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:

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