# Chapter 20

# CITY OF LOS ANGELES
# LARGE-DIAMETER INTERCEPTOR SEWER TUNNELS

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## ABSTRACT

The City of Los Angeles capital improvement program includes the construction of a new 35-km interceptor sewer. This sewer will be built as a deep tunnel with finished diameters ranging from 2- to- 4 meters. The project will be constructed concurrently in two phases; an 18-km East-West and a 17-km North-South segment. The new sewer provides additional conveyance capacity for an existing deteriorating sewer that is scheduled for rehabilitation. Large sewage spills during the El Niño storms of 1998 resulted in a Cease and Desist Order that established an aggressive schedule for the completion of the project.

## INTRODUCTION

The City of Los Angeles and its surrounding communities have experienced rapid development and population growth in the past several decades. The City currently operates over 10,000 km (6200 miles) of sanitary sewers, numerous pumping plants, two treatment plants and two water reclamation plants. Increases in the quantity of sewage generated pose significant hydraulic burdens for portions of the existing sewerage system, particularly during wet weather conditions.

One of the major interceptor sewers serving the Los Angeles area is the North Outfall Sewer (NOS). Extreme wet weather events have caused several well-publicized overflows within the City's residential neighborhoods. In 1998, a state regulatory agency, the California Regional Water Quality Control Board, issued a Cease and Desist Order (CDO) that requires the City of Los Angeles to mitigate the overflow problems by upgrading sewers throughout the City. Two major projects, the East Central Interceptor Sewer (ECIS) and the Northeast Interceptor Sewer (NEIS) form the basis for much of this upgrading effort.

This paper summarizes the project and for these two projects.

### North Outfall Sewer (NOS)

The existing NOS is a major interceptor sewer serving many communities in the Greater Los Angeles area. Originating in the San Fernando valley, the NOS roughly follows the present course of the Los Angeles River flowing eastward toward the City of Glendale, where it turns southward passing Downtown Los Angeles. After undercrossing Interstate-10, the pipeline turns westward toward Culver City and ultimately terminates at the recently upgraded Hyperion Treatment Plant. A site location map for the existing NOS alignment is illustrated in **Figure 1**.

Improvements along the existing NOS have been carried out in stages. In the early 1990's, the City completed the first leg of a replacement sewer, from Culver City to Hyperion Treatment Plant. This section was completed using tunneling methods, and was referred to as the North Outfall Replacement Sewer (NORS).

The two segments of the new replacement sewer covered by the 1998 CDO are the sections from Los Angeles Glendale Water Reclamation Plant (LAGWRP) south to the I-10 interchange (Northeast Interceptor Sewer - NEIS) and from the I-10 interchange to Culver City (East-Central Interceptor Sewer - ECIS). The location for these two tunneling projects is illustrated in **Figure 2**. The CDO establishes completion dates for the ECIS and NEIS as November 2003 and November 2004, respectively.

The original NOS is a clay tile-lined concrete pipe that was constructed between 1924 and 1930. The majority of the pipe was constructed using open trench methods, with hand-mined tunnels under the Los Angeles River. The NOS cross-section is roughly semi-elliptical in shape, as illustrated in Figure 1.

In periods of wet weather, the NOS becomes hydraulically overloaded, especially along the downstream portion. In addition to reaching capacity limits, the pipe lining has deteriorated due to hydrogen sulfide attack, and has collapsed in localized areas. The replacement sewers will provide additional hydraulic capacity for anticipated future flow increases, as well as the means to divert existing flows from NOS to permit rehabilitation. (City of Los Angeles, 1993)

### Design and Construction Planning

The Bureau of Engineering of the City of Los Angeles is performing the design work for the replacement pipelines. Jacobs Associates, in association with Montgomery Watson and URS Greiner/Woodward Clyde, provides additional engineering support for the design of the NEIS. Parsons Brinckerhoff Quade & Douglas is providing engineering support to the City for the design of the ECIS. Construction management will be performed by City staff.

The milestone completion dates are as follows:

| MILESTONES | ECIS | NEIS |
|---|---|---|
| **Environmental Impact Report** | November 1998 | December 1999 |
| **Final Design** | June 2000 | June 2001 |
| **Bid & Award** | December 2000 | December 2001 |
| **Construction** | November 2003 | November 2004 |

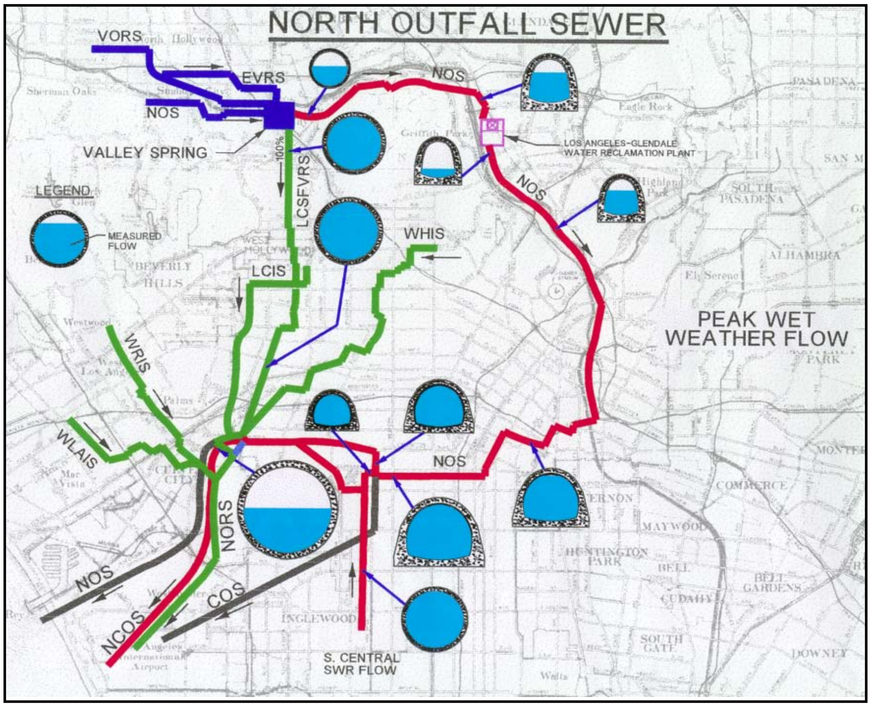


**Figure 1. North Outfall Sewer**

The ECIS project will be in service prior to the upstream NEIS portion, and will provide immediate hydraulic relief for the NOS in the Los Angeles South Central area.

Given the limited project schedule, the City anticipates that multiple construction contracts will be awarded to permit concurrent construction activities. Each project will include a minimum of four construction contracts, which will consist mostly of tunneling and micro-tunneling, as well as construction of shafts, drop shafts and maintenance holes. The rehabilitation of the NOS will be addressed in future projects after the completion of the ECIS and NEIS.

## PROJECT DESCRIPTIONS

Many large-diameter interceptors and small-diameter local sewers are connected to the NOS. After the completion of the ECIS and NEIS projects, flows will be diverted from the NOS to allow the rehabilitation of some of these existing large diameter tributary sewers. Only the larger connecting sewers will be connected to the new pipe. Sufficient flow will be retained in the rehabilitated NOS to maintain the required scouring velocity in existing inverted siphons and the main line itself. The final tunnel lining will be protected from corrosion using either fiber reinforced pipe or PVC lining.

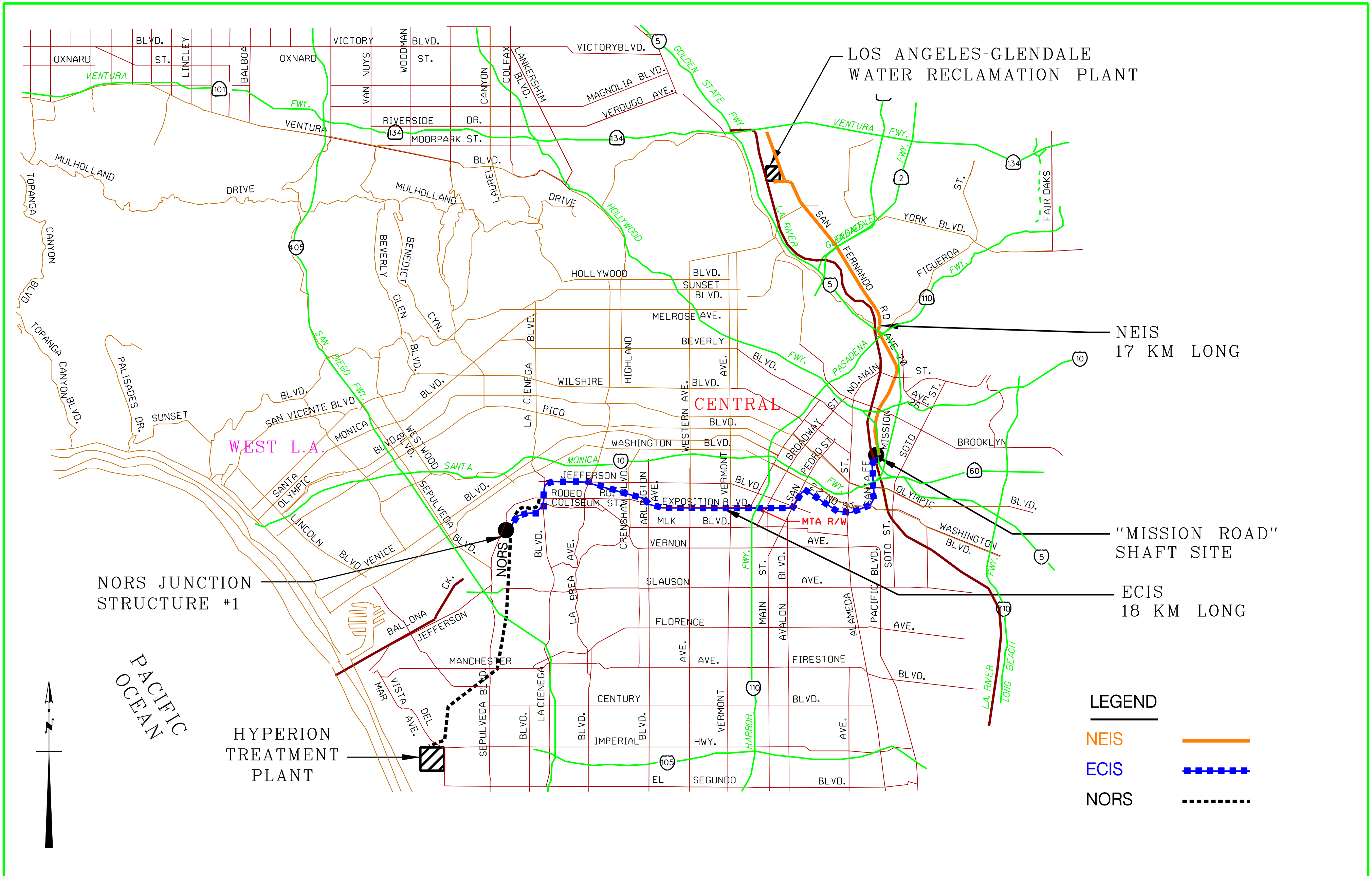


Figure 2. NEIS and ECIS site location

Both the ECIS and NEIS projects will be designed to handle anticipated peak dry weather flow (PDWF) in the Year 2050. The design flows at downstream terminuses of ECIS and NEIS are 9 m3/sec (320 cfs) and 5 m3/sec (175 cfs), respectively. The design depth of the sewerage will be 50 percent of the inside diameter of the pipe (d/D=0.5), and the proposed grade no more than 0.3 percent. The resulting inside diameter of the final lining will range from 2- to 4-meters (6.5 feet to 13 feet).

### East-Central Interceptor Sewer (ECIS)

The alignment of the ECIS sewer has been the subject of years of planning, community meetings and two Environmental Impact Reports. A key factor affecting the alignment selection process was the availability of portal/shaft sites. The final approved project alignment traverses industrial, commercial, and residential areas of the City. The alignment is maintained within existing rights-of-way as much as possible. (Myra Frank & Associates, Inc., 1998)

**ECIS Tunnel Alignment.** The main tunnel of the ECIS project will be constructed in four major concurrent segments. The alignment plans for these segments are illustrated in **Figures 3 through 6**. From upstream to downstream, these construction contracts are designated as Units 4, 3, 2, and 1. Construction of two smaller tributary sewers, units 5 and 6 will occur concurrently. They are shown in **Figure 7 and 8**.

**ECIS Unit 4.** The upstream end of ECIS Unit 4 is the downstream terminus of the NEIS project and a temporary diversion point for the NOS. The entire unit will be in river alluvium consisting primarily of clean sand, gravel, cobbles, and some boulders. The project area includes commercial, industrial, and residential neighborhoods.

The Unit begins at the intersection of Mission Road and Jesse Street. The ECIS pipeline will cross in a westerly direction under the concrete lined Los Angeles River, and proceeds along Santa Fe Avenue, crosses the I-10 freeway, and Olympic Blvd., terminating at the “Jail Site” located on 14th Street approximately one block East of Santa Fe Avenue. This site will be used for launching the TBM and for muck haulage.

The alignment will continue under Santa Fe Avenue to Washington Blvd where it will cross under the ongoing Alameda Corridor construction project. The sewer will continue in a generally westerly direction on 22nd Street, crossing the MTA Blue Line on Long Beach Avenue, to San Pedro Street. The alignment follows San Pedro south until it reaches the MTA rights-of-way. The downstream terminus of Unit 4 is located at the intersection of Grand Avenue and 35th Street.

**ECIS Unit 3.** ECIS Unit 3 will begin at the downstream terminus of Unit 4, the intersection of Grand Ave. and 35th Street. The alignment will continue in the MTA Right of Way under the I-110 Freeway where it will continue westerly under Exposition Blvd for the balance of the contract. As was the case for Unit 4, this entire reach will be in river alluvium. The project area includes commercial districts, educational institutions, and residential neighborhoods with minimal setbacks.

**ECIS Unit 2.** Unit 2 begins at the downstream terminus of Unit 3, on Arlington Avenue between Exposition Blvd. and Rodeo Road. The project area is also a mix of commercial districts, educational institutions, and residential neighborhoods with minimal setbacks. The entire unit will also be excavated in river alluvium.

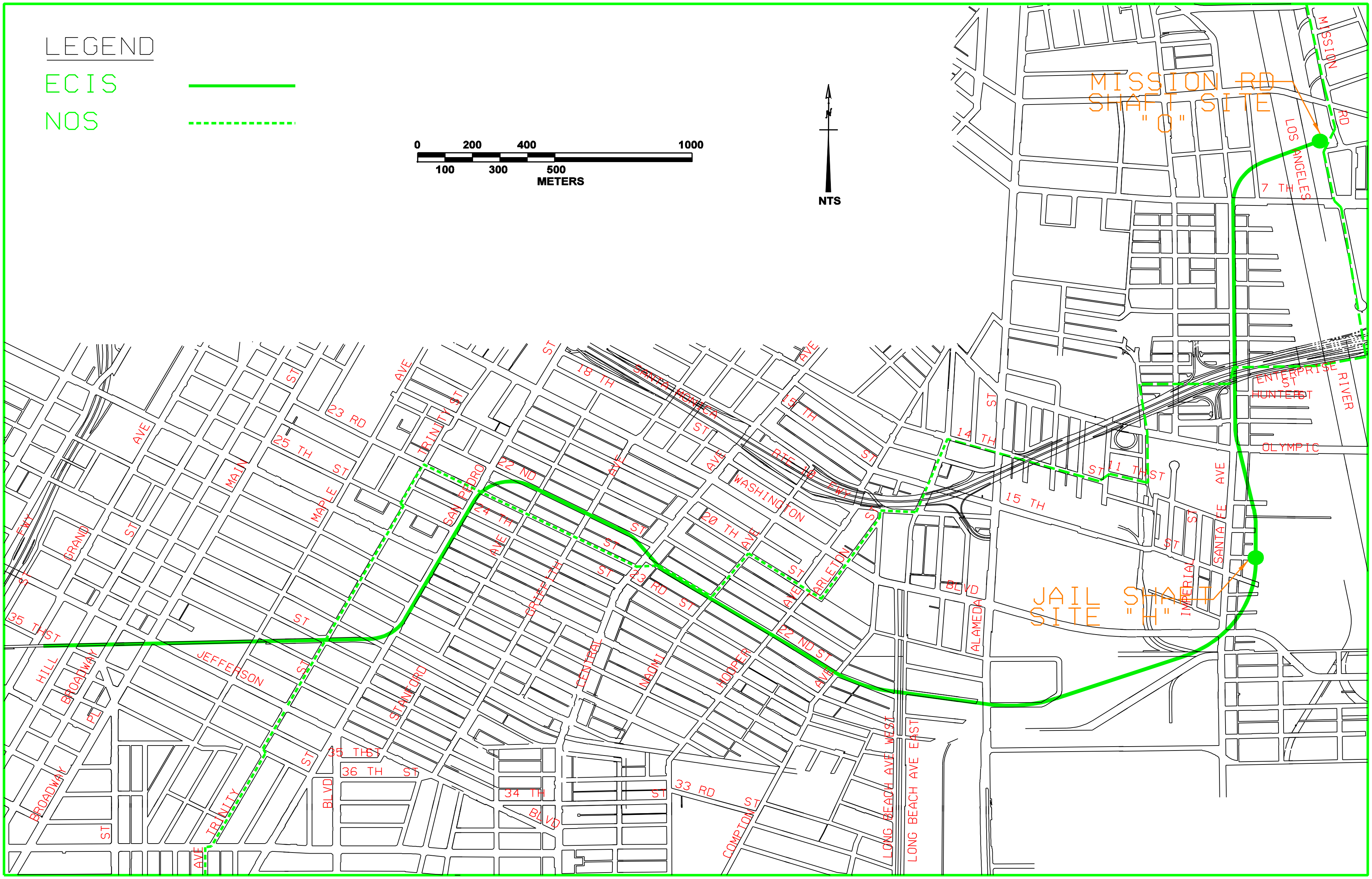


Figure 3. Final ECIS alignment - Unit 4

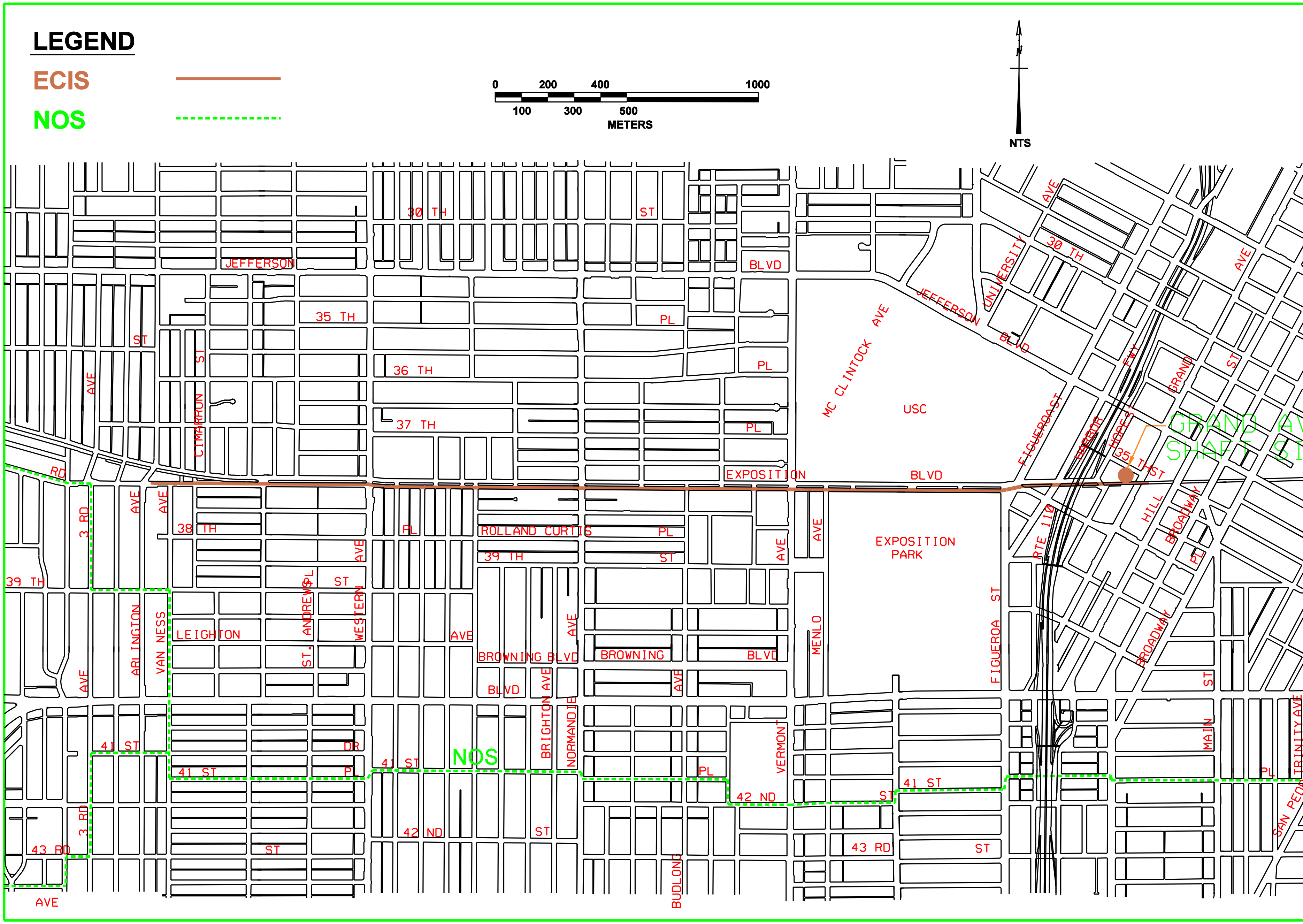


Figure 4. Final ECIS alignment - Unit 3

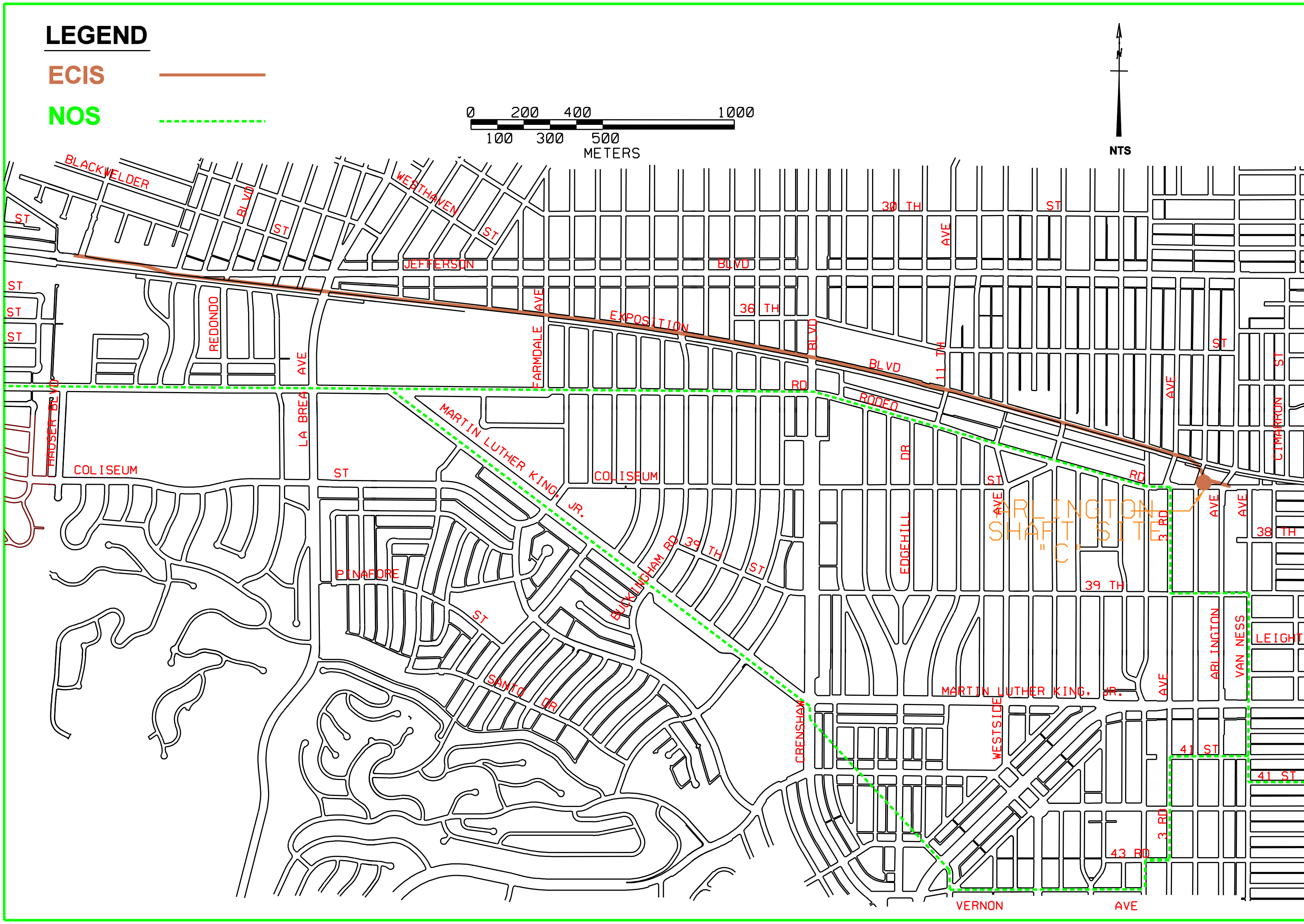


Figure 5. Final ECIS alignment - Unit 2

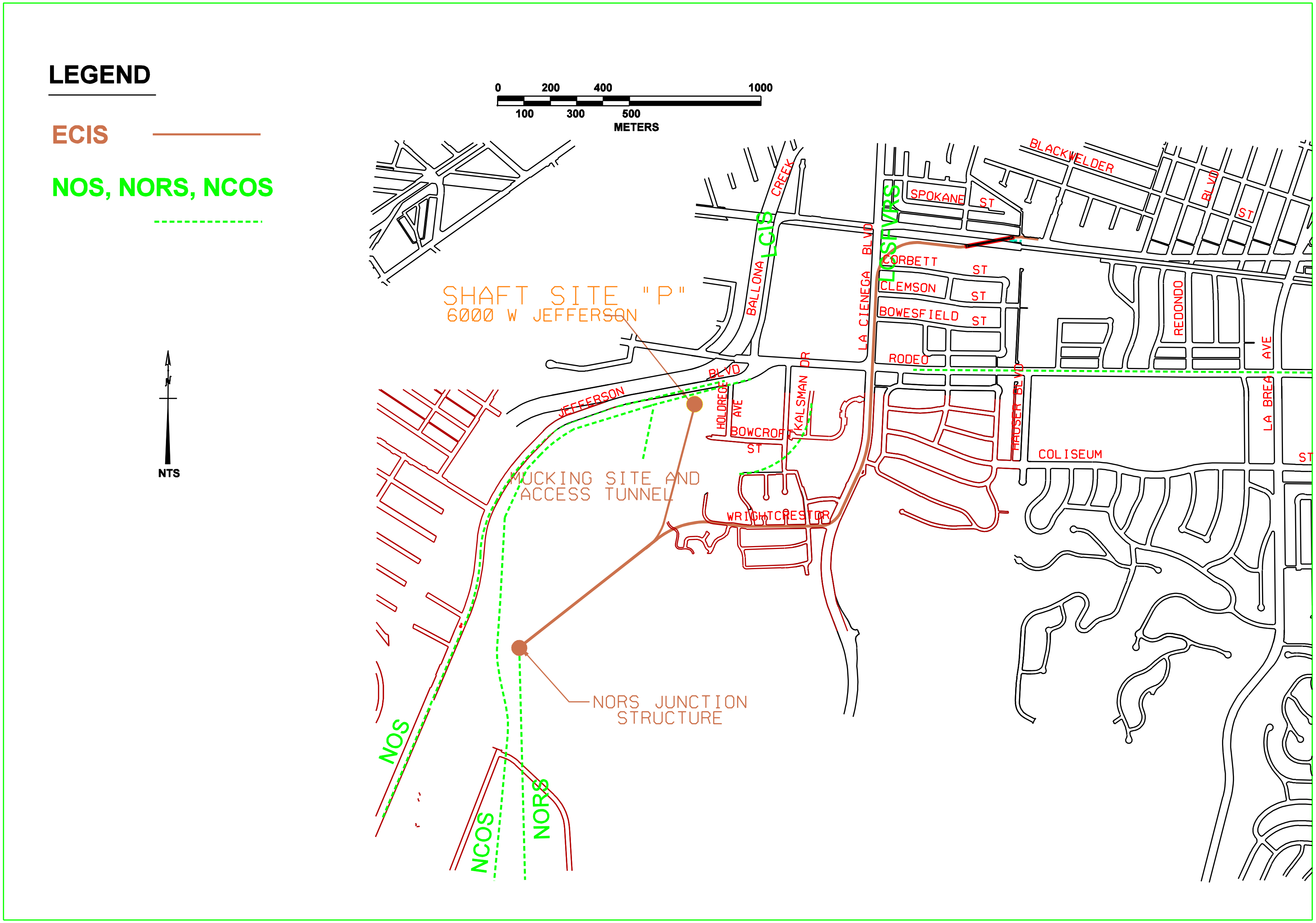


Figure 6. Final ECIS alignment - Unit 1


Figure 7. Final ECIS alignment - Unit 5

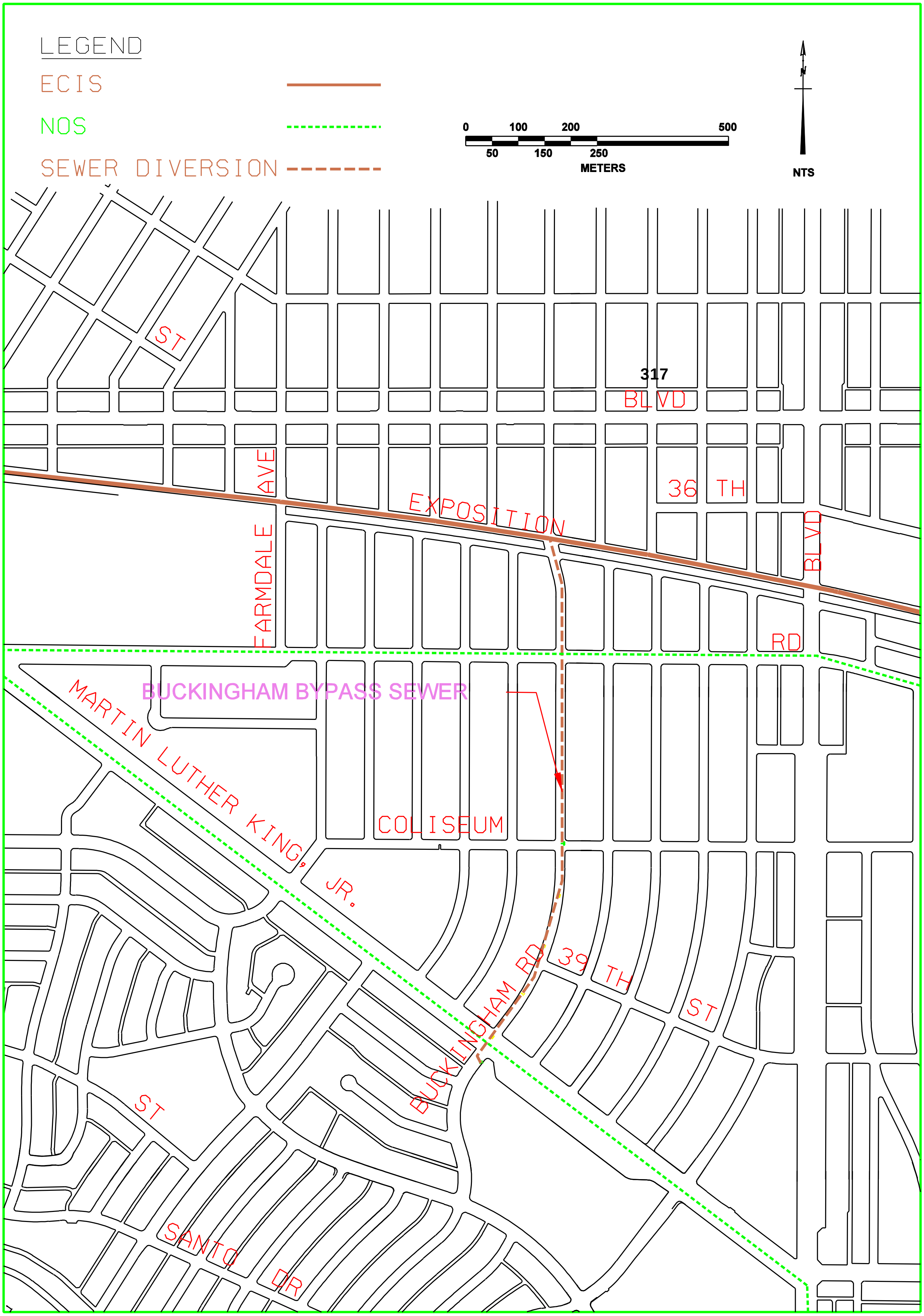


Figure 8. Final ECIS alignment - Unit 6

The construction of this section of the alignment will be constrained by the presence of several large-diameter underground utilities, including large storm drains in Exposition Blvd., a 1.5-meter (59-inch) diameter sewer, a 1.6-meter (63-inch) diameter Department of Water and Power trunk line, and several other major storm drains.

Unit-2 ends at Carmona Ave. at the inlet structure of an inverted siphon that is required to cross the storm drain in Jefferson Blvd.

**ECIS Unit 1.** From the downstream terminus of Unit 2, the ECIS alignment crosses Jefferson Blvd. in an inverted siphon. An adit tunnel of approximately 600 meters (1970 feet) will be excavated in the soft bedrock of the San Pedro Formation from a proposed shaft location to the ECIS tunnel alignment under the Blair Hills. The project area includes an active oil field commercial districts, and residential neighborhoods.

From the siphon outlet, Unit 1 proceeds in a westerly direction crossing under La Cienega Blvd. where it turns south parallel to the existing La Cienega San Fernando Valley Relief Sewer. At Rodeo Road the alignment crosses underneath the existing North Outfall Sewer (NOS) and a concrete box storm drain where there is minimal vertical clearance between the invert of the storm drain and the crown of the excavated ECIS tunnel. The alignment continues south until at the intersection of La Cienega and Wrightcrest the sewer crosses the active Newport-Inglewood fault. Special construction considerations will be designed into this fault crossing.

The alignment continues along Wrightcrest Drive in Culver City to Shedd Terrace where it diverges through an active oil field to its connection point at the existing NORS stub-out.

**ECIS Unit 5**. Unit 5 consists of abandoning an existing pump plant and installing a gravity sewer by micro-tunneling on Buckingham from Martin Luther King Blvd. to Exposition Blvd.

**ECIS Unit 6.** Unit 6 consists of the construction of a diversion structure on the existing NOS at 23rd and Trinity Street, a diversion sewer from Trinity Street to San Pedro Street, and a plunge-type dropshaft at San Pedro Street which connects to the NEIS.

**ECIS shaft locations.** The ECIS project will have five major shaft sites and several minor sites for junction structure connections, flow measurement, and maintenance hole construction. The design team expects that the shaft sites identified on the attached Figures 3 to 8 will be sufficient for work areas, although construction contractors may have to obtain additional off-site areas for material storage and lay-down.

**Connections to existing/future sewers.** The existing NOS will be connected to the ECIS at two locations: Mission/Jesse and 24th/Trinity. In addition to these two connections the existing Buckingham pump plant will be abandoned and the flow in the connecting sewers will be diverted to the ECIS.

Provisions will also be made for the future connection to ECIS of seven major sewers and one additional pumping plant. These provisions will be made by the construction of tributary junction structures, that will also serve as maintenance holes for the new sewer.

**Northeast Interceptor Sewer (NEIS)**

Given the project's location in an urban setting, it will no doubt have a significant impact on the local communities. In order to adequately address environmental and local community concerns, as well as the construction issues, the alignment selection process for the NEIS must be both systematic and unbiased. (Jacobs Associates, 1999)

**Alignment Selection Process.** The alignment selection process for NEIS began in 1993 and six candidate alignments were developed. After the CDO was issued, a detailed analysis of all of the proposed alternatives was performed in order to narrow the candidate alignments down to two (plus two minor variations) for the Environmental Impact Report (EIR) study.

A comprehensive ranking system was developed to account for the all major factors that may affect the alignment selection. Factors such as environmental impacts on sensitive receptors, odor generation, and traffic were included. Tangible and measurable attributes of these impacts, such as the length of time that local communities would be subjected to construction activities were then estimated. In addition, the various alignments factors that may affect and delay the construction activities, such as acquisition of real-estate easements and permits were considered.

The data gathered for each candidate alignment was normalized on a uniform scale for comparison. Each alignment was compared to others and ranked using a combination of "best public value" and estimated construction cost. Not surprisingly, the higher value options were associated with tunneling methods, since surface impacts during construction were minimized. The lower value alternatives would have greater surface impacts since these options included micro-tunneling where multiple access pits would be required.

**Horizontal Alignment(s).** Based on the results of the ranking comparison, one alignment (with four different minor variations) consistently scored better than the other identified alternatives, and was recommended to be included in the final EIR evaluation. The preferred alignment and the variations are presented in **Figures 9 and 10**.

The north terminus of the project is located at Doran Street near Highway 134, where it will be connected to the future upgraded NOS. From Doran Street, the proposed pipeline will follow roughly along public rights-of-way to the south terminus at Mission Road and Jesse St., where it will connect to the downstream ECIS pipeline. The four variations represent two possible routings between Goodwin Avenue and the Eagle Rock Road site and between Future Street and the Lincoln Heights site.

**Shaft Locations.** For tunneling alternatives, a total of five to six construction shafts is anticipated for each proposed variation. The location of these shafts is selected based on land availability, limits of proposed construction contracts, environmental impacts on local neighborhood, and traffic coordination.

The City will acquire the necessary land where the shafts will be located. However, the Contractor may have to negotiate with private property owners for additional work space or laydown area.

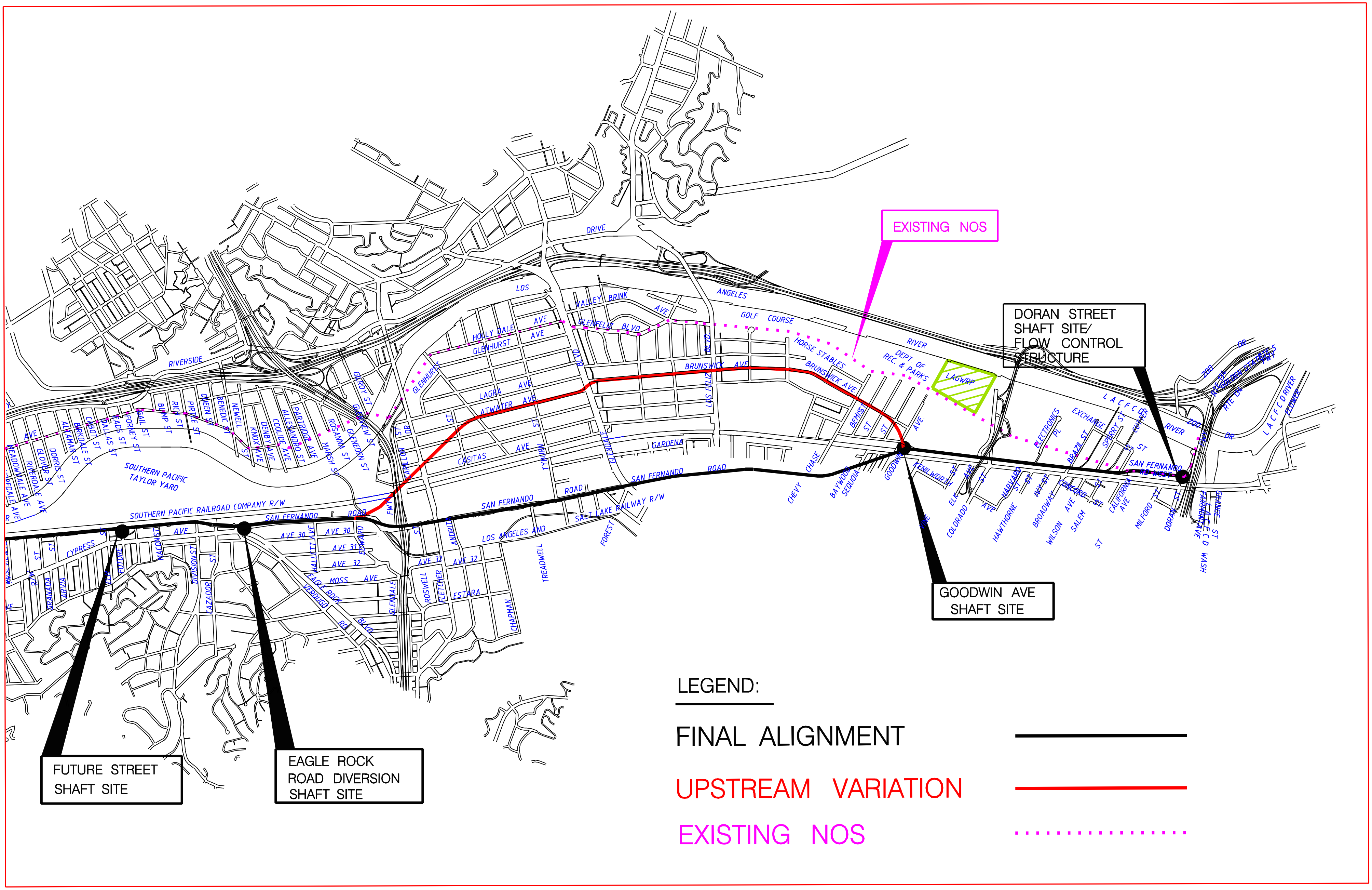


Figure 9. Candidate NEIS alignment - Upstream

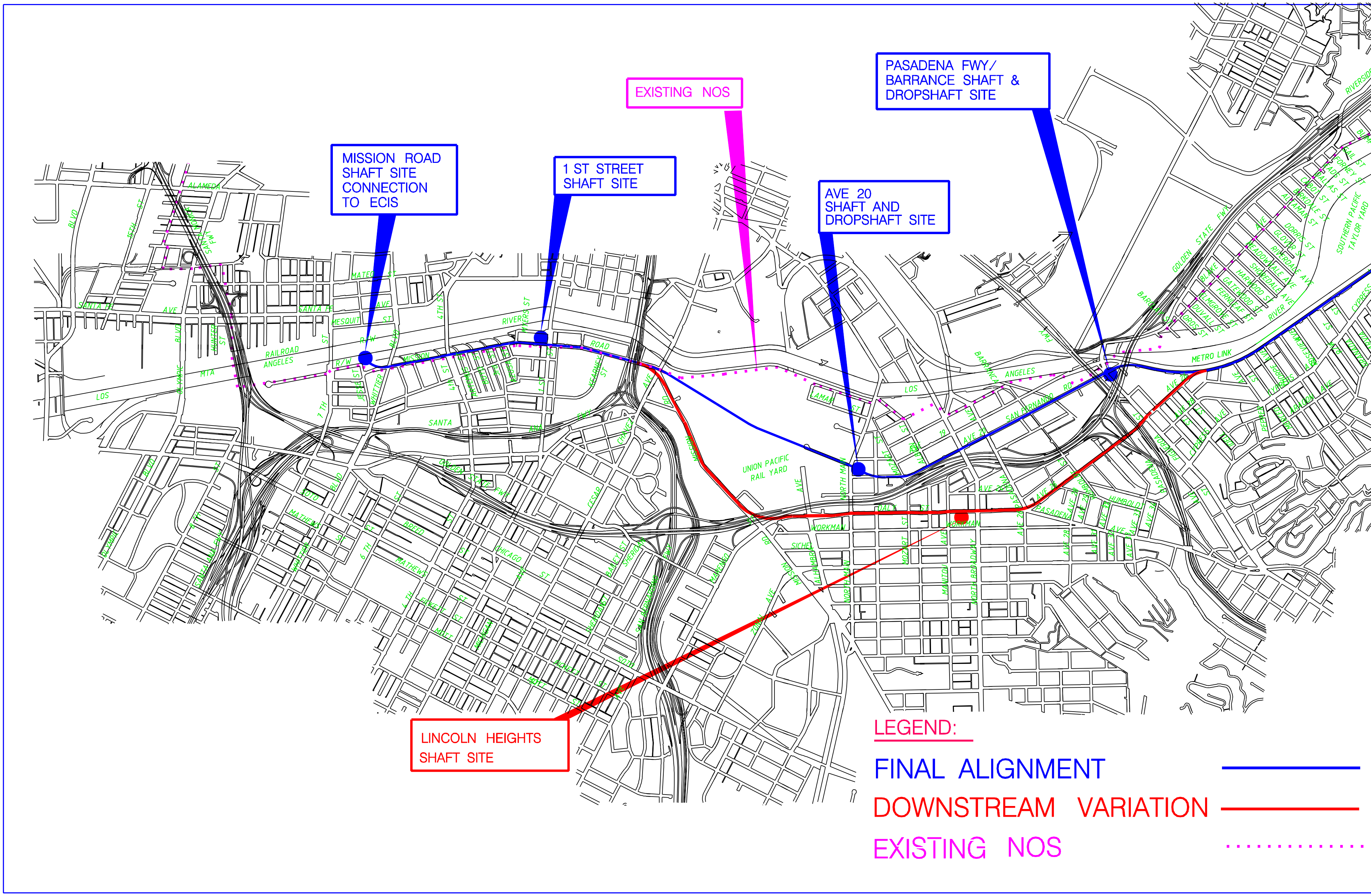


Figure 10. Candidate NEIS alignment - Downstream

**Vertical Alignment(s).** The selection of the vertical alignment(s) was equally challenging. The proposed depth to NEIS tunnel invert varies from 15 to 30 meters (50-100 feet) below existing grade, and will be one of the deepest sewer tunnels in the City of Los Angeles. Several factors were considered in selecting the vertical profile(s):

- Vertical Obstructions - To provide adequate clearance under roadways, utilities, and storm drains;
- Top of bedrock and groundwater elevations - To avoid mixed face and/or running ground conditions; and
- System hydraulics - Attributes such as design grade, flow velocity, dropshafts, and flow capacity are critical to ensure the successful operation and performance of the complete NEIS pipeline.

Sewer flow in pipes with steep slopes is inherently unstable (super-critical flow) and can generate foul odors anywhere along the alignment. Except for short stretches, the majority of the NEIS pipeline should not be placed on steep slopes. In addition, the proposed grade along ECIS will be much flatter than NEIS, and therefore, the potential for hydraulic instability at the NEIS/ECIS junction could be significant.

The governing factor for the final selection of the NEIS vertical alignment is the design grade. The existing ground surface along the NOS and the proposed alignments slope gradually from north to south, with a total vertical relief from Doran Street to Mission Road of more than 60 meters (200 feet). If the pipeline were constructed at a fixed depth below the ground surface, the average grade would be 0.45 percent, significantly more than the recommended slope of 0.3 percent. To alleviate this problem, vertical drop(s) along the main line of the NEIS pipe will be required. The decision whether to incorporate one single drop, approximately 20 to 25 meters (65-80 feet) in depth, or several smaller drops along the alignment has not yet been made. Drop structures may create odors, but since they are generated in discrete locations the odors are easier to control. For instance, permanent odor control facilities can be installed at the top of shaft.

## GEOLOGICAL CONDITIONS

At the time of this writing, the City is conducting a detailed geotechnical investigation along the ECIS project alignment to better define the subsurface conditions and the tunneling medium. For the NEIS project, an initial exploration program consisting of 40 borings is being developed to assist the Engineer finalizing the alignment selection process during the EIR phase.

### Geology

The project is located at the northern margin of the Los Angeles Basin, from Baldwin Hills on the west at the downstream terminus of ECIS and to Los Angeles Narrow salong the NEIS alignment. The basin comprises an approximately

80-km (50-mile) long by 32-km (20-mile) wide lowland coastal plain that slopes gradually southward and westward toward the Pacific Ocean. This plain is interrupted by a line of hills and mesas that lies along the Newport-Inglewood fault zone.

The Los Angeles basin forms a broad synclinal structure that contains a thick sequence of Holocene, Pleistocene, and Miocene periods of marine and non-marine sediments that were deposited as the basin subsided. The uppermost Holocene deposits include poorly consolidated alluvium at the center of the basin and marine terrace and sand dune deposits along the western margin of the basin. These sediments are underlain by more than 350 meters (1,000 feet) of San Pedro Formation and Lakewood Formation of Pleistocene ages, that consist of early to middle Pleistocene gravel, sand, silt and clay. Underlying the Pleistocene are the soft rocks of the Pliocene and Miocene ages. These soft rocks crop out in the northern portion of the project area.

The melting of the last glacial ice sheets initiated the final phase of the basin development. Erosion and deposition from migrating streams have created the present day coastal plain. However, continued uplift along the Newport-Inglewood fault has created ponded surface water and marshy areas, also forming organic rich deposits. (City of Los Angeles, 1992)

### ECIS

Based on the preliminary information, the geological units along the ECIS project rights-of-way consist primarily of the Pleistocene San Pedro and Lakewood Formations, older alluvium, recent alluvium including river channel and flood plains deposits, peat deposits, localized landslide debris and man-made fill. Due to the relatively shallow overburden for the ECIS tunnel profile, it will be located primarily in the recent alluvium.

The alluvium reaches a maximum thickness of approximately 60 meters (200 feet) and is highly variable in composition. The Los Angeles River and local streams have meandered throughout the area, depositing both high energy coarse grained materials, including granitic boulders near the LA River channel, as well as fine grained flood plain deposits. Therefore, abrupt changes in the alluvium should be anticipated.

Unit 1 of the ECIS tunnel may also encounter the Lakewood and San Pedro Formations in Baldwin Hills. The Lakewood Formation consists of poorly sorted non-marine sand and gravel with lenses of silt and clay. San Pedro is primarily a light gray to reddish brown, well bedded siltstone with interbedded shale and fine sandstone. The formation is massive, but moderately consolidated and considered rippable.

### NEIS

The proposed NEIS alignment will be primarily within the recent alluvial deposits. However, since the NEIS tunnel profile will be considerably deeper than the ECIS alignment, with a proposed depth varying from 15 to 30 meters (50 to 100 feet) below existing grade, soft bedrock of the Puente Formation will also be encountered. The Miocene aged Puente Formation underlies the Elysian Hills in the central portion of the corridor. It is a sedimentary rock of marine origin, and consists of interbedded sandstone, siltstone, shale and conglomerate.

Based on the recent LA Metro tunneling experience, the bedrock of the Puente Formation appears to be a favorable tunneling medium. However, due to the limited subsurface information currently available, the interface between the recent alluvium and the Puente Formation is not well defined. Tunneling is anticipated to encounter mixed face conditions along any stretch of the proposed alignment. Given a relatively shallow groundwater table along the NEIS project alignment, unstable flowing ground conditions should be anticipated if the tunneling heading is not properly supported.

**Groundwater Conditions**

Within the Los Angeles Basin the primary source of recharge includes the Los Angeles River which directs water through the Los Angeles Narrows from the north, and Rio Hondo River from the east. The surface recharge area within the Basin has been greatly reduced in recent years due to the large area covered by buildings and paved streets.

Groundwater movement within the Basin is toward pumping depressions located in the Vernon area, and where the Los Angeles River crosses the Newport-Inglewood Fault. High groundwater levels are anticipated in the northerly portion of the alignment due to the constant recharge of the permeable alluvial deposits at the unlined river channel.

Based on the preliminary subsurface information and proposed tunnel profiles, the groundwater table will be located above the tunnel crown throughout the NEIS alignment from Doran Street to the Mission Road and 1st Street intersection. Groundwater, with the exception of perched water, generally lies below the project vertical alignment downstream, including all sections of ECIS. In the vicinity of the Blair Hills groundwater may be found at tunnel depth.

Contaminated groundwater may occur locally throughout the project, mostly likely along the upstream portion of the NEIS alignment where several active Superfund sites are located.

**Oil and Gas**

The Los Angeles Basin is one of the most prolific oil producing regions in the United States. The faults and folds associated with the Newport-Inglewood Uplift form structural traps for the major oil fields located within the project area. One of the largest of these fields is the Inglewood Oil Field in the Baldwin Hills.

The ECIS Unit 1 will be tunneled through the northern edge of the Inglewood Oil Field. Oil drilling in the area has created paths alongside of the oil well bores that would permit methane gas to move from one location to another or to the ground surface. Since methane gas has been detected in preliminary borings conducted near the Blair Hills, it is possible that methane would be encountered at levels that could be problematic for tunneling.

The NEIS alignment will not pass through any known oil fields, except along the edge of the Union Station Oil Field and Boyle Heights Oil Field. However, since methane or natural gas occurrences have been noted throughout the Los Angeles

Basin, it is anticipated that natural gas will be encountered at random along the NEIS alignment, and for the balance of the ECIS alignment.

Therefore, the Cal-OSHA tunnel classification is expected to be “potentially gassy” or “gassy”.

### Faults and Seismicity

The seismicity of southern California is dominated by the intersection of the northwest trending San Andreas fault system and the east-west trending Transverse Ranges fault system. The NEIS and ECIS project alignment will encounter and is located in close proximity to several active and potentially active faults in the Los Angeles Basin, as summarized in the table on the following page.

Typically, ground shaking does not have a major impact on a subsurface structure such as pipelines. The greatest risks associated with seismic-related events include adverse tunneling conditions across the fault lines, ground surface rupture and liquefaction.

Tunnel construction across fault lines is anticipated to be difficult where sheared and fractured bedrock are likely to be encountered. Recent tunneling experience across the San Andreas Fault at the Inland Feeder project indicates the importance of selecting the proper Tunnel Boring Machine (TBM) for such an undertaking. For the ECIS and NEIS projects, however, the crossing of the faults may be located in the shallow overburden materials and may not present any additional tunneling problems.

Ground rupture, due to displacement, is generally considered to occur along a pre-existing fault. For instance, the scarp formed by the vertical displacement of the Newport-Inglewood Fault at the northern end of Baldwin Hills along ECIS alignment is approximately 60 meters (200 feet) high. The City estimates the total theoretical displacement along this fault is 0.5 meter (1.5 feet) for the design life of the project.

For the NEIS alignment, the Hollywood Fault represents the greatest potential for ground surface rupture. However, since there is no evidence of recent Holocene seismic activities, the potential for ground surface rupture along Hollywood Fault can be considered low.

### Ground Contamination

Many industrial sites along the project alignment, historic and current, have known or suspected soil or groundwater contamination. Currently, active EPA investigation and clean-up are being performed at several Superfund sites located along the NEIS alignment.

These industrial and/or hazardous waste sites are potential sources of contamination that could affect the proposed tunneling activities by direct contamination of subsurface soils along the alignment, through surface runoff, muck haulage and disposal, and/or migration of contamination plumes by groundwater to the project alignment. The primary issues of concern are worker health and safety and potential public exposure to hazardous materials during construction and waste handling.

At the time of this writing, the extent of the adverse exposures on the project due to ground contamination is still being evaluated. However, due to the depth of

| Fault Name | Minimum distance from Project Alignment (km) | Activity | Maximum Credible Earthquake |
|---|---|---|---|
| **Baldwin Hills** | Cross ECIS alignment | Active | 6.0 |
| **Newport-Inglewood** | Cross ECIS alignment | Active | 7.0 |
| **Malibu-Santa Monica** | Cross NEIS alignment | Active | 7.0 |
| **Hollywood** | Cross NEIS alignment | Potential Active | 7.0 |
| **Echo Park** | Less than 2 km | Active | 6.5? |
| **McArthur Park** | 4 km | Active | 6.5? |
| **Raymond** | 5 km | Active | 7.0 |
| **Elysian Park** | 13 km | Active | 6.9 |
| **Whittier-Elsinore** | 24 km | Active | 7.7 |
| **Palos Verdes** | 24 km | Potential Active | 7.0 |
| **Sierra Madre** | 25 km | Active | 7.4 |
| **San Fernando** | 37 km | Active | 7.0 |
| **San Andreas** | 65 km | Active | 8.25 |
| **San Jacinto** | 95 km | Active | 7.0 |

the invert, tunnel excavation may miss much of the ground contamination that exists near the ground surface. The probable use of Earth Pressure Balanced Machine (EPBM) may also prevent the movement of groundwater which may spread contamination plumes.

## CONSTRUCTION CONSIDERATIONS

Based on the Year 2050 design flow estimates, depth to pipe diameter requirement, recommended design grade and maximum flow velocities, the minimum inside diameter of the NEIS and ECIS ranges from 2 to 4-meters (6.5 - 13 feet).

To minimize the impact of construction on surface activities and communities, open trench excavation will not be acceptable. The ECIS project will be constructed entirely using tunneling methods. For NEIS, since the pipe diameter is smaller, a combination of tunneling and micro-tunneling, including pipejacking methods, may be acceptable.

Conventional open shielded tunneling methods including dewatering and grouting along the alignments may not be appropriate for tunneling below the groundwater table. In addition, the NEIS alignment(s) are located in close proximity to several Superfund sites, where removal of contaminated groundwater during dewatering activities may pose unnecessary liabilities to the City. Therefore, extensive dewatering lowering the groundwater table will be prohibited. Limited dewatering for short duration during the construction of shafts or access pits may be acceptable.

Systematic grouting from the surface to improve tunneling ground conditions along the alignment(s) is not expected to be cost effective and is not recommended due to the excessive impacts on and disruption of surface activities. However, localized ground treatment to minimize ground settlement will be required in certain locations to protect sensitive structures.

There are several proven underground construction techniques that may be applicable, such as slurry and/or EPB machines. These types of machines have been used on other projects to negotiate similar ground conditions. Undoubtedly, the use of these machines will be more costly and their longer procurement lead times (depending on availability) may pose additional burdens on the overall cost and schedule of the project.

Microtunneling and perhaps even pipejacking techniques may be feasible for the construction of several segments along the NEIS alignment(s). Since the proposed NEIS will be located along public rights-of-way, the major concern is the localized impact of excavating jacking and/or receiving pits on the traffic and neighborhood. By eliminating street parking and intermediate turning lanes, the City can provide work areas within the street for these operations. The final acceptance or rejection of the microtunneling/pipejacking options will depend on the outcome of the detailed EIR investigation.

### Tunnel Lining

A systematic primary tunnel lining such as precast concrete segments will have to be erected within the TBM tail shield to provide immediate support against unstable ground and excessive groundwater infiltration. This primary lining will be designed to withstand the permanent earth and hydrostatic pressures, and temporary construction loading such as jacking loads from the TBM, and pressure from the backfill grouting.

To protect the concrete from corrosion, hydrogen sulfide gas attack and future deterioration, the interior of the final pipe will require a corrosion-resistant lining. Precast pipe with pre-installed PVC lining may be placed inside the primary tunnel support and the circumferential joints vulcanized in place. Alternatively, as has been done in several rehabilitation projects, the City may install the PVC cover with a cast-in-place concrete lining.

The PVC lining, if installed correctly, can withstand a design flow velocity up to 3.5 meters per second. In limited stretches of tunnels where the flow velocity may be higher, fiber reinforced pipes may have to be installed in lieu of the PVC lining.

### Shafts and Dropshafts

Large diameter TBM launching and recovery shafts will be constructed using conventional soft ground excavation methods, such as backhoe and crane-mounted clamshell bucket. Ground support using soldier pile and lagging is acceptable. However, at shaft locations where groundwater is high and in close proximity to known contaminated areas, watertight diaphragm walls will be required. An impervious concrete slab will have to be constructed in the shaft bottom to prevent water leakage.

The detailed design of dropshafts for NEIS and ECIS has not been finalized. Plunge-type dropshafts, as were used during the initial stage of the Chicago TARP project, and more recently in Cleveland and Houston, may be acceptable, although they are more susceptible to odor generation. However, they have the advantages of being less expensive to construct and more accessible for maintenance and clean-up.

It is expected that all dropshafts will be constructed within the construction shafts once the tunnel excavation is completed. To divert existing flow from NOS or from tributary sewers, near-surface diversion sewers will also have to be constructed from the tie-in locations to proposed dropshafts.

### Maintenance Holes

To facilitate future maintenance and to provide access for remote conditional survey of the NEIS and ECIS, the City mandates manholes of a minimum 2-meters (6.5 feet) diameter at longitudinal spacing of no more than 750 meters (2500 feet). In addition, all manholes will be positioned directly over the tunnel alignment for ease of access.

The construction of these access maintenance holes can be performed by large diameter drilled caisson prior to or after the advancement of the tunnel. They may also function as air holes for tunnel ventilation for long-distance tunnel advancement.

### Settlement Control

Given unfavorable public tunneling in the Los Angeles area, ground settlement controls and mitigation will be subjected to great scrutiny and demands special attention. To minimize settlement risk on surface buildings, candidate tunnel alignment(s) under consideration are primarily located along public rights-of-way. Minimum turning radii along tunnel alignment(s) is maintained at no less than 150 to 300 meters (500 - 1000 feet) to minimize over-excavation and associated settlements.

The use of pressure balanced TBM or micro-tunneling equipment may be required for all underground construction. Technical specifications may also include specific requirements to perform extensive instrumentation and pre-and post-construction compensation grouting at critical, settlement sensitive locations.

## CONCLUSIONS

At the dawn of the next millennium, the City of Los Angeles faces a herculean task in upgrading its existing sewer system. The centerpiece of this effort is the construction of a new 35-km (22 miles) long interceptor sewer (NEIS and ECIS) to provide additional conveyance capacity along the route of the current North Outfall Sewer, to mitigate the existing sewer overflow problems, and to provide for rehabilitation of the existing sewer network.

The project is located in a crowded, unforgiving urban environment; and the work tasks will be subjected to challenging ground conditions, stringent performance criteria, a tight construction schedule, and close public scrutiny. This will require a concentrated effort from the City, their consultants, and responsible Contractors to ensure the successful execution of the work and its completion by the mandated deadlines.

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