Evaluation of Passive and Low-Energy Technologies to Improve Water Quality of Residential Canals in the Florida Keys

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List of Acronyms and Abbreviations

Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
BMP	Best Management Practices
BOD	biochemical oxygen demand
Chla	chlorophyll a
CMMP	Canal Management Master Plan
CMT	Callaway Marine Technologies, Inc.
CO_2	carbon dioxide
CRDP	Canal Restoration Demonstration Program
CWA	Clean Water Act
DO	dissolved oxygen
DOC	dissolved organic carbon
EPA	US Environmental Protection Agency
FDEP	Florida Department of Environmental Protection
FI	floating islands
FKNMS	Florida Keys National Marine Sanctuary
FKRAD	Florida Keys Reasonable Assurance Documents
GUTS	Giga Unit Transplant System
H_2S	hydrogen sulfide
HDP	high-density polyethylene
mg/L	milligrams per liter
N	nitrogen
N_2	nitrogen gas
NEPA	National Environmental Policy Act
NPDES	National Pollution Discharge Elimination System
O&M	operation and maintenance
O2	oxygen
PON	particulate organic nitrogen
RA	Reasonable Assurance
T	temperature
TMDL	total maximum daily loads
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
WQPP	Water Quality Protection Program

EXECUTIVE SUMMARY

The Water Quality Protection Program (WQPP) Action Plan of the Florida Keys National Marine Sanctuary, identified impaired water quality in residential canals as a priority for corrective action [Florida Department of Environmental Protection (FDEP, 2013)]. Monroe County has undertaken a Canal Restoration Demonstration Program to initiate water quality improvements in the residential canals. One of the needs for this project involves evaluating alternative methods, not included on the Monroe County Canal Management Master Plan (CMMP), that will restore and maintain water quality conditions in canal systems to levels that are consistent with the State water quality criteria for Class III waters.

To provide additional options for treatment to the eutrophic and hypoxic waters in Florida Keys residential canals, Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) evaluated potentially cost-effective passive and low-energy technologies. Technologies evaluated include seagrass planting, macro-algae farming, oyster aquaculture, floating mangrove islands and bioremediation. This technologies were evaluated based on

- Development status (research, pilot study, large scale implementation)
- Effectiveness
- Ease of Implementation and Permitting
- Footprint and Homeowner disruption
- Cost

A tabulated summary of each technology scoring is found on the Table E1. Overall, aquatic plants appeared to be the most amenable technology to improve dissolved oxygen; with aquatic animals only capable of indirectly influencing dissolved oxygen through nutrient removal, and micro-organisms having a potential to negatively impact dissolved oxygen. Our desktop study and technology evaluation showed best alternatives for Florida Keys residential canals are,

- Macro-algae farming: primarily due to macro-algae tolerance to highly eutrophic waters, the ability to introduce them at different locations in the water column to take advantage of limited light on highly turbid canals, their quick cultivation time (45-60days), and their high biomass demand which can offset the maintenance cost.
- Floating mangrove islands: primarily due to the well documented ability of mangrove plants to filter water and the high success expectation for this technology.

TABULAR ABSTRACT

Table E1. Scoring Summary of Evaluated Technologies

Passive In-Situ Technologies	Development Status (0-5)	Effectiveness (0-5)	Ease of Implementation (0-5)	Footprint (0-5)	Ease of Permitting (0-5)	Homeowner Disruption (-5-5)	Time (0-5)	Cost (-10-10)	Total Score (-15-50)
Seagrass Planting	3	2	3	3	3	5	2	-2	19
Macroalgae Farming	3	3	4	4	2	5	2	10	33
Floating Mangrove Islands	5	4	4	4	4	5	3	6	35
Oyster Aquaculture	5	3	2	4	4	5	2	5	30
Bioremediation	2	2	3	4	4	4	2	-5	14

1.0 Introduction

1.1 Florida Keys Water Quality Protection Program

The Florida Keys National Marine Sanctuary (FKNMS) Water Quality Protection Program (WQPP) (WQPP) started in 1992. The FKNMS WQPP is an important component of the overall South Florida Ecosystem Restoration Program, and was created to identify and implement priority corrective actions to protect, maintain and restore water quality in the FKNMS. This program also recommends compliance schedules to address point and nonpoint pollution, to restore and maintain the chemical, physical and biological integrity of the FKNMS. Recently, the WQPP identified impaired water quality in residential canals as a priority for corrective action (FDEP, 2013).

Most of the residential canals in the Keys do not meet the State's water quality standards and are a source of nutrients and other pollutants to near shore waters. Water quality in residential canals have degraded over time due to previous inadequate treatment of wastewater and storm water, poor tidal circulation, and accumulation of organic material. As a result, many residential canals suffer from low Dissolved Oxygen (DO), eutrophication, increased production of hydrogen sulfide (H_2S), increased inflow of fecal bacteria, and sedimentation.

Monroe County has undertaken a Canal Restoration Demonstration Program (CRDP) to initiate water quality improvements in the residential canals. Among others, restoration initiatives include (1) implementation of new State laws (Florida State Law 99-395, effective June 1999) which establish effluent limitations and standards applicable to sewage treatment, reuse, and disposal systems on Monroe County, (2) implementation of stricter storm water management, and (3) improved water quality monitoring programs. These improvements are an essential first step, but will not fix all the water quality problems existing at the canals. Accordingly, through the CRDP efforts Monroe County and its consultant, Amec Foster Wheeler, have developed a broad and detailed understanding of what additional studies and data collection is needed to achieve its water quality goals.

Given the prevalence of water degradation in Monroe County residential canals, and the prohibitive cost to improve water quality, especially in large canals, through available engineering approaches, an evaluation of passive and low energy alternative technologies was determined essential. Alternative technologies should be ecologically sound, economically feasible and easy to implement and maintain. Furthermore, proposed cost-effective solutions should,

- Improve canal management practices throughout the Keys,
- Satisfy the existing and future needs of the community,
- Reflect key stakeholder concerns, and
- Satisfy environmental and regulatory criteria and guideline.

1.2 Overview of Traditionally Preferred BMP's for Water Quality Improvement

Best Management Practices (BMPs) proposed for water quality improvement at Monroe County Residential Canals, based on canals physical and water quality attributes, include installation of seaweed gates and air curtains to minimize additional organic accumulation in the canals, construction of culverts to facilitate flushing, removal of accumulated organics from the bottom of the canals, backfilling to remove deep stagnant zones, and water pumping. The preferred technology to flush stagnant canal systems is a flushing culvert. However, many canals do not have a viable location for the installation of a culvert; either from the presence of residential structures, or the lack of a possible receiving water body. Therefore, water pumping is the preferred technology for stagnant canal systems that do not have a potential location for the installation of a culvert.

Water pumping improves circulation and mixing on water, thus reducing nutrient accumulation and poor water quality. Water pumping consists in pump installation to promote water circulation within a canal. Water can be pumped from a 'dead end' canal to another adjacent canal or mangrove creek to increase turnover of water in a canal system. Pump installation must be designed to prevent adverse secondary effects such as resuspension of sediments, bottom scouring, entrainment or impingement of marine life, or impact to adjacent waters. Tidal circulation studies and hydraulic modeling by a qualified coastal engineer would be needed to provide an effective design. An effective circulation and flushing design should also promote circulation within the system.

1.3 Potential Opportunity to Reduce Treatment Costs

Cost estimates that have been developed for the implementation of a pumping system in a large canal system demonstrate that the use of pumping is costly, both for installation and maintenance. It is projected that the cost for buying, installing and operating a circulation pump to address the water quality concerns in one of Monroe County residential canals would be approximately $480,000. This fee does not include the cost of electricity or maintenance of the equipment, which is estimated to be approximately $45,000 per year.

The circulation pumping technology could be augmented to improve efficiency and implementability. For example, the circulation system could be a closed loop system that incorporates a treatment gallery (a shallow structure augmented with macro-algae) or a fluidized bed media reactor; both of which would reduce the nutrient load and increase dissolved oxygen in the canal. However, an evaluation of potential improvements to circulation pumping is not a part of the current, passive technology evaluation. Additionally, alternative lower intensive technologies that may be capable of achieving the same results as more robust technologies could also be evaluated. Examples include, reducing the footprint of weed gates by implementing swing gates, using check dams or sheet piles to reduce momentum loss in deep canals rather than uniform backfilling, and capping organic material rather than dredging.

However, the subsequent evaluation focused on passive and low energy technologies that are capable of improving dissolved oxygen in stagnant canals. The greatest cost benefit can be achieved from alternative passive technologies which can be implemented in a larger scale and have minimal to no long term maintenance. Therefore, the evaluation focused on technologies that once established would become self-sustaining, such as aquaculture and bioremediation. Aquaculture uses organisms, such as macro algae and filter feeders to improve water quality, and bioremediation uses microbes and fungi to promote decomposition and digestion to reduce nutrient loads.

1.4 Project Goals

The main goal of this study was to identify passive and low energy remediation technologies, not included on the Monroe County Canal Management Master Plan (CMMP), that will restore and maintain water quality conditions in canal systems to levels that are consistent with the State water quality criteria for Class III waters. To achieve this Amec Foster Wheeler,

- Performed a desktop study to identify passive and low energy technologies, which have been implemented or evaluated to improve water quality.
- Developed a ranking matrix for all identified viable technologies.
- Developed conceptual designs and engineering cost estimates for the two highest ranked technologies.

2.0 Sources of Water Quality Degradation

There is limited canal specific water quality data available in the Keys. Also many sampled canals are only characterized by one event. The FKNMS Water Quality Protection Program is the most comprehensive Keys-wide monitoring program, with 154 stations monitored quarterly for total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), chlorophyll a (Chla), dissolved oxygen (DO) and temperature (T). Overall, residential canals show nutrient enrichment, fecal coliform contamination (>104 CFU Enterococci) and low dissolved oxygen (<4mg/L) due to former on-site sewage disposal practices and stormwater runoff. In addition, large canals with poor flushing often show salinity concentrations higher than nearshore waters, resulting in density stratification, with a deep layer of high-salinity water essentially trapped beneath an upper, lower-salinity layer. The resulting stagnation of the lower portion of the water column inhibits oxygen circulation and releases nutrients from canal-bottom sediments, further deteriorating the water quality.

Degradation of water quality is also be exacerbated by organic material that accumulates in the bottom of Monroe County residential canals. The accumulation of organic material in canal bottoms is primarily the result of weed wrack migrating from Florida Bay and Everglades, into the canal, decomposing, and sinking. Organic matter produced by terrestrial and aquatic plants settles to the sediment and decomposes by aerobic or anaerobic processes, during which different carbon, nitrogen and phosphorus compounds are produced. Further, decomposing organic matter affects changes in oxygen concentrations and redox potential and can generate anoxic conditions at the sediment-water interface.

Although many of these water quality problems are linked to former wastewater and stormwater discharges, and organic matter and sediment loading, the degree of water quality degradation in Monroe Canals is also impacted the physical structure, depth, and orientation of these canals.

In 2011 the FDEP funded the development of Reasonable Assurance (RA) plans for the surface waters of the Keys, as an alternative to the development of Total Maximum Daily Loads (TMDLs). The RA plans suggested that implementation of appropriate wastewater treatment in Monroe County would achieve the narrative nutrient criterion, but that the presence of organic material and poor flushing in the residential canals would not allow for the dissolved oxygen criteria to be achieved.

2.1 Priorities for Water Quality Improvement

Based upon reviews of the Monroe County Comprehensive Plan, Monroe County Sanitary Wastewater Master Plan, Monroe County Stormwater Management Master Plan, Florida Keys National Marine Sanctuary Management Plans, Florida Keys Reasonable Assurance Documents (FKRADs), and other sources, the following water quality management issues were identified as priorities:

- Nutrient loading, nutrient enrichment and eutrophication,
- Dissolved oxygen/hypoxia,
- Organic matter (e.g., weed wrack),
- Human pathogen levels, and
- Compliance with regulatory requirements (e.g., WQ criteria; WBID impairments; TMDL/ Reasonable Assurance process; NNC when adopted)

3.0 Evaluation of Alternative Technologies

This desktop study focused both on published research and industry technology. Overall, published research was typically limited to pilot studies intended to evaluate the efficiency of novel approaches for in-situ water quality remediation, with few case studies to demonstrate the feasibility of implementation. A limited number of passive alternative technologies were identified from the industrial sector. Since, there is little published information to demonstrate the feasibility of implementation for the technologies presented herein, implementability was determined based on professional judgment and prior experience with remediation technologies for water quality improvement.

3.1 Characteristics of Targeted Canal

Proposed alternative technologies are intended to address water quality remediation in large residential canals with poor flushing. In this report, a large poor flushing canal will be primarily characterized by its length and shape as described in Table 1. Additional characteristics considered when evaluating poor flushing canals are also described in Table 3-1.

Table 3-1. Description of targeted canal

Parameter	Description	Implication
Primary Characteristics		
Size	A ≥ 5 acres L ≥ 2,500 ft D= 15 ft	Large size canals negatively influence natural flushing, increasing potential for water quality degradation.
Shape	Finger-shaped	Larger ratio of length to area results in a larger shoreline area, greater nutrient loading from the shoreline, and poorer canal circulation.
Additional Characteristics		
Convolutions	> 2 (1 = 1-90° turn)	The greater the number of convolutions in the canals, the poorer the water quality performance of the waterway.
Mouths & outfalls	1 opening	The more openings in a canal, the greater the circulation within the canal system is likely to be.
Wind & wave energy	Low	Canal mouths opening to low energy shorelines receive limited tidal flushing and wind driven mixing.

3.2 Ranking Methodology

Each of the technologies were evaluated based on its development status, effectiveness, implementability, permitting, homeowner disruption, time, and cost. The purpose of the evaluation criteria is to rank technologies by its potential for success and implementation cost. All criteria were scored from 0 to 5 with the exception of homeowner disruption and cost. Homeowner disruption was scored from -5 to 5 to devalue technologies that could potentially result in homeowner complaints. Additionally, cost was effectively assigned a weighting factor of 2 by being scored from -10 to 10, with the negative range being used to devalue technologies that would not provide a cost benefit relative to traditional circulation pump technology.

A circulation pump is a standard method used to increase hydrologic turnover in dead-end canals, and it was selected as the benchmark for the evaluation of the alternative technologies. Median values were chosen for most criteria, with the exception of development status and effectiveness, since water circulation is a widely implemented technology that eventually removes the source of water quality degradation. Detail description on benchmark scoring is described on Table 3-2.

Table 3-2. Scoring of benchmark technology

Technology	Development Status	Standalone vs Treatment Train	Effectiveness	Ease of Implementation	Footprint	Ease of Permitting	Homeowner Disruption	Time	Cost	Total Score
	(0-5)	(0-5)	(0-5)	(0-5)	(0-5)	(0-5)	(-5-5)	(0-5)	(-10-10)	(-15-50)
	★	☆	★	☆	☆	☆	☆	☆	☆	
Circulation pump	5	3	5	3	3	3	3	3	0	28

★ above average, ☆average

The ranking evaluation for the alternative technologies was completed by comparison to the following characteristics for traditional water pumping assuming pumping rate to achieve a 4 day residence time is 4,000 gpm with a 1 foot tidal range:

- Development Status – Large scale implementation.
- Effectiveness – Reduce nutrient concentration in water by ≥ 90%.
- Ease of Implementation – Requires <1 acre for equipment (only during construction phase).
- Ease of Permitting – Previously permitted.
- Homeowner Disruption – Closed canal for the duration of pump installation.
- Time – Technology has to be implemented permanently, but improvements in the water quality should be expected within a month.
- Cost – $480,000 for installation and $45,000/year for operation and maintenance.

4.0 Alternative Technologies

Water treatment technologies can be classified as physical, chemical, or biological treatment techniques. They can also be classified as *in-situ* or ex-situ technologies. *In-situ* remediation techniques involve treatment in place, while *ex-situ* involves the removal of contaminants at an external location, such as a treatment structure. *In-situ* bioremediation has many advantages when compared to other techniques, such as low costs, less adverse impacts on the environment, and no secondary production of pollutants. This section provides a general review of the latest, low cost and passive, surface water remediation technologies, not included on the Monroe County Canal Management Master Plan (CMMP), which can be applied *in-situ* to improve water quality at Monroe County residential canals.

Ecological engineering approaches for the removal of pollutants at low cost is an emerging field dedicated to the design and construction of sustainable ecosystems that provide a balance of natural and human values (Mitsch et al., 2002).

4.1 Aquatic Plants

Plants with strong tolerance for pollutants can improve water quality through adsorption, absorption, accumulation, and degradation of contaminants.

4.1.1 Seagrass Planting

Background

Seagrass planting techniques have shown to be effective at restoring ecosystem function (Fonseca et al. 1996a; Sheridan 1999; Short et al. 2000). Seagrasses play a valuable role in nutrient cycling, through assimilation of nitrogen and phosphorus from the sediments via their roots and rhizomes, and from the water column via their roots and leaves. They also trap organic particles from the overlying water and enrich the sediments by exuding dissolved organic carbon (DOC) through their roots. Seagrass roots also release photosynthesis-produced O^2 into sediments, which results in less-reducing conditions than in unvegetated sediments. Dissolve oxygen production and seagrass-sediment microbial interaction, could ameliorate the accumulation of sulfides, which could lead to dieback events in seagrass meadows. On the other hand, the baffling effect of seagrasses beds combined with a low water flow of poor mixing areas could lead to increased hypoxia, nutrient enrichment of sediments, and increased nutrient release to surrounding waters.

Figure 4-1. Seagrass Meadow

Seagrasses also improve the stability of bottom sediments, and serve as a refuge and food source for aquatic fauna (TBEP, 2006). By providing food and shelter to a range of fish, in 2010, seagrass beds supported an estimated $13.9 million in stone crab, spiny lobster, shrimp, yellowtail snapper, gray snapper, and blue crab harvests for Monroe County.

Numerous technologies have been developed and implemented, both small and large scale, in attempts to find the most successful and cost-effective plating technique. Tested techniques include seed sowing (Orth et al. 1994; Harwell & Orth 1999), seedling/single shoot planting (Thorhaug 1974;

Fonseca et al. 1985; Balestri et al. 1998), shoot bundles (Derrenbacker & Lewis 1982; Fonseca et al. 1982), peat pots and plugs (Robilliard & Porter 1976; Fonseca et al. 1994), and wire frames (Short et al. 1999, 2002). Although planting seagrass is not technically complex, the ability to plant large areas remains constrained by the costly, time-consuming nature of manual methods mentioned above, and the cost of post-planting monitoring and oversight (Fonseca et al. 1998), which comprises most of this technology's cost.

It costs about $25,000-$50,000 to restore an acre of seagrass if you count only the cost of collecting, preparing, and planting the seagrass plugs (price levels reflect 2001 dollars). However, the total cost of a seagrass restoration project can be more than five times that amount, or about $200,000-$250,000 per acre over the time of the project. More recent studies in the USA have agreed upon an "all-inclusive" price, including monitoring, between $230K and $375K/acre (Fonseca, 2006). By far, the greatest single cost of restoring seagrass is the cost of monitoring the project after its completion. Primarily due to the logistics of underwater monitoring. Additional activities that account for significant project costs in seagrass planting include:

- Environmental Site Assessment, and identification of potential limiting factors,
- Site selection and mapping, including bathymetric surveying,
- Development of site-specific methods for planting,
- National Environmental Policy Act (NEPA) compliance permit, and
- Labor costs.

The success of this technology is limited by the success of seagrass establishment and growth. Water clarity and light penetration play a major role in determining the amount of sunlight that is available to support seagrass growth. Sediment quality (grain size distribution and organic content), also seem to be particularly important factors affecting seagrass distribution and growth, due to their effects on dissolved oxygen (DO) levels and concentrations of sulfide, which can be toxic to seagrasses at concentrations as low as >1 millimolar (Carlson et al., 2002).

Methodology

In recent years, seagrass restoration has changed from a series of labor-intensive, hand-planting techniques to mechanical methods. Furthermore, seagrass planting restoration has been implemented at the Florida Keys, to mitigate degradation of seagrass communities due to sediment dredging near Long Boat Key canal. From April 14-May 29, 2003, Callaway Marine Technologies, Inc., (CMT), conducted replanting activities. Seagrasses were transplanted using a recently developed mechanized method that extracts and plants blocks of seagrass (Giga Unit Transplant System [GUTS]; U.S. Patent No. 6,684,536). Previous attempts to transplant seagrass using the GUTS have been limited to mitigation and have not followed rigorous scientific method. In this study, however, Baron et al. examined the survival and expansion of seagrass (Halodule wrightii and Thalassia testudinum) units planted using the GUTS.

Mechanical planting of seagrasses offers a high successful rate of seagrass survival and a lower cost per acre than by hand-planting procedures. However, these mechanical devices typically have limited ranges of application with unknown cost effectiveness (Uhrin et al., in press). Technology success should be accomplished by selecting suitable sites, developing methodology appropriate to site conditions, improving seagrass spreading and coverage rates, accounting for self-facilitative properties, minimizing donor bed damage, overcoming high labor and time costs and preventing bioturbation.

Conclusion

There seems to be sufficient information to show seagrass planting is an ecologically defensible technology in regard to donor meadow recovery, return of function and self-facilitative properties (Paling et al 2009). From an economic viewpoint, however, it is clearly far more cost effective to

preserve a seagrass habitat from damage than to restore an area after its degradation. This is especially true for areas > 50 acres large, because it will simply be too expensive to establish a healthy seagrass community where declining water quality, sedimentation and limited light penetration, is a major cause of declining natural communities.

Given the current water quality in many residential canals, it is expected that establishment of seagrasses would be an extensive effort involving a number of components, and it may not be possible for an established community of seagrasses to thrive in a canal without on-going support; such as an aeration system.

Technology Summary

- Development Status (**3**) – The technology is widely used, and as indicated above has been implemented in Monroe County. However, the ability to establish seagrasses in degraded water bodies has not been widely evaluated.
- Effectiveness (**2**) – Nutrient reductions and DO improvement by seagrass planting alone are expected to be minimum in large canals with low mixing. Furthermore, the prevalent high hydrogen sulfide production in these canal sediments would be toxic for seagrasses, making seagrass growth and community establishment in these areas difficult without sufficient supporting technologies such as aeration and filtration.
- Ease of Implementation (**3**) – Although the initial implementation effort is an improvement from circulation pumping, the effort required to monitor and maintain seagrass beds makes implementation of this technology more difficult. In addition, effort will not translate to success or effectiveness, since this will depend greatly on the health of seagrass community.
- Footprint (**3**) – Seagrasses improve ecosystem services by providing refuge and food to manatees, sea turtles, and important fisheries species. Seagrass meadows have been estimated to provide ecosystem services worth about $7,700 per acre/yr (in 1994 $U.S.) (Costanza et al., 1997).
- Permitting (**3**) – Seagrass restoration projects have been permitted before for Monroe County. Support information that explains the benefits of seagrass planting on large residential canals should be provided.
- Homeowner Disruption (**5**) – Seagrass planting will provide a great aesthetic benefit, and wildlife habitat that will be appreciated by homeowners.
- Time (**2**) – Seagrass can be highly efficient at nutrient cycling and uptake.
- Cost (**-2**) – Overall cost of implementing and maintenance dependent on acre treated. This technology is more expensive and requires more effort and maintenance than a circulation pumping.
- Total: **19**

4.1.2 Macroalgae Farming

Background

Macroalgae can grow, like oysters, within aquaculture systems designed for growth and harvest. Similar to oysters, macroalgae take up nutrients (Nitrogen, Phosphorus and Carbon) directly within the aquatic system, temporarily improving the water quality. Macroalgae produce oxygen via photosynthesis, yet they also respire, consuming oxygen. When algal mats are dense in light limited layers, respiration will consume more oxygen than photosynthesis will produces, creating a net BOD. Furthermore, BOD can be further increased when decaying macroalgae are colonized by bacteria, resulting in re-mineralization of nutrients to the water column. A permanent removal of nutrients can also be achieved through harvest. In addition to taking up nutrients (approximate ratio, N: 3.5%, P: 0.1% and C: 30%), the macroalgae is a source of food for many ornamental reef fish.

A benefit of this technology, compared to seagrass planting, is that macroalgae growth is less limited by the water quality of the system, making them able to thrive in eutrophicated waters. They take up CO_2 and nutrients from their environment, improving water quality as they grow by drawing down levels of the dissolved acid along with nutrients. Macroalgae also give off oxygen, potentially reducing the extent of dead zones and create habitat for marine species.

Methodology

Sporophytes, or seedlings, of macroalgae can be cultured and seeded onto twine (manually) for deployment and growth at residential canals. Macroalgae can be growth/farmed through different methods including, floating raft method, fixed to bottom, and single floating line method. In warm regions with high nutrient content, macroalgae can be harvested every 45 to 60 days or higher depending on the specie. Macroalage saprophytes are replaced upon farming of adult macroalage.

Design Improvements

- *Caulerpa prolifera* could be cultured on nets tied to the sides of the canal, and anchored to the canal bottom to avoid interrupting the passage of aquatic vehicles, and prevent wildlife entrapment.

Conclusion

This new practice is can be implemented as a standalone technology or as part of a treatment train. The potential environmental benefits of a macroalgae aquaculture system are to:

- Mitigate a portion of excess nutrients in eutrophic waterways,
- Assist oxygen levels for marine life, and
- Increase biodiversity and thus resiliency of the aquatic system

Figure 4-2. Macroalgae *Caulerpa prolifera*

Macroalgae can provide good ecosystem services by extracting organic and inorganic nutrients from seawater. Virginia's Marine Resource Commission, Chief of Habitat Management Division, Tony Watkinson discussed harvested macroalgae as a superior nutrient removal method to harvested clams (Myers, 2015). Furthermore, nutrient reduction in the water column will reduce the incidence of unwanted algal blooms, reducing organic matter accumulation on sediment bottoms, which will in turn increase the DO of the system. Challenges of this technology include:

- Marine space required if raft or single line methods are implemented, may interrupt navigation.
- Nutrient absorption rates of the biomass may require more space to significantly impact nutrient levels at levels than society/the government find desirable.

The ability of seaweeds to be farmed without freshwater, arable land or nutrient inputs uniquely positions them as an ecologically and economically efficient source of biomass. A demonstration project of macroalgae farming could be one project tested under research provisions to establish new and effective Best Management Practices. Maintenance of macroalgae population and farming is expected to be subsidized by selling the retrieved macroalgae biomass. Therefore, it is expected that the maintenance of the macroalgae would be completed by a local macroalgae retailer at no cost to the County.

Technology Summary

- Development Status (**3**) – The technology has been implemented in pilot scale studies to evaluate macroalgae potential to clean nutrient rich waters.
- Effectiveness (**3**) – Macroalgae farming will not "fix" eutrophication in highly polluted systems, but it will have an evident improvement in the nutrient concentration and ecosystem function. Biomass harvest must be timed to take advantage of oxygen production and prevent organic matter decomposition, which could lead to hypoxia.
- Ease of Implementation (**4**) – The initial implementation effort is an improvement from circulation pumping, and the effort required to monitor and maintain macroalgae should not exceed the cost of O&M for a circulation pumping system. The system is expected to be self-sustaining within two to three years.
- Footprint (**4**) – Macroalage improve ecosystem services by providing refuge and food to aquatic fauna. No energy and is required for continuous monitoring and operation.
- Permitting (**2**) – Not permitted before for water quality improvement. Supporting information indicates that benefits from macroalage farming should be expected.
- Homeowner Disruption (**5**) – macroalgae farming will provide wildlife habitat that will be appreciated by homeowners.
- Time (**2**) – Macroalgae can be highly efficient at nutrient cycling. With continuous farming, water quality improvements should be evident within the first year.
- Cost (**10**) – Implementation is less expensive than circulation pumping (similar to seagrass planting). Maintenance of macroalgae installed on the side of canal walls is expected to require less effort than seagrass and be less expensive than circulation pumping.
- Total: **33**

4.1.3 Floating Mangrove Island

Background

The use of floating islands (FI) to improve water quality and ecosystem function, has increased worldwide in recent years, especially in developing countries. Hydrophytes have been widely applied in FI for the remediation of surface water and wastewater due to their efficacy in assimilating nutrients and creating favorable conditions for the microbial decomposition of organic matter (Wang et al., 2009). Restoration using floating emergent and submersed hydrophytes is fundamental to regulating biological structure of aquatic systems, as aquatic plants limit algal growth by competing for nutrients and sunlight and can also increase herbivorous fish biomass by providing food and refuge (Li et al., 2010). In addition, it is conceivable that plant assimilation of metal elements may be higher in a floating island system compared to a sediment-rooted plants, as the roots hanging beneath the floating mat are in direct contact with polluted water to be treated.

Plant biomass must be removed periodically from the water bodies to maintain purification efficiency. If not harvested, the nutrients that have been incorporated into the plant tissue may be returned to the water during the decomposition processes (Brix, 1997; Lu et al., 2010). There are many potential economic opportunities for the reuse of hygrophytes (Licht and Isebrands, 2005). Removed plants could be dried and used as a food source for domestic animals, partially offsetting the cost of harvesting. The plants could also be harvested and subsequently processed into biogas, bio-fertilizer and other bio-materials. The potential economic return may justify the practical application of the technology (Li et al., 2007, 2010).

Floating islands, regarded as a low-cost, solar-energy-based and eco-friendly technology for in situ purification of surface water, have been used in Europe (Hoeger, 1988; Garbett, 2005), Japan (Miyazaki et al., 2000; Nakai et al., 2008), the United States (Todd et al., 2003; Stewart et al., 2008), Australia (Wen and Recknagel, 2002) and China (Nduvamana et al., 2007; Gao and Sun, 2008; Wu et al., 2008) as an important ecological remediation to control water eutrophication. However, this technology can also have certain limitations. First, it is difficult to control the hydraulic retention time and the pollutants loading rate when this treatment system is applied at real field sites. In addition, these systems are especially vulnerable to natural disasters such as hurricanes or typhoons.

Design and cost example:

A 10 feet by 16 feet floating island with a positive buoyancy of approximately 168 pounds can be constructed of high-density polyethylene plastic shipping pallets. The pallets can be bolted together with 3/8-inch stock stainless steel hardware and have a 3.5-inch space between the top and the bottom surface. The attached pallets will form the planting surface of the floating island.

After planting the floating islands with emergent vegetation, such as mangroves, they should be covered with a layer of heavy-duty plastic fence. This fence layer should be fastened tight to the pallets holding the newly planted vegetation in the pallets, until the vegetation can develop a root system and become self-anchoring (**Figure 4-3**). The majority of the cost, for floating island project is the construction of the floating platforms.

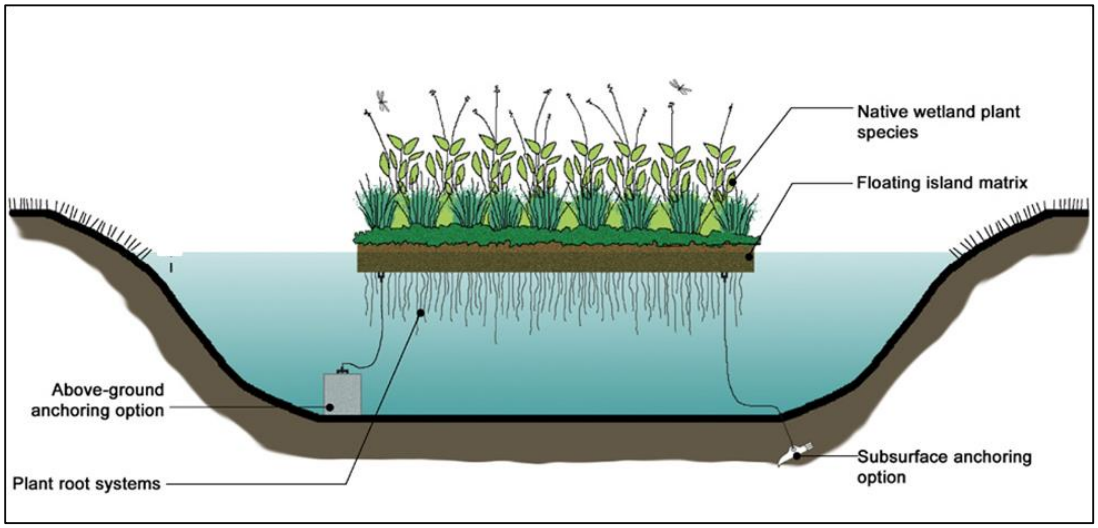

Figure 4-3. Floating Island

Estimated cost for a floating island:

- 8 high-density polyethylene (HDP) pallets: $1,600.
- Hardware (nylon locking nuts, bolts and washers): $200.
- Plastic fencing and other materials and supplies: $1,500.
- Solar powered aeration system: $2,500.
- Labor: $2,000.
- Total: $7,800.

The total cost to build the floating islands was approximately $88,700 or about $23/ft2 ($250/m^2). However, pricing could vary according to the project needs, thickness of the island, materials used, and additional services offered by the installer. For instance, if the floating platform (for the example

above) was replaced with a floatation pontoon system, thereby eliminating the superstructure and walkways, and pallets were made from recycled HDP, it is possible that the cost of a similar size structure could be built for approximately $60,000 or about $16/ft2 ($170/m^2).

At the lower end, Aqua BioFilter™ reports that floating wetland installations have ranged from $30 to $120 per m2 (about $3 to $11 per ft2). At the higher end, Canadian Pond Products offers a 15-sq ft island that costs about $700 (about $46 per ft2). For context, assuming that 10 percent of the surface of a 20-acre canal would be installed with floating islands, approximately 2 acres (or 87,120 sq ft) of floating islands would be needed. This coverage equates to an installed cost of about $260,000 to $4 million. O&M costs are not reported but would be about $13,000 to $200,000 per year at an assumed five percent of the installation cost.

Design Improvements:

- Microbial fuel cells could also be integrated to the Floating Island design. This biotechnology can be used to improve the water treatment.
- A solar system could be installed to generate electricity for the monitoring equipment, and thus reducing the O&M costs.
- The floating platform could be equipped with a severe weather anchoring points and marking buoys. The anchoring points would be used to attach weights, such as 5 gallon buckets of concrete, to make the platform sink, and the marking buoys would notify boaters of the navigational hazard and allow for retrieval of the platform following the severe storm event.
- Floating islands could be placed on the sides of the canal, to decrease water surface obstruction and thus passage of boats.

Technology Summary:

- Development Status (**5**) – The technology has been implemented large scale to reduce nutrient concentration in water column of eutrophic lakes, ponds and coastal areas.
- Effectiveness (**4**) – FI will provide an evident improvement in the nutrient concentration and ecosystem function. Biomass harvest must be timed to prevent organic matter decomposition, which could lead to low DO.
- Ease of Implementation (**4**) – The initial implementation effort is an improvement from circulation pumping, and the effort required to monitor and maintain a FI is then times less than a circulation pumping system.
- Footprint (**4**) – FI's improve ecosystem services by providing a nesting area to wading birds.
- Permitting (**4**) – Has been permitted before in the USA as a passive technology to improve water quality. Support information that explains the benefits of FI should be provided. A severe weather anchoring system will need to be incorporated to facilitate permitting.
- Homeowner Disruption (**5**) – FI's will provide wildlife habitat that will be appreciated by homeowners.
- Time (**3**) – Mangroves are highly efficient at nutrient cycling. They will not only filter the surrounding water but will also uptake about six gallons of water a day.
- Cost (**6**) – Although the cost of implementing is highly variable depending on the area covered, it has the potential to be half the cost of a circulation pumping system.
- Total: **35**

4.2 Aquatic Animals

Aquatic animals such as clams, snails and other filter-feeding shellfish are also an alternative for nutrient removal in eutrophic water bodies. However, unlike aquatic plants they do not provide direct improvement to dissolved oxygen. Rather, aquaculture of aquatic animals remove nutrients and improve water clarity. The rate of dissolved oxygen consumption in a water body is highly dependent

on the nutrient concentrations. A bench scale study completed by the South Florida Water Management District (SFWMD) (2004) demonstrated that the rate of oxygen consumption could range from 1 mg O_2/L-wk to 10 mg O_2/L-wk depending on the nutrient concentration in the bottom water.

4.2.1 Oyster Aquaculture

Background:

Bivalves and other suspension feeding organisms remove a portion of the phytoplankton biomass from the water column as they feed (Figures 1-2), thereby reducing turbidity and concentrations of particulate organic nitrogen (PON) in the water column (Kennedy and Newell, 1996; Newell, 2004; Newell and Koch, 2004; Grizzle et al., 2008; Dame, 2012 and references therein).

The time required to remove nitrogen contained in phytoplankton and other particulate organic matter from the water column can vary from hours to permanent removal depending upon the fate of the N after consumption, for example phytoplankton can be ingested but not digested, or it can be digested and assimilated into the shell and soft tissue (Figures 1-2). While different processes may occur, there are three primary ways bivalves can remove N from the water column for substantial amounts of time: 1) assimilation into animal tissue or shell (Songsangjinda et al., 2000; Higgins et al., 2011), 2) long-term burial in the sediments, and 3) conversion of bioavailable N to N^2 gas through the microbially mediated coupling of nitrification-denitrification (Newell et al., 2002, 2005; Higgins et al., 2011; Piehler and Smyth, 2011; Smyth et al., 2013; Kellogg et al., 2013).

The amount of N removed from the water column or recycled in a system ultimately will depend on biological, geochemical and physical interactions. Assimilation and biodeposition rates, for example, depend heavily upon filtration and ingestion rates that are in turn influenced by temperature, salinity, tidal regime, water residence time, and the abundance of phytoplankton and other particulates in the water column (Newell and Langdon, 1996; Cranford et al., 2011). Whether biodeposits are resuspended or buried will depend on the local hydrodynamic regime. The proportion of N in biodeposits that is returned to the atmosphere as N^2 gas versus N that is remineralized will be influenced by a variety of factors including dissolved oxygen concentration and redox condition in the sediment (Cornwell et al., 1999; Joye and Anderson, 2008 and references therein), sediment geochemistry (Sündback et al., 1991; Joye and Hollibaugh, 1995), water column nutrient concentrations, effects of the benthic macrofaunal community (Pelegri et al., 1994, Nizzoli et al., 2007), microbial community abundance and composition (Fulweiler et al., 2013), and the presence or absence of microphytobenthos and macroalage that can alter both the availability of dissolved inorganic nitrogen and oxygen concentrations (Thouzeau et al., 2007). Even within the same system, N removal pathways are expected to differ between natural or restored oyster populations growing on the bottom and those growing in an above-bottom aquaculture setting. Nitrogen removal pathways are expected to be further modified by light availability, oxygen concentrations in the sediments, and aerial exposure.

The potential for wild (Cloern, 1982; Officer et al., 1982; Dame et al., 1984) and cultivated (Smaal et al., 2001; Lindahl et al., 2005; Lindahl, 2011) populations of suspension-feeding bivalves to alter water quality through top-down control of phytoplankton, biodeposition of suspended sediments, and alteration of nutrient dynamics has long been recognized. These effects have led several authors to suggest that enhanced populations of suspension feeding bivalves could mitigate eutrophication in coastal waters (Officer et al., 1982; Newell, 2004; Lindahl et al., 2005; Cerco and Noel, 2007; Bricker et al., 2014; Rose et al., 2014). Others have expressed concern that this approach could have negligible positive effects or even negative effects (Dame et al., 1992; Newell, 2004; Pomeroy et al., 2006; Fulford et al., 2010; Burkholder and Shumway, 2011; Carmichael et al., 2012), due to bio-deposits introduced into the system. Nitrogen budgets developed thus far for oysters, mussels and

clams from wild and cultured populations over a range of environments (e.g., Jordan and Valiela, 1982; Dame et al., 1984; Mazouni, 2004; Nizzoli et al., 2006; Burkholder and Shumway, 2011 and references therein) reveal that the portion of N consumed that is returned to the environment (as DIN and biodeposits) varies widely, but generally exceeds the amount incorporated into shellfish biomass. A recent review examined the potential use of bivalves either to remove particles from the water column or remediate N loads to coastal waters and found that at least 30 studies since 1980 have assessed some aspect of the bioremediation potential of at least 16 different species of bivalves from around the world (Carmichael et al., 2012). This review found that, although these studies suggest that bivalves can reduce local particle concentrations by 30-45%, reported removal of N is much lower.

This technology can also have limitations. For example, an "oyster mats" program will fail unless there is already a natural oyster population with free-swimming larvae passing through the treatment area. Oysters also require the proper levels of salinity, dissolved oxygen, and water depth, as well as protection from natural enemies like the boring sponge. Furthermore, the amount of nitrogen removed in an aquaculture setting will depend upon farm productivity, which depends upon temperature, food availability, disease occurrence, and unpredictable weather events, making annual productivity highly variable and difficult to predict. On the other hand, it is worth emphasizing that when cost and efficiency (i.e., nitrogen removal per unit area) are taken into account, it is clear that shellfish compares more favorably to management practices for nonpoint sources of nitrogen than point sources such as wastewater treatment. This view is supported by previous work that has indicated shellfish aquaculture may have the largest impact, in terms of percentage of total nitrogen load offset, in suburban areas dominated by nonpoint source nitrogen, as opposed to heavily urbanized areas dominated by point sources (Carmichael et al., 2012).

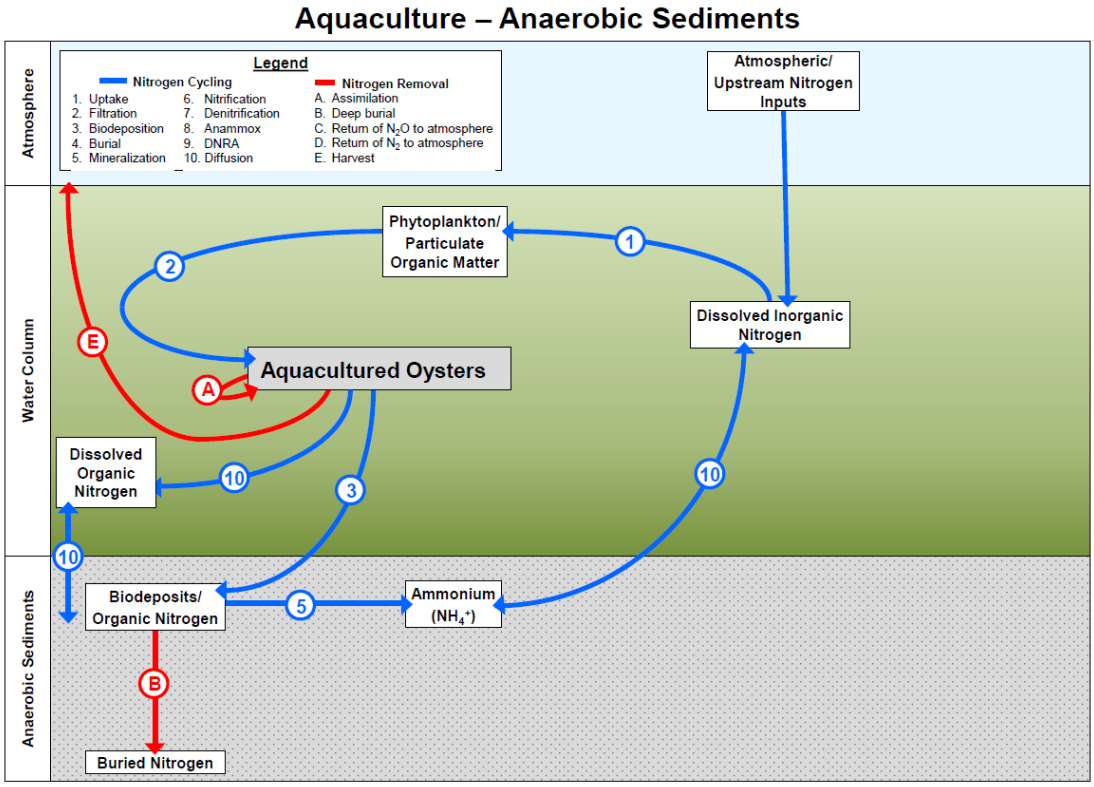

Figure 4-4. Nutrient Cycling for Oyster Aquaculture in Anaerobic Sediments. *Source: Kellogg et al 2014.*

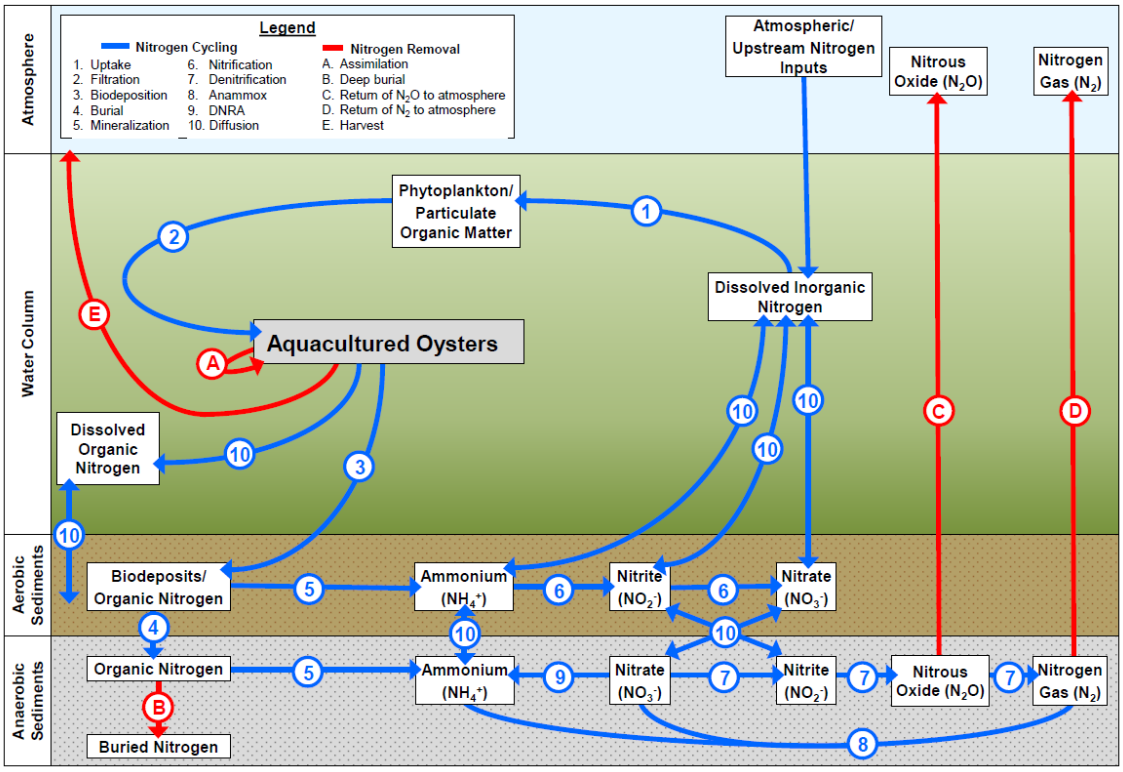

Figure 4-5. Nutrient Cycling for Oyster Aquaculture in Aerobic Sediments Below Euphotic Zone. *Source Kellogg et al. 2014.*

Method:

Establishing a mat program for oyster aquaculture requires supplies like oyster shells, zip ties, and aquaculture mesh to build mats, and donut weights to anchor them to the floor, as well as boats and trucks for transportation. A project like this could take about $150,000 to fund its first year of operation.

Figure 4-6. Oyster Mat

Conclusion:

Oyster aquaculture is a direct way to reinstate the water natural pollution processing abilities, providing on-going benefits for water quality plus habitat and erosion prevention at a relatively low cost. Oyster aquaculture compares favorably to existing best management practices for agriculture and stormwater nutrient controls, in terms of cost-effectiveness and quantity of nitrogen removed per unit area (Table 4-1), which makes it a good candidate for inclusion in comprehensive strategies that address anthropogenic eutrophication. The cost per unit of nitrogen removed from shellfish aquaculture also is thought to compare favorably to existing best management practices for agricultural and stormwater runoff (Gren et al., 2009; Stephenson et al., 2010). The upper range of estimated costs for shellfish aquaculture ($150 per pound of N removed) was comparable to those upper estimates for agricultural BMPs ($23 to $2800 for three types of BMPs in four locations) and consistently less than upper estimates for urban BMPs ($366 to $2215 for five types of BMPs) (Stephenson et al., 2010).

Table 4-1. Nitrogen Content in soft tissue and shell

Source	Location	Conditions	%N
Newell 2004	Choptank River, Chesapeake Bay	Natural oyster reef	Soft tissue: 7.0 Shell: 0.3
Higgins et al. 2011	2 tributaries in Chesapeake Bay	Cultured oysters in floats Oyster density = 286 m-2 High and low energy sites	Soft tissue: 7.86 Shell: 0.19
Carmichael et al. 2012	5 estuaries on Cape Cod	Cultured oysters in floats Oyster density = 429 m-2 Variation in N loading across watersheds	Soft tissue: 8.6
Carmichael et al. unpublished	2 locations in Mobile Bay	Cultured oysters in cages	Soft tissue: 12
Kellogg et al. 2013	Restored reef in Choptank	Subtidal oyster reef Hatchery-produced spat 2 -7 year-old oysters Oyster density = 131 m-2	Soft tissue: 9.2 Shell: 0.21

This technology can be used as part of an integrative approach to improve water quality, along with storm water treatment (reduce pollution loading) and dredging projects (mechanically remove polluted muck from the floor of the canals). Furthermore, this technology can be implemented along with seagrass planting. In this case, oysters would filter the water, improving water quality and increasing the water clarity for seagrasses to grow, while seagrasses provide both filtering and increased DO to the water and sediments.

Technology Summary:

- Development Status (**5**) – The technology has been implemented large scale to reduce nutrient concentration in water column of eutrophic lakes, and coastal areas.
- Effectiveness (**3**) – Oyster aquaculture will provide evident improvements in the nutrient concentration and ecosystem function. This technology alone will not have a direct effect on DO in water. However, fast water filtration rates are expected to improve both nutrient concentration and water quality, which will in turn be beneficial to photosynthetic plants that could increase DO in the water column.
- Ease of Implementation (**2**) – Initial implementation, monitoring and maintenance are time consuming and requires specialized skills (e.g. diving). Success dependent on presence of larvae on site.
- Footprint (**4**) – oyster beds improve ecosystem services, do not interrupt the passage of boats, do not require energy for operation.
- Permitting (**4**) – Has been permitted before in the USA as a passive technology to improve water quality.
- Homeowner Disruption (**5**) – oyster beds provide ecosystem services that will be appreciated by homeowners.
- Time (**2**) – Oysters are highly efficient filters (up to 50 gallons in one day). Water quality improvements should be evident within 6 months.
- Cost (**5**) – Minimal material costs will be associated with installation. However, proper placement of the oysters will be labor intensive.
- Total: **30**

4.3 Bioremediation-Microorganisms

Background:
Microorganism-based technologies are used to decompose, transform, and absorb water pollutants. Results to date generally confirm the existence of the appropriate microbial functional groups responsible for removing specific pollutants from wastewater. Practically, two microorganism-based methods are used for in-situ surface water remediation. The first method is microbial dosing and the second utilizes biofilms. Microbial dosing uses specific and efficient microorganisms to remove pollutants present in the water, while the bio-film technology utilizes bio-membrane attached to the natural river bed and micro-carrier to move the pollutants in the river through adsorption, degradation and filtration under the conditions of artificial aeration or dissolved oxygen.

Bioremediation using microorganisms shows great potential for future development due to its environmental compatibility and possible cost-effectiveness. A wide range of microorganisms, including bacteria, fungi, yeasts, and algae, can act as biologically active methylators, which are able to at least modify toxic species.

Method:
Microorganism films can be incorporated into the roots of floating islands to improve decomposition and adsorption.

Technology Summary:
- Development Status (**2**) – This technology has not been implemented large scale.
- Effectiveness (**2**) – Bioremediation will improve the system's ability to decompose organic matter, and can also work as a filter to remove pollutants. Although it has a potential to remove phosphate its effect on DO is limited.
- Ease of Implementation (**3**) – easy to implement, and limited maintenance required.
- Footprint (**4**) –Improve ecosystem's ability to decompose organic matter, do not require energy for operation or monitoring.
- Permitting (**2**) – Has been permitted before in the USA as a passive technology to improve water quality in freshwater. However, there may be concern of the ability of the organisms to proliferate to a nuisance level.
- Homeowner Disruption (**4**) – Microbial addition to recreational water systems might not be well appreciated by the community. However, biofilms is a more accepted method.
- Time (**2**) – This technology alone will not be able to achieve expected results of nutrient reduction and DO increase.
- Cost (**-5**) – Will require pumping to circulate the water through filter and aerator to improve efficiency of microorganisms. O&M require filter replacements and electricity consumed by pump and aerator.
- Total: **14**

5.0 Conceptual Designs

The following conceptual designs summarize the process for implementation of the selected technologies. Conceptual design drawings are provided in **Appendix A**. Due to the passive nature of the evaluated technologies, it is likely that the selected technologies are most appropriate for implementation in canals with fair water quality.

5.1 Floating Island

The primary design aspect for a floating mangrove island will be selection of available installation locations. It is expected that successful implementation will require involvement from homeowners willing to give up boat storage areas for water quality improvement. Also, many canals that have "trunks" in addition to "fingers", with trunks being the section of the canal that fingers tie into, have areas along the trunks where boat storage is not occurring. Therefore, the trunk sections of canals provide numerous potential areas to install floating mangrove islands.

The process for implementation will be to:

- Identify installation locations,
- Install anchoring hardware,
- Construct support structure (HDPE pallots),
- Place and anchor support structure,
- Plant and secure mangroves,
- Install aeration system, and
- Submerge floating island during severe weather as necessary.

As indicated in section 4.1.3, the construction of a single floating mangrove island is expected to cost $7,800. It is estimated that approximately 23 floating mangrove islands would be required for a five acre canal, resulting in a total project cost of $180,000.

5.2 Macro-algae Farming

The construction process for the macro-algae farms would be very similar to the process for a mangrove island.

The process for implementation will be to:

- Identify installation locations,
- Install anchoring hardware,
- Construct support structure (PVC pipe with floats),
- Place and anchor support structure,
- Plant and secure macro-algae,
- Install aeration system, and
- Submerge floating island during severe weather as necessary.

It is estimated that the material costs for macroalgae farm would be slightly less than for a mangrove island, and that the total cost per structure would be approximately $7,000. A similar number farm structures would be required, resulting in a total project cost of $160,000.

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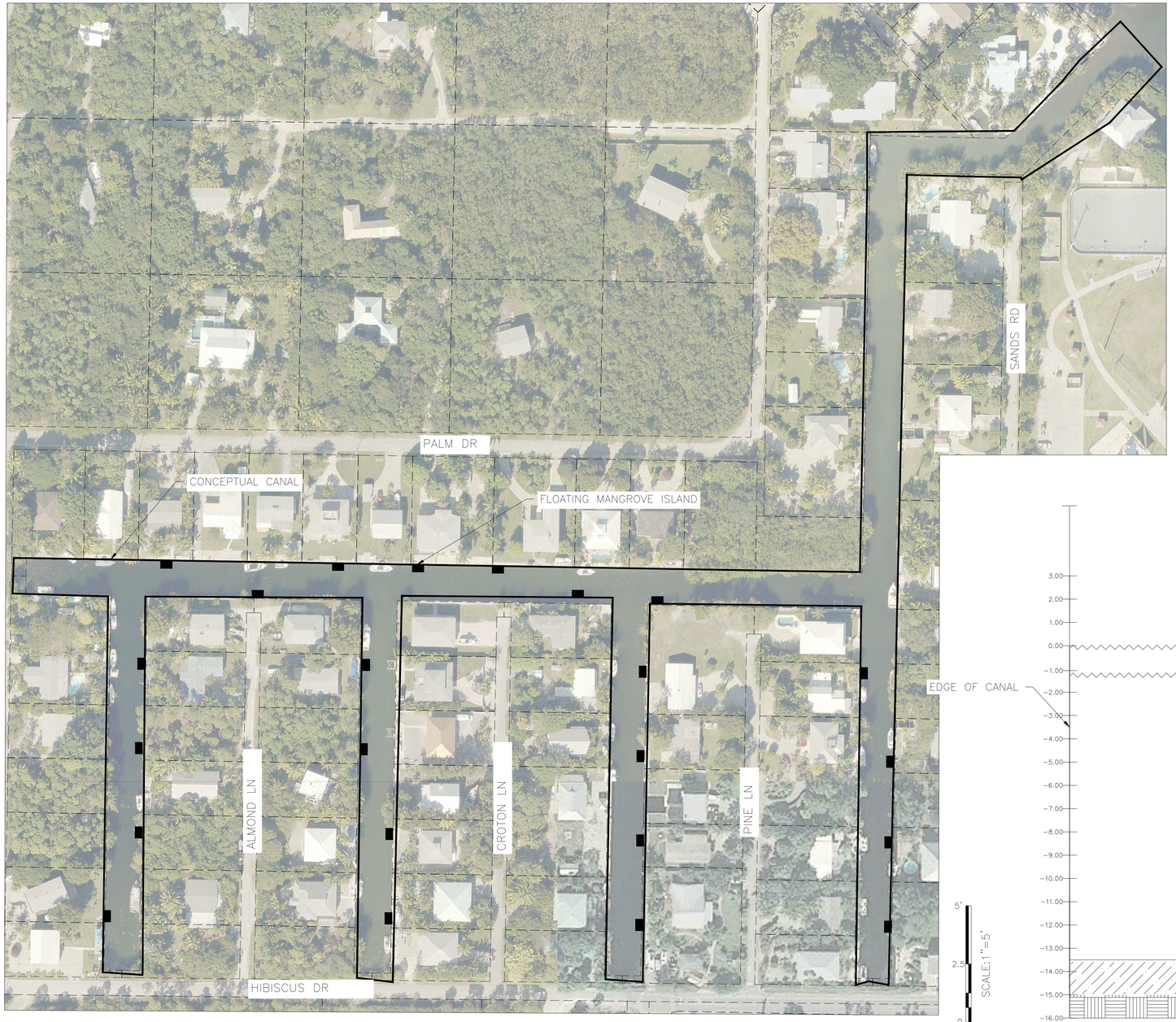
APPENDIX A

CONCEPTUAL DESIGN DRAWINGS



LEGEND

CONCEPTUAL CANAL AREA (> 5 ACRES, 2,500 FT LONG, 15 FT DEEP)

MONROE COUNTY PARCELS, 2010

PLAN VIEW

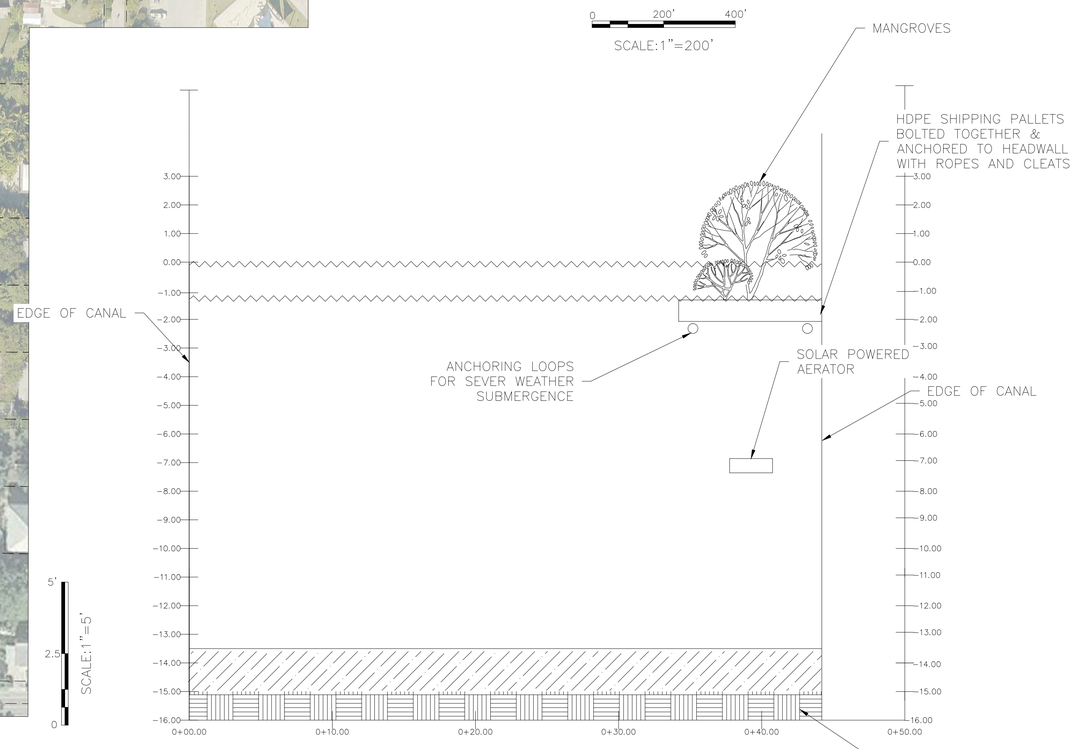
0 80' 160'

SCALE:1"=80'

DETAIL SITE LAYOUT

0 200' 400'

SCALE:1"=200'



5' 2.5 0

SCALE:1"=5'

0 5' 10'

SCALE:1"=5'

A CROSS-SECTION

amec foster wheeler

ENVIRONMENT & INFRASTRUCTURE, INC
5845 NW 158TH STREET
MIAMI LAKES, FL 33014
TEL: (305) 818-8414

ENGINEER OF RECORD
STEPHEN HANKS
FL PE #72253

PROJECT:
EVALUATION OF PASSIVE AND LOW ENERGY TECHNOLOGIES TO IMPROVE WATER QUALITY OF RESIDENTIAL CANALS IN THE FLORIDA KEYS

APPLICANT:

AMEC PROJECT No:
6783-15-2757.03

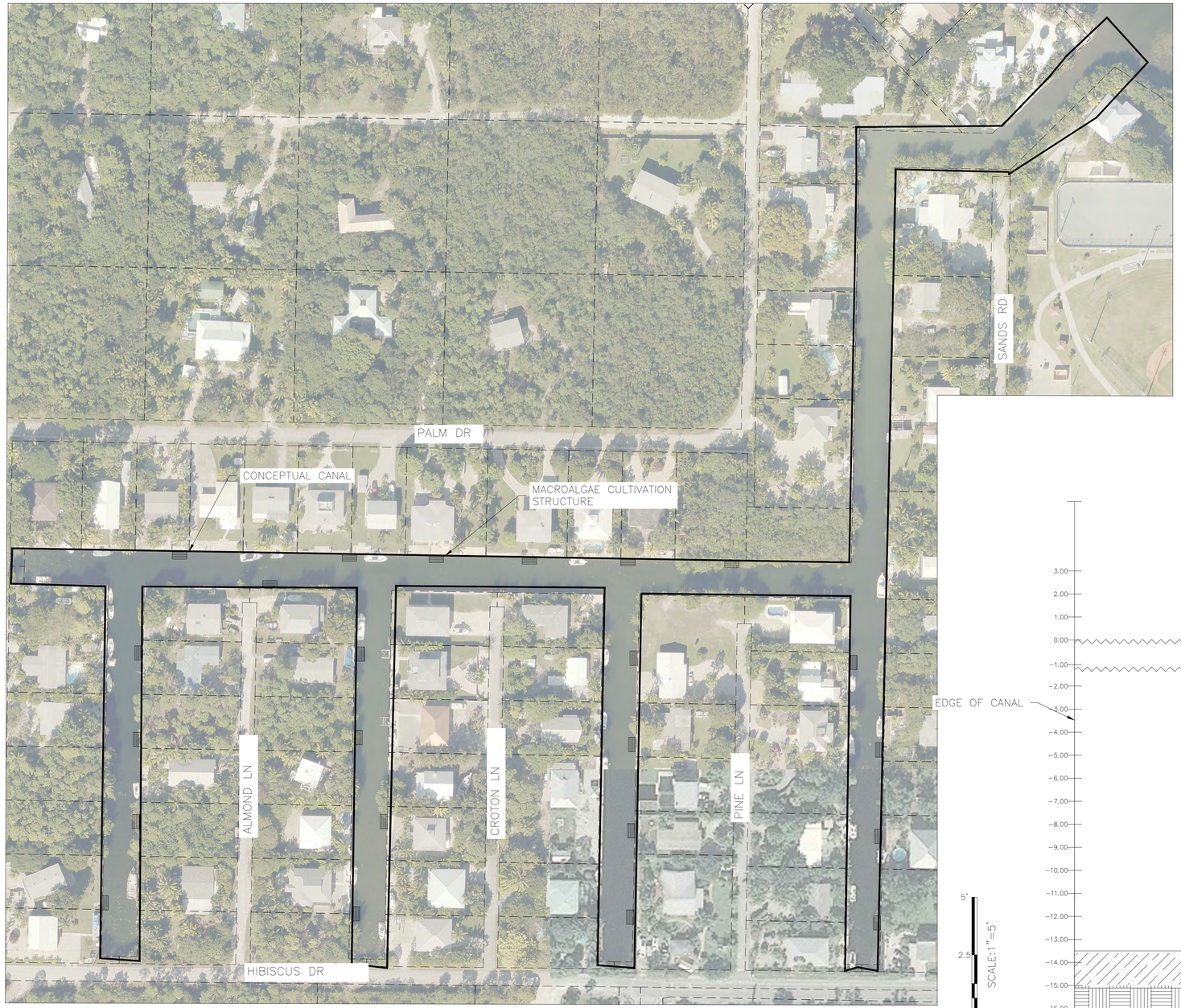
REVISIONS			
NO.	DATE	BY	APPROVED

DESIGNED BY:	SJH
DRAWN BY:	DJD
CHECKED BY:	SJH
APPROVED BY:	SJH
DATE:	06/10/2016

SHEET TITLE:

CONCEPTUAL DESIGN FOR A FLOATING MANGROVE ISLAND

SHEET NUMBER:	REV. #
SHEET OF SHEETS	



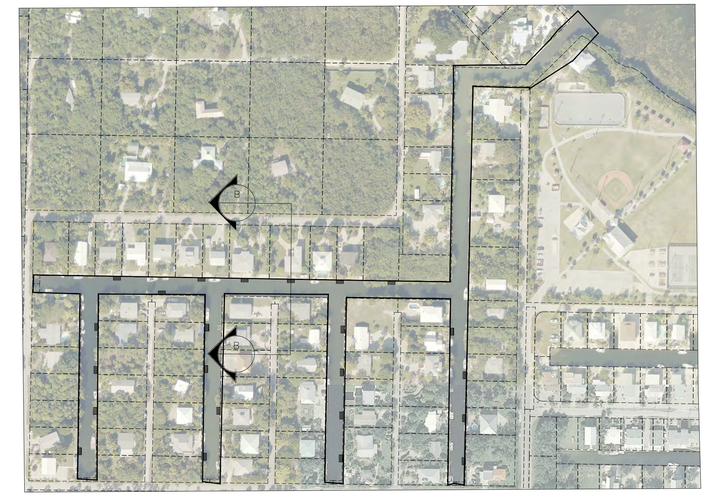
PLAN VIEW

0 80' 160'

SCALE:1"=80'

LEGEND

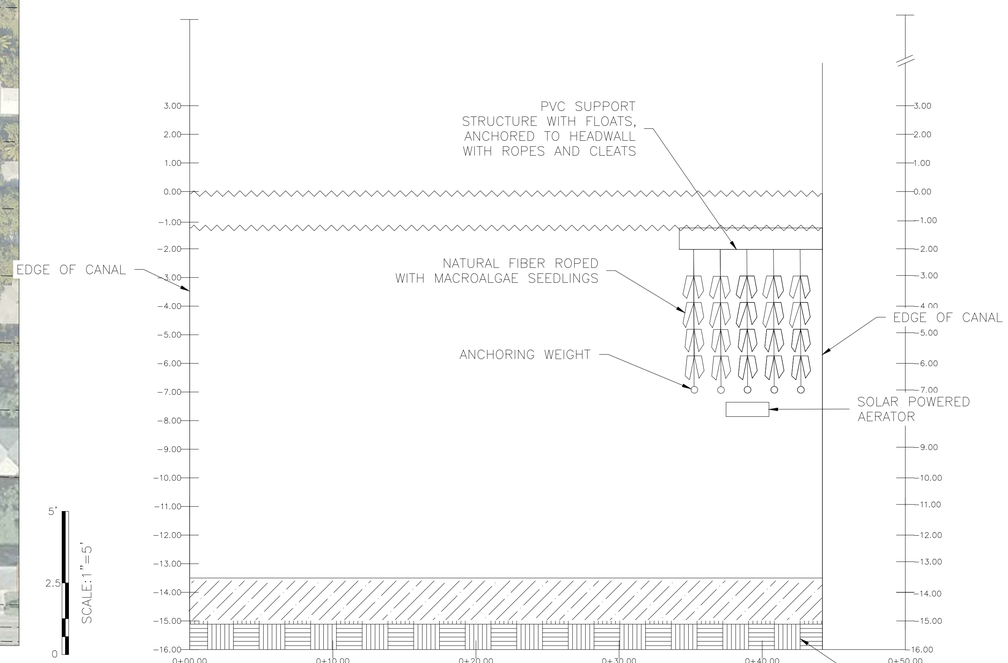
- CONCEPTUAL CANAL AREA (> 5 ACRES, 2,500 FT LONG, 15 FT DEEP)
- MONROE COUNTY PARCELS, 2010
- TURBIDITY BARRIER



DETAIL SITE LAYOUT

0 200' 400'

SCALE:1"=200'



5' 2.5' 0

SCALE:1"=5'

0 5' 10'

SCALE:1"=5'

B CROSS-SECTION

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DESIGNED BY:	SJH
DRAWN BY:	DJD
CHECKED BY:	SJH
APPROVED BY:	SJH
DATE:	06/10/2016

SHEET TITLE:

CONCEPTUAL DESIGN FOR A MACROALGAE CULTIVATION STRUCTURE

SHEET NUMBER:	REV. #
SHEET OF SHEETS	