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TO: File: Laguna de Santa Rosa; TMDL Development and Planning

FROM: Steve Butkus

DATE: December 7, 2011

SUBJECT: Development of the Laguna de Santa Rosa Watershed Pre-European Settlement Spatial Data Model

The development of the Total Maximum Daily Load (TMDL) for nutrients and dissolved oxygen in the Laguna de Santa Rosa (Laguna) requires a pollution source analysis. The goal of the Source Analysis is to provide a complete inventory and description of all sources of the pollutant of concern, including point, nonpoint, and background sources in the watershed. An estimate of the relative pollutant loading from the major sources informs the TMDL allocation process. The Laguna TMDL Nutrient Source Analysis uses a model to estimate loads from differ land covers.

The spatial representation of the Laguna watershed showing pre-settlement hydrology and land cover was developed by Regional Water Board staff to help estimate historical pollutant loading and to help assess natural background sources. Historical ecological analysis can provide a better understanding of former conditions to support habitat restoration and water quality management goals and objectives. The analysis of natural conditions provides context for setting TMDL allocations for desirable and feasible future conditions.

Historic accounts of water quality in the Laguna describe it as a productive, low gradient system that included a mosaic of open channels, wetlands, and lake-like features. The swampy riparian forests and freshwater marshes reduced the quantity of sediment and nutrients available for algal blooms in the open water areas of the mainstem Laguna and the lower portions of the tributaries. The conditions of the Laguna watershed have been altered due to land cover changes that began during European settlement in the mid-1800s. Land cover changes included the removal of vegetation and the alteration of hydrologic features to reduce threats from flooding and increase acreage of arable land for agriculture. Urbanization of the watershed has increased impervious surfaces resulting in removal of important watershed infiltration processes. These land cover changes have created major impacts to the hydrologic functions of the open water, wetland, and riparian habitats within the Laguna watershed.

Pre-settlement in the Laguna watershed was defined as the period of time prior to the General Land Office surveys conducted from 1850 to1870.

The pre-settlement spatial data model was designed to delineate the boundaries between six land cover categories:

1. Streams and Open Water
2. Perennial wetlands (i.e., bulrush, cattails, and marsh pennywort)
3. Riverine wetlands (i.e., willow, Oregon ash, and box elder)
4. Oak Savanna (includes seasonal wetlands)
5. Forest (more than 6 trees per acre)
6. Rangeland (i.e., grasses, forbs, shrubs, and brush)

Hydrology

Streams

Historic maps provided the extent and general location of the stream and pond features. Three maps found in the Historical Atlas of Sonoma County (Thompson, 1877) cover most of the Laguna watershed (Figure 1).

Online images of these maps were obtained from the David Rumsey Map Collection (http://www.davidrumsey.com) and geo-rectified into a spatial data set using the Public Land Survey System grid. The corner locations of the surveyed Sections were linked to the historic maps using GIS mapping software. The use of multiple ‘Section’ corner locations greatly reduced alignment errors during geo-rectification.

The upland area streams that were not shown on the 1877 Atlas were extended to the headwaters using the 2008 National Hydrography Dataset flow lines. These stream reaches are found in confined valleys and have not likely migrated laterally over time. The pre-settlement confluence of Mark West Creek with the Laguna was derived from the geo-rectified copy of another early map (Bowers, 1867), as shown in Figure 2. Comparing the pre-settlement hydrology with the current National Hydrography Dataset (http://nhd.usgs.gov/data.html) shows the past 130 years of engineering efforts to channelize streams (Figures 3 and 4). However, some of the variation of stream locations in the figures may be due to historical surveying issues and not due to actual channel migrations (e.g., upper Mark West Creek).

Open Water

The mainstem Laguna prior to European settlement contained large areas of open water even in the summer. Three lakes have been identified from early records: Ballard Lake, Lake Sebring, and Cunningham Lake (Cummings, 2004). Lake Sebring was renamed locally as Lake Jonive around 1900 after the northern portion of the water body had filled with sediment. None of the earliest maps of the Laguna region dating from 1867 to 1908 specifically show these lakes (Figures 5 – 10). These early maps provide only a generalized representation of open water boundaries and do not indicate the time of year depicted.

Ballard Lake

Ballard Lake was formed near the original location of the mouth of Mark West Creek. A sediment plug deposited from Mark West Creek in the mainstem Laguna partially blocked the mainstem and formed a wider open water area of the lower Laguna upstream of the confluence with Mark West Creek, between what is today Guerneville Road and River Road. Ballard Lake was reported to be 25 feet deep in places. A resort that operated on the lake was a well-visited local destination that offered fishing, boating, and swimming. In the 1940s dynamite was used to remove the sediment plug forming Ballard Lake. Sediment from Mark West Creek was used to fill the lake area for conversion to agricultural purposes.

Lake Sebring / Lake Jonive

Lake Sebring was a permanent open water area that stretched from south of Santa Rosa Creek to Sebastopol. The Lake was formed by a sediment plug deposited by Santa Rosa Creek. Increased erosion from watershed development filled the northern portion of the lake with sediment in the late 1800s. By 1900, the remaining southern portion of the open water area had been renamed locally as Lake Jonive. Early reports described Lake Jonive as 150 feet wide and 30 feet deep, large enough to support navigation uses. In 1889, the *Sebastopol Times* suggested that gunboats with "torpedo destroyers" be deployed in the Laguna to guard the town from a potential invasion by the Spanish coming up the Russian River. Early reports also describe Lake Jonive as supporting a cold water fishery. In 1902, the *Sebastopol Times* reported "from the clear waters have been caught salmon-trout that filled the sportsman's heart with joy" (Cummings, 2004).

Cunningham Lake

Blucher Creek was a source of the sediment plug that resulted in the formation of a large open water area near the Cunningham business area (near the current location of Todd Road). Cunningham Lake does not specifically appear on any early maps, but the lake is referred to in early newspaper reports as being used by local residents for swimming and fishing.

Annual Climatic Boundaries

The open water boundaries of the lakes in the Laguna varied considerably depending on annual climate. The wide range of open water boundaries on early maps was influenced by the antecedent precipitation immediately prior to when the map was drawn. The early maps do not indicate the time of year the maps were drawn. The open water boundaries from year-to-year likely varied considerably prior to European settlement and hydraulic modifications placed in the watershed. The boundaries between open water and marshlands were very dynamic depending on the season and annual climate. For example, in early photos Lake Jonive essentially disappeared about 1910 and reappeared again in the late 1920s (Cummings, 2004).

The historical boundaries of the open water areas during both wet and dry climate years are shown in Figure 11. The historical open water boundary for wet years was derived from boundaries of open water depicted on two early maps (Bowers, 1867; Thompson, 1877). Adjacent areas with hydric soil type within the basin floor landforms were added to define the upper elevation boundary of open water areas (NRCS, 2007) as shown in Figure 12.

Hydric soils are defined by U.S. Department of Agriculture as “sufficiently wet in the upper part to develop anaerobic conditions during the growing season" (USDA, 2010). Hydric soils are formed under conditions of saturation, flooding or ponding that exists long enough to develop anaerobic conditions. The anaerobic environment results in biological and chemical changes in the soil that influence vegetation. Soils become hydric after exposure to anaerobic conditions for prolonged periods that are repeated annually. These areas were assumed submerged through the summer during wet climatic years.

The historical open water boundary during dry years was derived from the boundary of open water depicted on the 1860 Laguna map (Figure 9). The 1860 map presented the smallest open water area of all the available early maps. The open water boundaries from an image of the 1860 map were digitized and rectified into spatial data (LSRF, 2009). The area between the boundaries of the open water for wet and dry years was assumed to represent perennial marshes during the dry years.

Wetlands

The pre-settlement Laguna watershed contained large areas of wetlands. Wetlands have unique biogeochemical cycles, with numerous chemical transformations and chemical transport processes that are not shared by many other ecosystems. Wetland soils, when submerged, become highly reduced due to anaerobic conditions.

Wetlands likely removed nutrients from runoff from the pre-settlement landscape. Anaerobic microbial populations cause the transformation of nutrients and other pollutants affecting their availability to the ecosystem. Hydrologic conditions are extremely important to wetlands structure and function by affecting anaerobic bacterial activity and nutrient availability. Physical wetland features such as hydroperiod, water depths, and saturation duration affect processes that support the biotic functions of the wetland system.

For the pre-settlement nutrient loading conceptual model, Regional Water Board staff assumed that perennial and riverine wetland areas reduce nutrient loading before water flows to the Laguna receiving waters. The nutrient load from the upstream terrestrial areas is delivered through the riverine wetlands and through the perennial wetlands prior to discharge to receiving waters (both lentic and lotic). The conceptual model for estimating pre-settlement nutrient loading was based on the reduction of loading by these perennial and riverine wetland areas before delivery to receiving waters (Figure 13).

Perennial Wetlands

Perennial wetlands are areas with dominant submergent plants that included bulrush, cattails, and marsh pennywort. The historical boundaries of perennial wetland areas for the Laguna pre-settlement spatial data model were based on soil type and land form. Perennial marshes were located in non-open water areas with hydric soils within the basin floor landforms (NRCS, 2007). These areas were assumed submerged through the summer during dry climatic years.

Riverine Wetlands

Riverine wetlands are areas located on the flood plain and extending laterally beyond channel banks. They include flood plain areas that are forested or consist of shrub vegetation dominated by broadleaf deciduous trees. Historically, riverine wetlands occurred on a variety of soils adjacent to marshland areas and flowing streams. Vegetation was dominated by willow, Oregon ash, and box elder in the wettest areas with adjacent valley oak, walnut, and cottonwood species found slightly higher on the flood plain. Riparian areas located in upland areas out of the floodplain were not included in this land cover category for the Laguna pre-settlement spatial data model.

The historical boundaries of riparian wetland areas on the Laguna pre-settlement spatial data model were based on soil type, landform, and historical maps. Riverine wetlands were located in non-marshland areas with a floodplain landform (NRCS, 2007). Riverine wetlands were also located in areas of Pajaro, Blucher, and Cortina soils that support the dominant vegetation. Areas estimated as riparian wetlands by David W. Smith Consulting (1990) were also identified as riverine wetlands on the Laguna pre-settlement spatial data model.

Upland Areas

Oak Savanna

Much of the pre-development Santa Rosa Plain was covered by oak woodland that varied in density from open savanna to patchy forest. For example, Marryat (1859) reported that the Santa Rosa Plain was a "thickly wooded plain that extended for miles." The dominant tree was the valley oak*,* with occasional black oak and live oak species generally with a density of 4 to 6 trees per acre (David W. Smith Consulting, 1990).

The terrain was mostly flat with an undulating topography of mounds and depressions containing vernal pools and wet meadows dominated by grass-like perennial plants such as water plantain, loosestrife, and rushes. Vernal pools stored water that otherwise would have run off directly into the Laguna and acted as seasonal wetlands within the savanna. These habitats were considered non-persistent emergent wetlands because the plants die and senesce at the end of the growing season. Dominant species such as smartweeds, watergrass, spiked rush, docks, and flowering annuals formed dense stands in early spring, but by mid-summer there might have been no apparent signs of emergent vegetation on what appeared to be a dry hard soil surface.

The historical boundaries of oak savanna areas for the Laguna pre-settlement spatial data model were based on soil type. Oak savannas were located in areas with hydric soils outside of marshlands or riparian wetlands. Soils of these areas were predominantly the Wright and Huichica loams above a shallow hardpan that could support vernal pools. These shallow hardpan soils caused ponding by preventing rainwater percolation.

Rangeland and Forest

Most of the upland areas of the Laguna watershed were covered by forested or rangeland areas. The dominant trees in forested areas were black oak, live oak, redwood, Douglas fir, madrone and bay laurel species. These forested areas were located on dryer soil types and have resulting higher tree densities than in the savanna areas.

Rangeland is one of the land cover classes identified in the National Land Cover Database (USGS, 2006; Homer et al., 2007). Rangeland was defined as land where the natural vegetation is predominantly grasses, forbs, shrubs, and brush. Rangelands do not contain managed open areas of pasture or dry land crops. Rangelands differ from oak savanna areas by the types of vegetation supported by the soil characteristics. Soils in rangelands do not support the types of vegetation that exist within the wet meadow and vernal pool habitats of the oak savanna created by shallow hardpan soils.

The historical boundaries of rangeland and forested areas for the Laguna pre-settlement spatial data model were based on current maps, soil, and landscape metrics. Areas currently identified as ‘Rangeland’ or ‘Forest’ in the National Land Cover Database (USGS, 2006; Homer et al., 2007) were assumed to have been rangeland or forest during pre-settlement times. These are areas generally undisturbed by current landscape management.

Gradient analysis was conducted by Regional Water Board staff to distinguish between rangeland areas and forested areas for the Laguna pre-settlement spatial data model (Butkus, 2010a). The assumption was made that those environmental conditions with the most influence on the distribution of today's remaining rangeland and oak forests could be used to estimate pre-settlement native vegetation. The gradient analysis found that four environmental variables had a significant influence on the vegetation type: elevation, slope, soil hydrogroup, and soil percent silt. These variables were then used to predict which areas should be identified as forest and rangeland for the remaining unidentified areas of the Laguna pre-settlement spatial data model.

Pre-settlement Spatial Data Model Results

The final resulting spatial data model estimating areas of pre-settlement land cover is shown in Figure 14 and Table 1. The data used and assumptions used to develop the pre-settlement map are discussed below for each of the selected land cover categories. Steps taken by Regional Water Board staff to evaluate the model are also discussed.

Table 1. Laguna Watershed Pre-settlement Land Cover Areas

Land Cover Category	Acres	Percent
Forest	84,515	51.9%
Oak Savanna (includes seasonal wetlands)	28,823	17.7%
Rangeland	24,292	14.9%
Perennial wetlands*	16,969	10.4%
Riverine wetlands	5,145	3.2%
Open Water*	3,045	1.9%
Total	162,609	100.0%

* Area estimates are for a wet climate year

Pre-Settlement Spatial Data Model Evaluation

The final resulting spatial data model estimating areas of pre-settlement land cover (Figure 15) was evaluated to assess model performance. Model evaluation is the process for generating information that helps determine the quality of modeling results to serve as the basis for management decisions. The U.S. Environmental Protection Agency provides guidance on the elements required to properly evaluate a model (USEPA, 2009). Regional Water Board staff evaluated the pre-settlement spatial data model following the U.S. Environmental Protection Agency guidance (Butkus, 2010b). Model evaluation elements include:

- Sensitivity analysis – evaluates the effect of assumptions on model results.
- Uncertainty analysis - investigates the effects of lack of knowledge and other potential sources of error in the model.
- Model corroboration - evaluating the degree to which the model results correspond to reality.

Sensitivity analysis
A sensitivity analysis was conducted to evaluate two of the assumptions made during development of the model:

(1) Areas currently identified as 'Forest' or 'Rangeland' have not changed since European pre-settlement, and
(2) Annual climatic differences in the size of open water areas are represented by comparison of early maps.

These assumptions were evaluated because of their potential influence on the results of the pre-settlement loading estimates. The results of these sensitivity evaluations were variations in the total areas of open water, perennial wetlands, rangeland, and forested land covers. This variation in land cover areas will be used to assess the effect of these assumptions on the results from modeling watershed loading (i.e., Land Cover Loading Model).

Uncertainty analysis
Regional Water Board staff quantified the level of certainty of the pre-settlement spatial data model based on the number and quality of information sources. The uncertainty analysis approach followed a commonly applied qualitative approach to assessing uncertainty in historical map reconstructions (Grossinger, 2001). The evaluation suggested that the model is somewhere between a 'Probable' and 'Possible' level of uncertainty.

Model Corroboration
Regional Water Board staff corroborated the pre-settlement land cover spatial data model by evaluating data from the General Land Office (GLO) surveys. The surveys were conducted during the mid 19^{th} century and they provide a key data source of forest and environmental conditions of the pre-European settlement period (Bourdo, 1956). Overall, the pre-settlement spatial data model corroborated well with the information recorded in the GLO surveys. The results of the comparison showed that for seventy-one percent (71%) of the survey locations, the land cover data model was in full agreement with the GLO survey information. Nineteen percent (19%) of the survey locations showed some agreement and ten percent (10%) showed no agreement between the GLO survey records and the pre-settlement land cover.

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Figures

Figure 1. Historical Atlas of Sonoma County (Thompson, 1877) overlaid with Laguna watershed boundary.

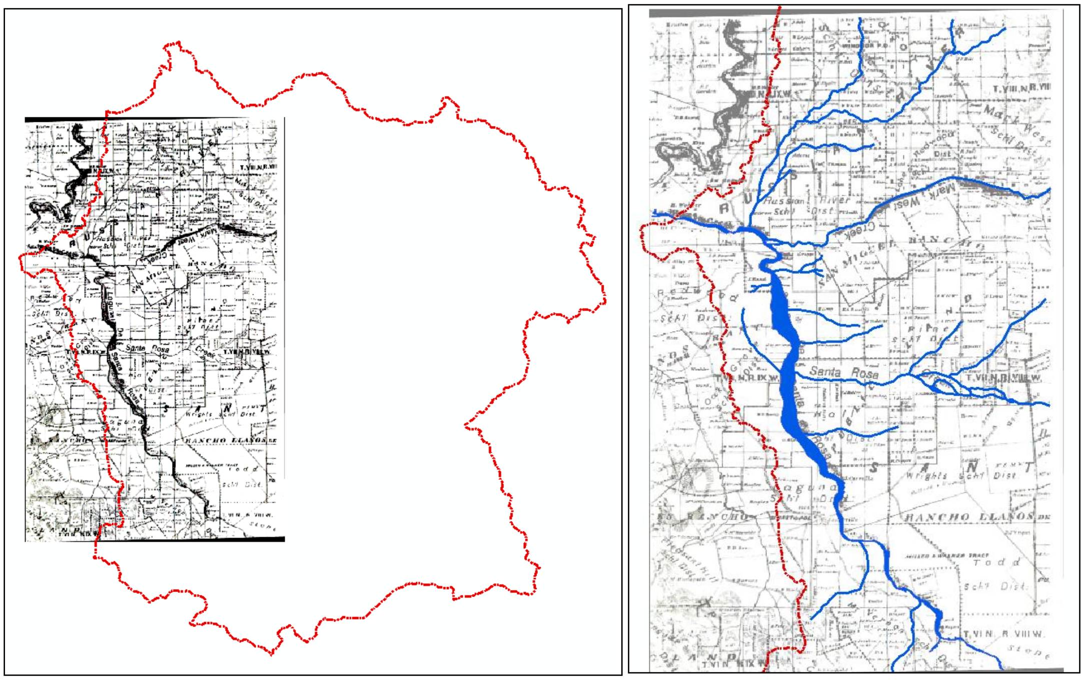

Figure 2. Bowers 1867 Laguna Map overlaid with Laguna watershed boundary.
Stream and open water areas are shown in blue.

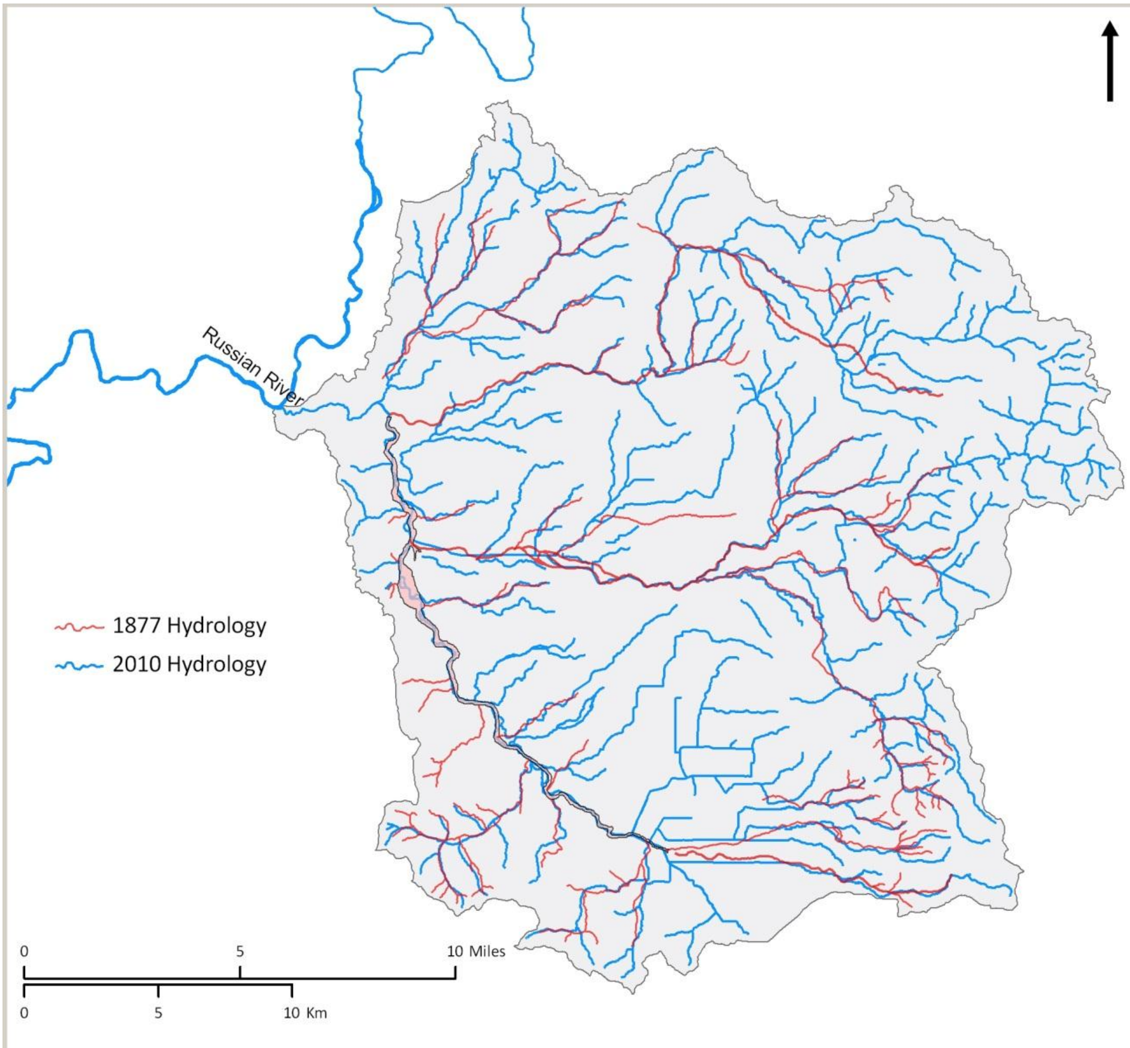

Figure 3. Laguna Watershed Current and Historical Hydrology

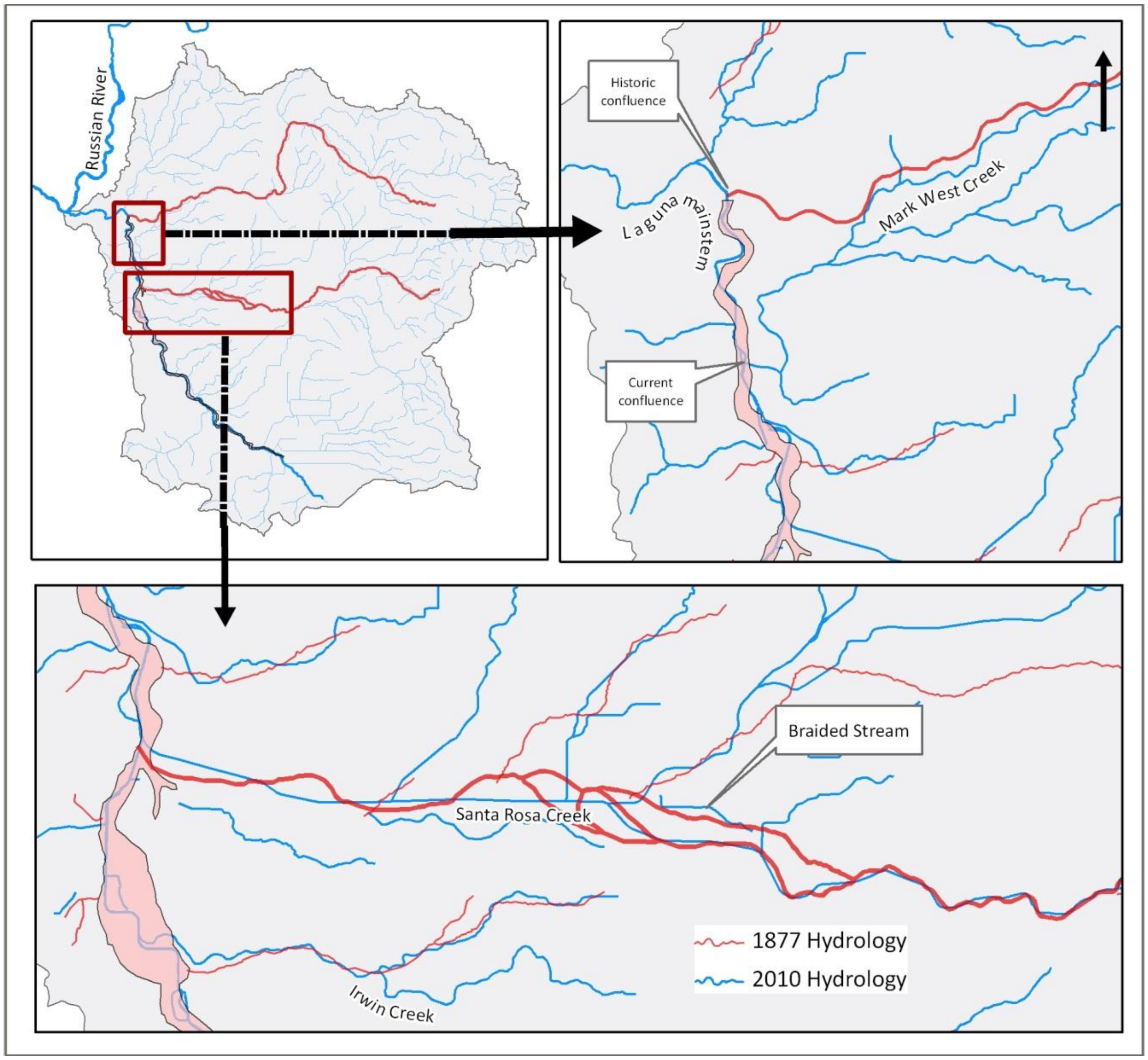

Figure 4. Laguna Watershed Hydrologic Channel Modifications

Figure 5. 1840 Map of the Laguna (B-492 El Molino).
Courtesy of The Bancroft Library, University of California, Berkeley, CA 94720-6000; http://bancroft.berkeley.edu/

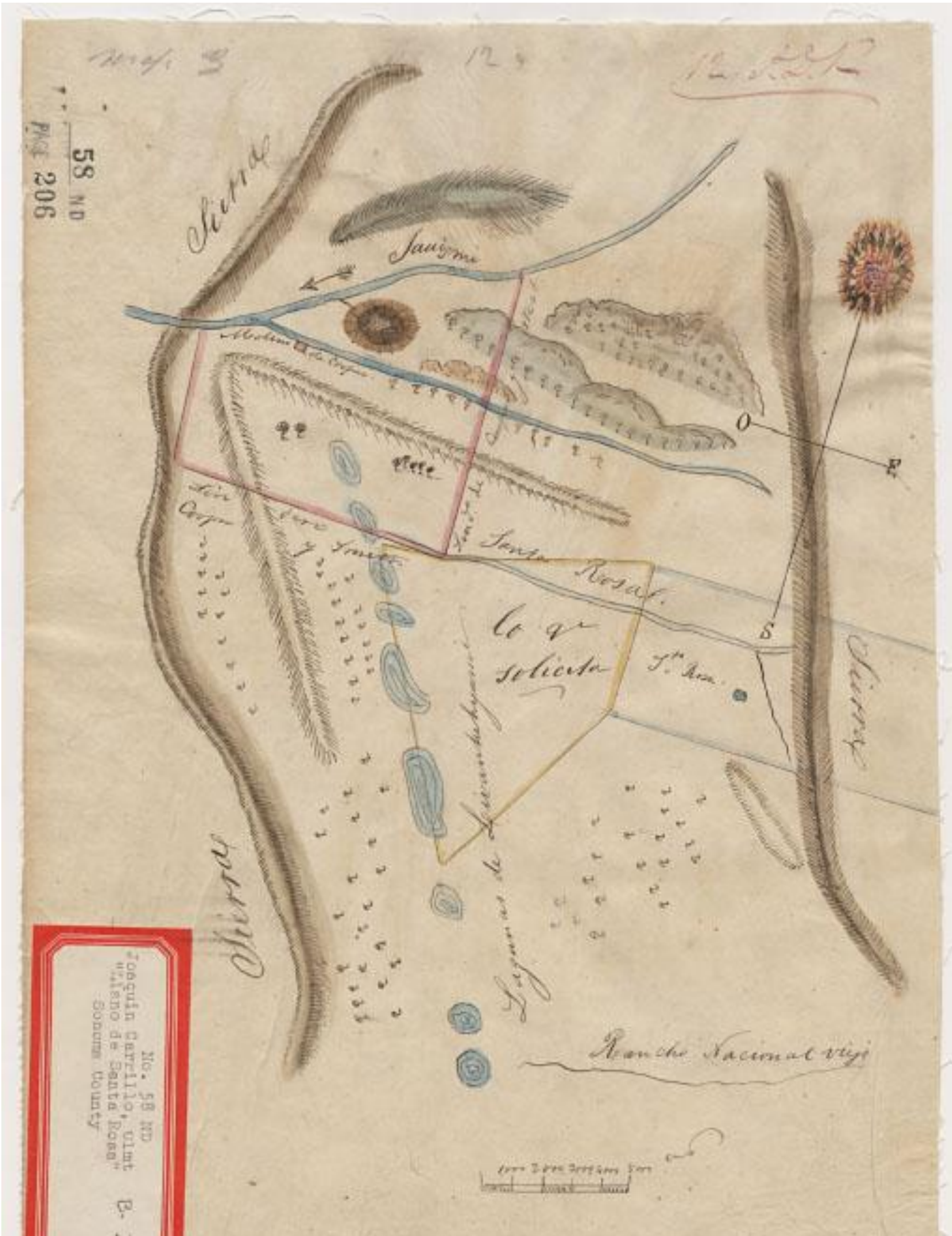

Figure 6. 1844 Map of the Laguna (B-128 Llano de Santa Rosa)
Courtesy of The Bancroft Library, University of California, Berkeley, CA 94720-6000; http://bancroft.berkeley.edu/

Figure 7. 1845 Map of the Laguna (B-664 San Miguel)
Courtesy of The Bancroft Library, University of California, Berkeley, CA 94720-6000; http://bancroft.berkeley.edu/

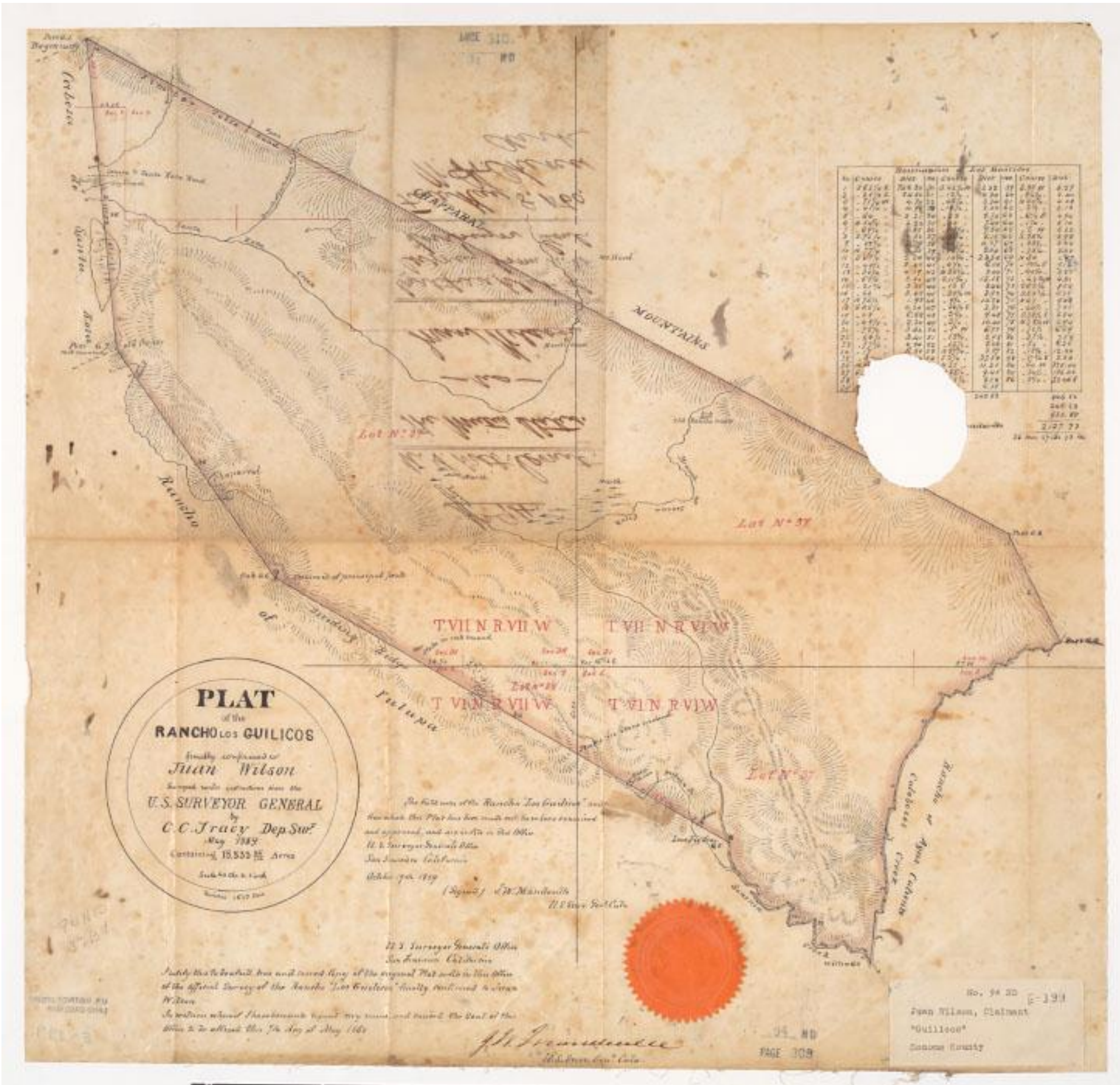

Figure 8. 1859 Map of the Laguna (E-199 Rancho Los Guillicos)
Courtesy of The Bancroft Library, University of California, Berkeley, CA 94720-6000; http://bancroft.berkeley.edu/

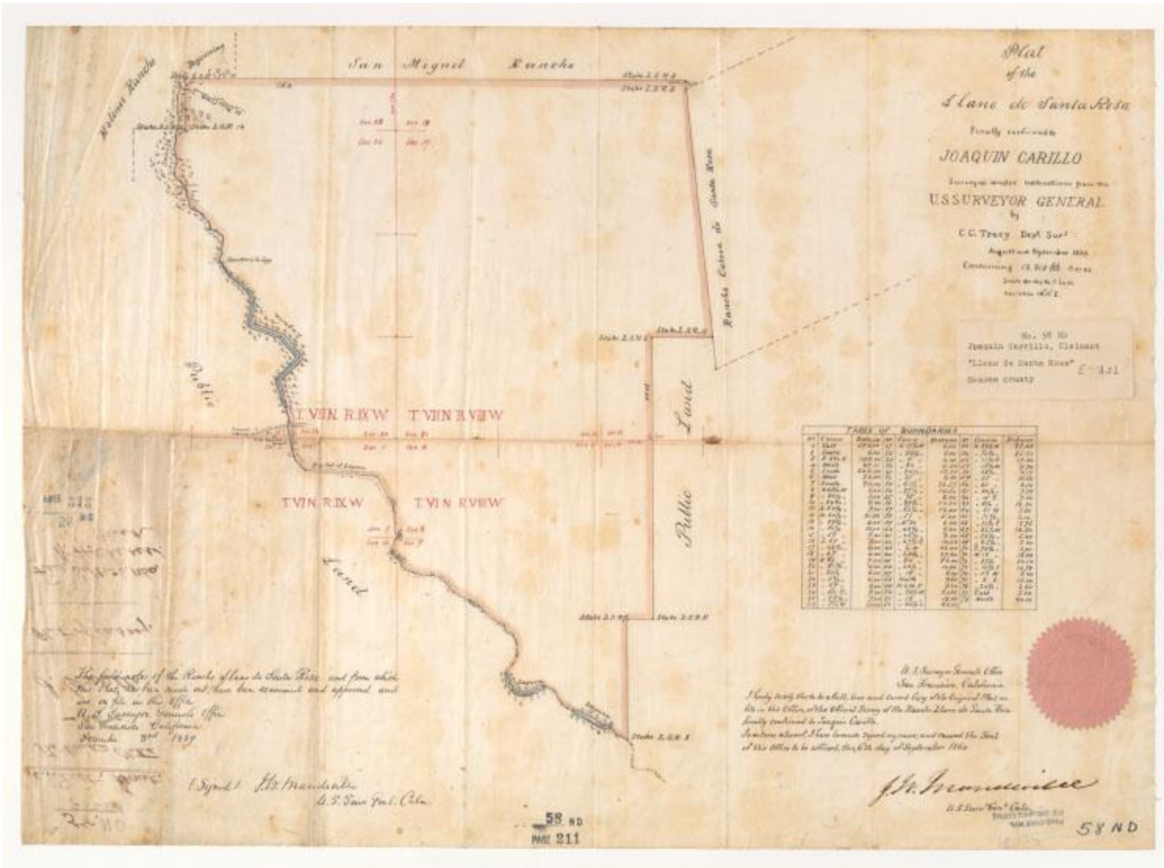

Figure 9. 1860 Map of the Laguna (E-131 Llano de Santa Rosa)
Courtesy of The Bancroft Library, University of California, Berkeley, CA 94720-6000; http://bancroft.berkeley.edu/

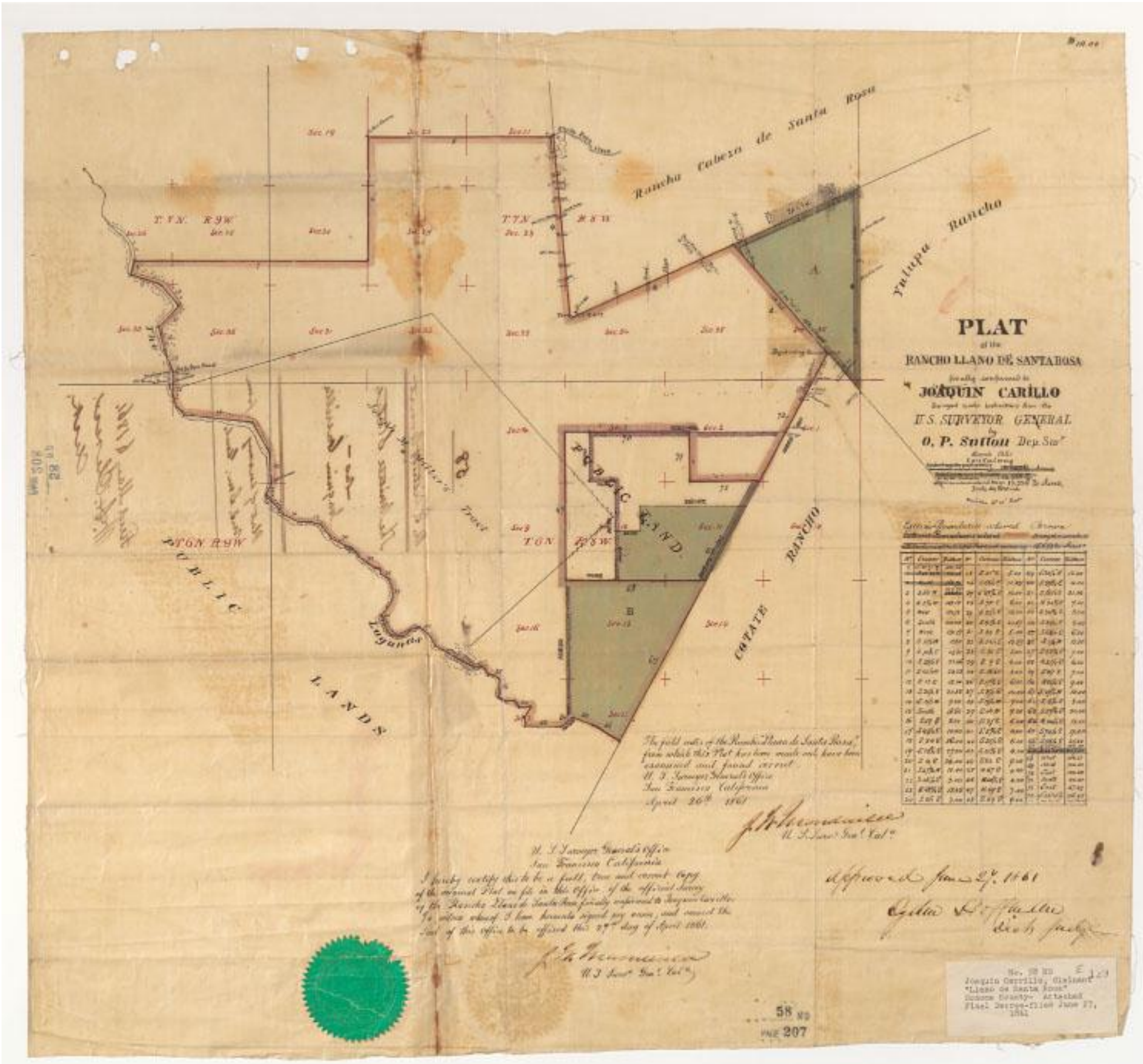

Figure 10. 1861 Map of the Laguna (Llano de Santa Rosa)
Courtesy of The Bancroft Library, University of California, Berkeley, CA 94720-6000; http://bancroft.berkeley.edu/

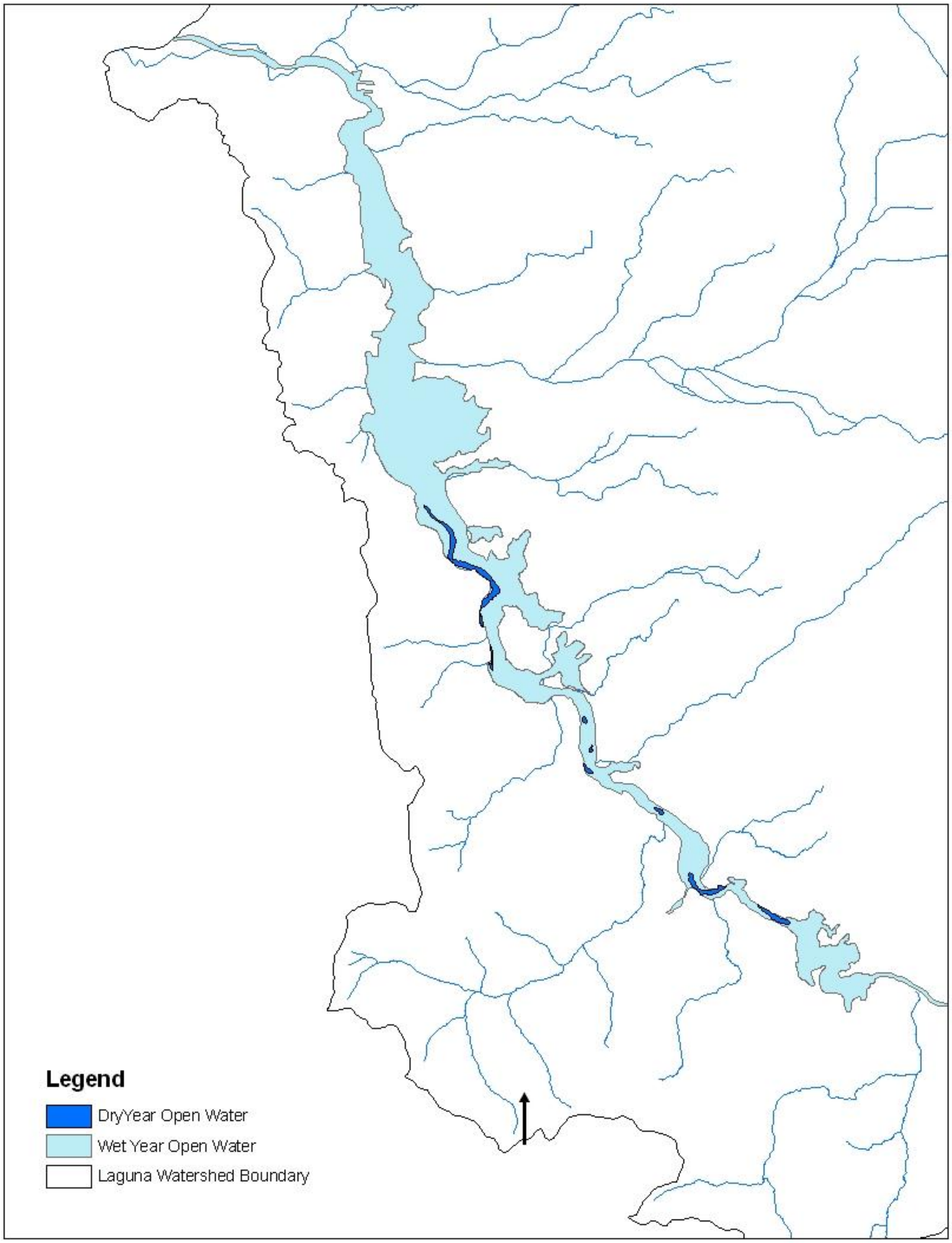

Figure 11. Boundaries of Historical Laguna Open Water Areas in Wet and Dry Climate Years.
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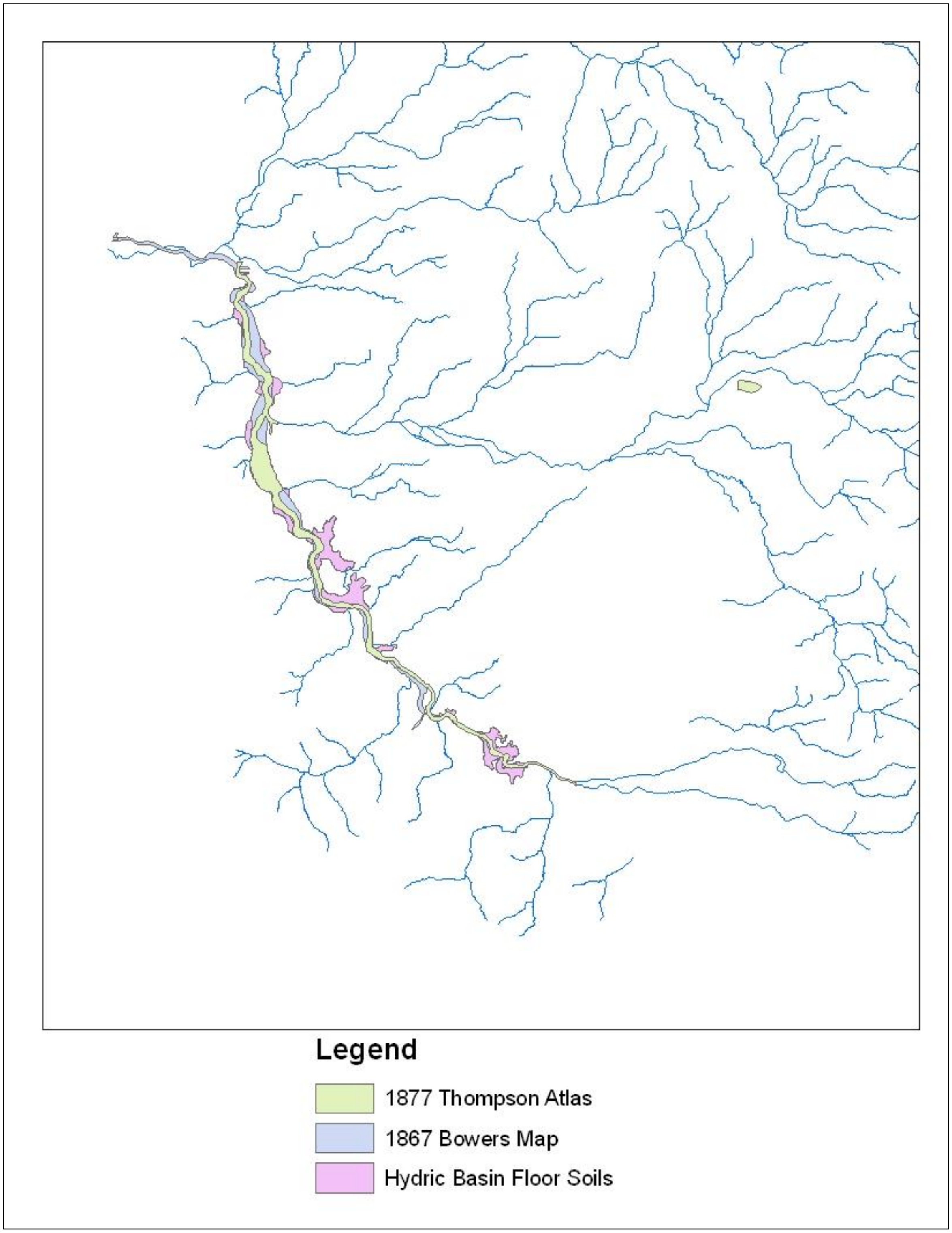
Legend
1877 Thompson Atlas
1867 Bowers Map
Hydric Basin Floor Soils

Figure 12. Boundaries of Laguna Open Water Areas from Historical Maps with adjacent Basin Floor Hydric Soils.
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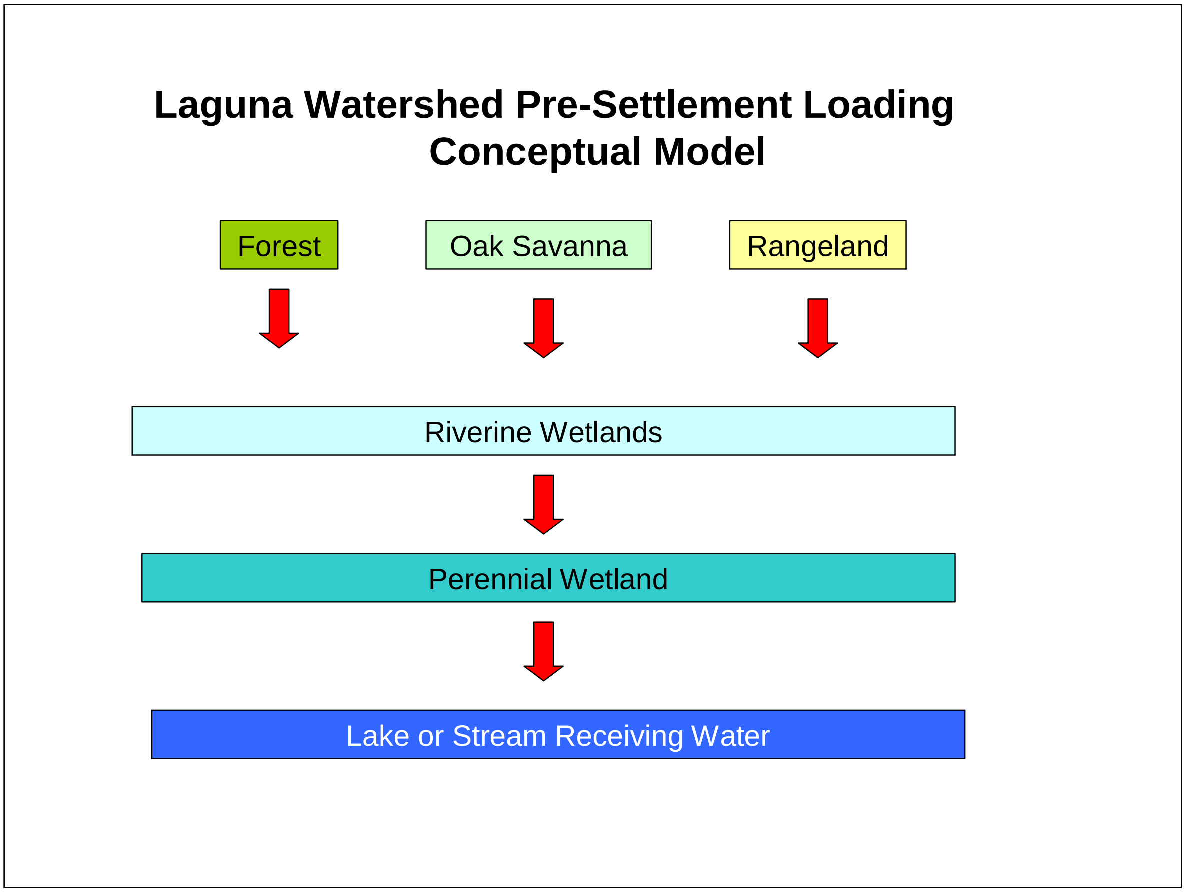

Figure 13. Laguna Watershed Current Loading Conceptual Model

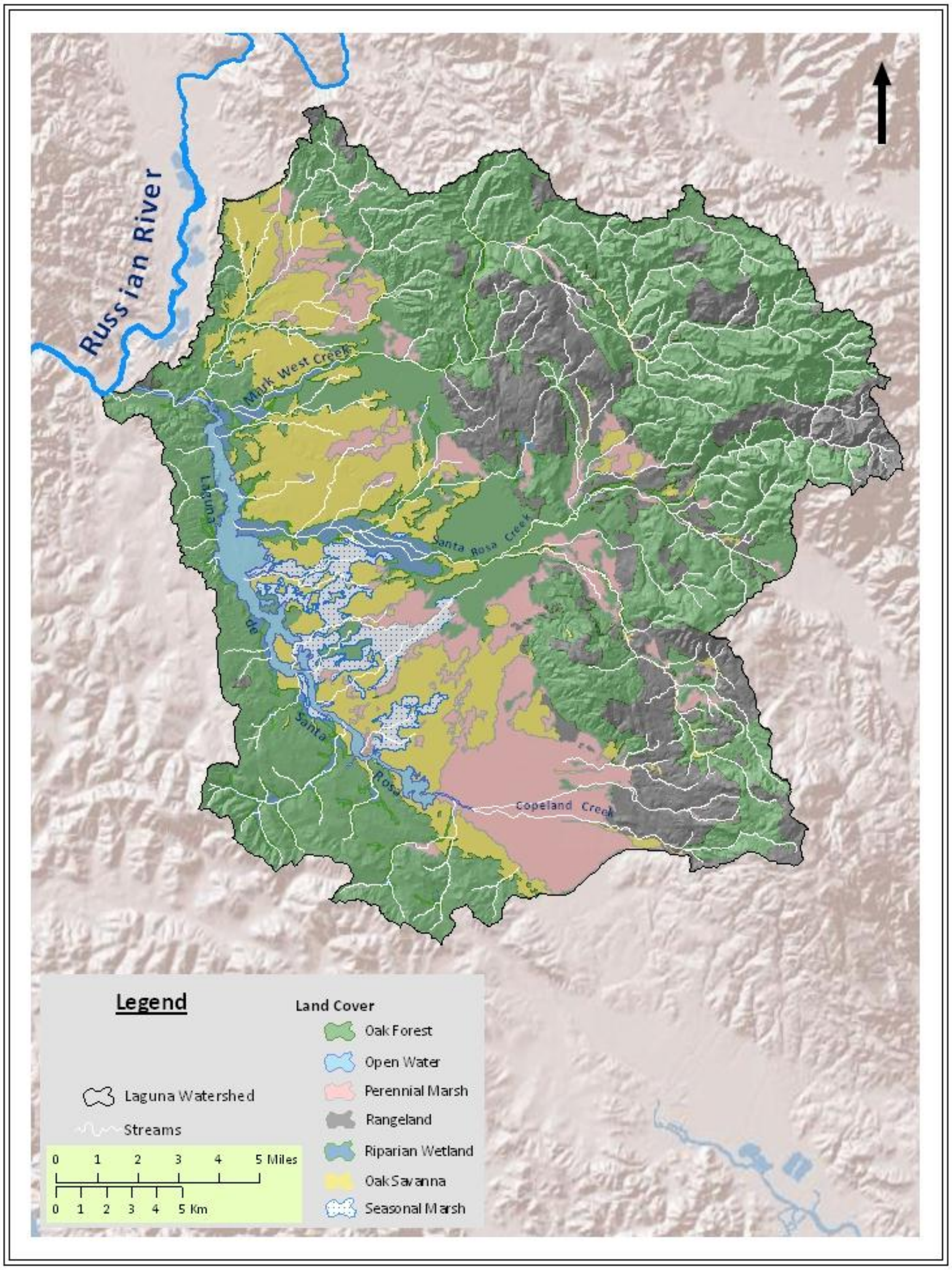

Figure 14 . Laguna Watershed Land Cover Map prior to European Settlement
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