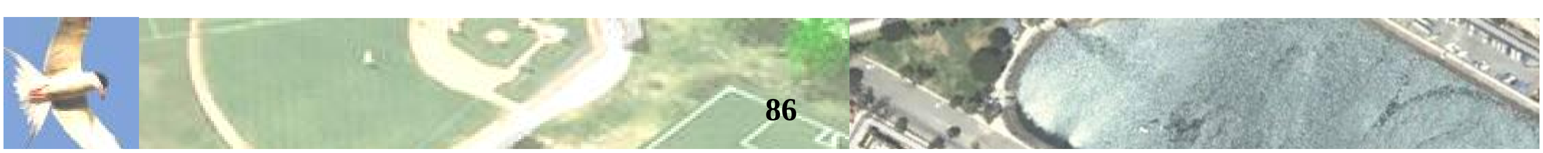
APPENDIX C
Geomorphology Report



Blue Line Consulting
Stream & Wetland Planning ◊ Design ◊ Monitoring

Geomorphic Study for Phase II of the

Colorado Lagoon Restoration Project

Prepared for

Moffatt & Nichol

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TABLE OF CONTENTS

List of Figures

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1.0 INTRODUCTION

1.1 BACKGROUND

Moffatt & Nichol (M&N) is working with the City of Long Beach (City) and Port of Long Beach (Port) to evaluate opportunities for improving tidal circulation and water quality in Colorado Lagoon, a muted tidal basin located in Long Beach, California (Figures 1 and 2). The project partners are also investigating opportunities to restore various wetland habitats in the study area (Figure 2). M&N has developed four alternatives that would meet the main objective of improved tidal circulation. The alternatives are as follows:

Alternative 1: Construct a new culvert connecting Colorado Lagoon with Marine Stadium to improve tidal circulation. The existing culvert would remain in place to provide additional conveyance.

Alternative 2: Construct a tidal channel to connect Colorado Lagoon with Marine Stadium. Bridges would be constructed at the transitions to Colorado Lagoon and Marine Stadium. The existing culvert would remain in place to provide additional conveyance. This alternative was evaluated in an Environmental Impact Report (EIR) (City of Long Beach, 2008), and is referred to as the EIR-conforming alternative.

Alternative 3: Construct an open channel with the addition of new culverts (i.e., no bridges) at the transitions to Colorado Lagoon and Marine Stadium. The existing culvert would remain in place to provide additional conveyance.

Alternative 4: Construct an expanded open channel/wetland area to maximize the extent of various sub-tidal and tidal habitats. A bridge would be constructed at the Marine Stadium transition. The connection to Colorado Lagoon would be culverted. The existing culvert would be demolished.

Conceptual designs for each alternative are provided in Appendix A of the *Alternatives Analysis Report for the Phase 2 Study of the Colorado Lagoon Restoration Project* (Moffatt & Nichol, 2010).

Blue Line Consulting is assisting M&N with the geomorphic evaluation of the study alternatives. Specifically, this includes: (1) interpretation of the geomorphic setting and historical conditions; (2) providing guidance on geomorphically-appropriate channel design and bank materials; and (3) evaluation of long-term channel stability and maintenance requirements.

1.2 REPORT ORGANIZATION

The report is organized into four sections: Section 1 provides an introduction and a general description of the setting; Section 2 describes the geomorphic setting, presents analyses of channel morphology, and discusses channel stability; and Section 3 provides an assessment of the alternatives, and conclusions of the study. References are provided in Section 4.

1.3 LOCATION AND SETTING

The study area is located in the southeastern portion of the City, encompassing the eastern portion of Marina Vista Park (Figure 2). Marina Vista Park is a City-owned facility that includes several ball fields, tennis courts and other recreational improvements. The study area is bounded by Colorado Lagoon to the north, Marine Stadium to the south, residential and municipal development to the east, and the remainder of Marina Vista Park to the west.

The study area is situated on artificial fill that separates Colorado Lagoon from Marine Stadium. A concrete box culvert connects Colorado Lagoon with Marine Stadium. Colorado Lagoon is an approximately 11.7 acre muted tidal basin; Marine Stadium is an unrestricted tidal arm of Alamitos Bay. Tidal datums for the study area are provided in Table 1.

Table 1. Tidal datums for the study area (Moffatt & Nichol, 2004)

Datum	Elevation (ft, NGVD 29)
Mean Higher High Water	2.85
Mean High Water	2.11
Mean Sea Level	0.18
Mean Low Water	-1.70
Mean Lower Low Water	-2.64

The Colorado Lagoon watershed is designated as Basin 21 in the Long Beach Storm Water Management Plan (2001). Basin 21 totals 1,172 acres, including 773 acres of residential, 125 acres of commercial, 219 acres of open space, and 55 acres of institutional. Open space includes the City Recreation Park Area, consisting of two golf courses and adjacent park areas, the Pacific Electric right-of-way greenbelt, and picnic and park areas surrounding the lagoon (City of Long Beach, 2008). The watershed ranges in elevation from 125 feet above mean sea level at the northwestern portion to sea level within the lagoon.

The Colorado Lagoon watershed was historically part of the larger San Gabriel River watershed, which drains 689 square miles from Los Angeles, Orange, and San Bernardino counties. Numerous flood control and land use activities have effectively disconnected the Colorado Lagoon watershed from the San Gabriel River system. The upper San Gabriel River watershed is characterized by the steep, sparsely developed San Gabriel Mountains, while the lower watershed is a shallow, densely developed alluvial plain. The study area lies just north of the mouth of the San Gabriel River and is located within the Los Cerritos Channel and Alamitos Bay Water Management Area (WMA) of the San Gabriel River watershed.

2.0 GEOMORPHIC ASSESSMENT

2.1 GEOMORPHIC SETTING

2.1.1 Geologic Controls

The study area lies at the distal end of the alluvial plain formed by the San Gabriel-Los Angeles River complex. This broad alluvial plain is composed of Holocene (11,700 years ago to present) and late Pleistocene (126,000 to 11,700 years before present) sediments (Figure 3a). Old paralic deposits (late to middle Pleistocene), composed of a mixture of marine and non-marine sediments, border the younger alluvium mapped in the area of Colorado Lagoon (Figure 3a). Historically a fully tidal system, Colorado Lagoon contains marine sediments deposited at the interface with the alluvium. The study area (i.e., Marina Vista Park) is situated on artificial fill placed during the mid 20th century (See Section 2.1.2). The fill varies in composition, but is primarily composed of silts (Kinnetic Laboratories, 2008).

2.1.2 Historical Information

Historical documentation relevant to the geomorphic assessment includes topographic maps, aerial photographs and investigations conducted by others (e.g., Stein et al, 2007; City of Long Beach, 2009). This information, as it pertains to this study, is discussed below.

Topographic Maps

The earliest topographic map that encompasses the study area was completed in 1872 by the U.S. Coast Survey (USCS). This map provides a detailed depiction of the landscape features that existed in the study area prior to significant anthropogenic modification. Figure 4 provides the 1872 USCS map overlaid on a recent (2007) aerial photo. As shown on Figure 4, Colorado Lagoon was in fact a natural landscape feature, as the morphology depicted on the historical map is similar to the contemporary landscape feature. This map shows that the study area was part of a tidal basin composed of slough channels, mudflat, shoals and salt marsh that transitioned rather abruptly to what was likely alkali meadow.

It should be noted that the tidal slough/salt marsh complex which historically occupied the western portion of Marina Vista Park is similar in scale to the wetland restoration alternatives being evaluated in this study. In addition, it appears that the main tidal slough that serviced Colorado Lagoon had a top width of approximately 100 feet (measured at the bottleneck in Marina Vista Park), which is similar to the dimension being proposed for the open channel alternatives (See Section 2.2). There are limitations to using analysis of the historical map for designing a tidal channel in the study area because contemporary versus historical tidal prism is difficult to accurately quantify, and the tidal connections have been greatly modified. Nevertheless, this map provides a useful reference point for establishing the geomorphic and ecological context of the study area.

Historical Aerial Photos

Historical aerial photos of the study area were assembled from various sources including previous investigations (e.g., City of Long Beach, 2008) and the Friends of the Colorado Lagoon website. Oblique aerial photographs are available from the early 1920s, and orthogonal images span 1928 to present day. The oblique images from the early 1920s depict Alamitos Bay prior to significant modifications of the tidal channels, though it is evident that significant amounts of fill had been placed for development of areas such as Naples and Belmont Shore (Figure 5). The boundaries of Colorado Lagoon are difficult to discern in these photos, but it is clear that broad expanses of intertidal wetlands were dispersed throughout the lower San Gabriel River floodplain. These early images, along with the USCS topographic map (Figure 4), provide snapshots of what was a likely a highly dynamic estuary with variable zones of erosion and deposition associated with the historical alignments of the San Gabriel River.

Alamitos Bay and the San Gabriel River were significantly modified over the course of the next few decades. Large-scale modification included dredging of approximately 7 million cubic yards of sediment from tide lands in 1923 and construction of Marine Stadium, which was built for the 1932 Olympics (City of Long Beach, 2009). An aerial image from 1928 shows Marine Stadium near completion, yet Colorado Lagoon retained full tidal connection (Figure 6). This image also shows that the distal ends of the lagoon arms had been filled, yet remnant tidelands can be seen in the landscape to the northeast in the area that is now Recreation Park Golf Course. By 1938, much of the large-scale modification to the landscape that exists today had taken place. In the 1938 aerial photo it appears that a small crossing had been built to separate Colorado Lagoon from Marine Stadium (Figure 6). This crossing reportedly included a tidal gate which was used to control water levels in the lagoon so that it could be used for diving trials during the 1932 Olympics (City of Long Beach, 2009). By 1958, the embankment separating the lagoon from Marine Stadium had been widened, yet remained relatively narrow (Figure 6). In the late 1960s, extensive fill was placed in the study area to construct the proposed Pacific Coast Freeway, which was never completed (City of Long Beach, 2008). The fill placed in the late 1960s created what is now Marina Vista Park, and included construction of the existing culvert which connects Marine Stadium with Colorado Lagoon. An aerial photo from the late 1960s shows that the extent of fill appears largely analogous to that which exists in the current condition (Figure 6).

Historical Assessments

The *Historical Ecology and Landscape Change of the San Gabriel River and Floodplain* (Stein et al., 2007) provides an excellent account of landscape-scale changes that have occurred over the past 150+ years along lower San Gabriel River. Prior to the early 1900s, the alignments of the sediment-rich San Gabriel and Los Angeles rivers migrated about the alluvial plain of the lower watershed; channel avulsions were common in these rivers. During a major flood in 1891 the San Gabriel River was described as being 1,200 feet wide (Stein et al. 2007). Figure 7, taken from Stein et al. 2007, illustrates that in the period time between 1825 and 1930 the San Gabriel River changed course several times in response to large flood events. Between 1825 and 1867 the San Gabriel functioned as a tributary to the Los Angeles River (Figure 7). A large flood in 1867 shifted most of the river to the south, and a new mouth was formed on the north end of Alamitos Bay. Another large flood in 1884 reinforced the dominant channel to the south, and the San Gabriel no longer contributed flow to the lower Los Angeles River. The alignment of the mouth of the San Gabriel River also migrated to the south end of Alamitos Bay. In the early to mid 1900s much of the lower San Gabriel River was modified for flood control. These channel modifications, along with dams and sedimentation basins, have limited the dynamism of the river system and its ability create or modify landforms (e.g., Colorado Lagoon) in the lower watershed. Thus, the separation of the study area from the San Gabriel River floodplain has important implications for the long term stability and morphology of the study area (See Section 2.3.2).

2.2 CHANNEL MORPHOLOGY

Historical maps, aerial photos, and empirical geomorphic relationships are tools commonly used to inform the design of tidal channels. The 1872 USCS topographic map and historical aerial photos provide some information regarding the historical condition of the study area, but are of limited value for channel design because the landforms, physical processes and drainage networks have been substantially altered. Thus, the use of empirical geomorphic relationships is considered a better quantitative tool for developing design guidelines for the morphology of an open channel in the study area.

For this study, hydraulic geometry relationships developed from San Francisco Bay tidal marshes (Williams et al., 2002) were applied to approximate the ideal cross-sectional area, depth and top width for the open channel, in the absence of other constraints/criteria. It was assumed that the hydraulic geometry relationships derived from San Francisco Bay marshes provide a suitable analog for the study area because tidal wetlands in both locations experience mixed semidiurnal tides with similar range, are formed in similar substrate (i.e., marine silts and clays), and develop climax marsh plains at an elevation approximating mean higher high water (MHHW).

Williams et al. (2002) provides equations to derive various components of channel geometry based on tidal prism. M&N estimates the potential diurnal tidal prism [i.e., volume of water between MHHW and Mean Lower Low Water (MLLW)] at the mouth of Colorado Lagoon to be 76 acre-feet. Table 2 provides the theoretical channel cross-sectional area, depth and top width derived from the hydraulic geometry relationships presented in Williams et al. (2002) in comparison to the dimensions of the proposed open channel alternatives.

Table 2. Comparison of channel morphology parameters derived from hydraulic geometry relationships and proposed open channel alternatives[1]			
Cross-section	**Maximum Depth**	**Top width**	**Cross-sectional area**
	(feet)		(feet^2)
Theoretical channel[2]	8.31	94.5	515.3
Alternative 2 (@ Section 2a)	9.35	78	434 channel + 97 culvert = 531
Alternative 3 (@ Section 3a)	9.35	90	424 channel + 97 culvert = 521
Alternative 4 (@ Section 4a)	9.85	125	660

1. Hydraulic geometry relationships from Williams et al. 2002.
2. Based on potential diurnal tidal prism of 76 acre-feet.

Maximum channel depths for the open channel alternatives exceed the value derived from the hydraulic geometry relationships by 1 to 1.5 feet. The invert for the open channel alternatives was set an elevation that would provide adequate tidal exchange with Colorado Lagoon, and maximize the extent of potential eelgrass habitat. By sloping the channel bed (in cross-section), considerable variability has been incorporated into the design of channel bottom to encompass the range of potential eelgrass habitat (Moffatt & Nichol, 2010). This bed configuration is desirable from a habitat perspective, and the small differences in maximum channel depths are not likely to be problematic from a geomorphic perspective.

Top width (measured at MHHW) for Alternative 2 is somewhat less than the theoretical channel (due to this alternative's objective of minimizing the footprint within Marina Vista Park), while the top width for Alternative 4 is substantially greater than the theoretical channel (due to this alternative's objective of maximizing the amount of wetland habitat created). Top width for Alternative 3 is very similar to the theoretical channel. The cross-sectional area for Alternatives 2 and 3 (including conveyance capacity of culvert) is very similar to the theoretical channel, while the cross-sectional area for Alternative 4 is greater than the theoretical channel (again because of that alternative's objective of maximizing wetland habitat acreage).

From the perspective of this study, concern would be warranted if the channel dimensions for the proposed alternatives were substantially less than that predicted from the hydraulic geometry relationships. This would indicate that the channel would have the tendency to expand, which could result in undesirable erosion. For example, the proposed top width of Alternatives 2 is approximately 78 feet, while the theoretical channel is approximately 95 feet, suggesting that the proposed channel may have a tendency to widen. While this difference in dimensions is not at a scale that would warrant great concern, it should be considered in subsequent design phases of the open channel.

Conversely, the top width and cross-sectional area of Alternative 4 exceed the dimensions predicted from the hydraulic geometry relationships. An oversized channel would have the tendency to aggrade over time, the rate of which would be dependent on sediment supply and hydraulics. This condition would not necessarily be problematic, and a conservatively designed channel with a tendency toward aggradation, may be desirable given the study setting.

Sinuosity of a channel with similar dimensions (notably top width) is often used as reference for designing channel planform. Sinuosity (calculated as the ratio of channel length to valley length) for the tidal channel in the study area depicted in the 1872 USCS map was approximately 1.3. Sinuosities calculated for the open channel alternatives are 1.19, 1.15 and 1.12 for Alternatives 2, 3 and 4, respectively. These relatively small differences suggest that the sinuosities for the open channel alternatives are appropriate for the scale of the channel. Given that channel planform in the study area is highly constrained due to adjacent land uses, a more sinuous alignment is not likely feasible. The channel is unlikely to migrate laterally and develop a more sinuous alignment because there are no significant sources of sediment and hydraulics forces are not anticipated to cause large-scale bank erosion (See Section 2.3.3).

2.3 CHANNEL STABILITY

2.3.1 Channel lining Materials

Because the study area is located in an urbanized setting, large-scale channel adjustments (e.g., lateral migration) or instability (e.g., excessive bank erosion) are undesirable. Therefore, the channel boundary must be composed of materials that can withstand the maximum hydraulic forces that are anticipated to occur. The channel lining materials should also provide the maximum benefits with respect to habitat value and aesthetics.

The selection of channel lining materials is most commonly performed by evaluating hydraulic parameters such as maximum velocity and boundary shear stress. For this preliminary evaluation of the alternatives only velocity is considered; shear stress should be considered as the design of the preferred alternatives progresses.

Predicted velocities for each of the open channel alternatives were derived from the RMA2 model. Estimated peak velocities for each of the open channel alternatives are summarized in Table 3.

Table 3. Estimated peak velocities for open channel alternatives

Alternative	Location in open channel	Spring tides	50-yr storm event
		(ft/s)	
Alternative 2	@ Colorado Lagoon transition	1.27	1.57
	@ halfway point in channel	1.20	1.38
	@ Marine Stadium transition	1.68	2.42
Alternative 3	@ Colorado Lagoon transition	1.32	1.95
	@ halfway point in channel	1.52	1.96
	@ Marine Stadium transition	1.52	2.19
Alternative 4	@ Colorado Lagoon transition	1.68	2.47
	@ halfway point in channel	0.89	1.33
	@ Marine Stadium transition	1.58	2.31

Peak velocities modeled for spring tide conditions range from 0.89 to 1.68 feet per second (fps); for the 50-yr storm event peak velocities range from 1.33 to 2.47 fps. Peak velocities are significantly greater at the transitions because the channel is confined into smaller cross-sections at these locations.

A literature review of permissible velocities for open channels was conducted to inform the selection the appropriate channel lining materials. The results of the literature review are provided in Table 4.

Table 4. Permissible velocities for select channel lining materials.

Material	Source			
	Fischenich[1]	Schwab[2]	Webber[3]	Thasgen[4]
	velocity (ft/s)			
Fine Sand (colloidal)	1.5	-	2.5	2.5
Ordinary Firm Loam	2.5	3.5	-	3.4
Stiff Clay (very colloidal)	3-4.5	5	4.9	4.9
Alluvial Silts (noncolloidal)	2	5.5	3.3	3.4
Coarse Gravel (noncolloidal)	3-6	6	5.9	6.1
Cobbles and Shingles	4-12	5.5	5.6	5.6

[1]Fischenich, C. 2001. *Stability Thresholds for Stream Restoration Materials*, EMRRP Technical Notes Collection ERDC TNEMRRP-SR-29. U.S. Army Engineer Research and Development Center, Vicksburg, MS. (p. 5)

[2]Schwab, O., et. al. 1955. *Soil and Water Conservation Engineering*. Glenn John Wiley & Sons, Inc. New York.

[3]Webber, N.B. 1971. *Fluid Mechanics for Civil Engineers*. Chapman & Hall. London, UK. (p. 166)

[4]Thasgen, B. (ed). 1996, *"Highway and Traffic Engineering in Developing Countries"*, E. & F. N. Spon, London, UK. (p. 197).

Ideally, the channel lining materials would be composed of substrate similar to natural tidal wetlands in the vicinity of the study area, as this type of material would be most conducive to supporting native wetland flora and fauna. Tidal wetlands in the study vicinity are generally formed in soft organic clays, loose to medium sands and silts, and/or peat (CWIS, 2009). Soils in the immediate vicinity of the study area have been disturbed, thus it is difficult to discern the native soil type. Soil logs from the subsurface investigation conducted by Kinetic Laboratories (2008) as part of the project EIR note "grey clay" and "grey silty clay" in the deepest portion of several soil cores. Although it is unlikely that these borings encountered native material, it is reasonable to assume, based on general knowledge of local tidal wetlands, that the native materials consisted of mineral soil with a texture in the range of silty loam to silty clay.

Several of the soil types listed in Table 4 with silt or clay textures are capable of withstanding the estimated peak velocities modeled for all alternatives (Table 3). This suggests that the boundary of the open channel can be lined with clay or silt provided that the material is conditioned, placed and compacted in accordance with standard engineering practices. More robust channel lining materials may be warranted in select areas (e.g., transitions to Colorado Lagoon and Marine Stadium) to account for higher velocities, steeper channel banks, and to protect infrastructure (e.g., bridges). Fischenich (2001) provides a literature review of permissible velocities for various channel lining materials (Table 5). Of the materials listed in Table 5, riprap (or rock slope protection, RSP) with a D_{50} of approximately 6 inches would likely be the most suitable for the study setting. If additional bank stabilization is needed, riprap is recommended for slope protection in favor of other "bioengineered" treatments for several reasons. Treatments that rely on vegetation to provide stability are not recommended because vegetation growth in tidal channels is limited to the upper portions of the banks (with the exception of eelgrass); hence these treatments would not protect the entire bank profile. While bioengineered treatments such as turf reinforcement mats (referred to as non-biodegradable RECPs in Table 5) can provide effective erosion control and scour protection, these materials may be prone to failure if not properly installed and maintained. Non-biodegradable erosion control products can also become hazards to marine organisms if they become dislodged or separated from the placement substrate. Whereas, RSP has the ability to adjust and conform to changes in slope geometry and requires little maintenance. Temporary channel lining materials (e.g., erosion control fabric) are not recommended in areas regularly inundated by tidal action; biodegradable erosion control fabrics may be placed on slopes in wetland-upland ecotone to provide erosion protection as vegetation becomes established.

Boundary Category	Boundary Type	Permissible Shear Stress (lb/sq ft)	Permissible Velocity (ft/sec)	Citation(s)
Soils	Fine colloidal sand	0.02 - 0.03	1.5	A
	Sandy loam (noncolloidal)	0.03 - 0.04	1.75	A
	Alluvial silt (noncolloidal)	0.045 - 0.05	2	A
	Silty loam (noncolloidal)	0.045 - 0.05	1.75 – 2.25	A
	Firm loam	0.075	2.5	A
	Fine gravels	0.075	2.5	A
	Stiff clay	0.26	3 – 4.5	A, F
	Alluvial silt (colloidal)	0.26	3.75	A
	Graded loam to cobbles	0.38	3.75	A
	Graded silts to cobbles	0.43	4	A
	Shales and hardpan	0.67	6	A
Gravel/Cobble	1-in.	0.33	2.5 – 5	A
	2-in.	0.67	3 – 6	A
	6-in.	2.0	4 – 7.5	A
	12-in.	4.0	5.5 – 12	A
Vegetation	Class A turf	3.7	6 – 8	E, N
	Class B turf	2.1	4 - 7	E, N
	Class C turf	1.0	3.5	E, N
	Long native grasses	1.2 – 1.7	4 – 6	G, H, L, N
	Short native and bunch grass	0.7 - 0.95	3 – 4	G, H, L, N
	Reed plantings	0.1-0.6	N/A	E, N
	Hardwood tree plantings	0.41-2.5	N/A	E, N
Temporary Degradable RECPs	Jute net	0.45	1 – 2.5	E, H, M
	Straw with net	1.5 – 1.65	1 – 3	E, H, M
	Coconut fiber with net	2.25	3 – 4	E, M
	Fiberglass roving	2.00	2.5 – 7	E, H, M
Non-Degradable RECPs	Unvegetated	3.00	5 – 7	E, G, M
	Partially established	4.0-6.0	7.5 – 15	E, G, M
	Fully vegetated	8.00	8 – 21	F, L, M
Riprap	6 – in. d_{50}	2.5	5 – 10	H
	9 – in. d_{50}	3.8	7 – 11	H
	12 – in. d_{50}	5.1	10 – 13	H
	18 – in. d_{50}	7.6	12 – 16	H
	24 – in. d_{50}	10.1	14 – 18	E
Soil Bioengineering	Wattles	0.2 – 1.0	3	C, I, J, N
	Reed fascine	0.6-1.25	5	E
	Coir roll	3 - 5	8	E, M, N
	Vegetated coir mat	4 - 8	9.5	E, M, N
	Live brush mattress (initial)	0.4 – 4.1	4	B, E, I
	Live brush mattress (grown)	3.90-8.2	12	B, C, E, I, N
	Brush layering (initial/grown)	0.4 – 6.25	12	E, I, N
	Live fascine	1.25-3.10	6 – 8	C, E, I, J
	Live willow stakes	2.10-3.10	3 – 10	E, N, O
Hard Surfacing	Gabions	10	14 – 19	D
	Concrete	12.5	>18	H

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

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TABLE 5: Permissible shear and velocity for selected lining materials. (Fischenich, 2001)

2.3.2 Bank Slopes

Philip Williams and Associates (PWA) (1995) provides design guidelines for slope stability of channels constructed in estuarine sediments. Very soft bay mud with shear strength of 100 lbs/ft^2 is expected to be stable at a gradient near 7:1, while well-consolidated bay mud with shear strength of 150 lbs/ft^2 will support a bank 10 feet high with a slope of 3:1 (PWA, 1995). Unvegetated slopes should be expected to hold up a maximum 6:1 slope, while vegetated banks should be expected to build near vertical to vertical slopes due to the restraint of the near-surface soils by the root mass (PWA, 1995). Thus, engineering design of the preferred alternative will need to consider the geotechnical properties of the proposed channel lining materials and estimates of shear stresses in the open channel to further refine calculations of bank stability and equilibrium slope angle.

2.3.3 Long-term Channel Stability

The primary mechanisms for large-scale adjustments (e.g., avulsion, lateral migration) in the morphology of tidal channels are changes in hydrology and sediment supply. The role these factors would play in the long-term stability of a tidal channel in the study area is discussed below.

<u>Hydrology</u>

The open channel alternatives have been designed to accommodate the existing tidal prism and stormwater discharge associated with Colorado Lagoon and the surrounding watershed (Moffatt & Nichol, 2010). In the study area, tidal prism is the dominant driver of hydrology and hydraulics in the system, though inputs from large, infrequent storm events do increase peak velocities in the channel (Table 3; Moffatt & Nichol, 2010). Results from hydraulic modeling indicate maximum velocities would be relatively low (less than 2 fps) in the main portions of the open channel. Provided that the open channel is constructed of suitable material, large-scale channel adjustments under the existing hydrologic regime are unlikely.

The effective tidal prism in the study area could increase as a result of sea level rise or scour in Colorado Lagoon, or decrease as a result of sedimentation in the lagoon. It is most plausible that tidal prism will increase to some degree due to sea level rise. An increase in tidal prism would likely cause the channel to widen. While widening of the channel as a result of increased tidal prism may occur, it is not anticipated to be of a magnitude that would present threats to adjacent infrastructure[1]. M&N has considered the impacts of sea level rise on the tidal dynamics, and the design of the open channel alternatives accommodate the range of projected hydrologic and hydraulic changes associated with changes in tidal prism due to sea level rise (Moffatt & Nichol, 2010).

<u>Sediment Supply</u>

Historically, large inputs of alluvial sediment to the study area were associated with the San Gabriel- Los Angeles river complex. The San Gabriel River watershed produces some of the highest sediment yields in southern California as a result of the extreme topography, rainfall patterns and granitic geology (Stein et al, 2007). With the study area separated from these influences by changes in land use and river management, the mechanism for excessive sedimentation to occur in the study area has been greatly diminished. The only remaining source of alluvial sediment is from the relatively small Colorado Lagoon watershed. Sediment supply from the Colorado Lagoon watershed is not anticipated to be significant because most of the watershed is developed, and open space areas within the watershed are recreation facilities (primarily golf courses) that do not produce significant amounts of sediment. In addition, some of the sediment that is supplied from the watershed will bypass the channel and lagoon with the proposed re-routing of the Termino Avenue Drain (City of Long Beach, 2008). Hence, there is no longer a mechanism for large-scale channel avulsion due to sedimentation now that the study area is no longer connected to the San Gabriel River flood flows and sediment supply.

The other source of sediment to the study site will be of marine origin. Significant deposition of marine sediments in the study area is not likely because: (1) the open channel will be sized to accommodate the potential tidal prism; and (2) the sediment load from marine sources is relatively low and would not result in significant accretion of tidal areas in the anticipated lifespan of the project (approximately 100 years). Thus, excessive sedimentation that would result in channel avulsion, or decrease tidal prism and cause the channel to narrow, is unlikely to occur.

[1] See Moffatt & Nichol Colorado Lagoon Alternatives Report for a discussion on the impacts of sea level rise.

3.0 EVALUATION AND CONCLUSIONS

3.1 ALTERNATIVES EVALUATION

The analyses presented in the previous section indicate that with relatively minor adjustments to channel geometry and bank materials all of the proposed alternatives could be designed to function properly from a geomorphic standpoint. The benefits and constraints that can be distinguished among the alternatives are discussed below.

Alternative 2 and 3: These alternatives are essentially equivalent from a geomorphic standpoint, with the exception of bank slopes. The maximum bank slope for Alternative 3 is steeper than Alternative 2 (2:1 versus 3:1). The maximum slope recommended for design of tidal channels in estuarine sediments is 3:1 (PWA, 1995). Banks that exceed the maximum recommended slope would need to be constructed of channel lining materials that are more stable than soil (e.g., riprap). This is not necessarily problematic, but armored banks may diminish habitat values and aesthetics.

Both of these alternatives have adequate cross-sectional area to convey the potential diurnal tidal prism assuming the capacity of the parallel culverts is maintained. If the parallel culverts were to become blocked or were not adequately maintained, the tidal channels would likely erode to accommodate the additional tidal prism. This could be problematic because the channel is highly constrained by adjacent land uses. Thus, these alternatives would require on-going maintenance of the parallel culverts. It may be feasible to "over-design" the new parallel culvert to accommodate loss of capacity due to biofouling, and therefore avoid the need for on-going maintenance. No additional maintenance of capacity (e.g., dredging) or bank stability is anticipated, provided that the channel is constructed according to the engineer's technical specifications.

Alternative 4: This alternative has the lowest flow velocities, largest cross-sectional area and shallowest slopes of the three alternatives. This indicates that it would be the least prone to erosion and would require the least amount of maintenance to maintain channel stability. Moreover, this alternative is not dependent on maintenance of the parallel culvert for conveyance capacity. The cross-sectional area and top width at the widest section exceeds the geometry predicted from empirical geomorphic relationships. An "oversized" channel would have the tendency to aggrade over time, the rate of which would be dependent on sediment supply and hydraulics. This condition would not necessarily be problematic, and a conservatively designed channel with a tendency toward aggradation, may be desirable given the study setting. Finally, of the alternatives presented, Alternative 4 provides the greatest opportunity to create a diverse wetland environment that is resilient to changes in sea level.

3.2 CONCLUSIONS

Colorado Lagoon is essentially a relic landform that was shaped by the complex interaction of the tides and alluvial deposition/erosion associated with the San Gabriel River. Historical maps and images provide evidence that Colorado Lagoon and the study area were historically tidal habitats with landscape features of similar dimensions to those proposed in the open channel alternatives. Thus, all of the proposed open channel alternatives present restoration concepts that closely match the historical landscape morphology at a local scale. When restoring wetlands in southern California Stein et al. (2007) caution against "type conversion" i.e., creating specific wetland habitats at a location where they historically did not exist. The proposed open channel provides an excellent opportunity to restore wetlands in the appropriate historical context. Further refinement of channel geometry, substrate type, slope stability and transitional habitats (e.g., alkali meadow) should be components of the subsequent phases of design. As with all restoration projects, channel morphology will need to be monitored and adaptive management measures may be warranted if adjustments exceed thresholds established for lateral erosion or sediment deposition.

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Geomorphic Study for Phase II of the
COLORADO LAGOON RESTORATION PROJECT

FIGURES

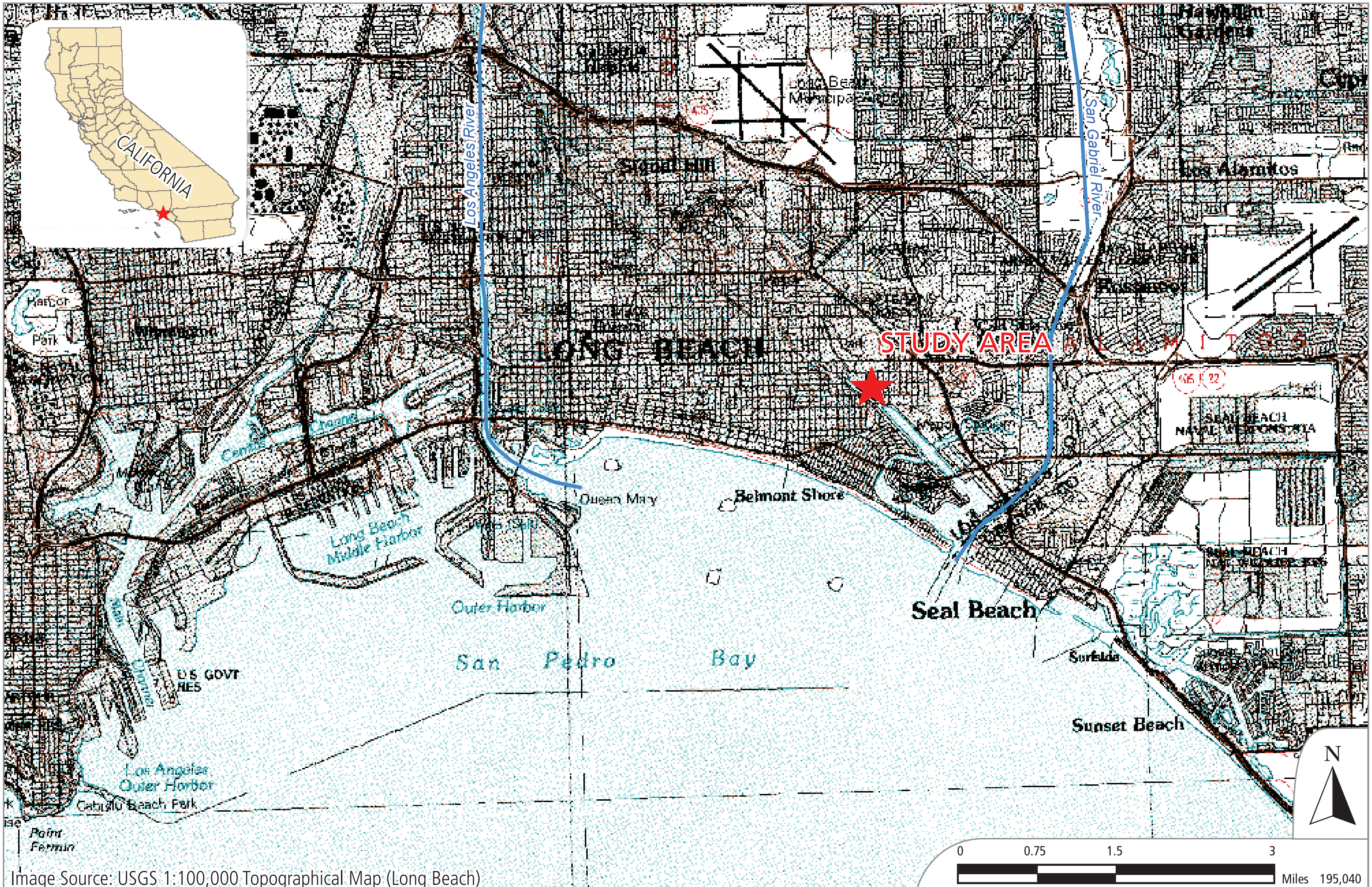

FIGURE 1: Vicinity map.

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FIGURE 2: Map of the study area.

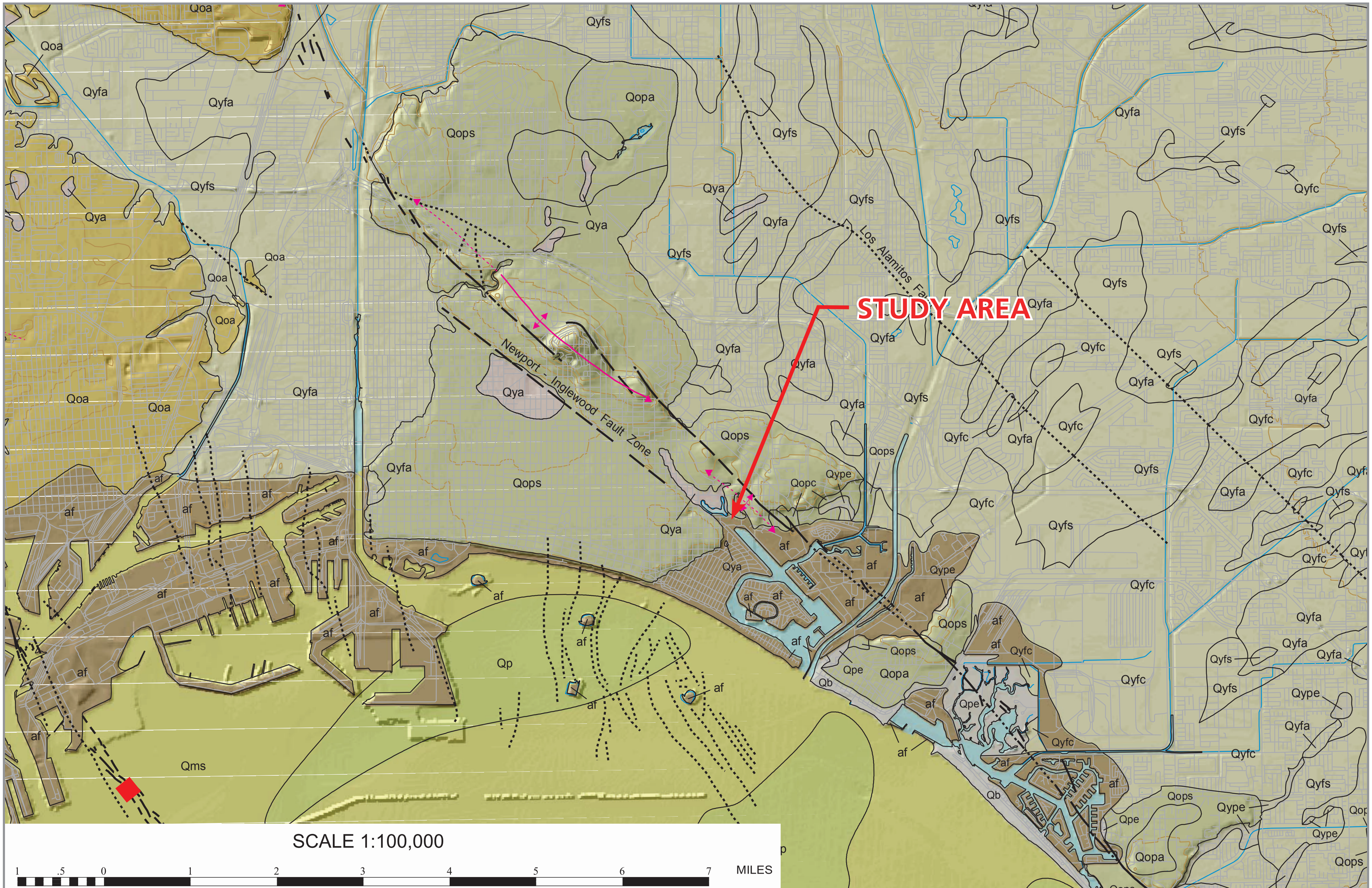

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FIGURE 3a: Geology map of the project vicinity (Courtesy California Department of Conservation).

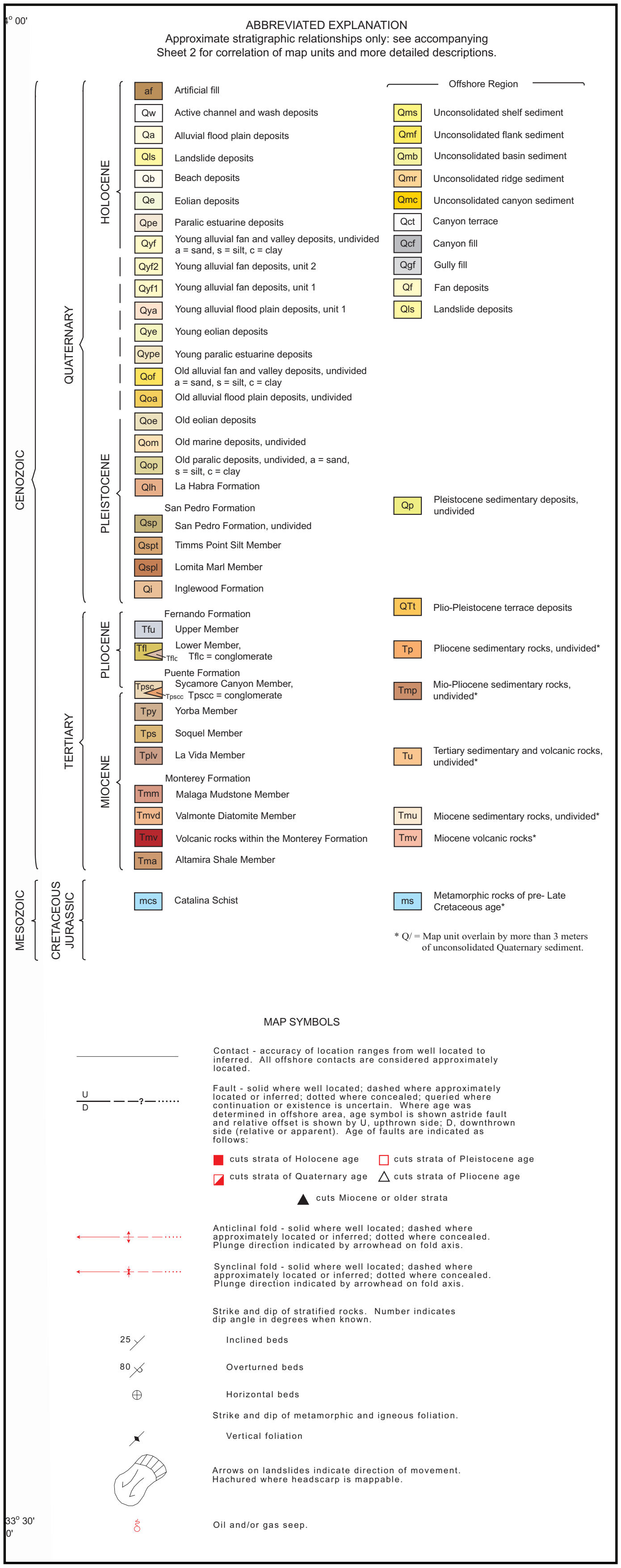

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FIGURE 3b: Key for geology map (California Department of Conservation).

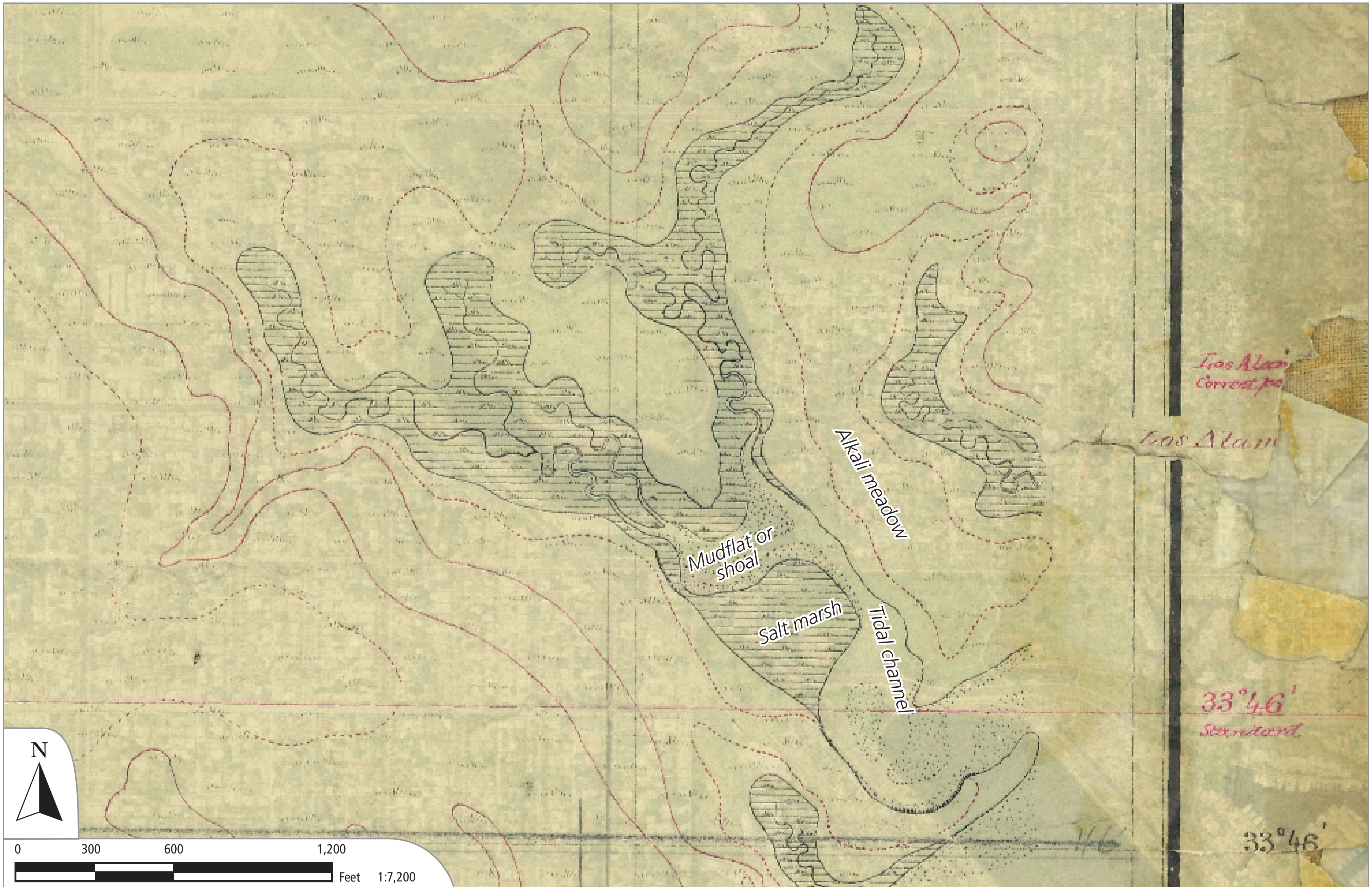

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FIGURE 4: 1872 US Coast Survey map overlaid on 2007 aerial image.

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FIGURE 5: 1921 oblique aerial photos of Long Beach / Alamitos Bay and the project area.

FIGURE 6: Chronosequence of aerial photos (Courtesy of LSA).

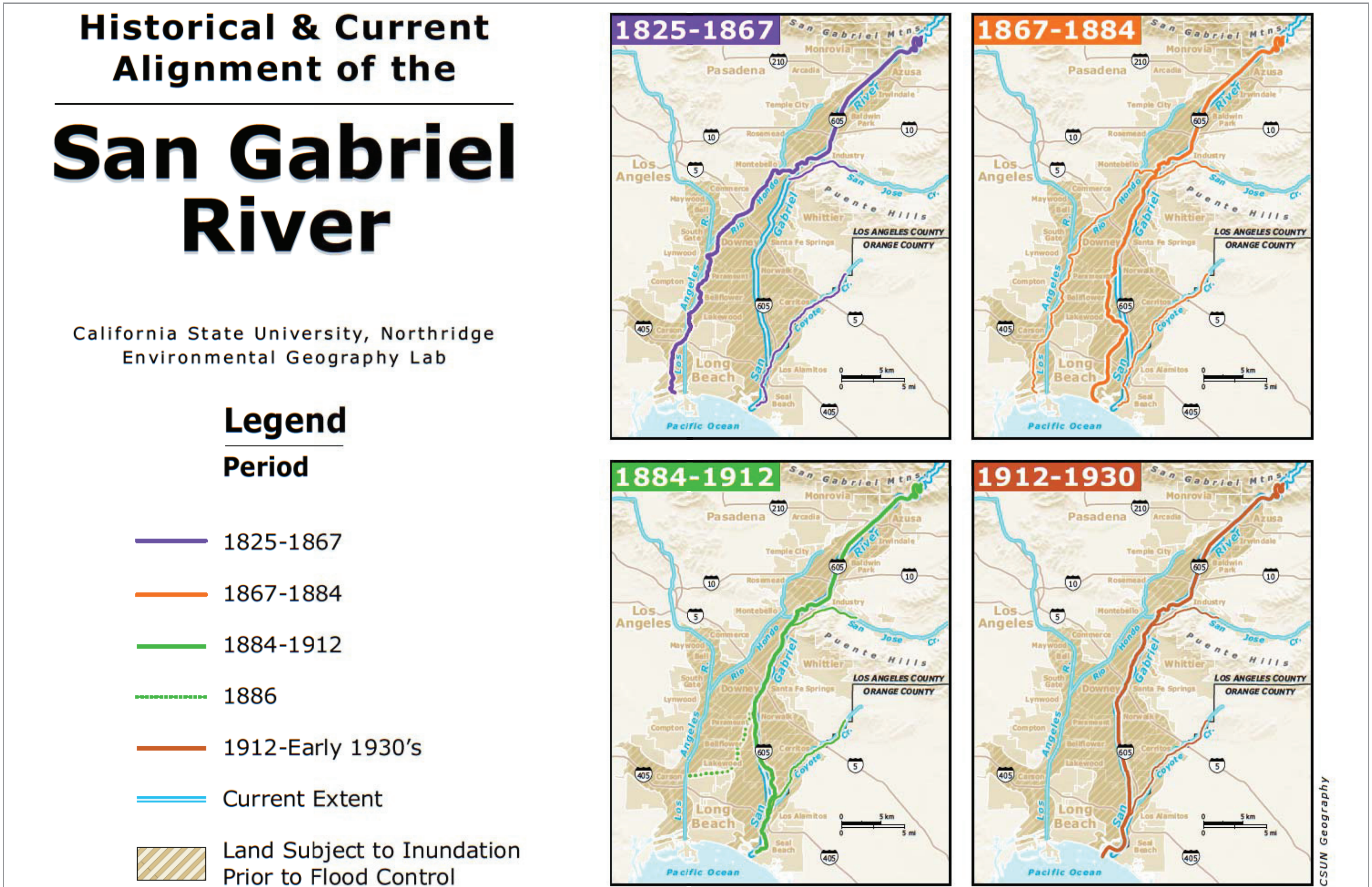

FIGURE 7: Historical and current alighment of the San Gabriel River (after Stein et al 2007).

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