Laguna de Santa Rosa – Restoration Opportunities for Crediting (Revised)

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PREPARED FOR

U.S. Environmental Protection Agency
and
North Coast Regional Water Quality Control Board

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TETRA TECH

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1.0 INTRODUCTION

The Laguna de Santa Rosa ("Laguna") is the largest tributary to the Russian River, draining approximately 254 square miles of watershed area in Sonoma County, California. The Laguna Watershed is the urban center of the North Coast Region, encompassing the cities of Santa Rosa, Rohnert Park, Cotati, Sebastopol, and the Town of Windsor. Major tributaries to the Laguna de Santa Rosa include Windsor Creek, Mark West Creek, Santa Rosa Creek, Blucher Creek, and Copeland Creek. Land cover varies widely across the watershed, ranging from high-density residential and commercial, to croplands and pastures, vineyards and orchards, and some forested areas.

Since the arrival of European settlers in the mid-1800s, the lands and waterways of the Laguna Watershed have been subject to major alterations in support of agricultural and urban development such as deforestation, channel realignment, and draining and filling of wetlands. Over the years, these alterations and associated land use changes have led to declines in ecosystem functions and associated assimilative capacity and the impairment of water quality. As a result of these interconnected historical and ongoing sources of impairment, the designated uses [Cold Freshwater Habitat (COLD); Fish Spawning (SPWN); Fish Migration (MIGR); Rare, Threatened, or Endangered Species (RARE); Wildlife Habitat (WILD); and Warm Freshwater Habitat (WARM)] uses are not supported in the Laguna de Santa Rosa Watershed in all locations. Accordingly, portions of the Laguna Watershed and its tributaries are listed by the U.S. Environmental Protection Agency (USEPA) as impaired for nutrients, sediment, temperature, and dissolved oxygen under section 303(d) of the federal Clean Water Act. To address these impairments, North Coast Regional Water Quality Control Board ("Water Board") staff are working with the USEPA and local stakeholders to develop and implement Total Maximum Daily Loads (TMDLs) and a restoration Action Plan.

Over the last several years, Tetra Tech has provided technical support to the Water Board for the development of the Laguna TMDLs. Based upon this work, it is clear that a solution set for this waterbody will require not only source control, but also active restoration to increase assimilative capacity for nutrients and repair sediment dynamics in order to restore water quality and support designated uses.

Fundamental to the impairments in the Laguna is the underlying altered hydrology of the watershed due to urbanization and other anthropogenic causes. Reconciling this altered hydrology demands a multifaceted and multidimensional solution set. The work described in this report was funded by USEPA to support the Laguna restoration effort. Specifically, this report addresses the task "Document Restoration Plan Opportunities for Crediting." This task in general is to "review the restoration concepts and project types identified in the Laguna de Santa Rosa Master Restoration Plan and propose opportunities where credits can be quantified relative to the nutrient and sediment TMDLs." The deliverable is intended to describe "how restoration priorities identified in the Vision Plan and Sonoma Water 2012 may be used to establish quantitative measures of change in assimilative capacity for sediment, phosphorus, nitrogen, indicators, and surrogate measures in the proposed TMDLs for the Laguna", accompanied by GIS-based mapping of engineered and ecologically based restoration opportunities.

This task had a limited budget and short schedule, so it was important to be judicious in choosing which components to focus on. It is also important to recognize what work has already been accomplished by others and not unnecessarily duplicate efforts. The original request from the Water Board assumed that this task could build on the San Francisco Estuary Institute (SFEI) Master Restoration Plan for the Laguna floodplain, which will include information on prioritization, ranking, and sequencing of restoration

opportunities. The Master Restoration Plan had not been finalized as of May 2021, and so was not timely for supporting this task. However, the SFEI Restoration Vision[1] had been finalized and describes the general concepts that will inform the final Restoration Plan.

The SFEI Restoration Vision and forthcoming Restoration Plan concentrate on work within the 100-year floodplain of the Laguna de Santa Rosa and are not focused on identifying opportunities within the larger watershed. The Restoration Vision also has a primary focus on wetland and aquatic habitat restoration opportunities, not all of which are directly associated with increasing assimilative capacity for sediment and nutrients. However, SFEI has recognized that the success of floodplain restoration activities will be affected by the state of and pollutant loading from the upstream watershed and provides a discussion of watershed-scale management needs for supporting the Vision. The Task Order for this project also cites the work done for Sonoma County Water Agency (SCWA) in 2012 by Winzler & Kelly – GHD[2]. Like the SFEI Vision, this work had a multi-objective focus, but is primarily aimed at opportunities to increase flood protection by identifying and encouraging groundwater recharge projects. Unlike the SFEI work, this study addresses only areas outside the 100-year floodplain. Both the SFEI and SCWA reports cite a variety of associated studies on specific aspects.

The Vision discussion of watershed-scale management addresses the concepts summarized in Table 1-1:

[1] San Francisco Estuary Institute-Aquatic Science Center. 2020. Restoration Vision for the Laguna de Santa Rosa. An SFEI-ASC Resilient Landscapes Program report developed in cooperation with Sonoma Water, the Laguna de Santa Rosa Foundation, a Technical Advisory Committee, and a Management Advisory Committee. Publication # 983. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

[2] Winzler & Kelly – GHD. 2012. Laguna - Mark West Creek Watershed Planning Scoping Study, Screening Technical Memorandum. Prepared for Sonoma County Water Agency. https://evogov.s3.amazonaws.com/185/media/165584.pdf, accessed 2/12/2021.

Table 1-1. Watershed-Scale Management Components in the Laguna Vision Document

1. Flow Management and Groundwater Recharge
   - 1.1. Intercept precipitation for moderate events with less than a 5-year recurrence
     - 1.1.1. Enhance native woody vegetation in undeveloped areas
     - 1.1.2. Implement low-impact design and green infrastructure (LID/GI) practices in developed areas.
   - 1.2. Capture, Store, and Recharge Flood Flows
     - 1.2.1. Develop groundwater recharge opportunities in less developed areas with high recharge capacity, following the recommendations in Winzler & Kelly – GHD.
     - 1.2.2. Increase channel-floodplain connectivity and maintain/enhance floodplain depressional wetlands.
2. Sediment Management
   - 2.1. Sediment Source Control
     - 2.1.1. Reestablish vegetation on eroding slopes and steep headwater channel banks
     - 2.1.2. Increase vegetative cover on uplands
     - 2.1.3. Stabilize eroding channels using bank setbacks, large woody debris, etc.
   - 2.2. Sediment Capture and Storage
     - 2.2.1. [Mostly congruent with flow capture and storage under 1.1. and 1.2]
     - 2.2.2. Direct removal of excess sediment from channels on the Santa Rosa Plain
3. Nutrient Management
   - 3.1. Nutrient Source Control
     - 3.1.1. Reduce upland erosion using techniques described for sediment in 2.1.
     - 3.1.2. Address loads from onsite wastewater system
     - 3.1.3. Support urban and agricultural nutrient best management practices (BMPs).
   - 3.2. Interception of Nutrient Loads
     - 3.2.1. Promote detention and retention of nutrients via LID and stormwater control measures (as in 1.1 and 1.2)
     - 3.2.2. Encourage increased infiltration and decreased surface runoff on agricultural lands
   - 3.3. Processing and Removal of Nutrients
     - 3.3.1. Encourage wetland denitrification
     - 3.3.2. Encourage increased nutrient storage in healthy soils.

Existing studies already address some of these components in detail and thus were not the focus of the current work:

- Winzler & Kelly – GHD (2012) focus on groundwater recharge opportunities (topic 1.2.1) and identified over 100 potential project sites, of which eight were recommended as priorities. The screening is largely based on a 2011 memorandum prepared by Todd Engineers for the Sonoma Ecology Center and SCWA, *Santa Rosa Plain Groundwater Recharge Potential Mapping*, which is attached as an appendix to the Winzler & Kelly – GHD report.
- Floodplain depressional wetlands (1.2.2) were the subject of a 2017 report by SFEI[3]. This report identified all potential depressional wetland restoration areas within the Lower Santa Rosa Creek study area. SFEI used their GreenPlan-IT tool to model feasibility of restoration, potential

[3] SFEI. 2017. Demonstration of a Watershed Approach to Wetland Restoration Planning Using GreenPlan-IT. Technical Memorandum

associated load reductions, condition and habitat value, and factors such as ownership to develop priority rankings.

Based on consultation with Water Board staff we determined that the most valuable contribution to be pursued under this Task Order was the further development of a surrogate measure that can provide a simplified estimate of the contribution of land areas within the watershed to the reduced assimilative capacity of the Laguna. Analysis of the surrogate measure is provided in Section 2. The second priority of Water Board staff was developing a method to distinguish which fraction of the "herbaceous" land cover represents anthropogenic land uses (e.g., dairies) that are subject to regulatory orders from the Water Board. This was done through the integration of tax parcel data with the existing land use/land cover information, as described in Section 3. Finally, the funds remaining after completing these two tasks were used to conduct GIS analyses relevant to targeting additional restoration opportunities for areas that are suitable for infiltration of storm water, have poor soil cover, or have an elevated degree of connectedness to stream channels that deliver sediment and nutrients to the Laguna (Section 4). The detailed approach to completing the task was described in a memorandum *Restoration Opportunities,* dated 3/9/2021, from Jon Butcher, Tetra Tech, to Emily Cira (EPA TOCOR), Kelsey Cody (Water Board), and Lisa Bernard (Water Board).

2.0 SURROGATE MEASURE ANALYSIS

Assimilative capacity is increased only when a project is both feasible and results in a reduction in excess loads. Estimation of avoided loads is difficult, especially in the absence of a detailed watershed model. To address this issue Tetra Tech has proposed and Water Board staff have accepted a surrogate measure that can stand in for the risk of loads elevated above natural background (*Laguna de Santa Rosa: Surrogate Measures (Revised)*, 12/23/2020). The general concept of the surrogate is that increases in surface runoff above natural background conditions provide an index to both excess pollutant loading and increased flow that causes channel degradation. To make the surrogate easy to calculate and apply the approach does not involve continuous flow simulation, but rather compares current and natural conditions for a specified design storm. Further development and testing of the surrogate measure are the most immediate needs for documenting restoration plan opportunities for crediting within the available budget and using available data. This report begins to fill these needs through a fine-scale GIS application of the proposed surrogate method to the Laguna watershed and demonstrates how the method could be applied to identify relative contributions of different land areas to the impaired condition of the Laguna. Field verification studies may be needed to further support the analysis and there is a need for additional work to develop methods that can account for the effects of existing and proposed stormwater control measures on design storm runoff.

2.1 SURROGATE ANALYSIS METHODS

The concept of calculating the contribution of a site or area to increases above natural, undeveloped storm event runoff has aspects in common with Maryland's Environmental Site Design (ESD), although ESD is applied only to new development and redevelopment in Maryland. Maryland's Stormwater Design Manual[4] provides the following summary of the ESD concept: "The criteria for sizing ESD practices are based on capturing and retaining enough rainfall so that the runoff leaving a site is reduced to a level equivalent to a wooded site in good condition as determined using United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) methods (e.g., TR-55)." The evaluation is made on the basis of the 1-year 24-hour storm event, eliminating the need for continuous simulation or total runoff volume calculations. The 1-year 24-hour event is selected because channel-forming flows in evolving urban streams are typically found to be in the 1 to 1.5-year recurrence range. The channel forming flow or dominant discharge is the flow that does the greatest work on the channel by integrating a moderately high shear stress with a high frequency of occurrence. Larger flows will do more work on the channel in an individual event but occur less often. Bledsoe and Watson (2001) also recommend using the 1-year 24-hour event for stream stability analysis[5].

The NRCS TR-55 method is based on runoff curve numbers (CNs), which are a function of hydrologic soil group, impervious cover fraction, and condition of the land cover. Tables are widely available, and the City of Santa Rosa Storm Water Calculator provides automated lookup of TR-55 recommended curve numbers[6]. The MDE ESD guidance lays out the calculation methods and also provides reduced curve

[4] MDE. 2009. 2000 Maryland Stormwater Design Manual, Volumes I and II (Revised May 2009). Maryland Dept. of the Environment (MDE).

[5] Bledsoe, B.P., and C.C. Watson. 2001. Logistic analysis of channel pattern thresholds: meandering, braiding, and incising. *Geomorphology*, 38:281-300.

[6] https://srcity.org/DocumentCenter/View/18757/LID-Calculator-Ver-8110, accessed 6/1/2021

numbers (RCNs) to be used to account for at least some types of BMPs that reduce runoff from impervious surfaces. Evaluations can be made at the site, development, or larger scale through the calculation of area weighted CNs; however, for simplicity it is recommended that the analysis be conducted at the site or parcel level, removing the need to simulate downstream routing.

The CN method was originally developed in English units, but is now most commonly presented in metric units. estimates runoff (Q) from a storm event with depth (P) in units of millimeter (mm) as:

$$Q = (P - \lambda * S)^2 / (P + [1 - \lambda] * S)$$

Where λ represents the initial abstraction fraction and is typically assumed to be equal to 0.2 in U.S. practice[7]. The storativity, S (mm), is defined in terms of the dimensionless curve number (CN, maximum value 100) at a depth of 10 in (254 mm) as:

$$S = \frac{25{,}400}{CN} - 254$$

The ESD calculation approach simplifies the analysis by focusing on a single design storm, which greatly increases ease of applicability and avoids the need for continuous simulation. Application to the Laguna watershed does require modification to local conditions for the design storm event, land use, soils, and estimated curve numbers. These are discussed below.

In sum, the analysis of the surrogate measure assumes that the natural condition runoff is calculated using the 1-year, 24-hour storm and the CN for the appropriate pre-development soil group and land cover in good condition. The corresponding post-development runoff is then calculated with the CN appropriate to the present-day land cover and impervious fraction. The extra contribution or responsibility of the developed land area is then equal to the difference between these two numbers expressed as a volume by multiplying by area (e.g., as acre-feet of runoff). The method is readily applied to developed areas. It can also be applied to different types of agriculture, or even parks, based on their changes in land cover and impervious extent.

The key data inputs for the ESD method are as follows:

Design Storm: The 1-year, 24-hour storm for Santa Rosa is 2.87 inches as estimated in NOAA Atlas 14 but varies across the watershed. Interpolated grids for this event covering the whole watershed are available from the NOAA PFDS server (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html) and summarized in Figure 2-1.

[7] Various authors have suggested that a smaller value for the initial abstraction, λ, may be appropriate; however, a value of 0.2 is common practice and has been retained here. Most reference tables providing CN estimates are based on the assumption that λ = 0.2.

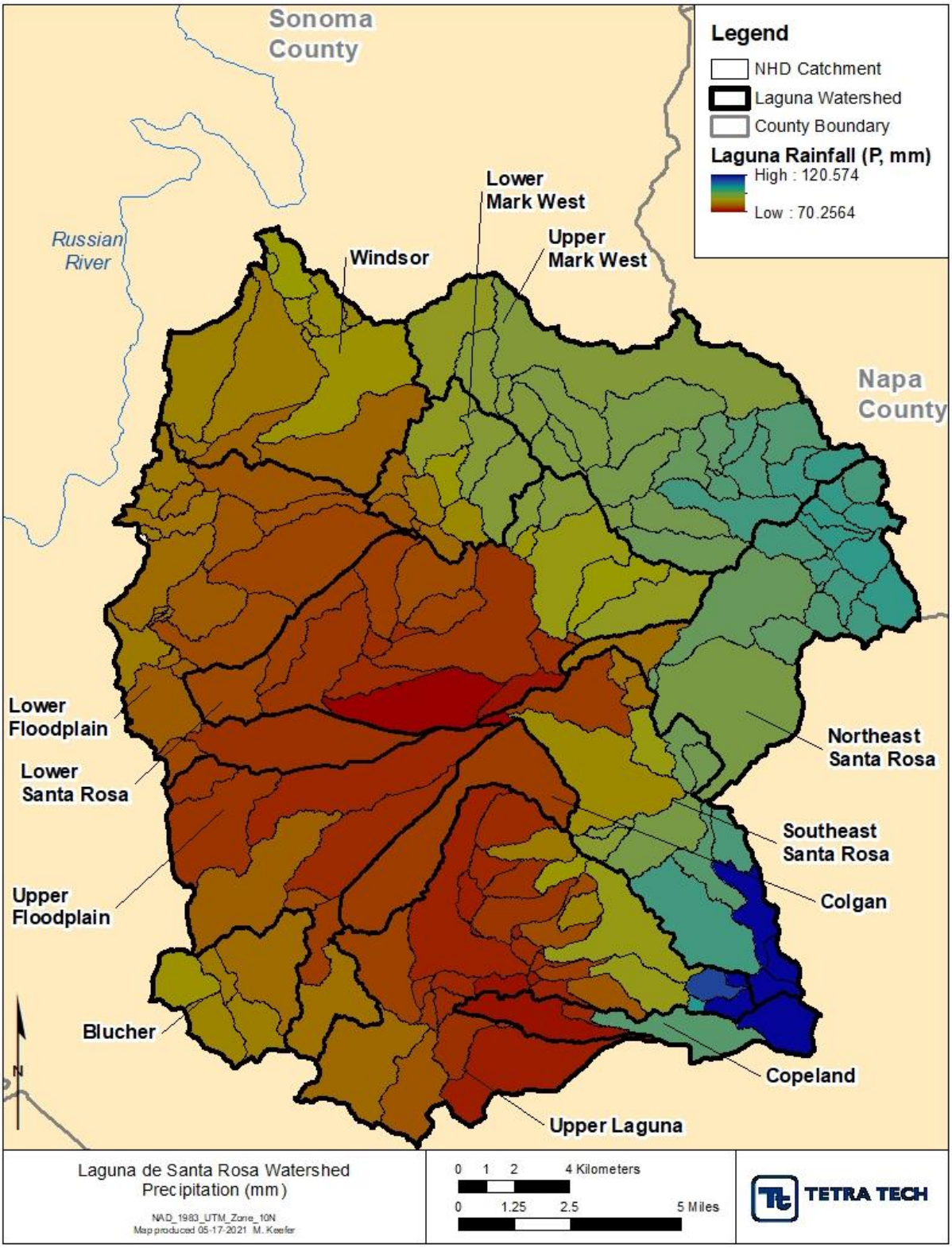

Figure 2-1. 1-yr 24-hr Storm Precipitation Depth for the Laguna de Santa Rosa Watershed, Averaged by Sub-Catchment

Land Use/Land Cover: High resolution LiDAR based spatial coverages of current land use and land cover, including impervious surface areas, have already been assembled for the Laguna watershed, as described in Tetra Tech (2020a) and can be used as the default basis for defining current condition CNs. Individual jurisdictions could be given the opportunity to revise these CNs based on factors such as presence of stormwater management controls. MDE (2009) provides techniques for accounting for such controls. The MDE ESD method assumes that the natural condition is woods in good condition. For application to the Laguna watershed we would instead use the pre-development land cover map developed by the Water Board[8]. This identifies six classes of pre-development land cover: Open Water, Perennial Wetland, Riverine Wetland, Rangeland, Oak Savanna, and Forest.

Soils: For the CN approach the primary need is for Hydrologic Soil Group (HSG), which is a measure of infiltration capacity that is incorporated into the CN lookup tables. A gridded map of HSG has already been developed from soil survey data as part Tetra Tech' previous work.

Curve Numbers: The most challenging input is the selection of appropriate runoff CNs. Tables of CNs are widely available, with a comprehensive summary in Chapter 9 of the National Engineering Handbook[9]. CNs vary by land use, hydrologic soil group (HSG), soil hydrologic conditions, and antecedent soil moisture condition (AMC). Because we are assessing runoff from a relatively large event associated with winter storms we use the central AMC value (AMC II), defined as "The average case for annual floods, that is, an average of the conditions that have preceded the occurrence of the annual flood on numerous watersheds."

CNs are provided for soil hydrologic conditions classified as good, fair, or poor. For some, but not all, cover types, the hydrologic condition is defined in terms of cover. For instance, for simulation of urban open spaces, fair condition is defined as grass cover on 50% to 75% of the area. It is important to note that the "cover" referred to here is not the same as the erosion cover fraction used to develop the C factor in the RUSLE erosion prediction method, which tends to be much lower than the ranges cited for CNs. (For example, the expected erosion cover fraction for urban open space is around 0.22.) It is also not the same as the cover estimates provided by Sonoma VegMap, which are correctly interpreted as qualitative measures of canopy density (0 to 1 ranking from "no canopy" to "very dense canopy") and does not include surface residue. Instead, the hydrologic condition component of CNs is a largely subjective evaluation that is defined in different ways for different cover types. For example, for forest cover good hydrologic soil condition is defined as "No grazing, adequate litter and brush cover", fair condition as "Grazed but not burned, some forest litter", and poor condition as "poor litter, small trees and brush destroyed by fire or heavy grazing."

General purpose CNs selected to represent current conditions are summarized in Table 2-1 and are primarily derived from the National Engineering Handbook (NRCS, 2004) and (with the exception of wetlands) match those recommended by the low impact design manual adopted by the MS4 permittees[10], which directly references the tables of CNs provided in the NRCS TR-55, *Urban Hydrology for Small*

[8] Butkus, S. 2011. Development of the Laguna de Santa Rosa Watershed Pre-European Settlement Spatial Data Model. Memo to file, California Regional Water Quality Control Board, North Coast Region, Santa Rosa, CA.

[9] NRCS. 2004. Hydrologic Soil-Cover Complexes. Chapter 9 in Part 630, Hydrology, National Engineering Handbook. Natural Resources Conservation Service, U.S. Dept. of Agriculture. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17758.wba.

[10] City of Santa Rosa. 2017. Low Impact Development Technical Design Manual. https://srcity.org/1255/Low-Impact-Development.

Watersheds.. The specific CNs adopted for this analysis assume that developed open space and cropland/vineyard land uses have good hydrologic soil condition, while shrub/brush, pasture/hay, and forest have fair hydrologic soil condition due to the likelihood of seasonal grazing and frequent fire events. CN values for wetlands are from a separate NRCS recommendation[11]. Because the analysis is for the 1-year, 24-hour event, stream channels (whether natural or man-made) are assumed to be (for the purposes of the event) open water and subject to the open water CN. Adjustments could be made to reflect conditions of individual parcels on a site-by-site basis if needed.

Land use categories developed by Water Board staff for conditions prior to European settlement are somewhat different than those used by Sonoma VegMap, but can also be translated to CNs (Table 2-2). For this table forest is considered to be in good hydrologic condition, while oak savanna is represented as a combination of good condition forest and grass.

Table 2-1. Curve Numbers Selected for Representation of Current Conditions

Land Use Class	HSG A	HSG B	HSG C	HSG D	Source
Developed Pervious	39	61	74	80	NRCS 2004, Table 9-5
Shrub/Brush	35	56	70	77	NRCS 2004, Table 9-1
Herbaceous (grazed)	49	69	79	84	NRCS 2004, Table 9-1
Pasture/Hay	49	69	79	84	NRCS 2004, Table 9-1
Cropland/Vineyard (contoured & terraced)	62	71	78	81	NRCS 2004, Table 9-1
Forest	36	60	73	79	NRCS 2004, Table 9-1
Barren, Open Water, Stream Channels	98	98	98	98	NRCS 2004, Table 9-1
Wetland	85	85	85	85	See footnote 11
Impervious	98	98	98	98	NRCS 2004, Table 9-5

Note: CNs are for AMC II with units of mm. HSG = Hydrologic Soil Group.

[11] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022388.pdf.

Table 2-2. Curve Numbers Selected for Representation of Conditions Prior to European Settlement

Land Use Class	HSG A	HSG B	HSG C	HSG D	Source
Rangeland	35	56	70	77	Equivalent to shrub/brush in Table 2-1.
Oak Savanna	32	58	72	79	NRCS 2004, Table 9-1
Forest	30	55	70	77	NRCS 2004, Table 9-1
Open Water, Stream Channels	98	98	98	98	NRCS 2004, Table 9-1
Perennial Wetland	85	85	85	85	See footnote 11
Riverine Wetland	78	78	78	78	See footnote 11

Note: CNs are for AMC II with units of mm. HSG = Hydrologic Soil Group.

One potential area for future investigation could be to consider adjusting CNs for high slope areas. The NRCS CNs are most appropriate to a catchment average slope of around 5 percent. Adjusting the CN for slope is a complex and somewhat controversial topic. For instance, the EPIC model has, since 1990, included an adjustment of CN for slope, but the theory manual for SWAT, which is a descendant of EPIC, discusses this option but then declines to implement it. A recent paper[12] discusses the history of slope adjustments to the CN and tests eight different slope-adjustment equations for mountainous catchments in South Korea. The evaluation of slope-adjustment equations is also tied up with arguments about whether the initial abstraction fraction in the standard CN method is too high, and it does not appear that there is a clear consensus on which adjustments, if any, would be applicable to the North Coast region. Note also that most of the slope adjustment methods are based on watershed average slope and may not be applicable to point estimates of runoff potential such as are presented here.

2.2 SUBCATCHMENT ANALYSIS

The surrogate calculations were carried out in two ways. First, we divided the Laguna watershed into the 181 small subcatchments defined in the National Hydrology Dataset and calculated area-weighted average runoff for current and pre-settlement conditions, as well as their difference. This provides a straightforward way to visualize changes in the surrogate measure across the watershed. We then performed the same calculations on a raster pixel basis, as described in Section 2.3.

Resulting average runoff rates by catchment and by land use (all catchments) for current and pre-settlement conditions are shown in Table 2-3 and Table 2-4, respectively. The estimated runoff difference between current and pre-settlement conditions is mapped in Figure 2-2.

[12] Ajmal, M., M. Waseem, D. Kim, and T.-W. Kim. 2020. A pragmatic slope-adjusted curve number model to reduce uncertainty in predicting flood runoff from steep watersheds. *Water*, 12, 1469; doi:10.3390/w12051469

Table 2-3. Current Condition Average Runoff Rate for 1-yr 24-hr Storm by Land Use (all catchments)

Land Use Classification	Average Event Runoff (Q, mm)
Barren	75.85
Cropland/Vineyard	33.17
Developed	26.26
Forest	35.79
Herbaceous	40.58
Impervious	73.27
Pasture/Hay	36.43
Shrub	35.27
Water/Wetland	45.14

Table 2-4. Natural Condition Average Runoff Rate for 1-yr 24-hr Storm by Land Use (all catchments)

Land Use Classification	Average Event Runoff (Q, mm)
Forest	27.49
Rangeland	32.87
River/Wetland	30.75
Oak Savanna	28.70
Riparian Wetland, Open Water	72.18
Perennial Wetland	42.08

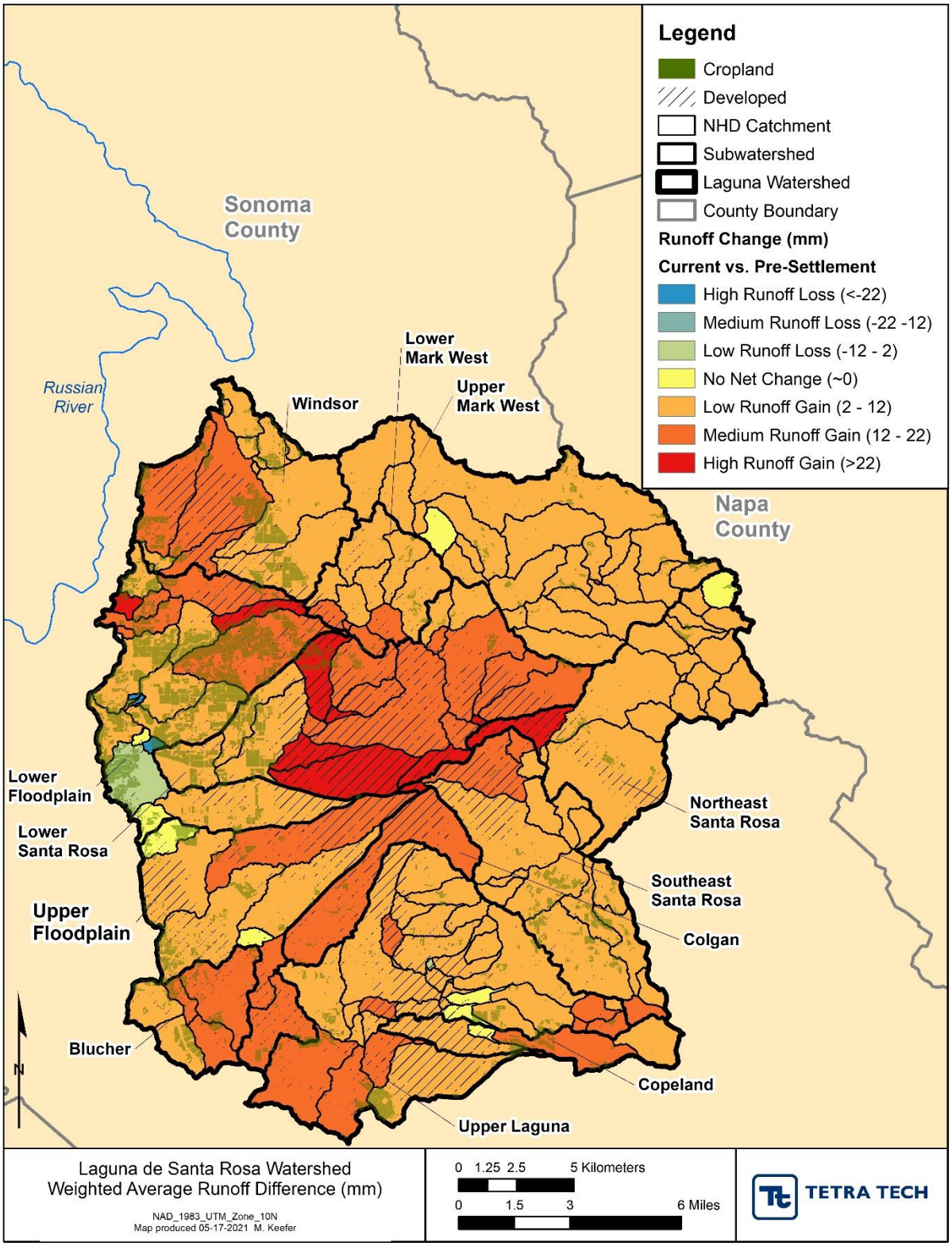

Figure 2-2. Change in Runoff Response to the 1-yr 24-hr Storm Event from Pre-European Settlement to Current Land Uses

2.3 RASTER ANALYSIS

The same surrogate calculations were carried out on a pixel by pixel basis across the input rasters. This results in a highly detailed, but complex coverage (supplied electronically) that can be used to evaluate specific areas of interest but is less useful for a broad overview. Figure 2-3 and Figure 2-4, respectively, show the high-resolution estimates of the surrogate measure runoff for current and pre-settlement conditions.

Some further insight can be gained from a closeup view, which is provided for the area immediately surrounding the Water Board offices on Skylane Boulevard in Santa Rosa, adjacent to the Charles M. Schultz airport and just south of Windsor, CA (Figure 2-5). The current landscape shows large areas of anthropogenically modified developed land with runoff rates for the event greater than 70 mm (blue), interspersed with undeveloped areas in the 25 - 50 mm range. In contrast, the pre-settlement runoff is predominantly in the 25 – 40 mm range. It will be noted that there are some small undeveloped areas where the estimated event runoff under current conditions is less than that estimated for pre-settlement conditions (e.g., 33 vs. 43 mm), such as the area just north of the airport that is red on the pre-settlement map. These are predominantly areas where land use is believed to have shifted from perennial wetlands to herbaceous. Wetlands have higher curve numbers because the soil is saturated, resulting in higher runoff.

All coverages used in the surrogate measure analysis are provided separately in an ESRI map package.

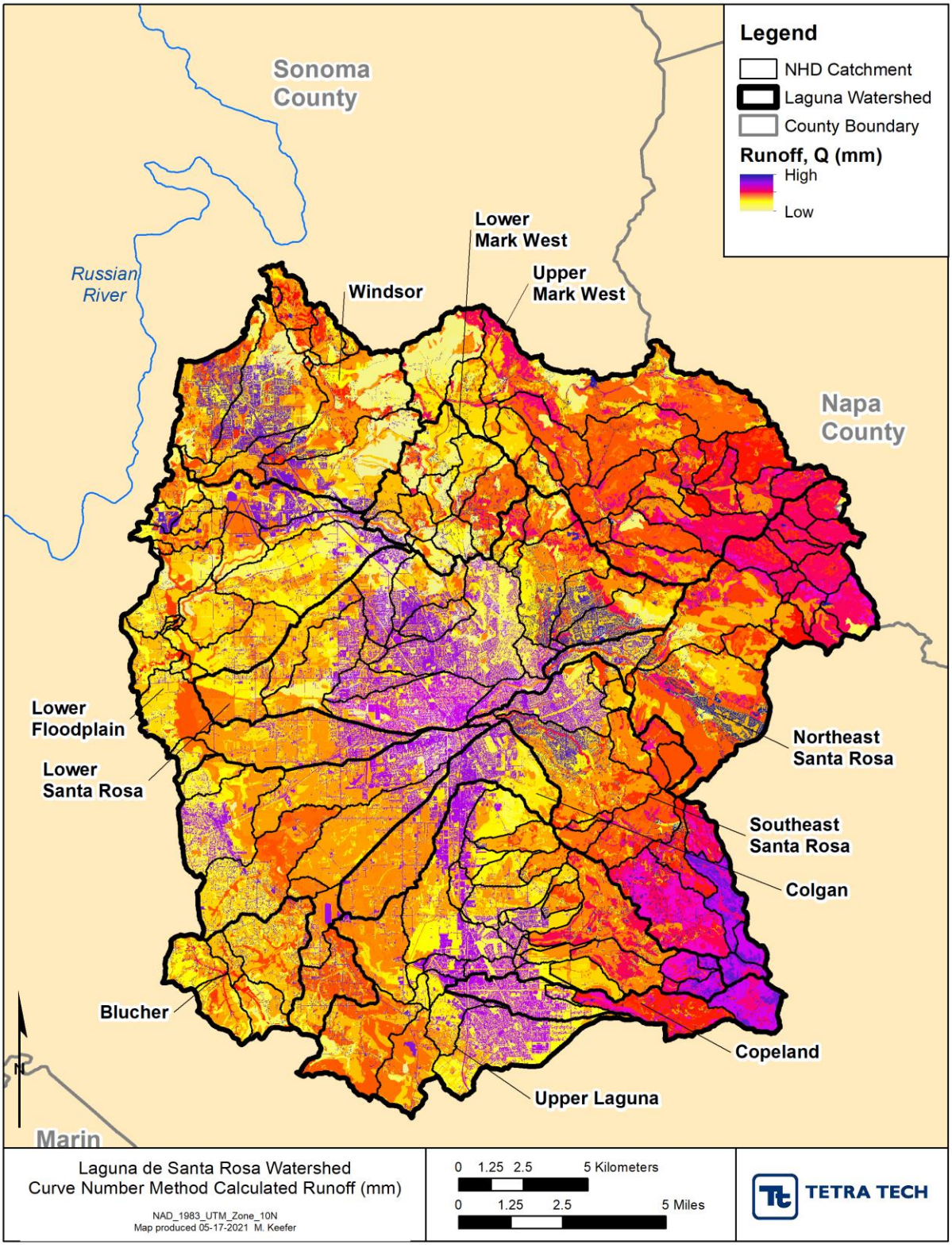

Figure 2-3. Raster-based Analysis of Runoff from 1-yr 24-hr Storm Event, Current Conditions

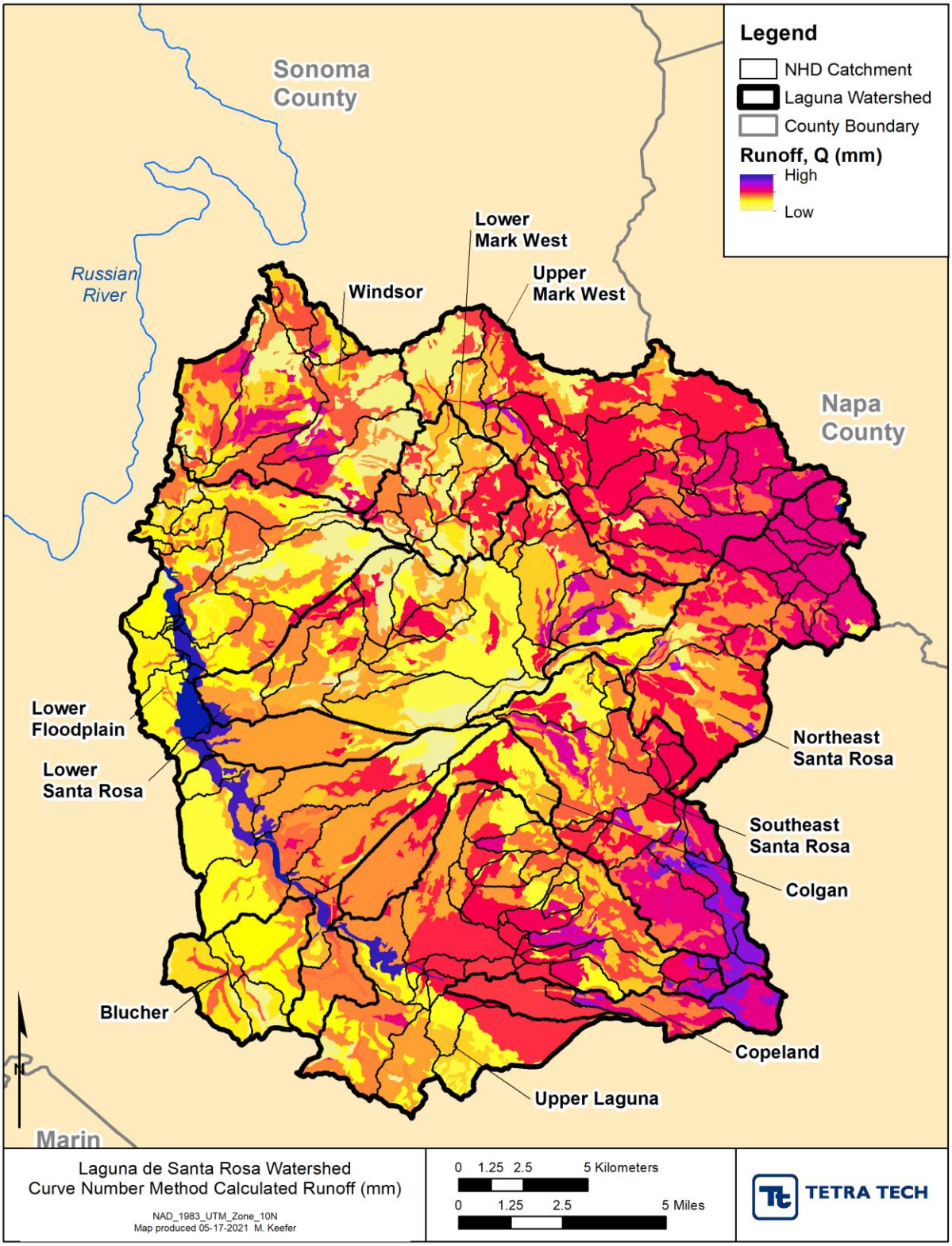

Figure 2-4. Raster-based Analysis of Runoff from 1-yr 24-hr Storm Event, Pre-settlement

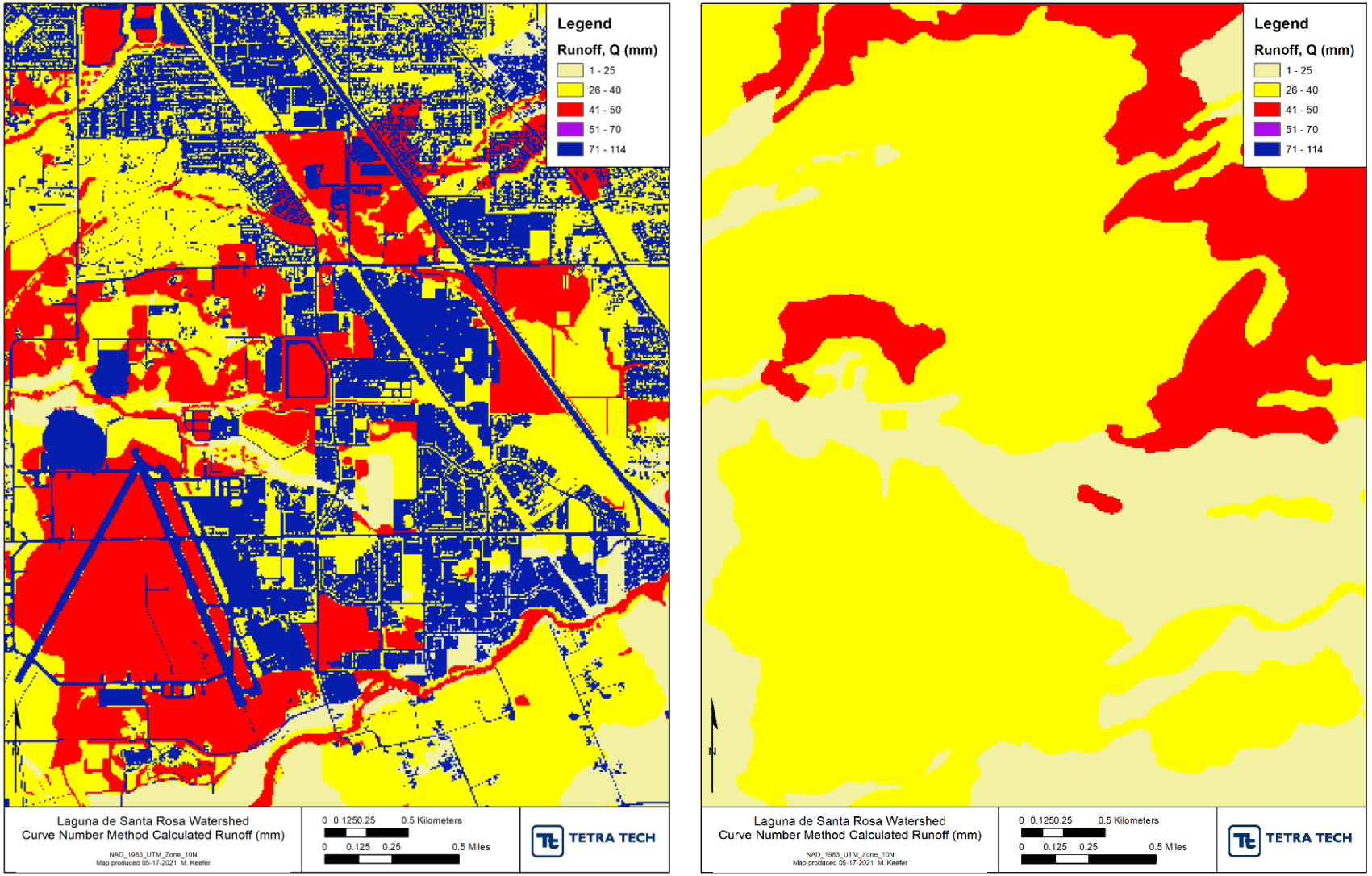

Figure 2-5. Close-up of Runoff from 1-yr 24-hr Storm Event for Area around Skylane Boulevard for Current (left) and Pre-settlement Land Use (right)

3.0 LAND USE TABULATION WITH SONOMA CO. PARCEL DATA

Prior work by Tetra Tech on estimating pollutant loads from different land uses in the Laguna watershed relied on the high (1 m) resolution land use/land cover information provided by Sonoma VegMap and developed using 2013 LiDAR surveys.

The primary VegMap resource used in the sediment and nutrient linkage analysis reports is the Sonoma County Vegetation and Habitat Map, which delineates 23 unique lifeform classes (http://sonomaopenspace.maps.arcgis.com/home/item.html?id=2d7728a8aba44df5b154c80aa8588d79). There is also a separate Impervious Map, which provides fine scale delineations of impervious features, including identification of paved roads, unpaved roads, building footprints, and other impervious surfaces. One quirk of the Vegetation and Habitat Map is that it does not distinguish vegetation types within the city limits of Santa Rosa, Windsor, Sebastopol, Rohnert Park, and Cotati, but instead classifies these areas as “Urban Window.” However, the Impervious Map does provide a full tabulation of impervious surfaces within the city limits, allowing identification of a general urban pervious classification for the remainder of the Urban Window area. A simplified representation of the Lifeforms Map as used in the sediment linkage analysis (aggregated into 14 categories) is reproduced in Figure **3**-**1**.

The focus of the Vegetation and Habitat Map is more on land cover than on land use. This is useful for modeling sediment erosion, but less useful for understanding land management practices. For instance, a focus on land cover does not readily distinguish which areas of shrub (predominantly chaparral) and herbaceous cover are subject to seasonal grazing.

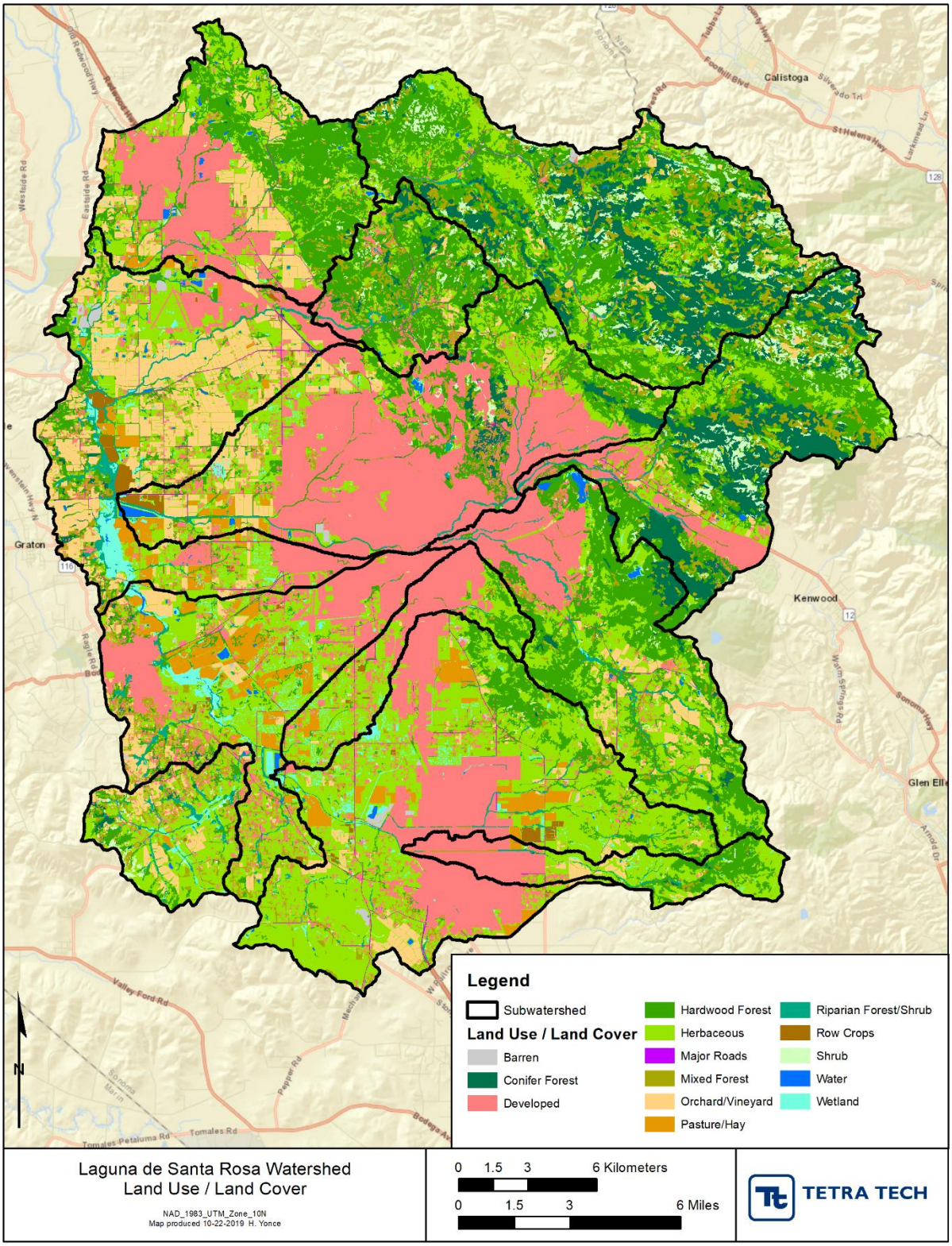

Figure 3-1. Simplified Lifeforms Distribution from Sonoma VegMap (2013 Data)

3.1 LAND USE COMPARISON

We examined tabulating the land use based on the Sonoma Co. parcel data, rather than relying on the VegMap classifications. It is first obvious that the total area in the parcel coverage (151,669 acres) is much less than the total area in the VegMap coverage (161,067). This is primarily because the parcel data omits publicly owned (and thus non-taxable) road rights-of-way.

A second issue is that (other than roads) impervious surfaces are included within parcels whereas they are tabulated separately by VegMap, so we aggregated pervious and impervious areas for comparison. We then find, as anticipated, that the parcel data attributes a much larger area to developed land because parcel boundaries for larger parcels typically contain areas of undeveloped grassland, forest, or chaparral. This results in a radically different tabulation of land use:

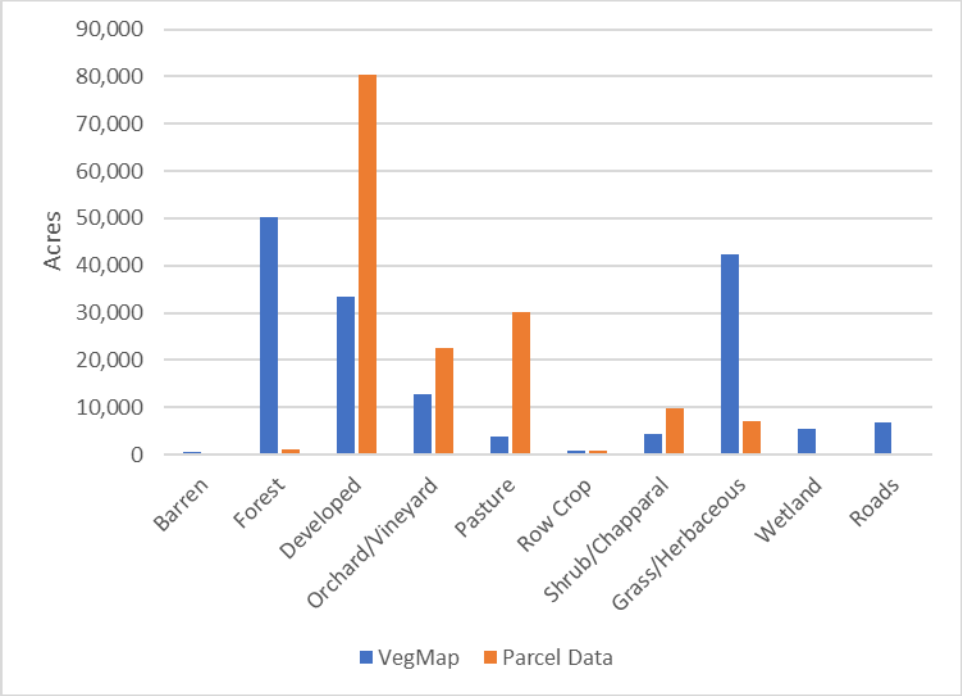

Figure 3-2. Comparison of Laguna de Santa Rosa Watershed Land Use from Sonoma VegMap and from Sonoma County Parcel Data

The parcel data also identifies very little area as Forest, with much of that land cover apparently being identified as part of the Developed tax class. It also appears that much of what VegMap identifies as Herbaceous is identified by parcel data as Pasture. These are likely less intensively grazed rangeland areas.

3.2 REFINEMENT OF ANTHROPOGENIC LAND USES

The VegMap coverage has some disadvantages from a regulatory standpoint. In particular, there are large areas characterized as “herbaceous” that appears to contain a mix of residential land, dairies, pasture, hay, and vacant grassland, some of which are subject to specific regulatory programs and others not. Parcel data provides additional information to help distinguish among these land uses.

Water Board staff developed and provided coverages of anthropogenic land uses as derived from the parcel data using the following procedures (email from Kelsey Cody to Jonathan Butcher, 5/13/2021). Beginning with a clipped and cleaned version of parcel data for the watershed they reported the following steps:

1) *Export as separate shapefiles only those parcels zoned as residential, commercial, or agricultural. There is no shapefile that contains only the multi-family zoning, since those are a miniscule contribution that I consider de minimis and are likely covered under the "developed" footprint from Sonoma VegMap anyway.*
2) *Use the "Fix Geometries" tool in QGIS to address the geometry issues on all three shapefiles.*
3) *Identify which land use types were anthropogenic using the "UseCDesc" attribute. "Anthropogenic" in this classification means "actively managed", especially grazing, mowing, turf, hay, irrigation, etc.*
    a. *In some cases, e.g. "18-hole golf course", the land use was clearly anthropogenic.*
    b. *In other cases, e.g. "Hardwoods and Chaparral" the land use was clearly not anthropogenic.*
    c. *Where the UseCDesc was ambiguous, satellite imagery was used to determine whether the category was anthropogenic. Where evidence of active management was missing, the land cover class was assumed to be natural.*
    d. *Satellite imagery revealed some error in the above classification procedure. In some cases, there were large parcels that deviated from the classification of the remainder of the parcels in the same UseCDesc category. This occurred mostly in publicly owned lands that were sometimes wilderness parks and other times utility yards or airports.*
    e. *Therefore, parcels were added or removed from the anthropogenic classification based on satellite imagery.*
        i. *NOTE: Inevitably, some error and ambiguity in classification will remain. However, the above procedure was undertaken by a resident of the watershed familiar with the land uses through personal experience. Because of how the satellite imagery was used, the error is likely concentrated in smaller parcels that have less herbaceous cover.*
        ii. *NOTE: The Sonoma VegMap classifications of land cover are from 2013. The Satellite imagery is from ESRI and is more recent than 2013. The county's land use classification is from 2020. Therefore, there may be some mismatch between what was on the land in 2013, what the imagery shows, and how the county classified the land use. This is inevitable and unavoidable. This error is likely strongest recently converted vineyards and subdivisions. So, while the Sonoma VegMap may indicate that a land use was pasture or herbaceous land, the County may now classify it as Vineyard.*
4) *Edit the shapefiles to remove all parcels that are not anthropogenic.*
5) *Add an attribute to all remaining (i.e. anthropogenic) parcels in all three shapefiles called "PermClass" that denotes the general category of permit that might deal with the parcel in question. This will simplify the assignment of the sediment loads and excess runoff, since there are over 100 values that UseCDesc can take.*

A further update to the ComAnthro and AgAnthro attributions was provided in June (email and Google drive transfer from Kelsey Cody to Jonathan Butcher, 6/17/2021).

Water Board staff requested that Tetra Tech complete the process of merging the parcel-based estimates of anthropogenic land uses with Tetra Tech's processed analysis of the VegMap land use to ensure consistency with the land use coverage used in the RUSLE analysis.

We used the following steps:

- Merged all the anthropogenic parcel shapefiles provided by the Water Board (AgAnthro, ComAnthro, ResAnthro) into one: ***ResAnthro_ComAnthro_AgAnthro_merge.shp***
- Union of merged shapefile and the RUSLE land use coverage.

- Retained original parcel coverage identification for areas outside the anthropogenic area coverages
- Created ***SonomaVegMap_RUSL_agglulcherb_imp_perv.shp.***

The shapefile includes the following attributes:

- FID_Sonoma (values -1 to 7). Autogenerated field from the VegMap processing. Values 0 to 7 correspond to the VegMap classes for pervious land used in the RUSLE analysis. Where FID_Sonoma = -1, there was no coverage from the VegMap shapefile because these pixels were impervious surfaces not relevant to RUSLE and were removed. These may be assumed to be impervious surfaces and are included in the parcel-based analysis.
- RUS_AG_LU2. Sonoma VegMap pervious land use class as aggregated by Tetra Tech and used in the RUSLE analysis.
- FID_ResAnt. Autogenerated field from the processing of the "Anthro" coverages. Where FID_ResAnt = -1, the area is not in the Anthro coverages. This corresponds in part to road rights-of-way and other non-taxable land; however, our review confirms that the area with FID_ResAnt = -1 also contains multifamily apartment buildings that show up in the base parcel coverage and the impervious surface coverage, but are not included in the ResAnthro coverage consistent with Kelsey Cody's step 1 noted above. As a result, these do not have a PermClass assigned. In performing tabulations (below) we have assigned a PermClass designation of "NA-" plus the VegMap land use to these parcels so an evaluation can be made of how significant these omissions are.
- UseCDesc. Water Board staff identification of the anthropogenic land use classes. This is blank when FID_ResAnt = -1.
- PermClass: Water Board staff determination of permit class for the anthropogenic land uses, representing a consolidation of the many UseCDesc classes.

The resulting shapefile has been supplied electronically.

3.3 RETABULATION OF RUSLE DELIVERED SEDIMENT LOADS

The revised land use interpretation, specifically the PermClass identification, was used to retabulate the delivered sediment loads from the RUSLE delivered loads raster with delivery ratio provided by the Connectivity Index (described in *Laguna de Santa Rosa – Linkage Analysis for Sediment Impairments*). The estimated annual average total delivered sediment load (excluding the areas upstream of Lake Ilsanjo and Matanzas Reservoir) is 24,384 English tons/year. This is somewhat greater than the Linkage Analysis estimate of 21,106 tons/year due to a change in the calculation method. For the Linkage Analysis we calculated the average delivered load per acre for each land use then multiplied by the area of that land use. For the current analysis, the raster that shows estimates of delivered load on the 1-meter RUSLE grid was summed directly, which we believe is a more appropriate method for calculating the total delivered RUSLE load. Loads by Subbasin and Permit Class are summarized in Table 3-1, while Figure 3-3 summarizes percentages by the broader Use CTypes. Overall, about 50% of the upland sheet and rill erosion load is associated with parcels in various agricultural use permit classes. Note, however, that this presentation does not separately characterize non-anthropogenic land uses within tax parcels that have anthropogenic permit classes, such as sections of forest within a vineyard parcel.

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Table 3-1. Revised Tabulation of RUSLE Delivered Sediment Loads (tons/yr) by Permit Class

Subbasin	Crop-land	Dairy	Developed _Com	Developed _Res	Developed_ Rur_Res	Grazing	Orchard	Poultry	Vineyard(s)	NA-Barren	NA-Row Crops	NA-Residential	NA-Forest	NA-Vacant Grassland	NA-Pasture	NA-Shrub/ Chaparral	NA-Water/ Wetland	Total
Blucher	1	11	3	2	127	38	22	0	171	0	2	2	1	2	0	0	0	382
Colgan	0	1	23	28	36	90	0	1	7	0	0	16	2	6	0	0	0	211
Copeland	2	0	6	3	76	136	0	0	126	0	3	3	11	5	0	1	0	372
Lower Floodplain	1	104	143	38	223	114	11	0	2,486	11	27	33	13	16	0	1	1	3,223
Lower Mark West	0	0	115	183	609	73	0	0	298	0	0	15	61	16	0	4	0	1,375
Lower Santa Rosa	44	12	301	1,060	607	301	2	0	1,077	0	4	153	73	32	0	3	0	3,669
NE Santa Rosa	0	0	53	240	492	644	0	0	397	232	13	36	949	161	0	168	4	3,388
Southeast Santa Rosa	0	0	83	173	153	53	7	0	56	0	3	38	199	88	0	8	0	860
Upper Floodplain	2	42	35	60	186	90	5	0	148	0	2	42	2	8	1	0	0	623
Upper Laguna	13	45	89	70	358	403	1	0	686	2	42	26	20	33	1	3	0	1,792
Upper Mark West	0	0	295	43	1,255	1,618	108	0	1,047	46	30	7	1,117	189	11	285	4	6,056
Windsor	1	2	99	119	432	288	12	1	1,725	1	12	29	160	32	0	7	0	2,922
Total	66	218	1,244	2,020	4,555	3,849	169	2	8,223	291	137	400	2,609	588	14	480	9	24,873
Percent	0.27%	0.89%	5.10%	8.28%	18.7%	15.8%	0.69%	0.01%	33.7%	1.19%	0.56%	1.64%	10.7%	2.41%	0.06%	1.93%	0.04%	
Use CType	Agr.	Agr.	Commercial	Residential	Residential	Agr.	Agr.	Agr.	Agriculture	Vacant	Agriculture	Residential	Vacant	Vacant	Agr.	Vacant	Vacant	

Note: “NA”: Not classified by Permit Class. Southeast Santa Rosa total excludes area upstream of Matanzas Reservoir and Lake Ilsanjo

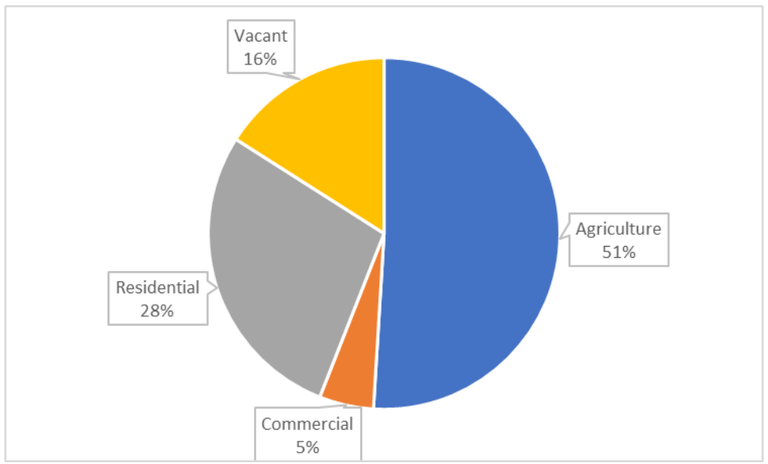

Figure 3-3. Distribution of Delivered RUSLE Sediment Loads by Parcel “Use CType”

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4.0 ADDITIONAL RESTORATION OPPORTUNITIES

This section provides initial GIS analyses for several other types of restoration opportunities in the watershed that have not yet been fully addressed.

4.1 INFILTRATION OPPORTUNITIES

As noted above, previous analyses have identified areas with potential for diversion and infiltration of streamflow. The WInzler & Kelly – GHD 2012 analyses were focused on high-capacity groundwater recharge projects, which could be important components of restoration planning. However, the 2012 analyses do not address opportunities for smaller-scale, distributed recharge using GI or modified agricultural practices. The analyses were also completed before the high-resolution LiDAR-based DEM was available. We have augmented the earlier analysis by developing spatial coverages that identify areas that combine high soil infiltration potential and low slope.

Infiltration stormwater control measures include infiltration basins and infiltration trenches. Bioretention on highly permeable soils can also be a significant contributor to infiltration. In general, infiltration measures must be set back from buildings and highway pavement to protect against structural damage. The design manual used by both Sonoma County and the MS4 cities that intersect the Laguna watershed does not appear to specify exact setback requirements for these types of measures; however, California Stormwater Quality Association (CASQA) guidance suggests a 6 m setback should be used[13]. Elevated water tables may also limit infiltration opportunities on a site-specific basis.

To help identify infiltration potential we began with polygon coverage of pervious land only, then deleted area classified by VegMap as water or wetlands. The resulting polygon has edges that represent either impervious surfaces or wet areas. A -6 m interior buffer was then imposed to provide the necessary setbacks and resulting polygon fragments with area less than 100 m^2.

Areas potentially suitable for infiltration measures are first defined as those that have hydrologic soil groups A or B. Suitability is also somewhat limited by slope, so we limited the analysis to areas with local average slope (based on 10 m DEM) of 0 – 2%, 2 – 5%, and 5 – 10% in declining order of preference. The resulting areas are shown in Figure 4-1.

Several things are evident from this figure. First, the areas with A or B soils at slopes of 10% or less are rather rare. Second, while the buffer approach seems to work well for imposing setbacks from impervious surfaces, it often does not achieve a 6 m setback from stream bluelines. This occurs because these stream channels are often dry and not classified as water or wetland by VegMap. Another issue is that the buffer needs to be created after converting the land use raster to polygon, which creates some edge discrepancies such that a setback distance of 6 m is not always exactly enforced.

The spatial coverage, which is supplied electronically as a map package, can be used as a preliminary indicator of where infiltration opportunities are most likely. However, there are many other site-specific considerations that will need to be considered (e.g., utilities, depth to water table, setbacks from ephemeral streams not identified in VegMap) before planning and permitting specific projects.

[13] CASQA. 2003. Infiltration Trench, TC-10. California Stormwater BMP Handbook; New Development and Redevelopment. www.cabmphandbooks.com

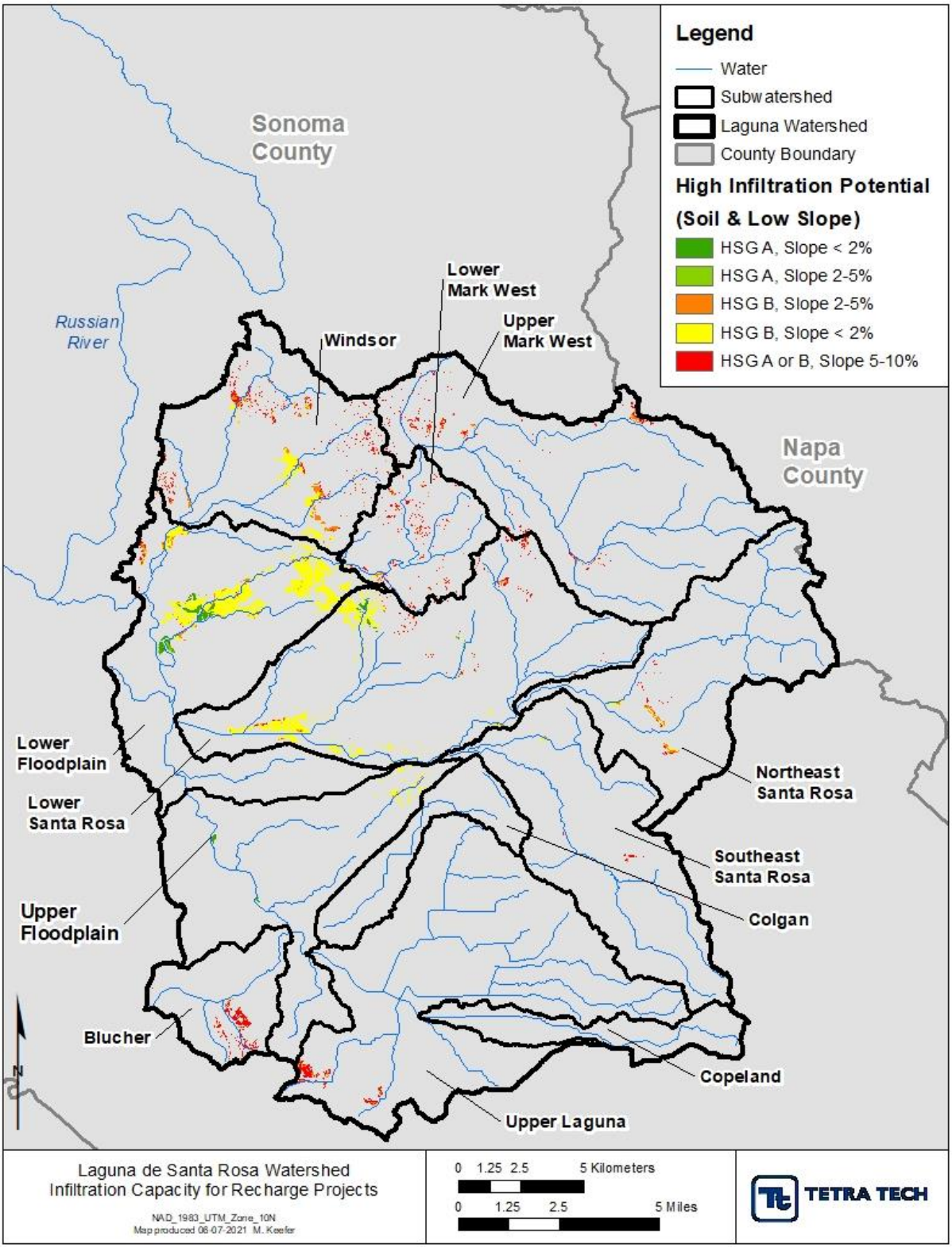

Figure 4-1. Watershed Areas with Potential High Infiltration Capacity

4.2 POOR SOIL COVER

Areas with soil cover that is less than expected for similar land use / slope combinations is at greater risk for increased erosion and pollutant load generation. Direct analysis of areas with poor soil cover would thus be a useful tool for targeting and crediting restoration efforts.

We hoped to identify areas with poor soil cover by using the Sonoma VegMap LiDAR analyses of cover; however, as noted in Section 2.1, the Sonoma VegMap estimate of cover is primarily a measure of canopy density and not a direct measure of erosion cover, which also includes residue on the ground surface. This problem was addressed in the RUSLE estimates for the sediment linkage analysis by renormalizing VegMap cover to the expected value of the C factor by land use type derived as part of the Sonoma Creek sediment TMDL. That approach, however, is too coarse an approximation to identify specific pixels with poor soil cover except in the forested areas. Most other land uses have a median VegMap cover of zero prior to the renormalization. The VegMap cover is thus most useful to identify areas of high canopy cover, but not to identify areas of poor total soil cover. Therefore, an analysis of poor soil cover based on VegMap has not been reported.

Other data sets are available that should be useful to identify areas with bare soil or limited vegetative cover. This is typically done through use of the Normalized Difference Vegetation Index (NDVI) and other spectral methods that distinguish between bare earth, dead organic residue, and living plant matter. These methods have often been used in the Midwest to assess soil cover in agricultural areas[14].

A useful source for such information is provided by the National Agricultural Imagery Program (NAIP), which conducts automated aerial image analysis during the growing season. NAIP imagery has been analyzed to estimate NDVI at a 60-cm resolution for all of California and is available from the State Geoportal, with 2018 being the last year currently available (https://gis.data.ca.gov/datasets/07bbc452e55445a19d1cc3a643a78838). An example for the Santa Rosa area is shown in Figure 4-2.

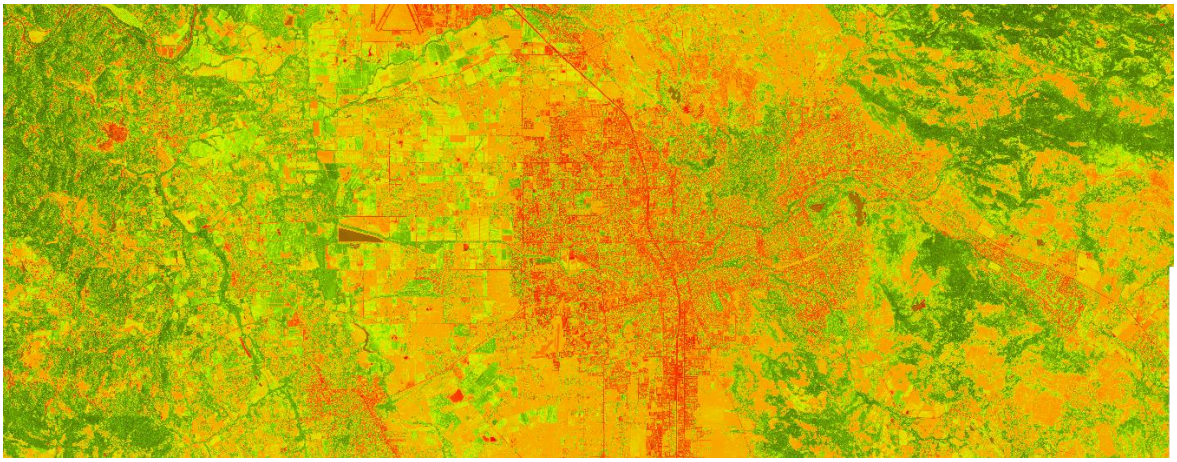

Figure 4-2. 60-cm NDVI Imagery for the Santa Rosa Area, 2018

[14] For a recent summary of techniques see Laamrani, A.; Joosse, P.; McNairn, H.; Berg, A.A.; Hagerman, J.; Powell, K.; Berry, M. 2020. Assessing Soil Cover Levels during the Non-Growing Season Using Multitemporal Satellite Imagery and Spectral Unmixing Techniques. *Remote Sens.*, 12, 1397. https://doi.org/10.3390/rs12091397.

NDVI imagery has been used by Sonoma Water to evaluate land use change in the Russian River watershed, as well as in California Fish & Wildlife studies to evaluate the impacts of the 2017 fires[15]. Combining NDVI with land use information would likely provide a useful basis to identify areas with sub-optimal soil cover (e.g., condition by pixel relative to the distribution for the land use type.) However, available resources are not sufficient to pursue that analysis under the current project.

4.3 CONNECTIVITY ANALYSIS

Land areas that have greater connection to the stream network due to the combination of proximity, slope, and upgradient flow accumulation have greater risk of delivering pollutant loads to the Laguna and are thus potential hotspots for restoring assimilative capacity. Tetra Tech developed the topography-based Connectivity Index[16] primarily as a means to estimate sediment delivery ratios (SDR)[17] for the RUSLE analysis in the Sediment Linkage Analysis report. Tetra Tech reanalyzed the Connectivity Index outputs to provide a high-resolution spatial tool for fine-scale analysis of potential project locations.

Specifically, we work with the Vigiak-based estimate of SDR, which is a measure of the likelihood of local surface erosion products being delivered to the Laguna to map areas where the predicted SDR is above the median (0.01238) for the watershed (Figure 4-3). The distribution is highly skewed, so the histogram equalize stretch method is used for the color ramp. Output for individual pixels is available in the electronic files.

[15] Green, K., M. Tukman, D. Loudon, A. Schichtel, K. Gaffney, and M. Clark. 2020. Sonoma County Complex Fires of 2017: Remote sensing data and modeling to support ecosystem and community resiliency. California Fish and Wildlife, *Fire Special Issue*; 14-45.

[16] Borselli, L., P. Cassi, and D. Torri. 2008. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. *Catena,* 75: 268-277.

[17] Vigiak, O., L. Borselli, L.T.H. Newham, J. McInnes, and A.M. Roberts. 2012. Comparison of conceptual landscape metrics to define hillslope-scale sediment delivery ratio. *Geomorphology*, 138: 74-88.

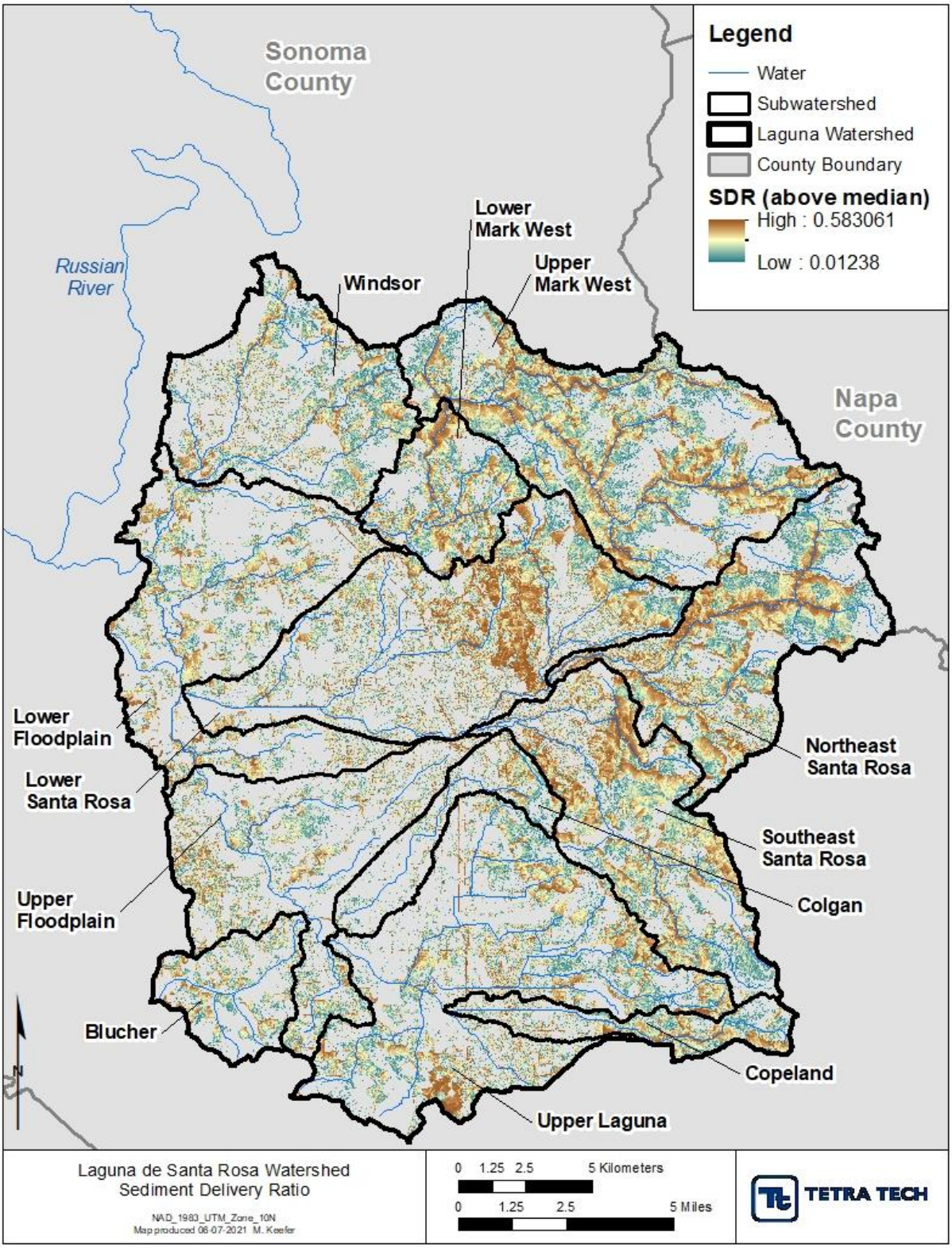

Figure 4-3. Identification of Upland Areas with High Connectivity to the Laguna de Santa Rosa