Historical ecology as a tool for assessing landscape change and wetland restoration priorities

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ABSTRACT

Vast resources are devoted annually to watershed management and wetland restoration. Historical wetland losses are often cited as a motivation for prioritizing ambitious wetland restoration efforts. However, analysis of historical conditions is often underutilized in the planning process. In this paper, we demonstrate the use of historical ecological analysis for wetland and riparian restoration planning in the San Gabriel River watershed in southern California. We integrate multiple disparate data sources collected at different spatial and temporal scales to describe historical wetland extent and distribution. We compare historic wetlands to contemporary conditions to calculate wetland losses. From the results of this analysis, we conclude that the widely held view of southern California as naturally dry and desert-like with mainly ephemeral and intermittent streams may be an over generalization. Historically, the San Gabriel watershed has supported complex expanses of channels, ponds, sloughs, seeps, marshes, and seasonal wetlands that alternated between wet and dry conditions on multi-year to decadal cycles. We estimate that >86% of historical wetlands have been lost since ca. 1870, with the greatest losses occurring to palustrine alkali meadows in the lower floodplain. Despite the extensive losses, the analysis reveals areas of the watershed conducive to wetland re-establishment and provides insight into the most appropriate wetland types to prioritize for specific watershed settings.

INTRODUCTION

Where have our greatest wetland losses occurred and what types have been most heavily impacted? Where in a watershed should wetland restoration be prioritized? What is the appropriate restoration target? How should we determine whether a restoration effort has been successful? These commonly asked questions are central to successful wetland restoration and management. Optimally, wetland and riparian habitat preservation and restoration should be guided by a comprehensive understanding of the ecosystem in its natural state (Steyer *et al*. 2003, Simenstad *et al*. 2006, Montgomery 2008). This understanding should serve as a reference for restoration planning and performance monitoring by determining wetland types that have experienced greatest loss, identifying appropriate positions in the landscape for re-establishing wetlands and providing insight into the structure and function of undisturbed systems.

Numerous studies, including the 2001 National Research Council (NRC) report on compensatory wetland mitigation, have recommended that that restoration and mitigation planning would be greatly improved if done within the context of ecosystem function at both the site and landscape scales (Kentula 1997, Kershner 1997, NRC 2001, White and Fennessy 2005, Kentula 2007). Unfortunately, much of our understanding of wetland and riparian ecology is derived from systems already highly modified by human activities. As a result, it can be difficult to identify appropriate reference conditions or to distinguish natural processes from anthropogenic effects.

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While not meant to provide a blueprint for the future, reconstructing historical patterns can inform decisions regarding restoration and management by improving our understanding of both cultural and natural processes that led to current conditions and by providing insight into key drivers of change over a long-term period (White and Walker 1997, Rhemtulla and Mladenoff 2007, Etter *et al*. 2008). Previous studies have demonstrated the feasibility of historical analysis for providing insight into natural patterns of shorelines and estuaries (Van Dyke and Wasson 2005, Engstrom 2006), and large river valleys (Andersen *et al*. 1996, Collins *et al*. 2003).

With the exception of a few studies (e.g., Grossinger *et al*. 2007), previous historical analysis of wetland and riparian systems has either covered large geographic areas with coarse resolution (Etter *et al*. 2008) or focused primarily on more limited areas driven by program-specific objectives (Mattoni and Longcore 1997, Cooper 2008). The latter analysis is often restricted to a single habitat type at a given point in time and/or relies on limited historical resources (e.g., aerial photography). Site specific analysis does not allow for full understanding of landscape scale patterns that may influence historical condition. Analysis based on a single data source, such as aerial photography, may be misleading. For example, historical aerial photo analysis of rivers and wetlands may be limited by substantial changes to the landscape already present at the time of earliest aerial photographs (Timoney 2006, White and Greer 2006). In addition, because landscapes vary through time, particularly in areas prone to regular disturbance such as flood and fire, analysis of multiple time periods is necessary to draw reliable conclusions about historical conditions. To be instructive for restoration planning, historical analysis should be geographically focused, holistic, use multiple data sources, and aim to reveal landscape-scale processes over time (Marcucci 2000).

In this paper, we demonstrate the utility of historical ecology to environmental planning by assessing the historical condition of wetland and riparian systems of the San Gabriel River watershed in southern California, USA, over time in context of natural and anthropogenic processes. We use historical ecology to "reconstruct" the wetland mosaic prior to large scale modification and assess regions and wetland types that have been most impacted. The approach and challenges of historical analysis are shown as we integrate multiple disparate data sources collected over a variety of spatial and temporal scales. We also apply methods for assigning confidence estimates to the conclusions about historical wetland extent and distribution based on the number and reliability of corroborating data sources for the location or type of a particular wetland.

METHODS

San Gabriel Watershed

The San Gabriel River receives drainage from a 1,865-km^2 (720-mi^2) area of eastern Los Angeles County, California. We focused our analysis on the lower floodplain (circa 1870) from the base of the San Gabriel foothills (near present day Azusa) to the boundary with the historic San Gabriel/Los Angeles River estuary (Figure 1).

The San Gabriel River watershed provides an excellent case study for historical ecological analysis. First, human history of the region is fairly well

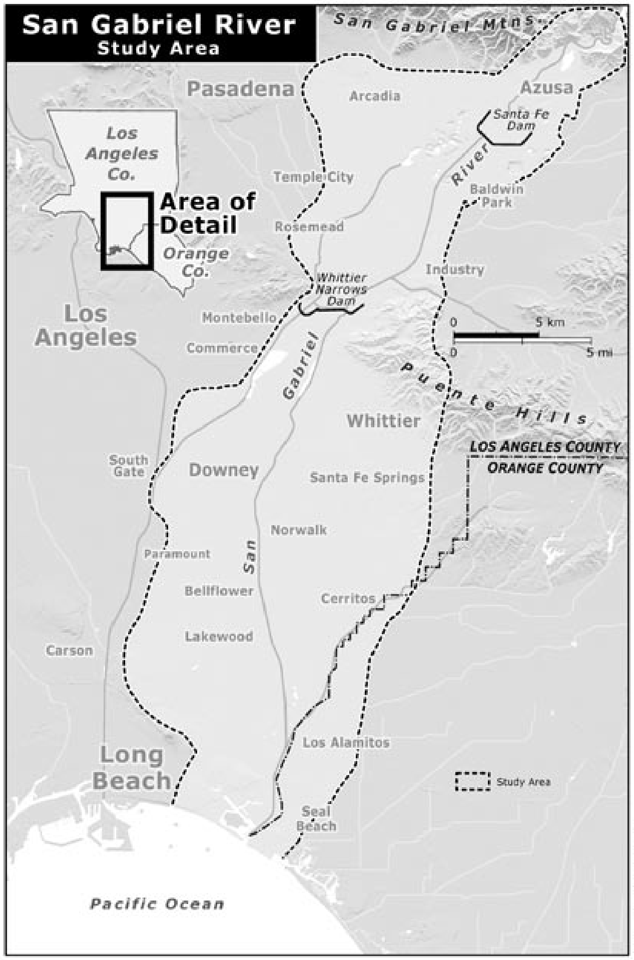

Figure 1. San Gabriel Watershed showing boundaries of the study area. Analysis focused on the historical lower river floodplain.

documented. Second, the natural watershed processes have been dramatically altered. Four dams have been constructed in the upper watershed to control flow and sediment. Downstream of the dams a series of large spreading grounds takes advantage of deep alluvial deposits at the base of the San Gabriel Mountains for groundwater recharge. The combination of the dams and spreading grounds has dramatically altered the hydrology and geomorphology of the lower watershed. The lower portion of the San Gabriel River flows through a concrete-lined channel in a heavily urbanized portion of Los Angeles County before discharging into the ocean. Third, the San Gabriel River watershed is currently the subject of several integrated resource management and planning efforts that could be informed by the results of this analysis.

General Approach

Unlike contemporary habitat analysis, historical analysis relies on interpretation of multiple data sets that were not collected with this use in mind (Egan and Howell 2001). Conclusions must be developed from multiple data sources that collectively provide a “weight of evidence” that supports inferences about historical condition. This is particularly true in the western United States (US) where the period of historical documentation is often shorter than in other parts of the country. Our methodology was structured from previous historical wetlands and watershed mapping projects conducted in California by Grossinger (2005) and Grossinger *et al*. (2007).

The southern California landscape is dynamic across both spatial and temporal scales, particularly with regard to streams and wetlands (Gumprecht 1999). This dynamism complicates historical wetlands mapping, but does not preclude it given available historical data sets, a clearly defined study area boundary, and a well defined target time period. In light of this dynamism, we mapped features that are controlled by geomorphic and climatic processes that have been relatively stable in the western US for the past several hundred years (Meko *et al*. 2001) and appear to be persistent over the 100-year time period covered by our data set. These features include topographically controlled wetlands and the larger floodplain of the San Gabriel River.

We used a wide variety of source materials to document prevailing conditions prior to significant Euro-American modification. While recognizing natural inter-annual and decadal variation, we attempted to map average conditions in the decades surrounding initial Euro-American occupation, circa 1850-1890. We found that palustrine, depressional wetlands were typically relatively stable and documented by multiple sources during this time period (Hall circa 1886, Gannett 1893, Dunn and Holmes 1921). For the more dynamic fluvial and riparian features of the San Gabriel River channel, we documented average conditions during the period of 1867-1884. There is a wealth of data available for this period which coincided with rapid settlement of the Los Angeles area following California statehood in 1848. Furthermore, this 17-year period included two major and several minor floods separated by intervening years with average rainfall conditions. This climatic sequence facilitated migration of the San Gabriel River channel to an alignment very similar to its current position in the landscape, making it useful for comparison to contemporary conditions.

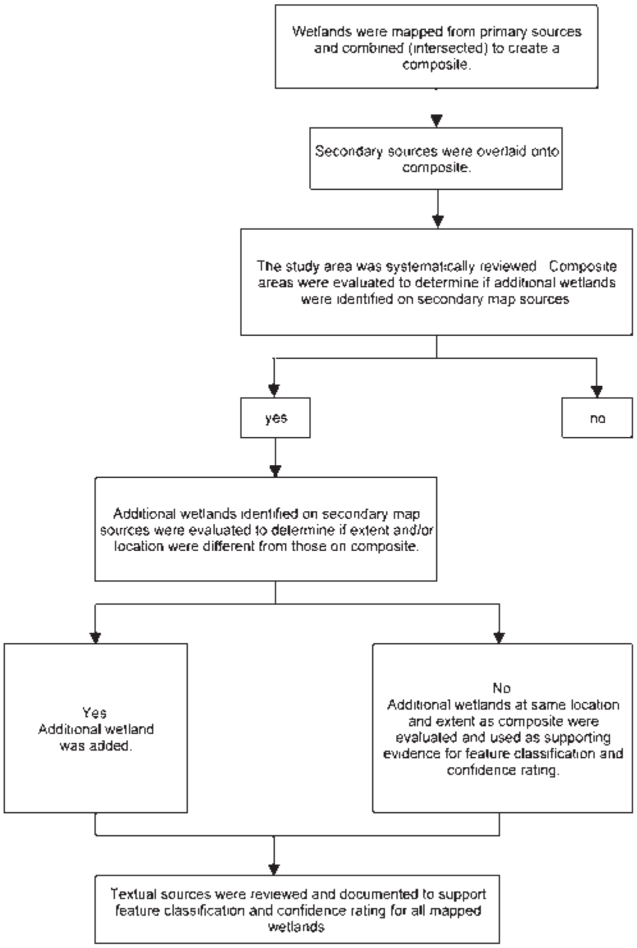

Figure 2. Methodology for historical ecological analysis from data discovery through analysis.

The process of compiling, analyzing, and synthesizing historical data sources into a "wetland map" consisted of the general steps illustrated in Figure 2; each of these steps is discussed in detail below.

Historical Data Sources, Collection, and Compilation

Historical information covering the period of 1769-1930 was compiled from a diverse range of sources. Mapping was based on data representing average conditions over the period of 1850-1890. Data from 1769 to 1930 were used to provide additional insight into the origins, persistence, and dynamism of wetland features and to supplement analysis and interpretation derived from the primary mapping sources.

Primary data sources included maps produced around the period of California statehood. Mexican land grant sketches (diseños) provide some of the earliest detailed maps of water features in southern California and often include distinctive features such as wetlands, rivers, creeks, and woodlands. General Land Office (GLO) surveys were the first extensive federal surveys of lands and generally conformed to the original land grant boundaries. The GLO data include field notes that provide precise locations of markers, which can be used to substantiate the location of historical aquatic resources. Useful irrigation maps and reports were prepared by California's first State Engineer, W.H. Hall, in 1886 and 1888. The Hall (1886) maps use a number of standard mapping symbols and textual annotations to represent water resources, such as springs and seep, creeks and reservoirs, marshes or ciénegas, areas of moist soil, and natural depressions present in the study area. The US Department of Agriculture (USDA) Reconnaissance Soil Survey and Report was conducted in 1917 and published in 1921. The soil survey map proved to be an important initial data source for the identification of historical wetlands based on the locations of soils described as having the potential to support wetland and alkali conditions (Dunn *et al*. 1921). The oldest US Geological Survey (USGS) topographic map used in our study area was dated 1893 and covers a major portion of the study area. While these maps were produced on a much smaller scale than local sources, such as Hall (1886), they illustrate larger features and use a standardized mapping convention. These maps provide a basis for identification of historical wetlands, and their consistency with contemporary maps facilitated comparisons across multiple time periods.

The earliest available aerial photographs of the study area were taken in 1928. These aerial photos (obtained from the Los Angeles County Department of Public Works) were comprehensive for the entire study area. However, by 1928, much of the San Gabriel Valley was already converted to either agriculture or urban land uses. As such, we relied on this dataset to identify the presence and timing of change to persistent wetland features. The photos, when analyzed in comparison with earlier historical map documents, exhibited numerous landscape changes brought about by natural disturbance and human modification.

The primary cartographic data sources were supplemented by a general survey of key historical and geographical aspects of Los Angeles area rivers. Collections of essays on indigenous peoples, development, and historical environmental conditions describe land use/cover prior to and at the beginning of European contact (Gutiérrez and Orsi 1998, Gumprecht 1999, Orsi 2004, Deverell and Hise 2005). The most important secondary resource was a collection of oral histories of floods as told by residents interviewed by Los Angeles County flood engineer James W. Reagan and his assistants in 1915 (Reagan 1915). Reagan's report provided the most specific and crucial evidentiary information on the nature of the San Gabriel River during the latter half of the 19th century, including accounts of the extent and duration of inundation, and major shifts in the course of the river associated with large storms. Primary and secondary data sources are described in greater detail by Stein *et al*. (2007).

Data Integration and Wetland Mapping

The general process of integrating cartographic and textual data sources follows the methods described by Grossinger *et al*. (2007). Historical cartographic data were collected and scanned to create high-resolution digital copies and georeferenced so that each data set could be overlaid using ArcGIS 9.1. A geodatabase was then created to store wetland features, including spatial and associated attribute data.

A set of primary cartographic sources were used to systematically assess historical wetland features within the study area. Wetland polygons were identified using a set of pre-defined rules (Figure 2) that guided integration of multiple data sources into an overall wetland map. To qualify as a primary data source, a map had to provide comprehensive coverage of the study area and have been produced using a standardized, documented, and generally accepted mapping methodology. Two available data sources met these criteria and were used to generate the initial wetland base map: the 1917 USDA soil survey and the 1886 irrigation map produced by Hall. Soil series mapped on the 1917 survey were compared to the regional lists of hydric soils prepared by the USDA Natural Resources Conservation Service. This provided detailed textual and spatial information about soils that have the potential to support wetlands. The extent of these soils were digitized and attributed into the historical wetland geodatabase as the first base wetland polygon layer.

The Hall (1886) irrigation maps provided the most detailed and earliest maps of wetlands, streams, creeks, and other aquatic features. Hall (1886) demonstrated a wealth of standard mapping symbols and textual annotations to represent water resources present in the study area. All natural wetland and riparian features mapped on the Hall (1886) irrigation maps were digitized and attributed as the second base wetland polygon layer.

The soil survey and irrigation map base layers were augmented with multiple ancillary data sources included digitized GLO maps, diseño maps, US Coast survey sheets, and topographic maps (Figure 3). These data were used to map wetlands that were not identified on the soil and irrigation maps, corroborate the two primary data sources, provide increased certainty in the extent and location of wetland features, and provide insight into temporal fluctuations in spatial extent. Ancillary data sources were particularly important in the southern region of the study area at the transition between with San Gabriel River and its estuary, where the irrigation maps did not illustrate as much detail as in other portions of the study area. In situations where a feature, such as a stream, was present on two or more map sources in the same location with the same meander, we chose to map the feature from the most detailed and earliest source. This prevented over inflation of area that could result from merely merging polygons that were at slightly different locations because of the georeferencing of the original map sources. Locations of probable wetland features were further corroborated based on descriptions collected from diverse data

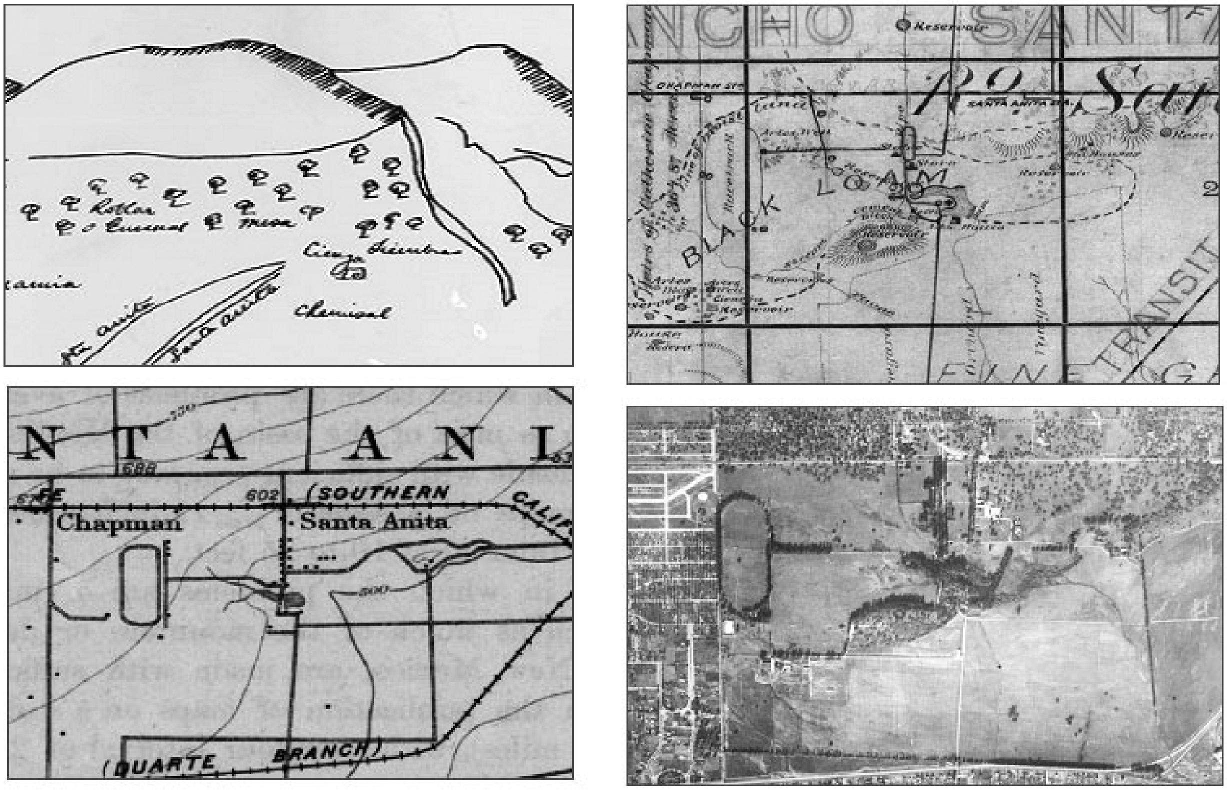

Figure 3. Sample of maps at the same location in the northern region of the study area showing the presence of several springs. Clockwise from Top Left: Diseño map, circa 1800, note the word "cienega" a Spanish Colonial term for spring, courtesy of USC Digital Library; Detailed irrigation map, Hall 1886; Topographic map surveyed in 1894, (Gannett, 1894); and Aerial photos of the same location taken in 1928 (photos courtesy of Los Angeles County Department of Public Works).

sources, including oral histories, essays, and historical ground level photographs. Each resultant wetland polygon was attributed with all data sources that contributed to its delineation.

Streams were mapped slightly differently from other wetland features. Because the irrigation maps were of the largest scale and provided detailed outlines of river beds, we chose this as our primary layer for mapping the San Gabriel River. Hall (1886) did not map smaller streams that were present as lines on the topographic maps. To compare the areal distribution of all wetland features, we created polygons of these smaller streams in the study area by adding a 2.5-m buffer around the historical stream line, consistent with contemporary National Wetlands Inventory protocol for mapping streams as polygons (FGDC 2009).

To provide additional insight into historical wetland areas, we characterized the general floristic composition of representative wetland types using available herbaria records. The initial data for this effort was obtained via the electronic data portal at the Jepson Flora Project's online interchange (http://ucjeps.berkeley.edu/interchange.html). We searched for all specimens that included a series of place names in the "locality" field. These place names included current and historic names of all places that could be identified along the coastal plain of the San Gabriel River. Herbaria records were corroborated by a review of the two classic floras of Los Angeles (Abrams 1904, 1911; Davidson and Moxley 1923). Based on these sources, we created a list of potential species by either place name or habitat description. All plant species that might have been found in wetlands or riparian zones of the San Gabriel River were recorded based on their known habitat and any unequivocal specimen localities along the river.

Each wetland polygon was attributed with a general habitat description and classified using the US Fish and Wildlife Service NWI classification system. This system was developed to map contemporary wetlands and riparian areas in southern California and uses the standard classification developed by Cowardin *et al*. (1979), but adds a set of modifiers based on the Corps of Engineers hydrogeomorphic (HGM) classification system (Brinson 1993). The resultant historical wetland maps were compared with recently updated contemporary NWI mapping to assess changes in the extent and distribution of wetlands areas within the study area.

In addition to these standardized contemporary wetland classifications, we also classified wetland habitats using the California Department of Fish and Game (CDFG) List of California Terrestrial Natural Communities (CDFG 2003). The CDFG classification provided specific ecological land cover types with which land managers are more familiar, and allowed for easier comparison to contemporary wetlands. Similar habitats were aggregated to more general categories to simplify the analysis and to account for some of the uncertainty associated with interpretation of historical maps (Table 1).

Assessing Certainty in Historical Wetland Mapping

The level of certainty in the reconstructed/synthetic maps of historical wetlands can be affected by many factors, including: accuracy of the source maps, condition of the maps, goals of the original data collection, timing of the original mapping, and contemporary interpretation. We assessed certainty in our conclusions based on three factors using a method developed by Grossinger *et al*. (2006, 2007): interpretation (i.e., did the feature exist?), location (i.e., did we map the feature in the correct location?), and size (Table 2). Certainty in a feature's interpretation was assigned based on the number and quality of sources, with soil and irrigation maps being of the highest quality. For example, a feature would receive a high certainty rating for "interpretation" (i.e., we were certain that the feature existed) if present on both of the primary mapping sources (irrigation and soils maps) and supported by other cartographic and textual data sources. Certainty in a wetland's historical location was assessed by mapping the range of all possible locations based on available evidence, placing a wetland polygon in the center of this range, and measuring the estimated possible error associated with decisions regarding wetland location. We then estimated how much larger and smaller the feature could be drawn while fitting all constraints, and assigned the feature a corresponding "size" certainty classification.

RESULTS

Temporal and Spatial Dynamism of the San Gabriel River

Prior to 1870, the San Gabriel River was a dynamic system (Figure 4). This is in sharp contrast to the current condition in which the lower San

Table 1. Extent of historical wetlands and associated habitat types in the San Gabriel River floodplain. Area mapped and numbers of polygons are estimates of historical features in the study area.

Habitat Classification	Cooresponding Cowardin *et al.* (1979) Classification(s)	Cooresponding Natural Communities from the California Natural Diversity Database (2003)	No. Unique Wetlands Mapped	Area (ha)
Alkali Meadow	Palustrine Emergent Saline Wetland	Alkali Meadow	33	9.400
Tidal Marsh	Palustrine Emergent Saline Wetland	Salt-alkali Marsh Pickleweed Wetland	2	760
Willow Woodland	Palustrine Forested Wetland	Arroyo Willow Riparian Forests and Woodlands Black Willow Riparian Forests and Woodlands	9	600
Wet Meadow	Palustrine Emergent or Scrub Shrub Wetland	Rush Riparian Grassland Freshwater Seep	50	3.800
Perennial Freshwater Wetland	Palustrine Persistent Emergent or Scrub Shrub Freshwater/Saline Wetland	Marsh (various habitat associations)	42	360
Perennial Freshwater Pond	Palustrine Permanently Flooded Wetland	N/A - no vegetation community	6	60
Alluvial Scrub Shrub Dry Sandy Wash	Braided Unvegetated Channel, Riparian Scrub Shrub. Gravel Beds. Islands and Bars	Riversidian Alluvial Fan Sage Scrub Sandy to Cobbley Wash Bottom	4	2.300
		Alluvial Fan Sage Scrub	2	220
Riparian Woodland	Palustrine Forested Wetland	California Sycamore - Coast Live Oak Southern Cottonwood - Willow Riparian	9	190
Riparian Scrub Shrub	Braided Unvegetated Channel, Riparian Scrub Shrub	Mulefat Scrub Scrub Willow	10	750
Streams	Not classified as wetlands by Cowardin *et al.*	N/A - no vegetation community	47	630
Freshwater Slough	Palustrine Emergent	Slough-Sedge Common Rush	18	30
TOTALS			***232***	***19,100***

Table 2. Certainty levels for historical landscape synthesis (based on Grossinger *et al.* 2007). Certainty is evaluated based on the existence of the feature (interpretation), the size of the feature, and its location in the watershed.

Certainty Level	Interpretation	Size	Location
Extra High (Location Only) "Definite"	--	--	Expected maximum horizontal displacement <15 meters.
High "Definite"	Feature definitely representative of conditions circa 1870.	Accurate source of material that probably closely follows actual shape; estimated to be correct to within 10% of actual area.	Expected maximum horizontal displacement <50 meters.
Medium "Probable"	Feature probably representative of conditions circa 1870.	Less accurate source material that probably generally follows actual shape; estimated to be correct within 50% of actual area.	Expected maximum horizontal displacement <150 meters.
Low "Possible"	Feature possibly representative of conditions circa 1870.	Not necessarily representative of actual shape/size.	Expected maximum horizontal displacement <500 meters.
Extra Low (Location Only) "Possible"	--	--	Expected maximum horizontal displacement <2500 meters.

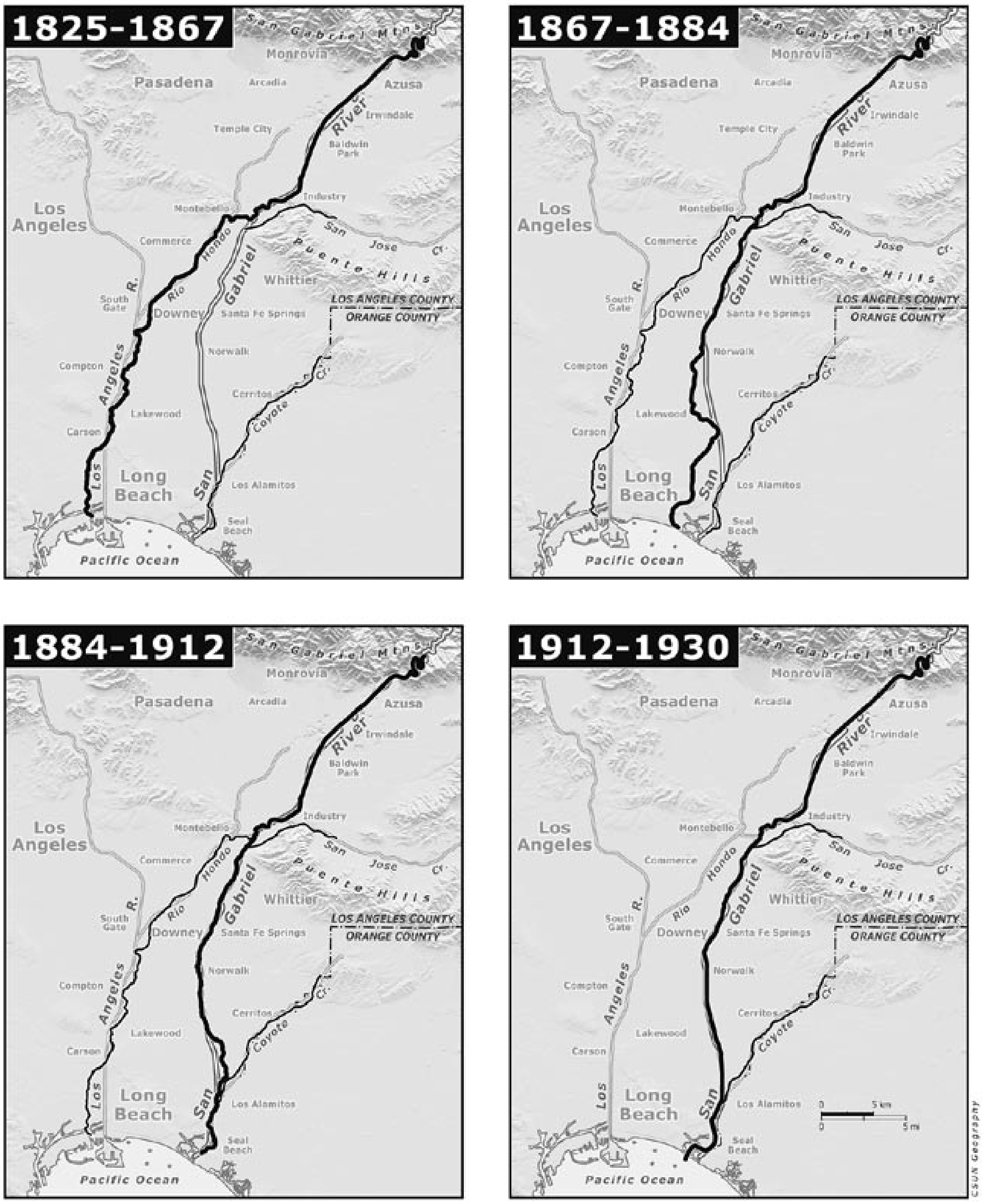

Figure 4. Major alignments of the San Gabriel River between 1825 to the present day. The current Los Angeles and San Gabriel Rivers (grey double line) have been excavated and are encased in concrete causing them to have a very straight and unnatural appearance with regard to alignment.

Gabriel River is confined between the levees of concrete flood control channel and largely devoid of native wetland habitat. Historical dynamism created a volatile combination of periods with little to no flow and periods of massive flooding. Changes in river alignment over time likely resulted from a combination of variability in precipitation patterns (and associated sediment discharge) and heterogeneity of the valley floor geology.

Between 1825 (the earliest available maps) and 1912, the San Gabriel River had at least four major alignments (Figure 4). Between 1825 and the 1861-1867 period, the San Gabriel River was a tributary to the neighboring Los Angeles River. During the flood of 1861-1862, facilitated by dense willow growth in the channel, a portion of the flow from the San Gabriel River migrated eastward. During the storms of 1867-1868, in which nearly 127 cm (50 in) of rain fell over a 30- to 40-day period, the majority of flow migrated east and was referred to as the "New River". The New River appears to have followed the earlier Arroyo San Gabriel, as illustrated with distinctive meanders in early diseño maps. The

Arroyo San Gabriel may have been a former or overflow channel, as primary flow moved back and forth between the Los Angeles and San Gabriel alignments. Beginning in 1912, a series of levees and other flood control measures, combined with aggressive ground water extraction, resulted in a more "stable" alignment of the San Gabriel River, approximating its contemporary course.

The dynamic quality of the San Gabriel River Valley made characterization of the floodplain particularly difficult. We chose to focus on the analysis of wetland and riparian condition circa 1868, when the San Gabriel River assumed an independent course into Alamitos Bay (i.e., was no longer, tributary to the Los Angeles River). However, as noted earlier, it is important to recognize that the river likely also flowed along this independent course at some point prior to 1867.

Despite the dynamic nature of the San Gabriel River floodplain, historical data suggests consistent spatial patterns that allow delineation of the floodplain into four distinct regions. These regions are governed by geology and physiography, and each is associated with distinct plant communities. The Upper San Gabriel River floodplain, starting below the foothills of the San Gabriel Mountains, was a broad alluvial fan averaging 2,500 m (8,200 ft) wide with highly braided channels. Approximately 12 km (19 mi) below the base of the foothills, the alluvial wash began to consolidate into a distinct channel above the Whittier Narrows, where bedrock outcrops likely forced ground water to the surface and allowed this area to be dominated by a mosaic of riparian areas and perennial wetlands.

Downstream of the Whittier Narrows area, the San Gabriel River again flowed over a more permeable surface, resulting in an increase in subsurface flow and decrease in the duration and extent of surface flow. The floodplain in this area meandered dramatically across the valley floor during major flood events and was indistinguishable from the Los Angeles River floodplain. The boundary between the southern San Gabriel River floodplain and the San Gabriel/Los Angeles River estuary was a dynamic zone that changed on both annual and interannual cycles.

Historical Wetland Extent and Composition

Historical analysis of the lower San Gabriel River floodplain resulted in an estimate of 19,100 ha (47,200 acres) of wetlands and riparian habitat which can be classified into 12 general wetland types (Table 1; Figure 5). Two depressional wetland types and one riverine wetland type dominated the historic wetland distribution. The most common historical wetlands were the estimated 9,400 ha of expansive alkali meadows found along the tidal fringe area of the lower floodplain and the 3,800 ha of wet meadows in the Whittier Narrows area. In the upper floodplain, the estimated 2,300 ha of riverine wetlands supported a mix of alluvial scrub shrub and riparian habitats. Of particular note are the approximate 100 ha of slope/seep/spring wetlands, most of which have been extirpated from the contemporary landscape.

The southern floodplain supported the broadest diversity of wetland types, supporting willow woodlands, wet meadow, perennial freshwater wetland, perennial freshwater ponds, dry sandy washes, and riparian scrub. This floodplain was extremely dynamic from year to year and likely consisted of a mosaic of depressional wetlands, secondary channels, and riparian habitat -- channels interspersed

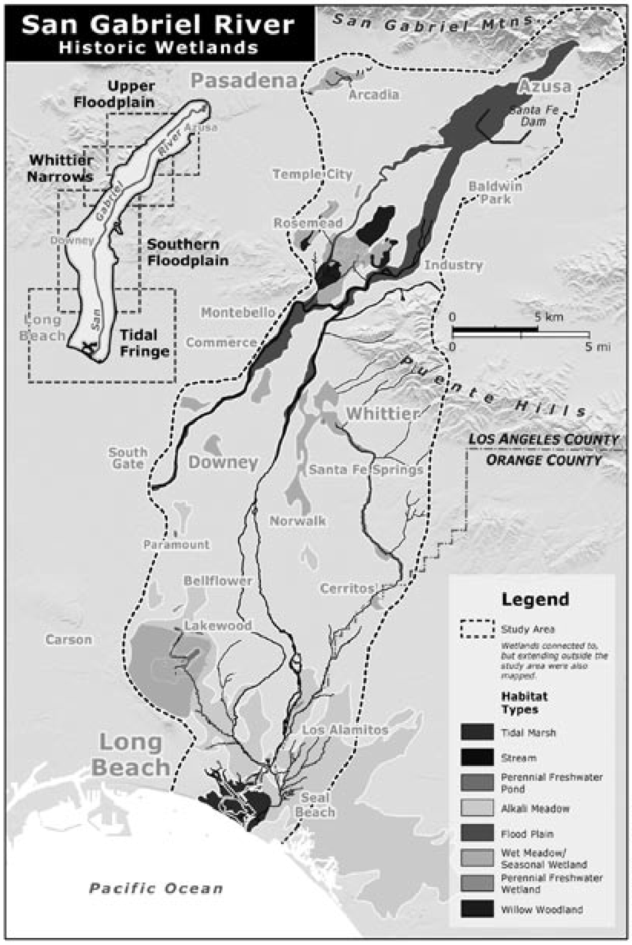

Figure 5. San Gabriel River historical wetlands.

among an upland matrix in varying proportions depending on the specific year, the time of year and the amount of rainfall the previous winter.

Certainty in Historical Estimates of Wetland Extent

Overall certainty in data interpretation was relatively high; we had a high level of certainty in 71% of polygons, and a low level of certainty in only 3% of polygons. Our certainty in the size of wetland polygons (and hence the overall area) was lower, with a medium level of certainty in the size of 77% of polygons and a low level of certainty in the size of 11% of polygons. As stated above, the extent of wetland type was not uniform, with total area per wetland type varying from 9,300 ha for alkali meadow to 6 ha for tidal slough. To account for this variation on overall certainty estimates, we calculated a weighted average of overall certainty. This analysis showed that we had high or medium certainty in our interpretation of 94% of the wetlands (i.e., we are fairly confident in their presence). In contrast, we have low certainty in the size estimates for 50% of the wetland area (i.e., there is moderate to high uncertainty in the actual extent of historical wetlands; Figure 6).

Certainty varied by wetland type based on numerous factors such as size, extent, likely persistence, and location in the watershed (Figure 6). One wetland type, alkali meadow, accounted for 50% of the total estimated historical wetland area, causing it to dominate our overall certainty estimates. To account for this, we estimated certainty levels

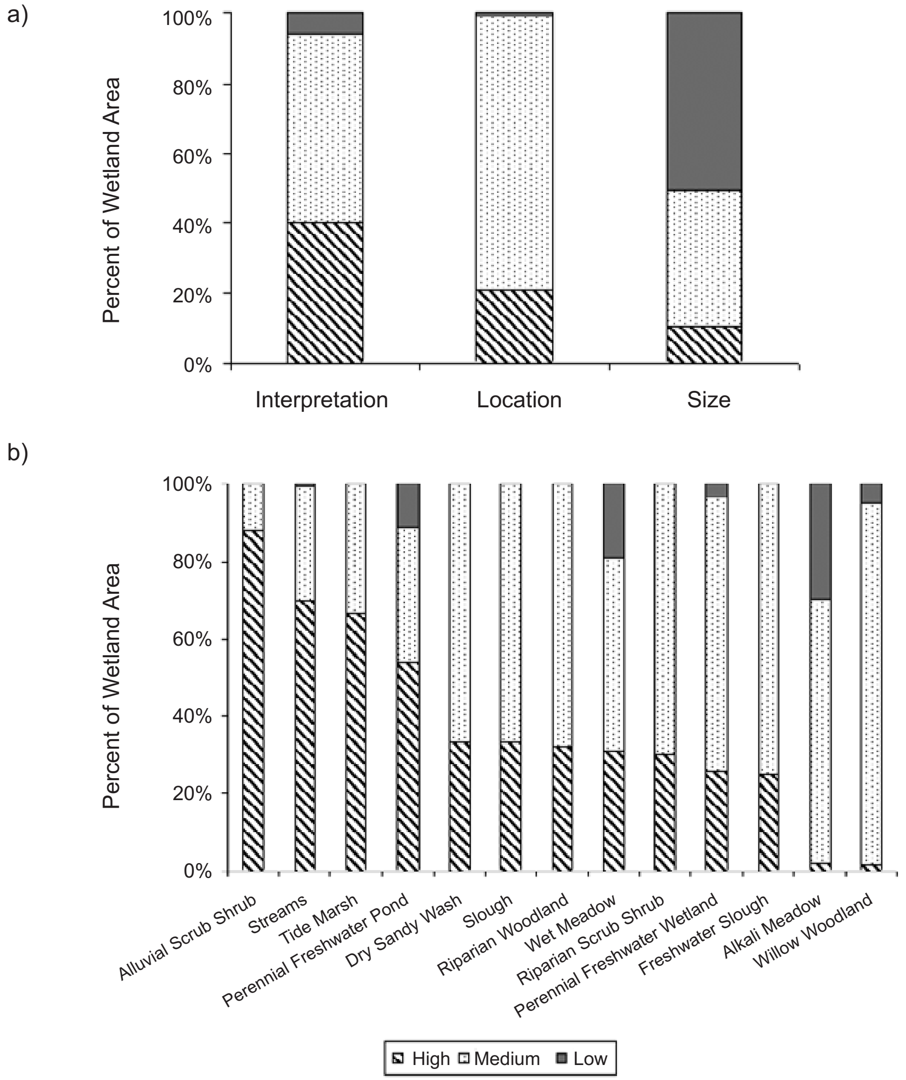

Figure 6. Certainty estimates by category based on percent of total wetland area for all wetland types (a) and for each wetland type individually (legend shows overall certainty estimates; b).

excluding the alkali meadow areas. This analysis improved the certainty in our estimates of wetland extent to 77% of wetland area exhibiting high or medium certainty levels.

Estimates of Wetland Loss

Dramatic wetland loss has occurred since the circa 1870 period of our historical analysis. The study area currently supports approximately 2,500 ha of wetlands (Dark *et al*. 2006), compared to approximately 19,100 ha historically. However, the losses have not been evenly distributed across the study area. The greatest losses have been to palustrine wetlands in the tidal fringe and riverine wetlands of the upper floodplain (Figure 7).

Overall, palustrine wetlands have experienced the greatest loss of any wetland category, with approximately 94% reduction in area. Palustrine wetlands include seasonal and perennial wetlands, alkali meadows, and small ponds. Within our study area, these wetlands were most likely supported by a combination of shallow ground water and surface flow associated with precipitation. The most dramatic loss within this wetland class was the vast expanses of alkali meadow that dominated the southern floodplain and tidal fringe areas. These wetlands were once the most expansive type in the lower watershed, yet today they are totally absent from the landscape. Losses are likely due to a combination of dewatering due to extensive groundwater extraction in the early 20th century, followed by channelization of the San Gabriel River between 1914 and 1935, and finally conversion to urban and industrial uses. Another palustrine wetland type heavily affected by changes in land use was the series of seeps and springs along the foothills of the San Gabriel Mountains. Historic maps often document chains of small slope and seep wetlands supported by ground water that surfaced along the topographic transition zone between the foothills and the valley. These wetlands have also been largely eliminated, except in

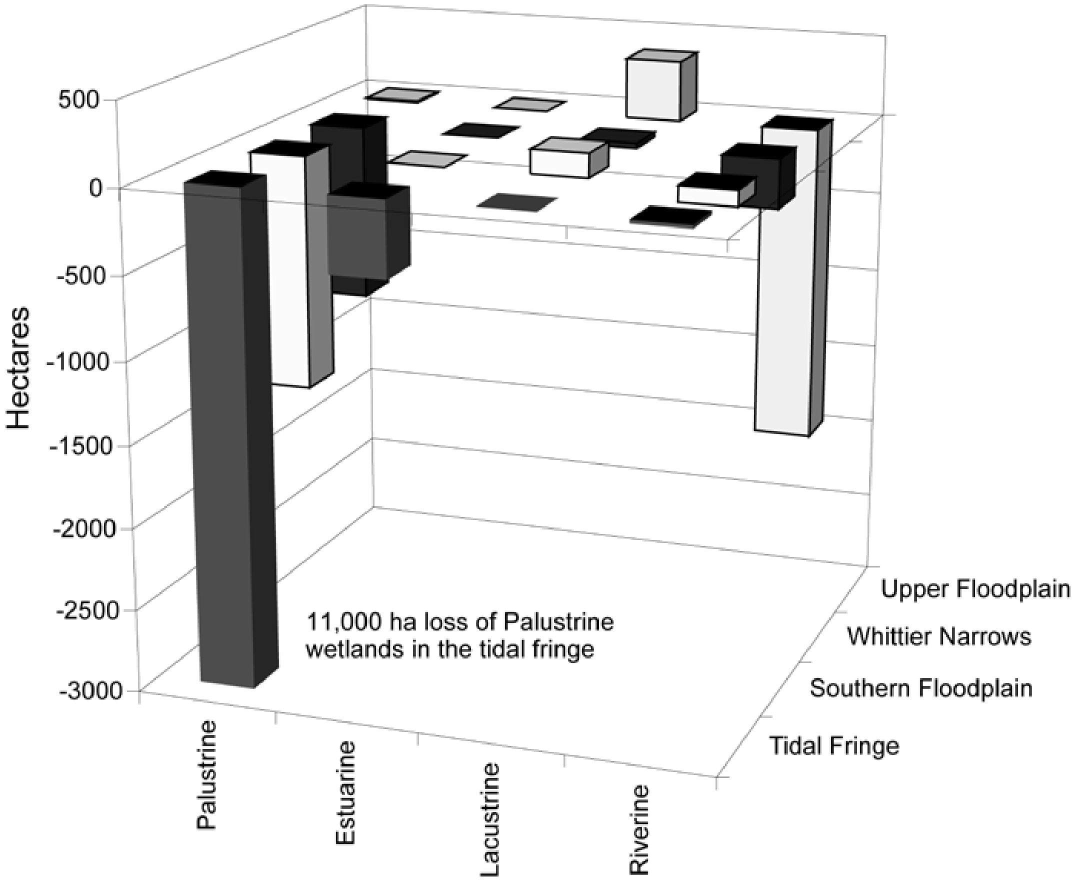

Figure 7. Wetland loss (or gain) by class (Cowardin *et al*. 1979) and portion of the study area. Note that approximately 11,000 ha of palustrine wetlands have been lost from the tidal fringe; the plot has been truncated to facilitate presentation. Palustrine wetlands include alkali marsh, tidal marsh, wet meadow, and freshwater wetland.

remote areas in the upper San Gabriel watershed.

Approximately 75% of the historical riverine riparian area has also been lost since the 1870s. The most dramatic change has been the conversion of the broad alluvial floodplains of the upper watershed and the meandering streams of the southern floodplain to flood control channels. Historically, the valley floor was covered with small intermittent streams carrying water from the foothill areas or places with a shallow water table out to the ocean. These streams likely ran at their highest during the rainy season and became dry stream beds during the summer. The dynamism of the San Gabriel River during major flood events contributed to large surface flows that overtopped the active channel banks and engaged the broad flat floodplain areas. Today, the alluvial aquifer has been largely dewatered, and its access to the floodplain has been eliminated by groundwater extraction, and a series of dams, diversions and channels.

The addition of lacustrine wetlands to the landscape is indicative of the effect of humans within the study area. Virtually, all present day lacustrine systems within the study area were created by humans for the purpose of either containing water during periods of high flow or retaining and infiltrating water for ground water recharge. Other current day lacustrine systems within the study area are either in parks (serving a recreational purpose) or gravel pits. Historically, there was little evidence of lacustrine systems. This may be due to the shallow topography of the study area and dynamic flow of the San Gabriel River across the valley floor. The addition of lacustrine wetlands to the contemporary landscape is illustrative of the wetland type-conversion (from riverine and palustrine to lacustrine) that commonly occurs as an area is converted from natural to developed land uses.

Discussion

Investigation of the historical San Gabriel River floodplain provides a glimpse of the impressive dynamism and diversity that was likely characteristic of many of southern California's coastal rivers and streams. These conclusions suggest that the traditional view of southern California watersheds as naturally dry and desert-like with mainly ephemeral and intermittent alluvial streams may be an over generalization. Historically, many wetlands would dry, be grazed, and convert to a scrub dominated habitat between periodic heavy rains. Larger periodic storms would recharge the aquifers and allow wetland and riparian habitats to recolonize. Dry periods could persist for several years to a decade, promoting a view of the Los Angeles region as more arid than it was. However, historical accounts clearly suggest that prior to floodplain modification, damming, and groundwater extraction, many wetlands persisted from year to year, and overall the watersheds were much "wetter" than contemporary conditions.

Climatic conditions likely influenced conclusions about historical wetland extent, and serve to further dispel the common perception of southern California wetlands as depauperate. The period of investigation for this study was characterized by a generally warmer climate, which was associated with higher than average rainfall and streamflow. Biondi *et al*. (2001) used six tree ring sites located in southern California to reconstruct climate records between 1610 and 1995. Their analysis showed wetter than average weather patterns between 1750 and 1905. Lynch (1931) analyzed long-term rainfall and runoff records in southern California and noted significant rain events between 1849-53, 1859-62, 1866-68, and 1873-76. Similarly, Bradley (1976) concluded that 1861-1875 was an extraordinary wet period, followed by drought conditions between 1905 and 1950. The somewhat unprecedented series of ENSO events during this period shaped the physical structure of the San Gabriel River and contributed to wetland diversity. Contemporary comparisons should be cognizant of these longer-term climatic cycles and the differences between historical and contemporary climate.

Historical analysis can provide a template for restoration and conservation by: illuminating the areas most conducive to re-establishment of wetland and riparian habitats; identifying where the greatest losses have occurred, both geographically, and in terms of specific habitat types; providing an understanding of factors affecting local habitats and how they have adapted to changes in the landscape; and highlighting historical wetland areas with significant, often unrecognized, potential for restoration and enhancement. For example, the geologic constriction, narrowing floodplain, and shallow groundwater around the Whittier Narrows area historically supported a complex of emergent wetlands and willow-riparian forest. Remnants of these systems still exist, suggesting that the location may be conducive for future wetland restoration efforts. Furthermore, the historic vegetation descriptions (see Stein 2007 for full details) should provide guidance to practitioners on plant choice in restoration projects. The regional perspective provided by historical analysis also reduces the likelihood of a continued gradual shift in the distribution of wetland types and a homogenization of wetlands across respective regions (Sudol and Ambrose 2002).

Historical analysis also reveals the danger of accepting traditional perceptions of a landscape as a template for restoration and management. The most widespread historical wetland types, alkali meadow and non-tidal freshwater marsh, are seldom included in local wetland restoration plans, despite the fact that these wetland types have been most heavily impacted and locations that could support these types still exist. Instead, wetland "creation" or "restoration" efforts are often focused on other habitats such as intermittent streams and lacustrine fringe wetlands, which, in comparison, may be relatively over represented in the contemporary landscape. Walter and Merritts (2008) similarly showed that the single channel meandering streams used as a restoration archetype for the mid-Atlantic Piedmont region of the US are actually artifacts of sediment storage and subsequent incision associated with tens of thousands of 17th-19th century milldams. In the Sacramento-San Joaquin Delta area, Brown and Pasternack (2005) showed that a fluvial disturbance regime, rather than a tidal regime, historically typified leveed farmland proposed for restoration, and recommended that restoration planning should account for these processes following levee breaching.

Historical analysis provides valuable context for restoration planning. However, it should not be considered in a vacuum. Recreating the past through restoration may not be practical or desirable in all places or instances, particularly in highly modified landscapes. For example, hydrology may be substantially altered by contemporary water management practices, and optimal landscape settings for restoration may be precluded by contemporary land use. Furthermore, restoration goals may be influenced by policy or management priorities for protecting specific species or habitats. Such constraints must be balanced against the desire to recreate historical wetlands. Nevertheless, knowledge of historical wetland extent and distribution may provide insight into restoration opportunities not previously apparent.

Since completion of this study, we have continued to refine our methods through historical analysis of other California watersheds. The discovery and use of historical property ownership maps has allowed for us to link detailed photographs and textual data (such as survey notes and newspaper articles) to specific geographic locations. Consequently, data sources considered "secondary" for this study have become key data sources for subsequent studies, and the distinction between these two types of data has become less important. We expect approaches to historical ecological analysis will continue to evolve to take advantage of new GIS technologies and new data sources to provide ever more robust conclusions. The analysis presented in this paper is a first step in providing insight into how historical data can be used and the importance of historical interpretation in habitat planning and restoration. Future studies will build on these initial efforts. In the absence of a historical perspective, it is likely that restoration efforts will overlook some of the more important local habitat types and opportunities to recreate regionally rare wetlands. Over the long-term, comprehensive historical analysis of coastal watersheds and wetlands can provide a valuable perspective for regional conservation planning and help spur imagination of alternative future landscapes.

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following individuals and organizations whose cooperation and assistance has been instrumental to the success of this project. We thank the California State Library, along with Alan Jutzi, from the Huntington Library, and Mike Hart, with Sunny Slope Water Company, for their assistance in obtaining historic irrigation reports and maps. John Patton from the Bureau of Land Management's General Land Office was instrumental in acquiring field notes and plats. Jim Shuttleworth and Steven Lipshie of the Los Angeles County Department of Public Works provided us with workspaces, map resources, and access to the historic aerial photo collection. We also thank Ron Davidson, who assisted with the creation and compilation of oral history notes; Chris Tasick, who helped in the collection and scanning of historic maps and aerial photos; and Danielle Bram, who provided GIS support and developed some analysis tools. Finally, we thank David Deis for his cartography work. Map creation was critical to the success of this project and our ability to visualize historical conditions. This would not have been possible without David's hard work, expertise, and attention to detail. The following peer reviewers have provided valuable insight and comments to improve the quality of the document: William Deverell, Paula Schiffman, Barry Hecht, and Jessica Hall. Funding for this project was provided by the State of California Rivers and Mountains Conservancy under Agreement #RMC3556.