MEMORANDUM

TO: Amanda Roa/Delta Diablo Sanitation District

FROM: John Dickey, Ph.D, CPSS/Ag, RPSS[1]/NewFields Agricultural and Environmental Resources

REVIEWED BY: Dave Richardson, P.E./RMC Water & Environment

DATE: February 10, 2010

SUBJECT: Nitrogen Loading Analysis for Antioch Recycled Water Project

Delta Diablo Sanitation District (DDSD) is developing a project in which landscaped park areas and a golf course would be served with recycled water for irrigation. State Water Resources Control Board (SWRCB) staff provided an analysis of projected nitrogen loading, indicating that the planned loading appears to be excessive. The purpose of this memo is to respond to this concern and to discuss the principal assumptions and processes to which the results are sensitive. Calculations employing ranges of assumptions from the literature are provided. Our analysis indicates that the resultant loading of nitrogen associated with meeting the agronomic water needs of the turf grasses in the project area is expected to be below the crop requirement for nitrogen under most scenarios.

KEY ASSUMPTIONS

The assumptions involved in nutrient loading calculations for new projects are developed based on monitoring of existing projects, performed over a range of environmental conditions to which the parameters themselves are sensitive. References supporting all of our assumptions are found in the subsequent tables attached to this memo. It is important to consider the local environmental conditions in which the project will be operated when planning. While this is common practice when calculating irrigation or water storage capacity requirements, it is frequently overlooked when selecting values of other parameters. When uncertain about a parameter, it is best to define and analyze a reasonable range of possible values. EPA provides useful guidelines for parameter values, but the broader literature often provides a fuller context. Once beyond the planning phase, when the project is operating, standard good practice for monitoring of plant health and soil conditions can be applied to ensure that actual fertilization is in line with actual site-specific requirements.

The key assumptions in the analysis are listed below, along with a brief discussion of the sensitivity of each assumption to environmental conditions. An illustration of the nitrogen cycle (Figure 1) shows a schematic of the many inter-relationships of these parameters and processes.

Applied irrigation water. Reuse project planning begins with an analysis of average conditions, but requires analysis of seasonal peaks to properly size pipes. Seasonal and inter-annual variation need to be analyzed to ensure adequate capacity. One luxury of this system is that there is no need to assume 100% consumption of available recycled water, since it may also be reused at other sites

[1] CPSS/Ag stands for Certified Professional Soil Scientist and Agronomist (ARCPACS), and RPSS stands for Registered Professional Soil Scientist (National Society of Consulting Soil Scientists)

and when insufficient demand exists, the balance is disposed of through an outfall to the San Joaquin River. However, it is a project goal to make beneficial use of the maximum amount of recycled water, within the limits of the permit conditions and good environmental performance. For us, environmental performance is fully implied by the word "beneficial". Irrigation requirements for this planning-level analysis are therefore based on average climatic conditions from the CIMIS station at Brentwood. A range of crop coefficients (0.6 to 1) were considered; all of these are within the common range for turf grasses. Ultimate hydraulic loading limits will depend on site-specific irrigation scheduling.

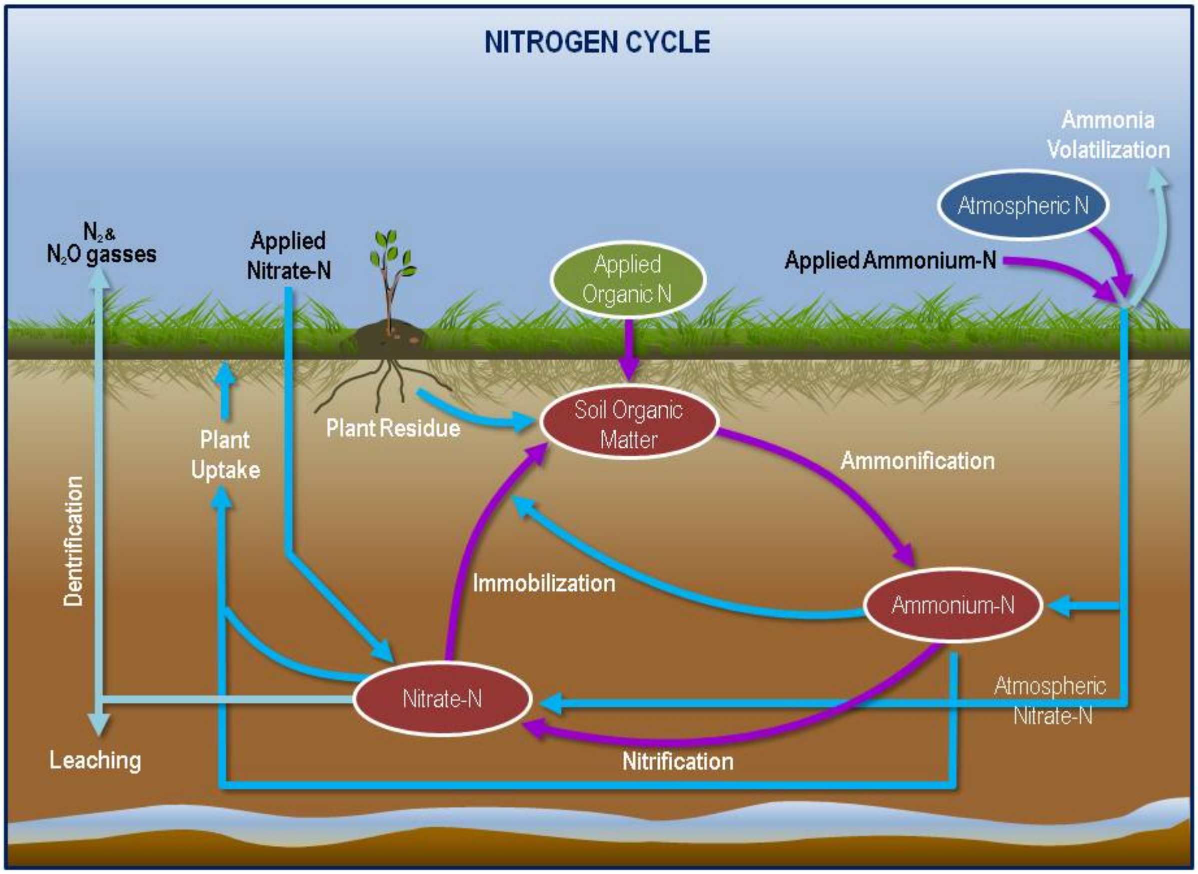

Figure 1. Schematic of the nitrogen cycle, showing principal N sources, sinks, uptake, and loss processes.

Nitrogen (N) uptake. Uptake of N can be conservatively calculated as the product of clipping yield and their N content (this is conservative since all unclipped plant parts are ignored, although they too contain N). A range of yield and N content values from the literature were evaluated. A range of values from the lower end of the nitrogen content spectrum (235 to 411 lb/a-y) was employed. Loading calculations were also run with the figure cited by the SWRCB (174 lb/a-y), and with the mean of the two previous values (323 lb/a-y).

Ammonia volatilization. Loss processes depend strongly on environmental conditions, so that the best planning is done with a range of values from the literature. Ammonia volatilization depends on pH, weather, irrigation method, and canopy properties. Acid soil conditions that depress volatilization are rare in California, and not present in Antioch. A range of 15 to 30% was analyzed, as was the upper end of the range cited by the SWRCB (25%). Almost all of the applied N will be in the NH4-N form and subject to volatilization during and after application.

Nitrification. In well-drained soils, water re-distributes shortly after an irrigation or rainfall event, producing conditions favorable to nitrification (conversion of applied NH4-N to NO3-N). The nitrate so produced is subject to denitrification, uptake, and leaching. The goal of irrigation management is to minimize the amount that leaches, and to meet the needs of the growing plant.

Denitrification rate. Denitrification depends on soil texture, percent soil saturation (% of soil porosity filled with water), temperature, organic carbon availability, and composition of the microbial community. Even without a saturated profile, periodic saturation at the surface (during irrigation of this fine textured soil) can hasten denitrification. This is particularly so in the presence of adequate organic C supply in the turf, and with the robust microbial community that often results from supplying nutrients in recycled water. A range of 20 to 30% denitrification rate was analyzed, as was the upper end of the range cited by the SWRCB (25%). A helpful reference regarding the dependencies and ranges of denitrification rates in turf is Mancino et al. (1988).

Ammonification (mineralization)/immobilization rates. These processes move N into and out of the organic N pool. There is practically no organic N in the recycled water, so the soil organic N pool is composed primarily of plant and microbial biomass in various states of decomposition. In a stably managed golf course, the organic matter pool should be stable and the rates of ammonification (conversion of organic to inorganic N) and immobilization (conversion of inorganic to organic N) in long-term balance. Therefore, there is little need in a planning analysis to complicate calculations with this equilibrium.

Plant-available N. In this analysis, plant available N is applied N available for uptake after accounting for all loss processes.

CALCULATION RESULTS AND INTERPRETATION

An annual nitrogen balance was developed, assuming that the full irrigation requirement is met with recycled water (although this is not a requirement of the system). Thirty scenarios were calculated considering the ranges of parameter values discussed previously. The main index of environmental performance for each scenario is the N deficit, which is defined as the difference (N uptake - plant available N). The results are shown in Table 1. If the N deficit is 10%, the sites would be deficient by that % of their annual N demand if no other N were added to the soil. If the N deficit were -10%, the sites would be over-fertilized by that % if their entire irrigation requirement were met by recycled water.

The negative N deficit results do not imply a potential for overloading the system with N. Rather, they demonstrate potential for the system to be nutrient limited (i.e., the full nitrogen requirement met by recycled water without exceeding the irrigation requirement). However, the ensemble of scenarios demonstrates that, within the range of assumptions documented in the literature, it is quite probable that the system will be hydraulically limited (i.e., the full irrigation requirement met by recycled water without exceeding the N requirement). The expected result, when considering the range of scenarios with varying parameters, is that the recycled water will not normally fulfill the total crop nitrogen requirement and that supplemental nitrogen may be needed.

*Table 1. Summary of loss scenarios**					
Item	***Scenario set 1***	***Scenario set 2***	***Scenario set 3***	***Scenario set 4***	***Scenario set 5***
Max uptake assumed (lb/a-y):	323	411	411	411	411
Min uptake assumed (lb/a-y):	174	235	235	235	235
Assumed denitrification:	25%	30%	30%	20%	20%
Assumed ammonia volatilization:	25%	30%	15%	30%	15%
Max N deficit	56%	70%	64%	66%	58%
Min N deficit	-43%	8%	-11%	-5%	-27%
* Each scenario includes 6 combinations of high and low irrigation and turf N demands.					

In practice, even if a denitrification, volatilization, and N demand scenario resulting in a nutrient-limited condition occurred, the overloading conditions shown would not occur due to proper management (discussed in the next section).

Examination of this broad range of scenarios is instructive, and serves to remind us that the soil-plant-water system is natural, biological, and variable in time and space. The responsible party must therefore monitor and evaluate its development and performance. This analysis suggests that it is quite likely that the system has adequate capacity for the N in the recycled water in most years.

References

Mancino, C.F., W.A. Torello, and D.J. Wehner. 1988. Denitrification losses from Kentucky bluegrass sod. Agronomy Journal 80:148-153.

All other references are cited in the following tables.

DDSD N Loading and Demand

Kc	in/in	0.6	0.8	1.0	0.6	0.8	1.0	http://www.water.ca.gov/pubs/conservation/a_guide_to_estimating_irrigation_water_needs_of_landscape_plantings_in_california__wucols/wucols00.pdf
N uptake	lb/a-y	174	174	174	323	323	323	
Item	**Units**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**	**Notes**
Nitrate N	mg/L	1	1	1	1	1	1	
Ammonia N	mg/L	36	36	36	36	36	36	Caltest Analytical Lab order J110843, 11/18/09 sample
Organic N	mg/L	0	0	0	0	0	0	
Total N	mg/L	37	37	37	37	37	37	Caltest Analytical Lab order J110843, 11/18/09 sample
Net mineralization		100%	100%	100%	100%	100%	100%	Assumes full decay series of organic N mineralizes
	mg/L	0	0	0	0	0	0	
Ammonia volatilization		25%	25%	25%	25%	25%	25%	Assumes only volatilization of initially applied ammonia. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1000&context=cafes_dean; http://cedb.asce.org/cgi/WWWdisplay.cgi?8904892;
	mg/L	9.0	9.0	9.0	9.0	9.0	9.0	
Denitrification		25%	25%	25%	25%	25%	25%	http://jeq.scijournals.org/cgi/content/abstract/19/1/1; http://www.springerlink.com/content/gf7kttq2hv43tl7q/; C. F. Mancino, W. A. Torello, and David J. Wehner. "Denitrification Losses from Kentucky Bluegrass Sod" Agronomy Journal 80.1 (1988): 148-153. Available at: http://works.bepress.com/dwehner/22.
	mg/L	7.0	7.0	7.0	7.0	7.0	7.0	
	kg/ha-d	0.15	0.20	0.25	0.15	0.20	0.25	http://www.publish.csiro.au/paper/SR9950089.htm
	lb/a-y	47.32	66.27	82.78	47.32	66.27	82.78	
Plant available N	mg/L	21.0	21.0	21.0	21.0	21.0	21.0	
	lb/a-f	57	57	57	57	57	57	
Growing season	months	7	7	7	7	7	7	http://www.cimis.water.ca.gov/cimis/pdf/etomap1.pdf
Eto	inches/y	55	55	55	55	55	55	CIMIS/Brentwood
Etc	inches/y	33	44	55	33	44	55	CIMIS/Brentwood
Precip	inches/y	13	13	13	13	13	13	CIMIS/Brentwood
AW	inches/y	30	42	54	30	42	54	CIMIS/Brentwood
	ft/y	2.5	3.5	4.5	2.5	3.5	4.5	
Irrigation efficiency		85%	85%	85%	85%	85%	85%	
Reclaimed/total water		100%	100%	97%	100%	100%	97%	Assumes total water demand met by reclaimed water
N uptake	lb/mo-1000 sf	0.33	0.33	0.33	0.62	0.62	0.62	"1 to 1.5 pounds of nitrogen per 1,000 sq. ft. per month may be applied during the growing season" (http://aggie-horticulture.tamu.edu/plantanswers/turf/publications/bermuda.html). 6 lb/1000 sf on tall fescue (http://ucrturf.ucr.edu/UCRTRAC/BTTA/BTTA%20November%201997.pdf).
	lb/y-1000 sf	4.0	4.0	4.0	7.4	7.4	7.4	
	lb/a-y	174	174	174	323	323	323	Figure cited by SWRB is 174. See also "uptake" worksheet.
Total PAN in applied WW	lb/a-y	142	199	248	142	199	248	
Under-fertilization	lb/a-y	32	(25)	(74)	181	124	75	Requirement - N in applied WW
		18%	-14%	-43%	56%	38%	23%	% of N requirement unmet by WW
Irrigated area	a	115	115	115	115	115	115	
WW supplied	a-f/y	286	400	500	286	400	500	

Depending on the assumptions, satisfaction of the full irrigation requirement of this 115 acres of mostly golf course results in -43 to 56% under-fertilization with N. This depends on the assumptions relative to turf needs, irrigation requirement, and volatilization and denitrification rates. Only at a Kc of 1 does the irrigation requirement in an average year appear to exceed the available 500 a-f/y.

DDSD N Loading and Demand

Kc	in/in	0.6	0.8	1.0	0.6	0.8	1.0	http://www.water.ca.gov/pubs/conservation/a_guide_to_estimating_irrigation_water_needs_of_landscape_plantings_in_california__wucols/wucols00.pdf
N uptake	lb/a-y	411	411	411	235	235	235	
Item	**Units**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**	**Notes**
Nitrate N	mg/L	1	1	1	1	1	1	
Ammonia N	mg/L	36	36	36	36	36	36	Caltest Analytical Lab order J110843, 11/18/09 sample
Organic N	mg/L	0	0	0	0	0	0	
Total N	mg/L	37	37	37	37	37	37	Caltest Analytical Lab order J110843, 11/18/09 sample
Net mineralization		100%	100%	100%	100%	100%	100%	Assumes full decay series of organic N mineralizes
	mg/L	0	0	0	0	0	0	
Ammonia volatilization		30%	30%	30%	30%	30%	30%	Assumes only volatilization of initially applied ammonia. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1000&context=cafes_dean; http://cedb.asce.org/cgi/WWWdisplay.cgi?8904892;
	mg/L	10.8	10.8	10.8	10.8	10.8	10.8	
Denitrification		30%	30%	30%	30%	30%	30%	http://jeq.scijournals.org/cgi/content/abstract/19/1/1; http://www.springerlink.com/content/gf7kttq2hv43tl7q/; C. F. Mancino, W. A. Torello, and David J. Wehner. "Denitrification Losses from Kentucky Bluegrass Sod" Agronomy Journal 80.1 (1988): 148-153. Available at: http://works.bepress.com/dwehner/22.
	mg/L	7.9	7.9	7.9	7.9	7.9	7.9	
	kg/ha-d	0.16	0.23	0.29	0.16	0.23	0.29	http://www.publish.csiro.au/paper/SR9950089.htm
	lb/a-y	53.13	74.42	92.95	53.13	74.42	92.95	
Plant available N	mg/L	18.3	18.3	18.3	18.3	18.3	18.3	
	lb/a-f	50	50	50	50	50	50	
Growing season	months	7	7	7	7	7	7	http://www.cimis.water.ca.gov/cimis/pdf/etomap1.pdf
Eto	inches/y	55	55	55	55	55	55	CIMIS/Brentwood
Etc	inches/y	33	44	55	33	44	55	CIMIS/Brentwood
Precip	inches/y	13	13	13	13	13	13	CIMIS/Brentwood
AW	inches/y	30	42	54	30	42	54	CIMIS/Brentwood
	ft/y	2.5	3.5	4.5	2.5	3.5	4.5	
Irrigation efficiency		85%	85%	85%	85%	85%	85%	
Reclaimed/total water		100%	100%	97%	100%	100%	97%	Assumes total water demand met by reclaimed water
N uptake	lb/mo-1000 sf	0.79	0.79	0.79	0.45	0.45	0.45	"1 to 1.5 pounds of nitrogen per 1,000 sq. ft. per month may be applied during the growing season" (http://aggie-horticulture.tamu.edu/plantanswers/turf/publications/bermuda.html). 6 lb/1000 sf on tall fescue (http://ucrturf.ucr.edu/UCRTRAC/BTTA/BTTA%20November%201997.pdf).
	lb/y-1000 sf	9.4	9.4	9.4	5.4	5.4	5.4	
	lb/a-y	411	411	411	235	235	235	See "uptake" worksheet.
Total PAN in applied WW	lb/a-y	124	174	217	124	174	217	
Under-fertilization	lb/a-y	287	237	194	111	61	18	Requirement - N in applied WW
		70%	58%	47%	47%	26%	8%	% of N requirement unmet by WW
Irrigated area	a	115	115	115	115	115	115	
WW supplied	a-f/y	286	400	500	286	400	500	

Depending on the assumptions, satisfaction of the full irrigation requirement of this 115 acres of mostly golf course results in 8 to 70% under-fertilization with N. This depends on the assumptions relative to turf needs, irrigation requirement, and volatilization and denitrification rates. Only at a Kc of 1 does the irrigation requirement in an average year appear to exceed the available 500 a-f/y.

DDSD N Loading and Demand

Kc	in/in	0.6	0.8	1.0	0.6	0.8	1.0	http://www.water.ca.gov/pubs/conservation/a_guide_to_estimating_irrigation_water_needs_of_landscape_plantings_in_california__wucols/wucols00.pdf
N uptake	lb/a-y	411	411	411	235	235	235	
Item	**Units**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**	**Notes**
Nitrate N	mg/L	1	1	1	1	1	1	
Ammonia N	mg/L	36	36	36	36	36	36	Caltest Analytical Lab order J110843, 11/18/09 sample
Organic N	mg/L	0	0	0	0	0	0	
Total N	mg/L	37	37	37	37	37	37	Caltest Analytical Lab order J110843, 11/18/09 sample
Net mineralization		100%	100%	100%	100%	100%	100%	Assumes full decay series of organic N mineralizes
	mg/L	0	0	0	0	0	0	
Ammonia volatilization		15%	15%	15%	15%	15%	15%	Assumes only volatilization of initially applied ammonia. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1000&context=cafes_dean; http://cedb.asce.org/cgi/WWWdisplay.cgi?8904892; http://soil.scijournals.org/cgi/content/full/67/5/1352
	mg/L	5.4	5.4	5.4	5.4	5.4	5.4	
Denitrification		30%	30%	30%	30%	30%	30%	http://jeq.scijournals.org/cgi/content/abstract/19/1/1; http://www.springerlink.com/content/gf7kttq2hv43tl7q/; C. F. Mancino, W. A. Torello, and David J. Wehner. "Denitrification Losses from Kentucky Bluegrass Sod" Agronomy Journal 80.1 (1988): 148-153. Available at: http://works.bepress.com/dwehner/22.
	mg/L	9.5	9.5	9.5	9.5	9.5	9.5	
	kg/ha-d	0.20	0.28	0.34	0.20	0.28	0.34	http://www.publish.csiro.au/paper/SR9950089.htm
	lb/a-y	64.08	89.75	112.11	64.08	89.75	112.11	
Plant available N	mg/L	22.1	22.1	22.1	22.1	22.1	22.1	
	lb/a-f	60	60	60	60	60	60	
Growing season	months	7	7	7	7	7	7	http://www.cimis.water.ca.gov/cimis/pdf/etomap1.pdf
Eto	inches/y	55	55	55	55	55	55	CIMIS/Brentwood
Etc	inches/y	33	44	55	33	44	55	CIMIS/Brentwood
Precip	inches/y	13	13	13	13	13	13	CIMIS/Brentwood
AW	inches/y	30	42	54	30	42	54	CIMIS/Brentwood
	ft/y	2.5	3.5	4.5	2.5	3.5	4.5	
Irrigation efficiency		85%	85%	85%	85%	85%	85%	
Reclaimed/total water		100%	100%	97%	100%	100%	97%	Assumes total water demand met by reclaimed water
N uptake	lb/mo-1000 sf	0.79	0.79	0.79	0.45	0.45	0.45	"1 to 1.5 pounds of nitrogen per 1,000 sq. ft. per month may be applied during the growing season" (http://aggie-horticulture.tamu.edu/plantanswers/turf/publications/bermuda.html). 6 lb/1000 sf on tall fescue (http://ucrturf.ucr.edu/UCRTRAC/BTTA/BTTA%20November%201997.pdf).
	lb/y-1000 sf	9.4	9.4	9.4	5.4	5.4	5.4	
	lb/a-y	411	411	411	235	235	235	See "uptake" worksheet.
Total PAN in applied WW	lb/a-y	150	209	262	150	209	262	
Under-fertilization	lb/a-y	261	201	149	86	26	(26)	Requirement - N in applied WW
		64%	49%	36%	36%	11%	-11%	% of N requirement unmet by WW
Irrigated area	a	115	115	115	115	115	115	
WW supplied	a-f/y	286	400	500	286	400	500	

Depending on the assumptions, satisfaction of the full irrigation requirement of this 115 acres of mostly golf course results in -11 to 64% under-fertilization with N. This depends on the assumptions relative to turf needs, irrigation requirement, and volatilization and denitrification rates. Only at a Kc of 1 does the irrigation requirement in an average year appear to exceed the available 500 a-f/y.

DDSD N Loading and Demand

Kc	in/in	0.6	0.8	1.0	0.6	0.8	1.0	http://www.water.ca.gov/pubs/conservation/a_guide_to_estimating_irrigation_water_needs_of_landscape_plantings_in_california__wucols/wucols00.pdf
N uptake	lb/a-y	411	411	411	235	235	235	
Item	**Units**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**	**Notes**
Nitrate N	mg/L	1	1	1	1	1	1	
Ammonia N	mg/L	36	36	36	36	36	36	Caltest Analytical Lab order J110843, 11/18/09 sample
Organic N	mg/L	0	0	0	0	0	0	
Total N	mg/L	37	37	37	37	37	37	Caltest Analytical Lab order J110843, 11/18/09 sample
Net mineralization		100%	100%	100%	100%	100%	100%	Assumes full decay series of organic N mineralizes
	mg/L	0	0	0	0	0	0	
Ammonia volatilization		30%	30%	30%	30%	30%	30%	Assumes only volatilization of initially applied ammonia. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1000&context=cafes_dean; http://cedb.asce.org/cgi/WWWdisplay.cgi?8904892;
	mg/L	10.8	10.8	10.8	10.8	10.8	10.8	
Denitrification		20%	20%	20%	20%	20%	20%	http://jeq.scijournals.org/cgi/content/abstract/19/1/1; http://www.springerlink.com/content/gf7kttq2hv43tl7q/; C. F. Mancino, W. A. Torello, and David J. Wehner. "Denitrification Losses from Kentucky Bluegrass Sod" Agronomy Journal 80.1 (1988): 148-153. Available at: http://works.bepress.com/dwehner/22.
	mg/L	5.2	5.2	5.2	5.2	5.2	5.2	
	kg/ha-d	0.11	0.15	0.19	0.11	0.15	0.19	http://www.publish.csiro.au/paper/SR9950089.htm
	lb/a-y	35.42	49.61	61.97	35.42	49.61	61.97	
Plant available N	mg/L	21.0	21.0	21.0	21.0	21.0	21.0	
	lb/a-f	57	57	57	57	57	57	
Growing season	months	7	7	7	7	7	7	http://www.cimis.water.ca.gov/cimis/pdf/etomap1.pdf
Eto	inches/y	55	55	55	55	55	55	CIMIS/Brentwood
Etc	inches/y	33	44	55	33	44	55	CIMIS/Brentwood
Precip	inches/y	13	13	13	13	13	13	CIMIS/Brentwood
AW	inches/y	30	42	54	30	42	54	CIMIS/Brentwood
	ft/y	2.5	3.5	4.5	2.5	3.5	4.5	
Irrigation efficiency		85%	85%	85%	85%	85%	85%	
Reclaimed/total water		100%	100%	97%	100%	100%	97%	Assumes total water demand met by reclaimed water
N uptake	lb/mo-1000 sf	0.79	0.79	0.79	0.45	0.45	0.45	"1 to 1.5 pounds of nitrogen per 1,000 sq. ft. per month may be applied during the growing season" (http://aggie-horticulture.tamu.edu/plantanswers/turf/publications/bermuda.html). 6 lb/1000 sf on tall fescue (http://ucrturf.ucr.edu/UCRTRAC/BTTA/BTTA%20November%201997.pdf).
	lb/y-1000 sf	9.4	9.4	9.4	5.4	5.4	5.4	
	lb/a-y	411	411	411	235	235	235	See "uptake" worksheet.
Total PAN in applied WW	lb/a-y	142	198	248	142	198	248	
Under-fertilization	lb/a-y	269	212	163	93	37	(13)	Requirement - N in applied WW
		66%	52%	40%	40%	16%	-5%	% of N requirement unmet by WW
Irrigated area	a	115	115	115	115	115	115	
WW supplied	a-f/y	286	400	500	286	400	500	

Depending on the assumptions, satisfaction of the full irrigation requirement of this 115 acres of mostly golf course results in -5 to 66% under-fertilization with N. This depends on the assumptions relative to turf needs, irrigation requirement, and volatilization and denitrification rates. Only at a Kc of 1 does the irrigation requirement in an average year appear to exceed the available 500 a-f/y.

DDSD N Loading and Demand

Kc	in/in	0.6	0.8	1.0	0.6	0.8	1.0	http://www.water.ca.gov/pubs/conservation/a_guide_to_estimating_irrigation_water_needs_of_landscape_plantings_in_california__wucols/wucols00.pdf
N uptake	lb/a-y	411	411	411	235	235	235	
Item	**Units**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**	**Notes**
Nitrate N	mg/L	1	1	1	1	1	1	
Ammonia N	mg/L	36	36	36	36	36	36	Caltest Analytical Lab order J110843, 11/18/09 sample
Organic N	mg/L	0	0	0	0	0	0	
Total N	mg/L	37	37	37	37	37	37	Caltest Analytical Lab order J110843, 11/18/09 sample
Net mineralization		100%	100%	100%	100%	100%	100%	Assumes full decay series of organic N mineralizes
	mg/L	0	0	0	0	0	0	
Ammonia volatilization		15%	15%	15%	15%	15%	15%	Assumes only volatilization of initially applied ammonia. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1000&context=cafes_dean; http://cedb.asce.org/cgi/WWWdisplay.cgi?8904892; http://soil.scijournals.org/cgi/content/full/67/5/1352
	mg/L	5.4	5.4	5.4	5.4	5.4	5.4	
Denitrification		20%	20%	20%	20%	20%	20%	http://jeq.scijournals.org/cgi/content/abstract/19/1/1; http://www.springerlink.com/content/gf7kttq2hv43tl7q/; C. F. Mancino, W. A. Torello, and David J. Wehner. "Denitrification Losses from Kentucky Bluegrass Sod" Agronomy Journal 80.1 (1988): 148-153. Available at: http://works.bepress.com/dwehner/22.
	mg/L	6.3	6.3	6.3	6.3	6.3	6.3	
	kg/ha-d	0.13	0.18	0.23	0.13	0.18	0.23	http://www.publish.csiro.au/paper/SR9950089.htm
	lb/a-y	42.72	59.84	74.74	42.72	59.84	74.74	
Plant available N	mg/L	25.3	25.3	25.3	25.3	25.3	25.3	
	lb/a-f	69	69	69	69	69	69	
Growing season	months	7	7	7	7	7	7	http://www.cimis.water.ca.gov/cimis/pdf/etomap1.pdf
Eto	inches/y	55	55	55	55	55	55	CIMIS/Brentwood
Etc	inches/y	33	44	55	33	44	55	CIMIS/Brentwood
Precip	inches/y	13	13	13	13	13	13	CIMIS/Brentwood
AW	inches/y	30	42	54	30	42	54	CIMIS/Brentwood
	ft/y	2.5	3.5	4.5	2.5	3.5	4.5	
Irrigation efficiency		85%	85%	85%	85%	85%	85%	
Reclaimed/total water		100%	100%	97%	100%	100%	97%	Assumes total water demand met by reclaimed water
N uptake	lb/mo-1000 sf	0.79	0.79	0.79	0.45	0.45	0.45	"1 to 1.5 pounds of nitrogen per 1,000 sq. ft. per month may be applied during the growing season" (http://aggie-horticulture.tamu.edu/plantanswers/turf/publications/bermuda.html). 6 lb/1000 sf on tall fescue (http://ucrturf.ucr.edu/UCRTRAC/BTTA/BTTA%20November%201997.pdf).
	lb/y-1000 sf	9.4	9.4	9.4	5.4	5.4	5.4	
	lb/a-y	411	411	411	235	235	235	See "uptake" worksheet.
Total PAN in applied WW	lb/a-y	171	239	299	171	239	299	
Under-fertilization	lb/a-y	240	171	112	64	(4)	(64)	Requirement - N in applied WW
		58%	42%	27%	27%	-2%	-27%	% of N requirement unmet by WW
Irrigated area	a	115	115	115	115	115	115	
WW supplied	a-f/y	286	400	500	286	400	500	

Depending on the assumptions, satisfaction of the full irrigation requirement of this 115 acres of mostly golf course results in --27 to 58% under-fertilization with N. This depends on the assumptions relative to turf needs, irrigation requirement, and volatilization and denitrification rates. Only at a Kc of 1 does the irrigation requirement in an average year appear to exceed the available 500 a-f/y.

		Irrigation Efficiency =	0.85		
			Kc = **0.6**	Kc = **0.8**	Kc = **1**
Month	**Average ETo (in)**	**Average precip (in)**	Applied Water	Applied Water	Applied Water
Jan	1.1	2.6	0.0	0.0	0.0
Feb	1.8	2.6	0.0	0.0	0.0
Mar	3.7	1.5	0.9	1.8	2.7
Apr	5.3	0.7	2.9	4.1	5.4
May	7.1	0.6	4.3	5.9	7.6
Jun	8.0	0.2	5.4	7.3	9.1
Jul	8.4	0.1	5.8	7.8	9.8
Aug	7.2	0.1	5.0	6.7	8.4
Sep	5.6	0.2	3.7	5.0	6.4
Oct	3.8	0.8	1.8	2.7	3.6
Nov	1.9	1.2	0.0	0.4	0.8
Dec	1.1	2.3	0.0	0.0	0.0
Total	55.1	13.0	29.8	41.8	53.8

Turfgrass	N (% DM)		kg N/ha-y			lb/a-y		
Species	Low	High	Low	High	Average	Low	High	Average
Blue	2.36	3.49	263	460	362	235	411	323
Fescue	3.7		413	-	206	369	0	184
Rye	3.34	5.4	373	712	542	333	636	484
Bent	2.4	8.3	268	1,094	681	239	977	608
Mills, H.A., and J.B. Jones. 1996. Plant analysis handbook II. MicroMacro Publishing. Athens, GA.								

Dry matter (kg DM/ha-y)		
Item	**Low**	**High**
Clippings	11,158	13,181
http://www.cababstractsplus.org/abstracts/Abstract.aspx?AcNo=20043119594		