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MEMORANDUM

Date: 31 May 2011

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

From: Steve Butkus

Subject: Water Quality Model Development History for the Laguna de Santa Rosa TMDL

The development of the Laguna de Santa Rosa (Laguna) Total Maximum Daily Load (TMDL) for impairment of beneficial uses due to low dissolved oxygen and high nutrients requires a “linkage analysis” (CSWRCB, 2005). A linkage analysis describes the method used to establish the relationship between pollutant loading and instream water quality response. The basic goal is to describe the process for establishing a linkage between nutrient loads and the instream dissolved oxygen (DO) conditions.

Regional Water Board staff considered several water quality models, and eventually selected QUAL2Kw to model surface water response and LCLM to model watershed pollutant delivery. Providing the results of the pollutant load delivery as input to the receiving water model provides the linkage analysis required of the Laguna TMDL. The linkage analysis describes the method used to establish the relationship between pollutant loading and instream water quality response. Combining the models establishes a linkage between nutrient loads from the upland sources to the instream dissolved oxygen conditions in lotic and lentic surface waters in the Laguna watershed.

Recommendations from the Conceptual Model

The Laguna de Santa Rosa Foundation, in collaboration with Philip Williams and Associates (PWA), Tetra Tech, and a Technical Advisory Group developed a conceptual model of the Laguna water quality problems (Sloop et al. 2007). The conceptual model was prepared to help direct the Laguna TMDL development to a watershed-scale. The conceptual model report made recommendations on the data collection needed to support the TMDL development. The conceptual model report also made recommendations for model selection and development (Figure 1).

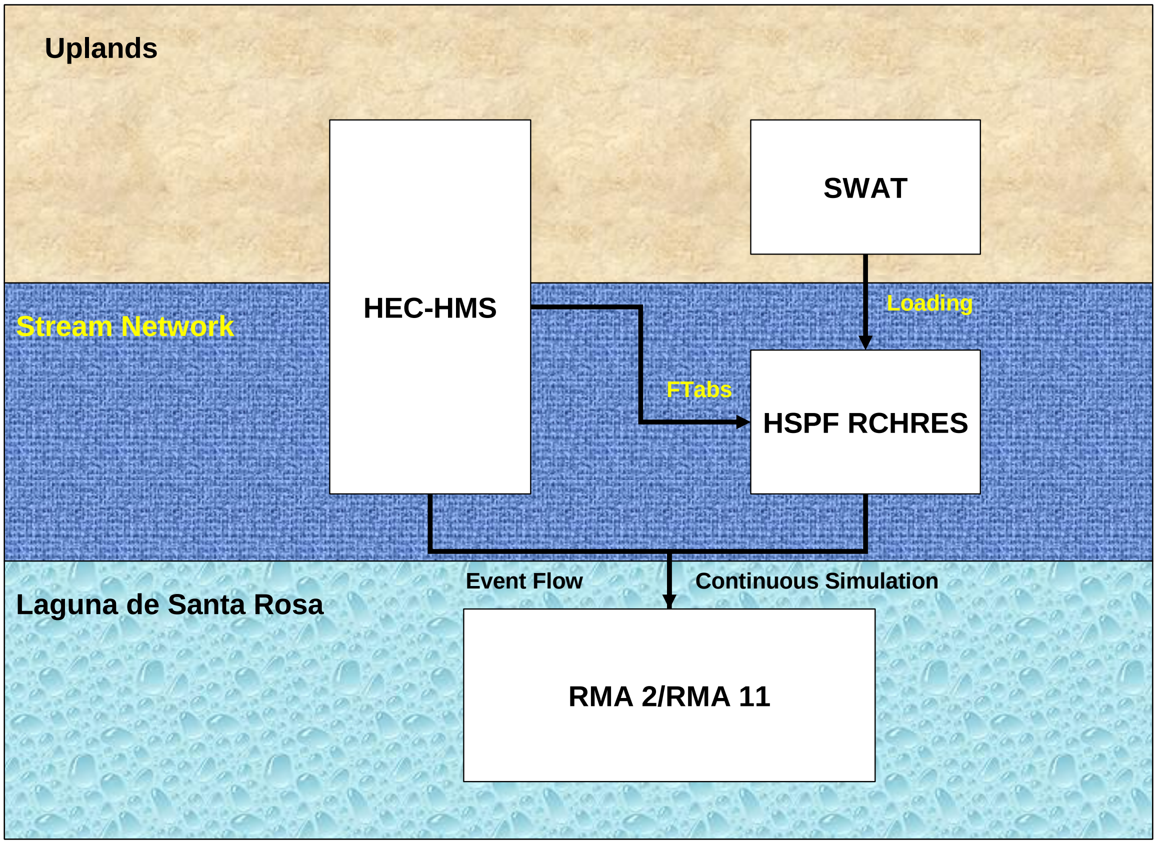

Figure 1. Modeling Framework Recommended for the Laguna TMDL from Sloop et al. (2007)

The modeling recommendations from Sloop et al. (2007) included linking upland watershed models through a network of stream reaches to the Laguna as the receiving water (Figure 1). The conceptual model report recommended a linked set of dynamic models, incorporating HEC-HMS, SWAT, HSPF, and RMA 2/RMA 11. The modeling recommendations were designed to meet a variety of simulation needs. The report acknowledges the level of resources that would be required to parameterize these models for watershed-wide, dynamic, water quantity and water quality simulations. In particular, the recommended watershed models require adequate monitoring of stream flows to accurately predict pollutant transport. The Laguna watershed does not currently have a sufficient number of stream gages operating to calibrate a dynamic watershed model.

The level of model complexity needed should be considered to determine the suitability of the model framework. A model should be no more complicated than necessary to inform management questions and decisions. A common misconception is that model accuracy increases with model complexity. Models that are more complex to treat more physical processes show degradation in predictive performance because they require more input variables with greater levels of uncertainty. Complex models have problems with error accumulation and predictive performance. The lack of available input data for complex models requires estimation of many model parameters through calibration. As such, model uncertainty increases with model complexity.

Errors may also come from the use of unrealistic assumptions. For example, a model based on one-dimensional equations of flow should not be used to represent conditions of a stratified lake. The accuracy of the results is suspect if a model is based on unrealistic assumptions. Available watershed pollutant transport models differ in complexity, modeled processes, and basic assumptions. Simpler watershed models have shown similar predictive performance as more complex models (Loague and Freeze, 1985; Jakeman and Hornberger, 1993).

Dissolved Oxygen & Surface Water Response Model Development

Selection & Subsequent Elimination of the WASP Model

We reviewed the modeling recommendations of Sloop et al. (2007) with available resources and decided on use of the U.S.EPA (2006) model: Water Quality Analysis Simulation Program (WASP). The WASP modeling framework provided the following benefits:

- Ability to be constructed with a fairly limited amount of additional data collection.
- The recommended models for loading from upland areas in the watershed could be simulated as point sources in the WASP model using measurements collected from the major Laguna watershed tributaries.
- The WASP model also could be constructed to simulate the thermal stratification of the mainstem observed in previous Laguna studies.

A watershed-wide WASP model was constructed representing the major tributaries in the watershed (Figure 2).

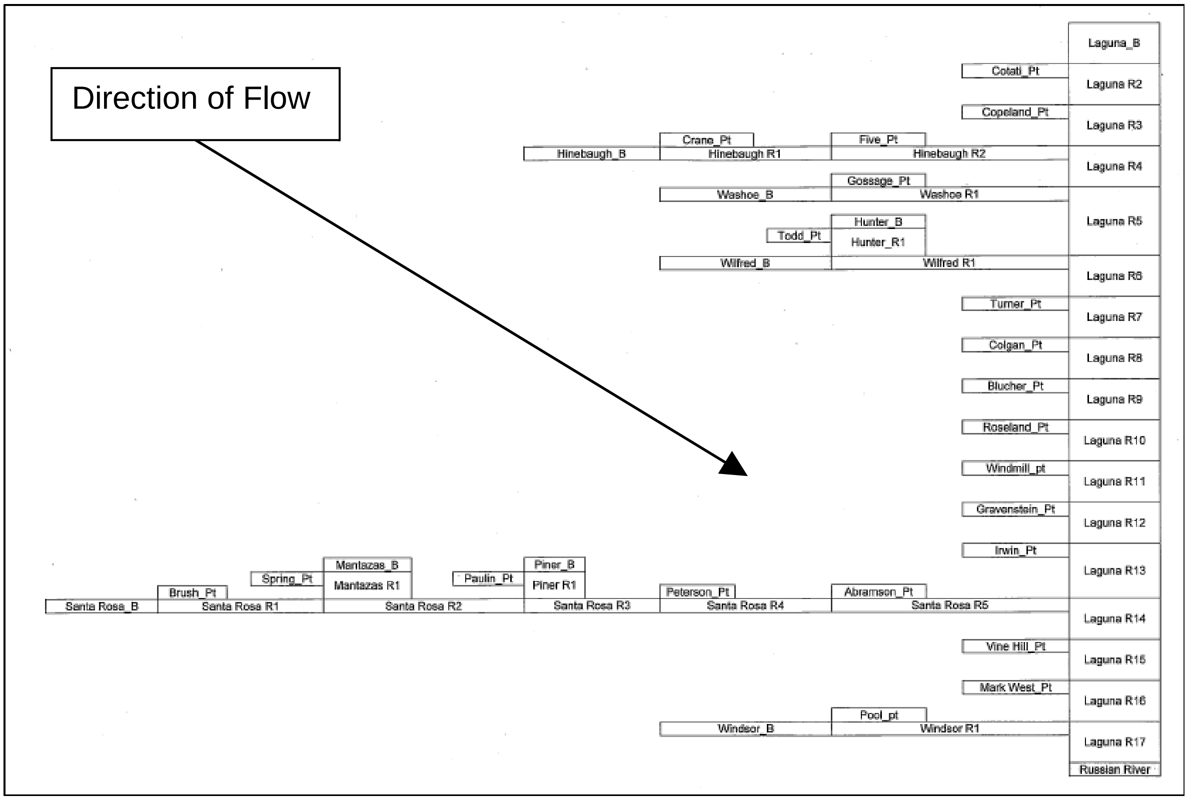

Figure 2. Geometric Construction of the Laguna WASP Model

Regional Water Board staff collected samples and compiled data for development of the Laguna watershed WASP model during the summer of 2008 (NCRQWCB, 2008). Water samples were collected for nutrients and chlorophyll at numerous locations in the Laguna watershed. Stratification of Lake Jonive was measured.

A severe long-term drought was in effect during the summer of 2008. The 2006-2008 hydrologic years (April-March) had a return frequency of 11%, 13%, and 10%, respectively, based on the 72-year precipitation record recorded in Santa Rosa (Meteorological Station 47965). As a result of the drought, many of the lotic areas in the Laguna watershed became completely dry at the surface, separated by ponded areas without surface flow. Therefore, the summer of 2008 represented the critical condition of the Laguna water quality as required for TMDL development (CSWRCB, 2005).

The Laguna watershed WASP model required continuity of surface water flow. The Laguna watershed WASP model could not be used to represent critical conditions (i.e., 2008 drought) since it required flowing waters to transport the pollutants. We decided to focus the modeling effort on only two reaches to represent the surface water areas of the Laguna watershed during critical conditions. Lower Santa Rosa Creek, from downstream of Piner Creek to the Laguna confluence, was selected to represent lotic reaches in the Laguna watershed. Lake Jonive (Cummings, 2004), south of Occidental Road to Sebastopol, was selected to represent the lentic reaches in the Laguna watershed. Stream flows were gaged in both of these reaches and had continuous surface water throughout the reach during 2008.

The dynamic WASP modeling framework proved to be unstable for both of these reaches. WASP requires that segments of the model contain roughly the same volumes. Segment volumes need to be adjusted as flows increase (or decrease) in downstream segments. In order to accommodate widely varying flow rates, different WASP models would have to be developed, since segment sizes need to be adjusted to accommodate different flow regimes.

In addition, the WASP model graphic user interface was very unstable. Selection of check boxes often caused the computer to crash requiring rebooting the system. The same problem occurred on several different computers. U.S. EPA technical support staff for the model were not responsive to these issues claiming lack of adequate funding. Due to these instable flow rates and model coding issues, we decided to find another modeling framework for the Laguna TMDL.

Selection and Use of the QUAL2Kw Model

The River and Stream Water Quality Model (QUAL2K) is a receiving waters quality response model (Chapra et al. 2006). The model can help interpret and predict water quality responses to natural phenomena and man-made pollution to support various pollution management decisions. The QUAL2K construct is one-dimensional model that simulates steady state hydraulics by assuming a channel that is well-mixed vertically and laterally within each model segment. The model simulates diel water-quality conditions under steady-state conditions.

The QUAL2K model was written as open source code for model improvements. One such model upgrade is the QUALKw model version (Pelletier et al. 2006; Pelletier and Chapra 2008). The QUAL2Kw framework includes the following improvements over the QUAL2K model. The QUAL2Kw model:

- Allows multiple loadings and inflows to be input to any reach.
- Accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations.
- Calculates light extinction as a function of algae, detritus and inorganic solids.
- Simulates both alkalinity and total inorganic carbon. The pH is then simulated based on these two quantities.
- Explicitly simulates attached bottom algae. Most water quality models simulate effects of only pelagic phytoplankton on diel variation in water quality. *Ludwigia* is both a submerged and an emergent aquatic macrophyte that may not be represented well if modeled as pelagic phytoplankton.

Due to these improvements, the QUALKw model framework was selected for development of a model to simulate dissolved oxygen responses for waters in the Laguna watershed. The steady-state hydraulics modeled with the QUALKw model framework is appropriate for Laguna surface waters since the dissolved oxygen linkage analysis will focus on critical low flows periods that typically do not exhibit highly dynamic flows. In addition, we expected to have technical support for any model problems since I have known the model developer, Greg Pelletier, for over 30 years. The largest issue with the use of the QUAL2Kw model framework for application to

Laguna surface waters is the inability to simulate the stratification within lentic areas. The stratification observed in Laguna lentic areas is polymictic and typically de-stratifies each evening (Butkus, 2010).

Two QUAL2Kw models were developed to represent the lentic and lotic surface water quality. Lower Santa Rosa Creek downstream of the Piner Creek confluence was selected to represent lotic reaches in the lower Laguna watershed. The lower Santa Rosa Creek model was divided into five (5) segments 1-kilometer each in length (River Kilometer 0.0 to 5.0). Lake Jonive (Cummings, 2004), the open water area south of Occidental Road near Sebastopol, was selected to represent lentic areas of the Laguna. The Lake Jonive model was divided into eighty-one (81) segments 0.01 kilometers each in length (River Kilometer 17.30 to 18.11). The epilimnion was modeled assuming that the hypolimnion could be estimated based on the data on stratification measured in 2008 (Butkus, 2010).

Diel data were collected in 2009 for QUAL2Kw model development and evaluation. The lower Santa Rosa Creek model was calibrated using 3 days of diel data sets for the dates: August 25-27, 2009. The lower Santa Rosa Creek model was corroborated using 3 days of diel data sets for the dates: July 29, 2009, and August 1-2, 2009. The Lake Jonive model was calibrated using 5 days of diel data sets for the dates: September 3-7, 2009. The Lake Jonive model was corroborated using 5 days of diel data sets for the dates: July 22-26, 2009. Results of the QUAL2Kw model development and evaluation are reported in Butkus (2011).

Watershed Loading Model Development

Selection and Use of the LCLM

We reviewed the modeling recommendations of Sloop et al. (2007) with available resources and decided on use of the Land Cover Loading Model (LCLM). The LCLM is an empirically-based simple pollutant delivery model based on different land covers. The LCLM allows estimates of pollutant loading from catchments based on land cover areas and representative loading rates (i.e., load per area of land). The LCLM allows a comparison of pollutant loading among different land covers.

One possible limitation to the LCLM is the aggregate nature of the loading estimate. The method does not directly estimate loading from individual sources, only the loads that are delivered to the Laguna as categorized by land cover. In addition, the high variability of the load estimates among land covers can result in similar mean load estimates from the different land covers.

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