To: Lynn Small, Deputy Director
Environmental Compliance
City of Santa Rosa, CA

Date: July 17, 2012

From: James A. Klang, PE, K&A
Mark S. Kieser, K&A

cc: Dave Smith, Merritt Smith Consulting

RE: Pepperwood Preserve Summary of Best Management Practice Reduction Estimation Methods for City of Santa Rosa Offset Credits

This Kieser & Associates, LLC (K&A) memorandum provides information on the calculations used to determine the offset credits from the City of Santa Rosa Offset credit proposal for Pepperwood Preserve BMPs. The City of Santa Rosa submitted a June 28, 2012 proposal for nutrient offset credits associated with future installation of erosion control practices and restoration at the Preserve. These were submitted as part of their commitment to a no net discharge requirement under the Nutrient Offset Program established by the North Coast Regional Water Quality Control Board. In general, these calculations use estimated sediment loads and soil nutrient concentrations from current sites of erosion or threatened sites of erosion at the Pepperwood Preserve. Soil erosion methods come directly from Pacific Watershed Associates (PWA) site documentation for the Pepperwood Preserve.

Calculation Description

A simple calculation methodology using site-specific soil nutrient concentration data was selected because of the readily available erosion volume estimates provided by PWA. The PWA methods for estimating soil erosion involved an analysis of aerial imagery to document the road network, and extensive field inventories of current and potential road-related sources of erosion (PWA, 2008). K&A obtained site-specific soil nutrient concentration data from the Soyotome Resource Conservation District (RCD).

Soil Erosion Volume Estimation

The methods used by PWA are summarized from their 2008 Report No. 08081301 to the Soyotome RCD (PWA, 2008). PWA analyzed orthophoto imagery from USDA Aerial Photography Field Office to document all roads within the project area. PWA developed a composite map using GIS to depict the locations of inventoried erosion and sediment delivery sites and road segments. The map was used as a reference for on-site field inventories.

PWA completed field inventories of all roads in the project area to identify existing and potential future erosion sites. Erosion sites were defined as locations where direct evidence of current or future erosion or mass wasting, caused by or related to the road network, may deliver sediment to a stream channel. Sites where PWA determined there was no potential for future erosion were not included. Their report noted that the purpose of the study was to evaluate erosion impacts on fish-bearing streams, and thus sites that had no evidence of impacting the stream channel were excluded.

Their 2008 report describes their site assessments as an inventory of stream crossings, gullies below ditch relief culverts, and various other discharge points (e.g., roadside gullies and berm breaks) for uncontrolled sites of erosion (PWA, 2008). PWA recorded a description of the site, nature/magnitude of connected road surface, likelihood of erosion, length of hydrologically connected road surface, and necessary treatment(s). For sites that showed existing problems, they measured the width, depth and length of the potential erosion area to derive a sediment volume. The final recommendation was restoration for 32 of 40 sites that were inventoried. In 2012, PWA conducted a follow-up site assessment to update project costs. In this updated report, PWA recommended restoration at two additional stream crossing sites. (See Attachments A and B of the June 28, 2012 City of Santa Rosa Pepperwood Preserve Credit Proposal for the full PWA reports from 2008 and 2012, respectively.)

PWA (2008) further described their empirical methods on page 9 of their original report. The methodology explains how the lengths of hydrologically connected roads were measured and how an empirical estimate of sediment delivery (cubic feet) is derived. The PWA equation description is presented as Equation 1:

$$SD = L * 25 * 0.2 \qquad \textbf{(EQ. 1)}$$

Where:

SD= Sediment Delivery (cubic feet)
L = Measured Length
25 = 25 ft average width, including cutbanks, per decade
0.2 = 0.2 ft average lowering of road per decade

To predict sediment delivery at stream crossings, PWA used tape and clinometer surveying techniques to record measurements and develop longitudinal profiles and cross sections of the sites. Data were then compiled to calculate road fill and potential sediment delivery with the STREAM computer program (see the 2008 PWA report in Attachment A of the Pepperwood Preserve Credit Proposal). Table 2 in the 2008 PWA report presented the sediment delivery results for the 32 recommended restoration and protection sites in cubic yards of sediment delivered to a stream. The total predicted sediment delivery for these sites was 3,094 cubic yards (PWA, 2008). Table 1 in the PWA, 2012 report estimates an additional 48 cubic yards of sediment delivery from the two additional sites.

K&A combined the delivered sediment values from PWA's 2008 and 2012 reports and used 3,142 cubic yards of sediment in the offset credit calculations. (Note: To remain consistent, the City's Pepperwood Preserve Credit Proposal used the same terms as the PWA reports where erosion sites were divided into three categories: 1) stream crossings, 2) road surfaces/ditches, and 3) other sites. "Other sites" refers to any other sources of sediments identified in PWA's assessment, including ditch relief culverts, discharge points for road surfaces, and springs).

Nutrient Loading Calculations

K&A used the combined PWA estimated volume of delivered sediment as a first step to quantify nutrient loading. It is assumed that with appropriate restoration or protection, the sediment erosion losses from these locations will cease. Thus, estimated sediment delivery can be equated to sediment reduced, which can then be equated with nutrient load reduction. As such, the cubic yards of sediment delivered (as estimated by PWA) are first converted into a mass equivalent of tons of sediment reduced. Second, tons of sediment reduced are equated to pounds of nutrient reduced (using measured soil nutrient concentrations from erosions sites in the Pepperwood Preserve).

The calculation steps for determining nutrient load reductions are described by Equations 2 and 3. Equation 2 calculates tons of total sediment reduction to the stream by multiplying cubic yards of delivered sediment by the dry density of soil (in tons/cubic foot) and an appropriate unit conversion value.

$$TSR = EM * DD * 27 \qquad \textbf{(EQ. 2)}$$

Where:

TSR = Total Sediment Reduction (tons)
EM = Erosion Measurement (cubic yards) [reported by PWA]
DD = Dry Density (tons/ft^3)
27 = Conversion Factor (ft^3/cubic yard)

K&A used the Michigan Department of Environmental Quality's, "Pollutants Controlled Documentation for Section 319 Watersheds Training Manual" (MDEQ, 1999) for assigning dry density soil weight values to soil types encountered at Pepperwood sites. K&A selected a dry density value of 0.0375 tons/ft^3 for stream crossings corresponding to clay loam, 0.055 tons/ft^3 for road surfaces/ditches corresponding to sands/loamy sands, and 0.045 tons/ft^3 for other sites corresponding to loams/sandy clay loams/sandy clay. The range of dry densities for all soil types is provided in Table 1. K&A selected a dry density weight corresponding to sand for sites associated with roads and ditches because road surfaces are commonly improved by using borrow material hauled in from offsite that results in a mix of soils rich in sands and gravels. According to USDA's Web Soil Survey[1], the sediment at Pepperwood Preserve consists of sands, hummocks, and silts. Therefore, K&A selected lower dry density values for stream crossings and other sites consisting of silts and clays.

Next, Equation 3 was used to calculate the total load reduction of a particular nutrient (TN and TP). The equation is applied separately for TN and TP.

[1] See: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

LR = TSR * NC * BIO (**EQ. 3**)

Where:

LR = Nutrient Load Reduction (lbs TN or lbs TP)
TSR = Total Sediment Reduction (tons)
NC = Nutrient Concentration (lbs/ton)
BIO = Bioavailability Factor (dimensionless)

Equation 3 requires the total sediment reduction volume from Equation 2, the nutrient concentration, and a bioavailability factor. For nutrient concentrations, K&A used TN and TP data reported by Environmental Technical Services (in ppm). (See the laboratory analytical results in Attachment C of the City of Santa Rosa Pepperwood Preserve Credit Proposal.) Nutrient concentrations in ppm were converted by K&A to pounds per ton using a conversion factor of 500 ppm = 1 lb/ton. This reflects one pound of nutrient per ton of soil equaling 500 (ppm of nutrient) times 2,000 (lbs/ton) divided by 1,000,000 parts in a ton. K&A calculated separate TN and TP average concentrations (in lbs/ton) for soil samples collected from road surfaces/ditches versus stream crossings. This is due to the above noted assumption that road surfaces generally consist of imported sands and gravels while stream crossings and other sites would be more representative of native soils. These differences are especially important for phosphorus that has an affinity for charged particles (e.g., clays). Thus, clay commonly has higher concentrations of phosphorus than silts and sands due to ionic bonding potential.

Two elevated TN concentrations identified by the lab as high in organic content were also removed when calculating the average concentration for TN. This resulted in a 40 percent lower average TN value for stream crossings and other sites. For TN, K&A used a nutrient concentration of 2.7 lbs TN/ton for stream crossings and other sites, and 3.4 lbs TN/ton for road surfaces/ditches. K&A used a nutrient concentration of 0.4 lbs TP/ton for stream crossings and other sites and 0.2 lbs TP/ton for road surfaces/ditches.

It is worth noting that these average concentrations used results from soil samples collected in April 2012. In addition to removing data with elevated TN values, the timing of the soil sample collection introduces another conservative assumption into this credit estimation process. The organic content of the soils will be richest at the end of a growing season. During the winter, natural decay processes occur releasing some nutrients from plant matter that have accumulated in the soils. The wet season rains and related runoff also typically occur before April, further reducing the organic content in soils. Therefore, the TN and TP concentrations measured in April are considered conservative because samples likely reflect a lower organic content than what would be delivered to the stream during the wet season. This, in effect, lowers nutrient load estimates and reduces the number of credits to be claimed by proposed BMPs. In addition, the reduction estimate from this credit equation accounts for only the sediment-attached nutrients. Many types of BMPs proposed for implementation in the Preserve will reduce soluble nutrient loading as well. For instance, rolling dips redirect road surface runoff into adjacent fields before channel erosion can occur. This redirection of runoff allows for infiltration and plant uptake of nutrients and water in addition to the prevention of road surface erosion. Other BMPs that reduce the soluble nutrient loading include swales and insloping or outsloping of roads. These soluble losses are not included in calculations providing an additional margin of safety for offset crediting.

Following the requirements of the Nutrient Offset Program, K&A applied a bioavailability factor to the total load reductions expected from the Pepperwood Preserve BMP projects. A bioavailability factor takes into account the extent to which a particular nutrient is biologically available in the water environment based on the source of the nutrient. This factor is generally based on the differences in bioavailability of a nutrient discharged from two different sources in a watershed. For this offset program, the two types of discharges are treated wastewater from the City of Santa Rosa's Laguna Treatment Plant and the nonpoint source discharge from soil erosion in Pepperwood Preserve. The bioavailability factors applied here by K&A include a factor of 85% for TN and 51% for TP. Refer to Attachment A for a detailed description of the data sources and calculations used to derive the bioavailability factors applied in Equation 3.

References:

Michigan Department of Environmental Quality (MDEQ), 1999. Pollutants Controlled Calculation and Documentation for Section 319 Watersheds Training Manual. Water Division Nonpoint Source Unit, Revised June 1999. http://www.michigan.gov/documents/deq/deq-wb-nps-POLCNTRL_250921_7.pdf. Accessed July 6, 2012.

Pacific Watershed Associates, Inc. (PWA), 2008. Pepperwood Preserve/Upper Mark West Creek Erosion Inventory and Assessment, Sonoma County, California. Prepared for Soyotome Resource Conservation District, March 2008.

Pacific Watershed Associates, Inc. (PWA), 2012. Summary of Adjusted Costs Based on Re-Evaluation of Site Conditions and 2012 Implementation Costs to Execute Control and Sediment Reduction Measures at Pepperwood Preserve. Prepared for Sotoyome Resource Conservation District under Control #SRNO-002, May 2012.

Table 1. Dry Density Soil Weights (Source: MDEQ, 1999).

SOIL TEXTURAL CLASS	DRY DENSITY (Tons/Ft^3)
Sands, loamy sands	.055
Sandy loam	.0525
Fine sandy loam	.05
Loams, sandy clay loams, sandy clay	.045
Silt loam	.0425
Silty clay loam, silty clay	.04
Clay loam	.0375
Clay	.035
Organic	.011

Attachment A

Santa Rosa Nutrient Offset Program Bioavailability Review

To: Lynn Small, City of Santa Rosa
Control Board

Date: July 3, 2012

From: James A. Klang, PE, K&A

cc: Dave Smith, Merritt Smith

RE: Santa Rosa Nutrient Offset Program Bioavailability Review

Addressing Nutrient Bioavailability in Offsets

This memorandum provides a brief review of published literature and selected water quality trading programs, analyzing various approaches for addressing nutrient (phosphorus and nitrogen) bioavailability between sources. This background information forms the basis for recommended bioavailability factors included in equations for calculating Santa Rosa nutrient offset credits. For water quality offsets, discount factors are often applied to nutrient load reductions to ensure that the environmental outcome from the offset is equivalent to the protection that would be achieved under conventional methods of additional wastewater treatment. Such factors are used in crediting proposals to account for bioavailability equivalence in the Santa Rosa Nutrient Offset Program for loading between non-point sources and the City's treated wastewater discharge.

Phosphorus:

The State of Minnesota addressed phosphorus bioavailability issues in the Statement of Needs and Reasonableness (SONAR) document written to support Water Quality Trading rule promulgation[1]. The Minnesota Pollution Control Agency (MPCA) based this document on a study entitled, "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" (Barr, 2004). An appendix to the 2004 study compiles phosphorus bioavailability by source. The table from this appendix is reproduced below as Table 1.

The literature reviewed for this memo most commonly determined bioavailability using a one-month period after release to a water environment. Applying the results of these bioavailability studies to longer time periods (as would be the case in the Laguna de Santa Rosa setting), provides a conservatively low range. The nutrients in the Laguna setting have substantially more time to undergo chemical and biological changes. To address bioavailability, a coefficient can be calculated that reflects the bioavailability of the different phosphorus forms discharged by each source.

[1]MPCA. 2010. A Scientifically Defensible Process for the Exchange of Pollutant Credits under Minnesota's Proposed Water Quality Trading Rules. Accessed July 3, 2012, available at: http://kieser-associates.com/uploaded/MPCA_Defensible_Processs_Exchange_Credits_072809.pdf

K&A used Table 1 to calculate recommended equivalence factors that incorporate phosphorus bioavailability considerations for the Laguna de Santa Rosa. An equivalence factor accounts for differences in phosphorus bioavailability from each type of source. For point source domestic wastewater treatment plants (WWTPs) using agricultural nonpoint source offsets (without presence of manure), the recommended equivalence factor is 58/85.5 (or 0.68). When working on agricultural sites that are seeking to improve manure management, this factor becomes 80/85.5 (or 0.94).

Table 1. Estimates of phosphorus bioavailability fractions for specific source categories (from Barr, 2004).

Phosphorus Sources		Fraction of PP that is Bioavailable (Range)	Fraction of PP that is Bioavailable (Most Likely)	Fraction of DP that is Bioavailable (Most Likely)	Fraction of TP that is Particulate (Most Likely)	Estimate of TP that is Bioavailable (Most Likely)
Publicly Owned WWTP for domestic use (effluent)		**0.6 - 0.8**	**0.7**	**1.0**	**0.5**	**0.855**
Privately Owned WWTP for domestic use (effluent)		**0.6 -0.9**	**0.8**	**1.0**	**0.3**	**0.94**
Commercial/Industrial WWTPs (effluent)		**0.2 - 0.8**	**0.6**	**1.0**	**0.3**	**0.88**
Agricultural Runoff						
	Manure Management	**0.5 -0.7**	**0.6**	**1.0**	**0.5**	**0.8**
	Cropland Runoff	**0.2 - 0.7**	**0.4**	**1.0**	**0.7**	**0.58**
Urban Runoff						
	Turfed Surfaces	**0.2 - 0.7**	**0.4**	**1.0**	**0.7**	**0.58**
	Impervious Surfaces	**0.10 - 0.5**	**0.2**	**1.0**	**0.5**	**0.6**
Forested Land		**0.2 - 0.8**	**0.3**	**1.0**	**0.8**	**0.44**
Roadway and Sidewalk Deicing Chemicals						
	salt	**0.2 - 0.8**	**0.6**	**1.0**	**0.2**	**0.92**
	sand	**0.1 - 0.3**	**0.2**	**1.0**	**0.8**	**0.36**
Stream Bank Erosion		**0.1 - 0.5**	**0.3**	**1.0**	**0.8**	**0.44**

Nitrogen:

Total nitrogen (TN) consists of dissolved and particulate nitrogen. Dissolved nitrogen can be further subdivided into inorganic and organic forms. Organic forms of particulate nitrogen also can be present. The dissolved inorganic nitrogen (DIN) forms (NO_2, NO_3 and NH_4^+) are commonly assumed to be 100 percent bioavailable (Berman, 1999). However, independent study findings regarding the bioavailability of organic nitrogen, dissolved organic nitrogen (DON) and particulate organic nitrogen (PON) suggest that the bioavailability of these forms might vary widely. The predictability of this range in bioavailability also might vary substantially, in part due to results based on algal bioassays (Seitzinger, 2002). DON in freshwater riverine systems was historically thought to be available only for bacterial uptake, rather than direct algal uptake. Research indicates that humic systems release more DON during summer periods than previously thought. Up to 20 percent of the DON can be photo-ammoniafied (Bushaw, 1996; Dagg, 2003).

The Laguna de Santa Rosa nitrogen loading affecting the low flow dissolved oxygen conditions, is likely in the forms of DON and PON that remain in the system for longer periods of time (e.g., when disconnected summer pools develop). These longer time periods likely expose the DON and PON to photochemical breakdown, zooplankton grazing and bacterial uptake resulting in NH_4-N or NO_3 release. Therefore, non-point source DIN is assumed to be 100 percent bioavailable (as discussed above) while DON and PON collectively are conservatively estimated at 20 percent bioavailable during the summer period for various Ag non-point sources. This is conservative because it does not include bacterial and zooplankton uptake. In the Laguna de Santa Rosa setting, the application of nitrogen bioavailability might be further complicated by limited laboratory or bioassay testing methods, which can use three-week incubation periods (Urgun-Demirtas *et al.*, 2008; Berman, *et al*. 1999). The use of this lab analysis is considered conservative due to the longer time periods and numerous chemical and biological activities that occur when the low flow polls trap nitrogen beyond the three-week timeframe of the lab tests.

Total Nitrogen to Dissolved Organic Nitrogen Ratios in Non-point Source Dominated Streams

Research indicates a broad range of ratios comparing stream TN to DON in non-point source dominated streams. Seitzinger (2004) conducted a literature review that suggested a range from 10 to 80 percent. Assessing the cropping and pasture runoff results from the Laguna de Santa Rosa TMDL source monitoring program, the 34-sample mean concentration was 2.6 mg/l TN. The dataset did not provide flow estimates. Therefore, a flow-weighted mean could not be generated. The mean concentration of the 34 samples of the total DIN fraction (NO_3- and NH_4-N) was 2.0 mg/l DIN.

A comparison of the two concentration means indicates approximately 76 percent of the total nitrogen is DIN. This can be roughly confirmed by solving for the DON fraction independently for each sampling event (TN - DIN = DON + PON) and then averaging the estimated percent of organic nitrogen results. The average organic nitrogen percentage of total nitrogen plus the 76 percent DIN fraction should be approximately 100 percent (not taking into account difficulties regarding sampling variability). The result of this calculation indicates approximately 29 percent of the total nitrogen is in the form of organic nitrogen. The 76 percent plus 29 percent is a reasonable indicator that these assumptions are within an acceptable range for the Laguna de Santa Rosa setting. Therefore, using a 75 percent bioavailable fraction as DIN and 25 percent as organic nitrogen form in non-point source runoff was deemed reasonable for nitrogen offset credits.

After combining the stream fractions of inorganic and organic nitrogen (and bioavailability of each), the TN bioavailability of crop and pasture sources can be estimated as follows: DIN bioavailability (75 percent times 100 percent bioavailable) plus organic nitrogen bioavailability (25 percent times 20 percent bioavailable) equals 80 percent total nitrogen bioavailability. This estimate is used in Ag settings with high organic content as a conservative estimate. However, as previously mentioned, in settings where there is a substantial presence of particulate organic nitrogen, the estimate is unreasonably low because it is based on three week lab analysis methods. In settings where the credit estimation method is dominated by PON, a higher bioavailability factor will be used.

The bioavailability of WWTP nitrogen also must be determined. Assessing the same forms of nitrogen (e.g., particulate and dissolved, further subdivided into inorganic and organic) the inorganic fractions are assumed to be 100 percent bioavailable. Literature indicates that secondary effluent WWTPs that denitrify have DON percentages around 10 percent of the TN discharged (Pehlivanoglu, 2004). However, advanced treatment with low total nitrogen levels (below 3 mg/l) increases the fraction of DON to 40-50 percent of TN (Chandran, 2010). Therefore, an analysis of the Laguna WWTP pond storage system sampling was performed. The results provided in Table 2 indicated that average concentrations were:

Table 2. Average nitrogen concentrations from Delta Pond samples (City of Santa Rosa, Delta Pond monitoring results, 2006-2010).

Nutrient Form	Concentration (mg/l)	Number of Samples
Nitrate Nitrogen	8.19	20 samples
Organic Nitrogen	1.34	24 samples
Ammonia nitrogen	0.48	14 samples
Total Nitrogen	9.8	Sum of nitrate, organic and ammonia samples (same day) from Delta Pond

These values indicate that approximately 89 percent of the discharged pond effluent was DIN (assumed to be 100 percent bioavailable). A conservative assumption for the Santa Rosa offset program would be to use a 50 percent bioavailable fraction of DON, assuming algal uptake is enhanced by bacteria (Pehlivanoglu, 2004). Therefore, the contributing DON bioavailable fraction is assumed to be 5.5 percent of the total nitrogen loading. The estimated wastewater bioavailable fraction result is 94.5 percent. The nitrogen bioavailability discount factor for cropping and pasture land offsets is determined by 0.8 non-point source bioavailability/0.945 WWTP bioavailability, or a discount factor of 0.85 times the credited loading reduction.

References:

Barr Engineering Company, 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Supporting Technical Memorandum: Assessment of Bioavailable Fractions of Phosphorus and Annual Phosphorus Discharge for Each Major Basin memo. Available on line at: http://www.pca.state.mn.us/index.php/viewdocument.html?gid=3987

Berman, T., Chava, S., 1999. Algal growth on organic compounds as nitrogen sources. *J. of Plankton Research* 21(8): 1423-1437.

Bushaw, K.L., Zepp, R.G., Tarr, M.A., Schulz-Jander, D., Bourbonniere, R.A., Hodson, R.E., Miller, W.L., Bronk, D.A., Moran, M.A., 1996. Photochemical release of biologically available nitrogen from aquatic dissolved organic matter. *Nature* 381: 404-407 doi:10.1038/381404a0.

Chandran, K., 2010. Methylotrophic microbial ecology and Kinetics. WERF Opportunistic Research Project. WERF presentation 2010.

Dagg, M., Ammerman, J., Amon, R., Gardner, W., Green, R., Lohrenz, S., 2007. Water column processes influencing hypoxia in the northern Gulf of Mexico. *Estuaries and Coasts* 30: 735-752.

Dagg, M., Breed, G.A., 2003. Biological effects of Mississippi River nitrogen on the northern Gulf of Mexico—a review and synthesis. *J. of Marine Systems* 43: 133–152.

Pehlivanoglu, E., Sedlak, D.L., (2004). Bioavailability of wastewater-derived organic nitrogen to the alga Selenastrum Capricornutum. *Water Research* 38: 3189–3196.

Seitzinge, S.P, Sanders, R.W., Styles, R., 2002. Bioavailability of DON from natural and anthropogenic sources to estuarine plankton. *Limnol. Oceanogr*., 47(2):353–366.

Urgun-Demirtas, M., Sattayatewa, C., Pagilla, K.R., 2008. Bioavailability of dissolved organic nitrogen in treated effluents. *Water Environment Research* 80(5): 397-406.