# Methane Production in Inlet Sediments:
## Spatial Variability and Alternatives for Mitigation

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**KEYNOTES:**

(1) Methane-producing microorganisms inhabit anaerobic (low-oxygen) sediments, such as those in the Cayuga Inlet

(2) Laboratory tests indicate that if anaerobic conditions in sediment persist after dredging, up to 30,300 kg of methane could be released into the atmosphere

(3) A number of methane mitigation measures, such as promoting aerobic conditions during dewatering or capturing any methane produced, could be incorporated into the dewatering process to prevent the release of this greenhouse gas.

### Introduction

Methane ($CH_4$) is one of the most significant greenhouse gasses after carbon dioxide. Since pre-industrial times, atmospheric methane concentrations have increased from approximately 715 parts per billion (ppb) to 1774 ppb in 2005 as a result of human activity. This has contributed a radiative forcing of 0.48 $W/m^2$, nearly a third the radiative forcing of carbon dioxide despite methane's much lower atmospheric concentration (IPCC 2007). Thus, the release of even a small amount of methane is of concern for global climate change.

Dredging the Cayuga Inlet has the potential to release methane into the atmosphere. Low-oxygen sediments are home to a community of methanogenic archea, microorganisms which produce methane as the final step of fermenting organic matter in anaerobic respiration. This sort of methane biogenesis constitutes most of the recent methane production (Reeburgh 1996).

Inlet sediments, like most sediments at the bottoms at lakes, are likely to be anaerobic, or low in oxygen, and thus home to methanogens. How much methane production can we expect from the dredging of the Cayuga Inlet? Is this production uniform, or are there hotspots of particular concern? To find out, we collected sediment samples from a variety of locations and measured their total methane production over a month.

### Methods

Sediment samples were collected from above the 60-foot dam at the Six Mile Creek Reservoir (Fig. 5.1) and the Cayuga Inlet (Fig. 5.2) using canoes and a small Ekman dredge. Initial plans called for sample collection only from the inlet, but the presence of Hydrilla verticillata in the inlet postponed sample collection, so samples were first collected from the reservoir. Sediment samples were placed in mason jars and the headspace

**Figure 5.1** - Sediment collection sites, Six Mile Creek Reservoir

filled with water, following standard Fahey-Yavitt lab procedures. Samples were left to rest and settle in a dark cabinet for approximately a week after collection.

After a week of rest, samples were stirred to free any methane produced and briefly left to settle again before the water filling the headspace was drained. Then the mason jars were sealed and all air evacuated to create an anoxic environment. Approximately every week (for reservoir samples) or twice a week (for inlet samples) for a month following, a 20 milliliter gas sample was drawn through a septum in the lid of each jar using a syringe. Each gas sample was then

**Figure** 5.2 - Sediment collection sites, Cayuga Inlet

injected into a gas chromatograph to measure methane concentration.

Samples of lab air and standard 2000 parts per million methane were also measured to test for anomalous conditions in the lab and establish proper calibration, respectively.

Parts per million of methane were converted to micromoles and standardized to the amount of sediment in each sample, thus returning results in micromoles of methane production per liter of sediment over time.

## Results

*Reservoir samples*

Because methane production in the inlet, not the reservoir, was the primary concern, reservoir samples were used to test and refine methods. Methane production in all reservoir samples increased substantially over the testing period (Table 5.1), confirming the presence of methanogens and organic carbon in the samples. Because jar headspace was not recorded for reservoir samples, meaningful comparisons between samples was not possible; however, all samples showed significant methane production over the testing period.

Taking into account the reservoir sample results, methods were altered as follows:

| Sample ID | Concentration [ppm] 10.14.2011 | Concentration [ppm] 10.21.2011 | Concentration [ppm] 10.31.2011 |
|---|---|---|---|
| R1 | 83094 | max | max |
| R2 | 1175 | 4081 | 8756 |
| R3 | 1221 | 11871 | 38779 |
| R4 | 55942 | 91305 | max |
| R5 | 2139 | 13358 | 41613 |
| R6 | 4418 | 17011 | 47511 |
| C1 | 106537 | max | max |
| C2 | 21986 | 58476 | 104395 |
| C3 | 3752 | 22871 | 57598 |
| C4 | 52594 | 114861 | max |
| C5 | 23330 | 69842 | max |
| C6 | 8283 | 38066 | 82299 |
| L1 | 20677 | 59468 | 100834 |
| L2 | 6675 | 31150 | 59371 |
| L3 | 6795 | 23605 | 20551 |
| L4 | 2979 | 22868 | 53980 |

**Table** 5.1 - Methane production in Reservoir samples, parts per million

sample testing increased in frequency, from once to twice per week; the sensitivity of the gas chromatograph was adjusted to be able measure higher expected methane concentrations; future sediment samples were collected in larger jars, to facilitate drawing off gas samples; and headspace in the jars was measured to allow conversion from parts per million to moles.

*Inlet samples*

Most inlet samples produced methane over the testing period, with the only exception being sample 1W (Table 5.2). Methane production in inlet samples sorted into three groups and two anomalous samples. The first group, consisting of samples 1C, 2C, 3C, 4C, and 6C, produced very little methane throughout the experiment, with total methane production remaining below 200 umol per liter of wet sediment. The second group, comprising samples 1E and 2E, produced very little methane initially, but slowly increased production to 500-1000 umol/L wet sediment over the course of the month. The third group, samples 5W and from the adjoining culvert, produced methane rapidly during the first week before tapering off to a final production between 1000 and 2000 umol/L wet sediment. Sample 1W appears to have reached its peak methane production before testing even began and methane concentration in the jar declined for unknown reasons over the month. Finally, sample 5C produced methane in substantial quantities throughout the month, peaking at about 4,700 umol/L wet sediment at the end of the testing period with no definite signs of tapering off.

With the exception of 5C, center samples showed very low methane production (Fig. 5.3). Samples showing appreciable methane production (Fig. 5.4) were generally located near the east and west banks of the channel. In addition, higher methane production is concentrated in certain hotspots, such as the narrow Six Mile Creek inlet, while lower methane production is scattered in the center of the wider flood control channel (Fig. 5.5).

| Sample ID | 11-Nov-11 | 15-Nov-11 | 18-Nov-11 | 22-Nov-11 | 29-Nov-11 | 2-Dec-11 |
|---|---|---|---|---|---|---|
| 1E | 117.94 | 25.08 | 191.35 | 404.38 | 675.49 | 850.74 |
| 1C | 15.20 | 46.54 | 63.65 | 57.06 | 48.82 | 55.85 |
| 1W | 429.78 | 50.42 | 64.45 | 7.07 | 0 | 4.3 |
| 2E | 60.95 | 89.95 | 311.11 | 454.02 | 607.89 | 602.64 |
| 2C | 118.54 | 105.9 | 68.1 | 3.59 | 2.87 | 2.03 |
| 3C | 96.66 | 63.7 | 7.82 | 2.81 | 72.35 | 126.26 |
| 4C | 30.17 | 26.24 | 32.85 | 50.44 | 174.68 | 151.56 |
| 5C | 729.42 | 1764.37 | 2726.77 | 3699.59 | 4761.17 | 4733.22 |
| 5W | 408.34 | 963.74 | 1357.89 | 1532.43 | 1498.98 | 1708.33 |
| 6C | 105.94 | 68.25 | 15.59 | | 1.09 | 1 |
| Culvert | 251.57 | 692.45 | 1109.23 | 1229.57 | 1311.65 | 1267.82 |

**Table** 5.2 -Methane production in Inlet samples, umol methane per liter of wet sediment

## Discussion and conclusions

The results suggest several alterations to the procedure for future studies of methane production in the Cayuga inlet.

The peculiar pattern of methane production over time in inlet sample 1W, which peaked before testing started and apparently consumed methane throughout the testing period, suggests that methane concentrations should be measured sooner than a week after samples are prepared; in fact, establishing a baseline methane concentration immediately after evacuating the air in the jar might be a good idea. In addition, a more thorough study would continue measurements of methane concentration until all samples had ceased production, unlike sample 5C, whose methane concentration was still increasing when the experiment was ended.

The non-uniform spatial distribution of methane production also suggest that a more thorough survey is necessary to accurately estimate potential methane production from inlet sediments. In particular, the hotspot of methane production in Six Mile Creek is also the only source of sample from

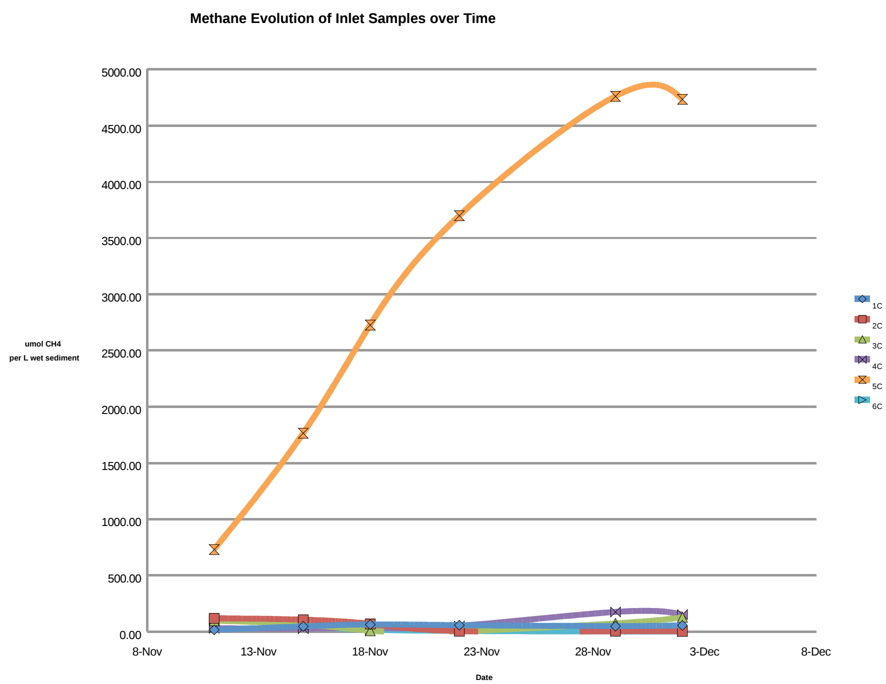


**Figure** 5.3 -Total methane production in center Inlet samples over time

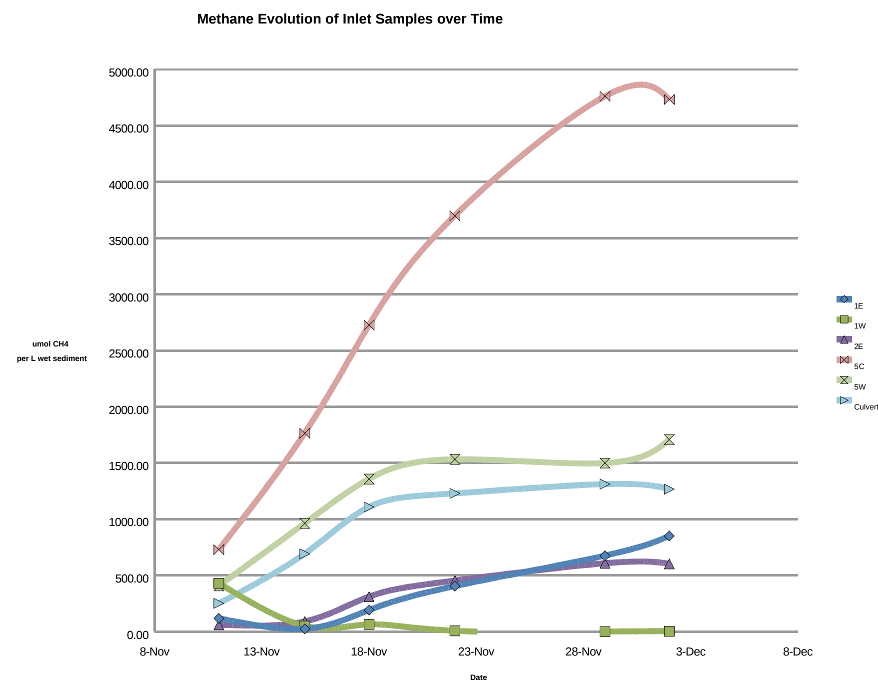


**Figure** 5.4 - Total methane production in higher-range Inlet samples over time

Six Mile Creek; most samples were taken from the Flood Control Channel, which the city of Ithaca is not responsible for dredging. Are methane production values in the hotspot typical of the Six Mile Creek channel? Does methane production further downstream in the Inlet more closely resemble that in the Flood Control Channel or in Six Mile Creek channel? To be able to accurately assess the methane output of the dredging project, these questions must be addressed, and more thorough sampling throughout the inlet would do so.

Input of organic matter may contribute to the observed geographical distribution of hotspots of methane production (Fig. 5.5). The only hotspot in the flood control channel occurs near the west bank; the Six Mile Creek hotspot, near the Buffalo Street Bridge, is in a narrow channel. Both these locations will receive a higher input of organic matter than the center of the broad flood control channel, thus providing more food for the methanogens. In addition, the Six Mile Creek hotspot is downstream of a wooded area with overhanging vegetation, which will also contribute substantial quantities of organic matter to the channel sediments. This stands in contrast to the flood control channel, whose rip-rapped banks and grassy verge can contribute relatively little organic matter for decomposition.

Several possible approaches to pre-

Figure 5.5 - Geographical distribution of methane production

**Peak Methane Production of Inlet Samples**

**Key**

**2000-4000 umol $CH_4$ per uL Air**

**500-2000 umol $CH_4$ per uL Air**

**150-500 umol $CH_4$ per uL Air**

**0-150 umol $CH_4$ per uL Air**

1E = 009
1C = 007
1W= 011
2E = 012
2C = 013
3C = 014.5
4C = 015
5C = 005
5W=006
6C = 017
Culvert = 014

venting or mitigating methane release from dredging might be incorporated into the sediment dewatering and reuse plans. The first option is to artificially hasten the onset of aerobic, rather than anaerobic, conditions in the sediment. This would shift the microbial community from methanogens to $CO_2$-producing bacteria. Three possibilities for promoting the diffusion of oxygen into the sediment are turbation, aeration, and spreading the sediment thinly. Periodic turbation, or mixing, of the sediment would incorporate oxygen further down into the sediment column, thus promoting aerobic conditions. Aeration could be done either mechanically or biologically, using pipes, roots, or burrowing worms to let oxygen penetrate further down. However, dense vegetation growing on the sediment is likely to decrease oxygen diffusion. Finally, since the most anaerobic conditions are deep in the sediment and oxygen diffusion is highest near the surface, simply spreading the sediment thinly would increase oxygen concentration and prevent anaerobic conditions.

Methane capture has been used on landfills (Bracmort et al, 2009). This approach sees methane production as a resource rather than a liability. The dewatering site would be capped and methane collected as it rose. The methane could then be burned as biofuel. However, since methane production in most samples was relatively low and ceased after approximately two weeks, methane capture might not be economically viable.

In fact, methane production may be low enough to consider methane mitigation as only a secondary concern in sediment dewatering and processing, taking a back seat to more pressing concerns such as Hydrilla treatment. If the low methane production of the samples taken from the center of the flood control channel are typical, then dredging would produce approximately 100 or 700 kg of methane for 100,000 and 670,000 cubic yards of sediment, respectively. Even if all the sediment dredged produced methane at a high rate comparable to 5C, methane production would be approximately 4,500 kg, for the lower dredging volume, or 30,300 for the higher. Especially considering that dredging will be spread over several years, this may not be enough production to justify incorporating elaborate mitigation strategies into dewatering. However, if methane mitigation can easily be incorporated into some other aspect of the project, such as Hydrilla treatment, then it might be worth taking into account.

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# Managing *Hydrilla verticillata* for the Cayuga Inlet

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**KEYNOTES:**
(1) *Hydrilla verticillata* is an invasive aquatic plant species.
(2) Dessication alone cannot kill fragments.
(3) Additional treatment will be needed.
(4) Not all existing turions will sprout after drying and natural recreation attraction.
(5) To ensure proper control, we require a monitoring-management plan

**Figure** 5.1 - Cayuga Inlet Hydrilla distribution (August 29, 2011). Open white circles indicate dense infestations and purple circles indicate presence of rooted fragments. *Image from Dr. Holly Menninger*

## Introduction

*Hydrilla verticillata* is an aggressive aquatic invasive from Eastern Asia, which has taken over much of the Southeastern and some Western US watersheds. Known to grow in almost any freshwater body and in only 1% of full sunlight, Hydrilla is an invasive capable of out-competing most native species in areas where it colonizes. Its cold-tolerant, monoecious biotype was discovered in the Cayuga Inlet of Ithaca, NY in early August. Initial identifier R. Johnson derived its population to be less than two years old as of 2011 (Menninger 2011). Hydrilla populations were limited to the immediate inlet area as of August 2011.

**Figure** 5.2 - Turion growth from *Hydrilla verticillata*

However, additional colonies of Hydrilla have been discovered further upstream in the inlet channel as well as channelized portions of Cascadilla creek since the initial August recording. This demonstrates Hydrilla's capability to spread relatively quickly, emphasizing the importance of a well-maintained quarantine and eradication protocol. Its high potential for spread using waterways as vectors is a critical hindrance in utilizing dredge material from the Cayuga Inlet in aquatic settings.

Monoecious *Hydrilla verticillata* utilizes its subterranean tubers, growing up to 1/2 inches long, to overwinter and re-sprout in the spring. Hydrilla produces turions, or overwintering buds, which will sink to lake bottoms during winter and sprout again when spring arrives. Finally, external force, like traveling boats, fragment Hydrilla stems deeper into waterways. These fragments will attach to boat exteriors or enter ballast water and will potentially spread to other waterways, where the individual nodes (areas where leaves are attached) on a fragment are capable of taking root. In order to execute a proper management protocol it is necessary to create a plan that will simultaneously account for fragments, turions, and tubers as negligence of one or more of these items will increase probability of Hydrilla introduction to any given water body.

## Materials and Methods

Hydrilla is present at the site to be dredged, so fragments of Hydrilla stems, turions, and tubers will also be present in the dredge material. If the Hydrilla in the dredge material is still viable, Hydrilla could be spread during the dredging process, at the dewatering site, when the dredged material is trucked, or when it is reused. The presence of *Hydrilla verticillata* is the very reason the DEC wants the dredge material kept away from water bodies. However, if desiccation itself could effectively kill the Hydrilla, then no such restriction would be necessary. To test this, we performed three quasi-experiments.

We collected *Hydrilla verticillata* from the Farmer's Market dock at the beginning of the semester by hand and shovel. Two buckets of soil were also collected at the docks. The Hydrilla were then kept in a greenhouse kept at 70 ˚F in a large bucket full of water. All Hydrilla used in the following experiments were from this collection.

## Stem Fragment Experiment

For the fragments of the plant itself, we wanted to test whether the length of the plant, the depth it was buried, and how completely it was buried affected its ability to re-grow. To test this, we created 12 samples with 20 fragments each buried in soil material collected from the Farmer's Market dock. We lined four plastic flats with fabric, so that the contents would drain, but would not fall out of the flat, and filled the flats with three samples each. The fragments had either 5 or 10 nodes (aka the point where the leaves formed a swirl). The fragments were buried 5 centimeters deep, which was nearly the bottom of the tray, 2.5 cm deep, or placed on the surface. They were either buried horizontally, so they would be completely covered, or vertically, so some of the Hydrilla fragments would be exposed to air. The flats were left undisturbed in the greenhouse for one week.

At the end of the week, the *Hydrilla verticillata* fragments were carefully dug up. The soil material did not dry evenly. The surface was almost completely dried out, grey, and caked, but at lower levels the soil was darker, granular, and slightly damp. Parts of the Hydrilla that were left exposed appeared dried out and grey or yellow, while the segments that were buried

**Figure** 5.3 - *Hydrilla verticillata* in flats - picture 1

**Figure** 5.4 - *Hydrilla verticillata* in flats - picture 2

**Figure** 5.5 - *Hydrilla verticillata* in flats - picture 3

still appeared green. The fragments were almost completely recovered; some nodes and leaves were lost digging them up.

Each sample was placed in a mason jar half-full of water. It was left to rehydrate for two weeks. To act as a control, two samples each of twenty 5 and 10 node Hydrilla that had been sitting in the bucket were put in half-full mason jars as well. At the end of those two weeks, algae was growing in most of jars. The samples were removed and placed in shallow dishes.

Each sample was visually divided into living and dead. Hydrilla fragments were classified as living if they retained shape out of water or were green, versus becoming limp and brown. They were also called alive if there was new growth or a turion off the original fragment.

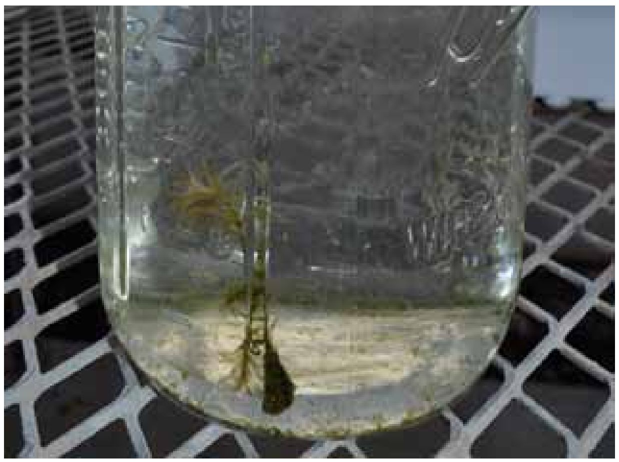

**Figure** 5.5 - *Hydrilla verticillata* fragment in a mason jar

**Figure** 5.6 - Mason jars containing *Hydrilla verticillata*

New growths and turions were also collected if they were not connected to a fragment. Each jar was rinsed out and refilled with water and a squirt of fertilizer. The living samples were put back in their respective jars. The process was repeated the next week, but no fertilizer was added. The following graphs show the results by treatment, depth, and number of nodes.

We observed the fragments for an additional week. No new growths formed. However, one sample decomposed, one turion sprouted, and one node grew further. The Controls continued to grow as well.

Our results showed that the dried Hydrilla did not survive as well as the controls (Fig 5.7, 5.8, & 5.9 on the following page). The number of life signs increased with the depth of the sample, presumably because moisture content increased. This would also explain why the samples that were buried completely did better than those that were vertically planted and partially exposed to air. The Hydrilla fragments that were longer survived better than the five-node Hydrilla. This might be because the longer fragments have more matter in them, so they can retain turgor and have enough storage to create new growths.

The second experiment involved only turions. These turions grew in the bucket of Hydrilla over several weeks. Ninety-eight turions were used in this experiment. Some were completely free-floating, some were still attached to short stems, and some were still fully attached to Hydrilla plants. The turions were divided equally between two flats lined with fabric. One flat was left to dry for a week, the other was left out to dry for two weeks. After the drying period was complete, the turions were placed in jars full of water. The free-floating turions were divided between two jars, the turions with some stem were placed in one jar, and the turions attached to plants were divided between two jars as well. After drying, the turions seemed bleached, but were still green. The leaves were very distinct. However, none of the turions sprouted.

This is interesting when contrasted with our first experiment, where one of the turions did sprout. The sprouted turion grew after the fragment had been dried. This suggests there might be a stress response.

We found one tuber in the dredge material. It was dried for one week during the stem fragment experiment at about 2.5 cm. It was then rehydrated in its own mason jar. It sprouted. This agrees with the literature, which suggests drying induces growth in tubers.

Our results are not concrete. All our Hydrilla were only dried for one or two weeks. It will take at least a year for the dredge material to dewater. Considering that the dredge will not dry evenly, further studies should consider the water content of the soil the Hydrilla is drying in. Re-growth, while easy to measure, is also not a concrete measure of survivability, especially for turions and tubers. The literature suggests tubers can remain dormant for up to five years. Dewatering can induce growth and end this dormancy period in Hydrilla, but more studies would need to be done to see what percentage of tubers would grow, and the length and severity of the desiccation needed.

From all of this, it seems unlikely desiccation alone will kill the *Hydrilla verticillata*, so some other treatment method is necessary. Treatment methods are discussed later in the report.

We were unable to do a light-curve for the Hydrilla. However, the literature says the plant has a Light Compensation Point (LCP) of 15 μmol/m2/s. Light extinction measurements were done at 13 points along the inlet. These measurements were performed with a secchi disk. Most reached this point between 1.5 and 2.5 feet. However, two points, the Cascadilla Creek boat docks and near the Science Center, reached bottom before this level of turbidity was reached. The Hydrilla infestation was heavy near these places. These two points were also the deepest parts of the channel that were measured. *Hydrilla verticillata* can grow past the LCP, but it is difficult for the plant to establish itself past these depths. This means that while Hydrilla will still float in the water column, it is

**Figure** 5.11 - *Hydrilla verticillata* turions in flats

**Figure** 5.10 - *Hydrilla verticillata* tuber

**Figure** 5.12 - *Hydrilla verticillata* turion closeup

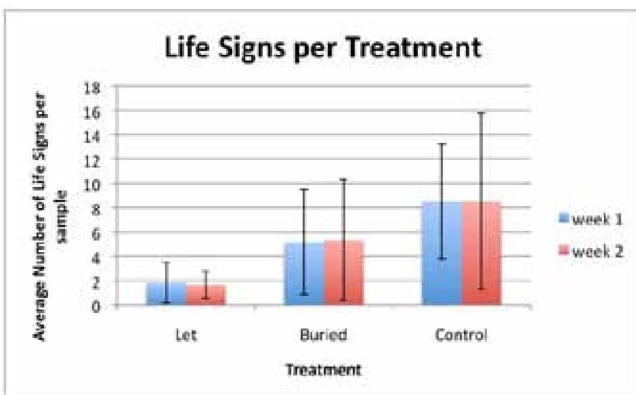


**Figure** 5.7 - *Hydrilla verticillata* life signs by treatment

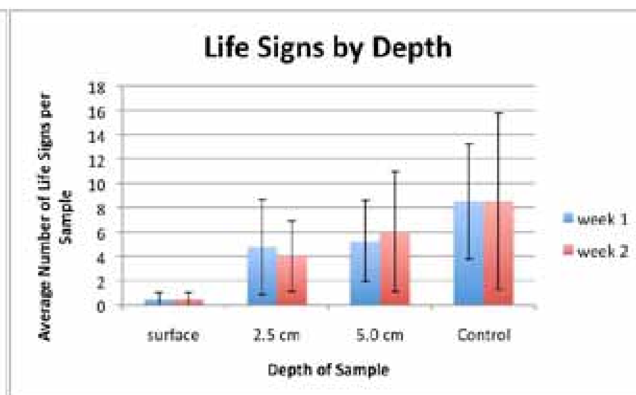


**Figure** 5.8 - *Hydrilla verticillata* life signs by depth

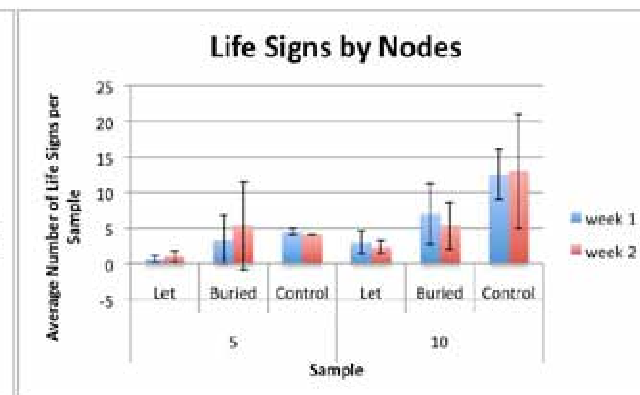


**Figure** 5.9 - *Hydrilla verticillata* life signs by node unlikely the Hydrilla will root in deep waters or persist in turbid areas. It would also be highly improbably for sprouting tubers in turbid sections of the channel to survive long enough to grow past the LCP without being able to gain energy from photosynthesis.

## Potential Management Plan

Management plans for Hydrilla in aquatic settings range from physical removal to chemical treatment to natural predator introduction. Due to the scope of our study, Hydrilla management will be a problem of what to do with fragments, tubers, and turions once dredge material has been taken out of the Inlet area. Thus Hydrilla should be treated as undesirable weed material within dewatering dredge material, and it would be more accurate to discuss potential strategies

**Figure** 5.13 - Light extinction measurements with secchi disk

to treat Hydrilla as belonging to an independent terrestrial system with high risk of spread to aquatic systems.

For the purposes of dredge material management, establishing complete eradication of Hydrilla from dewatering sites as the primary goal would be ideal. If the dredge material will enter water-bodies that already have populations of Hydrilla, the Hydrilla could be managed to a certain level. As the threat of spreading Hydrilla will remain, it is important to establish control measures for spread out dredge materials. One possible example of control measures for near-water usage would be the installation of silt fences around the site boundaries to ensure Hydrilla doesn't escape to the nearby water bodies.

The first item to note is that spreading dredge material over multiple locations for dewatering will also increase the potential for Hydrilla to enter any nearby waterways or streams. The dewatering processes typically involves dredge material being spread out over large areas of land, which means that during heavy rain, it is possible the runoff will contain Hydrilla. Thus, it would be more beneficial to minimize the number of dewatering sites and limit the spread of dredge material to watersheds where Hydrilla is already existent, at least until monitoring can confirm that Hydrilla reintroduction is unlikely.

The National Invasive Species Council dictates that there needs to be three phases to a monitoring program: detection, rapid assessment, and rapid response. Assuming the dredge material is under controlled surveillance, detecting Hydrilla in drying dredge material should be given top priority. Hydrilla requires constant human input and an adaptive management mindset. One potential monitoring method would be to combine Hydrilla monitoring with dewatering monitoring, which is a required process for dredge material usage.

Hydrilla is very similar on sight to local *Elodea canadensis* (Fig 5.14), and monitors will have to account for the fact that both species are likely to be in the dredge material. A key note on identifying the differences between the two is the number of leaves on individual nodes. Hydrilla stems will typically have whorls of five leaves, whereas elodea stems typically has whorls of three leaves.

It is to be expected that Hydrilla will not be growing or expanding in dewatering sites as they would in aquatic settings. Because of this, Hydrilla observation is difficult. It might be worth it taking soil column samples at randomly designated locations within the dewatering sites and sample for Hydrilla within the columns.

Lastly, Hydrilla propagule growth seasons and dredging seasons should not overlap. Hydrilla sprouts turions and produces tubers during the fall season in the Northeastern US, which means dredge material movement should be avoided during the months of August to October.

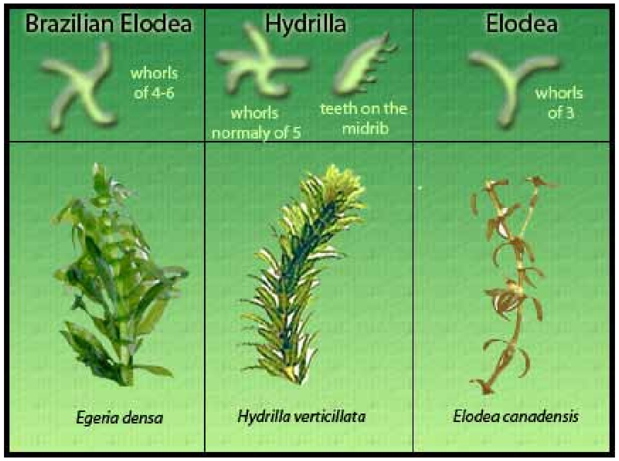


**Figure** 5.14 - Hydrilla-Elodea comparisons

## Potential Treatment Methods

Some potential treatment methods for Hydrilla in dewatering dredge material include physical removal, chemical treatment, and solarization. Although relevant, we will not discuss in detail other recognized means of Hydrilla management in aquatic environments such as biological control through grass carp or water level drawdown as they do not apply to terrestrial environments. We chose to focus on Hydrilla removal from the drying dredge material, and therefore terrestrial, setting. It is important to remember that all potential methods are fully theoretical; further experimentation and field trials will be necessary to ensure that Hydrilla do not spread after any such treatments.

**Physical Removal**

Physical removal of Hydrilla in aquatic environments is carried out by employing divers who use suction dredges to remove the invasive or by raking stems and rooted material by mechanical harvesters. Mechanical harvesters have been criticized as creating more fragments, which are capable of spreading the species. However, a different means of harvesting may be possible. Assuming that the dredge material is spread out on a field for dewatering, we can allow for the material to dry out to a certain period where we can employ machinery to till the land. Monitors will ensure Hydrilla do not spread while drying occurs. Ploughing the land with machinery will loosen and aerate the land, hastening the dewatering processes, but also upturn any vegetative matter hidden within the top layers of dredge material. If a monitor were to follow the ploughing vehicle along chosen plots and observe for any Hydrilla parts, the observers could make note of this and assign removal as parts are discovered. The advantage to this method is that the process will be highly target specific while allowing for dewatering and aeration of the dredge material at the same time, decreasing overall time taken to ready the material for further usage. Disadvantages here are the fact that intensive manual labor might not be cost effective and if the material is spread out too thick, the upturned top layer may not reveal all the Hydrilla. Thus, it may be possible to combine this method with the chemical treatment to be explained below.

**Figure** 5.15 a - Physical removal

**Figure** 5.15 b - Chemical treatment

**Figure** 5.15 c - Solarization

**Chemical Treatment**

Hydrilla chemical treatment typically involves the use of Aquathol K; a contact herbicide endothall, to kill Hydrilla growth. The City of Ithaca has deployed Aquathol K in the Cayuga Inlet area to remove biomass and stop turion and tuber production with mixed results; although biomass loss has been noted further treatment for turion and tuber removal will be necessary. Success cases for Hydrilla removal all indicate repeated spraying over multiple seasons, and tuber removal has been noted to be especially difficult. This in part has to do with the fact that Hydrilla cannot be efficiently sprayed due to water currents and the presence of subterranean organs like roots and tubers. Any Hydrilla biomass that does not come into proper and sufficient contact with Aquathol K will not be removed. If dredge material is spread out on a terrestrial patch, a similar method of chemical spray can be utilized with common herbicides such as Roundup, but as terrestrial patches would be more accessible, a more thorough application of chemicals will be possible. This will also remove any other weeds that could grow in the soil, and the method can be combined with monitoring efforts to ensure proper dewatering of dredge material.

**Soil Solarization**

Soil solarization involves controlling in-soil agents by capturing heat and energy from sunlight; the controller would cover the soil with plastic covers like polyethylene to trap solar energy for several weeks during the hot season of the year. Solarization has been known to increase soil temperature up to 131°F (55°C) at 2 inches deep and 99°F (37°C) at 16 inches deep. Hydrilla growth, tuber and turion production has been shown to cease at 86°F (30°C). Given that our experiments saw most, but not all, of the Hydrilla dry out at 70 °F (21°C), there is a likelihood that this procedure, if properly conducted, will allow for sufficient desiccation of Hydrilla that can properly eliminate fragments and tubers as well. Again, further experimentation will be necessary to determine at what soil temperature and relative water content tubers, the hardiest propagule, will die out. In short, it would be worth investigating whether it is possible to cook the Hydrilla to death in the soil. This will also assist in soil aeration and any other weed elimination from within the dredge material, both of which are known effects of soil solarization.

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# Alternative and Reference Sites

Gene Fifer

There are several potential uses for the sediments that will be removed from Cayuga Inlet. These fall into three categories: building material production, dry land fill or amendments, and wetland creation. There are thousands of dredging projects underway worldwide and the products that our restoration ecology class found are described in this section.

# Industrial Products: An Introduction

Matthew Horvath

In a sustainable city where recycling and reuse are prevalent, off-site product creation is certainly a viable option. The various alternatives include using dredge material in conjunction with other materials to create valuable products such as synthetic soil, lightweight aggregate, cement, and bricks. While this option reduces the need for a large disposal site, it might require new infrastructure in some cases since many of these products require specialized machinery to be created.

The city should not overlook these options because they have the ability to provide jobs and perhaps revenue from a continuous dredging process. This alternative has the potential to create a powerful image for the city. By taking a seemingly useless sludge, and reforming it into a valuable product, the city would be promoting sustainability, profiting, as well as improving its built environment.

**Mixing mineral and organic soil components at LI Firewood and Mulch in Suffolk County, New York**

# Synthetic Soils

Becky Mikulay

**KEYNOTES:**
(1) 7,000 cubic yards available between Cayuga Compost and Cornell Compost, and 2,000 cubic yards coarse organic material available.
(2) This should bring pH closer to 7, which may make Zn, Fe, Mn, and Al more bioavailable, but it will dilute concentrations of all nutrients.
(3) Addition of compost would also dilute and stabilize lead levels, possibly making material acceptable as topsoil for lawns, golf courses, etc. but not garden soil or high human contact soil.

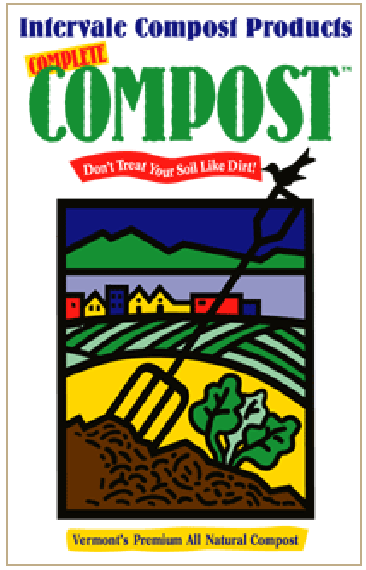


**Figure** 6.1 a - Intervale Compost Product, Burlington, VT

SCENARIO

Dredging channel for navigation 100' wide by 10'
= 100,000 cy of dredge material

| Dredge Amount(cy) | Organic Matter (cy) | % of Mix | Total cy | Retail value |
|---|---|---|---|---|
| 9,000 | 9,000 | 50 | 18,000 | $801,000 |
| 20,000 | 9,000 | 31 | 29,000 | $1,290,500 |
| 30,000 | 9,000 | 23 | 39,000 | $1,735,500 |
| 40,000 | 9,000 | 18 | 49,000 | $2,180,,500 |
| 50,000 | 9,000 | 15 | 59,000 | $2,625,500 |

* Based on Hydraulic Dredging Method
* Cubic Yards are per year dredge amount
* Retail value based $44.50 /cubic yard

**Figure** 6.1 b - Average production rate for the Canal Corporation sediment removal by hydraulic dredge = 80,000 cy per season

The process of manufacturing a synthetic topsoil requires fine-tuning the balance of sand, silt and clay content of the soil with the nutrient content and the organic matter content to blend a soil which can be used as a growing medium or for another specified purpose on a landscape project. Adding organic matter to a dredged sediment medium improves the quality of the soil and dilutes the quantity of any less desirable nutrients in the soil. A study by Ruiz Diaz and Darmody of the University of Illinois finds that dredged sediment can make excellent growing medium.

Using a manufactured topsoil on a landscape project is considered more environmentally friendly than harvesting a topsoil from agricultural fields for use in residential or commercial growing mediums. This is a "green" industry that Ithaca could be involved in continuously in conjunction with the ongoing Inlet dredging effort. While the dredged material on it's own may not have desirable properties – it can be considered a structureless "minute soil" which can transform quickly from a concrete-like consistency to a highly liquid sludge – the addition of organic matter (i.e. compost) begins to give the mineral dredge material some structure.

The city of Ithaca could work with Cayuga Compost, Cornell compost and Ithaca Brewing compost to transform a waste product into a useable product and a revenue stream, which would help cover the expense of dredging. It is estimated that about 7,000 cubic yards of organic matter are available in Ithaca and 2,000 cubic yards to course organic matter, which could be combined with the Inlet sediment.

Depending on the quantity of the annual dredged material and the required dilution of the sediment, a significant portion of the dredged sediment could be transformed into a new soil product. This process must be undertaken cautiously so as not to dangerously alter the pH balance of the soil material and suddenly make the heavy metals bioavailable. This synthetic soil product could become an acceptable material for lawns and golf courses, especially within Tompkins County, but would not be recommended for use in garden beds where more human contact occurs.

# Brick Production

Amy McLean

**KEYNOTES:**

(1) Hanseaten-Stein Brickworks industrially processes dredged sediment to bricks.
(2) Brick products are in compliance with German brick standards.
(3) Heavy metals are immobilized.
(4) The Georgia Institute of Technology found that brick samples consisting of 100% dredged material to be in compliance with ASTM criteria for building brick.

## Hanseaten-Stein Brickworks Bremen, Germany

Hanseaten-Stein Brickworks is an example of dredged material that can be processed into bricks at an industrial scale. Hanseaten-Stein uses a mixture comprising (by weight) 50% harbor sediments, 10% crushed bricks and 40% of two clays. 21,189 cubic feet per year of dredged material is collected from the Bremen Harbor and converted to over 5 million structurally stable bricks complying with German building standards. In 2002 a study was conducted analyzing the dredged sediment contaminant pathways in the environment during brick production. Little environmental impact was found and arsenic and other heavy metals were immobilized during the process.

## 100% Dredged Material Sand and Clay Substitution Bricks, Georgia

Researchers at Georgia Institute of Technology recently performed studies on the viability of making fired bricks from materials dredged from the Savannah River. Whereas most of the scientific literature focuses on using dredged materials as a partial clay and sand replacement, this study uses dredged materials as the primary component. Other additives include soybean oil, to improve lubricity, and barium carbonate to prevent the formation of scum. Brick properties were in compliance with ASTM criteria for building brick. The research concludes with identifying the potential for marine and river sediment

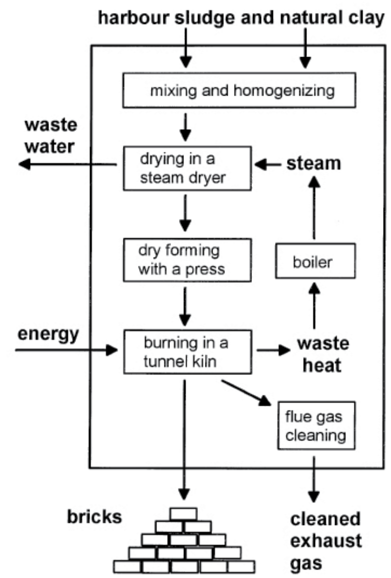


**Figure** 6.2 b - Brick processing method used by Hanseaten-Stein

Chemical composition of the raw material mixture [wt.%]

| Wt.% | Harbour sediment[a] 50% | Clay 1[b] 27% | Clay 2[b] 13% | Crushed bricks 10% |
|---|---|---|---|---|
| $SiO_2$ | 63 | 67 | 70 | 66 |
| $Al_2O_3$ | 11 | 22 | 19 | 16 |
| $Fe_2O_3$ | 8.3 | 6.1 | 6.4 | 7.7 |
| $TiO_2$ | nv[c] | 1.3 | 1.0 | 064 |
| CaO | 1.8 | 0.19 | 0.44 | 1.2 |
| MgO | 0.9 | 0.40 | 0.80 | 0.84 |
| $Na_2O$ | 1.9 | 0.20 | 0.18 | 1.0 |
| $K_2O$ | 1.6 | 2.5 | 2.0 | 1.6 |
| S | 0.3 | nd[d] | nv[c] | nv[c] |
| MnO | nv[c] | 0.01 | nv[c] | nv[c] |
| LOI | 10 | 6.3 | 5.5 | nd[d] |

[a] Nonpublished data of the port authorities, RFA-analyses, 1998.
[b] RFA-analyses of the clays.
[c] No value.
[d] Not detectable.

**Figure** 6.2 a - Composition of raw brick material from the Bremen Harbor (Both Images: Hamar & Volker) as an alternative source for manufacturing bricks and the recognition that these products comply with construction standards and legislative environmental requirements.

## Inlet Applications

Hanseaten-Stein Brickworks offers insight to industrial scale brick production as the amount of dredged sediment is similar to the amount that has been predicted of dredged sediment from the Cayuga Inlet to be removed per year over a period of approximately 20 years. More studies would be needed to determine the location, environmental impact and economic feasibility of a brick processing facility in Ithaca. In addition, Georgia Institute of Technology researchers show that it is possible to manufacture bricks that are structurally sound and in compliance with U.S. building standards.

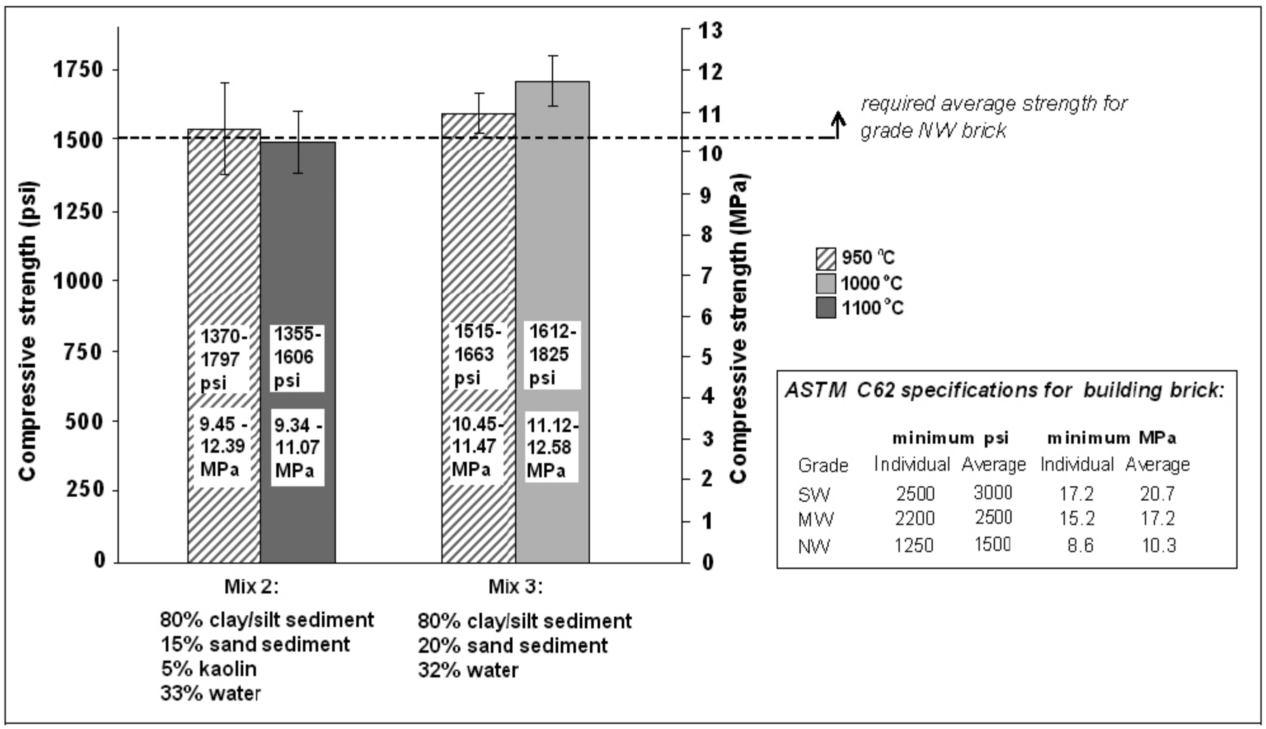


**Figure** 6.2 c - Average compressive strengths of bricks made of dredged sediment from the Savannah River. Error bars (standard deviations). (All images: Mezencevova)

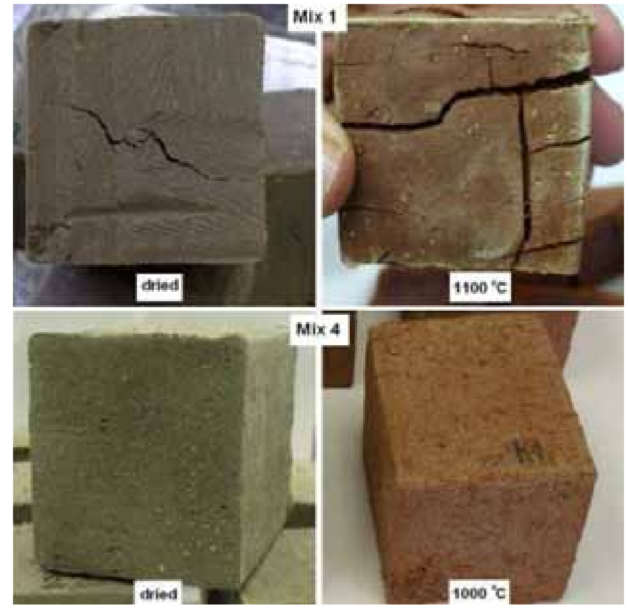


**Figure** 6.2 d - Effect of raw mix composition on formation of shrinkage cracks. Mix 1: 100%clay/silt dredged sediment, 45% water; Mix 4: 80% clay/silt and 20% sand dredged sediment, 36% water, 0.1% soybean oil, 0.5% $BaCO_3$

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# Lightweight Aggregate: Glen Mills, Pennsylvania

Amy McLean

**KEYNOTES:**
(1) The thermal process destroys organic compounds and binds metals within the aggregate.
(2) The end product has been proven to be inert and pass all environmental tests.
(3) Plants process sediments ranging from 250,000 to over 2,000,000 cubic yards per year.

## HarborRock
## Glen Mills, PA

HarborRock is a company that developed a process for manufacturing lightweight aggregate from dredged materials. Lightweight aggregate has applications in the construction industry including masonry blocks, structural grade concrete, hot mix asphalt, and geotechnical fill. The thermal process destroys organic compounds and binds metals within the aggregate and the end product has been proven to be inert and pass all environmental tests. HarborRock has partnered with state and federal agencies, including the Maryland Port Authority and the states of New Jersey and Delaware, to perform pilot tests on dredged material from various rivers and harbors. The tests ensure that the lightweight aggregate meets all ASTM standards as well as environmental regulations.

## Inlet Applications

This process is currently unsuitable within the Cayuga Inlet context. HarborRock plants process sediments ranging from 250,000 to over 2,000,000 cubic yards per year. In addition, there are no local processing facilities.

## References

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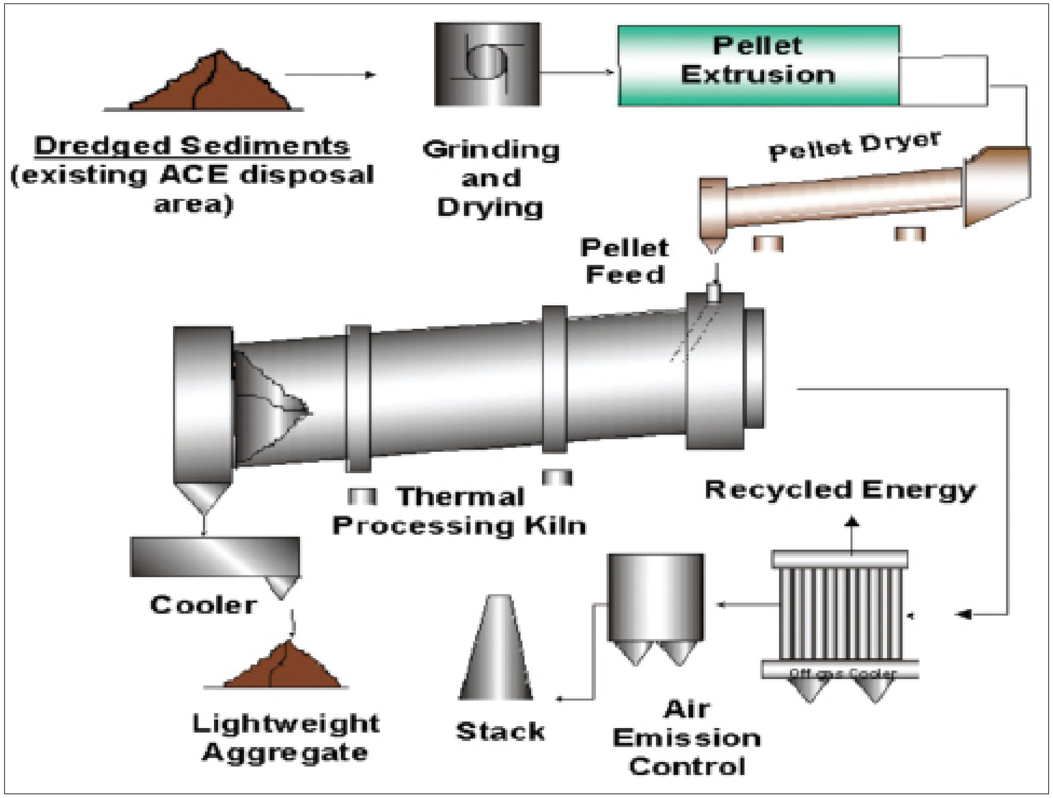


**Figure** 6.3a - Lightweight aggregate manufacturing process.

# Cement Lock®

Amy McLean

**KEYNOTES:**
(1) This process creates an opportunity where dredged material can be used as a partial replacement for Portland Cement. Construction grade cement product is ideal for general construction applications
(2) Organic contaminants are destroyed during manufacturing process.
(3) Heavy metals are immobilized.
(4) Demonstration plants are suited for treating 10,000 cubic yards/year.

## Gas Technology Institute
## Des Plaines, Illinois

Cement Lock® is a thermochemical manufacturing process developed by the Gas Technology Institute, that decontaminates and processes dredged material to be used as a partial replacement for Portland cement. During the manufacturing process, organic contaminants are destroyed and heavy metals are immobilized. A construction grade cement product is created, which is ideal for general construction applications. Demonstration plants are suited for treating 10,000 cubic yards per year.

## Inlet Applications

This process could potentially be applied to fit within the dredging process and would create a product useful to the community. However, a processing facility near the inlet would be required.

## References:

Jones, Keith W. "Cement-Lock® Technology for Decontaminating Dredged Estuarine Sediments." (2008). Gas Technology Institute, Nov. 2008. Web. 16 Nov. 2011. <http://www.bnl.gov/wrdadcon/publications/reports/GTI-FR-11-2008/FinalReport-15372-Cement-Lock-approved.pdf>.

**Figure** 6.4 b - Demo Plant in Bayonne, NJ.

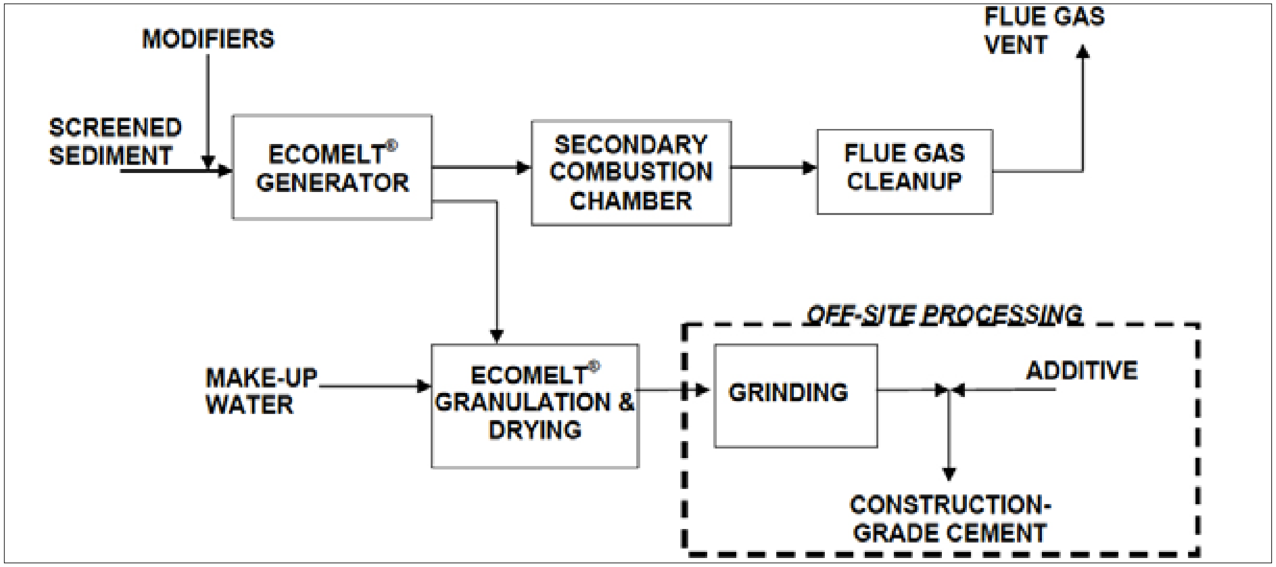


**Figure** 6.4 a - Cement Lock® manufacturing process. (All images: Jones)