In the Matter of the Sacramento Regional County Sanitation District's Petition for Review, SWRCB/OCC File Nos. A-2144(a) and A 2144(b) (Consolidated)

Brief Report in Response to Selected Issues Raised by Sacramento Regional County Sanitation District in Petition for Review of Discharge Permit Issued by the Central Valley Regional Water Quality Control Board

Prepared by Dr. Richard Dugdale, Dr. Frances Wilkerson, and Dr. Alexander Parker

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This Report is prepared to respond to selected issues raised by Sacramento Regional County Sanitation District in its Petition for Review to the State Water Resources Control Board of the waste discharge permit (Permit) issued to the Sacramento Regional Wastewater Treatment Plant (SRWWTP) by the Central Valley Regional Water Quality Control Board (Regional Board). Our more complete analyses and findings regarding the Bay-Delta are found in our body of work, including scientific papers and contributions to reports submitted to the State and Regional Water Boards.

1. The Regional Board relied, in part, on our research to support the total ammonia nitrogen limits in the Permit. In general, we have found that ambient ammonium from the Sacramento Regional discharge is suppressing nitrogen uptake and algal primary production in both Suisun Bay and the Delta. Our data indicate that ammonium above 4 μmol L^{-1} (0.056 mg-N L^{-1}) suppresses nitrate assimilation and primary production rates at concentrations as low as 0.014 mg-N L^{-1}, with complete shutdown when concentrations reach 0.056 mg-N L^{-1}. This ammonium-induced inhibition of nitrate uptake prevents algal blooms important to the health of aquatic life from developing when conditions are otherwise favorable. Indeed, as the Permit summarizes, ambient ammonium concentrations in 2009 and 2010 would need to be reduced by a factor of 2 to 7 at Chipps Island and by a factor of 1 to 21 in the main channel of the Sacramento River between Rio Vista and Chipps Island to eliminate the suppression of nitrogen uptake and primary production. *See* Permit at Table J-2. The total ammonia nitrogen permit limits reduce the maximum daily concentration 20-fold (45.4 to 2.2 mg N L^{-1}) and the average monthly value 13-fold (24.5 to 1.8 mg N L^{-1}). These are comparable to the decreases needed for the Delta and Suisun Bay to remove the impairment of nitrogen uptake and primary production by the phytoplankton community.

2. In its Petition, Sacramento Regional appears to argue that it is uncertain whether there would be a benefit to the Bay-Delta ecosystem if the ammonium was removed from their discharge; that its discharges do not affect the occurrence or extent of phytoplankton blooms. Petition at 85-89. Those arguments are not supported by scientific data.

3. For example, Sacramento Regional asserts that it is uncertain whether removing nutrients from its discharge would enhance phytoplankton blooms because the invasive clam, *Corbula amurensis*, grazes on phytoplankton biomass during the summer-fall seasons. Accordingly, Sacramento Regional submits, the clam would preclude a summer-fall phytoplankton bloom. It further suggest that even if a spring blooms returns, the levels of chlorophyll-a during the spring were never very high. Petition at 85-86. In support, Sacramento

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[1] Drs. Dugdale, Wilkerson and Parker are scientists and faculty with the Romberg Tiburon Center for Environmental Studies at San Francisco State University. Collectively we have many decades of experience investigating nutrient and phytoplankton dynamics. Our CVs are attached here as Exhibit 1.

Regional has included a figure (SR-Figure 4, Petition at 86)[2] that graphs the average chlorophyll-a (in μg L^{-1}) during each month of the year from 1975 to 1986.

4. Initially, Sacramento Regional is mistaken if it is in fact suggesting that a spring bloom would not improve the quality of aquatic life in the Bay-Delta. Promoting phytoplankton blooms, even if only in spring, would enhance the Bay-Delta system. The life cycles of aquatic organisms are often synchronized to the timing of when there is adequate and appropriate food supply. In the case of Delta smelt, the spring is considered an important time for spawning and rearing, and thus restoring the spring food supply (diatom blooms) that existed before the ammonium levels increased would surely be valuable.

5. Further, Sacramento Regional's presentation in SR-Figure 4 does not provide a complete picture of the data, particularly during the spring months. According to SR-Figure 4, the mean spring (April) chlorophyll value for the period 1975 to 1986 in Suisun Bay was ~ 5 μg L^{-1}. This depicts the average for each month over the course of ten years. It does not, however, represent the range of chlorophyll levels that were present at various times during those months. Nor does it accurately reflect the historic, maximum spring bloom of chlorophyll. Rather, during the 1975 to 1986 time period used by Sacramento Regional, there were spring blooms, as the peak chlorophyll ranged from 30-35 μg L^{-1} during February to May. (*See* Figure 1, below, plotting data for Suisun Bay stations D2, D6, D7, D8, D9 and D10.) Also, Ball and Arthur (1979) show, for the earlier period of 1969 – 1977, that Suisun Bay chlorophyll concentrations were as high as 30-40 μg L^{-1} during spring (*See* Figure 2 , below, that also shows the >30 μg L^{-1} that was reached in spring 2000 and 2010).[3] The 1969-1977 time period is more representative of the historic water quality than the period used by Sacramento Regional because it is before the decline began that coincided with the startup of the Sacramento Treatment Plant in 1982. Diatoms were also the dominant phytoplankton during that time period (Ball and Arthur, 1979) and in 2000 and 2010.

[2] For ease of reference, to distinguish from the figures we are including in this report, we will refer to Sacramento Regional's figures as "SR-Figure."

[3] Ball, M. and J. Arthur, *Planktonic Chlorophyll Dynamics in the Northern San Francisco Bay and Delta*, in T. Conomos, *San Francisco Bay: The Urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco* at 265-285 (1979).

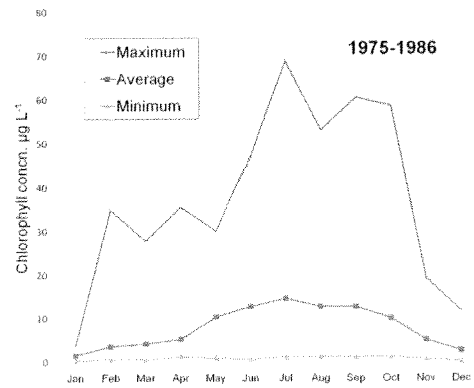

Figure 1. Chlorophyll concentrations in Suisun Bay from 1975-1986. Data are from California Department of Water Resources Environmental Monitoring Programs Stations D2, D6, D7, D8, D9 and D10.

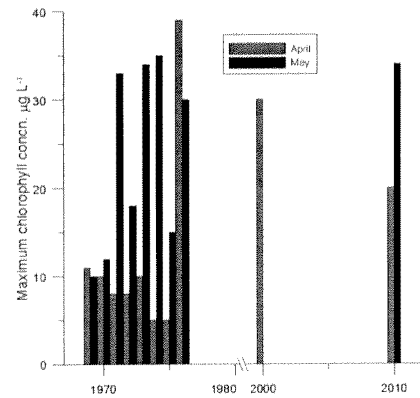

Figure 2. Maximum April and May chlorophyll concentrations measured by Ball and Arthur (1979) for Honker Bay from 1969-1977 and by Dugdale et al. (Dugdale et al. 2007 for 2000 data and unpubl. for 2010 data). Showing concentrations often greater than 30 $\mu g\ L^{-1}$

6. Moreover, consistent with our research, published data from 1969 to 1977 suggest that these periods of historically higher chlorophyll concentrations correlate generally with periods of low ammonium (NH_4) concentrations. Specifically, according to Cloern and Cheng (1981, their Table 1) the median NH_4 concentrations in Suisun for the period 1969 to 1977 (the same period for which chlorophyll was reported by Ball and Arthur, 1979) were low, 1.8 $\mu mol\ L^{-1}$ during summer and 4.0 $\mu mol\ L^{-1}$ during winter.[4]

7. This correlation is consistent with the results we have observed in recent years. The bloom of chlorophyll in Suisun Bay during spring 2000 reached concentrations of 30 $\mu g\ L^{-1}$ (Wilkerson et al., 2006); while the chlorophyll concentrations in the Suisun Bay spring 2010 bloom reached 35 $\mu g\ L^{-1}$. Both blooms (shown on Figure 2) occurred when NH_4 concentrations fell significantly – to 1.9 $\mu mol\ L^{-1}$ (0.0266 mg N L^{-1}) during spring 2000 and to 0.5 $\mu mol\ L^{-1}$ (0.007 mg N L^{-1}) during spring 2010. These results strongly suggest that high chlorophyll concentrations characteristic of the pre-1987 period should occur more frequently during spring if the low NH_4 conditions were restored to Suisun Bay. This would be particularly helpful to the species for which the spring bloom is vital to their survival. Moreover, the pre-1987 levels would occur in summer as well if clam abundance declined, as is already the case in San Pablo Bay and South Bay.

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[4] Cloern, J. and R. Cheng, *Simulation model of Skeletonema costatum population dynamics in northern San Francisco Bay, California*, Estuarine, Coastal and Shelf Science vol. 12 at 83-100 (1981).

8. Citing our work, Sacramento Regional further contends that our data suggest that there are times when the chlorophyll blooms did not occur when the reported ammonium concentration was below 4 μmol L^{-1}. Accordingly, Sacramento Regional argues, that the Permit "overstates the evidence in Wilkerson et al., (2006) and Dugdale et al., (2007) to state that 'ammonium induced inhibition of nitrate uptake prevents spring algal blooms from developing when other conditions are otherwise favorable.'" Petition at 86. In support of their claim, Sacramento Regional uses a figure from our work (SR-Figure 5, Petition at 87) that graphs chlorophyll and ammonium data from January 2000 to April 2003. Sacramento Regional's contentions misinterpret our conclusions and the data we reported in our research.

9. For one, what our research has found is that chlorophyll blooms are unlikely to occur when the ammonium concentration exceeds 4 μmol L^{-1}. That is the major point presented in the two papers referenced by Sacramento Regional (Wilkerson et al., (2006) and Dugdale et al., 2007) – that if ammonium is above approximately 4 μmol L^{-1} (0.056 mg N L^{-1}), chlorophyll accumulation (i.e., a bloom) is unlikely to occur. The papers do not suggest that once the NH_4 concentration is at or below 4 μmol L^{-1} (0.056 mg N L^{-1}), there will always be a chlorophyll bloom regardless of other environmental conditions (such as light availability, water temperature) or other factors (such as the presence of clams). As the Regional Board correctly understood, our work shows that if "conditions are otherwise favorable," then the initiation of the bloom will vary depending on the ammonium concentration. In other words, if favorable light conditions are achieved in the Bay-Delta, NH_4 concentrations of <4 μmol L^{-1} (0.056 mg N L^{-1}) are a necessary condition for bloom initiation, but are not a sufficient condition, as low NH_4 is not the only factor limiting phytoplankton growth and chlorophyll accumulation.

10. Sacramento Regional is similarly mistaken in its use of our data in SR-Figure 5 (Petition at 87). Sacramento Regional points out that three times during our time-series study when NH_4 was below 4 μmol L^{-1} (0.056 mg N L^{-1}), there was no corresponding chlorophyll bloom. These results are not surprising and fully consistent with our research, as we would expect that other factors necessary to bloom formation resulted in suppressed chlorophyll concentrations during those months. All three instances occurred during the summer (Aug. 2000, Aug. 2001 and June 2002) when clam grazing rates were likely high. Although we have no clam grazing data specifically from this period, given the months and years involved, it is reasonable to conclude the low summer chlorophyll reflects the increased grazing pressure.

11. Sacramento Regional also argues that the last of the five periods when the average ammonium was at or below 4 μmol L^{-1} did not yield a bloom above 10 μg L^{-1}. Petition at 87. As can be seen in SR-Figure 5, during the bloom in Suisun Bay in spring 2003, the chlorophyll did reach 10 μg L^{-1}. Even at that level, the concentrations are 5-10 times greater than without the bloom. However, that was when the field program ended so we do not have any information about the full magnitude and extent of the spring 2003 bloom. There are no data to support the assertion that 10 μg L^{-1} was the peak chlorophyll, as that value could very well have represented the beginning of an upward slope in chlorophyll. That type of upward slope would be comparable to what we observed in April 2000 when the spring bloom reached 35 μg L^{-1} chlorophyll with ammonium reduced to 1.9 μmol L^{-1}.

12. Sacramento Regional further mistakenly suggests that our time series measurements of ammonium and chlorophyll cannot rule out the possibility that low ammonium

is a result of a bloom triggered by non-nutrient factors, rather than the cause. Petition at 88. Without rate measurements of phytoplankton nitrogen (that is, ammonium and nitrate) uptake the suggestion could potentially be correct. However, the processes leading to blooms in the San Francisco estuary have been analyzed with phytoplankton rate measurements using stable isotope tracer techniques in addition to standing stock data. The potential for a chlorophyll bloom is initiated by favorable environmental conditions, *e.g.*, increased irradiance (Dugdale et al., 2007). With this condition met, phytoplankton NH_4 uptake rates increase and phytoplankton are able to reduce (drawdown) NH_4 concentrations. If favorable light conditions are maintained for a sufficient period of time, this uptake will reduce NH_4 concentrations to below inhibition thresholds. It is this point in the bloom sequence, when phytoplankton NO_3 uptake rates increase with rapid assimilation of NO_3, that a chlorophyll bloom develops. However, if favorable conditions (i.e. light) are not maintained, and NH_4 is not drawn down below threshold values, chlorophyll concentrations will be proportional to the available NH_4 concentration and the maximal chlorophyll that can be made is consequently much lower than if NO_3 had been accessed and used.

13. Sacramento Regional cites our enclosure/grow-out experiments and makes the argument that our results suggest there are nitrogen limited phytoplankton upstream of the Treatment Plant which actually benefit from the total ammonia discharge. Petition at 89-90. This argument is not an accurate conclusion to draw from our work.

14. The "grow-out" experiments involved collecting water from a particular location, putting the water and all aquatic life collected with it in an enclosed container under controlled light and temperature conditions. As part of the research, a series of experiments were carried out that compared phytoplankton responses to ambient nutrients in water from one location above the SRWWTP at Garcia Bend (station "GRC") with water from another station located shortly downstream of the SRWWTP at River Mile marker 44 (Station "RM-44"). The primary purpose for conducting these enclosures was to assess whether there was a change in phytoplankton growth rates downstream of the SRWWTP.

15. In SR-Figure 6, Sacramento Regional compared the total biomass in the GRC upstream enclosure to the RM-44 enclosure downstream of the Plant after a five-day test and concluded that the phytoplankton "grew better in water collected at River Mile 44 below the SRWWTP discharge than they did in Sacramento River water collected above the discharge, even though the ammonium concentration at River Mile 44 were well above the Dugdale threshold of 4 μM." Petition at 89. This comparison is not a useful one, however, because comparing the total biomass levels in an enclosure does not provide information about the physiological growth conditions (i.e. growth rates) leading to the accumulation of chlorophyll. In these enclosure experiments, with sufficient time, NH_4 will first be drawn down below inhibition levels and eventually all NH_4 and NO_3 will be taken up and phytoplankton will build biomass (observed as chlorophyll). As a result, the final chlorophyll observed in enclosure experiments is proportional to the initial dissolved inorganic nitrogen, either as NH_4 or NO_3. The 4 $\mu mol\ L^{-1}$ threshold has no relevance to the resulting chlorophyll observed in these experiments because in a closed system as in the enclosure experiments there is sufficient time (96-hr) to reduce NH_4 to below the inhibition threshold. In contrast, in the Sacramento River, the travel time (residence time) of the phytoplankton is not sufficiently long to draw down NH_4

to below the inhibition threshold and so in the natural, open system, the inhibition threshold acts to reduce phytoplankton growth and suppresses the buildup of chlorophyll.

16. However, the enclosure experiments are useful to assess phytoplankton growth rates, and in these experiments, we found both that (1) the growth rates went down in the upstream enclosure when we added more ammonium to that enclosure and (2) the growth rates were lower in the downstream enclosure, as compared to the upstream enclosures. The best proxy for phytoplankton growth rates are the biomass specific N uptake rates (VN). During the March 2009 enclosure experiment, we took the Sacramento River water collected from above the SRWWTP (at GRC) and amended it with (added) NH_4; this experimental treatment showed a lower ammonium uptake (lower VNH_4) than the control treatment (with no NH_4 added). This indicates the NH_4 uptake was suppressed by the elevated NH_4 concentrations. Our enclosure experiments cannot be used to assess nutrient limitation in a natural system because by definition the enclosures are limited to the nutrients that were collected in a single grab sample. The observed nutrient (nitrogen) limitation in the enclosure experiments from GRC during July 2008 was an obvious result given that the ambient dissolved inorganic nitrogen (DIN) concentration in the river upstream of the SRWWTP was $< 2\ \mu mol\ L^{-1}$ ($0.028\ mg\ N\ L^{-1}$) (Parker et al., 2010).[5] The ambient DIN at RM-44 was higher and so the enclosures collected at this station did not run into nitrogen limitation as quickly as those collected at GRC. However, given sufficient time, the enclosure experiment could have been carried out until RM-44 ran into nitrogen limitation. If this had been shown experimentally, it would not necessarily mean that the phytoplankton community in the Sacramento River is nitrogen limited downstream of the SRWWTP. Enclosures do not allow for additional inputs of DIN that are continually occurring in the Sacramento River from upstream sources as well as nutrient recycling within the river.

17. In addition to the enclosure experiments, other experiments similarly confirm that water with higher ammonium concentrations due to the SRWWTP effluent showed reduced productivity. We conducted small bottle (160 ml) experiments in which we added increasing levels of SRWWTP effluent to water collected at GRC. The results showed a strong suppression of phytoplankton carbon uptake, NO_3 uptake and NH_4 uptake with increasing concentrations of wastewater effluent NH_4. Parker et al. 2010

18. We also note that after further review of the data which clearly show a detrimental effect of the SRWWTP effluent on phytoplankton growth rates, we now believe that our enclosure results may actually underestimate the effect of the discharge on the Sacramento River phytoplankton community. We now know that the distribution of NH_4 concentrations along the Sacramento River show that RM-44 does not represent the highest NH_4 concentrations downstream of the Treatment Plant, where effluent effects may be greatest, even though it is the station closest to the discharge. Although it is generally accepted that there are no additional significant sources of NH_4 to that region of the Sacramento River, in four out of the five other Sacramento River sampling events (transects) completed for the Regional Board, NH_4 concentrations were found to be significantly elevated downstream of RM-44 at station "HOD,"

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[5] Parker, A.E., A.M. Marchi, J.Drexel-Davidson, R.C. Dugdale, and F.P. Wilkerson. "Effect of ammonium and wastewater effluent on riverine phytoplankton in the Sacramento River, CA. Final Report to the State Water Resources Control Board (Parker et al., 2010).

(Hood) approximately 10 km downstream of the SRWWTP (Parker et al., 2010). Dr. Chris Foe of the Regional Board has also observed this elevated NH_4 concentration downstream of RM-44.[6] In two additional spring Sacramento River surveys completed in 2009 by the Dugdale Lab, Sacramento River NH_4 concentrations were significantly elevated at HOD and the next downstream station (KEN; Kenady Landing) compared to RM-44 (Parker et al., 2010). Curiously, during the April 2009 transect, NH_4 concentrations at RM-44 were essentially unchanged from NH_4 concentrations observed upstream of the SRWWTP (<1.0 µmol L^{-1} or 0.014 mg N L^{-1}) suggesting no observable input from SRWWTP. While the explanations for the low NH_4 at RM-44 and the increase in NH_4 concentrations with distance from the SRWWTP are unresolved, there is consensus that the source of the elevated Sacramento River NH_4 is from the SRWWTP discharge and that likely variation in river flow, timing of effluent discharge and mixing play a role in the observed pattern.

19. Sacramento Regional also attempts to make an issue out of the lack of an observed "step change" in chlorophyll concentrations at station RM-44 during Sacramento River transects. Petition at 91. The referenced transects were sampling events at locations in the River from the I-80 Bridge above the discharge down to Suisun Bay well below the discharge. According to Sacramento Regional, because the chlorophyll data do not show a step decline after the effluent is added to the River, these data contradict our conclusions that the SRWWTP discharge causes a decrease in phytoplankton biomass and primary production rates. Petition at 91-92 (and SR-Figure 7).

20. In fact, there is no reason to expect a step change in chlorophyll concentrations immediately downstream of the SRWWTP at RM-44. Chlorophyll is a proxy for phytoplankton biomass and that biomass is the sum of primary production that has occurred over a number of days within the Sacramento River. As a result, the full effect of the ammonium on total biomass will not be seen until further downstream. This is because the chlorophyll biomass observed in the Sacramento River at RM-44 can be thought of as the sum of the primary production of phytoplankton in the Sacramento River in excess of losses of phytoplankton (*e.g.* lost due to zooplankton grazing or phytoplankton settling) and the inflowing biomass at RM-44 (the result of primary production above RM-44). In other words, the total biomass in samples taken at RM-44 reflects and includes the biological community that is coming from upstream. The time required for the phytoplankton community to be replaced (i.e. growth rate) is longer (> 3 days) than the travel time of the water as it moves through the upper portion of the Sacramento River (from the I-80 Bridge to Isleton (ISL)). As a result, we would expect to see a reduction in biomass further downstream. In fact, that is what our studies have found. As we described in our report to the Regional Board, downstream of the treatment plant chlorophyll declines by up to 75% compared to chlorophyll above the SRWWTP discharge. Parker et al., 2010 (Table 28).

21. In contrast to the total chlorophyll data which represents inputs from upstream, both primary production rates and phytoplankton nitrogen uptake rates are suppressed in downstream stations below RM-44, and especially between HOD and ISL stations, as compared to rates above the discharge. Step changes do occur in the phytoplankton rate processes. Using

[6] Foe, C., A. Ballard, and S. Fong, Nutrient Concentrations and Biological Effects in the Sacramento- San Joaquin Delta, Central Valley Regional Water Quality Control Board (July 2010).

stable isotope tracer techniques we observed, a step change reduction in both NO_3 and NH_4 uptake, as NO_3 uptake is shut down and NH_4 uptake is reduced at high effluent NH_4. Specifically, beginning immediately downstream of the SRWWTP discharge, primary production and phytoplankton NH_4 uptake rates decline by 20 to 36% and NO_3 uptake decreases by 80%. Parker et al. 2010. The suppressed phytoplankton carbon and nitrogen uptake rates are likely not sufficient to keep up with, let alone exceed, losses such as grazing and phytoplankton settling, and as a result chlorophyll would inevitably decline, as has been observed in the Sacramento River. Parker et al., 2010.

22. Sacramento Regional also points to the decline in chlorophyll concentrations above the discharge as evidence that the decline below the discharge must be due to something other than the discharge. Petition at 91-92 and 95-96. The decline in chlorophyll that has been observed in the Sacramento River from station "I-80" to station "GRC" and the decline in chlorophyll-a from station "RM-44" to station "ISL" do not need to be the result of the same processes. The underlying process leading to the decline in chlorophyll found at upstream stations (I-80 to GRC) is not well understood at this time, although the input of freshwater from the American River (between I-80 and station "TOW; Tower Bridge") has been suggested to dilute chlorophyll in the Sacramento River. Additional losses from zooplankton grazing or sinking of phytoplankton cells may also be important. In contrast, the downstream changes are well defined, including the changes in water quality and the documented suppression of production and uptake rates.

23. Sacramento Regional further claims that the data shown in SR-Figures 8 and 9 contradict our conclusion that primary production does not consistently decline in the downstream direction. Petition at 92-94. However, the ability to observe consistent spatial patterns in primary production rates and phytoplankton nitrogen uptake rates along Sacramento River transects appears to be in part a function of river flow. This can be clearly seen during the spring 2009 transects conducted for the Regional Water Board (Parker et al., 2010). During March and May, Sacramento River flows were high (>25,000 cubic feet per second (cfs) and there was no clear decline in primary production (Parker et al., 2010). However, during April, Sacramento River flow was significantly lower than March and May (approximately 13,000 cfs) and a clear decline in primary production rates were observed. High flows smear out spatial patterns of any phytoplankton processes further downstream.

24. Finally, Sacramento Regional points to SR-Figure 10 to draw the conclusion that because carbon fixation begins to increase in the confluence zone despite ammonium being the dominant form of inorganic nitrogen, factors other than ammonium must be controlling phytoplankton biomass and primary production in the Sacramento River. Petition at 95-96. SR-Figure 10 – which came from a presentation we made – does not support this conclusion. The decline in primary production downstream of the SRWWTP was the result of both the shutdown of NO_3 uptake by NH_4 and the inhibition of NH_4 uptake by the elevated ammonium concentration. We interpret the increase in carbon fixation at the confluence as a result of the declining NH_4 concentration allowing NH_4 uptake and associated primary production to increase at that location.

R.C. Dugdale 5/4/2011

Dr. Richard Dugdale Date

5/4/2011

Dr. Frances Wilkerson Date

5/4/2011

Dr. Alexander Parker Date