Technical Appendix 3

(**<u>Geology, Seismic, Soils and Groundwater</u>**)

to

Attachment A

5-Cities Alliance
Comment Letter

WILSON GEOSCIENCES
Engineering and Environmental Geology

M E M O R A N D U M

DATE: July 8, 2015

TO: Laurel L. Impett, AICP, Urban Planner, Shute, Mihaly & Weinberger LLP

FROM: Kenneth Wilson, Wilson Geosciences Inc. (California Professional Geologist #3175 and Certified Engineering Geologist #928)

WGI PROJECT #: EG14-12

WGI PROJECT NAME: SR 710 North Study DEIR/S Review—Geology/Seismic/Soils/Groundwater

SUBJECT: Review of March 2015 SR 710 North Study DEIR/S

INTRODUCTION

At the request of the 5-Cities Alliance and Shute, Mihaly & Weinberger LLP, Wilson Geosciences Inc. (WGI) in cooperation with GeoDynamics Inc. (GDI, Ali Abdel-Haq, Registered Civil Engineer #46989 and Geotechnical Engineer #2308), reviewed selected portions of the SR 710 North Study DEIR/S and the appendices that relate to geology, seismic, soils, and the Raymond Basin, San Gabriel Basin and Raymond Fault groundwater barrier issues. This memorandum provides comments on the following DEIR/S sections:

- 1. PROJECT DESCRIPTION
- 2. ALTERNATIVES
- 3.10. GEOLOGY/SOILS/SEISMIC/TOPOGRAPHY (March 2015)
- 3.9. WATER QUALITY AND STORM WATER RUNOFF (Raymond Basin Groundwater Portion (March 2015)
- 4. CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA) EVALUATION, Sections 4.2.6 (Geology and Soils) and 4.2.9 (Hydrology and Water Quality)

In order to review these portions of the DEIR/S, it was necessary also to review all or parts of numerous other support documents, including but not limited to the following:

1. DEIR/S Sections 2, 3.8, 3.9, 3.10, 3.12, 3.22, 3.23, 3.24.8, 3.24.9, 3.24.10, 3.24.12, 3.25, 4.1, 4.2.6, 4.2.8, 4.2.9, and corresponding tables, figures, and Appendix A (March 2015; 260 pages)

- Preliminary Geotechnical Report, Figures, and Plates (November 2014; 166 pages)
    - SR 710 Preliminary Geotechnical Appendix C Groundwater Monitor (November 2014; 9 pages)
    - SR 710 Preliminary Geotechnical Appendix E Fault Rupture Memo (December 2013; 20 pages)
    - SR 710 Preliminary Geotechnical Appendix G Fault Investigation (February 2014 ;27 pages)

- Water Quality Assessment Report (May 2014; 156 pages)
- SR 710 Tunnel Evaluation Report (September 2014; 374 pages)
- Geologic Hazard Evaluation (November 2014; 130 pages)

2. Alternatives Analysis Report and Appendices A, C, G, J, and T (December 2012; 226 pages)

This review addresses the following deficiencies in the DEIR/S:

1. PROJECT DESCRIPTION/ALTERNATIVES

a. The DEIR/S lacks information, including specific definition and consequences, of the fatal flaw analysis contained in the geotechnical feasibility study affecting the bored tunnel and LRT alternatives.

2. GEOLOGY/SOILS/SEISMIC/TOPOGRAPHY (SECTION 3.10)

a. Caltrans has no established tunnel site selection criteria or tunnel design criteria for earthquake fault rupture; therefore, the DEIR/S does not adequately analyze the risk that active fault tunnel crossings entail.

b. The DEIR/S does not accurately characterize potential active fault rupture offset for the Raymond, Eagle Rock, and San Rafael faults at the proposed tunnel crossings thereby underestimating the Project's risks to public safety.

c. The DEIR/S does not adequately evaluate the bored tunnel design for near-source ground-shaking effects from an earthquake on the Raymond fault, or one involving the Raymond, Eagle Rock, and San Rafael faults together, thereby potentially underestimating ground shaking values.

d. The DEIR/S does not identify significance criteria relating to fault offset and ground shaking, fails to determine the significance of the Project's impacts, and defers mitigation until after Project approval.

e. The DEIR/S fails to analyze adequately potential impacts from ground settlement and fails to mitigate for these effects.

f. Caltrans improperly rejected a safer tunnel design in favor of a less expensive, more quickly built design, but one with more potential for severe stress to the tunnel.

3. WATER QUALITY AND STORM WATER RUNOFF (SECTION 3.9, RAYMOND BASIN GROUNDWATER PORTION)

a. The DEIR/S does not describe the Raymond Basin and Pasadena Subarea groundwater characteristics in sufficient detail to allow an evaluation of groundwater flow in the tunnel area. It also does not include sufficient geotechnical detail including information relating to bedrock fracture patterns.

b. The DEIR/S lacks analysis to determine the potential impacts on the Raymond Basin and Pasadena Subarea groundwater supplies that could result from a penetration of the Raymond Fault groundwater barrier.

c. *The DEIR/S lacks analysis to determine the potential degradation of Main San Gabriel Basin groundwater quality from penetrating the Raymond fault groundwater barrier*

These issues render the document's analysis of geology, seismic, soils, and groundwater impacts severely deficient, and the mitigation measures ineffective and inadequate.

1. PROJECT DESCRIPTION/ALTERNATIVES

The DEIR/S lacks information, including specific definition and consequences, of the fatal flaw analysis contained in the geotechnical feasibility study affecting the bored tunnel and LRT alternatives.

DEIR/S Section 1 (pages 1-1 through 1-7) presents a series of alternatives, including a freeway tunnel alternative that would satisfy the goal of providing "transportation improvements to improve mobility and relieve congestion". In subsection 1.1.2 (page 1-6), the DEIR/S states a geotechnical feasibility assessment concluded that the tunnel concept was feasible to complete a freeway, and no "fatal flaws"[1] were identified. The DEIR/S does not indicate whether a similar geotechnical feasibility assessment was conducted for the LRT alternative.

The DEIR/S also never identifies or defines the phrase "fatal flaws", nor does it identify the particular characteristics that would be considered a fatal flaw. As discussed below, potentially significant geologic, seismic, geotechnical, and groundwater constraints occur in the study area, especially near the tunnel alternative alignment.

Did the feasibility assessment evaluate the constraints associated with crossing one or more active faults capable of generating vertical and horizontal movements across the 60-foot tunnel excavations? Did the assessment consider penetrating a groundwater barrier between two currently separate groundwater storage basins, potentially allowing transmission of groundwater and chemical contaminants between these independently operated basins? Did Caltrans and Metro ever evaluate the technical and design limitations that were used to eliminate the individual tunnel alignments from consideration? Was there an alternative that met the following criteria: (1) sufficient portal[2] depth; (2) does not cross an active fault[3]; (3) meets the minimum curvature design; and (4) would not potentially join two groundwater basins[4]? These are fundamental flaws with the proposed tunnel and LRT alignment, yet these questions remain unanswered. The DEIR/S's failure to identify the criteria that Caltrans and Metro used to identify the proposed tunnel alignment makes it impossible to determine whether other Project alternatives or tunnel alignment locations would avoid these serious constraints. The DEIR/S should have disclosed this information and identified the associated alignment. Without this information, the public has no way of determining whether any tunnel alignment is practical and/or safe. Unfortunately, it is not possible to verify independently the accuracy of the geotechnical feasibility assessment since it was not included in the DEIR/S.

At a minimum, the tunnel design alternative must take into account geologic, seismic, geotechnical, and groundwater constraints. Equally important, the DEIR/S must apprise the

[1] Fatal flaw = A condition that would prevent the alternative from meeting the project objectives.
[2] Portal = The beginning (entrance) and ending (exit) points for the tunnel alternative.
[3] Active fault = An earthquake fault that has moved (fault offset) within the past approximately 11,000 years.
[4] Groundwater basins = Subterranean areas where water naturally collects and is stored for pumping and use.

public of these constraints and the public safety and environmental implications associated with building a tunnel along the proposed alignment.

2. GEOLOGY/SEISMIC/SOILS (SECTION 3.10)

Using the established geology and soils thresholds from CEQA (CEQA Guidelines Appendix G), the DEIR/S states that the Project will be considered to have a significant impact if it:

> "Expose[s] people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:
>
> i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault. Refer to Division of Mines and Geology Special Publication 42.
>
> ii) Strong seismic ground shaking."

The following questions are critical for determining whether the Project would have a significant impact to geology and soils: 1) have Caltrans and Metro used a vetted, tunnel-specific fault rupture offset standard in their analysis; 2) did the agencies use a current and sufficiently conservative methodology to determine the design fault rupture; 3) did they properly consider whether the added effects of near-source/near-fault ground shaking would amplify fault offset damage; and 4) will the preferred tunnel design accommodate offset at/near a threshold that could cause collapse?

To determine properly whether a tunnel project constructed in a seismically active region would expose people to injury or death and structures to damage, the DEIR/S must undertake the following steps. First, the DEIR/S must identify thresholds of significance. That is, it should identify the point at which the project's seismic impacts will be considered significant. Second, the DEIR/S must identify and describe existing active fault and earthquake conditions specifically where the crossings are to occur. This should include sympathetic movement[5] on non-active faults and parallel geologic bedding[6] between the Raymond and San Rafael faults. Third, given the known conditions affecting Project construction, the DEIR/S must provide a detailed description of the Project's fault rupture and near-source[7] earthquake ground shaking effects on the geologic formations that could affect the tunnel, on the construction elements of the tunnel, and on the users of the tunnel. This information would then allow the agency to select the appropriate performance standard, and therefore the appropriate tunnel design, for tunnel construction and operation within the seismically active setting.[8]

The DEIR/S preparers should have considered this information to accurately identify and analyze the Project's seismic impacts. If the DEIR/S determines the impacts to be significant (again, a

[5] Sympathetic movement = Movement (offset) on secondary/subsidiary fractures or along geologic bedding near parallel to, but away from, the main fault(s) rupture; this can be caused by earthquake-induced stresses/forces affecting geologic materials within the interfault mass (e.g., between the Raymond and San Rafael faults).

[6] Parallel geologic bedding = In this case geologic bedding parallel to nearby active faults.

[7] Near-source = A surface or subsurface location that is near the earthquake fault (source) causing the subject earthquake and where ground shaking is usually stronger than at more distance locations.

[8] Performance standard = A specific criterion or statement (most often quantifiable) to judge the adequacy of a design or of a study for its intended purpose or use; how you know when you have it right.

significance determination can only occur once thresholds of significance are established), it must then identify feasible design and mitigation measures capable of reducing these impacts to a level of less than significant. Substantial evidence in the record must support both the analysis of impacts and the efficacy of mitigation. As explained below, the DEIR/S errs in each of these steps.

a. Caltrans has no established tunnel site selection criteria or tunnel design criteria for earthquake fault rupture; therefore, the DEIR/S does not adequately analyze the risk that active fault tunnel crossings entail.

Fault offset is the combination of the vertical and horizontal ground movement experienced on opposite sides of an earthquake fault during a large earthquake as viewed from a fixed point on one side. Fault offsets can cause damage to structures, including tunnels that straddle the fault. Any appropriate standard for assessing fault offset for a freeway tunnel must establish the acceptable post-earthquake performance requirements of the freeway tunnel crossing an active fault.[9]

Here, Caltrans and Metro did not use a fault offset performance standard related to tunnels when evaluating the Project's impacts. In purporting to mitigate impacts to geology and soils, the DEIR/S states "The [Freeway tunnel] design will meet the performance criteria of the operating agency." (page 3.10-23). However, the Preliminary Geotechnical Report (PGR) indicates that Caltrans *has* no tunnel fault offset design standard (PGR Appendix E, page 15). Without such a standard that can be used to evaluate the chosen tunnel design, Caltrans cannot defend its methodology for applying its fault offset design values to the LRT and Freeway Tunnel alternatives.

A tunnel fault offset performance standard is necessary to ensure that sufficiently conservative analytical methods are used to ensure the following: minimal tunnel damage (no collapse); the ability to reach quickly the faulted/damaged area to rescue tunnel occupants (occupants will be sufficiently protected, minimal injury and loss of life); the public will have confidence to use the tunnel system; capability of repairing the four- to eight-lanes of the freeway tunnel in a reasonable timeframe. The standard should also enable Caltrans to justify a specific methodology for determining the fault offset amount, e.g., a low displacement value based on earthquake probabilities or a high value based on actual observations for other similar faults that have moved in an earthquake. This information could be derived from a study of historic earthquakes such as the 1971 San Fernando and 1999 Taiwan Chi-Chi earthquakes, or determinations from paleoseismic investigations on the fault in question (the Raymond fault) or a similar fault in the area (e.g., the Sierra Madre, Hollywood, or Santa Monica faults). Where a tunnel crosses a zone of several active or potentially active faults, as the SR 710 tunnel would here, each fault should be addressed individually and cumulatively. The effects of all faults moving in the same earthquake should be considered over the length of the zone in question. A proper fault offset performance standard would also include or take into account the following components: 1) descriptions of optional freeway tunnel designs that were evaluated considering

[9] Tunnel fault offset = When an earthquake fault ruptures near a tunnel, the tunnel structure is shifted on each side of the fault causing the tunnel walls to no longer be aligned or possibly to collapse.

the size and capacity of the specific tunnel alternative, 2) the considerable design requirement differences between a two-lane tunnel and an eight-lane tunnel that could potentially carry truck traffic, and 3) an explanation of the various design options that are generally available to accommodate fault movements of various magnitudes and directions.

The more comprehensive type of analysis is possible for a *complex* freeway tunnel with thousands of users at any given time. For the Century City area of its Westside Subway Extension Project, for example, Metro (2011, page 5 of 13) issued a tunneling safety and fault investigation report. The report describes the concerns with fault rupture design for a *complex* underground station as follows:

> "In the case of rupture during an earthquake on an active fault, large concentrated fault offsets are imposed on structures located directly on the fault. Metro underground stations are sited so that they are not on active faults."
>
> And,
>
> "Even with a complex and sophisticated design, unacceptable risks would remain in the ability to limit damage and protect the public if faulting were to intersect a station."

Applying this fault avoidance strategy to a complex of eight-lane underground freeway system with thousands of occupants is as reasonable as applying it to a complex underground station with hundreds of occupants.

In lieu of developing and vetting a design-offset standard for tunnels, Caltrans and Metro used a standard evidently developed for *bridges*. When explaining the design criteria used for earthquake fault rupture, the DEIR/S indicates that Caltrans' "preferred strategy" is the April 2013 Caltrans Seismic Design Criteria (SDC) (DEIR/S, page 3-10.1 and SDC, page 6-2). The SDC does not mention tunnels; it refers readers to a "20-10 Fault Rupture Memo to Designers" authored by Caltrans and updated in 2013 (SDC, page 6-2). The 20-10 Memo also does not mention tunnels. All of its fault rupture references are to "structures", which are presumably bridges since the memo was prepared by the State Bridge Engineer.

The DEIR/S cannot rely on the SDC to conclude that impacts related to fault rupture would be less than significant. The project under consideration is not a bridge. Rather than simply promising to comply with a vague regulatory standard intended for use with a different type of structure, the DEIR/S must clearly identify and explain, for each tunnel fault crossing, how the individual fault offsets were determined. If Caltrans believes that the SDC is the optimal strategy, it must demonstrate that it is adequate to support the construction of a single and/or dual-bore tunnel. This explanation must include examples of the suitable technical analytical methods available to determine the magnitude of the fault offsets that would be acceptable for the specific tunnel design. It must also demonstrate how the respective designs will best prevent serious impacts to tunnel users by integrating discussions of cross-passages and other safety measures for long and deep transportation tunnels. This is necessary to assure the public that the users of the tunnels will have various means of coping with potential accidents caused by earthquake and non-earthquake forces. It also must address the cumulative effect of the offsets along the tunnel section bracketed by the Raymond and San Rafael faults, including the Verdugo–Eagle Rock fault. Because the DEIR/S does not disclose these effects, and because Caltrans has no tunnel fault offset standard (PGR Appendix E, page 15), the DEIR/S cannot conclude that the project would have no significant impacts caused by active faulting.

b. The DEIR/S does not accurately characterize potential active fault rupture offset for the Raymond, Eagle Rock, and San Rafael faults at the proposed tunnel crossings thereby underestimating the Project's risks to public safety.

The DEIR/S does not accurately estimate the likely magnitudes of earthquake-related fault movements associated with the Raymond, Eagle Rock, and San Rafael faults where they cross the freeway tunnel or LRT alternatives (DEIR/S, p. 3.10-19; PGR, pages 4-12 and 4-13; and PGR Appendix E, pages 2 and 11). It also presents conflicting explanations of the earthquake-related fault movements likely to occur.

There are two principal methodologies for estimating the magnitude of fault ruptures. The DEIR/S selects and applies the older of the two methodologies, which favorably influences the outcome of its analysis. The most up-to-date and applicable methodology is contained in a study published in 2008 by Wesnousky. However, the DEIR/S rejects this methodology in favor of an older methodology published in 1994 by Wells and Coppersmith. The DEIR/S contains no satisfactory explanation for this decision, except to state that that "Currently, there is no agreement on the validity of one relationship over the others, as all are considered statistically valid" (PGR Appendix E (page 11).

On the contrary, the Wesnousky study is the most recent methodology. The methodology was presented in 2008, and included a compilation of data obtained from 37 earthquakes, including sixteen post-1980 earthquakes. Overall, it considered a greater number of earthquakes than the Wells and Coppersmith methodology. As it turns out, choosing the older methodology generates lower values for fault rupture offset predictions to be used in tunnel design. For example, Caltrans and Metro use the "average" Wells and Coppersmith offset of 0.5 meters over the "maximum" Wesnousky offset (2.2 meters). The 2.2 meter offset prediction would result in a much safer design for users of the freeway tunnel. Since Caltrans has no tunnel fault offset design standard (PGR Appendix E, page 15), it has no basis to select the "average" Wells and Coppersmith (0.5 meter) offset versus the "maximum" Wesnousky offset (2.2 meters). What's more, the 2.2-meter offset prediction is nearly the same as the offset observed in the 1971 San Fernando earthquake, which was on a very similar fault, and thus appears to be more accurate.

In apparent justification for not selecting and using the Wesnousky method, the PGR states that the Wesnousky method "would result in larger average and maximum displacements than those estimated using the Wells and Coppersmith (1994) models" (PGR Appendix E, page 11). Larger fault offsets create more damage and risk. While this may be disadvantageous for Caltrans and Metro because it may require more rigorous design engineering (and therefore may be more costly), it is not a sound basis for rejecting the newest available methodology for predicting fault ruptures.

The U.S. Geological Survey (USGS) has expressed a preference for the Wesnousky methodology. For instance, the Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3; USGS, 2013) Appendix F highlights the 2008 Wesnousky analyses with respect to development of improved estimates of average fault displacement as a function of fault/fault rupture length. This document mentions Wells and Coppersmith in various contexts, mainly to show how this older method compares with the latest concepts (Figures F5 through F8). Figure F8 (UCERF3, Appendix F page 13) shows that for normal and reverse faults (the Raymond is a reverse fault) the average fault offset per event using Wesnousky "consistently is greater than would be predicted by the segment length" approach, which is the Wells and Coppersmith approach.

Absent a technical and scientific reasoning for why the Wells and Coppersmith is superior—which Caltrans has not provided—its decision to reject the Wesnousky methodology is indefensible. Because it relied on an inappropriate methodology, the DEIR/S provides insufficient evidence to conclude that the tunnel would be constructed in a manner that protects the public's safety. There is no basis not to select either the Wesnousky B (Power-law) or C (Log-linear)[10] relationship options.

The DEIR/S's conclusion regarding "the problem of displacement magnitude and risk" relies on insufficient study; yet critical design decisions affecting the suitability of the selected route are also based on it. PGR Appendix G (page 19) admits published data and opinions on the Raymond fault vary by almost a full order of magnitude for the following: (a) slip rates (from 0.5 to 5 millimeters per year), (b) recurrence intervals (from 1,000 to more than 6,000 years), and (c) earthquake fault rupture displacement estimates (from 0.5 to more than 5 meters). In its analysis, Caltrans consistently accepts the published data that minimizes the amount of fault offset they will consider in their design.

The DEIR/S further understates the public safety risk from the tunnel alternatives because it does not consider cascading fault rupture scenarios (PGR Appendix E, pages 6–8). Cascading scenarios occur when an earthquake causes other earthquakes on faults in related fault systems. These triggered earthquake events could also cause fault rupture and fault offset on these related faults.[11] A cascading fault rupture would cause larger fault rupture displacements than are currently suggested for the freeway tunnel design. The most likely of these would occur at the Hollywood–Raymond faults raising the potential earthquake magnitude from a M6.5 to a M6.9. However, Appendix E dismisses the cascading scenario entirely by indicating, "At this time, it does not seem realistic to design for this scenario event." There is no discussion of a "performance standard" for the tunnels, or of what design standard would need to be created to

[10] Power-law and log-linear relationships = Mathematical relationships that are not purely linear (e.g., length compared to length), but involve the use of probability and higher mathematical functions such as logarithms.
[11] Triggered earthquake event = An example in southern California would be an earthquake on the Hollywood fault that triggers earthquakes and fault offsets on the Santa Monica, Raymond, Eagle Rock, and San Rafael faults.

accommodate this potentially much larger offset, or whether the selected segmental design would be adequate. Caltrans and Metro cannot determine the likelihood of this event without performing further study. The DEIR/S may not simply decline to consider cascading scenarios on this basis.

The Project is similar in some respects to the California High Speed Rail project, a large-scale transportation infrastructure project for which the tunnel portions cross numerous active faults, including the Garlock, Ortigalita, Greenville, and Calaveras faults. See the California High-Speed Rail Project EIR/EIS (Parsons Brinckerhoff Inc. [PBI], 2004. The High-Speed Rail project is similar to the SR 710 Project because it calls for tunnels carrying passenger railcars and must be designed to minimize tunnel damage, injury, and death. The California High Speed Rail project design option for crossing each of these faults is an oversized mined vault[12], a design that Caltrans rejected in the PGR, and consequently in the DEIR/S. PBI states that the California High Speed Rail design would be for faults with offsets in the 1- to 3-foot range. This range is similar to the minimum values for the 710 Project where the tunnels would cross the Raymond fault.

The DEIR/S must develop and use tunnel-specific fault offset standards to justify its methodology used to determine the design tunnel fault offset[13] for this project. This methodology must be justifiable and based on the best science available. Caltrans may not select one methodology (e.g., Wells and Coppersmith) over superior methodologies—especially if the decision prompts Caltrans to use a less conservative design tunnel fault offset—without substantial justification. It is not sufficient simply to state (PGR Appendix E, page 16) "the Wells and Coppersmith (1994) model is the most widely used model in practice and is considered appropriate for these preliminary estimates." Without knowing the performance standard and acceptable consequences of fault rupture, it is impossible to evaluate the selected design. The larger potential fault offset cannot be adequately "addressed with specific design features" as currently proposed (DEIR/S page 4-59). The performance standard and acceptable consequences of fault rupture are discussed further below.

c. The DEIR/S does not adequately evaluate the bored tunnel design for near-source ground shaking effects from an earthquake on the Raymond fault, or one involving the Raymond, Eagle Rock, and San Rafael faults together, thereby potentially underestimating ground shaking values.

The DEIR/S fails to evaluate the potential impact of the near-source ground shaking hazard on the tunnel from an earthquake on the Raymond fault or the Raymond, Eagle Rock, and San Rafael faults together. The intensity of ground shaking generally depends on the distance from any location to the earthquake epicenter (closer has stronger, more severe shaking) and to the

[12] Vault = An extra large mined opening around a conventionally excavated tunnel that is used in theory to absorb fault offset; for larger predicted offsets it is often filled with crushable materials to absorb more movement.

[13] Design tunnel fault offset = This is the magnitude of fault offset (horizontal and vertical) chosen by Caltrans as the basis for designing the tunnel structure after considering the predicted offset characteristics of the fault or faults crossing the tunnel at any given location.

causative earthquake fault (near-source shaking is more severe). As with fault rupture, Caltrans has produced no seismic design criteria for tunnels (PGR Appendix F, page 8) that account for ground shaking. Because this hazard is not addressed, there is no evidence that the recommended design measures, which are intended to accommodate vertical and lateral offset movements, would be sufficient to protect the tunnel. Very strong near-source ground shaking, in addition to fault rupture, could potentially severely affect a 50-foot wide zone (the typical setback zone from a fault trace) or more. Effects could include ground/grout cracking, and local permanent ground deformation, thereby resulting in further tunnel damage. Caltrans' failure to identify design criteria that would account for the potential hazards associated with near-source ground shaking undermines the effectiveness of any proposed design measures[14].

A tunnel design will affect not only its response to the magnitude of the fault rupture displacement hazard, but also its response to the intensity of near-source ground shaking at the location where the tunnel crosses the earthquake fault. Tunnels are underground structures that are typically confined by the surrounding soil or rock. As such, studies and observations from recent earthquakes—1995 Kobe, Japan; 1999 Chi-Chi, Taiwan; and 2004 Niigata, Japan—indicate that tunnels located within close proximity to a causative fault during a seismic event suffered severe damage (Corigliano et al. 2011). For example, a survey of tunnel damage due to the Chi-Chi, Taiwan earthquake indicates that 49 of 57 tunnels surveyed experienced moderate to severe damage (Wang et al. 2001; Xiaoqing-Lin et al., 2008). Based on a study by Xiaoqing-Lin et al., a tunnel would be expected to suffer severe damage when ground acceleration from the near earthquake is expected to exceed 0.5g (peak ground acceleration). The Tunnel Evaluation Report (TER; Appendix H TM-6, pages 5, 29, and 30) also cites the 2008 Wenchuan earthquake, which caused extensive damage due to a one-meter fault offset and to a tunnel collapse. The proposed freeway tunnel and LRT alignments cross the Raymond fault (DEIR/S Section 3.10.2.6, page 3.10-4). The Project's tunnel can be expected to suffer high ground acceleration that could cause severe damage to the tunnel in the event of an earthquake.

d. The DEIR/S does not identify significance criteria relating to fault offset and ground shaking, fails to determine the significance of the Project's impacts, and defers mitigation until after Project approval.

Caltrans and Metro did not establish a fault offset performance measure to judge what offset is an unacceptable level of displacement damage to the tunnel. Instead, the DEIR/S simply recognizes that "there is the potential for substantial adverse effects due to fault rupture" (DEIR/S page 4-59). This potential is the same for a large Raymond fault earthquake and the underestimated effects of near-source ground shaking discussed in section 2.c of this report. The DEIR/S never evaluates the potential for the tunnel to fail partially or completely.

Tunnel accidents, whether caused by fault rupture or not, can be disastrous. As noted above, observations from the earthquakes in 1995 Kobe, Japan, in 1999 Chi-Chi, Taiwan, and in 2004

[14] Design measures = These are the specific factors in the design of a structure (e.g., size of the foundations, amount of reinforcing, and thickness of concrete) that allow the structure to perform adequately (defined by performance standards) in an earthquake event.

Niigata, Japan indicate that tunnels located within close proximity to a causative fault during a seismic event suffered severe damage (Corigliano et al. 2011). The 0.7-mile long Caldecott tunnel fire in 1982 illustrates the potential effects on tunnel users from a fire. This was caused by a gas-tanker truck collision followed by fire and smoke that killed six people died and injured two. Those involved were apparently unaware of the exit cross-passages and passageways. Such a tunnel fire could accompany earthquake damage to the SR 710 Project tunnel. The Gotthard, Switzerland, tunnel fire killed 11 people and injured many more. The Gotthard tunnel has only two traffic lanes, not the four to eight lanes contemplated here. The SR 710 Project could expose two to four times the more people to collapse and fire dangers in case of an accident caused by a seismic event.

Dr. Kenneth Hudnut, a U.S. Geological Survey (USGS Pasadena) Geophysicist, discussed earthquake issues in relation to the SR 710 tunnels in a presentation in September 2012. He stated, "Tunnels have collapsed, and suffered damage in many earthquakes, so seismic countermeasure designs is *essential* for these new tunnels" (Hudnut 2012). Dr. Hudnut reviewed various cases of tunnel damage or even collapse, and pointed out that "damage and collapse of tunnels has occurred even in newly built and very strong tunnels in advanced nations. . . ." (Hudnut 2012). He recommended not building tunnels on or along fault lines, or at least building on the less active sections of fault lines, and noted that most of the proposed tunnels cross fault lines at more than one place. Dr. Hudnut's findings regarding the potential for severe damage from faults due to significant earthquakes are consistent with observations from recent earthquakes in advanced nations (Corigliano et. al., 2011). For the SR 710 Project, an obvious solution is to avoid constructing a tunnel across active faults.

The DEIR/S's lack of significance threshold criteria means that it does not adequately disclose to the public that significant, non-routine seismic events are possible and could result in significant property damage, severe injury, or even death. With regard to fault rupture and earthquake ground shaking, the DEIR/S (PGR Appendix E, pages 11 and 15) concludes, with insufficient evidentiary support, that cascading earthquake events[15] have a "low probability of occurrence" and "cannot be demonstrated geologically" for known active faults connected to the active Raymond fault. The consequences of such events are much larger magnitude earthquake and surface fault offset similar to large magnitude events such as occurred in 1995 Kobe, Japan, in 1999 Chi-Chi, Taiwan, and in 2004 Niigata, Japan. For a project such as this, it must be demonstrated that such events would not adversely impact the public. In essence, the DEIR/S ignores the potentially catastrophic consequences of these events by focusing on the alleged improbability of them occurring. As discussed below in the context of impacts to the area's groundwater basins, large earthquakes are quite common in southern California. The DEIR/S has no basis to conclude that these larger events are so improbable that they can be dismissed out of hand.

[15] Cascading earthquake events = With cascading events, several faults could rupture together with slip/offset transferring from one fault to the other; a cascading event would result in a larger magnitude event and much larger displacements on each of the faults than an event on a single shorter fault.

The DEIR/S also defers mitigating seismic impacts until after project approval. The DEIR/S (page 3.10-22) proposes to mitigate the Project's geotechnical/seismic impacts by conducting future studies and analysis, and preparing geology and geotechnical reports designed to "provide design recommendations for seismic hazards such as fault-induced ground rupture, ground shaking, co-seismic deformation[16], slope instability, seismic settlement, liquefaction, or related secondary seismic impacts that may be present along the alignment of the selected Build Alternative project." This is precisely the type of analysis that should have been conducted prior to the selection of a proposed tunnel alignment. Nor can the DEIR/S rely on a promise to conduct detailed geotechnical investigation to conclude that impacts associated with these seismic hazards are less than significant without specifying quantifiable performance measures. As discussed in 2.a, 2.b, and 2.c above, proposing a freeway tunnel or LRT design for a 0.5-meter fault offset and then performing studies that show the design must accommodate 2.2- to 5-meters would necessitate design changes after Project approval that would not have been reviewed in the DEIR/S.

Design changes like the above could have other very significant impacts. For example, changing the tunnel design from a small vault to a large vault filled with compressible materials (the original design) would have a dramatically greater effect on groundwater flow along the outside of the tunnel north of and across the Raymond fault and potentially cause a substantial impact on the City of Pasadena Subarea groundwater storage. These design changes would substantially increase by many feet the opening size between the tunnel structure and the surrounding bedrock, and this space would be filled with a purposefully high permeability crushable material. Groundwater would much more readily flow through this larger opening and through the highly permeable material filling it. Given that Caltrans and Metro are considering only one freeway tunnel alignment, there is no justifiable reason to delay the important studies that would allow a proper mitigation to be determined now.

Because the DEIR/S calls for deferring the preparation of these plans, and because it fails to provide details on how these plans will mitigate for the Project's seismic impacts, let alone provide enforceable measures and performance criteria, there is no assurance that these significant impacts will be mitigated at all. In order to satisfy CEQA's requirement that an agency propose feasible, enforceable mitigation that it shows will actually mitigate the project's impacts, Caltrans must conduct these studies *before* the DEIR/S can be approved.

e. The DEIR/S fails to analyze adequately potential impacts from ground settlement and fails to mitigate for these effects.

The DEIR/S states that "the proposed excavation would result in the potential for ground settlement and differential settlement[17] immediately above and adjacent to the bored tunnel

[16] Co-seismic deformation = A large earthquake does not always rupture the ground surface above buried fault planes. However, deformation of the ground (e.g., uplift, subsidence, tilting) may occur at certain distances away from (e.g., to the north of) a lateral-reverse fault such as the Raymond fault.
[17] Differential settlement = When the ground surface settles unevenly due to activity beneath the surface such as an excavation (e.g., a tunnel) or groundwater withdrawal for porous alluvial sediments.

portion, and the portal and station excavations of the LRT Alternative" (pages 3.10-10 and 3.10-12). It further states that "Open excavation and tunneling in unconsolidated and/or saturated alluvium have the potential for groundwater inflows and flowing ground conditions at the heading of the excavation, which could potentially result in settlement of the ground surface if not properly controlled" (page 3.10-12). Despite these acknowledgements, the DEIR/S does not adequately evaluate the extensive impacts that could result from ground settlement.

According to other studies, such as Dubnewych et al. (2011), "Settlement could damage surface facilities such as existing buildings, streets, utilities, and other improvements," and further that "Uncontrolled and/or excessive groundwater inflow during tunnel construction could result in loss of ground, which could lead to surface settlements." Groundwater inflow into excavation areas may require dewatering, which in turn could potentially cause more settlement. Many of the areas above the SR 710 tunnel alignment are occupied with improvements such as residences, roads, and businesses. These improvements could be damaged in the event of ground settlement. With respect to 2009 Shanghai Yangtze River Tunnel the TER (Table 1) indicates that the "Highest recorded settlement occurred near portals with shallow ground cover".

In order to evaluate properly the potential hazards associated with the settlement of overburden soils and the consequent impact on existing improvements, Caltrans should have: (a) estimated the anticipated total and differential settlements; (b) identified the tolerance limits of the existing improvements to such settlements; and (c) studied alluvial deposits and groundwater characterization in the area. The DEIR/S includes none of this. These studies are necessary at the outset, to determine whether the proposed excavation and tunneling techniques require adjustment or augmentation through mitigation. In particular, the studies would evaluate the specific groundwater conditions within the alluvial deposit portions of the tunnel alignments, including the densities, porosities, and transmissivities of the materials. Only with such information, can Caltrans and Metro evaluate the Project's impacts, and identify necessary design changes and mitigation.

In lieu of these studies, the DEIR/S speculates that use of certain construction techniques may limit ground settlement: "tunneling equipment and procedures as well as portal and station support methods are capable of controlling ground movements to limit surface settlements and in turn minimize damage to existing structures" (page 3.10-11). The DEIR/S also suggests other measures, such as chemical or cement grouting, but it does not explain the effectiveness of these measures. The DEIR/S's failure to evaluate adequately effective construction techniques makes it impossible to determine whether sufficient measures will be employed to prevent damage from ground settlement. Caltrans cannot defer these important studies.

f. Caltrans improperly rejected a safer tunnel design in favor of a less expensive, more quickly built design, but one with more potential for severe stress to the tunnel.

Generally, large backfilled vaults should perform better than small steel-lined vaults in earthquakes producing fault offset and high near-source ground motions. As originally proposed, the freeway tunnel design called for a large vault backfilled with crushable materials in the sections of the tunnel crossed by active faults (see PGR Section 11.8.1.3, pages 11-9 and 11-10).

Ultimately, however, Caltrans settled on a smaller, less expensive, and more quickly built design that employs vault sections utilizing steel segmental lining. This change in tunnel design was made due to "constructability issues as well as risk, cost, and schedule implications" (PGR page 11-10). The DEIR/S (pages 2-58, 2-85, and 3-10.21, and the TER (Appendix H TM-6) do not demonstrate that the newer tunnel vault design will mitigate potential Raymond fault movements in the range of 5-feet (Appendix H TM-6, page 5). Caltrans made this design change without a specific analysis of how either design would perform in response to an earthquake and in reliance on "future design studies". On page 2-4, the TER states "Site-specific geotechnical investigations have yet to be completed at each of the various fault zones; future design studies will require site-specific data to be obtained in order to refine the design concepts discussed herein."

The change in design includes a thicker concrete tunnel lining that could potentially increase the damage to the tunnel due to an earthquake (Xiaoqing et. al. 2008), not mitigate it. Recent evaluations of tunnel performance during earthquakes indicate that tunnel sections with thick lining have a higher damage percentage (Xiaoqing et al. 2008). While thicker lining may be needed to mitigate potential damage to the tunnel lining from non-earthquake ground pressures, thicker lining in turn is more susceptible to damage from severe ground shaking (Xiaoqing et al. 2008). Where, as here, steel plate lining is proposed to be used, the agency must undertake seismic loading[18] analyses (in addition to static loading analyses) in order to ensure it is sufficient to mitigate the fault-offset hazard. Caltrans and Metro did not perform this analysis of the seismic loading resulting from earthquake ground shaking. This difference in the thickness of the vault lining becomes critical if further study determines that the assumed fault offset parameters assumed are far too low and cannot be accommodated by the steel segmental lining approach. Not accounting for the higher potential offsets could lead to the consequences described in previous subsections 2.a though 2.e.

The TER (Appendix H TM-6, page 5) states:

> "When tunnels are subjected to larger offsets (greater than about 5 feet) and the linings are not designed for offset, major cracking of the lining and collapse of the lining is possible, if not probable, as illustrated in Figure 5. In addition, significant lengths of lining on either side of the fault offset zone would probably be heavily cracked and damaged and may require replacement."

As explained immediately above, with this greater than or less than 5 feet of fault offset serving as an apparent critical fault offset design threshold, it is even more important that Caltrans employ the appropriate fault offset determination methodology, i.e., Wesnousky rather than Wells and Coppersmith. As explained above, the Wesnousky 2.2-meter (over 5-feet) offset prediction is approximately the same as the offset already observed in the 1971 San Fernando earthquake along an oblique slip fault (the north side moves up and to the left) very similar to the Raymond fault.

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[18] Seismic loading = The force on a structure caused by ground acceleration induced on the structure mass by an earthquake.

The DEIR/S must document how the proposed design option will protect tunnel users. This documentation must include examples of the expected design performance under various fault offset and near-source ground motion scenarios. In particular, it must consider sympathetic movement[19] on non-active faults and parallel geologic bedding between the Raymond and San Rafael faults. Rigorous analyses, using finite element/finite difference methods[20], are needed to evaluate the performance of the tunnel under static and seismic loading conditions. Cost, risk, and construction time trade-offs must be detailed to justify the final design selected by Caltrans that will prevent serious impacts to tunnel users, and assure the public that the cost and time considerations are properly balanced with safety.

3. WATER QUALITY AND STORM WATER RUNOFF (SECTION 3.9 RAYMOND BASIN GROUNDWATER PORTION)

Using the established hydrology and water quality thresholds from CEQA (Appendix G of CEQA Statute and Guidelines), the project will be considered to have a significant impact if it:

a. Substantially depletes groundwater supplies or interferes substantially with groundwater recharge such that there would be a net deficit in aquifer volumes or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?

b. Otherwise substantially degrade water quality?

In order to evaluate the Project's potential impacts relating to groundwater, the DEIR/S must undertake a series of steps. First, it must identify and describe existing groundwater conditions. Second, since the Project would be constructed in a seismically active zone, it must provide a detailed description of the Project's fault rupture and near-source ground shaking impacts on the geologic formations and on the construction elements of the tunnel. This would allow the DEIR/S to examine how the construction of a tunnel would impact groundwater resources taking into account, the tunnel's construction in a seismically active setting. Third, if the DEIR/S determines that the Project would result in potential impacts, the DEIR/S must evaluate the severity and extent of these impacts. Fourth, the DEIR/S must then identify feasible measures capable of reducing these impacts. The analysis of impacts and the efficacy of mitigation must be supported by substantial evidence.

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[19] Sympathetic movement = Offsets along faults, fractures, or bedrock bedding planes due to strain release along the main fault or vibratory ground motion that disturbs the state of stress on these other faults (they may be active or non-active), fractures, and bedding planes causing them to undergo displacement.

[20] Finite element/finite difference methods = Computer software (programs) based on complex numerical methods and mathematical models used for analyzing complex engineering problems utilizing the geometry and properties of the subject materials to simulate the response of project to loads and seismic ground shaking. Such programs can simulate the propagation of movement along secondary faults, fractures, or bedding planes due to a movement along a main fault during an earthquake. This requires a thorough understanding of the physical properties of the secondary faults, fractures, or bedding planes.

a. The DEIR/S does not describe the Raymond Basin and Pasadena Subarea groundwater characteristics in sufficient detail to allow an evaluation of groundwater flow in the tunnel area. It also does not include sufficient geotechnical detail including information relating to bedrock fracture patterns.

The San Gabriel Valley includes two groundwater basins: the Raymond Basin and the San Gabriel Basin (DEIR, p. 3.9-9). The Raymond Fault separates the Raymond and the Main San Gabriel Groundwater Basins. The Pasadena Subarea is the major portion of the overall basin and abuts the Raymond Fault where the bored tunnels would be located (RBMB Annual Report 2014, Figure 6). The Fault acts as a natural subsurface dam[21] holding back the groundwater in the Raymond Basin on the north from water in the Main San Gabriel Basin on the south (DEIR/S p. 3.10-3).

Studies indicate that groundwater from the northwestern and western portions of the basin flow toward the proposed bored tunnel locations (NASA/JPL 2007). Water levels are 160 feet lower in the Main San Gabriel Basin than immediately across the Raymond fault in the Raymond Basin. This suggests that penetration of the Raymond Fault barrier could cause a pathway for water flow (including possibly along the Eagle Rock and San Rafael faults) to be extended across the barrier into the Main San Gabriel Basin.

The DEIR/S mentions the Raymond and the San Gabriel Basins, but it does not provide sufficient context to allow an evaluation of the Project's impact on the groundwater system. The DEIR/S does not, for example, identify or include groundwater depth contour maps, groundwater flow maps, basin thickness descriptions or contour maps, basin groundwater volumes, or the locations of pumping wells. The DEIR/S also does not describe the groundwater interactions between the Raymond and Main San Gabriel Basins or provide information relating to groundwater recharge and withdrawal. Nor does the document identify the basins' existing groundwater quality or explain how it could be affected by specific sources of contamination (e.g., Jet Propulsion Laboratory (JPL)). In addition, the DEIR/S does not provide sufficient hydrogeologic and geotechnical information to allow for an evaluation of groundwater flow constraints associated with constructing a tunnel in a seismically active zone. For example, the DEIR/S does not quantify flow characteristics of the alluvial geologic units and fracture patterns in the surrounding bedrock. Without these fundamental details relating to groundwater characterization and geotechnical setting, the DEIR/S consultants are unable to evaluate how specifically the bored tunnels may affect the groundwater system.

Some of this information is readily available, while other information would require additional investigation. For example, existing groundwater data from the Raymond Basin Management

[21] Natural subsurface dam = Subsurface groundwater basins are separated from one another by natural barriers such as dense bedrock (e.g., intervening hills or mountains) and active faults, such as the Raymond fault. Active fault movement can grind bedrock and alluvial deposits into clay-sized particles that form "fault gouge" parallel to the fault that may be several feet thick. If natural barrier is not disturbed this gouge can hold back groundwater that would otherwise tend to flow down gradient (south in this case) in the subsurface trying to seek a stable, continuous horizontal surface.

Board are readily available. Groundwater elevations for the proposed bored tunnel penetration areas could be extrapolated using Department of Water Resources (DWR) well data (GeoTracker 2015) and project borings. To evaluate the risk to groundwater from an earthquake, however, Caltrans/Metro must conduct a detailed geologic investigation of geologic units and fracture patterns in bedrock. It must evaluate the groundwater pathways that could be created by sympathetic movement on non-active faults and parallel geologic bedding between the Raymond and San Rafael Faults. Borings and monitoring wells should be installed in areas east of the Arroyo Seco, north of the Raymond Fault, and west of Arroyo Parkway to identify groundwater elevations and groundwater flow properties in alluvium and fractured bedrock. Finally, pumping tests would be necessary to estimate groundwater storage in the bedrock and flow rates from the fracture zones.

The DEIR/S should have included these background investigations in order to document the specific groundwater conditions of the Pasadena Subarea. Only from the results of these specific studies can potentially significant impacts to the Raymond and Main San Gabriel Basins be determined.

b. The DEIR/S lacks analysis to determine the potential impacts on the Raymond Basin and Pasadena Subarea groundwater supplies that could result from a penetration of the Raymond Fault groundwater barrier.

Because the Raymond Fault acts as a natural subsurface dam holding back water in the Raymond Basin on the north from water in the Main San Gabriel Basin on the south, perforating this groundwater barrier, either as a result of the tunnel's construction or because of an earthquake, could create significant pathways for Raymond Basin groundwater to flow into the Main San Gabriel Basin. Any failure would potentially deplete groundwater supplies in the Raymond Basin–Pasadena Subarea. Water levels within the Raymond Basin are already dropping because of the drought. With Governor Brown's April 2015 mandate to reduce water consumption by 25 percent, pressure on the Raymond Basin Management Board to conserve groundwater will increase.

The DEIR/S dismisses the potential threat to groundwater resources that could result from perforating this subsurface groundwater barrier either because of tunnel boring or in the event of an earthquake. Initially, the DEIR/S should have identified the estimated groundwater inflow and expected flow rates, and identified the expected treatment volumes from groundwater discharged at the surface. Neither the DEIR nor the Water Quality Assessment Report (WQAR) provides any information in this regard. While it may be a difficult to accurately estimate groundwater inflow into tunnels, this is no excuse for foregoing this critical analysis altogether. As Katibeh and Aalianvari (2012, page 75) explain, failure to account accurately for groundwater inflows during tunnel construction can have catastrophic consequences:

"During construction, groundwater flows freely into these tunnels through fractures in the rock. Where the rock is tight and the potentiometric head above the tunnel is low, the inflow will be small. Where the rock contains large, open fractures or where the head is high, the inflow will be substantial. Where the rock contains large fractures and a high groundwater head, the inflows can be catastrophic." Katibeh and Aalianvari (2012, page 76) go on to explain that there are several analytical methods to calculate groundwater discharges into tunnels. Caltrans should have conducted this investigation and included the results in the DEIR/S. Instead, the DEIR/S appears to ignore the potential for groundwater inflow altogether. Instead, it merely states, "special care would have to be exercised" when tunneling through a fault zone. While the Tunnel Evaluation Report describes the proposed tunneling process, none of this is brought forward to the DEIR/S for evaluation. The DEIR/S never describes the tunneling process other than to state that a pressurized-face tunnel boring machine[22] (TBM) would be used and that grout and a concrete lining with rubberized gaskets would be used to control water inflows (DEIR/S page 3.10-21; 3-24.7).

The DEIR/S (page 4-66) looks to the use of grouting to suggest that the potential for the Project (LRT and Tunnel Alternatives) to deplete groundwater supplies or interfere with groundwater recharge[23] is "low". The DEIR/S provides no documentation about the effectiveness of grouting to control groundwater. Other studies on tunneling, however, including those undertaken by Jacobs Engineering (Bedell et al. 2013), evaluate grouting as a solution for leaking tunnels and conclude that tunnels leak. Grouting certainly helps but does not eliminate leaks through or around a tunnel lining. Bedell et al. state (page 460) that:

> "While it is tempting to say "no leakage allowed," the goal of "no leakage" can be quite expensive and is probably unattainable. As long as there is a substantial head difference between the inside of the tunnel and the outside, groundwater will tend to find its way through even "impermeable membranes". The leakage will occur at the joints, seams and other imperfections. These imperfections are inevitable over the length of a long tunnel."

Jacobs Engineering supports these statements with data from three Atlanta area tunnel projects, Nancy Creek (16-foot diameter), South Cobb (27-foot diameter), and South River (14-foot diameter) (Table 1 in Bedell et al. 2013). The 27-foot diameter, 5.5-mile-long South Cobb hard rock tunnel in Georgia has the most recent data and projections, but all three tunnels have similar results. The South Cobb tunnel had a target groundwater inflow criterion[24] of 252 gallons/minute (gpm) and after the most advanced modified contact grouting (MCG) was performed, flow rates were projected to be reduced to 152 gpm, a 40 percent reduction from the criterion. This is a positive outcome considering the reduction in wastewater treatment costs. However, despite the annual reduction in water volume loss, a 152-gpm loss remained, indicating that 80 million gallons (MG; 245 acre-feet) per year were still leaking despite the grout.

[22] Tunnel boring machine = A machine used to excavate tunnels with a circular cross-section through soil and bedrock. This may be in lieu of drilling and blasting or other mining techniques.
[23] Groundwater recharge = Precipitation and surface water that enters a groundwater basin to restore the volumes of water lost through normal uses, pumping, or leakage.
[24] Target groundwater inflow criterion = For tunneling, this is the expected amount of water that would enter a tunnel excavation during tunneling and during operation of the tunnel project. This prediction requires knowledge of the groundwater system gained through collection of geologic, geotechnical and hydrologic studies, the analysis of data, and the numerical modeling to define flow paths and flow velocities.

The Pasadena Subarea groundwater storage on June 30, 2014 (RBMB Annual Report 2014, Table 4B) was 24,811.4 acre-feet, of which the City of Pasadena portion was 10,996.1 acre-feet. Because the DEIR/S makes no projections of target groundwater inflow or expected flow rates upon completion of the Project, we assumed for purposes of this report that the SR 710 tunnel could result in the same relative amount of leakage as that from the South Cobb tunnel. While the comparative lengths and diameters of the SR 710 tunnel sections involved must be considered in any detailed analysis, a leakage amount of 245 acre-feet (from the single smaller diameter tunnel, not the larger diameter or twin-bore tunnel under consideration) would represent approximately a 237 acre-feet of the Pasadena Subarea storage lost in one year. Considering the proposed Project's tunnels are about 2.2 times larger in circumference/surface area than the South Cobb tunnel and about 44-percent the length, the Project could generate 475.8 acre-feet per year leakage (4.33 percent of annual storage) from the City of Pasadena Subarea to the Main San Gabriel Basin along the dual-bore tunnel. Taking the average groundwater leakage rate for the Nancy Creek, South River, and South Cobb tunnels combined, and applying that rate to the proposed Project, the Project could result in a 5.23 percent reduction in Pasadena Subarea storage each year. Construction of the Project could thus result in a substantial loss of the City of Pasadena's groundwater. If the grouting safeguard fails, and the DEIR/S provides no assurance of their effectiveness, dewatering[25] of the Pasadena Subarea would occur and effectively cause a substantial loss of the City's water. The DEIR/S does not identify this potential impact on groundwater resources as significant.

Of critical concern though is the fact that the proposed tunnel would be constructed across multiple active faults. The South Cobb tunnel analysis discussed above is for a steady state, seismically inactive environment in Georgia, not for an earthquake-prone region of California. The DEIR/S fails to analyze the potentially disastrous consequences from a moderate or large earthquake on any of the area faults. The DEIR/S must analyze the consequences from various scenarios such as a moderate or large earthquake, including sympathetic movement on non-active faults, fractures, and parallel geologic bedding between the Raymond and San Rafael faults. What would the condition of this "grout seal" be after years of degradation, leaching/dissolution, and ambient vibration or earthquake shaking?

In addition to grouting, the DEIR/S calls for monitoring groundwater levels at selected locations to prevent groundwater flow. Mitigation measures WQ-2 and WQ-3 (page 3.9-20, 21) mention construction site dewatering and groundwater levels. Measure WQ-2 refers to compliance with an NPDES General Permit for Storm Water Discharges, but these permits address the quality of discharged water not mitigation for the loss of groundwater. WQ-3 mentions monitoring of groundwater levels, but not in the context of groundwater depletion. Simple monitoring of groundwater levels at selected locations is not mitigation to prevent the groundwater flow. Therefore, there is no basis for the DEIR/S to conclude that the project would not detrimentally impact the groundwater levels in the Pasadena Subarea

The DEIR/S must disclose the severity and extent of the impact, e.g., how much water could the City of Pasadena potentially lose and the implications associated with this loss. In addition, the

[25] Dewatering = Pumping of groundwater from an excavation in order to facilitate underground construction.

DEIR/S must discuss whether this drawdown[26] of the City's water would require Caltrans and/or Metro to obtain permits from the City of Pasadena.

c. *The DEIR/S lacks analysis to determine the potential degradation of Main San Gabriel Basin groundwater quality from penetrating the Raymond fault groundwater barrier*.

The DEIR/S (Section 4.2.9) does not analyze the impacts of the potential groundwater pathways to transport contaminants in the Raymond Basin (Pasadena Subarea) groundwater into the Main San Gabriel Basin—either along the Raymond fault, along the tunnel contact with alluvium or bedrock, or through the tunnel. Potential contamination of Raymond Basin groundwater could come from sources such as JPL or from other incidents (e.g., chemical or fuels spills). GSSI (2009) documents actual and projected movements of contaminants from JPL (perchlorates[27]) and groundwater flow pathways from north and northwest to south and southeast, all toward the proposed bored tunnel location beginning at the SR-210/SR-134 interchange. Any current or future contamination events along this pathway could end up at the proposed bored tunnel north of the penetration of the Raymond fault.

As discussed above, the DEIR/S' WQAR (page 106) assumes that backfill grouting operations performed during the construction phase would mitigate potential contaminant migration by filling gaps between the tunnel lining and the excavated ground around the tunnel. However, the DEIR/S does not analyze static effects, such as vibration or chemical degradation, on the proposed grout. Nor does it consider the effect that a moderate or larger earthquake would have in disrupting the post-construction "impermeable" groundwater barrier. As discussed above, rigorous analyses, using finite element/finite difference methods, are needed to evaluate the extent of the severely impacted areas resulting from fault offset ground movements and near-source ground shaking. This is necessary to assess the extent of cracked and fractured areas that could contribute to and facilitate seepage along the outside of the tunnel potentially facilitating groundwater flow from the Raymond Basin and contamination into the Main San Gabriel Basin. This includes pathways developed by sympathetic movement on non-active faults, fractures, and parallel geologic bedding between the Raymond and San Rafael faults.

Without any evaluation of the geologic units and fracture patterns in bedrock, or of the potential deterioration of the "grout seal", the DEIR/S does not demonstrate that impacts related to groundwater contamination would be less than significant, even considering measures such as grouting.

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[26] Drawdown = Reduction in the elevation of the groundwater surface in a groundwater basin due to natural or manmade causes.
[27] Perchlorates = A natural and manmade chemical used to produce rocket fuel, fireworks, flares, and explosives, which can also be found in bleach and some fertilizers. Its adverse health effects can include disruption of hormone production needed for normal growth and development.

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5. TECHNICAL CONSIDERATIONS AND LIMITATIONS

The purpose of this memorandum is to provide a professional opinion regarding the adequacy of the DEIR/S and selected appendices identified herein with regard to the DEIR/S Sections 3.10 Geology/Soils/Seismic/Topography (March 2015), 3.9 Water Quality and Storm Water Runoff (Raymond Basin Groundwater Portion; March 2015), and 4. California Environmental Quality Act (CEQA) Evaluation, Subsections 4.2.6 (Geology and Soils) and 4.2.9 (Hydrology and Water Quality). This report does not present a structural analysis that satisfies the potential regulations governing construction of the facilities discussed.

This memorandum was prepared for the exclusive use of the client and his authorized representative. It may not contain sufficient information for other uses or the purpose of other parties. Professional judgments presented in this memo are based on evaluations of the information available, on our understanding of geologic conditions for the proposed tunnel, and our general experience in the field of geotechnical engineering and engineering geology. Wilson Geosciences Inc. and GeoDynamics Inc. do not guarantee the interpretations made, only that the engineering work and judgment rendered meet the standard of care of the engineering geology and geotechnical professions at this time.

Our interpretations and conclusions presented in this report are based on experience conducting similar assessments for other projects in California and should not be considered perfect. We have relied upon existing available data and report; those authors are responsible for their data, analysis, and conclusions. We cannot predict future events or their likelihood and, therefore, this report provides an estimate of the likelihood and magnitude of certain events that may occur. Events can occur that are not foreseen at this time. Wilson Geosciences Inc. and GeoDynamics Inc. make no warranties either expressed or implied regarding the content of this report.

We appreciate the opportunity to assist in the DEIR/S review. Please contact the undersigned if you have questions.

Sincerely,

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ENGINEERING
GEOLOGIST
STATE OF CALIFORNIA

Kenneth Wilson

REGISTERED PROFESSIONAL ENGINEER
ALI H. ABDEL-HAQ
NO. 2308
EXP. 12-31-15
GEOTECHNICAL
STATE OF CALIFORNIA

Ali H. Haq.

Kenneth Wilson, Wilson Geosciences Inc.
Principal Geologist
P.G. #3175, C.E.G. #928

Ali Abdel-Haq, GeoDynamics, Inc.
Principal Geotechnical Engineer
R.G.E #2308

KENNETH WILSON

Principal Engineering Geologist

EDUCATION

University of California at Riverside, B.S. Geological Sciences, 1967
University of California at Riverside, M.S. Geological Sciences, 1972

PROFESSIONAL REGISTRATIONS

Professional Geologist, California, #3175 [Issued 1-08-1974; Expires 2-28-2015]
Certified Engineering Geologist, California, #928 [Issued 1-08-1974; Expires 2-28-2015]

PROFESSIONAL SUMMARY

Kenneth Wilson is responsible for management, technical supervision and performance of engineering geology, geotechnical, environmental impact, and environmental geology projects, and is a Professional Geologist (#3175) and Certified Engineering Geologist (#928) in California. He performs and supervises environmental assessments for commercial, industrial and government projects covering the disciplines of hydrogeology, engineering geology, geology, hydrology, seismicity, tectonics, faulting, mineral resources, and waste management. Geotechnical studies include fault evaluations, ground failure assessments, slope stability and foundation materials characterization, liquefaction potential, flooding hazards and site selection. The emphasis of his work is on defining geologic and geotechnical conditions, and hazards, which may affect the feasibility and design of any type of development project. Mr. Wilson has over 40 years of technical performance/project experience in critical facilities studies, radioactive/mixed/hazardous waste management, energy plant site licensing, waste disposal site development, dams and reservoirs and numerous other engineered structures. Specialized experience is in engineering geology in support of geotechnical studies, site selection/evaluation, seismic safety, integration of multidisciplinary technical teams, project management, and EIRs, EAs, and EISs.

PROFESSIONAL EXPERIENCE

Wilson Geosciences Inc., Engineering and Environmental Geology [1989-Present]

Principal Engineering Geologist: Responsible for all management and technical activities for engineering geology, environmental impact, and environmental geology projects. Performs and supervises environmental assessments for commercial, industrial and government projects covering the disciplines of hydrogeology, engineering geology, geology, hydrology, seismicity, tectonics, faulting, mineral resources, and waste management. Geotechnical studies include fault evaluations, slope stability and foundation materials characterization, liquefaction potential, and site selection.

The Earth Technology Corporation [1974-1989]

Corporate Vice President: Mr. Wilson worked from late-1987 to mid-1989 for the Chairman/CEO and the President/COO performing the following tasks: assisting in evaluation of several potential acquisitions; management of pre-acquisition due diligence; evaluation of four new office geographic expansion options; managed preparation of corporate health and safety program and H/S technical procedures. In 1989 was principal-in-charge for start-up of environmental engineering and hydrogeology portion of Technical Assistance Contract with DOE/Nevada Operations.

Vice President; Director, Program Management: Mr. Wilson reported to the President of the Western Division (1985-1987) and was responsible for business development, project execution and strategic planning for market areas related to radioactive (high, mixed, and low-level) waste management programs, energy and mineral resources, geophysics and offshore technology. Emphasis was on geosciences, engineering, environmental, and program management disciplines for site selection, site evaluation/characterization, site remediation and specialized advanced technology considerations in hydrologic modeling, rock mechanics testing and geophysical exploration.

Vice President, Associate and Senior Manager: Mr. Wilson had numerous challenging technical and management responsibilities and assignments during the period 1974-1988. There was a wide range of projects for which he had a technical role, either performance, supervisory, or management in scope. A substantial portion of the time he was Program Manager for the Missile-X (MX) ICBM, Siting and Characterization Studies in the Western and Midwestern United States: for United States Air Force, Ballistic Missile Office, and the Southern Region Geologic Project Manager (SRGPM) in Mississippi, Louisiana, Texas, Georgia, South Carolina, Virginia, Maryland for Office of Nuclear Waste Isolation (ONWI) and Office of Crystalline Repository Development (OCRD). These projects were national in scope and involved most geologic, geotechnical, geophysical, environmental, and hydrologic disciplines

Converse Consultants (formerly Converse, Davis and Associates) [1970-1974]

Staff and Project Geologist: Conducted and supervised investigations in southern, central, and northern California, southern Nevada, and eastern Washington. Groundwater and related studies included permeability, transmissibility, and storage coefficient studies at Searles Lake, California; earth dam projects at Yucaipa, Littlerock, and Anaheim, California; groundwater contamination (hydrocarbons) evaluation in the Glendale, California area; wastewater and water treatment facilities in Solvang, Lompoc, Victorville, Thousand Oaks, and Sylmar, California. Numerous earthquake and fault risk studies were performed for earth dams and reservoirs, high-and low-rise buildings, hospitals and schools, proposed nuclear power plant sites, water storage tanks, and large-diameter pipelines. Landslide and other slope failure studies were performed in rock and soil terrains. Offshore studies planned and conducted include coastal geophysical (seismic reflection, side scan sonar, fathometer), sampling and scuba investigations near Monterey and Dana Point, California.

PROFESSIONAL ORGANIZATIONS
Member Association of Engineering Geologists, National and Southern California Sections
American Geophysical Union

COURSES, SEMINARS, AND WORKSHOPS

- Engineering Geophysics Short Course, Colorado School of Mines, Office of Continuing Education, Golden, Colorado
- Fundamentals of Ground-Water Monitoring Well Design, Construction, and Development, Las Vegas, Nevada
- New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice, Seminar organized by Applied Technology Council and funded by U.S. Geological Survey, Los Angeles, California
- Seismic Hazards Analysis, Course sponsored by Association of Engineering Geologists, Los Angeles, California

REPRESENTATIVE EXPERIENCE WITH GENERAL PLAN SAFETY ELEMENTS/TECHNICAL BACKGROUND REPORTS
Wilson Geosciences Inc. has been responsible for the geology, seismic, and soils [safety element technical background report and/or EIR section] portions of the following southern California General Plan updates:

- Arcadia
- Rosemead
- Azusa
- Claremont
- Laguna Hills
- Huntington Beach
- San Marcos
- Ontario SOI Amendment
- Chino
- Riverside
- City of Los Angeles Framework
- San Clemente
- California City
- American Canyon

REPRESENTATIVE TRANSPORTATION AND HIGHWAY/ROADWAY PROJECTS
Vandenburg Air Force Base Road Re-alignment
An initial site assessment was made for the feasibility of a major road re-alignment around a potentially unstable landslide area, Vandenburg Air Force Base, California. The study involved aerial photo interpretation, field mapping, and preparation of a report and cost estimate for performing a full geotechnical evaluation to design the roadway. Since the roadway was the only land route an important radar site it was necessary to accommodate very steep terrain and unfavorable geology along a major portion of the route. Environmental preservation of biological resources was an important consideration in planning the drilling and geophysical exploration sites.

Foothill Transportation Corridor (FTC) Geotechnical Investigations: Near Irvine and Mission Viejo, Orange County, California
Performed evaluations of the engineering geologic and geotechnical conditions, and recency of last fault movement on a potentially active fault along two several-mile-long sections of the Foothill Transportation Corridor, Orange County, California. Conducted geologic mapping, drilling, and trenching; logged deep (up to 140 feet) bucket auger borings and logged backhoe trenches to determine bedrock and soil characteristics, and potential for future fault movement. Analyzed data, prepared cross-sections, and co-authored a geotechnical reports presenting data, findings, and recommendations. Field investigations were targeted at specific bridges and interchange structures, as well as along this entire section of the tollway.

Engineering Geology and Geotechnical Investigations for the San Joaquin Transportation Corridor, Orange County, California
Also provided the supervision and review of geotechnical and engineering geology assessment for the San Joaquin Transportation Corridor, Orange County, California. Utilized existing geologic data and newly acquired borehole, trench and laboratory test information to evaluated various alternative routes through the San Joaquin Hills for the freeway complex. This reconnaissance and feasibility level study was the key input to the project environmental documents and final route selection. Presented data on maps and in a report, as well as at client/agency briefings.

Santa Barbara County Regional Transportation Agency, Santa Barbara County, California
Provided a full geologic and seismic evaluation of a large portion of the Santa Barbara County area as a part of their Regional Transportation Plan EIR. This study identified the potential hazards in the area of proposed transportation projects, and the potential impacts of these hazards. The text and tabular information was used in the preparation of the EIR documentation.

EDUCATION

Advanced Courses in Environmental Engineering, UCLA, 1989-1991
M.S. Engineering (Geotechnical), University of Ohio, 1985-1987
B.S. (Civil Engineering), Nottingham University-England, 1980-1983
Advanced Level in Mathematics, Further Mathematics, & Physics, Swindon College-England, 1978-1980.

REGISTRATIONS

Geotechnical Engineer, California, GE#2308
Professional Engineer (Civil), California, CE#46989

PROFESSIONAL HISTORY

GeoDynamics, Inc., Thousand Oaks, Principal Engineer, 2005-present
Bing Yen & Associates, Inc., Camarillo, Principal Engineer, 2000-2005
Leighton and Associates, Inc., Westlake Village, Senior Project Engineer, 1999-2000
Gorian & Associates, Inc., Westlake Village, Senior Project Engineer, 1997-1999
Burns & McDonnell, Kansas City, KS, Senior Project Engineer, 1994-1997
Gorian & Associates, Inc., Westlake Village, Senior Project Engineer, 1989-1994
Ensotech, Inc., Sun Valley, Senior Project Engineer, 1987-1989

AFFILIATIONS

American Society of Civil Engineers (ASCE), Member

REPRESENTATIVE EXPERIENCE

Mr. Abdel-Haq has over 27 years of professional experience in geotechnical engineering in the State of California, and 3 years of experience on projects throughout the United States. His project experience includes field explorations, laboratory testing, engineering analyses, and construction observation of various types of projects including hillside land development, commercial and industrial buildings, landslides, theme parks, schools, water tanks, airport facilities, wastewater treatment plants, transmission and distribution lines, and power generator facilities. Mr. Abdel-Haq has managed multiple projects with an emphasis on client and project management particularly on meeting project schedules and budgets.

Mr. Abdel-Haq has performed geotechnical engineering reviews for over 14 years for the cities of Simi Valley, Calabasas, Agoura Hills, Moorpark, Hidden Hills, Pasadena, Rosemead, Camarillo, Palmdale, Santa Barbara County, and Malibu. He also performed third party reviews of projects for private consultants. He has also served as a geotechnical engineer on public work projects for municipalities in Southern California, and other parts of the United States.

Mr. Abdel-Haq performed geotechnical investigations, including an evaluation of the potential for liquefaction and associated hazards, for projects including large tract home developments where high liquefaction potential is known to exist, or is suspected. Projects included Simi Village, Tracts 4923, 5164 and 5113 (Simi Valley, California), North Shores at Mandalay Bay, Tract 4424 (Oxnard, California), Tract 44986 (Santa Clarita, California), Mission Bell Plaza Shopping Center and Tracts 5147 (Moorpark, California). He also performed foundation investigations for a wide variety of projects across the United States including industrial buildings, Multi-story buildings and parking garages, bridges, water tanks, transmission and distribution lines and power substations, retaining walls, several rides at Six Flags Magic Mountain, and Naval Facilities. He has also evaluated foundation settlement due to noise vibration associated with jet engine test facilities, dynamic foundations for conveyor belts and electric generators, and the potential impact of adding fill, on large diameter (48" to 60"diameters) high-pressure water lines of the Calleguas Water Company.

Mr. Abdel-Haq's Master's thesis utilized finite element analyses to evaluate induced stresses in culverts due to different types and thicknesses of backfill materials.

PUBLICATIONS

Abdel-Haq, A and Hryciw, R. D. (1998). "Ground Settlement in Simi Valley Following The Northridge Earthquake." Journal of Geotechnical and Geoenvironmental Engineering, Vol. 124, No. 180-89.