



Evaluation of Alternative Technologies to Address Accumulated Organic Material in Canal Bottoms

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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 (CRDP) to initiate water quality improvements in the residential canals. Two dredging projects were completed as part of the CRDP, with a total cost of approximately \$1.8M.

In order to reduce the cost to address accumulated organic material in canal bottoms, an evaluation of alternative technologies was performed. A review of technologies from other industries and research identified five potential in-situ (in place) technologies and four potential ex-situ (off-site) technologies. Each technology was ranked based on effectiveness, ease to implement, permitting, homeowner disruption, time, and cost. Traditional dredge and disposal methodology was ranked along with the alternatives to provide a baseline for comparison for each technology. All ex-situ technologies were ranked lower than dredge and disposal due to the additional time and equipment required.

Of the in-situ technologies, a clay mat cap, aeration/bio-augmentation, and a sediment amendment were ranked the highest. A clay mat cap would consist of one foot of sand placed by sand shooter to stabilize the sediment surface, a geo-composite gas collection layer, a bentonite clay mat, and an additional foot of fill material to protect the mat. The impermeable mat would prevent the degradation of water quality by limiting the flux of oxygen into the underlying organic material, and would decrease the canal depth to promote benthic habitat.

For the conceptual application, a bentonite clay mat would provide a cost savings of approximately \$440,000 compared to dredge and disposal; which was estimated to cost \$725,000 for the conceptual application. The estimated cost savings is directly proportional to the thickness of organic material to be addressed, and the conceptual application evaluated an organic material thickness of five feet. Therefore, a cost savings of approximately \$260,000 would be expected for a canal with an organic material thickness of three feet.

Aeration and bio-augmentation appears to be the most cost efficient of all the technologies, and consists of an aeration system coupled with the application of a bacteria and enzyme bio-amendment to promote degradation of the organic material.

A sediment amendment would consist of mixing blast furnace slag into the canal sediment in a 0.25:1 ratio by volume to organic material. Blast furnace slag, a byproduct of steel production, is composed of oxidized minerals that can provide oxygen to the sediment as degradation of the organic material occurs.

The other technologies evaluated included the following:

- ▶ Directionally Drilled Bio-Sparge: Two inch HDPE pipe directionally drilled under the muck layer with low flow aeration to promote aerobic degradation of the organic material.
- ▶ Aerobic Stabilization: Closing the canal and using agitators that are typically used in wastewater treatment to mix and suspend the muck to promote aerobic degradation.
- ▶ Resistance Heating: Using smoldering technology that is typically used for heavy oil impacted soil to mineralize the dredged organic material following dewatering.
- ▶ Anaerobic Digestion: Using a reactor to anaerobically digest the dredged organic material and collect methane.
- ▶ Fuel Cell: Using electrodes to collect electricity from the digestion of the dredged organic material.
- ▶ Chemical Oxidation: Using an oxidant to mineralize the dredged organic material.

GRAPHIC ABSTRACT

Technology	Type	Effectiveness (0-5)	Ease to Implement (0-5)	Permitting (0-5)	Homeowner Disruption (-5 to 5)	Time (0-5)	Cost (-10 to 10)	Total
Aeration & Bio-Augmentation	In-Situ	2	5	2	5	0	10	24
Directionally Drilled Bio-Sparge		3	3	5	4	1	5	21
Aerobic Stabilization		2	1	4	-3	3	5	12
Clay Mat Cap		5	3	5	3	4	6	26
Sediment Amendment		2	4	4	3	5	6	24
Resistance Heating	Ex-Situ	5	0	3	0	3	-8	3
Anaerobic Digestion		5	0	3	0	2	-3	7
Humification Using a Fuel Cell		5	0	3	0	2	-3	7
Chemical Oxidation		5	0	1	-2	2	-10	-4

1.0 Introduction

1.1 Florida Keys Water Quality Protection Program

The Water Quality Protection Program (WQPP) Action Plan of the Florida Keys National Marine Sanctuary started in 1992. This program recommended corrective actions and compliance schedules to address point and nonpoint pollution, to restore and maintain the chemical, physical and biological integrity of the Sanctuary. 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 problems in residential canals are the result of historical inadequate treatment of wastewater and storm water, poor tidal circulation, and accumulation of organic material. As a result of these conditions, canals suffer from a high biochemical oxygen demand (BOD), eutrophication, an increased production of hydrogen sulfide (H₂S), an increase in fecal bacteria, and excess sedimentation.

Monroe County has undertaken a Canal Restoration Demonstration Program (CRDP) to initiate water quality improvements in the residential canals. The CRDP is in the process of implementing one culvert, one backfill, an air curtain, and two organic removal projects. The cost of the two organic removal projects was projected to be \$1.8M (AMEC 2013).

Given the prevalence of organic material accumulation across Monroe County, and the average cost to remove accumulated organic material; the cost to implement traditional dredge and disposal technology across the county represents a majority of the projected total canal cleanup costs. Therefore, an evaluation of alternative technologies is being completed to determine whether other viable, more cost effective technologies are available.

1.2 Overview of Traditional Dredge & Disposal Technology

Organic material dredging consists of removing the decomposed weed wrack material present at the bottom of a canal either mechanically or hydraulically. Due to the fine particle size of the decomposed weed wrack material, mechanical excavation of the organic material is not feasible. Therefore, a hydraulic dredge is the preferred means of removal of the organic material. A logistical limitation of the use of the hydraulic dredge is the large volume of suspended sediment and extracted water that requires stabilization, and the space requirements associated with the dewatering process.

Typical hydraulic dredging projects utilize constructed dewatering stabilization cells that are built with earthen berms. However, due to space limitations in the residential canal neighborhoods, an alternative method to dewater the dredged material is necessary such as mechanical dewatering or geo-tubes. In both instances, a polymer is used to separate the solids from dredged slurry.

Mechanical dewatering uses a baffled clarifier equipped with a screw auger to collect the flocculated solids that are then transferred to a belt press to remove excess water using pressure. The dewatered solids are transferred by conveyor from the belt press to a waste bin, and the filtrate is returned to the clarifier; where it can then overflow into a stabilization tank and then be returned to the canal. Geo-tubes use specially formulated geotextile to retain flocculated solids while allowing filtrate to drain outside of the geo-tube by gravimetric pressure. The filtrate is collected, pumped into a stabilization tank, and then returned to the canal. In both dewatering scenarios monitoring of toxicity and residual polymer concentration of the filtrate is required.

Figure 1-1. Vessel Based Vacuum Dredge Showing Auger



Figure 1-2. Mechanical Dewatering System



1.3 Potential Opportunity to Reduce Treatment Costs

As previously mentioned, it is projected that physical removal of the accumulated organic material will likely comprise the majority of the cost to address the water quality concerns in Monroe County. Dredging requires a team of specialized operators who need to be on site continuously during operation; which also contributes to high costs associated with removal of the organic material. The associated dewatering equipment and land requirements also present substantial economic challenges.

The dewatering process is the rate limiting step for organic material removal for the residential canal projects due to the limited space available. Additionally, the rate of dewatering is highly sensitive to minor changes in sediment composition, polymer dosing, and system operation. Finally, disposal of the dredged material is a significant component of the cost since the material must typically be disposed of in a landfill; which can be a significant distance in some cases. Costs are significantly reduced if sediment chemistry is acceptable, and a nearby disposal alternative is identified to accept the spoil material, but these areas are rare within the Keys.

Characterization of the sediment demonstrates that some of the removed organic material has the potential for beneficial reuse, while some of the removed organic material will need to be placed in a landfill due to anthropogenic metal concentrations (AMEC 2014). Additionally, many of the canals that will require dredging have a hard bottom depth that is too great to promote a healthy benthic community, and will require backfilling following the completion of organic removal. Therefore, in order for an alternative technology to provide a potential cost advantage over traditional dredging and disposal, one of the following benefits will need to be obtained:

- ▶ In-situ treatment of the organic material, thus eliminating the costs with dredging, dewatering, and disposal.
- ▶ Mineralize the dredged material, with the level of organic material conversion (mineralization) sufficient to allow for the dredged material to be placed back into the canal. An ex-situ mineralization process that would not require dewatering would likely provide a greater cost advantage than a technology that would require the material to be dewatered prior to mineralization.

Additionally, a cost benefit could potentially be provided from a programmatic standpoint if a disposal technology could use the organic material as a fuel source to produce energy.

1.4 Project Goal

The main goal of this study was to evaluate potential technologies to reduce the cost to address the accumulation of organic material in canal bottoms. To achieve this Amec Foster Wheeler,

- ▶ Performed a desktop study to identify technologies used in other industries to address organic material and its associated degradation to water quality.
- ▶ Develop a ranking matrix for all identified viable technologies.
- ▶ Develop conceptual designs and engineering cost estimates for the two highest ranked technologies.

2.0 Water Quality Degradation from Organic Material

2.1 Source and Migration of Organic Material

The organic material that accumulates in the canal bottoms in Monroe County is primarily the result of weed wrack migrating into the canal, decomposing, and sinking. Kryczynski (1999) defines weed wrack as detached blades of benthic seagrasses and algae that become wind-driven into large floating mats. Florida Bay and the Everglades are the primary sources of sea grass that become weed wrack.

Due to the predominant easterly direction of wind in the Florida Keys and the shoreline geometry, canals located in Big Pine Key and Marathon with a mouth orientation between 30 degrees and 220 degrees relative to north azimuth typically exhibit the highest accumulation of organic material. However, due to seasonal changes in wind direction and migration of weed wrack in the Loop Current, canals located on the Atlantic Ocean (south of US-1) with a mouth orientation between 90 degrees and 180 degrees also exhibit a significant accumulation of organic material.

Figure 2-1. Canal in Big Pine Key with Extensive Weed Wrack Loading



2.2 Degradation of Organic Material

The degradation of organic sediment occurs through multiple enzymatic pathways that involve multiple organisms and oxidants, and produces multiple intermediate compounds. During degradation, organic matter is oxidized using sequential terminal electron acceptors (TEAs) in a typical sequence of oxygen, nitrate, manganese, iron, and sulfate followed by methanogenesis or fermentation. The TEA that is utilized to degrade organic material is dependent upon the reduction-oxidation (red-ox) state in the

sediment, with oxygen being preferred and sulfate being less desirable due to energy yield (Arndt et al 2013). As the lower energy TEAs become reduced, the red-ox state of the sediment is lowered. Lower redox states require more oxygen to restore the sediment to an oxic state. Additionally, some of the degradation bi-products, such as hydrogen sulfide, can be toxic to marine organisms. Therefore, the degradation of organic material removes a significant quantity of oxygen from the water column. A study completed by Sakai et al (2012) demonstrates that anoxic soil conditions, indicated by the presence of hydrogen sulfide, were observed for sediment that exhibited a total organic carbon (TOC) content greater than 3.5 percent. As further described in Section 3.2, the TOC of the organic sediment in Monroe County is approximately 30 percent.

Figure 2-2. Degraded Organic Material Collected Using a Sediment Core



Studies completed to quantify the effects of redox conditions on the rate of organic material degradation have varying results. The study completed by Reimers et al (2013) demonstrated similar degradation rates for both oxic and anoxic conditions. However, other studies demonstrate a 3.5 times greater degradation rate for oxic conditions than for anoxic conditions.

The rate of dissolved oxygen consumption is dependent upon the composition of the organic matter, the deposition rate of organic matter, re-dox state of the sediment, the flow conditions at the sediment water interface, and available nutrients. 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 O₂/L-wk to 10 mg O₂/L-wk depending on the nutrient concentration in the bottom water.

The weed wrack present in most Keys canals typically consists of turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*), which are primarily comprised of cellulose (25%) (Dawes et al 2004). Cellulose is relatively labile, meaning that it is more rapidly degradable than refractory organic material such as lignin. Therefore, the organic material that accumulates in the canal bottoms can rapidly consume dissolved oxygen during degradation.

2.3 Characteristics of Organic Sediment in Monroe County Canals

Sediments of residential canals in the Florida Keys were characterized as part of the Florida Department of Environmental Protection (FDEP) Grant S0640, in 2013. This DEP Grant was funded in an effort to obtain information on the canal depths, organic accumulation and sediment characterization to assist in on-going canal restoration efforts. Sediment cores were collected from two separate canal systems. The sediment from one canal was adequate for beneficial re-use, while the sediment from the other canal exceeded the FDEP Soil Clean up Target Levels (SCTL) for copper and arsenic (AMEC, 2014) and required disposal in a lined landfill.

Dredged material with no contaminants of concern could be reused as a soil amendment. However, the high salinity content [>18 mS/cm or >11 parts per thousand (ppt)] limits the potential options for soil reuse. A bench scale study was completed to determine the most efficient method to reduce the salinity in the dredged sediment. The bench scale study demonstrated that a roll-off of dredged sediment could be desalinated with 8,000 gallons of fresh water and 615 pounds of gypsum (AMEC 2016)

Particle size distribution of sediments has been previously determined using ASTM D4422, Standard test Method for Particle-Size Analysis of Soils and D1140, Standard Test Methods for Amount of Material in Soils Finer than US Standard Sieve No. 200 (75 μ m) (AMEC 2014). Overall sediments are dark brown silt and fine sand with a high percentage of organic material and bottom clay layer. Details on additional physical and chemical properties are described on **Table 2-1**.

Table 2-1. Physical and Chemical Characterization of Sediments from Canal #266

Parameter	Concentration	Units
Solids content	14.1	%
Electrical conductivity (EC)	18.8	mS/cm
Organic content	28.6	%
Specific gravity	2.8	Gs
Particle size distribution		
Gravel	2.4	%
Sand	27.7	%
Finer than # 200 mesh	69.9	%
Chemical Analysis		
Arsenic	2.01	mg/Kg
Barium	8.7	mg/Kg
Cadmium	1.3 I	mg/Kg
Chromium	7.8	mg/Kg
Copper	40	mg/Kg
Lead	16	mg/Kg
Selenium	2.0 U	mg/Kg
Silver	1.0 U	mg/Kg
Mercury	0.0569 U	mg/Kg

Source: Amec, 2014

Notes:

1. mg/Kg: milligrams per kilogram
2. I: the reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.
3. J3: estimated value; value may not be accurate. Spike recovery or RPD outside of criteria.
4. U : indicates that the compound was analyzed for but not detected.

3.0 Evaluation of Technologies

The desktop research focused both on published research and industry technology. Overall, the published research was typically limited to bench scale studies for novel approaches to address organic sediment, with few case studies demonstrating the feasibility of implementation. Alternatively, several potential technologies were identified from other industries, such as environmental remediation and wastewater, which have yet to be applied to organic material remediation. Therefore, there is little information to demonstrate the feasibility of implementation for these technologies. As a result, for a majority of the technologies that have been evaluated, the feasibility of implementation was determined based on professional judgment and/or prior experience with organic material removal.

3.1 Ranking Methodology

Each of the technologies were evaluated for effectiveness, ease to implement, permitting, homeowner disruption, time, and cost. The purpose of the evaluation criteria is to rank technologies by potential success in addition to cost, and to identify technologies that would be difficult to implement. 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 would result in multiple 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 dredge and disposal.

Since traditional dredge and disposal is the standard method to remove accumulated organic material, it was selected as the benchmark for the evaluation of the alternative technologies. The rankings below were developed for dredge and disposal. Median values were chosen for most criteria, with the exception of effectiveness; since dredging removes the source of water quality degradation. Similarly, an effectiveness of 5 was assigned to all ex-situ technologies.

Table 3-1. Ranking of Traditional Dredge & Disposal

Technology	Effectiveness (0-5)	Ease to Implement (0-5)	Permitting (0-5)	Homeowner Disruption (-5 to 5)	Time (0-5)	Cost (-10 to 10)	Total
Dredge & Disposal	5	3	3	0	3	0	14

The ranking evaluation for the alternative technologies was completed by comparison to the following characteristics for traditional dredge and disposal of a half acre canal with 5,000 cubic yards of material:

- ▶ Effectiveness – Remove greater than 95% of the organic material.
- ▶ Ease to Implement – Requires a half acre staging area and specialized dredging and dewatering equipment.
- ▶ Permitting – Previously permitted, but requires toxicology and residual polymer testing during operation.
- ▶ Homeowner Disruption – Closed canal for the duration of the project with moderate noise.
- ▶ Time – 100 day duration.
- ▶ Cost – \$725,000.

3.2 In-Situ Technologies

The greatest reduction in cost can be realized by eliminating the need to remove the organic material from the canal, which subsequently eliminates the need for dewatering and disposal. However, in-situ treatment is difficult to implement due to the sensitivity of the marine environment. Therefore, the review of in-situ technologies focused on methods to increase rate of degradation or prevent oxygen consumption by the organic material, without impacting the nearby ecosystem.

3.2.1 Aeration & Bio-Augmentation

Aeration is widely used in both fresh and marine water bodies due to its ability to efficiently de-stratify and oxygenate the water column. A study completed by Harris et al (2015) demonstrates that aeration can also suppress the release of phosphorus, particularly for soils rich in iron. The study also demonstrated the ability of aeration to reduce ammonia flux to the water column, increase denitrification, and supply oxygen for aerobic degradation of sediment organic matter.

Clean-Flo is a commercially available aeration & bio-augmentation technology with numerous case studies, with the most recent case study completed for Lake Apopka (Jermalowicz-Jones 2016). The Lake Apopka case study demonstrated that the Clean-Flo aeration and bio-augmentation system “increased dissolved oxygen, reduced total suspended solids, reduced water column total nitrogen, reduced sediment ammonia and phosphorous, oxidized lake sediments and reduced conductivity.” The six month pilot study demonstrated an increase in water depth (corrected for seasonal variation in lake stage) and increase in bottom hardness. The Lake Apopka study did not quantify the mean increase in water depth, but other pilot studies indicate an average annual reduction in sediment thickness of 2.1 feet. The available case studies do not provide muck reduction rates for a period greater than 1 year. However it is expected that a reduction in the rate of organic material removal would occur as a result of the organic material becoming more refractory (difficult to break down) as digestion proceeded.

Figure 3-1. Increase in Bottom Hardness in Lake Apopka Case Study



Source: Jermalowicz-Jones 2016

The following rankings were determined for aeration & bio-augmentation:

- **Effectiveness (2)** – It is expected that aeration & bio-augmentation system will need to be operated for a period of at least 3 years, and that complete breakdown of the organic material to less 3.5 percent TOC will not be achieved.

- ▶ Ease to Implement (5) – The staging area for the aeration equipment will be seven feet by seven feet, and little site disturbance is required for installation.
- ▶ Permitting (2) – The most difficult aspect of the permitting is the bio-amendment. Due to the sensitivity of the nearby environment, the regulators may require for the canal to be closed during application of the bio-amendment, and may require toxicity testing prior to allowing the canal to be reopened.
- ▶ Homeowner Disruption (5) – Little to no disruption to the homeowners is expected.
- ▶ Time (0) – An operation period of at least three years is expected.
- ▶ Cost (10) – A cost quote by Clean-Flo indicates a unit cost of \$1.20 per square foot or \$26,000 for a half acre canal. Operation and maintenance costs are not considered in the evaluation, since it is not certain whether the costs to operate the system, including electricity, would be incurred by the homeowners, the county, or funded through an alternate source. Additionally, it is expected that all technologies will need to incorporate an air curtain to prevent future accumulation of organic material, and the operation and maintenance of an aeration system is similar to that for an air curtain.
- ▶ Total: 24

3.2.2 Directionally Drilled Bio-Sparge

Directionally drilled Bio-sparge wells are commonly used in environmental remediation. Case studies evaluating the effectiveness of directionally drilled bio-sparge wells to remediate marine sediment are not available. The bio-sparg pipe is 2-inch HDPE pipe with pressure activated slots. The pressure activated slots help ensure equal distribution of air along the length of the pipe. The pipe would be placed approximately two feet into the limestone bottom, and air would be injected into the sediment using a blower system. In principle, the bio-sparge would function similar to a standard aeration system, with the advantage of being able to aerate the entire sediment column rather than just the surficial sediment. If desired, the bio-sparge wells could be used to administer a bio-amendment as well, and the administration of a bio-amendment through a bio-sparge well may be easier to permit than surficial application. One potential drawback to using bio-sparge wells is the inability to remove mineral scale from the slots in the pipe. Therefore, the compressor system would have to have the ability to provide sufficient breakthrough pressure to overcome the scale buildup.

A bio-sparge system would be relatively easy to permit, as long as it was demonstrated that suspension of sediment would not occur during system operation. Therefore, the system flow rate should target 2-3 pore volume exchanges a day. For a half acre canal with 5,000 CY of sediment, the design flow rate would be 35 cfm.

The following rankings were determined for directionally drilled bio-sparge:

- ▶ Effectiveness (3) – Expected to be more effective than standard aeration since the entire sediment column is aerated.
- ▶ Ease to Implement (3) – Directional drilling requires a 3:1 offset, so a drill rig will need to be 30 feet away to get 10 feet below ground. Given the dense neighborhoods in Monroe County, the space necessary for directional drilling may not be available for all canals.
- ▶ Permitting (5) – Permitting is expected to be relatively easily, but could become slightly complicated if it was determined that a bio-amendment should be incorporated into the system.
- ▶ Homeowner Disruption (4) – Little to no disruption to the homeowners is expected except during the drilling activities, which should last less than 4 days.
- ▶ Time (1) – An operation period of at least two years is expected.
- ▶ Cost (5) – A cost quote by Directional Technologies, Inc indicates that three 550 foot long bio-sparg wells would cost approximately \$320,000. The aeration system would have a similar cost to the Clean-Flo system of \$26,000. Therefore, the estimated total cost is \$346,000.
- ▶ Total: 21

3.2.3 Aerobic Stabilization

Aerobic stabilization is widely used in wastewater as a means to reduce waste sludge volumes. In order to implement aerobic stabilization in a canal, the canal mouth would need to be closed (likely with sheet piling due to the wave action of the agitator that could bypass turbidity curtains), and the sediment would be suspended and aerated using a tank mixer. It is estimated that one mixer would be required every 30 feet. For the evaluation, it was assumed that homeowners would only allow the canal to remain closed for a period of 3 months.

Figure 3-2. Floating Mixer



Source: Fuchs-Germany

The following rankings were determined for aerobic stabilization:

- ▶ Effectiveness (2) – Full digestion of the organic material in 3 month period is not expected.
- ▶ Ease to Implement (1) – Power for each of the mixers would be required as well as specialized mounting equipment.
- ▶ Permitting (4) – Permitting should be easy as long as the canal will be closed with sheet piling.
- ▶ Homeowner Disruption (-3) – Excessive noise and odors may be generated.
- ▶ Time (3) – Similar timeframe to dredging.
- ▶ Cost (5) – The cost for the mixers will be approximately \$80,000, system installation and operation is expected to cost between \$200,000 and \$300,000. Therefore, the estimated total cost is \$330,000.
- ▶ Total: 12

3.2.4 Clay Mat Capping

Clay mat capping would eliminate the consumption of oxygen from the water column by covering the sediment with an impermeable mat. The installation of the mat would likely require that the surface of the muck be stabilized with sand first, otherwise suspension of the muck will likely occur during placement of the mat. The most effective method to stabilize the surface is using a sand shooter, as demonstrated by the Ibis Island Restoration Project (Palm Beach 2015). The sand shooter will place

sand in small quantities throughout the canal to avoid disturbance of the muck. Approximately one to two feet of sand will be required to stabilize the surface of the muck. A geo-composite gas collection layer and gas collection system will need to be installed before the impermeable mat. An additional foot of fill will need to be placed over the cap to protect it from prop wash and hurricane surge. Due to the two feet of fill required to stabilize the muck and protect the cap, the placement of a clay mat cap is not feasible for canals with a depth to the top of sediment less than six feet below Mean Lower Low Water (MLLW).

Figure 3-3. Placement of a Clay Mat



Source: Cetco

The following rankings were determined for clay mat capping:

- ▶ Effectiveness (5) – The cap will prevent water quality degradation, and the placement of fill will provide suitable substrate for benthic habitat.
- ▶ Ease to Implement (3) – It is expected that a 0.1 acre staging area is sufficient to handle the sand, and the geo-membrane and clay mat will be deployed by barge. However, installation of the geo-membrane and clay mat may require specialized skills and equipment.
- ▶ Permitting (5) – No issues with permitting.
- ▶ Homeowner Disruption (3) – Less noise and heavy equipment than dredging.
- ▶ Time (4) – It is expected that the sand and mat installation could be completed in less than 2 months.
- ▶ Cost (6) – The cost for the geo-membrane is \$20,000, the cost for the clay mat is \$20,000, and sand and installation is estimated to cost approximately \$220,000. Therefore, the estimated total cost is \$260,000.
- ▶ Total: 26

3.2.5 Sediment Amendment

Research into soil amendments to address organic marine sediment identified numerous potential technologies, including granular ferric oxide, crushed oyster shells, granulated coal ash, and blast furnace slag. All soil amendments use oxidized material as a TEA for the organic sediment to help maintain oxic soil conditions. Eventually the bound oxygen in the amendments will be consumed, and will either need to be recharged through aeration or augmented with additional material. Both granulated coal ash and steel slag are industrial byproducts, and were evaluated further due to the ability to be purchased in large quantities at low cost. However, granular ferric oxide is not an industrial byproduct that is generated in large quantities, and therefore cannot be economically acquired. Additionally, the research for the use of crushed oyster shells indicated that they were able to absorb the hydrogen sulfide being produced through anaerobic degradation, but not able to increase the redox conditions of the sediment to eliminate the production of hydrogen sulfide (Yamamoto, et.al 2012).

One limitation of granulated coal ash is that a significant lead time would be associated with a large order of material, since there is currently a shortage of fly ash in Florida. Also, the fly ash would need to be granulated using cement, water, and a granulator. Therefore, the evaluation was based on the use of blast furnace slag as a soil amendment. The evaluation completed by Asaoka & Yamamoto (2010) demonstrated that a 1:4 ratio of steel slag to organic sediment effectively reduces the flux of nutrients from the sediment and the production of Hydrogen Sulfide. Additionally, the augmentation of organic sediment with blast furnace slag was demonstrated to reduce the organic carbon content by 3 percent in the 25 day experiment. The elutriate from the soil mixture does not exhibit dissolved constituents that exceed the FDEP marine surface water CTLs.

The following rankings were determined for sediment amendment:

- ▶ Effectiveness (2) – The incorporation of the amendment is expected to be as effective as other aeration technologies, including limited expectation of the ability of the technology to reduce the organic content of the sediment to below 3.5 percent. However, the placement of the slag material will increase the bottom depth of the canal by approximately 1.5 feet, which may help support benthic habitat.
- ▶ Ease to Implement (4) – It is expected that a 0.1 acre staging area is sufficient to handle the blast furnace slag, and the material can be mixed into the canal from a barge. The suspension of muck mats may occur, and may require to be collected and disposed of.
- ▶ Permitting (4) – No expected issues with permitting since the material has been demonstrated to not have a leaching potential that would impact surface water quality.
- ▶ Homeowner Disruption (3) – Less noise and heavy equipment than dredging.
- ▶ Time (5) – It is expected that the material installation could be completed in less than 1 month.
- ▶ Cost (6) – The cost for 1300 cubic yards of blast furnace slag from Argos Cement in Tampa is \$140,000, the cost for freight to central Key Largo is \$35,000, and installation is estimated to cost approximately \$100,000. Therefore, the estimated total cost is \$275,000.
- ▶ Total: **24**

Table 3-2. Ranking of Alternative Technologies

Technology	Type	Effectiveness (0-5)	Ease to Implement (0-5)	Permitting (0-5)	Homeowner Disruption (-5 to 5)	Time (0-5)	Cost (-10 to 10)	Total
Aeration & Bio-Augmentation	In-Situ	2	5	2	5	0	10	24
Directionally Drilled Bio-Sparge		3	3	5	4	1	5	21
Aerobic Stabilization		2	1	4	-3	3	5	12
Clay Mat Cap		5	3	5	3	4	6	26
Sediment Amendment		2	4	4	3	5	6	24
Resistance Heating	Ex-Situ	5	0	3	0	3	-8	3

Technology	Type	Effectiveness (0-5)	Ease to Implement (0-5)	Permitting (0-5)	Homeowner Disruption (-5 to 5)	Time (0-5)	Cost (-10 to 10)	Total
Anaerobic Digestion		5	0	3	0	2	-3	7
Humification Using a Fuel Cell		5	0	3	0	2	-3	7
Chemical Oxidation		5	0	1	-2	2	-10	-4

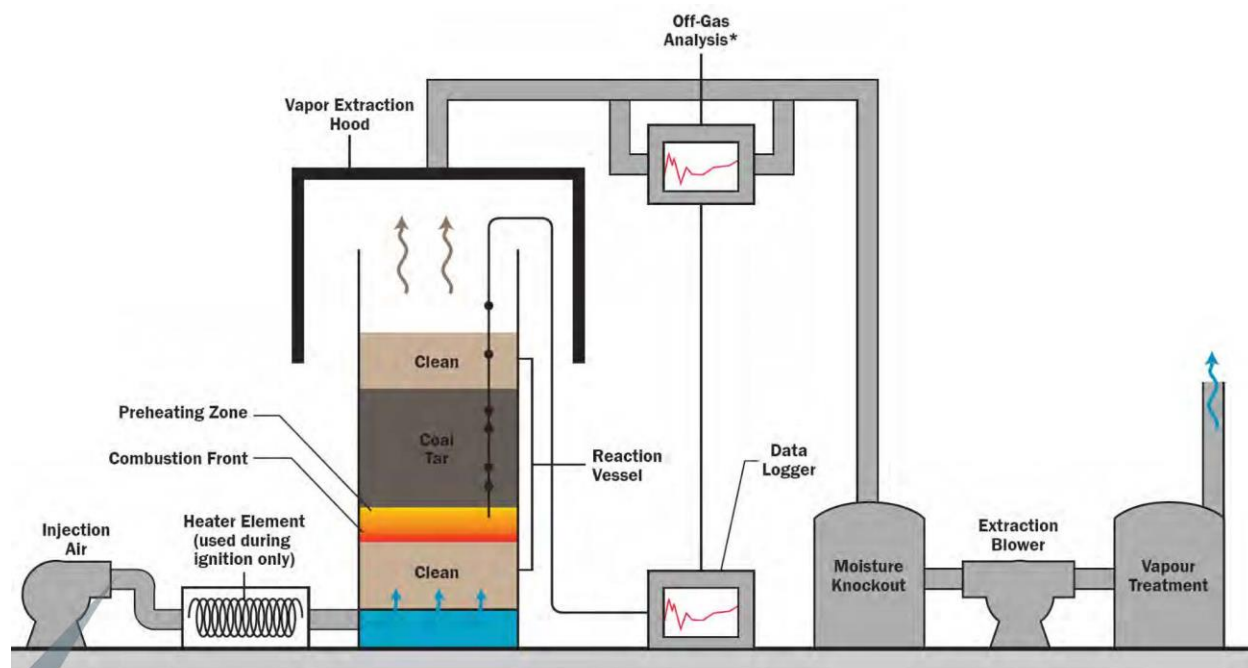
3.3 Ex-Situ Technologies

It is apparent in Table 3-2 above that none of the identified ex-situ technologies were ranked higher than traditional dredge and disposal, which was scored 14. The primary reason being that most technologies required more equipment and time than dewatering. Therefore, unlike for the in-situ technologies, detailed explanation of the rankings is not provided. Instead, the logistical difficulties and high cost aspects of the ex-situ technologies are detailed.

3.3.1 Electrical Resistance Heating

Electrical resistance heating is commonly used for tar and heavy oil impacted soil and sediment. It uses smoldering combustion to burn off the organic material (Savron 2015). Application of this technology to organic sediment is not feasible since the dewatered material would need to first be dried completely, and then augmented to allow sufficient airflow to sustain the smoldering process. Additionally, the organic material will likely not have sufficient heating value to maintain the smoldering process. One benefit of electrical resistance heating is that the treated material can be reused as fill material. However, it is estimated that the cost to complete electrical resistance heating would exceed the cost of landfilling the dredged material (assuming beneficial reuse was not feasible) and backfilling with quarried material.

Figure 3-4. Electric Resistance Heating Process



Source: Savron Solutions

3.3.2 Anaerobic Digestion

Anaerobic digestion would use reactor vessel and possibly an inoculum to promote the anaerobic breakdown of the organic material and produce methane in the process. A commercially available anaerobic digester, the MUCKBUSTER®, can process approximately 150 tons of material in a year, and fits inside a 40'x8' sea container (Seabenergy 2012). In order to achieve the same production rate of a mechanical dewatering approximately 20 containers would be required. The primary drawback to the use of anaerobic digestion is that it does not eliminate any of the processes required for dewatering and disposal, and it does not produce a suitable fill material. Therefore, the only benefit of anaerobic digestion is the production of energy.

3.3.3 Humification Using a Fuel Cell

Microbial fuel cells are similar to anaerobic digesters in that they produce energy from degradation of organic material. Similarly microbial fuel cells provide little benefit relative to dredging and disposal other than the production of energy. A microbial fuel cell is typically constructed with two electrodes, one to oxidize fuel and one to reduce oxygen, and the electrodes are typically separated by a proton-conducting membrane (Hong, Kim, Chung, 2010). The literature reviewed consisted of bench scale studies, so it is unclear what a full scale system would entail. Similar to anaerobic digestion, the only benefit of a fuel cell is the production of energy.

3.3.4 Chemical Oxidation

Chemical oxidation is widely used in environmental remediation to oxidize contaminants of concern, typically to carbon dioxide. Additionally, chemical oxidation is used to remove organics from soil samples for certain laboratory tests. For the purposes of remediation of Polycyclic Aromatic Hydrocarbons (PAHs) from sediment, a chemical oxidation dose of 85 pounds per ton of soil is adequate (Shih, et. al. 2016). However, for the purposes of removing organics from soil with an organic content of 30 percent, a 15:1 mass ratio is necessary. Therefore, approximately \$140M of oxidant would be required to remove the organic carbon from 5,000 cubic yards of organic material.

3.4 Summary of Rankings

A review of the available technologies to address accumulated organic material in canal bottoms indicates that only in-situ technologies have the ability to achieve cost savings relative to dredge and disposal. Of the in-situ technologies, a clay mat cap is ranked the highest, and sediment amendment using blast furnace slag and aeration with bio-augmentation were both ranked second. Since aeration/bio-augmentation is the lower cost option, it was selected over sediment amendment for the development of a conceptual design.

4.0 Conceptual Designs

The following conceptual designs summarize the process for implementation of the selected technologies. Conceptual design drawings are provided in **Appendix A**.

4.1 Clay Mat Capping

The preliminary design investigation for clay mat capping would consist of completing a bathymetric survey and the collection of sediment cores to determine volume of muck and to collect sediment samples to help characterize the muck. The sediment samples would be submitted for geotechnical analysis, such as shear strength, consolidation, and grain size analysis, to determine the structural stability of the organic material. It is expected that environmental analysis of the organic material will not be required for permitting.

The process for implementation will be to:

- ▶ Establish the staging area
- ▶ Install turbidity controls
- ▶ Place one foot of calcium carbonate sand using a sand shooter
- ▶ Place the geo-composite layer
- ▶ Install the gas collection laterals
- ▶ Install the clay mat
- ▶ Place at least one foot of sand over the clay mat

In order to ensure that the clay mat is effective, the most critical aspect of the installation will be to ensure that the sand is evenly placed, that the gas collection laterals are spaced close enough together, and that the mat is properly tied into the sidewalls and the canal opening.

The following cost estimate is provided below:

Table 4-1. Clay Mat Capping Cost Estimate

Item #	UoM	Approx Qty	Item	Unit Price In Figures	Total Amount
1	LS	1	Mobilization and Demobilization	\$ 25,000.00	\$25,000.00
2	LF	250	Water Quality Control System primary and secondary curtain system	\$ 60.00	\$15,000.00
3	LS	1	Maintenance of Traffic	\$ 2,000.00	\$2,000.00
4	LS	1	Conveyor Belt System	\$ 30,000.00	\$30,000.00
5	LS	1	Sand Shooter	\$ 20,000.00	\$20,000.00
6	CY	2,097	Sand Fill Material	\$ 20.00	\$41,946.67
7	CY	2,097	Trucking of Fill Material	\$ 8.00	\$16,778.67
8	CY	2,097	Placement of Fill	\$ 21.15	\$44,358.60
9	SF	21,780	Geo-Composite Membrane (installed)	\$ 2.00	\$43,560.00
10	LS	1	Gas Collection System	\$ 10,000.00	\$10,000.00
11	SF	21,780	Clay Mat (installed)	\$ 2.00	\$43,560.00
12	LS	3	Construction Surveys	\$ 10,000.00	\$30,000.00
				Subtotal	\$282,203.93

	10% contingency	\$ 28,220.39
	Total w/o CA & CO	\$310,424.33
Construction Administration		\$ 31,042.43
Construction Oversight (30 field days)		\$ 26,100.00
Total	TOTAL	\$367,566.76

4.2 Aeration & Bio-Augmentation

Implementation of aeration with bio-augmentation system is much less complex than a clay mat cap. Similar to the clay mat cap, a bathymetric survey to determine the organic material volume and the collection of sediment cores should be completed to facilitate design and permitting. The geotechnical composition of the organic material is not a concern for the implementation of aeration with bio-augmentation. However, the organic content of the material should be evaluated, along with a bench scale treatability study to select the most appropriate bio-amendment. It is likely that for permitting, the toxicity of the bio-amendment will need to be completed, and it is possible that the canal will need to be closed during the first application while the response of the canal is observed.

The process for implementation will be to:

- ▶ Obtain electric for the blower cabinets
- ▶ Install the blower cabinets
- ▶ Install turbidity controls
- ▶ Place the aeration diffusers and tubing
- ▶ Operate the aeration system until the water column is fully aerated (approximately 30 days)
- ▶ Apply the bio-amendment every six months

Detailed cost have not been developed for aeration with bio-augmentation since the vendor quote obtained from Clean-flo of \$26,000 for a half acre canal covers installation and one year of operation, excluding electricity costs.

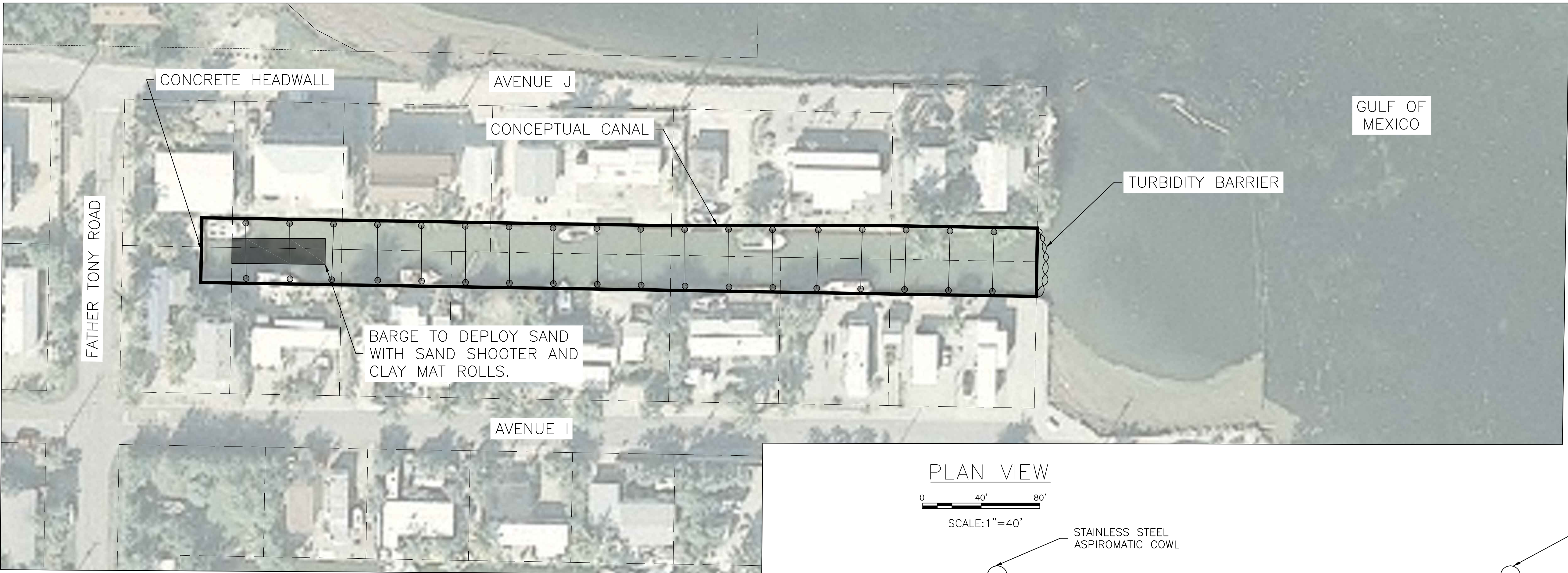
5.0 References

- AMEC Environment and Infrastructure Inc. 2013. Selection of Demonstration Canals for Water Quality Improvements. Prepared for Monroe County
- AMEC Environment and Infrastructure Inc. 2014. Organics Characterization in the Monroe County Canals; Sediments sampling and Analysis, Report of Findings. Florida Department of Environmental Protection Grant Agreement No. S0640. Prepared for Monroe County and FDEP
- AMEC Environment and Infrastructure Inc. 2016. Dredged Sediment Desalinization Study. EPA Grant No. X7-00D40915-0. Prepared for Monroe County and EPA
- Arndt, S., Jørgensen, B., Larowe, D., Middelburg, J., Pancost, R., & Regnier, P. 2013. Quantifying the degradation of organic matter in marine sediments: A review and synthesis. *Earth-Science Reviews*, 123, 53-86.
- Asaoka, S., & Yamamoto, T. 2010. Blast furnace slag can effectively remediate coastal marine sediments affected by organic enrichment. *Marine Pollution Bulletin*, 60(4), 573-578.
- Dawes, C.J., R.C. Phillips, and G. Morrison. 2004. Seagrass Communities of the Gulf Coast of Florida: Status and Ecology. Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute and the Tampa Bay Estuary Program. St. Petersburg, FL. iv + 74 pp
- EPA (U.S. Environmental Protection Agency). 2013. Florida Keys National Marine Sanctuary Water Quality Protection Program Report to Congress.
- Florida Department of Environmental Protection. 2013. Water Quality Assessment Report, Florida Keys. FDEP Division of Environmental Assessment and Restoration, Tallahassee, FL. 271 pp.
- Florida Keys National Marine Sanctuary. 2007. Florida Keys National Marine Sanctuary Revised Management Plan. FKNMS, Marathon, FL. 382 pp.
- Harris, L., Hodgkins, C., Day, M., Austin, D., Testa, J., Boynton, W., Van Der Tak, L., Chen, N. 2015. Optimizing recovery of eutrophic estuaries: Impact of destratification and re-aeration on nutrient and dissolved oxygen dynamics. *Ecological Engineering*, 75, 470-483.
- Hong, S. W., Kim, H. S., & Chung, T. H. 2010. Alteration of sediment organic matter in sediment microbial fuel cells. *Environmental Pollution*, 158(1), 185-191.
- Jermalowicz-Jones, J. L. 2016. Overall Trends in the Efficacy of Allied Group/Clean Flo's Laminar Flow Aeration and Bioaugmentation as a Treatment for Sediment Floc Reduction, Nuisance Algae Reduction, Water Quality Improvements, and Other Observed Ecological Benefits in Lake Apopka, Florida.
- Kruczynski, W.L. 1999. Water quality concerns in the Florida Keys: Sources, effects and solutions. Florida Keys National Marine Sanctuary, Water Quality Protection Program. Marathon, FL, 31 p
- Meier, L. P. 1997. A New, Efficient, One-Step Method for the Removal of Organic Matter from Clay-Containing Sediments. *Clay Minerals*, 32(4), 557-563.
- Palm Beach County BOCC. 2015. Ibis Isle – Lake Worth Lagoon Restoration Project.

- Reimers, C. E., Alleau, Y., Bauer, J. E., Delaney, J., Girguis, P. R., Schrader, P. S., & Stecher, H. A. 2013. Redox effects on the microbial degradation of refractory organic matter in marine sediments. *Geochimica Et Cosmochimica Acta*, 121, 582-598.
- Sakai, S., Nakaya, M., Sampei, Y., Dettman, D. L., & Takayasu, K. 2012. Hydrogen sulfide and organic carbon at the sediment–water interface in coastal brackish Lake Nakaumi, SW Japan. *Environ Earth Sci Environmental Earth Sciences*, 68(7), 1999-2006.
- Savron Solutions. 2015. Smoldering Solutions for Contaminated Soils and Liquid Organic Waste. Presented by Dr. Gavin Grant at AquaConSoil.
- Seabenergy. 2012. Turning Food Waste into Science Park Energy – MUCKBUSTER SEaB MB400. University of Southampton Science Park Case Study.
- Shih, Y., Binh, N. T., Chen, C., Chen, C., & Dong, C. 2016. Treatability assessment of polycyclic aromatic hydrocarbons contaminated marine sediments using permanganate, persulfate and Fenton oxidation processes. *Chemosphere*, 150, 294-303.
- South Florida Water Management District. 2004. Fate of Everglades Dissolved Organic Matter in Florida Bay. Coastal Ecosystems Division.
- Yamamoto, T., Kondo, S., Kim, K., Asaoka, S., Yamamoto, H., Tokuoka, M., Hibino, T., 2012. Remediation of muddy tidal flat sediments using hot air-dried crushed oyster shells. *Marine Pollution Bulletin*, Volume 64, Issue 11, 2428-2434.

Appendix A

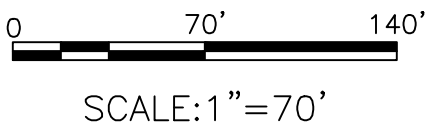
Conceptual Designs



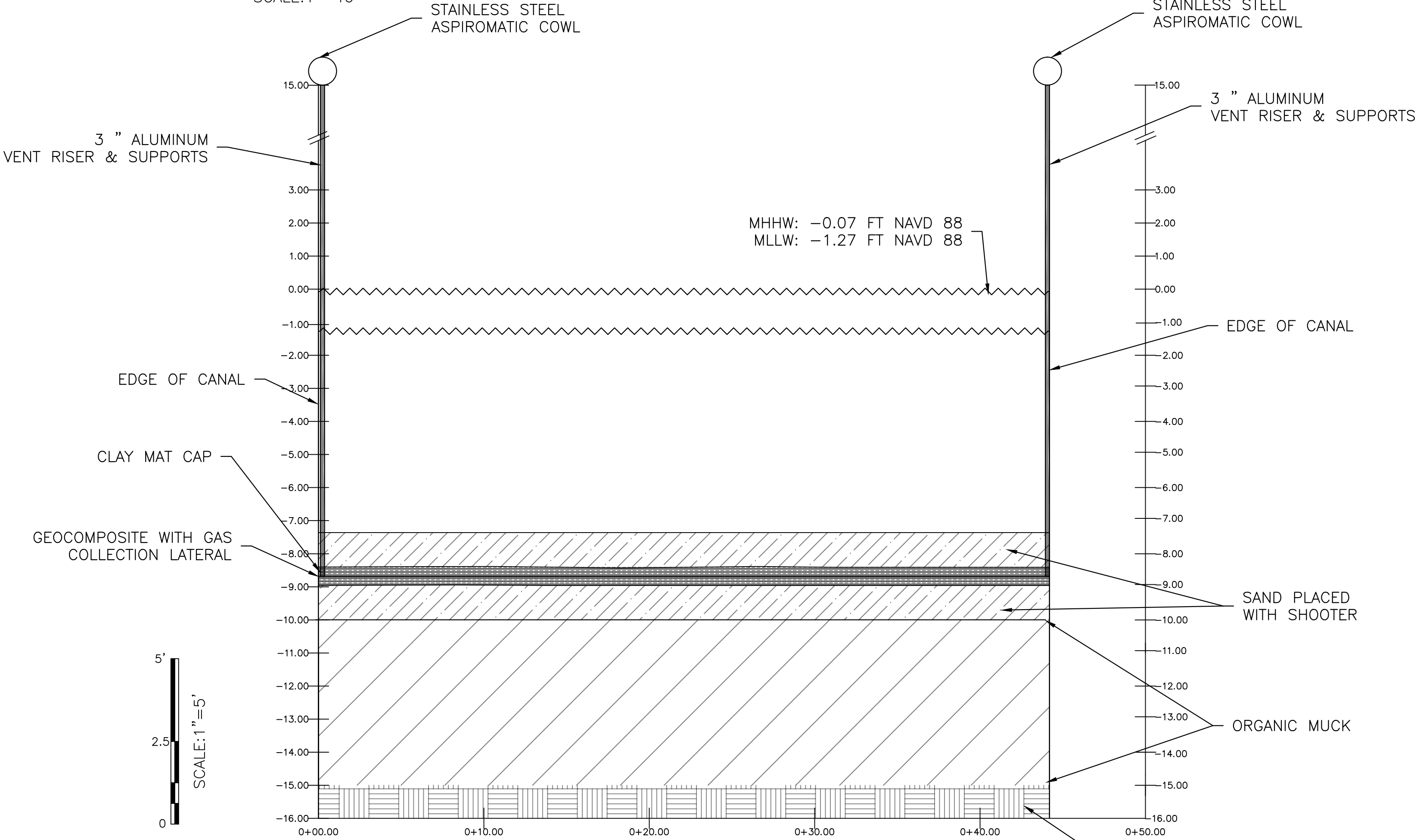
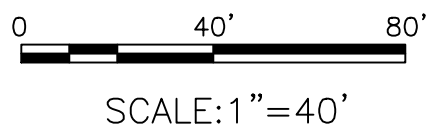
- LEGEND
- CONCEPTUAL CANAL AREA (0.5 ACRES WITH 5,000 CY OF ORGANIC MATERIAL)
 - GAS COLLECTION LATERALS
 - MONROE COUNTY PARCELS, 2010
 - TURBIDITY BARRIER



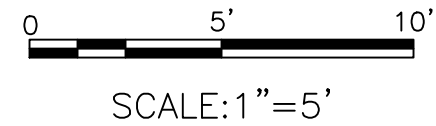
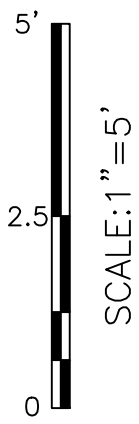
DETAIL SITE LAYOUT



PLAN VIEW



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
ALTERNATIVE
TECHNOLOGIES TO
ADDRESS ORGANIC
MATERIAL IN CANAL
BOTTOMS**

APPLICANT:



AMEC PROJECT No:
6783-15-2757.02

REVISIONS			
NO.	DATE	BY	APPROVED

DESIGNED BY:	SJH
DRAWN BY:	DJD
CHECKED BY:	SJH
APPROVED BY:	SJH
DATE:	05/31/2016

SHEET TITLE:
**CONCEPTUAL DESIGN
FOR A CLAY MAT CAP**

SHEET NUMBER:	REV. #
SHEET OF	SHEETS



NOTES:
1) THE CANAL WILL BE AUGMENTED WITH THE APPLICATION OF MICROBES AND ENZYMES EVERY 6 MONTHS TO PROMOTE DIGESTION OF THE ORGANIC MATERIAL.

LEGEND

[Solid Line] CONCEPTUAL CANAL AREA (0.5 ACRES WITH 5,000 CY OF ORGANIC MATERIAL)

[Dashed Line] MONROE COUNTY PARCELS, 2010

[Wavy Line] TURBIDITY BARRIER

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

0 30' 60'
SCALE: 1"=30'

ENGINEER OF RECORD
STEPHEN HANKS
FL PE #72253

PROJECT:
EVALUATION OF ALTERNATIVE TECHNOLOGIES TO ADDRESS ORGANIC MATERIAL IN CANAL BOTTOMS
APPLICANT:

AMEC PROJECT No:
6783-15-2757.02

REVISIONS			
NO.	DATE	BY	APPROVED

DESIGNED BY:	SJH
DRAWN BY:	DJD
CHECKED BY:	SJH
APPROVED BY:	SJH
DATE:	05/31/2016

SHEET TITLE:
CONCEPTUAL DESIGN FOR AN AERATION WITH BIO-AUGMENTATION SYSTEM

SHEET NUMBER:	REV. #
SHEET OF	SHEETS