TECHNICAL REPORT

GEOLOGY AND HYDROLOGY

LOS ANGELES RAIL RAPID TRANSIT PROJECT
"METRO RAIL"

Draft Environmental Impact Statement and
Environmental Impact Report

Prepared by

WESTEC SERVICES, INC.

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and

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INTRODUCTION

The following geology and hydrology analysis has been prepared specifically for the SCRTD Metro Rail Project Second Tier Environmental Impact Statement/Report (EIS/EIR). It is based primarily on information provided in Volumes I and II of the Metro Rail Project "Geotechnical Investigation Report" prepared by the project's General Geotechnical Consultant (Converse et al., 1981), and the "Draft Report - Seismological Investigation and Design Criteria" prepared by Converse Consultants (1982). Additional background information was provided in a U.S. Geological Survey study entitled "Geologic Aspects of Tunneling in the Los Angeles Area" (Yerkes et al., 1977).

The initial section of this report addresses existing landform, geology, seismicity and hydrology conditions along the proposed alternative alignments between the Los Angeles Central Business District and North Hollywood areas, including proposed auxiliary transit corridors, station locations and maintenance yards. Unless a regional perspective is necessary to fully describe potential environmental impacts (i.e., for the seismology analysis), the description of existing conditions focuses on localized, site-specific geologic and hydrologic features and only briefly summarizes regional features. To be consistent with the EIS/EIR format, all components of the proposed Metro Rail Project in the following discussion have been grouped into one of four segments: 1) the Los Angeles Central Business District (CBD); 2) the Wilshire Corridor; 3) Hollywood; and 4) North Hollywood (see Figure 1).

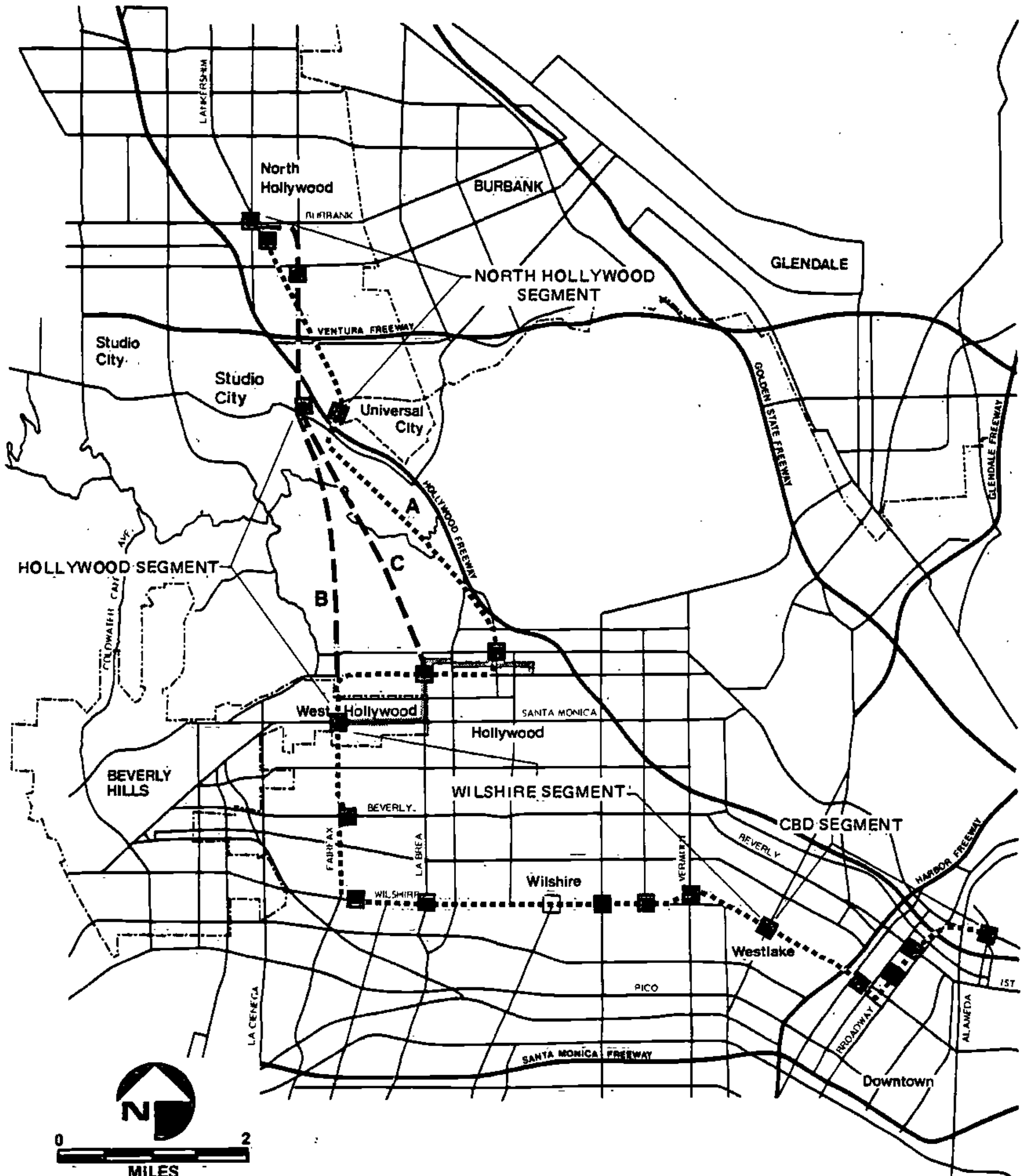
Following the description of existing conditions is an assessment of potential environmental impacts related to seismicity, other geologic hazards and hydrology/water quality, again organized by line segment. Impacts associated with both project operations and project construction are addressed. Where potentially significant adverse impacts have been identified, mitigation options are provided in the final section of this analysis.

EXISTING CONDITIONS

Landform

Regional Framework. On the basis of distinctive landform and geologic features, southern California is divisible into several natural physiographic provinces. As shown on Figure 2, the proposed Metro Rail Project crosses portions of two of these provinces: the Peninsular Ranges and the Western Transverse Ranges. The Peninsular Ranges province is composed of high, northwest-trending mountain ranges extending from Baja California on the south to the Transverse Ranges on the north. The west side of this province is marked by an irregular coastal plain that includes the Los Angeles Basin.

The Western Transverse Ranges are characterized by east-west oriented topographic and structural features which, in essence, cut across the more common northeast structural trend of southern California. This province extends from Pt. Conception and San Miguel Island on the west to the San Andreas fault on the east. The Santa Monica Mountains form the southern edge of the Western Transverse Ranges in the project



LEGEND

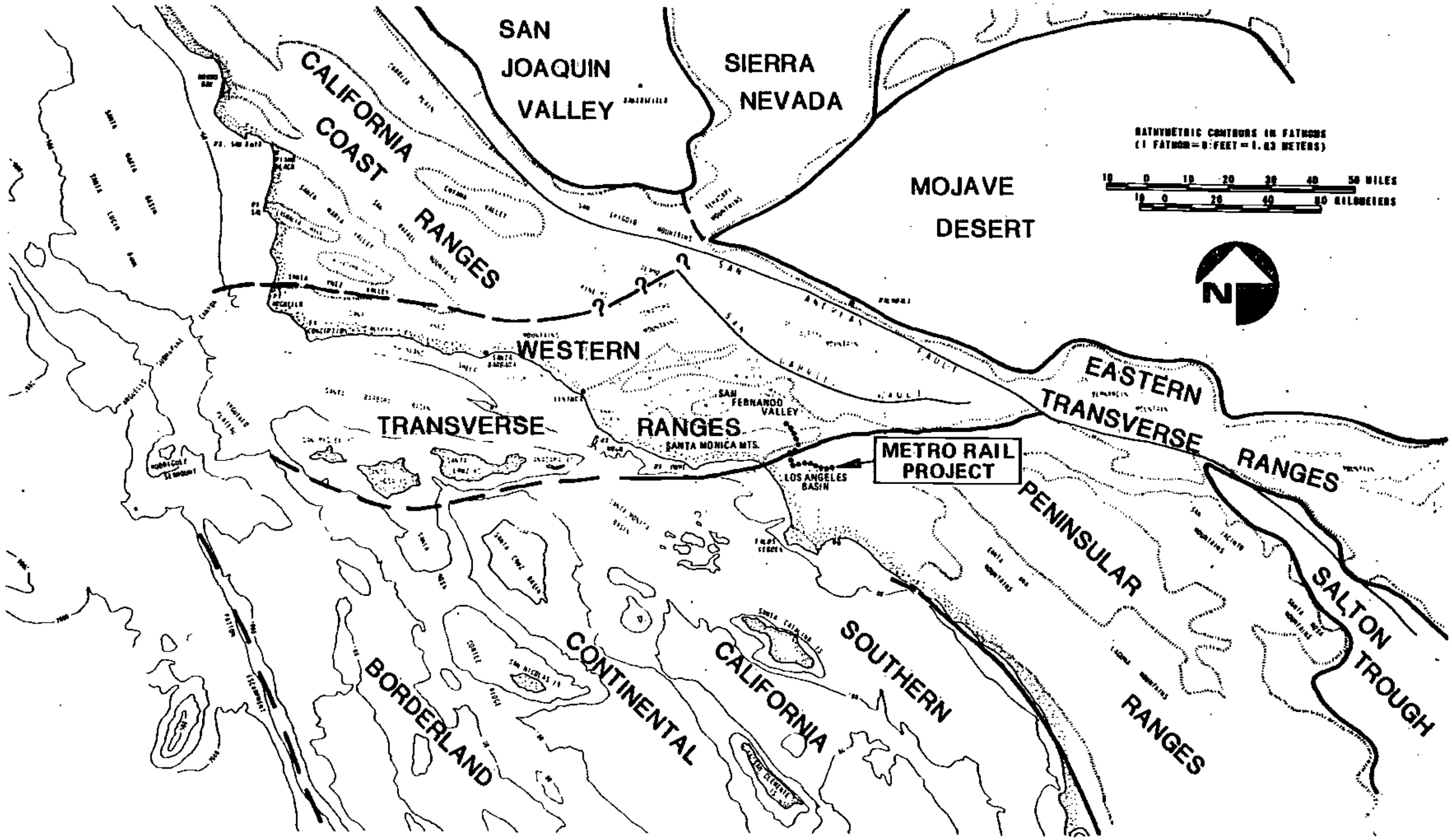
- Locally Preferred Alignment
- Alternative Subway Alignment
- Hollywood ICTS/LRT

Note: North Hollywood Segment Alignments may be Aerial or Subway

Source: SEDWAY/COOKE, 1983

Metro Rail Project Alternatives

FIGURE 1



SOURCE: AFTER JAHNS (1954)

Major Physiographic Provinces and Features in Southern California

FIGURE 2

WESTEC Services, Inc.

area. Directly north of the Santa Monica Mountains is the broad sedimentary basin known as the San Fernando Valley.

Local Setting. The proposed Metro Rail Project traverses parts of three major geomorphic and topographic subprovinces: the Los Angeles Basin, the Santa Monica Mountains and the San Fernando Valley. The Los Angeles Basin, at the northwest corner of the Peninsular Ranges, is an extensive coastal lowland extending from the Santa Monica Mountains to the Santa Ana Mountains and San Joaquin Hills 50 miles to the southeast. The basin is about 20 miles wide from the Puente Hills on its eastern edge and the Palos Verdes Hills and Pacific Ocean on the west.

The Santa Monica Mountains form a range 3 to 12 miles wide extending from the Los Angeles River on the east to the Pacific Ocean and Channel Islands on the west. Elevations on the crest of this range vary from about 500 to 3000 feet above sea level. To the north is the San Fernando Valley, a broad plain approximately 20 miles long and 10 miles wide lying between the Santa Monica and San Gabriel Mountains.

The following paragraphs provide descriptions of specific landform and topographic features along the four line segments of the Metro Rail Project.

Los Angeles CBD Segment. The Los Angeles CBD, Wilshire Corridor and a portion of the Hollywood segment of the proposed project all lie within the Los Angeles Basin. The Union Station and Main Yard at the eastern end of the line is situated in an area of low relief at an elevation of approximately 250 feet. Along the proposed alignment to the west the ground rises gently on the southeasterly flank of a low hill to an elevation of 320 feet at the Santa Ana Freeway. As the alignment curves to the southwest it descends gradually from this low hillside to the 7th/Flower Station and an elevation of about 260 feet at the western edge of the CBD line segment.

Wilshire Corridor Segment. From the 7th/Flower Station west to Fairfax Avenue the proposed alignment traverses land of low, rolling relief. Ground elevations range from a maximum of 320 feet about 1/2 mile west of 7th and Flower to a minimum of 160 feet at Fairfax. Slopes are very gentle, on the order of 0.5 percent, with the exception of a depression around MacArthur Park where slopes as steep as 20 percent (11 degrees from the horizontal) and 50 feet high are encountered.

The north-south reach of the Wilshire Corridor ascends gradually from 160 feet at Wilshire Boulevard north to 285 feet at the Santa Monica/Fairfax Station. The natural slope of the land in this area is approximately 1 1/2 to 2 percent to the southwest.

Hollywood Segment. The Hollywood segment of the Metro Rail Project consists of three alternative alignments between the Santa Monica/Fairfax Station and the San Fernando Valley. These alternatives, the Cahuenga Bend, Fairfax Extended, and La Brea Bend, are shown on Figure 1 in this report and described in detail in Chapter II of the Metro Rail Project EIS/EIR.

- Cahuenga Bend

This alignment proceeds north from the Santa Monica/Fairfax Station up a 3.6 percent slope to Sunset Boulevard at an elevation of approximately 390 feet. The alignment then turns east along Sunset Boulevard where the ground elevation drops gradually to 350 feet near Cahuenga Boulevard. At that point the alignment again turns north along Cahuenga where it reaches an elevation of about 410 feet at Yucca Street at the foot of the Santa Monica Mountains.

In the Santa Monica Mountains the landform along the Cahuenga Bend alignment is characterized by steep terrain. Northwest from Yucca Street the ground rises abruptly to an elevation of approximately 580 feet, then drops to the small canyon containing Highland Avenue and the Hollywood Bowl at 475 feet elevation. Northwest of this canyon steep slopes rise to a relatively level terrace where the alignment passes beneath Mulholland Drive at an elevation of about 990 feet, then rises along an additional steep slope to the crest of the mountains at nearly 1170 feet. Slopes on the southern flank of the Santa Monica Mountains along the Cahuenga Bend alignment have an average gradient of 20 percent (11 degrees) south of Mulholland Drive and 30 percent (17 degrees) to the north.

Along the proposed alignment north of the crest line of the mountains the ground drops over a series of steep-sided (20 to 30 percent) hills and intervening canyons to an elevation of 625 feet at the southern edge of the San Fernando Valley. From this point the alignment drops gently to the Studio City/Universal City Station at an elevation of 575 feet.

- <u>Fairfax Extended</u>

The Fairfax Extended alternative alignment proceeds directly north from the Santa Monica/Fairfax Station through the Santa Monica Mountains to Ventura Boulevard in North Hollywood. From the Santa Monica/Fairfax Station north to the foot of the mountains at Hillside Avenue the ground rises on a 4 percent slope to an elevation of 460 feet.

North of Hillside Avenue are steep-sided hills and canyons similar to those described above. The crest of the Santa Monica Mountains along the alignment is at 1065 feet near the Woodrow Wilson Drive crossing. At Ventura Bouelvard on the northern end of this segment the ground elevation is approximately 600 feet.

An auxiliary transportation system is proposed as part of both the Fairfax Extended and La Brea Bend alternatives to augment service in the Hollywood area. The Fairfax auxiliary alignment extends east along Santa Monica Boulevard on level ground to a station at La Brea Avenue at an elevation of 285 feet, then turns north to Hawthorn Avenue. Along this south-to-north reach the ground rises to 380 feet. At Hawthorn Avenue the alignment proceeds east about 1 1/4 miles, again on nearly level ground, to the terminus at Selma and Gower Streets where the elevation is approximately 370 feet.

- <u>La Brea Bend</u>

The La Brea Bend alternative alignment begins at the Santa Monica/Fairfax Station at an elevation of 285 feet, proceeds north to Fountain Avenue at 340 feet, then east to La Brea at about 320 feet. At La Brea this alignment turns north approximately 3/4 miles to Hillside Avenue and an elevation of 470 feet at the south edge of the Santa Monica Mountains.

The La Brea Bend alignment through the mountains rises along steep slopes similar to those described for the Cahuenga Bend alternative to the crest line at

1165 feet, then drops to approximately 600 feet at Ventura Boulevard. Hillsides in this area average from 20 to 30 percent in steepness, with even steeper slopes in localized areas.

The auxiliary system proposed as part of the La Brea Bend alternative extends from a station at Sunset north along La Brea to Hawthorn Avenue, then east to Selma and Grower Streets. This is the same alignment as that being considered for the eastern portion of the Fairfax Extended auxiliary system, and is described above.

- Hillside Management Areas

Portions of the Hollywood Segment alternative alignment lie within areas covered by Hollywood and Sherman Oaks-Studio City-Toluca Lake District Plans. These plans include density controls and other landform alteration (grading) guidelines where natural slopes exceed 15 percent in steepness. As described above, slopes significantly steeper than 15 percent are found along the Cahuenga Bend, Fairfax Extended and La Brea Bend alignments through the Santa Monica Mountains.

North Hollywood Segment. As shown on Figure 1 and described in Section II of the EIS/EIR, four alternative alignments - two south of Camarillo Street and two north of Camarillo - are being considered in the North Hollywood segment. Each of these alternatives lies entirely within the San Fernando Valley in an area where the natural topographic relief is relatively subdued.

- South of Camarillo

Both alternative alignments south of Camarillo traverse nearly level ground from an elevation of approximately 600 feet at their southern ends to about 570 feet at the Los Angeles River. North of the river the ground again rises to 598 feet at Camarillo Street.

- North of Camarillo

The two alternative alignments north of Camarillo rise gradually to the north and west to a maximum elevation of 635 feet at the North Hollywood Station and maintenance yard, which defines the northern extent of the project. The maximum steepness of natural slopes in the North Hollywood segment does not exceed 1 to 1 1/2 percent.

Geology

Regional Framework. As described in Section 1.1 and illustrated on Figure 2, the proposed Metro Rail Project traverses the northern Los Angeles Basin, the eastern Santa Monica Mountains, and the southeastern San Fernando Valley. The Los Angeles Basin was once a marine embayment and has been accumulating sediments eroded from the surrounding highlands since Miocene and Pliocene times (see Table 1, Geologic Time Scale). During this period the Santa Monica Mountains were being uplifted and eroded to provide much of the sediment filling the northern Los Angeles Basin.

Table 1
Geologic Time Scale

Absolute Time before Present (in millions of years)	ERAS	PERIODS (Approx. Duration)	EPOCHS (Approx. Duration)
0	CENOZOIC [1]	Quaternary (2 million years)	Holocene (Recent) (last 11,000 years)
			Pleistocene (2 million years)
2		Tertiary (63 million years)	Pliocene (3 million years)
			Miocene (18 million years)
			Oligocene (15 million years)
			Eocene (17 million years)
			Paleocene (10 million years)
65	MESOZOIC [2]	Cretaceous (60 million years)	
125		Jurassic (50 million years)	
175		Triassic (50 million years)	
225	PALEOZOIC [2]	Permian (40 million years)	
265		Pennsylvanian (56 million years)	
325		Mississippian (25 million years)	
345		Devonian (50 million years)	
395		Silurian (40 million years)	
435		Ordovician (60 million years)	
496		Cambrian (100 million years)	
595	ARCHAEOZOIC	Precambrian (to origin of earth 4.5 - 5 billion years ago)	
5000			

Relative Time Scale

Notes: 1. Cenozioc ages from La Brecque, J. L. Kent, O.V., and Cande, S.C., 1977, Revised magnetic polarity time scale for Late Cretaceous and Cenozoic time : Geology, V. 5, p. 330 - 335.

2. Mesozoic and Paleozoic ages from Braziunas, T. F., A geological duration chart, Geology, V.3, p. 342 - 343.

Extensive volcanic activity covered much of the granitic core of the Santa Monica Mountains with basalt during the Middle Miocene. Overlying or in fault contact with these basalts are claystones, siltstones, sandstones and conglomerates of Upper-Middle and Upper Miocene age. Together, these volcanic and sedimentary rocks of the Santa Monica Mountains constitute the Topanga formation.

The Los Angeles Basin and San Fernando Valley were uplifted during the Pliocene Epoch. Alluvium and alluvial terrace deposits of Pleistocene to Holocene age then covered the extensive lowland areas. The San Fernando Valley has been filled with considerably thicker deposits of these alluvial sediments than has the northern part of the Los Angeles Basin.

A number of distinct geologic formations are found in the area of the proposed Metro Rail Project. Each of these units is described below in order of oldest to youngest. Their approximate surficial extent along the various alternative alignments are shown on Figure 3. More detailed descriptions of these geologic units emphasizing their characteristics at the proposed tunneling and surface excavation depths are provided in the following section entitled "Local Setting."

Granitic Rock. Granitic rocks of Cretaceous age crop out along the southern flanks of the Santa Monica Mountains in the area of the Fairfax Extended and La Brea Bend alternative alignments (Figure 3). This rock consists chiefly of deeply weathered granodiorite. It is soft at the surface and hard and intact at depth.

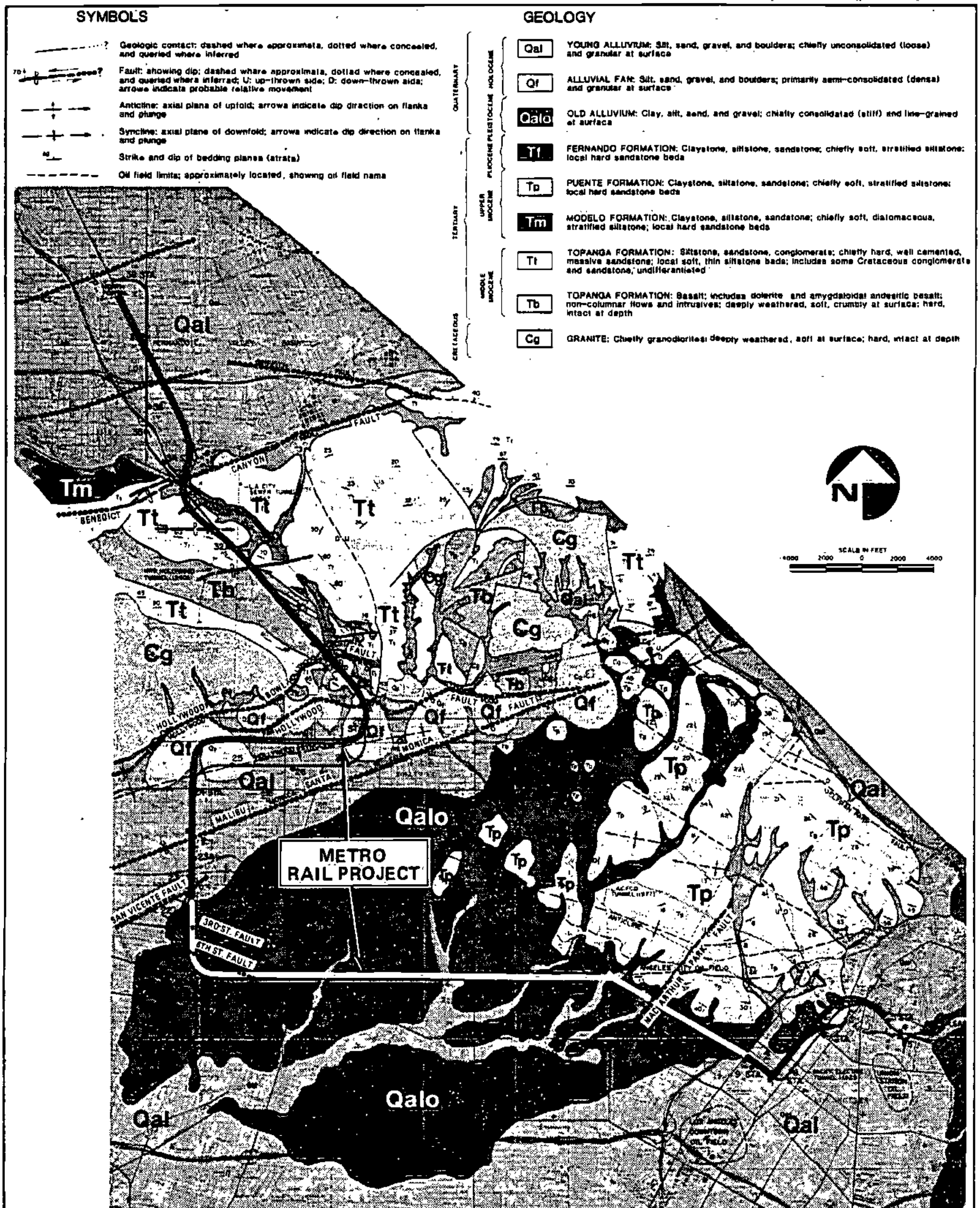
Topanga Formation. The Miocene Topanga formation consists of volcanic and sedimentary units. The volcanics are primarily basalts with lesser amounts of dolerites and andesites in the form of flows and intrusives. These rocks are deeply weathered and friable at the surface, hard and durable at depth, and moderately to intensely fractured. Topanga formation basalts are found chiefly along the crest of the Santa Monica Mountains in the Metro Rail Project area.

The Topanga formation sedimentary unit crops out on the north flank and middle south flank of the Santa Monica Mountains in the project area. The unit consists primarily of massive, hard, well-cemented sandstone with local, thin, soft siltstone beds. Also included in this unit are undifferentiated conglomerates and sandstones of Cretaceous age.

Modelo Formation. The Upper Miocene Modelo formation consists of soft, stratified diatomaceous siltstone with local hard sandstone beds. The unit is exposed at the surface at the north edge of the Santa Monica Mountains directly west of the proposed Metro Rail alternative alignments.

Puente Formation. The Puente Formation, of Upper Miocene age, underlies much of the northern Los Angeles Basin. It crops out at the surface in the hills just north of the Los Angeles CBD and east Wilshire Corridor segments of the Metro Rail Project. The unit consists primarily of thin to thickly bedded soft siltstone with local thin, hard, calcareous sandstone beds.

Fernando Formation. The Pliocene Fernando formation overlies the Puente formation in the Los Angeles Basin, and is exposed at the surface in parts of the CBD and at the eastern end of the Wilshire Corridor. The unit consists of thinly bedded, weak to moderately strong claystone, siltstone and sandstone with local hard, thin sandstone beds.



SOURCE: Converse et al. (1981, Drawing No.1)

Geologic Map of Metro Rail Project Area

FIGURE 3

San Pedro Formation. The Pleistocene San Pedro Foundation overlies the Fernando and Puente Formations beneath the ground surface along the Wilshire Corridor segment of the Metro Rail Project. It is a clean, relatively cohesionless, fine- to medium-grained sandstone with layers of silts, silty sands and fine gravels.

Old Alluvium. This unit blankets the northern Los Angeles Basin and Metro Rail Project from the eastern edge of the Wilshire Corridor to Fairfax Avenue. The Old Alluvium is of Pleistocene age and consists of clay, silt, sand and gravel, chiefly consolidated and stiff. For purposes of the Metro Rail Project geotechnical study the Old Alluvium has been differentiated into granular and fine-grained units, the granular unit occurring primarily as relatively thin, laterally discontinuous lenses within the fine-grained materials.

The granular Old Alluvium consists of medium dense to very dense clean sand, silty sand, gravelly sand and sandy gravel; the fine-grained Old Alluvium is firm to hard, stiff clay, clayey silt, sandy silt, sandy clay and clayey sand.

Alluvial Fans. This unit occurs as lobe-shaped surficial deposits at the mouths of major canyons draining the south slopes of the Santa Monica Mountains. The Alluvial Fans are of Holocene age and consist of semi-consolidated silt, sand, gravel and boulders.

Young Alluvium. The Young Alluvium, of Holocene age, mantles the ground surface along the Metro Rail Project in the CBD, from approximately Beverly and Fairfax north to the Santa Monica Mountains, and in the San Fernando Valley. Like the Old Alluvium, this formation has been divided into granular and fine-grained units. The granular Young Alluvium consists of loose to very dense, clean sand, silty sand, gravelly sand, sandy gravel and, locally, cobbles and boulders. The fine-grained Young Alluvium is firm to hard stiff clay, clayey silt, silt, sandy silt, sandy clay, and clayey sand.

Local Setting. Specific geologic conditions along each of the four segments of the Metro Rail Project are described below. For each segment, conditions are described from the ground surface to the depths expected to be reached by the proposed tunneling or surface excavations. Oil and/or gas in sediments beneath the Metro Rail alignment are a potential concern due to the effects these substances may have on soil strength and tunneling safety. Therefore, the potential for encountering subsurface oil or gas was assessed by the General Geotechnical Consultant (Converse et al., 1981). The results of this assessment for each line segment are also summarized in the following paragraphs.

Los Angeles CBD Segment. The CBD segment from its eastern end to the Santa Ana Freeway is underlain by siltstone, claystone and sandstone of the Puente Formation. East of the Los Angeles River in this reach is an overburden up to 30 feet thick consisting of granular Old Alluvium. West of the river the overburden is composed of up to 100 to 130 feet of granular Young Alluvium containing gravel lenses with cobbles and boulders from 8 inches to more than 4 feet in diameter. Near the Santa Ana Freeway the overburden thins significantly and the underlying Puente formation clays rise to within 10 feet of the surface.

From the Santa Ana Freeway crossing to the 7th/Flower Station the proposed Metro Rail alignment is underlain by claystone of the Fernando formation, with only a few feet of granular Young Alluvium overburden. This alluvial overburden increases in thickness to at least 130 feet beneath 6th and Broadway, then thins to about 55 feet at the 7th/Flower Station site.

Traces of gas were encountered in soil borings along the eastern portion of the CBD segment. Thus, the geological materials underlying the alignment east of approximately Union Station are classified as oily and gassy. Between Union Station and approximately the 7th/Flower Station the underlying sediments are rated as potentially gassy.

Wilshire Corridor Segment

- Eastern Wilshire Corridor

Geologic conditions along the eastern Wilshire Corridor from the 7th/Flower Station to Normandie Avenue are relatively uniform. Interbedded claystone, siltstone and sandstone of the Puente and Fernando formations underlie the alignment at depth. West of the Harbor Freeway the overburden ranges in thickness from 20 to 40 feet and consists primarily of stiff clays of the fine-grained Old Alluvium, with a few lenses of dense sand belonging to the granular Young Alluvium unit. East of the Harbor Freeway the overburden consists almost entirely of granular Young Alluvium. The sediments in this reach are considered to be gassy.

The MacArthur Park fault crosses the Wilshire Corridor segment near Alvarado Street (Figure 3). This fault is a northeast-striking, nearly vertical discontinuity within the Puente formation; it is overlain by unbroken Old Alluvium. The MacArthur Park fault forms a relatively weak zone possibly a few feet wide within the soft bedrock, and may form a barrier to the lateral migration of groundwater. The fault is inactive and considered to be typical of the many small faults likely to be encountered by tunneling through this area.

- Central Wilshire Corridor

West of Normandie Avenue in the central Wilshire Corridor the surface of the claystone Puente and Fernando formations slopes downward to a depth of about 90 feet, and remains at this depth to La Brea Avenue. Throughout this reach the claystone is overlain by the San Pedro formation, a relatively clean, cohesionless sandstone with an average thickness of approximately 20 feet. The San Pedro sand is overlain by 50 to 70 feet of Old Alluvium, consisting primarily of stiff clay and dense sand. This reach is considered to be potentially gassy.

- Western Wilshire Corridor

The Western Wilshire Corridor extends west from La Brea to Fairfax Avenue, then north to the Santa Monica/Fairfax Station. From La Brea to Fairfax the claystone Fernando Formation underlies the proposed alignment at depths of 60 to 110 feet. Overlying the claystone is the San Pedro sand, ranging in thickness from 20 to 55 feet. These sands are mantled by 30 to 65 feet of Old Alluvium, consisting of stiff clay.

North along Fairfax in the western Wilshire Corridor the claystone bedrock is at depths of from 100 feet at Fairfax to over 300 feet beneath Melrose Avenue. As the surface of the claystone steepens, both the overlying San Pedro and Old Alluvium units increase in thickness, the San Pedro to about 120 feet and the Old Alluvium to more than 150 feet. From about First Street north along Fairfax the ground is covered by clays and silts of the Young Alluvium unit, which thickens to approximately 60 feet at the Santa Monica/Fairfax Station.

Several faults have been mapped in the western Wilshire Corridor (see Figure 3). The 6th Street, 3rd Street and San Vicente faults offset strata of the bedrock Puente and Fernando formations, but do not disturb overlying Quaternary materials and are considered inactive. These faults may act as barriers to lateral groundwater migration and as structural traps for oil and gas in the bedrock formations. The Malibu-Santa Monica fault, which crosses the Metro Rail alignment approximately at Melrose, has offset the Old Alluvium unit and is considered to be potentially active. This fault also appears to be a barrier to groundwater movement.

The western Wilshire Corridor is adjacent to the La Brea Tar Pits and crosses two oil fields. The faults in this area have acted as oil traps in the bedrock formations and in places have provided conduits for the upward migration of oil and gas into overlying surficial units. The San Pedro formation in this reach is impregnated with oil and tar, and lenses of tar sand are found in the overlying alluvium, particularly near the La Brea Tar Pits. This reach has been classified as gassy, and will require extra precautions during tunnel construction. In addition, uncharted abandoned oil wells may be encountered during tunneling in this reach.

Hollywood Segment. All three Hollywood segment alternative alignments from the Santa Monica/Fairfax Station to the southern foot of the Santa Monica Mountains are underlain by geologic units with similar engineering properties. This area is a deep alluvial basin where the claystone bedrock is at depths of more than 200 feet. Approximately 120 to 200 feet of predominately fine-grained Old Alluvium overlain by 50 to 80 feet of fine-grained Young Alluvium mantle the area. Near the mountain front deposits of Alluvial Fan sediments are encountered. The Old Alluvium consists of stiff sandy clay and clayey sand with lenses of dense silty sand, while the Young Alluvium is composed of firm to stiff clays and silts with lenses of compact medium dense sand. The Alluvial Fans are semi-consolidated silt, sand, gravel and boulders. Sediments in this reach and all other alignments to the north are considered to be non-gassy.

The three alternative alignments of the Hollywood segment through the Santa Monica Mountains traverse the only hard rock along the ±18-mile Metro Rail Project. The Cahuenga Bend alternative passes entirely through Topanga formation rocks. From south to north through the mountains the following materials will be encountered:

- hard, well-cemented sandstone and conglomerate with local soft, thin siltstone beds,
- basalt, which is deeply weathered at the surface but hard and fractured at tunnel depth, and
- relatively soft, thinly bedded siltstone, with local hard sandstone beds.

According to available geologic maps (see Converse et al., 1981) the Fairfax Extended and La Brea Bend alignments will pass through Cretaceous granitic rock at the south edge of the mountains, then encounter rocks of the Topanga formation as described above. The granitic rocks consist primarily of granodiorite, deeply weathered at the surface and hard and intact at tunneling depth.

As shown on Figure 3, several fault zones cross the alternative rail alignments through the Santa Monica Mountains. The Hollywood fault, an east-west trending, nearly vertical feature at the southerly edge of the mountains, displaces strata of the bedrock Topanga formation, Old Alluvium, and possibly Young Alluvium. It is classified as seismically active, and may also serve as a barrier to groundwater.

The Hollywood Bowl fault branches northeasterly from the Hollywood fault near the Fairfax Extended alignment, then passes through the Hollywood Bowl area. The fault dips nearly vertically and appears to disturb a zone several hundred feet wide. It offsets Topanga formation strata and may displace Young Alluvium deposits near the Hollywood Bowl. Because of its apparent relationship to the Hollywood fault, the Hollywood Bowl fault may also be active. The fault is a barrier to the lateral movement of groundwater at depth, but may form a zone of enhanced vertical permeability due to fracturing.

An unnamed fault just north of the crest of the Santa Monica Mountains marks the contact between the volcanic and sedimentary rocks of the Topanga formation (Figure 3). This feature, along with a second unnamed fault about 2500 feet to the north, strikes approximately east-west and dips vertically. Both are considered inactive.

The Benedict Canyon fault crosses the northern, lower flank of the Santa Monica Mountains and offsets rocks of the Topanga formation. This near-vertical dipping feature is also considered inactive.

North Hollywood Segment. The North Hollywood segment is underlain by 50 to 100 feet of medium dense granular Young Alluvium on top of 40 to 100 feet of Old Alluvium. Interbedded claystone and siltstone bedrock of the Topanga formation underlie the alluvial sediments at increasing depths as the alternative alignments proceed north At the Universal City station, the bedrock is about 50 feet deep, drops to a depth of 180 feet beneath the Hollywood Freeway, and is more than 200 feet deep throughout the remainder of the alignment.

Two additional unnamed faults, as shown in Figure 3, have been postulated just north of the Ventura Freeway and near Chandler Boulevard at the north end of the Metro Rail project. Neither of these faults, if they actually exist, is considered to be active as they apparently do not displace Young Alluvium deposits.

Seismicity

The seismic setting of the Metro Rail Project is most realistically described from a regional perspective, focusing on the entire southern California area. Discussed below is the seismic history of this region and a description of regionally significant faults and the earthquakes they are considered capable of generating. This is followed by a discussion of expected seismic ground motions in the area of the Metro Rail Project.

Seismic History. Earthquakes and their effects have been recorded by man for the past 213 years in southern California. The earliest earthquake records did not include instrumental measurements and were thus not accurate or complete. Extrapolation of the historic record to predict future seismicity requires considerable judgment since the record does not contain a statistically valid sampling of larger events. Two to three hundred years simply represents too short a time in geologic history. On the other hand, the 213-year historic record should not be neglected. It is real, it does reflect actual events. and it most likely exceeds the service life of the proposed Metro Rail Project.

Pre-Instrumental Records. The California Institute of Technology began measuring earthquake ground motions and determining Richter magnitudes in 1933. Prior to that time, earthquakes were recorded without the use of instrumental measurements. The total pre-instrumental earthquake data record in southern California occupies the major portion of the historic record, and dates from 1769 to 1933. This pre-instrumental record is more than three times the length of the current instrumental earthquake catalog.

Prior to 1933, estimates of the size and epicentral location of earthquakes were based strictly on felt reports. These early earthquake recordings depended, in part, on the uneven geographic distribution of a growing population. As shown on Table 2, a number of large earthquakes occurred in southern California before 1933. The locations and sizes of these events are, in most cases, crudely known, and the threshold size for complete reporting varied widely with time and place. Nevertheless, some of these earlier reported earthquakes can be associated with particular faults and are useful in recognition of fault activity.

Instrumental Records. Initial earthquake recordings by Caltech were obtained from only four seismograph stations. The quality of the magnitude and epicentral location recordings has improved substantially with time and the installation of more instruments. In recent years, the number of seismographs operating in southern California has risen to well over 100, providing complete reporting of shocks with magnitudes exceeding 2.

With more recording stations and increased instrument sensitivity, the accuracy of reported epicenter locations has also increased. The probable error in epicentral locations was about 6 to 12 miles in 1934 and less than 3 miles in 1981. This substantial improvement now makes it possible to associate many recorded earthquakes with a specific fault. Considerable judgment is required when interpreting the older data, however, and few of the early events can be so associated.

The Caltech earthquake catalog lists nearly 800 earthquakes of magnitude 3.75 or greater within 100 miles of the Metro Rail route. Figure 4 shows earthquake epicenters exceeding magnitude 4.0 in southern California from 1932 through 1972.

Regional Historic Seismicity. From the pre-instrumental and instrumental earthquake records it is possible to calculate the seismicity of the Metro Rail Project region using the methodology reported by Allen et al. (1965). For this calculation the project region was considered to be an area extending about 100 miles from the proposed Metro Rail route. In addition, the numbers of recorded earthquakes were all normalized to a base period of 100 years and a base area of 1000 square miles.

The results of the calculation, taken from Converse Consultants (1982), are shown on Figure 5. This graph expresses the number of times an earthquake exceeding magnitude M is expected to occur in the project region within any 100-year period. As shown, the magnitude/recurrence relationships obtained from the instrumental data for the Metro Rail area (solid circles on Figure 5) are essentially in agreement with those reported by other researchers for all of southern California (dashed line). Regional seismicity as defined by the pre-instrumental data (open circles on Figure 5) appears

Table 2

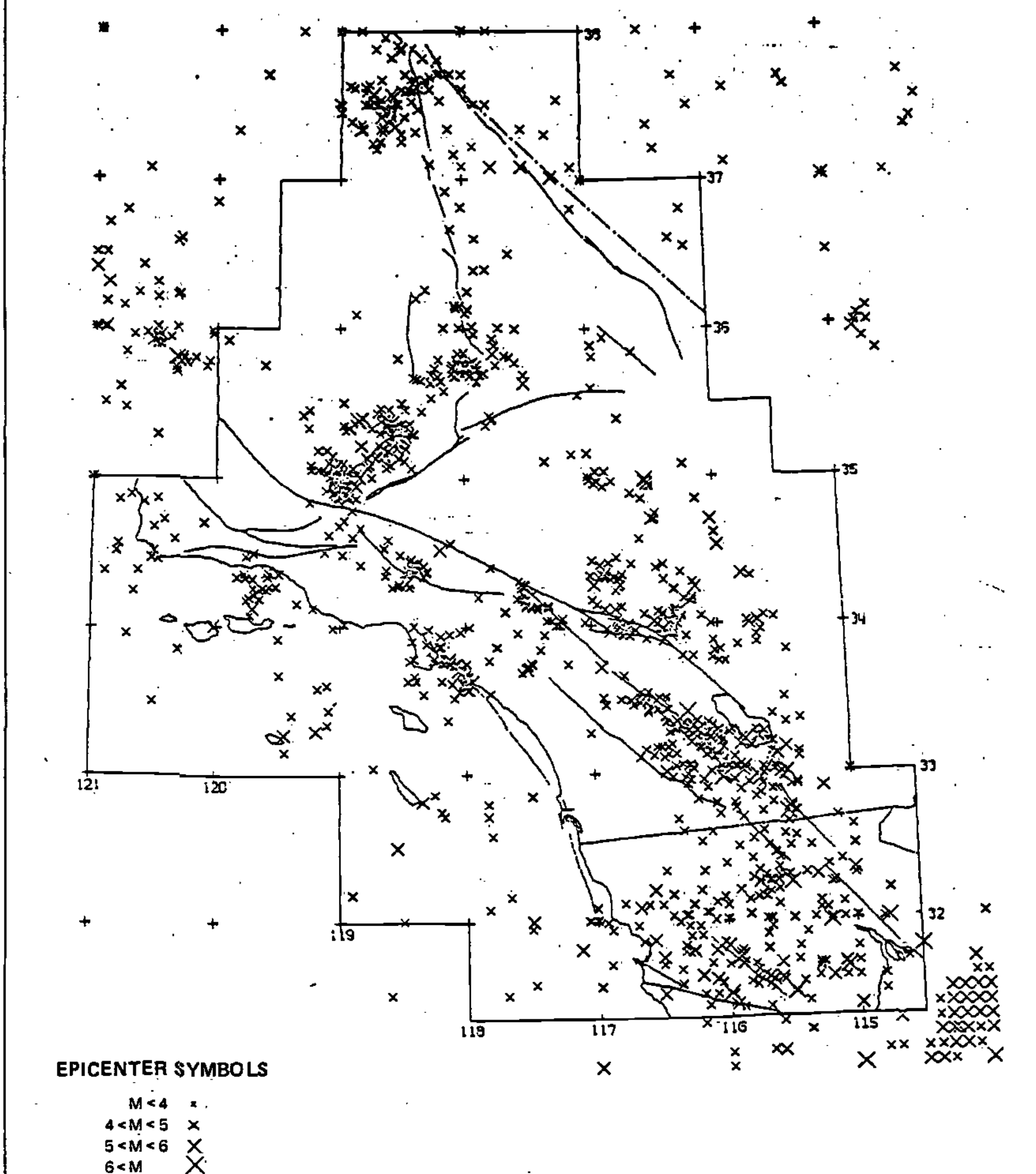
LIST OF PRE-INSTRUMENTAL EARTHQUAKES WITHIN 100 MILES OF METRO RAIL ROUTE FROM 1800 TO 1933

	Date		Latitude		Longitude		Estimated	Distance
Year	Mo	Day	Deg	Min	Deg	Min	Magnitude[1]	(Miles)
1800	0	1	34	30	119	30	5.6	72.4
1800	11	22	33	0	117	30	5.6	89.6
1806	5	24	34	30	119	30	5.6	72.4
1812	12	8	33	30	117	40	6.2	56.2
1812	12	21	34	0	120	0	7.3	95.8
1855	7	10	34	0	118	30	6.2	11.9
1857	1	9	35	0	119	0	7.3	73.1
1878	0	1	34	0	118	30	5.6	11.9
1889	8	27	34	0	118	0	5.0	20.1
1890	2	9	34	0	117	30	5.0	48.0
1893	4	4	34	30	118	30	6.2	29.3
1894	7	29	35	0	118	0	5.0	65.0
1899	7	22	34	30	117	30	6.2	54.9
1903	12	25	34	0	118	0	5.0	20.1
1907	9	19	34	0	117	0	5.6	76.4
1910	5	15	33	30	117	30	5.6	63.1
1912	12	14	34	0	119	0	5.0	39.0
1916	10	22	34	54	118	54	5.5	64.1
1918	4	21	33	45	117	0	6.8	79.9
1918	4	22	34	0	117	30	5.0	48.0
1918	11	19	34	0	118	30	5.0	11.9
1919	2	16	35	0	119	0	5.6	73.1
1920	6	21	34	0	118	30	6.2	11.9
1920	7	16	34	0	118	30	5.0	11.9
1923	7	22	34	0	117	15	6.2	62.2
1925	6	29	34	18	119	48	6.2	85.2
1926	2	18	34	0	119	30	5.0	67.3
1926	6	29	34	30	119	30	5.6	72.4
1927	8	4	34	0	118	30	5.0	11.9
1929	7	8	34	0	118	0	4.7	20.1
1930	1	15	34	12	116	54	5.2	82.1
1930	8	5	34	30	119	30	5.6	72.4
1930	8	30	33	0	118	0	5.6	78.3

Note:

1. Estimates of earthquake magnitude are based on empirical relationships between Modified Mercalli Intensity and Richter Magnitude.

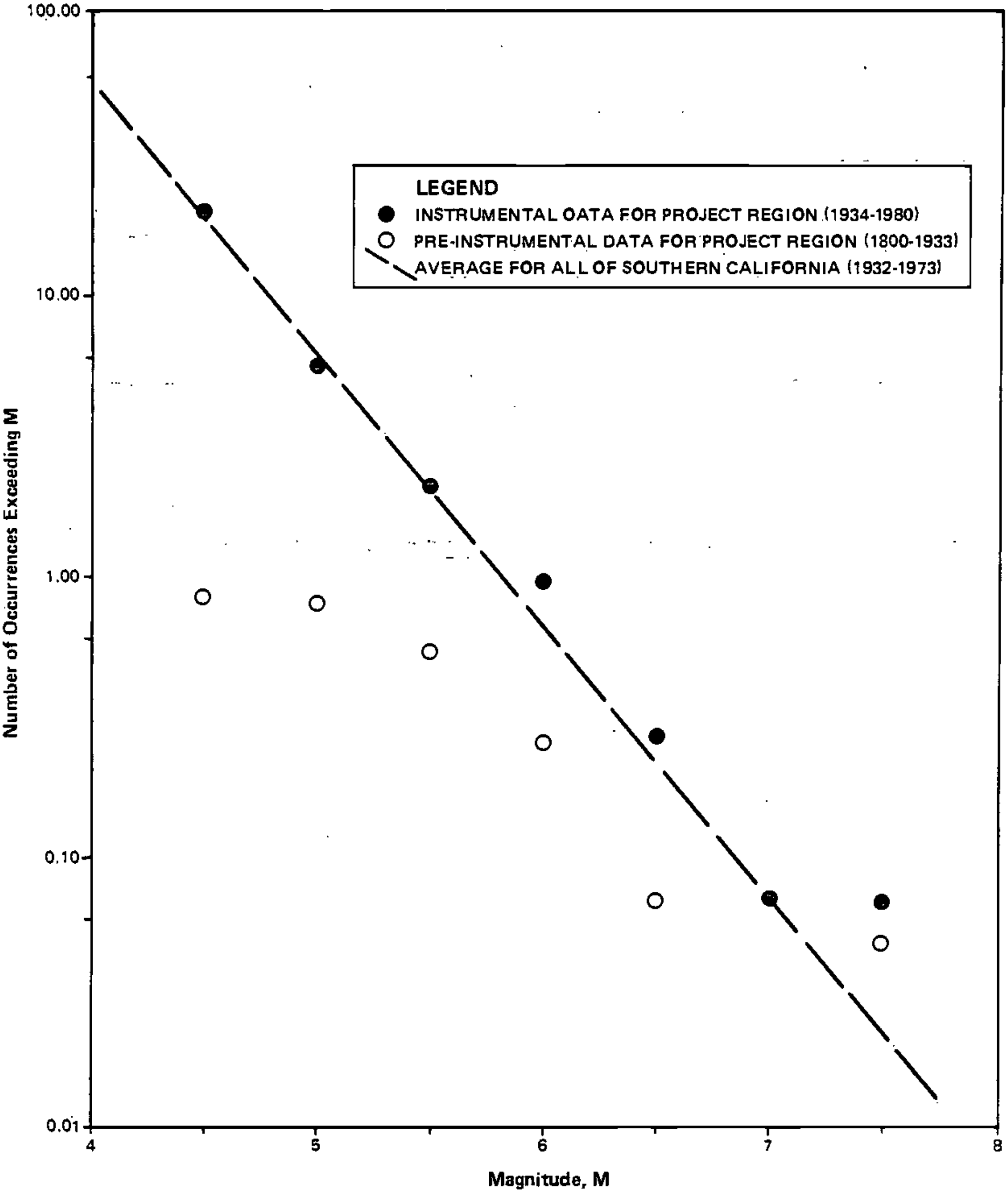
Source: Converse Consultants (1982, Table B1.2).



Source: Converse Consultants (1982, Figure 4-1)

Instrumental Epicenters Recorded from 1932 through 1972 for Earthquakes Equal to or Exceeding Magnitude 4

FIGURE 4



NOTE: Number of occurrences normalized to average 100 year period and average 1000 squere mile area.

SOURCE: Converse Consultants (1982, Figure 4-3)

Magnitude/Recurrence Relationship for the 100-mile Radius Around Metro Rail Project Region Based on Historic Seismic Record

FIGURE 5

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substantially lower than that calculated from the instrumental record, especially in the lower magnitude ranges. However, by recognizing the probable deficiencies in the pre-instrumental catalog, particularly the tendency for lower magnitude earthquakes to go unreported, this discrepancy can be at least qualitatively explained.

Regionally Significant Faults. For purposes of this report, a regionally significant fault is defined as one whose rupture might generate significant ground motions along the Metro Rail Project route. The regional faults considered important to the proposed project are shown on Figure 6. Other faults known to be present in the region but excluded from Figure 6 were either believed to be inactive or not considered capable of causing significant groundshaking in the project area (Converse Consultants, 1982).

Table 3 lists each of the faults shown on Figure 6, and gives their length and estimated long-term slip rates. The maximum credible earthquake each fault is considered capable of generating is also provided in Table 3.

As described previously, several faults are known to cross the proposed Metro Rail alignment. Geologic evidence indicates that only two of these features are of significant seismic concern: the potentially active Malibu-Santa Monica fault and the active Hollywood fault. Significant characteristics of these faults are provided in Table 3.

Seismic Groundshaking. Seismic groundshaking is generally addressed in terms of maximum probable and maximum credible ground motions. The maximum probable ground motion is that which is likely to occur during the design life of the proposed Metro Rail Project (considered to be 100 years). It is regarded as a probable occurrence, not as an assured event, that will occur within the specified time interval.

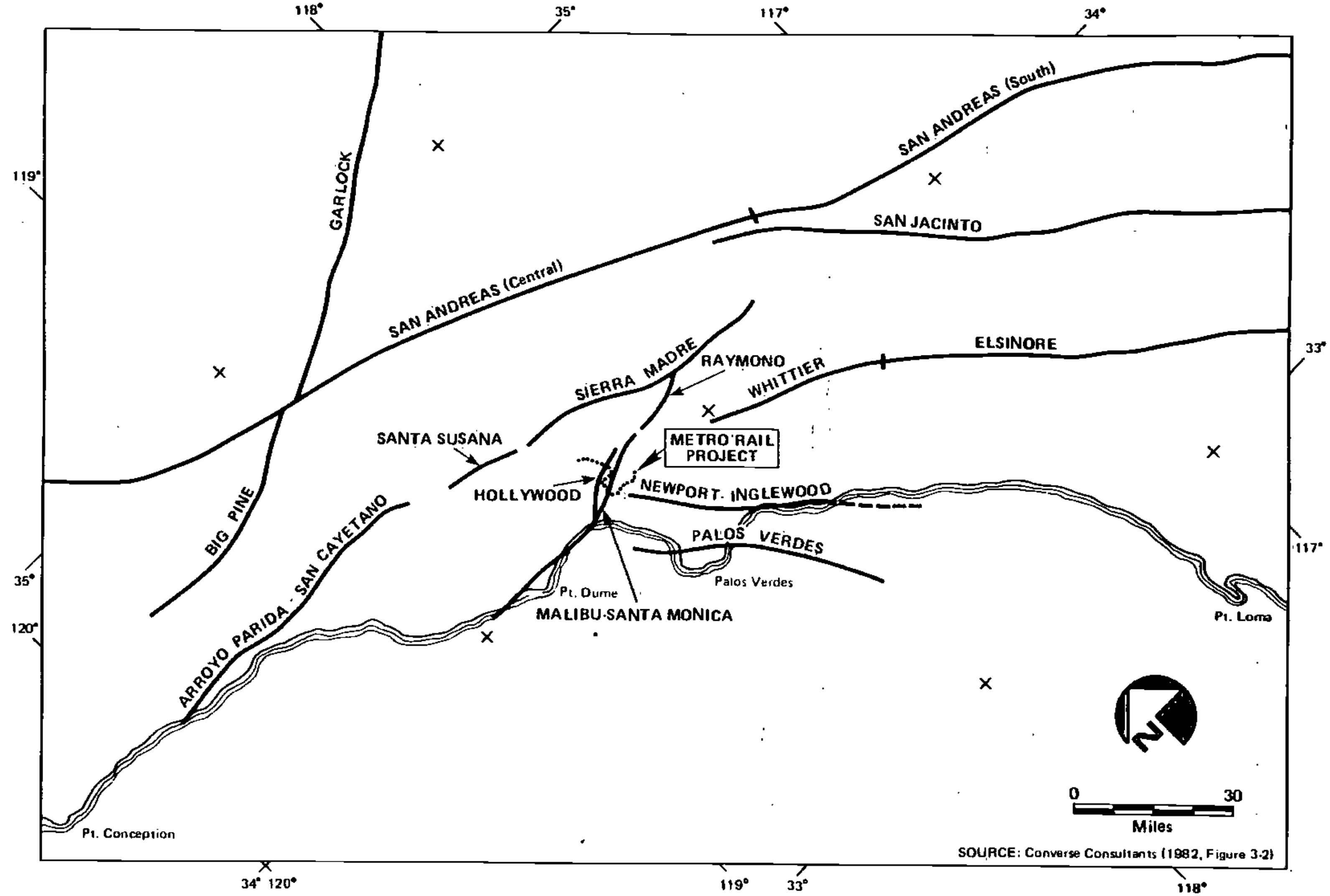
The maximum credible ground motion is defined as that resulting from the largest seismic event that can be reasonably postulated to occur in the project region based on known geologic and seismic evidence. The probability of occurrence is of less importance in the maximum credible event, which is more a measure of capability than probability. The maximum credible earthquake and resulting ground motions represent the reasonable upper limit event for the design of life-critical structures.

Seismic ground motions can be described in terms of several parameters which, in turn, can be used in the design of project elements to avoid earthquake damage. For purposes of this environmental impact analysis, seismic groundshaking is characterized by the following:

- Maximum peak horizontal ground acceleration,
- Maximum peak vertical ground acceleration, and
- Duration of strong ground shaking.

Additional quantitative descriptors of seismic ground motion for the proposed project, such as ground velocity and displacement and response spectra for design earthquakes, are provided in Sections 5.0 and 6.0 of Converse Consultants (1982).

Maximum Probable Ground Motions. Based on the expected maximum probable seismic activity on all significant faults in the Metro Rail Project region (see Figure 6) and appropriate distance-attenuation relationships, probable seismic ground motions in



Locations of Regionally Significant Faults Relative to Metro Rail Project

FIGURE 6

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Table 3

CHARACTERISTICS OF REGIONALLY SIGNIFICANT FAULTS

Fault	Length (mi)	Min. Distance to Metro Rail Project (mi)	Slip Rate (mm/yr)	Maximum Credible Earthquake (M)
Malibu-Santa Monica	39	0	0.2	7.0
Hollywood	7	0	0.1	6.5
Raymond	12	3.5	0.2	6.5
Newport-Inglewood	38	3.5	0.5	7.0
Sierra Madre	63	7.5	3	7.0
Whittier (northern Elsinore)	32	12	2	6.5
Santa Susana	14	12	1	6.5
Palos Verdes	45	14	0.3	7.0
San Andreas (central)	217	30	37	8.0
Arroyo Parida-San Cayetano	59	40	2	7.0
San Jacinto	130	38	17	7.5
Elsinore	83	31	2	7.5
San Andreas (south)	95	46	25	7.5
Garlock	156	60	7	7.5
Big Pine	43	57	2	7.0

Source: Converse Consultants (1982, Tables 3-1 and 6-1).

the project area can be estimated for various recurrence intervals. Using this approach, Converse Consultants (1982) conclude that the statistical 100-year probable maximum horizontal ground acceleration along the project route is 0.22 $\pm$0.01g (21 to 23 percent of gravity). Stated another way, a peak horizontal ground motion of about 0.22g is considered probable to affect the proposed project once during the next 100 years.

Groundshaking at the moderate level stated above may be caused by earthquakes occurring on any of several faults within approximately 30 miles of the project area. This includes 9 of the 15 regionally significant faults shown in Table 3. Nearby earthquakes would most likely occur on the Raymond, Newport-Inglewood, Sierra Madre or Whittier faults. The probable Richter magnitude of such shocks is expected to be in the range of M5.5 to M6.5. More distance earthquakes would most likely occur on the central segment of the San Andreas fault, with a probable magnitude of about 8.0. Because of the relatively recent high seismic activity on the San Andreas fault, the M8.0 earthquake is considered the more likely to occur during the next 100 years (Converse Consultants, 1982).

Maximum probable vertical ground accelerations may be conservatively assumed to be 75 percent of the maximum probable horizontal amplitudes for locations more than 5 miles from the causative fault (Converse Consultants. 1982). With the exception of the nearest points of the Raymond and Newport-Inglewood faults, the most significant active faults likely to generate the 100-year probable earthquake are more than 5 miles from the proposed Metro Rail system. Given a horizontal ground motion of approximately 0.22g. the maximum probable vertical ground acceleration is therefore 0.17g (75 percent of 0.22g).

The duration of strong ground motion, one of the most important factors in causing earthquake damage, generally increases with earthquake magnitude and decreases with distance from the fault rupture. Bracketed duration, a measure frequently used in the engineering community, is the time during which the ground acceleration equals or exceeds some threshold amplitude, such as 5 or 10 percent of gravity (0.05 or 0.10g). Converse Consultants (1982) estimate the bracketed duration of strong ground motion for 100-year peak accelerations exceeding 0.10g would be about 7 seconds at the project site for the M5.5 to M6.5 event on a nearby fault and 10 seconds for the M8.0 earthquake on the San Andreas fault. Bracketed durations for peak accelerations exceeding 0.05g would be on the order of 10 and 32 seconds for earthquakes on the nearby faults and San Andreas fault, respectively.

Table 4 summarizes earthquake and ground motion parameters for the nearby and distant 100-year probable earthquakes discussed above. The M8.0 earthquake on the San Andreas fault, because it is considered the more likely event in the next 100 years and has a much longer duration of strong groundshaking, should be the governing 100-year probable earthquake for Metro Rail system design (Converse Consultants, 1982).

Maximum Credible Ground Motions. Maximum credible earthquake magnitudes were conservatively estimated based on geologic and seismic evidence for each of the regional faults considered capable of affecting the Metro Rail system (see column 5 on Table 3). Maximum peak horizontal ground accelerations along the alignment were then calculated assuming the maximum credible earthquakes occurred on each fault at its closest approach to the proposed project. It was found that the maximum credible ground acceleration would be 70 percent of gravity (0.70g), and would result from an

Table 4

EARTHQUAKE AND GROUND MOTION PARAMETERS
FOR 100-YEAR PROBABLE SEISMIC EVENTS

Causative Fault(s)	Sierra Madre/ Whittier	San Andreas
Site Distance (mi)	11	30
Richter Magnitude	6.0	8.0
Peak Ground Acceleration (g)		
Horizontal	0.22	0.22
Vertical	0.17	0.17
Bracketed Duration of Strong Shaking (sec)		
Peak Acceleration > 0.05g	10	32
Peak Acceleration > 0.10g	7	15

Source: Converse Consultants (1982, Table 5-2).

M7.0 earthquake on the Malibu-Santa Monica fault where it crosses the project alignment. Other regionally significant faults, even if considered capable of generating a larger earthquake than an M7.0, resulted in maximum credible ground accelerations of less than 0.70g because of their greater distances from the project alignment.

Maximum credible vertical ground accelerations are assumed to be 50 percent higher than the horizontal values. This very conservative estimate is based on recent near-field seismic records from the 1979 M6.4 Imperial Valley earthquake. The 50 percent increase is considered reasonable for locations less than 5 miles from the potential fault rupture and results in a maximum credible vertical acceleration of 1.05g at the project site (Converse Consultants, 1982).

The bracketed duration of strong ground motion for a location close to a maximum credible earthquake of M7.0 is about 14 seconds for peak accelerations exceeding 0.10g and 26 seconds for accelerations exceeding 0.05g. Table 5 summarizes these data and other earthquake and ground motion parameters for the maximum credible earthquake.

Hydrology/Water Quality

Regional Setting. The Metro Rail Project area can be separated into two hydrologic basins. The CBD, Wilshire Corridor and Hollywood segments are within the Coastal Plain Area and the North Hollywood segment is within the San Fernando Valley Area as defined by the Regional Water Quality Control Board (RWQCB).

Due to the high level of urbanization in the project area, the majority of the surface hydrology is a function of rainfall and surface runoff into storm drain channels. Most surface streams and rivers have been channelized to provide effective stormwater runoff and no natural stream beds exist in the project area except in the Santa Monica Mountains.

Groundwater conditions vary between the two basins. In the CBD, the groundwater is of poor quality and fairly shallow as would be expected in basins near the ocean. In the San Fernando Valley, the groundwater is deeper in and of higher quality, and is used by LADWP for a significant portion of their water. Water from the Central Valley Project and the Owens Valley is spread and allowed to percolate into the groundwater reservoir for storage in the area.

Specific water quality objectives for groundwater and surface water for the project area are shown in Table 6. The following additional water quality objectives for inland surface waters and groundwaters have been established by the Los Angeles RWQCB. Objectives are excerpted in relation to the project location and the beneficial use criteria for the Los Angeles River deposition area.

- General Objective

  The following objective shall apply to all waters of the basin.

  Nondegradation. Wherever the existing quality of water is better than the quality of water established herein as objectives, such existing quality shall be maintained

Table 5

EARTHQUAKE AND GROUND MOTION PARAMETERS
FOR MAXIMUM CREDIBLE SEISMIC EVENT

Causative Fault	Malibu-Santa Monica	
Site Distance (mi)[1]	1	4
Richter Magnitude	7.0	7.0
Peak Ground Acceleration (g)		
Horizontal	0.70	0.57
Vertical	1.05	0.86
Bracketed Duration of Strong Shaking (sec)		
Peak Acceleration > 0.05g	26	26
Peak Acceleration > 0.10g	14	14

Note:

1. Distances along the Metro Rail alignment 1 and 4 miles from the causative fault rupture are believed representative for defining a practical and conservative range of groundshaking parameters.

Source: Converse Consultants (1982, Table 5-2).

Table 6

WATER QUALITY OBJECTIVES FOR
GROUNDWATER AND SURFACE WATERS

Groundwater	Objectives (mg/l)			
	Total Dissolved Solids	Sulfide	Chloride	Boron
Coastal Plan Subunit				
Hollywood Basin	750	100	100	1.0
Central Basin	700	250	250	1.0
San Fernando Subunit				
Sylmar Basin	600	150	100	0.5
Eagle Rock Basin	800	150	100	0.5
Verdugo Basin	600	150	100	0.5
San Fernando Basin (narrows)	900	300	150	1.5
North Hollywood/Burbank	200	250	100	1.5
Surface Waters				
L.A. River above Figueroa	950	300	150	*
L.A. River below Figueroa	1,580	350	150	*

*No agricultural use in this area, thus no objective established for bottom.

Source: Los Angeles RWQCB (1978).

unless otherwise provided by the provisions of the State Water Resources Control Board Resolution No. 68-16, "Statement of Policy with Respect to Maintaining High Quality of Waters in California," including any revisions thereto.

- Objectives for Inland Surface Waters and Enclosed Bays and Estuaries

  The following objectives apply to all inland surface waters and enclosed bays and estuaries of the basin: San Gabriel River Tidal Prism, Alamitos Bay and Los Cerritos Channel Tidal Prism, Los Angeles River Tidal Prism, Los Angeles-Long Beach Inner Harbor, Los Angeles-Long Beach Outer Harbor, Ballona Creek Tidal Prism, Marina del Rey and Venice Canals, King Harbor-Redondo Beach, and Malibu Creek Tidal Prism. Existing beneficial uses of the Los Angeles River to its tidal prism include areas for groundwater recharge (GWR), proposed water contact recreation (REC 1); existing non-water contact recreation (REC 2) and has limited use as wildlife habitat.

Color. No coloration that causes nuisance or adversely affects beneficial uses.

Tastes and odors. No taste or odor-producing substances in concentrations that impart undesirable tastes or odors to fish flesh or other edible products of aquatic origin, cause nuisance, or adversely affect beneficial uses.

Floating Material. No floating material, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect beneficial uses.

Suspended Material. No suspended material in concentrations that cause nuisance or adversely affect beneficial uses.

Settleable Material. No substances in concentrations that result in the deposition of material that cause nuisance or adversely affect beneficial uses.

Oil and Grease. No oils, greases, waxes or other materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect beneficial uses.

Substances. No biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.

The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

numerical receiving water objectives for specific toxicants will be established as sufficient data become available, and source control of toxic substances will be encouraged.

- Objectives for Groundwaters

The following objective applies to all groundwaters of the basin:

Tastes and Odors. Groundwaters shall not contain taste or odor-producing substances in concentrations that cause nuisance or adversely affect beneficial uses.

Surface waters in the Metro Rail Project area are generated primarily from storm runoff and is generally of poor quality. Due to the irregular nature of rainfall, contaminants on the ground are washed into the receiving system in one pulse, usually within the first hour of rainfall (Pitt and Bozeman, 1980; Pitt and Amy, 1973). As a result, there is a reduction in the oxygen level at the point of discharge and for a distance downstream. Toxic elements, if present, could create toxic or sublethal conditions for sensitive organisms. In addition, sediments transported in runoff would deposit in receiving water bodies. If the rainfall and runoff continues, the contaminants are moved downstream and diluted to lower levels, thus naturally mitigating the impact (Pitt and Bozeman, 1980).

Sources of urban runoff contaminants which are of concern with regard to project-related impacts include:

- Motor vehicles, with sources of potential contaminants such as:
  a. Fuels, oils, lubricants, hydraulic fluids, and coolants.
  b. Fine particles from tires, clutches, and brake linings.
  c. Particulates from exhaust emissions.
  d. Dirt, rust, and decomposing coatings from fenders and undercarriage.
- Paving materials, including asphalt and Portland cement.
- Atmospheric fallout and construction activities which generate:
  a. Motor vehicle exhaust emission particles.
  b. Products such as dust and silt.
- Litter, including trash, food, and animal wastes.

Several studies have been conducted on urban source contaminants in the Los Angeles River, and a large number of petroleum source products have been identified (Eganhouse and Kaplan, 1981; Eganhouse, Simoneit and Kaplan, 1981). Most of the organic compounds were of anthropogenic origin, although naturally occurring compounds were also isolated.

Local Setting. The following paragraphs summarize specific surface water and groundwater conditions within each of the four Metro Rail Project line segments.

Los Angeles CBD Segment. This segment is located in the lowest portions of the projected rail system. The geotechnical studies by Converse et al. (1981) documented shallow groundwater conditions, as would be expected, adjacent to the Los Angeles River Channel. Groundwater is commonly encountered in coarse-grained Young Alluvium at a depth of 20-35 feet. Groundwater quality is low, according to existing EPA standards, with a high total dissolved solids content and hardness. At the present time there are no significant commercial or domestic uses of the groundwater.

Surface waters in the CBD are limited to surface runoff from storms and commercial/domestic use. In this segment, the majority of the surface flow is directed toward the Los Angeles River flood control channel via storm drains and surface drain channels.

It has been estimated that 30 percent of the total surface flow in the Los Angeles River occurs during dry conditions, and the other 70 percent during infrequent fainfall periods (Eganhouse and Kaplan, 1981). Flow is regulated and controlled by a series of reservoirs, and flooding in the CBD is uncommon. The general deposition of rainfall in the basin is highest in the east and south-central areas and lowest in the mountain areas (Eganhouse and Kaplan, 1981). The high coverage of city surfaces by impermeable surfaces and the resultant low infiltration can lead to high runoff volumes, which can be accommodated by the major flood channels.

Wilshire Corridor Segment. From the CBD to the Harbor Freeway groundwater is located below 100 feet in claystone Fernando formation. Water quality is typically poor for this aquifer and no current use is made of the water.

The area is heavily urbanized and no natural surface waters are present. Subsurface storm drain systems collect surface runoff and direct it toward the Los Angeles River. No flood hazard areas are present in this segment.

In the corridor from the Harbor Freeway to Normandie Avenue, the permanent water table is below 100 feet. However, there is a perched water table in Old Alluvium at depths of 15-25 feet. Historically, there have been artesian springs and surface seeps in this area, especially between Normandie and Western. The lake in MacArthur Park may support a shallow groundwater table in that area.

The only surface water in this subsegment is located at the MacArthur Park Lake. Storm runoff is collected in subsurface drains and transported to the Los Angeles River flood control channel. No significant flood hazard areas are found in this subsegment.

In the subsegment between Normandie and Fairfax the permanent groundwater table is in excess of 150 feet. Perched groundwater is present at 15-30 feet in Old Alluvium. Much of the perched water is in fine and/or silty sands and percolation rates are low.

Significant tar sand deposits are found in the La Brea area. Permanent groundwater is greater than 100 feet and below the tar sand deposits. A perched water table at 10-25 feet is found in alluvial deposit interbeds. No surface waters exist in this area.

Hollywood Segment. In the subsegment from Fairfax to Santa Monica groundwater is found at depths in excess of 70 feet in Old and Young Alluvium. Percolation in the silty sands and clays is low. Surface waters in this subsegment are limited to stormflow; however, this can be extensive. Flooding of streets in the area around Laurel Canyon, Hollywood Boulevard and Fairfax has occurred frequently. At the present time, the City of Los Angeles in conjunction with the Los Angeles Flood Control District is designing a flood control system to collect stormflow in Laurel Canyon and from Hollywood Boulevard. This collector will proceed south along Fairfax, cross Fairfax High School grounds and end in a central basin at the Pan Pacific Park. This channel should reduce the flood potential in this area. (M. Dubrowski, Los Angeles City Central Engineering, personal communication, 1982).

The groundwater resources in the Hollywood area are similar to those found in the Fairfax subsegment. Permanent groundwater is found at variable depth, but generally below 100 feet in thick alluvial deposits. All surfaces are heavily urbanized, reducing effective infiltration to groundwater table. No gassy formations are found in this area and groundwater quality is similar to that in the rest of the basin.

Surface waters are the result of runoff from storms, and in general are rapidly removed from streets via surface and subsurface storm drain systems. Those streets at the mouth of the canyons can flood during peak rainfall periods but rapidly clear into storm drains. The system designed to deal with the Laurel Canyon area will also provide some flood protection to the Hollwood area.

Groundwater resources in the Santa Monica Mountain subsegment is erratic. The Topanga formation is generally non-waterbearing except in joints and fractures. Occasional perched water tables are found in overlying alluvium. Surface water is limited to non-infiltrated storm water. The Santa Monica Mountains in this region have a limited number of ephemeral creeks and the high degree of housing development has altered drainages into street flow. Flooding can occur in canyon areas but in general it is limited in duration. Surface flow is directed into surface and subsurface drains.

North Hollywood Segment. There is a significant groundwater resource in the Upper Los Angeles River Area (ULARA). The ULARA encompasses all the watershed of the Los Angeles River and its tributaries above a point in the river designated as Los Angeles County Flood Control District (LACFCD) Gaging Station F-57 C-R, near the junction of the Los Angeles River and the Arroyo Seco. ULARA encompasses 328,500 acres composed of 122,800 acres of valley fill referred to as the groundwater basins, and 205,700 acres of hills and mountains. ULARA is bounded on the north and northwest by the Santa Susana Mountains; on the north and northeast by the San Gabriel Mountains; on the east by the San Rafael Hills, which separate it from the San Gabriel Basin; on the south by the Santa Monica Mountains, which separate it from the Los Angeles Basin; and on the west by the Simi Hills.

ULARA has four distinct groundwater basins. The water supplies of these basins are separate and are replenished by deep percolation from rainfall and from a portion of the water that is delivered for use within these basins. The four groundwater basins in ULARA are the San Fernando, Sylmar, Verdugo, and Eagle Rock Basins (LADWP, 1981).

- The San Fernando Basin, the largest of the four basins, consists of 112,000 acres and comprises 91.2 percent of the total valley fill. It is bounded on the west and northeast by the San Rafael Hills, Verdugo Mountains, and San Gabriel Mountains;

on the north by the San Gabriel Mountains and the eroded south limb of the Little Tujunga syncline, which separates it from the Sylmar Basin; on the northwest and west by the Santa Susana Mountains and Simi Hills; and on the south by the Santa Monica Mountains (LADWP, 1981).

- The Sylmar Basin, in the northerly part of ULARA, consists of 5600 acres and comprises 4.6 percent of the total valley fill. It is bounded on the north and east by the San Gabriel Mountains; on the west by a topographic divide in the valley fill between the Mission Hills and the San Gabriel Mountains; on the southwest by the Million Hills; on the east by the Upper Lopez Canyon Saugus formation along the east bank of the Pacoima Wash; and on the south by the eroded south limb of the Little Tujunga Syncline, which separates it from the San Fernando Basin (LADWP, 1981).

- The Verdugo Basin, north and east of the Verdugo Mountains in ULARA, consists of 4400 acres and comprises 3.6 percent of the total valley fill. It is bounded on the north by the San Gabriel Mountains; on the east by a groundwater divide separating it from the Monk Hill Subarea of the Raymond Basin; on the southeast by the San Rafael Hills; and on the south and southwest by the Verdugo Mountains (LADWP, 1981).

- The Eagle Rock Basin, the smallest of the four basins, is in the extreme southeast corner of ULARA. It comprises 800 acres and consists of 0.6 percent of the total valley fill (LADQP, 1981).

Groundwater in ULARA is moderately hard to very hard. The character of groundwater from the major water-bearing formations is of two general types, each reflecting the composition of the surface runoff in the area. In the western part of ULARA, it is calcium sulfate-bicarbonate in character, while in the eastern part, including Sylmar and Verdugo Basins, it is calcium bicarbonate. Total Dissolved Solids (TDS) decreased in the western part of the San Fernando Basin by 2 percent over 1978-79; increased by less than 1 percent in the eastern part; increased by 33 percent in the Sylmar Basin; and no comparison data was available for the Verdugo Basin. Precipitation and water quality data from LADWP (1981) is presented in Tables 7 and 8.

Groundwater is generally within the recommended limits of the United States Public Health Service Drinking Water Standards, except perhaps for wells in the western end of the San Fernando Basin having excess concentrations of sulfate, and those in the lower part of the Verdugo Basin having abnormally high concentrations of nitrate (LADWP, 1981). Groundwater contour maps for the fall and spring of 1980 are presented in Figures 7 and 8. Existing well locations are shown in Figure 9. Changes in the groundwater elevations from the fall of 1979 to the fall of 1980 are shown in Figure 10.

Surface waters in the northern region originate as storm runoff from the hills and mountains, storm runoff from the impervious areas of the valley, operational spills of imported water, industrial and sanitary waste discharges, and rising water. The drainage system is made up of the Los Angeles River and its tributaries. The Los Angeles County Flood Control District (LACFCD) and the United States Geological Survey (USGS) maintain a number of stream-gaging stations throughout the area. Surface runoff data is shown in Table 9.

Table 7

PRECIPITATION[a/]
(Inches)

Station		100-Year Mean	1978-79 Precipitation	1979-80	
LACFCD Number	Name			Precipitation	Percent of 100-Year Mean
11D	Upper Franklin Canyon Reservoir	18.50	23.44	36.92	200
13C	Hollywood-Blix[b/]	16.63	20.79	32.95	198
14C	Roscoe-Merrill[b/]	14.98	20.73	27.95	187
15A	Van Nuys[b/]	15.30	21.85	32.45	212
17	Sepulveda Canyon-Mulholland Highway	19.82	27.06	41.04	207
21B	Woodland Hills[b/]	14.60	22.51	30.53	209
23B-E	Chatsworth Reservoir[b/]	15.19	18.93	27.77	183
25C	Northridge-LADWP[b/]	15.16	21.81	24.83	164
29D	Granada Hills	17.33	c/		
30B	Sylmar[b/]	17.91	21.40	c/	
33A-E	Pacoima Dam	19.64	23.32	29.55	150
47D	Clear Creek-City School	33.01	31.43	49.37	150
53D	Colby's Ranch	29.04	29.70	44.10	152
54C	Loomis Ranch-Alder Creek	18.62	20.29	28.87	155
210B	Brand Park	18.13	23.60	34.00	188
251C	LaCrescenta[b/]	23.31	26.17	38.61	166
259D	Chatsworth-Twin Lakes	18.70	22.52	30.51	163
293B-E	Los Angeles Reservoir[b/]	17.32	21.12	27.08	156
1074E	Little Gleason	24.34	30.77	c/	
1190	Pacoima Canyon-North Park Ranger Station	23.06	26.98	38.00	165

Weighted average for valley stations - 30.25 inches (1979-80)
Weighted average for mountain stations - 35.76 inches (1979-80)

a/ Data furnished by Los Angeles County Flood Control District (LACFCD)
b/ Valley Station
c/ Discontinued. Station 30B replaced by 293B-E and Station 1074E replaced by 1190.

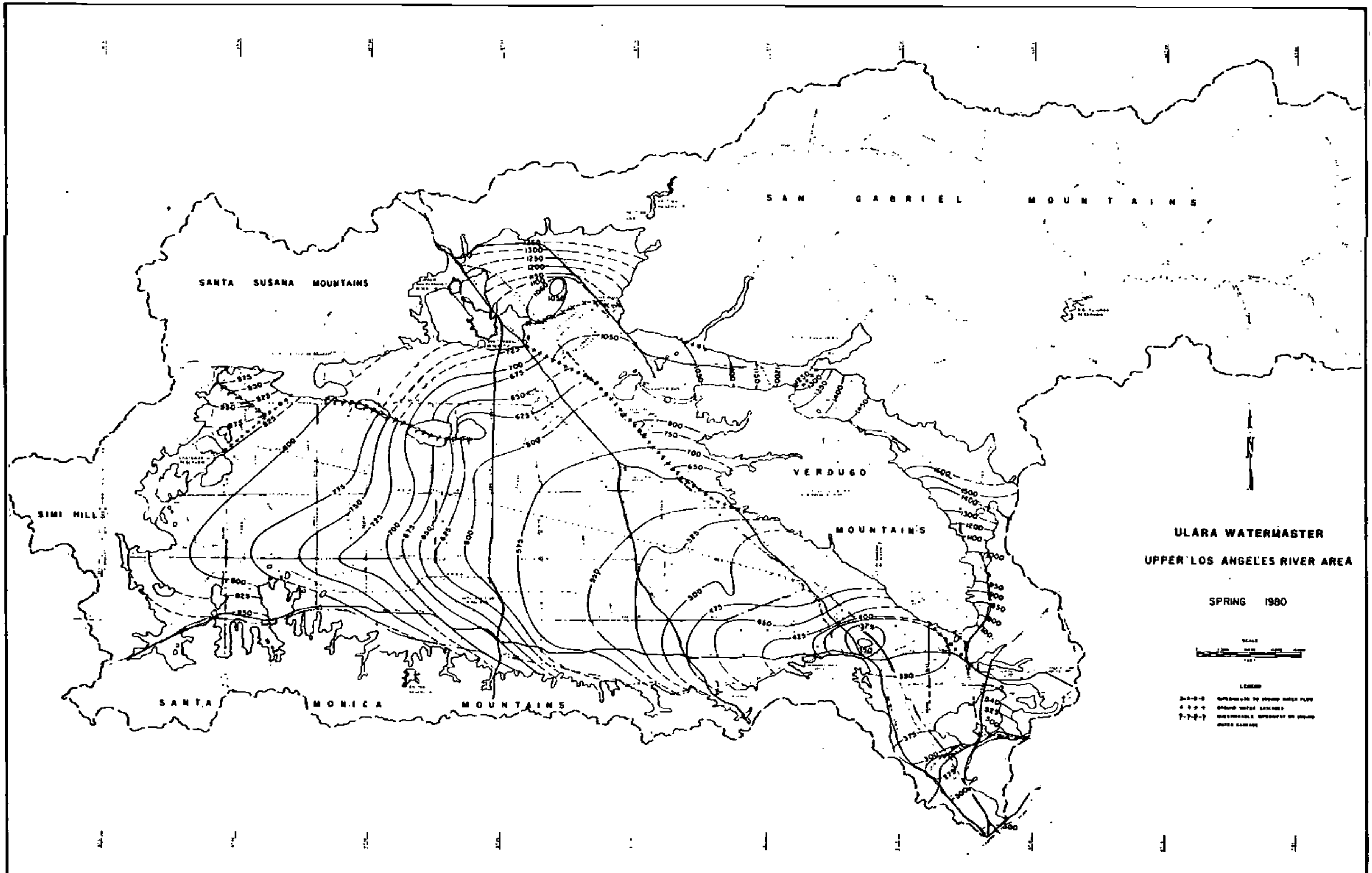
LADWP 1981

Table 8

REPRESENTATIVE MINERAL ANALYSES OF WATER

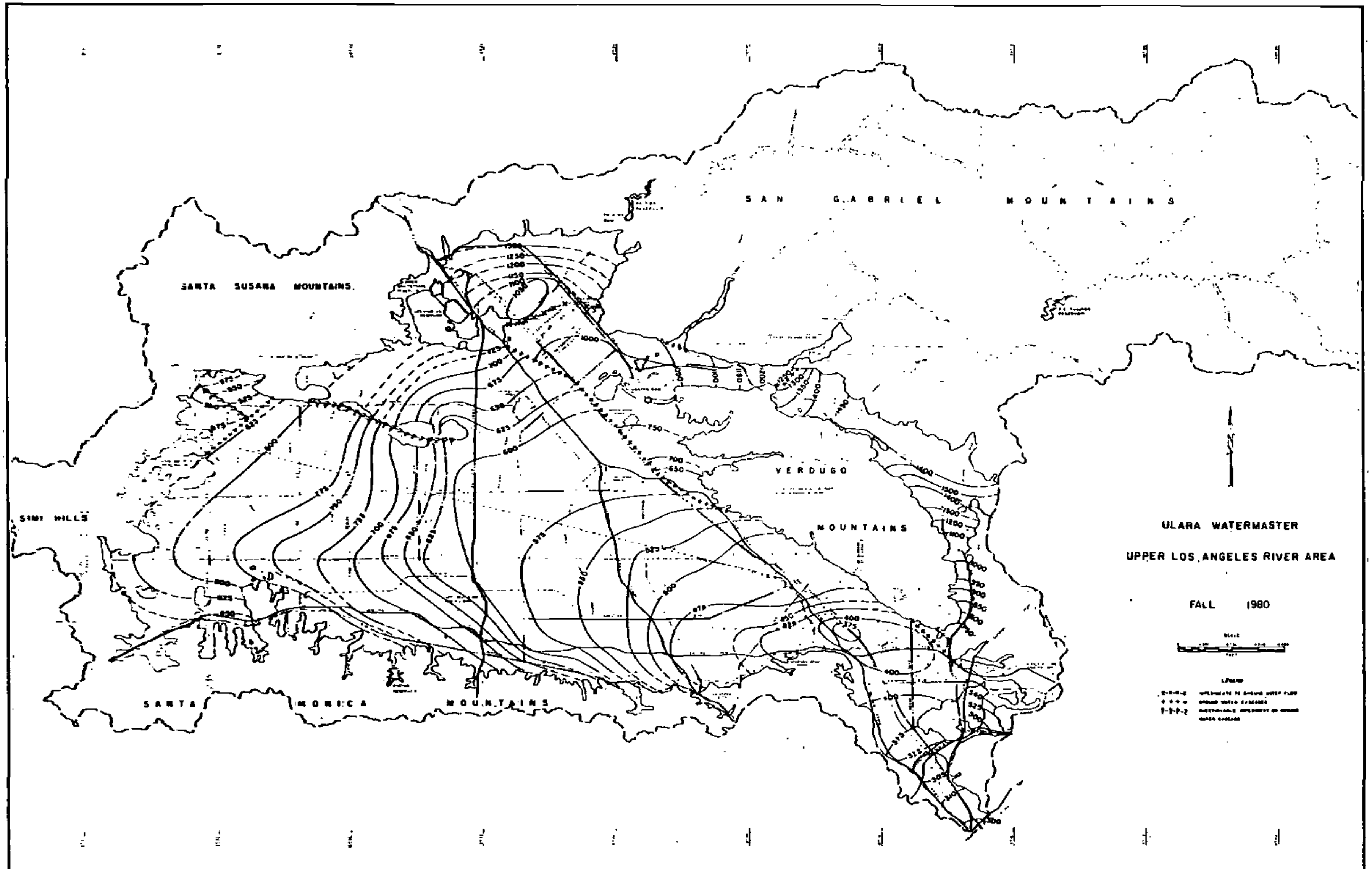
Well Number or Source	Date Sampled	ECx10^6 at 25°C	PH	Mineral Constituents in Milligrams per liter (mg/l) / Milliequivalents per liter (me/l)											TDS Total Dissolved Solids mg/l	Total Hardness as $CaCO_3$ mg/l
				Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B		
Imported Waters																
Blended State Project and Colorado River water at Eagle Rock Reservoir	79-80	850	8.01	55 / 2.74	22 / 1.81	86 / 3.74	3.7 / 0.09	0 / 0	102 / 1.67	193 / 4.02	81 / 2.29	2.4 / 0.04	0.28 / 0.01	0.21 / 0.06	515	227
Owens River water at Upper Van Norman Reservoir Inlet	79-80	283	7.89	22 / 1.10	4.0 / 0.33	29 / 1.26	3.2 / 0.08	0 / 0	97 / 1.59	23 / 0.48	13 / 0.37	1.3 / 0.02	0.52 / 0.03	0.40 / 0.11	177	72
State Project Water at Joseph Jensen Filtration Plant (Influent)	79-80	611	7.70	50 / 2.50	18 / 1.50	48 / 2.09	3.1 / 0.08	0 / 0	108 / 1.77	124 / 2.58	44 / 1.24	0.58 / 0.01	0.39 / 0.02	0.38 / 0.11	378	197
Surface Water																
Los Angeles River at Sepulveda Blvd.	11/21/79	1,400	8.36	132 / 6.59	46 / 3.78	104 / 4.52	6.0 / 0.15	0 / 0	238 / 3.90	340 / 7.08	102 / 2.88	3.0 / 0.05			868	520
	4/9/80	1,740	8.21	192 / 9.58	73 / 6.00	125 / 5.44	7.3 / 0.19	0 / 0	210 / 3.44	665 / 13.85	102 / 2.88	3.5 / 0.06			1,079	780
Los Angeles River at Burbank-Western Wash	11/21/79	1,350	7.35	60 / 3.00	26 / 2.14	148 / 6.43	12 / 0.31	0 / 0	114 / 1.87	240 / 5.00	151 / 4.26	5.5 / 0.10			837	256
	4/9/80	1,080	7.53	51 / 2.54	25 / 2.06	128 / 5.57	14 / 0.36	0 / 0	135 / 2.21	208 / 4.33	112 / 3.16	6.0 / 0.10			670	232
Los Angeles River at Colorado Blvd.	11/21/79	900	7.88	88 / 4.39	30 / 2.47	58 / 2.52	6.0 / 0.15	0 / 0	200 / 3.28	175 / 3.65	54 / 1.52	2.0 / 0.03			558	344
	4/9/80	950	8.28	95 / 4.74	31 / 2.55	86 / 3.74	6.4 / 0.16	0 / 0	192 / 3.15	244 / 5.08	74 / 2.09	5.1 / 0.08			589	362
Burbank Reclamation Plant Discharge to Burbank-Western Wash	8/6/80	950	7.08	- / -	- / -	112 / 4.87	- / -	0 / 0	- / -	- / -	94 / 2.65	1.03 / 0.02	0.80 / 0.04	- / -	573	-
L. A.-Glendale Reclamation Plant Discharge to L. A. River	9/80	642	6.80	49 / 2.45	17 / 1.42	133 / 5.78	13 / 0.33	0 / 0	181 / 2.97	163 / 3.40	122 / 3.44	4.9 / 0.08	1.1 / 0.06	0.9 / 0.25	642	-
Groundwaters																
(San Fernando Basin - Western Portion)																
4757C (Reseda No. 6)	11/27/79	953	7.20	120 / 6.00	29 / 2.39	45 / 1.96	2.0 / 0.05	- / -	250 / 4.10	208 / 4.33	29 / 0.82	7.4 / 0.12	0.36 / 0.02	0.32 / 0.09	591	420
(San Fernando Basin - Eastern Portion)																
3830D (No. Hollywood No. 19)	7/25/80	618	7.41	74 / 3.69	20 / 1.65	28 / 1.22	3.2 / 0.08	- / -	188 / 3.08	89 / 1.85	18 / 0.51	3.9 / 0.06	0.50 / 0.03	0.19 / 0.05	383	264
3841C (Burbank No. 6A)	11/29/79	-	8.00	52 / 2.61	8.8 / 0.72	33 / 1.44	3.5 / 0.09	0 / 0	207 / 3.39	45 / 0.94	18 / 0.50	- / -	0.50 / 0.03	- / -	292	173
3913H (Grandview No. 16)	4/27/78	580	8.10	52 / 2.61	10.8 / 0.89	55 / 2.39	3.6 / 0.09	0 / 0	188 / 3.08	43 / 0.90	66 / 1.86	- / -	0.50 / 0.03	- / -	376	175
(San Fernando Basin - L. A. Narrows)																
3958H (Pollock No. 6)	10/17/79	1,180	7.00	114 / 5.69	39 / 3.21	88 / 3.83	2.8 / 0.07	- / -	265 / 4.34	205 / 4.27	94 / 2.65	3.9 / 0.06	0.26 / 0.01	0.38 / 0.11	713	445
(Sylmar Basin)																
4840J (Mission No. 5)	7/10/79	768	7.60	90 / 4.49	18 / 1.48	41 / 1.78	5.1 / 0.13	- / -	205 / 3.36	118 / 2.46	43 / 0.70	4.2 / 0.07	0.27 / 0.01	0.28 / 0.08	476	296
5959 San Fernando No. 3	1/10/79	550	7.50	65 / 3.25	20 / 1.64	28 / 1.22	2.3 / 0.06	0 / 0	232 / 3.80	68 / 1.42	25 / 0.70	- / -	0.5 / 0.03	0.19 / 0.05	364	245
(Verdugo Basin)																
3971 (Glorietta No. 3)	7/14/78	820	6.40	98 / 4.42	31.5 / 2.59	32 / 1.39	2.6 / 0.07	0 / 0	194 / 3.18	96 / 2.00	70 / 1.97	- / -	0.2 / 0.01	- / -	514	351

LADWP 1981



Ground Water Contours - Spring 1980

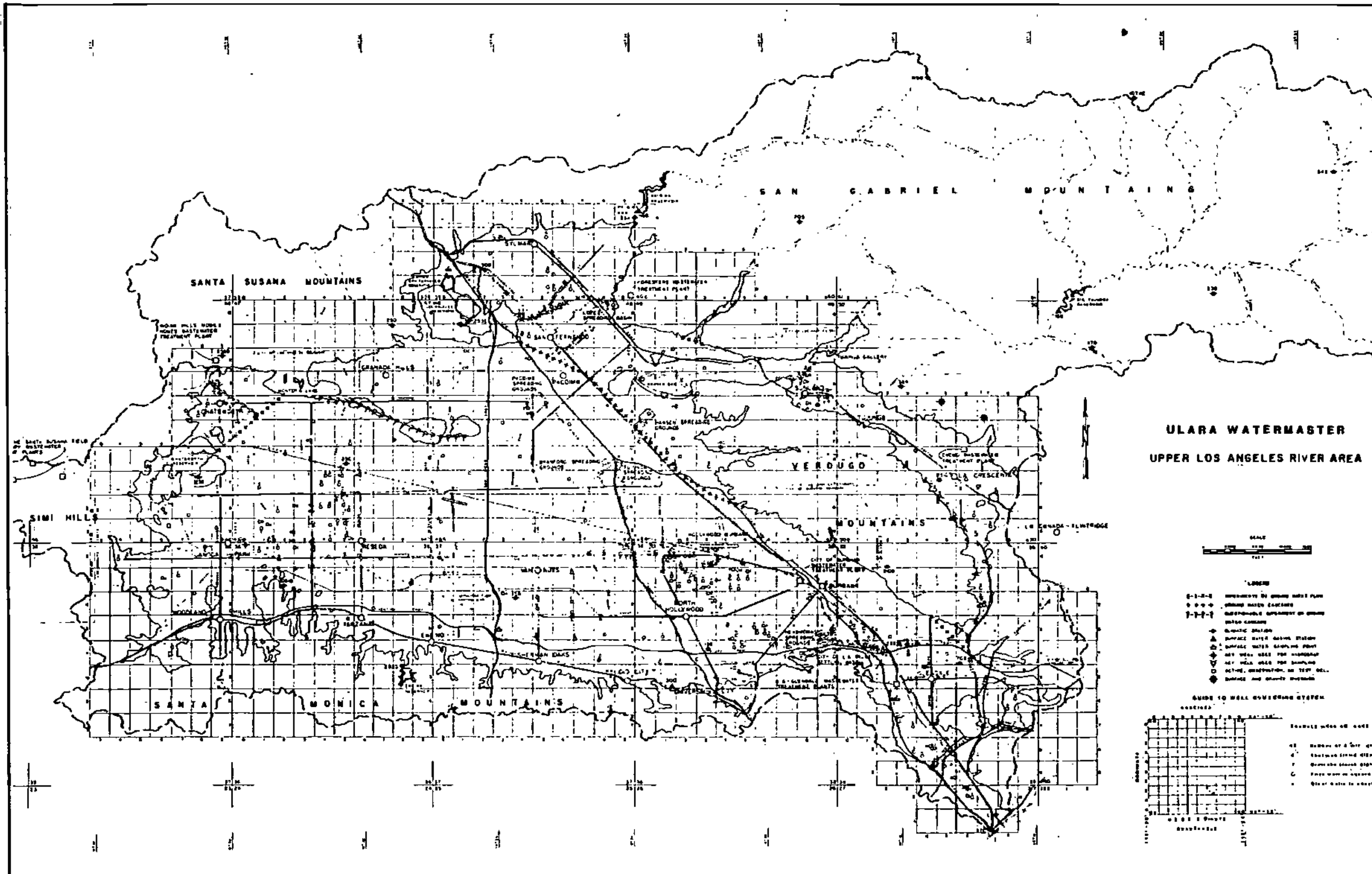
FIGURE 7



Ground Water Contours - Fall 1980

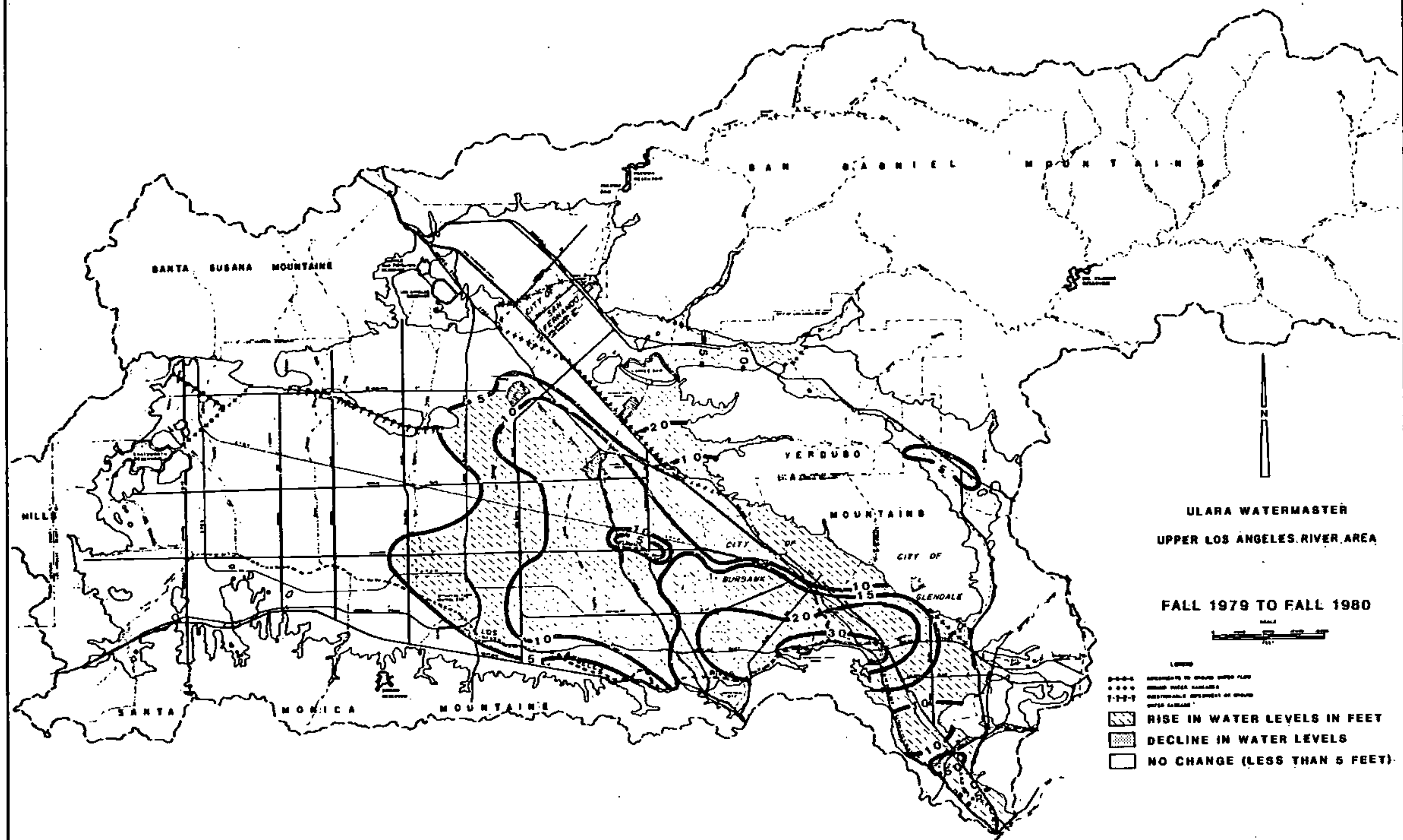
FIGURE 8

WESTEC Services, Inc.



Location of Wells and Hydrologic Stations

FIGURE 9



Line of Equal Change in Ground Water Elevation

FIGURE 10

WESTEC Services, Inc.

Table 9

MONTHLY RUNOFF AT SELECTED GAGING STATIONS
(in acre-feet)

Station	Water Year	Month												Total
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
F-57C-R	1978-79	3170	9270	6660	48460	16680	31430	4310	6290	3390	3260	3030	3150	139,100
Los Angeles River	1979-80	6490	4760	5500	45480	176400	incl.	incl.	4160	1510	1950	2710	1910	incl.
F-252-R	1978-79	12	19	1220	incl.	incl.	997	228	incl.	incl.	incl.	455	468	incl.
Verdugo Channel	1979-80	677	528	579	2760	3860	1030	574	507	594	616	355	822	12,902
E285-R	1978-79	589	878	1060	2310	1130	2060	556	845	565	603	921	868	12,385
Burbank Storm Drain	1979-80	977	875	850	3420	9090	3380	990	665	754	422	439	624	22,486
F-300-R	1978-79	1760	9160	5300	36880	11470	21540	3080	1970	1900	2180	1680	1390	98,310
L.A. River Tujunga Ave.	1979-80	3350	3100	2680	29400	115700	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
F-168-R	1978-79	849	748	1320	4170	4580	6640	5630	3160	1410	838	340	294	29,979
Big Tujunga Dam	1979-80	555	784	194	2709	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
118B-R	1978-79	242	232	478	418	320	3874	3334	2031	+	+	+	1091	12,020
Pacoima Dam	1979-80	6	+	+	893	13015	6120	1733	3405	722	3	+	+	25,897

LADWP 1981

The natural surface runoff contains some chemical salts dissolved from rocks in the drainage tributary area. These waters tend to be high in sodium and calcium bicarbonates and sulfates. In 1979-80, low flows which are generally considered natural surface flows in the Los Angeles River above the Los Angeles Narrows, had an average TDS of 670 mg/l and a total hardness of 230 mg/l. The quality of other sources of surface waters, including imported water overflows, waste discharges, and storm runoff from impermeable surfaces, is dependent upon initial source quality and, in the case of urban runoff, the amount of contamination accumulated during passage across the impermeable surfaces (LADWP, 1981).

The proposed corridor for the project is not within the critical zone for the U.S. Flood Insurance Program. Storm runoff in the San Fernando Valley is removed by the storm drainage system, which includes street drains, collectors and maindrains, and by area surface flow along streets. The area around Lankershim Boulevard drains generally through surface street flow in a southerly direction toward the Los Angeles River Channel. The streets do not present any significant flooding problem for the subsurface component of this project.

PROJECT OPERATION AND MAINTENANCE IMPACTS

An assessment of potential environmental impacts related to landform, geologic hazards and hydrology/water quality is provided in this section. Emphasis is placed on impacts associated with the operation and maintenance of the proposed Metro Rail system; impacts related to project construction are addressed in the following section.

It should be recognized that many of the potential impacts in the geology and hydrology categories were identified early in the design phase of the Metro Rail project, and specific actions have been or will be taken in the final design and construction phases to avoid such impacts. Thus, the detailed project design will contain the necessary measures to effectively mitigate adverse environmental impacts. These mitigation measures, which are part of the proposed project, along with other mitigation options identified in this study are described in the final section of this report.

Landform

Most of the proposed Metro Rail alignment alternatives and stations will be located underground and will not be evident from the land surface. Above-ground station elements, maintenance yards and at-grade or aerial guideway rail segments are all located in areas where very little landform alteration, such as the creation of artificial cut and fill slopes, will be necessary. Thus, once construction is completed and the Metro Rail system becomes operational, no significant, long-term impacts to existing landforms are expected.

Geologic Hazards

Seismicity. A number of potential geologic hazards fall into the general category of seismicity. As described below, these include seismic ground shaking, fault rupture and soil liquefaction/vibration densification.

• Seismic Ground Shaking. As described in previous sections, the Metro Rail project, like most of California, is in a seismically active area. It is considered statistically probable that a peak horizontal ground motion of about 0.22 g will affect the project once during the next 100 years. Descriptive ground shaking parameters for this maximum probable seismic event are given in Table 4.

In addition to probable ground shaking, active faults in the southern California region are considered capable of generating peak horizontal ground motions as high as 0.70 g at the project site. This maximum credible seismic ground motion, more fully described in Table 5, may or may not occur during the expected 100-year project life. However, it is considered to represent the upper limit design event for the construction of critical facilities.

The environmental effects of seismic ground shaking can be expressed by use of the Modified Mercalli scale of earthquake intensities (see Table 10). A number of researchers (Neumann, 1954; Gutenberg and Richter, 1956; Trifunac and Brady, 1975) have proposed emperical methods to relate various levels of ground acceleration to Modified Mercalli (MM) intensities. For the maximum probable horizontal ground acceleration of 0.22 g, each of these methods indicates a MM intensity of about VIII in the project area. Similarly, a MM intensity of approximately IX is indicated for the maximum credible acceleration of 0.70 g. Reference to Table 10 will show the structural and other effects of intensity VIII and IX ground shaking.

• Fault Rupture. Movement along a fault results in the displacement of a portion of the earth's crust at the ground surface and/or at depth. Such displacement can be either rapid, as occurs during an earthquake, or relatively slow and gradual, as associated with fault "creep." Whether at the ground surface or at the depth of the proposed tunnels, displacement along a fault crossing the Metro Rail system would seriously disrupt project facilities.

The only active or potentially active faults crossing any of the Metro Rail alternative alignments are the Hollywood and Malibu-Santa Monica faults (Figure 6). As shown on Table 3, the maximum credible earthquake (MCE) for these features is 6.5 and 7.0, respectively. The estimated fault displacements associated with these MCEs, based on late Quaternary data concerning fault slip rates, are 1.0 feet and 3.3 feet (Converse Consultants, 1982, Table 7-1). Such displacements would obviously adversely affect system operations. However, the probability is very low that these fault displacements would occur during any reasonable service life. For example, a MCE-type displacement of 1.0 feet on the Hollywood fault crossing would be expected to occur an average of once every 60,000 to 70,000 years (Converse Consultants, 1982). Similarly, the 3.3-foot MCE displacement on the Malibu-Santa Monica fault crossing might occur on the average of once every 20,000 to 30,000 years. Thus, while fault rupture impacts would be significant, their probability of occurrence is extremely low.

• Liquefaction/Vibration Densification. Liquefaction is a process whereby loose to medium dense, water-saturated, granular sediments lose their shear strength and become liquefied due to increased pore water pressure resulting from cyclical, dynamic (usually seismic) loading. In general, cyclical loading greater than approximately 0.2 g and of a relatively long duration is necessary to cause soils to liquefy. Densification is a similar phenomenon occurring when loose, granular soils densify or become more compact due to seismic ground shaking or vibrations from facility construction activities or, possibly, system operations. Soil liquefaction or densification

Table 10

The Modified Mercalli Scale of Earthquake Intensities

If most of these effects are observed	*then the intensity is:*
Earthquake shaking not felt. But people may observe marginal effects of large distance earthquakes without identifying these effects as earthquake-caused. Among them: trees, structures, liquids, bodies of water sway slowly, or doors swing slowly.	*I*
Effect on people: Shaking felt by those at rest, especially if they are indoors, and by those on upper floors.	*II*
Effect on people: Felt by most people indoors. Some can estimate duration of shaking. But many may not recognize shaking of building as caused by an earthquake; the shaking is like that caused by the passing of light trucks.	*III*
Other effects: Hanging objects swing. *Structural effects:* Windows or doors rattle. Wooden walls and frames creak.	*IV*
Effect on people: Felt by everyone indoors. Many estimate duration of shaking. But they still may not recognize it as caused by an earthquake. The shaking is like that caused by the passing of heavy trucks, though sometimes, instead, people may feel the sensation of a jolt, as if a heavy ball had struck the walls. *Other effects:* Hanging objects swing. Standing autos rock. Crockery clashes, dishes rattle or glasses clink. *Structural effects:* Doors close, open or swing. Windows rattle.	*V*
Effect on people: Felt by everyone indoors and by most people outdoors. Many now estimate not only the duration of shaking but also its direction and have no doubt as to its cause. Sleepers wakened. *Other effects:* Hanging objects swing. Shutters or pictures move. Pendulum clocks stop, start or change rate. Standing autos rock. Crockery clashes, dishes rattle or glasses clink. Liquids disturbed, some spilled. Small unstable objects displaced or upset. *Structural effects:* Weak plaster and Masonry D* crack. Windows break. Doors close, open or swing.	*VI*
Effect on people: Felt by everyone. Many are frightened and run outdoors. People walk unsteadily. *Other effects:* Small church or school bells ring. Pictures thrown off walls, knicknacks and books off shelves. Dishes or glasses broken. Furniture moved or overturned. Trees, bushes shaken visibly, or heard to rustle. *Structural effects:* Masonry D* damaged; some cracks in Masonry C*. Weak chimneys break at roof line. Plaster, loose bricks, stones, tiles, cornices, unbraced parapets and architectural ornaments fall. Concrete irrigation ditches damaged.	*VII*
Effect on people: Difficult to stand. Shaking noticed by auto drivers. *Other effects:* Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Furniture broken. Hanging objects quiver. *Structural effects:* Masonry D* heavily damaged; Masonry C* damaged, partially collapses in some cases; some damage to Masonry B*; none to Masonry A*. Stucco and some masonry walls fall. Chimneys, factory stacks, monuments, towers, elevated tanks twist or fall. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off.	*VIII*
Effect on people: General fright. People thrown to ground. *Other effects:* Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes. Steering of autos affected. Branches broken from trees. *Structural effects:* Masonry D* destroyed; Masonry C* heavily damaged, sometimes with complete collapse; Masonry B* is seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Reservoirs seriously damaged. Underground pipes broken.	*IX*
Effect on people: General Panic. *Other effects:* Conspicuous cracks in ground. In areas of soft ground, sand is ejected through holes and piles up into a small crater, and, in muddy areas, water fountains are formed. *Structural effects:* Most masonry and frame structures destroyed along with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes and embankments. Railroads bent slightly.	*X*
Effect on people: General panic. *Other effects:* Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. *Structural effects:* General destruction of buildings. Underground pipelines completely out of service. Railroads bent greatly.	*XI*
Effect on people: General panic. *Other effects:* Same as for Intensity X. *Structural effects:* Damage nearly total, the ultimate catastrophe. *Other effects:* Large rock masses displaced. Lines of sight and level distorted. Objects thrown into air.	*XII*

* Masonry A:	Good workmanship and mortar, reinforced, designed to resist lateral forces.
* Masonry B:	Good workmanship and mortar, reinforced.
* Masonry C:	Good workmanship and mortar, unreinforced.
* Masonry D:	Poor workmanship and mortar and weak materials, like adobe.

can lead to the failure of overlying structures through the loss of bearing capacity, lateral spreading or settlement.

In general, the granular deposits (primarily Young and Old Alluvium) along the proposed alternative alignments are dense to very dense. However, some of the granular alluvial deposits in the Los Angeles CBD segment beneath the Union Station west of the Los Angeles River, the 5th Street Station, and the 7th/Flower Station were found to be only loose to medium dense. Such materials are susceptible to liquefaction where below the water table and/or to densification due to vibrations.

Tunnel and Excavation Stability. The long-term stability of tunnels, cut and cover construction and other excavations will be of concern to owners and users of overlying and adjacent properties. In particular, the possibility of a tunnel caving upward to or near the ground surface with the settlement of overlying facilities, and the stability of vertical excavation side-slopes are important considerations in project design and construction.

Tunnel and excavation stability will be of primary concern during construction when tunnels or slopes may be unsupported for short periods of time. Directly following tunneling, however, precast concrete or steel ring tunnel liners will be installed to assure support and stability. An alternative tunnel support system being considered uses a recently developed technique of placing a continuously extruded steel-fiber reinforced concrete liner immediately behind the tunnel boring machine. This would provide virtually continuous support of the tunnel walls from the time they are driven, and, further, would eliminate the need for offsite liner casting yards, liner transport, bolting, grouting and caulking.

Upon completion of cut and cover excavations for Metro Rail system stations, reinforced concrete base slabs, exterior walls, intermediate level horizontal slabs and roof slabs will be installed and temporary construction bracing removed. The cross-station slabs and side walls, when fully installed, will be designed to provide an adequate support against lateral soil and groundwater pressures as well as imposed vertical loads.

The corrosive nature of some groundwaters in the project area could eventually lead to the deterioration of tunnel liners and station walls. General locations of such corrosive materials have been identified and, as required, resistant concrete mixtures and/or treated steel will be used for construction.

Hydrocarbon Accumulations. Much of the Metro Rail Project in the Los Angeles CBD and Wilshire Corridor segments passes through areas of known shallow hydrocarbon accumulation. Such accumulations can take the form of gas, asphalt, tar or free oil. The construction and safety hazards of tunneling through such areas are well known and are addressed in the following section. Where tunnels and stations are completed in areas of shallow hydrocarbons, long-term buildups of liquid tar or oil may occur. Thus, where necessary, a system of gravel-filled drainage channels will be provided to collect these substances and carry them to a series of sumps. From the sumps they will be removed to the surface and disposed of in accordance with RWQCB discharge requirements.

Long-term accumulations of gaseous hydrocarbons are not considered likely following project construction. However, should such buildups occur, special tunnel linings will be installed to prevent gas from entering the subway system, or a gas collection and ventilation will be provided to dissipate any hazardous concentrations.

Subsidence. Subsidence of the land surface can result from several causes. In the Metro Rail Project area the withdrawal of fluids, such as groundwater or hydrocarbons, has apparently caused the compaction of underlying sediments and land subsidence in the Union Station oil field and near Burbank in the San Fernando Valley. Subsidence rates on the order of 0.066 and 0.033 feet per year, respectively, have been reported for these two areas (see Yerkes et al., 1977). In addition, subsidence due to tectonic activity has been noted in the center of the San Fernando Valley, where Stone (1961) indicates a maximum subsidence rate of 0.045 feet per year based on repeated leveling surveys.

Vertical movement of the land surface would become a hazard to the Metro Rail system if it occurred within a small area, with adjacent land being unaffected. Such differential subsidence does not appear to be occurring in the project vicinity, where relatively uniform subsidence affects areas of several square miles. Yerkes et al. (1977) calculate an average subsidence rate of up to about 0.1 feet per year over a linear distance of about 3 miles in the Los Angeles CBD area, and conclude that, as presently known, subsidence would probably not be a problem to the construction of tunnels.

Loss of Mineral Resources. The Metro Rail project passes through geologic materials which, in a strict sense, might be considered mineral resources. These resources consist of sand and gravel which could be used as construction aggregate, or, in the Santa Monica Mountains, granitic or volcanic rock which could be used as rip-rap. However, the poor quality in terms of mineral value of most of these materials and their proximity to fully urbanized areas makes the mining of them both uneconomical and impractical.

The Los Angeles Basin has been one of California's most prolific oil producing districts, and hydrocarbons have been extracted from sediments in the Metro Rail Project area for nearly 100 years. While the presence of hydrocarbons in materials tunneled or excavated for the proposed project will present engineering and construction problems, the Metro Rail system will not adversely affect operations in any producing oil field.

Hydrology/Water Quality

Los Angeles CBD Segment. The potential hydrology/water quality impacts associated with the operation of the Metro Rail system in this segment are generated by the disposal of wastewater from the shop area. It is expected that all train cars will be washed weekly. The wash area will be provided with surface drains and all effluent will be contained in the wash area. Chemicals used for train cleaning include solvents, detergents and surfactants. These materials may require pretreatment prior to discharge into domestic sewer systems. An estimated 160 cars per week will be automatically washed at the shop yard.

Domestic sewage generated by the shop and stations in this segment will have no significant effect on the existing sewage system. No other operational impacts on hydrology and water quality are expected in this segment.

Wilshire Corridor Segment. Operational impacts related to hydrology and water quality in this segment are limited. The project will not increase the surface flooding potential due to increased impermeable surface area, since proposed paved areas are small compared to the total surface already covered.

The potential for groundwater contamination from products generated in the tunnels is low. The tunnels will be sealed tubes and any aqueous materials generated will flow toward sumps to be treated if necessary, then removed to the surface storm drain system or into the existing domestic sewage system.

The proposed storm drain from Laurel Canyon to Pan-Pacific Park should reduce the potential for street flooding in the northern extension of the Wilshire Corridor. Domestic sewage generated at the stations will be limited, and no significant impact is expected on sewage treatment facilities.

The potential for increased levels of urban source pollution from parking and access facilities is not significant. The same general level of contamination would be generated with or without the project. The reduction of automotive emission particulates may be reduced by park and ride facilities, but this should not have a signifícnt effect on the urban non-point source water pollution currently existing in the basin.

One potential area of concern is the discharge of dewatering fluids from the La Brea area and from other areas with tar sand substrates and gas formations. The discharge of wastewater with oil and gas in it is not acceptable to the Los Angeles RWQCB for NPDES disposal permits, and, treatment would be required. The separation of oil and gas from the discharged water will be required using an oil/water separator. Monitoring of discharged water would also be required for suspended solids and hydrocarbons.

Hollywood Segment. Operational impacts of hydrology and water quality in this segment are generally minimal. Increased flooding of streets and buildings adjacent to stations is not expected. The existing drainage system is adequate to provide a high level of flood protection. None of the alternative alignments or configurations should increase the flood hazard. Design criteria will maintain adequate flood protection and all tunnel systems are capable of removing water via sumps and pumping systems. All drainage flow in tunnels will be pumped into storm drainage systems. The disposal of domestic sewage wastewater from the stations is limited and will be discharged into existing sewer lines.

No flooding problems are anticipated in the section of tunnel through the mountains. Any groundwater entering the tunnel would be removed by the sump system. Some dewatering may be necessary in this segment, and waters will be discharged into storm drains. No oil or gas contamination is anticipated in this segment and silt removal should be all that is necessary prior to discharge.

North Hollywood Segment. Hydrological impacts in this northern segment are generally not significant. The groundwater is deep in this aquifer and is used to support municipal and domestic uses. The tunnel and operational activities are not adjacent to major recharge basins or spreading areas. No water-borne products are expected to be able to enter the groundwater from the tunnel. The major streets in this area are used to convey flood waters, since no significant flood control system is in place. All water in the tunnel will be collected in sumps and discharged to the domestic sewer system. Station waste disposal will be carried out as previously described.

The projected maintenance yard facility at the north terminus is not a cleaning facility and no significant surface water contamination is expected.

Flooding in this segment may be a problem since the surface streets are used as floodways. Designing floodproof stations will be required. No significant increase in ambient non-point source surface contaminants are expected from the vehicular traffic generated around station locations.

PROJECT CONSTRUCTION IMPACTS

Introduction

Construction of the proposed Metro Rail system entails extensive subsurface earthwork involving both tunneling and excavation from the ground surface. As discussed below, this excavation process and the activities associated with it will create the largest potential for construction-related environmental impacts in the geology, hydrology, and water quality categories.

Based on current plans, approximately 18 miles of rail line will be placed in tunnels ranging in depth from 30 feet to over 200 feet below the existing ground surface. Exceptions to tunneling will occur in several relatively small areas where cross-overs and pocket tracks will necessitate open cut or cut-and-cover surface excavations. In addition, a possible project alternative in the San Fernando Valley would entail constructing about 3 miles of the alignment as an aerial guideway.

Approximately 11 miles of tunnel will be excavated by tunnel boring machines (TBMs) through soft-rock formations and competent soils of the Old Alluvium unit. About 2.5 to 3.5 miles of the alignment, depending on the specific alternative selected through the Santa Monica Mountains, will encounter hard-rock formations and require tunnel excavation by either conventional drilling/blasting techniques or hard-rock TBMs. The remaining 3.6 to 4.4 miles of the alignment will be in Young Alluvium soils that are poorly consolidated and/or saturated with groundwater. Tunneling through these materials, which occur in the Los Angeles CBD segment and near the Los Angeles River crossing in the San Fernando Valley, may require special tunneling procedures.

Proposed stations will be constructed in surface excavations. The Vermont station excavation will be by the open cut method, while the remaining 16 stations will be in cut-and-cover excavations.

Detailed descriptions of the tunneling and surface excavation methods to be used for transit line and station construction are contained in the previously mentioned "Report on Construction Methods" by the Metro Rail Project's Ways and Structures Consultant (DMHM/PBQD, 1982). Summary descriptions of these construction techniques, as modified from the project EIS/EIR, follow.

Surface Excavations. Two types of surface excavation are proposed: cut-and-cover and open cut. In an urban area these methods involve a sequence of activities. In general, construction begins by opening the ground surface and digging to an adequate depth to permit support of existing utility lines and to set piles or other means of retaining the excavation as it proceeds. In the cut-and-cover method, the surface opening is then covered with a temporary decking so that traffic and pedestrian movements can be maintained during the construction period. After the decking is in place, excavation continues to the necessary depth. A concrete structure is then built, a portion of the excavated material replaced, and the surface restored to its original condition.

The cut-and-cover or open cut excavations must be retained by temporary walls and, very often, extensive reinforcement of adjacent building foundations is required to maintain their stability and structural integrity. Because of the generally more disruptive characteristics of the process, this type of construction is minimized for line segments. However, there are certain advantages to open cut and cut-and-cover construction techniques, including: reasonably predictable cost, accommodation of any structural configuration, greater flexibility in work sequencing, and minimal construction for entrances and vent shafts.

Tunnel Excavations. Generally, tunneling has less adverse effect on the neighborhood than the open cut or cut-and-cover method since utilities are not appreciably disturbed and there is less dust, noise, and traffic disruption. The specific tunneling technique used depends largely upon the type of material to be tunneled. In soft ground, the Metro Rail tunnels will be constructed using full-face tunnel boring or digger-arm machines mounted inside shields in order to hold the ground in place and prevent surface settlement. In hard rock sections, drill and blast mining techniques may be used; however, the construction contractor will have an option of using full-face hard rock tunnel boring machines.

Tunnels for the Metro Rail Project will have several configurations:

- In soft ground, two circular tunnels will be bored side-by-side at a similar elevation.

- Through hard rock formations, the tunnels would again be side-by-side at a similar elevation, but would be horseshoe-shaped.

- A third alternative is the one-over-one configuration, where one tunnel is bored directly above the other. This stacked arrangement is proposed only where an interchange with another line might be required in the future.

Potential Geologic Impacts.

Potential environmental impacts associated with the above construction methods can be divided into several categories: excavation stability, groundwater, muck disposal, and hydrocarbon accumulations. A general discussion of each of these impact categories is provided below, followed by an assessment of how such impacts could affect the various line segments of the proposed Metro Rail Project.

Excavation Stability

Tunneling. There are two primary environmental (as opposed to engineering) concerns associated with excavation stability when tunneling. These concerns are: 1) possible caving of the tunnel upward to or near the ground surface (such caving generally occurs in soft rock at the tunnel working face ahead of the TBM); and 2) settlement of the land surface above the tunnel.

The potential for caving and settlement will be of greatest concern in the Los Angeles CBD and North Hollywood segments, where tunneling will be through poorly consolidated Young Alluvium. Caving and settlement will be of lesser concern in tunnels through the better consolidated Old Alluvium and bedrock formations in the Wilshire Corridor and soft rock portions of the Hollywood segments. Through the Santa Monica Mountains, caving and/or settlement is possible but unlikely.

Surface Excavations. Cut-and-cover or open cut excavations will be necessary for the Metro Rail stations, several short line segments, and ventilation shafts. The primary environmental concern associated with the stability of such excavations is the protection of adjacent properties. Many of the proposed stations, shafts and potential cut-and-cover line segments will be constructed in proximity to existing structures. In several areas, especially in the Los Angeles CBD and Wilshire Corridor segments, there may be no more than 10 to 20 feet between the excavation and existing building foundations. If unsupported, such surface excavations could result in the lateral movement of soils supporting adjacent foundations and severe damage to the overlying structures.

Groundwater. The principal engineering problems encountered in tunnels or deep surface excavations are often related to the presence of groundwater. Large volumes of groundwater entering an excavation can seriously disrupt operations, and the presence of interstitial water significantly reduces soil strength, sometimes causing such soils to flow as a viscous fluid.

Geotechnical investigations indicate that shallow groundwater is present in the Young Alluvium in the eastern portion of the Los Angeles CBD segment and near the Los Angeles River crossing in the North Hollywood segment. Relatively shallow groundwater also appears to be present in the non-tar-impregnated sands of the San Pedro formation in the central portion of the Wilshire Corridor segment. Shallow perched groundwater is believed to exist within the alluvium throughout much of the alignment, and may also exist in isolated pockets or lenses of granular soils in otherwise non-water-bearing formations.

Muck Handling. Substantial volumes of saturated and unsaturated soil will be generated by the boring of tunnels and construction of stations and maintenance yards for the Metro Rail system. These spoil materials, known collectively as muck, will be removed from the excavation areas, possibly stored temporarily in the project vicinity, then transported by truck to available solid waste disposal sites in the region. Excavation spoil totaling approxiately 6,550,000 cubic yards will be generated during the 1984-1990 Metro Rail construction time frame. An estimated 560,000 cubic yards of this material may be oil or tar contaminated and require disposal at a Class I or II-1 landfill; the remainder of the excavated spoil is expected to be inert and suitable for disposal as a Class III waste.

Environmental impacts associated with transporting muck from project excavations to disposal areas fall primarily into the categories of air quality (dust), truck traffic, noise, energy consumption, water quality, and landfill capacity. These impacts are described in the Metro Rail Project EIS/EIR and in a muck disposal study prepared for the Metro Rail Project (Sedway/Cooke, 1982).

Hydrocarbon Accumulations. Excavations for the Metro Rail alignment in portions of the Los Angeles CBD and Wilshire Corridor segments will encounter hydrocarbons in relatively shallow sediments. Granular soils impregnated with liquid hydrocarbons, commonly referred to as tar sands, are common in the western parts of the Wilshire Corridor segment. These tar sands are a potential environmental and engineering concern for two reasons: 1) when they are rapidly unloaded, as during excavation or tunneling, dissolved natural gas in the tar comes out of solution causing the sediment to expand and lose much of its strength; and 2) there is some evidence tar sands may exhibit considerable creep, especially at higher temperatures, causing excavation, shoring and bearing capacity problems.

In addition to tar sands, free natural gas in sediments to be tunneled can be of significant concern. Such gas was the cause of an explosion that killed 17 workers during excavation of the Metropolitan Water District's San Fernando tunnel in 1971.

The proposed Metro Rail alignment passes over or near six major oil fields and, based on geotechnical studies, over 50 percent of this alignment is in ground classified as gassy or potentially gassy. As described in the "Existing Conditions" section of this report, gassy ground is found in the eastern reaches of the Los Angeles CBD segment near the Los Angeles River and in the eastern and western portions of the Wilshire Corridor segment. Potentially gassy ground is found in the western Los Angeles CBD and central Wilshire Corridor segments. Tar-impregnated sands are likely to be found in the eastern CBD and western Wilshire segments.

Potential Hydrologic/Water Quality Impacts.

Construction impacts on hydrology and water quality are derived from the need for dewatering in various tunnel segments and the potential for erosion and sediment flow in various construction areas. Construction activities include surface excavations for stations, track crossovers and pocket tracks, tunneling for line segments, and muck hauling.

Hydrological impacts may occur during tunneling activities. Perched groundwater in a number of segments may infiltrate the tunnel during construction and will require removal. This type of inflow is normally high in suspended solids and the disposal of this water into surface storm drains without desilting does not conform to RWQCB water quality objectives.

Waste water discharge from dewatering of tar sands and gassy sediments in the Wilshire Corridor segment between Western and Fairfax will require treatment to remove oil and gas. Specific treatment requirement will be part of an NPDES permit issued for these activities, and the monitoring of discharge will be instituted by the RWQCB.

Station construction and muck hauling has the potential to increase the level of sediment on the streets which could be washed away during storms. This can be a significant problem in light of the total yards of material to be removed during this project. The turbidity induced will drain into Los Angeles River and Ballona Creek via the storm drain system.

The volume of water expected in dewatering activities is limited. Estimates have been made by geologists which range from 0 to 6000 gallons per hour. Dewatering is not expected to be a significant problem due to the depth of the permanent water table over most of the alignment. All water will be discharged into existing storm drainage systems. The existing system can easily accommodate the anticipated dewatering volume, even during peak rainfall periods. All excavation sites have the potential for flooding due to being below grade.

No significant water quality impacts are anticipated during construction activities, although limited impacts may be encountered. These include fuel spills from vehicles and equipment operating in the tunnel or excavations, and the loss of greases, oils and lubricating fluids to bare ground in the tunnel. The depth to groundwater should limit any significant impacts from infiltration of contaminants.

MITIGATION OPTIONS

Operations

Many of the potential impacts in the geological and hydrological categories were identified early in the design phase of the Metro Rail Project and specific engineering actions and design considerations, as described below, have been or will be taken in the final design and construction phases to avoid such impacts.

Geologic Hazards.

Seismicity.

o Seismic Ground Shaking The mitigation of seismic ground shaking impacts will be achieved through project design and construction. All elements of the Metro Rail system that are considered to be "life critical" (that is, facilities whose structural failure during an earthquake would endanger life) will be designed and built to resist strong ground motions from the maximum credible earthquake, the largest seismic event reasonably expected to occur in the project region. Metro Rail system facilities considered to be life critical would include high occupancy structures such as stations and tunnels.

System facilities considered to represent lower risk to life safety in the event of structural failure would include the maintenance yards and other above-ground, low-occupancy structures. Ground shaking parameters associated with the maximum probable seismic event will be used in the design and construction of these elements of the proposed project.

o Liquefaction/Vibration Densification. Prior to construction, more detailed geotechnical work will be completed in the CBD area, where a liquefaction/densification potential may exist, to fully define the horizontal and vertical extent of loose granular soils both above and below the water table. Should soils subject to liquefaction or densification be found to exist, more conservative site preparation and foundation design measures will be implemented to avoid adverse effects. Depending on the specific nature of the conditions found, such measures will include in situ compaction of soils, permanent lowering of the water table, use of special foundations such as pilings, additional underpinnings, and/or other available procedures.

Tunnel and Excavation Stability. The Metro Rail Project design documents address the long-term, operational stability of the proposed tunnels and excavations in considerable detail. For technical design information beyond that provided above in the Impact Analysis section the reader is referred to the "Report on Construction Methods" prepared in September 1982 by the Metro Rail Project Ways and Structures Consultant (DMJM/PBQD, 1980).

Hydrocarbon Accumulation. As described in the Impact Analysis section, drains and sumps will be installed in the portions of the Metro Rail system constructed in oil and tar impregnated sediments to prevent liquid accumulations. Any gas or special tunnel linings will be installed to prevent gas from entering the system.

Construction Impacts

In general, standard construction techniques will reduce the potential impacts associated with the construction of stations, tunnels and peripheral facilities. Design criteria and engineering plans have examined potential construction problem areas and construction techniques have been revised as necessary. Specific mitigation measures already incorporated into the design are described below.

Excavation Stability

Tunneling. To avoid the potential for caving or settlement impacts, several alternative tunnel support systems have proven to be effective and economical in similar tunneling projects in Los Angeles and elsewhere. To support the proposed tunnels through soft-rock segments of the Metro Rail alignment, a shield will first be driven into the ground ahead of the TBM, and excavation will take place within the shield. A permanent support system consisting of precast concrete or steel ring segments, or extruded steel-fiber-reinforced concrete, will be installed immediately behind the shield as the tunnel is driven. In the hard-rock tunnels, support will be provided by rock bolts. Potentially unstable reaches through blocky ground or fault zones in hard rock will be supported by shotcrete or cast-in-place concrete.

Surface Excavations. Several measures to mitigate potential surface excavation stability impacts have been incorporated into the design of the Metro Rail Project. These measures include:

- To the extent possible, major surface excavations will be located adjacent to undeveloped areas (such as parks and parking lots) and/or areas containing small structures.

- Small or relatively inexpensive structures may be relocated or condemned. In many cases, the additional cost of an excavation designed to protect such structures may be more costly than the structures themselves.

- In some areas, it may be feasible to design and construct temporary shoring systems which, with adequate bracing, limited excavation stages and controlled dewatering, would minimize earth movements and allow the excavation to be constructed adjacent to existing structures. However, regardless of the care taken in the design and construction of the shoring walls, there is a risk that the adjacent structure may be damaged. This risk increases with increasing excavation depth and decreasing distance between the existing building foundation and the new excavation. Thus, to the extent possible, deep excavations will be started adjacent to non-critical areas. The experience gained from the initial excavations will improve the level of knowledge for subsequent construction in more critical areas and reduce the possibility of damage.

- There will be locations where the risk and consequence of damage due to earth movements will be unacceptable, and underpinning may be prudent. These include areas of poor soil conditions, deep excavations in close proximity to existing structures, and/or areas of major structures. Underpinning consists of installing piles beneath a structure to provide additional foundation support. Such piles must extend beneath the structure through the zone of influence of the excavation.

o In lieu of underpinning there are two additional foundation strengthening alternatives:

a) Chemical grouting in sandy soils can be used to prevent soil runs and strengthen soil in critical areas. Grout can be injected from the surface under existing foundation elements.

b) Compaction grouting in sands, silts and clays can be effective in lifting and supporting lightly loaded structures. Again, the grouting is carried out from the surface.

Both a) and b) above have been successfully used in the Los Angeles area, in the Washington, DC and Baltimore Metro projects, and throughout Europe and Japan.

Groundwater. Tunnels or surface excavations in the above-mentioned reaches of the Metro Rail Project will require that the soils be dewatered before and/or during construction. Such dewatering is generally accomplished by advancing slotted pipes into the soil then pumping or allowing water to flow from the pipes, thus lowering the water table. Alternatively, groundwater may be removed by pumping from shallow ditches or sumps within an excavation. The mitigation of environmental impacts associated with these dewatering activities is described in the following section on hydrology/water quality.

Muck Handling. A recent muck disposal study (Sedway/Cooke, 1982) has been prepared for SCRT. This study contains an analysis of available landfill capacities and alternative disposal options, and recommends truck haul routes which are designed to minimize impacts to sensitive land uses in the project area.

Hydrocarbon Accumulation. The mitigation of potential impacts related to the presence of tar sands will include the following activities:

o Additional soil borings will be made in critical areas to precisely define the vertical and horizontal extent of tar sands. These borings will also include in situ measurements of gas content and soil expansion potential.

o Laboratory testing of tar sand samples from the borings will be conducted to provide information on their strength and deformation characteristics at different temperatures, confining pressures, strain rates and stress levels.

o Based on data derived from the above tests, specific excavation, shoring and foundation design criteria will be formulated to assure short- and long-term stability of project facilities in tar sand areas. Conversely, once the location of shallow tar sands is precisely known, it may prove more economical to increase tunnel depth or change station locations in problem areas.

The avoidance of safety hazards due to explosive gas in tunnels will be a major element in project planning and construction efforts. As currently planned, the following measures will be implemented when tunneling in gassy or potentially gassy ground:

- A multiple-station, constant gas monitoring system will be used.

- Small-diameter holes will be drilled at least 20 feet into the tunnel working face ahead of the TBM to relieve pressurized gas pockets before being encountered by heavy excavation equipment.

- An adequately sized collection and ventilation system will be installed to prevent the buildup of explosive gas concentrations anywhere in the tunnel.

Hydrology/Water Quality. It is not expected that the Metro Rail Project construction will create significant hydrology or water quality impacts.

As noted under in the Impact Analysis section, however, some short-term problems may arise. These deal with the removal of suspended solids and oil and gas from dewatering activities. Siltation basins designed in the sump system should adequately remove the majority of suspended solids and no discharge permit would be required. Notification of the Regional Water Quality Control Board of significant dewatering activities may be necessary.

The disposal of water containing gas and oil will require NPDES permitting through the Regional Water Quality Control Board. In areas requiring oil/gas separation, permits will be applied for well in advance of construction.

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