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DRAFT MEMORANDUM

C-43 Water Quality Treatment Area – Expert Panel Review

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DATE:	June 24, 2010

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Introduction

The South Florida Water Management District (District) and Lee County are partnering to reduce nutrient concentrations and loads in the C-43 Canal (Caloosahatchee River) upstream of the S-79 water control structure east of Ft. Myers and in the Caloosahatchee Estuary (Estuary) downstream of S-79. Elevated concentrations of nitrogen and phosphorus in these water bodies are contributing to impairment of beneficial uses in the Caloosahatchee River and Estuary, primarily through the creation of excessive algae blooms and resulting decreased water clarity and dissolved oxygen content. The primary focus of the District's and Lee County's efforts is reduction of bioavailable forms of nitrogen and ultimate compliance with a Total Maximum Daily Load (TMDL) requirement for the

Estuary. While the focus is on nitrogen (N) load reduction, loads of phosphorus (P) and suspended solids are also of concern and are being considered.

The effect of excessive nutrient loads from the C-43 Basin (including Lake Okeechobee) is exacerbated by unnaturally high and variable flows that bring excessive nutrients and tannic colored water into the river and estuary (Knight and Steele 2005). One component of this restoration effort mandated by the Northern Everglades and Estuary Protection Plan of 2007 is implementation of a Water Quality Treatment Area (WQTA) just upstream of S-78 on the south side of C-43. Other activities in this overall restoration plan that are outside the consideration of this review but may be critical for the success of the WQTA project include a proposed water storage reservoir (C-43 Storage Reservoir) to restore some normality to flows and source controls in the basin to reduce nutrient and solids loads in the C-43 Canal.

A 1,750-ac site has been purchased by the District and Lee County for the proposed WQTA. Preliminary studies and engineering for the proposed WQTA facility are being conducted by CH2M HILL (Consultant) under contract with the District. A number of project deliverables have been completed by the Consultant to identify the best option(s) for achieving the project goals of nutrient reduction in C-43 and the Estuary. Key activities completed under this contract to-date include:

- Initial Data Collection and Total Nitrogen Reduction Technologies Assessment
- Water Quality Evaluation and Characterization of Dissolved Organic Nitrogen (DON)
- C-43 Water Quality Treatment Project Test Facility Conceptual Plan Development

The Consultant's work efforts have resulted in a proposed treatment train of natural nutrient removal technologies (i.e., "green" wetland and aquatic processes that rely more on solar and other natural energy inputs/plants and processes and less on the consumption of fossil fuels or chemicals) to reduce concentrations of bioavailable nitrogen and phosphorus compounds in C-43 prior to discharge to the Estuary. The Consultant has prepared a conceptual plan for development of a research/demonstration facility on the C-43 WQTA site as the next step prior to full-scale implementation of nutrient removal in the Caloosahatchee River.

The District is conducting a peer review of the Consultant's findings and recommendations prior to proceeding with final design and implementation of the research/demonstration project. A panel of three scientists (Panel) with extensive credentials in water quality treatment and wetland and natural systems, were selected for this peer review:

- Dr. Robert Knight, Panel Chair (Wetland Solutions, Inc. [WSI] and University of Florida)
- Dr. Alex Horne (University of California Berkley)
- Dr. John White (Louisiana State University)

The District has directed the Panel to complete the following four tasks as part of this review effort:

- Review and Evaluate Consultant Deliverables including the following:

    - Total Nitrogen Reduction Technologies Review (April 2008);
    - Organic Nitrogen Methodology Screening Analysis (Deliverable 3.2.1 Draft, November 2009);
    - Findings Memorandum (Deliverable 3.1.2 Final, December 2009),
    - Water Quality Treatment Area Test Facility Parameter Plan (January 2010); and
    - C-43 Water Quality Treatment Area Draft Conceptual Plan Technical Memorandum (Deliverable 4.2.8 Draft, March 2010).
- Provide guidance on the C-43 WQTA Test Facility design, including:
    - Identify promising approaches to TN removal; and
    - Recommend Test Facility changes as needed to evaluate these promising approaches.
- Recommend parallel work efforts (experimental and/or data review) to improve the information derived from the Test Facility; and
- Participate in a two-day workshop to discuss and review Panel findings and to reach consensus on the conceptual plan for the proposed C-43 WQTA Test Facility.

Additional detailed requests under these four major tasks are presented in the District's Scope of Services for the Panel members and addressed below. This draft technical memorandum (TM) is organized based on the first three tasks described above and represents the work of Dr. Knight with WSI (Reviewer). Prior to the two-day workshop, the Panel Chair will prepare a draft consolidated technical memo with the panel findings. Following the completion of the workshop listed as Task 4 above, a consensus TM will be prepared and issued that includes the combined findings of the entire Panel.

Task 1 – Review and Evaluate Consultant Deliverables

Total Nitrogen Reduction Technologies Review (April 2008)

General Comments

The information included in this document is well organized and presented. However the scope is too narrow. This document should treat both nitrogen and phosphorus with equal weight since both elements are thought to be involved in eutrophication of the Caloosahatchee Estuary (Knight and Steele 2005).

The title of this report indicates that it is intended to be a review of existing information about all available and feasible treatment technologies for reduction of TN, with a focus on wetland/natural systems and the biogeochemistry of the most recalcitrant forms of N, including dissolved organic nitrogen (DON). The discussion of the feasibility and cost of using conventional (energy and chemical intensive) nitrogen removal technologies should be expanded and more conclusive.

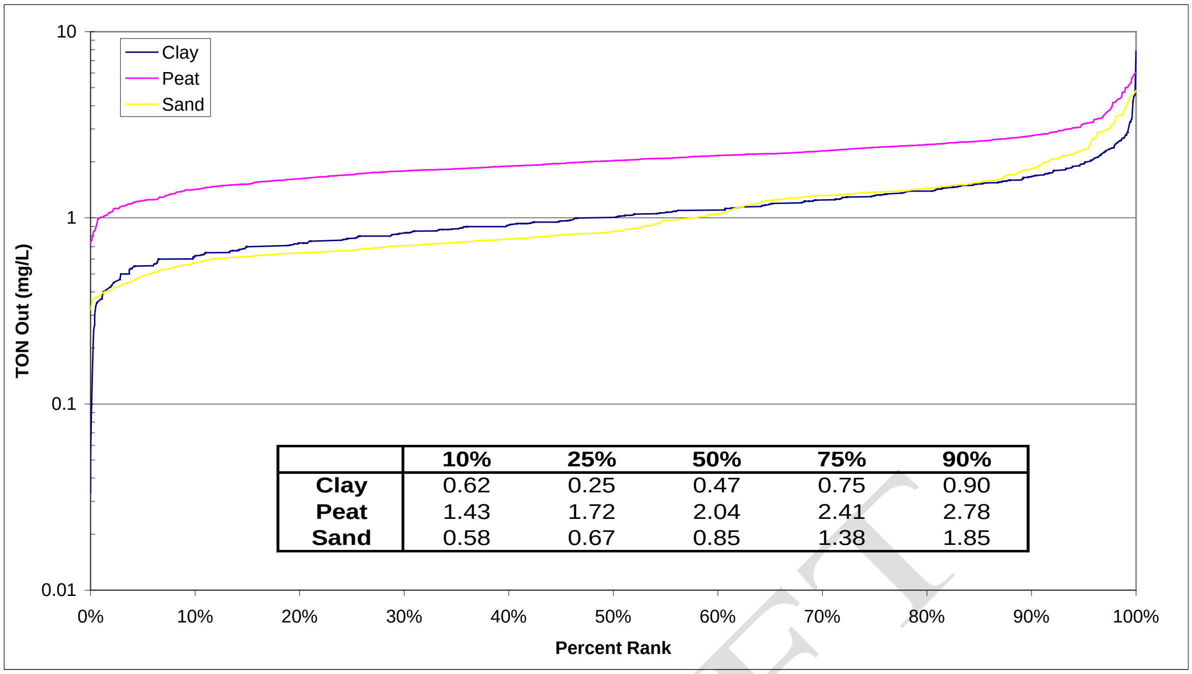
The discussion of organic nitrogen forms and nitrogen transformations needs more explanation. While the focus is on DON, there should be more discussion on transformations to and from ammonium or nitrate forms and on particulate organic nitrogen (PON). PON consists of living and dead algal cells and to a lesser extent suspended organic sediments. When these particulates are trapped in treatment wetlands a fairly large fraction of the liberated organic nitrogen is bioavailable following ammonification.

This Reviewer suggests a different focus from the one proposed by the Consultant. This suggested alternative approach would highlight the relationship between "biologically available nitrogen" (BAN) and "recalcitrant nitrogen" (RN). The District's basic goal is to reduce the concentration and load of BAN in the Caloosahatchee River and Estuary, rather than TN or DON. The Consultant has put a considerable effort into defining biologically-available DON (BDON) but the resulting definition should be more comprehensive with better explanation of the assumptions. Suggested definitions are:

- BAN includes all inorganic nitrogen forms ($NH_3 + NO_X$) and biologically available organic N (urea, uric acid, amino acids and sugars, amides, etc.); and
- RN includes all other nitrogen forms that will not degrade in the freshwater or salt water environment within a reasonable period (e.g., 30 day half life to be estimated based on eventual dilution and breakdown in the marine environment). RN could be assumed to be the TN remaining in the outflow from a well-designed/constructed treatment wetland that has a nominal hydraulic residence time of at least 30 days.

The DON conceptual model proposed by the Consultant is not comprehensive and ignores significant components of the nitrogen budget in treatment wetlands. Specifically, the conceptual model does not acknowledge the direct release of DON from organic soils or include the contribution of rooted macrophytes as they release nitrogen from the soil pool to the BDON pool or to recalcitrant DON (RDON).

The whole issue of soil interactions with DON should be addressed in this TM. Natural treatment systems built on organic soils may have a higher irreducible background TN concentration (C^*_{TN}) than systems built on mineral soils with low organic matter content. Examples include the Iron Bridge Treatment Wetland east of Orlando built on sandy soils with low organic matter content and a C^*_{TN} less than 0.8 mg/L, and the EAA STAs with C^*_{TN} values as high as 2.2 mg/L in the northern EAA with highly organic soils and a C^*_{TN} value of about 1.45 mg/L in STA 6 in the western EAA where soils are sandy and less organic. **Exhibit 1** illustrates the monthly outflow TON concentration data from eleven Florida wetland and aquatic systems based on their predominant soil characteristics. These data indicate that treatment wetlands built on sandy or clayey soils have consistently lower outflow TON concentrations than wetlands built on organic soils. On treatment wetland soils saturated with sorbed ammonium nitrogen (from antecedent conditions including fertilization of orange groves or application of wastewater residuals), the release of this inorganic nitrogen form can be very significant.



	10%	25%	50%	75%	90%
Clay	0.62	0.25	0.47	0.75	0.90
Peat	1.43	1.72	2.04	2.41	2.78
Sand	0.58	0.67	0.85	1.38	1.85

EXHIBIT 1
Florida Wetland and Aquatic System Monthly Average TON Outflow Concentration vs. Percent Rank by Substrate Type

The focus of this TM and the Consultant's approach to the reduction of nitrogen in the Caloosahatchee River and Estuary appears to be to develop a theoretical process to convert BDON to RDON and to conduct basic research concerning this transformation. The proposed Atmospheric Pressure Photoionization-Electrospray Ionization – Mass Spectrometry (APPI-ESI-MS) fractional methods and the bioassay methods are in early stages of research/development and are experimental. With as many as 3,000 organic nitrogen compounds to evaluate using these methods, there is little possibility of cost effective and timely implementation of a treatment process to solve a long-standing problem of eutrophication in the Caloosahatchee River and Estuary. Loh (2008) concludes that DON released from the S-79 to the Caloosahatchhe Estuary is not susceptible to degradation by estuarine bacteria and that DIN is the most bioavailable form. The priority of this project and this review should be on determining which alternative technologies for TN removal are feasible, effective, and ready for implementation. Theoretical processes that will take considerable time and monetary investment to prove do not offer a realistic solution for the current problems in this aquatic ecosystem.

The nitrogen loading graphs provided by the Consultant should be better explained. Loading rate vs. removal rate graphs (Exhibits 10-12 in the TM) typically show high correlations due to the autocorrelation of the variables on the x and y-axes. The Consultant should emphasize the difference between the loading vs. concentration graphs presented in Exhibits 13, 14, and 18 and the three preceding graphs in the TM. The latter three graphs are more valuable as an empirical tool for assessing treatment wetland performance (Kadlec and Wallace 2008). It should also be noted that both axes in these loading vs. concentration graphs are plotted with logarithmic scales, de-emphasizing the actual variability of data between different treatment wetlands with highly different designs and antecedent soil conditions.

The point of this explanation is that the focus for this analysis should be on why some treatment wetlands attain very low organic N outflow concentrations compared to others that have higher C* values. Specific attention should be drawn to Exhibit 17 in the TM that shows the effluent organic N from STA 5 being between about 1 and 1.5 mg/L, compared to the more northern STAs that have outflow organic N concentrations above 2 mg/L, probably due to their differing antecedent soil properties. The discussion of the data presented in Exhibit 18 (North American Treatment Wetland Database v. 2) should focus on what is different/special about the wetlands with data points below 1 mg/L of organic nitrogen.

Exhibit 2 provides a more detailed look at organic nitrogen loading vs. outflow concentration data from large-scale Florida wetland and aquatic systems. Of particular importance are the data from systems such as Orlando Iron Bridge, Titusville, and STAs 5 and 6 that indicate that wetlands constructed on sandy or clayey soils and dominated by emergent marsh vegetation consistently achieve TON concentrations less than 1.5 mg/L.

The Consultant emphasizes the data collected from the Wellington Pilot study. The data collection period for this system only lasted about 15 months and ammonia nitrogen was not measured so it was not possible to calculate organic nitrogen by difference between total kjeldahl nitrogen (TKN) and NH_3. The Wellington cells were very small, flows were difficult to measure accurately, and the system data are probably more representative of start-up performance than long-term sustainable operation. While the Consultant's conclusions concerning the effectiveness of constructed wetlands dominated by emergent and submerged aquatic plants are based on a very large data set derived from numerous projects many of which have long-term data sets, the use of the Wellington data set to summarily discard a periphyton-based stormwater treatment area technology (PSTA) and to promote the use of a Floating Aquatic Vegetation (FAV) technology is not sufficient to justify the investment of millions of dollars for additional research and demonstration. The Consultant is very aware of the much larger PSTA data set from the District's own Advanced Treatment Technologies (ATT) project (CH2M HILL 2003). There are also extensive data sets available for FAV systems (e.g., the 30-acre Orlando Iron Bridge water hyacinth treatment system and more recent Hydromentia systems).

The three-year data set from the Everglades Nutrient Removal (ENR) project buffer cell that was dominated by water hyacinths is probably more useful than the Wellington data set, but it was still of comparatively short duration for a pond system. Unharvested water hyacinth ponds can accumulate considerable organic solids that result in an eventual feedback of DON to the water column following the first few years of operation.

Exhibit 3 illustrates the percentile ranking of average monthly TON outflow concentrations reported for Florida treatment wetland and aquatic systems dominated by various plant communities and open water. This data analysis indicates that FAV systems do not always have the lowest TON outflow concentrations. In fact, a comparison of data from 1987 to 1999 for Lakeland Cell 4 (cattail-dominated) and Cell 7 (dominated by FAV for about 10 years during this period) indicate that a FAV-dominated cell may actually increase TN concentrations following emergent wetland cells (Cell 4 – TN = 1.33 mg/L and Cell 7 – TN = 1.71 mg/L). The point of this paragraph is that while the data analysis for emergent wetlands is fairly sound as a basis for recommending that technology, the basis for recommending FAV as the most significant component of a treatment train is less substantiated.

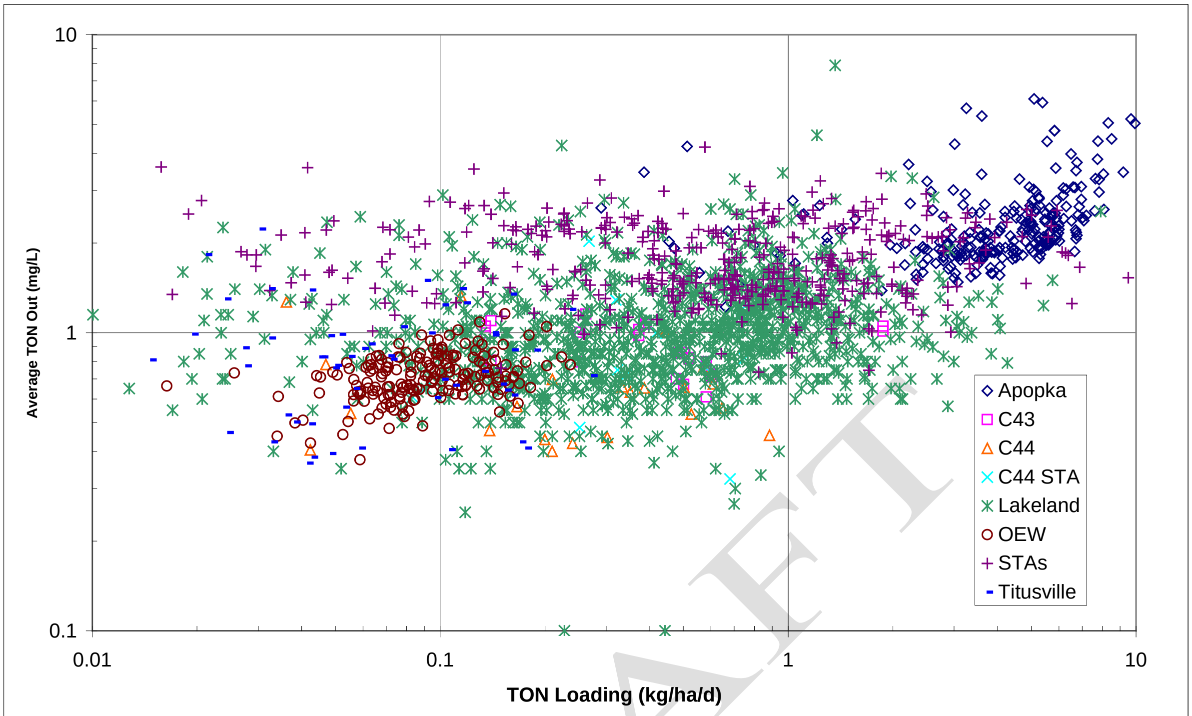
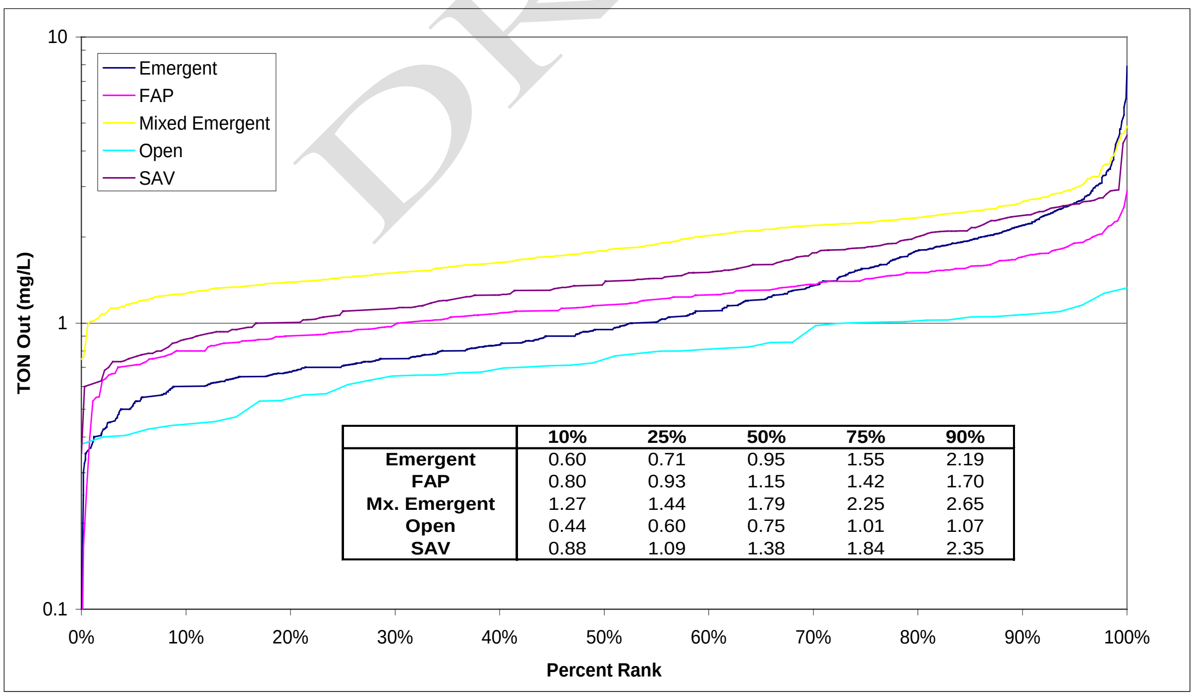


EXHIBIT 2
Florida Wetland and Aquatic System Monthly TON Loading vs. Outlet Concentration by System



	10%	25%	50%	75%	90%
Emergent	0.60	0.71	0.95	1.55	2.19
FAP	0.80	0.93	1.15	1.42	1.70
Mx. Emergent	1.27	1.44	1.79	2.25	2.65
Open	0.44	0.60	0.75	1.01	1.07
SAV	0.88	1.09	1.38	1.84	2.35

EXHIBIT 3
Florida Wetland and Aquatic System Monthly Average TON Outflow Concentration vs. Percent Rank by Vegetation Type

There are additional concerns with a recommendation for an FAV system that limit the feasibility of this technology for consistent and cost effective removal of biologically available nitrogen. Inherent limitations for full-scale FAV treatment systems include the following:

- Water hyacinths are the most commonly used plant species in FAV systems and have a very long history of use (Kadlec and Knight 1996). This history indicates that they need to be harvested regularly to successfully function for consistent nutrient removal and to keep the plants healthy. Harvesting and disposal of water hyacinths is impractical and problematical on any but the smallest scale due to their very high moisture content and fast growth rates. Water hyacinth systems typically have highly anaerobic water conditions that are attractive for breeding of adapted nuisance mosquito species in the genus *Mansonii*. Water hyacinths are not tolerant of any frost and they are susceptible to failure due to cold weather.
  Water hyacinth systems are subject to herbivory by a suite of biological control agents introduced in Florida to eradicate the species and must be sprayed with insecticides to maintain high growth rates. Some water hyacinth systems have required fertilization with nitrogen and iron to achieve high growth rates in nutrient-poor environments. Water hyacinths are difficult to control in large open cells that are subject to appreciable wind fetch.
- FAV systems dominated by pennywort and water lettuce are possible but have some of the same limitations as those listed above for water hyacinths and have never been used on a large scale.
- Duckweed systems have been used for water quality treatment, but they are even more sensitive to wind effects than water hyacinths and water lettuce and require an expensive floating grid system when used in large ponds, and they have only been used effectively at relatively high nitrogen concentrations.
- The nitrogen-fixing water fern *Azolla* is likely to invade any FAV system with low available nitrogen, thus negating the perceived benefit of these systems as an alternative to nitrogen-fixing algal based treatment technologies.

The merits and applicability for using tussock, Soil Aquifer Treatment (SAT), and Riverbank Filtration (RBF) systems are not very convincing. For instance, there are no full-scale projects in Florida with long-term operational data for either of these "technologies". Existing engineered "tussock" systems (e.g., beemats) are extremely small and have no relevant applications with long-term operational data sets. There are full-scale emergent treatment wetland cells that have been dominated by tussocks (e.g., ENR Cell 3 and Lakeland Cells 3 and 4), but data from these cells have not been specifically analyzed to defend the pursuit of this idea. One practical problem with a tussock vegetation community observed in both the ENR and at Lakeland is that it is highly unstable due to changing buoyancy of the supporting vegetation, which can cause a catastrophic failure with loss of the floating plant community and an inevitable shift to open water during and following storm events.

Soil Aquifer Treatment systems have been used throughout the western U.S. but more for general wastewater reclamation and groundwater recharge, rather than as high performance nitrogen removal systems. SAT systems have generally been judged to be successful if they can lower nitrate in groundwater to the drinking water standard of 10 mg/L, which is about 200 times higher than the natural background in Florida's ground and surface waters. I am not aware of any SAT systems specifically designed or optimized for removal of DON. There are no operating Riverbank Filtration systems in Florida that indicate either feasibility or cost effectiveness of this proposed technology.

There are some surface water-ground water studies previously conducted in Florida that might shed light on the effectiveness of filtering surface water with elevated organic nitrogen concentrations through natural soils (e.g., the C-43 and C-44 Storage Reservoir Test Cell projects funded by the District). Water quality studies conducted at the Storage Reservoir Test Cells constructed at C-43 indicate that the TN declined from 1.05 to 0.76 mg/L and TON declined from 0.91 to 0.67 mg/L from the Test Cell to the adjacent Seepage Canal (WSI 2007a). At the C-44 Reservoir Test Cells, TN declined from 0.87 to 0.61 mg/L and TON declined from 0.76 to 0.48 mg/L from the Test Cells to the adjacent Seepage Canals (WSI 2007b). Although promising from a concentration standpoint, Soil Aquifer Treatment or Riverbank Filtration technologies are likely to be hydraulically limited and impractical on a large scale.

While additional data analysis and testing of tussocks, SAT, and RBF systems may be warranted, it is the opinion of this Reviewer that such testing may not be able to provide a defensible alternative for solving the nutrient problems in the Caloosahatchee River and Estuary within a realistic time frame or a reasonable research & development cost.

Summary and Conclusions

It is the Reviewer's conclusion that some of findings and recommendations provided in this TM are not supported by adequate evidence:

- The Consultant concludes that particulate organic nitrogen is not important for project planning and design. The proven ability of emergent treatment wetlands to capture particulate nitrogen (especially algal solids) provides an opportunity to utilize their enzymatic systems to trap otherwise unavailable nitrogen before it can move downstream to the estuary;
- The Consultant concludes that the use of experimental and expensive methods for assessing nitrogen recalcitrance is justified for this project due to the perceived need to open the "green box" of these natural treatment systems so we can better manipulate their internal processes. Based on the immediate need to develop an applied solution to a real water quality problem, dependence on highly theoretical and experimental technologies will not be the most cost effective approach to success. For the timely success of this project it is important to focus on technologies and knowledge that are well established and have been proven elsewhere. Research and experimentation can continue in parallel with implementation of the best available technology but should not become a bottleneck that slows restoration of the water quality in the Caloosahatchee River;
- The Consultant concludes that PSTA and emergent wetland systems add DON and that only floating aquatic plant systems remove it. These conclusions do not appear to be supported by data;

- The Consultant concludes that only treatment systems that have a light limited water column (shaded) can remove significant DON concentrations. This conclusion is not supported by an adequate review of existing data.
- The Consultant concludes that FAV and tussock-dominated treatment technologies should be highly ranked as being proven and cost effective. These alternative natural treatment systems are based on plant groups that do not have a long track record or have not been shown to be feasible on a large scale;
- The Consultant concludes that SAT and RBF systems may be an important component of a test and demonstration project. There does not appear to be data provided from comparable systems that support this conclusion;

The following important considerations were omitted in the Consultant's report:

- The conceptual model for organic nitrogen processing in the proposed treatment train appears to not consider the important feedbacks from site soil and nutrient release due to antecedent soil conditions;
- The Consultant's TM should provide a preliminary estimate of the size and cost of a WQTA needed to meet the TMDL requirements for the Caloosahatchee Estuary. There will be significant costs associated with the TMDL goal of removing up to 23% of the total upstream nitrogen load at S-79 considering the very high seasonal flows in the C-43 Canal. For example, the average C-43 flow at S-78 is about 940 cfs (607 MGD) and maximum recorded flows are about 9,720 cfs (6,300 MGD). It is important at this preliminary stage in the implementation process to have some idea of the approximate land area requirements and present worth costs.

Based on this review and the Reviewer's experience, the supportable conclusions from the Consultant's report are:

- Emergent wetlands are highly reliable and relatively cost effective at reducing all forms of biologically available nitrogen in surface waters to levels that appear to be highly recalcitrant and do not stimulate further biological activity over a reasonable half life; and
- Conventional technologies that are technically proven for high-level nitrogen removal are not as cost effective as an emergent wetland technology operating with the benefit of natural energies.

This Reviewer presents these additional conclusions based on prior experience with a number of similar evaluations of nutrient-removal technologies in Florida:

- Existing relevant information and a careful consideration of the need for an effective and rapid implementation of nitrogen removal in C-43 justifies installation of a large-scale demonstration project with a variety of natural treatment alternatives (emergent wetlands, submerged aquatic plants, floating aquatic vegetation, and algal-dominated treatment systems). No replication is suggested due to the size of each cell in the demonstration project (about 10 to 40 acres each) and these cells should be designed with the flexibility to incorporate them into the eventual full-scale WQTA facility;

- Theoretical/experimental approaches to removal of nitrogen and speciation of BDON and RDON will not be productive if they are in the critical path for project implementation. The focus of this report should be on the demonstrated effective technologies and not on approaches that have not been proven effective under similar circumstances. The primary goal of the C-43 WQTA Project should be on optimization of design parameters for constructed wetlands. This conclusion is discussed in more detail under a latter section of this report, but a preliminary list of design issues that might benefit from optimization studies are: the effectiveness of various mixes of wetland/aquatic plants, the effects of water depth on these plant communities and their nitrogen removal kinetics, the effects of antecedent soil conditions on the C* for DON, and the effects of hydraulic residence time on system performance.

Organic Nitrogen Methodology Screening Analysis (Deliverable 3.2.1 Draft, November 2009)

General Comments

The results of the organic nitrogen screening analyses are interesting from a scientific viewpoint and could generate considerable discussion. From a practical standpoint of implementing nitrogen control in the Caloosahatchee Estuary, these findings are not likely to provide a timely solution or a 'silver bullet" approach to solve an existing water quality crisis. For these reasons, this review does not include a detailed critique of the methods and findings of these analyses.

The Consultant continues with the assumption that "…treatment of DON must transform BDON to RDON…" and that "…the DON removal process needs to be based on an understanding of the compounds to be treated…" The Reviewer does not agree with these statements. There are many examples of limited scientific understanding of processes used every day in the pollution control industry. Examples include hundreds of constructed treatment wetlands used by municipalities, industries, agricultural and industrial interests for reduction of nutrient levels to meet permit limits. The Everglades STAs are an example of how the use of wetlands for phosphorus removal has advanced without a clear understanding of many of the detailed process-level transformations of inorganic and organic phosphorus compounds. It is this Reviewer's opinion that not all of the internal workings of natural treatment systems (and for that matter, conventional treatment systems that rely on biological communities of microbes) will ever be completely understood nor need to be understood to use these systems for highly reliable pollution control. This does not preclude detailed research of the processes to help optimize the performance of these systems. The point is that a "green box" can be relied upon for consistent nutrient removal as long as we have an adequate understanding of how to control the major external forcing functions that affect its performance.

Based on data presented in this report and by others (Knight and Steele 2005), it is clear that organic nitrogen can be degraded/assimilated in the C-43 Canal environment. This is a notable but unmentioned conclusion from the Consultant's observation that more of the DON is recalcitrant in C-43 during the dry season than in the wet season. Based on the existing seasonal comparisons it appears that this *in situ* degradation is significant and should be better understood to optimize the natural attenuation occurring in the canal environment. This may well be the most cost effective nitrogen removal that will occur in this basin other than source control (the ultimate solution for much of the problem).

The Virginia Institute of Marine Science (VIMS) team states categorically that the high variability in the bioassay results is due to variation in the field duplicates rather than to variability in the analytical methods. Given a personal knowledge of collecting field duplicates in the C-43 and tributary canals, this statement does not seem probable. Perhaps the Consultant should better explain why this conclusion was accepted and repeated elsewhere in this series of reports.

The VIMS bioassay method had other problems as well. For example there was only 8 to 10% removal of DON in the assays at 120 hours incubation time. This finding does not indicate that there is a highly significant effect of recalcitrant nitrogen forms in a saline estuarine environment. The other apparent problem with the bioassay procedure was the observation that the total amount of DON increased in many of the tests. It was stated in the report that these increases were likely due to nitrogen fixation by the inoculums or death and lysis of the algal/bacterial cells. Both of these possible complications can be expected to result in additional cell growth that is not based on the DON in the original water sample. Perhaps this is a partial explanation of the relatively high variability observed in the results.

The bioassays only measure chlorophyll and its degradation products (total pigments), rather than the entire inoculated community of algae and bacteria. Perhaps it would be better to use total biomass rather than total pigments. A fundamental question is why didn't the Consultant use the readily available Algal Growth Potential (AGP) test for measuring nitrogen bioavailability in these samples? This test is widely used and while not very useful for accurately predicting the stimulatory effects of nutrients on complex natural algal systems, it is already developed and has over 40 years of data to aid with interpretation of results. At a minimum the Consultant and their VIMS team should have compared the results of the two tests on these samples.

This memo offers the statement that "…shallow STAs increase DON because they are ideal for nitrogen fixing cyanophytes…" Based on this Reviewer's experience most wetland treatment systems increase the concentration of RDON to some extent due to releases from organic soils and plant detritus. Certainly nitrogen fixation is also possible but emergent wetlands generally have relatively small plant biomass in the form of blue green algae. On the other hand, emergent wetlands are extraordinarily rich in aerobic and anaerobic bacteria.

Summary and Conclusions

It is this Reviewer's conclusion that some of the findings and recommendations provided in this TM are not supported by adequate evidence:

- The Consultant concludes that based on the literature the removal of DON on a concentration basis is not possible. On the contrary, evidence from dozens of full-scale treatment wetlands shows that various fractions of DON are highly susceptible to removal in emergent wetlands;
- The Consultant concludes that the transformation of BDON to RDON is the only way to reduce the DON that is stimulating red tide blooms. While I personally agree

that red tide blooms are increasing as a result of anthropogenic nitrogen loads, that conclusion is controversial (K.A. Steidenger, personal communication). More importantly for this evaluation, this Reviewer does not agree with this statement since it ignores the array of BON compounds that are mineralized to ammonia in natural treatment systems and in the Caloosahatchee River and subsequently used by the ecosystem.

- The Consultant makes the assumptions that an effective natural treatment system for conversion of BDON to RDON will have to be aerobic and require dominance by floating aquatic vegetation. However, conversion of DON to inorganic nitrogen forms occurs under both aerobic and anaerobic conditions (Kadlec and Wallace 2008). FAV dominated systems do not have an adequate track record of successful management and performance to justify this proposed reliance. FAV systems also typically overlie anaerobic waters due to the very high organic decomposition that they create through high plant productivity. Experience to-date from a variety of natural treatment systems indicates that this low oxygen environment cannot be aerated effectively either by upstream high oxygen pond environments or by artificial reaeration on a practical scale.

This Reviewer concludes that other more generally available, affordable, and consistent surrogates of DON bioavailability/recalcitrance are needed. Examples include: the use of color measurements and the use of analytical procedures that hydrolyze urea and other easily degraded forms of organic nitrogen. The Consultant's suggested reliance on highly theoretical/experimental and costly analytical procedures for measuring the quantity and effects of DON appear to this Reviewer to be impractical.

Findings Memorandum (Deliverable 3.1.2 Final, December 2009)

General Comments

It is interesting to note that the FAV sampling stations have some of the highest TN and DON concentrations observed. This finding seems to contradict the Consultant's conclusion that FAV systems are the most capable of reducing DON concentrations.

This document states that at the C-43 Canal sampling stations nearly all of the nitrogen is in the organic form and that the levels of DIN and NH_3 are an order of magnitude lower than the DON and therefore negligible. This conclusion is a slight exaggeration of the data reported. The maximum DIN concentration in each data set varied between 0.35 and 0.65 mg/L. The mean DIN concentrations varied between 0.186 and 0.294 mg/L. The mean DIN in these samples ranges up to more than 20% of the TN at the C-43 Canal stations. Between the removal of DIN and particulate N in these samples it may be possible to approach the TMDL requirement of 23% reduction in TN, especially during those times when a significant fraction of the DON is susceptible to ammonification.

Water Quality Treatment Area Test Facility Parameter Plan (January 2010)

General Comments

This document is intended to provide the details of the proposed two-year sampling plan for the WQTA test facility. It focuses attention on the DON compound-specific and bioassay procedures and provides little discussion of the rest of the parameters. The plan should provide a summary of the total number of samples to be collected and the associated costs of the plan.

The plan recommends a significant use of resources for monitoring chlorophyll *in situ* in the treatment cells by use of fluorometers. This sampling component may not be of much use since most of these cells are supposed to be covered by some form of floating or emergent vegetation that will shade out planktonic algae.

Reviewer Conclusions

This parameter plan is insufficient to provide a basis for sampling at the proposed WQTA test facility. Recommended changes include the following:

- This plan should describe the justification for all recommended sample parameters as well as for the sampling frequency and locations of sampling stations.
- A detailed list of parameters, numbers of samples collected, and estimated costs associated with labor, equipment, and laboratory analysis should be included.

C-43 Water Quality Treatment Area Draft Conceptual Plan Technical Memorandum (Deliverable 4.2.8 Draft, March 2010)

General Comments

Many of the comments provided above are relevant to this TM also. A brief list of relevant comments follows:

- There is no "rationale" for the design and components of the Test Facility as required by the Consultant's scope of work;
- The focus of the proposed WQTA Test Facility should be on optimizing the use of natural treatment technologies for reduction of bioavailable nitrogen and not on TN or organic nitrogen;
- If DON is at C*, then BDON must convert to RDON without going through an inorganic nitrogen form. There is no known process that converts biologically available organic nitrogen directly to recalcitrant organic nitrogen;
- The proposed test facility should include an evaluation of the effects of soil type and nutrient-loading history on NTS nitrogen removal performance. The proposed mesocosms should also include soils or they will not be representative of any full-scale NTS project. The proposed Test Cells and Demonstration cell should include an evaluation of legacy soil nutrient conditions to be able to accurately evaluate start up and long-term release/sequestration of nitrogen and phosphorus;
- Data from existing full-scale constructed wetlands that are able to achieve low TN and organic N concentrations should be completely evaluated to provide design criteria needed for success of this Test Cell project. Phosphorus removal data from NTS should be thoroughly evaluated and considered in design and operation of this facility;

- Will the operators of the Test Facility need to be concerned about controlling populations of nitrogen fixers? The water fern *Azolla* is likely to invade the proposed FAV and emergent wetland cells;
- The Consultant states that an "open slough-type cell" will provide passive aeration to elevate dissolved oxygen concentrations in downstream cells. This is not likely to work (consider low DO concentrations in Everglades slough plant communities receiving elevated nutrient levels);
- This plan needs a better description of the methods that will be used for data analysis. For example, will tracer tests be conducted to provide an understanding of the actual cell hydraulics? Will k, C*, and theta values be estimated from the data?
- Section 8 should provide a justification for the need for additional geotechnical work or for the use of FSU and VIMS for analytical services;
- This plan should provide preliminary estimates of the operation and monitoring costs for the project and undefined "research into nitrogen removal processes".

Task 2 – Guidance on C-43 WQTA Test Facility Design

Promising Approaches to Removal of Total Nitrogen

This Reviewer has considerable experience with the use of natural treatment systems for nitrogen control, including all major types of engineered wetlands and ponds. This experience indicates that wetland treatment systems are generally highly superior to pond-based systems. The diversity and rates of processes in shallow-water wetland environments are significantly greater than similar processes in pond systems. Nitrogen removal rates are typically several times greater in vegetated treatment systems than in algal dominated ponds.

The Reviewer's experience also indicates that not all vegetated wetland systems are equal in their effectiveness for nitrogen removal. Some wetland systems have faster nitrogen removal kinetics than others. Some wetland plant communities require considerably less management than others and as a direct result are more cost effective for large-scale nitrogen removal project implementation. Some wetland and algal-based nutrient removal technologies are more dependent than others on the use of fossil fuel energies and complex engineering, construction, and operations. These differences all factor into the comparison of present worth cost of different alternatives.

The considerations described above result in a range of cost/benefit ratios for different natural treatment system alternatives. The preferred method for ranking alternatives from most preferred to least preferred is to provide realistic estimates of performance and present worth cost and to compare the ratio of the estimated pounds of nitrogen removed per dollar. Detailed spreadsheets have been prepared previously to evaluate nutrient treatment alternatives throughout the District (e.g., the Water Quality Treatment Technology Ranking method, WSI 2006). The design of the C-43 WQTA Test Facility and the full-scale project design should be based on such an analysis.

In general, this Reviewer's experience indicates the following ranking (from most cost effective to least) of natural treatment system alternatives in terms of the amount of nitrogen that can be consistently removed over an extended project life (e.g., 50 years):

- Emergent macrophyte dominated constructed wetland cells;
- Ponds dominated by a mix of floating and submerged aquatic vegetation without harvesting;
- Ponds dominated by algae;
- Harvested FAV ponds;
- Algal turf scrubber systems; and
- Subsurface flow wetlands consisting of vertical and horizontal flow through gravel substrates.

Of these potential natural treatment technologies this Reviewer concludes that only the first two are promising enough to warrant study/demonstration at the C-43 WQTA Test Facility. This conclusion is essentially in agreement with the Consultant's recommendations.

In addition to these natural treatment technologies, this Reviewer is also aware of more highly engineered technologies for nitrogen removal that are more dependent upon external inputs of energy and chemicals. Examples include extended aeration activated sludge processes, biological nutrient removal, coagulation technologies, and reverse osmosis. This Reviewer agrees with the District's Consultant that none of these "conventional" technologies are viable for the C-43 project due to cost considerations.

This Reviewer is also peripherally aware of the SAT and RBF technologies proposed by the District's Consultant for the C-43 Project. It is this Reviewer's understanding that these technologies are used primarily for groundwater recharge. Nitrogen removal is secondary and is usually based on meeting the nitrate drinking water criterion. It is this Reviewer's conclusion that the design basis, hydraulics, water quality performance, ancillary benefits, and costs of these technologies are not currently developed to the point of consideration needed for implementation of the C-43 Project.

Recommended Test Facility Changes to Evaluate Most Promising Approaches

The following recommendations for the C-43 WQTA Test Facility are offered:

- The focus of the Test Facility should be the development of the most optimal design criteria for full-scale implementation of a natural treatment system for reduction of TN on the C-43 Canal;
- The only natural treatment technologies that are currently developed to the point of serious consideration at the Test Facility are constructed wetlands dominated by emergent, submerged, and/or floating plants;
- Testing/demonstration at the proposed C-43 Test Facility is most needed for developing a more precise understanding of the benefits of various plant

combinations, effects of water depth, hydraulic loading rates, and antecedent soil conditions on nitrogen removal;

- The Test Facility should be designed in such a way that it can be flexible in controlling the above-listed variables of water depth, loading rates, and substrates and ultimately be integrated into the full-scale project implementation at this site;
- Mesocosms, if used at all, should only be used for looking at processes related to substrate and plant community effects on release and uptake of nitrogen but not for assessing full-scale design criteria such as hydraulic loading rates, vegetation establishment techniques, or expected system performance;
- Test cells should be large enough (about 10 to 40 acres each) to eliminate edge effects and to provide a realistic plant establishment experience, but should not be used for replicated experiments. They should be used for demonstration of the effects of differing water depths, hydraulic loading rates, plant communities, and cell-in-series effects on sustainable nitrogen and phosphorus removal. The number of Test Cells should be based on the number of distinctly different natural treatment technologies supported by an updated summary of feasible alternatives.
- A larger Demonstration Cell/Treatment Train should not be put into operation until preliminary design criteria optimization is complete from the proposed Test Cells. The Demonstration Cell(s) or Treatment Train should be constructed in parallel with the monitoring/optimization work in the Test Cells. The Demonstration Cell(s) will be comparable to the ENR in STA-1W and will provide lessons in full-scale project implementation.
- Monitoring should be limited to well understood parameters and should not be dependent upon experimental techniques that are not fully developed or costly;
- A complete Monitoring and Sampling Plan should be prepared that fully describes the work to be accomplished, the schedule for that work, and the estimated cost for implementation.

Task 3 - Recommendations for Parallel Work Efforts to Improve the Information Derived from the Test Facility

The following recommendations are offered for parallel work efforts while the Test Facility Design and Monitoring Plan are completed:

- Review additional and updated relevant data sets for nitrogen dynamics in Florida wetland and reservoir systems (e.g., Iron Bridge, Lakeland, C-43 and C-44 Reservoir Test Cells, Lake Apopka, Lake Griffin Flow Way, Taylor Creek STA, Ten Mile Creek Reservoir and STA, Everglades STAs, PSTA systems, ENR Test Cells, etc.). Focus analysis on systems with low organic nitrogen in outflows and on the range of vegetation, water depth, and antecedent substrate effects. Calibrate P-k-C* model for each system and for each substrate and vegetation type and/or develop a DMSTA-type model for predicting nitrogen transformations and removal under dynamic operating conditions;

- Continue work to develop reliable and cost effective surrogates for fractionation of DON into biologically available and unavailable forms. Candidate tests include the AGP test, dissolved color, and measurement of hydrolysable DON;
- Based on existing treatment wetland calibration data prepare a preliminary conceptual performance model and design for a full-scale WQTA facility to meet the TMDL for the Caloosahatchee Estuary. Utilize the model to optimize the costs and benefits of load reduction in the watershed vs. end of pipe treatment with constructed wetlands;
- Coordinate the functionality of the proposed C-43 West Storage Reservoir and the C-43 WQTA and consider a trade-off in area of the reservoir and the ultimate full-scale nitrogen treatment wetland. This concept of coordinating the projects is worthy since relatively small gains in N removal that could be achieved in the WQTA could be undone if the Storage Reservoir exports N. The test cell data set was too short to state that N removal is consistently positive in deep reservoirs. During the one-year study period, there was no natural development of a floating plant cover, algal solids increased, but associated organic N and TN decreased slightly (about 10%) (WSI 2007a).

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