Synthesis of Literature on Wetland Assimilation Capacities, Models, and Pollutant Loads and Pathways to Support Implementation of the Laguna de Santa Rosa TMDL through Landscape Scenario Planning

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This literature review is focused on 1) nutrient assimilation capacities for the common wetland types of the Santa Rosa Plain; 2) previous studies and modeling effort on hydrology and loads and pathways of nutrients and sediment into the Laguna; and 3) existing models and tools that can be used to simulate wetland assimilation of pollutants and identify and prioritize wetland restoration efforts using GIS-Based landscape scenario planning.

Landscape scenario planning is the use of GIS coupled to numerical simulation models to explore the likely effects of changing the physical characteristics of a landscape or its land uses on selected ecosystem services.

1. Wetland assimilation capacities

Wetlands are among the most productive ecosystems that provide numerous beneficial services, including protecting and improving water quality, providing fish and wildlife habitats, storing floodwaters, recharging groundwater, and maintaining surface water flow during dry periods. These valuable functions are the result of the unique natural characteristics of wetlands.

Wetland can effectively remove or convert many pollutants including organic matter, suspended solids, metals, and excessive nutrients to reduce their environmental risks. The specific hydrogeological and hydrochemical conditions relating to these benefits include their natural abilities to slow waterflow and their biochemical and biological processes of sedimentation, denitrification, absorption or plant uptake that entrap and transform pollutants.

The processes of wetland systems to store sediments and transform nutrients are highly efficient and effective but each system has a threshold. An overabundance of nutrient input from fertilizer runoff, sewage effluent, or non-point pollution will cause eutrophication and habitat degradation. Upstream erosion can overwhelm wetlands with sediment making them shrink in size and lose biodiversity. The capacity of wetland vegetation to store heavy metals is affected by water flow, wetland size, climate, and plant species composition.

2. Previous study for Santa Rosa Plain

- **USGS hydrological model**

  U.S. Geological Survey (USGS) undertook development of a fully coupled groundwater and surface-water model to better understand and to help manage the hydrologic resources in the Santa Rosa Plain watershed to address the challenge of meeting increasing water demand (Woolfenden and Nishikawa, 2014). The Santa Rosa Plain hydrologic model was developed by using the USGS groundwater and surface-water flow model, GSFLOW, which consists of two integrated model components: (1) a watershed-component model developed by using Precipitation Runoff Modeling System (PRMS); and (2) a groundwater-component model developed by using MODFLOW-NWT. The model was calibrated to both measured streamflow and groundwater levels. The calibrated GSFLOW was used to provide water budgets; to investigate the stream and aquifer interactions; and to simulate the effects of current hydrologic stresses, potential climate change, and projected groundwater pumping stresses on the hydrologic system.

- **North Coast Regional Board modeling work**

  The development of the Santa Rosa Laguna TMDL for nutrients and dissolved oxygen (DO) requires both a pollution source analysis and the establishment of a linkage between nutrient loads and instream DO conditions. To assist TMDL development, the North Coast Regional Water Board staff developed two models: 1) an empirical, data-based model based on simple pollutant transport from various land covers to estimate the relative nutrient loading from the major sources in the watershed (Butkus, 2013); and 2) a one-dimensional water quality model to simulate receiving water dissolved oxygen responses to nutrient loads from the Laguna watershed (Butkus, 2011a, 2012).

  1) Watershed loading model

  A watershed loading model, referred to as the Land Cover Loading Model (LCLM), was developed to estimate nutrients loads from the Laguna watershed. The LCLM is a simple spreadsheet model that estimates pollutant loading from catchments based on land cover areas and representative loading rates (i.e., load per unit area of land). The nutrient loading rates for each land cover category was determined from sampling pollutant concentrations in runoff from seven categories (forest, rangeland, crop and pasture, orchards and vineyards, non-sewered residential, sewered residential, and commercial) for 2009-2010, and also compared to literature values. The total loads from each land cover category were then estimated by multiplying its loading rate by land cover area.

  The LCLM was applied to produce load duration curves for each land cover to represent estimated changes in annual loads over a range of stream flow conditions, and current and pre-settlement load duration curves were developed to compare each of the historical open water catchment areas (Butkus, 2011b, 2013). Within the model structure, the reduction of pollutant loads due to attenuation of nutrients by natural processes in riparian wetlands was based on USEPA published estimates of pollutant load removal, while for perennial wetlands load reduction was estimated by using PREWet, a simple wetland model developed by the U.S. Army Corps of Engineers (Dortch and Gerald, 1995).

Although the LCLM is useful in providing annual loads delivered to the Laguna from major land cover categories, the model lacks key watershed processes that are essential for assessing wetland assimilation capacity and prioritizing their locations at a watershed scale. Therefore, a process-based watershed model that is capable of simulating nutrient loads and wetland capacity is more desirable.

2) Receiving water quality model

The QUALKw model, also referred to as the River and Stream Water Quality Model, is a one-dimensional, steady state model developed to simulate DO responses for waters in the Laguna watershed (Butkus, 2011a, 2012). The model simulates steady-state hydraulics and diel water quality conditions in a one-dimensional channel that is assumed to be well-mixed vertically and laterally. Two QUAL2Kw models were developed to represent the lentic and lotic surface water quality, and applied to simulate summer critical low flow periods (Butkus, 2011a).

The nutrient loads from the watershed was simulated by the LCLM and used as inputs to QUAL2Kw model. A linkage analysis with the QUAL2Kw models was undertaken to establish a relationship between nutrient loads, sediment oxygen demand, and instream water quality response; in particular, DO concentration. Model results of daily minimum DO concentration were used to assess support key beneficial uses of the Laguna (e.g., SPWN, WRM, and COLD). Current external and internal nutrient loads were reduced by factors of 10 percent to 90 percent as well as increased by 120 percent to evaluate the effect of nutrient loading on resulting daily minimum DO concentrations (Butkus, 2012).

- **Tetra Tech Sediment Budget and Nutrients Analysis**

  Quantifying the sources and status of sediment loads is a key component for the successful completion of the full suite of pending TMDLs for the Laguna de Santa Rosa – both for sediment and for other stressors. In supporting U.S. Environmental Protection Agency (USEPA) Region 9 and California's North Coast Regional Water Quality Control Board (NCRWQCB) for this effort, Tetra Tech completed a sediment budget for current land use and pre-settlement conditions in the Laguna watershed, and also provided an analysis of nutrients association with sediment (Tetra Tech, 2015a).

  The sediment budget was developed by assembling available information on the major sources and sinks of sediment in the watershed, comparing the results to data where available, and ensuring that the resulting mass flux estimates are consistent with a physically realistic balance. Specifically, this analysis used MRUSLE to estimate Upland Sheet and Rill Erosion, and draws significantly on work carried out in an adjacent watershed and reported in the Sonoma Creek Sediment TMDL (Low and Napolitano, 2008) and the accompanying sediment source analysis (Sonoma Ecology Center, 2006), as well USGS analysis of sediment deposition.

The current sediment budget in the Laguna de Santa Rosa watershed was estimated as 85255 tons/yr. On the source side, 56% sediment load to the Laguna de Santa Rosa is estimated to be from channel incision; 19% from upland erosion; 14% from soil creep, gully erosion, and landslides; and 11% from roads. On the sink side, 72% sediment is deposited in the Laguna; 23% is removed through Channel Maintenance Activities; and 5% is exported to the Russian River. Under pre-settlement condition, the total sediment budget is estimated as 7658 tons/yr, with soil creep, gully erosion, and landslides as the largest sources, and deposition in the Laguna de Santa Rosa serving as the main depositional sink.

In a companion report, Tetra Teach also summarized information available on loading of nutrients and organic material to the Laguna (Tetra Tech, 2015b). The report presented a review of both NCRB's QUAL2Kw model of simulating nutrients and DO responses for waters and an empirical, data-based model (LCLM) of simulating nutrient loading from the watershed. An alternative analysis was developed to relate phosphorus loads to sediment loading in the watershed, in which phosphorus loads were estimated through application of sediment potency factors (pounds of phosphorus per ton of sediment). The estimated phosphorus load from the entire watershed using the sediment potency approach was 128,435 lb/yr, lower than the median LCLM load of 167,730 lb/yr. In addition, annual loads for total phosphorus, total Kjeldahl nitrogen, nitrate nitrogen, and ammonium nitrogen were estimated using a bias-corrected regression of concentration on daily flow collected through SCWA monitoring and USGS gage records. The report concluded that estimates of stormwater nutrient loading in the Laguna de Santa Rosa watershed are highly uncertain and additional monitoring in small watersheds with relatively homogenous land cover would provide data that could in the future support the development of a process-based model.

3. Wetland Evaluation Models

Models are a valuable and widely used tool in environmental planning. Models are applied to solve a wide range of wetland related problems and to improve wetland planning and management at different spatiotemporal scales. The review of modeling tools in this report is limited to existing tools that could support a framework for identifying and assessing alternative wetland and stream restoration scenarios for the Santa Rosa Plain Laguna for wetland simulation, and is therefore limited in scope.

- **North Carolina Coastal Wetland Tools**
  The Costal Management Division of the North Carolina Department of Environmental Quality (DEQ) has developed a set of GIS tools to help wetland management and protection (**http://portal.ncdenr.org/web/cm/wetlands_documents**). In specific, three GIS tools are used to help support land-use planning and regulatory decisions, as outlined below.

Wetland identification and Mapping - this tool uses the best available GIS layers to determine the location, type, and extent of wetlands in 37 coastal plain counties in North Carolina. GIS allows users to view the wetland data in relation to other land features.

Wetland Functional Assessment Mapping – The North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS) is a wetland functional assessment and mapping tool that uses GIS to assess the level of water quality, wildlife habitat, and hydrologic functions of individual wetlands. The primary objective of the NC-CREWS is to provide users with information about the relative ecological importance of wetlands for use in planning and the overall management of wetlands. It is useful in determining where development should not be planned, or where certain types of development are best suited to and compatible with the habitat.

Potential Wetland Restoration and Enhancement Site Mapping - This procedure uses several GIS layers to locate potential wetland restoration and enhancement sites. Land cover and hydrology data are then used to classify sites according to their disturbance type and to differentiate between restoration and enhancement sites. Digital soil data are used to classify potential restoration and enhancement sites based on the type of wetland they would support after restoration or enhancement has taken place. Using the procedure, potential restoration and enhancement sites were mapped in 37 Coastal Plain counties.

- **WRAMP tools.**
  The California Wetland and Riparian Area Monitoring Plan (WRAMP) includes a toolset for mapping and assessing wetlands in the landscape context. These tools have already been applied to the Santa Rosa Plain to provide the base map of wetland distribution, abundance, diversity and condition needed for landscape scenario planning.

- **HSPF model**
  HSPF (Hydrological Simulation Program - FORTRAN) is a watershed model that simulates nonpoint source runoff and pollutant loadings for a watershed, combines these with point source contributions, and performs flow and water quality routing in stream reaches (Bicknell et al., 2005). HSPF uses continuous rainfall and other meteorological records to compute streamflow hydrographs and pollutographs. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of model simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed.

  Beginning with the 2014 update to EPA BASINS 4.1, a new option is available for simulating wetlands with HSPF. This option uses a DEM grid and a wetlands map layer to determine the amount of land area draining to a wetland before reaching the stream reach. Using this option, the HSPF can simulate the performance of raparine wetland and isolated wetlands

The objective of modeling work for this pilot project is to identify and assess alternative wetland and stream restoration scenarios to help implement the Laguna TMDL for nutrients and sediment. Therefore, the model selected needs not only to simulate sediment and nutrient loadings from the watershed but also the wetland assimilation of pollutants and linkage between wetland performance and its locations, types, and conditions. As a comprehensive watershed model, HSPF is capable of performing all these functionalities, and therefore deemed as a proper platform to carry out the modeling analysis.

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