TETRA TECH

August 21, 2018

City of Huntington Beach

Master Plan of Drainage

City of Huntington Beach, Public Works Department
2000 Main Street | Huntington Beach, CA 92648

Tetra Tech
9444 Balboa Ave, Suite 215 | San Diego, CA 92123
17885 Von Karman Avenue, Suite 500 | Irvine, CA 92614

Master Plan of Drainage

August 21, 2018

PRESENTED TO

City of Huntington Beach
2000 Main Street
Huntington Beach, CA 92648

PRESENTED BY

Tetra Tech, Inc.
9444 Balboa Avenue
Suite 215
San Diego, CA 92123

P +1-858-268-5746
F +1-858-268-5809
tetratech.com

EXECUTIVE SUMMARY

As the City of Huntington Beach (City) undergoes further development and urbanization, there is a need to establish a strategy that evaluates the existing storm drain infrastructure and identify the necessary recommendations to respond to growth. This Master Plan of Drainage (MPD) has been developed to address changes in stormwater runoff, as well as improvements/additions to the storm drain network since the previous MPD (2005) was completed, to ensure the storm drain network is able to meet its intended level of service. Specifically, several objectives were characterized as a part of this 2018 MPD:

- Leverage the existing storm drain facility inventory to generate a ***fully articulated stormwater model***,
- Define ***clear flood control performance criteria*** for which stormwater infrastructure could be assessed,
- Utilize an ***advanced, high-resolution urban stormwater model*** (PCSWMM), and
- Support the identification and characterization of ***specific infrastructure improvements***.

High resolution data and powerful analytical tools allowed for the assessment of the existing condition to the inlet scale, highlighting discrete flooding concerns throughout the City. Many of the subwatersheds indicating flooding drained to downgradient pump stations or channels that are at or above operating capacity. Due to constraints with increasing capacity in those infrastructure types, a methodical approach for increasing capacity in conveyance, inlet, and storage structures was developed.

Execution of the above strategy facilitated a structured process for assessing the existing condition of City stormwater infrastructure, determining performance criteria for the 10-yr and 100-yr, 24-hour design storms, and recommending a proposed set of improvements to increase capacity of the drainage system. The recommendations include ***62 miles of conduits improvements*** (19 miles new, 43 miles upsized), ***1,353 inlet improvements*** (266 new and 1,087 upsized), ***50.3 acre-feet of additional capacity at existing detention locations***, and ***7.47 acre-feet of new distributed detention*** (e.g., suspended vaults or surface detention).

Planning-level costs were determined for all proposed improvements which included material costs, construction costs, and a 40% mark-up for contingency. The total estimated cost of all recommended improvements was estimated at $255.6 million dollars. To prioritize projects for implementation given budgetary and time constraints, the City could correlate received flood complaints with the location of proposed improvements, as well as implement based on the net increase in infrastructure size (e.g., the assets with the greatest change in size between the existing and proposed condition have the greatest need to be upsized).


Courtesy: City of Huntington Beach

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
1D	1-dimensional
2D	2-dimensional
ABS	acrylonitrile-butadiene-styrene
ac	acre
ac-ft	acre-feet
AC	asbestos cement
Caltrans	California Department of Transportation
CFS	cubic feet per second
CI	cast iron
CIS	combo in sump
COG	combo on grade
CM	corrugated metal
CURMP	Citywide Urban Runoff Management Plan
DEM	digital elevation model
DI	ductile iron
FHWA	Federal Highway Administration
EPA	Environmental Protection Agency
EPA SWMM	Environmental Protection Agency Storm Water Management Model
GIS	geographic information system
H&H	hydrologic and hydraulic
HARN	high accuracy reference network
HDPE	high density polyethylene
HGL	hydraulic grade line
LAC	LA County
LiDAR	light detection and ranging
MPD	Master Plan of Drainage
NAD	North American Datum
NAVD	North American Vertical Datum
NDVI	Normalized Difference Vegetation Index
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NRCS	National Resources Conservation Service
OCFCD	Orange County Flood Control District

Acronyms/Abbreviations	Definition
PCSWMM	Personal Computer Storm Water Management Model
PK	parkway width
PVC	polyvinyl chloride
RC	reinforced concrete
RCP	reinforced concrete pipe
ROW	right-of-way
STL	steel
SWPPP	Stormwater pollution prevention plan
US	United States
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
VCP	vitrified clay pipe
WPCP	Water pollution control program
WSE	Water surface elevation

1.0 INTRODUCTION

In January of 2005, the City of Huntington Beach (City) Citywide Urban Runoff Management Plan (CURMP) was adopted, serving as a guidance document for the identification and prioritization of stormwater infrastructure and water quality projects. The Drainage Element within the CURMP, also referred to as the Master Plan of Drainage (MPD), consisted of (1) the development of an existing storm drain facility inventory, (2) assessment of deficiencies in the sizing and siting of facilities per City drainage goals, and (3) prioritizing system upgrades using planning level cost estimates for the recommended upgrades.

Since 2005, the City has experienced further development and urbanization, and has completed drainage improvements throughout its jurisdiction—both of which resulted in changes to the hydrologic and hydraulic (H&H) conditions within the City. Additionally, the modeling platforms and geospatial data that support the development of a MPD have been significantly enhanced, allowing for the development of high-resolution inputs and characterization of the City within H&H models.

The methodology proposed in this document will achieve the goal of enhancing the 2005 MPD by:

- Incorporating newly collected and developed datasets, including updates for proposed drainage improvements,
- Generating dynamic, high-resolution H&H models that have the computational capacity to reduce the uncertainty in boundary conditions and modeling assumptions, and
- Supporting the identification and prioritization of specific, cost-effective infrastructure improvement projects to meet the City's stormwater management goals.

1.1 PURPOSE OF MPD

The purpose of this MPD is to provide a comprehensive drainage study for the City, including an updated inventory of existing storm drain facilities and assessment of whether these facilities meet the requisite City levels of service. The MPD also evaluates and prioritizes the undersized or newly proposed facilities per the magnitude of improvements needed. This drainage study leverages the assessment completed as part of the CURMP to the maximum extent feasible and incorporates newly collected data and modeling advancements that have been developed since 2005.

Recommended drainage system characteristics (e.g., pipe diameter, detention volume) and planning level cost estimates have been developed for each of the proposed improvements to equip the City with the data necessary to identify priority projects for further design and implementation.

1.2 CITY WATERSHED CHARACTERISTICS

Huntington Beach is a 32.1-square-mile municipality located in northwest Orange County (County), adjacent to the Cities of Seal Beach, Westminster, Fountain Valley, Newport Beach, and Costa Mesa. The City is bounded by the Bolsa Chica Channel to the north, the Santa Ana River to the east, and the Pacific Ocean to the west (Figure 1-1). The City's climate borders between a semi-arid and Mediterranean (sunny, dry, and cool with damp evenings), with an average annual precipitation of 12 inches that falls predominantly in winter months.

Huntington Beach is highly urbanized with 22.6 square miles of impervious cover, making up 70% of the City's landcover. Water and pervious cover account for 1.0 square mile and 8.5 square miles, respectively.

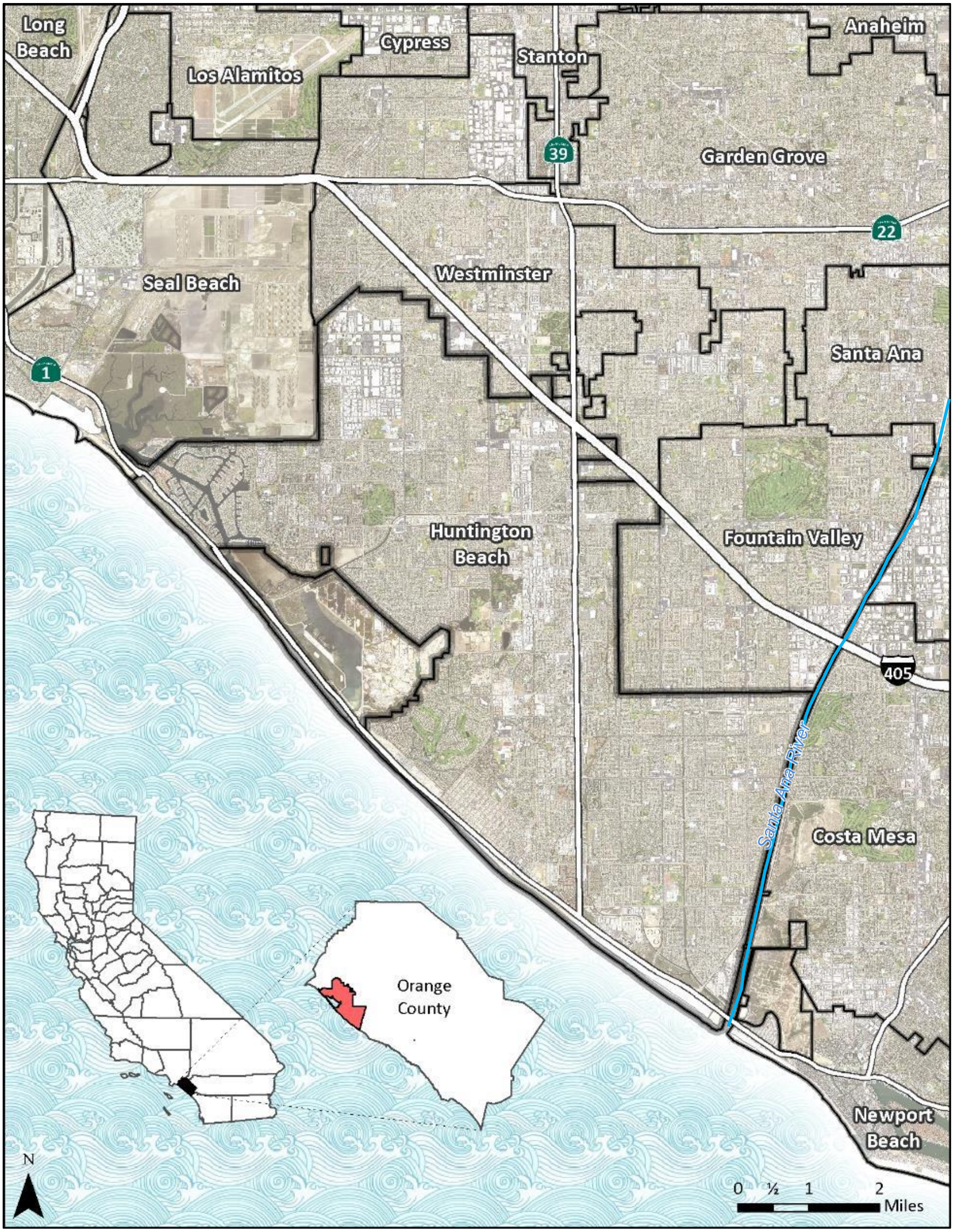


Figure 1-1. Location of the City relative to nearby municipalities

Because the storm drain network spans such a considerable area, the City has been subdivided into several drainage regions to better group and characterize the drainage network. The 2005 MPD subdivided the City into 33 drainage regions based upon topography and the extent of the storm drain infrastructure (Figure 1-2, left). The 2018 MPD effort utilized a similar methodology; however, improved datasets and geospatial processes (e.g., high-resolution Light Detection and Ranging (LiDAR), advanced ArcGIS processing, etc.) were supplemented to more effectively characterize extents of the drainage networks. Through this process, 37 hydrologically distinct drainage regions were delineated, each of which ultimately drain to either City pump stations, detention storages, County channels, or the ocean (Figure 1-2, right).

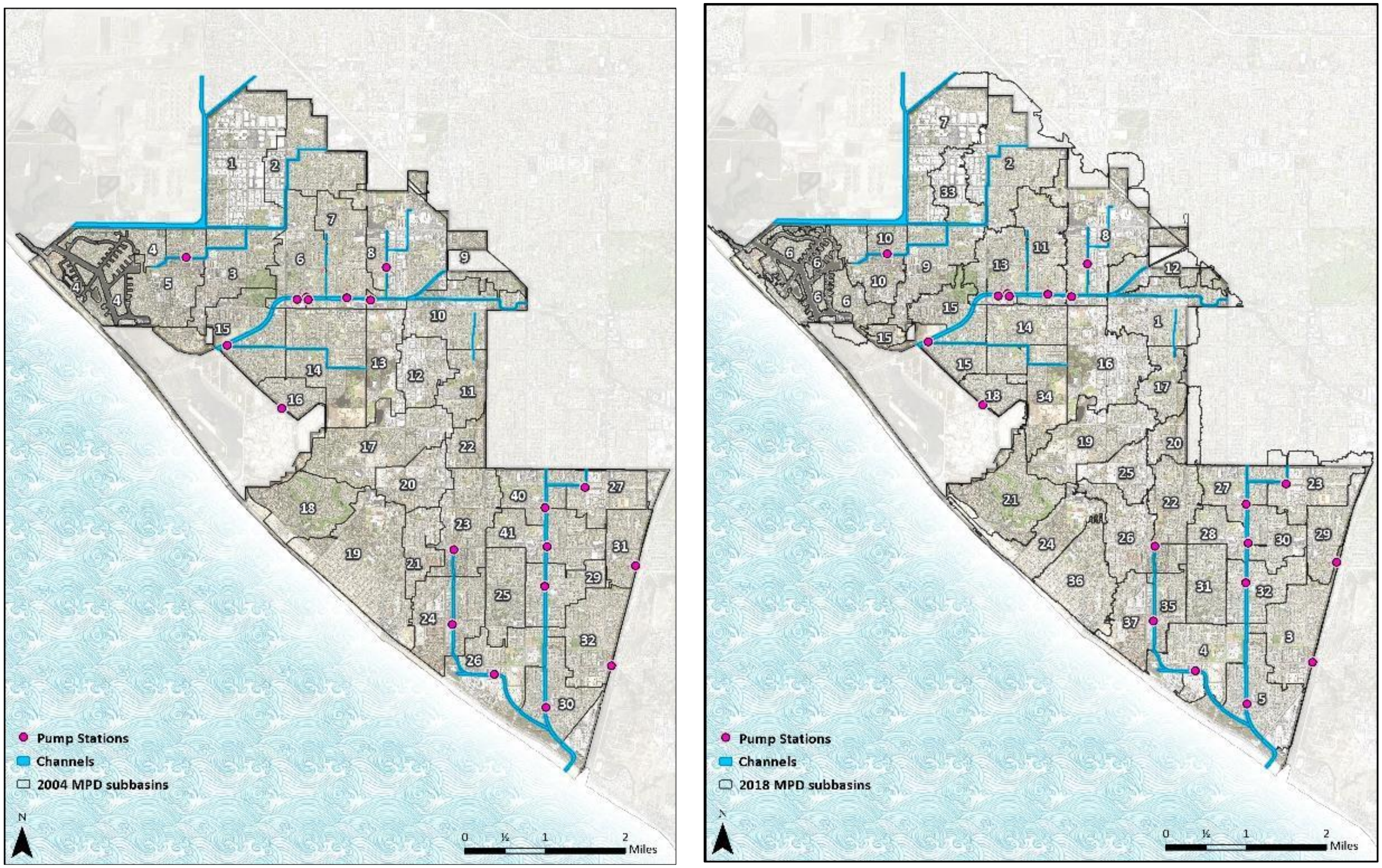


Figure 1-2. Major drainage regions as created in the 2005 MPD (left). Major drainage regions as created in the 2018 MPD (right)

Within City boundaries, the storm drain network is composed of 218 miles of stormwater conveyance. The City owns and maintains 120 miles of this storm drain system (Figure 1-3).

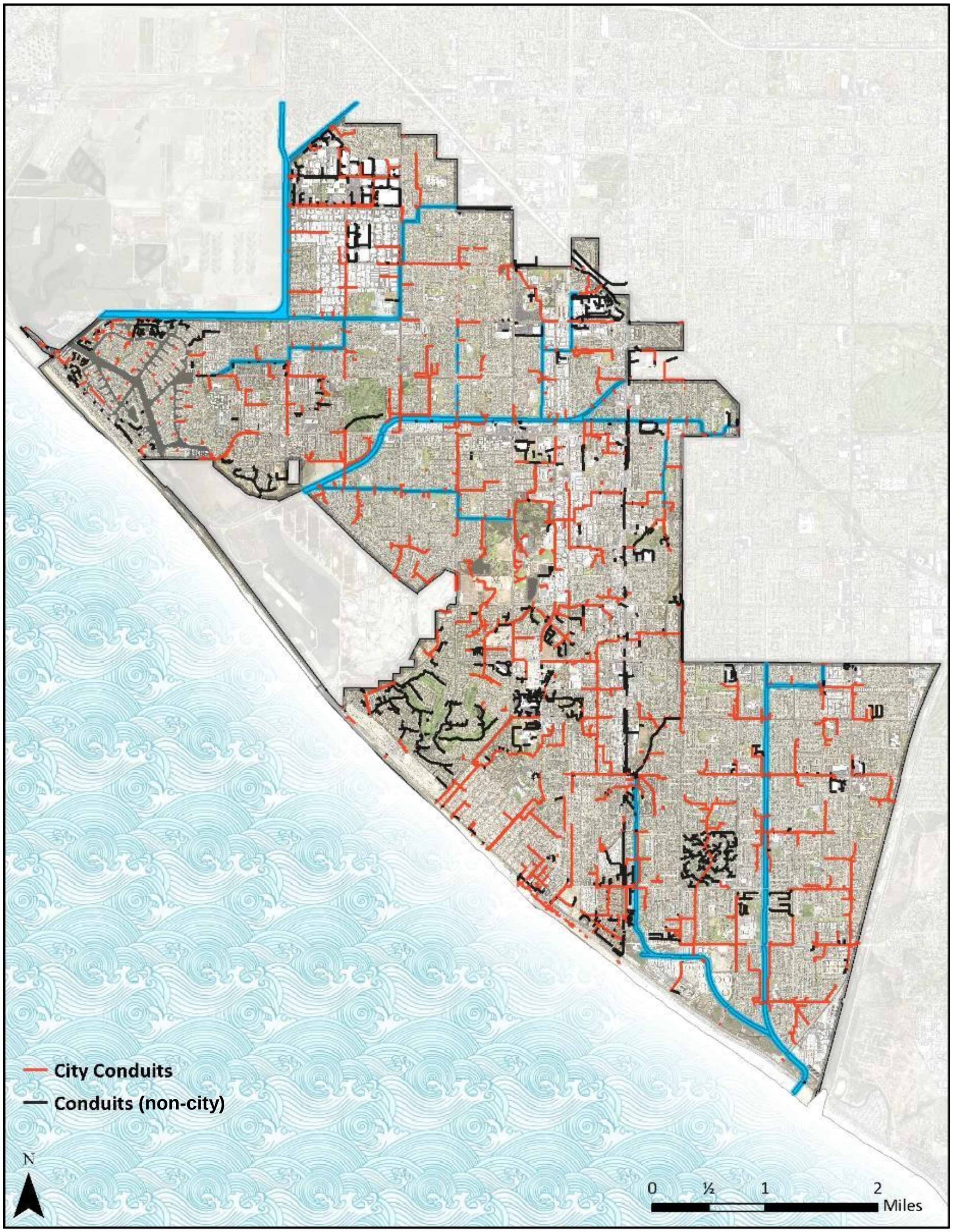


Figure 1-3. Location of City and non-city owned conduits

Within City boundaries, there are 13 channels with City, County, or outside ownership. The City owns and maintains four channels, the County owns portions of eight channels, and the remaining are owned by bordering cities or outside entities (e.g., U.S. Army Corps of Engineers (USACE)) (Figure 1-4).

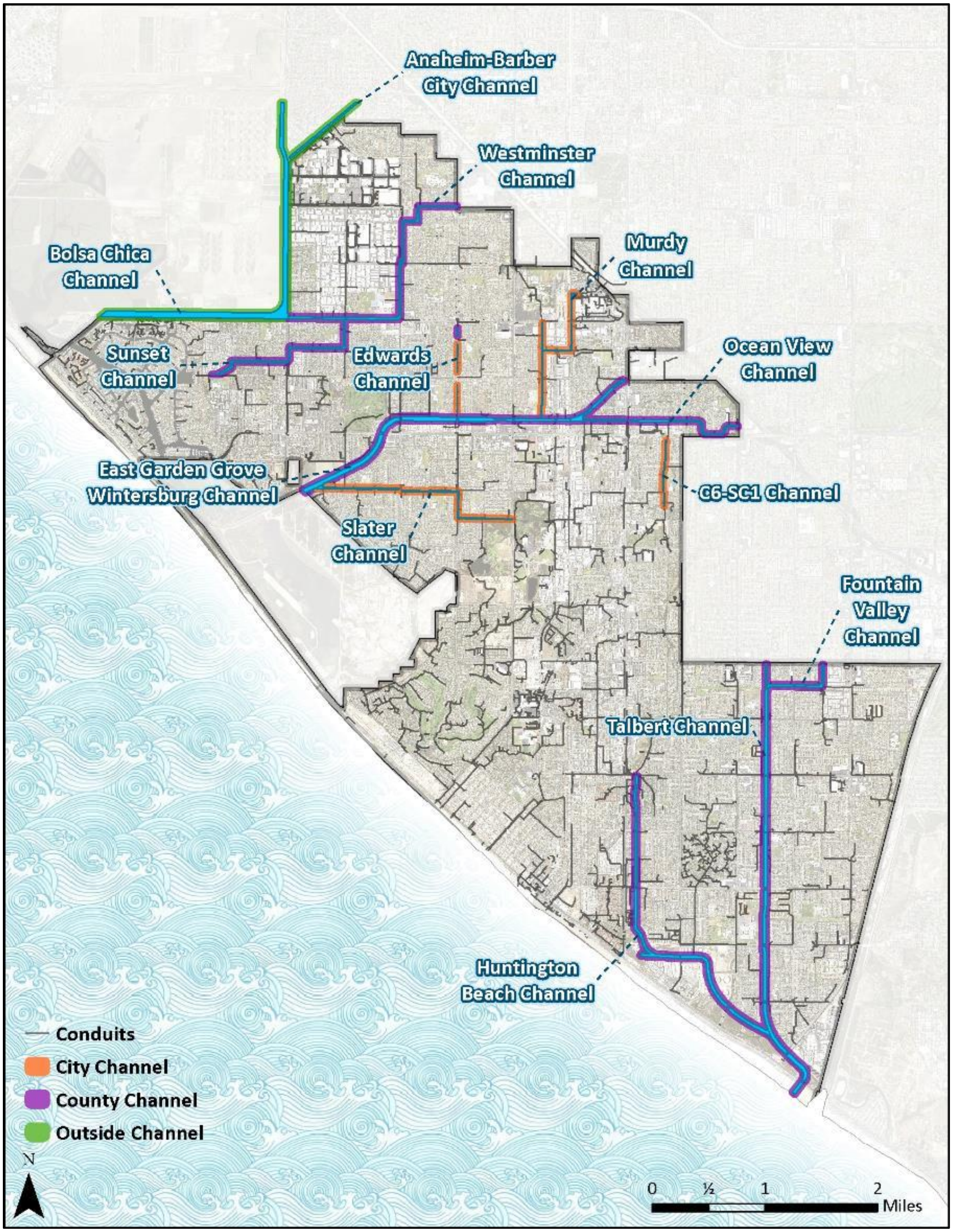


Figure 1-4. Location of City and non-city owned channels and names

Nineteen major pumps operate within the City adjacent to channels. The City owns, and maintains fifteen of these pumps, and the remaining five are owned and operated by other entities (Figure 1-5).

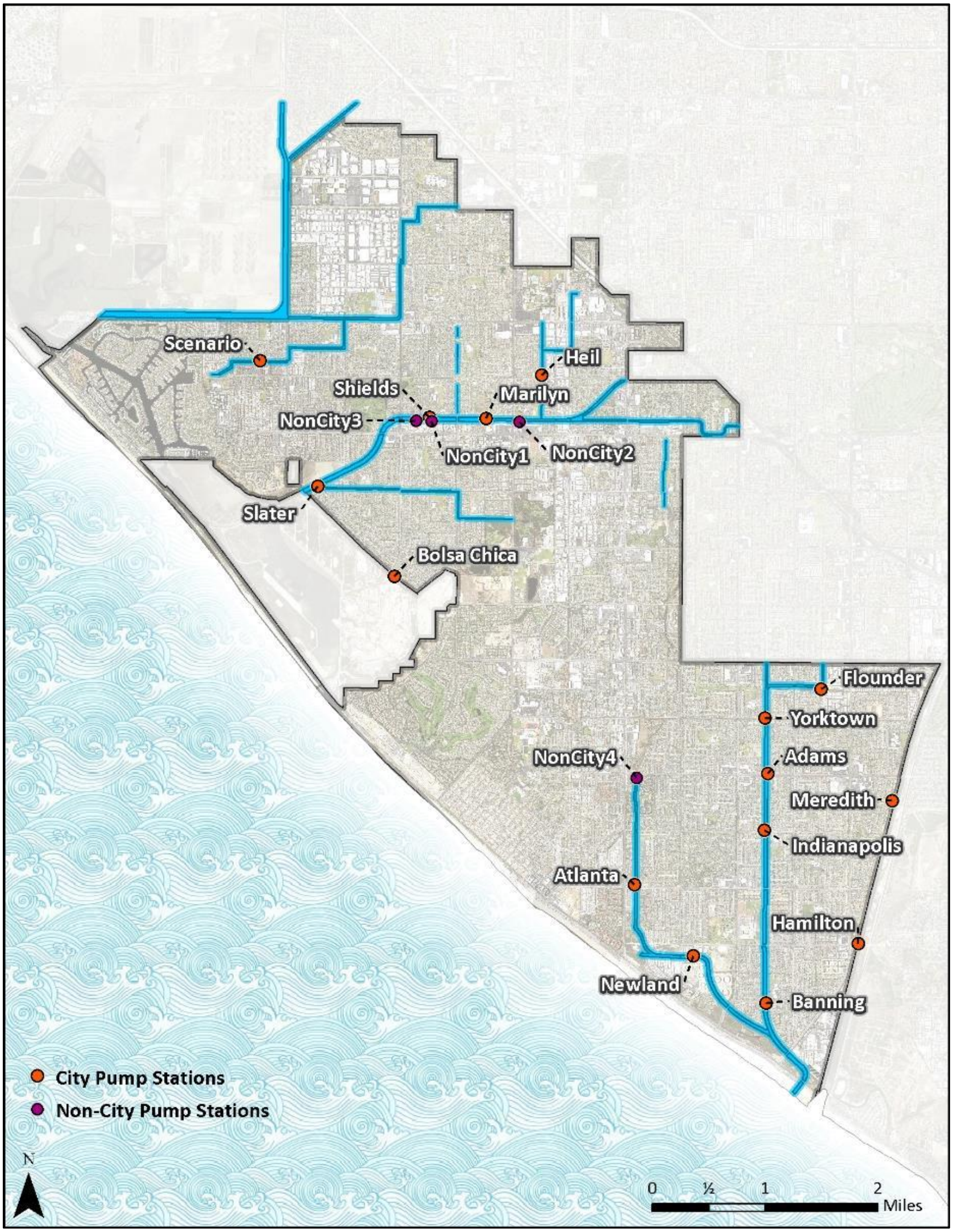


Figure 1-5. Location of City and non-city owned pumps and corresponding names

1.3 FLOOD CONTROL DESIGN GUIDANCE AND PERFORMANCE

To assess the level of service provided by existing storm drain network, local guidelines (e.g., Orange County flood manuals), as well as the 2005 MPD, were referenced to establish performance criteria and assess potential deficiencies. These standards established the basis for the development of a structured pathway to propose improvements to the City's stormwater assets.

The 2005 MPD presented a suite of flood criteria for assessing City stormwater infrastructure by referencing the Orange County Hydrology and Orange County Flood Control Manuals and integrating input from the City (Table 1-1). The 2018 MPD employs many of the same criteria from the previous MPD, apart from three changes:

(1) Performance criteria for City channels were considered.

(2) A more conservative interpretation of the "Maximum Street Flow Depth - 100-Year" was applied; the previous MPD assumed that stormwater could reach one foot *above* the back-of-walk without flooding any habitable structures. Because of the generally flat topography across the City, the 2018 MPD interpreted the Orange County Flood Control Manual more conservatively by limiting the ability of stormwater to pond up to one foot *behind* the back-of-walk. This assumption provides approximately two inches of additional water depth above the back-of-walk rather than one foot of depth assumed in the 2005 MPD. This conservative assumption was decided to ensure the Orange County Local Drainage Manual goal to provide protection for all habitable structures for the 100-year storm event was met.

(3) Finally, according to the 1986 County Hydrology Manual, the 85% confidence interval should be used to model proposed flood control facilities. Simulation of existing facilities may use the 85% confidence interval or a lesser confidence interval (but not less than 50%) to assess existing facilities. The 2005 MPD modeled the 50% and 85% confidence interval for the existing and proposed condition, respectively. The 2018 MPD modeling effort selected the 85% confidence interval for both existing and proposed to maintain consistency between conditions.

Table 1-1. Table of MPD modeling criteria

Criteria	MPD 2005	MPD 2018	Source
Return Event	10- & 100-year	10- & 100-year	MPD 2005
Existing & Proposed Condition Confidence Interval	10-yr and 100-yr event, 50% and 85% confidence interval, respectively	10-yr and 100-yr event, 85% confidence interval	Orange County Hydrology Manual – Addendum 1
City Channel Freeboard (leveed)	N/A	10-yr event – 0.5 ft 100-yr event – 1.5 ft	Orange County Flood Control Drainage Manual
City Channel Freeboard (non-leveed)	N/A	100-yr event – 1.5 ft < 100-yr event[a] – 1.0ft < 100-yr event[b] – 1.5ft	Orange County Flood Control Drainage Manual
Maximum Street Flow Depth	10-yr – Top-of-Curb 100-yr – 1 ft above back-of-walk	10-yr – Top-of-Curb 100-yr – 1 ft behind back-of-walk	MPD 2005
Total Street Flow Depth at Arterial Intersections	100-yr – One lane dry in each direction	100-yr – One lane dry in each direction	MPD 2005
Max Street Flow Depth * Street Flow Velocity	≤ 25-yr event - 6	≤ 25-yr event - 6	Orange County Flood Control Drainage Manual

[a] *drainage area < 500 acres.*
[b] *drainage area 500-4000 acres.*

2.0 DATA COLLECTION AND MODEL INPUTS

The development of a robust H&H model of the City required the collection of various precipitation, watershed (e.g., soil, topography, etc.), and infrastructure (e.g., conduit slope, diameter) data. The following sections describe the data sources used, process of data assembly and analysis to create an informed model of the complete existing conditions and facilities in the City.

2.1 PRECIPITATION DATA

Design storms simulated in this analysis utilized the LA County (LAC) hyetograph at a one-minute time step (LAC, 2006). Because a hyetograph specific to Orange County has yet to be developed, it was assumed the LAC hyetograph was sufficient to describe regional precipitation across Huntington Beach. The National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency data was used to determine the appropriate 24-hr design storm depths for the City (NOAA, 2014). These values were used to find the 85% confidence interval design storm depths.

A spatial assessment of the precipitation data was completed to confirm that the modeled storm depths for each event could be applied across the entire City area, meaning that the spatial distribution of precipitation did not vary significantly from coastal regions to inland areas within City jurisdiction. Results from the assessment indicated that the range of precipitation from coastal to more inland areas was less than 4%; which is a relatively small difference when considering the uncertainty in overall model variables. Therefore, a single storm depth for each event was simulated throughout the entire City jurisdictional area.

2.2 GEOSPATIAL DATA

Geospatial data was collected and compiled to inform the hydrologic conditions across the City. To represent the infiltration of stormwater, soils data within the City were obtained and synthesized for model consumption. Additionally, land cover data for the City was assessed to inform the quantity and timing of stormwater runoff. These data were paired with the storm drain network information provided by the City, which was augmented and adjusted based on field reconnaissance, desktop geospatial analysis, and a series of assumptions to develop a fully connected and articulated drainage network. The following sections introduce each of these geospatial datasets and their pertinence to the modeling effort.

2.2.1 Soils Data

Surficial soil types and their distribution across the City inform the infiltrative capacity of soils and subsequent runoff propensity. Soils data were obtained from the Web Soil Survey portal provided by the US Department of Agriculture (USDA) National Resources Conservation Service (NRCS, 2017). This dataset provides a soil name (e.g., Bolsa silt loam, Alo clay, etc.) and geographic extent across the City (Figure 2-1). Each soil name has associated modeled soil characteristics that are input into the modeling platform (Green-Ampt soil infiltration method was used) from the Volume I Revised SWMM Reference Manual (US EPA, 2016).

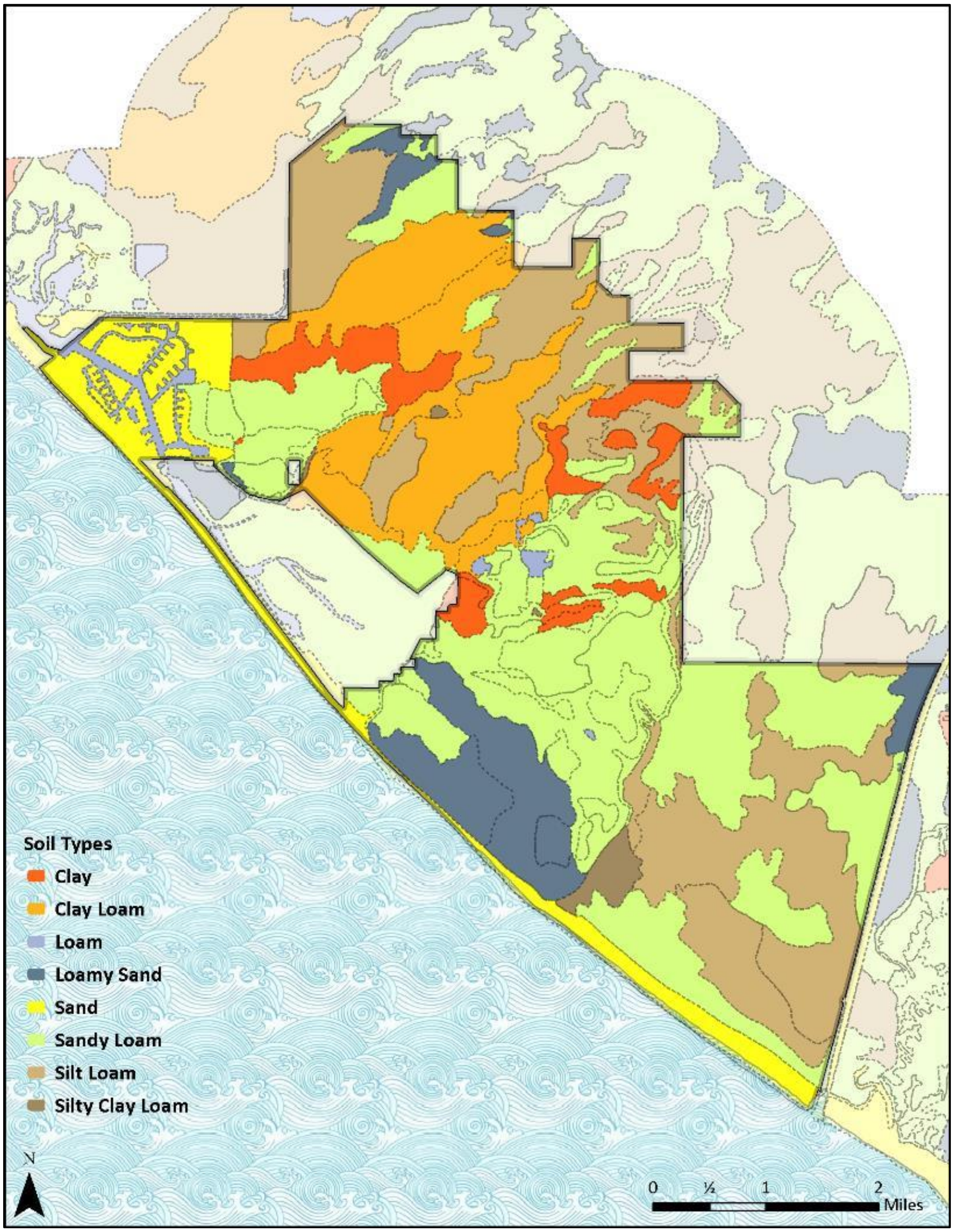


Figure 2-1. Surficial soil distribution across the City (NRCS, 2017)

2.2.2 Land Cover Data

To generate high-resolution land cover data, remotely-sensed imagery was used to classify surfaces between impervious and pervious. The infrared band (along with the red spectrum band) of high-resolution satellite imagery can be used to differentiate between surface covers because it is typically reflected by vegetation and absorbed by impervious areas (and vice versa for the red spectrum band). The measured signals for these bands from the imagery data were converted to the Normalized Difference Vegetation Index (NDVI), which was then analyzed to determine the local threshold value of the NDVI between impervious and vegetated surfaces. Threshold values were iteratively varied until surface cover classification best matched a visual inspection of satellite imagery for areas across the City bounds. Finally, areas of open water were classified separately using municipal data, as these are often misclassified as impervious using this automated methodology (Figure 2-2).

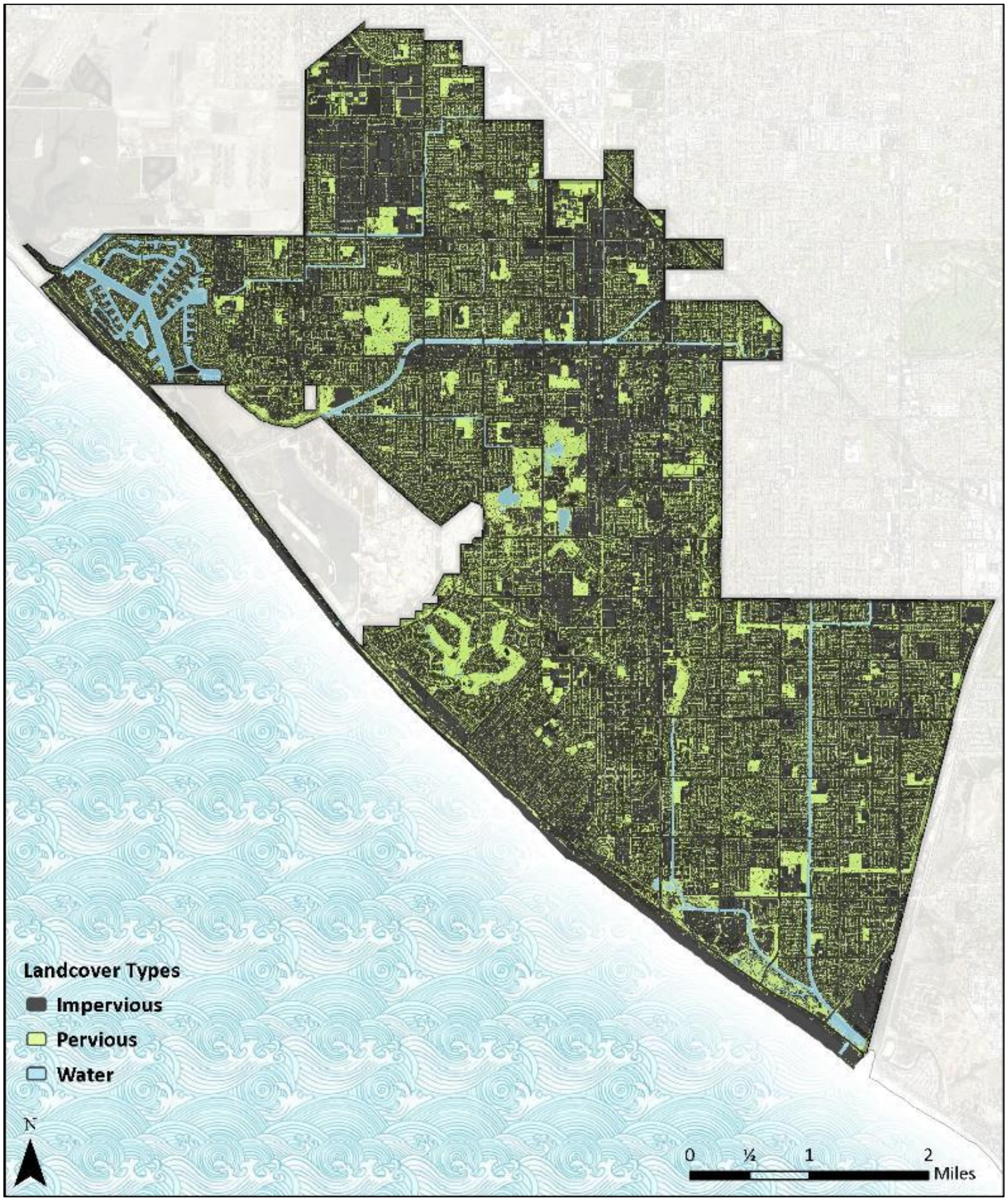


Figure 2-2. Land cover data from remotely-sensed imagery across the City

2.2.3 Topography

Elevation products are critical inputs to simulate stormwater routing across a drainage region. Developing an understanding of hydrologic routing across a landscape requires a high-resolution Digital Elevation Model (DEM). The best available datasets are provided as LiDAR point clouds, which are then processed in geographic information systems (GIS) into DEMs. The primary LiDAR dataset used in this effort was collected by Orange County with a typical point spacing (horizontal resolution) of approximately 2 feet and vertical resolution of up to 0.8 feet (Orange County, 2017). Alternative topography products included contour datasets, which were provided by the City in 1-foot vertical resolution. Because elevation data drive overland flow in the model, the dataset with greater resolution (County DEM) was selected for the modeling effort. Appendix A offers additional analysis comparing both elevation products as well as the source for Orange County LiDAR.

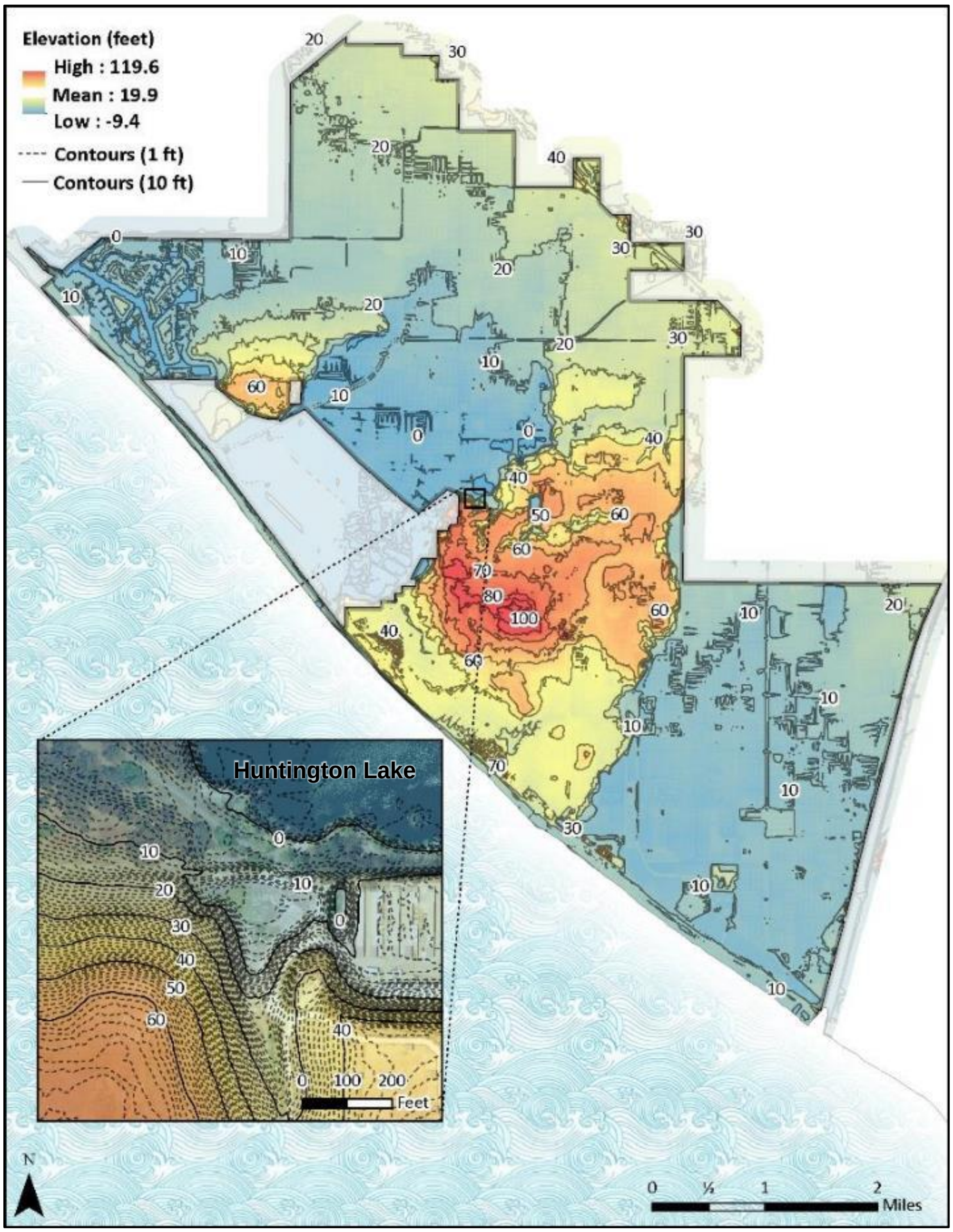


Figure 2-3. DEM from LiDAR (from Orange County) and 1-ft topography lines (from the City)

2.2.4 Storm Drain Network Data

The City provided a georeferenced storm drain infrastructure dataset composed of “Storm Lines” and “Storm Points”. The Storm Lines layer included linear assets and associated conduit attributes, including: location, direction, length, size, material, and ownership of many of the existing conduits and channels. The Storm Points layer included nodal data for each asset, including the infrastructure type (e.g., catch basin, inlet, cleanout, and junction, etc.), location, ID, ownership, and size. The following subsection summarizes the received Storm Lines and Points data and assesses it from the perspective of completeness for developing an H&H model.

2.2.4.1 Storm Lines

Approximately 10,000 “Storm Lines” (or conduits) were provided by the City for this analysis; however, the existing data were not sufficiently complete to form a full and uninterrupted storm drain network from end to end, which is necessary for modeling. Several additional conduits were inferred to exist to connect all provided nodes. The entity type for inferred conduits in the GIS database was “Model conduit” for both surface and subsurface connections. Model conduits were employed to connect isolated nodes to the larger storm drain network. In these instances, the location of pipes that likely exist were assumed based on shortest distance to nearest node. They were also used to connect outlets and grates along roadways, over bare earth, or to connect outfalls to nearby channels. The result of supplementing the received dataset with assumed conduits was a complete and unbroken storm drain network summarized in Table 2-1.

Table 2-1. Summary of length for major conduit entity types and percent City ownership

Entity Type	Total (miles)	City (miles)	City (percent of total)
Pipe	5.20	4.03	78%
Channel	29.27	5.28	18%
Ditch	6.15	1.97	32%
Unknown	177.3	108.3	61%
Model Conduit	33.73	-	-
Total	**278**	**120**	**-**

Note – Model conduits do not necessarily have ownership because they can represent overland flow, or inferred conduits for which ownership is not known

2.2.4.2 Storm Points

Storm Points (or nodes) are storm drain infrastructure situated between conduits, which connect the conduits to the surface, other conduits, channels, or the ocean. The City provided node locations, and types for many City-owned assets (Table 2-2). A ‘Storm Index’ attribute was also provided for nearly all City-owned nodes. This attribute will be maintained in the deliverable geodatabase to provide continuity between the received and deliverable database.

Table 2-2. Count of major point entity types and percent City ownership

Entity Type	Total (count)	City (count)	City (percent of total)
Inlet	5,437	2,535	47%
Pump	102	75	74%
Best Management Practice	140	54	39%
Outfall	757	448	59%
Unknown	104	24	23%
Other[a]	4,035	2,245	56%
Total	**10,575**	**5,381**	**-**

[a] *Other includes manhole, junction, transition, plug, cleanout, collar/pipe change entities*

2.2.5 Additional Facilities

Due to the low-lying and relatively flat topography of the City (i.e., some neighborhoods are situated at elevations below sea level or nearby channels), the City contains nineteen pump stations, generally located proximal to Orange County drainage channels. Runoff is conveyed to each pump station through the upstream storm drain network, and then pumped to the nearest channel, which ultimately conveys stormwater to the ocean. City pumps were simulated in a steady-state manner for this modeling effort using the provided maximum pump capacity, and recommendations for upsizing were not made per direction provided the City.

The City also owns and maintains several detention storage facilities, which serve to temporarily store runoff during large precipitation events. All identified detention facilities are explicitly simulated in this MPD and recommendations for increased storage in the proposed condition are made as necessary.

2.2.5.1 Pump Stations

The maximum flow rate for each of the City's fifteen pump stations was provided, which was assumed consistent for the duration of the model runtime. Flow rates for pumps operated by commercial owners or the County were not provided and assumed to have sufficient capacity for flow, meaning they were modeled as pumping all incoming stormwater to the pump's discharge.

Updates to two of the City-operated pump station flow rates were made after conversations with the City: (1) Slater pump station capacity increased by 147 cfs to a total of 904 cfs due to the addition of a new pump to manage runoff received from new residential development north of the East Garden Grove Wintersburg Channel (Hunsaker & Associates, 2017), and (2) future plans for Heil pump station to relocate the station just east to the opposite side of Murdy Channel and increase from 2 pumps to 4 (increase in capacity from 102 cfs to 179 cfs) (T. Broussard, personal communication, 5/9/2018). Table 2-3 lists the City pumps by name, and capacity. Figure 2-4 illustrates the location of each pump and their respective upstream drainage area.

Table 2-3. City pump capacities

Pump Name	Pump Operating Capacity (cfs)
Scenario Pump	142
Marilyn Pump	131
Shields Pump	375
Slater Pump	904
Bolsa Chica Pump	243
Flounder Pump	280
Adams Pump	401
Meredith Pump	238
Indianapolis Pump	379
Atlanta Pump	600
Hamilton Pump	441
Newland Pump	596
Banning Pump	412
Yorktown Pump	229
Heil Pump	179

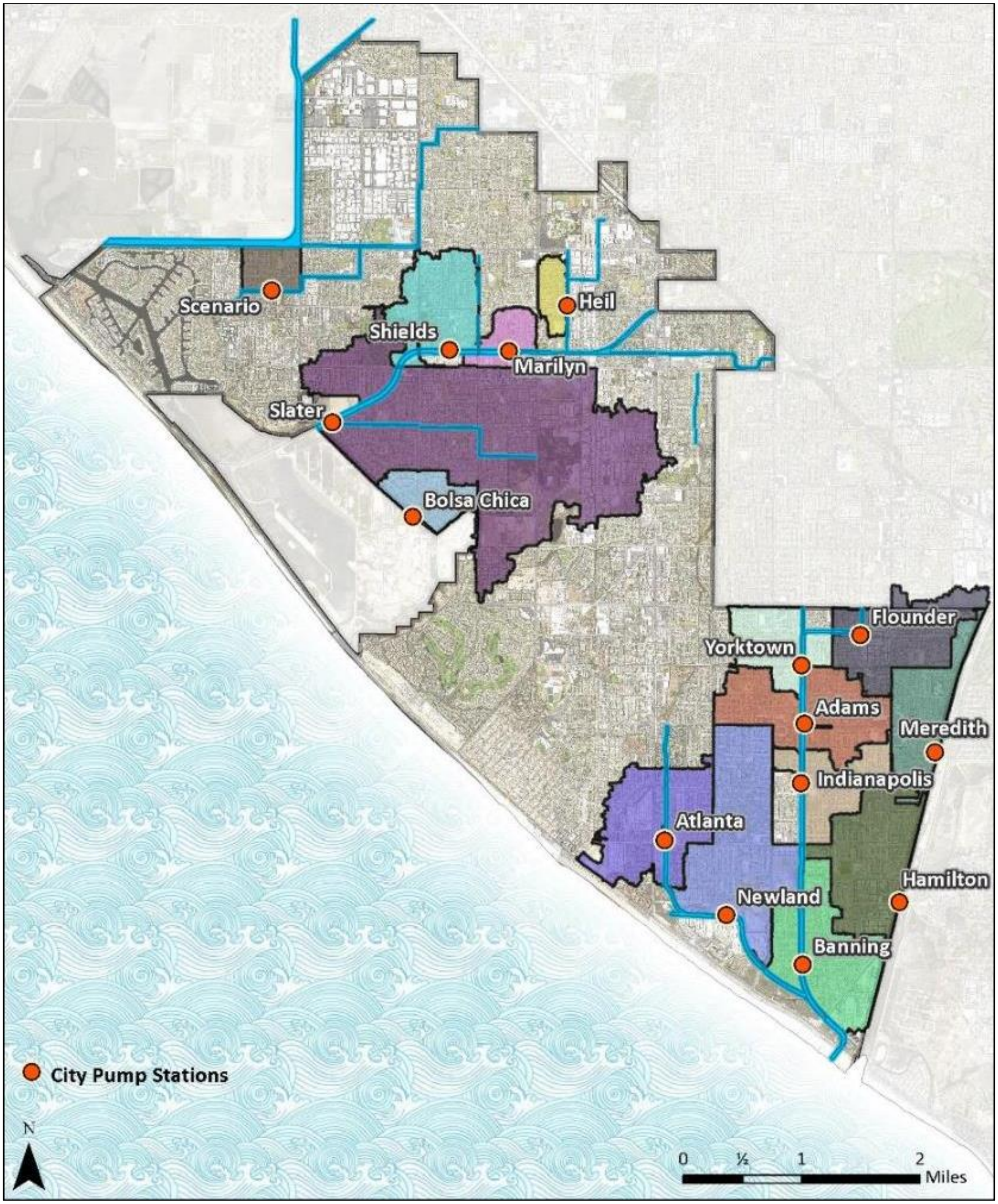


Figure 2-4. City pump stations and their respective upstream drainage areas

2.2.5.2 Detention Storage

Fifteen detention storage facilities were identified and characterized in the City through a desktop geospatial analysis, which relied on aerial imagery and topography. The DEM was used to determine the stormwater capacity at each facility (See Appendix A). Of the fifteen identified and modeled storages, ten were found to be on City property and the remaining were identified as being privately owned. Table 2-4 lists the storage facilities and their total volume of storage. Additionally, Figure 2-5 shows the location of each detention basin and their respective upstream drainage areas.

Note, although Shipley Nature Center is indicated as a detention facility, its design is somewhat unconventional compared to the other facilities. Reference Appendix A for details on how the Shipley Nature Center was identified and simulated.

Table 2-4. Detention storage volumes

Storage Name	Storage Volume (ac-ft)	Ownership
Good Shepard Cemetery	1.42	Private
Meadowlark Golf Course	0.99	Public
Oceanview High School	1.92	Public
Seacliff Golf Course - 1	0.22	Private
Seacliff Golf Course – 2	4.07	Private
Seacliff Golf Course – 3	1.10	Private
South Central Park	1.43	Public
Carr Park	11.14	Public
John Baca Park	4.15	Public
Sully Miller Lake	432.75	Public
Huntington Lake	34.02	Public
Talbert Lake	95.55	Public
Greer Park Pond	1.42	Public
Shipley Nature Center	19.87	Public
Slater Parkside Estates	10.3	Private

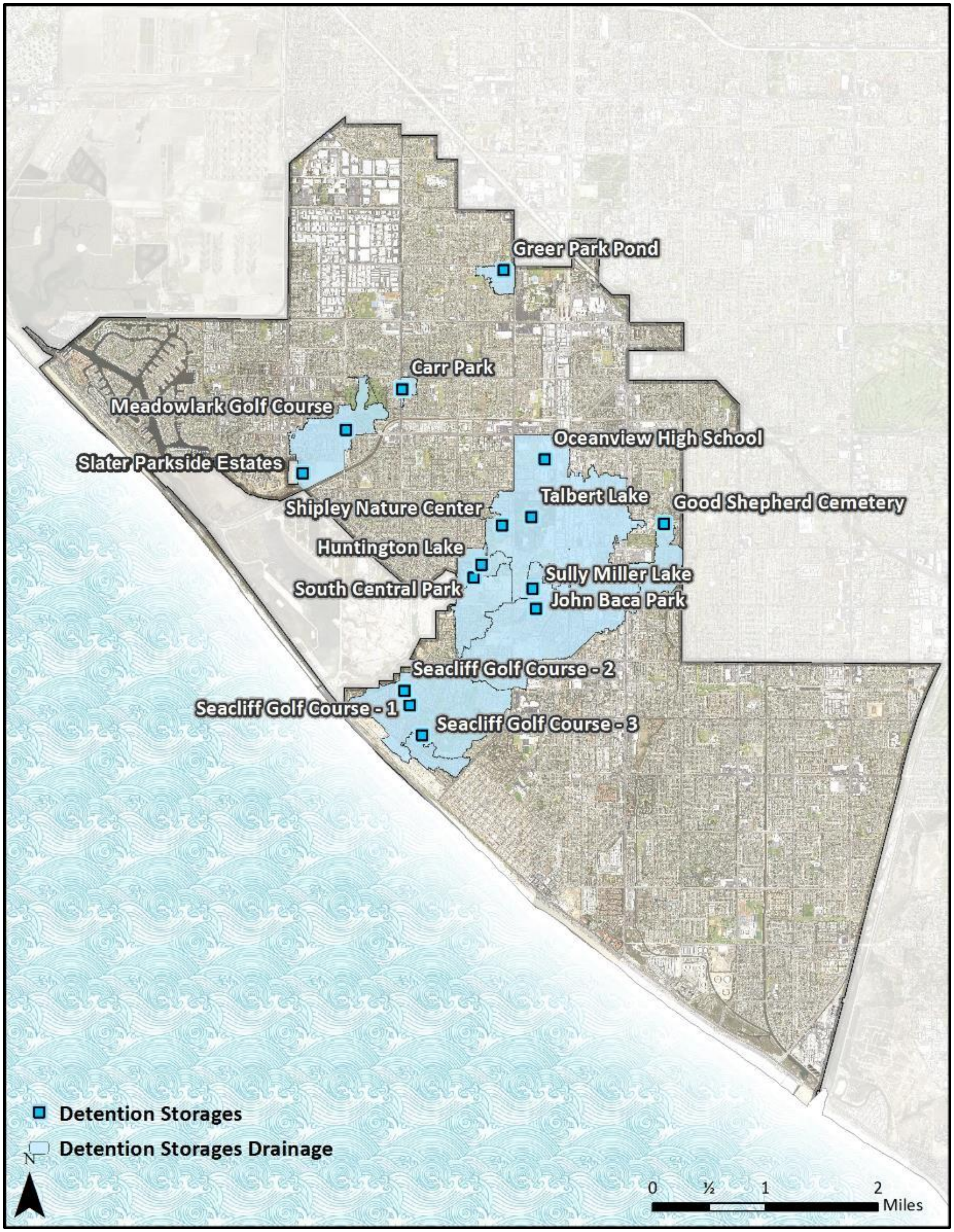


Figure 2-5. Detention storage and their respective upstream drainage areas

2.3 COUNTY OF ORANGE DRAINAGE FACILITIES

The Orange County Flood Control District (OCFCD) owns and/or maintains approximately 25 miles of storm drain systems within the City. Additionally, the County owns and maintains the Huntington Beach Pump Station, located on Adams Ave at the head of the DO-1 channel. This pump station was assumed to have sufficient capacity for all incoming stormwater, meaning that all inflows were immediately directed to the outfall of the pump as they arrived at the node.

2.4 OTHER PUBLIC AGENCY DRAINAGE FACILITIES

The eastern-most portion of the City is adjacent to the Santa Ana River Channel, channelized and operated by the USACE. Two City pump stations, Meredith and Hamilton, and a private outfall discharge to the Santa Ana River Channel.

No modeling was conducted in conjunction with the California Department of Transportation (Caltrans) Interstate 405 freeway drainage facilities, which utilize a County channel as the discharge point.

3.0 MPD MODEL METHODOLOGY

To assess the City's drainage system, a H&H analysis was performed. The focus of the hydrologic assessment was the quantification of runoff and peak flow rates from selected design storms. Multiple design storms were simulated to capture the varying levels of protection offered by the existing drainage system. The hydraulic assessment analyzed the capacity of the existing stormwater conveyance system (streets, pipes, and box structures) to drain and convey the runoff determined from the hydrologic analyses. The hydrologic and hydraulic analysis was performed using a single integrated model: the Personal Computer Storm Water Management Model (PCSWMM) platform. Results from the PCSWMM model indicate where deficiencies in the stormwater conveyance may exist and their degree of magnitude. Deficiencies were determined by use of the flood control design guidance and performance criteria outlined in Table 1-1.

3.1 HYDROLOGIC MODEL DEVELOPMENT

The two primary inputs to the hydrologic model are precipitation (hyetograph and rainfall depth) and land surface composition. Land surface composition uses various geospatial datasets (e.g., soil type, imperviousness, etc.) to characterize the upstream drainage area to each inlet in the network. This level of modeling detail at the "inlet scale" enables a robust hydrologic simulation of approximately 5,600 discrete inlet drainage areas and provides a resolution that is appropriate for meeting the requisite performance criteria.

3.1.1 Precipitation

To simulate rainfall in the model, an appropriate hyetograph and storm depth for each storm was developed. As indicated in Section 2.1, the Orange County Hydrology Manual (1986) recommends that the 85% confidence interval estimates of runoff should be used for the existing and proposed conditions. NOAA Atlas 14 point precipitation frequency estimates were used to estimate the storm depths for the modeled events (Table 3-1). The LAC hyetograph was used to temporally distribute rainfall over a 24-hr period (Figure 3-1)

Table 3-1. Modeled design storm depth and confidence intervals

24-hour Storm Event	85% Confidence Depth (in)
10-year	2.90
100-year	5.88

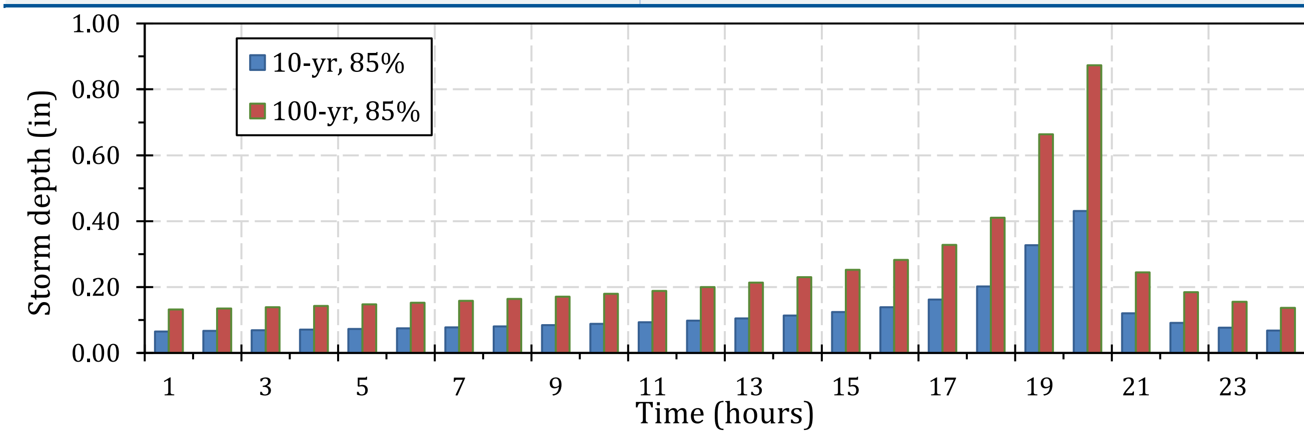


Figure 3-1. Hyetograph for the 10- and 100-year 24-hour storm events

3.1.2 Subcatchments

The drainage areas within the City were delineated upstream of every node with an inlet entity type (e.g., catch basin, grate, etc.) using ArcGIS tools, and high-resolution LiDAR data. Subdividing the City into thousands of discrete subcatchment areas enables characterization of spatial variability and captures the unique composition of each drainage area. Model parameters (e.g., inlet type, pervious and impervious area, flow length, slope, impervious cover, Manning's n, depression storage, zero impervious, infiltration method and values) were developed to appropriately capture these nuances.

Inlet type

Most (99% of) features within the City-provided data included an entity type. If the entity type was an inlet (e.g., catch basin, inlet, or grate) it was assumed to transmit stormwater from the land surface to the storm drain network, and an upstream drainage area to the entity was delineated (Figure 3-2). Area for each subcatchment was calculated as the region within the upstream drainage area using the California State Plane North American Datum (NAD) 1983 High Accuracy Reference Network (HARN).

Flow length

An important parameter for estimating timing of peak flows within PCSWMM is the subcatchment flow length. Flow length refers to the length of the overland flow path from the furthest drainage point of the subcatchment to its discharge. Flow length, in conjunction with subcatchment area, enables subcatchment width to be calculated—all three of these values inform the quantity and timing of surface runoff from each subcatchment. Arc Hydro (a set of advanced tools developed for use within ArcGIS) was used to calculate flow length for each individual subcatchment using the DEM (Maidment, 2002).

Slope

As with flow length, slope for each catchment was calculated using the DEM. The slope across each subcatchment was averaged and applied as a single value.

Impervious Cover

To characterize the impervious cover of each subcatchment, the infrared band of the high-resolution satellite imagery was used. The measured signal from these bands was used to differentiate land cover based on the reflection from vegetation and the absorption of impervious cover. These values were converted to NDVI to use the local threshold value between vegetation and imperviousness. Percent imperviousness across each subcatchment was averaged and applied as a single value to each subcatchment.

Figure 3-2. Location of all delineated drainage areas draining to their respective inlet node

Manning's n

Manning's n is the roughness value associated with overland flow which considers the impact of precipitation, drag over a surface, and obstructions in the flow path. Manning's n must be provided for overland flow on both impervious and pervious surfaces; in both cases composite "look-up" values for Manning's n were used to approximate the modeled value for each (Engman 1986). For all subcatchments, the roughness coefficient for impervious areas was assumed to be 0.011, which corresponds to smooth surfaces such as concrete or asphalt. Aerial imagery of City pervious areas indicated surface cover was mostly low grass, therefore the corresponding Manning's n of 0.015 was used universally for pervious areas.

Depression Storage

Consistent with Manning's n, look-up values were applied for the pervious and impervious depression storage parameters: impervious surfaces were set at 0.10 inches, and pervious surfaces were set at 0.20 inches (ASCE, 1992).

Zero Impervious

Zero impervious is defined as the percent of impervious area without depression storage. The default value within PCSWMM of 25% was assumed for all subcatchments.

Infiltration Method

The Green-Ampt method of infiltration was used to simulate stormwater saturating and infiltrating into the subsurface in modeled pervious area. The USDA NRCS dataset was used to extract soil data across the City (Appendix A), and standard look-up values were used to correlate soil classes (e.g., sandy loam) to Green-Ampt soil parameters (Table 3-2). For each delineated drainage area, a weighted average of the contributing soil area's parameter values within each area were tabulated.

Table 3-2. Green-Ampt parameters for different soil classes (Rawls et al., 1983)

Soil Class	Porosity	Wetting Front Suction Head (in)	Saturated Hydraulic Conductivity (in/hr)
Sand	0.437	1.95	4.74
Loamy sand	0.437	2.41	1.18
Sandy loam	0.453	4.33	0.43
Loam	0.463	3.5	0.13
Silt loam	0.501	6.57	0.26
Sandy clay loam	0.398	8.6	0.06
Clay loam	0.464	8.22	0.04
Silty clay loam	0.471	10.75	0.04
Sandy clay	0.43	9.41	0.02
Silty clay	0.479	11.5	0.02
Clay	0.475	12.45	0.01

3.2 HYDRAULIC MODEL DEVELOPMENT

To generate a comprehensive hydraulic system, the existing storm drain network provided by the City was amended and adapted to be imported into PCSWMM. The major components of this network are comprised of a system of conduits and nodes, which convey surface runoff downstream to detention storage, channels, or outfalls to the ocean. In addition to the City-provided conduits and nodes, a street flow system was developed to assess street flooding criteria. The street flow system enables stormwater to overflow from the subsurface network of conduits to simulate overflow routing between inlets along the roadway. Additionally, detention storage facilities were simulated by their calculated capacity. Finally, boundary conditions of the model were established based on the City's drainage system and the assessment objectives of this MPD.

3.2.1 Storm Drain Network

The storm drain network modeled in PCSWMM was predominantly comprised of the City-provided inventory data; however, the modeling process required a fully articulated storm drain system with key attributes (e.g., invert, size, slope) to be specified. Assumptions were made to inform the system and are described in further detail in the following sections.

3.2.1.1 Nodes

Nodes serve as the connection points between conveyance structures, as well as inlets to convey surface runoff into the storm drain network in PCSWMM. Modeling assumptions associated with various node attributes are explained in the subsections below.

Invert Elevation
Invert elevations were not included in the provided GIS data and required characterization using a step-wise method which: (1) investigated as-built engineering drawings, (2) completed field assessments for key locations, and (3) used the DEM and assumptions about conduit slope and depth to estimate the invert (Table 3-3).

The first step in determining invert elevation used City-provided as-built documents, which produced over 1,100 "known" inverts. This invert investigation focused on the main trunks of the storm drain network (conduits with diameters greater than 42 inches, Figure 3-3). The received as-builts spanned two reference vertical datums: National Geodetic Vertical Datum (NGVD) 1929 and North American Vertical Datum (NAVD) 1988. The former was updated to the latter so that all elevations were in a consistent and more up-to-date format.

Next, a field team was dispatched to retrieve invert elevations from key locations along the main trunk of the drainage network. The team collected field data (86 inverts) from storm drain structures using a handheld laser distance meter to measure the distance from the ground surface to the bottom of the infrastructure (the height of the infrastructure). The height was used in conjunction with the DEM ground elevations at each location to calculate the invert for the measured infrastructure.

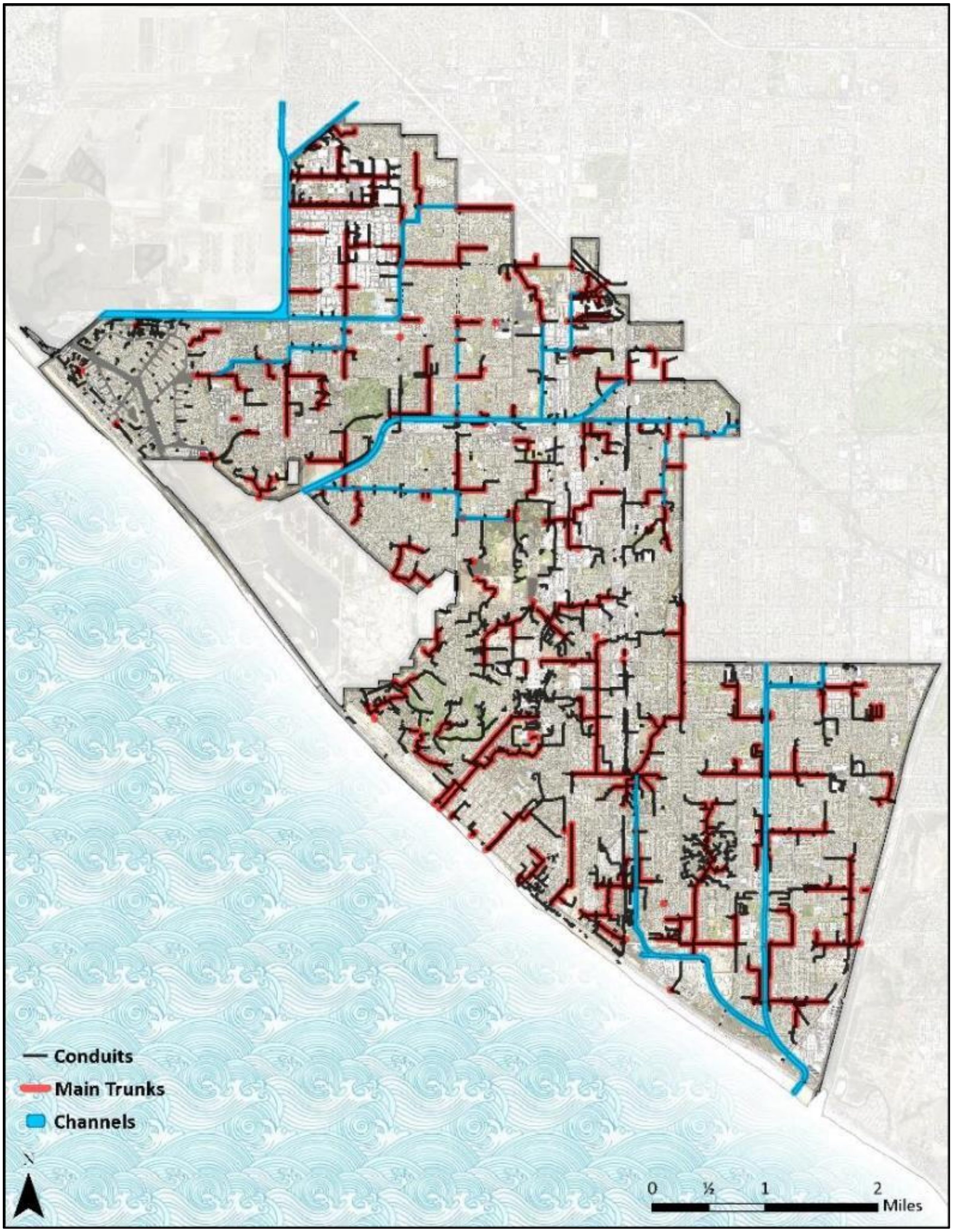


Figure 3-3. Main trunks of the storm drain network (Conduits greater than 42 inches in diameter)

The remaining unknown inverts were estimated using a desktop analysis with a series of assumptions. For nodes located along open channels, the following methodology was employed:

- When nodes with unknown inverts were located in between known inverts along open channels, a consistent slope between known inverts was assumed, and the inverts for unknown nodes were interpolated.
- For nodes with unknown inverts at the most upstream location in a channel (meaning there was no known invert upstream to calculate an assumed slope from a downstream known invert) an assumption was made that the invert was 1 foot below the DEM elevation. In other words, nodes along the channel at the upstream most point with an unknown invert were assumed to be 1 foot below the DEM elevation at that location. This conservative assumption enabled slopes across the fairly flat City to be more consistent throughout the network.
- All unknown outfall nodes within channels were assumed to outfall 0.77 feet above the channel invert (calculated above). This value is the average difference in outfall elevation and channel invert observed in as-built documents. When 0.77 feet above the channel invert was too high in elevation (invert at outfall was higher than that of the upstream node) the average of channel invert downstream and the structure upstream was applied.

For the remaining unknown inverts within the storm drain network (upstream of channels), a similar methodology was used:

- When nodes with unknown inverts were located in between known inverts, a consistent slope between knowns was assumed and the unknown inverts were calculated via linear interpolation.
- For the remaining unknown inverts, a 0.5% conduit slope was applied from known inverts to all unknown nodes up and downstream. In instances when this slope was too steep, meaning the elevation of the slope was greater than that of the ground elevation, the slope was decreased until its upstream invert was 1 foot below the DEM elevation. Again, this is a conservative assumption that ensured consistent slopes throughout the network.

Table 3-3. Summary of the assumptions for determining invert elevation

Conduit Type	Parameter	Assumption
Channel	Slope	Calculated using the difference in elevation of two known inverts and applied to all channel nodes in between
	Depth	1 foot below DEM when no upstream known invert existed
	Outfall	0.77 feet above channel depth, or between upstream and downstream known values
Storm Drain Conduit	Slope	0.5% slope, or calculated using known elevations and the minimum invert elevation
	Depth	1 foot below DEM when no upstream known invert existed

Rim Elevation

Rim elevations for nodes were obtained using the DEM, where elevations at the location of the nodes was applied. For nodes that fell within an open channel, use of the DEM would indicate the rim would be at or near the invert. In these instances, the height of the channel, as indicated by its geometry, was summed with invert elevation to determine a rim elevation.

Ponded Area

Ponded area in PCSWMM is the footprint around a node where stormwater collects when the conduit system is above capacity (i.e., when runoff at a node exceeds the intake capacity, stormwater will pond). Ponded areas create an opportunity for excess stormwater to flood and store until capacity in the conduit is restored. Each node in the system was given a ponded area of 1,000 square feet to allow for water surcharging from the system to pond. The maximum height and volume of flooded stormwater from each node in the model is used to assess localized flooding at each location. Nodes at intersections were assigned a larger ponded area (2,000 square-feet) to account for the larger space likely to exist along the right-of-way at intersections.

Assigning ponded area to nodes is an inherently discretionary exercise because it is impossible to determine the appropriate ponded area at all nodes in the system individually. An alternative is the creation of a complete 1D-2D (one dimensional - two dimensional) integrated model that does not use the ponded area attribute to account for flooding and routing across the land surface. Further details on the advantages and limitations of 1D-2D model are detailed in Section 9.0 Next Steps.

Surcharge Depth

Nodes were assigned a surcharge depth based on the type of the surface feature. A surcharge depth is a value that can be assigned individually to each node and indicates the depth of stormwater that can accumulate on the surface *before* flooding occurs. When surcharge height is zero at a node, stormwater floods at the rim elevation; however, if the surcharge height is changed to three feet for example, stormwater will only flood at the node if stormwater surcharges three feet above the rim elevation. By default, all nodes have a surcharge depth of zero feet, but increasing the surcharge depth to a greater value enables upward pressure associated with specific entity types to be simulated. Table 3-4 shows how node types are grouped by surface feature and assigned a surcharge depth.

Table 3-4. Surcharge depth and reasoning for nodes types grouped by surface feature

Node grouping (Node types included)	Surcharge depth (feet)	Reasoning
Open surface (Channel, street flow, etc.)	0	There is no overhead surface feature that would prevent water from flooding the node immediately.
Partially open surface (Grate, catch basin, etc.)	2	There is an overhead surface feature which restricts surcharging stormwater but is relatively minimal, therefore flooding at the node is possible when sufficient pressure exists.
Closed surface (Manhole, cleanout, etc.)	5	A significant overhead structure exists (closed surface) therefore flooding at the node would require significant pressure before stormwater could flood at the node.
No surface (Transitions, plugs, etc.)	∞	These nodes do not have a surface feature and are therefore incapable of flooding at the surface. The assigned surcharge value is so great it inhibits the possibility of flooding.

Road Type

One of the main criteria for assessing existing infrastructure capacity is the height of water surface elevation (WSE) along roadways for the 100-year storm (Section 3.3.2). Determination of road types (and corresponding curb height) is assigned for each node within the right-of-way (ROW) enabling this flood criteria to be assessed. Further detail on the process for determining road types for nodes and conduits is provided in Section 3.2.3

Inlet flow

As the intermediary between surface and subsurface flow, inlets play a significant role in how and where flooding may occur specifically their type (grate, curb opening, or combination; Figure 3-4), length and sump condition (in sump or on grade).

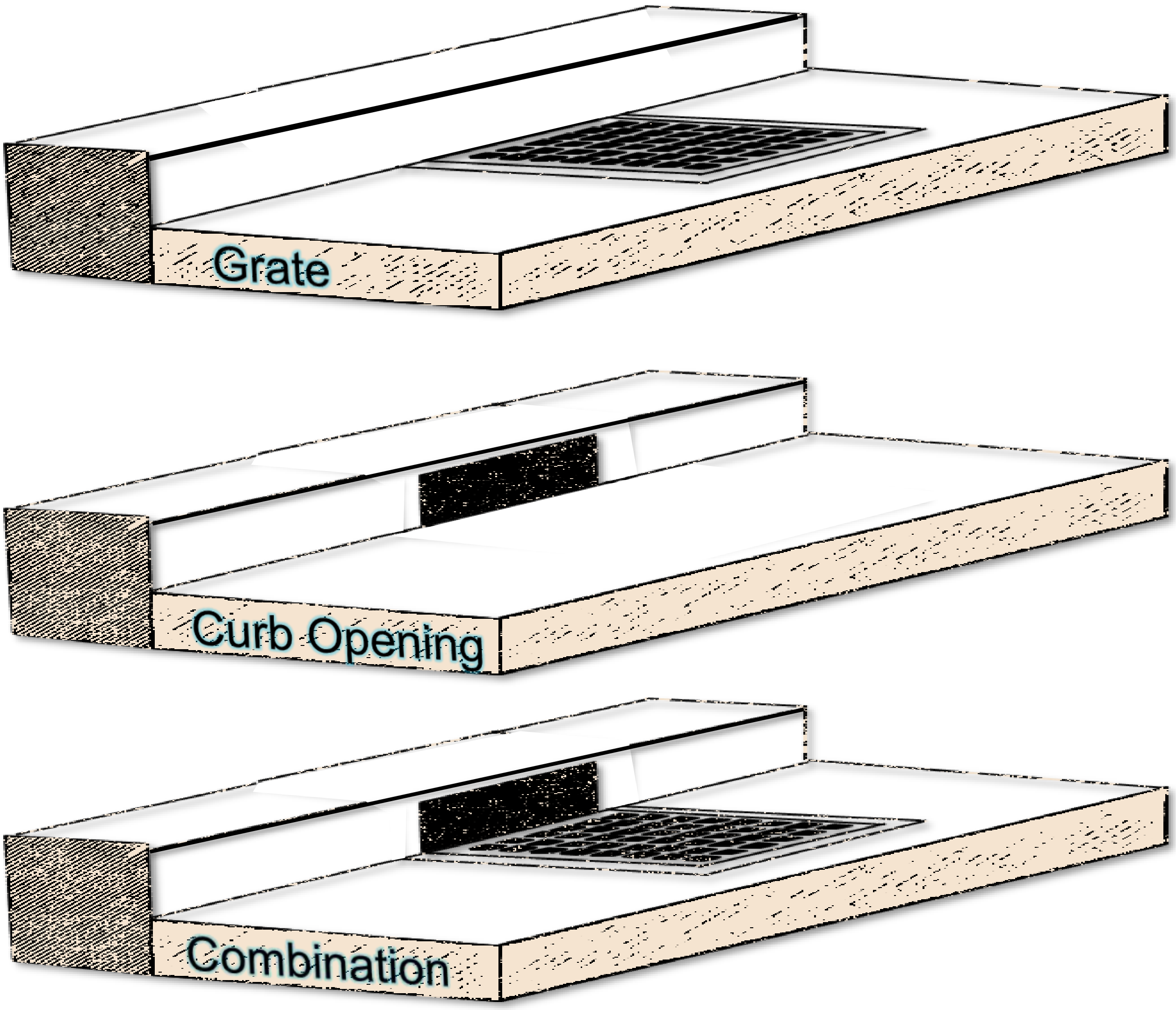


Figure 3-4. Three major inlet variations considered

Nearly all City inlet nodes had a size (curb opening or grate dimension) provided. To translate the dimensions into maximum flow capacities at each inlet, a number of assumptions were made:

(1) When only curb opening size was listed, it was assumed to be a curb opening (i.e., no grate). Determining flow rate through a curb opening relied on modeling results from the Federal Highway Administration (FHWA) Hydraulic Engineering Center Model (FHWA, 2013). This process created head-flow relationships for varying inlet conditions (in sump or on grade) and varying lengths (3 to 20 feet). Because flow rates change with depth, a maximum assumed ponding height was chosen as the upper

bound for in sump (18 inches) and on slope (8 inches) based on similar studies (City of LA, 1965; Denver, 2016).

(2) When no curb opening length was indicated, but instead a length by width dimension (e.g., “36 X 24”) was provided, the inlet type was assumed to be a grate without a curb opening. Furthermore, the value that was greater was assumed to be the length along the curb and the lesser value was assumed to be the width into the street. Determining the flow rate through a grate opening also relied on modeling results from the FHWA Model (FHWA, 2013). Again, maximum ponding heights for in sump (18 inches) and on slope (8 inches) were assumed.

(3) Combination (curb opening and grate) inlets were not identified in the received data; however, they are simulated when inlet upsizing was proposed. Determining head-flow relationships for combination inlets also relied on the FHWA Model (FHWA, 2013)

Results for curb opening only and combination inlets were compiled for a range of standard lengths (Table 3-5). Flow rates for grate-only inlets had many more possible combinations, therefore their results are in Appendix A. When provided lengths fell in between the standard lengths, an interpolation exercise was completed to approximate their flow rates.

Table 3-5. Maximum flow rates through various inlet and sump/grade conditions (see Appendix A for grate inlet results)

Inlet Length (ft)	Combination		Curb opening Only	
	Max Flow in sump (cfs)	Max Flow on grade (cfs)	Max Flow in sump (cfs)	Max Flow on grade (cfs)
3.5	45.6	6.6	10.5	4.4
7	57.4	9.4	21.0	8.7
14	81.0	15.1	41.9	17.5
21	104.5	20.7	62.9	26.2

3.2.2 Conduits

Conduits are the stormwater conveyance structures in the model, which include subsurface pipes, culverts, channels, and surface drains. The process for determining model attributes are indicated in the sections below.

Geometry (Size)

Of the 11,000+ conduits within the complete storm drain network, size (e.g., diameter) was provided for approximately 83%. For all provided sizes, it was assumed that the value was in inches. To approximate size for unknown conduits, a series of assumptions were applied in the following order:

1) If a conduit was the most upstream in the network *and* it was in the public ROW, a size of 18 inches was applied. The Orange County Local Drainage Manual stipulates that publicly maintained conduits must have a minimum diameter of 18 inches, therefore all unknown pipe sizes within the public ROW were assigned a diameter of 18 inches (Orange County, 1996).
2) If a conduit was highest in the network and in the *private* ROW a size of 12 inches was applied. The 12-inch assumption was used as a conservative estimate for what was likely installed within a privately-owned area.
3) If a conduit of known size was adjacent to a conduit of unknown size (whether upstream or downstream),

the known size was applied to the adjacent unknown. This process was completed for the two adjacent conduits upstream and downstream of each unknown. This assumption was applied *only* when the known conduit size was the only conduit entering or exiting the unknown conduit, meaning when there were multiple conduits entering or exiting an unknown, no assumption of size was applied.

4) Remaining unknown conduits were assigned by a desktop survey of the storm drain network in ArcMap and assigning size by most proximal known conduit. When multiple known conduits were entering or exiting an unknown conduit, the largest of the conduits was applied to the unknown as a conservative assumption.
5) When the entity type “drainage ditch” was an unknown size, a desktop assessment using aerial imagery and the DEM was completed to determine an average size that could be applied across all conduits with this entity type. Results of the survey indicated a trapezoid with center width of 18 inches and 51 inches tall was the most appropriate size to be applied to drainage ditches.
6) When the entity type “channel” was an unknown size, as-builts were reviewed to determine the appropriate size and geometry. If as-builts were unavailable, transects created from the DEM were used to determine height and width.
7) When the entity type “surface drain” was an unknown size, it was either located:
    a. Over a roadway, where a standard cross-section in PCSWMM for a half-road was applied (curb height: 0.5’, half-road width: 15’, parkway height: 0.25’, road and parkway slope: 2%);
    b. Over a channel, where it was assumed to be the same dimensions of the proximal channel;
    c. Over a parking lot, where it was assumed to be a rectangular triangular cross section with a width of 4’, triangular depth of 0.25’ and a total height of 0.75’; or
    d. Over bare earth, where a desktop assessment was completed to determine an approximate geometry and size for surface drains over bare earth. The result was a rectangular triangular cross section with a width of 6’, triangular depth of 0.6’ and a total height of 1.65’.

The MPD GIS database indicates which conduit sizes were provided in the original dataset (“known”) and which were assumed from the above methodology (“assumed”). If a conduit’s size is assumed in the existing condition and upsized in the proposed condition, it is recommended that the first step is to provide field verification to ensure that the size of the proposed infrastructure is not already in place.

Cross-section

Generally, conduit cross-sections were provided as the entity type (e.g., arch pipe) however many were “unknown” (81% of the system by length). To determine which cross-section was to be assigned for each conduit a series of assumptions were made in the following order:

1) When conduit size was a single value (e.g., 36 inches), it was assumed to be a circular cross-section
2) When arch pipe was indicated as the entity type, the closest standard size for corrugated steel arch pipe preloaded in PCSWMM was assigned. Corrugated steel arch pipe was chosen because the standard sizes in PCSWMM aligned best with the dimensions in the provided data.
3) When channel was indicated as the entity type, it was assumed to be trapezoidal with 1:1 side slopes
4) When drainage ditch was indicated as the entity type, it was assumed to be trapezoidal with 1:1 side slopes
5) When elliptical pipe was indicated as the entity type, it was assumed to be a vertical ellipse. Vertical ellipse was chosen because many dimensions provided in the data indicated they were taller than they were wider
6) When an under-sidewalk drain was indicated as the entity type, it was assumed to be rectangular and closed
7) When a surface drain was indicated as the entity type and its size was assumed from the up or downstream conduit, its cross-section was assumed to be a trapezoid with 1:1 side slopes.
8) When the cross-section type was not indicated as unknown in the provided data, but the size was in the format of width by height (e.g., 60 X 24), a closed rectangular conduit was assumed as the cross-section type

Manning's n

A number of material types were indicated in the City-provided conduit data. For each material type, a roughness coefficient was assigned (Table 3-6). Of the known conduits, 6,861 had a Manning's n of 0.013 and the mean Manning's n of all known conduits was 0.013; therefore, a Manning's n of 0.013 was assumed for all unknown conduits, which is consistent with the reinforced concrete pipe (RCP) materials likely used.

Table 3-6. Manning's n for conduit material types (Ven Te, 1959; FHWA 1961; FHWA, 2013; ODOT, 2014)

Conduit Material	Symbol	Manning's n
Vitrified Clay Pipe	VCP	0.013
Acrylonitrile-Butadiene-Styrene	ABS	0.01
Steel	STL	0.012
Corrugated Metal	CM	0.024
Reinforced Concrete	RC & RCP	0.013
Asbestos Cement	AC	0.013
High Density Polyethylene	HDPE	0.012
Cast or Ductile Iron	CI or DI	0.013
Dirt	Dirt	0.03
Polyvinyl Chloride	PVC	0.01
Techite	Techite	0.009

Ownership

All infrastructure within the City, regardless of ownership, was modeled in this 2018 MPD; however, only City-owned infrastructure is recommended for upsizing. Approximately 2 miles (1% of total system length) of conduit length is of unknown ownership. Determining ownership for conduits was necessary to determine which of the conduits were eligible for upsizing. Ownership determination was completed by a desktop analysis investigating the connectivity and proximity to known-ownership conduits and using best professional judgement to assign ownership.

3.2.3 Street Flow

The development of a street flow conveyance system, which enables flooded stormwater to route over land between inlets along the road, requires the road type for each simulated curb and gutter to be determined. Determination of road types used three main databases: (1) the 'edge of pavement' geospatial layer provided by the City (2) the DEM, and (3) roadway cross-sections provided in the 2005 MPD. Transects were created every 100 feet along all sections of the edge of pavement layer and the DEM was used to determine the dimensions of each transects' cross-section. Figure 3-5 illustrates an example of the use of the DEM to create transects across the roadway and the resulting cross-section (DEM output) which were translated to the City's standard roadway cross-section (Figure 3-6, Table 3-7). This process enabled simulation of stormwater as it flows between inlets by assigning all roadway dimensions to each node and conduit within the street flow system.

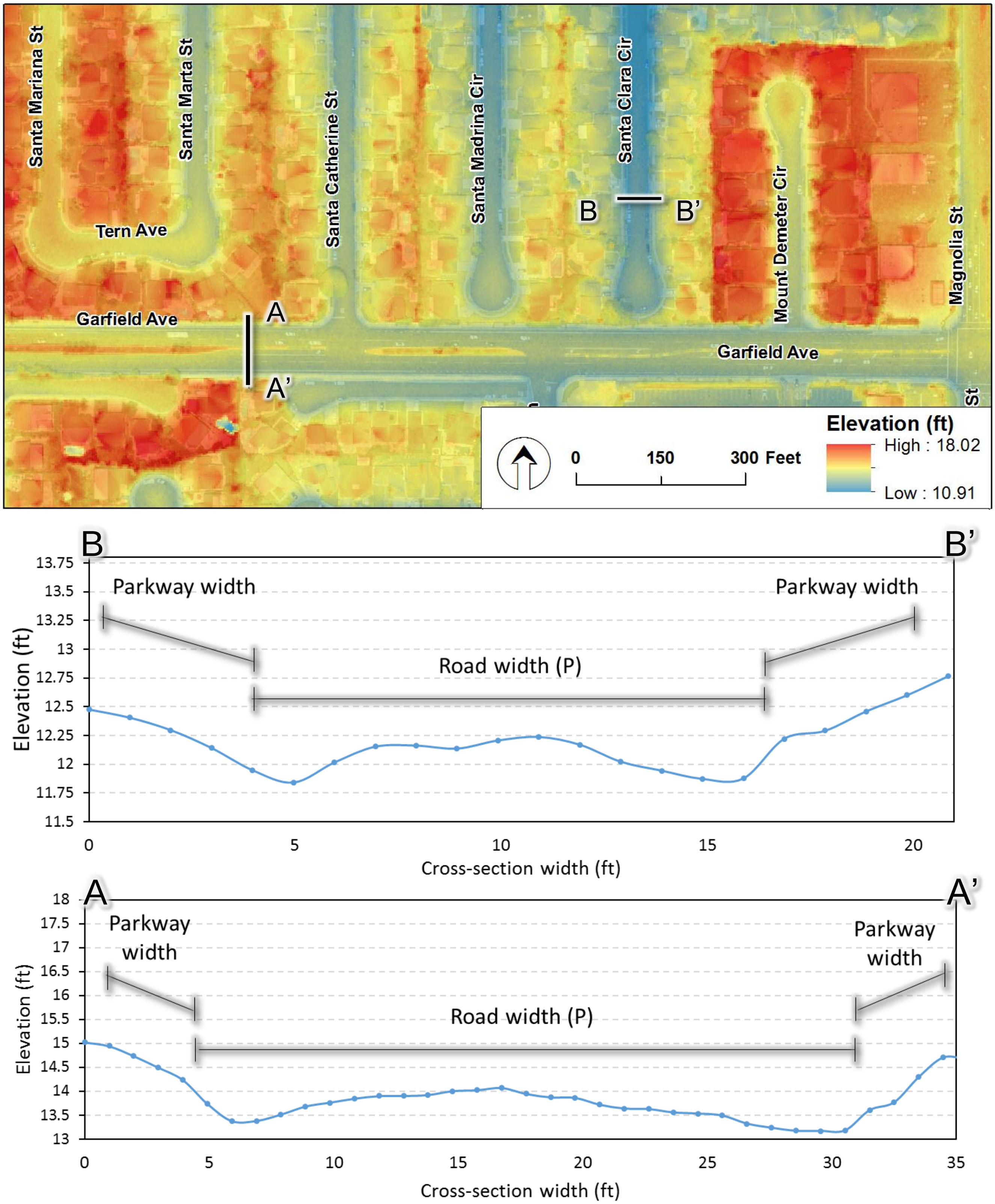


Figure 3-5. Aerial and DEM of two road transects in the City (top). Elevation plots of the transects (Bottom).

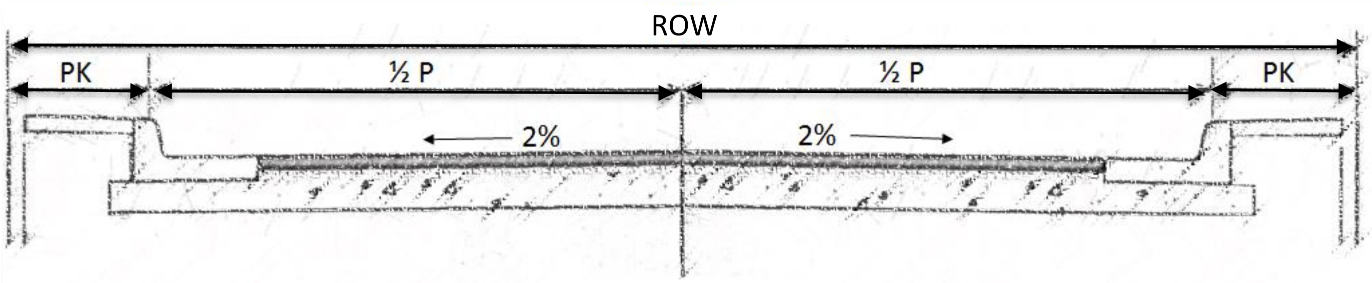


Figure 3-6. Standard roadway cross-section detail provided in the 2005 MPD

Table 3-7. Modeled road types and their associated dimensions provided in the 2005 MPD

Description	Major Arterial Highway	Primary Arterial Highway	Secondary Arterial Highway	Local Street Ind./Com.	Local Street Residential	Local Street Residential
ROW (ft)	120	100	80	60	52	44
Curb Height (ft)	0.67	0.67	0.67	0.5	0.5	0.5
Half Street Width (1/2 P) (ft)	52	42	32	22	20	16
Parkway (PK) Width (ft)	8	8	8	8	6	6
Distance from Crown to Grade Break	26	21	16	11	10	8
Interior Street Grade (%)	2	2	2	2	2	2
Exterior Street Grade (%)	2	2	2	2	2	2
Parkway Grade (%)	2	2	2	2	2	2

PCSWMM is capable of creating the street flow system parallel to anywhere the subsurface storm drain network exists. When subsurface storm drain conduits were located along the ROW, a conduit of matching length was modeled on the surface with the cross-section of the appropriate roadway type (as determined by the process described above) to represent gutter flow as well as the conveyance capacity at the curb and one foot behind the parkway (to assess the 100-yr flood criteria). In total, over 112 miles of street flow conduits were simulated in this process. Figure 3-7 provides an example of the street flow conveyance and its matching subsurface conveyance in a profile view. Note in this illustration overflow between runoff exists can exist between catch basins even if they are not surcharging if inlet capacity is exceeded. Figure 3-8 provides an example of how the street flow system is modeled across the City from a plan view.

In addition to subsurface conduits along the ROW, all arterial intersections were modeled as part of the street flow network to assess whether they met the 100-yr performance criteria.

Nodes “within” the arterial intersections were identified as being 170-feet from the center of the intersection. This assumption relied on a desktop analysis which confirmed that all inlets proximal to the intersections were included and connected to the street flow network created at the intersections. The intersection surface conduits were connected in PCSWMM to nearby catch basins to simulate water travelling along the intersection to be routed to a catch basin or water from an overflowing catch basin would be directed to the intersection conduits to then model flooding conditions in this area. Intersection conduits were also connected to the street flow conduits which follow the subsurface drainage network when they intersected.

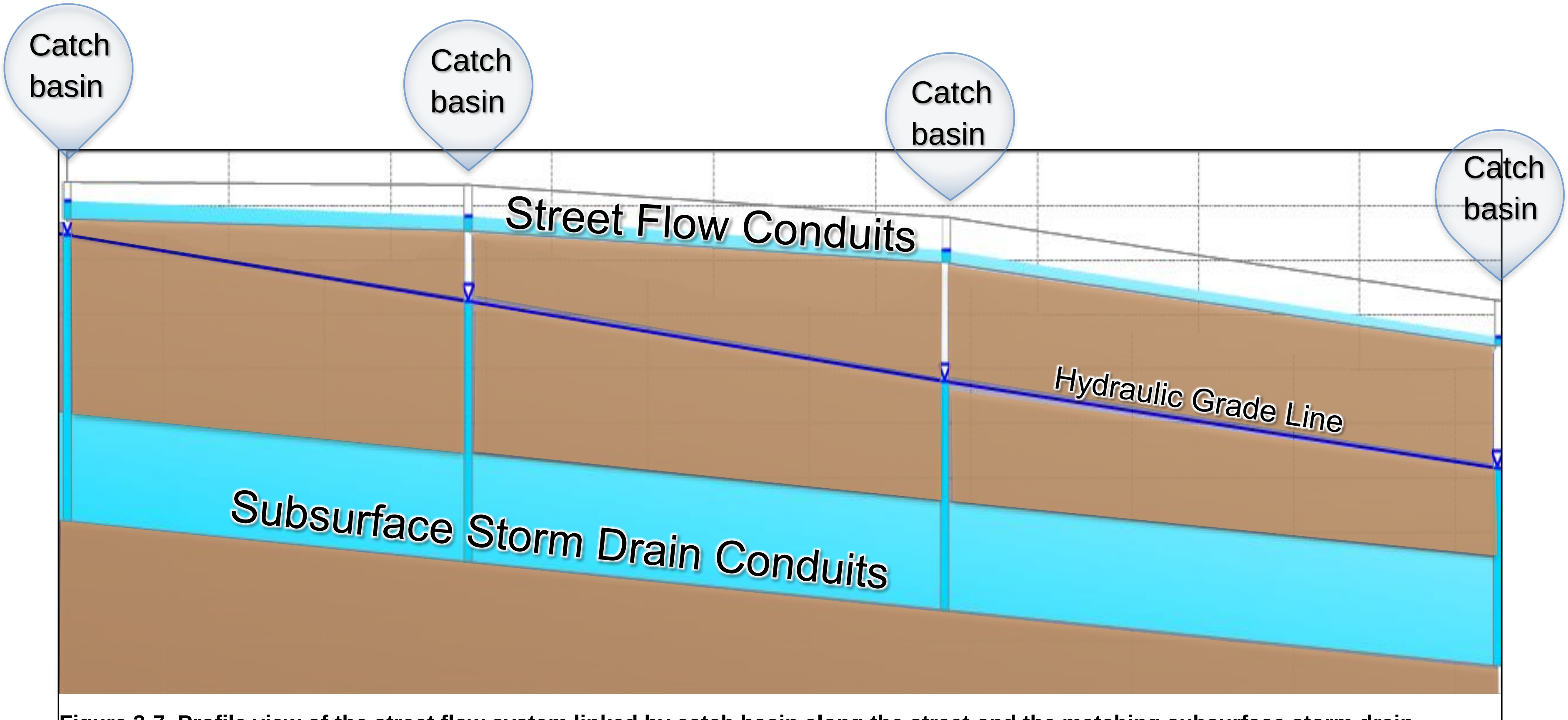


Figure 3-7. Profile view of the street flow system linked by catch basin along the street and the matching subsurface storm drain network.

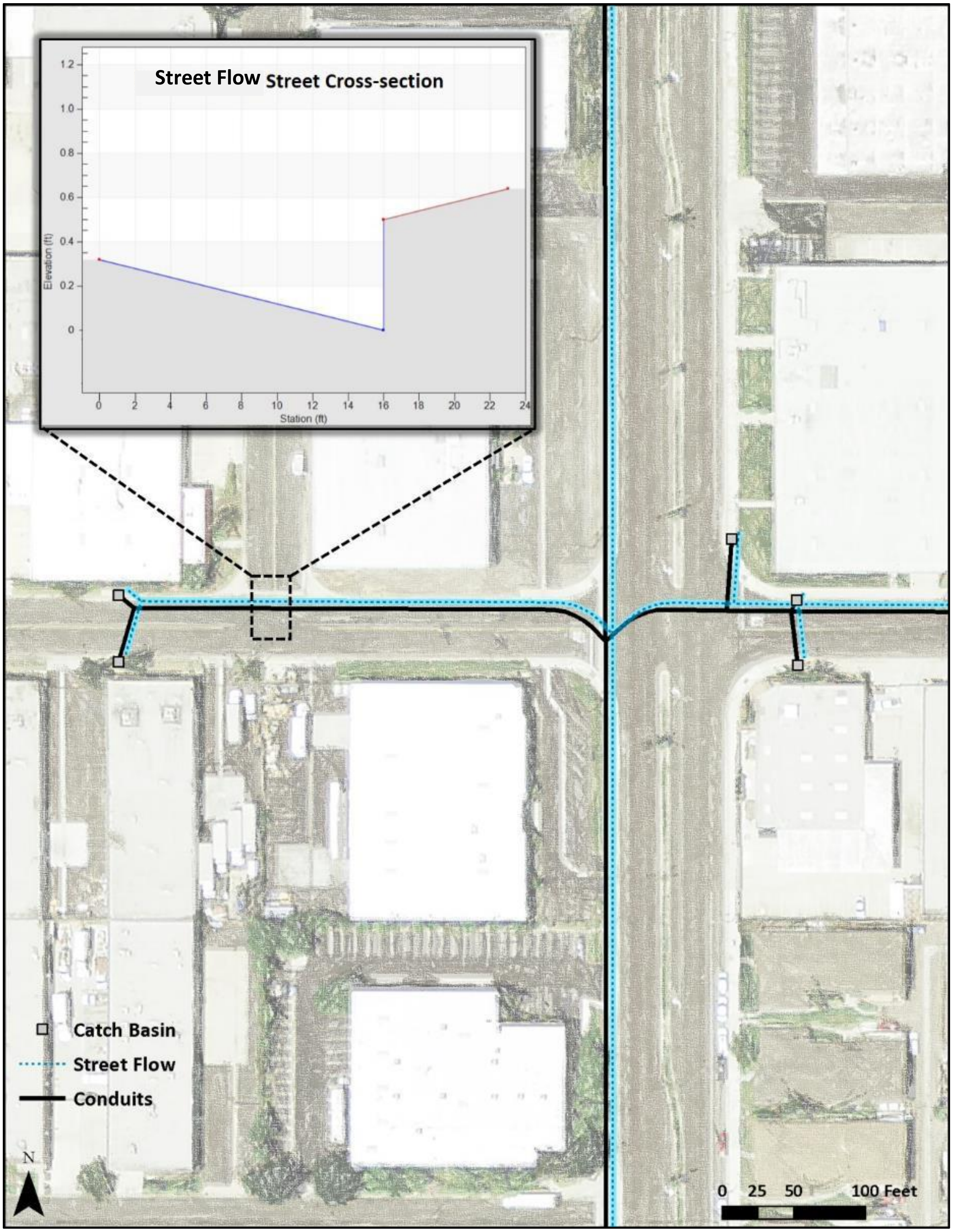


Figure 3-8. Illustration of street flow following the path of the subsurface conduits. Cross-section of the street flow conveyance (upper inset)

3.2.4 Storage Elements

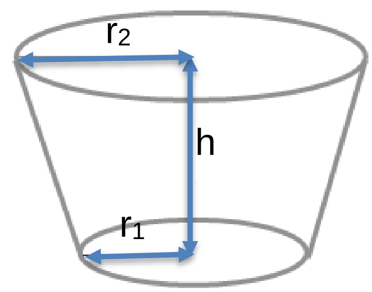
Fifteen storage detention facilities were identified and modeled throughout the City; twelve were modeled using PCSWMM storage nodes using an average height and footprint, the remaining thee detention ponds (Huntington Lake, Talbert Lake, and Greer Park Pond) were modeled with a 1D-2D integrated mesh to capture their complex surface features. A 1D-2D integrated mesh uses a mesh (collection of tightly spaced conduits and nodes) to transmit stormwater over the land surface (see Figure 3-9 as an example of Talbert Lake). The mesh is created using the high-resolution DEM, which assigns elevations and lengths to conduits and nodes enabling stormwater to flow over a simulated terrain surface and accumulate in topographic low areas.

Storage Nodes

Estimations of volume available at detention storage facilities were calculated within ArcGIS using the DEM. Contours were created at 3-inch intervals within the vicinity of each storage feature. The lower and upper bounding contours were then selected, representing the (1) dry-weather water level and the (2) highest elevation water can rise before overflowing onto neighboring land areas. These contour lines were converted into polygons, thus providing a surface area, perimeter, and elevation for the upper and lower limits. Two methods were then applied to arrive at an estimation of volume:

1. For each contour, a volume was calculated by multiplying the polygon surface area by the difference in height between the upper and lower limit.
2. The storage feature was assumed to be a circular truncated cone, wherein the perimeter was treated as a circumference, and the following formula for a circular truncated cone was applied:

$$Volume = \frac{1}{3}\pi(r_1^2+r_1r_2+r_2^2)h$$



The result of the two methods above were close in value and therefore averaged to represent to total capacity of each facility.

1D-2D Integrated Mesh

A 1D-2D mesh was created to account for water storage in three major detention ponds in the City. During the simulation, stormwater was directed to the pond by storm drain conduits and stormwater accumulated on the mesh starting at the lowest points. As the WSE increases, it follows the contours of the banks as dictated by the topography. The resolution for the mesh (as seen in Figure 3-9) was discretized into two zones; a coarser scale for the center of the pond because of its generally uniform elevation, and a finer scale for the region around the banks to capture the steep incline from the pond bottom to the top of the berm.

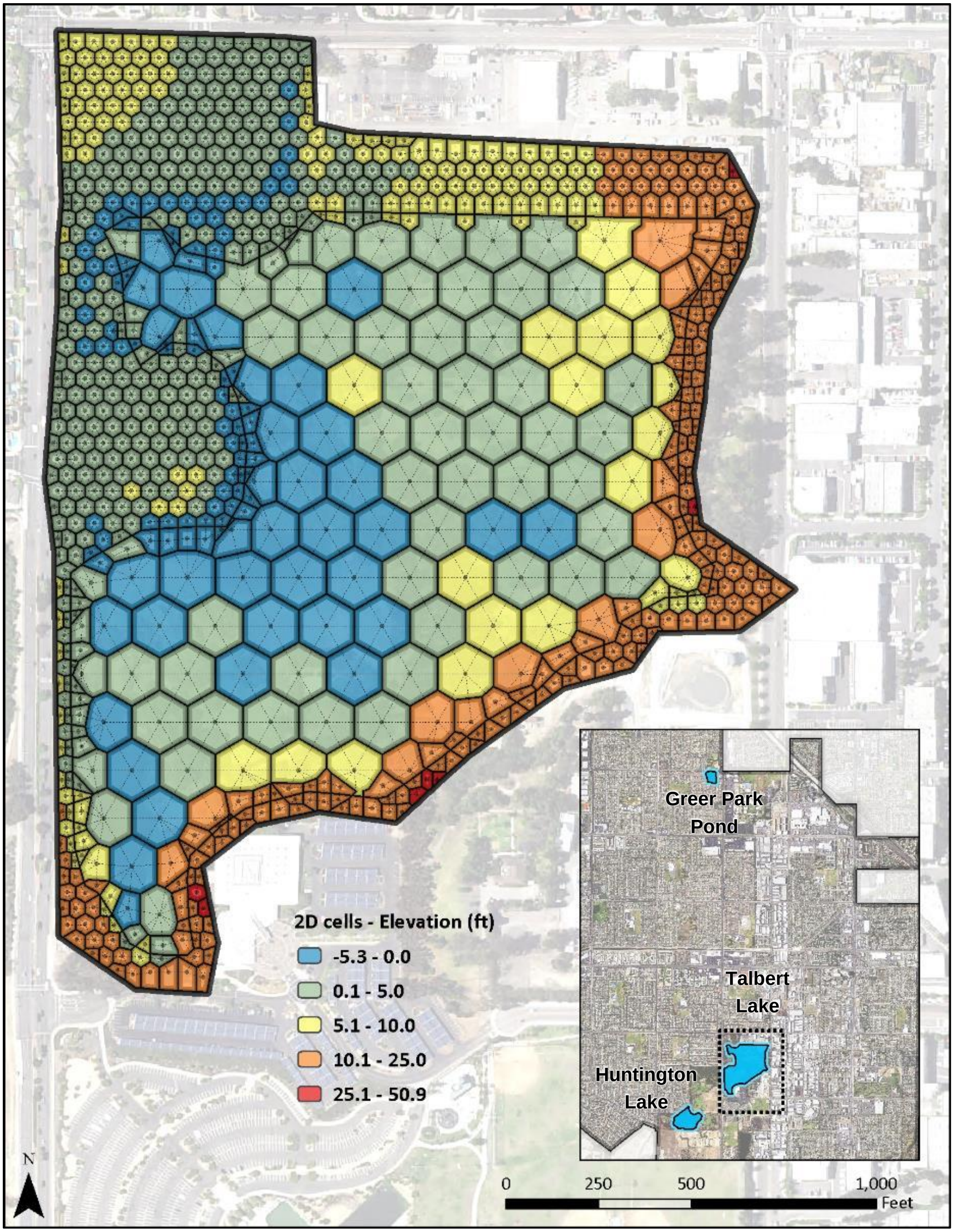


Figure 3-9. Location of the three 1D-2D mesh locations across the (lower inset). Plan view of Talbert lake (center).

3.2.5 Hydraulic Boundary Conditions

The purpose of this MPD is to assess the capacity of existing City-owned infrastructure and propose improvements where deficiencies were found. Boundary conditions were therefore needed to represent non-City owned channels, pump stations, and the ocean. Boundaries were modeled as outfalls, which are terminal nodes of the drainage system. At these points, capacity of non-City owned channels and the ocean were assumed to have sufficient capacity for incoming flows.

City-owned pump stations also served as a boundary condition to upstream infrastructure (see Figure 2-4). The City provided the capacity of the fifteen City pumps and flow rates were assumed consistent for the duration of the model runtime. Four City-owned channels were not modeled as boundary conditions; rather they were explicitly modeled using as-built geometries to assess freeboard during the different precipitation events. These channels at their terminus flowed into County channels or the ocean and were modeled with outfalls (boundary condition) at those confluence points. Limitations to the assumptions made for boundary conditions are detailed in Section 9.1.

3.3 PERFORMANCE CRITERIA

Based on the 2005 MPD and Orange County Flood manuals, modeling performance criteria were established to assess existing City infrastructure. When the defined criteria were not being met by City infrastructure in the existing condition, proposed improvements to the system were made (e.g., conduit upsizing) until the criteria were met.

3.3.1 Maximum Street Flow Depth – 10-year Criteria

For roadways in the City ROW, the volume corresponding to the 10-year, 24-hour event is required to be contained below top of curb. To successfully model street flow, PCSWMM's street flow capability was employed. Curb height was assigned based on road type (Section 3.2) for each section of street flow conveyance (Figure 3-10). Simulation results from PCSWMM contain water surface elevations along each of the conduits on the street flow system allowing for the 10-year flood criteria to be assessed.

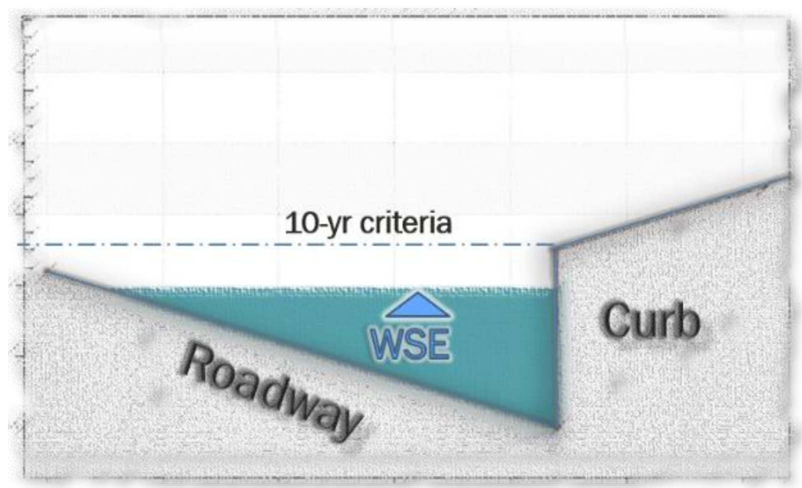


Figure 3-10. Conceptual cross-section of street flow conduit illustrating 10-yr, 24-hour storm criteria

3.3.2 Maximum Street Flow Depth – 100-Year Criteria

The same process developed for the 10-year maximum street flow depth is applied for the 100-year depth; however, the depth was defined as 1 foot behind the back-of-walk, and the volume that can occupy this space is correspondingly larger (Figure 3-11).

Figure 3-11. Conceptual cross-section of street flow conduit illustrating 100-yr, 24-hours storm criteria

3.3.3 Total Street Flow at Arterial Intersections – 100-year Criteria

Assessing total street flow at arterial intersections utilized two general assumptions:

- 'Arterial' intersections were defined as roads where major, primary or secondary arterial highways intersected.
- Width of the required traveling lane in both directions (26 ft) to be free and clear of ponded stormwater during a 100-year event

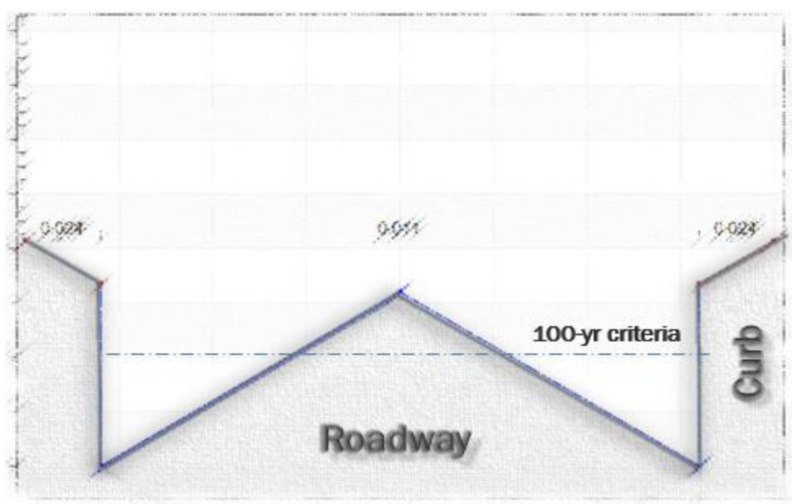


Figure 3-12. Conceptual cross-section of street flow intersection conduit illustrating 100-yr, 24-hour storm criteria

The process for determining height of street flow at the specified intersections relied on the same basic methodology described for maximum street flow depth, including the use of the cross-section of each roadway section in the intersection and their corresponding dimensions (e.g., curb height).

3.3.4 Freeboard, City Channels

Criteria for leveed and non-leveed City channels are applied differently for various design storm intensities (Table 3-8), and shown conceptually in Figure 3-13.

Figure 3-13. Conceptual cross-section of a City trapezoidal channel illustrating 100-yr, 24-hour criteria

Table 3-8. Freeboard criteria for leveed and non-leveed City channels

City Channel Freeboard	(leveed)	10-yr. event – 0.5 ft 100-yr. event – 1.5 ft
	(non-leveed)	10-yr event[a] – 1.0ft 10-yr event[b] – 1.5ft 100 yr. event – 1.5 ft

[a] *drainage area < 500 acres.*
[b] *drainage area 500-4000 acres.*

4.0 EXISTING CONDITION MODEL RESULTS

The existing condition model incorporated the City-provided storm drain network, as well as adjustments and additions made to capture surface/street flows and storage capacities. Model results were compiled for the 24-hour, 10- and 100-year storm events with an 85% confidence interval (see Section 2.1). The volume of runoff and peak flows generated during these two storms in PCSWMM quantify the level of service the City's existing infrastructure can provide. Additionally, the existing model assessment highlights potential deficiencies throughout the City. Performance criteria used in the existing model assessment were street flooding, intersection flooding, channel freeboard, and detention facility capacity (see Section 3.2.5).

4.1 STREET FLOODING

City storm points within the ROW were assigned a road type based on the edge of pavement layer provided by the City (see Section 3.2). Based on road type, the allowed depth of flooding at each node was applied. For the 10-year, 24-hour design storm, the WSE could reach—but not overtop—the curb height; model results suggest that approximately 1.4% of the existing nodes do not meet this criteria (Table 4-1).

For the 100-year precipitation event, the WSE must remain below one foot behind the back-of-walk. This depth was variable based on the road type and calculated to be between 7.7 inches and 10.2 inches in height. Model results suggest that approximately 8.7% of the existing nodes do not meet the maximum street flow depth criteria for the 100-yr event (Table 4-1).

Arterial roads serve as major thoroughfares for City traffic, necessitating criteria that maintains a non-inundated driving-lane in each direction at intersections. Modeling suggests that approximately 7% of the existing nodes at arterial intersections do not meeting the criteria for street flow at arterial intersections during the 100-year, 24-hour event (Table 4-1).

The location and magnitude of street flooding within the City can indicate regions where broader systemic inadequacies or undersized stormwater infrastructure exists. See Appendix C for detailed exhibits illustrating the modeled location and magnitude of modeled street flooding for the 100-year, 24-hour storm in conjunction reported/observed flooding data received from the City.

Table 4-1. Street flooding results predicted for the existing condition

Maximum street flow depth, 10-yr	Nodes (Count)	Nodes (%)
WSE Above Curb Height	228	1%
Maximum street flow depth, 100-yr		
WSE Above 1-foot Behind Back-of-walk	1,452	9%
Maximum arterial intersection depth, 100-yr		
WSE Below Driving Lane in Each Direction	33	7%[a]

[a] *Percent of total arterial intersection nodes, approximately 500 nodes representing 100 arterial intersections in total*

4.2 CHANNEL FREEBOARD

Based on the County Flood Manuals referenced in Section 1.3, the City channels were assessed based on the available freeboard at peak flows of the 10- and 100- year, 24-hour storm events. For the 10-year, 24-hour storm, the allowed freeboard varied from 0.5-1.0 feet based on the drainage area and presence of levies at the channel (see Table 1-1). For the 10-year storm, modeling suggested that all channels met this freeboard requirement, not including the section of Slater Channel directly north of Shipley Nature Center (see discussion in Appendix A). For the 100-year precipitation event, modeling suggested that major sections along Murdy and Slater Channel did not meet the criteria (had freeboards within 1.5-ft during the peak flow of the storm) which account for 47% of the total modeled length of City channels. Table 4-2 summarizes the extent of City channels expected not to meet the freeboard criteria for both storm events.

Table 4-2. Predicted channel freeboard results for the existing condition

Storm Event: 10-yr, 24-hr	Channels (Count)	Channels (Miles)	Channels (%[a])
Freeboard < 0.5-1 foot	0	0	0
Storm Event: 100-yr, 24-hr			
Freeboard < 1.5-ft	2	2.4	47%

[a] *Percent of total City channel length (4.9 mi)*

4.3 DETENTION FACILITIES

Modeled detention facilities were assessed for their capacity to contain runoff from the 10- and 100-year, 24-hour storm events. The extent of additional required detention storage was simulated in the model by calculating the volume of stormwater in excess of the available total storage volume, meaning the volume of overflow experienced at each node was reported in model output (Table 4-3).

Table 4-3. Detention facility results for the existing condition

Storage Name	Ownership	Estimated Storage Volume (ac-ft)	Estimated 100-yr Storm Volume (ac-ft, % utilized)
Good Shepard Cemetery	Private	3.28	6.93, 211%
Meadowlark Golf Course	Public	0.99	3.35, 337%
Oceanview High School	Public	1.96	3.31, 169%
Seacliff Golf Course – 1	Private	0.22	2.77, 1283%
Seacliff Golf Course – 2	Private	4.16	7.42, 178%
Seacliff Golf Course – 3	Private	1.10	1.1, 100%
South Central Park	Public	1.43	1.43, 100%
Carr Park	Public	11.48	0.46, 4%
John Baca Park	Public	4.26	3.5, 82%
Sully Miller Lake	Public	434.9	138.35, 32%
Huntington Lake	Public	34.02	58.85, 173%
Talbert Lake	Public	95.55	66.14, 69%
Greer Park Pond	Public	1.42	14.04, 798%
Shipley Nature Center	Public	19.87	13.64, 69%
Slater Parkside Estates	Private	10.29	6.02, 58%

4.4 PUMP STATIONS

City-owned pump stations were modeled as being able to convey stormwater at their maximum operating capacity as indicated in data received from the City. Pump stations were assumed to be static in their operating capacity and were not recommended for upsizing. A separate modeling analysis was completed to predict the variance between the assumed static maximum operating capacity and the modeled 100-year peak flow to the pump station. This separate simulation modeled City pumps with an unrestricted flow rate, meaning *all* flow to the pumps were immediately conveyed to their outfall. Results from both conditions compare the unrestricted peak flows to the assumed operating capacity (Table 4-4). For eight of the pumps, the unrestricted flow surpassed each of the pump capacities.

Table 4-4. Existing condition pump capacity and maximum modeled capacity

Pump Name	Pump Operating Capacity (cfs)	Unrestricted Modeled Capacity (cfs)	Pump Utilization (%)[a]
Scenario Pump	142	109	77%
Marilyn Pump	131	141	108%
Shields Pump	375	375	100%
Slater Pump	904	1381	153%
Bolsa Chica Pump	243	288	119%
Flounder Pump	280	283	101%
Adams Pump	401	534	133%
Meredith Pump	238	230	97%
Indianapolis Pump	379	566	149%
Atlanta Pump	600	787	131%
Hamilton Pump	441	441	100%
Newland Pump	596	796	134%
Banning Pump	412	412	100%
Yorktown Pump	229	229	100%
Heil Pump	179	125	70%

[a] *Maximum modeled capacity divided by pump operating capacity*

5.0 PROPOSED CONDITION MODEL METHODOLOGY

Following the assessment of the City's storm drain infrastructure for the existing condition, a process was developed to systematically audit individual City assets and propose upgrades and additions to the network. The performance criteria for the 100-year, 24-hour storm event was used to determine if the intended level of service was being met and where upgrades and network additions were required. After rightsizing the network for the 100-year criteria, the 10-year event was simulated to discern performance for this storm as well (but not to propose upsizing).

5.1 PROPOSED IMPROVEMENT TYPES

The following section provides the suite of solutions proposed to mitigate flooding and improve the City stormwater conveyance system to meet requisite levels of service. Solutions were focused on upsizing existing infrastructure, including pipes, inlets and detention facilities, and the addition of new conveyance/inlets where existing inlets/conveyance were overwhelmed.

5.1.1 Pipe Infrastructure Improvements

In locations where modeled upstream flooding indicated a larger diameter conduit or a new length of pipe is the appropriate solution, a catalog of standard sizes from the County Local Drainage Manual was applied (18 to 69 inches in increments of 3 inches, and 72 to 104 inches in increments of 6 inches).
Note that where pipe infrastructure improvements are identified as necessary to mitigate flooding, a survey or field assessment is recommended to verify existing pipe diameters if that data was unknown or unavailable in the data provided.

5.1.2 Inlet Improvements

In areas where an inlet is undersized and stormwater is unable to sufficiently enter the storm drain network, a larger inlet or an additional inlet upstream was proposed to alleviate the overwhelmed infrastructure. In all cases, the proposed inlet type was a combination grate and curb opening inlet because it has the greatest inflow capacity. In cases where existing inlet capacity was determined to be insufficient, a field survey should be completed to verify whether the modeled configuration is appropriate (e.g., where existing data were not provided in the GIS or as-builts).

Table 5-1. Maximum flow rates through various combination inlet lengths and sump/grade conditions

Inlet Length (ft)	Max Flow in sump (cfs)	Max Flow on grade (cfs)
3.5	45.6	6.6
7	57.4	9.4
14	81.0	15.1
21	104.5	20.7

5.1.3 Surface Detention Storage

Public and open space recreational parcels were identified as opportunities for surface detention of stormwater using the Orange County parcel GIS dataset. The 2015 Zoning Map from the City's Information Services Department was consulted to identify which of these parcels were public property or general open space (Huntington Beach, 2015).

Available detention storage footprint areas were determined using an automated GIS analysis. Open, primarily vegetated surfaces were identified using a NDVI, which uses spectral information (the ratio of values in the red and infrared bands of aerial imagery) to classify areas of vegetation growth. These areas were then further limited by eliminating portions of open space on steep slopes (elevation gradients > 10%) due to structural concerns. Remaining vegetated surfaces that have an area greater than 2,500 square feet were then manually inspected to validate the identification process. There were 95 opportunities identified as potentially feasible for detention storage using this criterion (Figure 5-1). See Appendix E for costs calculated to develop each opportunity.

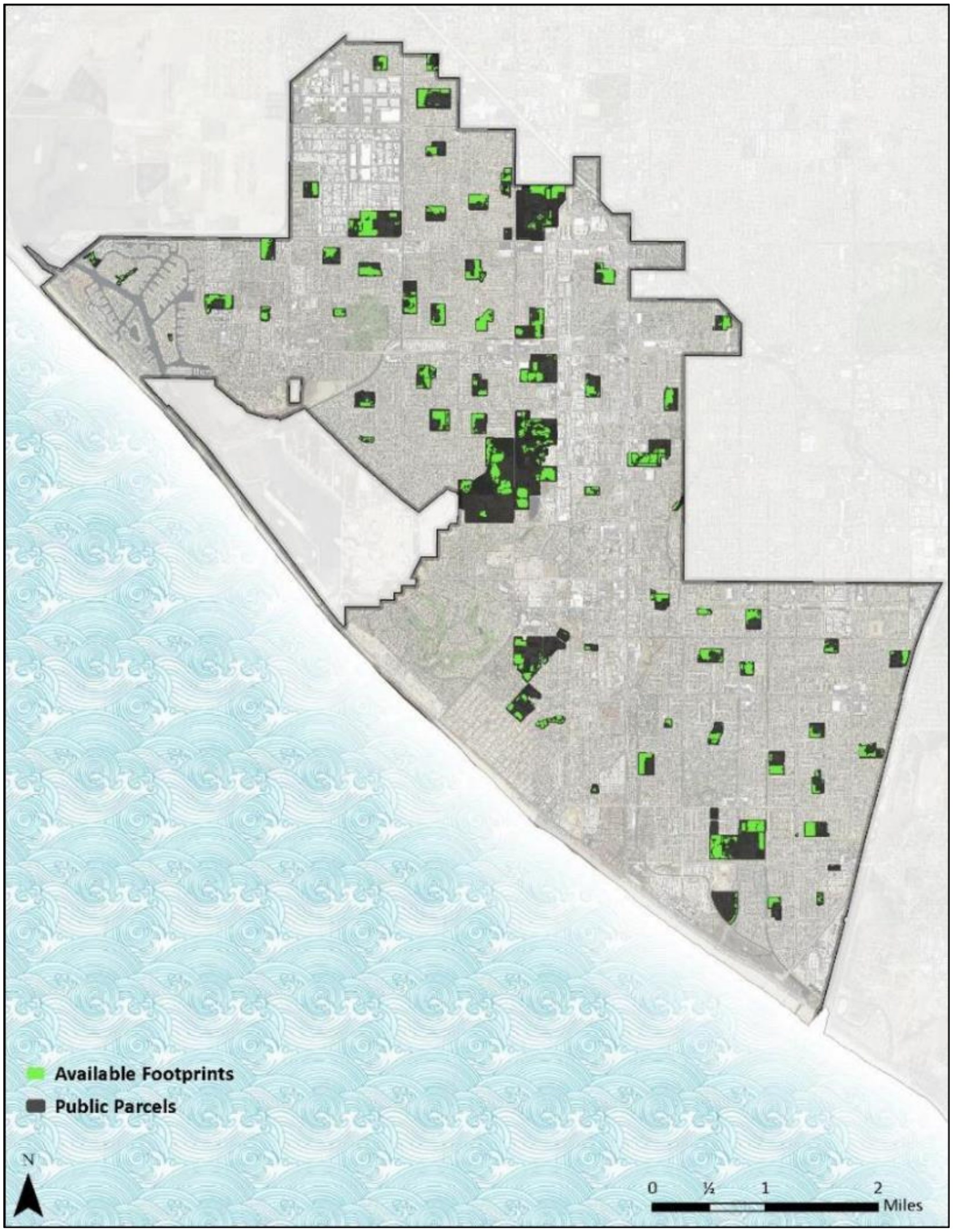


Figure 5-1. Location of potential public parcels for surface detention from the County GIS database

5.2 PROPOSED IMPROVEMENT METHODOLOGY

Deficiencies in the existing condition can be attributed to multiple and at times overlapping insufficiencies in the storm drain network. To determine which infrastructure improvements (e.g., inlet upsizing, pipe upsizing, etc.) should be proposed, a solution structure was created to discern the various combinations of stormwater infrastructure deficiencies. Note that pump capacities were assumed to be maximized and further capacity was not evaluated as part of this assessment. The following subsections contain the ordered stepwise approach employed to assess and propose upgrades to the existing condition for the 100-yr, 24-hour storm event. An example of how conduits were upsized to meet the 100-yr performance criteria is shown in Figure 5-2.

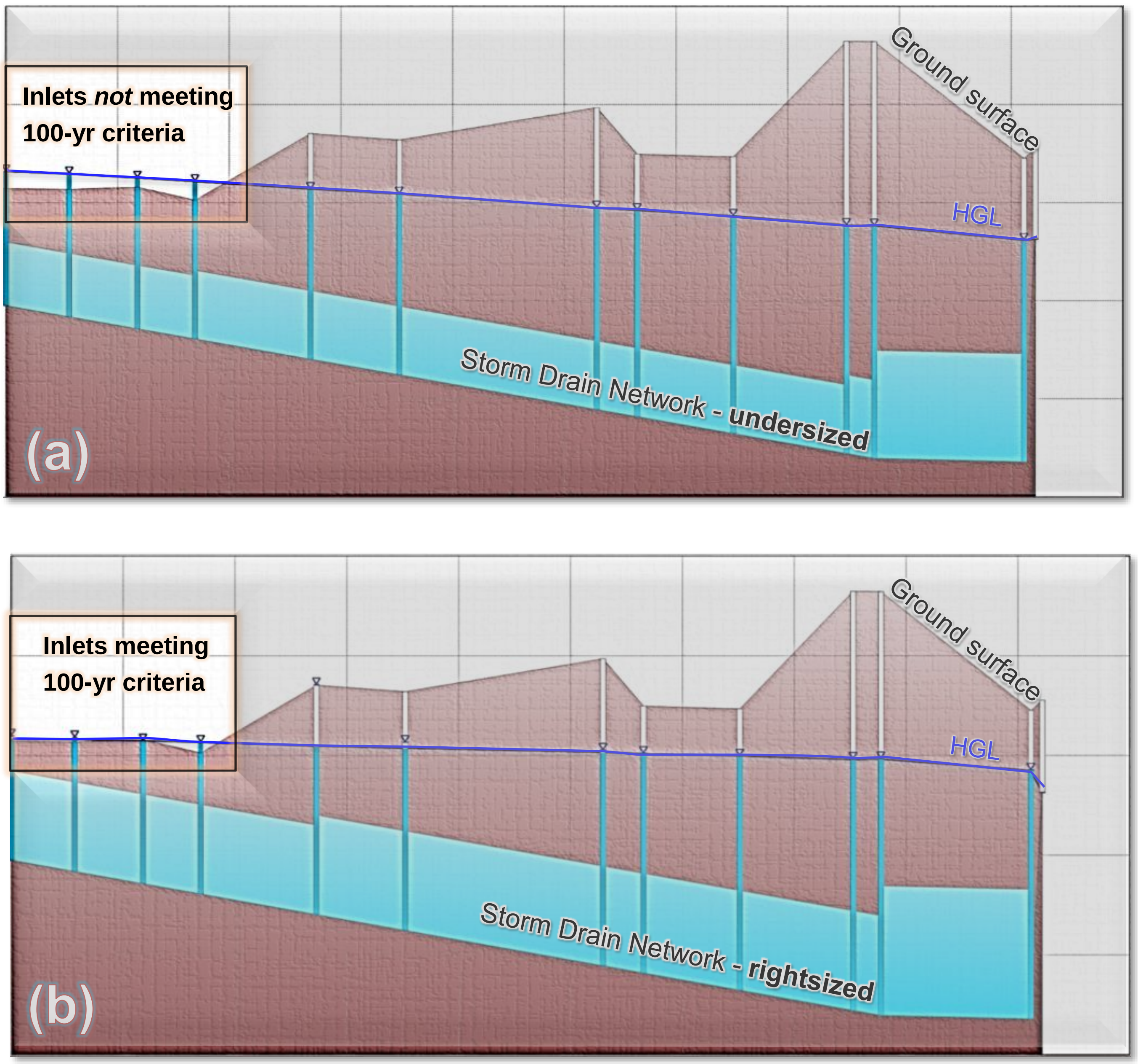


Figure 5-2. Existing Condition with inlets exceeding 100-yr performance criteria (a). Proposed Condition with inlets meeting 100-yr performance criteria (b).

5.2.1 Inlet Enhancements

In instances where modeled runoff exceeded the existing inlet configuration capacity (see Section 3.2.1.1, Nodes) an increase in inlet size was proposed. When upsizing an inlet was unable to mitigate stormwater flooding conditions to meet the 100-year performance criteria, new infrastructure (inlets and conduits) were proposed upstream to alleviate the flooded inlet. This solution would allow stormwater to enter the storm drain network at an upstream location, subsequently subdividing the drainage area and peak flows that were previously all being conveyed to a singular location. In these instances, the number of additional inlets and pipes were varied until all inlets met the 100-year performance criteria.

5.2.2 Pipe Improvements

Once inlets to the storm drain network were rightsized, the capacity of existing City conduits could be assessed. When a City conduit was undersized and caused flooding upstream such that the 100-year performance criteria could not be met, a larger pipe size was proposed. Pipes were increased by increments of 0.5-feet until the upstream flooding conditions were mitigated or the pipe was 8' in diameter (assumed maximum implementable diameter).

5.2.3 Detention Storage Expansions

The fifteen existing detention storage facilities within the City were modeled with their existing calculated capacity. If overflow from a detention storage caused flooding upstream such that flood performance criteria could not be met, the facility was proposed for upsizing. The volume proposed for upsizing was the excess volume of stormwater overflowing the facility.

5.2.4 Distributed Storage Improvements

Topographical constraints, undersized pumps, and high-water hydraulic grade line (HGL) levels in channels created conditions where upsizing pipes, inlets, and existing detention storage was insufficient to alleviate all flooding. Additional storage was proposed at nodes where these conditions led to flooding upstream such that the 100-year performance criteria could not be met. For nodes where additional storage is recommended, the volume of the flooded stormwater was tabulated and proposed as distributed storage. These small storage volumes could be implemented locally in the form of subsurface detention vaults or surface detention basins, or could potentially be combined into a larger regional detention storage in order to alleviate the need for several distributed storage nodes.

6.0 PROPOSED MODEL RESULTS

The stepwise methodology for increasing capacity in the storm drain network was executed and the proposed storm drain system recommendations were simulated to demonstrate how flood control levels of service could potentially be met across the City. This section summarizes the improvements recommended for City conduits, inlets, and storages. Costs shown for each proposed improvement include material, construction, and mark-up (40%) and detailed in Section 7.0.

Improvement Type	Quantity of Improvement	Total Cost[a] ($)
New Inlet	266	$3,010,000
New Conduit	272	$46,855,000
New Distributed Detention	258	$5,314,000
Upsized Conduit	1,263	$183,143,000
Upsized Inlet	1,087	$5,334,000 - $13,087,000 [b]
Upsized Regional Detention	5	$4,149,000[c]
Total	**3,150**	**$247,805,000 - $255,558,000**

[a] *Construction, unit, and mark-up*
[b] *Varies if inlet is on slope or in sump*
[c] *On public parcels only*

6.1 INLET CAPACITY

Flow into inlets is dependent on the depth of water at the inlet, inlet type and size (see Section 5.1.2). Due to the uncertainty in the condition of inlets (i.e., in sump versus on grade), maximum flow into each was modeled and an appropriately sized curb opening was identified for *both* in sump and on slope conditions. The appropriate proposed configuration can be identified when the actual conditions at each inlet (sump/slope and length) are field verified. Upsizing and new inlets was recommended for 266 and 1,087 nodes, respectively (Table 6-1). See Appendix D for detailed exhibits for where inlet improvements were proposed.

Table 6-1. Inlet improvements for the proposed condition (100-yr storm)

Proposed Upgrade	Nodes (Count)	Nodes (%)	Cost[a] ($)
Upsized Inlet	1,087	10.1%	$5,334,000 - $13,087,000
New Inlet	266	2.5%	$3,010,000
Total	**1,353**		**$8,344,000 - $16,097,000**

[a] *Varies if inlet is on slope or in sump*

6.2 CONDUIT CAPACITY

To improve conveyance capacity throughout the City, City-owned conduits were systematically upsized in increments of 0.5 feet up to a maximum of 8 feet to meet the 100-yr performance criteria at upstream locations. Throughout the City, 36% of the 120 miles of City conduits were upsized to meet the demands of the 100-year storm runoff flows and volumes. Conduit improvements focused on retrofitting major trunk lines in the system to target key areas restricting flow.

Additionally, new storm lines were added to the City infrastructure to connect new inlets to the existing storm drain network. A total of 19 miles of new conduits were proposed and sized to provide additional capacity to the system in large drainage areas without infrastructure. In total, 62 miles of City conduits were improved or added to allow conveyance of the 100-year storm event. See Appendix D for detailed exhibits for where conduit improvements were proposed, and Appendix E for a detailed table of model results, and proposed improvement for each conduit.

Table 6-2. Storm conduit improvements for the proposed condition (100-yr storm)

Proposed Upgrade	Conduit (Count)	Conduit (Miles)	Conduit (%[a])	Cost ($)
Upsized Conduits	1,263	43	36%	$183,143,000
New Conduits	272	19	16%	$46,855,000
Total	**1,534**	**63**	**-**	**$229,998,000**

[a] *Percent of total city existing conduit length*

6.3 DETENTION FACILITIES

Fifteen regional storages were modeled to assess whether the current storage volume was sufficient or if capacity improvements are needed. Although both private and public storages were modeled, only public facilities were costed and recommended for improvements. Of the 10 public storages, five were proposed to be upsized for flooding associated with the 100-year event. Table 6-3 presents the existing and proposed capacities at each of the regional detention facilities. See Appendix D for detailed of exhibits of proposed improvements for regional detention, and Appendix E for a detailed table of model results, and proposed improvement for each regional storage.

Table 6-3. Detention storage improvements and cost for the proposed condition (100-yr storm)

Storage Facility	Existing Capacity (ac-ft)	Additional Capacity (ac-ft)	Cost ($)[a]
Good Shepard Cemetery	3.28	3.7	
Meadowlark Golf Course	0.99	2.4	$240,000
Oceanview High School	1.96	1.3	$137,000
Seacliff Golf Course – 1	0.22	2.6	
Seacliff Golf Course – 2	4.16	3.3	
Seacliff Golf Course – 3	1.10		
South Central Park	1.43		
Carr Park	11.48		
John Baca Park	4.26		
Sully Miller Lake	434.9		
Huntington Lake	34.02	24.8	$2,524,000
Talbert Lake	95.55		
Greer Park Pond	1.76	12.3	$1,248,000
Shipley Nature Center	19.86		
Slater Parkside Estates	10.29	3.7	
Total	**625.3**	**50.3**	**$4,149,000**

[a] *Costs only for upsized storage on public parcels*

6.4 DISTRIBUTED STORAGE

After upsizing and adding infrastructure throughout the City, nearly all street and intersection nodes were predicted to meet the 100-yr performance criteria, as well as the 10-year performance criteria. When upsizing was unable to improve flood conditions, distributed detention facilities were proposed at flooded nodes. The volume of flooded stormwater at each node was the volume proposed as storage. Table 6-4 shows the quantity of nodes which new detention storage was proposed, the total storage volume, and costs. See Appendix D for detailed of exhibits of proposed improvements for distributed storage, and Appendix E for a detailed table of model results and proposed improvement for each distributed storage.

Table 6-4. Summary of proposed distributed detention facilities (100-yr storm)

	Nodes (Count)	Nodes (%)	Volume (ac-ft)	Cost ($)
Maximum street flow depth, 100-yr	258	2.40%	7.47	$5,314,000

6.5 PUMP STATIONS

The proposed condition was modeled with the existing City pump capacities. Section 4.4 provides the maximum modeled pump capacity, which is sized to handle the 100-year storm flows currently routed to each pump; however, these increased capacities were not modeled as a solution to the proposed condition due to footprint restrictions at existing City-owned pumps. Due to this restriction, numerous subwatersheds required extensive pipe and inlet improvements to compensate and allow for flood control levels of service to be met.

7.0 INFRASTRUCTURE COSTS

Infrastructure costs for proposed upgrades include material, construction, and mark-up. Cost estimates were developed for each improvement type utilizing values from a number of sources including; RS Means, similar projects within LAC, and other Watershed Master Plans in Southern California. Additionally, City cost data from previous MPD reports was referenced to verify values found through other sources. Specific costing for storm points, conduit, and detention facilities unit and construction costs are detailed below. Lastly, the following subsection indicates how mark-up costs are applied to calculate total costs.

7.1 STORM POINT STRUCTURES

Storm point structure improvements include the addition of new inlets, new manholes, and upsizing existing inlets. The equation for each improvement incorporates costing of the unit itself, and related construction components (sidewalk/asphalt removal, excavation, backfill), and unit removal when applicable:

$$Upsized\ Inlet\ Cost\ (\$) = Inlet\ Unit\ Cost + Construction\ Costs$$
$$New\ Inlet\ Cost\ (\$) = Inlet\ Unit\ Cost + Construction\ Costs$$
$$New\ Manhole\ Cost\ (\$) = Manhole\ Unit\ Cost + Construction\ Costs$$

Standard curb opening sizes from the Orange County Flood Control Design Manual (3.5, 7, 14 and 21 feet in length) were proposed and assumed to have an equal unit and construction cost, $12,000. This value is an aggregate derived from Southern California construction bids for material and install costs for various inlet configurations garnered by Tetra Tech. Additionally, a standard 5-foot diameter manhole was assumed every 400 feet of proposed new conduit ($5,000; unit and construction cost).

7.2 STORM DRAIN CONDUITS

Improvements to storm drain conduits included the replacement of undersized existing pipes and culverts, and the addition of new storm drain conduits. The equation for each improvement incorporates linear costing of the conduit, construction related components (sawcut removal & replacement of existing asphalt, excavation, backfill), and unit removal when applicable:

$$Upsized\ Conduit\ Cost\ (\$) = Linear\ Cost * (Conduit\ length) + Construction\ Costs + Existing\ Conduit\ Removal$$
$$New\ Conduit\ Cost\ (\$) = Linear\ Cost * (Conduit\ length) + Construction\ Costs$$

Pipe improvement lengths vary throughout the City, therefore Table 7-1 and Table 7-2 display linear material cost and construction costs, respectively, according to length.

Table 7-1. Linear material costs for pipes and culverts

Diameter (inches)[a]	Material	Pipe Material Cost[b]
18	RCP	$18/LF
24	RCP	$22/LF
30	RCP	$24/LF
36	RCP	$26/LF
42	RCP	$28/LF
48	RCP	$32/LF
54	RCP	$37.5/LF
60	RCP	$45/LF
72	RCP	$60/LF
Culvert Thickness (inches)	**Material**	**Culvert Material Cost[c]**
8	Structural Concrete	$1,840/CY

[a] *For diameters > 72* inch*, see Appendix C*
[b] *Source: 2017 RS Means cost database*
[c] *Source: Caltrans Cost Data District 8, structural concrete box culvert average price*

Table 7-2. Storm drain conduit cost components

Storm Point Structure Cost Components	Size (inches)	Cost
Existing Pipe Removal	Diameter ≥ 4 and < 18	$12/LF
	Diameter = 18	$23/LF
	Diameter > 18 and ≤ 24	$29/LF
	Diameter > 24 and ≤ 42	$39/LF
	Diameter > 42	Varies[a]
Asphalt Removal and Replacement	Varies[a]	$72/CY
Excavation	Varies[a]	$45/CY
Backfill	Varies[a]	$4/CY

[a] See equations in *Appendix B*

7.3 DETENTION STORAGES

The suite of proposed solutions also included storage capacity improvements to upsize existing detention basins or construct new distributed facilities. Upsized regional storage costs incorporated only excavation of the indicated flooded volume (shown in Table 6-3). New detention storage costs also incorporated the cost of excavating the flooded volume but also assumed detention would be stored in subsurface vaults (Table 7-3). Costs were derived from similar projects within LAC and the City of San Diego.

$$\begin{aligned} &\textit{Upsized Regional Storage Cost } (\$) &&= \textit{Excavation} \\ &\textit{New Distributed Storage Cost } (\$) &&= \textit{Excavation} + \textit{Detention Structure Costs} \end{aligned}$$

Table 7-3. Surface detention storage cost assumptions

Component	Cost
Excavation	$45/CY[a]
Structural concrete precast detention structure	$270/CY

[a] *Does not include removing or abandoning existing site utilities.*

In addition to upsizing existing surface storage and new distributed subsurface detention, 95 new regional surface detention opportunities were identified (see Figure 5-1). Costing components for these opportunities is detailed in Appendix E

7.4 MARK-UP COSTS

Mark-up costs, which account for an additional percentage of the total construction and material costs, are applied uniformly to all proposed infrastructure upgrades regardless of type (Table 7-4) The summation of construction, unit and mark-up costs is the total cost.

Table 7-4. Mark-up costs for all proposed infrastructure

Item Description	Percentage of Construction and Material Cost
Mobilization	2.5%
Bonds/Payment Performance	2%
Traffic Control	2.5%
Stormwater Pollution Prevention Plan (SWPP), Water Pollution Control Program WPCP)	2.5%
Field Orders	2.5%
Contingency	28%
Total Mark-up	**40%**

8.0 SYSTEM UPGRADE PRIORITIZATION

Contained in this 2018 MPD are 2,350 upsized conduits and inlets, 538 proposed new conduits and inlets, and recommendations for increasing storage volume—all of which cost as much as an estimated $255,558,000. Because of the significant cost and duration required for implementation, a prioritization is needed to systematically identify the most cost-effective improvements. Due to the uncertainty in many key infrastructure characteristics (e.g., invert, materials, etc.), a generalized prioritization methodology is recommended: improvements with the greatest recommended net increase in size would be prioritized highest. This ranking system would consider the planning level cost estimates for individual proposed upgrades from Section 7.0 as a method to further sort projects by cost-effectiveness. This system of ranking should also incorporate the proximity to flooding complaints reported to the City which would indicate the location of and magnitude of the improvements that could help alleviate the observed flooding.

Prioritization of assets would also rely on the assumptions detailed in this document (e.g., for unknown conduit size and cross-sections, inlet sump/grade condition, etc.) which influence flow and flooding in the model and therefore the results. A detailed confirmation of the assumptions made in this MPD is recommended to further inform a prioritized implementation system.

9.0 NEXT STEPS

The 2018 MPD developed a structured process for assessing the existing condition of City stormwater infrastructure, determined performance criteria for the 100-yr design storm, and recommended a proposed set of improvements to right-size the drainage system. Although the process and recommendations described herein provide a full and robust set of solutions for the City, this section provides a catalog of recommended measures to (1) understand the strengths and limitations of the MPD process, including recommended future activities, and (2) develop a strategy for prioritizing the most consequential proposed upgrades.

9.1 STRENGTHS AND LIMITATIONS

1D-2D Modeling

The fully integrated PCSWMM 1D-2D software used in this effort is an advanced tool for urban flood modeling. The majority of the PCSWMM model used for this MPD was 1D, meaning that stormwater moved along the storm drain system in only a linear fashion—back and forth along conduits between nodes. A limited utilization of the 1D-2D modeling mesh was applied at three detention storage facilities to represent surface conditions. Ideally, the 1D-2D mesh would encompass the entire project area so that overflow at inlets could more accurately be accounted for and flooding in the streets could be more explicitly represented.

A street flow system was created to simulate curb and gutter flow; however, this system was created in the 1D model, and stormwater could only flow along the path of the conduit. In many cases this simple approach is sufficient but in others where large volumes of stormwater ponds, multiple flow pathways may exist in the hydrologic landscape (e.g., through side-yards and backyards). Additionally, the street flow network uses a ponding area at each node to allow stormwater to flood when infrastructure is at capacity. Assigning ponded area is an inherently discretionary exercise because it is impossible to determine the appropriate ponded area at all nodes in the system individually. A 1D-2D model does not use the ponded area attribute to account for flooding and routing across the land surface; instead it uses the DEM to create a fine mesh of conduits and nodes that follow the topography of the ground surface. In this approach, the entire mesh itself is the ponding area where stormwater can flow across the path of least resistance and pond in local topographically low areas.

If this level of resolution is desired, a full 1D-2D model is recommended for future assessments.

Model Validation

Calibrating and validating model results to observed gage data is a central principle to stormwater modeling. City, County, and USGS gages are useful sources for acquiring observed streamflow data; however, no records were available for the City. Although model parameters were developed appropriately, it is impossible to truly evaluate the magnitude of runoff from City's land surfaces as it collects in major pipes and channels without monitoring data to validate the configuration. This reality impresses upon the City the need for stream flow gages, not only for model calibration purposes but also as a source of observed data for how various precipitation events translate to flows in City storm drains.

Boundary Conditions

Boundary conditions in this assessment represent nodes (pumps, County channels, the ocean) where stormwater outfalls out of the modeled environment. Over the course of the 24-hr simulation they are represented as static, meaning that outfalls at oceans, for example, do not account for the height of the tide. The height of the tide, and flows from other jurisdictions upstream of County channels can force WSEs up and a backwater effect into the City network may result. For ocean tides the possibility of backwater effects is highly dependent on seasonal variations, lunar cycle, wind speed, long-term climatic trends, among others. For County channels, the possibility of backwater effect is highly dependent on the spatial variation of the precipitation event across multiple jurisdictions, and a detailed hydraulic analysis of the complexity of the channel system. City pumps were simulated as being able to convey all flow up to the value of its maximum flow rate. This simplification does not take into account the relationship between head and flow rates as it varies over the course of the storm. As a result, pump performance as simulated in this MPD is likely overestimated.

The final boundary condition is the initial WSE in detention storage facilities. Detention was simulated with the available capacity of each location as determined by the DEM. This process assumed that whichever day LiDAR was captured, the subsequent WSE was appropriate to apply to detention. Throughout the year the available capacity of the facilities will vary with storm size and length of time between storms. Because this modeling analysis simulated only one WSE at each facility it was unable to capture a range of antecedent conditions.

If this level of detail is desired, a more rigorous analysis is recommended to investigate the range of possible effects from dynamic boundary conditions.

Data Collection

Section 2.2.4 presents the received conduit and node data from the City. Although many key details (e.g., location, size, ownership, etc.) were provided for City infrastructure, many unknowns existed in the dataset. For example, 92% of conduits were missing entity type (e.g., arch pipe, elliptical pipe, channel, etc.), and 16% of conduits by length were missing sizes. A number of assumptions were required to generate a fully connected storm drain network, including those regarding cross-section and geometries (see Section 3.2.1). It is recommended that a thorough investigation of conduits be executed to further characterize unknown conveyance attributes.

Within the GIS data that was received, invert elevations were not included in the node attribute data. This absence of data required a large effort to identify main trunks of the storm drain network and identify those inverts through manual entry from as-built drawings (see Section 3.2.1) to determine inverts of nodes, and assume slopes upstream. A full reconciliation of as-builts and survey with the GIS data is recommended to more accurately characterize and represent the storm drain network.

Additionally, inlet grade condition (in sump or on slope) was not provided for any nodes. Proposed upgrades for inlets were provided for both in-sump and on-grade conditions; however, it is recommended an inlet grate condition determination be made for all inlet types (this could be completed with a DEM in geospatial desktop analysis) to enable the correct condition to be simulated and downstream effects be modeled.

Lastly, asset identifiers were provided for nearly all City-owned nodes in the received data but not for City owned conduits. It is recommended a naming convention for conduits also be developed.

9.2 IMPLEMENTATION

As noted in the section above, as much as $255,558,000 in upgrades are proposed along with a ranking system that would prioritize the projects with the greatest increase in infrastructure size. Although this approach is an effective way to arrange individual assets with the greatest need, it may not be as comprehensive as alternatives that assess flood criteria on a drainage scale basis. This approach would focus on mitigating neighborhood scale flooding more holistically where the greatest grouping of infrastructure could be rightsized to have the greatest impact. Consequently, this method for categorizing infrastructure in this manner is a highly involved activity that would require dedicated time and resources to confirm model assumptions (e.g. conduit size, cross-section, inlet sump/grade condition, etc.), and re-model the ranked projects in a grouped fashion to discern where the least amount of improvements could be implemented for the greatest benefit.

If this cost-effective structure is desired, a follow-up analysis is recommended to implement the proposed upgrades in this way.

REFERENCES

American Society of Civil Engineers (ASCE). 1992. *Design & Construction of Urban Stormwater Management Systems*. New York, NY.

City of LA. 1965. *Design Charts for Catch Basin Openings as Determined by Experimental Hydraulic Model Studies*. City of Los Angeles Bureau of Engineering. Office Standard No. 108 Storm Drain Design Division

Denver. 2016. *Urban Storm Drainage Criteria Manual: Volume 1*. Urban Drainage and Flood Control District, Denver Colorado. Accessed 9/24/2018 http://udfcd.org/volume-one

Engman, E. T. 1986. *Roughness coefficients for routing surface runoff*. Irrig. Drain. Engrg., ASCE, 112(1), 39-53.

Federal Highway Administration (FHWA). 1961. *Design Charts for Open-Channel Flow.* Hydraulic Design Series No. 3 (HDS-3). Publication No. FHWA-EPD-86-102. www.fhwa.dot.gov/engineering/hydraulics/pubs/hds3.pdf

Federal Highway Administration (FHWA). 2013. *Hydraulic Engineering Circular No. 22, Third Edition: Urban Drainage Design Manual*. Publication No. FHWA-NHI-10-009. Revised August 2013. U.S. Department of Transportation

Hunsaker & Associates. 2017. *Slater Avenue Storm Drain Water Pump Station Improvements Plans*. Irvine, CA

Huntington Beach. 2015. Zoning Designations Available at https://www.huntingtonbeachca.gov/about/maps/zoning.pdf. Accessed 10/2017

Los Angeles County (LAC). 2006. *Hydrology Manual*. Department of Public Works Water Resources Division https://dpw.lacounty.gov/wrd/Publication/engineering/2006_Hydrology_Manual/2006%20Hydrology%20Manual-Entire.pdf

Maidment, David R. 2002. Arc hydro: GIS for water resources. Redlands, Calif: ESRI Press.

National Oceanic and Atmospheric Administration (NOAA). 2014. *Precipitation-Frequency Atlas of the United States Volume 6 Version 2.3: California*. U.S. Department of Commerce, National Weather Service. http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume6.pdf

Natural Resources Conservation Service (NRCS). 2017. United States Department of Agriculture. Web Soil Survey. https://websoilsurvey.sc.egov.usda.gov/. Accessed 07/2017

Orange County. 1996. *Orange County Local Drainage Manual*. County of Orange Environmental Management Agency. Santa Ana, CA

Orange County. 2017. *OC Survey – Geospatial Data Products.* OC Survey - Geospatial & Geodetic Unit. Data available at https://earthexplorer.usgs.gov/. Accessed 7/2017

Oregon Department of Transportation (ODOT). 2014. *ODOT Hydraulics Manual.* APPENDIX A - HYDRAULIC ROUGHNESS (MANNING'S n) VALUES OF CONDUITS AND CHANNELS

Rawls, W.J., D.L. Brakensiek, and N. Miller. 1983. *Green-Ampt Infiltration Parameters from Soils Data*. Journal of Hydraulic Engineering, vol. 109, no 1:62-70.

US Environmental Protection Agency (EPA). 2016. *Storm Water Management Model Reference Manual Volume I – Hydrology (Revised)*. EPA/600/R-15/162A. Office of Research and Development Water Supply and Water Resources Division, Cincinnati, OH

Chow, Ven Te. 1959. Open Channel Hydraulics. McGraw-Hill, New York, NY

APPENDIX A ADDITIONAL MODELING DETAILS

TOPOGRAPHY PROCESSING

The DEM used to assess the City required stitching together two datasets. The primary dataset was collected by Orange County in 2011 and 2012 with a typical point spacing of approximately 0.67 meters. The LiDAR points were classified into several categories, including ground returns (signifying that LiDAR pulses struck the ground surface as opposed to buildings or trees). This dataset was used to create a 1-meter ground surface DEM, covering the grey area in Figure 1.

The Orange County LiDAR dataset did not cover the entire City. As seen in Figure A-1, the blue area represents the edges of LiDAR point cloud tiles near the shore that were not collected. The highest resolution dataset available to fill in this area was collected by the Scripps Institution of Oceanography in 2004. This dataset was collected with average point spacing of slightly greater than 1 meter, and was not classified into any categories.

The two datasets were used to generate a 1-meter first-return DEM (all surfaces, including trees and buildings).

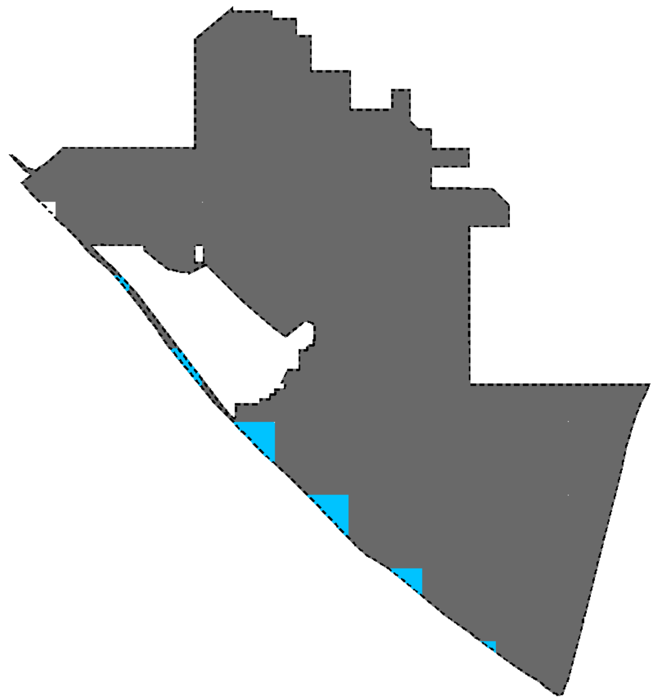


Figure A-1. Coverage of original LiDAR point cloud tiles (Grey = Orange County, Blue = Scripps)

TOPOGRAPHIC COMPARISON

Both County-provided LiDAR DEM and City-provided 1-ft contours products are sufficient for informing the necessary modeling processes; however, the LiDAR DEM dataset was preferred because it offers increased resolution over the 1-ft contours.

An analysis was performed to compare the two products and discern which has, overall, increased accuracy of the true ground surface to best inform the modeling exercise. The 1-ft contours were transformed into a raster DEM product of equal cell size in ArcMap to make this comparison one-to-one. The analysis focused on area within the City (Figure A-2, top) and selected two transects to compare the DEM and 1-ft contours (Figure A-2, middle and bottom). Although the 1-ft contours capture the general topography of the region, it is clear that it is an interpolated product, meaning at locations between the contours the data is averaged and smoothed, and not necessarily reflective of the ground surface. Conversely the LiDAR DEM has more data points in a more tightly spaced grid, enabling higher resolution of ground surface elevation. For this reason, the County DEM was selected for modeling purposes.

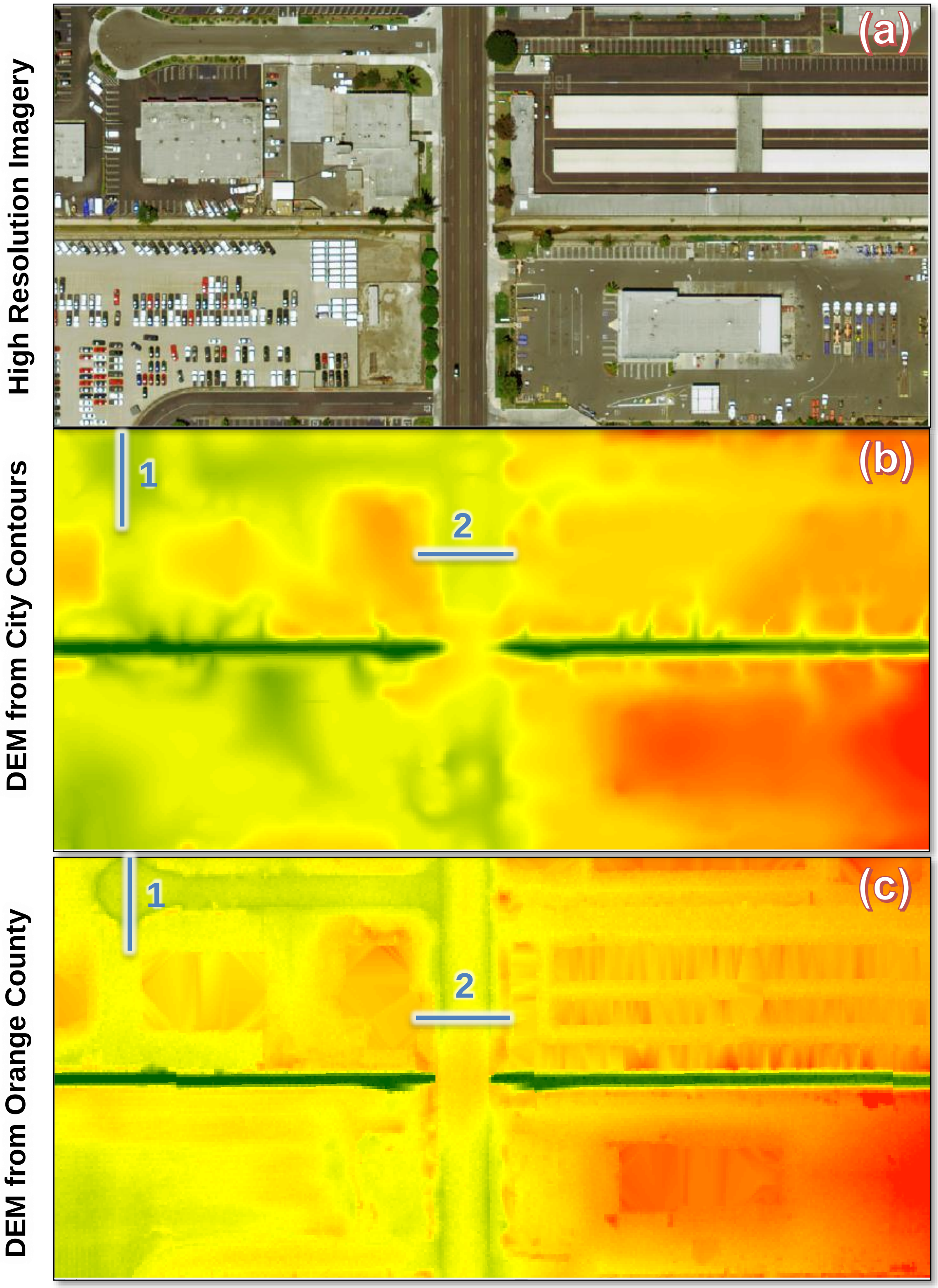
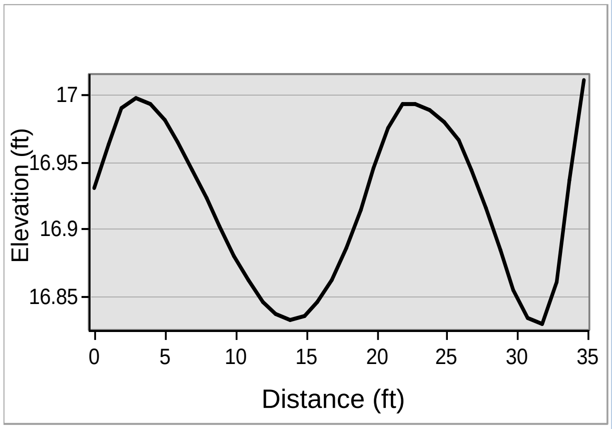
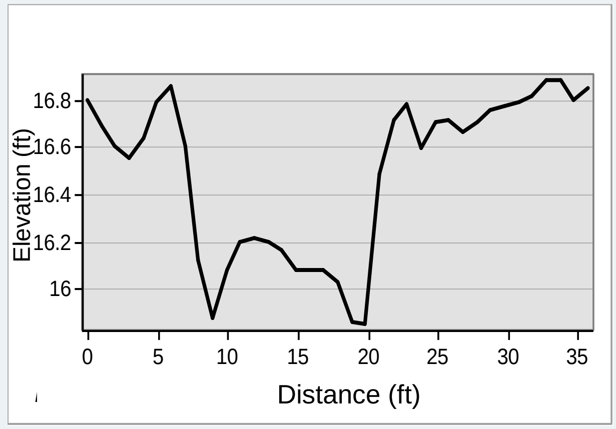
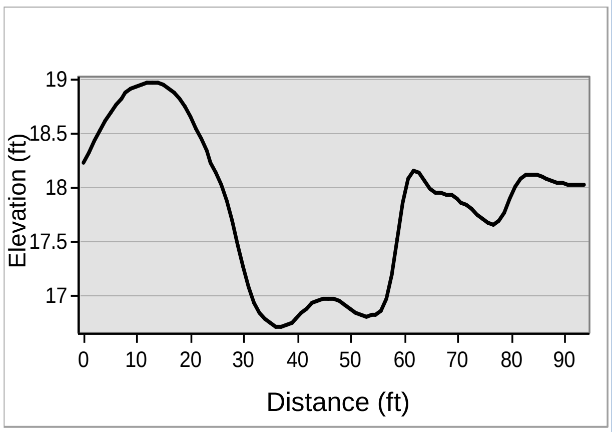
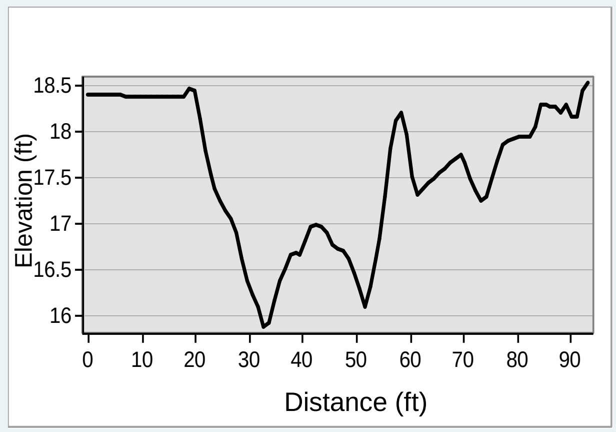


Figure A-2. Area selected for DEM comparison (a). Location of transects for comparing City contours DEM (b) and the County DEM (c)

Table A-1. Transects for the City Contours DEM and the County DEM from Figure A-2

	City Contours DEM	County DEM
Transect 1		
Transect 2		

CITY SOILS DATA

The name for each soil texture within the City is listed in Table A-2 from gathered data (NRCS, 2017), and the associated soil type which enables approximation of the suction head and hydraulic conductivity from look up tables (Rawls, et al; 1983)

Table A-2. Soil name, type across the City, and corresponding Green-Ampt parameters

Soil Name	Soil Texture	Wetting Front Suction Head (in)	Saturated Hydraulic Conductivity (in/hr)
Alo clay, 9 to 15% slopes	Clay	12.45	0.01
Alo clay, 15 to 30% slopes	Clay	12.45	0.01
Beaches	Sand	1.95	4.74

Soil Name	Soil Texture	Wetting Front Suction Head (in)	Saturated Hydraulic Conductivity (in/hr)
Bolsa silt loam	Silt Loam	6.57	0.26
Bolsa silt loam, drained	Silt Loam	6.57	0.26
Bolsa silty clay loam	Clay Loam	8.22	0.04
Bolsa silty clay loam, drained	Clay Loam	8.22	0.04
Bosanko clay, 15 to 30% slopes	Clay	12.45	0.01
Capistrano sandy loam, 2 to 9% slopes	Sandy Loam	4.33	0.43
Capistrano sandy loam, 9 to 15% slopes	Sandy Loam	4.33	0.43
Chino silty clay loam	Silty Clay Loam	10.75	0.04
Cropley clay, 2 to 9% slopes, warm MAAT, MLRA 19	Clay	12.45	0.01
Hueneme fine sandy loam	Sandy Loam	4.33	0.43
Hueneme fine sandy loam, drained	Sandy Loam	4.33	0.43
Marina loamy sand, 0 to 2% slopes	Loamy Sand	2.41	1.18
Marina loamy sand, 2 to 9% slopes	Loamy Sand	2.41	1.18
Metz loamy sand	Loamy Sand	2.41	1.18
Metz loamy sand, moderately fine substratum	Loamy Sand	2.41	1.18
Mocho loam, 0 to 2% slopes, warm MAAT, MLRA 19	Loam	3.5	0.13
Myford sandy loam, 0 to 2% slopes	Sandy Loam	4.33	0.43
Myford sandy loam, 2 to 9% slopes	Sandy Loam	4.33	0.43
Myford sandy loam, 2 to 9% slopes, eroded	Sandy Loam	4.33	0.43
Myford sandy loam, 9 to 15% slopes	Sandy Loam	4.33	0.43
Myford sandy loam, 9 to 30% slopes, eroded	Sandy Loam	4.33	0.43

Soil Name	Soil Texture	Wetting Front Suction Head (in)	Saturated Hydraulic Conductivity (in/hr)
Myford sandy loam, thick surface, 0 to 2% slopes	Sandy Loam	4.33	0.43
Myford sandy loam, thick surface, 2 to 9% slopes	Sandy Loam	4.33	0.43
Omni silt loam, drained	Silt Loam	6.57	0.26
Omni clay, drained	Clay	12.45	0.01
Pits	Sandy Loam	4.33	0.43
Riverwash	Sand	1.95	4.74
San Andreas sandy loam, 15 to 30% slopes, warm MAAT, MLRA 20	Sandy Loam	4.33	0.43
San Emigdio fine sandy loam, 0 to 2% slopes	Sandy Loam	4.33	0.43
San Emigdio fine sandy loam, moderately fine substratum, 0 to 2% slopes	Sandy Loam	4.33	0.43
Thapto-Histic Fluvaquents	Silty Clay Loam	10.75	0.04
Tidal flats	Sandy Loam	4.33	0.43
Xeralfic arents, loamy, 2 to 9% slopes	Loam	3.5	0.13

GRATE INLET FLOW RATES

Flow rates for grate inlet on grade and in sump are shown in Table A-3 and Table A-4, respectively. All values are derived from the FHWA model.

Table A-3. Flow rates (cfs) for grate only inlet types on grade

Length along Curb (ft)	Width into Road (ft)																									
	0.25	0.30	0.33	0.42	0.50	0.58	0.63	0.67	0.83	0.92	1.00	1.25	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50	2.92	3.00	3.17	3.33	3.50	4.00
0.50	0.9	1.1	1.2	1.4	1.7	2.0	2.1	2.3	2.8	3.1	3.3	4.1	4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.9	9.0	9.3	9.7	10.2	10.6	11.9
0.67	1.1	1.3	1.4	1.6	1.9	2.2	2.3	2.5	3.0	3.3	3.6	4.4	4.6	5.1	5.6	6.2	6.7	7.2	7.6	8.1	9.3	9.5	10.0	10.5	10.9	12.2
0.83	1.3	1.4	1.6	1.8	2.1	2.4	2.5	2.7	3.2	3.5	3.8	4.6	4.8	5.4	5.9	6.4	6.9	7.4	7.9	8.4	9.6	9.8	10.3	10.8	11.2	12.5
1.00	1.5	1.6	1.8	2.0	2.3	2.6	2.8	2.9	3.4	3.7	4.0	4.8	5.1	5.6	6.1	6.7	7.2	7.7	8.2	8.7	9.9	10.1	10.6	11.0	11.5	12.8
1.17	1.7	1.8	2.0	2.3	2.5	2.8	3.0	3.1	3.7	3.9	4.2	5.0	5.3	5.8	6.4	6.9	7.4	7.9	8.4	8.9	10.1	10.4	10.9	11.3	11.8	13.1
1.25	1.8	1.9	2.1	2.4	2.6	2.9	3.1	3.2	3.8	4.1	4.3	5.2	5.4	6.0	6.5	7.0	7.5	8.1	8.6	9.1	10.3	10.5	11.0	11.5	11.9	13.3
1.33	1.9	2.0	2.2	2.5	2.7	3.0	3.2	3.3	3.9	4.2	4.4	5.3	5.5	6.1	6.6	7.1	7.7	8.2	8.7	9.2	10.4	10.7	11.1	11.6	12.1	13.4
1.50	2.1	2.2	2.4	2.7	2.9	3.2	3.4	3.5	4.1	4.4	4.7	5.5	5.8	6.3	6.9	7.4	7.9	8.4	8.9	9.5	10.7	10.9	11.4	11.9	12.4	13.7
1.67	2.3	2.4	2.6	2.9	3.2	3.4	3.6	3.7	4.3	4.6	4.9	5.7	6.0	6.5	7.1	7.6	8.2	8.7	9.2	9.7	11.0	11.2	11.7	12.2	12.6	14.0
2.00	2.7	2.8	3.0	3.3	3.6	3.9	4.0	4.2	4.7	5.0	5.3	6.2	6.5	7.0	7.6	8.1	8.6	9.2	9.7	10.2	11.5	11.7	12.2	12.7	13.2	14.6
2.17	2.9	3.0	3.2	3.5	3.8	4.1	4.2	4.4	4.9	5.2	5.5	6.4	6.7	7.2	7.8	8.3	8.9	9.4	10.0	10.5	11.8	12.0	12.5	13.0	13.5	14.9
2.33	3.1	3.2	3.4	3.7	4.0	4.3	4.4	4.6	5.2	5.5	5.7	6.6	6.9	7.5	8.0	8.6	9.1	9.7	10.2	10.7	12.0	12.3	12.8	13.3	13.8	15.2
2.50	3.2	3.4	3.6	3.9	4.2	4.5	4.6	4.8	5.4	5.7	6.0	6.8	7.1	7.7	8.3	8.8	9.4	9.9	10.5	11.0	12.3	12.5	13.1	13.6	14.0	15.5
2.92	3.7	3.9	4.1	4.4	4.7	5.0	5.1	5.3	5.9	6.2	6.5	7.4	7.7	8.3	8.8	9.4	10.0	10.5	11.1	11.6	12.9	13.2	13.7	14.2	14.7	16.2
3.00	3.8	4.0	4.2	4.5	4.8	5.1	5.2	5.4	6.0	6.3	6.6	7.5	7.8	8.4	9.0	9.5	10.1	10.7	11.2	11.7	13.1	13.3	13.9	14.4	14.9	16.3
3.17	4.0	4.2	4.3	4.7	5.0	5.3	5.4	5.6	6.2	6.5	6.8	7.7	8.0	8.6	9.2	9.8	10.3	10.9	11.5	12.0	13.3	13.6	14.1	14.6	15.1	16.6
3.33	4.2	4.4	4.5	4.9	5.2	5.5	5.7	5.8	6.4	6.7	7.0	7.9	8.2	8.8	9.4	10.0	10.6	11.1	11.7	12.2	13.6	13.9	14.4	14.9	15.4	16.9
3.50	4.4	4.6	4.7	5.1	5.4	5.7	5.9	6.0	6.6	6.9	7.3	8.2	8.5	9.1	9.7	10.2	10.8	11.4	11.9	12.5	13.8	14.1	14.6	15.2	15.7	17.2
3.67	4.6	4.8	4.9	5.3	5.6	5.9	6.1	6.2	6.8	7.2	7.5	8.4	8.7	9.3	9.9	10.5	11.0	11.6	12.2	12.7	14.1	14.4	14.9	15.4	15.9	17.4
4.00	5.0	5.2	5.3	5.7	6.0	6.3	6.5	6.6	7.3	7.6	7.9	8.8	9.1	9.7	10.3	10.9	11.5	12.1	12.7	13.2	14.6	14.9	15.4	15.9	16.5	18.0
4.33	5.4	5.6	5.7	6.1	6.4	6.7	6.9	7.0	7.7	8.0	8.3	9.2	9.6	10.2	10.8	11.4	12.0	12.6	13.1	13.7	15.1	15.4	15.9	16.5	17.0	18.5
4.50	5.6	5.8	5.9	6.3	6.6	6.9	7.1	7.2	7.9	8.2	8.5	9.5	9.8	10.4	11.0	11.6	12.2	12.8	13.4	13.9	15.4	15.6	16.2	16.7	17.2	18.8
5.00	6.2	6.4	6.5	6.8	7.2	7.5	7.7	7.8	8.5	8.8	9.1	10.1	10.4	11.0	11.7	12.3	12.9	13.5	14.1	14.7	16.1	16.4	16.9	17.5	18.0	19.6
5.33	6.6	6.8	6.9	7.2	7.6	7.9	8.1	8.2	8.9	9.2	9.6	10.5	10.8	11.5	12.1	12.7	13.3	13.9	14.5	15.1	16.6	16.9	17.4	18.0	18.5	20.1
5.50	6.8	7.0	7.1	7.4	7.8	8.1	8.3	8.4	9.1	9.4	9.8	10.7	11.1	11.7	12.3	12.9	13.6	14.2	14.8	15.4	16.8	17.1	17.7	18.2	18.8	20.4
5.83	7.1	7.3	7.5	7.8	8.2	8.5	8.7	8.8	9.5	9.8	10.2	11.2	11.5	12.1	12.7	13.4	14.0	14.6	15.2	15.8	17.3	17.6	18.1	18.7	19.3	20.9
6.00	7.3	7.5	7.7	8.0	8.4	8.7	8.9	9.0	9.7	10.0	10.4	11.4	11.7	12.3	13.0	13.6	14.2	14.8	15.4	16.0	17.5	17.8	18.4	18.9	19.5	21.1
6.33	7.7	7.9	8.1	8.4	8.8	9.1	9.3	9.4	10.1	10.5	10.8	11.8	12.1	12.7	13.4	14.0	14.7	15.3	15.9	16.5	18.0	18.3	18.9	19.4	20.0	21.6
6.50	7.9	8.1	8.3	8.6	9.0	9.3	9.5	9.6	10.3	10.7	11.0	12.0	12.3	13.0	13.6	14.2	14.9	15.5	16.1	16.7	18.2	18.5	19.1	19.7	20.2	21.9
8.00	9.6	9.9	10.0	10.4	10.7	11.1	11.2	11.4	12.1	12.4	12.8	13.8	14.1	14.8	15.5	16.1	16.8	17.4	18.1	18.7	20.2	20.5	21.1	21.7	22.3	24.1
9.00	10.8	11.0	11.1	11.5	11.9	12.2	12.4	12.6	13.3	13.6	14.0	15.0	15.3	16.0	16.7	17.3	18.0	18.6	19.3	19.9	21.5	21.8	22.4	23.0	23.7	25.4
9.50	11.4	11.6	11.7	12.1	12.4	12.8	13.0	13.1	13.8	14.2	14.5	15.6	15.9	16.6	17.3	17.9	18.6	19.2	19.9	20.5	22.1	22.4	23.1	23.7	24.3	26.1
9.83	11.7	12.0	12.1	12.5	12.8	13.2	13.3	13.5	14.2	14.6	14.9	16.0	16.3	17.0	17.6	18.3	19.0	19.6	20.3	20.9	22.5	22.9	23.5	24.1	24.7	26.5
10.00	11.9	12.1	12.3	12.6	13.0	13.4	13.5	13.7	14.4	14.8	15.1	16.1	16.5	17.2	17.8	18.5	19.2	19.8	20.5	21.1	22.7	23.1	23.7	24.3	24.9	26.7
12.00	14.2	14.4	14.5	14.9	15.3	15.6	15.8	16.0	16.7	17.0	17.3	18.4	18.7	19.4	20.1	20.8	21.4	22.1	22.8	23.4	25.1	25.4	26.0	26.7	27.3	29.2
13.33	15.7	15.9	16.0	16.4	16.7	17.1	17.2	17.4	18.1	18.5	18.8	19.8	20.2	20.8	21.5	22.2	22.8	23.5	24.2	24.8	26.5	26.8	27.5	28.1	28.8	30.7
20.00	23.0	23.2	23.3	23.6	23.9	24.1	24.2	24.4	24.9	25.2	25.5	26.3	26.6	27.2	27.8	28.3	28.9	29.5	30.1	30.8	32.3	32.7	33.3	34.0	34.6	36.6
36.50	40.3	40.1	40.0	39.7	39.4	39.1	39.0	38.9	38.4	38.2	38.0	37.5	37.4	37.2	37.0	36.8	36.8	36.8	36.8	36.9	37.3	37.5	37.8	38.2	38.6	40.1

Table A-4. Flow rates (cfs) for grate only inlet types in sump

Length along Curb (ft)	Width into Road (ft)																								
	0.25	0.30	0.33	0.42	0.50	0.58	0.63	0.67	0.83	0.92	1.00	1.25	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50	2.92	3.00	3.17	3.33	3.50	4.00
0.50	1.0	1.1	1.2	1.4	1.5	1.9	2.0	2.1	2.6	2.8	3.1	3.8	4.0	4.5	5.0	5.6	6.0	6.6	7.2	7.7	9.2	9.4	10.0	10.7	11.3	11.8
0.67	1.3	1.5	1.6	1.9	2.0	2.5	2.7	2.8	3.4	3.7	4.0	4.9	5.3	5.9	6.5	7.2	8.3	8.5	9.1	9.8	11.5	11.8	12.5	13.2	13.9	15.9
0.83	1.7	1.9	2.0	2.4	2.5	3.1	3.3	3.5	4.2	4.6	5.0	6.1	6.4	7.2	7.9	8.7	10.0	10.2	11.0	11.8	13.7	14.1	14.9	15.7	16.5	18.6
1.00	2.0	2.3	2.4	2.9	3.0	3.7	4.0	4.2	5.0	5.5	5.9	7.2	7.6	8.5	9.3	10.2	11.7	11.9	12.8	13.7	15.8	16.3	17.1	18.0	18.8	21.2
1.17	2.4	2.7	2.9	3.4	3.5	4.3	4.6	4.8	5.8	6.3	6.8	8.3	8.8	9.8	10.7	11.7	13.3	13.6	14.6	15.5	17.9	18.3	19.3	20.2	21.1	23.6
1.25	2.5	2.8	3.1	3.6	3.7	4.7	4.9	5.2	6.2	6.8	7.3	8.8	9.4	10.4	11.4	12.4	14.1	14.4	15.4	16.4	18.9	19.4	20.3	21.3	22.2	24.8
1.33	2.7	3.0	3.3	3.8	4.0	5.0	5.2	5.5	6.6	7.2	7.7	9.4	9.9	11.0	12.1	13.1	14.9	15.2	16.3	17.3	19.9	20.4	21.4	22.3	23.3	26.0
1.50	3.0	3.4	3.7	4.3	4.5	5.6	5.9	6.2	7.4	8.0	8.7	10.5	11.1	12.3	13.4	14.6	16.4	16.9	18.0	19.1	21.8	22.3	23.4	24.4	25.5	28.2
1.67	3.4	3.8	4.1	4.8	5.0	6.2	6.5	6.9	8.2	8.9	9.6	11.5	12.2	13.5	14.7	16.0	17.9	18.4	19.6	20.8	23.7	24.2	25.4	26.4	27.5	30.4
2.00	4.0	4.6	4.9	5.7	5.9	7.4	7.8	8.2	9.8	10.6	11.4	13.7	14.4	15.9	17.3	18.8	20.9	21.5	22.9	24.2	27.3	28.0	29.2	30.3	31.5	34.6
2.17	4.4	4.9	5.3	6.2	6.4	8.0	8.4	8.9	10.6	11.4	12.3	14.7	15.5	17.1	18.6	20.1	22.4	23.0	24.5	25.8	29.1	29.8	31.0	32.2	33.4	36.7
2.33	4.7	5.3	5.7	6.7	6.9	8.6	9.1	9.5	11.4	12.3	13.2	15.8	16.6	18.3	19.9	21.5	23.8	24.6	26.0	27.5	30.9	31.5	32.8	34.1	35.3	38.7
2.50	5.1	5.7	6.1	7.2	7.4	9.2	9.7	10.2	12.1	13.1	14.0	16.8	17.7	19.5	21.2	22.8	25.2	26.0	27.6	29.1	32.6	33.3	34.6	35.9	37.2	40.6
2.92	5.9	6.7	7.1	8.3	8.7	10.7	11.3	11.8	14.1	15.2	16.2	19.4	20.4	22.4	24.3	26.1	28.7	29.7	31.4	33.0	36.8	37.6	39.0	40.4	41.7	45.3
3.00	6.1	6.8	7.3	8.6	8.9	11.0	11.6	12.2	14.5	15.6	16.7	19.9	20.9	22.9	24.9	26.8	29.4	30.4	32.1	33.8	37.7	38.4	39.8	41.2	42.6	46.2
3.17	6.4	7.2	7.8	9.1	9.4	11.6	12.2	12.8	15.2	16.4	17.6	20.9	22.0	24.1	26.1	28.1	30.8	31.8	33.6	35.3	39.3	40.1	41.5	42.9	44.3	48.0
3.33	6.8	7.6	8.2	9.5	9.9	12.2	12.8	13.5	16.0	17.2	18.4	21.9	23.1	25.2	27.4	29.4	32.2	33.3	35.1	36.8	40.9	41.7	43.2	44.6	46.0	49.8
3.50	7.1	8.0	8.6	10.0	10.4	12.8	13.5	14.1	16.8	18.0	19.3	22.9	24.1	26.4	28.6	30.7	33.5	34.7	36.5	38.3	42.5	43.3	44.8	46.3	47.7	51.5
3.67	7.5	8.4	9.0	10.5	10.9	13.4	14.1	14.8	17.5	18.9	20.2	24.0	25.2	27.5	29.8	32.0	34.9	36.1	38.0	39.8	44.1	44.9	46.5	48.0	49.4	53.3
4.00	8.1	9.1	9.8	11.4	12.0	14.6	15.3	16.1	19.1	20.5	21.9	26.0	27.3	29.8	32.2	34.5	43.8	38.8	40.9	42.8	47.3	48.1	49.7	51.2	52.7	67.6
4.33	8.8	9.9	10.6	12.4	12.9	15.8	16.6	17.4	20.6	22.1	23.6	28.0	29.3	32.0	34.6	37.0	40.1	41.6	43.7	45.7	50.3	51.2	52.9	54.4	55.9	60.0
4.50	9.2	10.3	11.0	12.8	13.4	16.3	17.2	18.0	21.3	22.9	24.5	29.0	30.4	33.1	35.8	38.3	41.4	42.9	45.1	47.2	51.9	52.7	54.4	56.0	57.5	61.6
5.00	10.2	11.4	12.2	14.3	14.9	18.1	19.1	20.0	23.6	25.4	27.1	31.9	33.5	36.4	39.3	42.0	45.3	47.0	49.3	51.4	56.4	57.3	59.0	60.6	62.2	66.4
5.33	10.9	12.2	13.1	15.2	15.8	19.3	20.3	21.3	25.1	27.0	28.8	33.9	35.5	38.6	41.6	44.4	47.8	49.6	52.0	54.2	59.3	60.2	62.0	63.7	65.2	69.5
5.50	11.2	12.6	13.5	15.7	16.3	19.9	20.9	21.9	25.9	27.8	29.6	34.9	36.5	39.7	42.8	45.6	49.0	50.9	53.3	55.6	60.8	61.7	63.5	65.2	66.7	71.1
5.83	11.9	13.3	14.3	16.6	17.3	21.1	22.2	23.2	27.4	29.4	31.3	36.8	38.6	41.9	45.1	48.1	51.5	53.5	56.0	58.4	63.7	64.6	66.4	68.1	69.7	74.1
6.00	12.3	13.7	14.7	17.1	17.8	21.7	22.8	23.9	28.1	30.2	32.2	37.8	39.6	43.0	46.2	49.3	52.8	54.8	57.4	59.8	65.1	66.1	67.9	69.6	71.2	75.6
6.33	12.9	14.5	15.5	18.0	18.8	22.9	24.0	25.2	29.6	31.8	33.8	39.7	41.6	45.2	48.5	51.7	55.2	57.4	60.0	62.5	67.9	68.9	70.8	72.5	74.1	78.5
6.50	13.3	14.9	15.9	18.5	19.3	23.4	24.6	25.8	30.4	32.6	34.7	40.7	42.6	46.2	49.6	52.9	56.4	58.7	61.4	63.8	69.3	70.3	72.2	73.9	75.5	80.0
8.00	16.4	18.3	19.6	22.7	23.8	28.7	30.2	31.6	37.1	39.7	42.2	49.3	51.6	55.8	59.7	63.4	67.2	70.0	73.0	75.7	81.7	82.7	84.7	86.5	88.1	92.7
9.00	18.4	20.6	22.1	25.6	26.7	32.3	33.9	35.4	41.5	44.4	47.2	55.0	57.5	62.1	66.4	70.3	74.2	77.4	80.6	83.5	89.7	90.7	92.7	94.5	96.1	100.8
9.50	19.5	21.8	23.3	27.0	28.2	34.0	35.7	37.4	43.7	46.8	49.7	57.8	60.4	65.2	69.6	73.8	77.7	81.1	84.3	87.3	93.6	94.6	96.7	98.4	100.0	104.8
9.83	20.2	22.5	24.1	27.9	29.2	35.2	36.9	38.6	45.2	48.3	51.3	59.7	62.3	67.2	71.8	76.0	80.0	83.5	86.8	89.8	96.1	97.2	99.2	101.0	102.6	107.3
10.00	20.5	22.9	24.5	28.4	29.7	35.8	37.5	39.3	45.9	49.1	52.1	60.7	63.3	68.3	72.9	77.2	81.1	84.7	88.0	91.0	97.4	98.5	100.5	102.3	103.9	108.6
12.00	24.7	27.5	29.4	34.0	35.7	42.8	44.9	46.9	54.7	58.4	62.0	71.8	74.8	80.5	85.8	90.6	94.6	98.9	102.5	105.8	112.5	113.6	115.7	117.4	119.0	123.7
13.33	27.4	30.6	32.7	37.8	39.6	47.4	49.7	52.0	60.6	64.6	68.5	79.2	82.5	88.6	94.2	99.3	103.4	108.2	112.0	115.4	122.3	123.4	125.4	127.2	128.6	133.3
20.00	41.3	46.0	49.1	56.6	59.5	70.6	73.9	77.2	89.4	95.1	100.5	115.3	119.7	127.9	135.3	141.8	145.5	152.8	157.2	161.1	168.4	169.5	171.3	172.7	173.8	177.7
36.50	75.7	84.1	89.6	102.9	107.9	127.4	133.1	138.6	159.3	168.7	177.6	201.2	208.1	220.6	231.3	240.6	223.0	254.9	260.2	264.4	270.8	271.4	272.1	272.1	271.5	272.4

DETENTION STORAGE, SHIPLEY NATURE CENTER

According to the DEM and aerial imagery, the southern levee of the section of Slater Channel north of the Shipley Nature Center is low (Figure A-3). Model simulation indicated that channel flow could overtop the southern levee and occupy the low-lying areas in the nature center as detention storage. This was discussed with the City who indicated changes (e.g., building up the levee) were not a likely path forward because of potential impact to proximal wildlife and vegetation; therefore, this condition was simulated in the existing and proposed condition. Available detention capacity for the nature center was determined as the volume of water that could fill the area before encroaching on any edifice in the nature center.

Figure A-3. Elevation of the Shipley Nature Center and Slater Channel (bottom). Street view and cross-section of the levees (top)

APPENDIX B ADDITIONAL COSTING DETAILS

STORM DRAIN CONDUITS

To estimate conduit costs for diameters greater than what was provided in RS Means (> 72 inches for install, and > 42 inches for removal) an equation that best fit the cost data was used an applied (Table B-1)

Table B-1. Cost equations for large diameter pipes

Conduit (inches)	Cost Equation
Cost of Pipe with Diameter > 72	$/LF = Diameter (ft) * 150 - 300
Cost of Removing Existing Pipe > 42	$/LF = Diameter (ft) * 1.6 + 1.9

Estimating construction costs uniformly for all with conduits required a number of assumptions that relied on professional experience on similar projects in LAC and the City of San Diego, and best professional judgement (Table B-2).

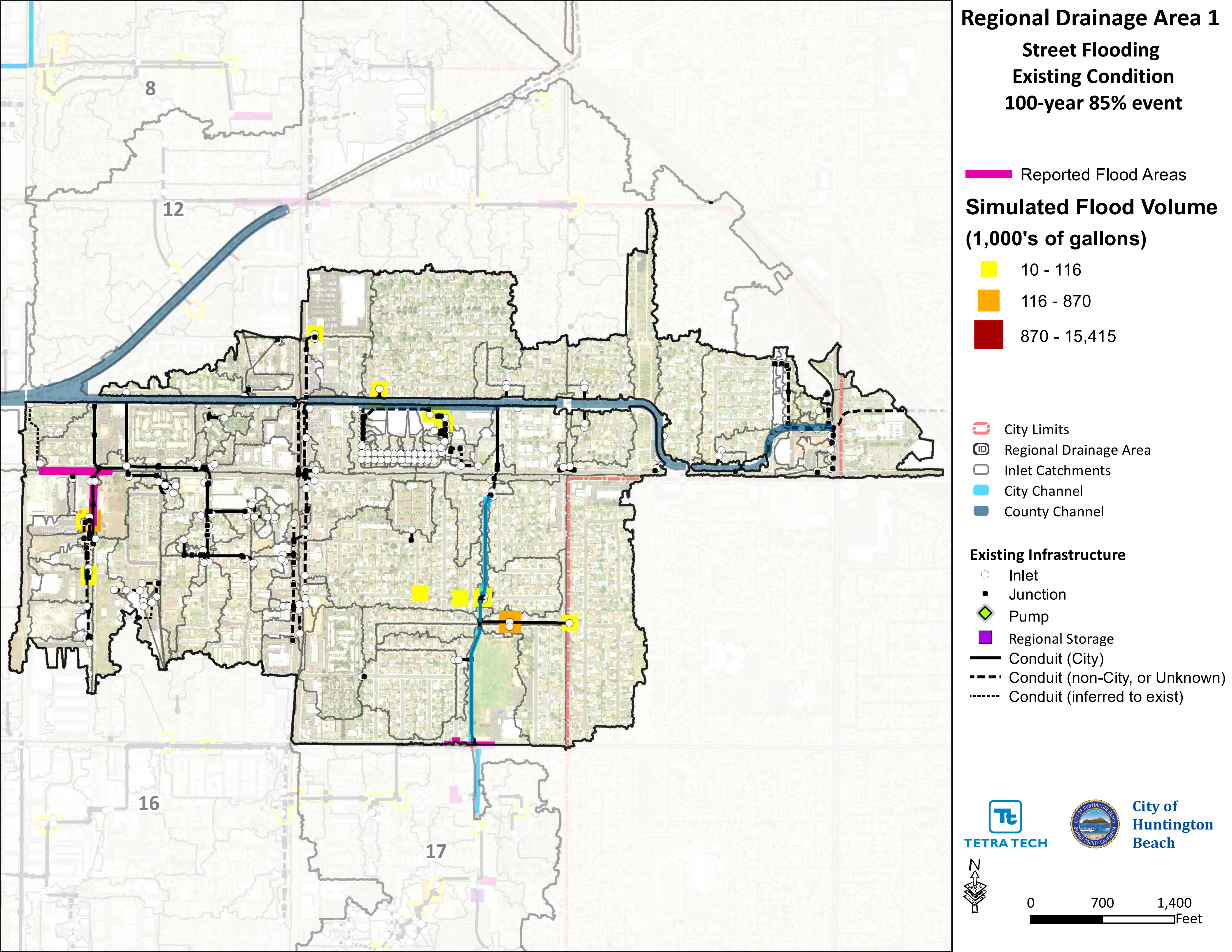
Table B-2. Construction cost assumptions for conduits

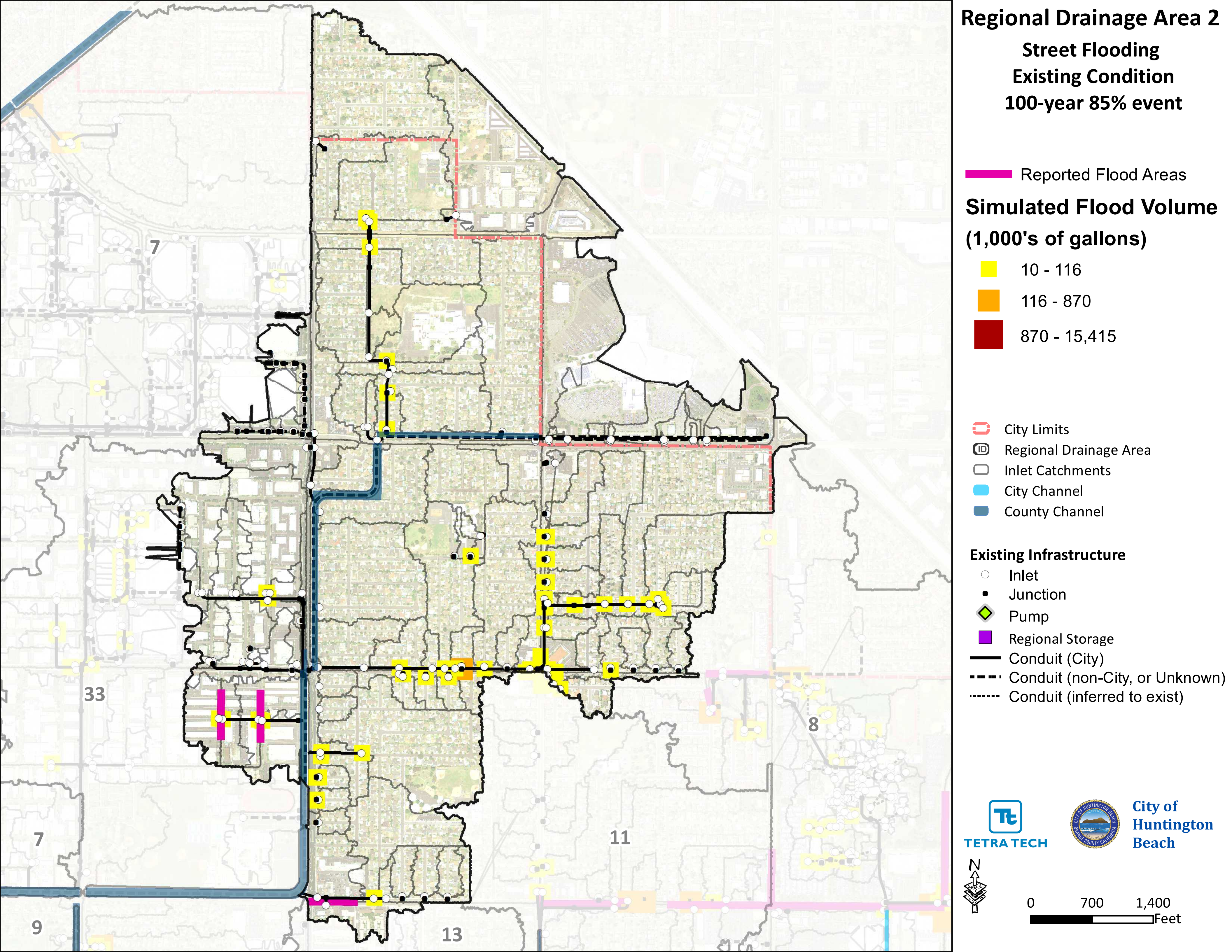
Conduit Improvement Component Values	Assumptions
Asphalt depth (ft)	0.25
Conduit depth (ft)	Depth of downstream node
Trench width for pipe diameters ≤18 inches	3’
Trench width for pipe diameters ≥19 inches and ≤42 inches	5’
Trench width for pipe diameters ≥ 43 inches and ≤47 inches	6’
Trench width for pipe diameters ≥48 inches and ≤72 inches	8’
Trench width for pipe diameters > 72 inches	10’
Asphalt Removal and Replacement	= Asphalt depth * Trench width * Conduit length
Conduit Excavation	= Trench width * Conduit length * Conduit depth
Pipe Backfill	= Trench width * Conduit length * Conduit depth - Π (Pipe diameter/2)^2 * Conduit length
Culvert Backfill	= Trench width * Conduit length * Conduit depth - Culvert height * Conduit length

APPENDIX C EXISTING CONDITION FLOOD PERFORMANCE, 100-YR

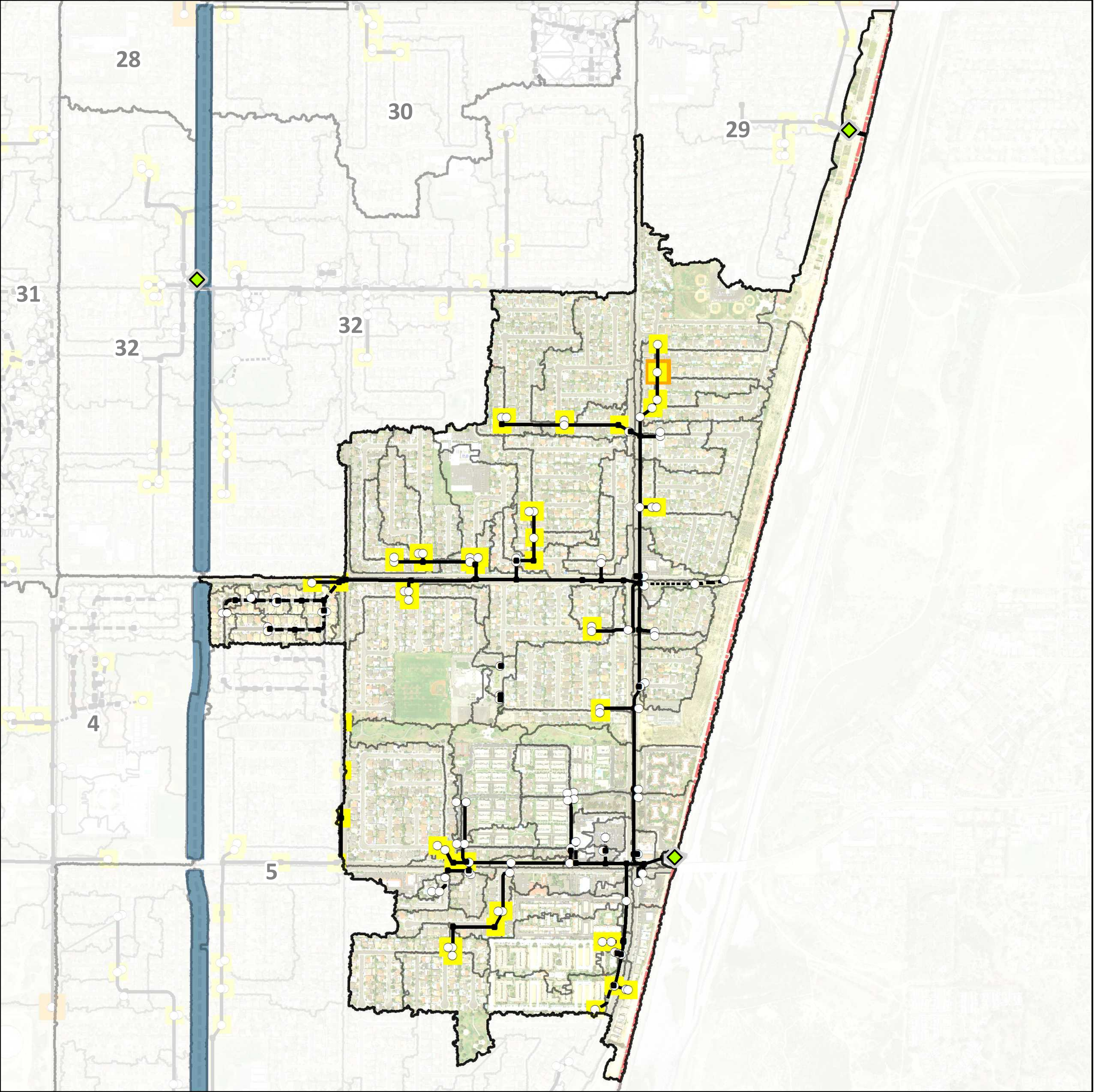
Regional Drainage Area 1

Street Flooding
Existing Condition
100-year 85% event





Regional Drainage Area 2
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
700
1,400
Feet
7
33
7
9
13
11
8



Regional Drainage Area 3

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

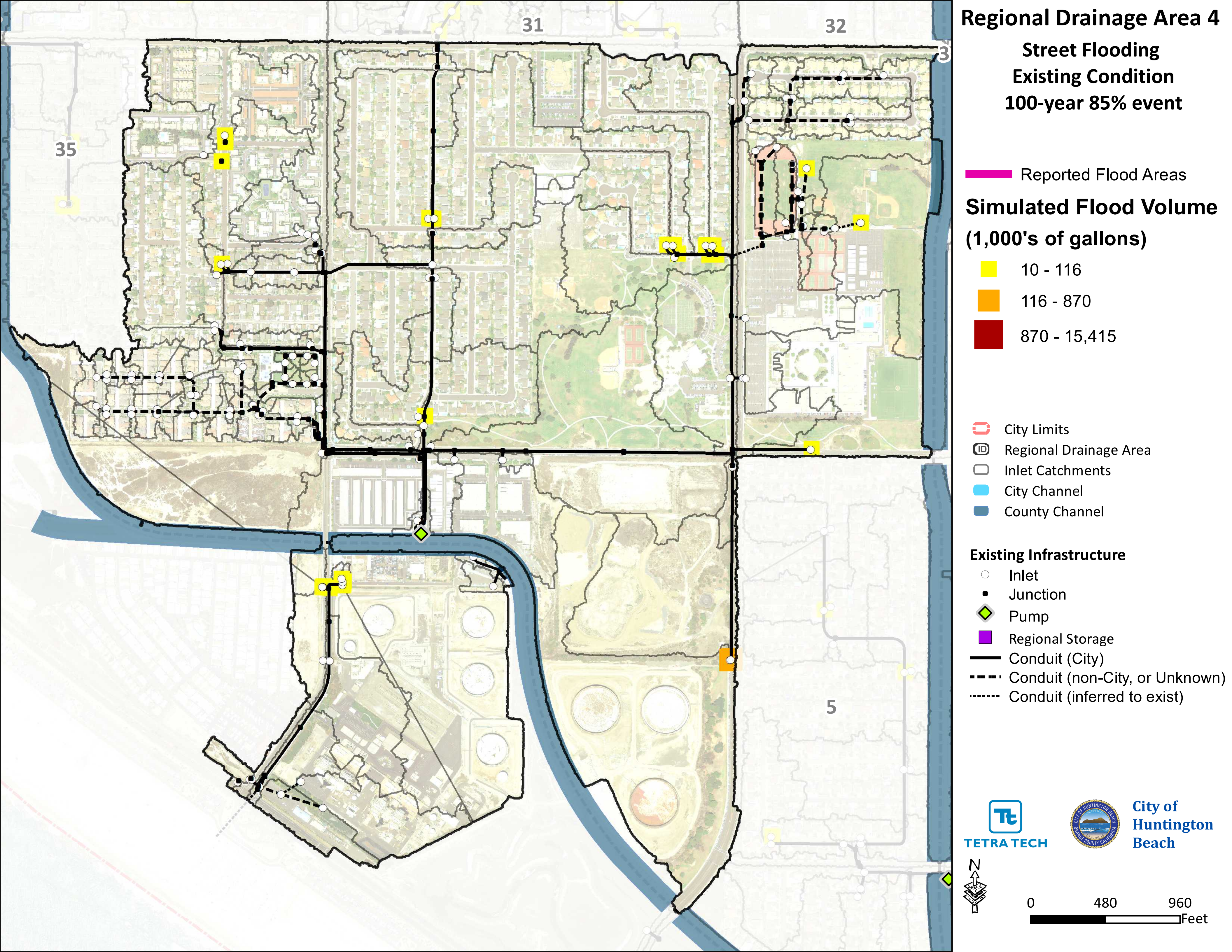
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

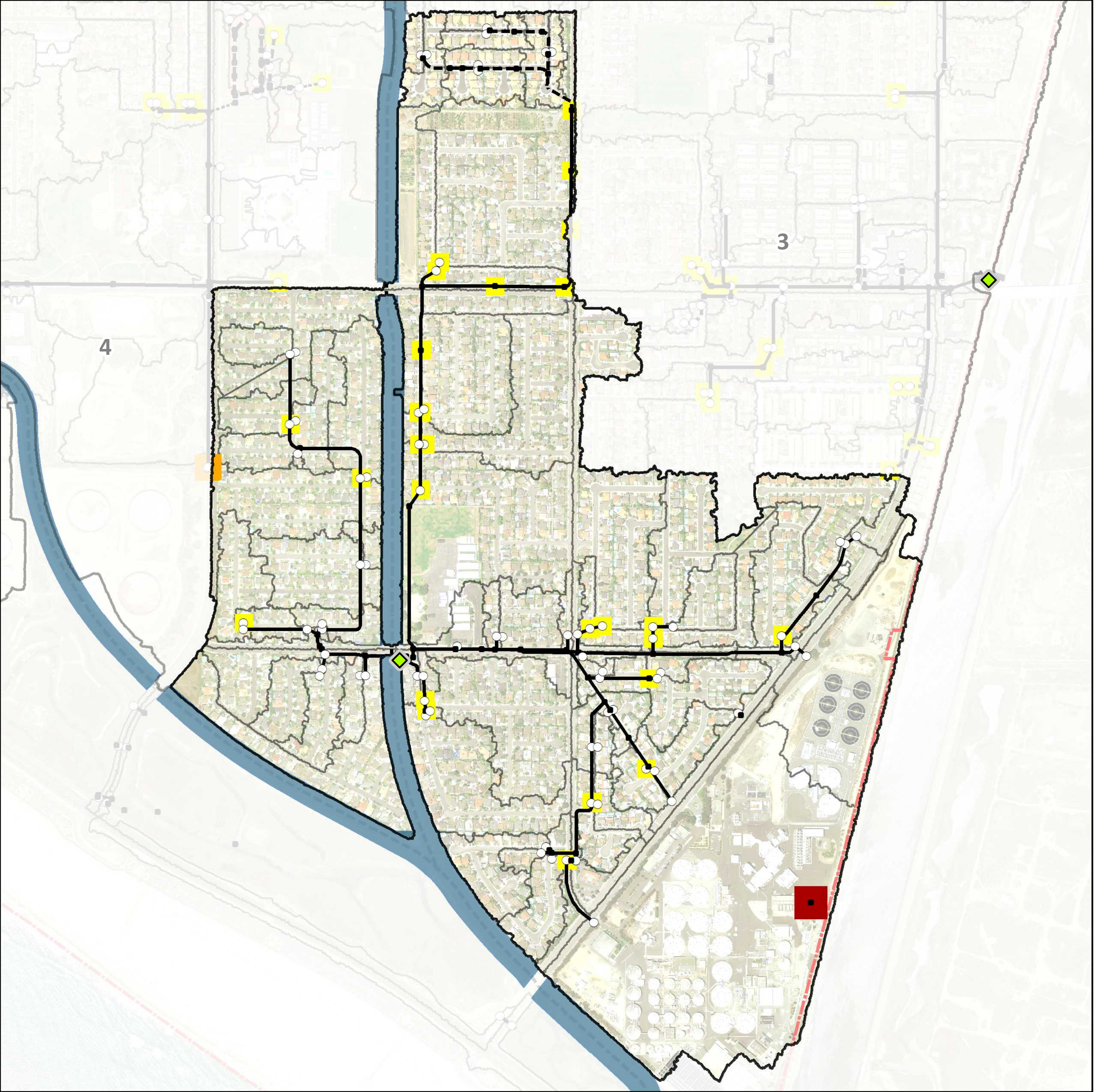
TETRA TECH

City of Huntington Beach

N

0 700 1,400 Feet


Regional Drainage Area 4
Street Flooding
Existing Condition
100-year 85% event
31
32
35
5
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
480
960
Feet



Regional Drainage Area 5

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

N

0 625 1,250 Feet

Regional Drainage Area 6

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

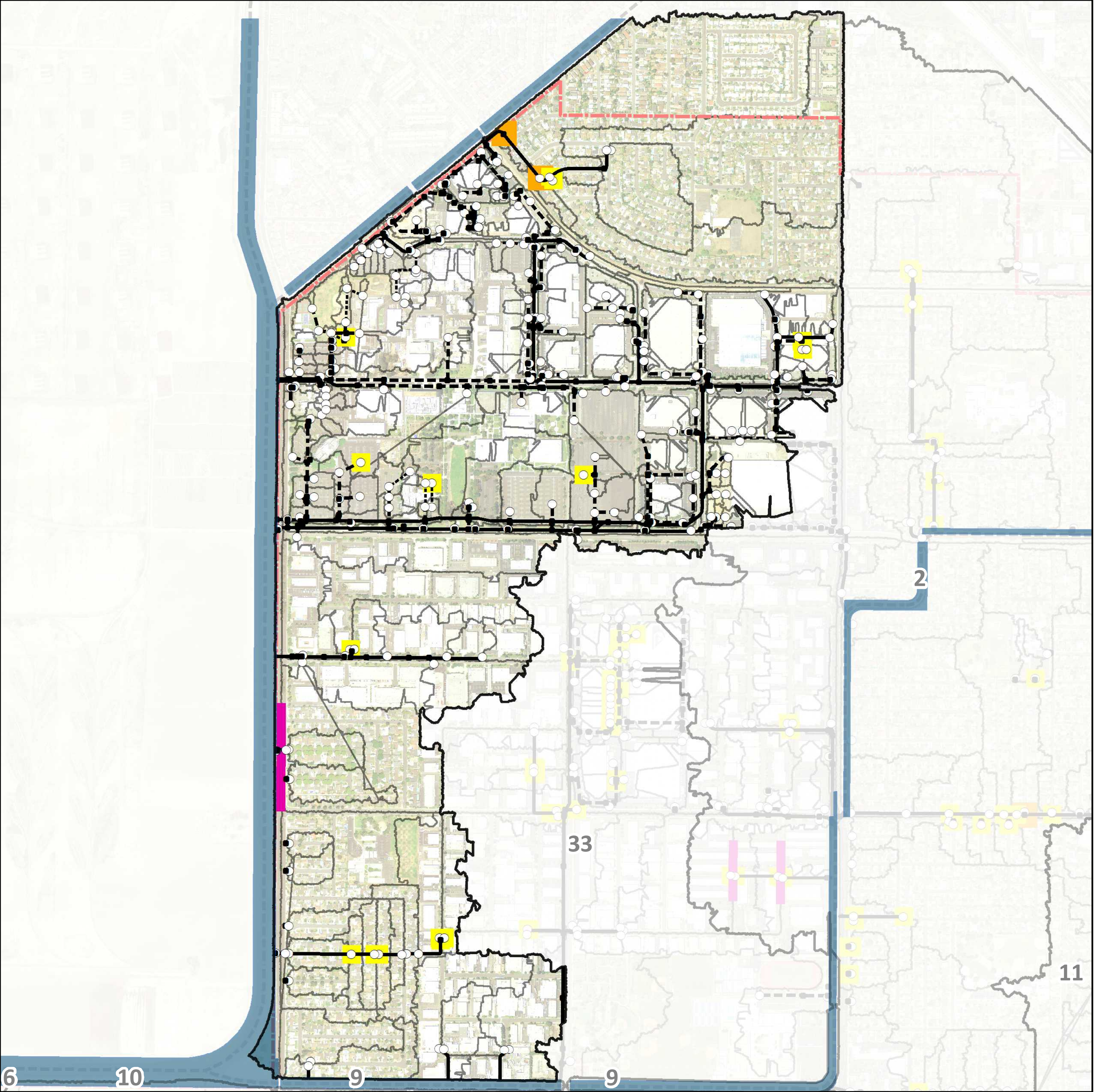
City of Huntington Beach

N

0 700 1,400 Feet

Regional Drainage Area 7

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

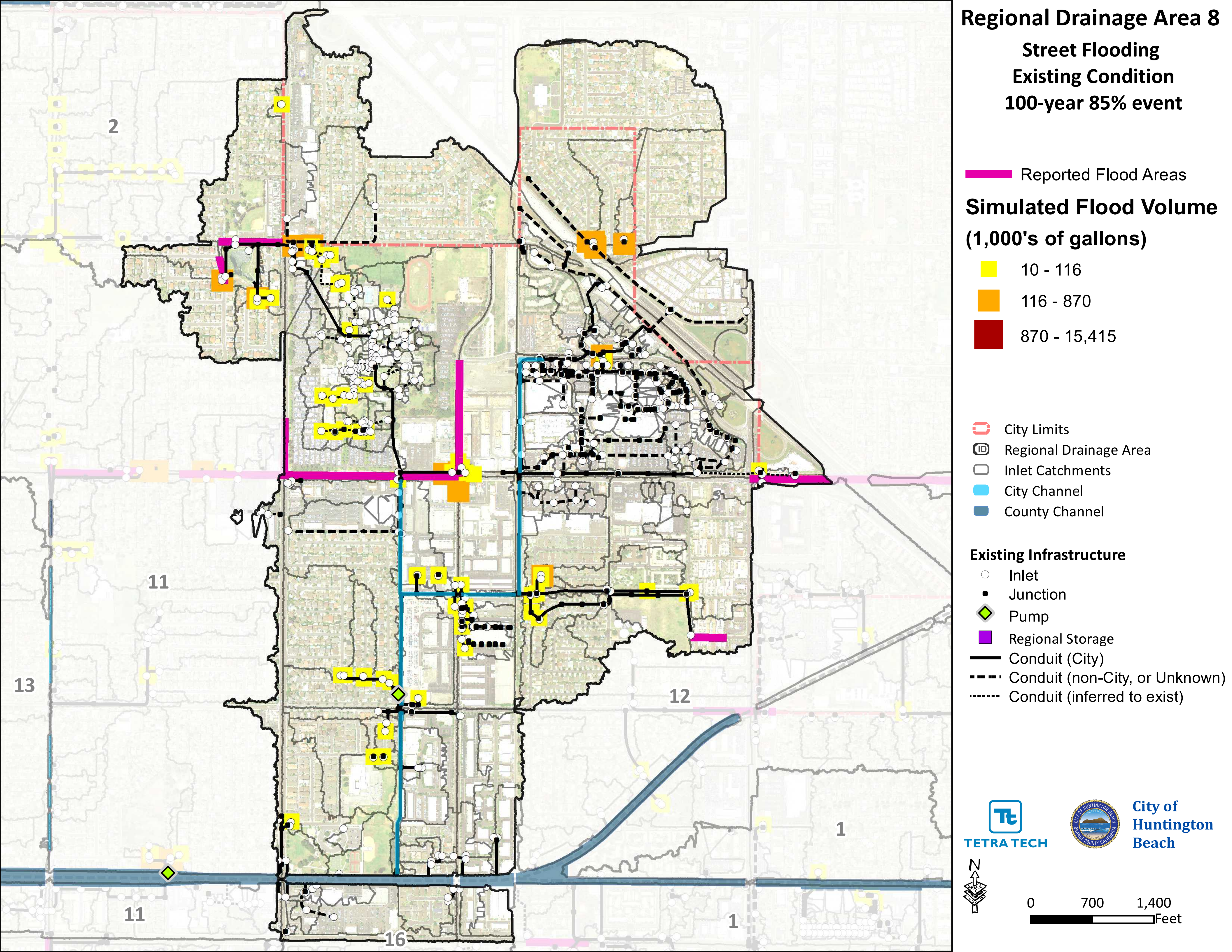
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

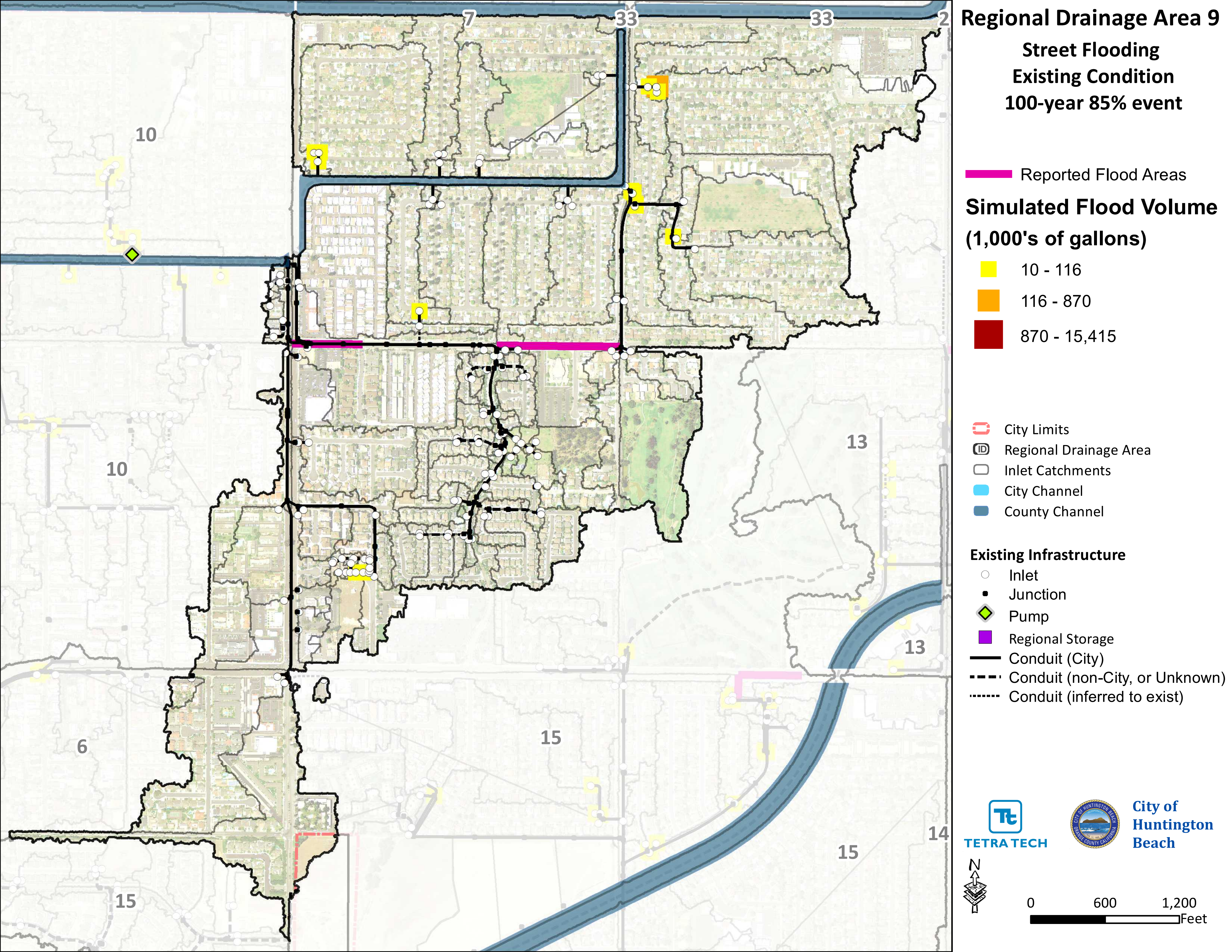
City of Huntington Beach

N

0 700 1,400 Feet



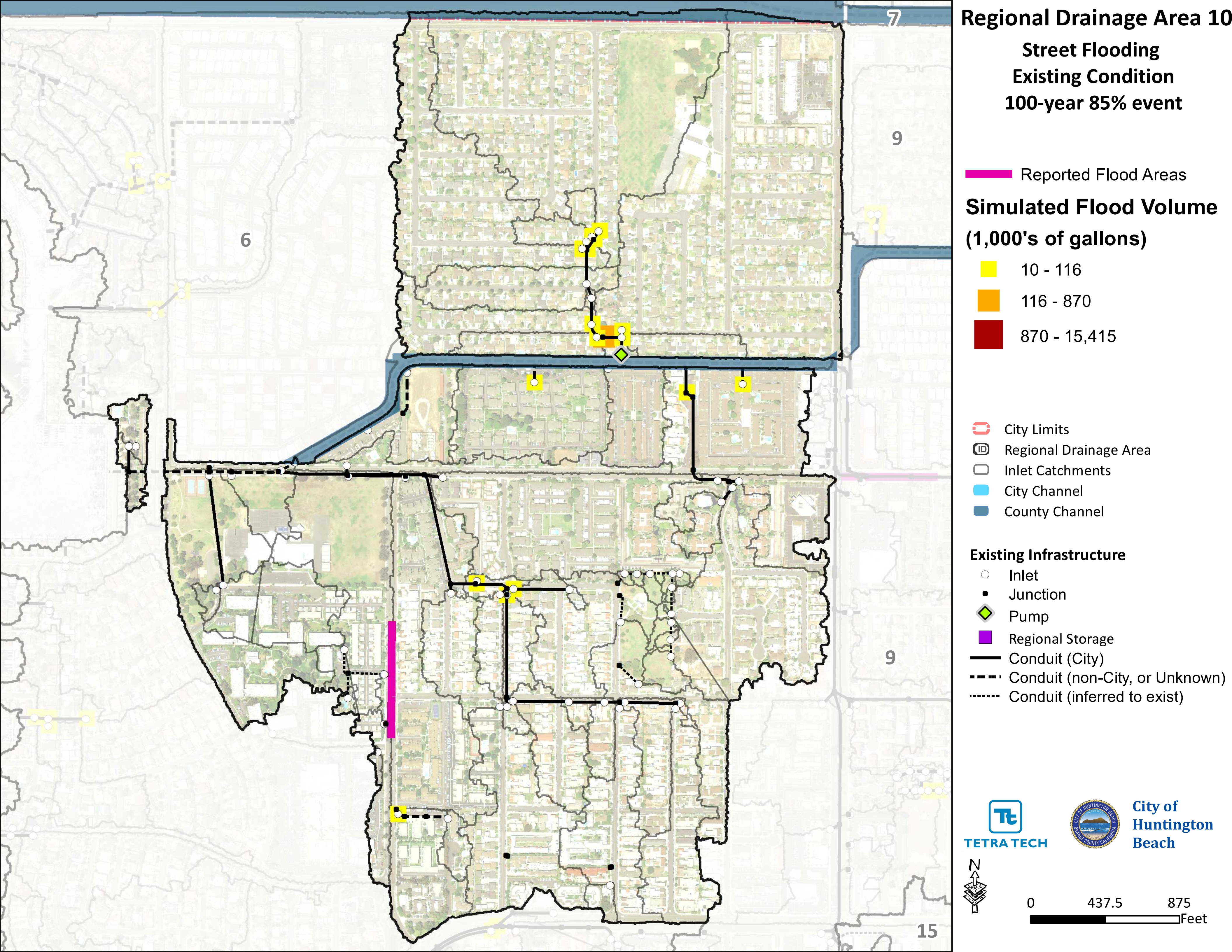
Regional Drainage Area 8
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
700
1,400
Feet
2
11
13
12
1
16

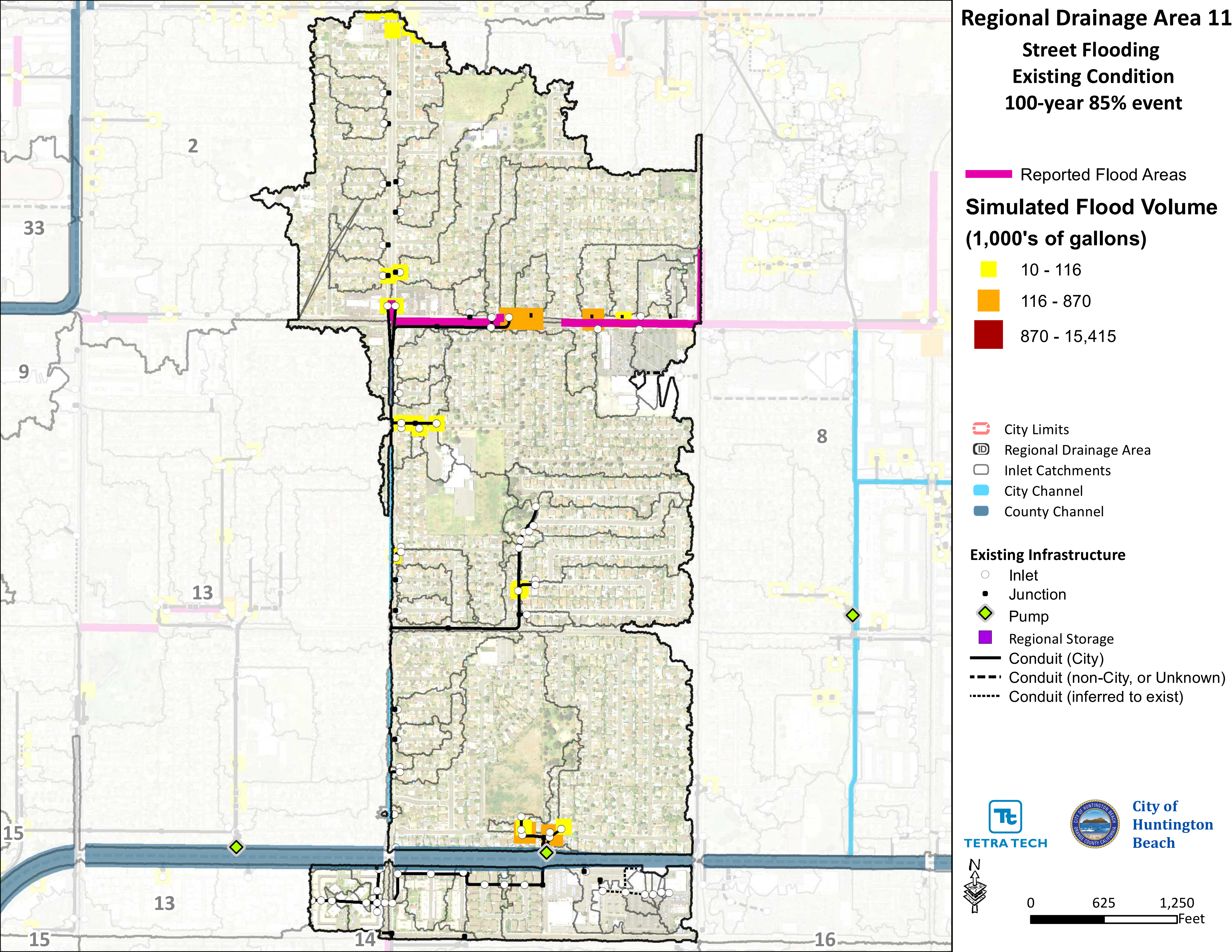


Regional Drainage Area 9
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
600
1,200
Feet
7
33
33
2
10
10
13
13
6
15
15
15
15
14

Regional Drainage Area 10

Street Flooding
Existing Condition
100-year 85% event

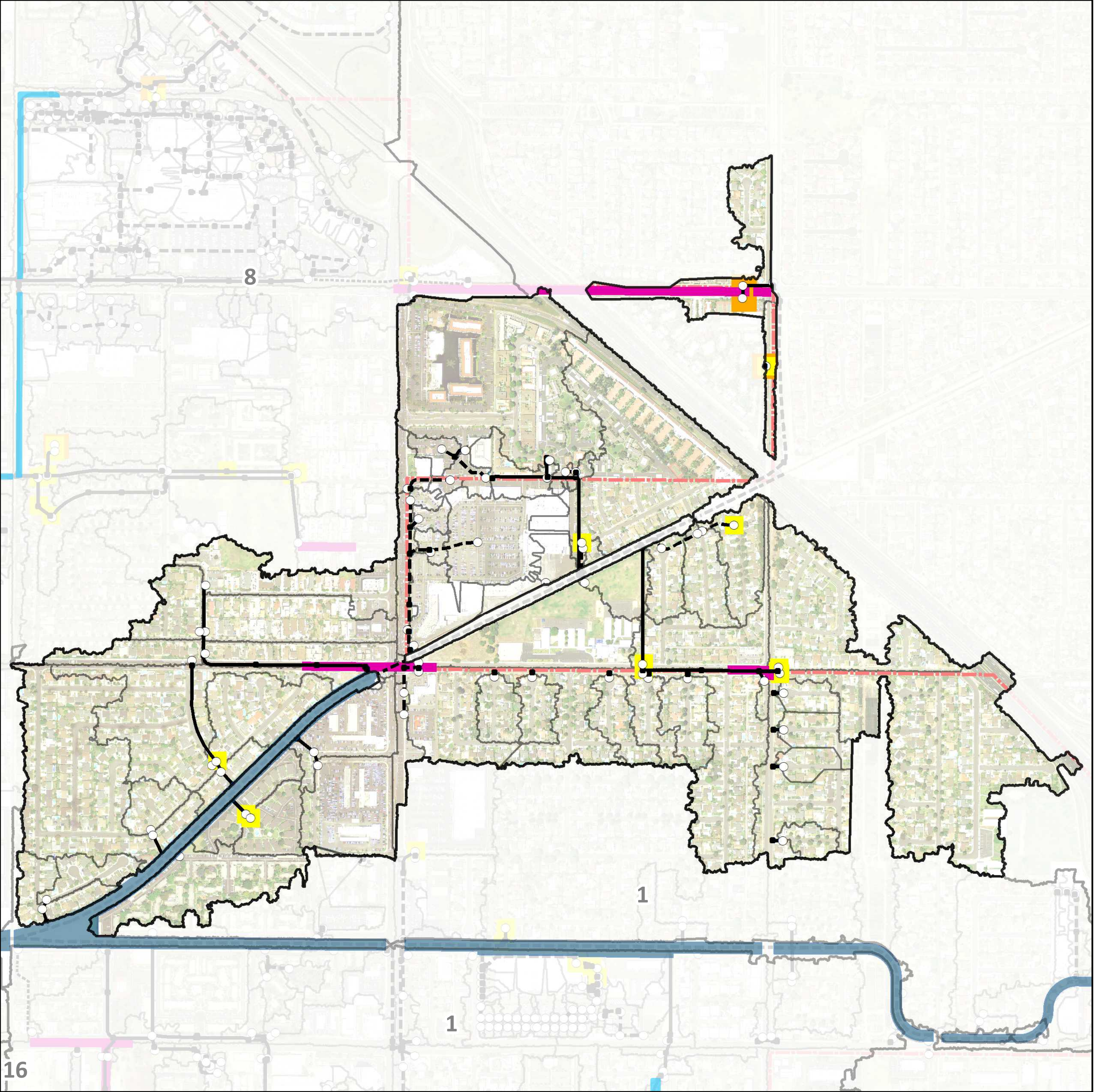




Regional Drainage Area 11
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
625
1,250
Feet
2
33
9
13
8
15
13
15
14
16

Regional Drainage Area 12

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

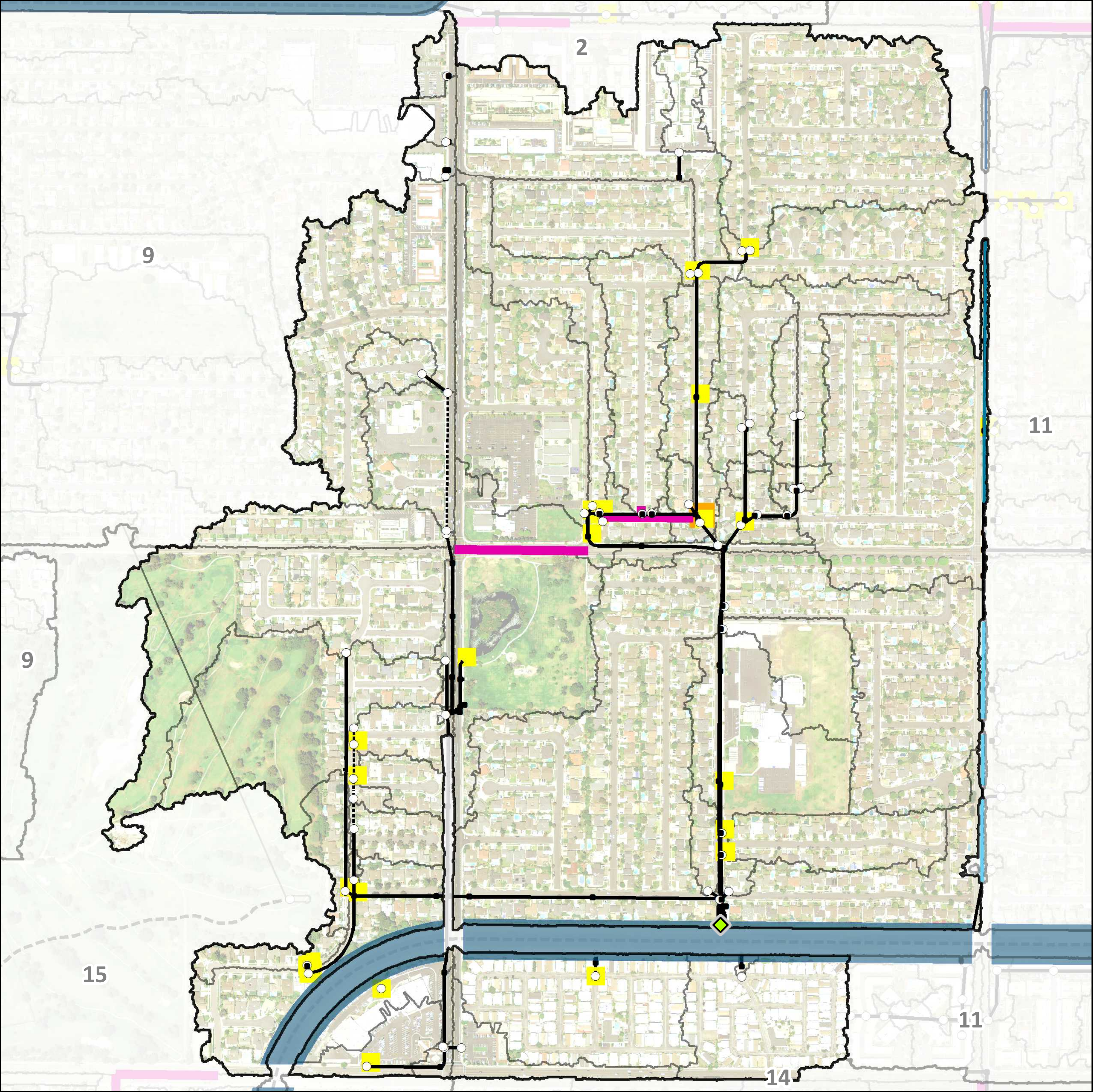
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

N

0 600 1,200 Feet



Regional Drainage Area 13

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

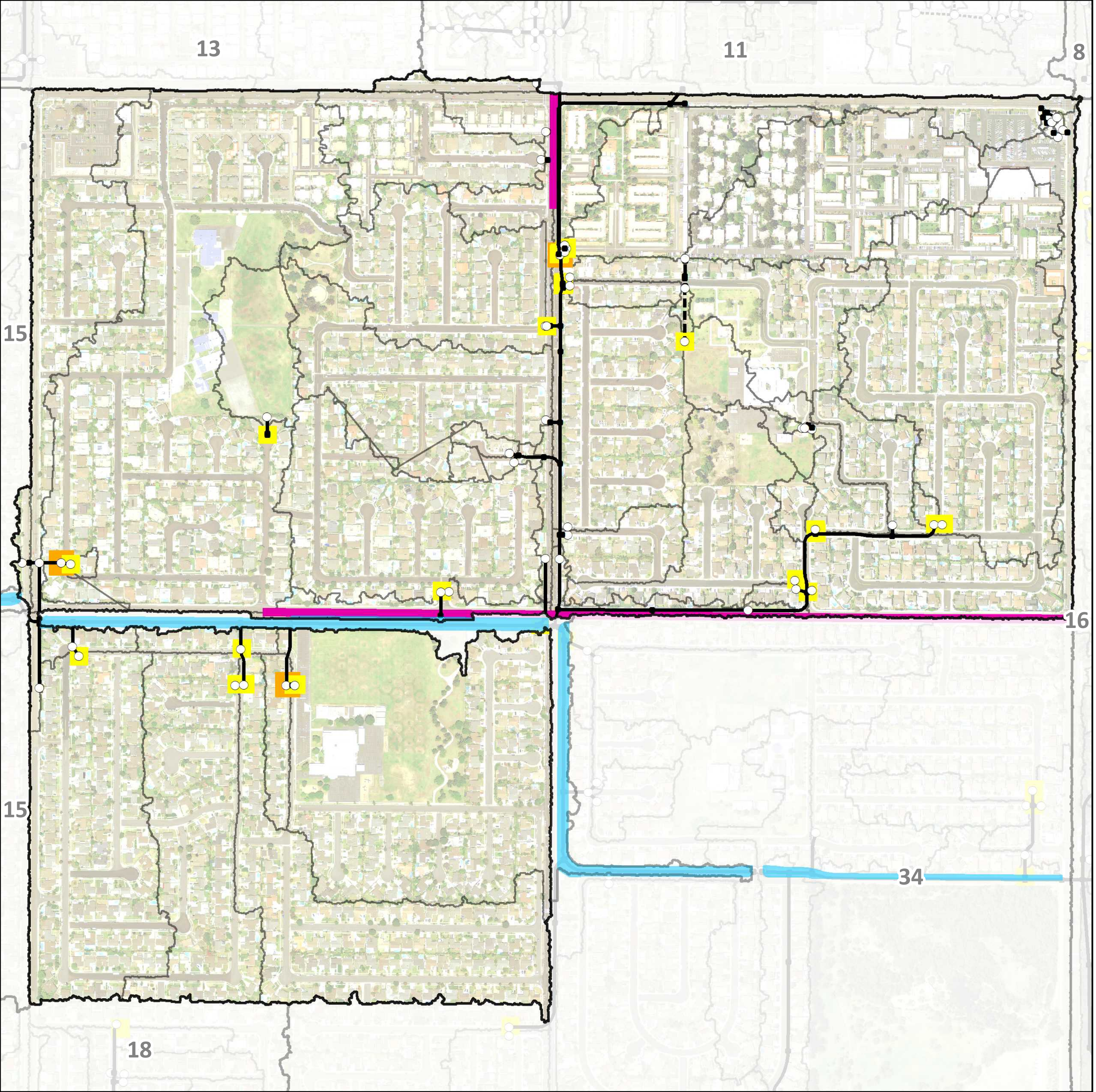
City of Huntington Beach

N

0 425 850 Feet

Regional Drainage Area 14

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

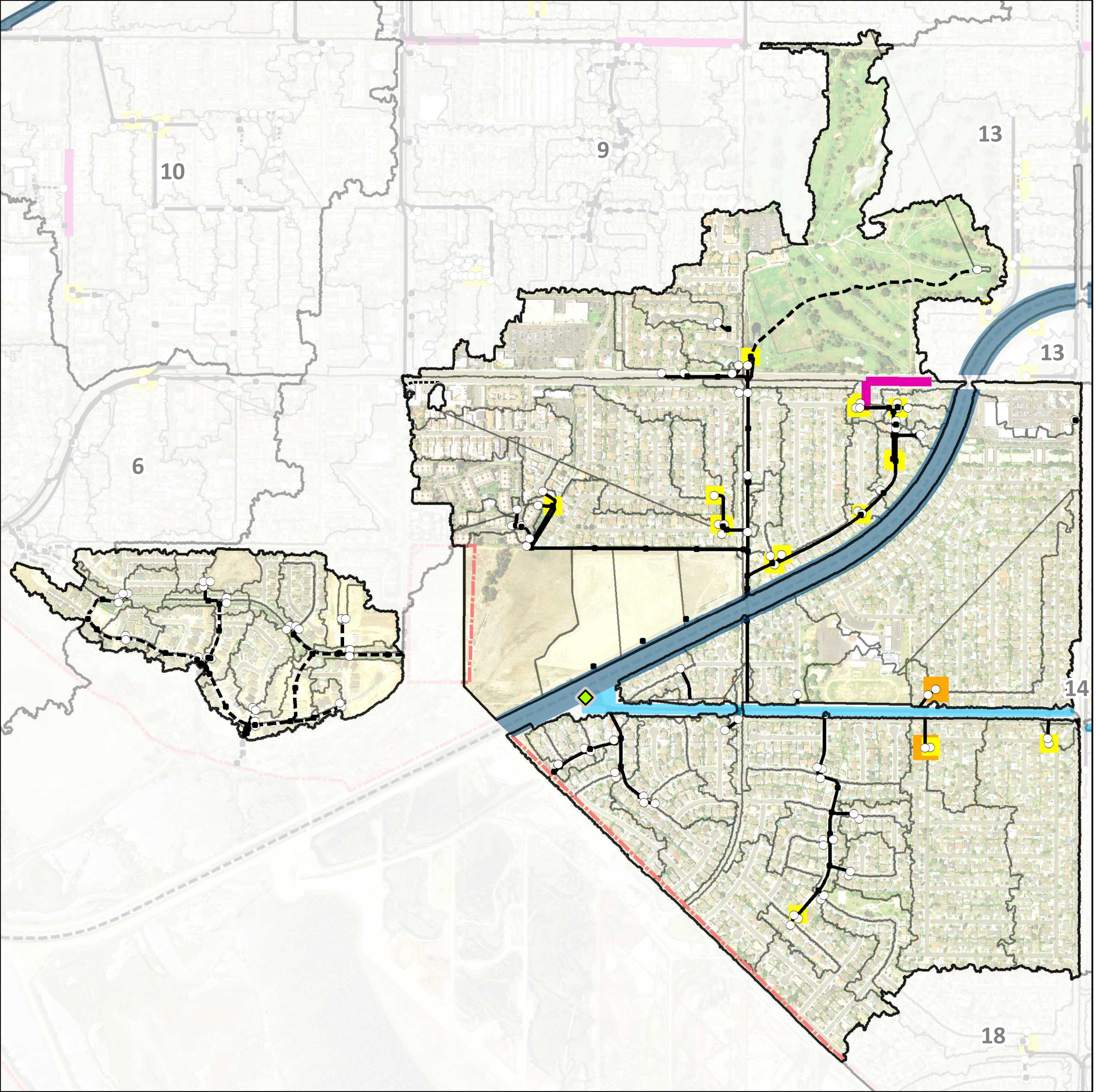
City of Huntington Beach

N

0 435 870 Feet

Regional Drainage Area 15

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116
116 - 870
870 - 15,415

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel

Existing Infrastructure

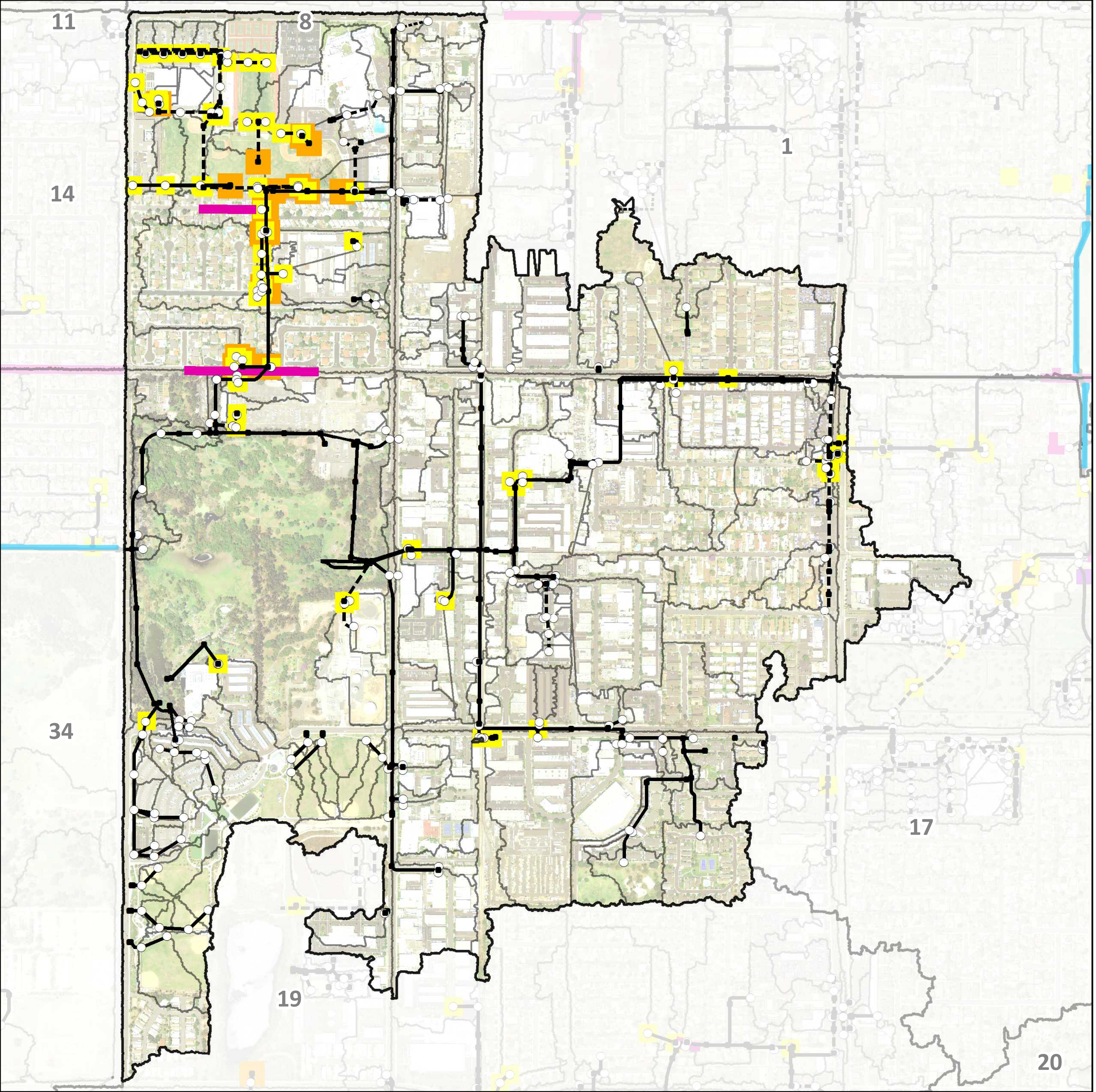
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

N

0 650 1,300 Feet



Regional Drainage Area 16

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116

116 - 870

870 - 15,415

City Limits

Regional Drainage Area

Inlet Catchments

City Channel

County Channel

Existing Infrastructure

Inlet

Junction

Pump

Regional Storage

Conduit (City)

Conduit (non-City, or Unknown)

Conduit (inferred to exist)

TETRA TECH

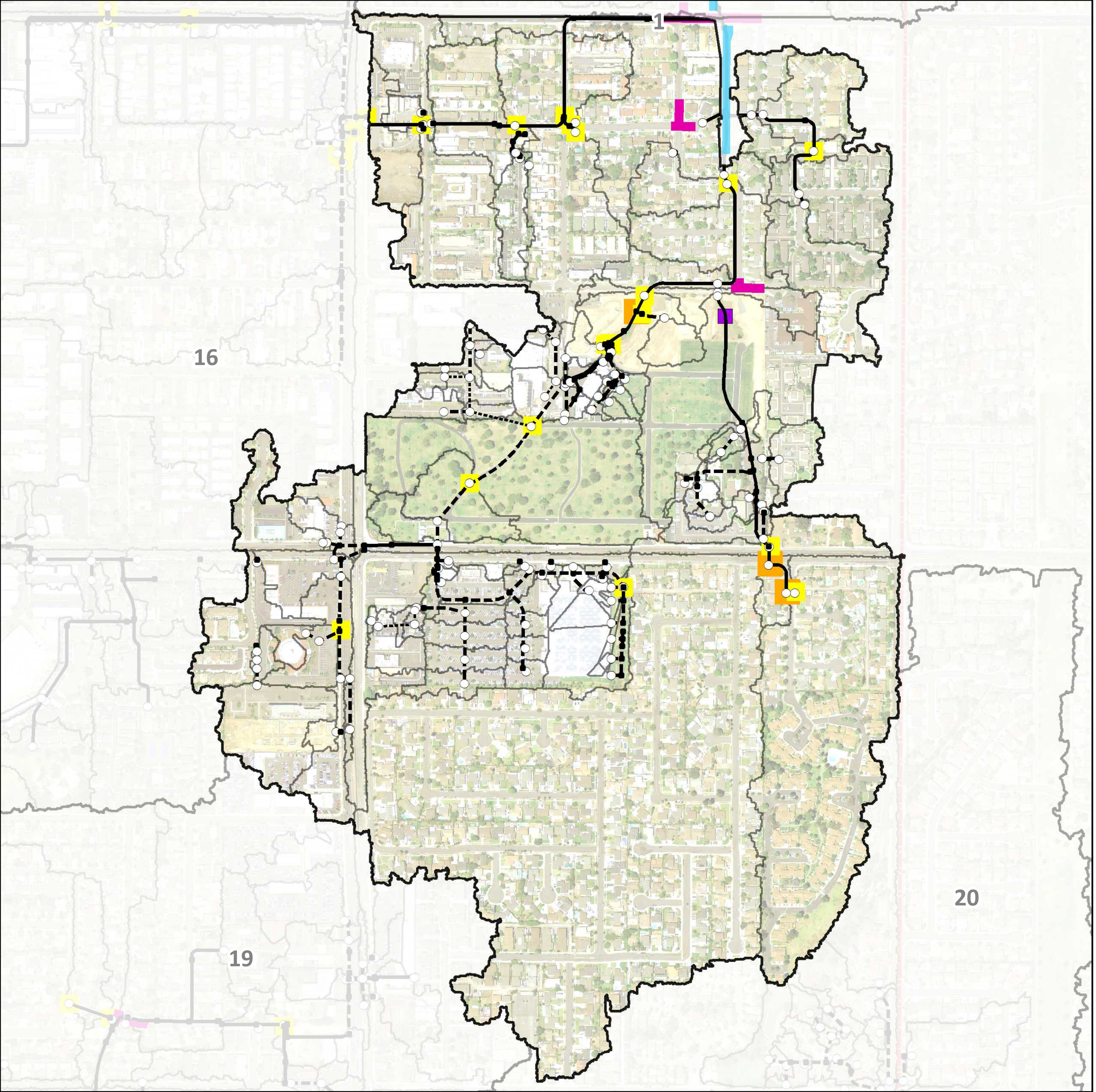
City of Huntington Beach

N

0 625 1,250 Feet

Regional Drainage Area 17

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

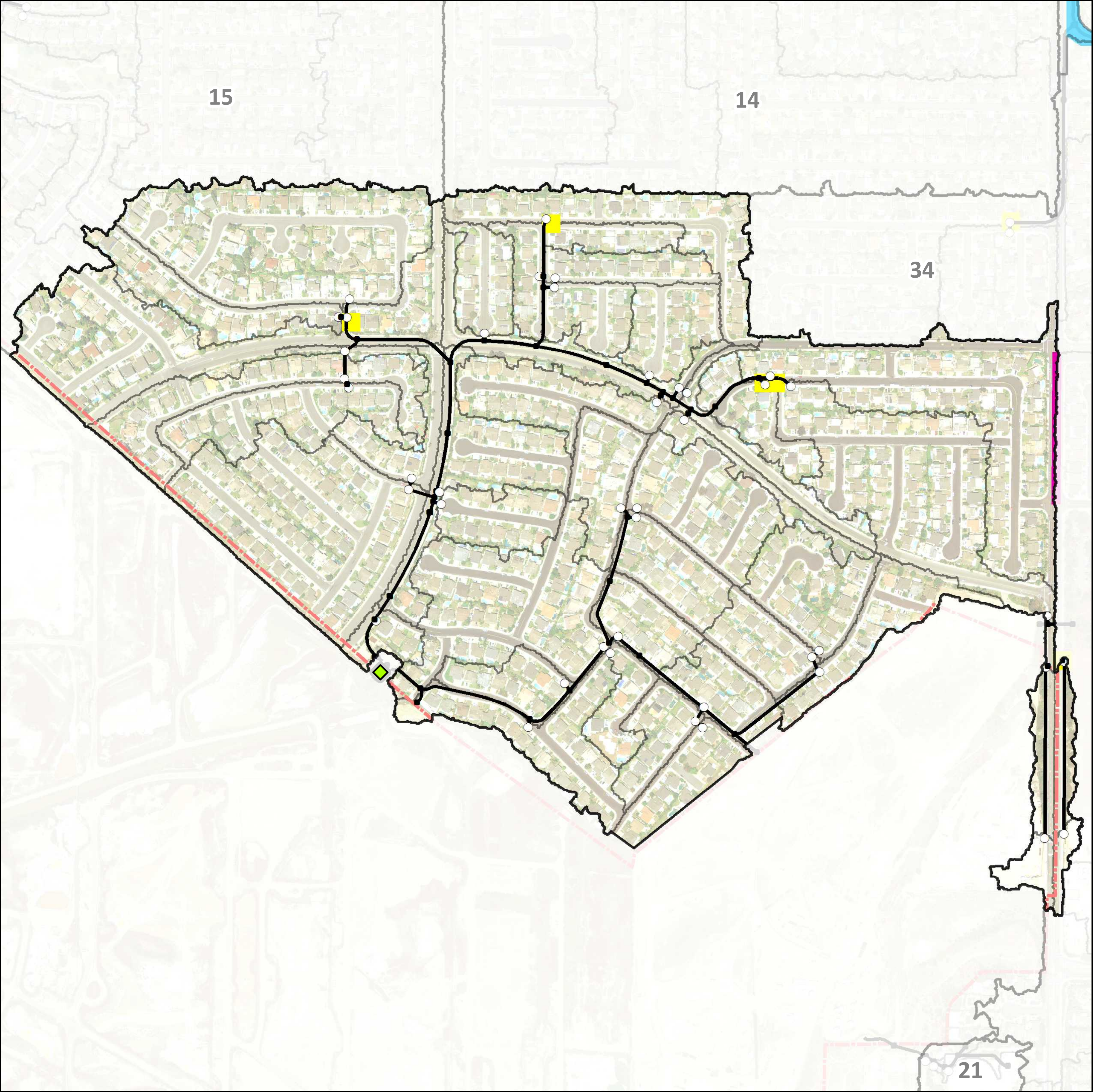
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

N

0 420 840 Feet



Regional Drainage Area 18

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116
116 - 870
870 - 15,415

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel

Existing Infrastructure

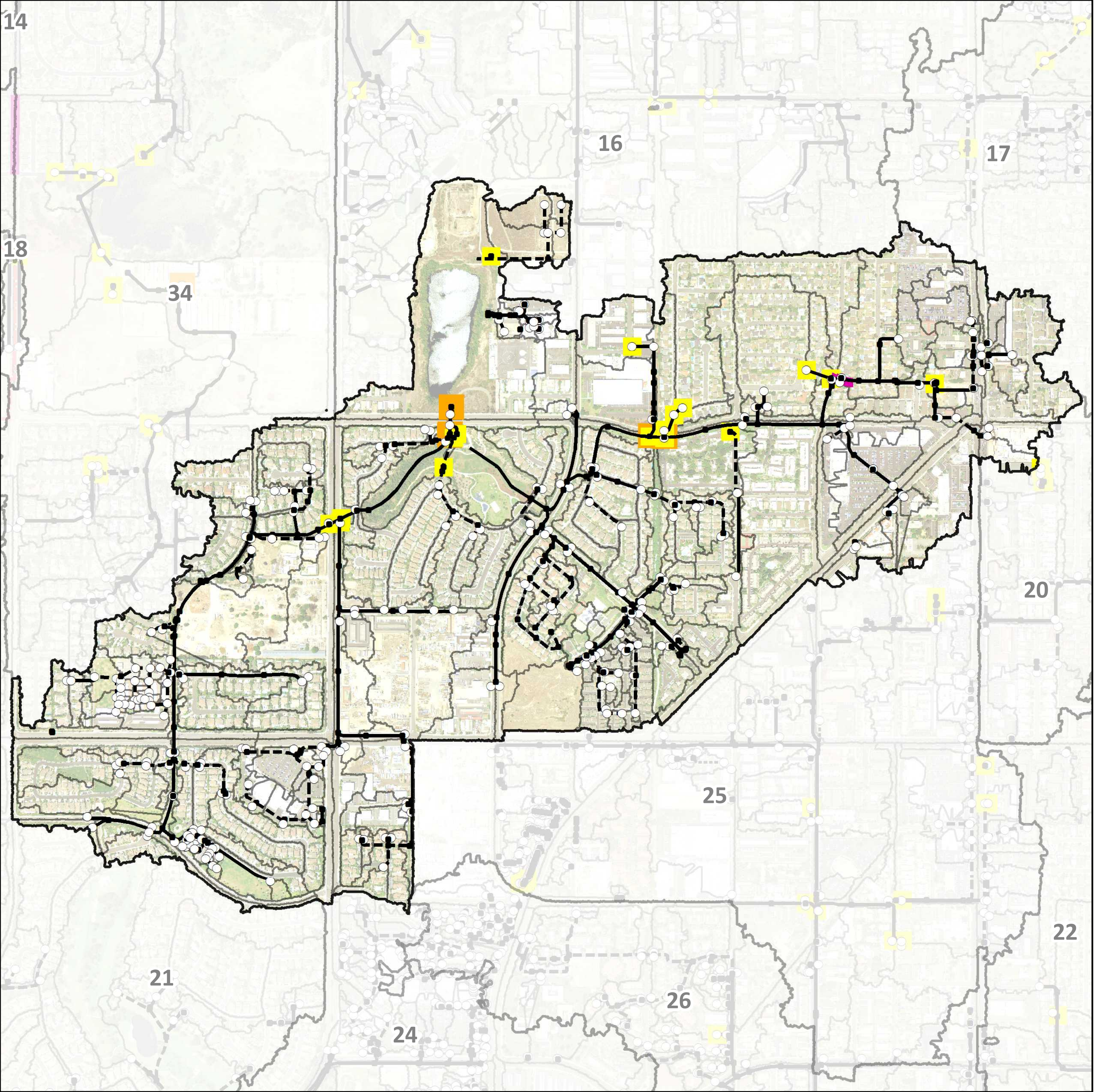
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

N

0 370 740 Feet



Regional Drainage Area 19

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116

116 - 870

870 - 15,415

City Limits

Regional Drainage Area

Inlet Catchments

City Channel

County Channel

Existing Infrastructure

Inlet

Junction

Pump

Regional Storage

Conduit (City)

Conduit (non-City, or Unknown)

Conduit (inferred to exist)

TETRA TECH

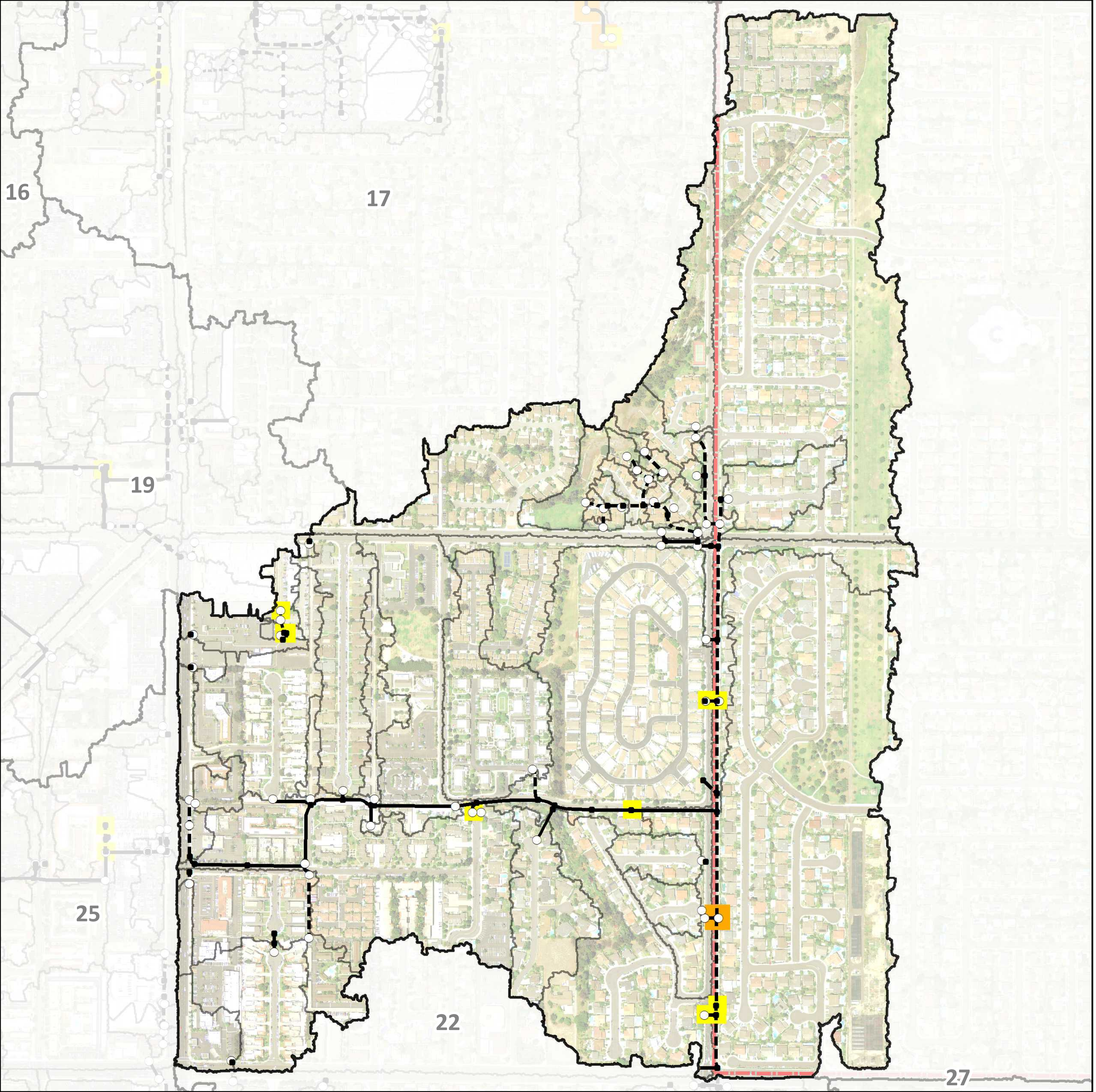
City of Huntington Beach

N

0 700 1,400 Feet

Regional Drainage Area 20

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

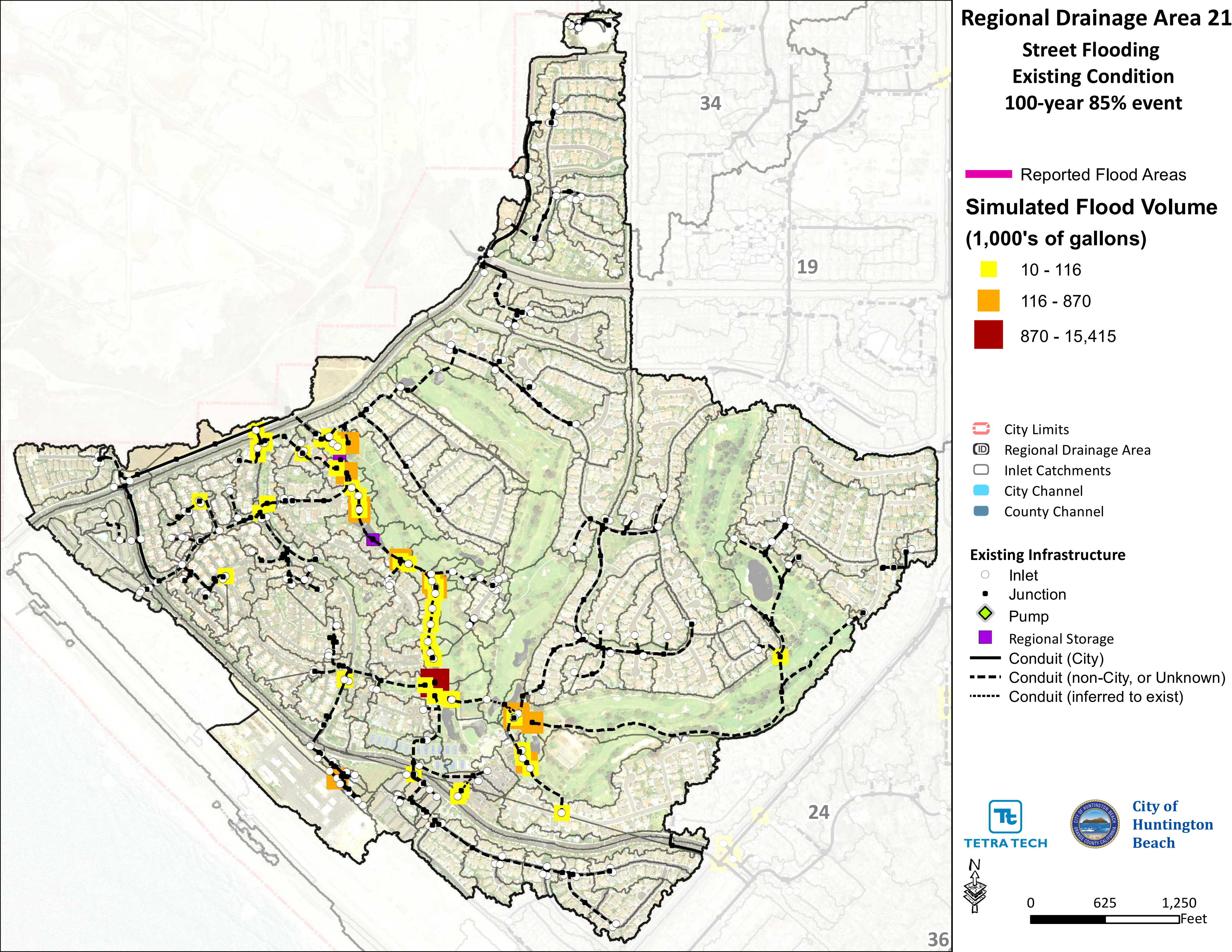
City of Huntington Beach

N

0 420 840 Feet

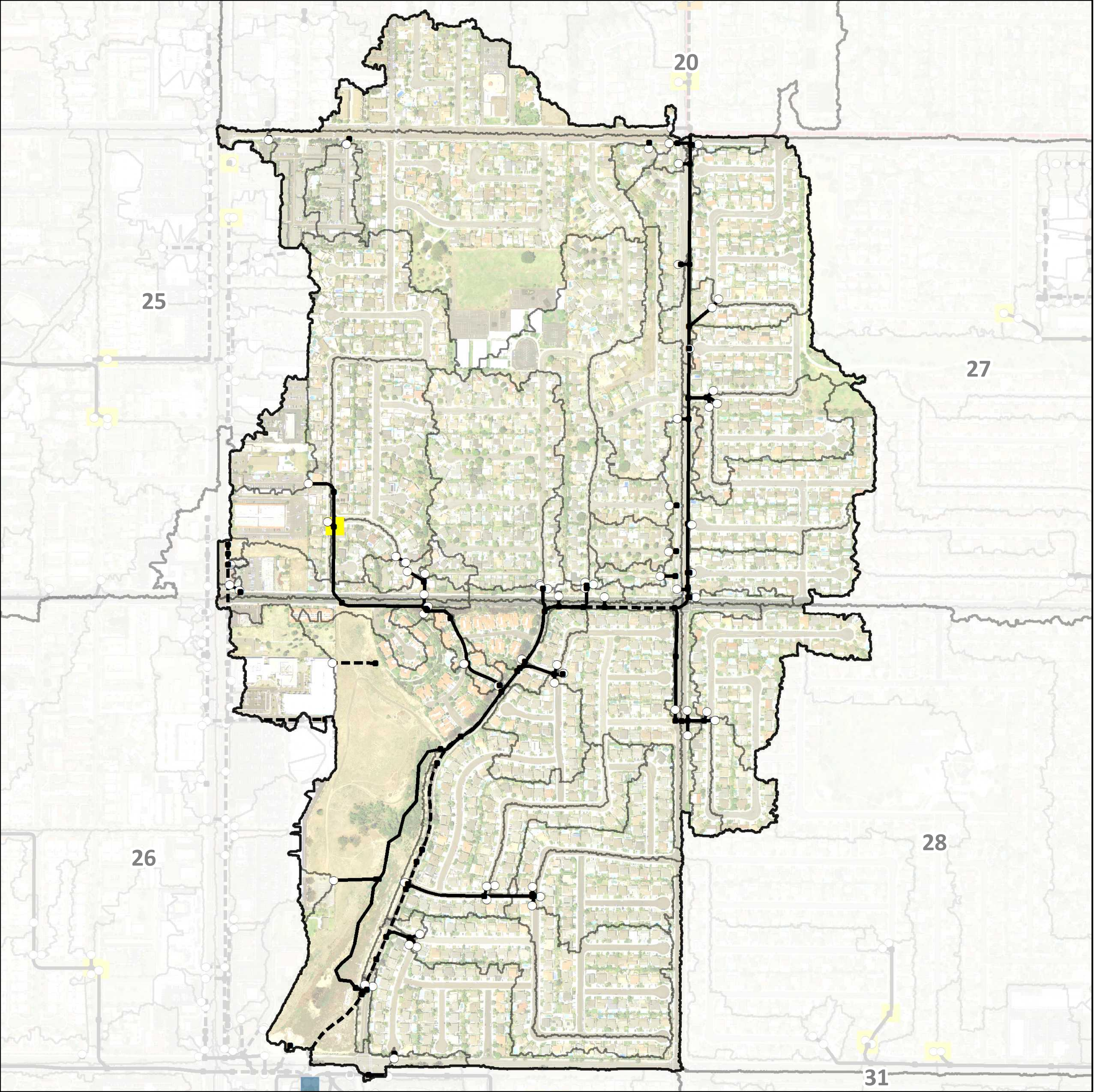
Regional Drainage Area 21

Street Flooding
Existing Condition
100-year 85% event



Regional Drainage Area 22

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

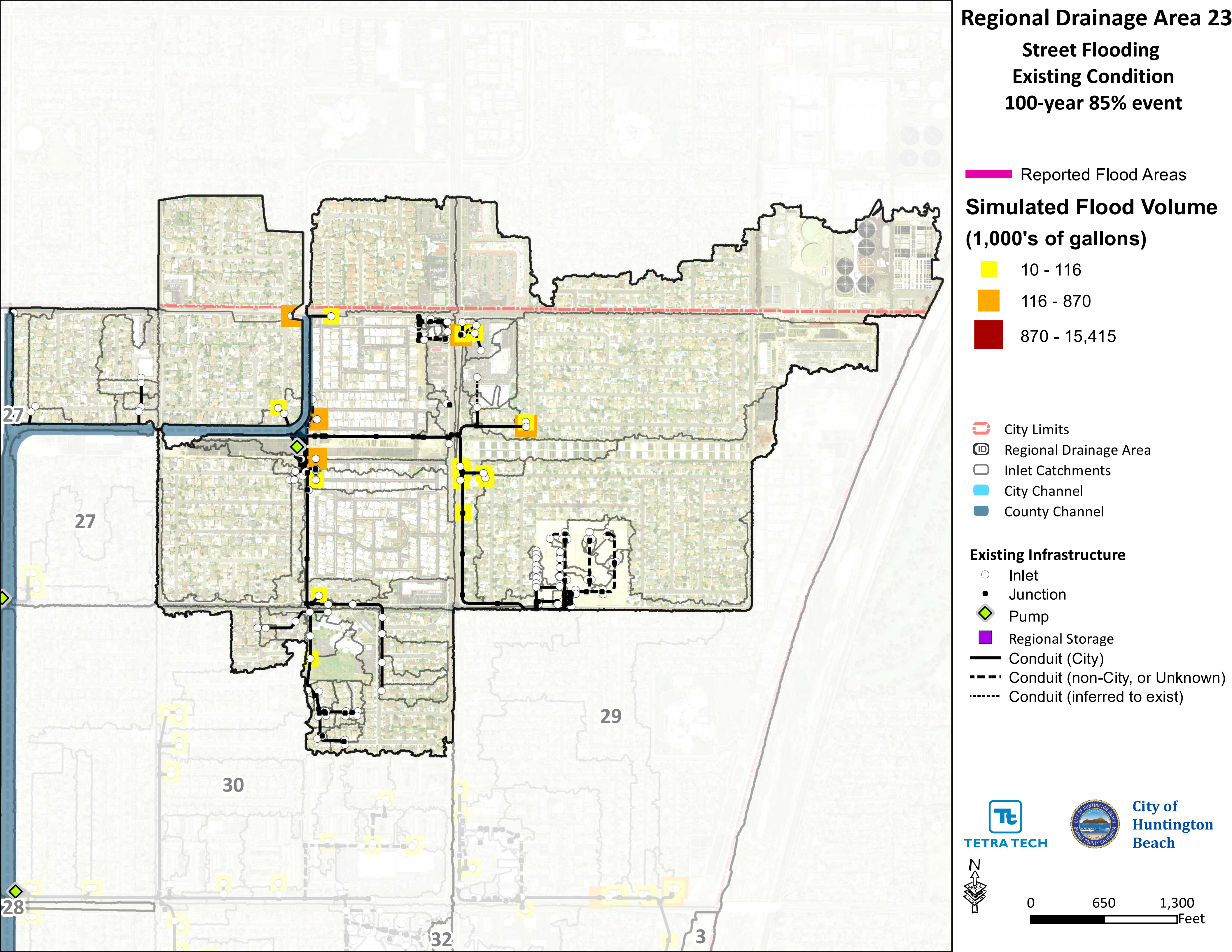
City of Huntington Beach

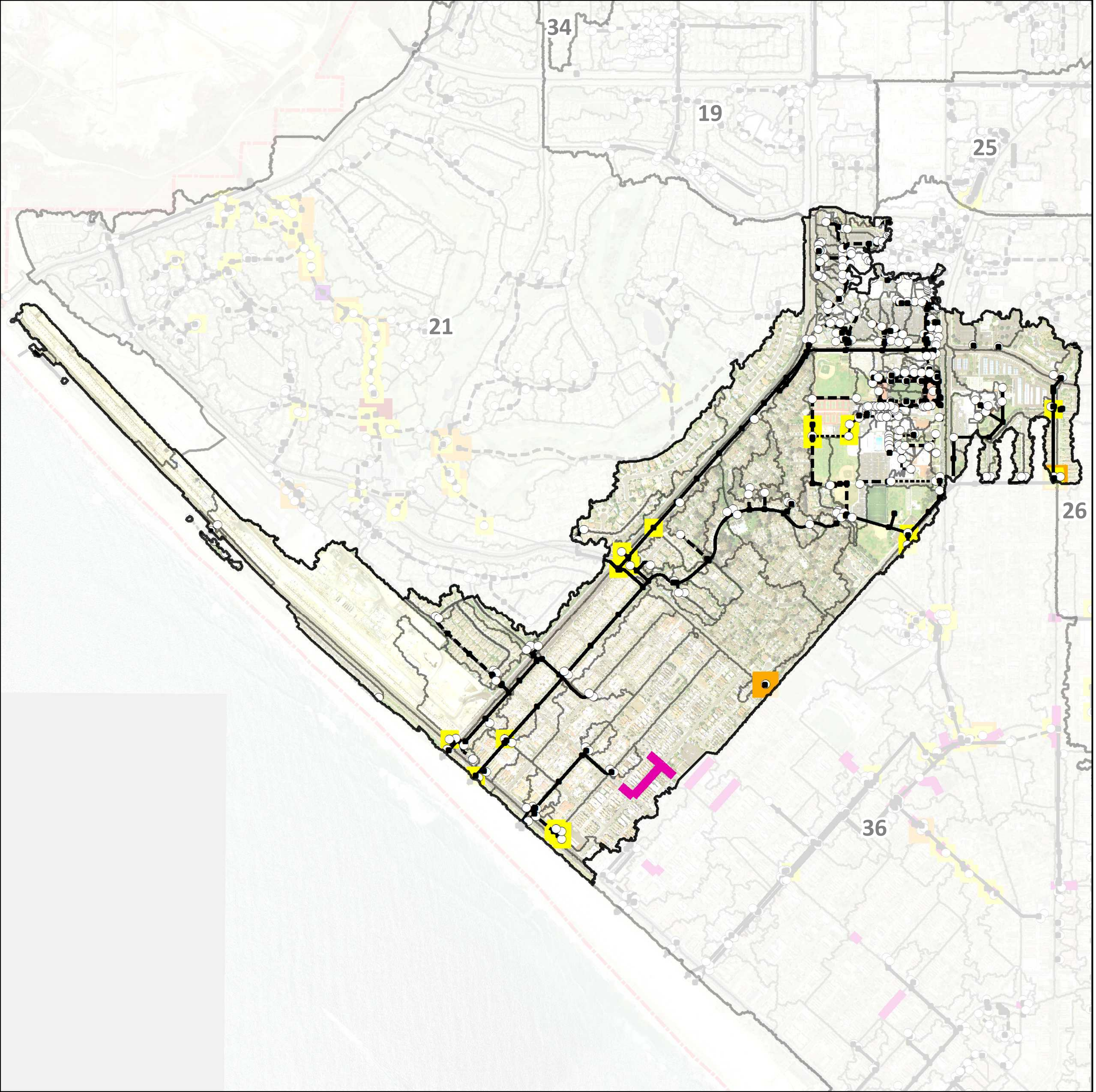
N

0 485 970 Feet

Regional Drainage Area 23

Street Flooding
Existing Condition
100-year 85% event





Regional Drainage Area 24

Street Flooding

Existing Condition

100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116

116 - 870

870 - 15,415

City Limits

Regional Drainage Area

Inlet Catchments

City Channel

County Channel

Existing Infrastructure

Inlet

Junction

Pump

Regional Storage

Conduit (City)

Conduit (non-City, or Unknown)

Conduit (inferred to exist)

TETRA TECH

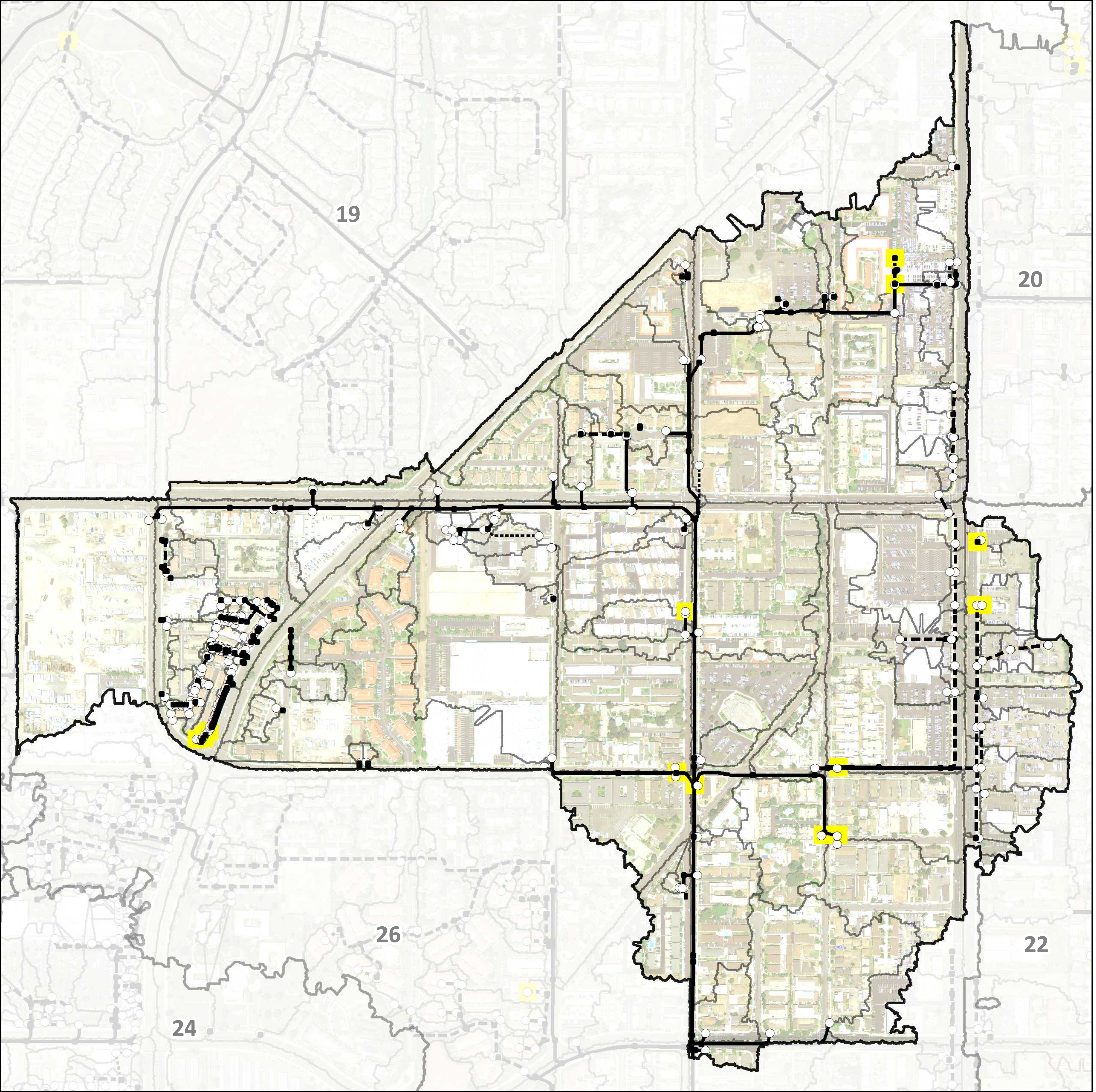
City of Huntington Beach

N

0 700 1,400 Feet

Regional Drainage Area 25

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

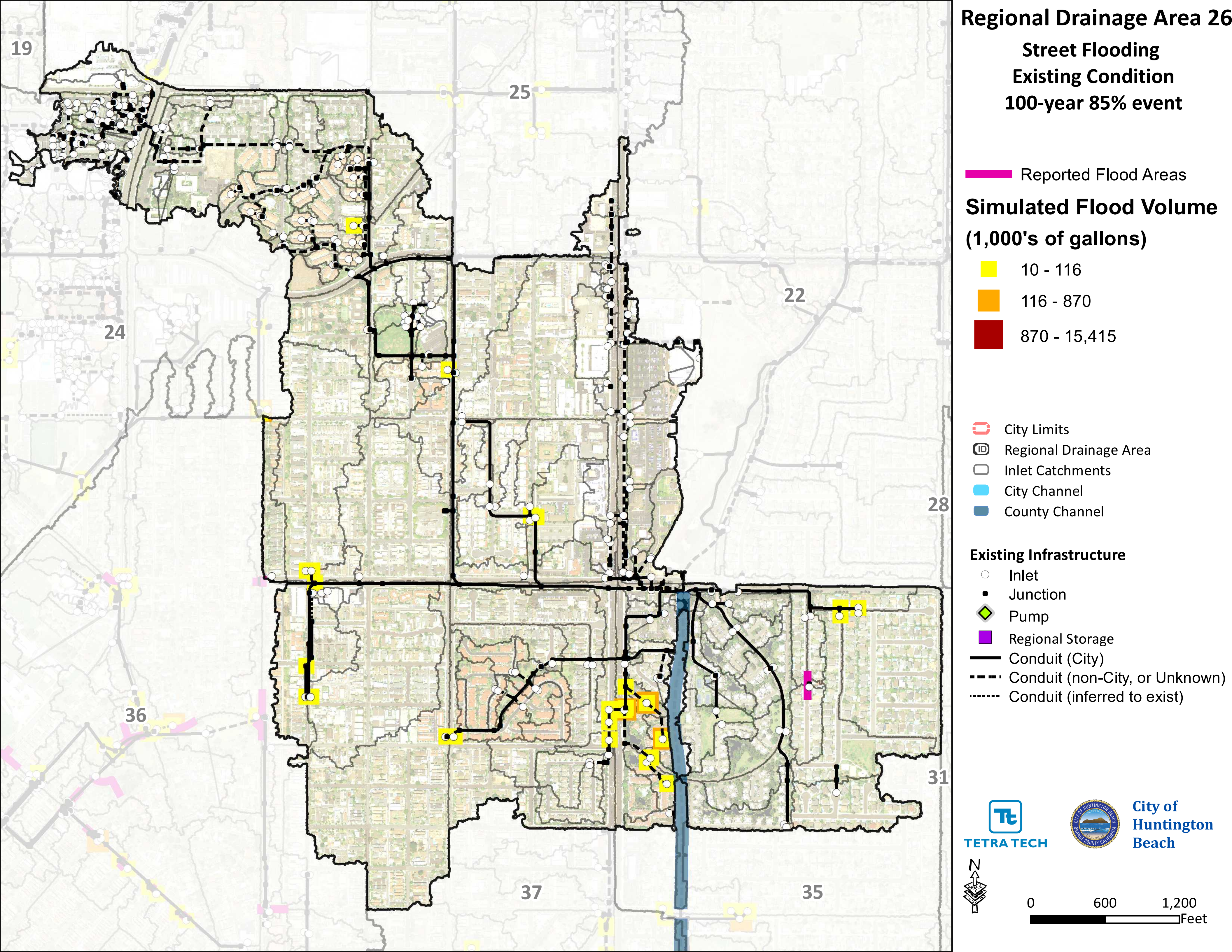
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

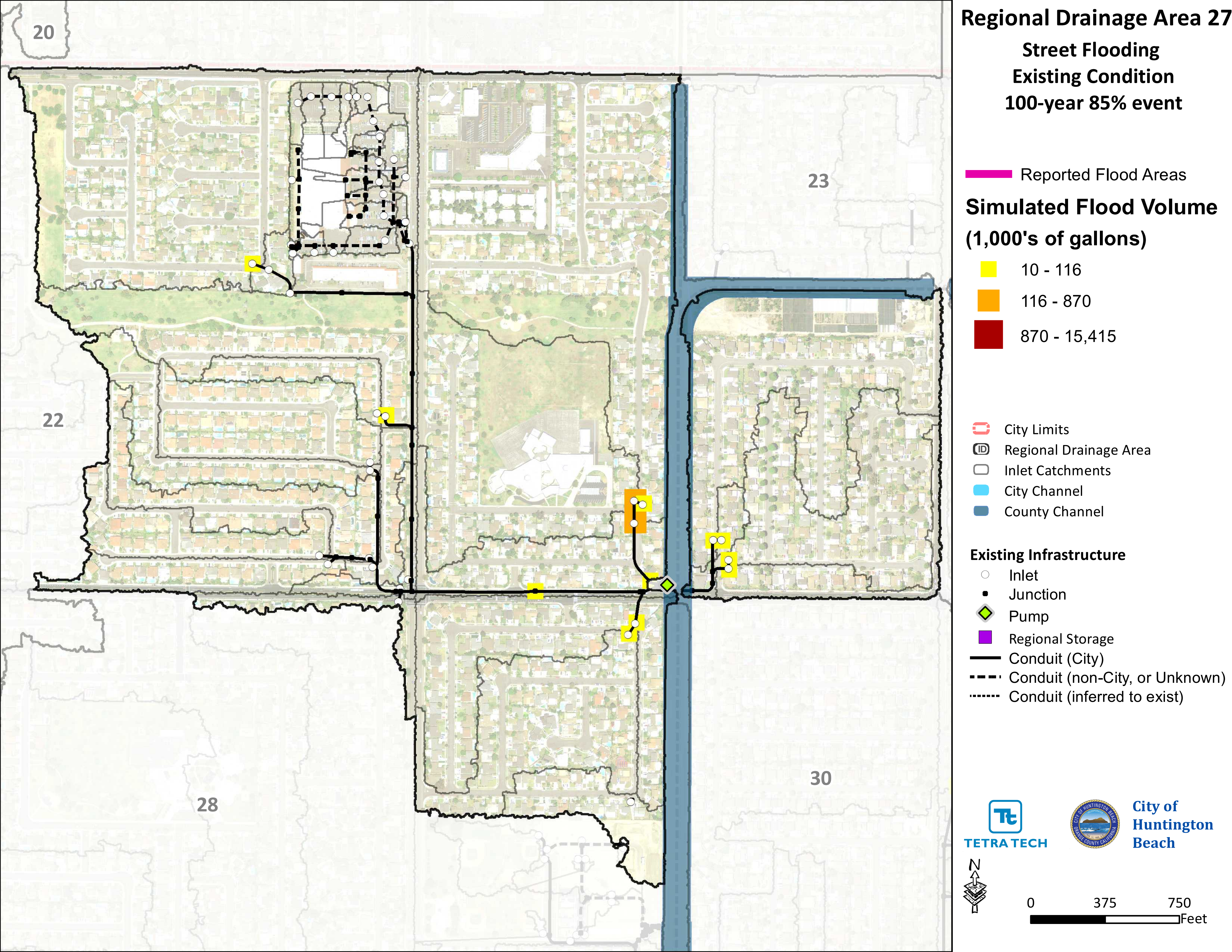
N

0 420 840 Feet


Regional Drainage Area 26
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
600
1,200
Feet
19
25
24
22
28
36
31
37
35

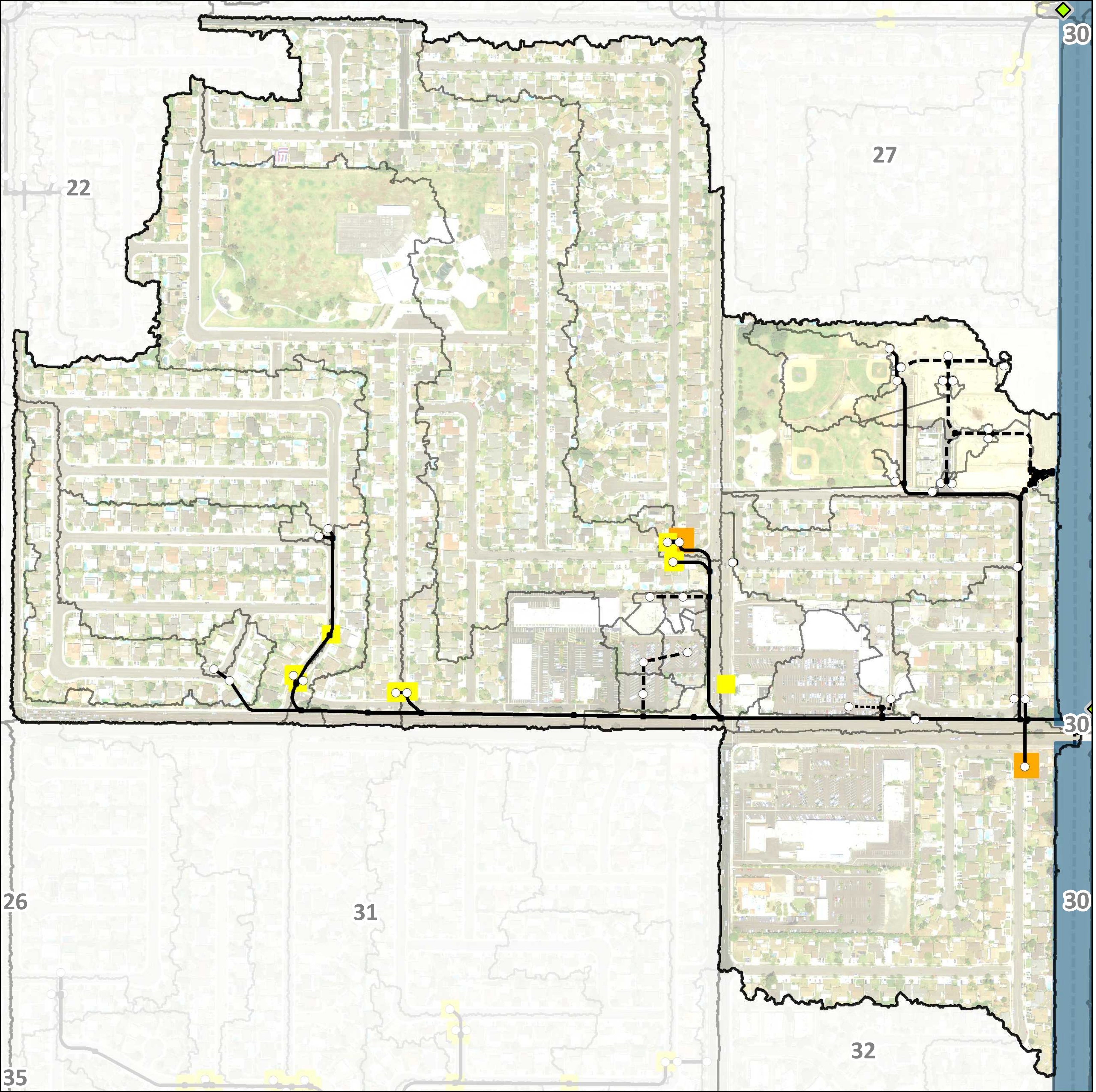
Regional Drainage Area 27

Street Flooding
Existing Condition
100-year 85% event



Regional Drainage Area 28

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

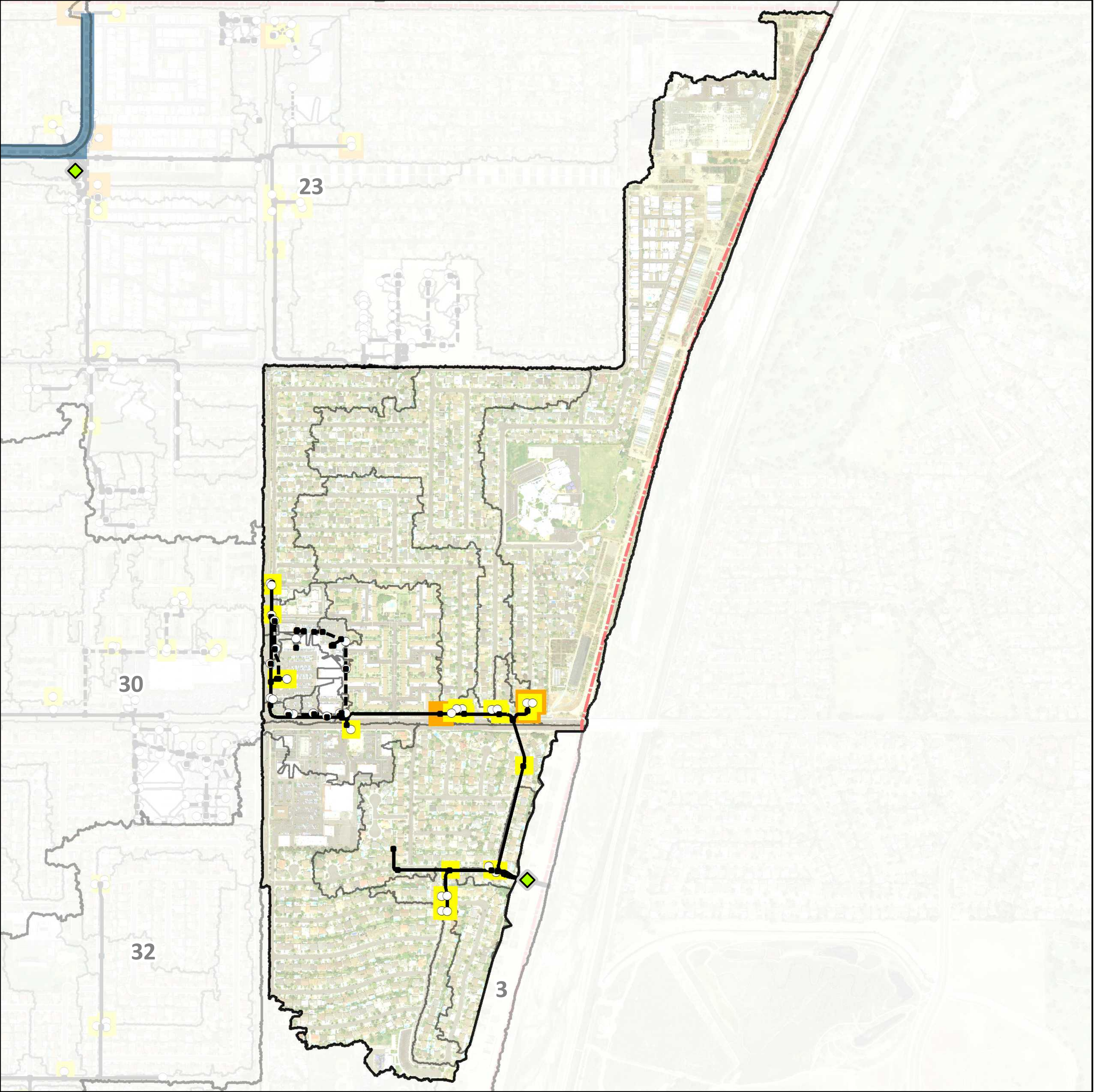
City of Huntington Beach

N

0 320 640 Feet

Regional Drainage Area 29

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

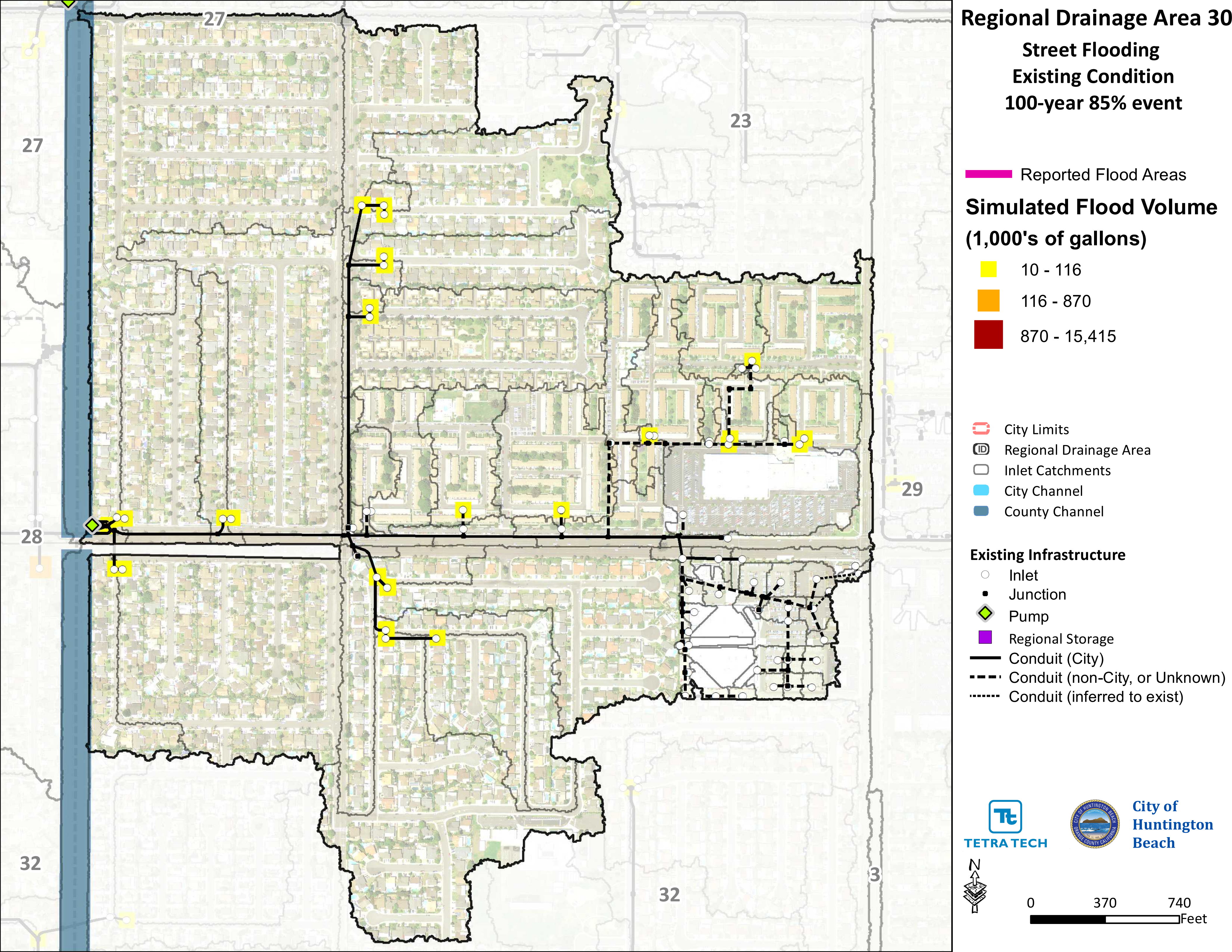
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

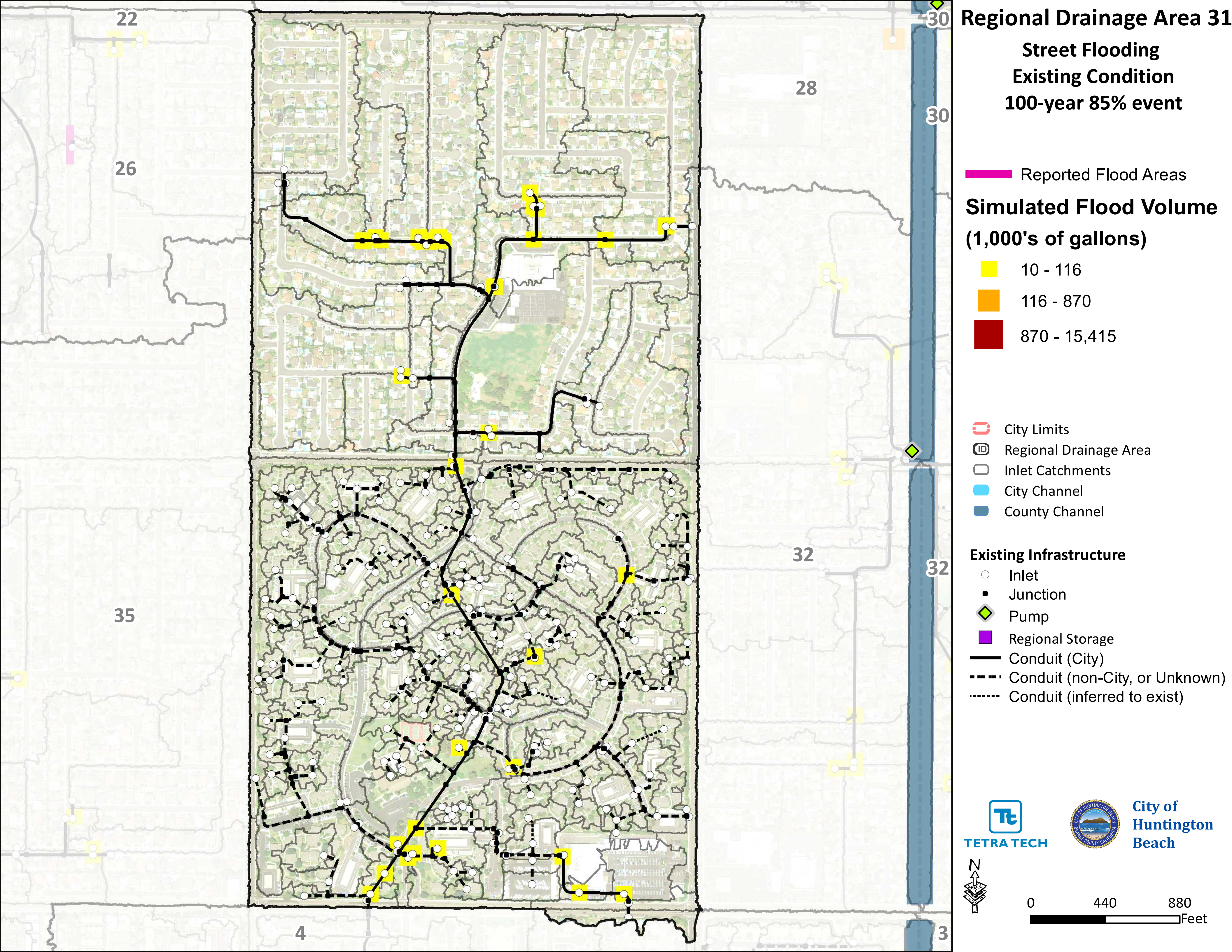
City of Huntington Beach

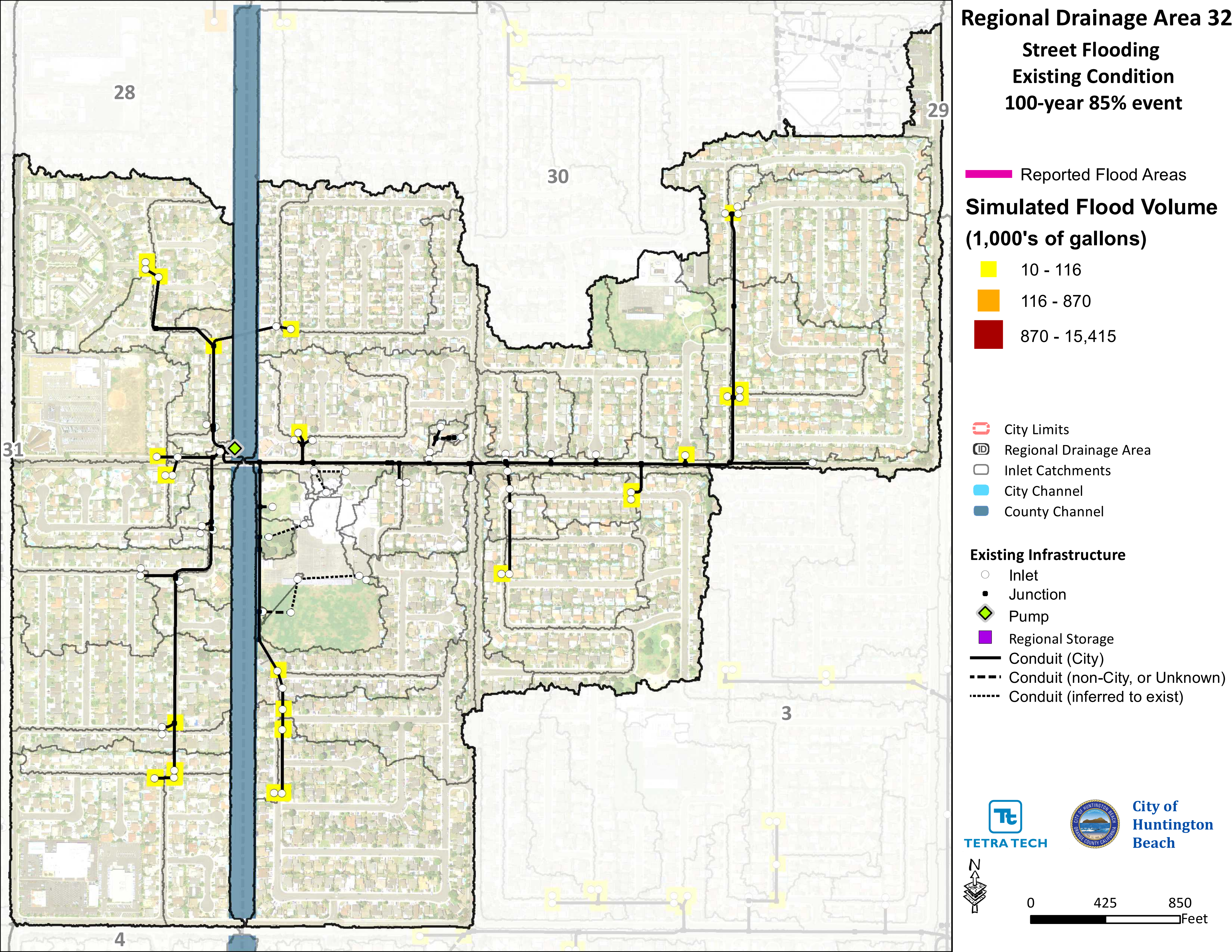
N

0 625 1,250 Feet



Regional Drainage Area 30
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
27
23
28
29
32
3
TETRA TECH
City of
Huntington
Beach
N
0
370
740
Feet

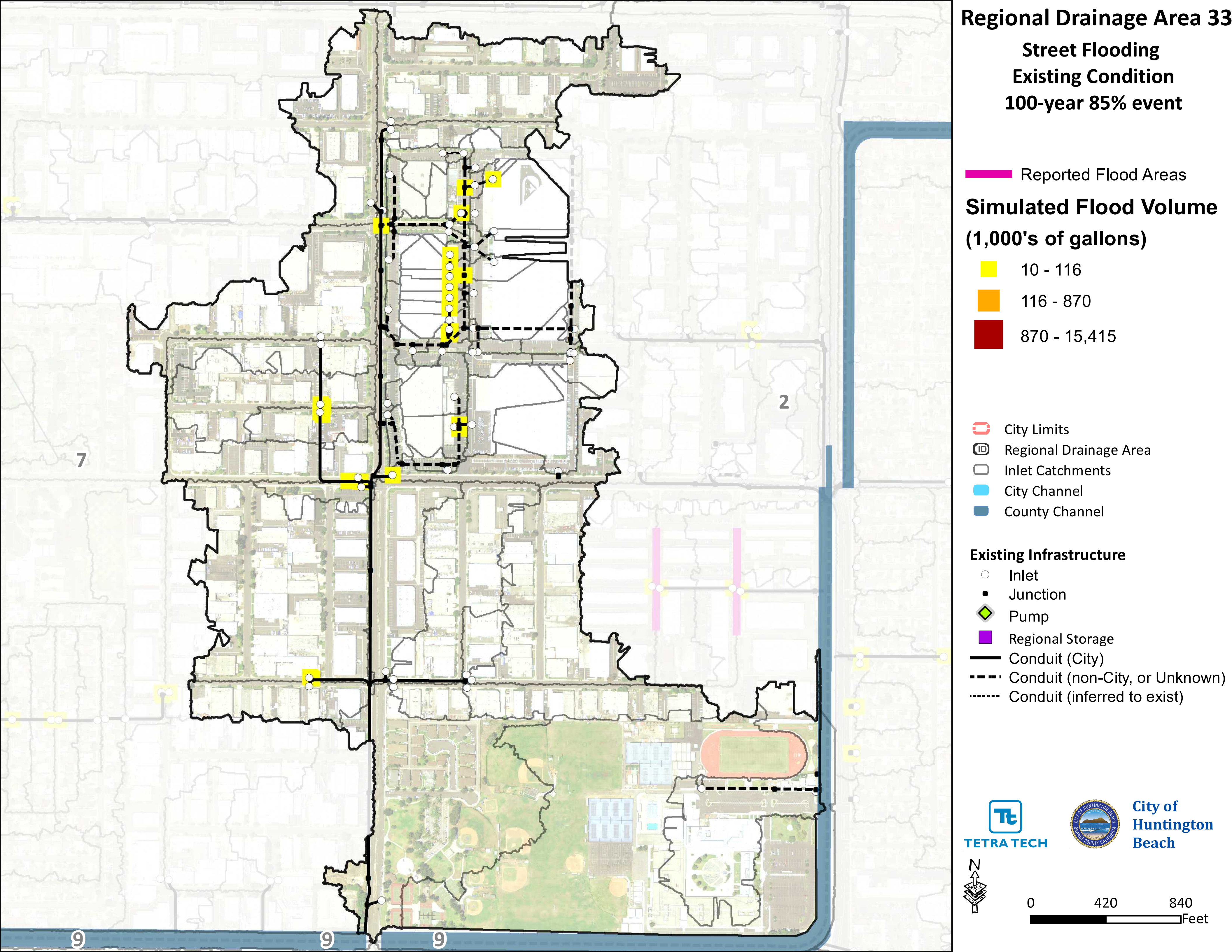

22
26
28
30
30
30
32
32
35
4
3
Regional Drainage Area 31
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of
Huntington
Beach
N
0
440
880
Feet

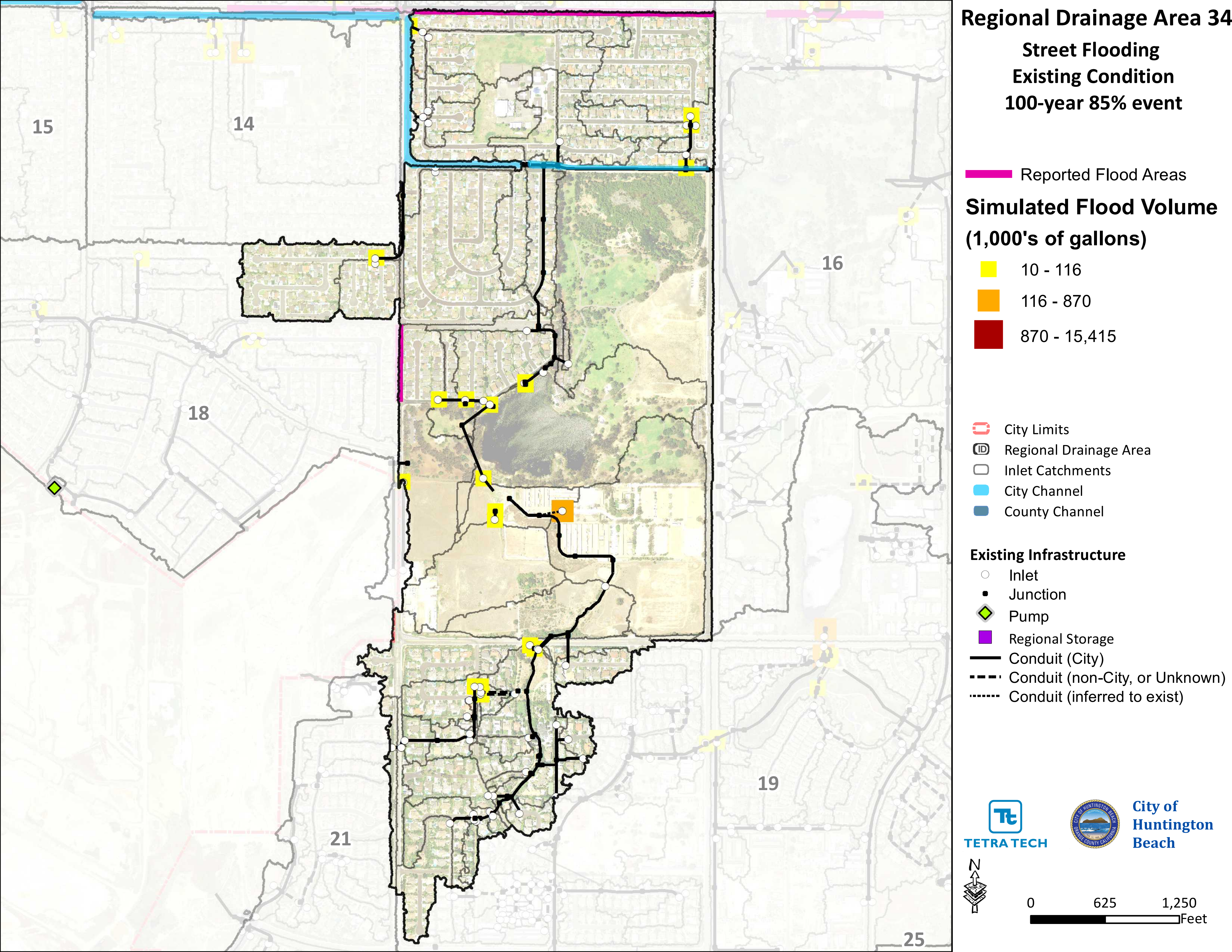


Regional Drainage Area 32
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
28
30
29
31
3
4
TETRA TECH
City of Huntington Beach
N
0
425
850
Feet

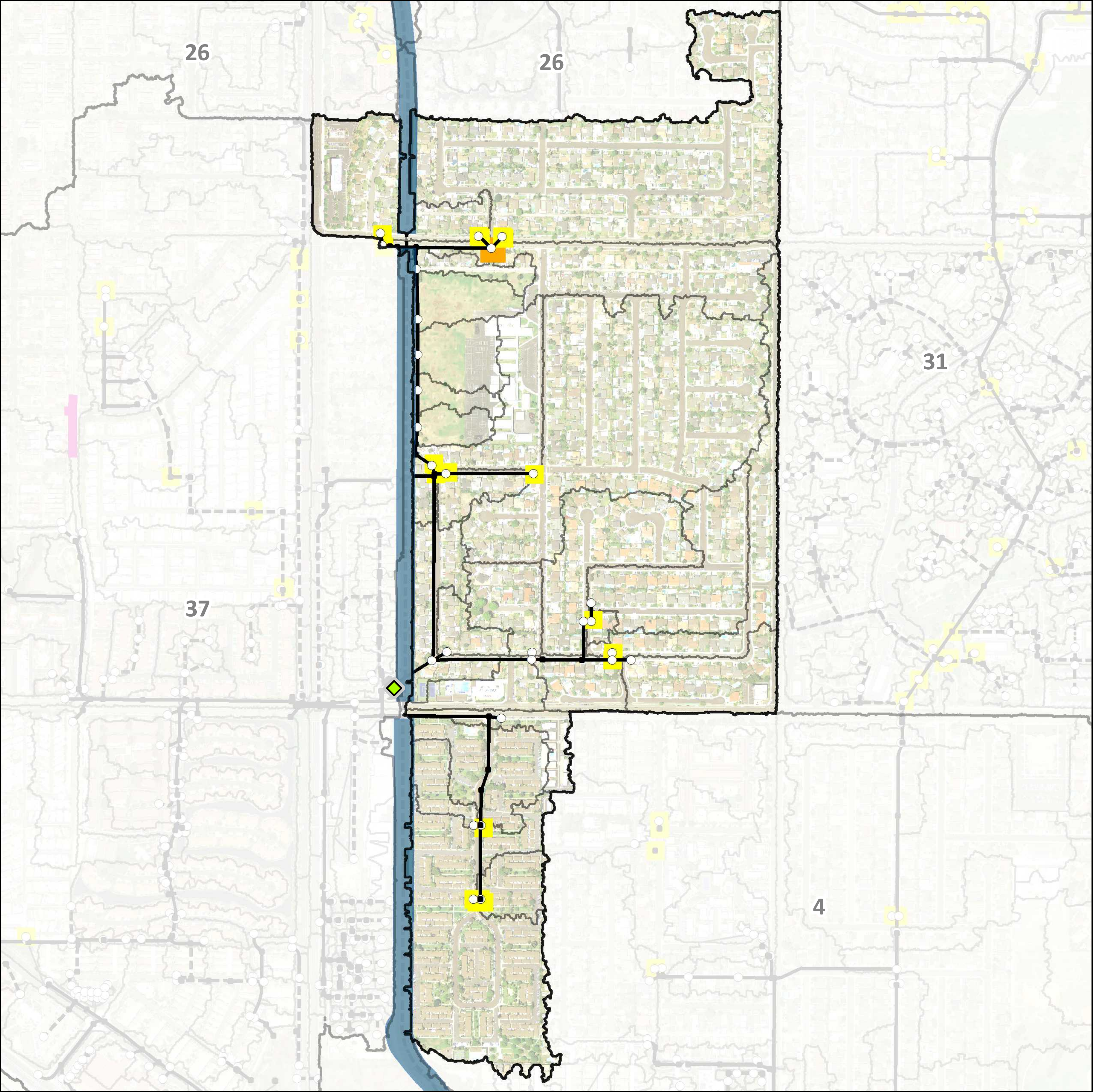
Regional Drainage Area 33

Street Flooding
Existing Condition
100-year 85% event





Regional Drainage Area 34
Street Flooding
Existing Condition
100-year 85% event
Reported Flood Areas
Simulated Flood Volume
(1,000's of gallons)
10 - 116
116 - 870
870 - 15,415
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel
Existing Infrastructure
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
TETRA TECH
City of Huntington Beach
N
0
625
1,250
Feet
15
14
16
18
19
21
25



Regional Drainage Area 35

Street Flooding
Existing Condition
100-year 85% event

Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116
116 - 870
870 - 15,415

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County Channel

Existing Infrastructure

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

TETRA TECH

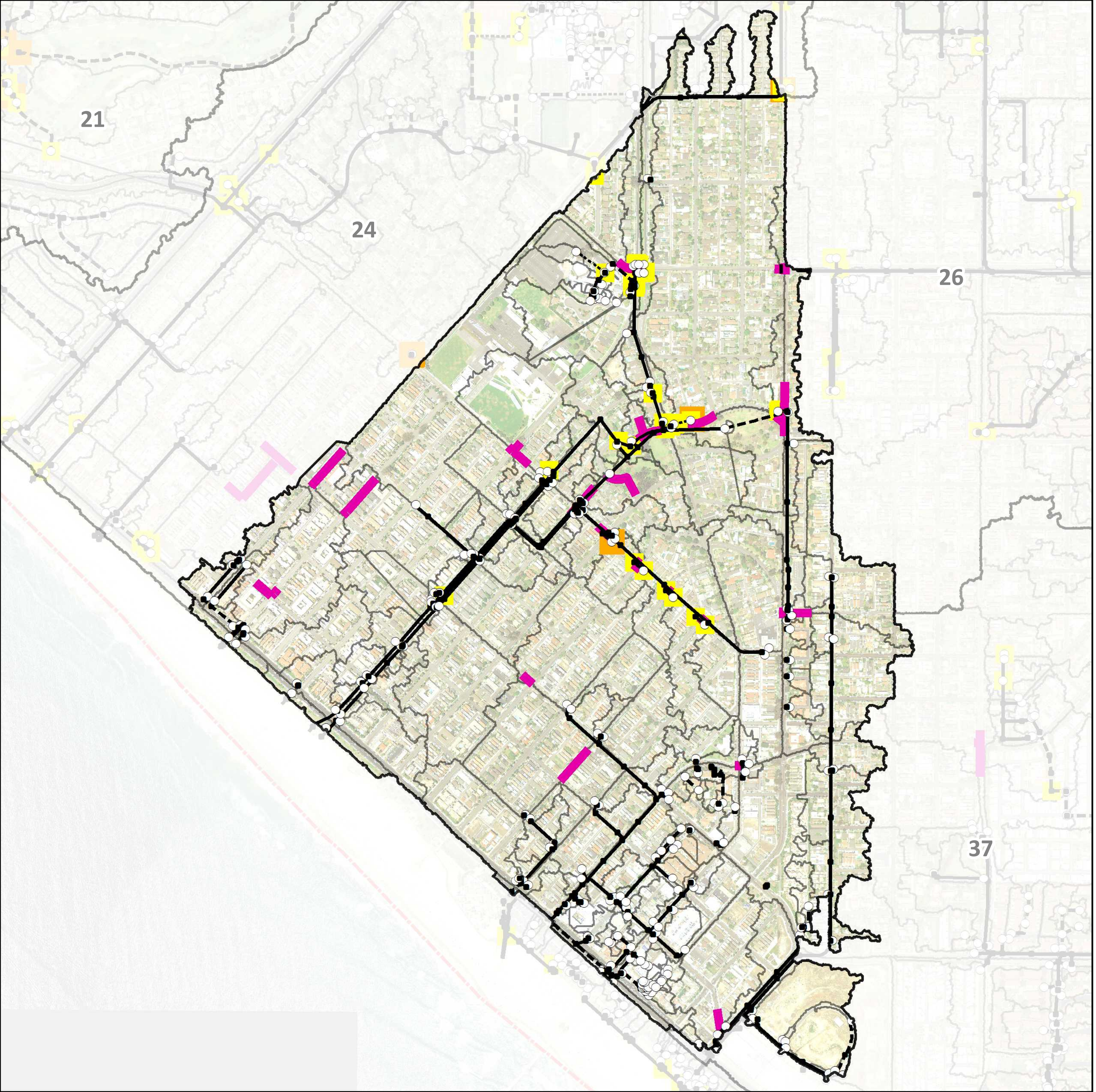
City of Huntington Beach

N

0 480 960 Feet

Regional Drainage Area 36

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

- 10 - 116
- 116 - 870
- 870 - 15,415

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County Channel

Existing Infrastructure

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

TETRA TECH

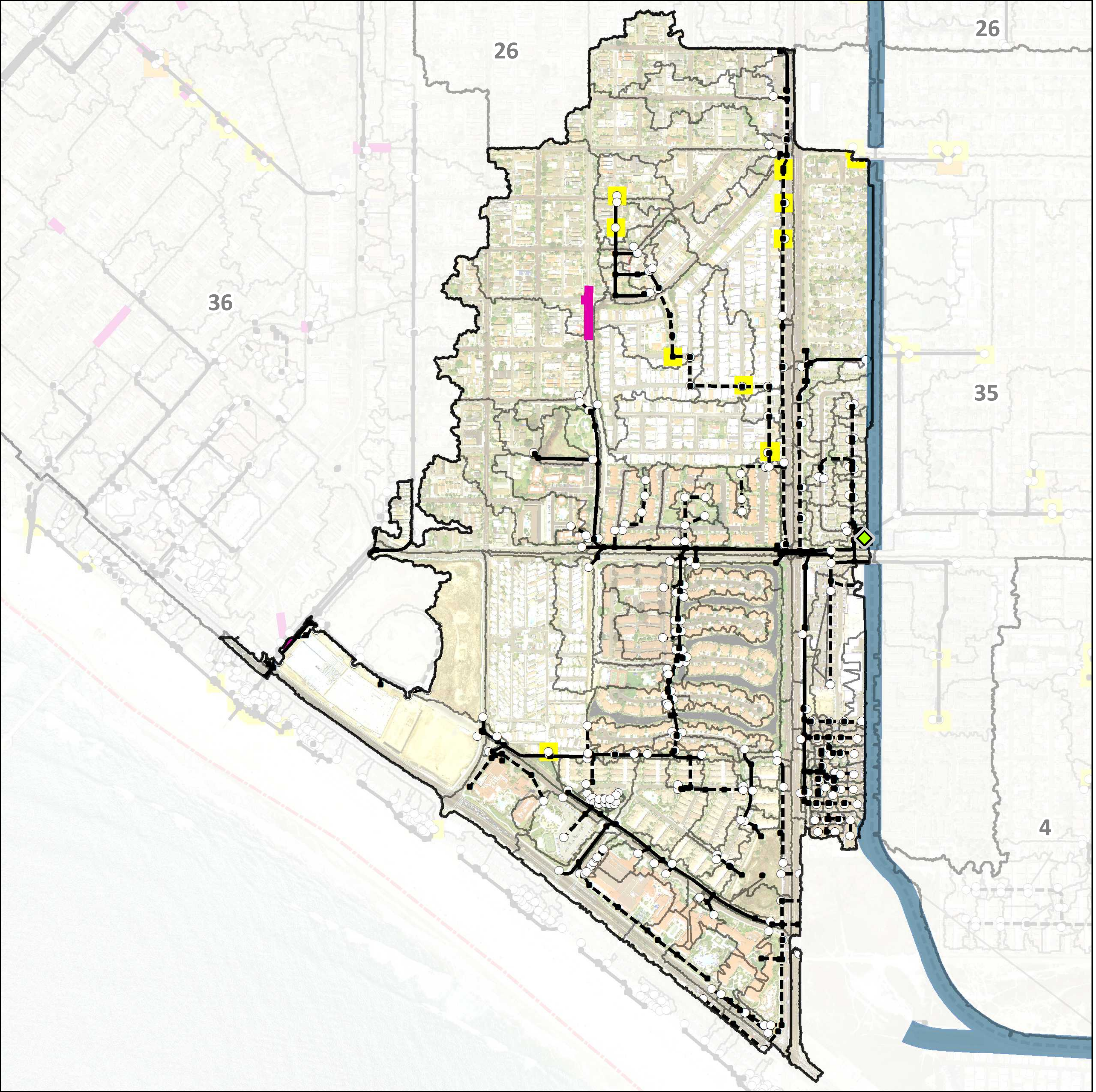
City of Huntington Beach

N

0 650 1,300 Feet

Regional Drainage Area 37

Street Flooding
Existing Condition
100-year 85% event



Reported Flood Areas

Simulated Flood Volume (1,000's of gallons)

10 - 116

116 - 870

870 - 15,415

City Limits

Regional Drainage Area

Inlet Catchments

City Channel

County Channel

Existing Infrastructure

Inlet

Junction

Pump

Regional Storage

Conduit (City)

Conduit (non-City, or Unknown)

Conduit (inferred to exist)

TETRA TECH

City of Huntington Beach

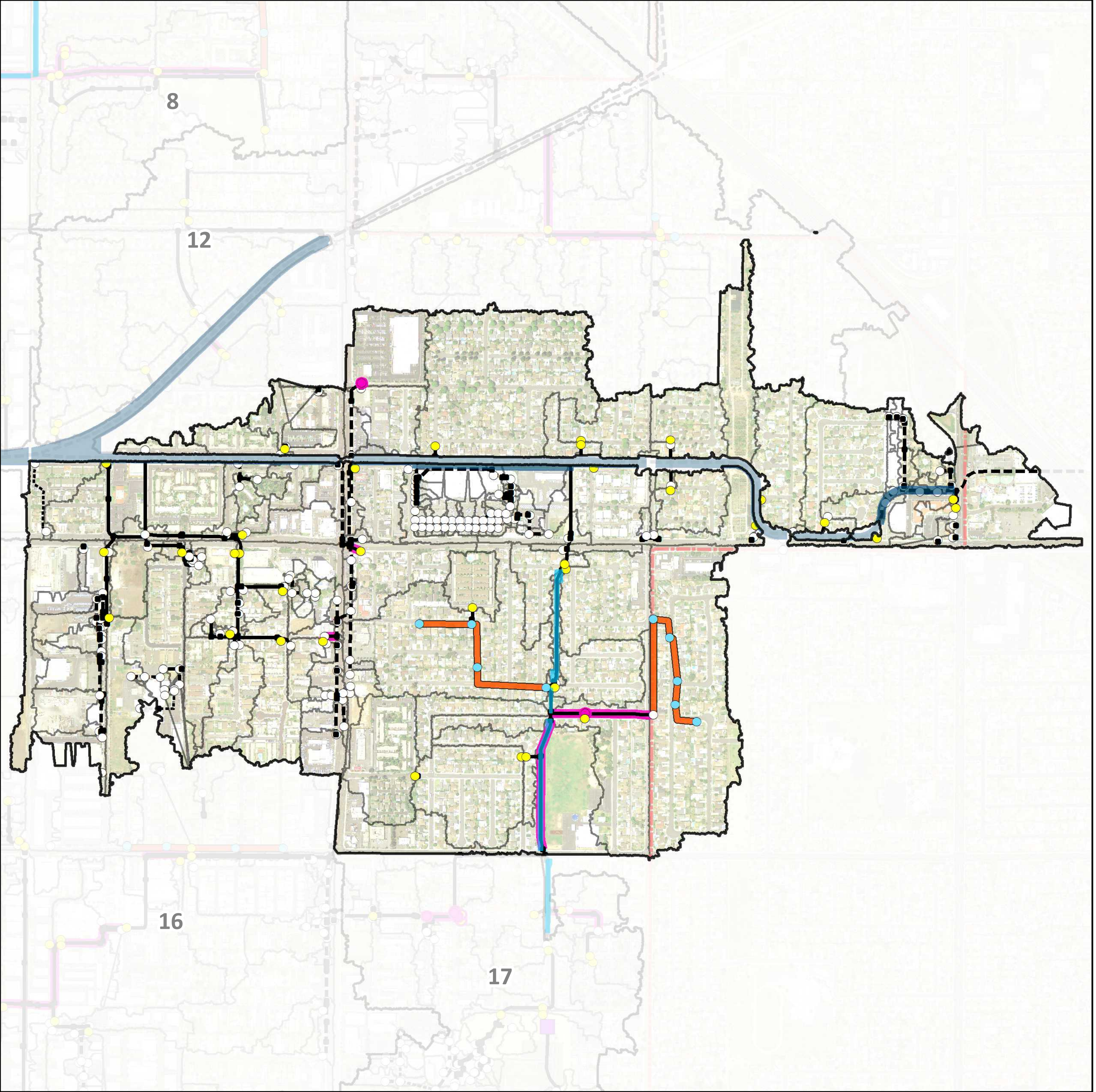
N

0 550 1,100 Feet

APPENDIX D PROPOSED CONDITION FLOOD PERFORMANCE, 100-YR

Regional Drainage Area 1

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	2,462 / 4.5%
New Conduits:	3,591 / 6.5%
	Count / %*
Upsized Inlets:	36 / 17.1%
New Inlets:	9 / 4.3%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	2 / 0.7 ac-ft

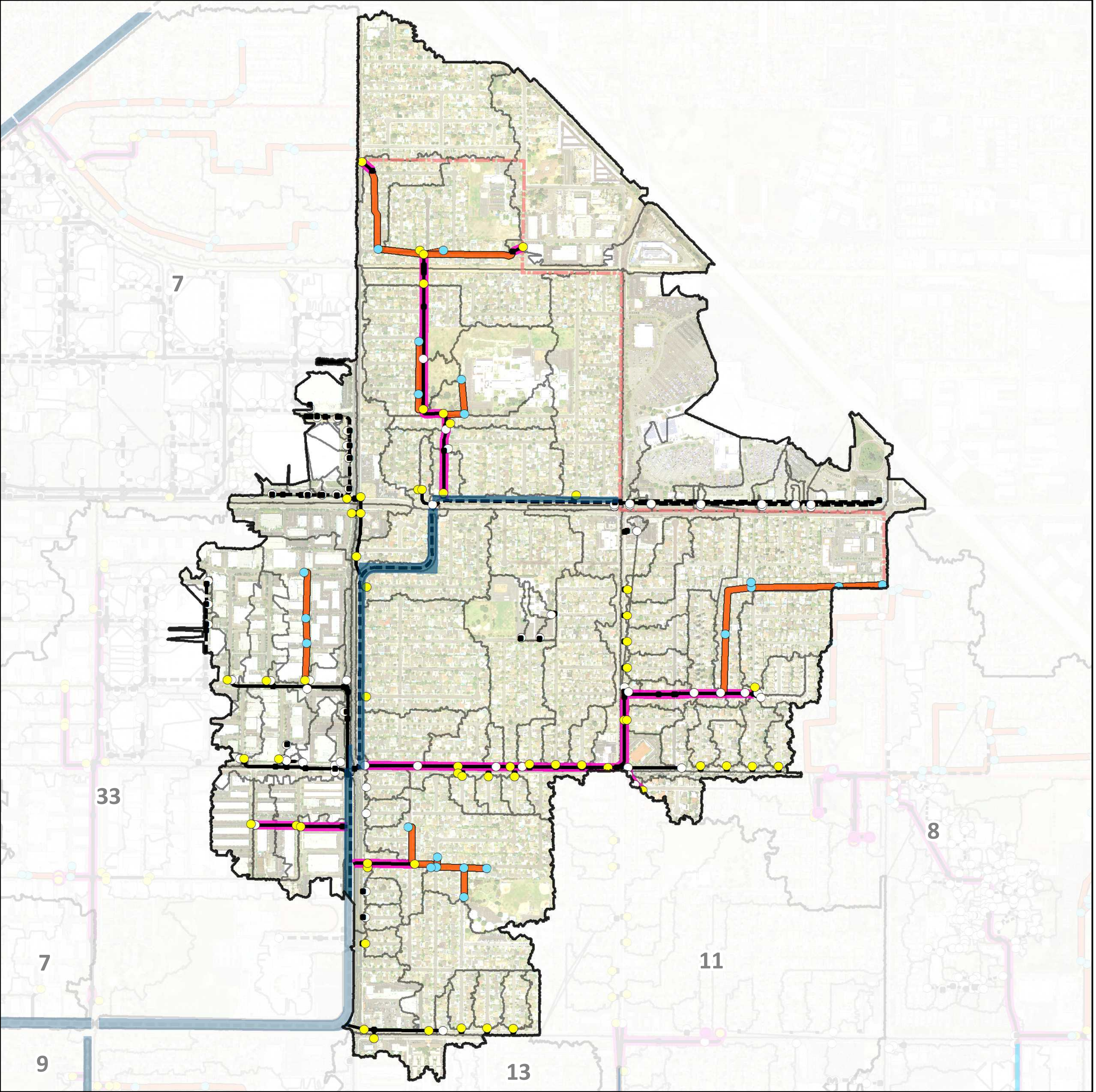
TETRA TECH

City of Huntington Beach

N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 2

Proposed Condition
100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	9,710 / 16.3%
New Conduits:	6,803 / 11.4%
	Count / %*
Upsized Inlets:	59 / 56.2%
New Inlets:	21 / 20%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

TETRA TECH

City of Huntington Beach

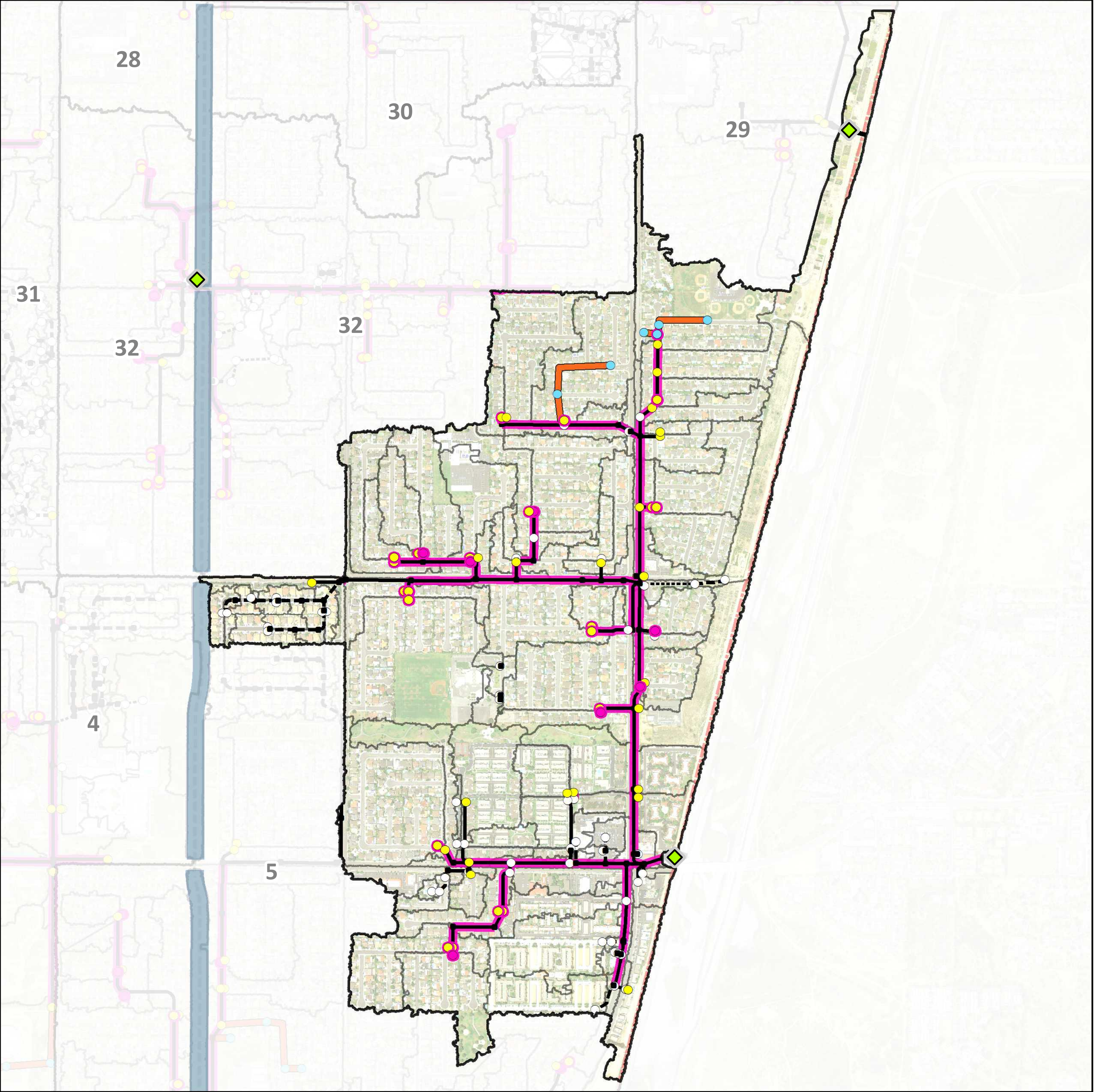
N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 3

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	16,829 / 34.4%
New Conduits:	1,810 / 3.7%
	Count / %*
Upsized Inlets:	48 / 47.1%
New Inlets:	5 / 4.9%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	29 / 16 ac-ft

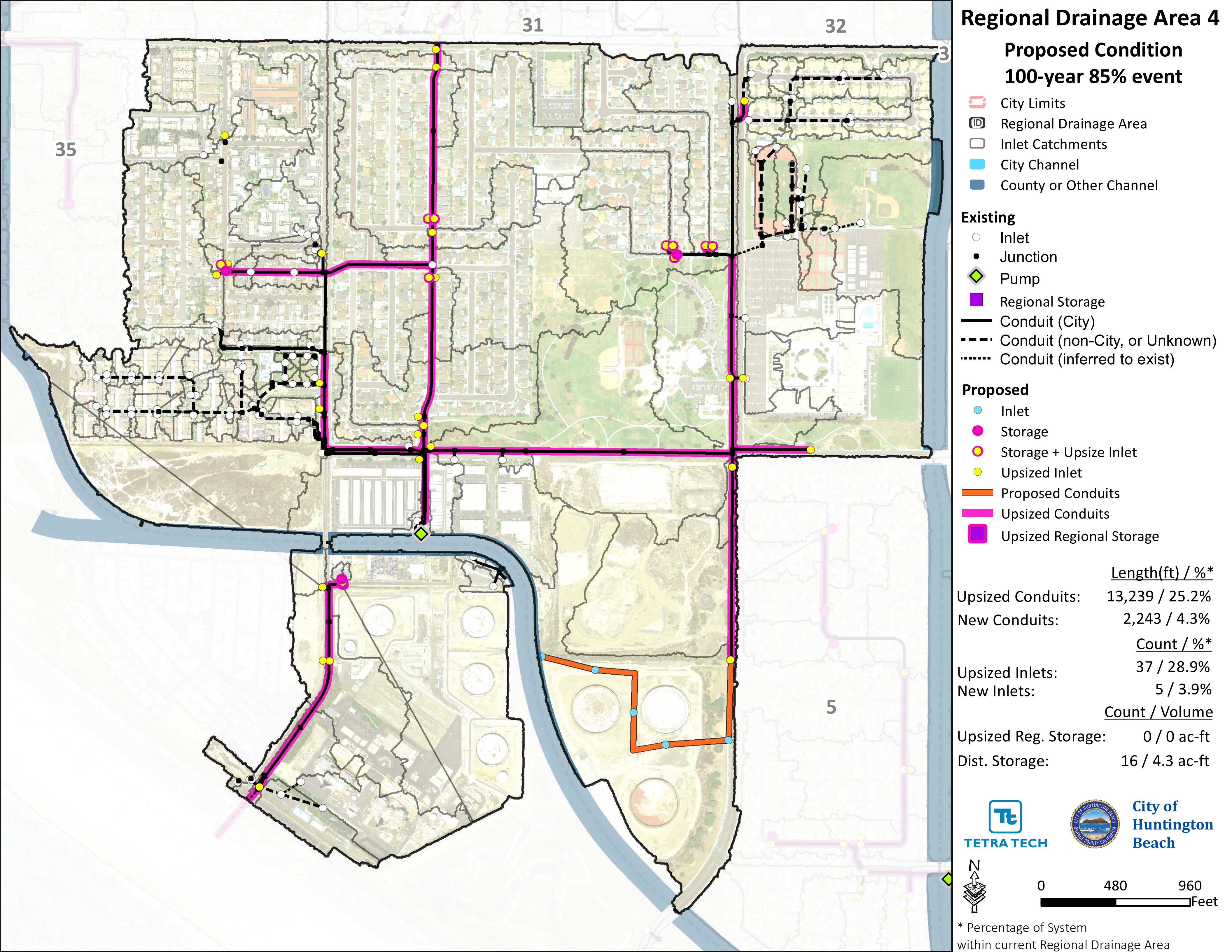
TETRA TECH

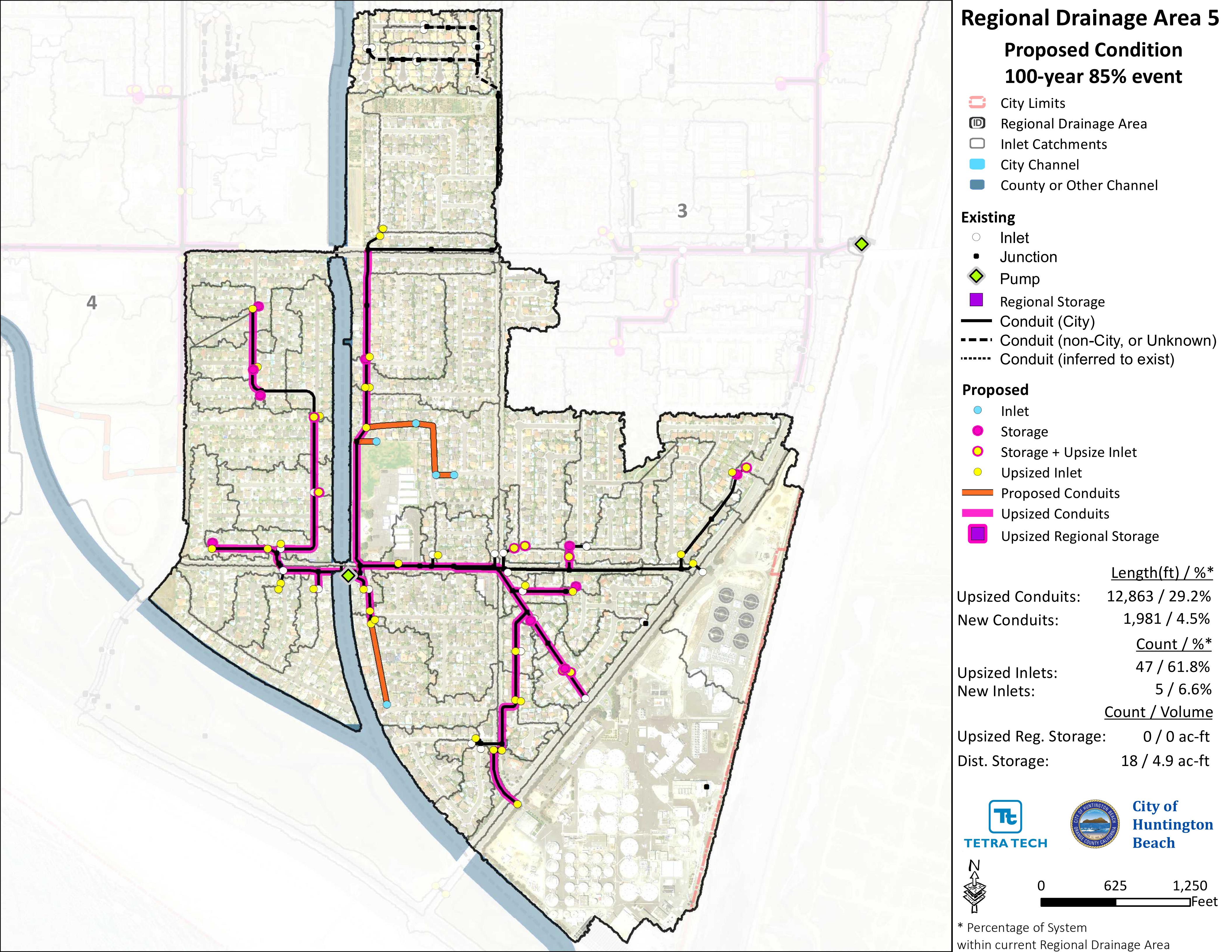
City of Huntington Beach

N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area


Regional Drainage Area 4
Proposed Condition
100-year 85% event
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel
Existing
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
Proposed
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage
Length(ft) / %*
Upsized Conduits: 13,239 / 25.2%
New Conduits: 2,243 / 4.3%
Count / %*
Upsized Inlets: 37 / 28.9%
New Inlets: 5 / 3.9%
Count / Volume
Upsized Reg. Storage: 0 / 0 ac-ft
Dist. Storage: 16 / 4.3 ac-ft
TETRA TECH
City of Huntington Beach
N
0 480 960 Feet
* Percentage of System within current Regional Drainage Area
31
32
35
5
3


Regional Drainage Area 5
Proposed Condition
100-year 85% event
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel
Existing
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
Proposed
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage
Length(ft) / %*
Upsized Conduits: 12,863 / 29.2%
New Conduits: 1,981 / 4.5%
Count / %*
Upsized Inlets: 47 / 61.8%
New Inlets: 5 / 6.6%
Count / Volume
Upsized Reg. Storage: 0 / 0 ac-ft
Dist. Storage: 18 / 4.9 ac-ft
TETRA TECH
City of Huntington Beach
N
0 625 1,250 Feet
* Percentage of System within current Regional Drainage Area
3
4

Regional Drainage Area 6

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	4,512 / 5%
New Conduits:	3,794 / 4.2%
	Count / %*
Upsized Inlets:	55 / 12.6%
New Inlets:	12 / 2.7%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	2 / 0.3 ac-ft

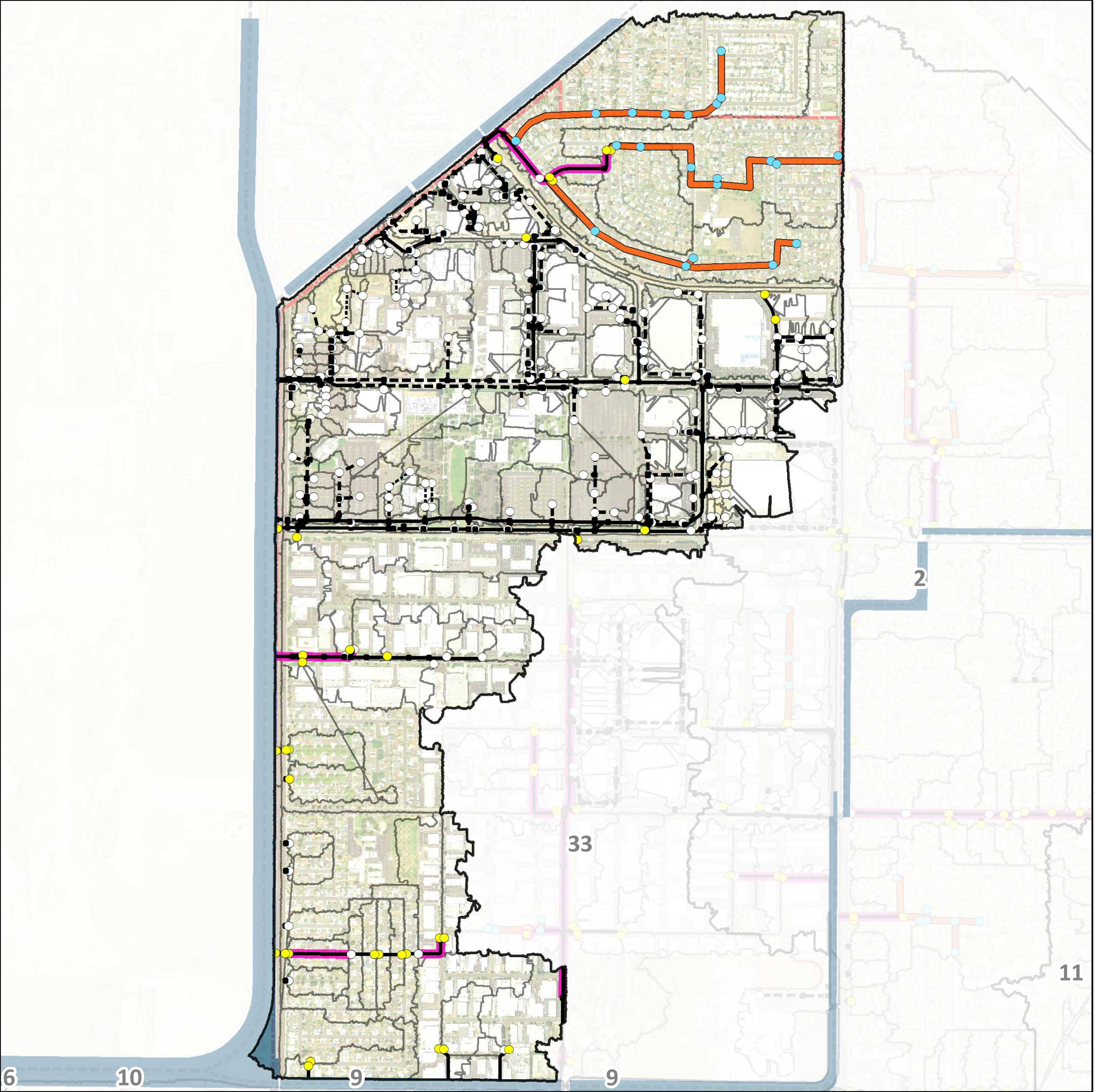
TETRA TECH

City of Huntington Beach

N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 7

Proposed Condition

100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	4,175 / 4.7%
New Conduits:	8,517 / 9.6%
	Count / %*
Upsized Inlets:	35 / 12.6%
New Inlets:	21 / 7.6%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

TETRA TECH

City of Huntington Beach

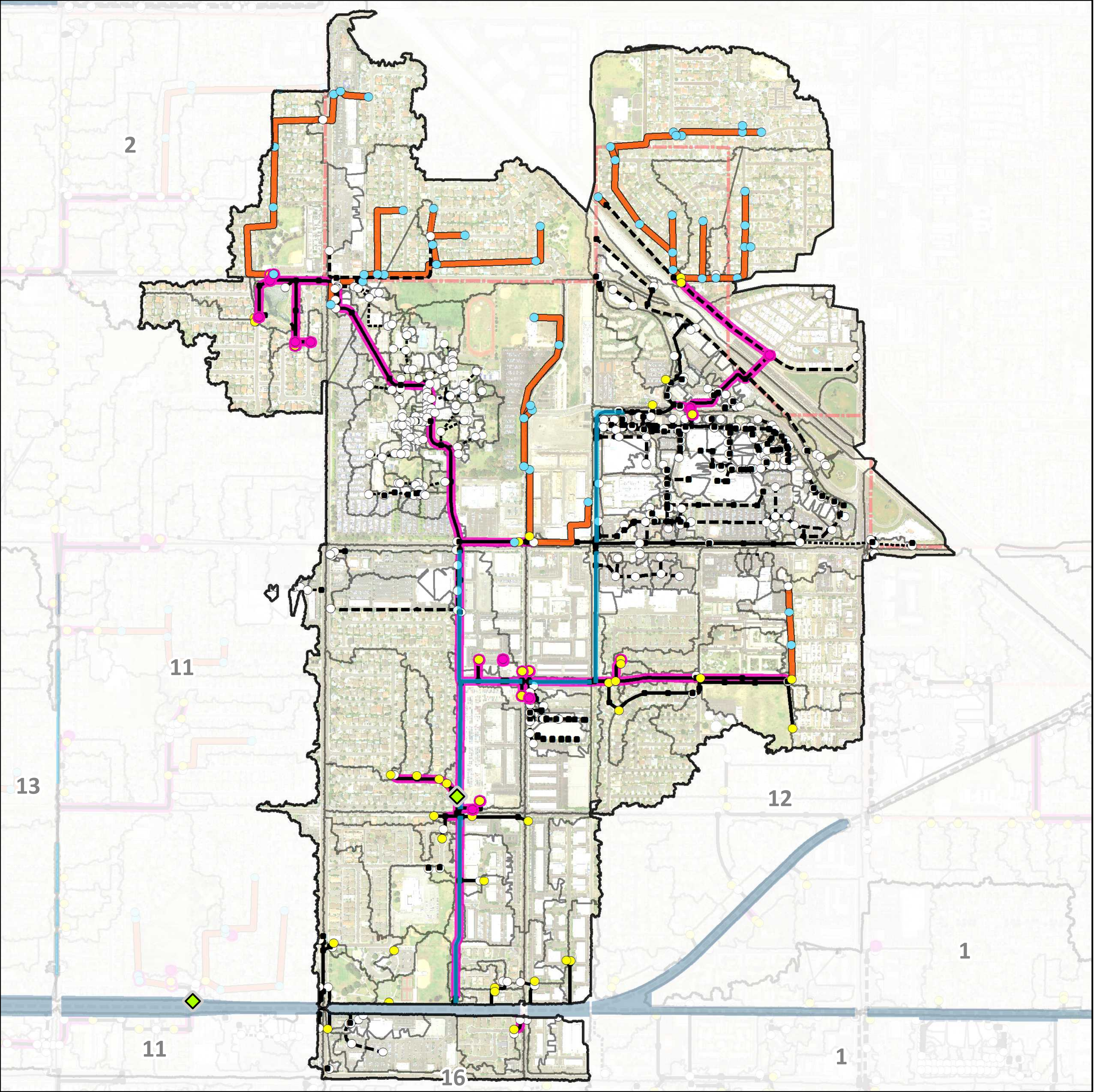
N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 8

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

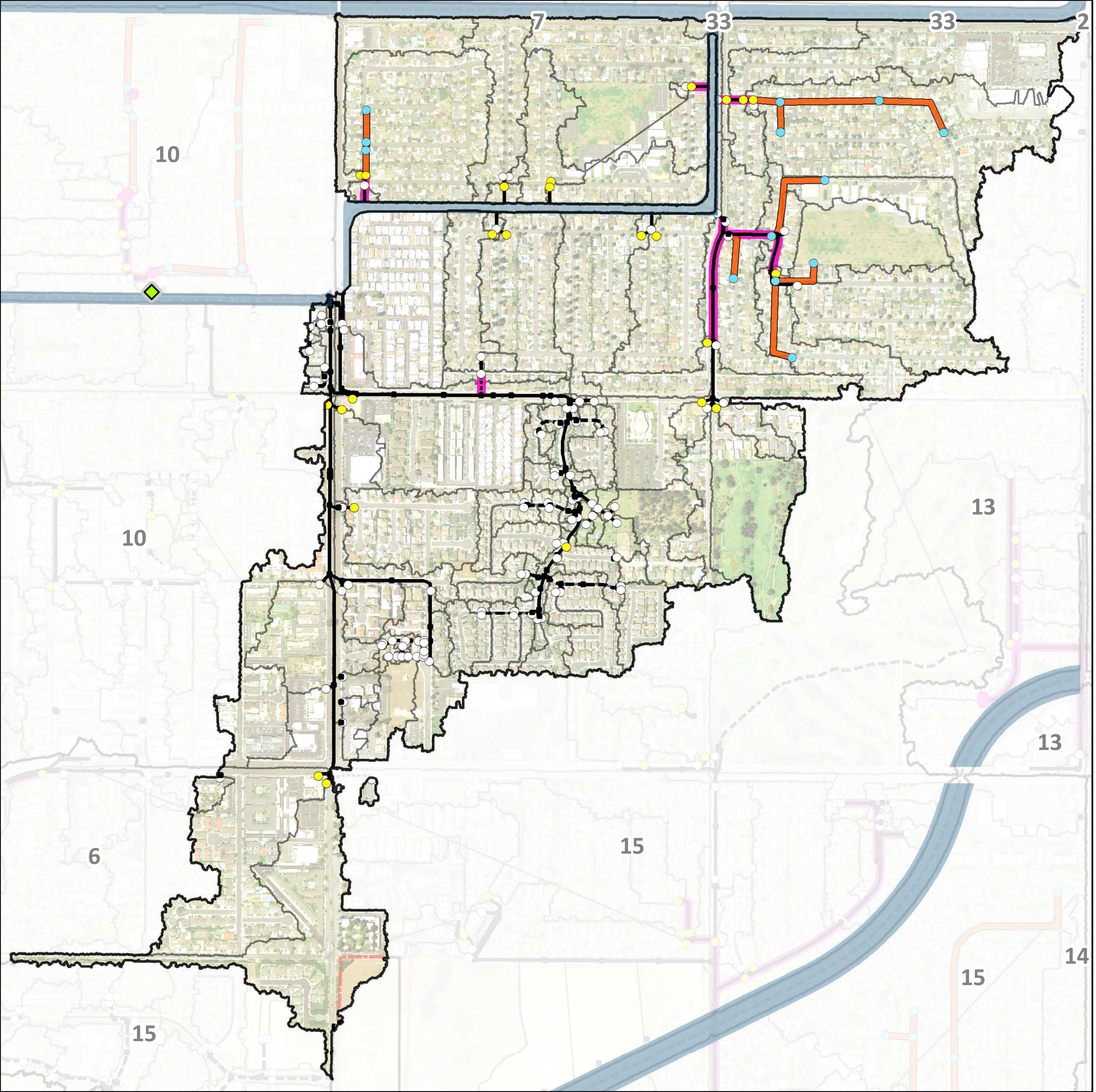
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	19,511 / 17.8%
New Conduits:	18,434 / 16.8%
	Count / %*
Upsized Inlets:	43 / 11.1%
New Inlets:	50 / 12.9%
	Count / Volume
Upsized Reg. Storage:	1 / 12.28 ac-ft
Dist. Storage:	22 / 18.4 ac-ft

TETRA TECH

City of Huntington Beach

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 9

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	2,518 / 6.2%
New Conduits:	4,291 / 10.5%
	Count / %*
Upsized Inlets:	24 / 18.3%
New Inlets:	13 / 9.9%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

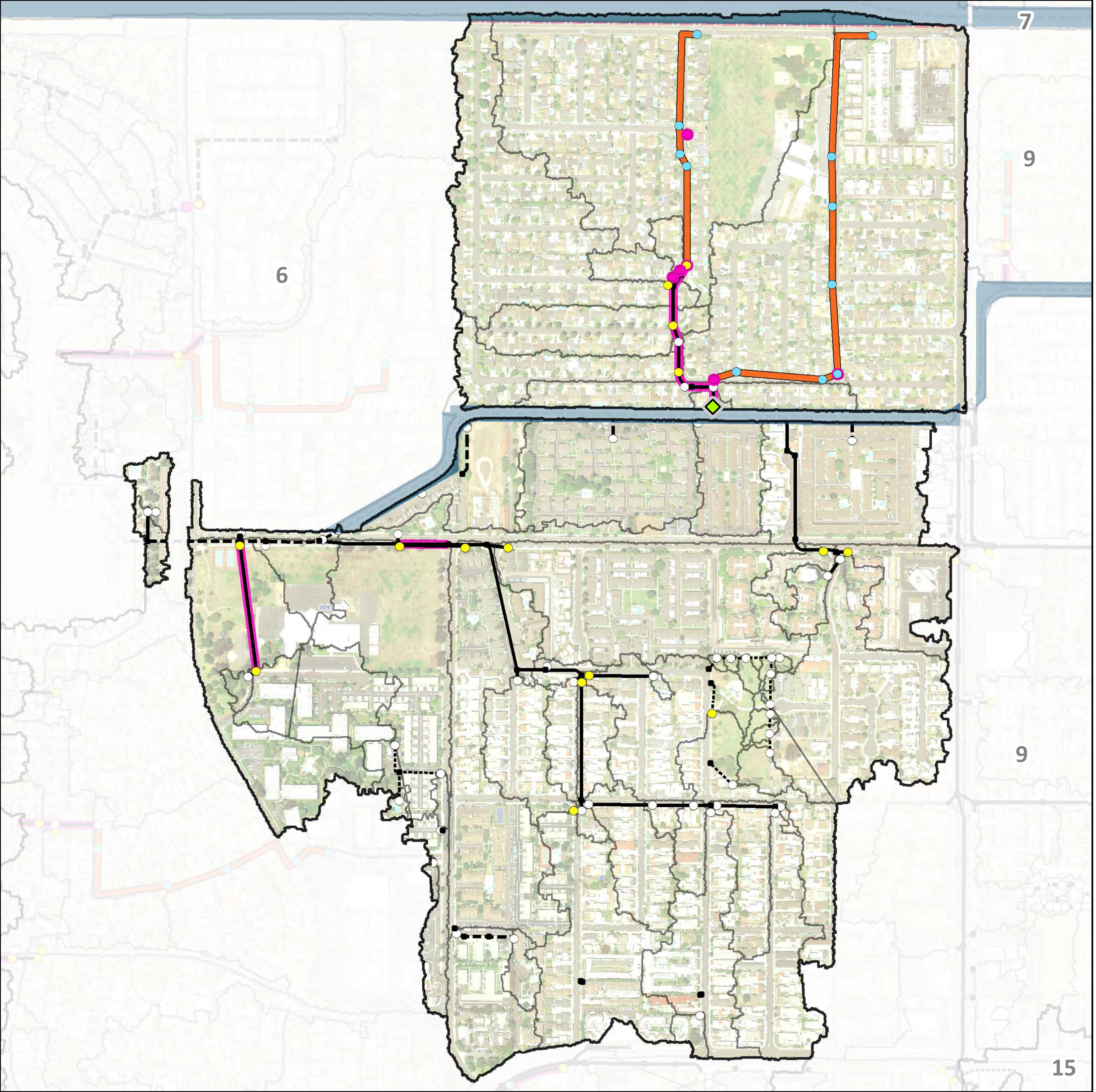
TETRA TECH

City of Huntington Beach

N

0 600 1,200 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 10

Proposed Condition
100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing
- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed
- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	1,903 / 7.5%
New Conduits:	3,842 / 15.1%
	Count / %*
Upsized Inlets:	16 / 23.9%
New Inlets:	11 / 16.4%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	6 / 1 ac-ft

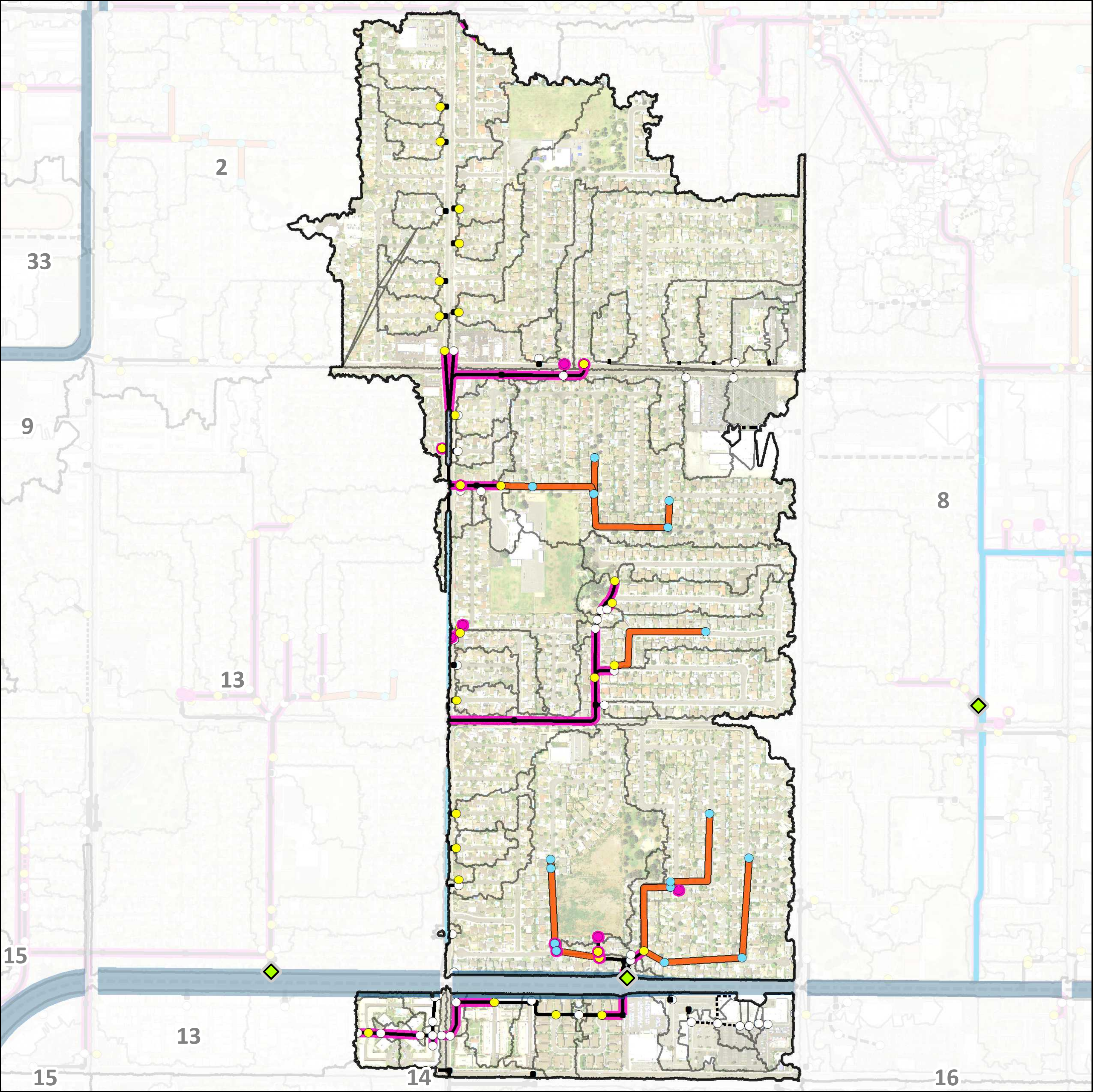
TETRA TECH

City of Huntington Beach

N

0 437.5 875 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 11

Proposed Condition

100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	7,595 / 23.9%
New Conduits:	6,620 / 20.8%
	Count / %*
Upsized Inlets:	30 / 37.5%
New Inlets:	16 / 20%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	12 / 4.4 ac-ft

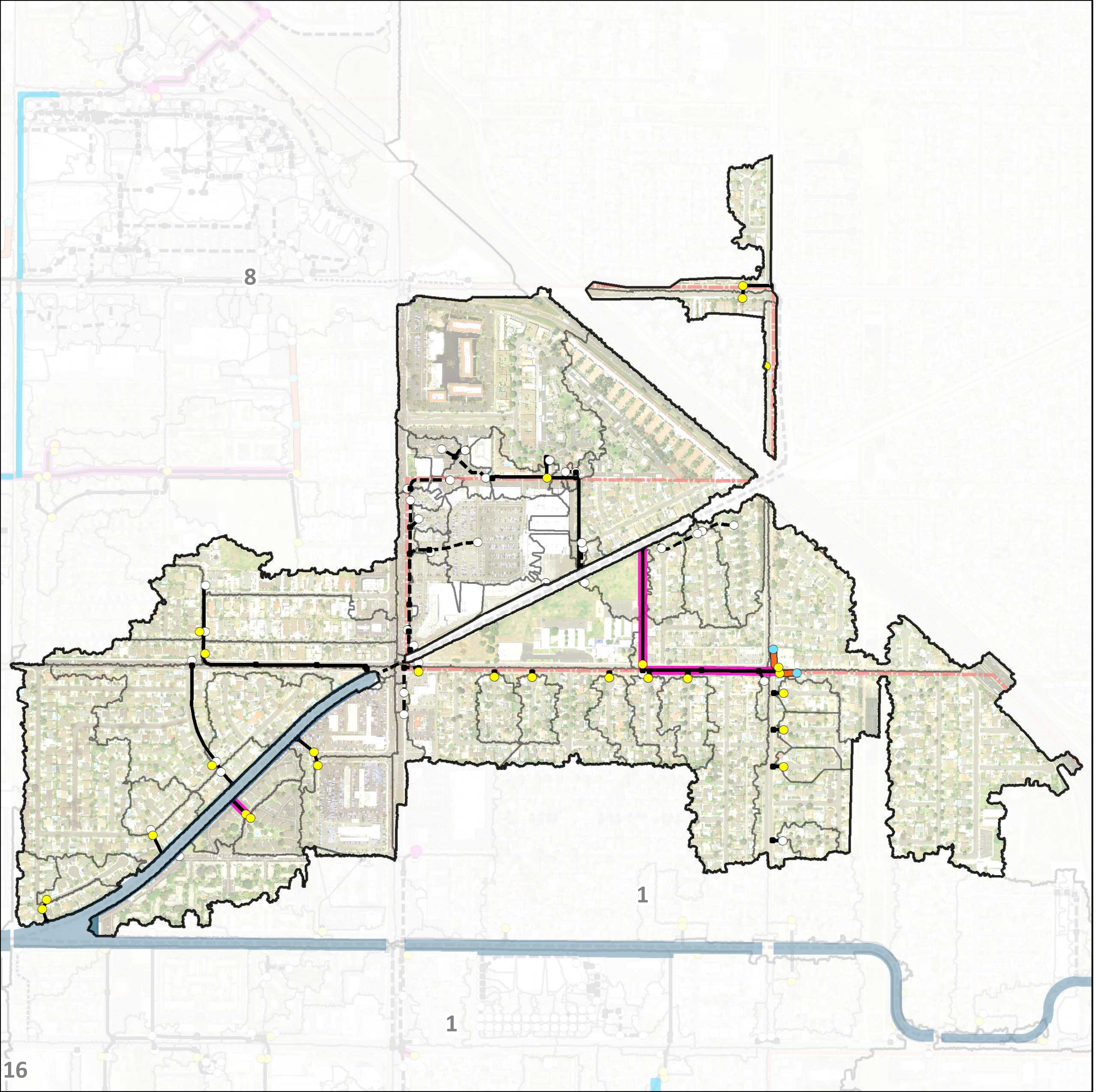
TETRA TECH

City of Huntington Beach

N

0 625 1,250 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 12

Proposed Condition
100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	2,211 / 10.3%
New Conduits:	271 / 1.3%
	Count / %*
Upsized Inlets:	26 / 42.6%
New Inlets:	2 / 3.3%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

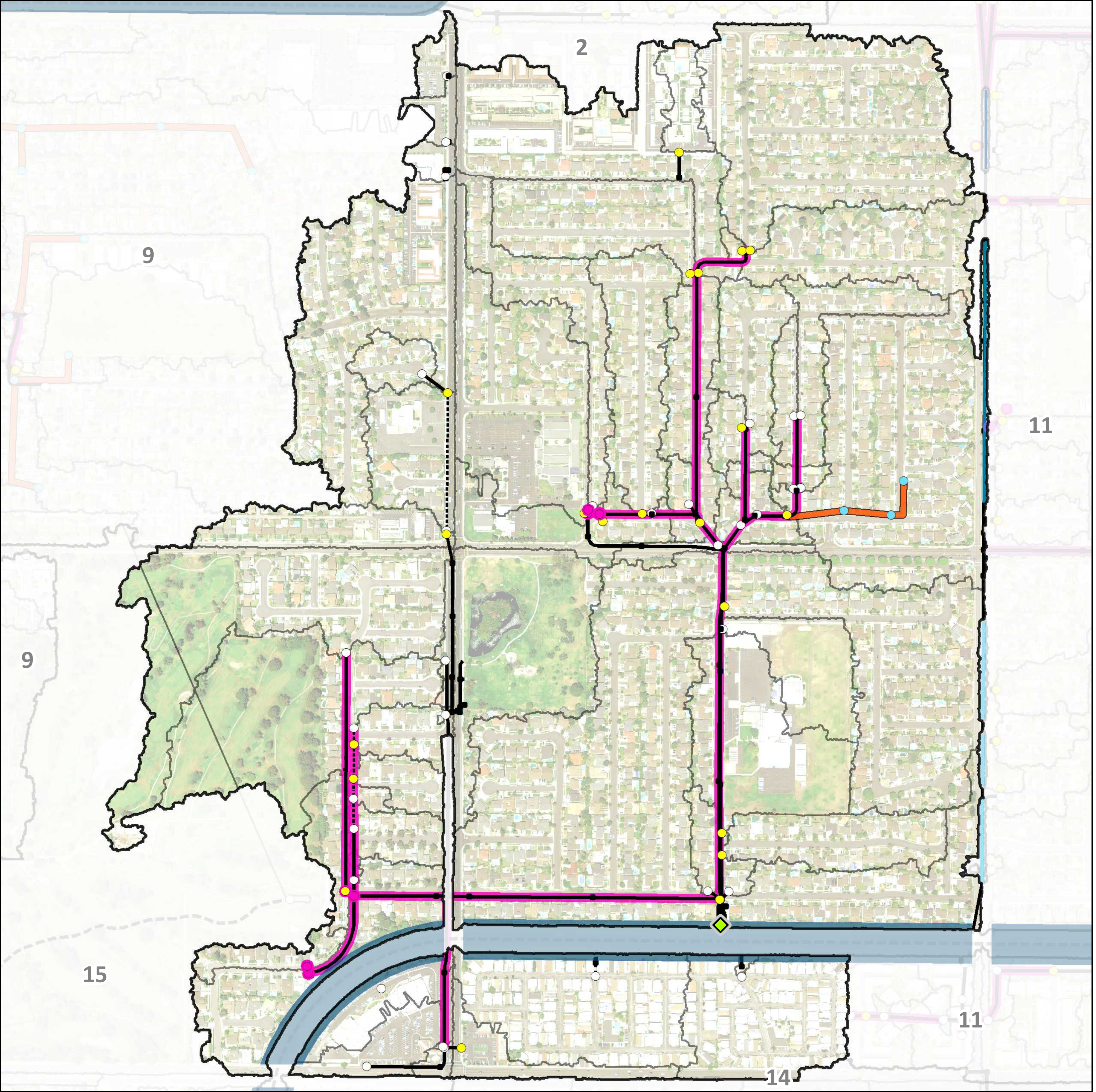
TETRA TECH

City of Huntington Beach

N

0 600 1,200 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 13

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	11,446 / 29.5%
New Conduits:	748 / 1.9%
	Count / %*
Upsized Inlets:	23 / 40.4%
New Inlets:	3 / 5.3%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	9 / 4.7 ac-ft

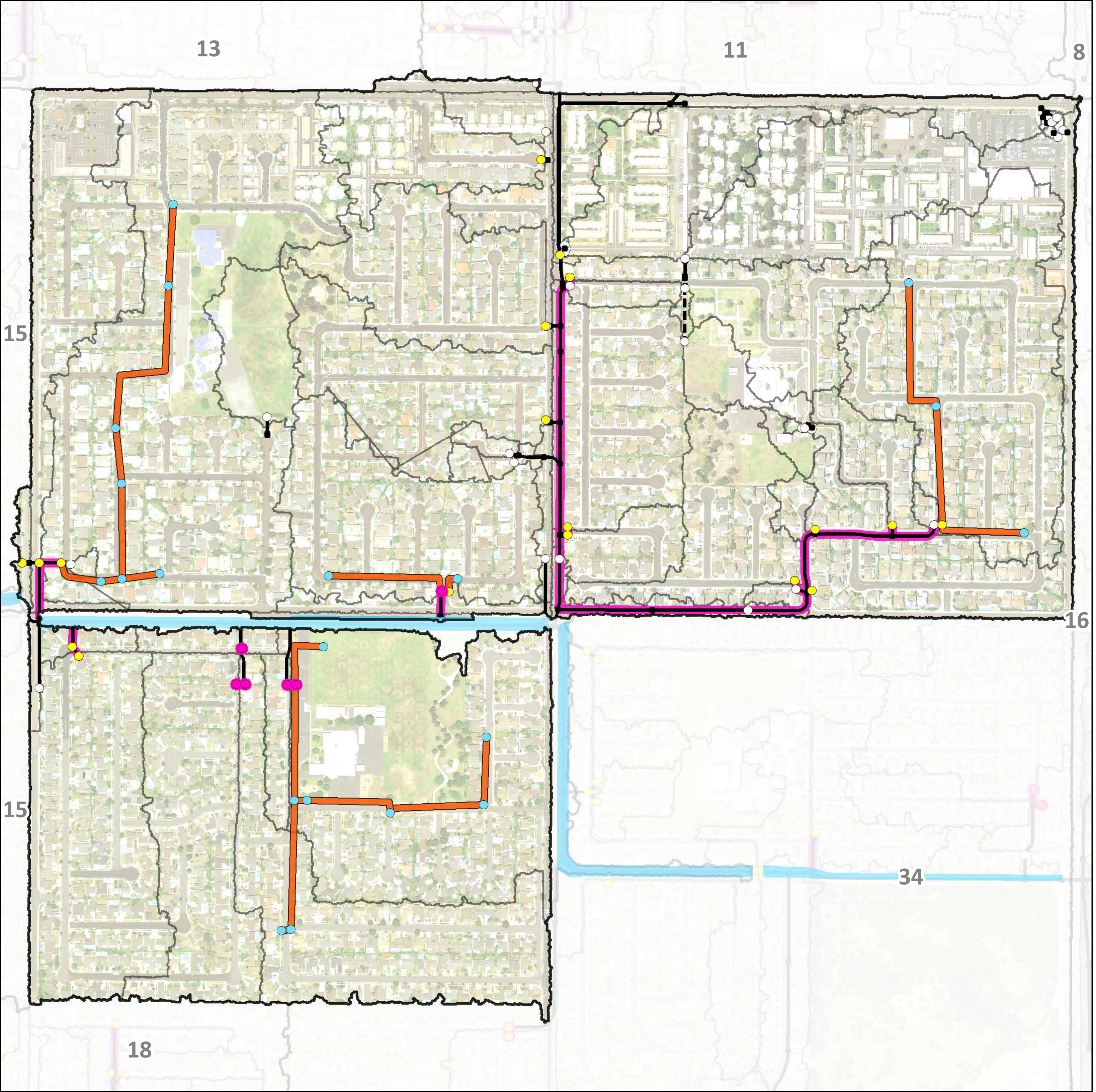
TETRA TECH

City of Huntington Beach

N

0 425 850 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 14

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	5,117 / 15.6%
New Conduits:	2,541 / 7.7%
	Count / %*
Upsized Inlets:	24 / 44.4%
New Inlets:	20 / 37%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	6 / 3.1 ac-ft

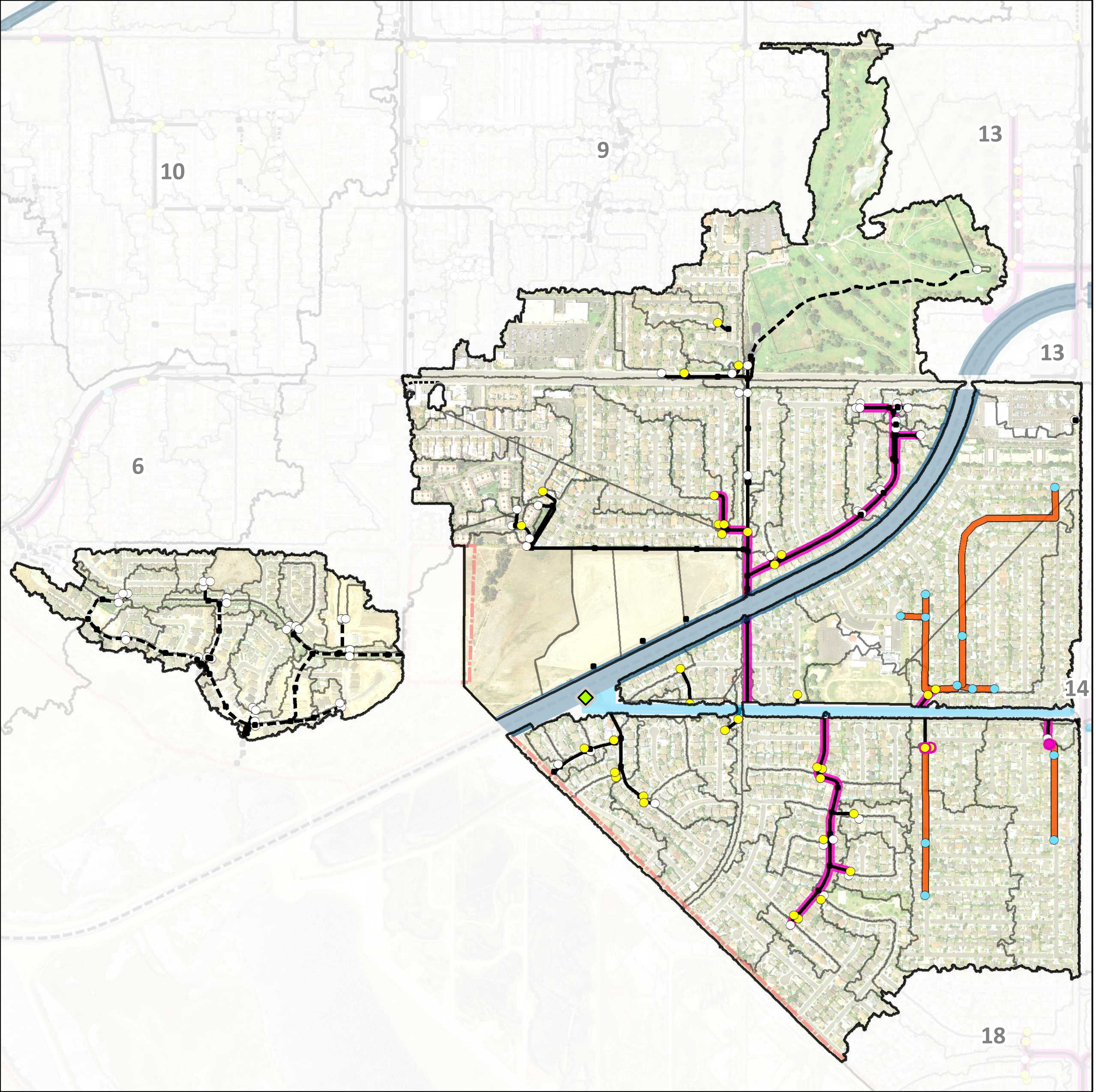
TETRA TECH
City of Huntington Beach

N
0 435 870 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 15

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	7,241 / 14%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	37 / 35.9%
New Inlets:	12 / 11.7%
	Count / Volume
Upsized Reg. Storage:	1 / 2.36 ac-ft
Dist. Storage:	3 / 3.3 ac-ft

TETRA TECH

City of Huntington Beach

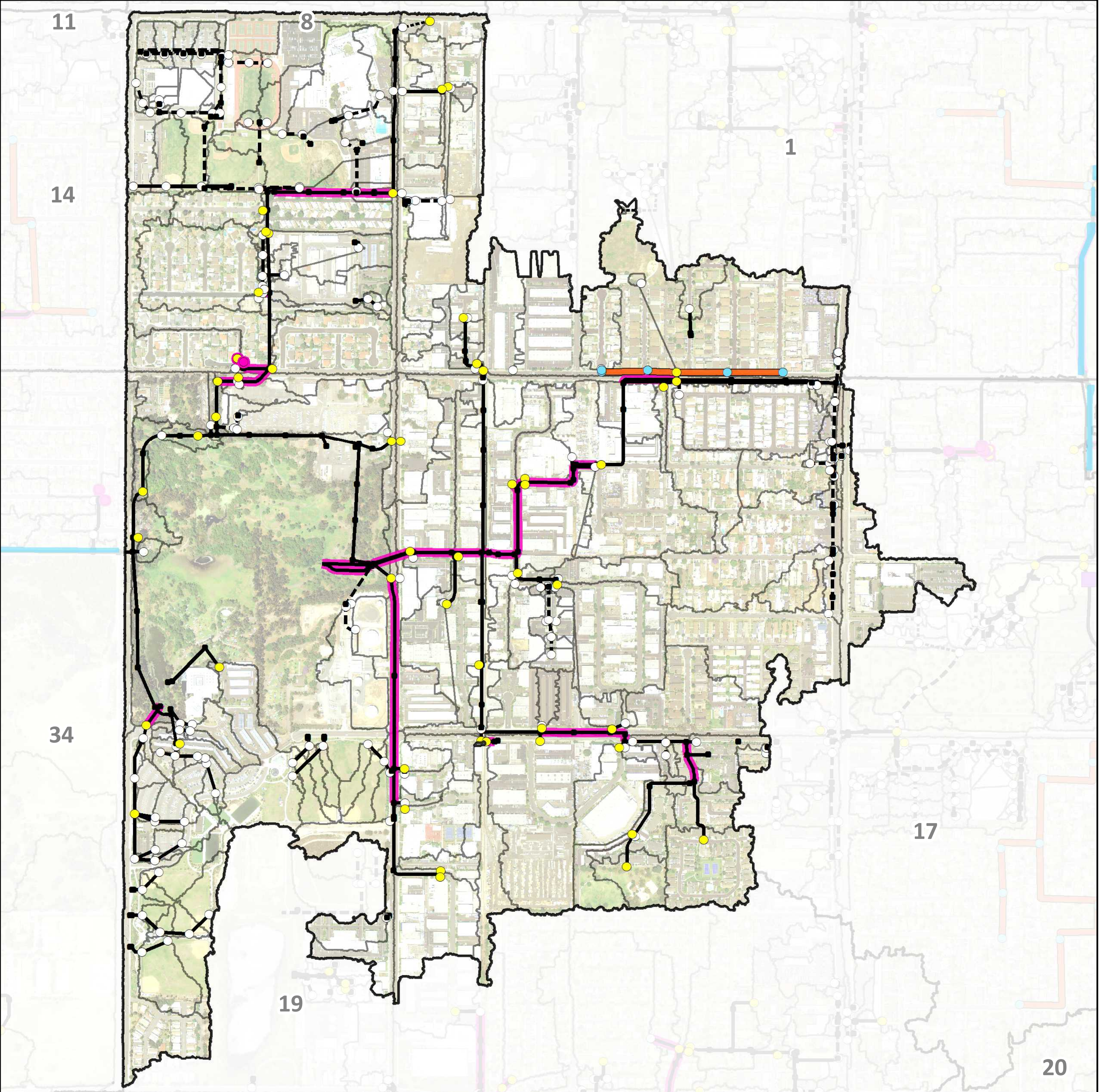
N

0 650 1,300 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 16

Proposed Condition
100-year 85% event



- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	8,598 / 10.7%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	52 / 24%
New Inlets:	5 / 2.3%
	Count / Volume
Upsized Reg. Storage:	1 / 1.35 ac-ft
Dist. Storage:	2 / 1.3 ac-ft

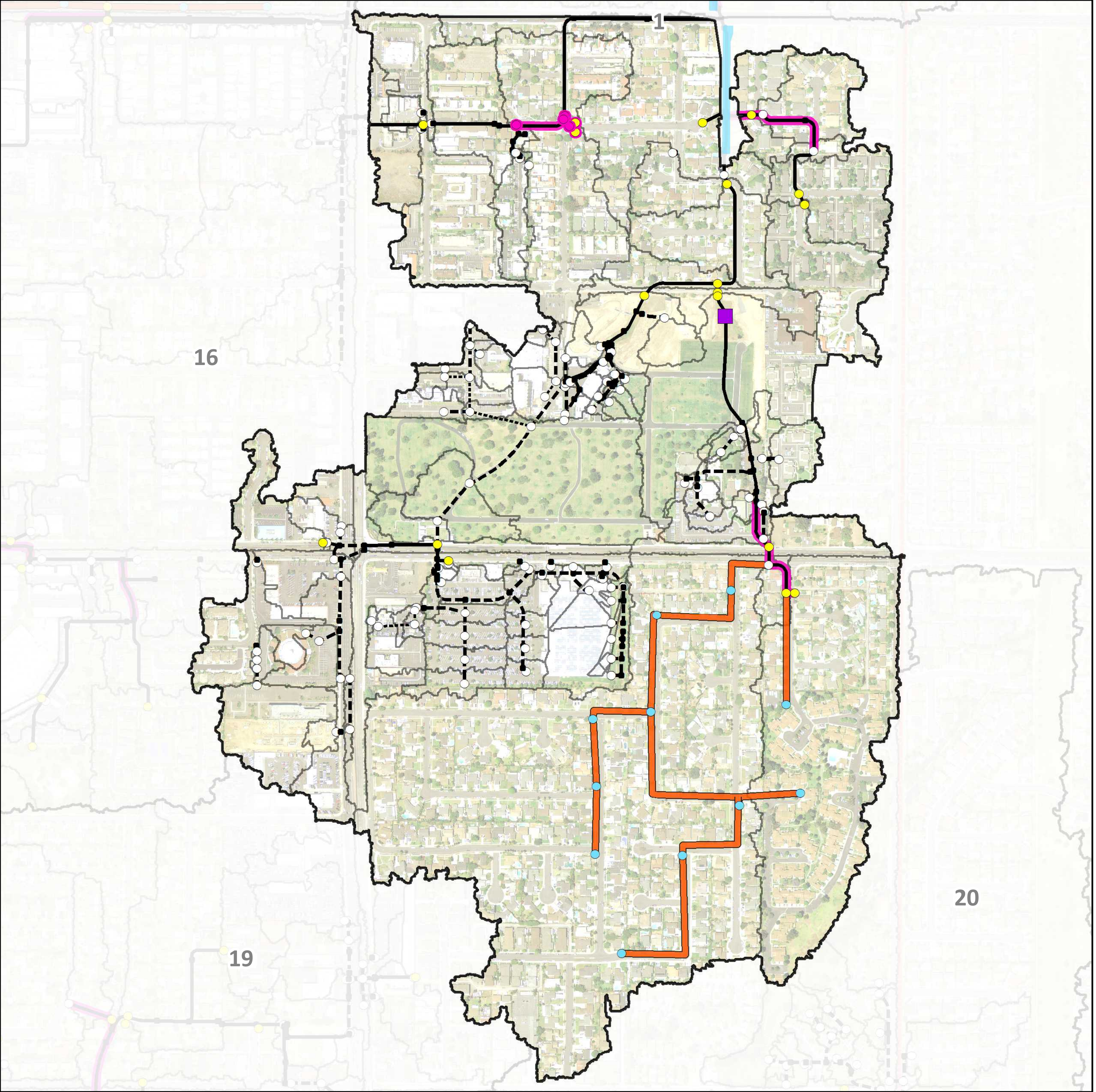
TETRA TECH

City of Huntington Beach

N

0 625 1,250 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 17

Proposed Condition

100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	1,533 / 5.2%
New Conduits:	5,359 / 18.3%
	Count / %*
Upsized Inlets:	18 / 14.8%
New Inlets:	11 / 9%
	Count / Volume
Upsized Reg. Storage:	1 / 3.65 ac-ft
Dist. Storage:	6 / 1.6 ac-ft

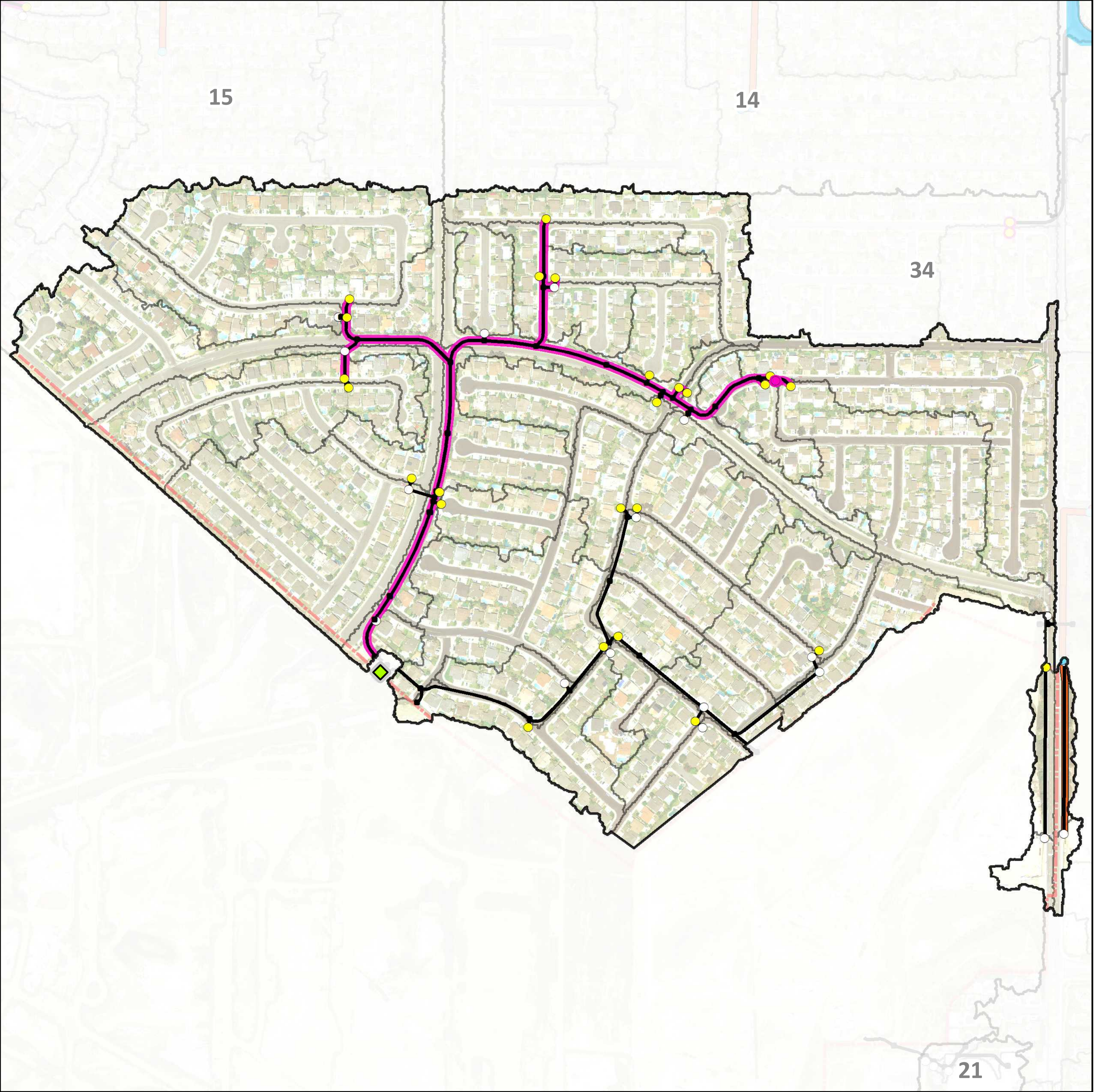
TETRA TECH

City of Huntington Beach

N

0 420 840 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 18

Proposed Condition
100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	4,646 / 22.3%
New Conduits:	1,503 / 7.2%
	Count / %*
Upsized Inlets:	25 / 58.1%
New Inlets:	1 / 2.3%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	1 / 0.1 ac-ft

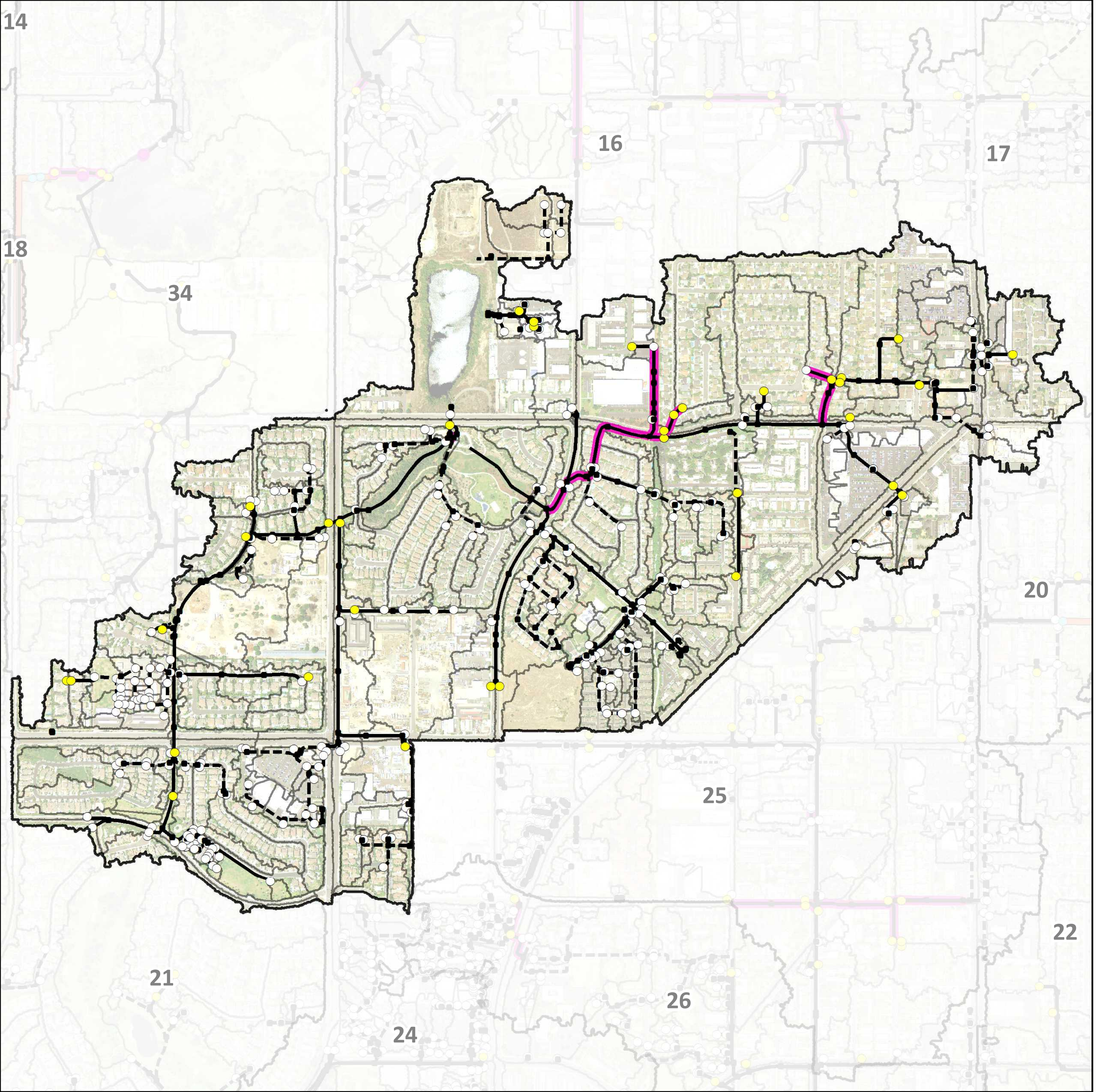
TETRA TECH

City of Huntington Beach

N

0 370 740 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 19

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	4,162 / 4.3%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	35 / 11.9%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

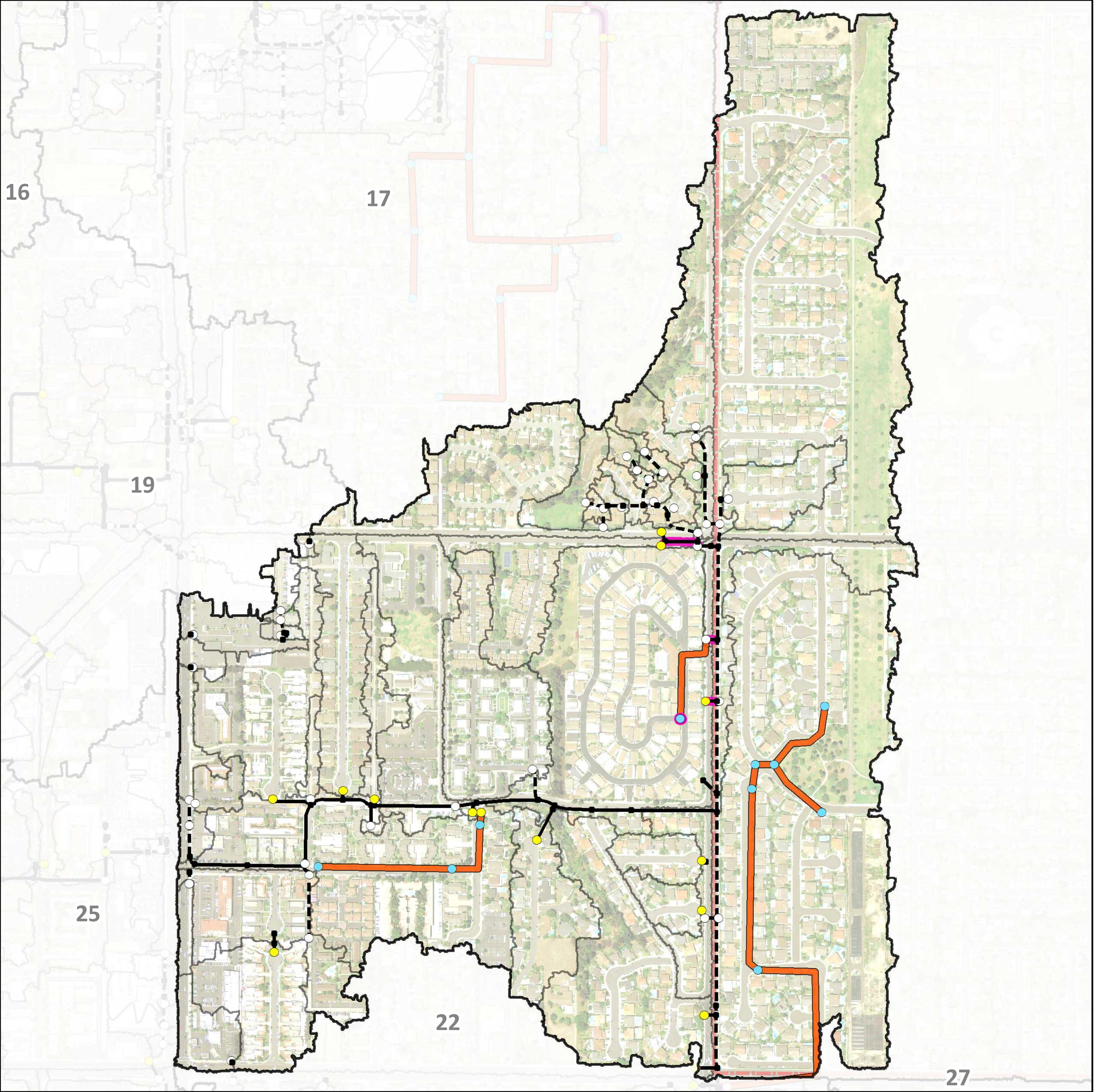
TETRA TECH

City of Huntington Beach

N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 20

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	324 / 1.4%
New Conduits:	4,679 / 20.9%
	Count / %*
Upsized Inlets:	13 / 24.1%
New Inlets:	10 / 18.5%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	1 / 1.4 ac-ft

TETRA TECH

City of Huntington Beach

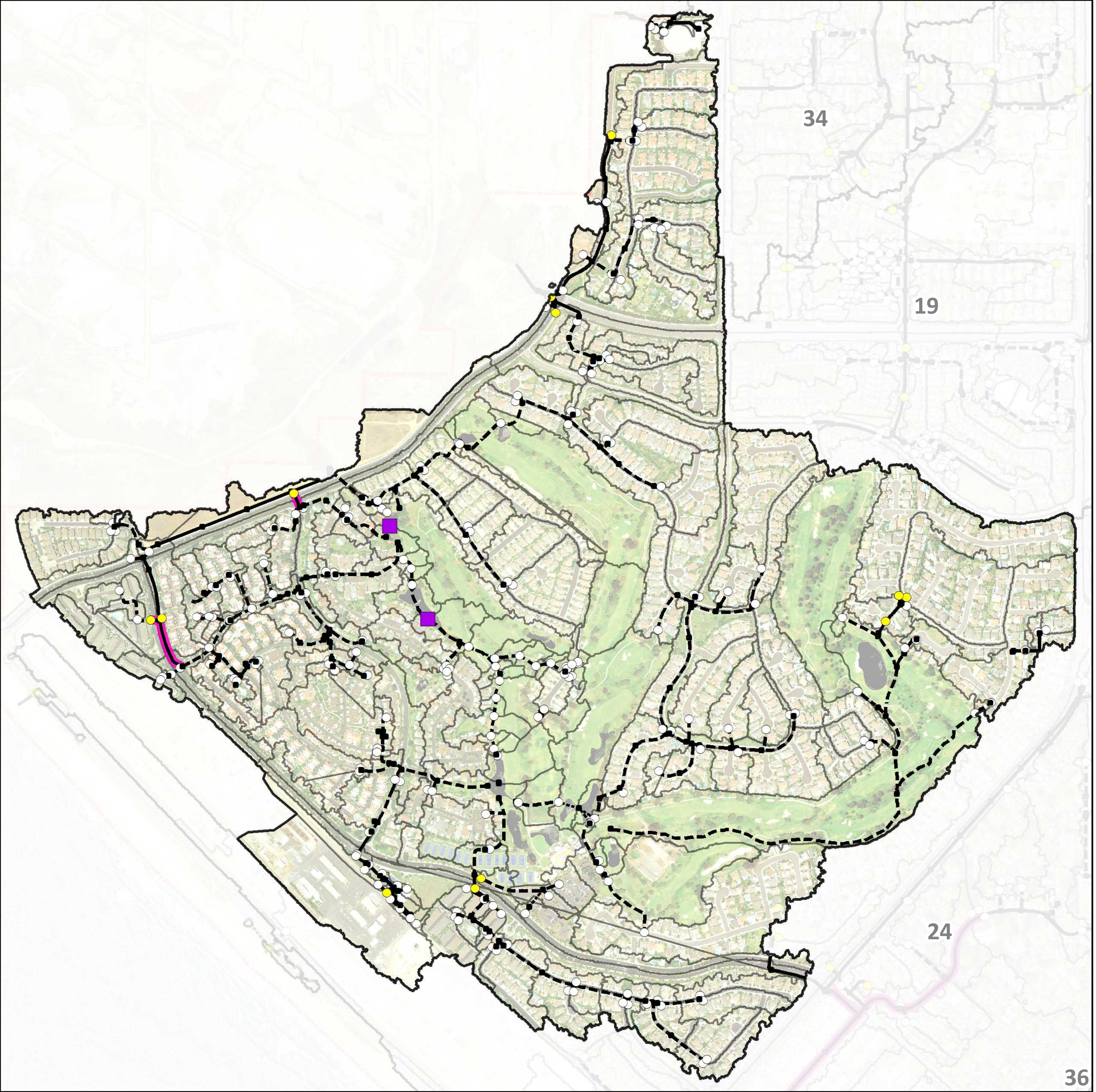
N

0 420 840 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 21

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	652 / 1.1%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	12 / 5.2%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	2 / 5.81 ac-ft
Dist. Storage:	0 / 0 ac-ft

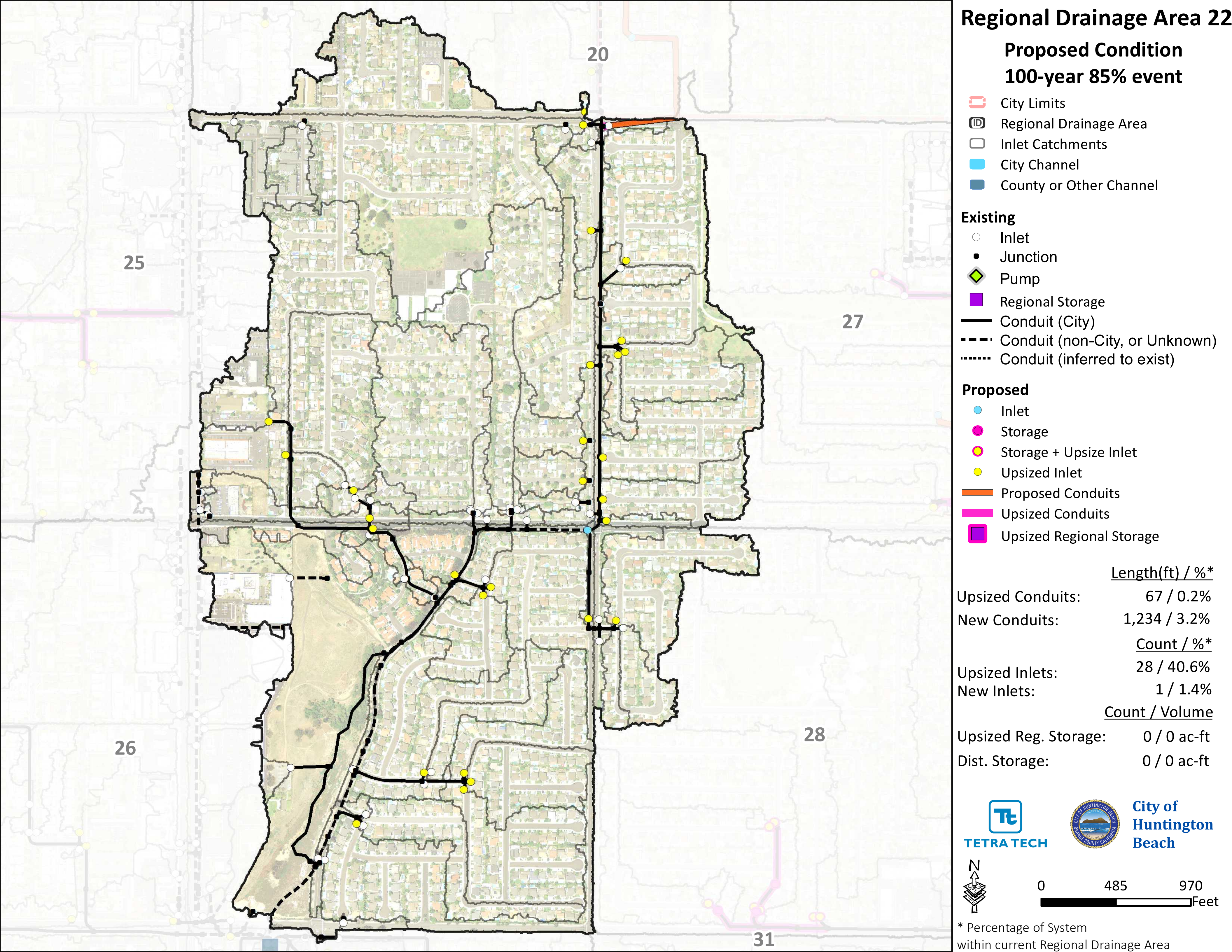
TETRA TECH

City of Huntington Beach

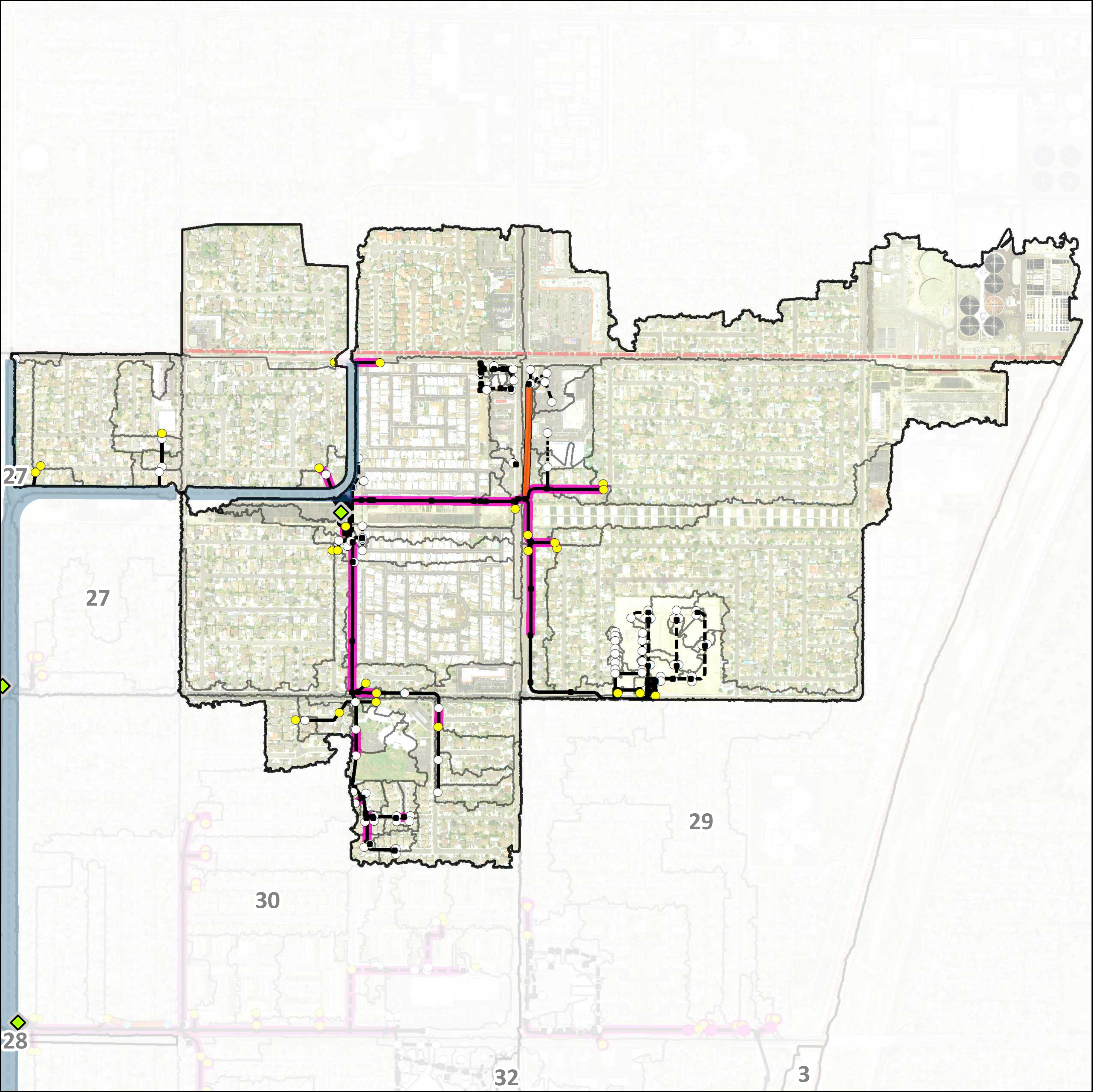
N

0 625 1,250 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 22
Proposed Condition
100-year 85% event
20
25
27
26
28
31
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel
Existing
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
Proposed
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage
Length(ft) / %*
Upsized Conduits: 67 / 0.2%
New Conduits: 1,234 / 3.2%
Count / %*
Upsized Inlets: 28 / 40.6%
New Inlets: 1 / 1.4%
Count / Volume
Upsized Reg. Storage: 0 / 0 ac-ft
Dist. Storage: 0 / 0 ac-ft
TETRA TECH
City of Huntington Beach
N
0
485
970
Feet
* Percentage of System
within current Regional Drainage Area



Regional Drainage Area 23

Proposed Condition

100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	6,326 / 17.2%
New Conduits:	893 / 2.4%
	Count / %*
Upsized Inlets:	25 / 21.9%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

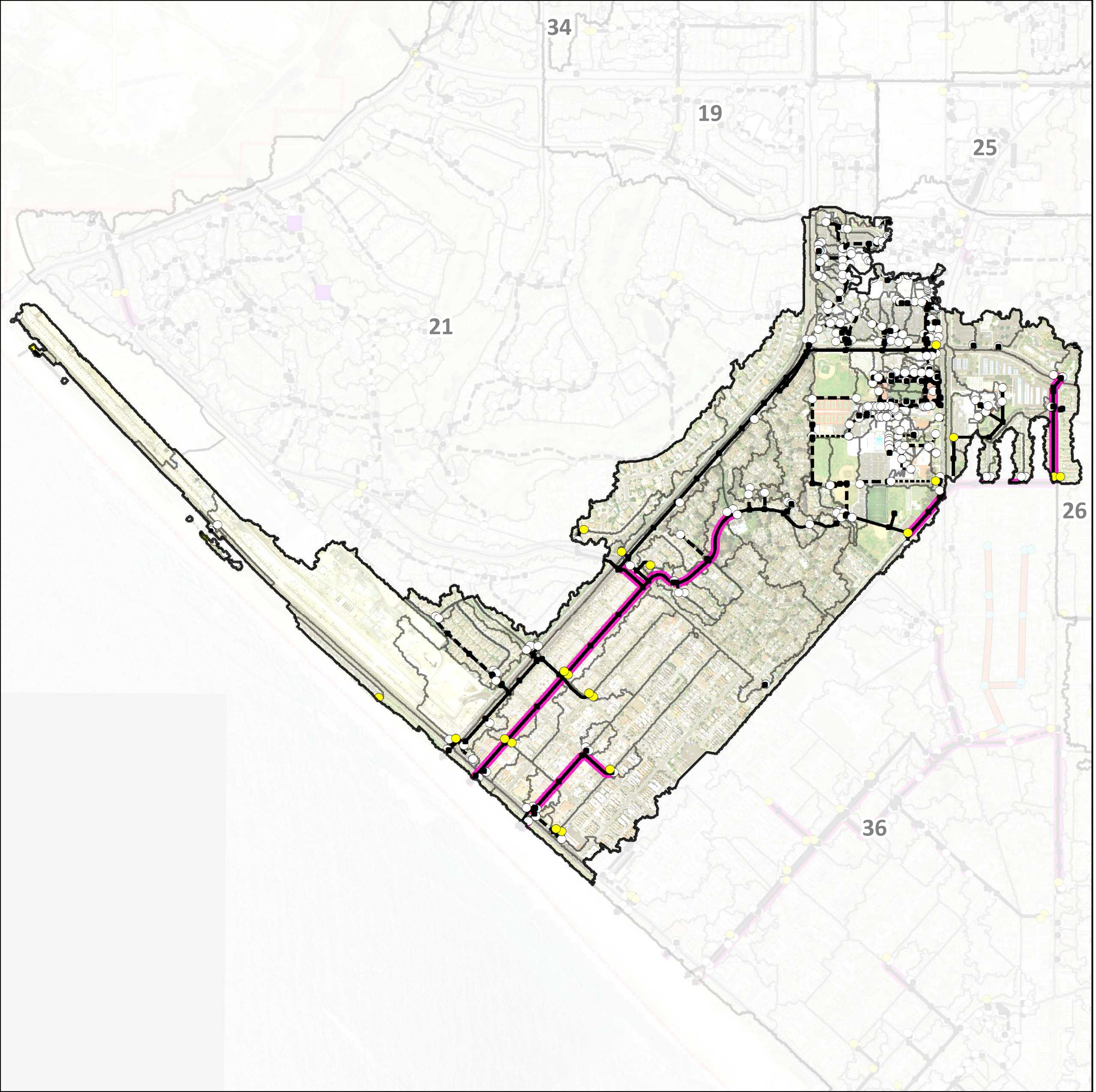
TETRA TECH

City of Huntington Beach

N

0 650 1,300 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 24

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	8,665 / 14.1%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	22 / 7.5%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

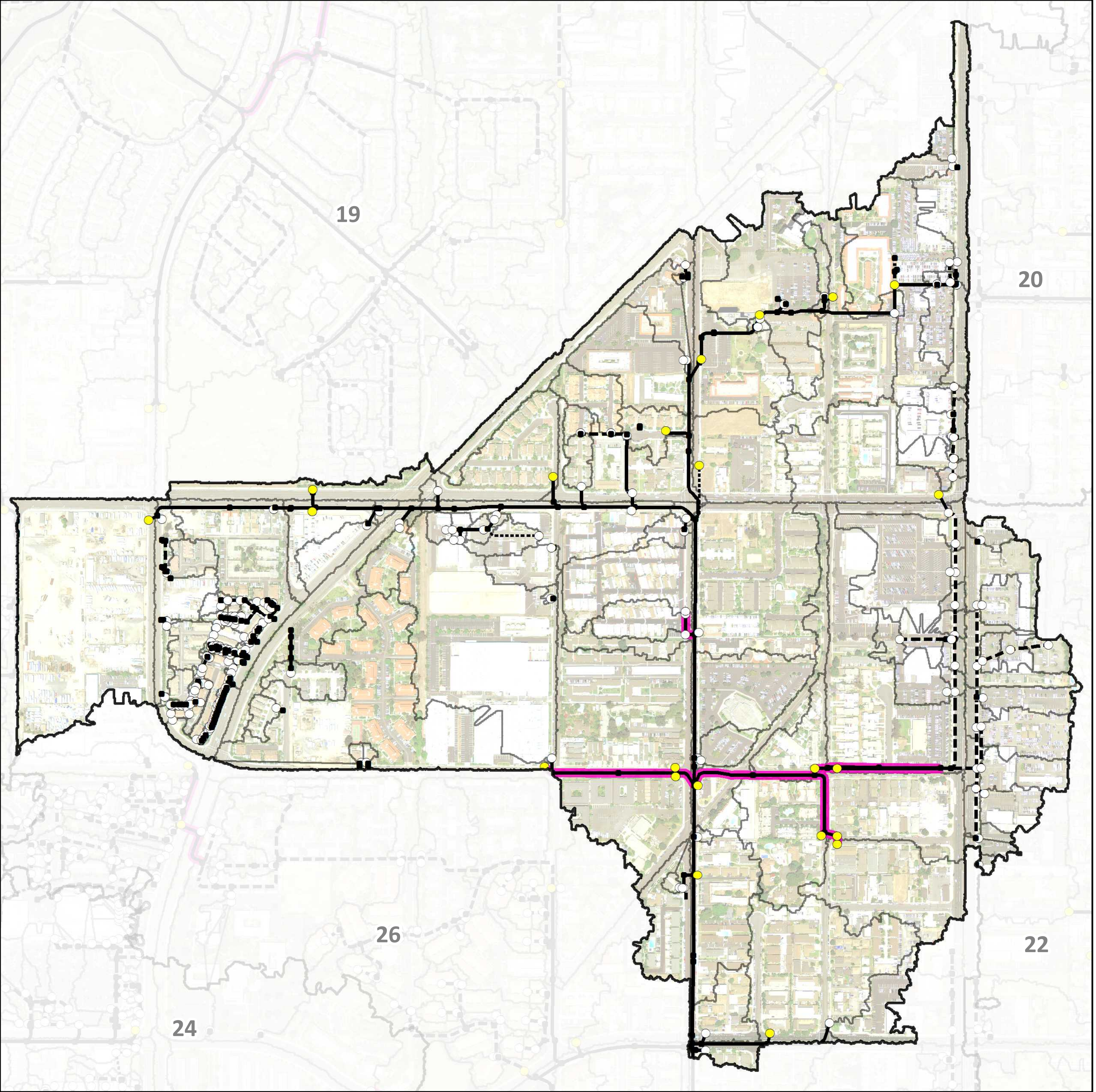
TETRA TECH

City of Huntington Beach

N

0 700 1,400 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 25

Proposed Condition
100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	3,176 / 6.4%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	22 / 9.6%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

TETRA TECH

City of Huntington Beach

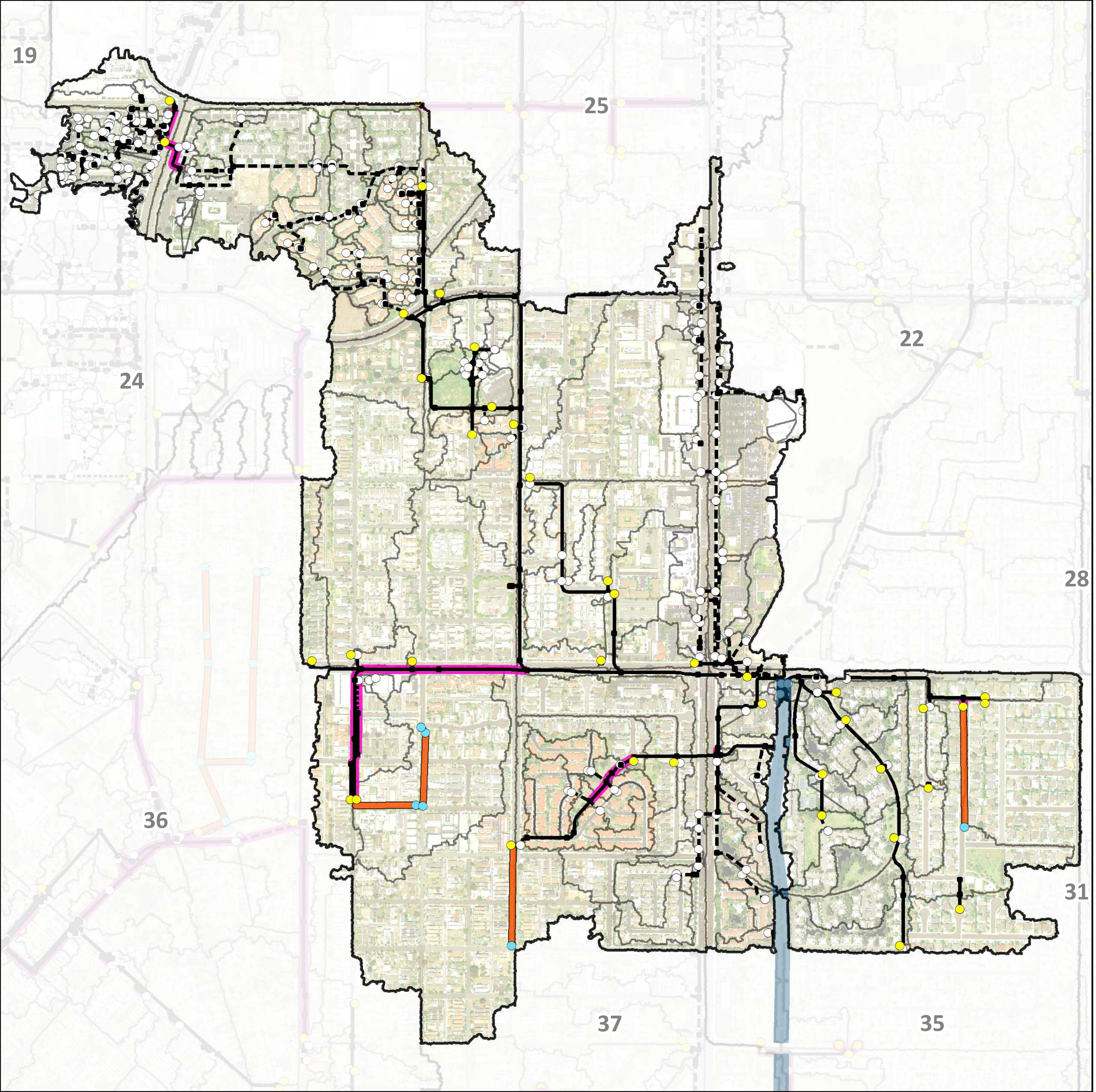
N

0 420 840 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 26

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	4,237 / 4.6%
New Conduits:	1,951 / 2.1%
	Count / %*
Upsized Inlets:	38 / 14.3%
New Inlets:	6 / 2.3%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	0 / 0 ac-ft

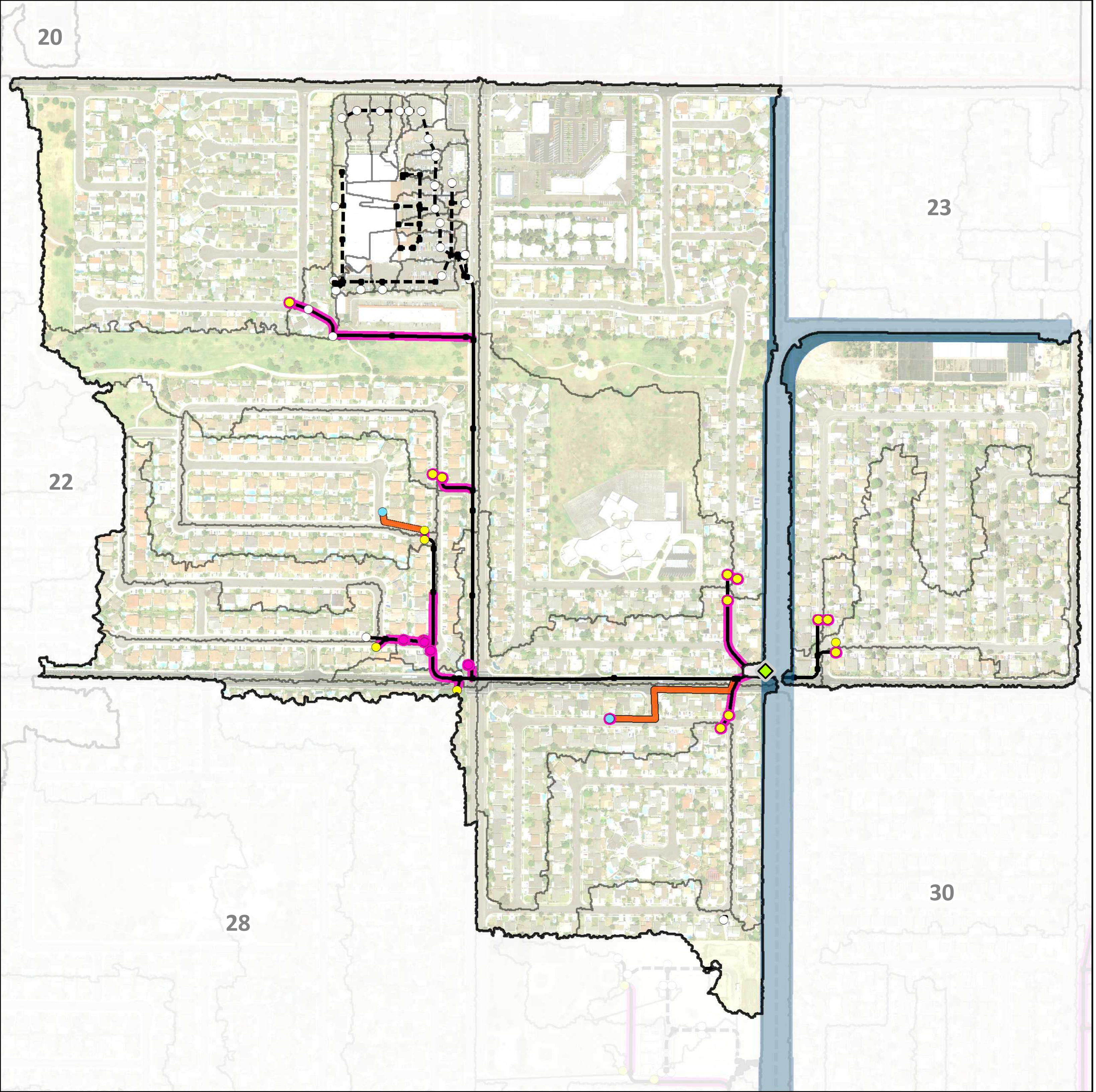
TETRA TECH

City of Huntington Beach

N

0 600 1,200 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 27

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

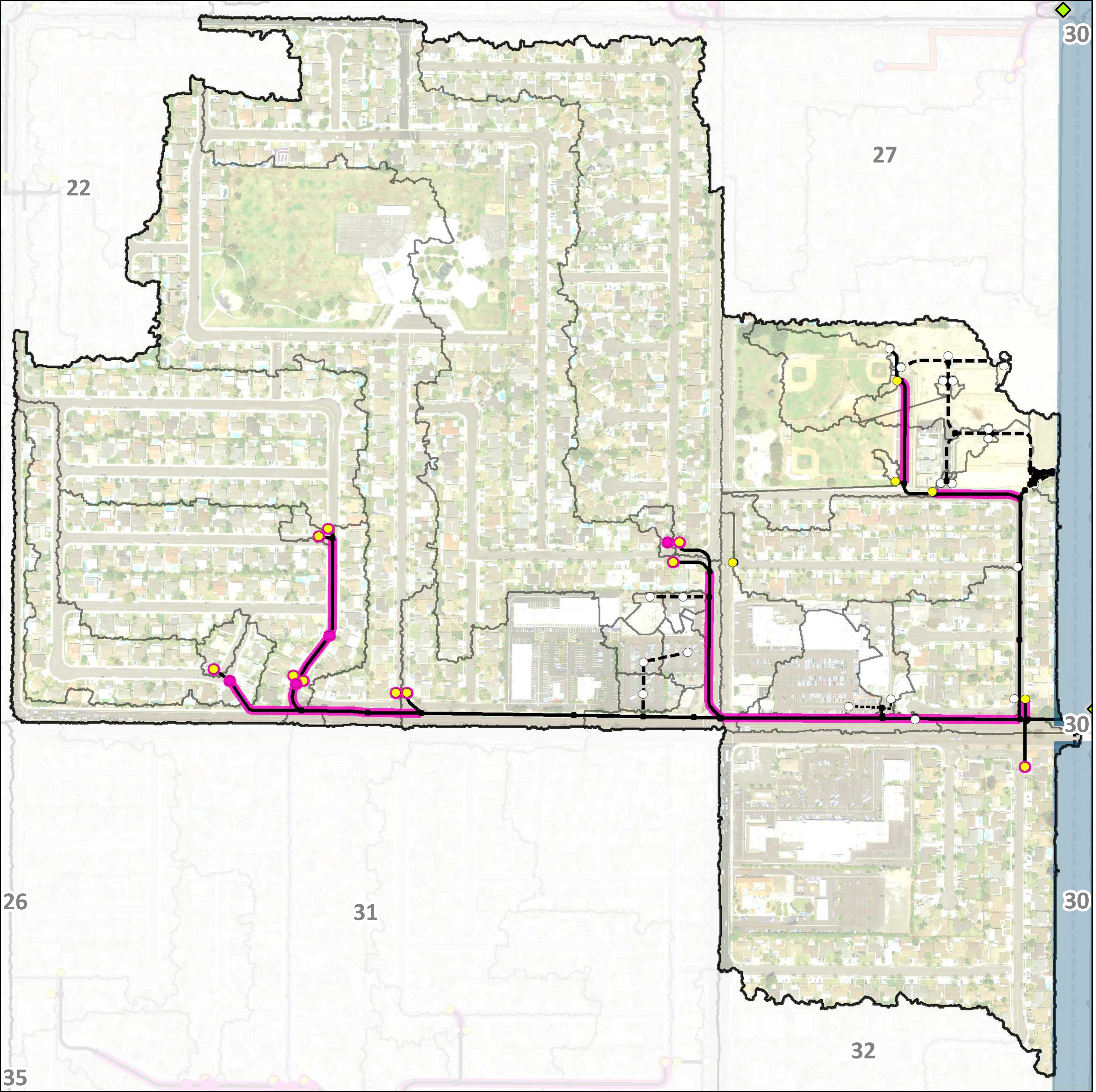
Proposed
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	2,716 / 15.5%
New Conduits:	947 / 5.4%
	Count / %*
Upsized Inlets:	17 / 36.2%
New Inlets:	2 / 4.3%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	17 / 7.7 ac-ft

TETRA TECH
City of Huntington Beach

N
0 375 750 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 28

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	3,975 / 18.5%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	15 / 38.5%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	14 / 5.8 ac-ft

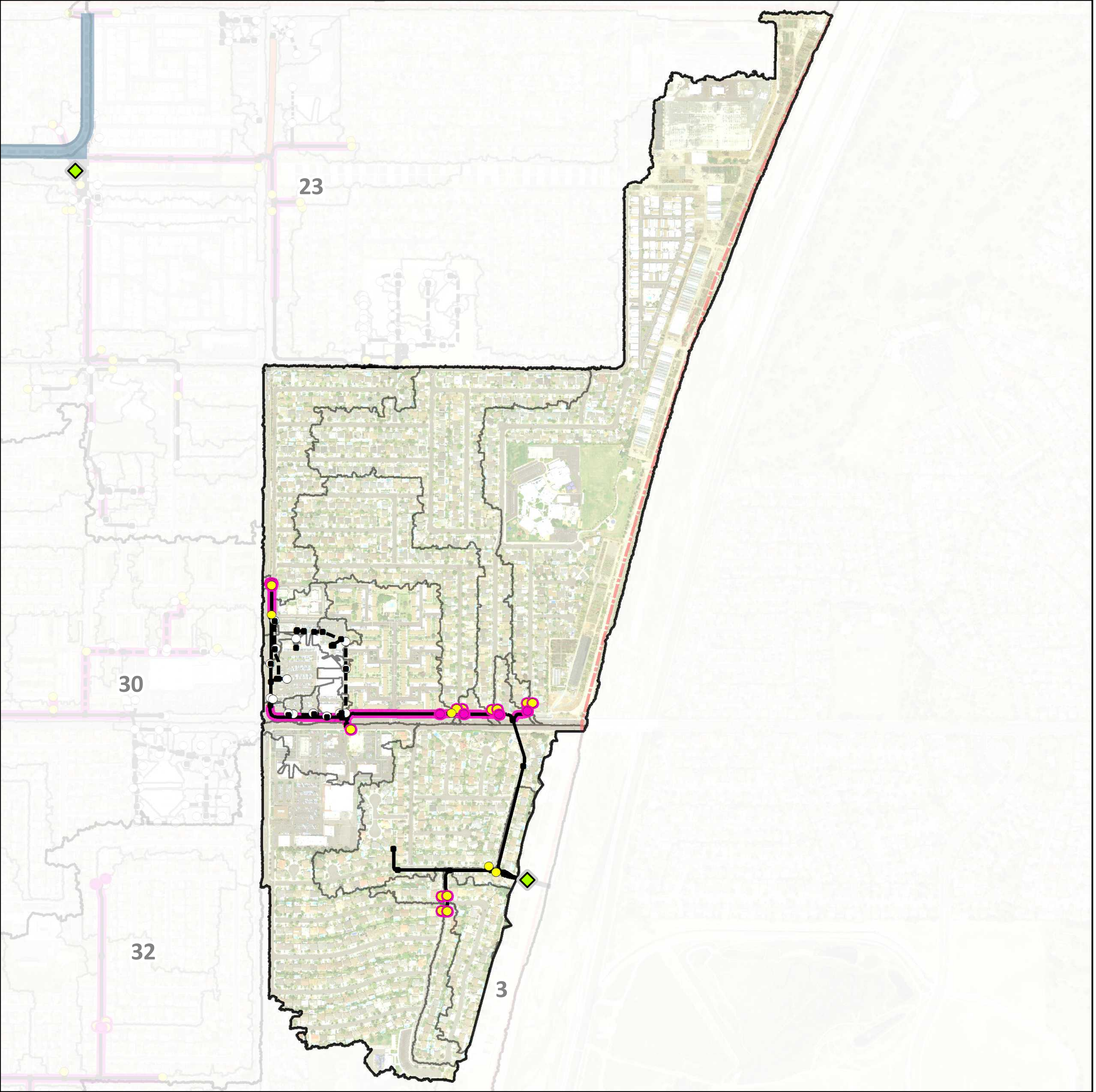
TETRA TECH

City of Huntington Beach

N

0 320 640 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 29

Proposed Condition
100-year 85% event

- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	2,497 / 15.9%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	16 / 50%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	18 / 14.7 ac-ft

TETRA TECH

City of Huntington Beach

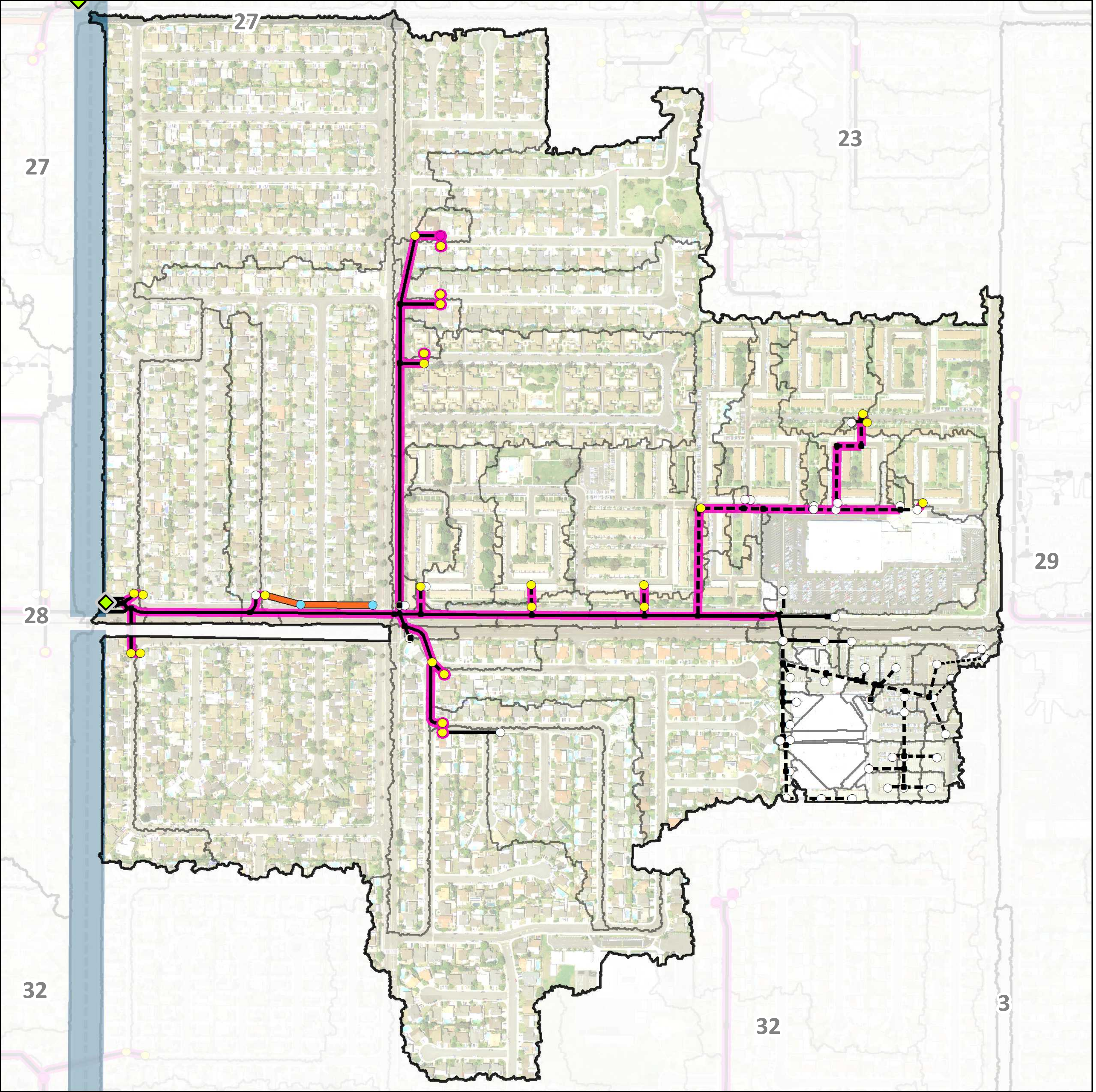
N

0 625 1,250 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 30

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	8,607 / 37.7%
New Conduits:	472 / 2.1%
	Count / %*
Upsized Inlets:	24 / 32.4%
New Inlets:	2 / 2.7%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	8 / 2.8 ac-ft

TETRA TECH

City of Huntington Beach

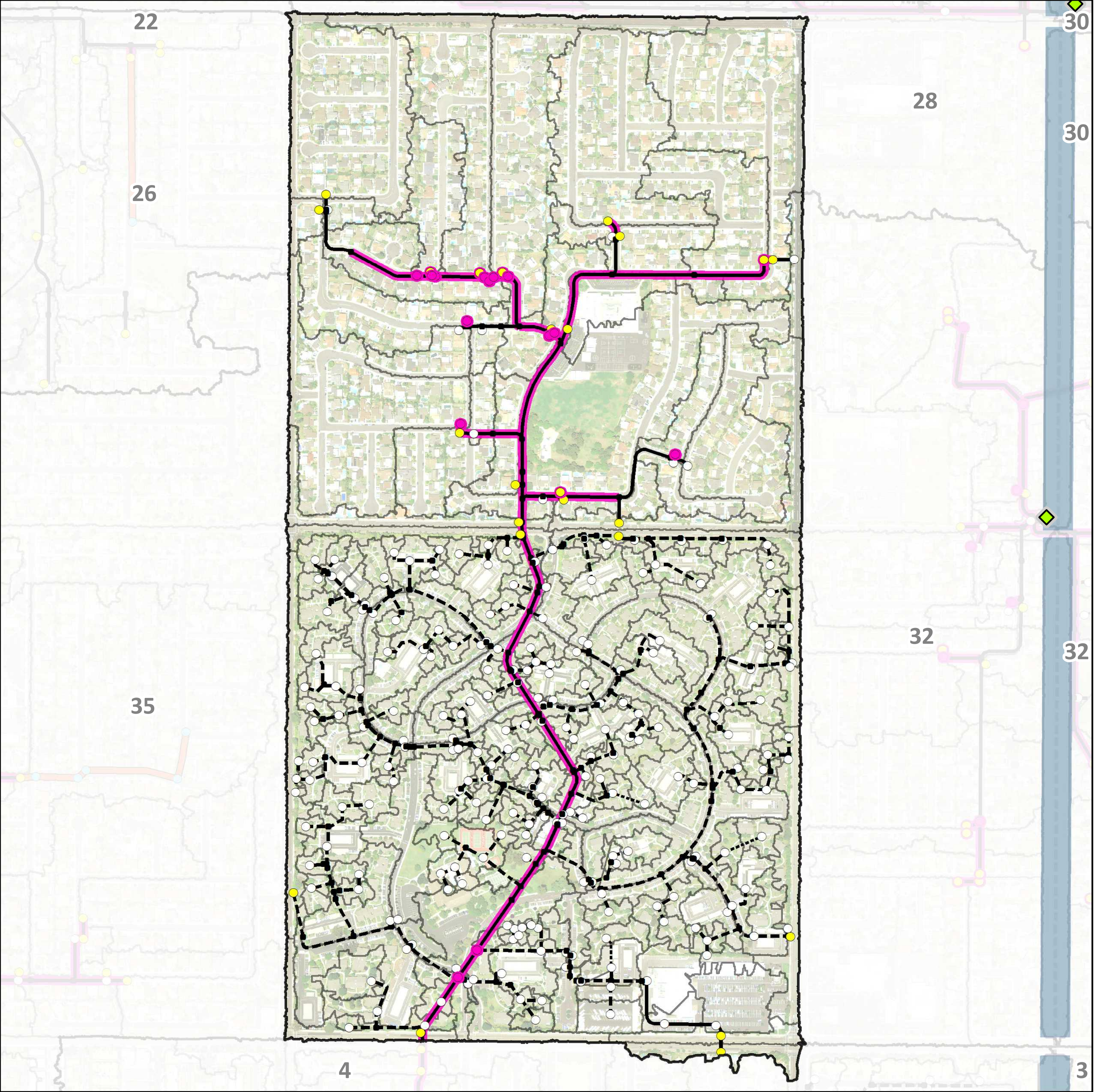
N

0 370 740 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 31

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	7,947 / 12.3%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	28 / 10.6%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	19 / 6 ac-ft

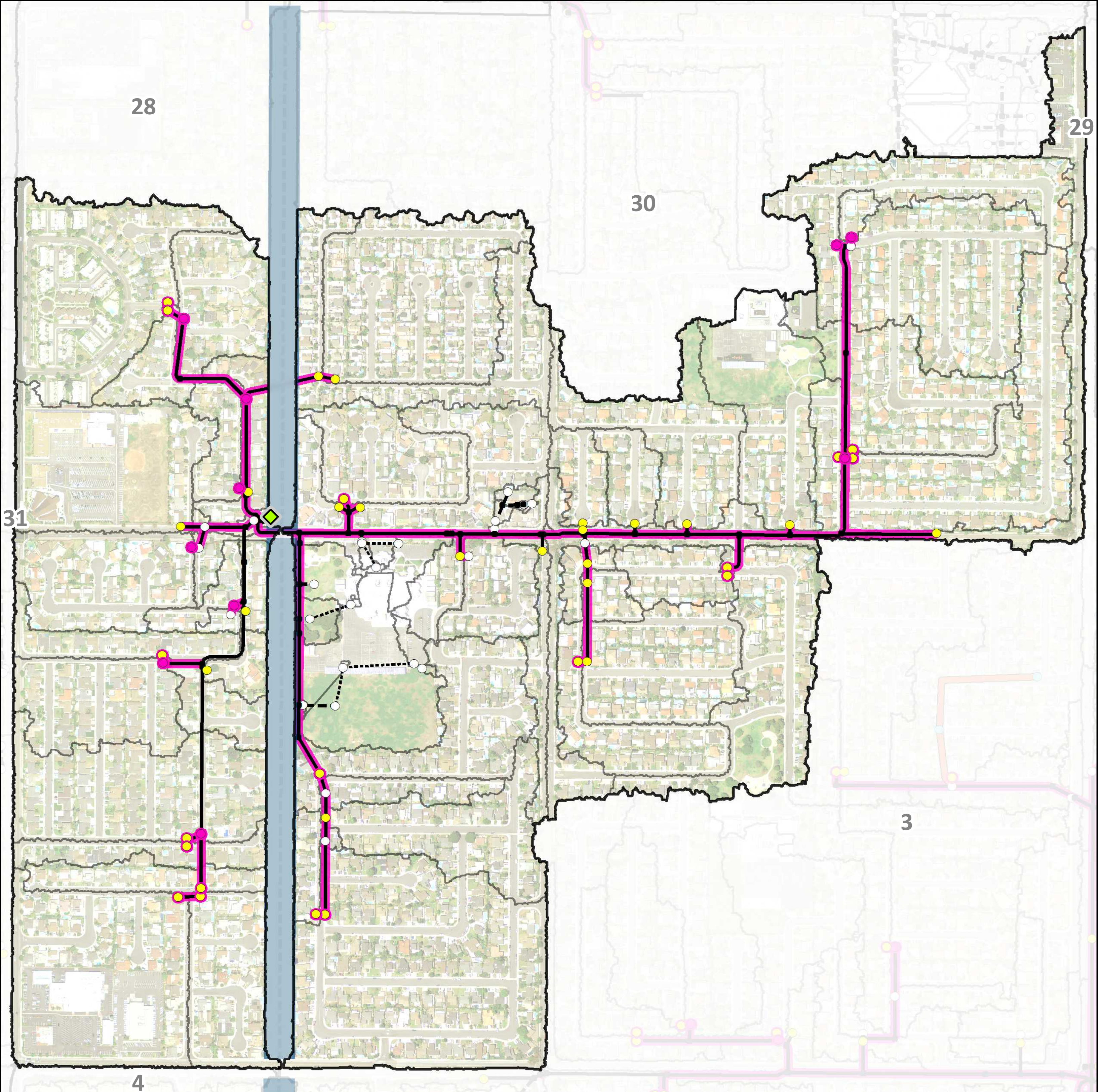
TETRA TECH

City of Huntington Beach

N

0 440 880 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 32

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	11,755 / 42.5%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	45 / 63.4%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	28 / 12.3 ac-ft

TETRA TECH

City of Huntington Beach

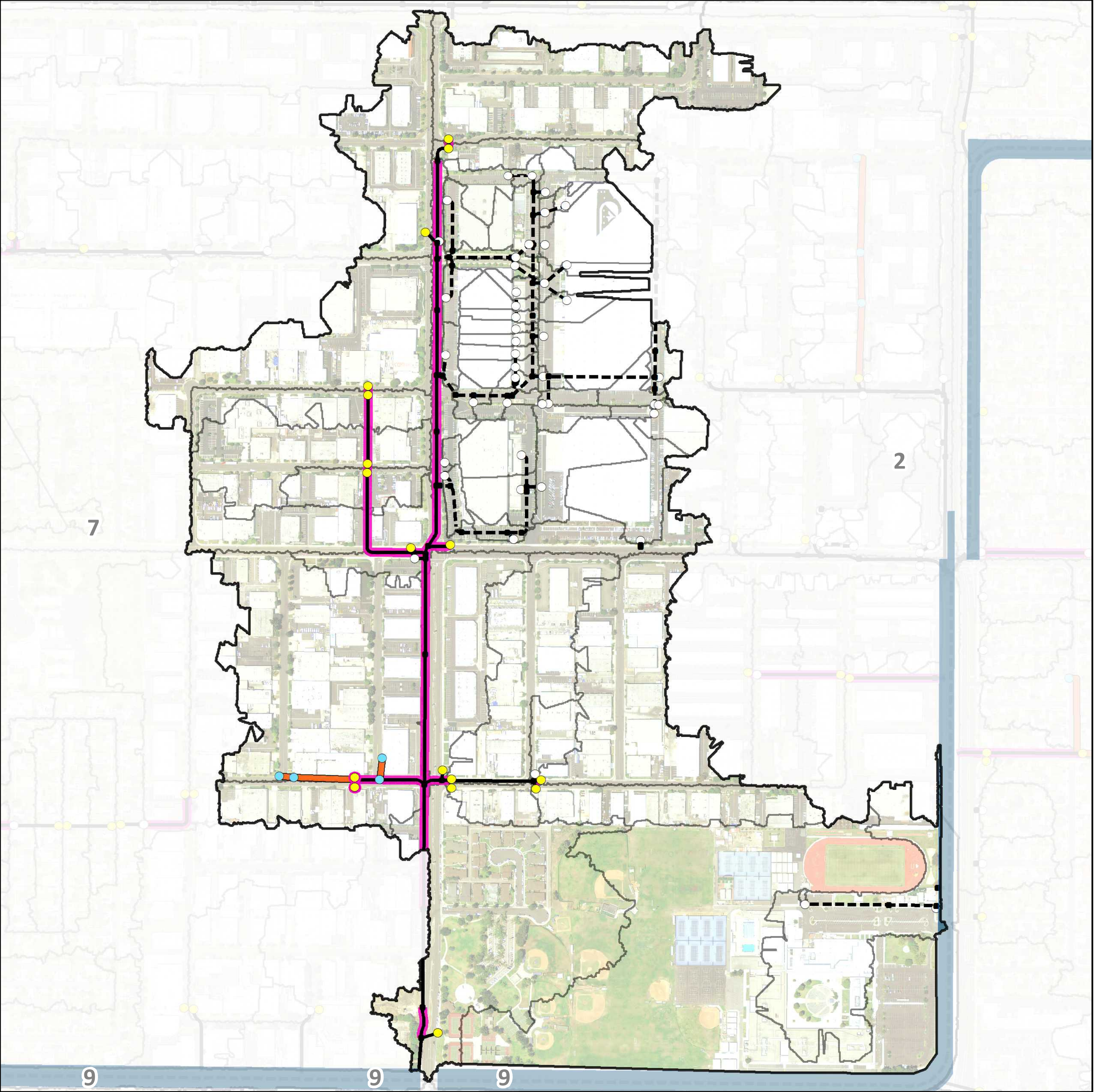
N

0 425 850 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 33

Proposed Condition
100-year 85% event



City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	5,314 / 22.6%
New Conduits:	821 / 3.5%
	Count / %*
Upsized Inlets:	17 / 27.4%
New Inlets:	4 / 6.5%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	2 / 0.4 ac-ft

TETRA TECH

City of Huntington Beach

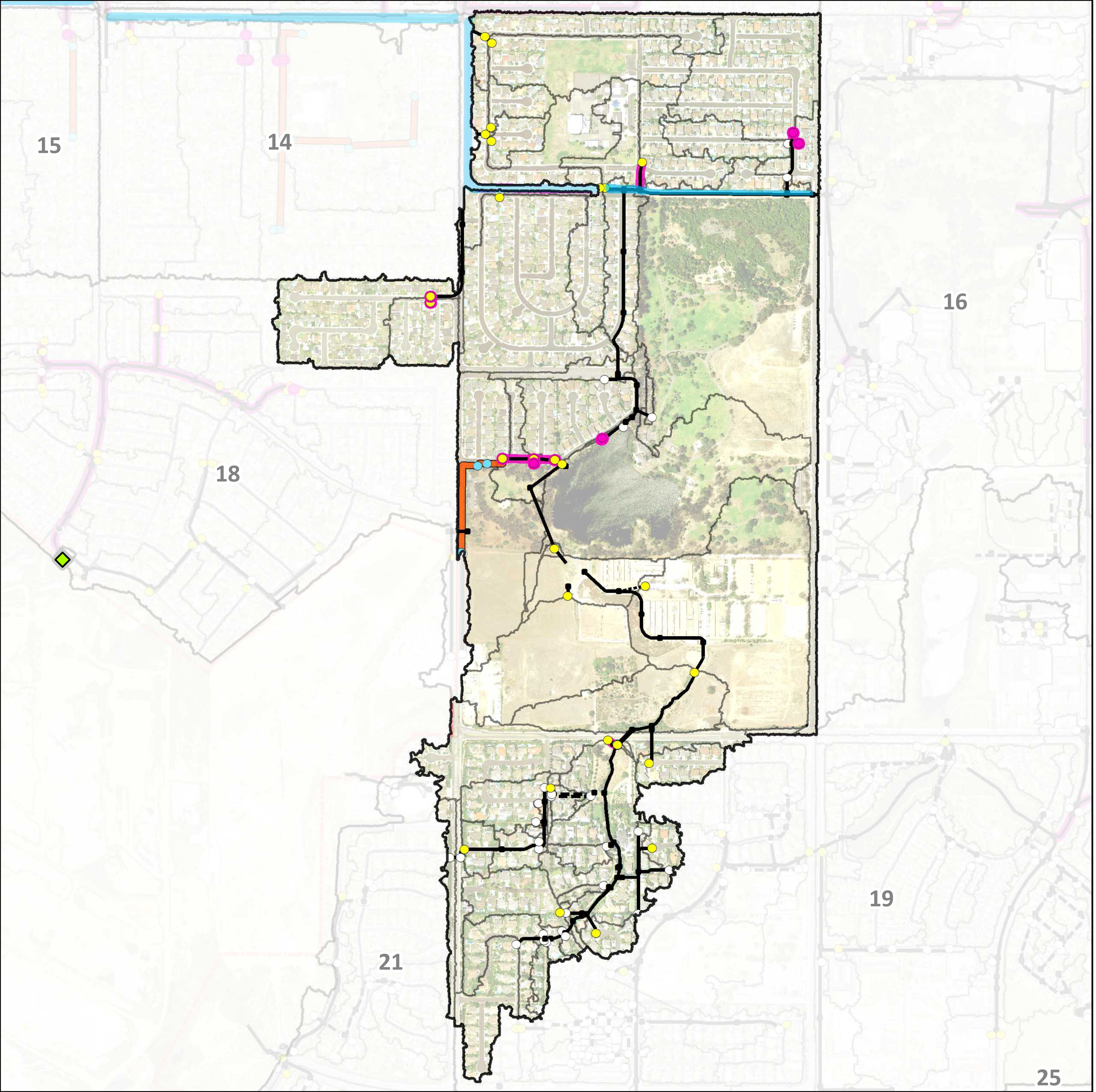
N

0 420 840 Feet

* Percentage of System within current Regional Drainage Area

Regional Drainage Area 34

Proposed Condition
100-year 85% event



- City Limits
- Regional Drainage Area
- Inlet Catchments
- City Channel
- County or Other Channel

Existing

- Inlet
- Junction
- Pump
- Regional Storage
- Conduit (City)
- Conduit (non-City, or Unknown)
- Conduit (inferred to exist)

Proposed

- Inlet
- Storage
- Storage + Upsize Inlet
- Upsized Inlet
- Proposed Conduits
- Upsized Conduits
- Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	3,119 / 11.7%
New Conduits:	985 / 3.7%
	Count / %*
Upsized Inlets:	29 / 47.5%
New Inlets:	2 / 3.3%
	Count / Volume
Upsized Reg. Storage:	1 / 24.84 ac-ft
Dist. Storage:	10 / 2.8 ac-ft

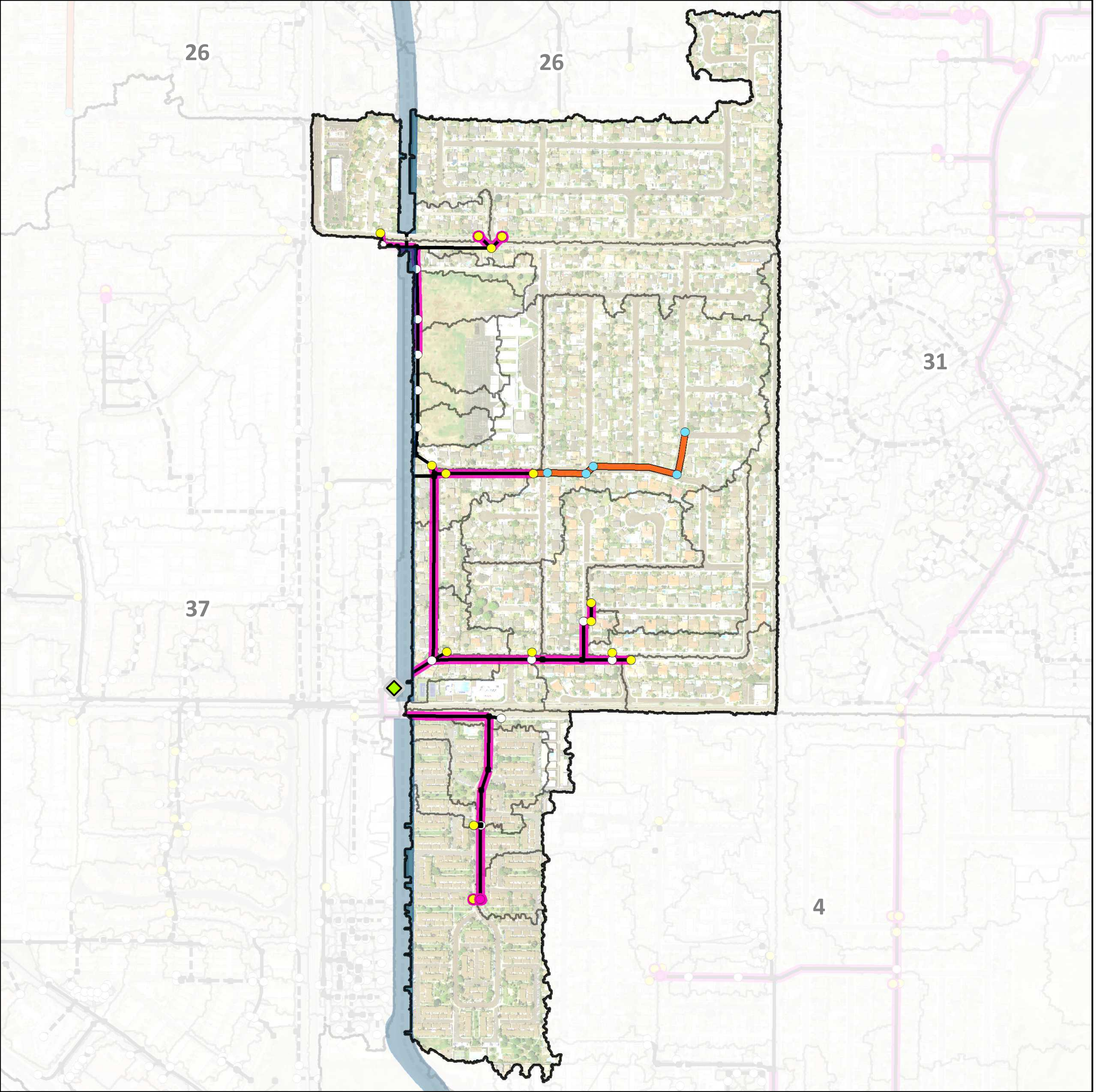
TETRA TECH

City of Huntington Beach

N

0 625 1,250 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 35

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	6,201 / 42.6%
New Conduits:	1,075 / 7.4%
	Count / %*
Upsized Inlets:	16 / 57.1%
New Inlets:	5 / 17.9%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	5 / 3.7 ac-ft

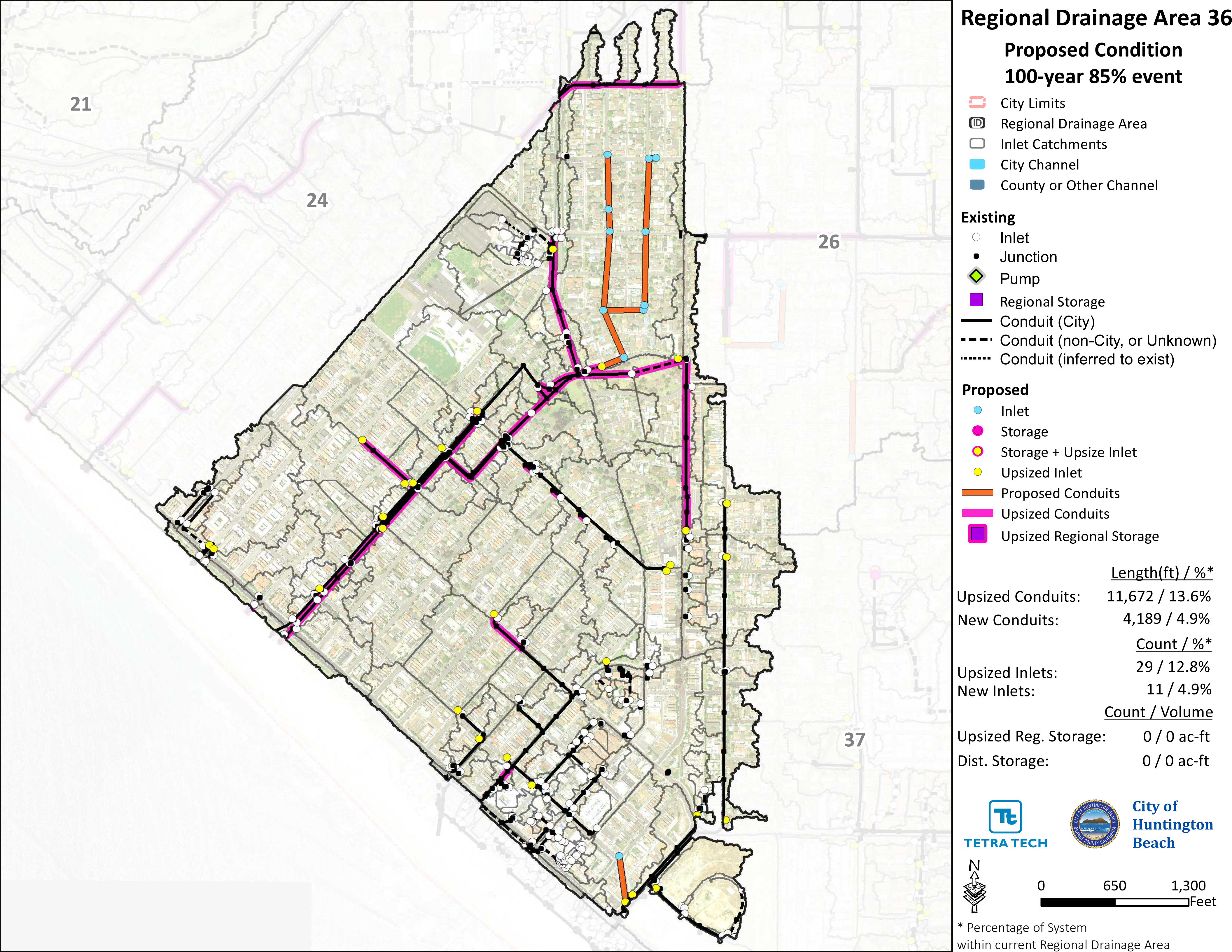
TETRA TECH

City of Huntington Beach

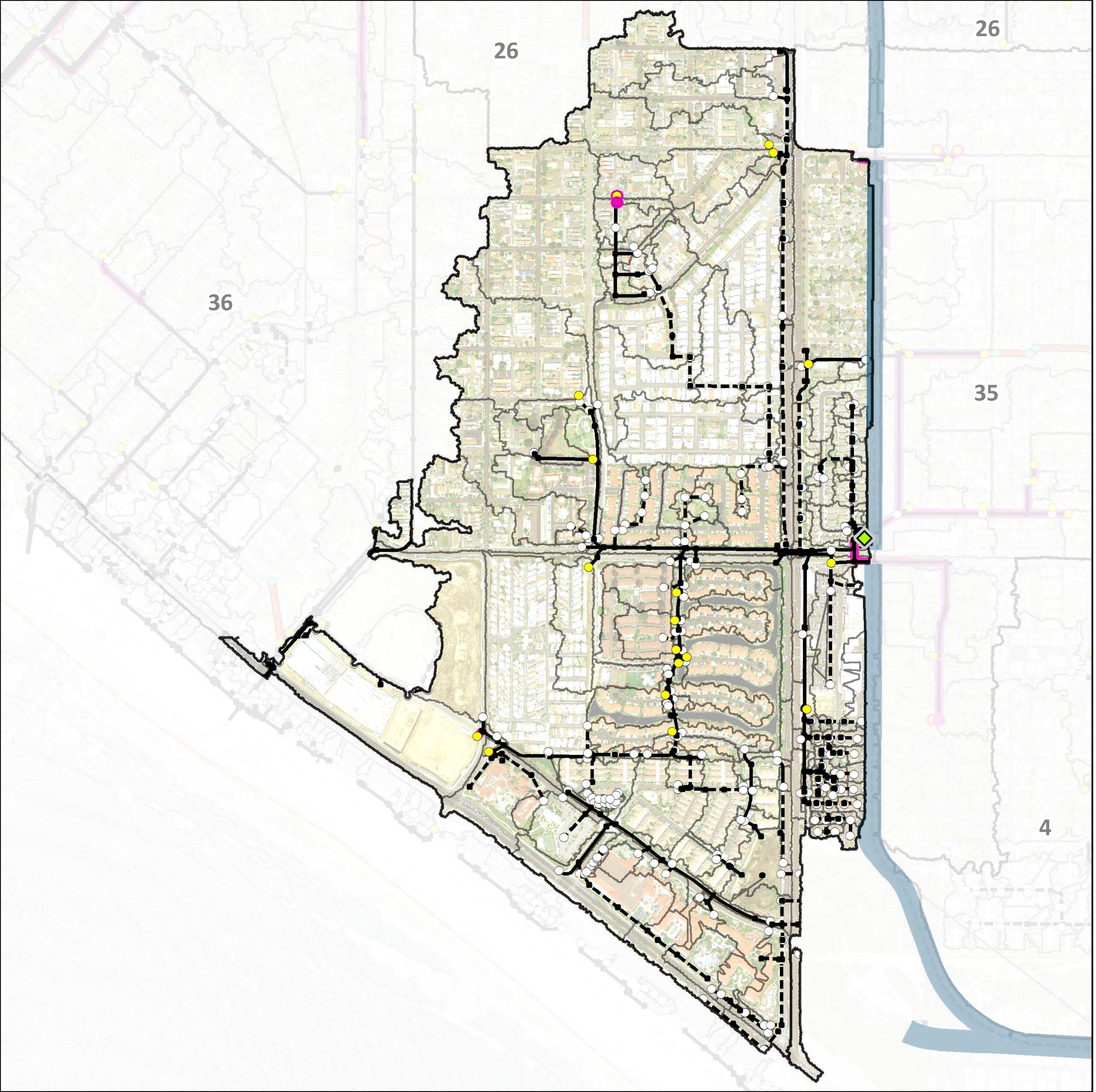
N

0 480 960 Feet

* Percentage of System within current Regional Drainage Area



Regional Drainage Area 36
Proposed Condition
100-year 85% event
City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel
Existing
Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)
Proposed
Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage
Length(ft) / %*
Upsized Conduits: 11,672 / 13.6%
New Conduits: 4,189 / 4.9%
Count / %*
Upsized Inlets: 29 / 12.8%
New Inlets: 11 / 4.9%
Count / Volume
Upsized Reg. Storage: 0 / 0 ac-ft
Dist. Storage: 0 / 0 ac-ft
TETRA TECH
City of Huntington Beach
N
0
650
1,300
Feet
* Percentage of System within current Regional Drainage Area
21
24
26
37



Regional Drainage Area 37

Proposed Condition
100-year 85% event

City Limits
Regional Drainage Area
Inlet Catchments
City Channel
County or Other Channel

Existing

Inlet
Junction
Pump
Regional Storage
Conduit (City)
Conduit (non-City, or Unknown)
Conduit (inferred to exist)

Proposed

Inlet
Storage
Storage + Upsize Inlet
Upsized Inlet
Proposed Conduits
Upsized Conduits
Upsized Regional Storage

	Length(ft) / %*
Upsized Conduits:	1,128 / 1.6%
New Conduits:	0 / 0%
	Count / %*
Upsized Inlets:	18 / 7.6%
New Inlets:	0 / 0%
	Count / Volume
Upsized Reg. Storage:	0 / 0 ac-ft
Dist. Storage:	2 / 0.3 ac-ft

TETRA TECH

City of Huntington Beach

N

0 550 1,100 Feet

* Percentage of System within current Regional Drainage Area

APPENDIX E PROPOSED RECOMMENDATION DETAILS

APPENDIX F COSTS FOR IDENTIFIED REGIONAL STORAGE

Ninety-five potential regional storage sites were located throughout the City (see Figure 5-1). Total estimated costs include all components included in Table F-1. Assumptions for each component are as follows:

- **Diversion structure**: $12,000 each. Two required for all opportunities to divert stormwater from the nearby conduit
- **Piping**: $325 per linear foot. Cost of the new 48 inches RCP to connect the diversion structure to the existing conduit
- **Excavation**: $45 per CY. Assumes removal of all soil across the detention footprint to 1-foot depth (assumed 1 ft ponding depth)
- **Total Mark-up**: 40% of construction and unit costs. See Table 7-4

Table F-1. Costs associated with each identified potential regional storage

Parcel Name	Project Footprint (ac)	Diversion Structure and Piping ($)	Excavation ($)	Total Mark-up ($)	Total Estimated Cost ($)
Therapeutic Riding Center of Huntington Beach	1.5	24,000	109,000	53,000	**186,000**
Lake Huntington	26.05	24,000	1,891,000	766,000	**2,681,000**
Bolsa View Park	1.18	34,100	86,000	48,000	**168,000**
Mesa View Middle School	5.03	99,700	365,000	186,000	**651,000**
Hope View Park and Elementary School	6.81	24,000	494,000	207,000	**726,000**
Hope View Park	1.87	24,000	136,000	64,000	**224,000**
Marine View Park and Middle School	2.35	24,000	171,000	78,000	**272,000**
Lark View School	6.63	465,400	481,000	379,000	**1,325,000**
Golden View Elementary School	2.58	226,500	187,000	166,000	**579,000**
Golden View Park	0.2	228,800	15,000	97,000	**341,000**
Lark View Park	1.24	397,400	90,000	195,000	**682,000**
Irby Park	9.1	60,400	661,000	288,000	**1,009,000**
Sibbs Park	2.67	130,600	194,000	130,000	**454,000**
Spring View Middle School	6.29	30,500	457,000	195,000	**682,000**

Parcel Name	Project Footprint (ac)	Diversion Structure and Piping ($)	Excavation ($)	Total Mark-up ($)	Total Estimated Cost ($)
Carr Park	6.15	242,400	446,000	276,000	**964,000**
St Bonaventure Church	0.86	197,900	62,000	104,000	**364,000**
College View Park	0.91	146,900	66,000	85,000	**298,000**
Meadow View School	6.98	77,300	507,000	234,000	**818,000**
College View Elementary School	6.47	175,800	470,000	258,000	**904,000**
Village View Elementary School	4.51	124,800	327,000	181,000	**633,000**
Grace Lutheran Church and School	0.1	385,100	7,000	157,000	**549,000**
Wheeler Park and Graham Branch Huntington Beach Public Library	2.71	52,600	197,000	100,000	**349,000**
Marina High School	19.2	54,600	1,394,000	579,000	**2,028,000**
Circle View Park and Elementary School	4.72	487,800	343,000	332,000	**1,163,000**
Glen View Park	6.79	501,100	493,000	398,000	**1,392,000**
Greer Park Pond	1.01	24,000	73,000	39,000	**136,000**
Robinwood Park and School	3.22	233,000	234,000	187,000	**653,000**
Greer Park	3.35	129,300	243,000	149,000	**522,000**
Schroeder Park	1.22	607,700	89,000	279,000	**975,000**
Schroeder Elementary School	1.8	402,300	131,000	213,000	**746,000**
Helen Stacey Middle School and Clegg-Stacy Park	10.19	24,000	740,000	306,000	**1,069,000**
Franklin Elementary School and Park	4.05	479,000	294,000	309,000	**1,082,000**
Cook School	2.97	173,800	216,000	156,000	**545,000**
Mini Park 1	0.2	125,700	15,000	56,000	**196,000**
Wieder Park	3.02	236,200	219,000	182,000	**638,000**

Parcel Name	Project Footprint (ac)	Diversion Structure and Piping ($)	Excavation ($)	Total Mark-up ($)	Total Estimated Cost ($)
Harbour View Elementary School	7.38	32,500	536,000	227,000	**796,000**
Harbour View Park	1.66	32,500	121,000	61,000	**214,000**
French Park South	0.12	24,000	9,000	13,000	**46,000**
French Park Central	0.93	24,000	68,000	37,000	**128,000**
Sea Bridge Park	0.8	24,000	58,000	33,000	**115,000**
Haven View School and Park	6.91	391,900	502,000	357,000	**1,251,000**
AES Huntington Beach East	2.13	456,900	155,000	245,000	**856,000**
John H Eader Elementary School	3.44	51,300	250,000	120,000	**421,000**
Seeley Park	1.13	282,400	82,000	146,000	**510,000**
Lutheran Church Resurrection	0.09	28,600	7,000	14,000	**49,000**
Edison High School	14.35	41,900	1,042,000	433,000	**1,517,000**
Huntington Beach Fire Department Station 4 and Edison Community Park	10.72	24,000	778,000	321,000	**1,123,000**
William E Kettler Elementary School	3.67	228,400	266,000	198,000	**693,000**
Gisler Park	0.12	44,800	9,000	21,000	**75,000**
Brethren Christian Junior and Senior High School	7.02	181,000	510,000	276,000	**967,000**
The Church of Jesus Christ of LDS 2	0.13	232,000	9,000	97,000	**338,000**
Huntington Christian School	1.95	219,700	142,000	144,000	**506,000**
Burke Park	0.63	519,000	46,000	226,000	**791,000**
Isaac Sowers Middle School	5.55	24,000	403,000	171,000	**598,000**
John R Peterson Elementary School	7.34	24,000	533,000	223,000	**780,000**

Parcel Name	Project Footprint (ac)	Diversion Structure and Piping ($)	Excavation ($)	Total Mark-up ($)	Total Estimated Cost ($)
Moffett Park	1.05	28,200	76,000	42,000	**146,000**
Hawes Park	0.34	126,400	25,000	60,000	**211,000**
S A Moffett Elementary School	2.71	27,600	197,000	90,000	**314,000**
Dr Ralph E Hawes Elementary School	2.4	174,200	174,000	139,000	**488,000**
Drew Park	1.14	275,900	83,000	143,000	**502,000**
LeBard Park	5.06	323,700	367,000	276,000	**967,000**
Sowers Park	0.77	24,000	56,000	32,000	**112,000**
Huntington Valley Little League	4.22	98,400	306,000	162,000	**567,000**
Wardlow Park	0.72	242,700	52,000	118,000	**413,000**
Newland Park	0.1	497,900	7,000	202,000	**707,000**
William T Newland Elementary School	6.21	490,400	451,000	376,000	**1,318,000**
Isojiro Oka Elementary School	2.35	24,000	171,000	78,000	**272,000**
Samuel E Talbert Middle School	5.15	165,700	374,000	216,000	**755,000**
Lagenback Park	2.54	266,800	184,000	180,000	**632,000**
Joseph R Perry Elementary School	3.71	267,100	269,000	215,000	**751,000**
Perry Park	0.76	464,400	55,000	208,000	**727,000**
Lambert Park	0.95	268,400	69,000	135,000	**472,000**
The Pegasus School	3.57	427,000	259,000	274,000	**961,000**
Manning Park	0.44	214,500	32,000	99,000	**345,000**
Farquhar Plaza and Circle Park	2.14	143,000	155,000	119,000	**418,000**
Lake Park	2.2	338,000	160,000	199,000	**697,000**
Ethel Dwyer Middle School and Agnes L Smith Elementary School	4.88	243,700	354,000	239,000	**837,000**

Parcel Name	Project Footprint (ac)	Diversion Structure and Piping ($)	Excavation ($)	Total Mark-up ($)	Total Estimated Cost ($)
Worthy Park	4.62	24,000	335,000	144,000	**503,000**
Huntington Beach High School	7.28	56,500	529,000	234,000	**819,000**
McCallen Park	0.68	42,200	49,000	37,000	**128,000**
Huntington Beach Police Department	0.5	77,600	36,000	46,000	**159,000**
Pacific Coast Mortgage Funding	0.14	328,200	10,000	135,000	**474,000**
Terry Park	2.67	331,800	194,000	210,000	**736,000**
Huntington Beach Sports Complex	17.05	244,400	1,238,000	593,000	**2,075,000**
Huntington Central Park	16.39	24,000	1,190,000	486,000	**1,699,000**
Oak View Center Park and Elementary School	4.3	233,600	312,000	218,000	**764,000**
Ocean View High School	11.1	24,000	806,000	332,000	**1,162,000**
Murdy Park	4.69	35,400	340,000	150,000	**526,000**
Huntington Beach Union High School	4.45	241,400	323,000	226,000	**790,000**
Sun View Elementary School	8.26	36,400	600,000	254,000	**890,000**
Sun View Park	0.76	26,900	55,000	33,000	**115,000**
Golden West College	18.8	24,000	1,365,000	556,000	**1,944,000**
Pleasant View School	4.72	384,400	343,000	291,000	**1,018,000**
The Good Shepherd Cemetery and Mausoleum	15.63	24,000	1,135,000	463,000	**1,622,000**
Lake View Park and Elementary School	5.9	24,000	428,000	181,000	**633,000**

APPENDIX G GEODATABASE DESCRIPTION

This document accompanies the geodatabase containing the existing and proposed feature classes for the Master Plan of Drainage (MPD) prepared for the City of Huntington Beach (City). This memo contains a catalog of the feature classes contained within the geodatabase followed by a short description of the contents, sources, and key assumptions. Each feature class within the database contains several attributes, for which a list of its column headers is provided in *italics* followed by a short description of the contents, sources, and key assumptions.

EXISTING NODES

Point feature class that contains all nodes within the existing storm drain network to create a fully articulated drainage system (e.g., includes data received from the City as well as 'model modes' digitized to create a complete storm drain network). Combines geospatial network received from the City, field reconnaissance, and as-builts.

New_ID

ID that combines the original model ID and the PCSWMM submodel number.

Invert Elevation (ft)

Elevation of bottom of pipe at node location, derived from as-built documents or assumed.

Rim Elevation (ft)

Elevation of ground surface at node location derived from DEM.

Entity Symbol

Indicates the type of node (e.g., catch basin, junction, collar, grate, etc.).

STRMINDEX

ID associated with the Original received dataset ('StormPT')

Q10

Flow rate associated with 10-yr 24-hr 85% storm event

Q100

Flow rate associated with 100-yr 24-hr 85% storm event

EXISTING CONDUITS

Linear feature class that contains the complete storm drain network with all conveyances, and their corresponding attributes. These data include the linear data provided by the City, as well as additional flowpaths to create a fully articulated flow network.

New_ID

ID that combines the original conduit ID and the PCSWMM submodel number.

Length (ft)

Distance from end to end of conduit between nodes.

Depth (ft)

Average depth of conduit below ground surface. Assumed from depth of downstream node.

Slope (ft/ft)

Indicates whether the conduit's slope was known (i.e., obtained from as-built documents) or assumed (Final MDP will include complete documentation of methods used to assess slope).

Cross-section

Type of conduit shape (i.e., circular, trapezoidal, etc.).

Geometry 1 (ft)

Diameter for circular conduits, height for rectangular or trapezoidal configurations.

Geometry 2 (ft)

Width for rectangular or trapezoidal configurations.

Geometry 3 (ft)

Horizontal component of left bank side slope ratio (for trapezoidal cross-sections).

Geometry 4 (ft)

Horizontal component of right bank side slope ratio (for trapezoidal cross-sections).

Barrels

Number of barrels.

Q10

Flow rate associated with 10-yr 24-hr 85% storm event

Q100

Flow rate associated with 100-yr 24-hr 85% storm event

Slope1

Indicates if the estimated slope was derived from as-builts or assumptions

Entity Symbol

Indicates the type of node (e.g., arch pipe, model conduit, etc.).

Size

Indicates whether the conduit's size was known (i.e., received data) or assumed

PROPOSED NODE IMPROVEMENTS (NEW AND EXISTING)

Point feature class that contains only nodes with proposed changes to meet flood control standards. For existing infrastructure, the invert elevation and/or the volume flooded at the node is specified. For new infrastructure (e.g., additional inlets needed to mitigate flooding in the watershed), the invert, rim, peak flow, and inlet type recommended are specified. Associated costs are provided. A full cost analysis will be provided in the MPD.

New_ID

ID that combines the original model ID and the PCSWMM submodel number.

Invert Elevation (ft)

Elevation of bottom of pipe at node location derived from as-built documents or assumed (final MPD will include complete documentation of methods used to estimate invert elevation).

Rim Elevation (ft)

Elevation of ground surface at node location derived from DEM.

Entity Symbol

Indicates the type of node (e.g., catch basin, junction, collar, grate, etc.).

Infrastructure Type

Indicates whether the proposed change is on existing or new infrastructure.

Peak flow (cfs)

Peak runoff (cfs) that needs to be managed by the inlet. This metric will ultimately drive the final design of specific inlets, as many inlets in the MPD were characterized in the models based on global assumptions due to unavailable data (e.g., if as-builts were unavailable or if the nodes were missing data in the geospatial database).

Sump Inlet size (ft)

Length of catch basin curb opening when built in a sump condition. For many inlets, the provided data did not specify if each catch basin exists ‘in sump’ (local depression) or ‘on-grade’ (on a slope), for this reason the required length of curb opening for both conditions is provided. Regardless of whether the catch basin is in sump or on-grade, the appropriate length to convey peak flow of runoff from the upstream drainage area is provided. Field verification will be required to determine if the existing catch basin is in sump or on grade.

Grade Inlet size (ft)

Length of catch basin curb opening when built in a sump condition. For many inlets, the provided data did not specify if each catch basin exists ‘in sump’ (local depression) or ‘on-grade’ (on a slope), for this reason the required length of curb opening for both conditions is provided. Regardless of whether the catch basin is in sump or on-grade, the appropriate length to convey peak flow of runoff from the upstream drainage area is provided. Field verification will be required to determine if the existing catch basin is in sump or on grade.

Volume of Storage

If distributed detention storage was indicated the stormwater volume in ac-ft is listed.

Reason for storage

A number of conditions arose in the models that required storage at or upgradient from a node (e.g., undersized downgradient pump, full channel, flat slope, etc.). Storage of stormwater (e.g., distributed detention vaults, regional detention, etc.) is necessary when upsizing the downstream conduits is infeasible, the downstream pump is at capacity and upsizing conduits cannot reduce flooding conditions, backwater conditions, etc. In these instances, the reasoning (e.g., undersized pump, full channel, flat slope, etc.) is provided to offer further context for why storage is needed.

Total Min cost ($)

Summation of all calculated costs if the inlet was on grade (unit, construction and 40% contingency).

Total Max cost ($)

Summation of all calculated costs if the inlet was in sump (unit, construction and 40% contingency).

Total Storage cost

Summation of all calculated costs (unit, construction and 40% contingency).

Notes

Indicates if an inlet cannot sufficiently handle max flows if currently on-grade. Because it has not been determined if catch basins exist within sump or on-grade, there may be proposed catch basins on-grade that are required to convey more flow than feasible in an on-grade environment (e.g., the slope causes flows to bypass without potential for intercepting them prior to flooding). In these instances, a note is added to indicate that a catch basin in sump either at the existing node location or further downstream is required to convey the incoming peak flows. Field verification is required to determine if the node is in sump or on-grade.

PROPOSED CONDUIT IMPROVEMENTS (NEW AND EXISTING)

Linear feature class that contains only conduits within the storm drain network whose cross-section and/or geometry was changed (e.g., upsized) and their corresponding proposed attributes.

New_ID

ID that combines the original conduit ID and the PCSWMM submodel number.

Length (ft)

Distance from end to end of conduit between nodes.

Depth (ft)

Depth of conduit below ground surface. Assumed from downstream node.

Cross-section

Type of conduit shape (i.e., circular, trapezoidal, etc.).

Geometry 1 (ft)

Diameter for circular conduits, height for rectangular or trapezoidal configurations.

Geometry 2 (ft)

Width for rectangular or trapezoidal configurations.

Geometry 3 (ft)

Horizontal component of left bank side slope ratio (for trapezoidal cross-sections).

Geometry 4 (ft)

Horizontal component of right bank side slope ratio (for trapezoidal cross-sections).

Barrels

Number of barrels.

Slope1

Indicates if the estimated slope was derived from as-builts or assumptions

Size

Indicates whether the conduit's size was known (i.e., received data) or assumed

Total cost ($)

Summation of all calculated costs (unit, construction and 40% contingency).

STORAGES

Fifteen regional detention storages have been identified by Tetra Tech and verified by the City. The storages on public parcels with proposed increases in volume and their attributes are provided.

Storage name

Name of regional detention storage facility.

Invert elevation (ft)

Assumed elevation of bottom of facility (derived from DEM).

Berm elevation (ft)

Elevation of spillover (i.e., elevation at which overflow occurs).

Spillover volume (ac-ft)

Volume of stormwater that overtops berm and represents the additional capacity that is needed at the detention facility.

Total cost ($)

Summation of all calculated costs to provide additional capacity for the spillover volume (includes +40% of construction costs for contingency).

PUMPS

Feature class describing the current pump capacities of the 15 City-owned pumps and their attributes.

Pump name

Name of pump.

Pump Operating Capacity (cfs)

Max operating flow rate, information provided to Tetra Tech by the City.

Proposed Pump Capacity (cfs)

Modeled max runoff rate to the pump location for the existing condition.

Pump Utilization (%)

Percent of proposed pump flow to existing pump capacity.

Drainage Area (acres)

Area of upstream drainage to each pump.

SUBWATERSHED DRAINAGE

Subwatershed (SWS) name

Unique identifier associated with each drainage subwatershed.

Area (ac)

The drainage area upstream of an inlet.