Subject:	**West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft)**
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1. Purpose

This technical memorandum (TM) summarizes a preliminary fault displacement hazard analysis (FDHA) of the West Tracy Fault, near Byron, California. This preliminary FDHA provides simplified probabilistic and deterministic estimates of fault displacement amplitude where the proposed South Delta tunnel crosses the West Tracy Fault (Figure 1), and it is intended to provide preliminary information for conceptual design purposes only.

This FDHA was completed as part of an initial screening study that previously identified the West Tracy Fault as a potential fault rupture hazard to the proposed project. It is important to note this information is intended for the conceptual design of the tunnel alignment only. It is not considered a detailed Phase 1 investigation, which would include a comprehensive review, compilation, and analysis of existing information at the fault crossing; field reconnaissance; and supplemental fault displacement analyses that would incorporate a broader range of uncertainty and a more thorough fault characterization at the tunnel crossing.

1.1 Organization

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1.2 Background

The West Tracy Fault is a part of a system of “blind” west-dipping thrust and reverse faults that form the western margin of the Central Valley referred to as the Great Valley fault system (Working Group on Northern California Earthquake Probabilities, 1999; Working Group on California Earthquake Probabilities, 2008). This system of faults produced the 1983 magnitude (M) 6.2 Coalinga earthquake (Wong et al., 1988;

Wakabayashi and Smith, 1994). The following other faults that make up the fault system and are near the West Tracy Fault (Figure 1):

- Vernalis Fault to the southeast
- Southern Midland Fault to the north (Unruh et al., 2015)
- Midway Fault to the south
- Black Butte Fault to the south-southeast

The approximately 16-kilometer (km)-long northwest-striking, reverse or reverse-oblique West Tracy Fault dips moderately to steeply southwest and is mapped along the southwestern margin of the delta (Figure 1) (Unruh and Hitchcock, 2015). The location of the fault is poorly known; however, the West Tracy Fault is mapped as intersecting the southwestern part of Clifton Court Forebay, as well as the proposed Southern Forebay (Figure 1). It is unclear whether the fault at this location is "blind" and does not reach the ground surface, or whether the West Tracy Fault represents a discrete zone of faulting at the ground surface. The fault is imaged at depth along multiple seismic reflection lines and is reinterpreted in the direct vicinity of the study area. Interpretation of the geophysical profiles indicates the West Tracy Fault (Unruh and Hitchcock, 2015):

> *"…produced uplift of strata in the hanging wall and northeast tilting above the blind fault tip; the updip surface projection of the fault is coincident with a synformal fold hinge across which the tilted strata flatten eastward into the San Joaquin Valley. Stratigraphic and structural relationships imaged by the reflection data, as well as regional map relationships, indicate that the West Tracy fault probably was active between Eocene and Miocene and has been reactivated to accommodate late Cenozoic transpression."*

Unruh and Hitchcock (2015) estimate the late Neogene (23 million years ago [Ma] to 2.6 Ma) separation rate (or slip rate) of the West Tracy Fault ranges between 0.23 and 0.34 millimeter per year (mm/yr), and they argue for a uniform late Cenozoic activity rate. Unruh and Hitchcock (2015) also argue that the West Tracy Fault may be capable of producing earthquakes as large as M7.1 based on the inferred offset of late Pleistocene–early Holocene fan deposits from geological mapping and an interpretation of regional borehole data.

2. Methodology

As part of the preliminary FDHA for the West Tracy Fault, the DCA compiled key fault parameters that are often considered as part of a fault rupture mitigation program and included in the engineering design for permanent ground displacement:

- Surface displacement estimate
- Fault location and uncertainty
- Style of faulting (that is, direction of displacement, horizontal and vertical components of slip)
- Distribution of fault displacement (for example, knife-edge dislocation or distributed shear across a zone)

The focus of the current study was to calculate the probabilistic and deterministic displacement estimates associated with a hypothetical rupture on the West Tracy Fault. This TM also provides a very generalized characterization of fault location, style, and width of deformation at the crossing, and discusses whether displacement would be localized along discrete faults or representative of a broader fold scarp formation. These fault characterization topics are typically part of a more comprehensive FDHA (see Section 5, Recommendations and Next Steps). This section summarizes the technical approach, inputs, and results for the probabilistic and deterministic methods.

2.1 Probabilistic Fault Displacement Hazard Analysis

LCI performed a simplified probabilistic fault displacement hazard analysis (PFDHA) to estimate the expected future fault displacements that could impact the proposed tunnel at the crossing of the West Tracy Fault. The PFDHA methodology followed that of Petersen et al. (2011), which is based on the more common probabilistic seismic hazard analysis (PSHA) of Cornell (1968). Instead of estimating the annual rate of exceeding a specified earthquake ground motion at a site, PFDHA estimates the annual rate of earthquake-induced displacement at a site. Table 1 lists the site coordinates for the proposed tunnel at the fault crossing (Figure 1), which are considered approximate given the poorly characterized fault location and continued alterations to the tunnel alignment.

Table 1. Geographic Points of West Tracy Fault Tunnel Crossing Used to Calculate PFDHA Hazard

PFDHA Hazard Point	Longitude	Latitude
1	-121.59602	37.84157

Table 2 summarizes the source characteristics for the West Tracy Fault used for this simplified PFDHA, and Figure 1 shows the rupture source. This source characterization defines the fault source location and geometry, the earthquake magnitude distribution, and the earthquake recurrence rate. It builds on and updates relevant parts of the Delta Risk Management Strategy (DRMS) source model (URS Corp./Benjamin & Associates, 2008) according to new research performed on the West Tracy Fault (Unruh and Hitchcock, 2015; LCI, 2019) that postdates DRMS (URS Corp./Benjamin & Associates, 2008).

Table 2. Preliminary West Tracy Fault Seismic Source Characterization

Probability of Activity	Rupture Model	Fault Length (km)	Fault Dip (Degrees)	Seismogenic Thickness (km)	Characteristic Magnitude[b]	Slip Rate (mm/yr)	Recurrence Model
0.9	West Tracy Fault Alt 2[a] (1.0)	16.4	60 (0.3)	12 (0.3)	6.25 (0.2)	0.2 (0.3)	M_{char} (0.7)
			70 (0.4)	15 (0.4)	6.5 (0.4)	0.4 (0.4)	M_{max} (0.3)
			80 (0.3)	18 (0.3)	6.75 (0.4)	0.6 (0.3)	—

[a] West Tracy Fault geometry defined in the updated PSHA by Dr. Jeffrey Unruh based on new data (e.g., Unruh and Hitchcock [2015] and LCI [2019]).

[b] Magnitudes applied to both the characteristic and maximum magnitude models.

Notes:

Weights are provided in parentheses for each parameter.

km = kilometer

M_{char} = characteristic earthquake magnitude recurrence model of Youngs and Coppersmith (1985)

M_{max} = maximum magnitude recurrence model (Wesnousky et al., 1983)

yr = year

As part the PFDHA, we estimate the earthquake magnitude probability density function (PDF), or the relative frequency distribution of earthquake sizes. Two earthquake magnitude PDFs are used and weighted appropriately. The characteristic earthquake magnitude PDF of Youngs and Coppersmith (1985) has a branch weight of 0.7 (Table 2). This model is implemented with a boxcar distribution 0.5 magnitude units wide, centered on a mean “characteristic” magnitude (M_{char}) (Table 2). The Wesnousky et al. (1983) maximum magnitude model has a branch weight of 0.3 (Table 2). This magnitude PDF model adopts a truncated normal distribution, centered on the tabulated maximum magnitude estimates (that is, characteristic magnitudes shown in Table 2), with a standard deviation of 0.125 magnitude units and a truncation at +2 standard deviations.

Table 3 shows the logic tree inputs for the fault displacement models, or fault displacement prediction equations (FDPEs). These terms are used to compute principal fault displacement at the proposed tunnel fault crossing location (Figure 1).

Table 3. Displacement Prediction Model Logic Tree Inputs for the West Tracy PFDHA

Probability of Nonzero Surface Rupture	Style of Faulting	Regression Form	Displacement Prediction Equations
Wells and Coppersmith (1993) (1.0)	Strike-slip (0.5)	D (0.5)	Petersen et al. (2011) bilinear (0.5)
			Petersen et al. (2011) quadratic (0.5)
		D/AD (0.5)[a]	Petersen et al. (2011) bilinear (0.5)
			Petersen et al. (2011) quadratic (0.5)
	Reverse (0.5)	D/AD (1.0)	Moss and Ross (2011) (1.0)

[a] For Petersen et al. (2011) D/AD model, AD is calculated using Wells and Coppersmith (1994) for strike slip faults following the suggested approach by Petersen et al. (2011).

Notes:

Weights are provided in parentheses for each parameter.

AD = average displacement along rupture

D = displacement at the site

The conditional probability of surface rupture recognizes that ruptures of some earthquakes do not reach the ground surface. This analysis followed Petersen et al. (2003) and used the model of Wells and Coppersmith (1993), which provides a conditional probability of surface rupture as a function of magnitude based on global empirical data. This model is generally applicable to all displacement types and was provided full weight in this preliminary analysis.

The next three columns in Table 3 provide the logic-tree values and weights for various displacement exceedance equations. Although the West Tracy Fault is recognized as a dominantly reverse fault, there is uncertainty as to whether FDPEs are most applicable to estimate principal displacement on the fault at the tunnel crossing. For this initial analysis, equal weight is applied to the set of models developed using strike-slip rupture data developed by Petersen et al. (2011) and the models developed using thrust and reverse fault data developed by Moss and Ross (2011). The FDPEs from Petersen et al. (2011) were used, which estimate the principal fault displacement at the site (D) directly and by using a regression normalized by the average displacement along the fault (D/AD). For reverse displacements, Moss and Ross (2011) developed two regressions based on normalized D/AD data. This analysis used the equations based on modeling displacements with a Weibull distribution (Table 3). Both Petersen et al. (2011) and Moss and Ross (2011) account for tapered slip along strike based on the position of the site relative to the end points of the fault source (Petersen et al., 2011; Moss and Ross, 2011). For Petersen et al. (2011), both the quadratic and bilinear FDPEs were used for D and D/AD estimates.

2.2 Deterministic Hazard Analysis

In addition to the PFDHA, a simplified deterministic hazard analysis was performed to understand displacement at the median and higher standard deviations that could be expected from a maximum design earthquake (MDE), and to assess the results related to the PFDHA results. For the deterministic fault displacement hazard analysis (DFDHA), a logic-tree-based procedure was used that was developed specifically for fault crossings of linear alignments such as pipelines and tunnels (Thompson et al., 2018). This DFDHA method includes two primary steps: (1) estimate the range of MDE magnitudes, and (2) estimating the range of possible surface displacements resulting from the MDEs using FDPEs. Unlike traditional deterministic fault displacement analyses, this DFDHA approach explicitly considers epistemic and aleatory uncertainty in the FDPEs (Thompson et al., 2018).

For this simplified DFDHA, an MDE of M6.7 was assumed for the scenario earthquake, which is consistent with the MDE used in the deterministic seismic hazard assessment (LCI, 2019). It is important to note that the scenario-based deterministic case for fault displacement hazard implicitly assumes this earthquake causes surface rupture at the site.

The DFDHA considers three weighted median models to predict the log of average fault displacement at a site along a fault rupture ($\log_{10} D_{med}$) from MDEs (Table 4). These median $\log_{10} D_{med}$-M models are based on the following models:

- Wells and Coppersmith (1994) (WC94) model developed using earthquake data from all slip types (WC94 all)
- WC94 model developed from strike-slip events (WC94 ss)
- Hecker et al. (2013) (HEA13) model

Each of these models was developed to predict the AD over the length of the rupture given an earthquake of magnitude M. The three empirical relations based on WC94 all, WC94 ss, and HEA13 are weighted 0.5,[0.2, and 0.3, respectively (Table 4).

Table 4. Logic Tree Values and Weights to Estimate Displacements for the West Tracy Fault

Parameter	Equations or Equation Forms[a]	Weight
Displacement-Magnitude Models (Pretaper)	$\log_{10} D_{med} = 0.69\mathrm{M} - 4.80 + 0.37\varepsilon$, based on WC94 (all)	0.5
	$\log_{10} D_{med} = 0.90\mathrm{M} - 6.32 + 0.30\varepsilon$, based on WC94 (ss)	0.2
	$\log_{10} D_{med} = 0.41\mathrm{M} - 2.79 + 0.35\varepsilon$, based on HEA13	0.3

[a] For the displacement-magnitude models, D_{med} is the median displacement at a point along a rupture of an earthquake of moment magnitude M. The slope and intercept terms are the empirical regression results of WC94 (all), WC94 (ss), and HEA13. The last term is the epistemic standard deviation times epsilon (ε), where ε represents the number of standard deviations above and below the median, and the epistemic standard deviation is derived from the published empirical regression standard deviations, an along-strike variability standard deviation, and an aleatory standard deviation (see Thompson et al. [2018] for details)

A weighting was assigned using the following rationale:

- The WC94, all slip types relation is given a weight of 0.5 because a review of additional data published since WC94 from large strike-slip earthquakes suggests the "all slip types" regression parameters produce a good fit to a strike-slip only dataset. This regression was also developed to cover all slip types and therefore, is appropriate for the West Tracy Fault, an oblique strike-slip fault.
- The WC94, strike-slip events only relation is given a weight of 0.2, as a review of recent data suggests the slope of this regression (a=0.9) is probably steeper than what the average global data would predict.
- The HEA13 relation, which is based on a least-squares fit to data from Wesnousky (2008), is given a weight of 0.3. This relation has the lowest slope (a=0.41), and likely overpredicts average displacements from lower-magnitude strike-slip events.

The global data contain large uncertainties in estimating average surface displacement from historical surface-fault ruptures, and it is likely that average surface displacement as a function of magnitude can vary considerably between faults. Therefore, it was considered appropriate to include all three empirical relations because they are each defensible models and they span a considerable range of slopes. Followup FDHA characterizations as part of design efforts should consider additional empirical relationships and weighting as part of the deterministic displacement analysis.

The uncertainty in the site-specific median displacement-magnitude models is captured by estimating an epistemic standard deviation. Table 4 shows the epistemic standard deviations as the third term in the displacement-magnitude equations and they have the form $+\sigma\varepsilon$, where σ is the epistemic standard deviation and ε is epsilon, or the number of standard deviations above or below the median model. The values of σ are calculated as described in Thompson et al. (2018) and are based on estimating the total standard deviation for displacement at a point, and subtracting the component of the total standard deviation that represents event-to-event natural variability in displacements at a point, or aleatory variability. The total standard deviation is estimated by the square root of the sum of the squares of the empirical regression standard deviation (for example, the published standard deviations in WC94 and HEA13) and a standard deviation for the along-strike variability in historic ruptures (Thompson et al., 2018). The additional epistemic uncertainty is sampled using a five-point approximation of a continuous uncertainty distribution (Miller and Rice, 1983), where values of ε represent the specified number of standard deviations to be multiplied by the epistemic standard deviations in Table 4. The aleatory uncertainty standard deviation value of 0.22 ($\log_{10}$) is estimated based on paleoseismic data analyzed by Hecker et al. (2013); justification for this value is provided in Thompson et al. (2018).

3. Results

The following sections present the findings of the PFDHA and DFDHA analyses of the West Tracy Fault.

3.1 Probabilistic Fault Displacement Hazard Analysis Results

The mean hazard results of the PFDHA for the proposed tunnel crossing are presented in terms of mean annual frequency of exceedance (MAFE) (in units of per year) as a function of net displacement amplitude (Figure 2). The mean, or "total," displacement hazard is the sum of all paths through the logic tree, with each path multiplied by its weight. The MAFE is the reciprocal of the average return period.

The mean PFDHA hazard curve for principal fault displacements falls below the 4E-04 MAFE (2,475-year return period) (Table 5; Figure 2, upper panel). At a lesser MAFE (or longer return periods), displacements of 3 centimeters (cm) (1 inch) to 300 cm (9.8 feet) correspond to MAFE from approximately 3.2E-04 (approximate 3,100-year return) to approximately 7.7E-06 (approximate 130,000-year return), respectively, were predicted (Table 5; Figure 2).

As the field of PFDHA is relatively new, it is important to consider the uncertainty in the mean hazard curves. Figure 2 (lower panel) shows the mean hazard curve (black line) along with hazard fractiles in colored solid lines at the 5th, 15th, 50th (median), 85th, and 95th percentiles. These fractile curves indicate the range of possibly correct hazard curves given the epistemic (or model) uncertainties in the logic trees. The hazard fractiles show that at the 95th fractile, the mean hazards at the 975-year-return period (10 percent in 100 years) and 2,475-year-return period (4 percent in 100 years) remain negligible and approximately 40 cm, respectively (Figure 2). Hazard uncertainty corresponding to 3 cm of displacement (about 1 inch) at 90 percent confidence interval (or between 5th and 95th fractiles) is about 8.4E-05 to 7.55E-04 AFE (approximate 12,000-year and 1,325-year return periods, respectively). Hazard uncertainty corresponding to a 30-cm displacement (about 1 foot) at 90 percent confidence interval is about 5.41E-05 to 4.88E-04 AFE (approximate 18,500-year to 2,050-year return periods, respectively). Hazard uncertainty corresponding to a 300-cm displacement (about 10 feet) at 90 percent confidence interval is about 1.9E-06 to 1.8E-05 AFE (approximate 520,000-year to 55,000-year return periods, respectively).

A review of the PFDHA sensitivities indicates at low displacement amplitudes (≤10 cm), uncertainties in M_{char} and slip rate are very important, because they translate to uncertainties in rates of surface-rupturing earthquakes. At greater displacement amplitudes, greater than about 1 meter (m), uncertainties in slip rate and the displacement prediction model have a greater impact on hazard.

Table 5. West Tracy Fault PFDHA Results

Uniform Displacement Hazard			
		Displacement	
Return Period (yr)	**MAFE (1/yr)**	**cm**	**inches**
2,475	4.040E-04 (4% in 100 years)	Negligible	Negligible
~3,100	3.2E-04 (3.2% in 100 years)	3.0	1.0
~5,100	2.0E-04 (2.0% in 100 years)	30	11.8
~15,000	~6.7E-05 (0.7% in 100 years)	100	39.3
~130,000	~7.7E-06 (0.04% in 100 years)	300	118

Notes:

Assume all slip is co-seismic; no after-slip based on lack of creep observations on the West Tracy Fault.

Cm = centimeters

MAFE = mean annual frequency of exceedance

yr = year

3.2 Deterministic Fault Displacement Hazard Analysis Results

The results from the simplified DFDHA model include a range of displacement hazard estimates that are summarized herein using exceedance plots (complimentary cumulative distribution functions [CCDFs]). Figure 3 shows total weighted (mean) displacement hazard for the M6.7 MDE, along with the CCDFs that show probability of exceedance versus displacement (in meters) on a semilog plot. The thick red line (upper panel) represents the weighted mean result from all logic tree branch combinations, and shows displacements at the 50th and 84th percentiles.

Using this DFDHA approach, the potential fault displacement estimates from the total mean displacement exceedance curve range from about 2.3 feet (0.69 m, 50th percentile) to 6.0 feet (1.84 m, 84th percentile) (Table 6; Figure 3). Table 7 Illustrates the sensitivity of the mean hazard to the FDPEs, and this range helps to emphasize the importance of considering multiple FDPEs. The deterministic estimates of fault displacement of about 2.3 feet (0.69 m, 50th percentile) to 6.0 feet (1.84 m, 84th percentile) correspond to return periods of approximately 9,500 and 45,000 years with respect to the mean PFDHA hazard curve (Figure 2).

Table 6. DFDHA Results

Maximum Credible Earthquake (M_w)	FDPEs and Weights			50th Percentile		84th Percentile	
	WC94 All	WC94 SS	HEA13	m	Feet	m	Feet
6.7	0.5	0.2	0.3	0.69	2.3	1.84	6.0

Notes:

FDPE = fault displacement prediction equations

M_w = moment magnitude

Table 7. DFDHA Sensitivities Analysis Using Different FDPEs

Sensitivity	Maximum Credible Earthquake (M_w)	FDPEs and Weights			50th Percentile		84th Percentile	
		WC94 All	WC94 SS	HEA13	m	Feet	m	Feet
1	6.7	1	0	0	0.66	2.2	1.8	5.9
2	6.7	0	1	0	0.91	1.7	1.21	4.0
3	6.6	0	0	1	0.91	3.0	2.36	7.7

Notes:

FDPE = fault displacement prediction equations

M_w = moment magnitude

3.3 Fault Location and Style of Faulting

The location, width, and of style of faulting along the West Tracy Fault at the tunnel crossing location are poorly known and are critical parameters in an FDHA (Figure 1). Based on available information, the width of the permanent deformation of soils in the shallow subsurface caused by a rupture on the West Tracy Fault during a large earthquake is uncertain and depends on the fault's specific geological and tectonic attributes (Roering et al., 1997; Kelson et al., 2001), as well as the overlying deposits in the project area

(Oettle and Bray, 2013; Moss et al., 2018). End-member types of shallow deformation include broad folding and tilting and localized fault rupture. Broad folding and tilting, where differential vertical displacement may be distributed over hundreds of feet (tens to hundreds of meters), may result if the West Tracy Fault locally is "blind;" that is, the top of the fault is hundreds to thousands of feet (hundreds of meters to a kilometer or so) deep. If the West Tracy Fault extends to the shallow subsurface (to within a hundred feet to tens of feet below ground), the width of deformation in the shallow subsurface may be about 30 feet (10 m) or less.

Tunnel deformation analyses could consider either broad folding over hundreds of feet to thousands of feet or a narrow deformation zone less than or equal to 30 feet wide. With the available information, the West Tracy Fault should be modeled as a northwest-striking, dextral-oblique reverse fault (southwest side up). Additional analyses are necessary as a part of a more comprehensive Phase 1 study to provide information on the horizontal-to-vertical ratio of slip, location, style, pattern, and width of deformation. The preliminary total displacements listed in Tables 5 and 6 should be considered related to the seismic design criteria for the conceptual design of the tunnel and embankment projects at the proposed Southern Forebay.

4. Summary

LCI (2019) completed a preliminary FDHA that provides estimates of fault displacement amplitude and is intended to represent information that can be used in the conceptual design of the proposed South Delta tunnel at the West Tracy Fault crossing (Figure 1). It is important to note that the information here should be used only to inform initial design concepts, and therefore additional studies may be warranted to constrain a broader range of uncertainty and evaluate key FDHA parameters as listed in Section 2.

As summarized, LCI (2019) completed both simplified probabilistic and deterministic estimates of fault displacement amplitude. These analyses indicate the following:

- Overall, the PFDHA results indicate the principal fault displacement hazard at the proposed tunnel is low to very low (Table 5; Figure 2).
- The mean PFDHA hazard curve for principal fault displacement is below the 2,475-year return period (Table 5; Figure 2).
- Displacements of 3 cm (1 inch) to 300 cm (9.8 feet) correspond to longer return periods (approximate 3,100-year return to approximate 130,000-year return) (Table 5; Figure 2).
- For the DFDHA, a maximum credible earthquake of M6.7 was assumed for the scenario earthquake, consistent with the weighted mean M_{char} estimates for the West Tracy Fault used in the revised PSHA (LCI, 2019) (Table 2).
- Using this DFDHA approach, the potential principal fault displacement estimates from the total mean displacement exceedance curve range from about 2.3 feet (0.69 m, 50th percentile) to 6.0 feet (1.84 m, 84th percentile) (Table 6,;Figure 3).
- The width of permanent deformation of soils in the shallow subsurface caused by rupture on the West Tracy Fault during a large earthquake is uncertain based on available information.
- Shallow deformation could include broad folding and tilting, if the West Tracy Fault is "blind" with deformation distributed over hundreds of feet or a localized (30 feet wide or less) fault rupture, or both.

- A critical uncertainty that cannot be answered with the existing data is understanding the exact location, width, and style of faulting, and placement of project facilities relative to the zone of fault hazard.

5. Recommendations and Next Steps

Based on the available data and our understanding of the project, LCI (2019) developed the following recommendations:

- To develop a conceptual design and considering the *Delta Conveyance Seismic Design Guidelines* (under development) that define a tunnel design envelope for the MDE of 2,475-year probabilistic and 84th percentile deterministic fault displacements, consider MDE at the 2,475-year probabilistic and 84th percentile deterministic fault displacements (see Tables 5 and 6 for displacements.) Furthermore, there is no well-constrained information on the width of deformation; for conceptual design, the design should consider a narrow (less than 30 feet) to wide (more than 100s of feet) zone of faulting. These values must be revaluated with a Phase 1 supplemental FDHA before any further planning and design efforts are initiated.
- Conduct a Phase 1 supplemental FDHA that includes a more detailed characterization of the West Tracy Fault and adjacent faults; this should include broader uncertainty and impacts on hazards based on a detailed review, compilation, and analysis of existing data (as outlined in the *Delta Conveyance Seismic Design* Guidelines that are currently under development). This Phase 1 supplemental FDHA would include developing maps of primary and secondary displacement hazard, and primary and secondary displacement amounts.
- Depending on the findings of the Phase 1 investigation, conduct additional Phase 2 studies to constrain the following:
  - Style and pattern of faulting in the shallow subsurface at tunnel depth or at ground surface (that is, “blind” broad folding or discrete folding)
  - Location and width of primary and secondary fault or fold uncertainty zones, or both

A Phase 2 multidisciplinary subsurface investigation should include the following three components:

1) High-resolution geophysical surveys (for example, seismic reflection profiles)
2) Borehole and cone penetration test transects
3) Trenching and test pits

These investigations will require a detailed dating program to evaluate the age of encountered deposits and evaluate the rate of possible deformation. This program should also include one or more of radiocarbon accelerator mass spectrometry or luminescence dating, or other techniques as deemed appropriate.

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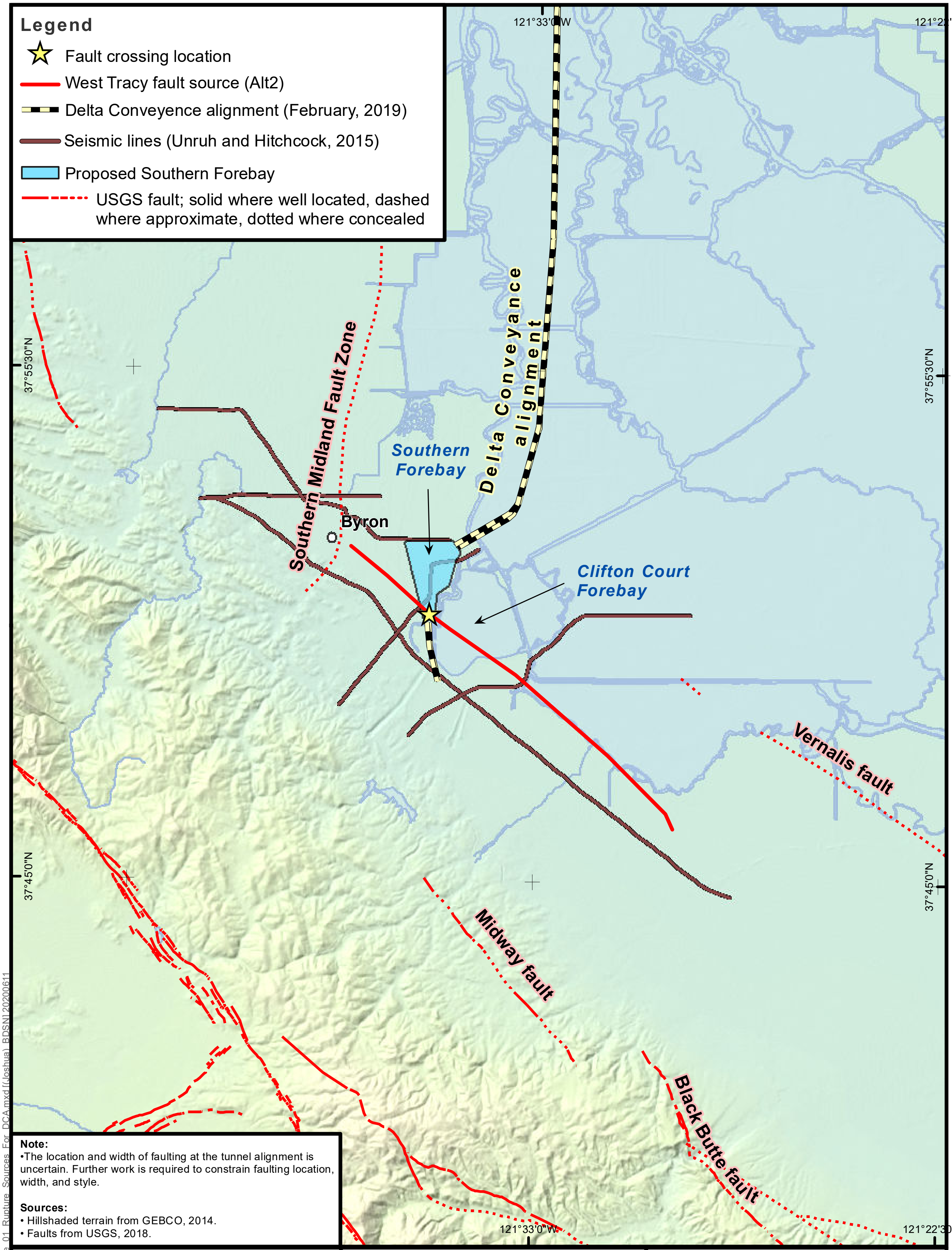
7. Document History and Quality Assurance

Reviewers listed have completed an internal quality review check and approval process for deliverable documents that is consistent with procedures and directives identified by the Engineering Design Manager and the DCA.

<table>
<tr><th colspan="4">Approval Names and Roles</th></tr>
<tr><th>Prepared by</th><th>Internal Quality Control review by</th><th>Consistency review by</th><th>Approved for submission by</th></tr>
<tr><td>R. Givler, A. Zandieh, J. Baldwin, and S. Thompson / LCI</td><td>Andrew Finney / EDM Geotechnical Lead
Dario Rosidi / EDM Seismic Lead</td><td>Gwen Buchholz / DCA Environmental Consultant</td><td>Terry Krause/EDM Project Manager</td></tr>
<tr><td colspan="4">This interim document is considered preliminary and was prepared under the responsible charge of Arash Zandieh, California Professional Engineering License C82118.</td></tr>
</table>

Note to Reader

This is an early foundational technical document. Contents therefore reflect the timeframe associated with submission of the initial and final drafts. Only minor editorial and document date revisions have been made to the current Conformed Final Draft for Administrative Draft Engineering Project Report version.



Note:

•The location and width of faulting at the tunnel alignment is uncertain. Further work is required to constrain faulting location, width, and style.

Sources:

- Hillshaded terrain from GEBCO, 2014.
- Faults from USGS, 2018.

DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

For Illustration Purposes Only

Figure 1
West Tracy Fault Rupture Source and Adjacent Faults

Map projection and scale: NAD 1983 StatePlane California III FIPS 0403 Feet, 1:200,000

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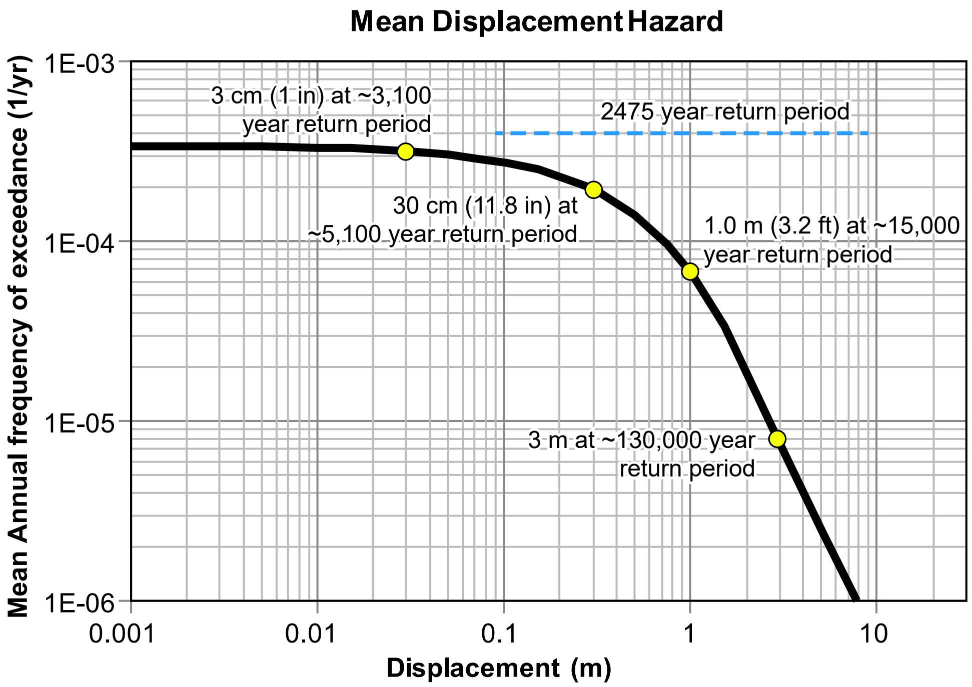
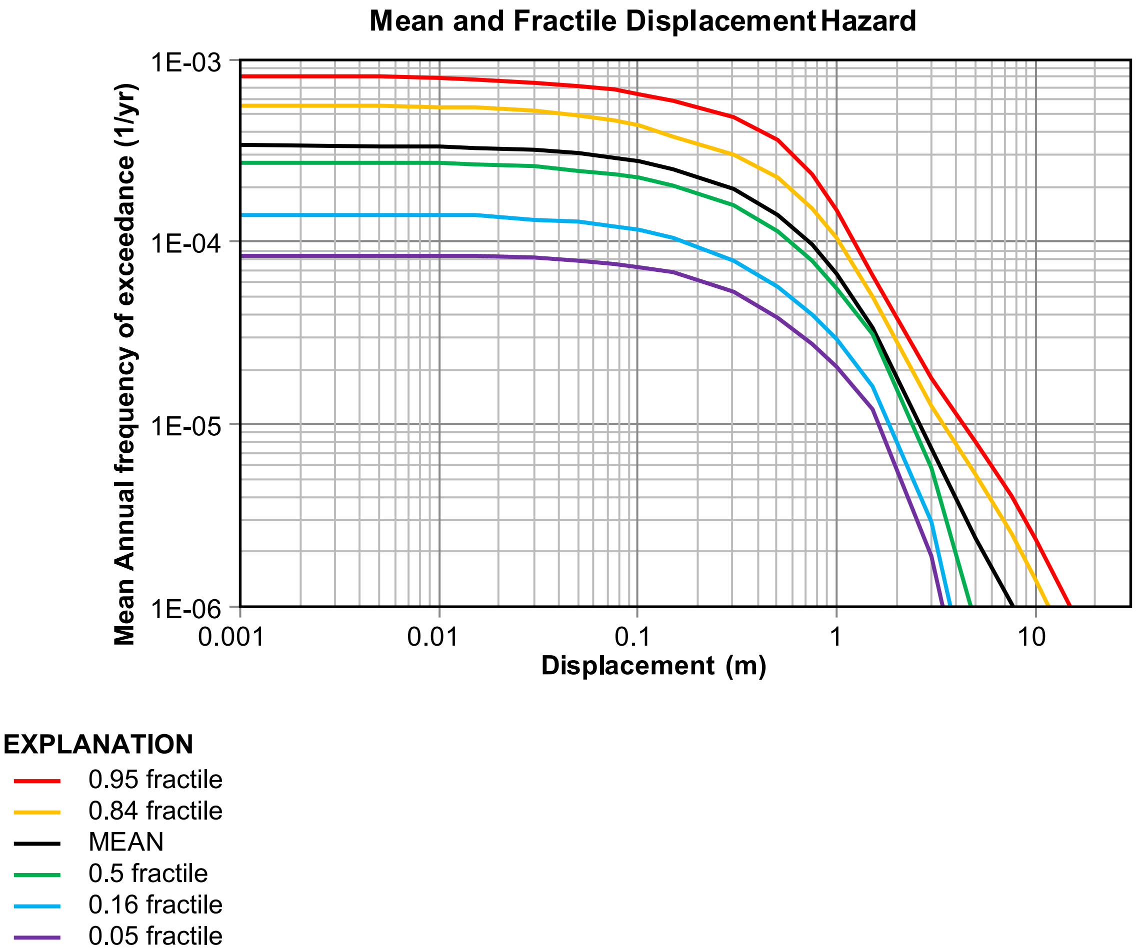


Mean Displacement Hazard



Mean and Fractile Displacement Hazard

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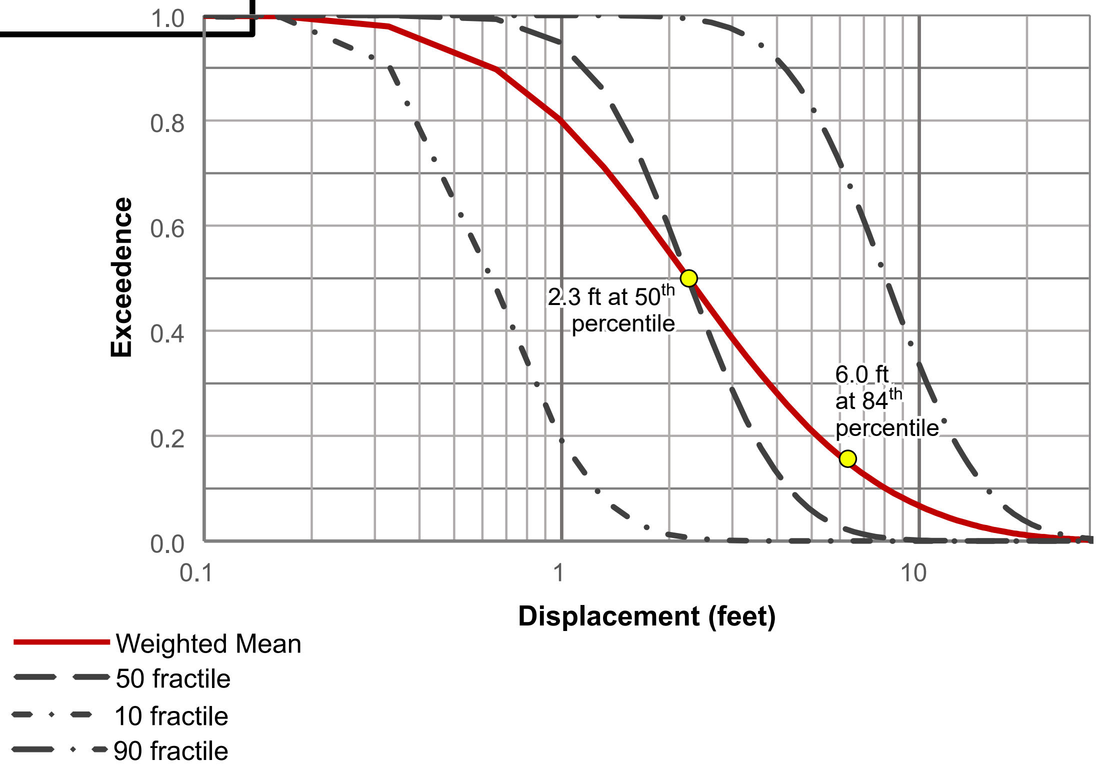
Figure 2
West Tracy Fault
Preliminary PFDHA Results

Data Source: DCA, DWR

File path: S:\1802\Figures\Figure_02_PFDHA.ai; Date: 06/09/2020; User: Whitney Newcomb, LCI

Legend

Primary Displacement Exceedance Curves



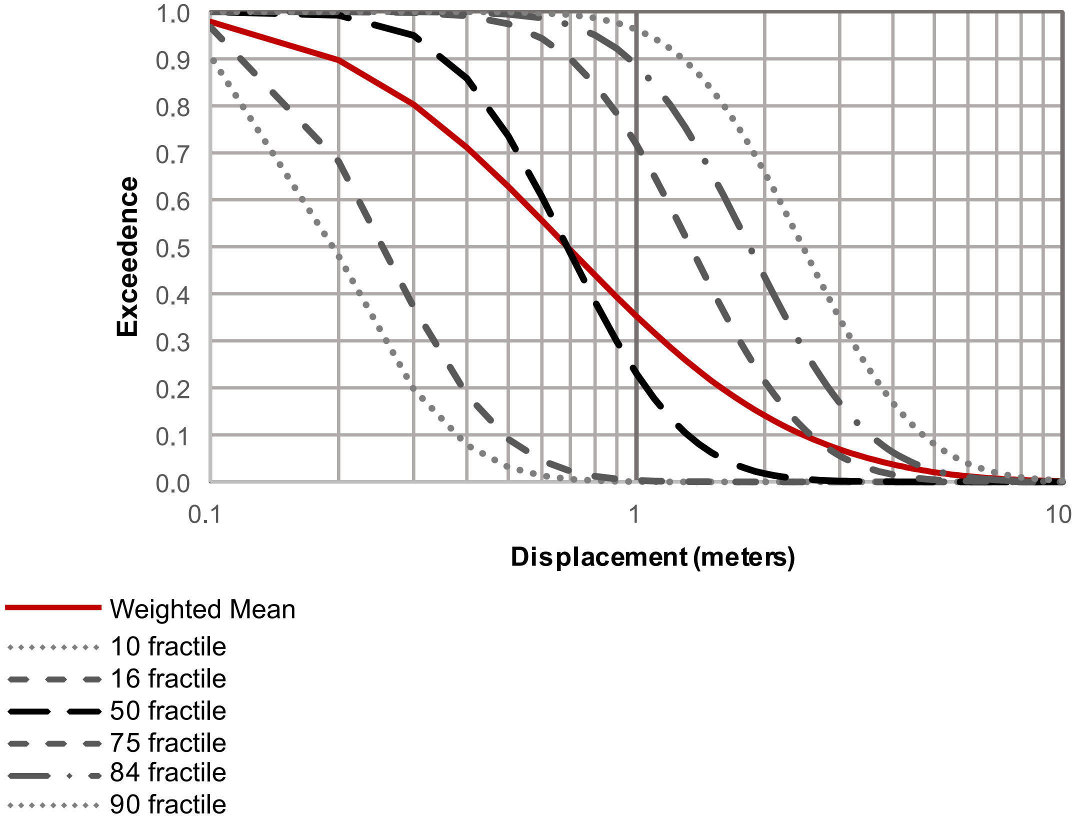


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Figure 3
West Tracy Fault
Preliminary DFDHA Results

Data Source: DCA, DWR

File path: S:\1802\Figures\Figure_03_PFDHA_2.ai; Date: 06/08/2020; User: Jch, LCI