaluate potential nonstructural and engineered solutions to address flooding issues consisting of portions of the cities of Santa Ana, Orange, Garden Grove, Anaheim, Westminster, Fountain Valley, and Huntington Beach. The study team considered an array of measures that support the primary purpose of flood risk management. There is also an opportunity to provide much-needed recreational opportunities concurrent with flood risk management.

The purpose of this appendix is to document the hydrology & hydraulic analyses completed in support of the Westminster East Garden Grove Flood Risk Management Study in Orange County, California.

2.1 Study Area

The two main drainage systems that are part of the study area include the Bolsa Chica (C02)/Westminster Channels (C04) and the East Garden Grove Wintersburg (C05)/Ocean View Channels (C06).

The East Garden Grove-Wintersburg Channel (EGGW) sub-watershed lies on a flat coastal plain surrounded generally by the Santa Ana River to the east, the Talbert Valley watershed and the Pacific Ocean to the south, and the C02 sub-watershed to the west and north. The watershed is drained by the manmade channel system consisting of Orange County drainage facilities EGGW Channel (C05); Oceanview Channel (C06); Slater Channel (C05S04) and pump station; Haster Basin; C05 channel upstream of Haster Basin; and storm drains—C05P19, C05P21, C05P22 that contribute storm runoff to the Haster Basin. These facilities collect storm runoff from a 27.3 square-mile drainage area consisting of portions of the cities of Santa Ana, Orange, Garden Grove, Anaheim, Westminster, Fountain Valley, and Huntington Beach. The channels terminate at the Pacific Ocean through Bolsa Bay in the City of Huntington Beach.

The upper Haster Basin drainage area consists of the C05 channel (from Haster Basin to Chapman Avenue); P21—Spinnaker storm drain (from Katella Avenue to Chapman Avenue); and P22—Holiday storm drain (along Chapman Avenue to State College Boulevard), which discharges to the C05 channel upstream of Haster Basin (from Chapman Avenue to Haster Basin); and P19—Oertley storm drain (from Chapman Avenue to Haster Basin).

Of the 27.3 square-miles drainage area for the EGGW sub-watershed, 5.1 square miles are tributary to the Oceanview Channel and 3.9 square miles are tributary to the Slater Channel. Elevations in the EGGW watershed range from 175 feet at the upper end of the basin to sea level at Bolsa Bay, with an average basin slope of 2 feet per 1,000 feet (12 ft/mi). Elevations in the Oceanview drainage area range from 64 feet at the upper end to 23 feet at the confluence with the EGGW Channel, with an average basin slope of 1.5 feet per 1,000 feet (8 ft/mi). Elevations in the Slater Channel drainage area range from 110 feet in the southern portion to sea level near the pump station, with an average basin slope of 6 feet per 1,000 feet (33 ft/mi).

The drainage area for the Westminster Channel (C04) is approximately 10.9 square miles and is located in the cities of Garden Grove, Huntington Beach, Santa Ana and Westminster. The topography of the land is relatively flat; however, it slopes gradually in a southwesterly direction. Ground surface elevations vary from 10 feet at the Bolsa Chica Channel to 107 feet at the intersection of Chapman Avenue and 9th Street, giving the area an average slope of 2.4 feet per 1,000 feet (0.002). The drainage area is assumed to be fully developed. Land use includes 37% single family dwellings, 36% commercial/industrial, and the remainder consists of apartments, condominiums, schools, public parks and mobile home parks (land use estimates based on various public record sources).

The drainage area for the Bolsa Chica Channel (C02) consists of approximately 8.8 square miles and includes portions of the Cities of Anaheim, Cypress, Garden Grove, Los Alamitos, Stanton and unincorporated Orange County territory. The topography is relatively flat. Elevations in the area vary from 91 feet at the intersection of Ball Road and Gilbert Street, to 15 feet at the San Diego Freeway (I-405), with an average slope of 1.8 feet per 1,000 feet (.0018). The land use is predominately residential and commercial.

The total drainage area upstream of the Haster Retarding Basin (Basin) is approximately 1,845 acres (2.9 square miles) and receives stormwater flows from the cities of Anaheim, Orange and Garden Grove. The fully developed drainage area is relatively flat and slopes gently in a southwesterly direction. Land use is predominantly residential and commercial. The Basin is located in the Haster Basin Recreational Park, at the southwest corner of Haster Street and Lampson Avenue. The two primary inlets to the Basin are the East Garden Grove-Wintersburg Channel, Facility No. C05, which drains approximately 1,195 acres (1.86 square miles) and Oertley Storm Drain, Facility No. C05, P19, which drains approximately 625 acres (0.97 square miles). The remaining 25 acres (0.04 square miles) drain directly to the Basin.

2.2 Study Authority

The study was authorized by a resolution adopted by the House of Representatives Committee on Public Works, dated 08 May 1964, which reads as follows:

> *"Resolution by the Committee on Public Works of the House of Representatives, United States, that the Board of Engineers for Rivers and Harbors is hereby requested to review the reports on (a) San Gabriel River and Tributaries, published as House Document No. 838, 76th Congress, 3d Session; (b) Santa Ana River and Tributaries, published as House Document No. 135, 81st Congress, 1st Session; and (c) the project authorized by the Flood Control Act of 1936 for the protection of the metropolitan area in Orange County, with a view to determining the advisability of modification of the authorized projects in the interest of flood control and related purposes."*

2.3 Previous Reports

Many federal and non-federal studies have been conducted pertaining to water and related land resources within the study area. The Army Corps of Engineers has conducted the following associated studies in the Westminster watershed Orange County and vicinity:

- Derivation of a Rainfall-Runoff Model to Compute N-year Floods for Orange County Watersheds. USACE – Los Angeles District and Orange County Flood Control District, November 1987.
- Hydraulics Appendix, San Diego Creek Watershed Management Study, F3 Feasibility Phase, USACE – Los Angeles District, August 2001.
- Hydrology Documentation for Feasibility Study, Santa Ana River Basin and Orange County, Interim 3, East Garden Grove – Wintersburg Channel, U.S. Army Corps of Engineers, Los Angeles District, September 1988.
- Santa Ana River Basin and Orange County, Final Feasibility Report, USACE – Los Angeles District, July 1992.

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Other Federal Agencies have conducted the following studies in the Westminster watershed and vicinity:

- Orange County Flood Insurance Study, Volume 1-4, & Flood Insurance Rate Maps. FEMA, November 1993.
- Orange County Soil Survey. U.S. Department of Agriculture, Soil Conservation Service, September 1978.

Private Consultants and local government agencies have conducted the following studies in the Westminster watershed and vicinity:

- Consolidated Report, FEMA Submittals Detailed Flood Insurance Study, Shea Homes Parkside Estates Tentative Tract Nos. 15377 & 15419, Expanded Watershed Analysis of East Garden Grove-Wintersburg Channel Watershed from Tide Gates to I-405 Freeway, Exponent, August, 2002.
- Hydrology Report No. C04-4, Westminster Channel Entire Drainage System Hydrology, Public Facility & Resources Department, County of Orange, December 2002.
- Hydrology Report No. C01-3, Hydrology Report for Los Alamitos Channel from Rossmoor Retarding Basin Outlet to Los Alamitos Retarding Basin, Public Facilities & Resources Department, County of Orange, July 2002.
- Approximate 100-year Floodplain Delineation Study Report, East Garden Grove-Wintersburg Channel (C05) / Ocean View Channel (C06) and Laterals, Agreement No. D97-043, Work Order No. 5, West Consultants, Inc., February 2000.
- Hydrology Documentation, San Juan Creek Watershed Management Study, F3 Feasibility Phase Appendices, Simons, Li & Associates, Inc., July 1999.
- Hydrology Report No. C05-13S, Hydrology Study for the Floodplain Analysis of East Garden Grove-Wintersburg Channel System Facility No. C05 Entire Drainage System, Public Facilities & Resources Department, County of Orange, December 1999.
- Hydrology Report No. C01-2, Hydrology Report of Entire Drainage System of the Los Alamitos Channel Facility No. C01, Public Facilities & Resources Department, County of Orange, June 1998.
- Hydrology Report No. C02-3A, Bolsa Chica Channel Facility No. C02 San Diego Freeway to Holland Avenue, Environmental Management Agency, County of Orange, June 1998.
- Project Report for East Garden Grove – Winterburg (C05) and Oceanview (C06) Channels, Williamson & Schmid, December 1994.
- Hydraulic Evaluation of the East Garden Grove Wintersburg (C05) Channel Outlet, Supplement to the East Garden Grove Wintersburg (C05) and Oceanview (C06) Channels Project Report, Williamson & Schmid, June 1993.
- Hydrology Report for East Garden Grove – Wintersgurg Channel (Facility No. C05) (Bolsa Chica Bay to Vermont Avenue), Environmental Management Agency, County of Orange, July 1990.
- Hydrology Report No. C06-2, Hydrology Report, Ocean View Channel, Facility No. C06 Entire Drainage System, Environmental Management Agency, County of Orange, November 1989.

- Hydrology Report No. C03-4, Hydrology Report Anaheim-Harbor City Channel, Facility No. C03 Entire Drainage System, Flood Program Division, Public Works Department, County of Orange, September 1986.
- Hydrology Report No. C02-3, Hydrology Report Bolsa Chica Channel Facility No. C02 Upstream of Huntley Avenue Including Tributary Facility Numbers C02S01, C02S03, C02P03, and C02P07, Orange County Environmental Management Agency, County of Orange, May 1978.
- Model Documentation for C02-C04, TetraTech, April 2018.
- Model Documentation for C05-C06, TetraTech, March 2018.

2.4 Present and Future Conditions

The Westminster Watershed is a highly developed and urbanized area and the watershed is not expected to dramatically change in the foreseeable future. Therefore, the present and the future conditions are the same. This assumption will be used for both hydrologic and hydraulic analyses.

3.0 Data Collection

3.1 Topographic Data

Digital topographic data were obtained from Orange County. The topographic data were collected during December 17, 2011 to February 9, 2012 by USGS and processed through the Digital Elevation Model (DEM) unto digital topographic data set. The DEM data set has horizontal datum in the CCS83, Zone VI (US Feet) and has vertical datum in NAVD 88 (US Feet).

3.2 As-Built Drawings

Most of the channels as-built drawings are based on NGVD 29 datum except as-built drawing C05-501-1A on C05 in the vicinity of Garden Grove Freeway which is based on NAVD 88 datum. Many of the drawings were dated earlier than 1980 and associated benchmarks are no longer in existence, therefore, current Orange County benchmarks are used in computing an average vertical datum adjustment. There are total of 35 benchmarks used (8 in the vicinity of C06, 9 in the vicinity of C05 below C06, and 18 in the vicinity of C05 above C06) and results in an average vertical datum adjustment value of 2.42 feet (i.e., NAVD 88 elevation = NGVD 29 elevation + 2.42').

3.3 Field Investigation

The USACE performed site visits were conducted in June 2005 as part of the previously conducted sedimentation analysis sampling. Subsequent visits were conducted on 13 and 22 August 2012 to verify channel improvements and structural dimensions used the hydraulic analysis and models. Personnel who attended were Van Crisostomo, Mylene Perry, and Simon Evans from the Hydraulics Section; Scott Sanderson from Planning Division (Los Angeles District); and Justin Golliher from OCFCD. The drainage systems are further broken down into Reaches, which are described later in this Appendix.

3.4 Sediment Samples

Sediment Samples were collected in June 2005 along C05 and C06. A total of 21 samples were collected. Among these samples, eleven samples were taken from the streambed and ten samples were taken from the stream bank. Samples were taken from approximately the top one foot of the bed layer. There is a small percentage of gravel and cobles in the EGGW Channel (C05) and Oceanview Channel (C06). Most of the samples consist of different grades of sand and silt.

3.5 Westminster Planning Charette

The Project Delivery Team (PDT) met on 22 September 2014 for a one day plan formulation charette workshop that was held in Los Angeles, California. The primary purpose of the charette was to use this collaborative process to expedite plan formulation for the preliminary array of alternatives. The intent of the charette was to formulate alternatives and identify study objectives as well as address problems, opportunities, and constraints. Participants in the charette workshop included representatives from the USACE and the OCFCD.

4.0 Existing Conditions

4.1 Westminster Watershed

The Westminster Study Area, consisting of the C02, C04, C05, and C06 Channels, lay within the historic overflow path of the Santa Ana River, which flowed through the downtown Anaheim area prior to the 1918 diversion of the Santa Ana River into its present alignment. Since the diversion of the Santa Ana River, the C02, C04, C05, and C06 Channels have served as local drainage facilities. These facilities have been improved at various locations on multiple occasions to account for development within the watershed.

4.1.1 Flood History

Significant regional storm events or floods have occurred over the last 175 years: 1825, 1862, 1884, 1891, 1916, 1927, 1938 (largest storm of record), 1941, 1969, 1974, 1978, 1980, 1983, 1993, 1995, 2010, and 2017. The historical storm seasons have consisted of nearly continuous periods of moderate to high intensity rainfall ranging from a few days to several weeks and have extended inland as far as the San Bernardino Mountains. Long duration storm events, covering large geographical areas are a threat to large drainage basins such as the Santa Ana River, but do not generally overburden local drainage facilities such as C02, C04, C05, and C06.

The major threat to local facilities, such as C02, C04, C05, and C06, are short duration high intensity storm events. Two storms of this type occurred in Orange County in 1974 and 1983. The storms of 04 December 1974 and 01 March 1983 were short duration, high intensity storms producing intense rainfall in excess of 1% ACE depths for several durations. Both flood events resulted in overflow from the C05 Channel at Golden West Street (upstream of Woodruff Street) and immediately upstream of the I-405. The 1974 storm also caused flooding on the C05 Channel near Bushard Street and on the C06 Channel immediately upstream of the 1-405 Freeway.

Additional, historic flooding events along the C02, C04, C05, and C06 have also occurred and been documented by Orange County in recent years. The floodplain mapping results were compared to these historic flooding events; however, associated discharges and frequencies are not available.

- Flooding at Goldenwest in 1974, 1983, 1993, and 1995 on C05
- Flooding at Euclid Street in 1986, 1992, and 2010 on C05
- Flooding at Haster Basin in 1986 and 1995
- Flooding between Newland Street and Magnolia Street in 1992 on C05
- Flooding between Lapson Avenue and Chapman Avenue in 1992
- Flooding at 1st Street in 1992 and 1995 on C05
- Flooding at Graham Street in 1993 on C05

- Flooding at Warner Avenue, Springdale Street, Edwards Street, and downstream of
- Newland Street in 1995 on C05
- Flooding between Magnolia Street and Bushard Street (dates not specified) on C06
- Flooding between Bushard Street and Brookhurst Street (dates not specified) on C06
- Flooding between Euclid Street and Newhope Street in 2010 and other dates not specified on C06
- Flooding downstream of Valley View Street in 2010 and other dates not specified on C02
- Flooding at Beach Boulevard in 2010 and other dates not specified on C04

4.1.2 Floodplain Studies

The Westminster Study Area, consisting of the C02, C04, C05, and C06 Channels has been analyzed in multiple previous studies mentioned. Studies have included hydrologic, hydraulic, and sedimentation analysis, including floodplain studies. Detailed floodplain and flood insurance studies were conducted in 1993 and most recently in 2002 (FEMA August 2002).

FEMA's standards for certifying levees for 1% A flood protection require that they have a minimum of 3 feet of freeboard.

The USACE process for the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) system evaluation is described in Engineering Circular (EC) 1110-2- 6067 (USACE 2010). The USACE probability of exceedance and uncertainty analysis procedure for proposed flood damage reduction plans is described in Chapters 4 and 5 of EM 1110-2-1619 (USACE 1996). Incised channels and those with levees require analysis to include the uncertainty in the discharge-probability function and in the stage discharge function. A Monte Carlo simulation in the USACE's Hydrologic Engineering Center's Flood Damage Analysis (HECFDA) program was used to compute the uncertainty and assurance (conditional non exceedance probability {CNP}) of the incised channels, as well as the channels with levees, to reduce the flood risks from the 1% ACE (design discharge) (USACE 2010, 2008). Essentially, this means that levees and floodwalls must have a "conditional non-exceedance probability" (performance reliability) of 95%, with a minimum of 2 feet of residual bank height added to the computed water surface elevation using the median estimate of the 1% ACE. Assurance between 90 and 95% can be found in accordance with NFIP system evaluation requirements if it is at least the FEMA required residual bank height above the 1% ACE. Assurance less than 90% cannot be found in accordance with NFIP levee requirements (USACE 2010).

Freeboard and performance requirements are considered preliminary and refinements to meet specific performance criterion would be addressed later in the study.

4.1.3 Existing Levees

Levees are currently located on the downstream reaches of C02/C04 and C05. Specifically, unarmored earthen levees align both banks for Reaches 23 of C02 and the upstream extent of Reach 1 on C05. Reinforced sheet pile levees align a portion of both banks of Reach 1 downstream of Warner Avenue Bridge on C05. The sheet pile levees were constructed in 2014 by the Orange County Flood Control District (OCFCD).

The existing unarmored earthen levees are not certified FEMA levees and are not expected to safely convey the 1% ACE storm event flows. The reinforced sheet pile levees were designed to convey the 1% ACE storm event flows based upon FEMA certification and Orange County design criteria.

4.2 Channel Reaches

The Westminster Study Area, consisting of the C02, C04, C05, and C06 Channels is comprised of multiple subdivided reaches, which are characterized by the channel geometry (shape) and channel materials.

4.2.1 Reach 1

Reach 1 is located on C05 and extends from the tidal gate to Golden West Street, which corresponds with approximate HEC-RAS stations 5+75 to 165+23. Reach 1 from the tide gate to approximately 60 feet upstream of Warner is partially constructed double reinforced sheet pile levee. From approximately 60 feet upstream of Warner Avenue to approximately 1,300 feet upstream of Edwards Street the earthen levees parallel the trapezoidal earthen channel with a riprap right bank between Warner Avenue and Springdale Street. C05 consists of rectangular concrete channel from approximately 1,300 feet upstream of Edwards Street to Goldenwest Street.

4.2.2 Reach 2

Reach 2 is located on C05 and spans Goldenwest Street to the confluence with C06, which corresponds with approximate HEC-RAS stations 165+23 to 192+93. C05 is an incised rectangular concrete channel in Reach 2.

4.2.3 Reach 3

Reach 3 is located on C05 and spans from the confluence with C06 to the I-405, which corresponds with approximate HEC-RAS stations 192+93 to 254+30. The confluence to Beach Boulevard of Reach 3 is an incised trapezoidal riprap channel. Woodruff to the I-405 is an incised rectangular concrete channel.

4.2.4 Reach 4

Reach 4 is located on C05 and spans from the I-405 to Bushard Street, which corresponds with approximate HEC-RAS stations 254+30 to 313+22. Reach 4 is an incised rectangular concrete channel from the I-405 to Quartz Street, then transitions to an incised trapezoidal riprap channel from Quartz Street to Bushard Street.

4.2.5 Reach 5

Reach 5 is located on C05 and spans from Bushard Street to 5th Street, which corresponds with approximate HEC-RAS stations 313+22 to 432+63. Reach 5 is an incised trapezoidal riprap channel from Bushard Street to Brookhurst Street. C05 from the Brookhurst Street to approximately 1,300 feet upstream from Brookhurst Street is an incised trapezoidal concrete channel, which then transitions to an incised trapezoidal riprap until 5th Street.

4.2.6 Reach 6

Reach 6 is located on C05 and spans from 5th Street to Rosita Park, which corresponds with approximate HEC-RAS stations 432+63 to 446+00. Reach 6 is an incised trapezoidal concrete channel.

4.2.7 Reach 7

Reach 7 is located on C05 and spans from Rosita Park to Hazard Avenue, which corresponds with approximate HEC-RAS stations 446+00 to 456+05. Reach 7 is a concrete conduit.

4.2.8 Reach 8

Reach 8 is located on C05 and spans from Hazard Avenue to the extension of Woodbury Road, which corresponds with approximate HEC-RAS stations 456+05 to 503+00. Reach 8 is an incised trapezoidal concrete channel.

4.2.9 Reach 9

Reach 9 is located on C05 and spans from the extension of Woodbury Road to Garden Grove Boulevard, which corresponds with approximate HEC-RAS stations 503+00 to 563+36. Reach 9 is an incised trapezoidal concrete channel.

4.2.10 Reach 10

Reach 10 is located on C05 and spans from Garden Grove Boulevard to Haster Basin, which corresponds with approximate HEC-RAS stations 563+36 to 578+49. Between Apenwood and Haster Basin, the channel is an incised rectangular concrete channel. The remaining section consisting of a single 11-foot wide by 6-foot tall reinforced concrete box.

4.2.11 Reach 11

Reach 11 is located on C05 and spans from Haster Basin to Twintree Circle, which corresponds with approximate HEC-RAS stations 596+61 to 608+22. Reach 11 is a covered concrete conduit, consisting of 9-foot wide by 6-foot tall reinforced concrete boxes.

4.2.12 Reach 12

Reach 12 is located on C05 and spans from Twintree Circle to Chapman Avenue, which corresponds with approximate HEC-RAS stations 608+22 to 622+76. Reach 12 is an incised trapezoidal concrete channel for approximately 1,400 feet upstream of Twintree Circle until transitioning to a covered concrete conduit for approximately 1,000 feet. The covered concrete conduit from 1,400 feet upstream of Twintree Circle to Chapman Avenue is not within the study area; therefore, it is not included in the modeling or analysis.

4.2.13 Reach 13

Reach 13 is located on C06 and spans from the confluence with C05 to Ross Lane, which corresponds with approximate HEC-RAS stations 2+30 to 68+98. Reach 13 is an incised rectangular concrete channel at the confluence with C05. The section is currently being repaired under the PL 84-99 program. Above the confluence with C05 to Beach Boulevard, C06 is an incised earthen trapezoidal channel. C06 is an incised trapezoidal channel with earthen invert and riprap side slopes from Beach Boulevard to Ross Lane.

4.2.14 Reach 14

Reach 14 is located on C06 and spans from Ross Lane to Riverbend Drive, which corresponds with approximate HEC-RAS stations 68+98 to 76+67. Reach 14 is an incised rectangular concrete channel.

4.2.15 Reach 15

Reach 15 is located on C06 and spans from Riverbend Drive to the I-405, which corresponds with approximate HEC-RAS stations 76+67 to 93+26. Reach 15 is a covered concrete conduit, consisting of two 11 feet wide by 9 feet tall reinforced concrete boxes.

4.2.16 Reach 16

Reach 16 is located on C06 and spans from the I-405 to Bushard Street, which corresponds with approximate HEC-RAS stations 93+26 to 113+84. Reach 16 is an incised rectangular concrete channel.

4.2.17 Reach 17

Reach 17 is located on C06 and spans from Bushard Street to Brookhurst Street, which corresponds with approximate HEC-RAS stations 113+84 to 140+28. Reach 17 is an incised trapezoidal channel with an earthen invert and riprap side slopes from Bushard Street to Tahoma Street. Upstream of Tahoma Street to Brookhurst Street the C06 channel transitions to an incised earthen trapezoidal configuration.

4.2.18 Reach 18

Reach 18 is located on C06 and spans from Brookhurst Street to Euclid Street through Mile Square Regional Park. Reach 18 corresponds with approximate HEC-RAS stations 140+28 to 193+74. Reach 18 is an incised trapezoidal channel with a concrete low-flow invert and earthen (grass) side slopes.

4.2.19 Reach 19

Reach 19 is located on C06 and spans from Euclid Street to Newhope Avenue, which corresponds with approximate HEC-RAS stations 194+29 to 217+84. Reach 19 is an incised trapezoidal channel with an earthen invert and riprap side slopes.

4.2.20 Reach 20

Reach 20 is located on C04 and spans from the confluence with Bolsa Chica Channel (C02) to the I-405, which corresponds with approximate HEC-RAS stations 89+11 to 150+74. C04 from the confluence with C02 to Bolsa Chica Street is a trapezoidal channel with an earthen invert, riprap side slopes, and a levee on the left bank. C04 is an incised trapezoidal earthen channel with a riprap on the left bank side slope from Bolsa Chica Street to Graham Street. C04 is an incised trapezoidal earthen channel from Graham Street to the intersection of McFadden Avenue and Springdale Street. C04 from the McFadden Avenue and Springdale Street intersection to Edwards Street is an incised trapezoidal channel with earthen invert and riprap side slopes, with the exception of bridge and culvert crossing, as well as two ninety degree bends, which include concrete armoring. Reach 20 from Edwards Street to approximately 100 feet downstream of Goldenwest Street is covered concrete conduit, consisting of three 14-foot wide by 9.5-foot tall reinforced concrete boxes. Reach 20 transitions at approximately 100 feet downstream of Goldenwest Street from the concrete conduit to an incised rectangular concrete channel for approximately 100 feet, before transitioning again to a covered concrete conduit to the I-405.

4.2.21 Reach 21

Reach 21 is located on C04 from the I-405 to Beach Boulevard, which corresponds with approximate HEC-RAS stations 150+74 to 313+68. Reach 21 from I-405 to Hoover Street is an incised rectangular concrete channel, while from Hoover to Beach Boulevard the reach is an incised rectangular concrete channel, with a parallel covered concrete conduit, consisting of two 12-foot wide by 6-foot tall reinforced concrete boxes.

4.2.22 Reach 22

Reach 22 is located on C04 from Beach Boulevard to the Garden Grove Freeway (SR-22), which corresponds to approximate HEC-RAS stations 313+68 to 502+20. Reach 22 from Beach Boulevard to Brookhurst Street is an incised rectangular concrete channel. C04 is an incised trapezoidal channel with earthen invert and a riprap side slopes from Brookhurst Street to Westminster Avenue. C04 from Westminster Avenue to SR-22 is an incised trapezoidal concrete channel.

4.2.23 Reach 23

This reach is located between the NWSSB and Huntington Harbour, which corresponds with approximate HEC-RAS stations 0+13 to 89+11. Reach 23 is earthen trapezoidal channel with earthen levees on both banks.

4.3 Haster Basin

Haster Basin is a multi-use 21.5-acre site owned and operated by the Orange County Flood Control District in the City of Garden Grove. The basin and pump station project was initially built in 1976 to reduce flood risk and provide recreation. In 2013 Haster Basin, which is also known as Twin Lakes Freedom Park, was improved to maximize available right of way for additional flood control capacity, deepened by 4 feet for water quality purposes, and updated recreational features to include a 4,000-foot long perimeter road around the basin, a decomposed granite jogging trail, a park plaza with 12 game tables, 11 exercise stations, and two large steel gazebos with cantilevered decks.

Haster Basin is designed to accept runoff equivalent to the 100-year (1% ACE) storm event, where the basin and pump station work in tandem. The pump station ensures that sufficient volume is available in the basin to accommodate the peak of the storm, while discharging flows to accommodate downstream channel constraints. Specifically, the basin is designed to receive the 100-year (1% ACE) discharge with a maximum outflow of 459 cfs.

The Haster Basin improvements are incorporated into the existing condition floodplains. Significant differences in the previously generated floodplains and those which were developed for this study are largely contributed to the increased available storage volume and improved operations of the basin.

4.4 Mile Square Park

Mile Square Park is owned and primarily operated by Orange County. The park consists of three golf courses, three soccer fields, three baseball and three softball diamonds, an archery range, and a nature area. In addition, there are two fishing lakes, concession operated bike and paddle boat operations, a wide expanse of picnic areas, and numerous picnic shelters.

Approximately 65 acres of the land located adjacent to Brookhurst Street is leased by the City of Fountain Valley for recreational purposes. This land has been developed by the city into a high-activity community park, including a community center building, ball diamonds, basketball courts, outdoor play areas, and a tennis court complex.

The C06 channel runs east to west along the southern portion of Mile Square Park, bisecting the park with a grass side slopes and concrete invert lined channel. C06 floods frequently, which results in inundation of Mile Square Park immediately adjacent to the channel. The Mile Square Park existing condition does not formerly function as a storage location for flood risk management; however, the site was considered for a potential storage location for this study.

4.5 Outer Bolsa Bay

Outer Bolsa Bay is an environmentally sensitive area that is located at the downstream extent (mouth) of the C05 channel system. Water exchange between the C05 channel and the bay is controlled by tide gates. Outer Bolsa Bay is connected to Inner Bolsa Bay and the Muted Tidal Pocket by separate tide gates. These tide gates allow water to flow from Outer Bolsa Bay into either Inner Bolsa Bay or the Muted Tidal Pocket. Water is discharged from Outer Bolsa Bay through the Warner Ave Bridge into Huntington Harbour. Outer Bolsa Bay is separated from the Pacific Ocean by Pacific Coast Highway and Bolsa Chica State Beach.

Analysis addressing improvements at the downstream extent of the C05 channel and Outer Bolsa Bay was conducted by or prepared for Orange County in the early 1990's. This analysis was documented in three reports published in the 1993 – 1994 timeframe, while a fourth draft report was produced in 2009 to summarize the findings and cumulative impacts. The findings of these reports concluded that in order for the 100-year (1% ACE) storm flows to safely exit the C05 channel system and discharge into Outer Bolsa Bay and Huntington Harbour without impacts and without damaging infrastructure, the tide gates, Pacific Coast Highway, and Warner Avenue Bridge must be modified. On-going channel improvements on C05 currently assume that these measures will be implemented. Modeling performed for this study also demonstrates that channel improvements on C05 will increase downstream discharges, and if improvements are not made to increase conveyance through the Warner Avenue Bridge opening, increased flooding will occur in Outer Bolsa Bay, Warner Avenue, and the Pacific Coast Highway.

5.0 Hydrology

Detailed hydrologic analysis for the study area including flood frequency analysis, rainfall runoff model development, and discharge-frequency calculations are presented in the F3 Hydrology Appendix (USACE 2007). The follow sections provide a summary of the methods used for the hydrology development.

Three rainfall-runoff models using the HEC-1 program were developed for the study. One model was developed for the C05 and C06 drainage area. The other two models were developed for C04 and C02 respectively. The major elements in the rainfall-runoff model development include watershed characteristics, basin "n" values, base flow, rainfall data, soil loss rate, S-graph, channel routing, detention basin routing, and model calibration.

5.1 Present and Future Condition

Since the Westminster Watershed is highly developed and urbanized, the watershed is not expected to dramatically change in the foreseeable future. Therefore, the present and the future conditions will essentially be the same. This assumption will be used for both hydrologic and hydraulic analyses.

5.2 Description of Drainage Area

The East Garden Grove-Wintersburg Channel sub-watershed lies on a flat coastal plain surrounded generally by the Santa Ana River to the east, the Talbert Valley watershed and the Pacific Ocean to the south, and the Bolsa Chica Flood Control Channel sub-watershed to the west and north. The watershed is drained by the manmade channel system consisting of Orange County drainage facilities EGGW Channel (C05), Oceanview Channel (C06), Slater Channel (C05S04) and pump station, and storm drains. These facilities collect storm runoff from a 27.3 mi^2 drainage area consisting of portions of the cities of Santa Ana, Orange, Garden Grove, Anaheim, Westminster, Fountain Valley, and Huntington Beach. The channel mouth ends at the Bolsa Bay/Huntington Harbour in the city of Huntington Beach. Flow from Bolsa Bay/Huntington Harbour enters into the Pacific Ocean at the border of Sunset Beach and Seal Beach.

Of the 26.2 mi^2 drainage area, 5.1 mi^2 are tributary to Oceanview Channel and 3.9 mi^2 are tributary to Slater Channel. Elevations in the EGGW watershed range from 175 feet at the upper end of the basin to sea level at the Bolsa Bay, with an average basin slope of 2 feet per 1000 feet (12 ft/mi). Elevations in the Oceanview drainage area range from 64 feet at the upper end to 23 feet at the confluence with EGGW Channel, with an average basin slope of 1.5 feet per 1000 feet (8 ft/mi). Elevations in the Slater Channel drainage area range from 110 feet in the southern portion to sea level near the pump station, with an average basin slope of 6 feet per 1000 feet (33 ft/mi).

The drainage area for the Westminster Channel (C04) is approximately 10.9 mi^2 and is located in the Cities of Garden Grove, Huntington Beach, Santa Ana and Westminster. The topography of the land is relatively flat but slopes gradually in a southwesterly direction. Ground surface elevations vary from 10 feet at the Bolsa Chica Channel to 107 feet at the intersection of Chapman Avenue and 9th street giving the area an average slope of 2.4 feet per 1,000 feet (13 ft/mi). The drainage area is assumed to be completely developed. Land use includes 37% single family dwellings, 36% commercial/industrial, and the remainder consists of apartments, condominiums, schools, public parks and mobile home parks.

The drainage area for the Bolsa Chica Channel (C02) consists of approximately 8.1 mi^2 and includes portions of the cities of Anaheim, Cypress, Garden Grove, Los Alamitos, Stanton and unincorporated county territory. The topography is relatively flat. Elevations in the area vary from 91 feet at the intersection of Ball Road and Gilbert Street, to 15 feet at the San Diego Freeway, with an average slope of 1.8 feet per thousand feet. The hydrologic soil groups include A, B, and C. The land use is predominately residential and commercial.

5.2.1 Soils

The Soil Conservation Service (SCS) classifies soils into four hydrologic soil groups based on their infiltration characteristics and runoff potential. The description and characteristics are summarized in the Table 1. According to this classification, soil groups C and D will produce more runoff volume and higher peak flow than soil groups A and B, under a given rainfall condition.

The Westminster watershed is mostly comprised of the Hueneme-Bolsa Association: nearly level, poorly drained, calcareous fine sandy loams, silt loams and silty clay loams (hydrologic soil groups B and C). The upper portion of the watershed is mainly the Metz-San Emigdio Association: nearly level, well drained sandy loams (hydrologic soil groups A and B). Part of the area that is tributary to the Slater Channel is made up of the Myford Association: moderately steep, well drained sandy loam (hydrologic soil group D). The outlet of the watershed at the ocean comprises the Chino-Omni association: level, poorly drained silt loams to clays (hydrologic soil groups C and D).

Table 1: Hydrologic Soil Groups and Their Characteristics

Group	Infiltration Rate (in/hr)	Runoff Potential	Soil Components and Characteristics
A	High (> 2.5)	Low	Deep, well-drained sands or gravels.
B	Moderate (1.25 – 2.5)	Moderately low	Moderately deep & moderately well drained sandy-loam with moderately fine to coarse textures.

C	Moderate Low (0.4 – 1.25)	Moderate	Silty-loam soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture.
D	Low (0.2 – 0.4)	High	Clay soil with high swelling potential, soils with permanent high water table, soils with a clay pan or clay layer at or near the surface, or shallow soils over nearly impervious material

5.3 Land Use

Prior to settlement by Europeans, the study area was most likely comprised of grasses and trees: oaks, cottonwoods, and sycamore. Early development was primarily agricultural with some residential. Today the area is 85 percent developed. Land use consists primarily of single family residents with some multi-family, commercial, light industrial, school and parks, and transportation uses. Future land use projections for the study area indicate that vacant and agricultural land will be developed within 50 years.

5.4 Meteorology and Runoff

In general, the area has a mild Mediterranean type climate characterized by warm, dry summers and cool wet winters. Three types of storms produce precipitation in the area: general winter storms, general summer storms resulting from dissipating tropical cyclones, and thunderstorms. Due to climatic and drainage area characteristics, little stream flow occurs except during and immediately following rains, and runoff increases rapidly in response to rainfall excess. The main flood season is from November to April. The storms occurring during these months can last for several days, are widespread, and produce the largest floods. However, local thunderstorms may occur at any time of the year. Dry season without rain for several months during the summer is quite common. The average annual precipitation is about 13 inches near the coast.

5.5 HEC-1 Rainfall / Runoff Model Development

The major elements in the rainfall-runoff model development include watershed characteristics, basin "n" values, base flow, rainfall data, soil loss rate, S-graph, channel routing, detention basin routing, and model calibration.

5.5.1 Meteorology and Runoff

Watershed characteristics can be represented by the delineation of sub-basins and streams. Both the EGGW Channel sub-watershed and the Westminster Channel sub-watershed are located in a developed coastal area. The watershed area lies on a flat alluvial fan. Figure 1 is the drainage boundary for the C02, C04, C05 and C06 channel system. Each sub-watershed was delineated by length of the longest watercourse (L), length along longest watercourse from the outlet to the sub-basin centroid (L_{CA}), overall slope of longest watercourse between headwater and collection point (S), and basin roughness factor (n).

5.5.2 Basin "n"

Basin "n" is the basin roughness factor and is used to calculate the lag time. The basin "n" is estimated through field investigation of the watershed and following the guidelines described in Table 2. The estimated "n" is the initial basin "n" value used in the calibration process. The "n" value is one of the variables used to calibrate the different frequency floods. Tables 2, 3, 4 and 5 present the watershed characteristics for the study area including sub-watershed, drainage area, longest watercourse (L), length along longest watercourse from the outlet to the sub-basin centroid (L_{CA}), overall slope of longest watercourse between headwater and collection point (S), and basin roughness factor (n) for C05 & C06 drainage area, C04 drainage area, and C02 drainage area, respectively.

5.5.3 Base Flow

After model calibration runs, the base flow was adjusted to 0 cfs per square mile for the 100-year event since it did not have significant impact on peak discharge during the 100-year or greater frequency flood.

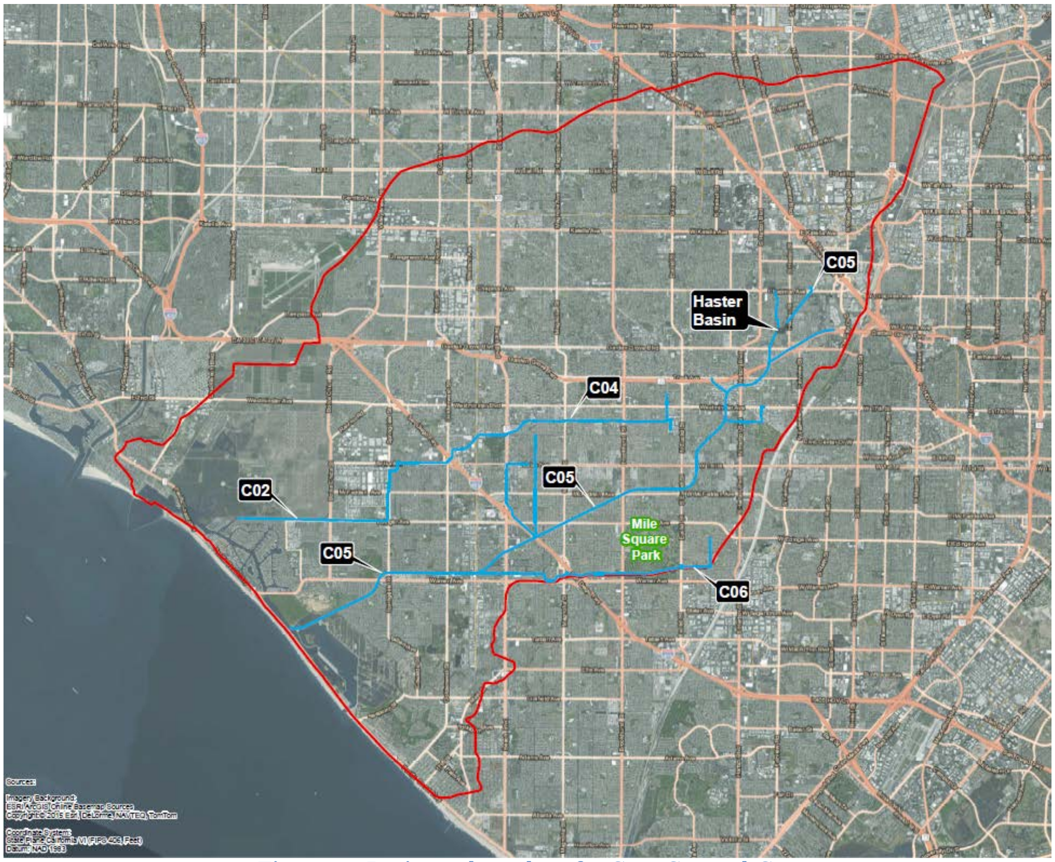


Figure 1: Drainage boundary for C04, C05 and C06

Table 2: Hydrologic Soil Groups and Their Characteristics

n = 0.015

1. Drainage area has fairly uniform, gentle slopes
2. Most watercourses either improved or along paved streets
3. Groundcover consists of some grasses - large % of area impervious
4. Main watercourse improved channel or conduit

n = 0.020

1. Drainage area has some graded and non-uniform, gentle slopes
2. Over half of the area watercourses are improved or paved streets
3. Groundcover consists of equal amount of grasses and impervious area
4. Main watercourse is partly-improved channel or conduit and partly greenbelt (see n = 0.025)

n = 0.025

1. Drainage area is generally rolling with gentle side slopes
2. Some drainage improvements in the area - street and canals
3. Groundcover consists mostly of scattered brush and grass and small % impervious
4. Main watercourse is straight channels which are turfed or with stony beds and weeds on earth bank (greenbelt type)

n = 0.030

1. Drainage area is generally rolling with rounded ridges and moderate side slopes
2. No drainage improvement exist in the area
3. Groundcover includes scattered brush and grasses
4. Watercourses meander in fairly straight, unimproved channels with some boulders and lodged debris

n = 0.040

1. Drainage area is composed of steep upper canyons with moderate slopes in lower canyons
2. No drainage improvements exist in the area
3. Groundcover is mixed brush and trees with grasses in lower canyons
4. Watercourses have moderate bends and are moderately impeded by boulders and debris with meandering courses

n = 0.050

1. Drainage area is quite rugged with sharp ridges and steep canyons
2. No drainage improvements exist in the area
3. Groundcover, excluding small areas of rock outcrops, includes many trees and considerable underbrush
4. Watercourses meander around sharp bends, over large boulders and considerable debris obstruction

n = 0.200

1. Drainage area has comparatively uniform slopes
2. No drainage improvements exist in the area
3. Groundcover consists of cultivated crops or substantial growths of grass and fairly dense small shrubs, cacti, or similar vegetation
4. Surface characteristics are such that channelization does not occur

Table 3: Watershed Characteristics of C05 / C06 Drainage Area

Subarea	Drainage Area (sq. mi.)	L (mi.)	Lca (mi.)	Representative Slope (ft./mi.)	Basin N
A1	1.867	3.552	1.776	17.589	.043
A2	0.977	2.379	1.190	12.156	.043
A3	0.625	1.805	0.902	13.804	.043
A4	0.65	1.849	0.925	2.973	.035
A5	0.18	0.836	0.418	19.15	.035
A6	2.436	4.188	2.094	10.816	.02
A7	0.106	0.602	0.301	8.309	.02
A8	0.555	1.677	0.838	14.308	.08
A9	0.542	1.653	0.826	7.259	.08
A10	0.291	1.125	0.562	8.005	.08
A11	1.308	2.850	1.425	10.000	.08
A12	0.803	2.108	1.054	9.963	.08
A13	0.238	0.993	0.497	4.030	.08
A14	0.806	2.112	1.056	14.440	.08
A15	0.522	1.615	0.807	10.218	.08
A16	0.494	1.560	0.780	5.125	.06
A17	2.077	3.794	1.897	6.588	.06
A18	0.609	1.776	0.888	7.319	.06
A19	1.645	3.285	1.642	7.611	.12
A20	0.745	2.012	1.006	6.461	.12
A21	0.719	1.968	0.984	5.589	.06
A22	4.228	5.890	2.945	14.261	.06
A23	0.316	1.184	0.592	43.935	.06
6A1	0.766	2.046	1.023	10.458	.04
6A2	0.172	0.812	0.406	28.324	.04
6A3	0.188	0.857	0.428	19.138	.04
6A4	0.484	1.542	0.771	20.239	.12
6A5	1.047	1.720	0.860	12.326	.11
6A6	0.188	0.857	0.428	20.072	.05
6A7	0.359	1.282	0.641	15.059	.05
6A8	0.484	1.542	0.771	10.833	.07
6A9	0.156	0.766	0.383	18.811	.07
6A10	0.172	0.812	0.406	14.109	.10
6A11	0.813	2.123	1.061	22.468	.12
6A12	0.172	0.812	0.406	32.388	.03
6A13	0.281	1.101	0.551	27.877	.03

Table 4: Watershed Characteristics of C04 Drainage Area

Subarea	Drainage Area (sq. mi.)	L (mi.)	Lca (mi.)	Representative Slope (ft./mi.)	Basin N
A1	1.38	2.18	1.63	16.89	0.035
A2	0.15	0.75	0.56	14.61	0.040
A3	0.34	0.99	0.75	20.11	0.039
A4	0.18	0.89	0.67	14.53	0.039
A5	0.39	1.09	0.82	13.71	0.039
A6	2.48	3.69	2.77	12.93	0.039
A7	0.83	2.46	2.00	11.39	0.050
A8	0.15	0.88	0.66	12.49	0.045
A9	0.76	2.13	1.60	13.61	0.050
A10	1.09	1.85	1.48	10.83	0.050
A11	0.44	1.52	1.14	9.21	0.050
A12	0.18	0.55	0.42	10.83	0.050
A13	0.52	1.43	1.20	9.06	0.100
A14	0.43	1.26	0.95	7.91	0.050
A15	0.19	0.98	0.74	6.12	0.050
A16	0.60	1.41	1.05	2.13	0.080
A17	0.27	0.64	0.32	4.69	0.015
A18	0.40	1.15	0.58	4.78	0.015
A19	0.09	0.72	0.36	2.76	0.015

Table 5: Watershed Characteristics of C02 Drainage Area

Subarea	Drainage Area (sq. mi.)	L (mi.)	Lca (mi.)	Representative Slope (ft./mi.)	Basin N
A1	0.58	1.35	0.68	3.69	0.041
A2	0.98	2.59	1.29	12.77	0.038
A3	3.31	4.64	2.32	7.11	0.032
A4	0.43	0.89	0.45	14.53	0.015
A5	0.53	1.29	0.64	6.21	0.015
A6	0.17	0.93	0.46	7.54	0.015
A7	0.20	2.46	1.23	2.78	0.015
A8	1.35	2.93	1.47	10.58	0.045
A9	0.46	1.33	0.66	10.78	0.030
A10	0.08	1.86	0.93	10.78	0.015

5.5.4 Rainfall

The N-year point rainfall depths for coastal (below 2000 feet) areas within Orange County were adopted from the Orange County Hydrology Manual (OCHM, 1987) because the entire study area is mostly below 2000 feet elevation. The Orange County rainfall frequency duration table only presents up to the 100-year frequency.

The Orange County 24-hour rainfall distribution is coded in the LAPRE-1 computer program, which is a preprocessor to HEC-1. Precipitation input requirements for LAPRE-1 are contributing area, and the 5-minute, 30-minute, 1-hour, 3-hour, 6-hour, and 24-hour point rainfall depths. The required point rainfall depths for 2-, 25-, 50-, 100-year rainfall from Orange County are listed in Table 6. Point rainfall depth from Orange County compares very favorably with the values from the NOAA Atlas 14.

In general, the average rainfall depth and intensities for a single storm event tend to decrease with respect to increasing area. The adopted precipitation depth-area adjustment for duration 5 minutes to 24 hours is given in the OCHM. It is also coded in the LAPRE-1 computer program so there is no need to adjust the point rainfall externally. There is no change in the depth-area adjustment for drainage areas larger than 150 square miles.

Since the rainfall does not change with development, the same rainfall depths will be used for present and future conditions. The rainfall depth for each subarea depends on elevation, which can be either mountain rainfall depths or coastal rainfall depths according to the Orange County method.

Table 6: Orange County N-year 24 Hour Point Rainfall

Frequency (year)	5-min. (inches)	30-min. (inches)	1 hour (inches)	3 hour (inches)	6 hour (inches)	24 hour (inches)
Point Precipitation for Mountain Area (above 2000 feet)						
2	0.26	0.45	0.66	1.34	2.09	3.81
25	0.63	1.04	1.51	3.08	4.81	8.86
50	0.71	1.19	1.73	3.52	5.51	10.02
100	0.78	1.34	1.94	3.96	6.19	11.27
Point Precipitation for Coastal Area (below 2000 feet)						
2	0.19	0.4	0.53	0.89	1.22	2.05
25	0.4	0.87	1.15	1.94	2.71	4.49
50	0.45	0.98	1.3	2.19	3.02	5.07
100	0.52	1.09	1.45	2.43	3.36	5.63

5.5.5 Loss Rate

The precipitation loss rate function used in this calibration study is based on the OCHM method, which is based on the Natural Resources Conservation Services (NRCS, formerly Soil Conservation Services or SCS) curve number (CN) approach, but modified to have an upper and lower bound. The loss rate, f(t), in in/hr is defined by:

$$f(t) = \mathrm{Y} * I(t) \quad for \quad \mathrm{Y} * I(t) \quad less \quad than \quad F_m$$

$$F_m \quad , \quad otherwise$$

where,

Y = the low loss fraction

F_m = the maximum loss rate (in/hr), and

I(t) = the design storm rainfall intensity (in/hr) at storm time (t).

The low loss fraction Y, acts as a lower bound fixed loss rate fraction, whereas F_m serves as an upper bound to the possible values of f(t)= Y*I(t). This loss accounting procedure is a hybridization of the NRCS CN approach. The low loss rate fraction is used to develop runoff hydrograph yields that are comparable to the NRCS 24-hr storm yields, and the peak rainfall loss rates are representative of values developed from the rainfall-runoff reconstitution studies.

Maximum Loss Rate (F_m). The maximum loss rate F_m is defined by:

$$F_m = A_p * F_p$$

where,

A_p = the actual* pervious area fraction of a subarea with corresponding maximum loss rate of F_p; and

F_p = the maximum loss rate for the pervious area fraction A_p for appropriate CN and antecedent moisture condition (AMC).

*Note – Actual pervious/impervious area is defined as the map measured value. In many instances it is necessary to distinguish between actual impervious area and hydraulically connected (or effective) impervious area because these values may differ significantly.

The maximum infiltration rate for impervious area is set at zero. Values for F_p can be calibrated to values obtained from rainfall-runoff reconstitution studies.

Low Loss Rate Fraction (Y). The low loss rate fraction is estimated from the NRCS loss rate equation by:

$$\mathrm{Y} = 1 - Y$$

where Y is the catchment yield (percent of 24-hour rain that runs off) computed by:

$$Y = \sum A * Y_A$$

with,

A = catchment area fraction with corresponding Y_A

Y_A = catchment yield in percent for catchment area fraction A.

Y_A is estimated using the NRCS CN by:

$$Y_A = \frac{(P_{24} - I_a)^2}{(P_{24} - I_a + S) * P_{24}}$$

where,

P_{24} = the 24-hour n-year precipitation depth.

I_a = initial abstraction (0.2S)

S = (1000/CN) – 10

Note, for P_{24} less than I_a, $Y_A = 0$.

The catchment yield for impervious areas is computed using a CN of 98. A CN of 98 is used rather than 100 to account for some depression storage.

Antecedent Moisture Conditions (AMC). The AMC I, II, and III conditions represent adjustments for antecedent soil moisture conditions of dry, average and wet, respectively. The designation of a particular AMC condition of a specific storm is usually determined by the evaluation of prior rainfall. The effect of AMC is built into the runoff curve number determination by providing adjusted CNs for AMC I and III, with the CN table based on AMC II. The prior rainfall criteria used to adjust the CN is based on the data used in the original estimation of the CN table. The AMC I and III CNs represent the extremes on the graphs of rainfall versus runoff volume.

The SCS Curve Numbers for developed and undeveloped areas were determined according to the soil and vegetation types using the tables published in the OCHM (Table 7). The percentage of actual impervious cover for developed areas was also determined using the table published in the OCHM (Table 8).

Orange County PFRD Geomatics/LIS Division provided digitized GIS data for hydrologic soil groups and vegetation cover of the whole Orange County area. The area extent of hydrologic soil groups, vegetation covers and land use for each sub-area were estimated from maps provide by Orange County.

Following the OCHM method above, the Low Loss Rate and Maximum Loss Rate for each subarea were computed for the 2-, 5-, 10-, 25-, 50-, and 100-year floods. The results were used as the initial loss rate for the 2-, 5-, 10-, 25-, 50-, and 100-year flood calibrations (described in the following sections). For the 200- and 500-year floods, the 100-year loss rate data was used as initial loss rate in the calibration process. The loss rate is one of the variable factors in rainfall-runoff calibrations.

Table 9 lists the final calibrated Low Loss Fraction and Maximum Loss Rate for each sub-area under present condition for the C05 & C06 drainage area.

Tables 10 and 11 list the final calibrated Low Loss Fraction and Maximum Loss Rate for each sub-area under present condition for the C04 and C02 drainage area respectively.

Table 7: Curve Number of Hydrologic Soil-Cover Complexes

Cover Type	Quality of Cover	Soil Group			
		A	B	C	D
NATURAL COVERS					
Barren					
(Rockland, eroded and graded land)		78	86	91	93
Chaparral, Broadleaf	Poor	53	70	80	85
(Manzonita, ceanothus and scrub oak)	Fair	40	63	75	81
	Good	31	57	71	78
Chaparral, Narrowleaf	Poor	71	82	88	91
(Chamise and redshank)	Fair	55	72	81	86
Grass, Annual or Perennial	Poor	67	78	86	89
	Fair	50	69	79	84
	Good	38	61	74	80
Meadows or Cienegas	Poor	63	77	85	88
(Areas with seasonally high water table,	Fair	51	70	80	84
Principal vegetation is sod forming grass)	Good	30	58	71	78
Open Brush	Poor	62	76	84	88
(Soft wood shrubs - buckwheat, sage, etc.)	Fair	46	66	77	83
	Good	41	63	75	81
Woodland	Poor	45	66	77	83
(Coniferous or broadleaf trees predominate.	Fair	36	60	73	79
Canopy density is at least 50 percent.)	Good	25	55	70	77
Woodland, Grass	Poor	57	73	82	86
(Coniferous or broadleaf trees with canopy	Fair	44	65	77	82
density from 20 to 50 percent)	Good	33	58	72	79
URBAN COVERS					
Residential or Commercial Landscaping	Poor	32	56	69	75
(Lawn, shrubs, etc.)					
Turf	Poor	58	74	83	87
(Irrigated and mowed grass)	Fair	44	65	77	82
	Good	33	58	72	79

Table 7 continued

	Quality of Cover	Soil Group A	B	C	D
AGRICULTURE COVERS					
Fallow					
(Land plowed but not tilled or seeded)		77	86	91	94
Legumes, Closed Seeded	Poor	66	77	85	89
(Alfalfa, sweetclover, timothy, etc.)	Good	58	72	81	85
Orchard, Evergreen	Poor	57	73	82	86
(Citrus, avocados, etc.)	Fair	44	65	77	82
	Good	33	58	72	79
Pasture, Dryland	Poor	68	79	86	89
(Annual grasses)	Fair	49	69	79	84
	Good	39	61	74	80
Pasture, Irrigated	Poor	58	74	83	87
(Legumes and perennial grass)	Fair	44	65	77	82
	Good	33	58	72	79
Row Crops	Poor	72	81	88	91
(Field crops – tomatoes, sugar beets, etc.)	Good	67	78	85	89
Small grain	Poor	65	76	84	88
(Wheat, oats, barley,etc.)	Good	63	75	83	87

Notes:

1. All curve numbers are for Antecedent Moisture Condition (AMC) II
2. Quality of cover definitions:
   Poor-Heavily grazed, regularly burned areas, or areas of high burn potential.
   Less than 50 percent to 75 percent of ground surface is protected by plant cover or brush and tree Canopy.
   Fair-Moderate cover with 50 percent to 75 percent of ground surface protected.
   Good-Heavy or dense cover with more than 75 percent of the ground surface protected.
4. Impervious areas are assigned curve number 98.

Table 8: Impervious Cover for Developed Areas

Land Use	Range-Percent	Recommended Value For Average Conditions - Percent
Natural or Agriculture	0 - 0	0
Public Park	10 - 25	15
School	30 - 50	40
Single Family Residential:		
2.5 acre lots	5 - 15	10
1 acre lots	10 - 25	20
2 dwelling/acre	20 - 40	30
3-4 dwelling/acre	30 - 50	40
5-7 dwelling/acre	35 - 55	50
8-10 dwelling/acre	50 - 70	60
More than 10 dwelling/acre	65 - 90	80
Multiple Family Residential:		
Condominiums	45 - 70	65
Apartments	65 - 90	80
Mobile Home Park	60 - 85	75
Commercial, Downtown Business or Industrial	80 - 100	90

Notes:

1. Land use should be based on ultimate development of the watershed. Long range master plan for the County and incorporated cities should be reviewed to insure land use assumptions.
2. Recommended values are based on average conditions which may not apply to a particular study area. The percentage impervious may vary greatly even on comparable sized lots due to differences in dwelling size, improvements, etc. Landscape practices should also be considered as it is common in some areas to use ornamental gravel underlain by impervious plastic materials in place of lawns and shrubs. A field investigation of a study area shall always be made, and a review of aerial photos, where available, may assist in estimating the percentage of impervious cover in the developed areas.
3. For typical equestrian subdivisions increase impervious area 5 percent over the values recommended in the table above.

Source:OCHM

Table 9: Summary of Calibrated Orange County Loss Rates for C05 and C06 Drainage Area

Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)	Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)
A1	0.247	0.0656	A19	0.249	0.0946
A2	0.247	0.0656	A20	0.350	0.1508
A3	0.239	0.0629	A21	0.306	0.1369
A4	0.454	0.1313	A22	0.300	0.1318
A5	0.372	0.1172	A23	0.195	0.0736
A6	0.369	0.1147	6A1	0.471	0.1347
A7	0.134	0.0300	6A2	0.471	0.1347
A8	0.323	0.0872	6A3	0.471	0.1347
A9	0.448	0.1283	6A4	0.608	0.1856
A10	0.211	0.0529	6A5	0.644	0.2262
A11	0.251	0.0665	6A6	0.363	0.1206
A12	0.421	0.1345	6A7	0.445	0.1376
A13	0.418	0.1423	6A8	0.202	0.0612
A14	0.316	0.1022	6A9	0.133	0.0350
A15	0.325	0.1173	6A10	0.355	0.1187
A16	0.333	0.1374	6A11	0.309	0.1010
A17	0.373	0.1309	6A12	0.288	0.0927
A18	0.278	0.1144	6A13	0.221	0.0868

Table 10: Summary of Calibrated Orange County Loss Rates for C04 Drainage Area

Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)	Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)
A1	.4000	.1500	A11	.5000	.2000
A2	.4500	.1750	A12	.5000	.2000
A3	.4000	.1500	A13	.5500	.2250
A4	.4000	.1500	A14	.5000	.2000
A5	.4000	.1500	A15	.5000	.2000
A6	.4000	.1500	A16	.5000	.2000
A7	.5000	.2000	A17	.3000	.0800
A8	.4500	.1750	A18	.4000	.1500
A9	.5000	.2000	A19	.3000	.0800
A10	.5000	.2000			

Table 11: Summary of Calibrated Orange County Loss Rates for C02 Drainage Area

Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)	Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)
A1	0.547	0.1730	A6	0.509	0.1938
A2	0.623	0.1420	A7	0.511	0.1940
A3	0.724	0.0990	A8	0.672	0.1224
A4	0.648	0.1310	A9	0.631	0.1404
A5	0.711	0.1066	A10	0.895	0.0277

5.5.6 Unit Hydrograph Procedure

The unit hydrograph is the hydrograph of direct surface discharge, at the concentration point of that drainage area, resulting from a unit effective rainfall. Unit rainfall is the net rainfall (excess) of 1 inch which occurs over all parts of a drainage area at a uniform rate during a specified unit period of time. The unit hydrograph is computed by the Los Angeles District unit hydrograph procedure through use of an S-graph. The S-graph is the time distribution of runoff as a function of basin lag time. Lag time is defined as the elapsed time (in hours) from beginning of unit effective rainfall (excess) to the instant that the summation hydrograph for the concentration point of that drainage area reaches 50 percent of ultimate discharge (in volume), or simply the time in hours for 50 percent of the total volume of runoff of the unit hydrograph to reach the outlet.

Since the watershed is located in a coastal alluvial fan area and the area is fully developed, a Coast Developed S-graph was adopted for this hydrologic study. The Coast Developed S-graph is coded within LAPRE-1.

5.5.7 Detention Basin Routing

Haster Retarding Basin is a dual purpose basin with an area of 22.4 acres. The basin initially was designed to be used as a flood control facility for the C05 channel only. However, in 1972 by a mutual agreement between the Orange County Flood Control District and the City of Garden Grove, it was agreed to develop the basin into a community park (Twin Lake Park) as a secondary use of the site. Levees of the basin were raised slightly in 1985 to accommodate more capacity for the 1820 acres tributary to the basin. A 9'H x 6'W RCB and a 96" RCP inlet discharge into the basin from the north.

In the rainfall-runoff model, the relationship between the detention basin volume, elevation, and discharge is shown in Table 12.

Table 12: Volume, Elevation, and Discharge Relationship for Haster Detention Basin

Volume (acre-ft)	0	50	75	100	125	150	175	200	225	250
Elevation (ft)	92.5	99	102.5	103.5	105.5	107	108.5	110.5	112	113.5
Discharge (cfs)	0	450	450	450	450	450	450	450	450	450

The Haster Basin information and data were based on the Orange County report entitled "Hydrology Report for East Garden Grove – Winterburg Channel (Facility No. C05) (Bolsa Chica Bay to Vermont Avenue), Volumes I and II" dated July 1990 and approved by the county on December 1, 1993.

5.5.8 Channel Routing

The Muskingum-Cunge method was used to route subarea hydrographs to the outlet. Muskingum-Cunge is physically based and is considered reliable. The Muskingum-Cunge method was applied with eight-point standard channel cross-section data. Topography data was available for the entire reach of EGGW Channel. The channel and overbank Manning's "n" coefficient were estimated based on channel materials, i.e., concrete riprap or earth, etc, vegetation cover, and topographic characteristics.

Table 13 lists the characteristics of each reach and input parameters for the Muskingum-Cunge routing method for the C05 & C06 channel drainage area rainfall-runoff model. Tables 14 and 15 list the Muskingum-Cunge routing parameters for the C04 and C02 drainage area rainfall-runoff models, respectively.

Table 13: HEC-1 Parameters for Muskingum-Cunge Routing for C05 and C06 Drainage Area

A1 to A2								
KK	Haster Basin Outlet(31.1)-GG Blvd							
KM	578+30 - 567.87 (11X6)							
RD								
RC	0.013	0.013	0.013	0.013	1043	0.0022		
RX	0	0.01	0.02	0.02	11.02	11.02	11.03	11.04
RY	6	6	6	0	0	6	6	6
KK	GG Blvd-GH Freeway(32)							
KM	563+87 - 551+03 (12X6.5)							
RD								
RC	0.06	0.014	0.06	1284	.0041			
RX	0	5	10	10	22	22	27	32
RY	6.5	6.5	6.5	0	0	6.5	6.5	6.5
A2 to A3								
KK	A3_RT							
KM	Garden Grove Freeway(32)-Trask Av(33):551.03 - 534.94 (20X7.5)							
RC	0.06	0.014	0.06	1609	.0029			
RX	0	5	10	10	30	30	35	40
RY	7.5	7.5	7.5	0	0	7.5	7.5	7.5
A3 to A4								
KK	A4_RT							
KM	Trask Av(33)-Harbor Blvd(34):534.94 - 514.70 (25X9)							
RC	0.06	0.014	0.06	2024	.0024			
RX	0	5	10	10	35	35	40	45
RY	9	9	9	0	0	9	9	9
A4 to A5								
KK	A5_RT							
KM	Harbor Blvd(34)-Pacific RR(35.1):534.94 – 500.03 (25X8)							
RC	0.06	0.014	0.06	3491	.0023			
RX	0	5	10	10	35	35	40	45
RY	8	8	8	0	0	8	8	8
A5 to A6								
KK	A6_RT							
KM	Pacific RR(35.1)-Westminster Ave(36):500.03-487.19 (30X11.5)							
RC	0.06	0.014	0.06	3491	.0027			
RX	0	5	10	10	40	40	45	50
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
A6 to A7								
KK	A7_RT							
KM	Westminster Ave(36)-Morningside Ave(37):487.19-475.60 (40X11)							
RC	0.06	0.014	0.06	1159	.0011			
RX	0	5	10	10	50	50	55	60
RY	11	11	11	0	0	11	11	11

Table 13 Continued

A7 to A8								
KK	A8_RT1							
KM	Morningside Ave(37)-Hazard St(37.1):475.60-456.10 (40X12)							
RC	0.06	0.014	0.06	1950	.0039			
RX	0	5	10	10	50	50	55	60
KK	A8_RT2							
KM	Hazard St(37.1)-(37.2):456.10-446.04 (16X10)							
RC	0.06	0.014	0.06	1006	.0028			
RX	0	50	100	100	116	116	166	216
RY	12	10	10	0	0	10	10	12
KK	A8_RT3							
KM	(37.2)-Fifth Ave(38):446.04-438.08 (30X12)							
RC	0.06	0.014	0.06	796	.0014			
RX	0	5	10	10	40	40	45	50
RY	12	12	12	0	0	12	12	12
A8 to A9								
KK	A9_RT							
KM	Fifth Ave(38)-Bolsa St(39):438.08-424.49 (40X11.5)							
RC	0.06	0.014	0.06	1359	.0039			
RX	0	5	10	10	50	50	55	60
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
A9 to A10								
KK	A10_RT							
KM	Bolsa St(39)-C-5_F Channel(40):424.49-402.98 (40X11.5)							
RC	0.06	0.014	0.06	2151	.0025			
RX	0	5	10	10	50	50	55	60
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
A10 to A11								
KK	A11_RT1							
KM	C-5_F Channel(40)-Euclid St(40.1):402.98-396.47 (40X11.5)							
RC	0.06	0.014	0.06	649	.0034			
RX	0	5	10	10	50	50	55	60
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
KK	A11_RT2							
KM	Euclid St(40.1)-Deming St:396.47-387.18 (40X10.5)							
RC	0.06	0.014	0.06	929	.0020			
RX	0	5	10	10	50	50	55	60
RY	10.5	10.5	10.5	0	0	10.5	10.5	10.5
KK	A11_RT3							
KM	Deming St-Ward St(41):387.18-370.05 (45X10)							
RC	0.06	0.014	0.06	1713	.0022			
RX	0	5	10	10	55	55	60	65
RY	10	10	10	0	0	10	10	10
A11 to A12								
KK	A12_RT							
KM	Ward St(41)-Brookhurst St(42):370.05-342.76 (45X10)							
RC	0.06	0.014	0.06	2729	.0015			
RX	0	5	10	10	55	55	60	65
RY	10	10	10	0	0	10	10	10

Table 13 Continued

A12 to A13								
KK	A13_RT							
KM	Brookhurst St(42)-(43):342.76-332.55 (50X11)							
RC	0.06	0.014	0.06	1021	.0032			
RX	0	5	10	10	60	60	65	70
RY	11	11	11	0	0	11	11	11
A13 to A14								
KK	A14_RT							
KM	(43)-Bushard St.(44):332.55-313.22 (50X11)							
RC	0.06	0.014	0.06	1933	.0006			
RX	0	5	10	10	60	60	65	70
RY	11	11	11	0	0	11	11	11
A14 to A15								
KK	A15_RT							
KM	Bushard St.(44)-Magnolia St.(45):313.22-283.64 (50X11.5)							
RC	0.06	0.014	0.06	2958	.0010			
RX	0	5	10	10	60	60	65	70
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
A15 to A16								
KK	A16_RT							
KM	Magnolia St.(45)-San Diego FWY(47):283.64-254.30 (60X12.5)							
RC	0.06	0.014	0.06	2934	.0004			
RX	0	5	10	10	70	70	75	80
RY	12.5	12.5	12.5	0	0	12.5	12.5	12.5
A16 to A17								
KK	A17_RT							
KM	San Diego FWY(47)-Beach Blvd.(48):254.30-224.72 (60X12)							
RC	0.06	0.014	0.06	2958	.0009			
RX	0	5	10	10	70	70	75	80
RY	12.0	12.0	12.0	0	0	12.0	12.0	12.0
A17 to A18								
KK	A18_RT							
KM	Beach Blvd.(48)-Union Pacific RR(49):224.72-191.67 (60X14)							
RC	0.06	0.014	0.06	3305	.0019			
RX	0	5	10	10	70	70	75	80
RY	14.0	14.0	14.0	0	0	14.0	14.0	14.0
A18 to A19								
KK	A19_RT							
KM	Golden West St. (50)-Edwards St. (51):165.22.67-138.80 (146X14.5)							
RC	0.06	0.018	0.06	2642	.0007			
RX	0	100	200	200	346	346	446	546
RY	16.5	14.5	14.5	0	0	14.5	14.5	16.5
A19 to A20								
KK	A20_RT							
KM	Edwards St. (51)-Springdale St. (52):138.80-112.39 (146X14.5)							
RC	0.06	0.022	0.06	2461	.0004			
RX	0	100	200	200	346	346	446	546
RY	16.5	14.5	14.5	0	0	14.5	14.5	16.5

Table 13 Continued

A20 to A21								
KK	A21_RT							
KM	Springdale St. (52)-Slater Ext Bridge(54):112.39-57.77 (146X14.5)							
RC	0.06	0.022	0.06	5462	.00017			
RX	0	100	200	200	346	346	446	546
RY	16.5	14.5	14.5	0	0	14.5	14.5	16.5
A21 to A22								
KK	A22_RT							
KM	Slater Ext Bridge(54)-Outlet Structure(55):57.77-6.08 (146X14.5)							
RC	0.06	0.022	0.06	4969	.0004			
RX	0	100	200	200	346	346	446	546
RY	16.5	14.5	14.5	0	0	14.5	14.5	16.5

6A1								
KK	6A1_RT							
KM	Newhope st(112)-(114):(Trap:9X12)Earth Channel							
RC	0.06	0.030	0.06	1320	.0012			
RX	0	5	10	28	37	55	60	65
RY	12.0	12.0	12.0	0	0	12.0	12.0	12.0
6A2								
KK	6A2_RT							
KM	Corta Dr(114)-Euclid St(115):(Trap:8X10)Earth Channel							
RD								
RC	0.06	0.030	0.06	1320	.0018			
RX	0	5	10	25	33	48	53	58
RY	10.0	10.0	10.0	0	0	10.0	10.0	10.0
6A3								
KK	6A3_RT							
KM	Euclid St(115)-(116):(Trap:40X7) Trap Channel							
RC	0.06	0.030	0.06	680	.0012			
RX	0	5	10	20.5	40.5	51	56	61
RY	7.0	7.0	7.0	0	0	7.0	7.0	7.0
6A4								
KK	6A4_RT							
KM	(116)-Brookhurst St(117):(Trap40X7) Trap Channel							
RC	0.06	0.030	0.06	680	.0012			
RX	0	5	10	20.5	40.5	51	56	61
RY	7.0	7.0	7.0	0	0	7.0	7.0	7.0
6A5								
KK	6A5_RT							
KM	Brookhurst St.(117)-(118):(10X12)Earth Trap. Channel							
RC	0.06	0.030	0.06	1240	.0008			
RX	0	5	10	28	38	56	61	66
RY	12	12	12	0	0	12	12	12
6A6								
KK	6A6_RT							
KM	(118)-Bushard St.(119):(10X12) Earth Trap. Channel							
RC	0.06	0.030	0.06	1400	.0008			
RX	0	5	10	28	38	56	61	66
RY	12	12	12	0	0	12	12	12

Table 13 Continued

6A7								
KK	6A7_RT							
KM	Bushard St.(119)-San Diego Freeway(120):(20X10)Conc Rec. Channel							
RC	0.06	0.014	0.06	2000	.0012			
RX	0	5	10	10	30	30	35	40
RY	10	10	10	0	0	10	10	10
6A8								
KK	6A8_RT1							
KM	San Diego Freeway(120)-Magnolia(121):(20X10)Conc. Covered Conduit							
RC	0.06	0.013	0.06	700	.0024			
RX	0	5	10	10	30	30	35	40
RY	20	20	20	0	0	20	20	20
6A9								
KK	6A9_RT1							
KM	Magnolia(121)-(123):(R19X11) Conc. Rec. Channel							
RC	0.06	0.014	0.06	1540	.0011			
RX	0	50	100	100	119	119	169	219
RY	14	11	11	0	0	11	11	14
KK	6A9_RT2							
KM	(123)-Newland St.(124):(8X14) Riprap Trap Channel							
RC	0.06	0.035	0.06	1590	.0010			
RX	0	50	100	121	129	150	160	210
RY	11	8	8	0	0	8	8	11
6A10								
KK	6A10_RT							
KM	Newland St.(124)-(125):(8X14)Earth Trap Channel							
RC	0.06	0.030	0.06	730	.0014			
RX	0	50	100	121	129	150	160	210
RY	11	8	8	0	0	8	8	11
6A11								
KK	6A11_RT							
KM	(125)-Beach Blvd.(126):(8X14)Earth Trap Channel							
RC	0.06	0.030	0.06	1910	.0014			
RX	0	50	100	121	129	150	160	210
RY	11	8	8	0	0	8	8	11
6A12								
KK	6A12_RT							
KM	Beach Blvd.(126)-P.E.Rd(128):(8X14)Earth Trap Channel							
RC	0.06	0.030	0.06	2640	.0017			
RX	0	50	100	121	129	150	160	210
RY	11	8	8	0	0	8	8	11
6A13								
KK	6A13_RT1							
KM	Union Pacific RR(49)-Golden West St. (50):191.67-178.42 (60X13)							
RC	0.06	0.014	0.06	1325	.0017			
RX	0	5	10	10	70	70	75	80
RY	13.0	13.0	13.0	0	0	13.0	13.0	13.0
KK	6A13_RT2							
KM	Union Pacific RR(49)-Golden West St. (50):178.42-165.22 (75X13)							
RC	0.06	0.014	0.06	1275	.0013			
RX	0	5	10	10	85	85	90	95
RY	13.0	13.0	13.0	0	0	13.0	13.0	13.0

Table 14: HEC-1 Parameters for Muskingum-Cunge Routing for C04 Drainage Area

A1 to A2

KK	RCH 1							
KM	Channel from Trask to Westminster							
RD								
RC	0.017	0.017	0.017	2174	.0027			
RX	0	1.5	3.5	13	17	26.5	28.5	30
RY	9	9.5	9.5	0	0	9.5	9.5	9

A2 to A3

KK	RCH 2							
KM	Channel Westminster to STA 179+97.89							
RD								
RC	0.023	0.039	0.023	1456	.0023			
RX	0	1	20	36.5	49.5	64.5	69	70
RY	10.5	11	11	0	0	10	10	9.9

A3 to A4

KK	RCH 3							
KM	Channel from STA 179+97.89 to STA 173+10.00							
RD								
RC	0.023	0.039	0.023	688	.0013			
RX	0	1	19	35.5	55	70.6	71	72
RY	11	11	11	0	0	10.4	10.4	10.4

A4 to A5

KK	RCH 4							
KM	Channel from STA 173+10.00 to STA 143+000.26							
RD								
RC	0.023	0.039	0.023	3010	.0013			
RX	0	1	20.5	35.5	55	70	73	74
RY	10	10	10	0	0	10	10	10

A5 to A6

KK	RCH 5							
KM	Rect. Channel from Brookhurst to Brushard – STA 143+.0026 TO STA 115+57.00							
RD								
RC	0.023	0.039	0.023	2743	.0014			
RX	0	0.01	0.02	0.03	35.03	35.04	35.05	35.06
RY	10	10	10	0	0	10	10	10

A6 to A7

KK	RCH 6							
KM	Rect. Channel from Brushard to Magnolia – STA 115+57.00 TO 87+56.00							
RD								
RC	0.017	0.029	0.017	2801	.0031			
RX	0	0.01	0.02	0.03	35.03	35.04	35.05	35.06
RY	8	8	8	0	0	8	8	8

A7 to A8

KK	RCH 7							
KM	Rect. Channel from Magnolia to Newland – STA 87+56.00 TO STA 61+94.63							
RD								
RC	0.023	0.023	0.023	2561	.0020			
RX	0	0.01	0.02	0.03	25.03	25.04	25.05	25.06
RY	9	9	9	0	0	9	9	9

Table 14 Continued

A8 to A9

KK	RCH 8
KM	Rect. Channel from Newland to C04O06 Inlet – STA 61+94.63 to 47+60.00

RD								
RC	0.017	0.018	0.017	1435	.0022			
RX	0	0.01	0.02	0.02	25.03	25.04	25.05	25.06
RY	8.5	8.5	8.5	0	0	8.5	8.5	8.5
A9 to A10								
KK	RCH 9							
KM	Rect. Channel : C04P06 Inlet to Beach – STA 47+60.00 to STA 33+07.54							
RD								
RC	0.020	0.020	0.020	1452	.0020			
RX	0	0.01	0.02	0.03	25.03	25.04	25.05	25.06
RY	8.5	8.5	8.5	0	0	8.5	8.5	8.5
A10 to A11								
KK	RCH 10							
KM	Trap Channel from Beach to Cedarwood (30% Box Culvert)							
RD								
RC	0.023	0.023	0.029	1521	.0017			
RX	0	1	2	10.5	25.5	34.0	34.01	34.02
RY	8.7	8.5	8.5	0	0	8.5	8.5	8.5
A11 to A12								
KK	RCH 11							
KM	Rectangular Channel from Cedarwood to Hoover							
RD								
RC	0.023	0.023	0.023	1535	.0030			
RX	0	0.01	0.02	0.03	36.03	36.04	36.05	36.06
RY	8.5	8.5	8.5	0	0	8.5	8.5	8.5
A12 to A13								
KK	RCH 12							
KM	Rectangular Channel from Hoover to STA 177+27.00							
RD								
RC	0.018	0.020	0.018	2552	.0011			
RX	0	0.01	0.02	0.03	38.03	38.04	38.05	38.06
RY	11	11	11	0	0	11	11	11
A13 to A14								
KK	RCH 13							
KM	Rec Channel STA 177+27.00 TO 163+00.00 (part under 405) Avg of 2 Ch used							
RD								
RC	0.020	0.027	0.020	1427	.0025			
RX	0	0.01	0.02	0.03	33.03	33.04	33.05	33.06
RY	10	10	10	0	0	10	10	10
A14 to A15								
KK	RCH 14							
KM	Rec Channel STA 163+00.00 137+30.39							
RD								
RC	0.023	0.023	0.023	2570	.0012			
RX	0	0.01	0.02	0.03	42.03	42.04	42.05	42.06
RY	9.5	9.5	9.5	0	0	9.5	9.5	9.5

Table 14 Continued

A15 to A16								
KK	RCH 15							
KM	Trap Channel STA 137+30.39 to 118+06.19 (Includes Downstream Box Culvert)							
RD								
RC	0.031	0.040	0.034	1924	.0011			
RX	0	0.01	20.25	36.5	50	70.25	99	100

RY	13.9	13.9	13.5	0	0	13.5	13.9	13.9
A16 to A17								
KK	RCH 16							
KM	Trap Channel STA 118+06.09 to STA 104+94							
RD								
RC	0.029	0.042	0.033	1312	.0011			
RX	0	0.01	7.75	28	52	72.25	89.99	90
RY	13.87	13.87	13.5	0	0	13.5	13.87	13.87
A17 to A18								
KK	RCH 17							
KM	Trap Channel STA 104+94 to McFadden (Includes Downstream Box Culvert)							
RD								
RC	0.040	0.040	0.027	1950	.0013			
RX	0	0.01	7.75	28	52	72.25	89.99	90
RY	13.87	13.87	13.5	0	0	13.5	13.87	13.87
A18 to A19								
KK	RCH 18							
KM	Trap Channel STA 83+44.22 To STA 59+70							
RD								
RC	0.029	0.039	0.029	2574	.0005			
RX	0	0.01	17	35	75	93	99.99	100
RY	12.34	12.34	12	0	0	12	12.14	12.14
A19 to A20								
KK	RCH 19							
KM	Trap Channel to 30' RCP STA 59+70 to STA 30+45							
RD								
RC	0.029	0.039	0.029	2925	.0005			
RX	0	0.01	17	35	75	93	99.99	100
RY	12.34	12.34	12	0	0	12	12.14	12.14
A20 to A21								
KK	RCH 20							
KM	Trap Channel to C02 STA 30+45 to STA0+00							
RD								
RC	0.022	0.032	0.022	3045	.0004			
RX	0	0.01	16	31	79	94	99.99	100
RY	9.68	9.68	10	0	0	10	9.88	9.88

Table 15: HEC-1 Parameters for Muskingum-Cunge Routing for C02 Drainage Area

A1 to A2								
KK	RCH 1							
KM	Cerritos To So. Pacific							
RD								
RC	0.014	0.014	0.014	1184	.0012			
RX	0	0.01	0.02	0.03	14.03	14.04	14.05	14.06
RY	8	8	8	0	0	8	8	8
A2 to A3								
KK	RCH 2							
KM	So. Pacific Drive RR & Plaza Dr. to Katella							
RD								
RC	0.014	0.014	0.014	1184	.0012			
RX	0	0.01	0.02	0.03	14.03	14.04	14.05	14.06
RY	9	9	9	0	0	9	9	9
A3 to A4								
KK	RCH 3							
KM	Katella to S01							
RD								
RC	0.050	0.035	0.035	1217	.004			
RX	0	0.5	1.5	15	25	38.5	39.5	40
RY	9	9	9	0	0	9	9	9
A4 to A5								
KK	RCH 4							
KM	Stanton Storm Drain Channel to Naval Bridge							
RD								
RC	0.012	0.014	0.012	2086	.0017			
RX	0	1	8.75	24.5	39.5	55.25	74	75
RY	11	11	11	0	0	10.4	10.4	10.4
A5 to A6								
KK	RCH 5							
KM	Naval Bridge to p01							
RD								
RC	0.014	0.014	0.014	786	.0017			
RX	0	1	8.75	24.5	39.5	55.25	74	75
RY	10.5	10.5	10.5	0	0	10.5	10.5	10.5
A6 to A7								
KK	RCH 6							
KM	p01 to p02							
RD								
RC	0.028	0.033	0.028	700	.0012			
RX	0	1	8	26	38	56	74	75
RY	12	12	12	0	0	12	12	12
A7 to A8								
KK	RCH 7							
KM	p02 to Santa Catalina Ave							
RD								
RC	0.026	0.033	0.026	1540	.0012			
RX	0	1	8	26	38	56	73	74
RY	12	12	12	0	0	12	12	12

Table 15 Continued

A8 to A9								
KK	RCH 8							
KM	Santa Catalina Ave. to Holland							
RD								
RC	0.024	0.033	0.024	1260	.0012			
RX	0	1	8.75	26	38	55.25	74	75
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
A9 to A10								
KK	RCH 9							
KM	Holland Ave to Belgrave Channel							
RD								
RC	0.024	0.033	0.024	1441	.0012			
RX	0	1	8.75	26	38	55.25	74	75
RY	11.5	11.5	11.5	0	0	11.5	11.5	11.5
A10 to A11								
KK	RCH 10							
KM	Belgrave to 405/22							
RD								
RC	0.014	0.014	0.014	3470	.0010			
RX	0	0.01	0.02	0.03	44.03	44.04	44.05	44.06
RY	11	11	11	0	0	11	11	11
A11 to A12								
KK	RCH 11							
KM	Triple Box Culvert Underneath 405/22 (256+17.25 250+69.85)							
RD								
RC	0.014	0.014	0.014	550	.0019			
RX	0	0.01	0.02	0.03	12.03	12.04	12.05	12.06
RY	10	10	10	0	0	10	10	10

5.5.9 Model Calibration

Stream gage peak discharges for San Diego Creek at Culver Drive were analyzed using the HEC-FFA program. Using the computed 100-year discharge at Culver Drive to relate to EGGW Channel at Gothard Street, the 100-year discharge for a drainage area of 20 square miles is 8,000 cfs. The HEC-1 rainfall runoff model for EGGW Channel was calibrated to this value.

The calibration parameters are loss rates, basin n, base flow, and Muskingum channel routing parameters. Initial model parameters were assumed based on the OCHM guideline. Model runs were conducted and the model discharge values at the CP18 (Gothard Street) were compared to the discharge value of 8,000 cfs. Then, the model parameters were adjusted and new model runs were conducted. Through iterative process the model was calibrated. The model calculated discharge at CP18 is 7,980 cfs which is 0.2% different from the calibration target value.

Orange County PF&RD also developed 100-year expected discharge values for C05 and C06 using Orange County Hydrology Manual procedures. Orange County Hydrology procedures were developed using stream gage data collected in all the county watersheds. The procedures use Orange County storm, rational method, and unit hydrograph. As mentioned in this report, the HEC-1 model developed for this study was based on the Orange County storm and county suggested parameters. The model was also calibrated against the San Diego Creek data of the county. Therefore, the county's 100-year expected discharge values provide an ideal reference to compare the calibrated HEC-1 model results. Table 16 presents the comparisons between Orange County 100-year expected discharge values and the calibrated HEC-1 model results for the C05 & C06 drainage area. As shown in the table, the calibrated model results are very close to the County's results.

Tables 17 and 18 present the comparisons between Orange County 100-year expected discharge values and the calibrated HEC-1 model results for the C04 drainage area and C02 drainage area respectively. As shown in the table, the calibrated model results are very close to the County's results.

Table 16: Comparisons between Orange County & HEC-1 100-year Discharge Values for C05 & C06 Drainage Area

Concentration Point	Drainage Area (mile^2)	County Q (cfs)	HEC-1 Model Q (cfs)	Difference in cfs	Difference in %
C05-CP2	3.47	990	980	10	1.0
C05-CP4	4.30	1540	1520	20	1.3
C05-CP6	6.84	3380	3330	50	1.5
C05-CP8	7.94	3790	3720	70	1.9
C05-CP10	9.54	4530	4460	70	1.6
C05-CP12	10.58	4770	4780	-10	-0.2
C05-CP14	11.91	5150	5210	-60	-1.1
C05-CP16	14.48	5910	5980	-70	-1.2
C05-CP18	20.37	7710	7980	-270	-3.4
C05-CP20	22.76	8300	8420	-120	-1.4
C05-CP22	27.70	9290	9340	-50	-0.5
C05-CP23	28.02	9290	9260	30	0.3
C06-CP2	1.12	920	920	0	0.0
C06-CP4	2.19	1280	1280	0	0.0
C06-CP6	3.20	1770	1640	130	7.9
C06-CP8	3.84	2020	2030	-10	0.5
C06-CP10	4.83	2310	2320	-10	0.4
C06-CP12	5.28	2420	2410	10	0.4

Table 17: Comparisons between Orange County & HEC-1 100-year Discharge Values for C04 Drainage Area

Table 18B – Comparisons between Orange County & HEC-1 100-year Discharge Values for C04 Drainage Area					
Concentration Point	Drainage Area ($mile^2$)	County Q (cfs)	HEC-1 Model Q (cfs)	Difference in cfs	Difference in %
C04-CP2	1.53	1220	1191	29	2.0
C04-CP4	2.06	1540	1576	-36	-2.0
C04-CP6	4.92	3010	2888	122	4.0
C04-CP8	5.91	3360	3244	116	3.0
C04-CP10	7.75	4000	4093	-93	-2.0
C04-CP12	8.38	4190	4275	-85	-2.0
C04-CP14	9.33	4310	4425	-115	-3.0
C04-CP16	10.12	4420	4645	-225	-5.0
C04-CP18	10.80	4520	4580	-60	-1.0

Table 18: Comparisons between Orange County & HEC-1 100-year Discharge Values for C02 Drainage Area

Table 18C – Comparisons between Orange County & HEC-1 100-year Discharge Values for C02 Drainage Area					
Concentration Point	Drainage Area ($mile^2$)	County Q (cfs)	HEC-1 Model Q (cfs)	Difference in cfs	Difference in %
C02-CP2	1.51	1200	1206	-6	0.0
C02-CP4	5.25	3000	2841	159	5.3
C02-CP6	5.95	3200	3141	59	1.8
C02-CP8	7.50	3800	3925	-125	-3.3
C02-CP10	8.76	4150	4051	99	2.4

5.5.10 Nth Value Flow Ratios

Nth value ratios were used to determine peak discharges for frequencies greater and less than the 100 year event. Table 19 shows the nth flow ratios used by Orange County that have been adopted for this study. In addition to San Diego Creek, a flow frequency analysis was completed for five gages operated by Orange County. These gage locations include Fullterton Creek (Station 2), Bolsa Chica (Station 225), Anaheim Barber (Station 232), East Garden Grove (217) and Westminster Channel (207). Figure 2 shows the comparison of the Nth value flow ratios for these gages. The orange line representing the ratios used by Orange County bounds the upper limit of most the computed ratios but shows a favorable comparison.

Table 19: Nth flow values used by Orange County

Frequency	Nth Year Ratio
1	0.22
2	0.32
5	0.47
10	0.67
25	0.82
50	0.92
100	1.00
200	1.14
500	1.29

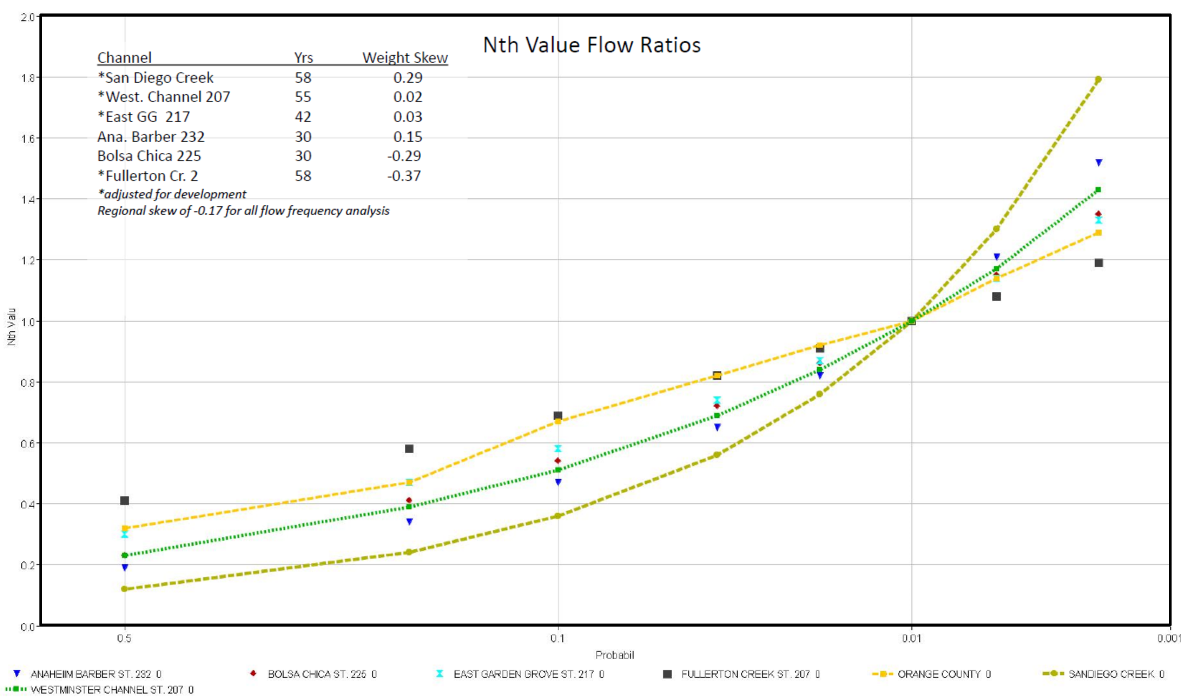


Figure 2: Comparison of between gages Nth value ratios and ratios used by Orange County.

5.5.11 Unsteady Model Discharges

The HEC-1 models for this study were developed for steady state analysis where channel routing was performed in the hydrologic model. HEC-1 hydrologic modeling was used along with and HEC-RAS steady state hydraulic models along with a FLO- 2D to evaluate overbank flooding in areas where breakouts occur.

Since the development of the original modeling suite using HEC-1, HEC-RAS (steady) and FLO-2D, HEC-RAS capabilities have expanded to include integrated one-dimensional, two-dimensional capabilities that will allow water movement both into and out of the channel. The HEC-RAS unsteady model developed for this study is later described in more detail Section 7. When the unsteady HEC-RAS model was used to route flows through the system, some notable differences in flow were observed in the flows. In generals flows exceeded the target calibration values by about 10% on the lower end of C05 and C04. As expected, some differences were observed between the Muskingum-Cunge routing and the unsteady model. To correct this issue, loss rate and 'Basin n' HEC-1 parameters were modified to provide a better match to the target flows for calibration.

Tables 20 and 21 present the watershed characteristics for the study area including along with the calibrated basin roughness factor (n) for C05 & C06 drainage area, C04 drainage area, respectively for the unsteady model. Tables 22 and 23 present the calibrated loss rates for the unsteady model. No model parameters were changed for C02. Figures 3, 4 and 5 present a comparison between the unsteady flow and steady flows.

Table 20: Watershed Characteristics of C05 / C06 Drainage Area (Basin N calibrated for unsteady model)

Subarea	Drainage Area (sq. mi.)	L (mi.)	Lca (mi.)	Representative Slope (ft./mi.)	Basin N
A1	1.867	3.552	1.776	17.589	.043
A2	0.977	2.379	1.190	12.156	.043
A3	0.625	1.805	0.902	13.804	.043
A4	0.65	1.849	0.925	2.973	.035
A5	0.18	0.836	0.418	19.15	.035
A6	2.436	4.188	2.094	10.816	.02
A7	0.106	0.602	0.301	8.309	.02
A8	0.555	1.677	0.838	14.308	.08
A9	0.542	1.653	0.826	7.259	.08
A10	0.291	1.125	0.562	8.005	.08
A11	1.308	2.850	1.425	10.000	.08
A12	0.803	2.108	1.054	9.963	.03
A13	0.238	0.993	0.497	4.030	.08
A14	0.806	2.112	1.056	14.440	.08
A15	0.522	1.615	0.807	10.218	.08
A16	0.494	1.560	0.780	5.125	.06
A17	2.077	3.794	1.897	6.588	.11
A18	0.609	1.776	0.888	7.319	.12
A19	1.645	3.285	1.642	7.611	.12
A20	0.745	2.012	1.006	6.461	.12
A21	0.719	1.968	0.984	5.589	.12
A22	4.228	5.890	2.945	14.261	.08
A23	0.316	1.184	0.592	43.935	.03
6A1	0.766	2.046	1.023	10.458	.04
6A2	0.172	0.812	0.406	28.324	.04
6A3	0.188	0.857	0.428	19.138	.04
6A4	0.484	1.542	0.771	20.239	.04
6A5	1.047	1.720	0.860	12.326	.04
6A6	0.188	0.857	0.428	20.072	.02
6A7	0.359	1.282	0.641	15.059	.02
6A8	0.484	1.542	0.771	10.833	.02
6A9	0.156	0.766	0.383	18.811	.12
6A10	0.172	0.812	0.406	14.109	.12
6A11	0.813	2.123	1.061	22.468	.12
6A12	0.172	0.812	0.406	32.388	.12
6A13	0.281	1.101	0.551	27.877	.12

Note: Changes made for the unsteady calibration are highlighted in red.

Table 21: Watershed Characteristics of C04 Drainage Area (Basin N calibrated for unsteady model)

Subarea	Drainage Area (sq. mi.)	L (mi.)	Lca (mi.)	Representative Slope (ft./mi.)	Basin N
A1	1.38	2.18	1.63	16.89	0.035
A2	0.15	0.75	0.56	14.61	0.040
A3	0.34	0.99	0.75	20.11	0.039
A4	0.18	0.89	0.67	14.53	0.039
A5	0.39	1.09	0.82	13.71	0.039
A6	2.48	3.69	2.77	12.93	0.039
A7	0.83	2.46	2.00	11.39	0.050
A8	0.15	0.88	0.66	12.49	0.045
A9	0.76	2.13	1.60	13.61	0.039
A10	1.09	1.85	1.48	10.83	0.060
A11	0.44	1.52	1.14	9.21	0.030
A12	0.18	0.55	0.42	10.83	0.030
A13	0.52	1.43	1.20	9.06	0.150
A14	0.43	1.26	0.95	7.91	0.015
A15	0.19	0.98	0.74	6.12	0.015
A16	0.60	1.41	1.05	2.13	0.015
A17	0.27	0.64	0.32	4.69	0.015
A18	0.40	1.15	0.58	4.78	0.015
A19	0.09	0.72	0.36	2.76	0.015

Note: Changes made for the unsteady calibration are highlighted in red.

Table 22: Summary of Calibrated Loss Rates for C05 and C06 Drainage Area (unsteady model)

Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)	Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)
A1	0.247	0.0656	A19	0.550	0.3318
A2	0.247	0.0656	A20	0.550	0.3318
A3	0.239	0.0629	A21	0.306	0.1369
A4	0.454	0.1313	A22	0.550	0.3318
A5	0.372	0.1172	A23	0.195	0.0736
A6	0.369	0.1147	6A1	0.471	0.1347
A7	0.134	0.0300	6A2	0.471	0.1347
A8	0.323	0.0872	6A3	0.471	0.1347
A9	0.448	0.1283	6A4	0.608	0.1856
A10	0.211	0.0529	6A5	0.644	0.2262
A11	0.251	0.0665	6A6	0.133	0.0350
A12	0.421	0.1345	6A7	0.133	0.0350
A13	0.418	0.1423	6A8	0.202	0.0612
A14	0.316	0.1022	6A9	0.133	0.0350
A15	0.325	0.1173	6A10	0.133	0.0350
A16	0.333	0.1374	6A11	0.309	0.1010
A17	0.373	0.1309	6A12	0.288	0.0927
A18	0.608	0.1856	6A13	0.221	0.0868

Note: Changes made for the unsteady calibration are highlighted in red.

Table 23: Summary of Calibrated Orange County Loss Rates for C04 Drainage Area

Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)	Subarea	Low Loss Rate (%)	Max. Loss Rate (in/hr)
A1	.4000	.1500	A11	.4000	.1500
A2	.4500	.1750	A12	.4000	.1500
A3	.4000	.1500	A13	.5500	.3000
A4	.4000	.1500	A14	.5500	.3000
A5	.4000	.1500	A15	.5500	.3000
A6	.4000	.1500	A16	.5500	.3000
A7	.5000	.2000	A17	.5500	.3000
A8	.4500	.1750	A18	.5500	.3000
A9	.4000	.1500	A19	.5500	.3000
A10	.2880	.0927			

Note: Changes made for the unsteady calibration are highlighted in red.

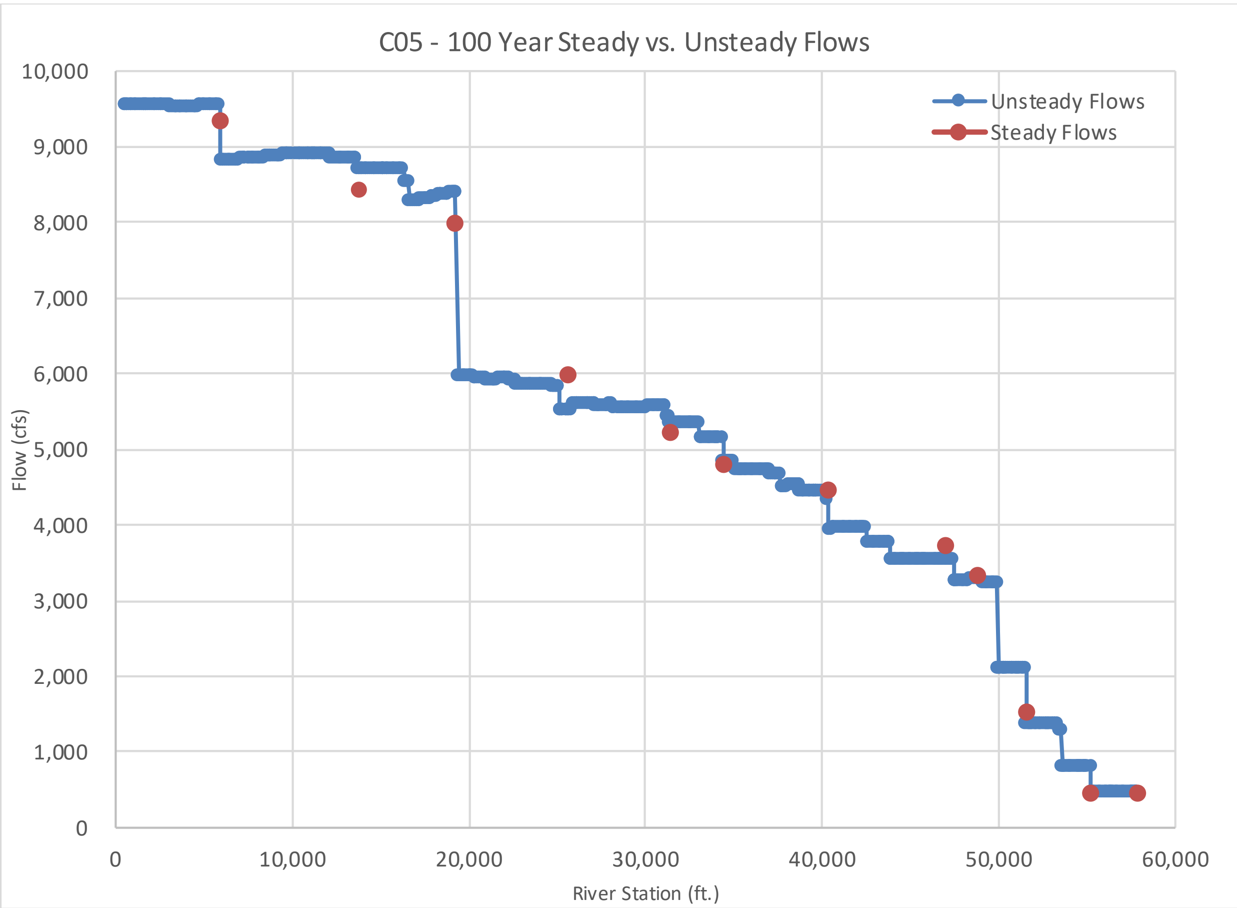


Figure 3: Comparison of 100 year steady and unsteady flows for C05

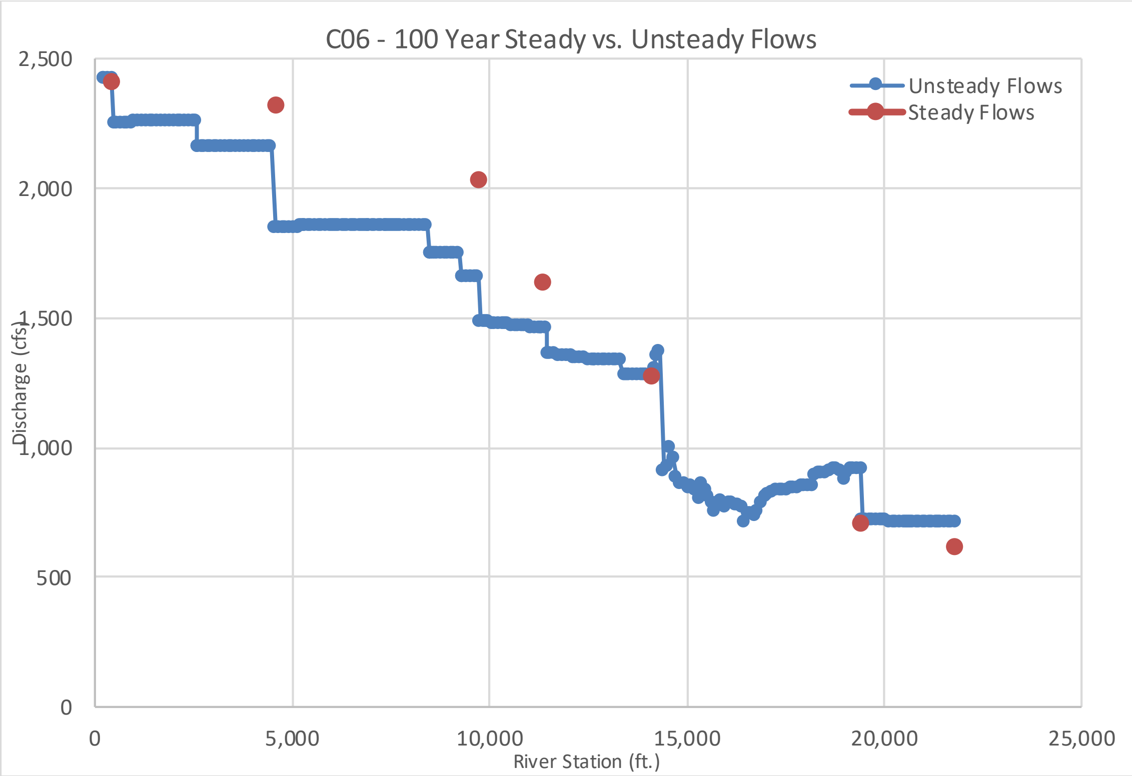


Figure 4: Comparison of 100 year steady and unsteady flows for C06

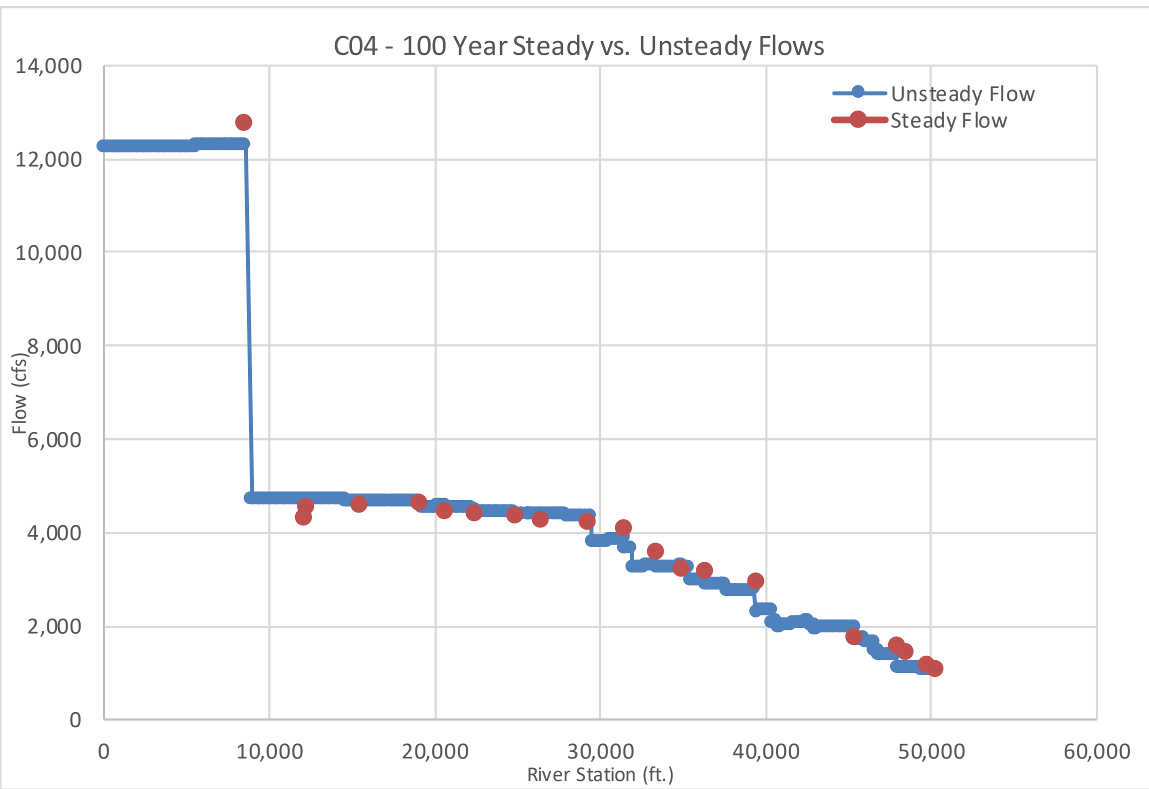


Figure 5: Comparison of 100 year steady and unsteady flows for C04

6.0 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. Orange County is considering impacts of climate change and has conducted multiple studies regarding the effect on the sustainable and reliable water supply. One such report that Orange County prepared entitled the "Integrated Regional Water Management Plan" (IRWMP) was published in July 2013. Section 12 and Appendix J of the report discuss potential water reliability impacts that may occur as a result of climate change to the region and has proposed solutions (Orange County 2013).

6.1.1 Climate Change Literature Review

There is strong consensus in the literature that air temperatures will increase in the study basin, and throughout the country, over the next century. The studies reviewed here generally agree on an increase in mean annual air temperature of up to 8 °F (4.5 °C), with extreme temperature projections increasing by the latter half of the 21st century for the California Region. The largest increases are generally projected for the summer months with temperature increases generally projected to be higher in inland areas compared to the coast. High consensus is also seen in the literature with respect to projected increases in both frequency and severity of extreme high temperature events compared to the recent past. Decreases in frequency of extreme cold temperatures are projected, with largest frequency decreases in the mountainous areas of the California Region, including northern California. Projections of precipitation in the study basin are less certain than those associated with air temperature. Results of some studies conflict with one another. In addition, they show seasonal and spatial variability in projected precipitation results throughout the California Region, which may be related to topographic or latitudinal variations. This variability may also be attributed to differences in time period over which the precipitation studies were conducted. The dominant trend appears to suggest an increase in precipitation in the northern areas of the region and a decrease in precipitation in the southern areas of the California Region. Moderate consensus among the reviewed studies was found regarding extreme precipitation events. Future storm events in the California Region are predicted to increase in frequency and intensity compared to the recent past.

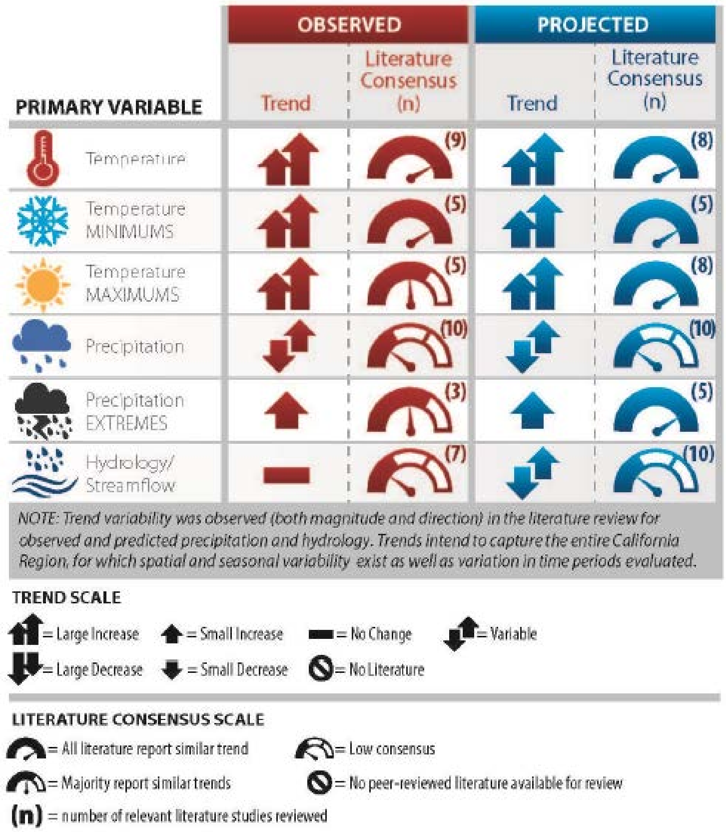


Figure 6: California Region 18 - Summary matrix of observed and projected climate trends and literary consensus. (USACE, 2015)

Future global climate change has the potential to change regional precipitation trends which would have a potential corresponding effect on flood control hydrology and basis for flood control improvements. The US Army Corps of Engineers has published an Engineering and Construction Bulletin No. 2016-25 (ECB 2016-25) Guidance for incorporating climate change impacts to Inland Hydrology in Civil Works Studies, designs, and projects. The guidance documents' recommended procedure is a qualitative approach to evaluate the general direction of climate change relevant to elements of the hydrology study, although the approach will not produce binding numerical outputs. In some cases, it may be possible to calculate an order of magnitude range of the relevant climate threats and impacts that can be considered in the context of project goals or design vulnerabilities and impacts. This, in turn, can be used to describe future without project conditions or inform decisions during the alternative formulation and selection phase, when one project alternative can be judged to reduce vulnerabilities or enhance resilience more than the others.

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. In Orange County, the average daily minimum/maximum temperatures range from about 50/64 (degrees Fahrenheit {° F}) in winter to 63/72 in the summer along the coast. In the intermediate valleys, the range is from about 46/70 in winter to about 63/85 in summer. The IRWMP study predicts an increase in temperature of 2 to 5° F by the latter 21st century.

Predictions of changes in precipitation are even more speculative, with some scenarios showing precipitation increasing in the future and others showing the opposite. Within the project area, over 90 percent of the season's total precipitation normally falls from November through April, with December-

March as the wettest months. Rainless periods of several months during the summer are common. 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 IRWMP study predicts a decrease in precipitation within the region up to 2 inches per year by the latter 21st century.

Increases in projected future flood magnitude and frequency could impact both the future with and without-project conditions. Increases in future flood magnitude or frequency could also alter project performance, including increased maintenance costs or repairs associated with overtopping events that are potentially more frequent than originally assumed. Due to the characteristic of the study area and the long term stream gage records, a qualitative analysis can potentially show the uncertainty involved and the relevancy of climate change to the project. No adjustments due to climate change were made to Future Condition discharges for this analysis.

6.1.2 Sea Level Rise

The project area includes the ocean outlets; therefore, potential sea level changes are a factor and adjustments were made for downstream boundary conditions in the hydraulic models. These adjustments are later described in the 'Boundary Condition' section.

6.1.3 Linear Trend Analysis

As outlined in ECB No. 2016-25, an investigation of the trends in the annual maximum flow gage data was performed to qualitatively assess impacts of climate change within the watershed using the USACE Climate Hydrology Assessment Tool. Due to the unavailability of gage data, the tool does not contain any gages located in the project area, so instead analysis was performed on a nearby gage on San Diego Creek near Irvine, California.

Figure 7 depict an increasing trend in annual peak streamflow for the period of record, with a p-value smaller than 0.05 (the generally accepted threshold for significance) which indicates that the trend is statistically significant.

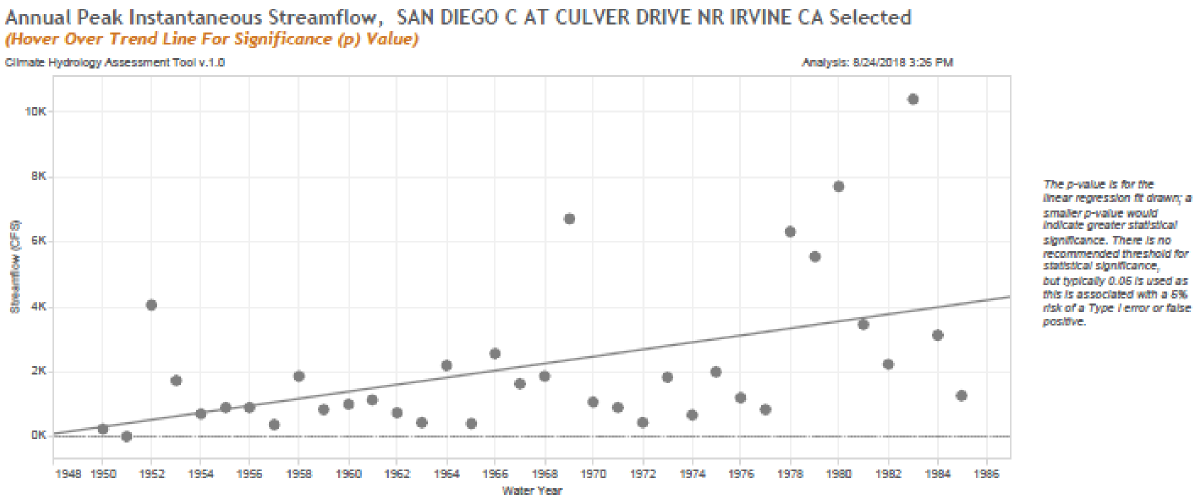


Figure 7: Annual Peak Streamflow for San Diego Creek at Culver Near Irvine.

Figure 8 displays the projected annual maximum monthly trends from the USACE Climate Hydrology Assessment Tool. As expected for this type of qualitative analysis, there is a considerable, but consistent spread in the projected annual maximum monthly flows. This spread is indicative of the uncertainty associated with climate changed hydrology. The trend in the mean projected annual maximum monthly streamflow indicates an increase over time. This increase is statistically-significant (p-value < 0.05) and suggests the potential for future increases in flow relative to current conditions.

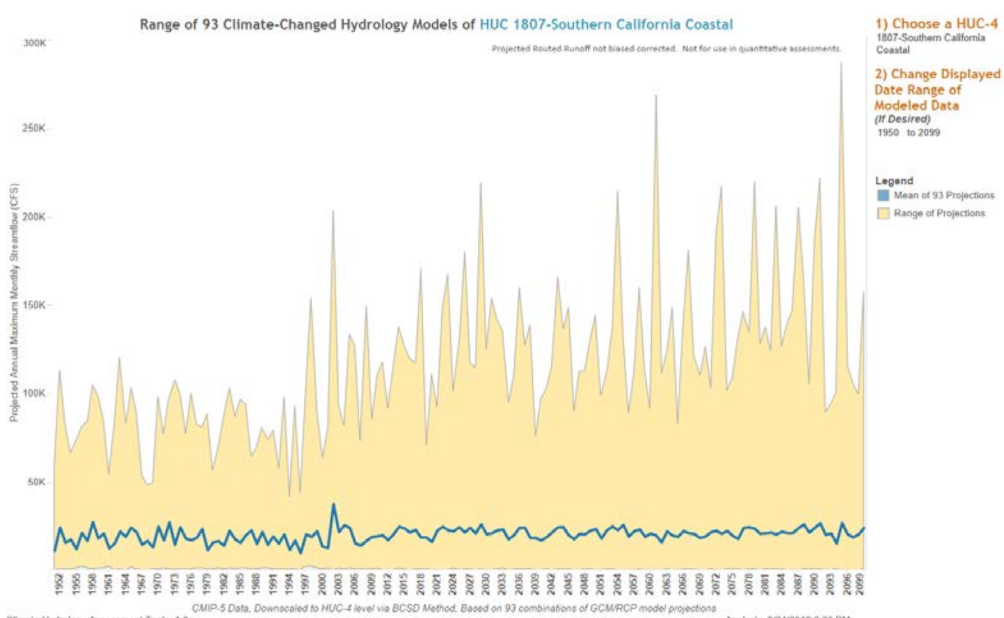


Figure 8: Project Annual Maximum Monthly Streamflow for HUC 1807 – Southern California Coastal

7.0 Hydraulic Analysis

7.1.1 Existing Conditions

HEC-RAS 1-D models were developed to match channel sections shown on the most current as-built drawings or 2016 surveyed data (from C06 PS&E Project). Using the steady state models as a base, Tetra Tech also developed 1-D unsteady HEC-RAS models for the channel component of the system.

Since little gage data existing for the study area, no hydraulic model calibration was performed on the existing conditions model. Model results and inundation mapping was coordinated with Orange County to determine that the results reasonably reflected the existing flood risk based on their flood surveillance.

Due to the regular nature of the channel cross-sections and the relatively uniform composition of the channel lining material and roughness, one of the greatest source of uncertainty in the hydraulic model is expected to be the bridges and the culverts. Bridge and culvert debris is expected to have a significant impact on the stage-discharge relationship in many channel reaches. Fences, walls, and other hydraulic obstructions parallel to the channel and in the overbank areas also are expected to affect flooding limits, but a detailed evaluation of all of these obstructions is beyond the scope of the modeling performed for the study.

7.1.2 Alternatives Analysis

In addition to modeling the baseline conditions, three alternative scenarios were modeled. Alternative modeling is based upon several sources including the existing Corps reports and models, and OCPW project reports. Maximum Channel Improvements is the Locally Preferred Plan (LPP) and was defined by OCPW project reports.

7.1.2.1 In-Channel Modification (Minimum Channel Improvements)

Consistent with the formulation strategy to "focus on improving channel conveyance," this alternative would reduce flood risk within the watershed by improving conveyance efficiency of existing channels. Trapezoidal channels within C04, C05, and C06 that currently have an earthen bottom and either earthen or riprap banks would be lined with concrete. There would be no alteration to reaches that are rectangular in shape or lined with concrete, nor to reaches of covered concrete conduit structures.

The leveed areas in the downstream reaches of C02 and C05 (reaches 23 and 1, respectively) would be improved to reduce the risk of levee failure. Improvements in these reaches would include installation of steel sheet pile channel walls and preservation of existing soft bottom, tidally-influenced habitat.

Additional downstream measures would be combined with the in-channel measures to address existing flooding in Outer Bolsa Bay and to account for increased flow volumes that result from increased conveyance capacity in the channels. The tide gates on C05 would be replaced in order to improve the flow conditions through the lower reaches of the C05 channel. The current tide gates leak and therefore allow saltwater to intrude upstream in C05. This saltwater influence extends upstream of Outer Bolsa Bay for approximately 2.5 miles. The replacement of the tide gates as part of this alternative would be configured to allow for continued tidal influence in the lower reaches of C05, thus lessening impacts to the existing ecological conditions.

This alternative also includes the widening of the Outer Bolsa Bay channel just upstream of the Warner Avenue Bridge. Widening of the channel would require that the Warner Avenue Bridge and the pedestrian bridge at the Bolsa Chica Conservancy be widened as well. Widening of the Outer Bolsa Bay channel would improve conveyance as well as the hydraulic efficiency of the lower reaches of C05.

The channel conveyance improvements in this alternative reduce overbank flooding but also increases flow rates in Outer Bolsa Bay between the tide gates and the Warner Avenue Bridge. A 2,500 foot long and an approximate 3 foot tall floodwall would be built along PCH at Outer Bolsa Bay to reduce impacts from flooding on traffic between the tide gates and the Warner Avenue Bridge. The floodwall would begin to be loaded at approximately the 10-year event with the 'Minimal Channel Improvements'.

Compatible nonstructural measures would be incorporated to lessen the life safety risk associated with flooding in the project area. Compatible nonstructural measures that were considered in the development of this alternative include development of a flood warning system and removal of impediments to flow.

7.1.2.1 In-Channel Modification (Maximum Channel Improvements)

Consistent with the formulation strategies to "focus on improving channel conveyance" and "focus on improving channel capacity," this alternative will reduce flood risk within the watershed by improving both conveyance efficiency and capacity of existing channels. Trapezoidal channels within C02, C04, C05, and C06 will be replaced with rectangular concrete (or steel sheet pile) channels to contain a 0.01 ACE storm event.

Additionally, floodwalls would be constructed in the existing channel right of way where necessary. Soft channel bottoms would be preserved in the tidally influenced downstream reaches of C02 and C05 to avoid impacts to marine habitat.

Additional downstream measures would be combined with the in-channel measures to address existing flooding in Outer Bolsa Bay and to account for increased flow volumes that result from the improved conveyance capacity in the channels. The tide gates on C05 would be replaced in order to improve the flow conditions through the lower reaches of the C05 channel. The current tide gates leak and therefore allow saltwater to intrude upstream in C05. This saltwater influence extends upstream of Outer Bolsa Bay for approximately 2.5 miles. The replacement of the tide gates as part of this alternative would be configured to allow for continued tidal influence in the lower reaches of C05, thus lessening impacts to the existing ecological conditions.

This alternative also includes the widening of the Outer Bolsa Bay channel just upstream of the Warner Avenue Bridge. Widening of the channel would require that the Warner Avenue Bridge and the pedestrian bridge at the Bolsa Chica Conservancy be widened as well. Widening of the Outer Bolsa Bay channel would improve conveyance as well as the hydraulic efficiency of the lower reaches of C05.

The channel conveyance improvements in this alternative reduce overbank flooding but also increases flow rates in Outer Bolsa Bay between the tide gates and the Warner Avenue Bridge. A 2,500 foot long and an approximate 3 foot tall floodwall would be built along PCH at Outer Bolsa Bay to reduce impacts from flooding on traffic between the tide gates and the Warner Avenue Bridge. The floodwall would begin to be loaded at approximately the 10-year event with the 'Maximum Channel Improvements'.

Compatible nonstructural measures would be incorporated to lessen the life safety risk associated with flooding in the project area. Compatible nonstructural measures that were considered in the development of this alternative include development of a flood warning system and removal of impediments to flow.

7.1.2.1 In-Channel Modification (Moderate Channel Improvements)

Under the Moderate Channel Improvements Alternative, individual reaches would be given either the minimum or maximum channel modifications, optimized to maximize benefits by utilizing an incremental analysis. The incremental analysis was completed after costs for the minimum and maximum improvement plans were developed for each reach. The Moderate Channel Improvements plan is described at this location in the document for consistency, but chronologically the reach-by-reach channel improvement decisions occurred following the incremental analysis.

Consistent with the formulation strategies to "focus on improving channel conveyance" and "focus on improving channel capacity," this alternative will reduce flood risk within the watershed by improving both conveyance efficiency and capacity of existing channels. This alternative is a hybrid between the minimum and maximum channel improvements.

The leveed areas in the downstream reaches of C02 and C05 (reaches 23 and 1, respectively) would be improved to reduce the risk of levee failure. Improvements in these reaches would include installation of steel sheet pile channel walls and preservation of existing soft bottom, tidally-influenced habitat.

Additional downstream measures would be combined with the in-channel measures to address existing flooding in Outer Bolsa Bay and to account for increased flow volumes that result from increased conveyance capacity in the channels. The tide gates on C05 would be replaced in order to improve the flow conditions through the lower reaches of the C05 channel. The current tide gates leak and therefore allow saltwater to intrude upstream in C05. This saltwater influence extends upstream of Outer Bolsa Bay for approximately 2.5 miles. The replacement of the tide gates as part of this alternative would be configured to allow for continued tidal influence in the lower reaches of C05, thus lessening impacts to the existing ecological conditions.

This alternative also includes the widening of the Outer Bolsa Bay channel just upstream of the Warner Avenue Bridge. Widening of the channel would require that the Warner Avenue Bridge and the pedestrian bridge at the Bolsa Chica Conservancy be widened as well. Widening of the Outer Bolsa Bay channel would improve conveyance as well as the hydraulic efficiency of the lower reaches of C05.

The channel conveyance improvements in this alternative reduce overbank flooding but also increases flow rates in Outer Bolsa Bay between the tide gates and the Warner Avenue Bridge. A 2,500 foot long and an approximate 3 foot tall floodwall would be built along PCH at Outer Bolsa Bay to reduce impacts from flooding on traffic between the tide gates and the Warner Avenue Bridge. The floodwall would begin to be loaded at approximately the 10-year event with the 'Moderate Channel Improvements'.

Lastly, compatible nonstructural measures would be incorporated into this alternative to lessen the life safety risk associated with flooding in the project area. Compatible nonstructural measures that were considered in the development of this alternative include development of a flood warning system and removal of impediments to flow.

At this time, the Moderate Channel Improvements Alternative is the same as the Minimum Channel Improvements.

7.1.3 Model Elevation Data

Digital topographic data were obtained from Orange County. The topographic data were collected during December 17, 2011 to February 9, 2012 by USGS and processed through the Digital Elevation Model (DEM) unto digital topographic data set. The DEM data set has horizontal datum in the CCS83, Zone VI (US Feet) and has vertical datum in NAVD 88 (US Feet).

7.1.4 Vertical Datum Adjustment

Most of the C05 and C06 channels as-built drawings are based on NGVD 29 datum except as-built drawing C05- 501-1A in the vicinity of Garden Grove Freeway which is based on NAVD 88 datum. All of the C02 and C04 channels as-built drawings are based on NGVD 29 datum. Many of the drawings were dated earlier than 1980 and associated benchmarks are no longer in existence, therefore, current Orange County benchmarks are used in computing an average vertical datum adjustment. There are total of 35 benchmarks used (8 in the vicinity of C06, 9 in the vicinity of C05 below C06, and 18 in the vicinity of C05 above C06) and results in an average vertical datum adjustment value of 2.42 feet (i.e., NAVD 88 elevation = NGVD 29 elevation + 2.42').

The stream centerline shape file was provided by OCPW. The cross-section layer was developed based on the as-built drawings by locating cross-sections where changes in channel invert slope, shape, dimensions, and/or materials occur.

7.1.5 HEC-RAS GeoRAS Layer Setup

Using HEC-GeoRAS, a GeoRAS export file was generated that contained river, reach, and station identifiers; cross-sectional cut lines; cross-sectional surface lines; cross-sectional bank stations; downstream reach lengths for the left over bank, main channel, and right over bank.

7.1.6 Lateral Structures

Lateral structures were placed on both sides of the open channel segments to compute channel overflow when the computed water surface elevation is higher than the lateral weir elevation. The lateral weir structures were delineated in ArcGIS with the aid of aerial photography and DEM data and imported into HEC-RAS. The lateral weir elevation profiles were further filtered to remove distorted DEM data points (due to trees, fences, buildings, overhang wires, etc.) and adjusted to match the as-built sections as needed (e.g., top of sheet pile or top of concrete channel, etc.).

In general, lateral structure weir coefficient should be in the range of 0.1 to 0.5 for an overland flow interface between the channel and adjacent floodplain (e.g., non-elevated overbank terrain). In this analysis, a weir coefficient of 0.5 was used for most of the channel reach to emulate the overland flow escaping the channel with block walls, fences, and/or buildings that restrict the overland flow within the channel right-of-way.

7.1.7 Manning's n Values

Table 24 lists the Manning's n-values adopted per Orange County Flood Control Design Manual (OCPW 2000) and used in the hydraulic model.

Table 24: Manning's n Values used in the cross-sections

Description	Value
Reinforced Concrete Pipe	0.013
Rectangular Concrete Lined Channel	0.014
Trapezoidal Concrete Lined Channel	0.015
Trapezoidal Earthen Channel with Riprap	0.035
Soft-bottom Channel	0.03
Sheet Piles Soft-bottom Channel	0.022

7.1.8 Debris Loading

Debris loading is applicable to the baseline conditions only. Two feet of debris loading was added to each side of all bridge piers that measure 6 feet or less in width (transverse dimension) for the full depth of flow and 6 feet of floating depth for piers without and with debris walls (USACE 2004), respectively. Debris loading is not used at any bridges in either of the alternatives. The proposed improvements will replace the earthen or rock lined channels with concrete; therefore, the future with-project conditions are expected to significantly reduce or completely eliminate the primary source of in-channel vegetation.

Concurrence on this approach was obtain from in a letter to the OCPW dated September 09, 2016. Per paragraph 21.2 of the USACE Hydrology and Hydraulics Policy Memorandum No. 4 Debris Loading on Bridges and Culverts (CESPL-ED-H 335-2-5c).

7.1.9 Two-dimensional Flow Areas

Lateral structures connect the one-dimensional channel to two-dimensional flow areas. Five two-dimensional flow areas were created and incorporated in the HEC-RAS model. Flow Area 1 is connected to the left overbank of C05 and C06. Flow Area 2 is connected to the right overbank of C06 and the left overbank of C05. Flow Area 3 is connected to the left overbank of C05 and the right overbank of C04. Flow Area 4 is connected to the right overbank of C04. Flow Area 5 is downstream of C05 and C04 and represents Outer Bolsa Bay, Huntington Harbour and Pacific Coast Highway.

The two-dimensional flow areas have a cell spacing of 50 feet, but breaklines were used to add additional detail to topographic features and changes in roughness (Manning's n values). Table 25 shows the Manning's n values used in the two-dimensional flow areas.

Table 25. Manning's n Values used in the two-dimensional flow areas

Description	Value
Residential	0.12
Commercial	0.12
Open Space	0.05
Soft-bottom Channel	0.03
Streets	0.012

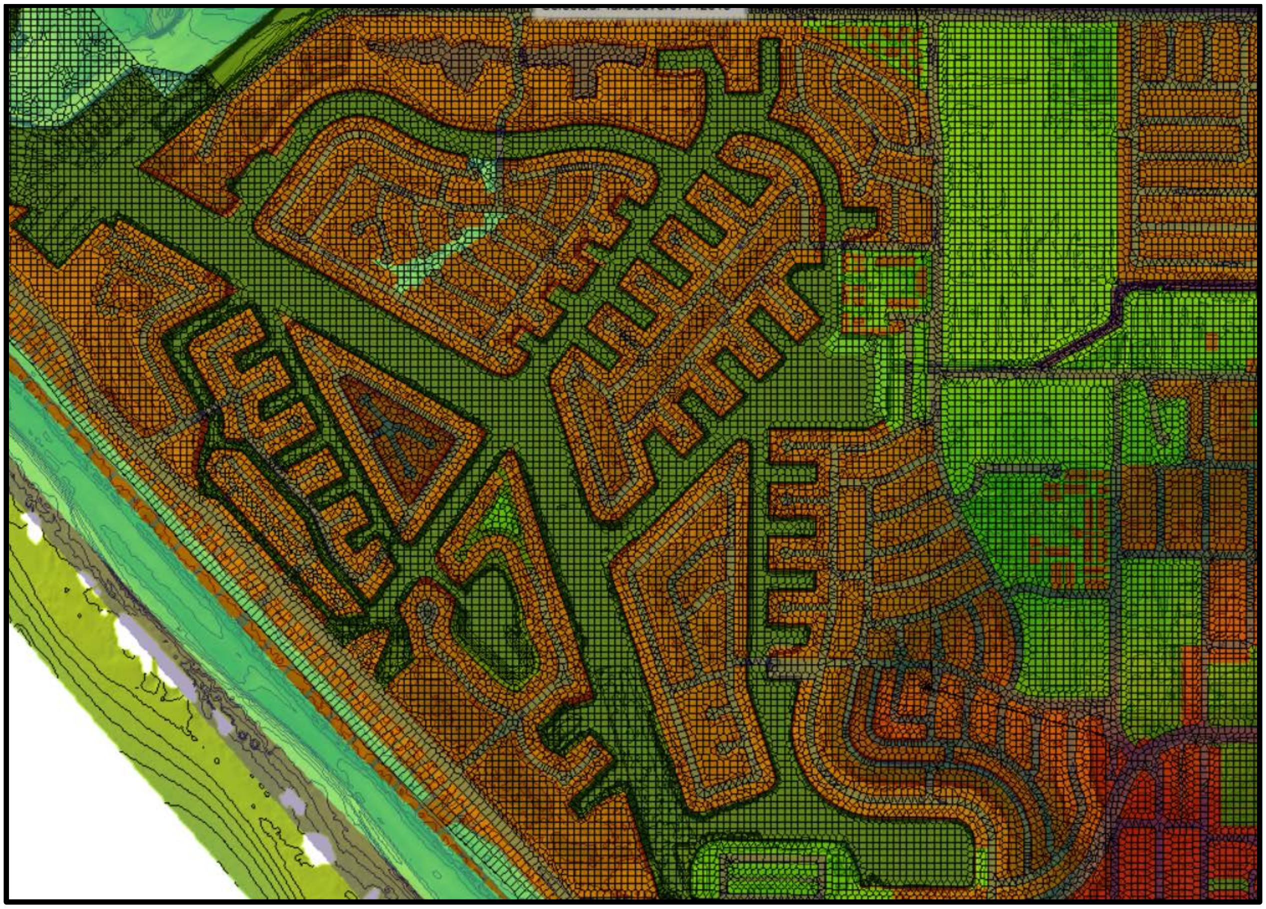


Figure 9: Two dimensional flow area in the Huntington Harbour area.

7.1.10 Storage Areas

Upstream of C05, flow enters the channel downstream of Haster Basin, which was designed to contain the 100 year event. Haster Basin is represented as a storage area with a pump station, so the maximum discharge during events less than or equal to the 100 year event are limited to the pump station capacity of 459 cfs. The storage area connects to the downstream two-dimensional flow area to simulate overbank flooding for events exceeding the 100 year event. Seal Beach National Wildlife Refuge on the downstream reach of C02 is also represented as a storage area.

7.1.11 Boundary Conditions

Previous hydraulic analysis performed by Orange County and the Los Angeles District used separate boundary conditions for C04 and C05. Losses through Huntington Harbour, the Warner Avenue Bridge and Outer Bolsa Bay were accounted for in the downstream boundary condition by using assumed losses determined from previous studies. For this study, a two-dimensional flow area was used on the downstream end of the model domain so only one boundary condition represents the ocean water level. Consistent with the previous analysis, historic tidal data near from the Los Angeles NOAA Gage # 9410660 was used. A Mean High High Water (MHHW) was used as the base water surface elevation for the hydraulic analysis (5.28 ft NAVD 88). EM 1110-2-1416 states that when the profile computation begins at the outlet of a stream influenced by tidal fluctuations, the maximum predicted tide, including wind setup, is taken as the starting elevation.

In addition to a MHHW of 5.28 ft NAVD 88, a setup of 0.7 ft. was added to account for setup. The Environmental Impact Statement for the Bolsa Chica Wetland Restoration Project documents a previous study conducted by TetraTech (1984) that looked at the correlation between riverine storm intensity and wave setup during a storm. The results showed no correlation between storm intensity and storm setup. The average wave setup, hindcasted from wind data for the six most severe storms in Orange County from 1932 to 1983, was estimated to be approximately 0.7 ft.

Consistent with ER 1100-2-8162, sea level rise was incorporated into the downstream boundary condition. Based on a future year of 2070, an intermediate rate of rise of 0.61 ft was added the MHHW base water level and 0.7 ft. of setup. The starting water surface elevation of 6.6 ft. (NAVD88) was used as the starting water surface elevation. Losses through Huntington Harbour, the Warner Avenue Bridge and Outer Bolsa Bay are computed in the two dimensional flow area.

A comparison of the water surface elevation at the downstream end of C05 shows water surface elevation of 8.98 is within 0.04 ft. of the previous analysis performed by the Los Angeles District. On C04, the water surface elevation is 0.9 ft. lower than the previous analysis.

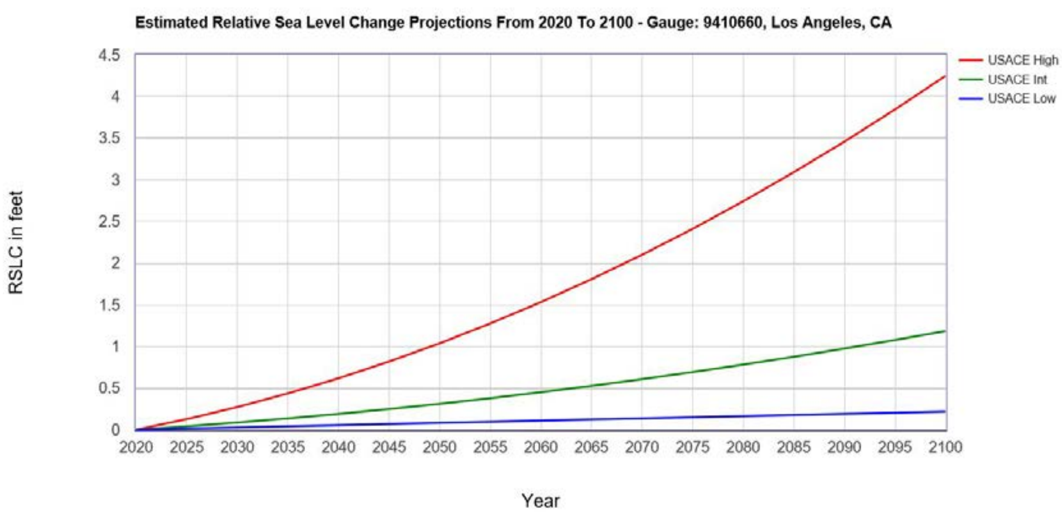


Figure 10: Estimated Sea Level Change Projections from 2020 to 2100.

7.1.12 Risk and Uncertainty

In accordance with EM 1110-2-1619 "Risk-Based Analysis for Flood Damage Reduction Studies", a risk analysis was performed for this study using HEC-FDA. This program incorporates a Monte Carlo simulation to sample the interaction among the various hydrologic, hydraulic, and economic uncertainties. Uncertainties in the hydrology and hydraulics include the uncertainties associated with the discharge-frequency curve and the stage-discharge curve. Both of these relationships have statistical confidence bands that define the uncertainty of the relationships at various target frequencies. The Monte Carlo simulation routine randomly samples within these confidence bands over a range of frequencies until a representative sample is developed. Reliability statistics are based on the results of the Monte Carlo random sampling.

Based on Table 4-5 in EM 1110-2-1619, equivalent record length was represented graphically using an equivalent record length of 30 years. While there are several gages located in and around the study area, the period of record for these gages is relatively short and the study area has been subject to development and other sources of hydrologic changes that lead to non-stationarity.

Preliminary hydraulic analysis was performed within the hydraulic model to evaluate the sensitivity of the stage-discharge relationship. The uncertainty of the stage-discharge relationship is expected to be reduced for the minimum and maximum channel improvements because the channel will uniformly concrete with less variability in roughness. Based on this sensitivity analysis, the following standard deviation parameters are currently used to define the uncertainty in the stage-discharge relationship:

Without / Existing Project Condition
Normal Distribution with a standard deviation of 1 foot, becoming constant at the 5 year profile.

Minimum Channel Improvements
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 10 year profile.

Maximum Channel Improvements
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 50 year profile.

Future modeling will include updates to this sensitivity analysis. These model results will be used to update the parameters used to define the uncertainty in the stage-discharge relationship. Additional discussion on the risk and reliability analyses can be found in the Economics Appendix.

8.0 Model Results

8.1 Existing Conditions

The inundation maps for existing conditions are shown on Plates 1-5. Significant breakout and inundation is observed for events exceeding the 10 Year event (10% ACE). Overtopping and breaching of the levees on the downstream end of C05 results in significant inundation for events exceeding the 10 Year event (10% ACE). For events exceeding the 50 Year event (2% ACE), overtopping and breaching of the levees on the downstream end of C02 result in additional flooding on the downstream end of C02.

8.2 In-Channel Modification (Minimum Channel Improvements)

The inundation maps for Minimum Channel Improvements are shown on Plates 6-10. Since the levees on the downstream end of C05 and C02 are fully improved, they contain events up to 200 Year event (0.5% ACE). Due to limited conveyance improvements upstream of the leveed sections, some overbank flooding remains for events greater including and greater than the 10 Year event (10% ACE), though flooding is reduced compared to existing conditions.

8.3 In-Channel Modification (Maximum Channel Improvements)

The inundation maps for Minimum Channel Improvements are shown on Plates 11-15. Consistent with the goals of Orange County, Maximum Channel Improvements contain up and including the 100 Year event (1% ACE). Minor overbank flooding is observed at the 500 Year event (0.2% ACE).

8.4 In-Channel Modification (Moderate Channel Improvements)

The inundation maps for Minimum Channel Improvements are shown on Plates 16-20. Like the Minimal Channel Improvements, the reaches of C05 and C02 do not experiences flooding for events less than the 100 Year events (1% ACE) because of levee improvements. Since conveyance improvements consistent with the Maximum Channel Improvements continue upstream further than the Minimum Channel Improvements, flood inundation is reduced over more area. However, some residual flooding still occurs through the improved areas because flood waters breaking out further upstream travel downstream in the overbank area. The maps on Plates 16-20 do not incorporate recent changes to the Moderate Channel Improvements.

9.0 References

Bonnin, G.M., Martin, D., Lin, B., Parzybok, T., Yekta, M., and Riley, M. 2006. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, NOAA, Silver Spring, MA.

Chow, V.T. 1959. Open Channel Hydraulics, McGraw-Hill, New York, NY.

Friedman, D., J. Schechter, B. Baker, C. Mueller, G. Villarini, and K. D. White. (2016), US Army Corps of Engineers Nonstationarity Detection Tool User Guide. US Army Corps of Engineers: Washington, DC.

U.S. Army Corps of Engineers, Los Angeles District, *Memorandum for Record Hydrology and Hydraulics Policy Memorandum No. 4 Debris Loading on Bridges and Culverts*, 2004.

U.S. Army Corps of Engineers. 2016. HEC-RAS River Analysis System User's Manual, Version 5.0, US Army Corps of Engineers, Davis, CA.

U.S. Army Corps of Engineers. Climate Hydrology Assessment Tool. http://corpsmapu.usace.army.mil/cm_apex/f?p=313:2:0::NO

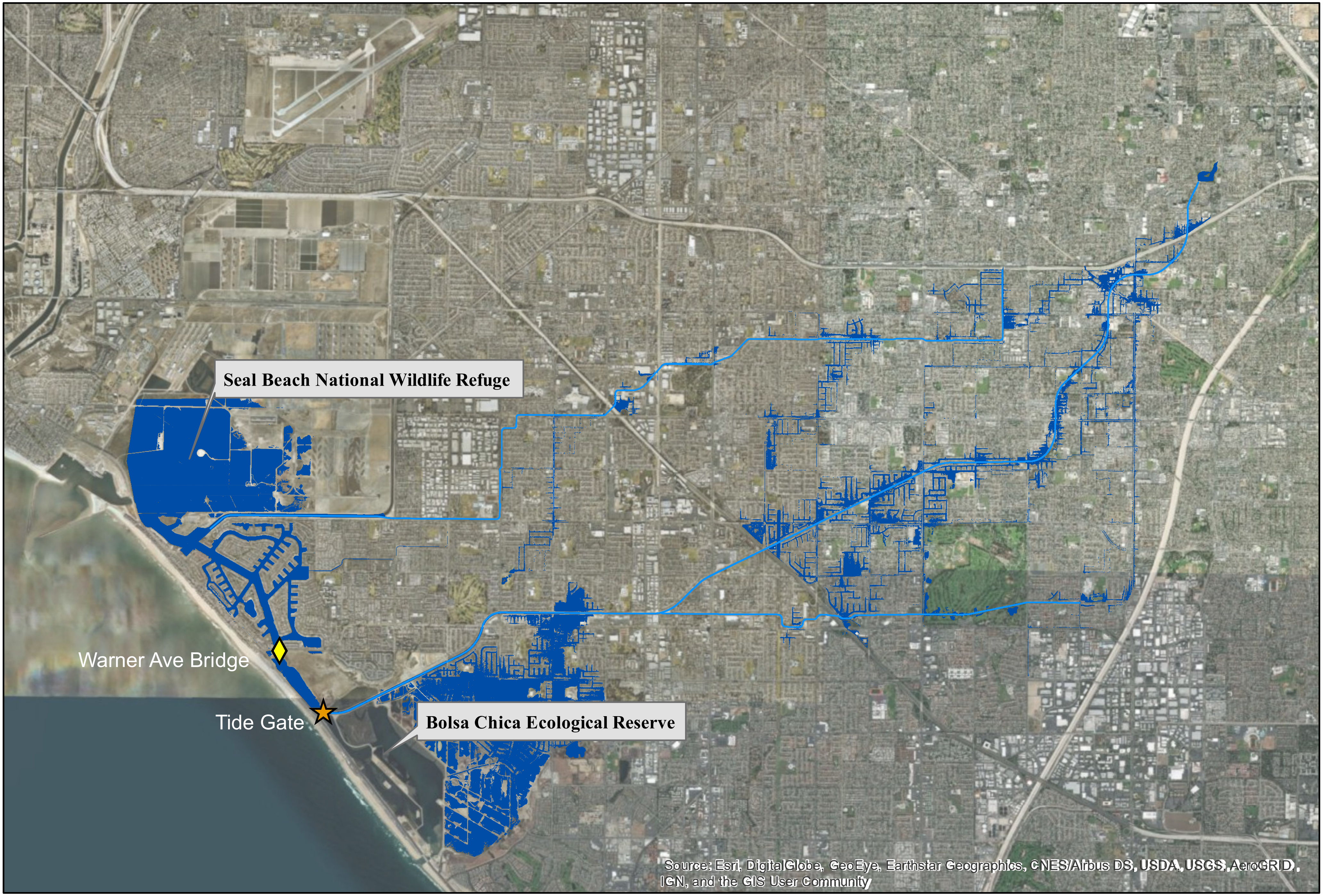
U.S. Army Corps of Engineers. Engineering and Construction Bulletin (ECB) 2016-25. Subject: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects, 16 Sep 2016.

U.S. Army Corps of Engineers. Nonstationarity Detection Tool (NSD). http://corpsmapu.usace.army.mil/cm_apex/f?p=257:10:0::NO

U.S. Army Corps of Engineers. Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Great Lakes Region 04. Civil Works Technical Report, CWTS-2015-07, USACE, Washington, DC, April 2015.

U.S. Army Corps of Engineers. Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Upper Mississippi Region 07. Civil Works Technical Report, CWTS-2015-13, USACE, Washington, DC, June 2015.

U.S. Army Corps of Engineers. USACE Screening-Level Climate Change Vulnerability Assessment (VA). http://maps.crrel.usace.army.mil/apex/f?p=170:1:Walsh J, Wuebble D, Hayhoe K, Kossin J, Kunkel K



U.S. Army Corps Of Engineers ®
Chicago District

Existing 10 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

Existing 10 Year Inundation

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September 2018

Plate 1

Chicago District, U.S. Army Corps of Engineers

U.S. Army Corps Of Engineers ®
Chicago District

Existing 25 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

Existing 25 Year Inundation

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September 2018

Plate 2

Chicago District, U.S. Army Corps of Engineers

U.S. Army Corps Of Engineers ®
Chicago District

Existing 50 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

Existing 50 Year Inundation

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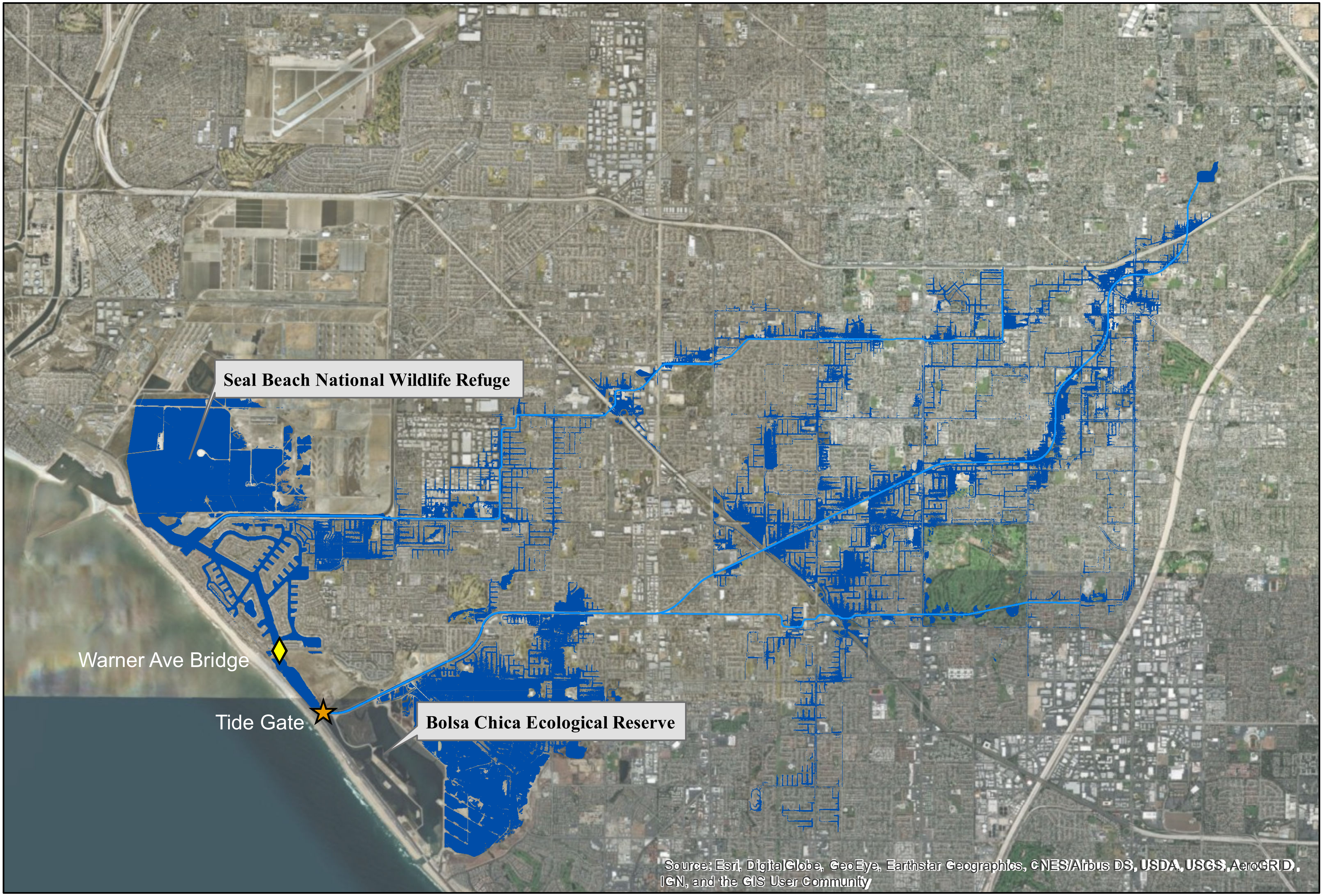
Plate 3

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps Of Engineers ®
Chicago District

Existing 100 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

Existing 100 Year Inundation

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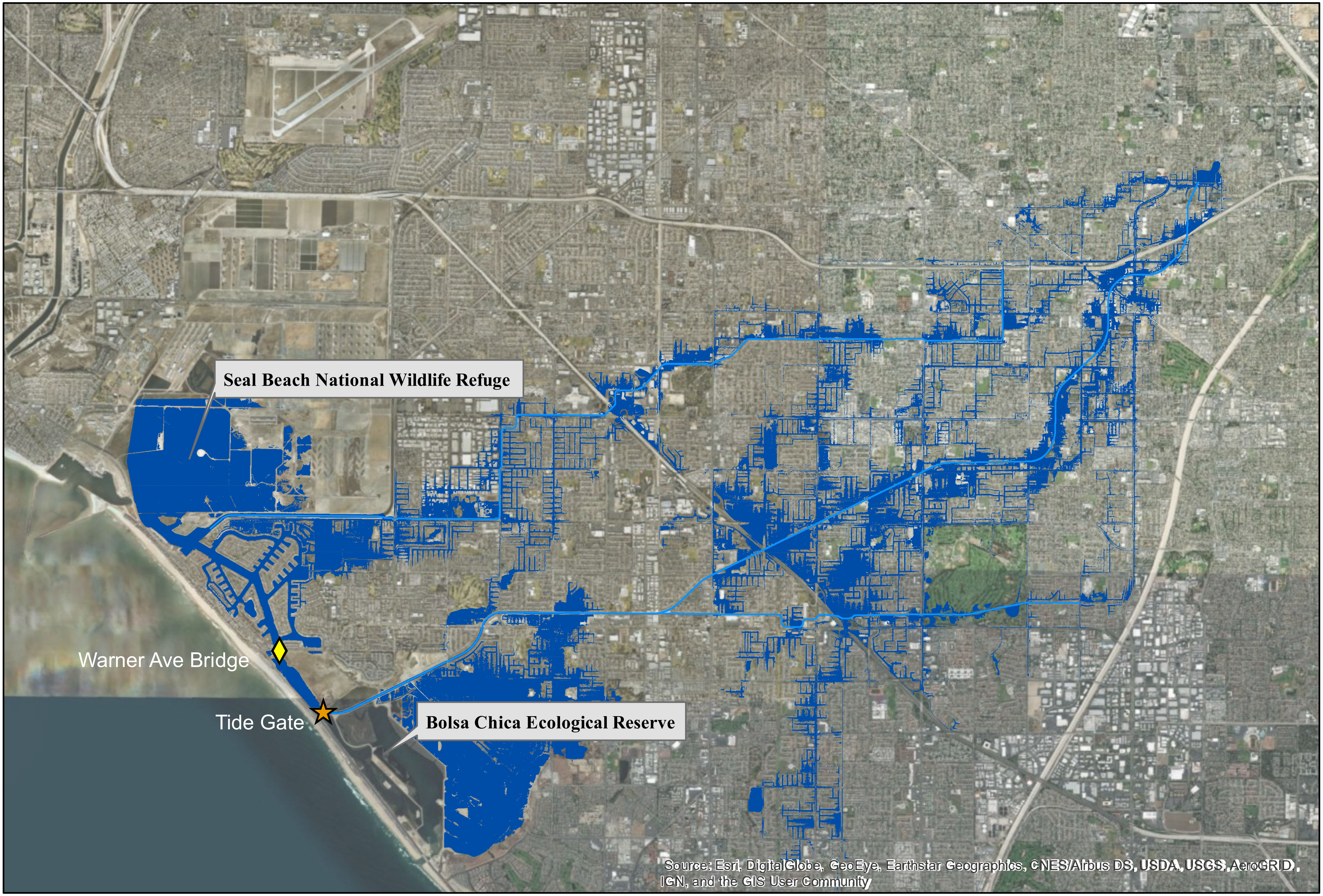
Plate 4



U.S. Army Corps Of Engineers ®
Chicago District

Existing 500 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM
Existing 500 Year Inundation

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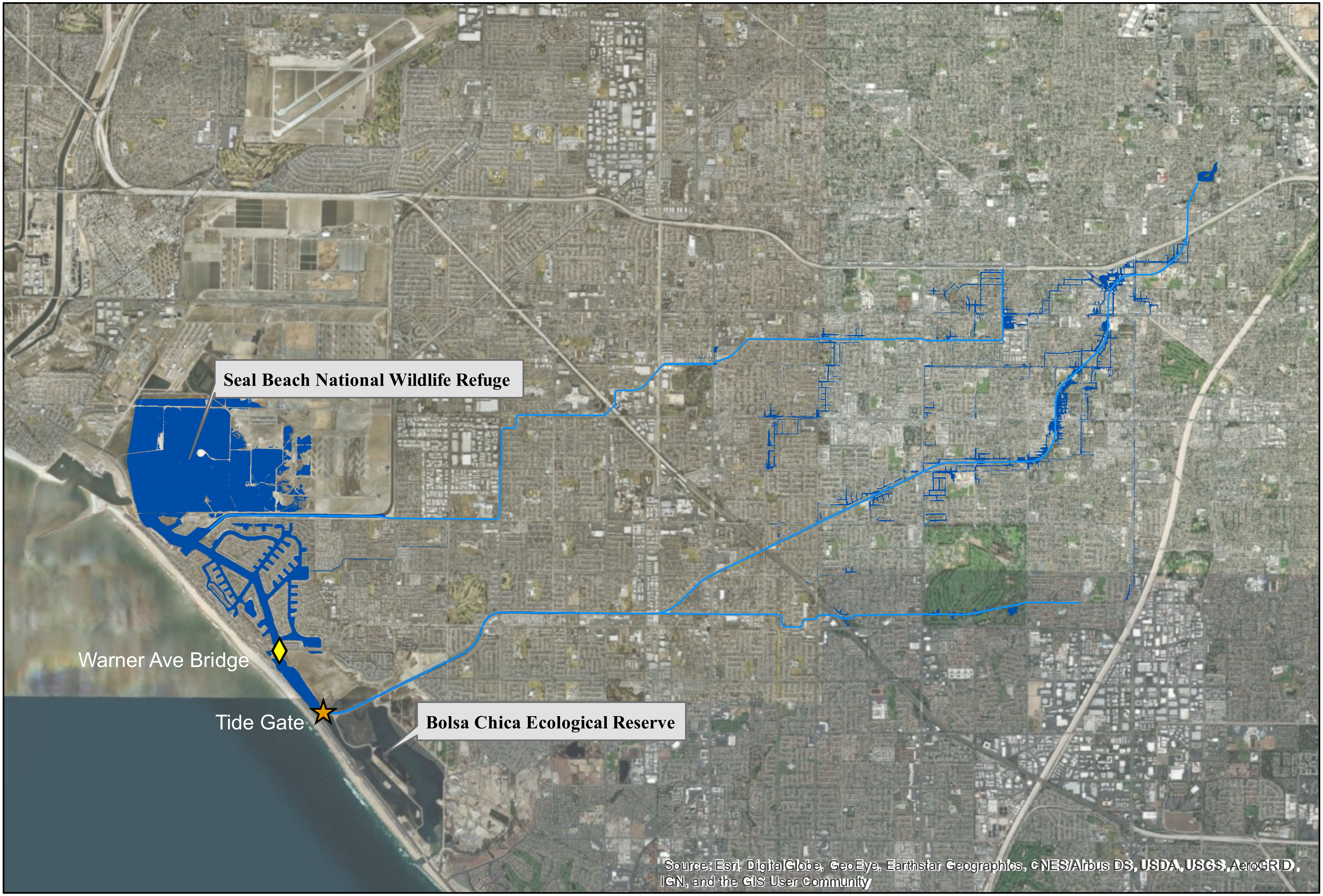
Plate 5

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps Of Engineers ®
Chicago District

Minimum Channel 10 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM
MINIMUM CHANNEL

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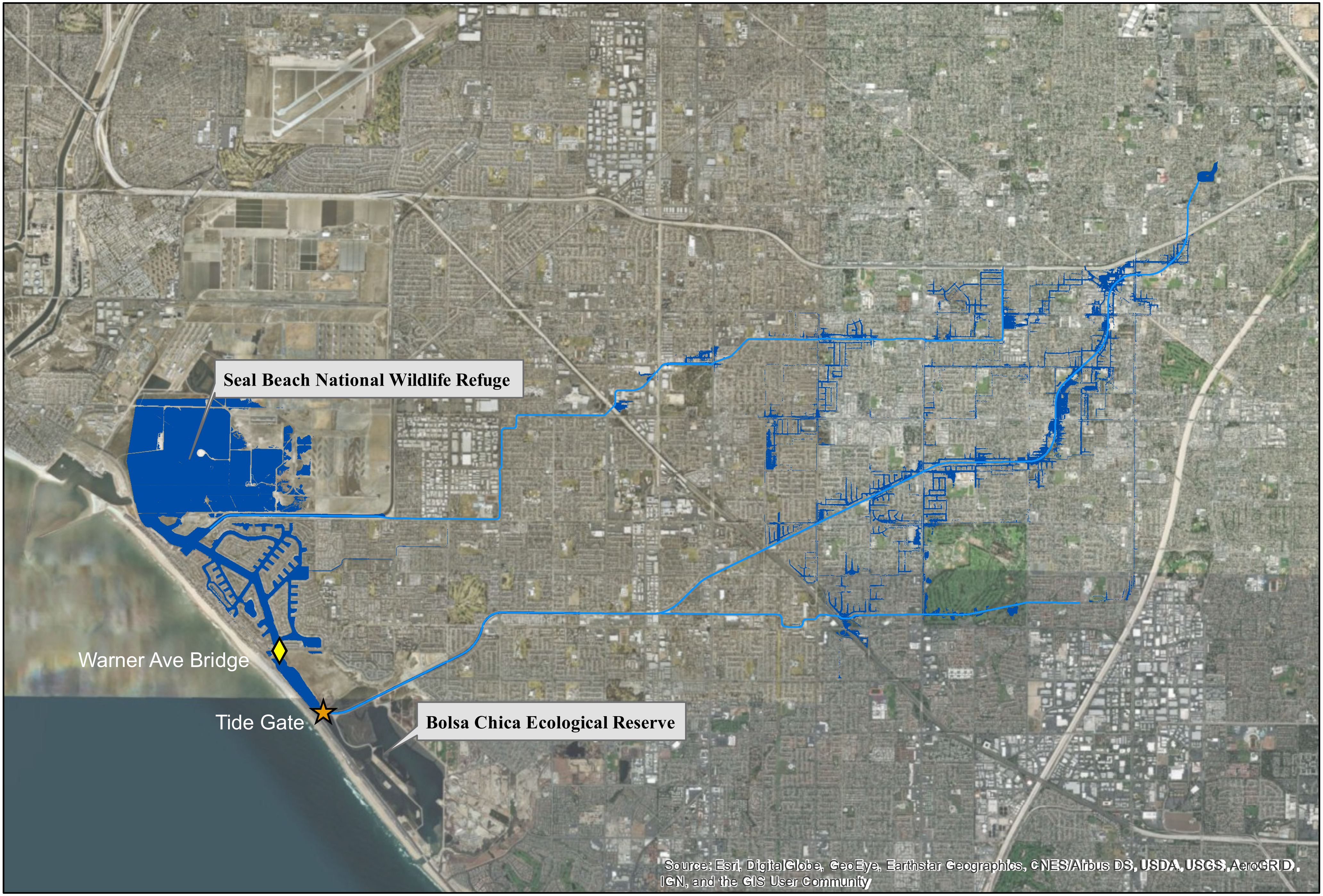
Plate 6

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps Of Engineers ®
Chicago District

Minimum Channel 25 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM
MINIMUM CHANNEL

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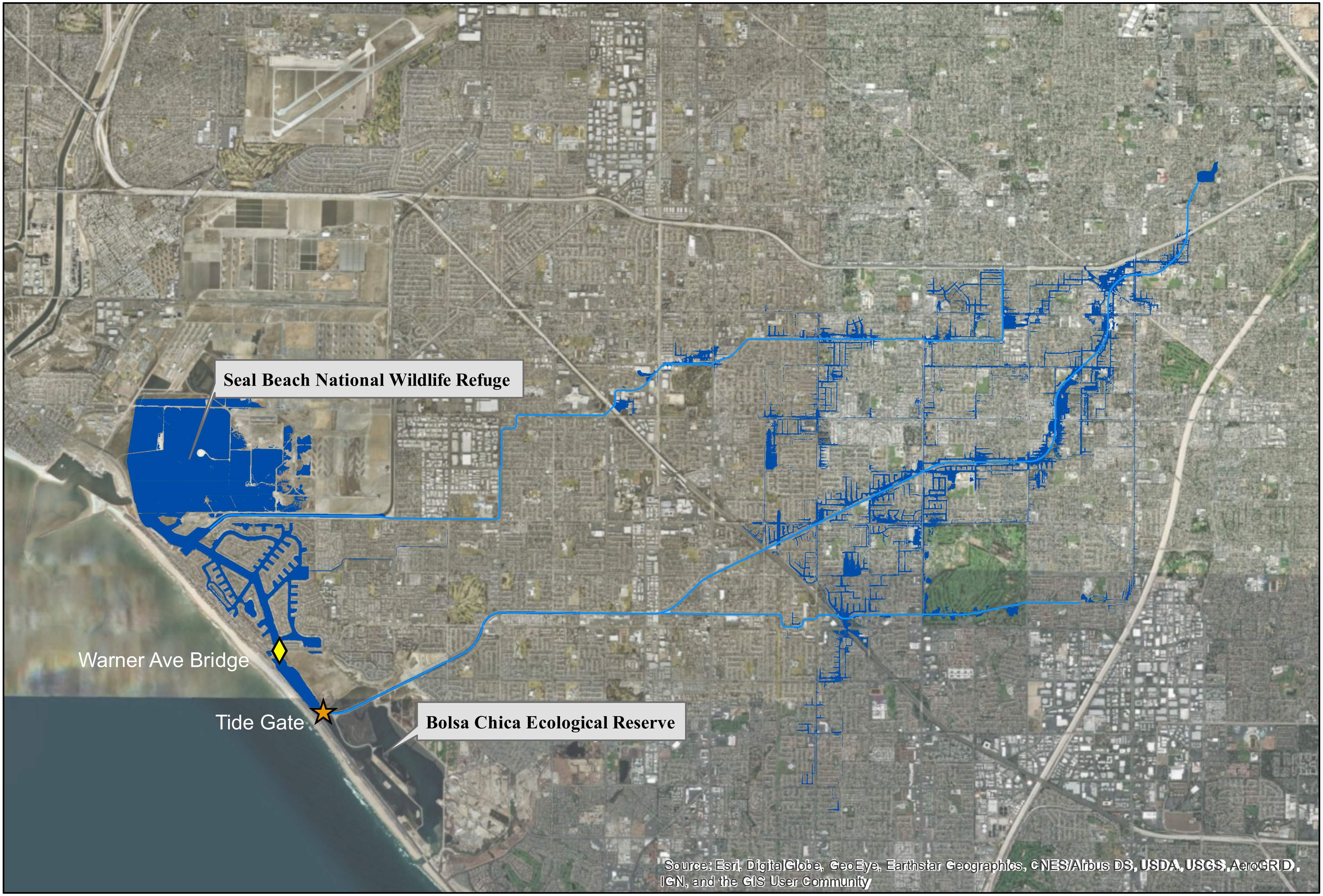
September 2018
Plate 7

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps Of Engineers ®
Chicago District

Minimum Channel 50 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

MINIMUM CHANNEL

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Plate 8

Chicago District, U.S. Army Corps of Engineers

U.S. Army Corps Of Engineers ®
Chicago District

Westminster, East Garden Grove FRM

MINIMUM CHANNEL

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Plate 9

Chicago District, U.S. Army Corps of Engineers

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Chicago District

Westminster, East Garden Grove FRM
MINIMUM CHANNEL

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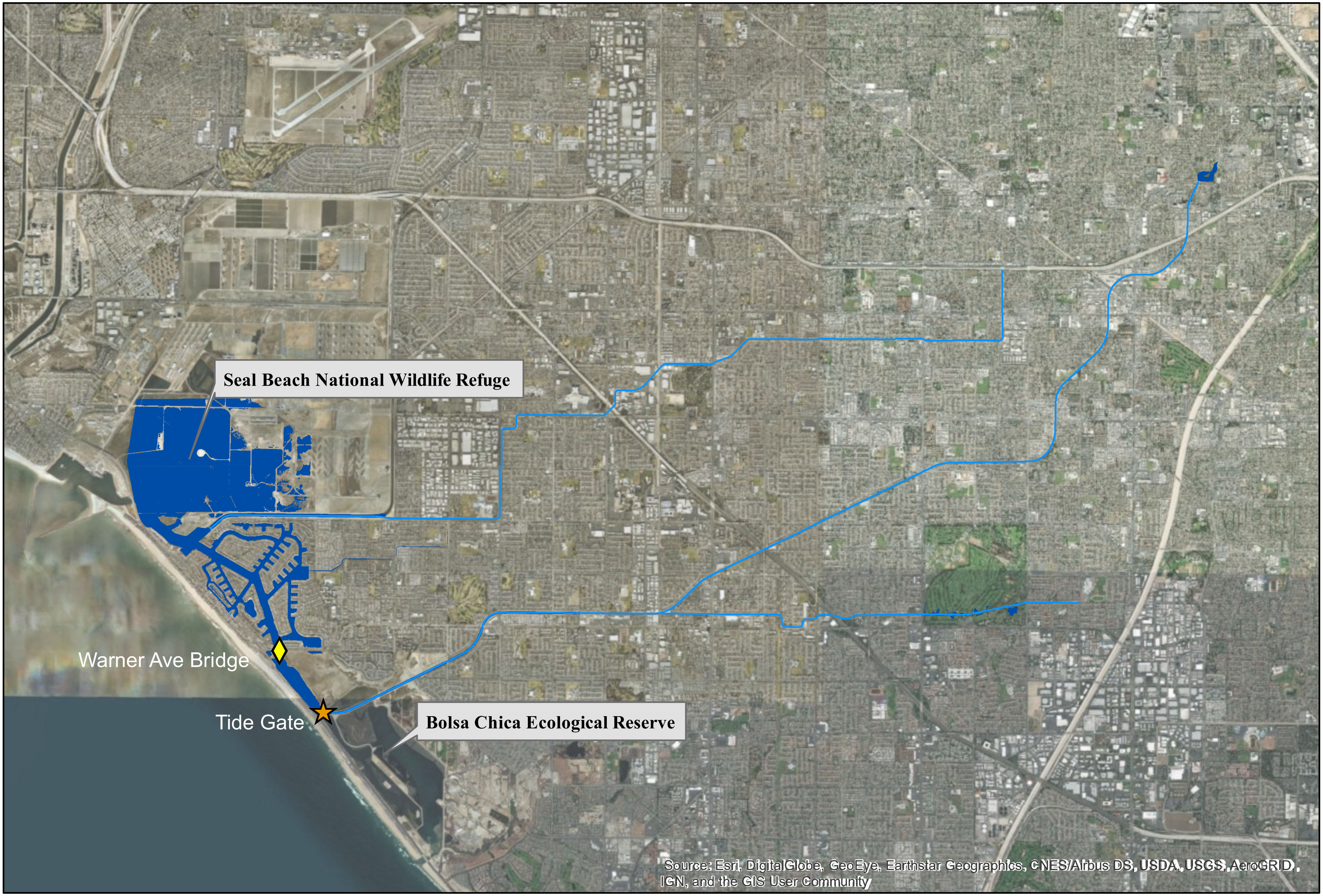
Plate 10



U.S. Army Corps Of Engineers ®
Chicago District

Maximum Channel 10 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM
MAXIMUM CHANNEL

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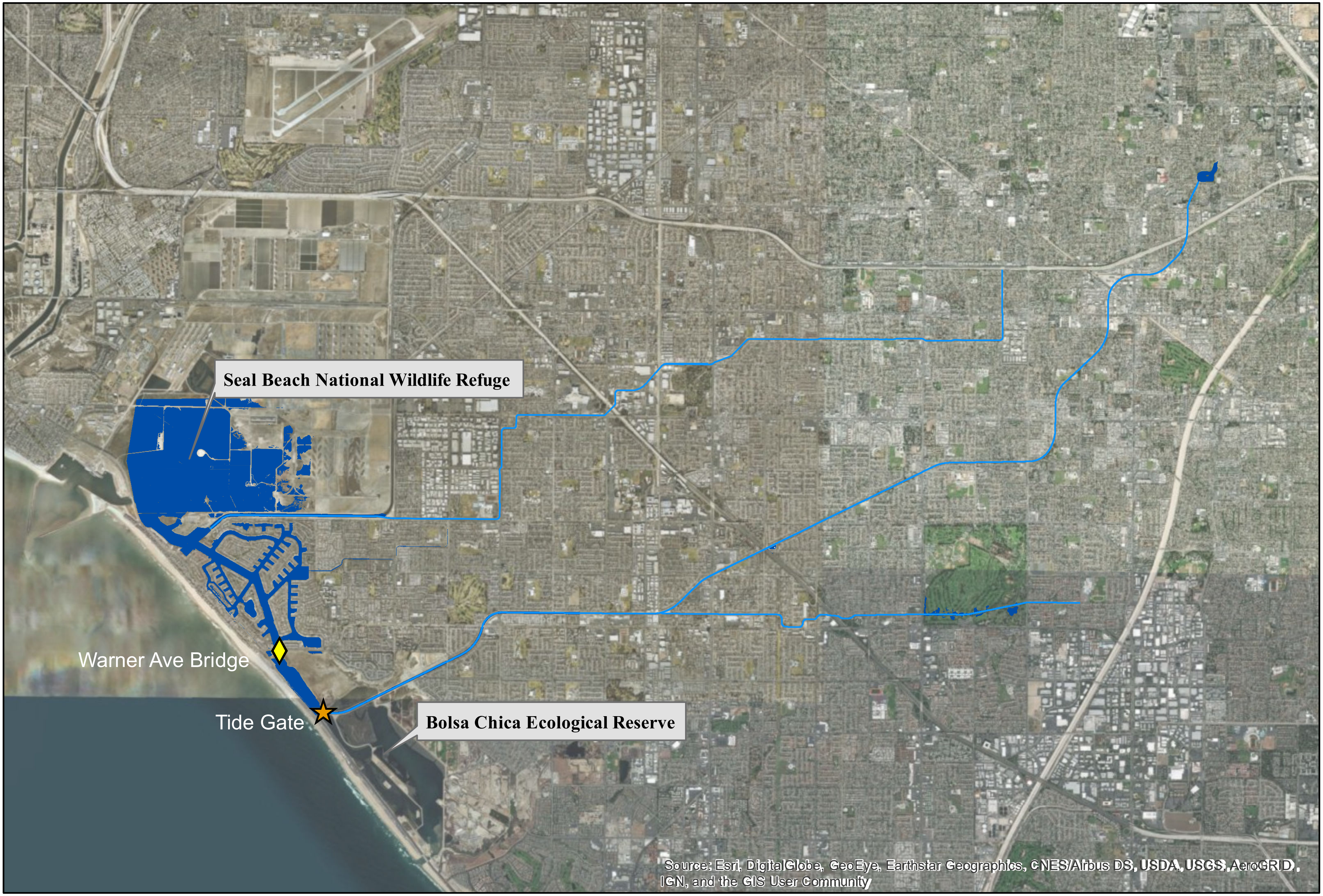
September 2018
Plate 11

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps Of Engineers ®
Chicago District

Maximum Channel 25 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

MAXIMUM CHANNEL

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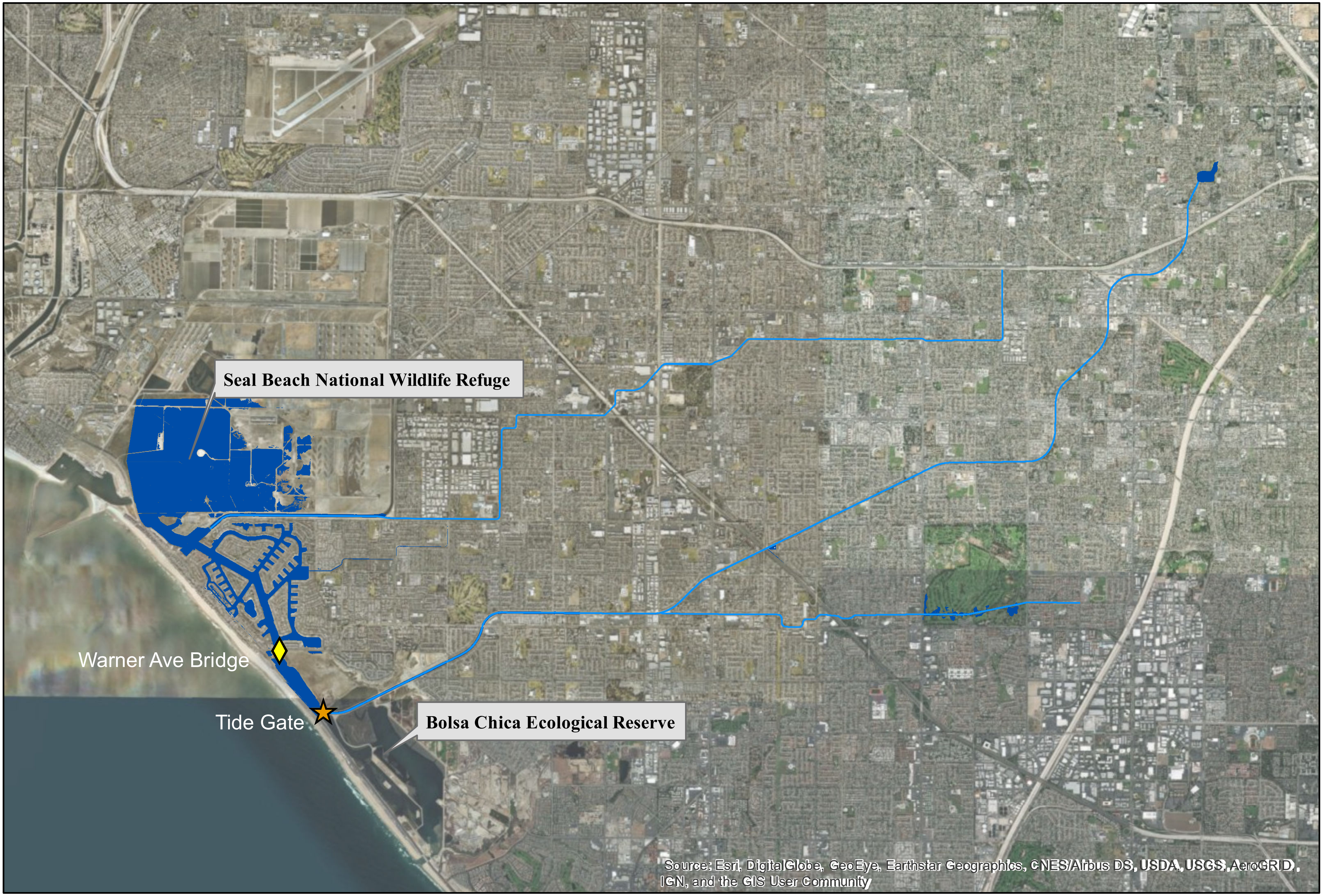
September 2018

Plate 12

Chicago District, U.S. Army Corps of Engineers



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Maximum Channel 50 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

MAXIMUM CHANNEL

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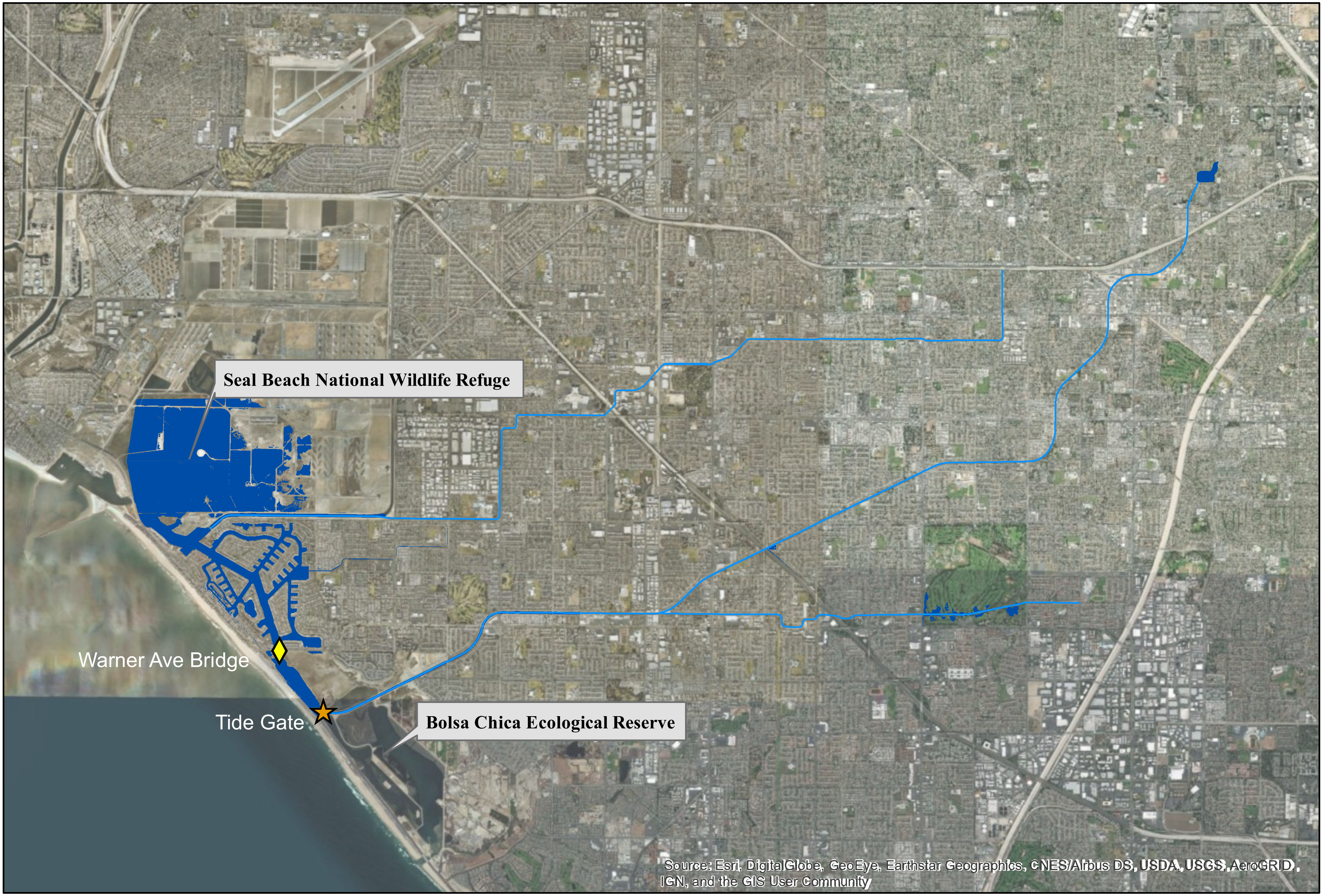
Plate 13

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps Of Engineers ®
Chicago District

Maximum Channel 100 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM
MAXIMUM CHANNEL

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Plate 14

Chicago District, U.S. Army Corps of Engineers

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Maximum Channel 500 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM
MAXIMUM CHANNEL

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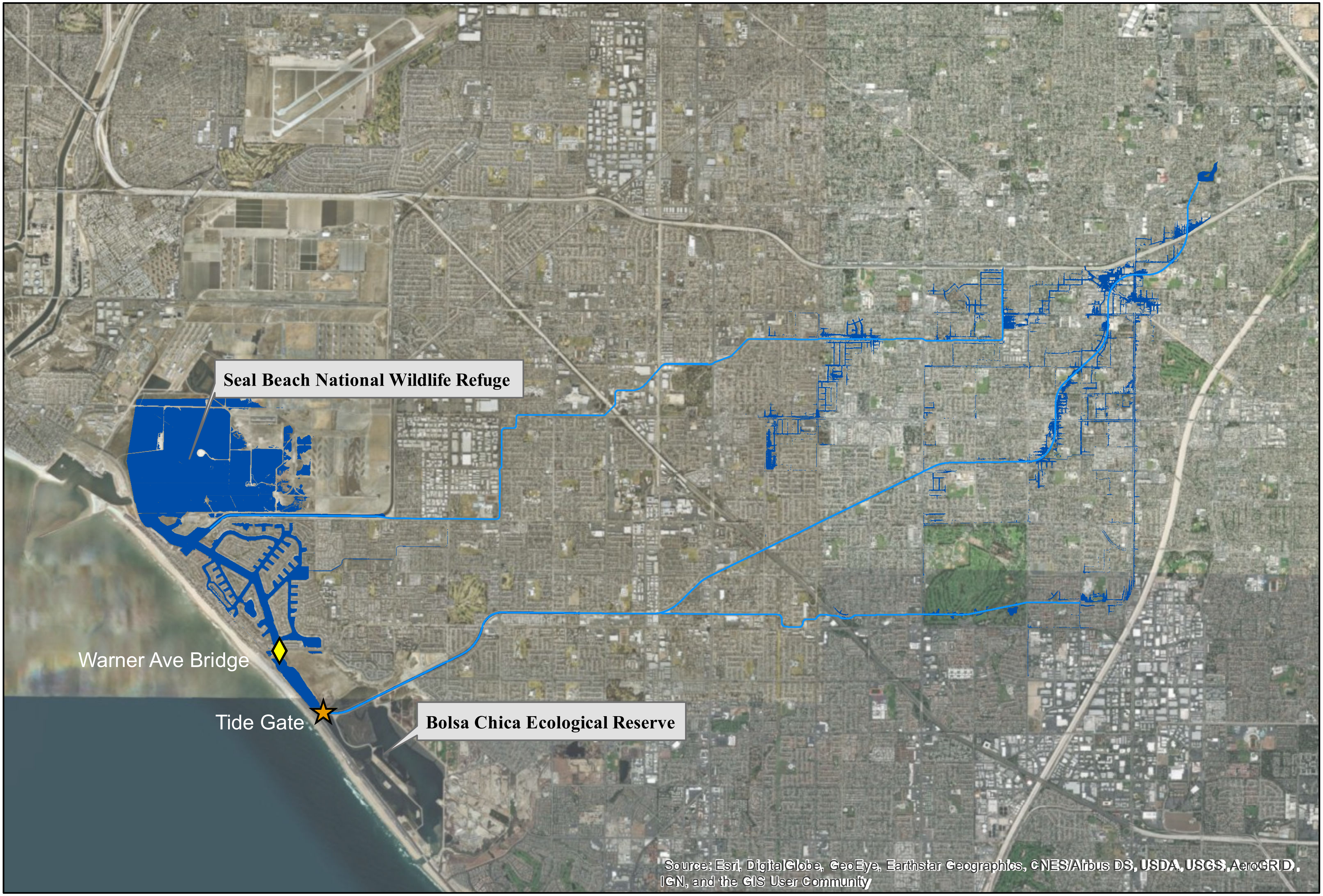
Plate 15

Chicago District, U.S. Army Corps of Engineers



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Moderate Channel 10 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

MODERATE CHANNEL

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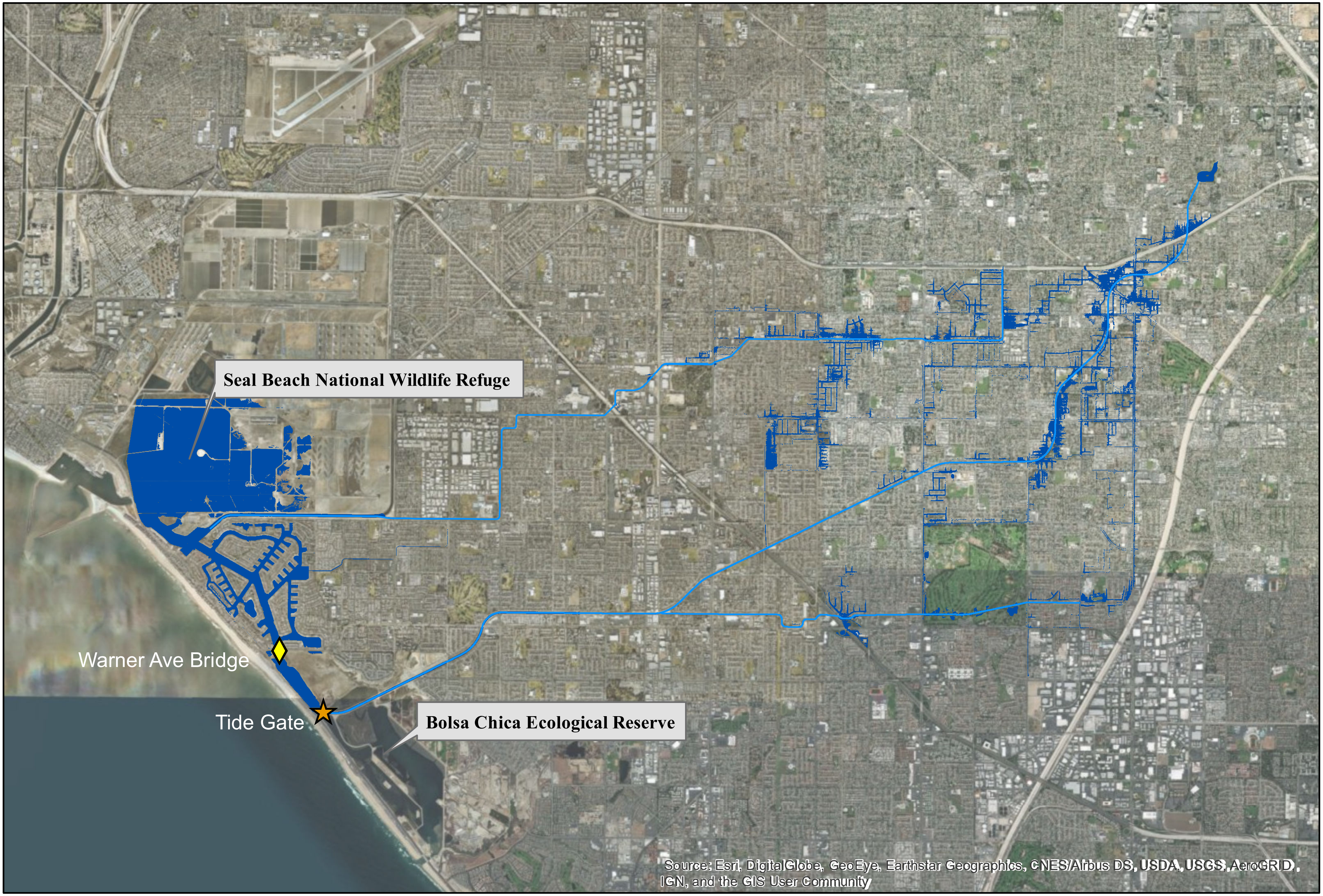
Plate 16

Chicago District, U.S. Army Corps of Engineers



U.S. Army Corps
Of Engineers ®
Chicago District

Moderate Channel 25 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

MODERATE CHANNEL

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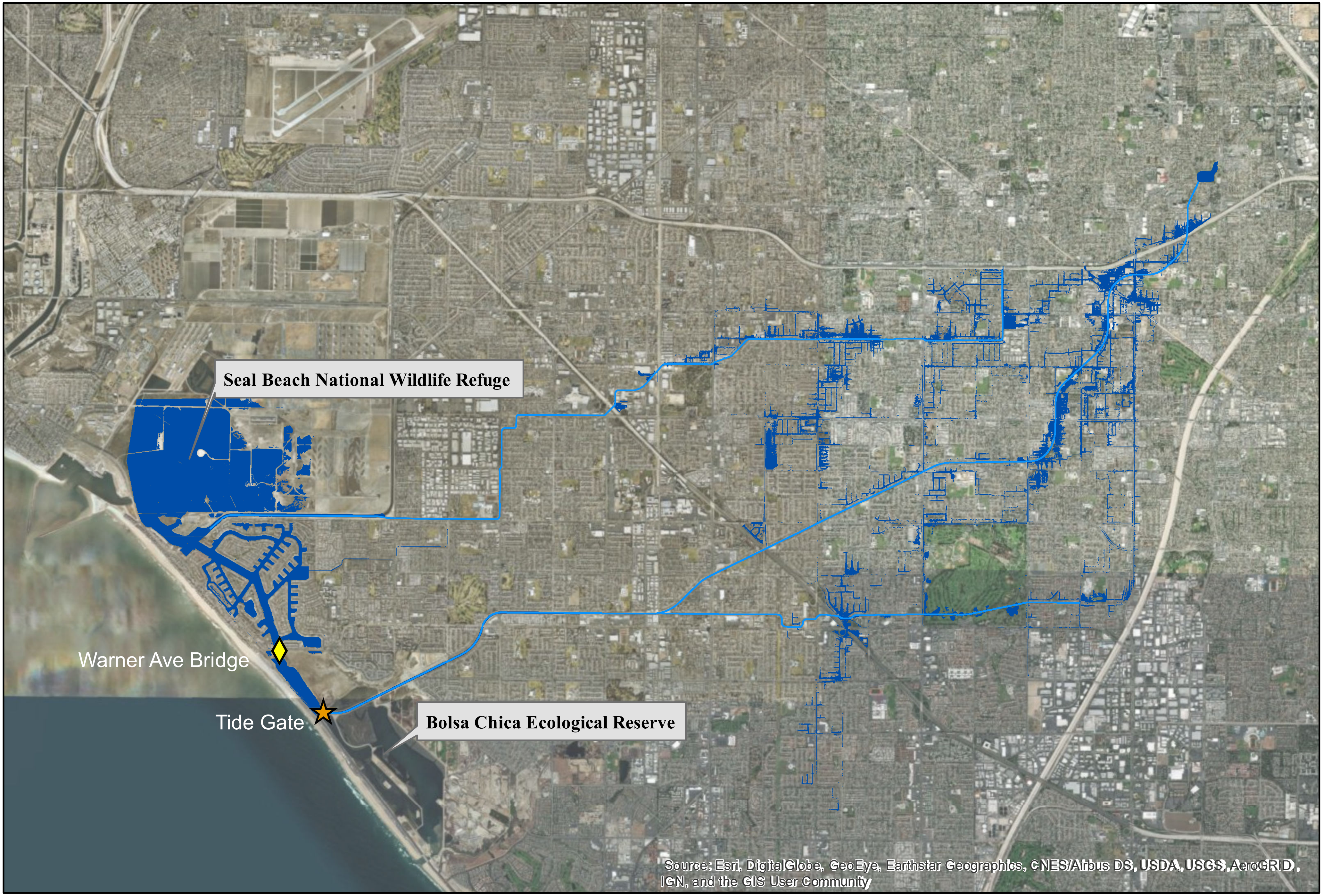
Plate 17

Chicago District, U.S. Army Corps of Engineers



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Chicago District

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MODERATE CHANNEL

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Plate 18

Chicago District, U.S. Army Corps of Engineers

U.S. Army Corps Of Engineers ®
Chicago District

Moderate Channel 100 Year Inundation

0 0.5 1
Miles

N

Westminster, East Garden Grove FRM

MODERATE CHANNEL

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Plate 19

Chicago District, U.S. Army Corps of Engineers

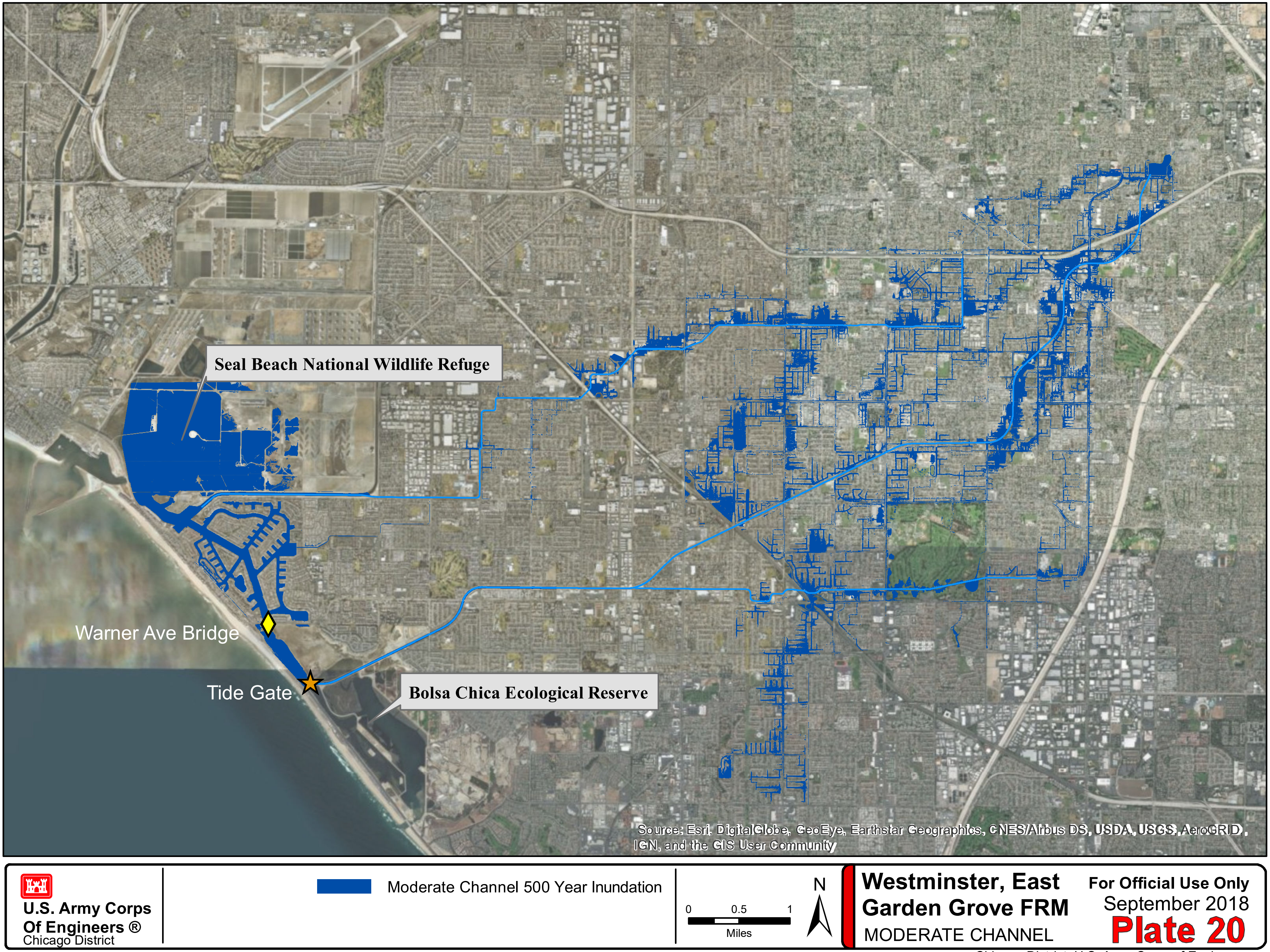

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Plate 20

Chicago District, U.S. Army Corps of Engineers