*BioGenesis*SM *Technology Summary Report*

Decontaminating Dredged Estuarine Sediments

Cleaning Today ...
For Tomorrow

March 1998

Prepared for:
Brookhaven National Laboratory
Upton, New York

U.S. EPA Region 2
New York, New York

BioGenesis Enterprises, Inc.
7420 Alban Station Blvd. · Suite B-208 · Springfield, Virginia 22150 USA · TEL (703) 913-9700 · FAX (703) 913-9704

ABSTRACT

BioGenesis® Sediment Washing is an innovative, emerging technology that removes organic and inorganic contaminants such as PCBs, PAHs, organochlorines (pesticides, herbicides), and heavy metals from sediment particles both larger and smaller than 75 micrometers (200 mesh) in size. It overcomes the limitations of conventional washing methods that have difficulty in decontaminating fine silt and clay mixtures.

This document describes the technology and summarizes the development testing that occurred from 1991 through 1997, under, successively, the auspices of the U.S. EPA Superfund Innovative Technology Evaluation (SITE) program, Environment Canada's SEDTECH program, and, since 1995, U.S. EPA Region 2's Water Resources Development Act (WRDA) Sediment Decontamination program. Brookhaven National Laboratory has provided program management for the latter work.

Report sections describe the technology and its conceptual model, summarize the testing that has occurred during development, identify the technology's current status, and outline the next steps in commercialization scale-up. The purpose of the report is to consolidate in one document information that has been derived from the extended development testing and project results. It will serve as a baseline for scale-up to full commercial applications.

Table of Contents

Page

1 EXECUTIVE SUMMARY 1
1.1 Nature of the Sediment Decontamination Problem 2
1.2 Conventional Washing Technology 2
1.3 BioGenesis℠ Sediment Washing Technology 3
1.4 BioGenesis℠ Technology Development and Testing Overview 5

2 DEVELOPMENT SUMMARY, 1991 - 1993 10
2.1 Large Particle Washing under the U.S. EPA SITE Program 10
2.2 Thunder Bay Study (SEDTECH) for Environment Canada 11
2.2.1 *Project Description* 11
2.2.2 *Experimental Design and Procedures* 12
2.2.3 *Data Management, Analysis, and Interpretation* 15
2.2.4 *Conclusions and Recommendations* 18

3 PROCESS THEORY AND EQUIPMENT DEVELOPMENT, 1993 - 1994 19
3.1 Process Theory 19
3.1.1 *Uncontaminated Sediment Structure* 19
3.1.2 *Contaminated Sediment Structure* 21
3.1.3 *Breaking the Sediment-Contaminant Structure* 23
3.1.4 *Transferring Contaminants to the Water Phase* 23
3.2 Development of Larger-Scale Equipment 24

4 SEDIMENT APPLICATIONS 1995 - 1997 25
4.1 Overview of WRDA Studies, 1995 to Date 25
4.2 Initial WRDA Bench Study, October 1995 25
4.2.1 *Project Description* 25
4.2.2 *Experimental Design and Procedures* 27
4.2.3 *Sampling and Analysis* 30
4.2.4 *Data Management, Analysis, and Interpretation* 31
4.2.5 *Discussion of Results* 31
4.2.6 *Conclusions and Recommendations* 33
4.3 WRDA Bench Study, February 1997 (BNL 2) 34
4.3.1 *Project Description* 34
4.3.2 *Experimental Design and Procedures* 35
4.3.3 *Sampling and Analysis* 38
4.3.4 *Data Management and Analysis* 39
4.3.5 *Conclusions and Recommendations* 47
4.4 WRDA Bench Study, August 1997 (BNL 3) 48
4.4.1 *Project Description* 48
4.4.2 *Experimental Design and Procedures* 50
4.4.3 *Sampling and Analysis* 52
4.4.4 *Data Management, Analysis, and Interpretation* 54
4.4.5 *Conclusions and Recommendations* 55

4.5 WRDA Bench Study Nov 97 (BNL 4) 55
4.5.1 *Project Description* 55
4.5.2 *Experimental Design and Procedures* 58
4.5.3 *Sampling and Analysis* 60
4.5.4 *Data Management, Analysis, and Interpretation* 61
4.5.5 *Conclusions and Recommendations* 64
4.6 Contaminant Transfer Study, October - December 1997 65
4.6.1 *Background* 65
4.6.2 *Purpose* 66
4.6.3 *Procedure* 66
4.6.4 *Results* 67
4.6.5 *Conclusions and Recommendations* 75

5 STATUS OF BIOGENESIS℠ TECHNOLOGY AS OF MARCH 1998 78
5.1 Surfactant Chemicals 78
5.2 Sediment Preprocessor Subsystem 78
5.3 Sediment Processor Subsystem 78
5.4 Collision Chamber Subsystem 79
5.5 Cavitation Subsystem 79

6 SEDIMENT HANDLING, PREPARATION, AND FEED; LIQUID-SOLID SEPARATION; AND WATER TREATMENT 80
6.1 Sediment Handling and Feed Subsystem 80
6.1.1 *Processing site within 400 - 800 feet of barge mooring* 81
6.1.2 *Processing site within 800 to 1,500 feet of barge mooring* 81
6.1.3 *Processing site outside pumping distance from the barge mooring* 82
6.2 Liquid-Solid Separation Subsystem 82
6.3 Water Treatment Subsystem 84

7 PILOT DEMONSTRATION PLANNING 86
7.1 Transition from Bench to Pilot Scale 86
7.2 Objectives 86
7.2.1 *Demonstrate BioGenesis℠ technology at pilot scale* 86
7.2.2 *Obtain design information for scale-up* 86
7.2.3 *Produce treated material for beneficial reuse evaluation* 89
7.3 Pilot Demonstration Overview and Schedule 90
7.3.1 *Planning, Preparation, and Permitting* 90
7.3.2 *Core System Operation* 91
7.3.3 *Liquid-Solid Separation and Water Treatment Evaluation* 91
7.3.4 *Integrated Operation* 91
7.4 Permitting Considerations 94
7.5 Process Flow Overview 94
7.6 Site Requirements 96
7.6.1 *Pilot Demonstration Site* 96
7.6.2 *Full-scale Site* 96
7.7 Site and Equipment Configuration 96

List of Figures

Figure 1. BioGenesis K Sediment Washing , PAHs, PCBs, Dioxins, Metals, Bench Testing Summary 1
Figure 2. Illustration of elements of a contaminated solid sediment particle. 2
Figure 3. BioGenesis K sediment washing process flow 3
Figure 4. Contaminated particle before washing. 4
Figure 5. Contaminated particle after washing step 2. 4
Figure 6. Contaminated particle after washing step 3. 4
Figure 7. Contaminated particle after washing step 4. 4
Figure 8. Contaminated particle after washing step 5. 4
Figure 9. Overall effectiveness, crude oil contaminated refinery soil. 10
Figure 10. Grain size distribution, Thunder Bay sediment 11
Figure 11. BioGenesis K sediment washing, functional flow 13
Figure 12. Overall removal effectiveness, BioGenesis K Sediment Washing, Thunder Bay Harbour, Ontario, sediment. 16
Figure 13. BioGenesis K washing, PAH removal effectiveness, lower concentration pollutants, Thunder Bay Harbour sediment 17
Figure 14. BioGenesis K washing, PAH removal effectiveness, higher concentration pollutants, Thunder Bay Harbour sediment 17
Figure 15. Cross-sectional model of uncontaminated sediment 21
Figure 16. Particle Size Distribution, WRDA Testing, 10/30/95 26
Figure 17. BioGenesis K system process flow, WRDA testing, 10/30/95 28
Figure 18. Particle size distribution, Newtown Creek sediment, WRDA testing, 2/28/97 . . 35
Figure 19. BioGenesis K system bench process flow, WRDA testing, 2/28/97 37
Figure 20. TOC and TPH results, WRDA testing, 2/28/97 40
Figure 21. PAH results, WRDA testing, 2/28/97 41
Figure 22. PCB results, WRDA testing, 2/28/97 42
Figure 23. Dioxin/furan results, WRDA testing, 2/28/97 43
Figure 24. Metals results, WRDA testing, 2/28/97 45
Figure 25. Removal summary, WRDA testing, 2/28/97 46
Figure 26. Particle size distribution, Newtown Creek sediment, 8/27/97 bench testing . . . 48
Figure 27. BioGenesis K system process flow, WRDA testing, 8/27/97. 51
Figure 28. BioGenesis K system flow, BNL bench testing, 11/14/97 59
Figure 29. Metals removal progression, successive chelation treatments 64
Table 23. Contaminant transfer study, high organic content case 69
Figure 30. Contaminant absorption and partitioning, total for 7 compounds, low organic content case 71
Figure 31. Sediment contaminant transfer, absorption by organic/inorganic solids, low organics case 72
Figure 32. Sediment contaminant transfer, liquid to organic solids and degradation 73
Figure 33. Contaminant absorption and partitioning, total for 7 compounds, high organic content case 73
Figure 34. Sediment contaminant transfer, liquid to inorganic solids 74
Figure 35. Sediment contaminant transfer, liquid to organic solids & degradation 75
Figure 36. BioGenesis K process flow (feed, processing, organic solids removal) 78
Figure 37. BioGenesis K process flow (washing, cavitation) 79

Figure 38. Liquid-solids separation flow using centrifugation and vacuum filtration. 83
Figure 39. Liquid-solid separation process flow using electro-coagulation and screw press technology. 84
Figure 40. BioGenesis K process flow (water treatment options) 85
Figure 41. BioGenesis K sediment decontamination pilot project schedule 92
Figure 42. BioGenesis K process flow diagram and mass balance. 95
Figure 43. Typical washing equipment and site layout 97

List of Tables

Table 1. Principal BioGenesis K Technology Development Testing 6
Table 2. Grain Size Distribution of BioGenesis K Technology Tests 6
Table 3. Unit Processes Used During BioGenesis K Development Testing 7
Table 4. Principal Results and Interpretation of Testing 7
Table 5. Untreated Sediment Contamination Levels, Thunder Bay 12
Table 6. Sediment Washing Analysis Matrix 14
Table 7. Thunder Bay Testing Results 15
Table 8. Newtown Creek Untreated Sediment, November 1995 Bench Testing 26
Table 9. Triangle PAH Results Summary 31
Table 10. Functional Description of Bench System Equipment 35
Table 11. BioGenesis K Bench System Sample Point 38
Table 12. Adjustment of Dioxin/Furan Results Using Toxicity Equivalent Factors 44
Table 13. Newtown Creek Untreated Sediment, August 1997 Bench Testing 49
Table 14. Functional Description of Bench System Equipment 50
Table 15. BioGenesis K Bench System Sample Point 52
Table 16. Untreated/Treated Comparison, August 1997 Bench Testing 54
Table 17. Untreated Test Results, BNL4 Reprocessing 57
Table 18. Functional Description of BNL 4 Bench System Equipment 58
Table 19. BioGenesis K Bench System Sample Point 60
Table 20. Treated Test Results, BNL4 Reprocessing 61
Table 21. Summary of Successive Treatments 62
Table 22. Contaminant transfer study, low organic content case 68
Table 24. Observed appearance changes 70
Table 25. BioGenesis Pilot Plant Equipment List 98

1 EXECUTIVE SUMMARY

BioGenesis K Sediment Washing is an innovative, emerging technology that removes organic and inorganic contaminants such as PCBs, PAHs, organochlorines (pesticides, herbicides), and heavy metals from sediment particles both larger and smaller than 75 micrometers (200 mesh) in size. It overcomes the limitations of conventional washing methods that cannot decontaminate fine silt and clay mixtures.

Starting in 1991, the BioGenesis K sediment washing technology was first tested at bench scale under the sponsorship of Environment Canada's Wastewater Technology Centre. From 1991 to 1995, the technology was demonstrated on several soil and sediment washing projects. Since 1995 the technology has been under evaluation by the U.S. Environmental Protection Agency Region 2 (EPA) and the U.S. Army Corps of Engineers New York District (USACE), working in conjunction with Brookhaven National Laboratory (BNL). The work has been supported by both private funding and public funding under the federal Water Resources Development Acts (WRDA) of 1992 and 1996 to develop technologies for decontaminating estuarine sediments from New York/New Jersey Harbor. Figure 1 gives an overall view of the results of bench testing. Details are contained in subsequent sections of this report.

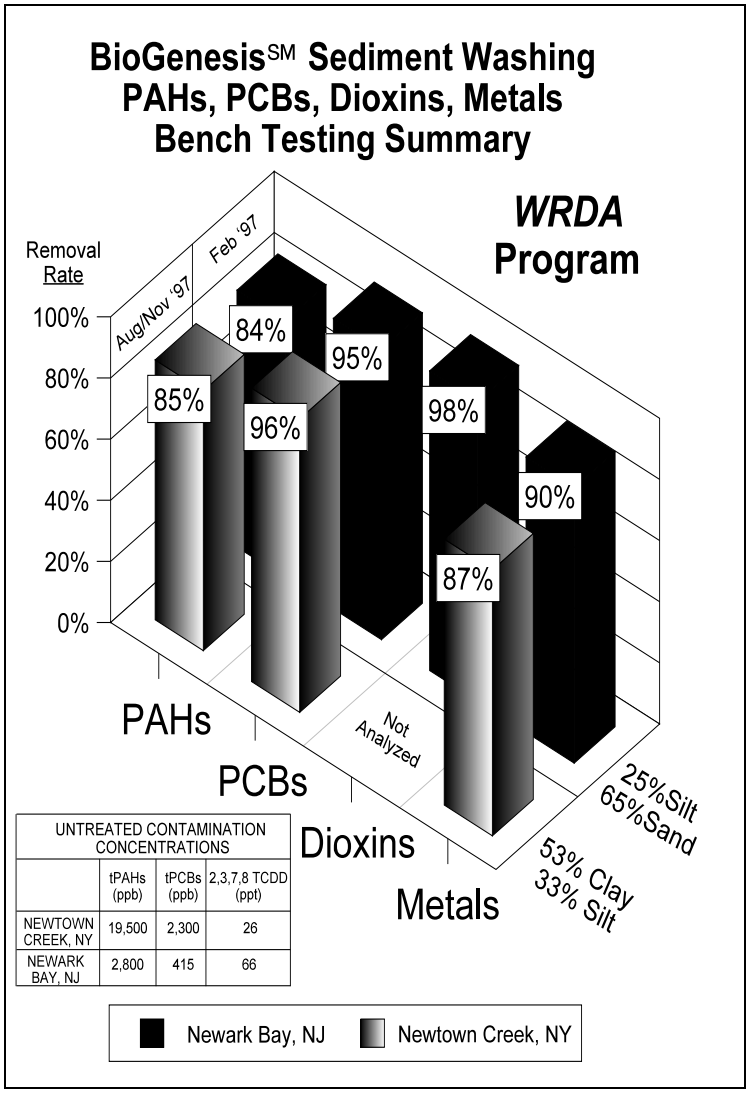


Figure 1. BioGenesis K Sediment Washing , PAHs, PCBs, Dioxins, Metals, Bench Testing Summary

Report sections that follow describe the technology and its conceptual model, summarize the testing that has occurred during development, identify the technology's current status, and outline the next steps in commercialization scale-up. The purpose of the report is to consolidate in one document information that has been derived from the extended development testing and project results. It will serve as a baseline for scale-up to full commercial applications.

Through research and testing conducted since 1991 with soils and sediments having varying organic content, grain size distribution, contamination types, and contamination levels, BioGenesis has developed a conceptual model that describes the nature of the sediment decontamination problem. This model gives insight to steps needed for successful decontamination of fine sediment particles, and is described in sections that follow.

1.1 Nature of the Sediment Decontamination Problem

Natural sediments consist of complex mixtures of solid inorganic materials (like silica) and biomass. Biomass may include any type of decayed organic material, including animals, fish, plants, and the products of natural biodegradation of chemical compounds. Contaminated sediment is created when toxic chemicals or contaminated material is released into the waterway from point, non-point, and atmospheric sources. Since waterways are highly active biologically, organic biomass is continuously created. The biomass has an affinity to absorb contaminants, both organic and inorganic. During the process of sedimentation, biomass settles over the solid particles in the water. The biomass first covers the solid particle with a very thin coating, the biofilm layer. This coating is quite sticky and bonds tightly to the solid. The coating is identified in figure 2 as the biofilm layer.

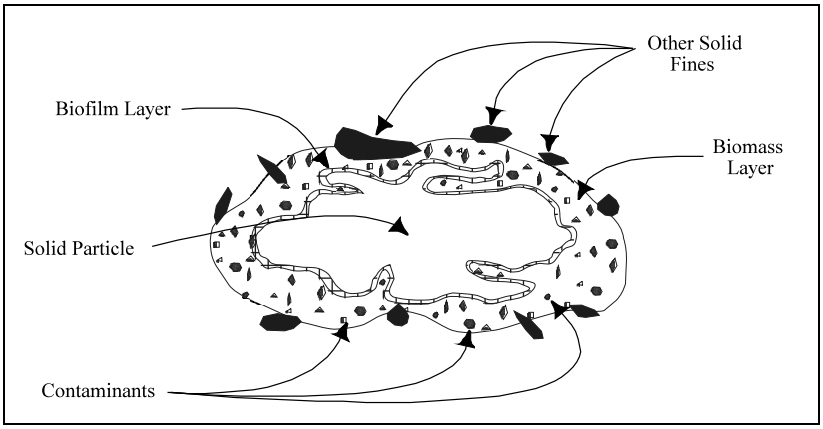


Figure 2. Illustration of elements of a contaminated solid sediment particle.

Subsequently, additional biomass settles over the particle through sedimentation. This biomass filters and absorbs chemicals in the water, either organic or inorganic. After the biomass containing contaminants settles on uncontaminated sediment, partitioning results in contaminant transfer between the sedimentary biomass and the biofilm formed over the sediment particles. The result of biomass affinity for both organic and inorganic contaminants, sedimentation action, and partitioning action is that contaminants are, over time, distributed throughout the biomass and biofilm layers. Thus the task of decontamination involves stripping the biomass layer, and then removing the sticky biofilm from the solid particle. Both actions are required in order to decontaminate the solid particle.

1.2 Conventional Washing Technology

As described above, contaminants migrate from water to sedimentary biomass to the biofilm formed over the surface of solids. The more surface area available for coating by a given mass of material, the more contaminant is absorbed. The amount of contaminant that can be absorbed

is related to grain size[1]. Any complex soil mixture contains a range of grain sizes. Because of the difference in surface areas, relatively more contaminant is contained in fine grains than in coarse grains. By example–1 cubic inch of gravel/sand having particle sizes between 1/8" and ½" inch diameter has approximately 1 to 2 square feet of surface. One cubic inch of sand/silt with grain sizes from 150 micrometers up to 1/8" contains approximately 600-1,000 square feet of surface. And 1 cubic inch of silt/clay with grain sizes from 1 micrometer to 150 micrometers can have as much as 12,000 square feet of surface area. These numbers tell us that with a mix of different particle sizes, by just simple separation we should be able to clean the large particles by a factor of from 10 to 100. This is the principle behind conventional washing. But that principle does not apply to sediment because sediment is not a mix of large and small grain sizes. Instead it is a more uniform mix of silt (75 to 5 micrometers) and clay (< 5 micrometers). The small particle size creates extremely large surface areas to clean which include biomass. Further, the presence of biomass (i.e. organic carbon) in the sediment creates a stronger affinity or binding of organic contaminants to the silt and clay particles. Conventional scrubbing technologies are ineffective under these conditions.

1.3 BioGenesis K Sediment Washing Technology

Figure 3 illustrates the equipment train used in BioGenesis K sediment washing. Figures 4 through 8 describe the process steps being performed by the chemicals and equipment.

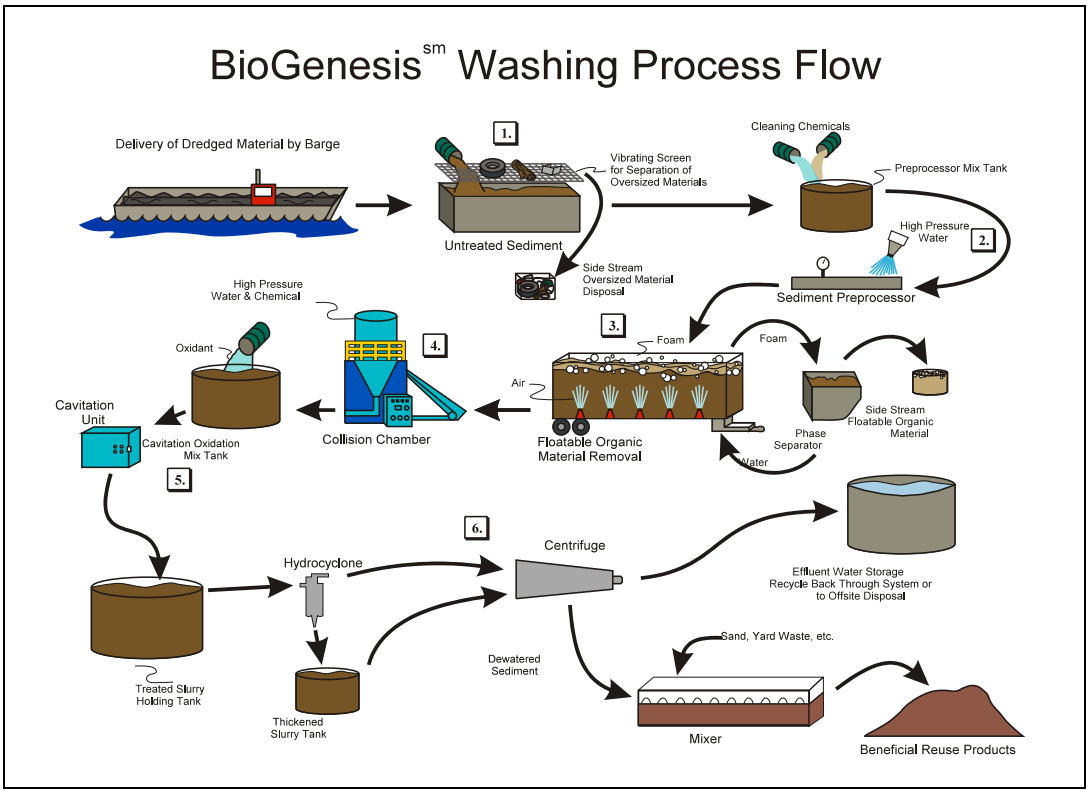


Figure 3. BioGenesis K sediment washing process flow

[1]References to particle size in this report use the AASHTO (American Association of State Highway and Transportation Officials) classification system.

BioGenesis K Technology is designed to separate fine particles, and to remove the biomass and biofilm coating on each particle (figure 4). The process uses a five step approach to solve the particle separation and contaminant removal problem. This approach has evolved during testing and development.

Step 1 blends biodegradable surfactant cleaning chemicals and chelating agents with the slurry to prepare the sediment. The surfactant chemicals prepare the solids for subsequent decontamination by decreasing the affinity between contaminants, solids, and biomass. The chelating agents solubilize inorganic contaminants.

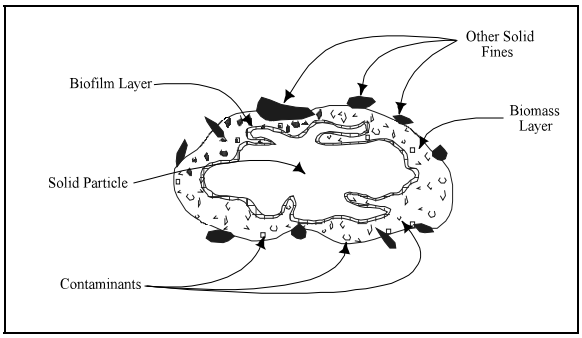


Figure 4. Contaminated particle before washing

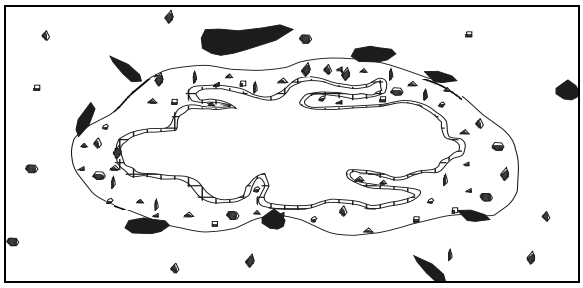


Figure 5. Contaminated particle after washing step 2.

Step 2 is shown in figure 5. The *sediment preprocessor* (see figure 3, item 2) uses physical action to separate sediment particles from each other and to homogenize the resulting slurry. Biomass and biofilm containing contaminants still coat the solid particles.

Step 3 is shown in figure 6. The *sediment processor* (see figure 3, co-located with item 2) separates the biomass from the biofilm coated particles. The result is that fine particles are separated, and biomass is separated from solids and transferred to the water phase. Biofilm containing contaminants still coats the solid particles.

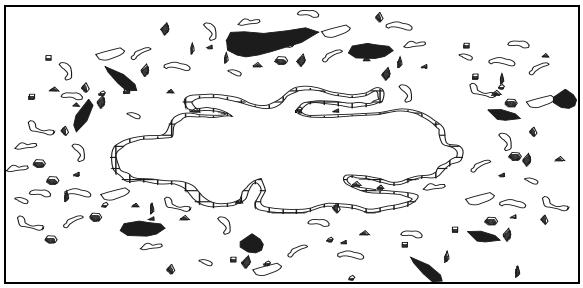


Figure 6. Contaminated particle after washing step 3.

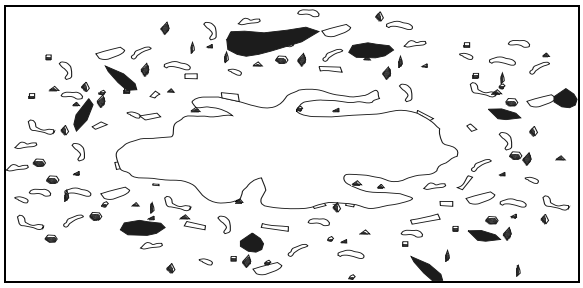


Figure 7. Contaminated particle after washing step 4.

Step 4 is shown in figure 7. Collision impact forces are applied to the particles in the collision chamber (see figure 3, item 4) to strip the biofilm layer from the solid particle and transfer it to the water phase. Thus, after Step 4, contamination that was sorbed to the individual solid particles in the biofilm has been transferred to the water phase.

Step 5 is shown in figure 8. This step destroys organic material including organic contaminants. This is accomplished through cavitation (see figure 3, item 5) that both oxidizes the suspended organic contaminants and biomass in the water phase, and has some oxidation effect on contamination still remaining in the biomass. The visual indication of the biomass/contaminant oxidation is that the slurry is a lighter color.

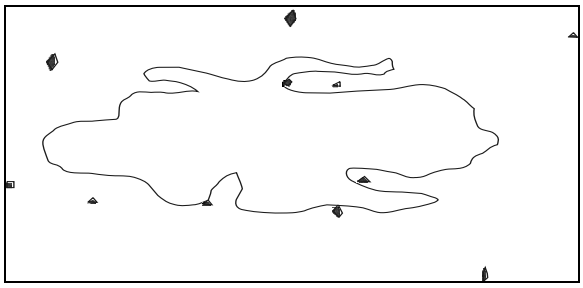


Figure 8. Contaminated particle after washing step 5.

Immediately after Step 5, the slurry consists of:

- Inorganic sediment solids from which contaminants have been washed.
- Suspended biomass that may still contain residual contaminants.
- Water that contains inorganic contaminants and any organic contaminants not destroyed during cavitation.

At this stage, the slurry is ready for immediate liquid/solid separation that results in a decontaminated solids fraction and a liquid fraction that contains organic contaminants that may have been resistant to oxidation in Step 5 plus any inorganic contaminants.

If the slurry is not agitated and subsequently separated following Step 5, sediment solids and biomass will settle based on their respective specific gravities. Unless liquid/solid separation is performed, as time passes, e.g. two to four weeks, the contaminant partitioning process will begin again, just as if a contaminant had been added to an uncontaminated slurry mixture. This means that organic contaminants will be attracted preferentially to suspended biomass and these organic particles will begin to be attracted to inorganic solids. Both the cleaned solids and biomass will begin reabsorbing contaminants, and the cleaning process reverses based on the partitioning coefficients of the contaminants, and thus contamination in the water phase will decrease.

For sediment that has a high percentage of organic material, the preprocessor begins to separate biomass and contaminant from the solid particle. The processor completes separation of the biomass from the solid particle, and with it the majority of contaminant. The reason for using the qualifying word "majority" is that the proportion of biomass to the biofilm on the solid particles is high. When there is low biomass in the sediment, the preprocessor mainly works as a particle separating unit, or a "shredder". In this case most of the cleaning takes place in the collision chamber, and the processor may not be needed. The flexibility inherent in the combination of preprocessor, processor, and collision chamber provides a versatile cleaning method that can be used for any small solid particle that is contaminated.

1.4 BioGenesis K Technology Development and Testing Overview

Table 1 depicts the principal tests conducted on BioGenesis K technology, including the time, sponsor, contaminants, and soil/sediment matrix tested. These tests provide the core validation of the technology since they were sponsored by the U.S. EPA and Environment Canada. Each of these tests will be discussed later in this report. During development, BioGenesis also performed treatability tests for commercial entities. The knowledge gained from these tests was integrated with the WRDA testing.

Table 1. Principal BioGenesis K Technology Development Testing				
Test Designation	**Date**	**Sponsor**	**Contaminants**	**Matrix**
A "SITE"	11/92	EPA SITE Program	TRPHs	Crude oil in sandy soil
B "SEDTECH"	6/93	Wastewater Technology Centre, Canada	PAH	Woodtreating waste in Thunder Bay Harbour, Canada, sediments
C "BNL 1"	10/95	WRDA EPA Region 2 BNL	PAHs, PCBs, dioxins, metals	NY/NJ Harbor sediments
D "BNL 2"	2/97	WRDA EPA Region 2 BNL	PAHs, PCBs, dioxins, metals	NY/NJ Harbor sediments
D "BNL 3"	8/97	WRDA EPA Region 2 BNL	PAHs, PCBs, dioxins, metals	NY/NJ Harbor sediments
F "BNL 4"	11/97	WRDA EPA Region 2 BNL	PAHs, PCBs, dioxins, metals	NY/NJ Harbor sediments

During the very first large scale washing test carried out under the EPA SITE Program, the relationships of grain size and organic content in the soil/sediment to be cleaned were determined to be very important. Table 3 shows the progression of grain sizes tested. Most system testing has taken place with mixtures of silt and clay.

Table 2. Grain Size Distribution of BioGenesis K Technology Tests				
Test	**% Gravel**	**% Sand**	**% Silt or Clay**	
Micrometer Range	***> 2,000***	***75 - 2,000***	***38 - 75***	***< 38***
SITE	13	76	6	5
SEDTECH	0	0	18	82
BNL 1(NY/NJ)	0	19	35	46
BNL 2(NY/NJ)	3	68	26	3
BNL 3(NY/NJ)	0	14	33	53
BNL 4(NY/NJ)	0	14	33	53

BioGenesis K technology development progressed in stages, with each stage contributing to understanding of what was needed to remove organic and inorganic contaminants from small grain size solids with high biomass. As each step was taken, new requirements developed that were successively solved by the invention, design, and construction of new equipment. The

collision chamber solved the problem of desorbing contaminants from extremely fine particles; the first version of the *preprocessor* solved the problem of separating fine solids; the *processor* added the capability to separate biomass from solids; and the *cavitation* unit gave high throughput capability for oxidizing organic contaminants entrained in a slurry. Different configurations of these equipments are planned for testing during the forthcoming WRDA pilot demonstration project. Table 3 shows the unit process used during development testing.

Table 3. Unit Processes Used During BioGenesis K Development Testing

Process in the Washing Sequence	Purpose	SITE	SED-TECH	BNL 1	BNL 2	BNL 3	BNL 4
Surfactant Addition 1	Loosen bonds	X			X	X	X
Aeration	Particle scrubbing	X					
Preprocessing	Solids separation			X	X	X	X
Cavitation	Fractionate organic solids					X	X
Chelation	Solubilize inorganic contaminants						X
Surfactant Addition 2	Solubilize organic contaminants		X	X	X		
Collision	Desorb organic contaminants		X	X	X	X	X
Chelation	Solubilize inorganic contaminants				X	X	
Cavitation	Oxidize organic contaminants				X	X	X
Organics Flotation	Separate organic solids						X
Liquid/Solid Separation	Dewater treated solids				X		X

Each major test contributed to system improvements and led sequentially to the next step. Table 4 tabulates the results, interpretation, and conclusions drawn from the principal tests.

Table 4. Principal Results and Interpretation of Testing			
Test	**Result**	**Interpretation**	**Conclusion**
SITE	1. High contamination of TRPHs cleaned from sandy soil (85 to 95%) 2. Weathered organic contaminants on fines are resistant to cleaning 3. Residual biodegradation of TRPHs proved	a. Aeration with chemicals is efficient for larger grain sizes. b. Multiple washes are required to treat high contamination levels. c. Aeration with chemicals is insufficient for fine particles.	Additional technology is needed for fines.
SEDTECH	4. Heavy concentration of PAHs cleaned from silt & clay fines (90 - 94%). 5. Partial removal of metals observed.	d. Collision technology validated.	***First proof that fines can be cleaned with washing.***
BNL 1 (NY/NJ)	6. Use of polymer as an aid to liquid/solid separation resulted in redeposition of contamination and interfered with analytical testing.	e. Coagulation of fine particles using polymer is not the method of choice for liquid/solid separation. f. Biomass must be fractionated prior to desorption with collision impact.	Additional test validation needed to demonstrate removals from sediments containing high biomass content.
BNL 2 (NY/NJ)	7. Particles larger than 400 mesh (38 micrometers) cleaned at 85 - 99%, including PAHs, PCBs, dioxins/furans, and metals. 8. Use of diatomaceous earth as a filter medium for liquids allowed the medium to absorb contaminants. The medium required reprocessing.	g. Organic/inorganic contaminant removal demonstrated on silt 38 microns or greater. h. A filter medium that absorbs organic contaminants should be avoided.	***Effectiveness is validated on NY/NJ Harbor sediment levels of contamination.***
BNL 3 (NY/NJ)	10. Cavitation effective in fractionating biomass prior to collision. 11. Samples exceeded laboratory holding time prior to extraction.	j. Samples for organic testing must be extracted without delay to prevent reabsorption of organic contamination. k. In the field, liquid-solid separation must be timely for the same reason.	Reprocess to desorb the contaminants resorbed during long holding time and to test the effect of repetitive processing.

Table 4. Principal Results and Interpretation of Testing			
Test	**Result**	**Interpretation**	**Conclusion**
BNL 4 (NY/NJ)	12. Lower chemical concentration, cavitation during preprocessing, then collision produced extraction rates of about 90%. 13. High chemical concentrations impeded collision and cavitation processes. 14. Lengthening the circulation time in the processor fractionated larger organic particles efficiently.	l. Preprocessing, collision, cavitation, and chelation effectiveness is revalidated on small grain size materials. m. Chemicals are not required in the collision chamber. n. Smaller organic particles created through longer processing are easier to remove through flotation.	***Process is ready for large scale field demonstration and selection of sediment handling, liquid-solid separation, and water treatment technologies.***

BioGenesis washing technology has been tested in the SITE (Superfund Innovative Technology) program of the U.S. EPA, the SEDTECH program of Environment Canada, and the WRDA (Water Resources Development Act) program of U.S. EPA Region 2. The technology has demonstrated the capability at bench and small pilot scale to decontaminate fine particles, and is ready for larger scale field testing and selection of sediment handling, liquid-solid separation, and water treatment technologies.

2 DEVELOPMENT SUMMARY, 1991 - 1993

BioGenesis' President and Technical Director is Dr. Mohsen Amiran. During 1987-1989, he worked in Germany to conceive a trailer-mounted soil washing machine that would, in combination with custom-tailored surfactant mixtures, be able to clean petroleum-based and organic chemical pollutants from soils.

2.1 Large particle washing under the U.S. EPA SITE program

BioGenesis constructed the first washing gondola during 1991, entered the U.S. EPA's Superfund Innovative Technology Evaluation (SITE) program, and demonstrated the soil washing technology during 1992 at a refinery in Minnesota. This experience is documented in *BioGenesis® Soil Washing Technology, Innovative Technology Evaluation Report, EPA/540/R-93/510, September 1993.*

Overall results of the evaluation are depicted in figure 9. The washing was effective in decontaminating 3,800 tons of soil. During the washing, it was apparent that both the smaller grain sizes of silt and clay, about 11% of the total, and the more heavily weathered materials were not being cleaned as efficiently as the larger particles of sandy soil that would not pass 200 mesh. As a result, BioGenesis undertook research on ways to improve washing effectiveness. Bench testing showed that aeration scrubbing with surfactant mixtures could not be effective on small grain sizes and high molecular weight chlorinated organic contaminants because of the sponge-like nature of sediment surfaces with their cracks/crevices and surface many thousands of times larger than that of sandy particles per unit weight. Also, aeration scrubbing simply did not have sufficient energy to break the high bonding forces holding the pollutants to the small

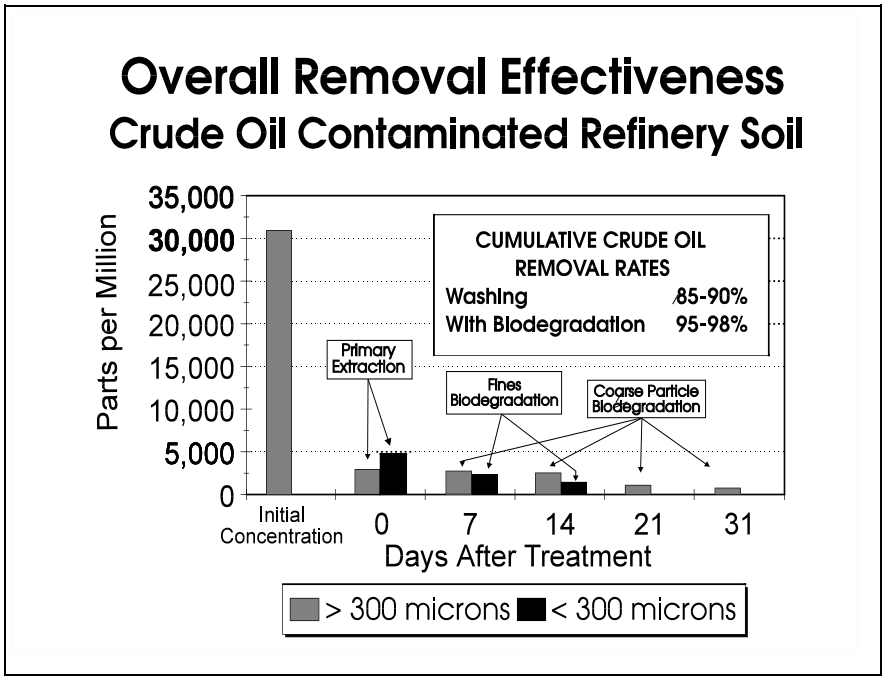


Figure 9. Overall effectiveness, crude oil contaminated refinery soil.

particles. The result was that BioGenesis conceived of a new way to clean small particles that involved mobilizing all possible means, including chemicals, impact forces, and temperature. The prototype machine was first tested on contaminated sediment under the auspices of a project from Environment Canada's Wastewater Technology Centre under the Contaminated Sediment Treatment Technology Program (SEDTECH).

2.2 Thunder Bay Study (SEDTECH) for Environment Canada

2.2.1 *Project Description*

2.2.1.1 Purpose and objectives

In mid-1992 Wastewater Technology Centre (WTC) requested proposals for bench scale studies of Thunder Bay Harbour, Ontario, sediment. The purpose of the program was to assess contaminated sediment treatment technologies which may be used in future years as part of the overall effort to clean up 43 "Areas of Concern" identified by the International Joint Commission, a joint Canada-U.S. body tasked to administer the Great Lakes Water Quality Agreement.

2.2.1.2 Sample source and description

WTC shipped 150 pounds of Thunder Bay sediment to BioGenesis during December 1992. The major contaminants at Thunder Bay Harbour are PAHs, with low levels of PCBs, phenols, and several metals. The PAHs were determined to be the primary target of the washing test. Over 80% of the sediment had grain sizes less than 38 micrometers, i.e. over 80% was medium silt and finer. The grain size distribution of the samples is shown in figure 10.

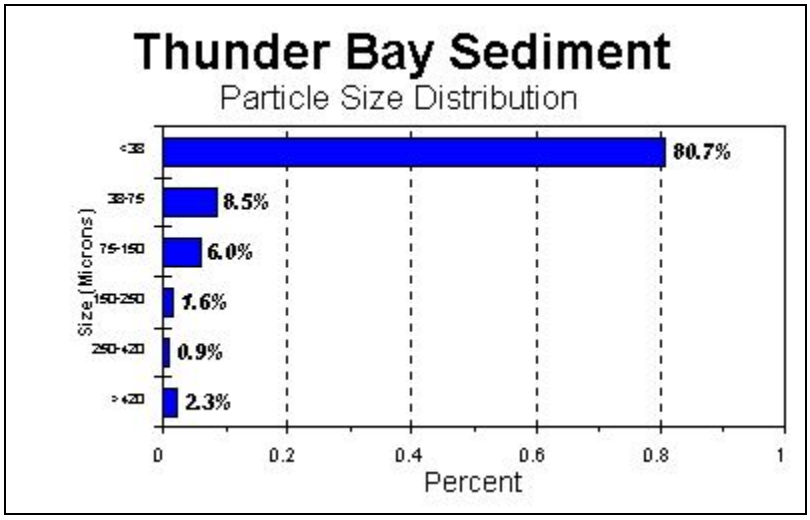


Figure 10. Grain size distribution, Thunder Bay sediment

2.2.1.3 Untreated contamination levels

Untreated sediment contamination levels were extremely high, with over 9% oil and grease, 2% semi-volatiles, and over 4,000 ppm of PAH. Total organic carbon was also high at 11%. Table 5 depicts the before treatment contamination levels. The high contamination combined with a grain size that was 80% fine silt and clay, made a challenging test for the new technology.

Table 5. Untreated Sediment Contamination Levels, Thunder Bay

TEST PARAMETER		***BEFORE WASHING***
		Parts Per Million, PPM
Total Petroleum Hydrocarbons (TPH)		**4,770**
Oil & Grease (O & G)		**91,600**
Semivolatile Petroleum HC (C12-C23 as diesel)		**21,000**
Total Organic Carbon (TOC)		**11.5%**
POLYAROMATIC HYDROCARBONS	***CAS***	***Parts Per Billion , PPM***
Naphthalene	91-20-3	1,400
Acenaphthylene	208-96-8	16
Acenaphthene	83-32-9	305
Fluorene	86-73-7	240
Phenanthrene	85-01-8	770
Anthracene	120-12-7	110
Fluoranthene	206-44-0	400
Pyrene	129-00-0	300
Benzo(a)anthracene****	56-55-3	115
Chrysene****	218-01-9	75
Benzo(b)fluoranthene****	205-99-2	120
Benzo(k)fluoranthene****	207-08-9	42
Benzo(a)pyrene****	50-32-8	82
Indeno(1,2,3-cd)pyrene****	193-39-5	30
Dibenzo(a,h)anthracene****	53-70-3	9
Benzo(g,h,i)perylene	191-24-2	28
Total PAHs		**4,042**

**** = Carcinogenic PAHs

2.2.2 *Experimental Design and Procedures*

2.2.2.1 Treatment System Description

Thunder Bay Harbour sediment was tested on June 1, 1993, at the BioGenesis facility in Milwaukee, Wisconsin. Mr. John Goodin represented Wastewater Technology Centre during the testing.

For this test, the sediment washing unit was configured so that sediment could make multiple passes through the machine. Considering the relatively small amount of sediment available for cleaning, and the relatively large capacity of the machine compared to the sediment amount,

BioGenesis decided to recirculate the sediment through the machine three times. In the full scale machine, sediment would not be recirculated through the same unit, but would be passed successively through from 3 to 5 machines depending on the situation. This would achieve continuous flow through the machine set.

With the exception of a leaking seal which was replaced, the test apparatus operated as designed.

2.2.2.2 Process Flow

Process flow is depicted in figure 11 and described in the following paragraphs.

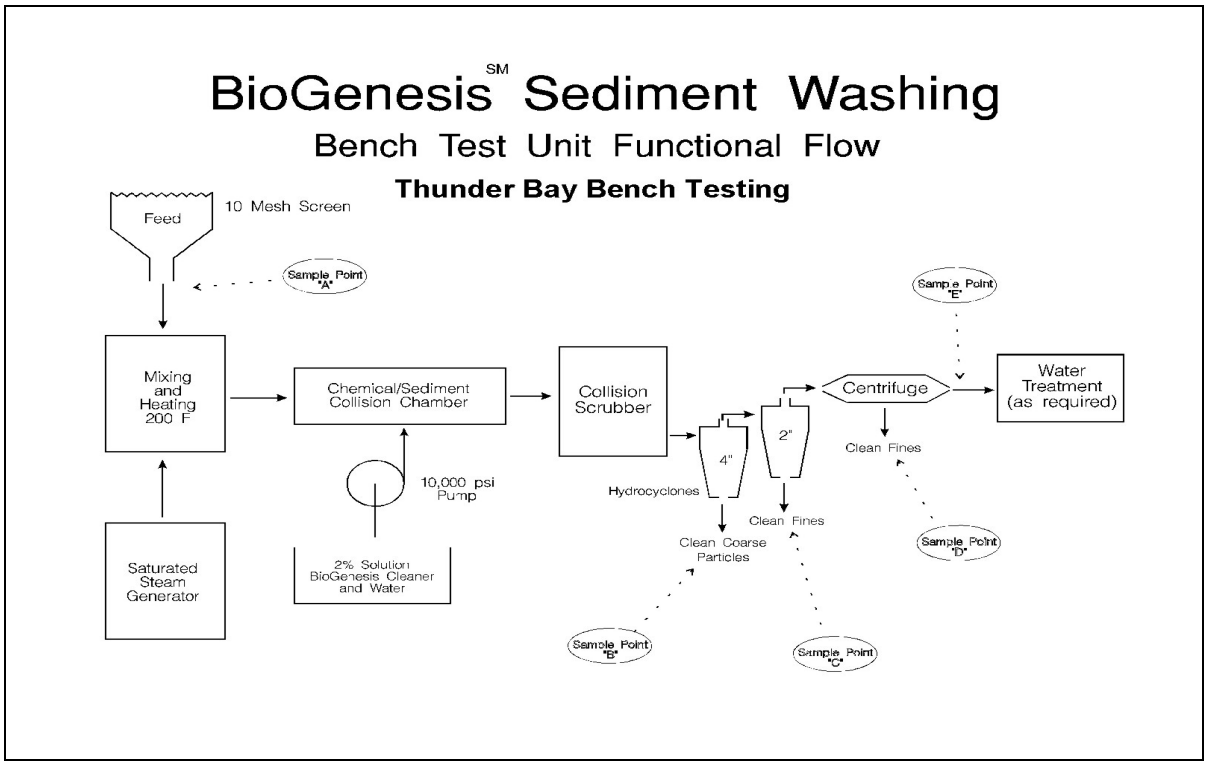


Figure 11. BioGenesis℠ sediment washing, functional flow

First a sizing step manually removed large particles. These were not further tested based on the rationale that contamination is concentrated on the particles which pass the screen. If the smaller particles and sediment can be cleaned, then large particles are a lesser included case. Then, using saturated steam, the sediment can be heated to 140 to 200ºF. For the SEDTECH test, sediment was washed at 80 to 90ºF[2].

Next the heated sediment is mixed with BioGenesis™ cleaner and water under up to 10,000 psi pressure. The combination of chemical and physical force of impact begins loosening the bonding forces between the small sediment particles and the contaminant. The loosening process

[2] BioGenesis bench testing shows that higher temperatures (140 - 200 °F) improve extraction effectiveness.

is completed in a collision scrubber wherein the charges on the contamination particles are aligned to facilitate separation.

Finally, using standard hydrocyclones and, if required, a centrifuge, the oil and water are separated from the sediment. Depending on the type of centrifuge used (two-phase or three-phase), water treatment using standard chemicals, filtration, or biodegradation may be used. Water treatment was not modeled for this testing.

2.2.2.3 Processing plan

The initial testing plan provided for extensive, multiple testing of both solids and liquids resulting from the testing. These included baseline, intermediate process, and after process sampling for 16 metals and inorganics, pH, sulfur, TOC, C_{10-22} hydrocarbons, oil and grease, TPH, chlorophenols, 16 PAHs, and total PCBs. Two factors led to amendments in the testing: reduced need for metals, PCB, and phenols testing because of low contaminant levels and restrictions on test extent because of limited sample quantities and the need for split samples.

The resulting testing plan is illustrated in table 6. It was designed to provide a thorough baseline result, an end result, with intermediate results assigned less importance. Final adjustments were made to the test matrix following the test in coordination with the project authority and laboratory director to maximize information derived.

Table 6. Sediment Washing Analysis Matrix

Test	Baseline	After Cycle 1	After Cycle 2	After Cycle 3	At Buffer Tank	After Cyclone
Metals	X					X
pH	X					X
Sulfur	X					X
TOC	X					X
C_{10-23}HC	X	X				X
Oil & Grease	X					X
TPH	X	X	X	X	X	X
16 PAHs	X	X	X		X	X
PCBs	X	X		X	X	X

2.2.3 *Data Management, Analysis, and Interpretation*

2.2.3.1 Data Summary and Comparison to Untreated Material Analysis

Table 7 presents the before and after testing results, and the computed percent removal. Analyses were performed by Galson Laboratory, Syracuse, NY.

Table 7. Thunder Bay Testing Results

TEST PARAMETER		*BEFORE WASHING*	*AFTER WASHING*	*Percent Removal*
		Parts Per Million, PPM	*Parts Per Million, PPM*	
Total Petroleum Hydrocarbons (TPH)		4,770	400	91.6%
Oil & Grease (O & G)		91,600	3,940	95.7%
Semivolatile Petroleum HC (C12-C23 as		21,000	2,200	89.5%
Total Organic Carbon (TOC)		11.5%	2.9%	74.8%
POLYAROMATIC HYDROCARBONS				
	CAS	*Parts Per Million , PPM*	*Parts Per Million , PPM*	
Naphthalene	91-20-3	1,400	73	94.8%
Acenaphthylene	208-96-8	16	1.5	90.6%
Acenaphthene	83-32-9	305	34	88.9%
Fluorene	86-73-7	240	30	87.5%
Phenanthrene	85-01-8	770	88	88.6%
Anthracene	120-12-7	110	16	85.5%
Fluoranthene	206-44-0	400	59	85.3%
Pyrene	129-00-0	300	44	85.3%
Benzo(a)anthracene	56-55-3	115	19	83.5%
Chrysene	218-01-9	75	12	84.0%
Benzo(b)fluoranthene	205-99-2	120	19	84.2%
Benzo(k)fluoranthene	207-08-9	42	6.1	85.5%
Benzo(a)pyrene	50-32-8	82	12	85.4%
Indeno(1,2,3-cd)pyrene	193-39-5	30	5	83.3%
Dibenzo(a,h)anthracene	53-70-3	9	1.4	84.3%
Benzo(g,h,i)perylene	191-24-2	28	3.9	86.1%
Total		**4,042**	**424**	89.5%

2.2.3.2 Interpretation of Results

The particle size distribution for Thunder Bay Harbour sediment was reported by WTC based on testing of samples during 1992. Using Wentworth classification scales, 81% of the sediment is medium silt and finer, about 8% is a coarser silt, and 6% is very fine sand. This distribution of small grain sizes had heretofore been considered untreatable using soil washing techniques.

Overall removal effectiveness of the BioGenesis K washing process is illustrated in figure 12. Three wash cycles with about 5 minutes of total contact time in the washing unit resulted in 90-

95% contaminant removal depending upon the test used. Oil & grease removal was 95.7%, semi-volatile petroleum hydrocarbons was 89.5%, total petroleum hydrocarbons was 91.6%, and total PAHs was 89.5%. The results reported by Galson are at the upper end of the estimated range, and are somewhat above expectations for the small pilot scale unit.

Galson Laboratory noted that the results for SVHC (C_{12-23} as diesel), TPH, and GC/MS results should not be confused since each method assesses petroleum content, different analytical techniques are utilized, and different types of contamination may respond differently to each of the techniques. Nevertheless, results from the principal tests performed by two different laboratories (Galson subcontracted the SVHC analysis) correlate very well and give confidence to the overall removal percentages.

Washing removal effectiveness for individual PAH contaminants varied between 83.3% and 94.8%. This can be observed visually in figure 13 where the extraction end points for contaminants with beginning concentrations greater than 100 ppm are all very similar. About 15% of contamination is removed during the first wash cycle. A further 75% is removed in cycles 2 and 3. Whether the additional removal was due to dwell time in the presence of the chemical, or to additional physical scrubbing in the collision chamber and collision scrubber was undetermined.

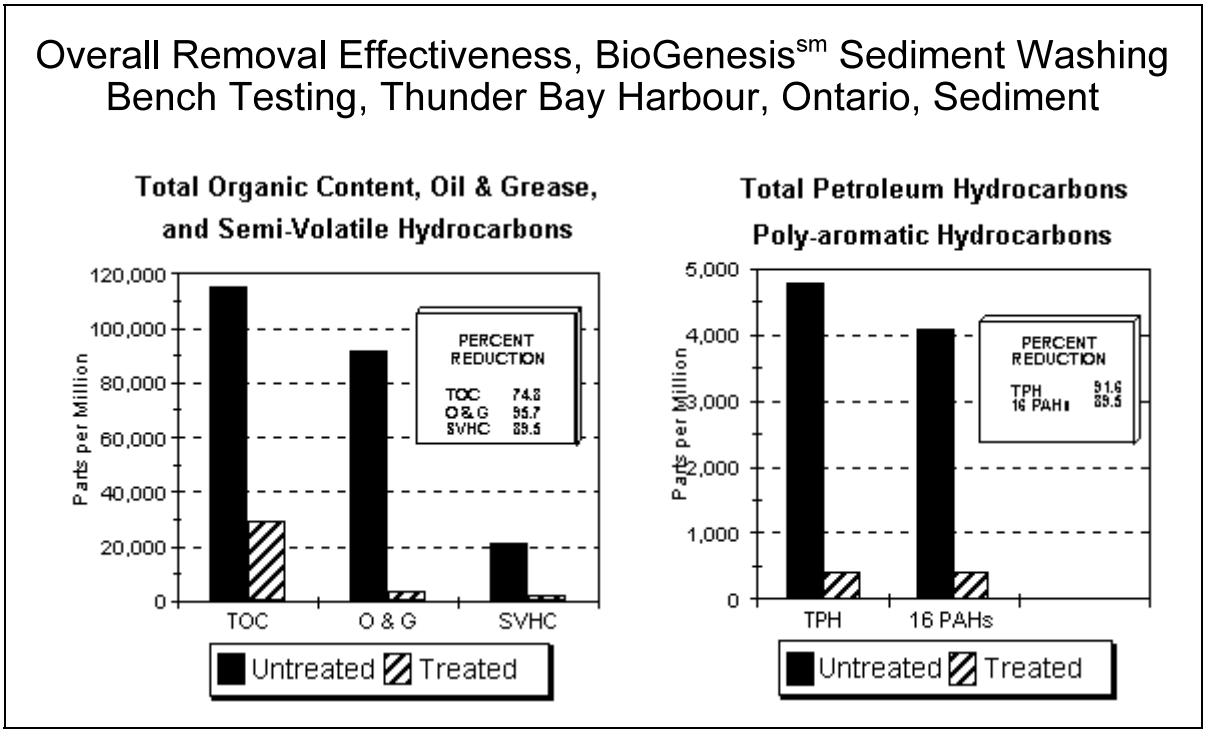


Figure 12. Overall removal effectiveness, BioGenesis K Sediment Washing, Thunder Bay Harbour, Ontario, sediment.

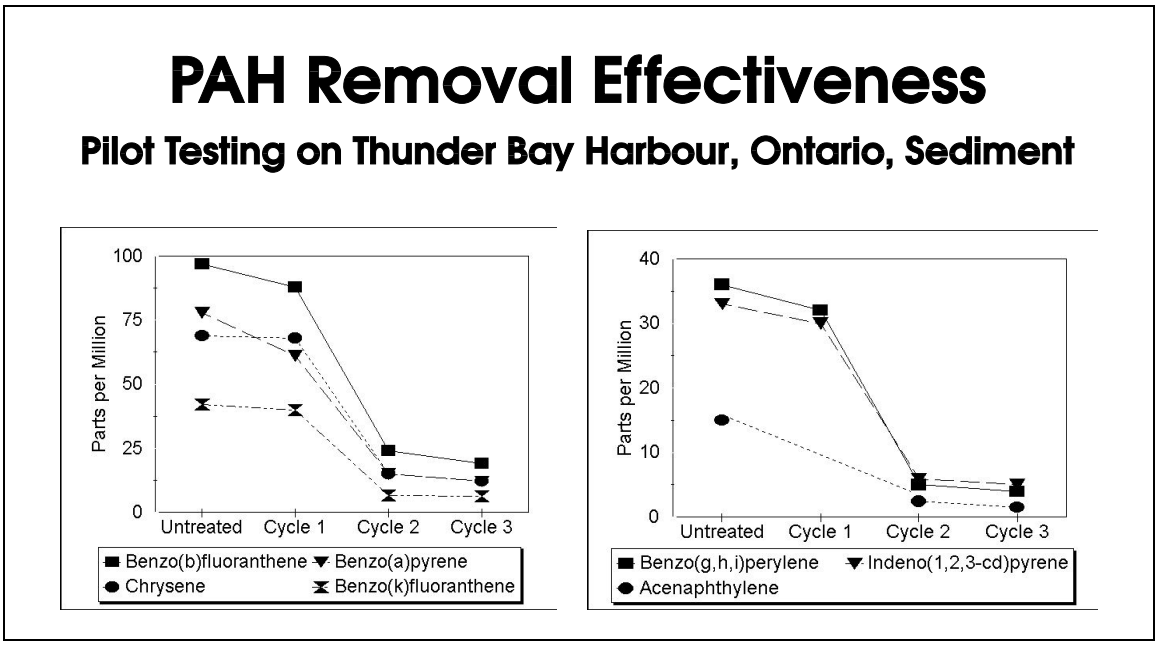


Figure 13. BioGenesis K washing, PAH removal effectiveness, lower concentration pollutants, Thunder Bay Harbour sediment

Likewise figure 14 shows much the same picture for PAH compounds having initial concentrations below 100 ppm.

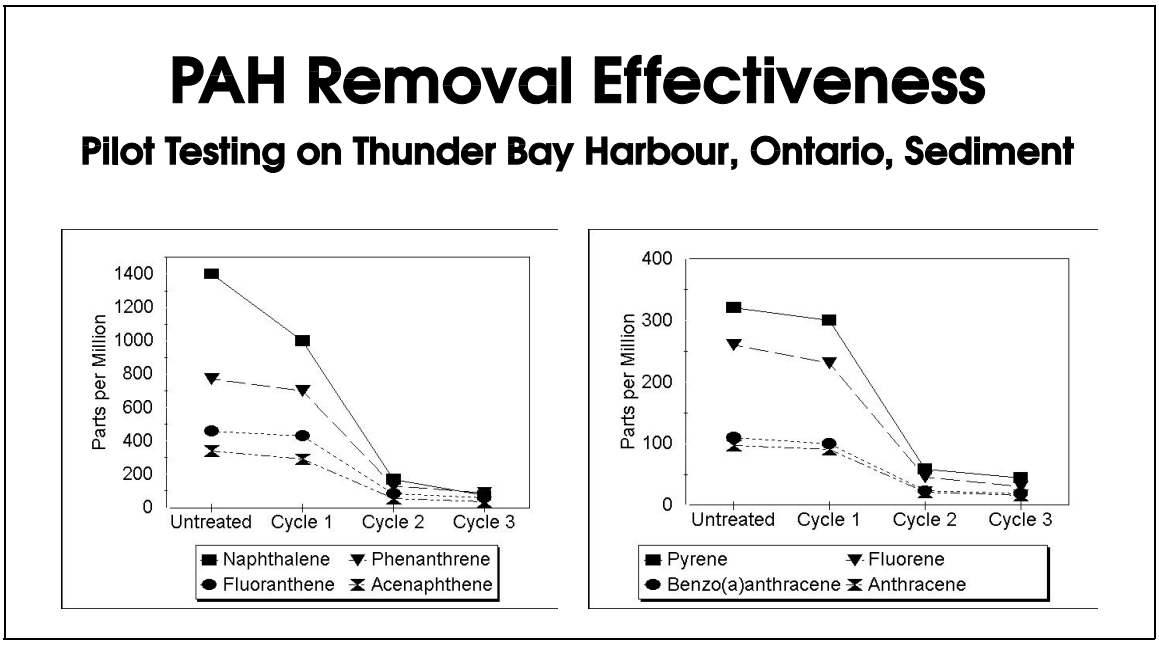


Figure 14. BioGenesis K washing, PAH removal effectiveness, higher concentration pollutants, Thunder Bay Harbour sediment

2.2.4 *Conclusions and Recommendations*

2.2.4.1 Conclusions

a.1. For the first time known to BioGenesis, PAH and hydrocarbon contamination was effectively extracted from sediments in a continuous washing process. This was a major advance in the state-of-the-art for sediment remediation. It has the potential to make obsolete the previous concept of washing technology as a pretreatment technique which leaves large quantities of fines needing further treatment.

a.2. The testing for this project used prototype pilot scale equipment. Extraction efficiency was 90-95%. The test proved that BioGenesis K sediment washing technology can physically/chemically extract relatively high levels of oil & grease, TPH, SVHCs, and PAHs from harbour sediment which is 81% medium silt and smaller.

2.2.4.2 Recommendations

b.1. The sediment washing equipment used in the June 1993 testing was the initial, proof-of-principal prototype. Second generation equipment capable of processing 5 to 7 cubic yards per hour should be built and tested. The goal of design revisions should be to raise extraction efficiencies above 99%, and provide for multiple processing units to be used in series.

b.2. Levels of PCBs, phenols, and dioxins were too low in the Thunder Bay Harbour sediment to calculate an extraction efficiency. But considering hydrocarbon similarities, it is reasonable to expect similar removal efficiencies on these substances. Pesticides also fall into this category. The washing system should be tested on the other major organic contaminant types besides PAHs.

b.3. The washing operation achieved a collateral effect of removing 30 to 40% of the metals present despite optimization of the chemical cleaner for hydrocarbons and PAHs. It is reasonable to expect that a chemical optimized for metals together with improvements in the cleaning machine will lead to increased rates of metals extraction. The washing system should be tested on a range of inorganic contaminants.

b.4. Given the performance on hydrocarbons, PAHs, and metals, it seems possible to design a sequential treatment train which first extracts hydrocarbons and then, with a different chemical, extracts metals. The ability to use the same equipment to clean different contaminants leads to the expectation that sediment washing will evolve to be an effective, economical, rapid means of treating multi- and mixed contaminant sediments. Mixed contaminant sediments should be tested using the treatment train approach.

3 PROCESS THEORY AND EQUIPMENT DEVELOPMENT, 1993 - 1994

The successful SEDTECH bench testing on Thunder Bay, Ontario, sediments showed the potential effectiveness of washing technology for sediment decontamination. It also gave a measure of practical validation to an evolving theoretical understanding of how to decontaminate very small solid particles.

3.1 Process Theory

3.1.1 *Uncontaminated Sediment Structure*

Uncontaminated sediment is a complex of organic and inorganic matter. The theoretical model developed by Dr. Amiran simplifies this complex structure for better understanding. In this model, solid inorganic particles are covered by a molecular layer of biofilm. The biofilm is tightly bonded to inorganic particles and completely seals all the exposed surfaces of the inorganic particle. The overlaid inorganic sediment particles have great affinity for and adhere to each other. The molecular biofilm over the inorganic sediment particles also has great affinity for any cationic or anionic particles. When the sediment particles settle, they attract other naturally occurring organic matter (NOM), which ultimately covers the molecular biofilm. As more NOM is deposited, the bonding between new organic matter and that previously deposited is weakened. In this theory we have classified the deposition of organic matter over the inorganic particles in a sedimentary environment into three categories: first, biofilm, which is the most active and has the highest absorbency; second, the plasmatic layer, which forms over the biofilm; third, the interplasmatic layer, which fills up the spaces between the sedimentary particles.

Two types of sedimentary models can be considered depending on whether the inorganic particle is contaminated (or not) prior to entering the water.

- In the first case, that of an uncontaminated inorganic particle entering the water, contaminants are mainly concentrated in the biomass of the plasmatic and interplasmatic layers. These biomass layers act as filters in the water that attract pollutants. The process of partitioning between the three phases of organic matter, as well as the inorganic phase, happens over time. The partitioning effect distributes the total contamination in the sediment by different percentages. The percentage of distribution depends on the nature of the contaminant as well as the chemical structure of the inorganic and organic matter. When the sediment is aged, most of the contaminant is found in the organic phase of the sediment. This is true even for inorganic contaminants (heavy metals). The chemical properties of different phases are discussed in section 3.1.2.

- In the second case, that of an already contaminated inorganic particle entering the water (e.g. suspended solids from industrial waste or from agriculture), the biofilm forms over the contaminant which itself overlays the inorganic particle. As in the first case, the plasmatic and interplasmatic layers of biomass accumulate and act as filters for accumulation of additional contaminants from the water phase. Over time, partitioning takes place among the inorganic particle, contaminant layer, biofilm, plasmatic layer, and interplasmatic layer. The difference between this case and the

first case is that even if the plasmatic and interplasmatic layers are stripped away, significant contamination remains tightly bound to the solid particle beneath the biofilm. In order to clean the particle, additional chemical and/or physical forces must be applied beyond those used in the first case.

The key to understanding the models is to understand the nature of the interface between water in the environment and extremely small solid particles. The following discussion of research by others gives the theoretical foundation for the BioGenesis theory of sediment structure.

Research by Neihof [3] showed that a layer of organic molecules forms over a solid surface as soon as the solid surface is contacted with non-pure water. In his study, three different materials (clay, calcite, and glass) were immersed in sea water. An ion and micro-molecule film immediately formed on the solid surface. Further studies [4,5] showed that the films formed over the solid surface had much higher concentrations of organic and inorganic matter than the surrounding water. BioGenesis describes this molecular film formed on the solid surface as the biofilm. Since the biofilm begins to form as soon as the solid particle is immersed in water, organic and inorganic material subsequently added to the water contact the biofilm, not the solid particle itself. Over time other sources of organic material join the sediment complex. These include animal or vegetative cells and mineralized organic matter derived from humus. The active bacterial surfaces of the organic material strongly attract to the active surface of the biofilm or to biomass already accumulated on the biofilm of a solid particle.

Figure 15, Cross-sectional model of uncontaminated sediment, extends the concept of biofilm to encompass a plasmatic layer of dense biomass that is attracted to and binds with the biofilm and a less dense layer of biomass that fills the spaces between particles. The less dense biomass is similar to a gel and is termed the interplasmatic layer by BioGenesis. Figure 15 shows a cross-section of solid particles of various sizes and shapes, each coated with a biofilm and a plasmatic layer, and with the spaces between the particles filled with the less dense interplasmatic layer.

---

[3]Neihof, R. A., and G. I. Loeb. "The Surface Charge of Particulate Matter in Seawater," *Limnol. Oceanogr.* 17:7-16 (1972).

[4]Loeb, G. I. and R. A. Neihof, "Marine Conditioning Films," in *Advances in Chemistry, Series 145: Applied Chemistry at Protein Interfaces*, R.E. Baier, Ed., pp. 319-335 American Chemical Society, (Washington, DC, 1975).

[5]Urrutia, M. M., M. Kemper, R. Doyle and T. J. Beveridge, "The Membrane-induced Proton-motive Force Influences the Metal-binding Ability of *Bacillus subtilis* Cell Walls, *Appl. Env. Microbiol.* 58:3837-3844 (1992).

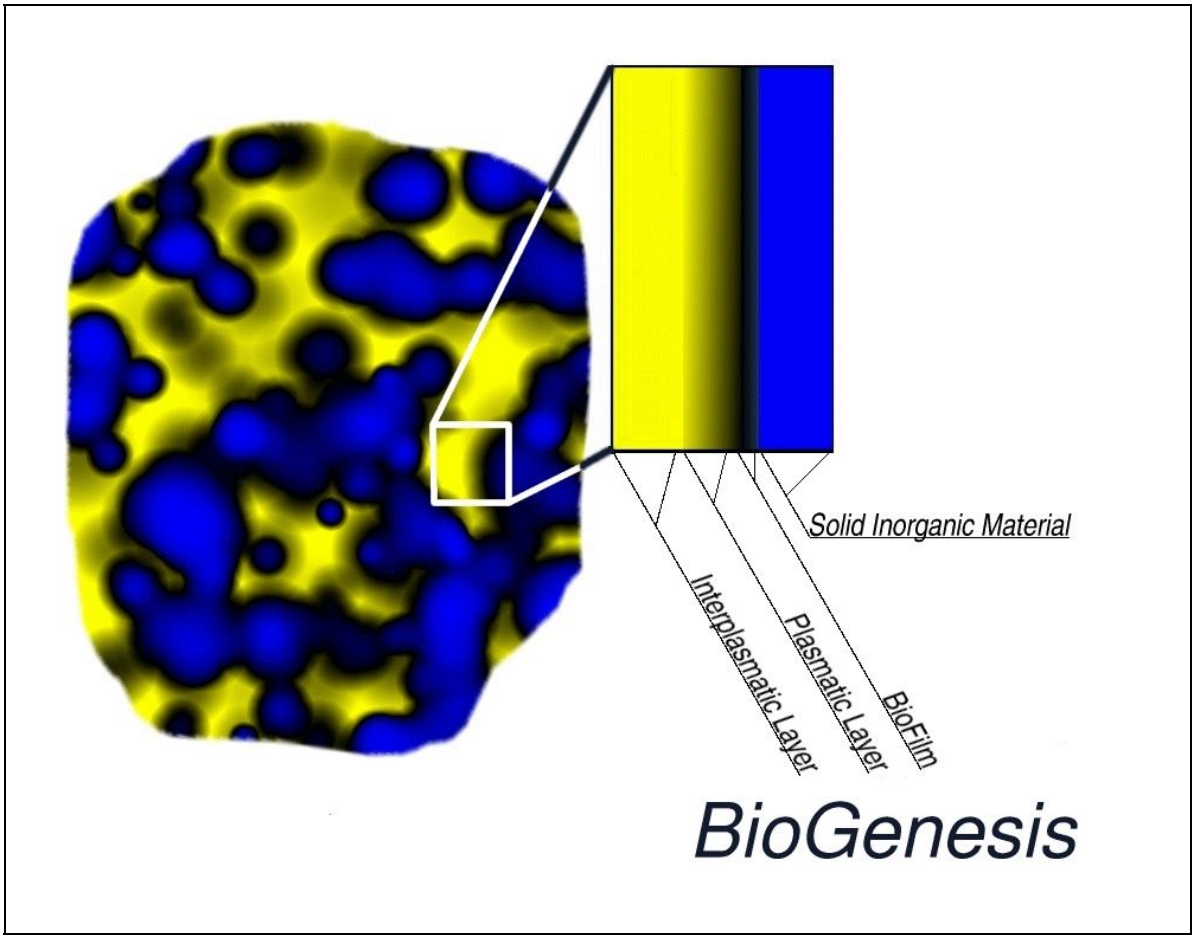


Figure 15. Cross-sectional model of uncontaminated sediment

3.1.2 *Contaminated Sediment Structure*

Organic and inorganic contaminants are attracted to the sediment structure by molecular forces that are strongest in the biofilm and progressively weaker in the plasmatic and interplasmatic layers. Succeeding paragraphs describe and illustrate the absorption and deposition of contaminants in the BioGenesis model of sediment structure.

The mechanism for metal deposition in an ion film has been studied [6,7] in bacteria cell walls. Initially, a stoichiometric interaction takes place between metal cations and active sites within the cell walls of the bacteria. Metal ions are deposited. Additional metal deposition then occurs until physically constrained by the size of the intermolecular spaces in the cell wall itself. In

---

[6]Beveridge, T. J. and R. G. E. Murray, "Sites of Metal Deposition in the Cell Wall of *Bacillus subtilis*," *J. Bacteriol.* 141:876-887 (1980).

[7]Mills, A. L. and R. Maubrey, "Effect of Mineral Composition on Bacterial Attachment to Submerged Rock Surfaces," *Micro. Eco.* 7:315-322 (1981).

contaminated sediment, the result of ion deposition in the biofilm is that the metals are not easily remobilized by water or replaced by protons or other ions.

The deposition phenomena can be understood by understanding the bacteria bi-layer. The two main categories of bacteria in the sedimentary environment and thus in the biofilm are gram-positive and gram-negative bacteria. [8,9,10]

In gram-positive bacteria, the bi-layer consists of two sections. These are the peptidoglycan (PG) layer which overlays the plasma membrane (PM) layer. The PG layer is composed of strands of chains of up to 50 dimers of N-acetylglucosamine and N-acetylmuramic acid. [11] This PG layer is the outer cell membrane and has substantial amounts of muramic acid attached to peptides that are rich in carboxyl groups. Carboxyl groups have a great affinity for positively charged particles, such as metal cations, which help to stabilize and prevent the decomposition of this layer. This has been shown in studies of fossilized bacteria. [12,13,14]

Gram-negative bacteria have three layers, an inner PM layer, a PG layer, and a second PM layer which is considered the outer membrane and is covered by an active plasmatic layer of polysaccharide. The plasmatic layer usually consists of a combination of unique sugars such as 2 keto-3-deoxyactonate or different hexoses which have carboxyl on phosphoryl groups. These groups also create strong negatively charged sites that attract and bind positively charged contaminants. [15]

When both organic and inorganic contaminants contact the sediment structure, they are attracted by molecular forces in the biofilm, plasmatic layer, and interplasmatic layer. First, organic and

---

[8]Beveridge, T. J., C. W. Forsberg and R. J. Doyle, "Major Sites of Metal Binding in *B Bacillus licheniformis* Walls," *J. Bacteriol.* 150:1438-1448 (1982).

[9]Beveridge, T. J. and R. G. E. Murray, "Uptake and Retention of Metals by Cell Walls of *Bacillus subtilis*," *J. Bacteriol.* 127:1502-1518 (1976).

[10]Nikaido, H. and M. Vaara, "Outer Membrane," in *Escherichia coli and Salmonella typhimurium: Cellular and Molecular Biology, Volume One*, F.C. Neidhardt, J. L. Ingraham, K. B. Law, B. Megasanik, M. Schaechter and H. E. Umberger, Eds., pp. 7-23 American Society for Microbiology, (Washington, DC, 1987).

[11]Rogers, H. J., J. B. Ward and I. D. J. Burdett, "Structure and Growth of the Cell Wall of Gram-positive Bacteria," *Symp. Soc. Gen. Microbiol.* 28:139-176 (1978).

[12]Beveridge, 1976.

[13]Beveridge, T. J., "Role of Cellular Design in Bacterial Metal Accumulation and Mineralization," *Ann. Rev. Microbiol.* 43:147-171 (1989).

[14]Ferris, F. G. and T. J. Beveridge, "Site Specificity of Metallic Ion Binding in *Escherichia coli* Lipopolysaccharide," *Can. J. Microbiol.* 32:52-55 (1986).

[15]Nikaido, 1987.

inorganic contaminants contact and mix with the interplasmatic layer. Over time, organic contaminants will distribute throughout the biomass and biofilm in accordance with their respective partitioning characteristics. Metals will tend to be attracted to the biofilm layer by their strong affinity for the carboxyl groups which have a strong affinity for heavily charged particles. Over an extended period of time, the contaminants have almost completely migrated to the biofilm layer and are tightly bound to it. [16,17,18]

3.1.3 *Breaking the Sediment-Contaminant Structure*

BioGenesis technology breaks the contaminated sediment structure by physical forces in the preprocessor and collision chamber. These forces separate the sediment particle complexes and strip the interplasmatic layer and plasmatic layer of biomass from the sediment particle. This separation lessens the amount of chemical force necessary to separate the contaminants from the biofilm and solid particle.

Once the sediment structure is broken, chemicals can form strong micelles with organic pollutants and remove them from the solid particle. For metals, chelating agents are used to make a ligand with heavy metal cations. Complex surfactants are used to enhance the solubility of the ligand complex and stabilize it in the water phase.

3.1.4 *Transferring Contaminants to the Water Phase*

The surfactant complex and chelating agents are selected based on the type of contaminant and the nature of the complex organic phase of the sediment. For example, most poly-aromatic hydrocarbons (PAH) are not soluble in water, and are not bound strongly to the biomass. However they can be emulsified and converted to micro-emulsions after breaking the organic phase (plasmatic and interplasmatic layers). To do this, a higher proportion of complex cleaner is used that emulsifies both the organic biomass and the PAH. In contrast, when dealing with diesel fuel or other light hydrocarbons, the bond between the biomass and the pollutant is very strong, and in this case a stronger surfactant complex is used to dissolve the contaminant and transfer it to the water phase.

In the case of mixed organic and inorganic contaminants in harbor sediment, a multi-acting complex can be used with the following components:

- Non-ionic surfactants to act as wetting agents to enhance the physical breakdown of the organic phase of the sediment complex.

---

[16]Marshall, K. C., "Mechanism of the Initial Events in the Sorption of Marine Bacteria to Surfaces," *J. Gen. Microbial.* 68:337-348 (1971).

[17]Marshall, K. C., "Bacterial Adhesion in Natural Environments," in *Microbial Adhesion to Surfaces,* R. C. W. Berkeley, J. M. Lynch, J. Melling, P. R. Rutter and B. Vincent, Eds., pp. 93-106, Ellis Horwood Ltd., (Chichester, 1980).

[18]McCoy, W. F., J. D. Bryers, J. Robbins and J. W. Costerton, "Observations of Fouling Biofilm Formation," *Can. J. Microbial.* 27:910-917 (1981).

- Amphoteric surfactants to stabilize metal micelles complexes.

- Organic or inorganic chelating agents to mobilize heavy metals and extract the heavy metals from the biomass. The selection of chelating agents depends on the inorganic nature of the solid sediment as well as the type of heavy metal.

- Ionic surfactants selected to react with the polar, non-halogenated, organic contaminants.

- Inorganic chemicals or very strong polar organic materials to bind with the biofilm and cap the bacteria to reduce their ability to absorb. These chemicals normally have temporary effects, sometimes as short as 30 minutes.

- Non-ionic surfactants to prevent re-adhesion of the biofilm over the solid particle.

3.2 Development of Larger-Scale Equipment

During the last half of 1993 and throughout 1994, BioGenesis designed, constructed, and tested a pilot-scale sediment washing system capable of processing from 8 to 10 cubic yards of sediment per hour. The design objective of the pilot equipment was to field a small scale unit built to commercial standards that would give the experience necessary to construct full scale units capable of 30 to 50 cubic yards per hour or more.

The pilot system consisted of two major equipments. The first equipment contained hydrocyclones, a wet screen, and a mixing feed tank to supply homogenized sediment slurry to the collision chamber. The second equipment contained the sediment collision chamber and collision scrubbers. Both units were designed to be transportable on a single lowboy trailer. Water at up to 10,000 psi was supplied to the collision chamber by a diesel-powered blaster unit made by NLB Corporation. This unit is transported on an auxiliary trailer together with a diesel generator, power distribution panel, and miscellaneous equipment.

Following delivery, the collision chamber unit was functionally tested with sand. This provided a “worst case” test since sand settles very quickly and can clog equipment. Tests were conducted at throughput rates of up to 40 tons per hour. This showed that the mechanical flow design was sound. Although material was processed through the machine at high rates, calculations indicate that lower rates of 10 to 15 tons per hour are necessary to provide contact time and good cleaning efficiency.

Testing of the wet screen indicated that it performed as designed for particle sizes that would not pass 400 mesh (about 38 micrometers). The hydrocyclones installed on the unit were designed to separate grain sizes as low as 10-15 micrometers. Testing showed that such efficiency was achieved at low overall flow rates. However separation efficiency degraded at higher throughput rates, and this raised questions about the suitability of these equipments for use at full-scale volumes of 40 cubic yards or more per hour.

4 SEDIMENT APPLICATIONS 1995 - 1997

4.1 Overview of WRDA Studies, 1995 to Date

From 1995 onward, BioGenesis has participated in the U.S. Environmental Protection Agency, Region 2, and U.S. Army Corps of Engineers, New York District, project to develop technology capable of decontaminating sediment dredged from New York and New Jersey Harbor. The program is federally funded under the Water Resources Development Act. Brookhaven National Laboratory manages the program under an Inter-agency Agreement between EPA and the Department of Energy (Brookhaven). BioGenesis was selected into the program to evaluate its washing process for decontaminating dredged sediments which contain aromatic hydrocarbons (PAHs), organochlorines (such as dioxins, furans), polychlorinated biphenyls (PCBs), chlorinated pesticides and herbicides, and metals.

Since 1995, BioGenesis has conducted five studies of significance to test its sediment washing technology. The core aspect of sediment washing is the desorption of contaminants from solid particles using collision impact forces. At the time of selection into the WRDA program, the technology concept had been defined and tested under the sponsorship of Environment Canada's SEDTECH program. The SEDTECH testing focused on treatment of high concentrations of PAHs. No testing had been conducted on contaminated sediment containing lower concentrations of PAH together with PCB, dioxin/furan, and inorganic contaminants. While there was evidence that desorption was effective on particles less than 38 micrometers in size, additional testing was needed on the contaminants not previously tested and on sediment from NY/NJ that had lower levels, but more complex mixtures of contamination. The resulting study series was intended to explore these points.

4.2 Initial WRDA Bench Study, October 1995 (BNL 1)

4.2.1 *Project Description*

4.2.1.1 <u>Purpose and Objectives</u>

The objective of this first treatability test was to evaluate the BioGenesis K Soil and Sediment Washing Process and develop enough information to make cost estimates and provide data necessary to establish a reference for selection of the BioGenesis K Soil and Sediment Washing Process for pilot-scale testing.

4.2.1.2 <u>Sample Source</u>

The sediment sample collected for the treatability test was collected on October 11, 1995, aboard the Army Corps of Engineers Survey Vessel *Gelberman.* A total of about 275 gallons of sediment were collected using a modified clamshell dredge of about 0.2 cubic yards capacity. For each grab, overlying water was drained prior to depositing the sampler's contents into the collection container. Composited material was then homogenized using an electric 3.5 HP mixer (food-grade stainless steel shaft and propeller). The sediment was characterized by collecting 6 samples from random x, y, and z locations in the collection container after 30 minutes of mixing. The results of the analytical testing show an average coefficient of variation of about

15% for all of the contaminants. The analytical results for the pre-treatability study were submitted to BNL by BioGenesis report dated February 8, 1996, subj: *Bench Scale Treatability Study Report; Decontaminating Dredged Estuarine Sediments.*

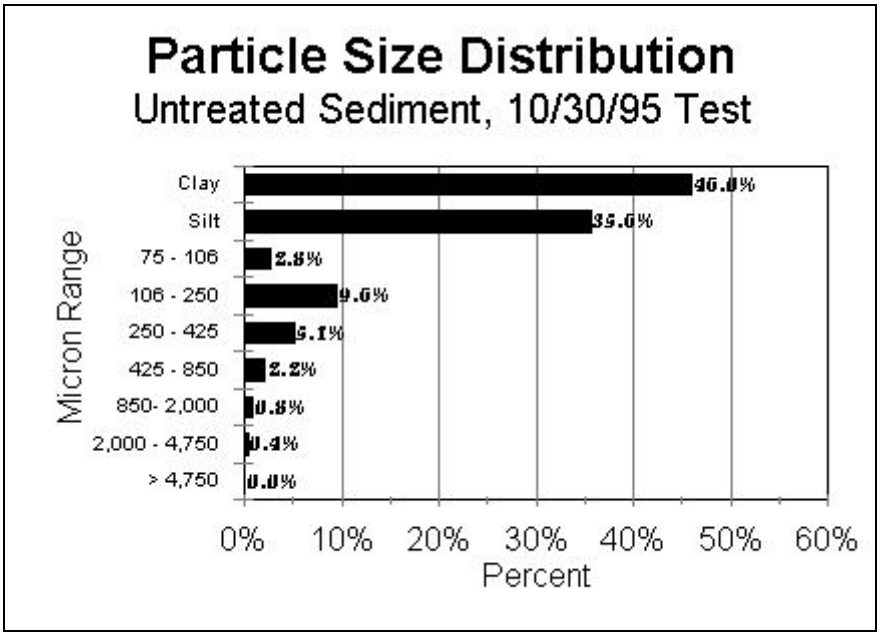


Figure 16. Particle Size Distribution, WRDA Testing, 10/30/95

4.2.1.3 Description

The grain size distribution of the sediment is shown in figure 16. This distribution is fairly typical of New York Harbor and Newark Bay sediments, with almost 50% classified as clay with a grain size less than 3 micrometers.

4.2.1.4 Untreated contamination levels

Untreated contamination levels are shown in table 8.

Table 8. Newtown Creek Untreated Sediment, November 1995 Bench Testing			
Total Organic Carbon		Polychlorinated Biphenyl (PCB)(ug/kg)	
TOC(%)	7.25	Total MonoCB	108
		Total DiCB	379
Polyaromatic Hydrocarbon (PAH)		Total TriCB	727
		Total TetraCB	1,588
naphthalene	2,729	Total PentaCB	487
acenaphthylene	1,288	Total HexaCB	1,237
acenaphthene	1,042	Total HeptaCB	809
fluorene	1,389	Total OctaCB	96
phenanthrene	6,586	Total NonaCB	20

Table 8. Newtown Creek Untreated Sediment, November 1995 Bench Testing			
anthracene	3,702	Total PCB	5,451
fluoranthene	10,323		
pyrene	7,101	DIOXIN/FURAN (ng/kg)	
benzo(a) anthracene	4,484		
chrysene	4,564	2378 TCDD	42
benzo(b)fluoranthene	2,922	Total TCDD	246
benzo(k)fluoranthene	1,107	Total PeCDD	378
benzo(a)pyrene	2,550	Total HxCDD	1,370
indeno(1,2,3-cd) pyrene	1,075	Total HpCDD	4,450
dibenzo(a,h)anthracene	397	Total TCDF	2,372
benzo(ghi)perylene	1,254	Total PeCDF	2,853
Total PAH	52,513	Total HxCDF	5,175
		Total HpCDF	6,068
METALS (ppm)			
As	33.5	Pb	617
Cd	37.1	Hg	1.29
Cr	377	Ni	297

4.2.2 *Experimental Design and Procedures*

4.2.2.1 <u>Treatment system description</u>

The process flow diagram for the treatment system is shown in figure 17.

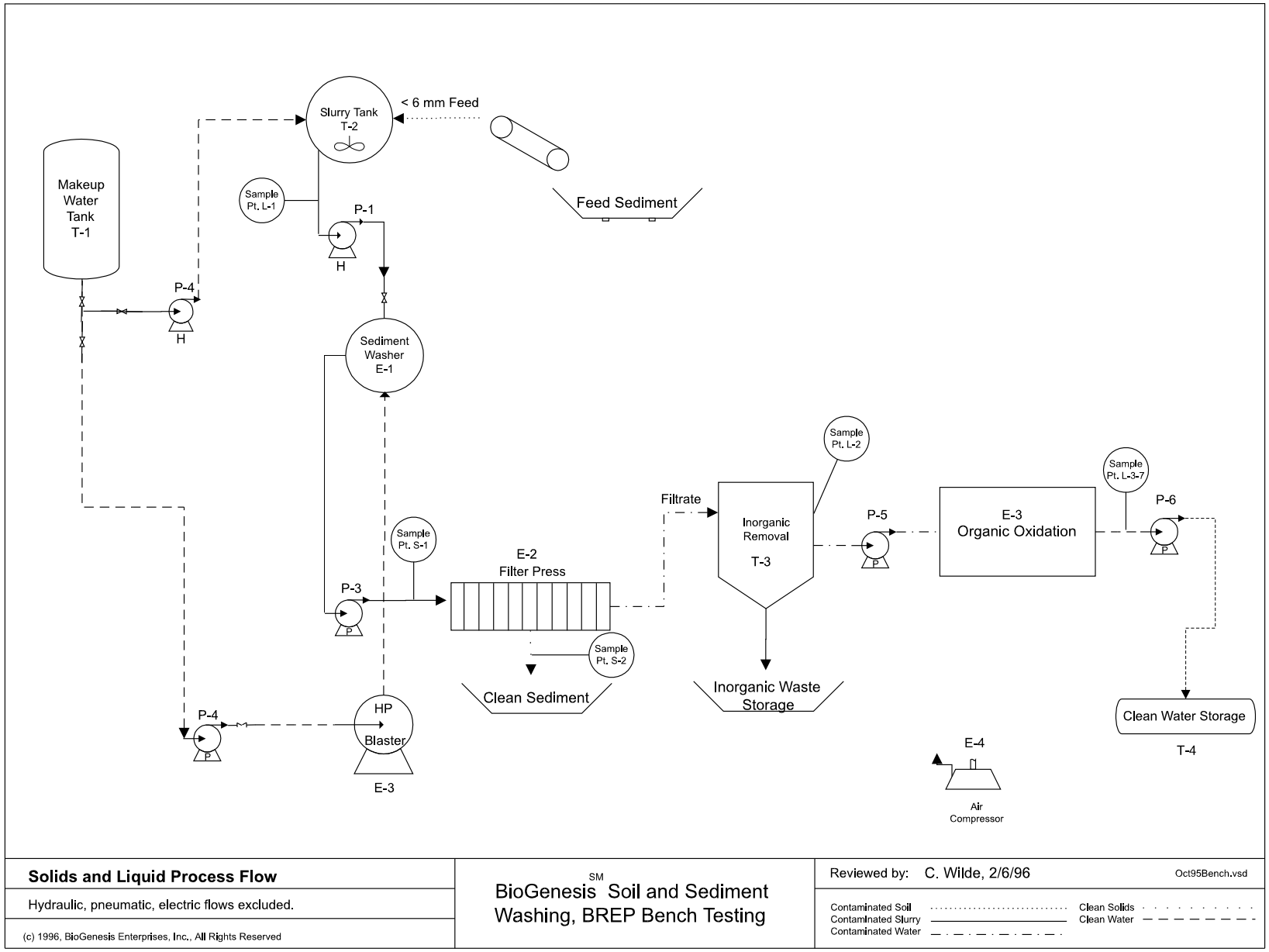


Figure 17. BioGenesis K system process flow, WRDA testing, 10/30/95

The equipment used during the bench test included the following:

- 55-Gallon capacity pre-treatment slurry tank with air-powered Lightnin Mixer motor, food-grade stainless steel shaft and propeller.
- 125-Gallon capacity BioGenesis K Sediment Washer with air-powered Lightnin Mixer motor, food-grade stainless steel shaft and propeller, pressure and slurry feed ports.
- 2" Wilden Sandpiper air diaphragm pump.
- 36" Rosedale Bag Filter with 1.5" air diaphragm pump.
- Setra Super Count high resolution counting scale (1.00g increment).
- Glasco GUS-15 Ultraviolet Water Purifier.
- HYDROX 1200 cavitation system.
- NLB 10120D water blaster.
- 1" Wilden air diaphragm pump.
- 55 Gallons of BG-Decon Industrial Cleaner
- 5 Gallons BG-S-N2 washing chemical
- 1 Gallon BG-S-N3 washing chemical
- 5 Gallons sodium sulfide precipitate solution
- 1 Gallon Nalco Polymer
- 10 Gallons 50% Solution hydrogen peroxide
-
- JWI 3" J-Press filter press
- P141 Enerpac Hydraulic Compressor w/ #10112512 filters
- 5 Gallons BG-Clean 1103N Wastewater Odor Treatment
- SKC Model 223-3 Low Flow air monitor with SKC 226 charcoal tubes

4.2.2.2 Process Flow Diagram and Test Narrative

The samples to be treated at the BioGenesis site were opened in the presence of all attendees and the temperature taken as 4°C. The samples were weighed and opened. A tank-bottom-like consistency with a heavy petroleum odor characterized the sediment material to be cleaned. Sample NC951011-11 contained a net weight of 17.138kg of material used in the treatment process. The sample was split into two five-gallon buckets to which one-half gallon of water was added to each bucket to facilitate screening of gross oversized material. The material was homogenized with a stainless steel trowel and poured through the screen into the pretreatment slurry tank. An archive sample of the material weighing 0.487kg was retained for BioGenesis' custody.

Sample NC951011-12 was weighed and a net 18.161kg of sediment material was split into the two five-gallon buckets to which one-half gallon of water was added to each to facilitate

screening of the gross oversized material. Again, the material was homogenized with a stainless steel trowel and poured through the screen into the pretreatment slurry tank.

One gallon BG-S-N2 and one gallon BG-S-N3 were added to the pre-treatment slurry tank and the slurry tank mixer turned on. The slurry mixture was agitated for a period of two hours to allow the BioGenesis™ chemicals enough time to mobilize any inorganic contaminants in the sediment. BioGenesis' information regarding the sediment characteristics, including potential contaminant concentrations was limited to the data in Tables 1 through 6 found on Page 8-13 in the Statement of Work contained in the RFP. For this reason, BioGenesis believed it prudent to extend the residence time of the organic mobilization chemicals.

From the pre-treatment slurry tank, the slurry was pumped into the BioGenesis K Sediment Washer's collision chamber. The pumping process took two minutes to complete after which the slurry was returned to the slurry tank where 50 ml of anti-foaming agent were added. The cycle was repeated whereupon the slurry was again pumped into the collision chamber for cleaning. After the two minute cycle was completed, the slurry was returned to the pre-treatment tank for post treatment consisting of dewatering and water treatment.

During the bench-scale treatment process, a total of 22 gallons of water was used in the collision chamber averaging 11 gallons of water per cycle. After the slurry was returned to the slurry tank the second time, 10 ml of polymer combined with 500ml water was added to flocculate the slurry as a dewatering aid. The air mixer was turned on for two minutes to properly combine the dewatering aid with the sediment.

An air diaphragm pump was used to transfer the cleaned material to the filter press. After 15 minutes of filter pressing, the first dewatered "biscuit" of decontaminated sediment was produced. At approximately noon the next day, BioGenesis had pressed the entire quantity of solids producing approximately 21 kg of cleaned material and 27.5 gallons of filtrate. The filtrate was processed by pumping the liquid through the HYDROX 1200 cavitation unit.

An air monitoring device was placed at the top of the pre-treatment tank for a period of two hours during which all tests were run on the sediment. The analytical results of the air monitor indicated that no air emissions were detected during the treatability study. The analytical results for these tests were included in the data report.

4.2.3 *Sampling and Analysis*

4.2.3.1 Sample points

BioGenesis returned 7.1 kg of treated sediment to Brookhaven for testing, as well as liquid samples designated below:

Sample ID	Description	Volume/ Weight
L-1	Liquid slurry after initial residence time	16 oz
L-2	Liquid supernatant after flocculation	16 oz
L-3-7	Treated liquid effluents	16 oz each

Sample ID	Description	Volume/ Weight
S-1	Slurry after mixing, washing & polymer addition	16 oz
S-2	Treated end product (soil)	7.1 kg

4.2.4 *Data Management, Analysis, and Interpretation*

4.2.4.1 Data summary and comparison to starting analysis

All data were included in the report to BNL, Bench Scale Treatability Study Report, Decontaminating Dredged Estuarine Sediments, February 8, 1996, which is not summarized here due to inconclusiveness of results. See discussion of results below.

4.2.4.2 Interpretation of results

Brookhaven National Laboratory sent a portion of the 7.1 kg of treated sediment to Triangle Laboratory, Research Triangle Park, North Carolina, for analysis. For analytical completeness, BioGenesis forwarded a sample from the archival sample to ANAlab in Edison, NJ, to test Polynuclear Aromatic Hydrocarbons (PAHs), Total Petroleum Hydrocarbon (TPH), and Total Organic Carbon (TOC). Selected results from the Triangle analysis are included in table 9 below. Complete results and QA/QC data are included in the appendixes of the BioGenesis K Bench Scale Treatability Report, dated February 8, 1996. Key results from Triangle are contained on pages 19-21 and 51-53 of Appendix A to that report. Key results from ANAlab are contained on pages 20-21 of Appendix B to that report.

4.2.5 *Discussion of Results*

The results from the analytical testing conducted by both Triangle and ANAlab were well correlated, despite differing presentation methods that are at the discretion of the laboratory. Unfortunately, the results from both laboratories were inconclusive, and no meaningful conclusions could be drawn about the efficiency of cleanup achieved at the bench scale. *The primary factor leading to this assessment is that the level of contamination in the sediment was significantly lower than the PQL (Practical Quantitation Limit) of Method 8270, PAH.* Instructive in this regard is the following extract from page 3 of the Triangle report:

> *... The quantitation limit for all analytes is half of the low point of the initial calibration adjusted for sample mass, percent moisture, or dilution when appropriate. ... Any concentrations reported at a level below the quantitation limit will be flagged with a "J" and should be considered estimated.* (emphasis added)

Table 9 below illustrates the inherent limitations of Method 8270 when applied to extremely low levels of analytes. The table derives from pp. 19-21, and 51-52 of the Triangle report.

Table 9. Triangle PAH Results Summary		
	Treated Sample S2-1	**Treated Sample S2-2**
Total number of compounds detected by the PAH test, excluding compounds detected in the blank	21	20
Number of "hits" above the PQL	3	2
Number of "hits" below the PQL, i.e. "J" quality estimates	18	18
Number of "hits" more than 50% below the PQL	12 of 18	14 of 18

To provide users with, at least, some insight to the analytes present below the PQL, estimated MDLs (Method Detection Limits) are established. These are machine calculated, theoretical values of the lowest level that a skilled technician can "see" on a given test, on a given instrument. The reliability of estimated values that are below the PQL decreases the farther the estimated value is from the PQL. Again, the Triangle report, page 3, is instructive:

> *... The estimated detection limits reported are the average detection limits achievable over time on an instrument type. The actual detection limit for a given compound on a given day may vary from the estimate reported. ... Below this point* (the PQL) *the calibration cannot be considered to be linear.* (emphasis added)

Note that 66% to 78% of the "hits" below the PQL *were more than 50% below the PQL*. This is a high indication of unreliability of the value because instrument calibration below the PQL is not linear.

The sensitivity of the Method 8270 analytical procedure is also strongly affected by the method used for sample preparation. In this case, confidence in results is further decreased by two factors: the extraction amount increased from one ml to two ml and the five times dilution of the extraction by Triangle before analyses which resulted in a ten times (10x) overall dilution factor. This dilution factor significantly reduces confidence in the data reported.

Because of the 10x dilution factor, the PQL for the Triangle tests was increased to 6,950 µg/kg and 7,057 µg/kg from a standard of 333 µg/kg. The difference between the standard and test PQLs is significant because it shows that while Method 8270 is capable of very low detection levels, in this case the PQL was adversely raised by the 10x dilution factor. Put another way, all but 2 of the 26 compounds in the "6 sample mean untreated" samples that are being used by Brookhaven National Laboratory as the baseline levels of contamination are below the PQL of 8270 for the Triangle tests. Most are more than 50% below.

The lack of precision in the results of the Triangle testing is compounded by the lack of precision found by examination of the standard deviations of the test results in the "6 sample untreated mean". Here the standard deviations varied from the mean by from 8% to 76%. This variability probably does not stem from lab or sampling errors. *It is simply inherent in the fact that low analyte levels are being tested using the best method available, but nonetheless one which is less*

repeatable and reproducible the farther below the PQL and closer to the MDL that results are reported.

A point about presentation of results--the format of results presented by the two laboratories, each qualified and certified, differed for the same Method 8270 test. Triangle presented data that are apparently highly accurate as indicated by two decimal places for the concentrations and for the MDLs. ANAlab presented MDLs with no decimal places and rounded to the hundreds. One could infer from this that Triangle was more precise than ANAlab. However such is not true because both labs used the same EPA test method with comparable equipment, procedures, and personnel. The explanation is that Triangle presented results as they came from the machine, while ANAlab presented results interpreted for the level of precision inherent in the analysis. In this case, for these samples, the level of precision is very low, and thus ANAlab, using legitimate laboratory discretion, reported MDLs rounded to the hundreds place, and again using laboratory discretion, chose to report potential hits below the PQL as non-detected instead of estimated values. Common practice says that in order for a detection of an analyte to be considered "real" or significant, it needs to be three to five times the detection or quantitative limits. Triangle, on the other hand, reported machine results. The comparability of the two lab's instruments can be seen by the roughly comparable MDLs determined by both labs. Neither reporting method is right or wrong, although the argument could be made that Triangle's presentation gives the non-expert user a feeling of greater confidence than is warranted by the data. *The overall lack of precision in the data is exactly why no conclusions can be reached for the bench testing.*

In summary, the results of any analytical data can only be considered in light of the data qualifiers, detection or quantitative limits, and a statistically sound number of replicates. In this case, to give any confidence at all to results so close to detection limits, a minimum of seven samples would have had to be analyzed. The inconclusiveness of the analytical data in no way can be interpreted to mean that removal did not occur. Physical examination of the products from the treatability test showed visible, tangible "removal" of petroleum by-products.

4.2.6 *Conclusions and Recommendations*

4.2.6.1 <u>Conclusions</u>

a.1. The data derived from this bench testing are inconclusive due to three problems encountered with the testing. These are the inability to compare before and after results due to variances in the laboratory data produced by the analytical testing, the inability of BioGenesis to properly optimize the chemical concentrations and synchronize them with other chemicals within the cleaning system before the testing, and insufficient quantity of contaminated sediment to provide for system optimization prior to testing.

a.2. Polymer additives were used to aid in dewatering the sediment by coagulating the fine particles. It is highly probable that polymer usage had the undesired effect, not recognized prior to testing, of retaining some of the organic contamination in the fines that had been transferred during cleaning to the liquid phase.

4.2.6.2 Recommendations

Additional testing is recommended as follows:

b.1. Increase the amount of sediment available for processing to about 60 gallons. Use 30 gallons for pretesting to optimize chemicals and equipment.

b.2. Perform the tests on sediment with contaminant concentrations three to five times the practical quantitative limit for the analytes. This will ensure that the limitations of laboratory test methods and presentation of results do not impact evaluation of system effectiveness.

b.3. Increase the degree of metals removal by adjusting chelation methodology.

b.4. Eliminate to the maximum extent the use of polymer as a dewatering aid. Use non-polymer based dewatering technology such as filtering or centrifugation.

4.3 WRDA Bench Study, February 1997 (BNL 2)

4.3.1 *Project Description*

4.3.1.1 Purpose and objectives

During the fall of 1996, discussions were held among Brookhaven National Laboratory staff, EPA Region 2, and BioGenesis to identify the means and requirements for additional BioGenesis K process testing that would address the limitations of the initial bench work and provide an accurate assessment of technology effectiveness.

As a result of these discussions, a bench scale testing project was established. This project included sediment dredged by the Corps of Engineers as directed by BNL and Region 2, preliminary testing carried out by BioGenesis with laboratory support from Envirogen, Inc., and record treatment runs under the supervision of BNL. The preliminary testing occurred during January and February 1997 with record runs occurring on February 28, 1997.

The objective of the testing was to achieve maximum extraction of PAHs, PCBs, dioxin/furan, and metals from the contaminated sediment.

4.3.1.2 Sample source

The sample source was Newtown Creek, NY. Using assessment data previously collected from Newtown Creek, BNL obtained sediment from the most highly contaminated area available. This was done to provide good discrimination among the laboratory results and avoid problems encountered in the previous test caused by contamination levels near or below the practical quantitation limits (PQL) of laboratory analytical tests.

4.3.1.3 Sediment Grain Size

Van Note-Harvey Associates, P.C. performed a grain size analysis on untreated sediment on behalf of Envirogen, Inc. which was providing laboratory testing. Results are shown in figure 18 below.

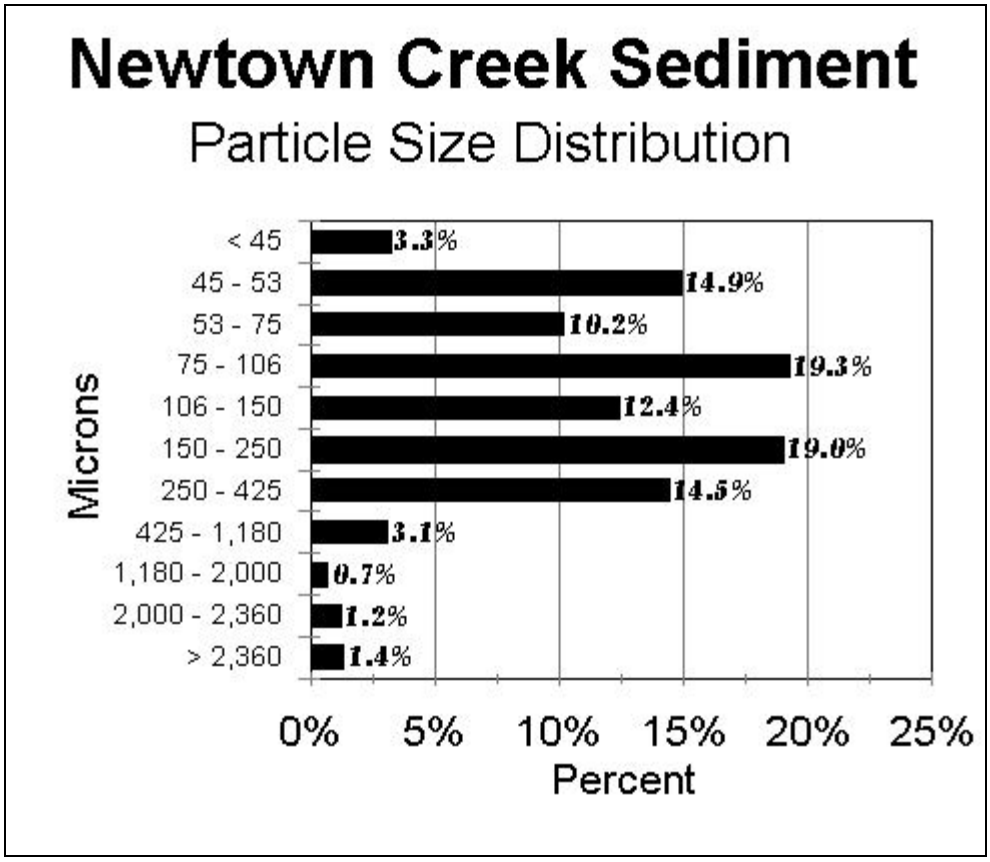


Figure 18. Particle size distribution, Newtown Creek sediment, WRDA testing, 2/28/97

The analysis showed that approximately 29% of the sediment passed a 200 mesh screen and was characterized as silt and clay. Note: See data interpretation results below. This grain size analysis was subsequently shown to understate the amount of fines in the sediment.

4.3.2 *Experimental Design and Procedures*

4.3.2.1 Treatment system description and process flow

Table 10 describes the components used in bench testing on February 28, 1997. The functional flow diagram, figure 19, showing processing flow follows the table.

Table 10. Functional Description of Bench System Equipment	
Equipment	**Functional Description**
E-1 Sediment Preprocessor	Physically separates sediment particles to prepare the particles for subsequent extraction.

Table 10. Functional Description of Bench System Equipment	
Equipment	**Functional Description**
T-1 Buffer Tank #1	Allows extraction chemical to wet each sediment particle and prevent the particles from re-adhering to each other. Sediment is circulated. Chemical pH adjustments are made here.
E-2 Sediment Collision Chamber	Physically separates contaminant and particles.
T-2 Buffer Tank #2	Prevents solid particles from re-adhering to each other.
E-3 Cavitation Oxidation Unit	Oxidizes organic contamination
E-4 Hydrocyclone	Concentrates solid components of the slurry. Other types of liquid/solid separation may be substituted.
T-3 Buffer Tank #3	Collects hydrocyclone overflow and wet screen flow-through. Provides feed to E-5 Rotary Vacuum Filter.
E-6 Wet Screen	Screens solids larger than 38 micrometers (400 mesh) from the E-4 hydrocyclone underflow. Treated solids may be further dewatered if needed or, if further organic removal is desired, sent to T-4.
T-4 Organic Material Flotation Tank	Separates fine particle organic material from clean sediment solids.
E-8 Batch Bioreactor	Treats organic material to remove any residual organic contamination.
T-5 Metals Precipitation Tank	Uses chemical adjustment to precipitate metals in the rotary vacuum filter flow-through. This tank and E-9 precipitation filter may be replaced by electro-chemical treatment or other metals extraction method.
E-9 Precipitation Filter	Filters output of the T-5 Precipitation Tank to remove inorganic precipitate.
T-6 Water Holding Tank	Provides holding tank for feed water to the Blaster E-7. Receives treated water for recirculation in the system.
E-7 Blaster	Provides water & chemical mixture to the E-1 Sediment Preprocessor and the E-2 Collision Chamber at 680 bar (10,000 psi).

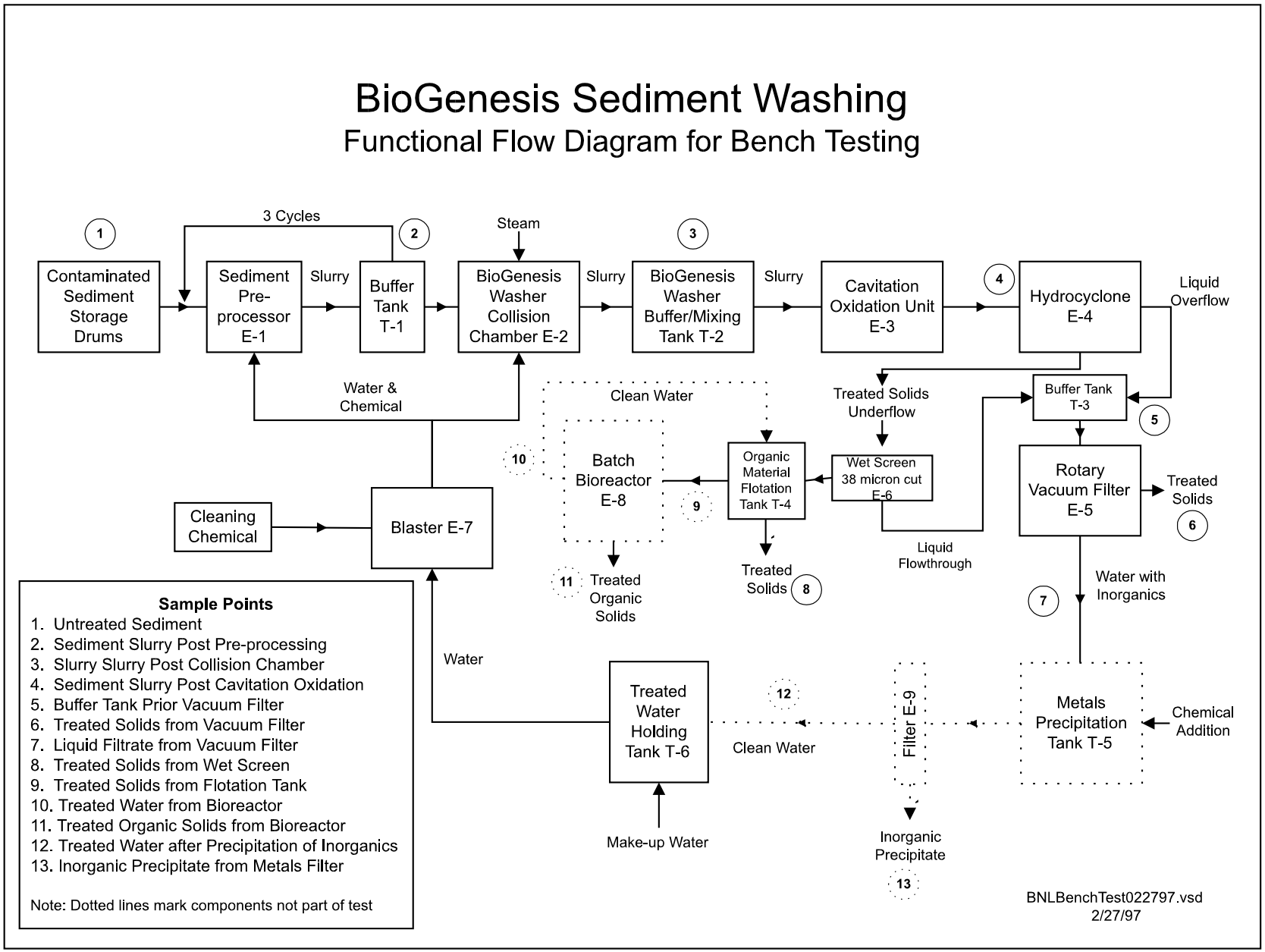


Figure 19. BioGenesis K system bench process flow, WRDA testing, 2/28/97

4.3.2.2 Processing plan

The processing plan consisted of the following steps:

- Feed sediment through the preprocessor E-1 in order to finely divide all particles and create a uniform slurry. Simultaneously add cleaning chemical to begin the desorption process and to prevent readherence of the fine particles after separation.

- Process the sediment through the collision chamber E-2 to desorb organic contaminants.

- Chelate inorganic contaminants for one hour in Buffer/Mixing tank T-2 and at the same time add oxidizing chemical to prepare the sediment for processing in the cavitation oxidation unit.

- Process the sediment slurry through Cavitation/Oxidation E-3 to oxidize as much organic contamination as possible.

- Dewater the sediment using a combination of hydrocyclone E-4 and wet screen E-6.

- Filter fine particles from the cyclone overflow and wet screen flow-through with rotary vacuum filter E-5.

4.3.3 *Sampling and Analysis*

4.3.3.1 Sample points, reasons for selection

Table 11 depicts the sample points selected for monitoring. These points were agreed on by BioGenesis and the BNL representative prior to the testing. The points were selected to give highest priority to defining untreated conditions (sample point 1) and the decontamination of the treated solids (sample point 8).

Table 11. BioGenesis K Bench System Sample Point (See figure 22)

Analysis Test	1	2	3	4	5	6	7	8
Sieve	X		X			X		X
pH	X		X			X	X	X
Sulfides	X		X			X	X	X
TOC	X		X	X		X	X	X
TPH by 8015	X		X	X		X		X
PAH by 8270	X		X	X		X	X	X
PCB	X		X	X		X	X	X
Metals	X		X		X	X	X	X

Table 11. BioGenesis K Bench System Sample Point (See figure 22)								
Analysis Test	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Pesticides, Herbicides	X					X	X	X

4.3.3.2 Analysis Methods

Analysis methods were selected to identify and quantify the full range of organic and inorganic contaminants. These include:

TOC — ASTM Method D4129-82M, Total Organic Carbon, to measure overall removal of organic material

Grain Size — ASTM Method D422 Modified

TRPH — EPA Methods 3550A and 8015M, Hydrocarbon Scan, to measure petroleum derivatives (total recoverable petroleum hydrocarbons)

PAH — EPA Method 8270A to measure semi-volatile hydrocarbons by high resolution gas chromatography / low resolution mass spectrometry, principally Poly-Aromatic Hydrocarbons

PCB — EPA Method 680 Modified to measure polychlorinated biphenyls by high resolution chromatography / high resolution mass spectrometry

Metals EPA Methods 6010A and 7471 to measure inorganic contaminants

Dioxin/Furan — EPA Method 8290, polychlorinated dibenzo-p-dioxins and dibenzo furans by high resolution chromatography / high resolution mass spectrometry

4.3.4 *Data Management and Analysis*

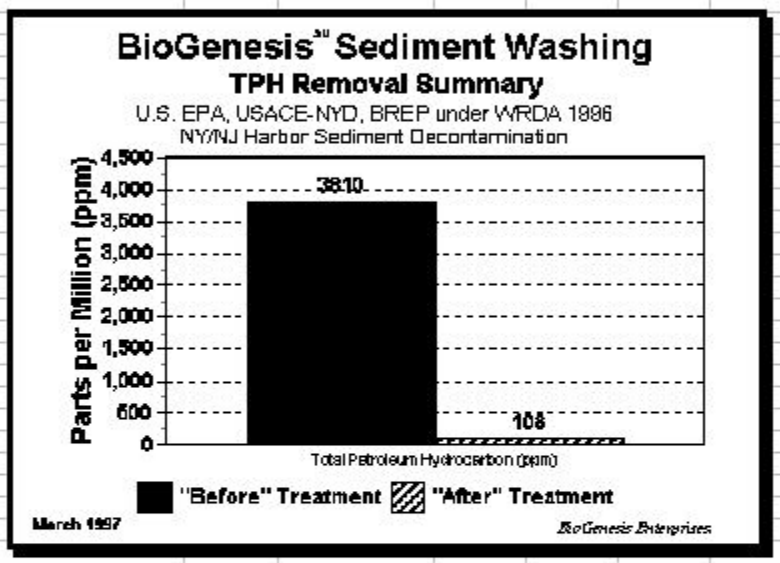
Figures 21 through 24 provide starting analysis results (sample point 1), ending analysis results (sample point 8), percentage reduction in contaminants, and graphic representations of the data. Samples from all 8 data points were collected by BNL for archiving and further analysis, while sample aliquots from points 1 and 8 were sent directly by BioGenesis to Triangle Laboratory for rapid turnaround analysis.

BioGenesis Sediment Washing

Testing on New York / New Jersey Harbor Sediment 2/28/97
For U.S. EPA, USACE-NYD, BREP under WRDA 1996
Analysis by Triangle Laboratories, Inc.

Analysis for TOC/TPH reported 3/15/97

	"Before" Sample 1-1	"After" Sample 8-1	Percent Removal
Total Organic Content (percent)	3.58	0.11	96.9%
Total Petroleum Hydrocarbon (ppm)	3810	108	97.2%



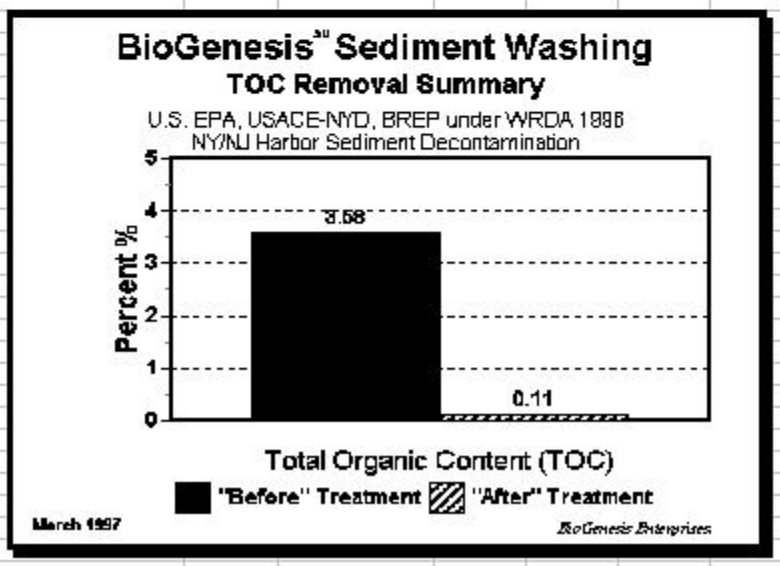


Figure 20. TOC and TPH results, WRDA testing, 2/28/97

BioGenesis Sediment Washing

Testing on New York / New Jersey Harbor Sediment 2/28/97

For U.S. EPA, USACE-NYD, BREP under WRDA 1996

Analysis by Triangle Laboratories, Inc.

Analysis for the Presence of Poly-Aromatic Hydrocarbons PAHs) reported 3/11/97

PAH	"Before" Sample 1-1 (ppb)	"After" Sample 8-1 (ppb)	Percent Removal
Acenaphthylene	48.01	10.67	77.78%
Anthracene	167.12	34.14	79.57%
Benzo (a) anthracene	283.4	44.01	84.47%
Benzo (a) pyrene	240.47	26.97	88.78%
Benzo (b) fluoranthene	291.88	39.35	86.52%
Benzo (g,h,i) perylene	81.86	17.17	79.03%
Benzo (k) fluoranthene	97.82	16.21	83.43%
Benzo(e) pyrene	182.62	22.00	87.95%
Chrysene	365.77	47.94	86.89%
Dibenzo (a,h) anthracene	9.99	8.9	10.91%
Fluoranthene	548.67	71.16	87.03%
Fluorene	42.43	17.5	58.76%
Indeno (1,2,3-cd) pyrene	59.35	10.16	82.88%
Naphthalene	45.46	11.63	74.42%
Phenanthrene	168.27	29.45	82.50%
Pyrene	348.96	48.99	85.96%
Total PAH	2982.08	456.25	
	Total PAH Extraction Percent	84.70%	

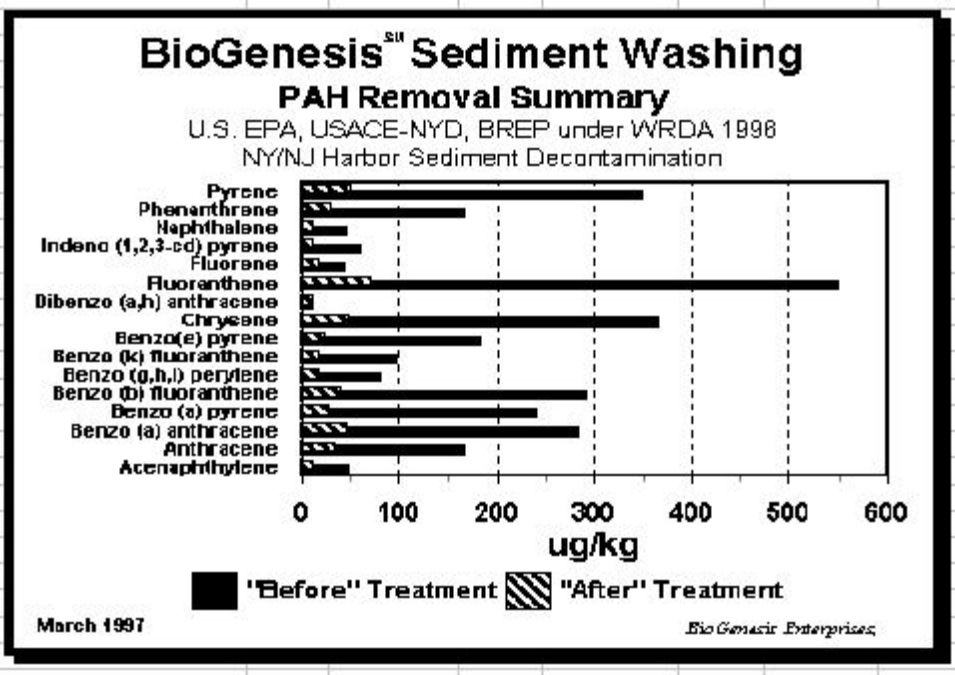


Figure 21. PAH results, WRDA testing, 2/28/97

BioGenesis Sediment Washing

Testing on New York / New Jersey Harbor Sediment 2/28/97
For U.S. EPA, USACE-NYD, BREP under WRDA 1996
Analysis by Triangle Laboratories, Inc.

Analysis for the Presence of Polychlorinated Biphenyls (PCBs) reported 3/13/97

		"Before" Sample 1-1 (ppb)		"After" Sample 8-1 (ppb)		Removal Efficiency %
2-MonoCB (#1)		0.34		0.005		98.5%
4,4'-DiCB (#15)		3.10		0.070		97.7%
2,4,4'-TriCB (#28)		10.20		0.360		96.5%
2,2',5,5'-TetraCB (#52)		11.80		0.580		95.1%
3,3',4,4'-TetraCB (#77)		1.30		0.040		96.9%
2,3',4,4',5-PentaCB (#118)		13.80		0.500		96.4%
2,3,3',4,4'-PentaCB (#105)		5.20		0.190		96.3%
3,3',4,4',5-PentaCB (#126)		0.06		0.006		90.0%
2,3,3',4,4',5-HexaCB (#156)		1.60		0.100		93.8%
3,3',4,4',5,5'-HexaCB (#169)		ND		ND		
2,2',3,4,4',5,5'-HeptaCB (#180)		12.20		0.690		94.3%
2,2',3,3',4,4',5,5'-OctaCB (#194)		3.00		0.140		95.3%
2,2',3,3',4,4',5,5',6-NonaCB (#206)		1.90		0.050		97.4%
DecaCB (#209)		6.00		0.080		98.7%
	Total All	70.50		2.811		96.0%
			Mean Removal Efficiency			95.9%
Total MonoCB		0.66		0.005		99.2%
Total DiCB		10.60		0.240		97.7%
Total TriCB		44.70		1.500		96.6%
Total TetraCB		87.80		3.900		95.6%
Total PentaCB		101.00		4.100		95.9%
Total HexaCB		101.00		5.900		94.2%
Total HeptaCB		50.10		2.900		94.2%
Total OctaCB		16.00		0.860		94.6%
Total NonaCB		3.30		0.070		97.9%
	Total All	415.16		19.475		95.3%
		Mean Total Removal Efficiency				96.2%

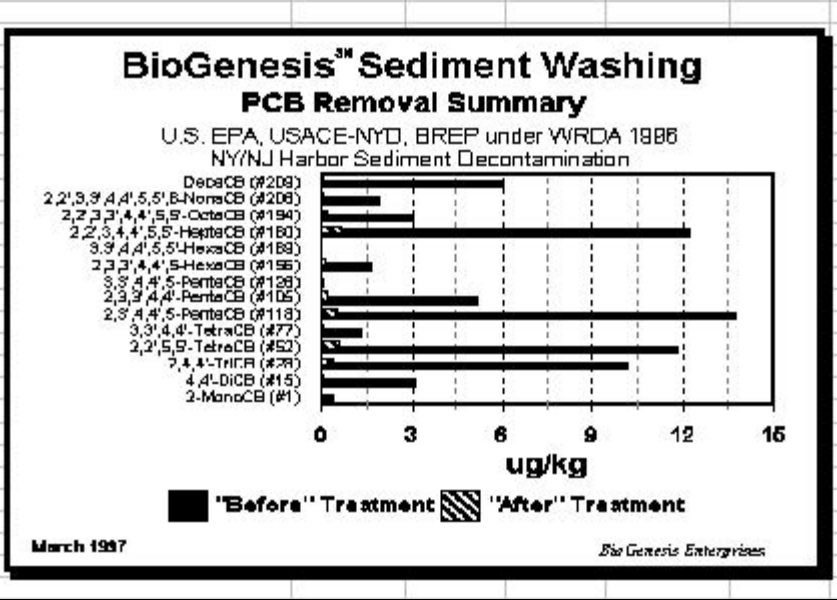


Figure 22. PCB results, WRDA testing, 2/28/97

BioGenesis Sediment Washing
Testing on New York / New Jersey Harbor Sediment 2/28/97
For U.S. EPA, USACE-NYD, BREP under WRDA 1996
Analysis by Triangle Laboratories, Inc.

Analysis for the Presence of Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans reported 3/13/97

Contaminate		"Before" Sample 1-1 (ppt)		"After" Sample 8-1 (ppt)	Detection Limit		Percent Removal
2,3,7,8-TCDD		66		ND	0.7	>	98.94%
1,2,3,7,8-PeCDD	>	5.7		ND	0.9	>	84.21%
1,2,3,4,7,8-HxCDD		9		ND	1.1	>	87.78%
1,2,3,6,7,8-HxCDD		28.8		ND	0.9	>	96.88%
1,2,3,7,8,9-HxCDD		20.2		ND	0.9	>	95.54%
1,2,3,4,6,7,8-HpCDD		529		4.8			99.09%
1,2,3,4,6,7,8,9-OCDD		5560		41.1			99.26%
2,3,7,8-TCDF		22.8		0.36			98.42%
1,2,3,7,8-PeCDF		12.9		ND	0.7	>	94.57%
2,3,4,7,8-PeCDF		20.6		ND	0.7	>	96.60%
1,2,3,4,7,8-HxCDF		116	>	1.2		<	98.97%
1,2,3,6,7,8-HxCDF		19.9		ND	0.6	>	96.98%
2,3,4,6,7,8-HxCDF		25		ND	0.8	>	96.80%
1,2,3,7,8,9-HxCDF		ND		ND	0.9		ND
1,2,3,4,6,7,8-HpCDF		355		4.1			98.85%
1,2,3,4,7,8,9-HpCDF	>	12.7		ND	1.3	>	89.76%
1,2,3,4,6,7,8,9-OCDF		558		27.1			95.14%
Total Dioxins and Furans		7361.6		78.66			
Total Dioxin and Furan Extraction Percentage			=	> 98.93%			

		"Before" Sample 1-1 (ppt)		"After" Sample *-1 (ppt)	Detection Limit (ppt)		Percent Removal
Total TCDD		120		ND	0.7	>	99.42%
Total PeCDD		18.9		ND	0.9	>	95.24%
Total HxCDD		271		ND	1	>	99.63%
Total HpCDD		1260		10.7			99.15%
Total TCDF		476		2.1			99.56%
Total PeCDF		357	>	1.7		<	99.52%
Total HxCDF		399	>	2.4		<	99.40%
Total HpCDF		621		4.1			99.34%
Total Dioxins and Furans		3522.9		21			
Total Dioxin and Furan Extraction Percentage			=	> 99.40%			

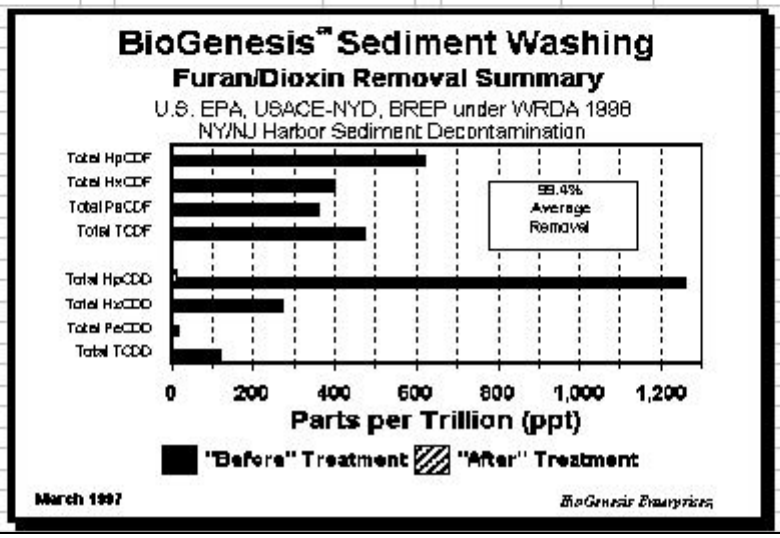


Figure 23. Dioxin/furan results, WRDA testing, 2/28/97

In 1989, U.S. EPA developed factors to denote the relative toxicity of different dioxin/furan congeners. Table 12 applies the Toxicity Equivalent Factors to the untreated and treated analysis results to compute a weighted extraction efficiency. This efficiency, 98.07%, is approximately 1% less than the unadjusted computations shown in table 12.

Table 12. Adjustment of Dioxin/Furan Results Using Toxicity Equivalent Factors

	Unadjusted Results			Adjusted Results		
	Untreated	Treated		Toxicity Equivalent Factor	TEF Weighted Untreated	TEF Weighted Treated
2,3,7,8-TCDD	66	0.7	ND	1	66	0.7
1,2,3,7,8-PeCDD	5.7 EMPC	0.9	ND	0.5	2.85	0.45
1,2,3,4,7,8-HxCDD	9	1.1	ND	0.1	0.9	0.11
1,2,3,6,7,8-HxCDD	28.8	0.9	ND	0.1	2.88	0.09
1,2,3,7,8,9-HxCDD	20.2	0.9	ND	0.1	2.02	0.09
1,2,3,4,6,7,8-HpCDD	529	4.8		0.01	5.29	0.048
1,2,3,4,6,7,8,9-OCDD	5560	41.1		0.001	5.56	0.0411
2,3,7,8-TCDF	98.5	1.1		0.1	9.85	0.11
1,2,3,7,8-PeCDF	12.9	0.7	ND	0.05	0.645	0.035
2,3,4,7,8-PeCDF	20.6	0.7	ND	0.5	10.3	0.35
1,2,3,4,7,8-HxCDF	116	1.2	EMPC	0.1	11.6	0.12
1,2,3,6,7,8-HxCDF	19.9	0.6	ND	0.1	1.99	0.06
2,3,4,6,7,8-HxCDF	25	0.8	ND	0.1	2.5	0.08
1,2,3,7,8,9-HxCDF	5 ND	0.9	ND	0.1	0.5	0.09
1,2,3,4,6,7,8-HpCDF	355	4.1		0.01	3.55	0.041
1,2,3,4,7,8,9-HpCDF	12.7 EMPC	1.3	ND	0.01	0.127	0.013
1,2,4,6,7,8,9-OCDF	558	27.1		0.001	0.558	0.0271
Total	7442.3	88.9			127.12	2.4552
Percent Extraction		98.81%				98.07%

Notes: 1. DL and EMPC values are substituted in the calculation where applicable to maintain a conservative computation approach.
2. ND=Not Detected; EMPC = Estimated Maximum Possible Concentration

BioGenesis Sediment Washing

Testing on New York / New Jersey Harbor Sediment 2/28/97
For U.S. EPA, USACE-NYD, BREP under WRDA 1996
Analysis by Triangle Laboratories, Inc.

Analysis for Metals reported 3/10/97

Contaminant		"Before" Sample 1-1 (ppm)		"After" Sample 8-1 (ppm)	Removal Efficiency %
Ag		4.1	<	0.241	94.1%
As		14.8		3.01	79.7%
Be	<	0.546	<	0.241	55.9%
Cd		5.94		0.437	92.6%
Cr		171		8.43	95.1%
Cu		212		12.1	94.3%
Hg		2.21		0.103	95.3%
Ni		45.2		7.91	82.5%
Pb		300		9.69	96.8%
Sb	<	2.19	<	0.962	56.1%
Se		3.77	<	0.722	80.8%
Tl	<	2.73	<	1.2	56.0%
Zn		526		41.3	92.1%
		1290.486		86.346	

Total Metals Extraction Efficiency 93.3%

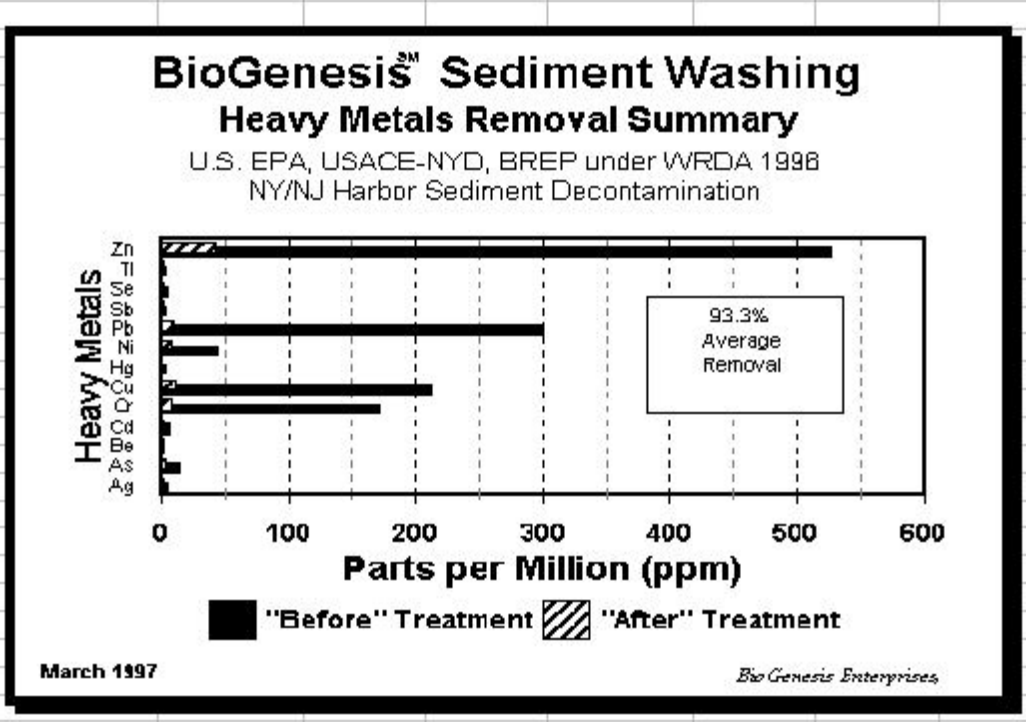


Figure 24. Metals results, WRDA testing, 2/28/97

These data are the results for grain sizes larger than 400 mesh, which was the size of the screen that collected the solids output from washing. They show overall effectiveness as summarized in figure 25.

BioGenesis Sediment Washing

Testing on New York / New Jersey Harbor Sediment 2/28/97

For U.S. EPA, USACE-NYD, BREP under WRDA 1996

Analysis by Triangle Laboratories, Inc.

		"Before" Total	"After" Total	Overall Percent Removal
Dioxin/Furan	ppt	3522.9	21.0	99.4%
Poly-Chlorinated Bi-phenol (PCB)	ppb	415.16	19.475	95.3%
Poly-Aromatic Hydrocarbon (PAH)	ppb	2982.08	456.25	84.7%
Total Petroleum Hydrocarbon (TPH)	ppm	3810	108	97.2%
Total Organic Carbon (TOC)	%	3.58	0.11	96.9%
Metals	ppm	1290.49	86.346	93.3%

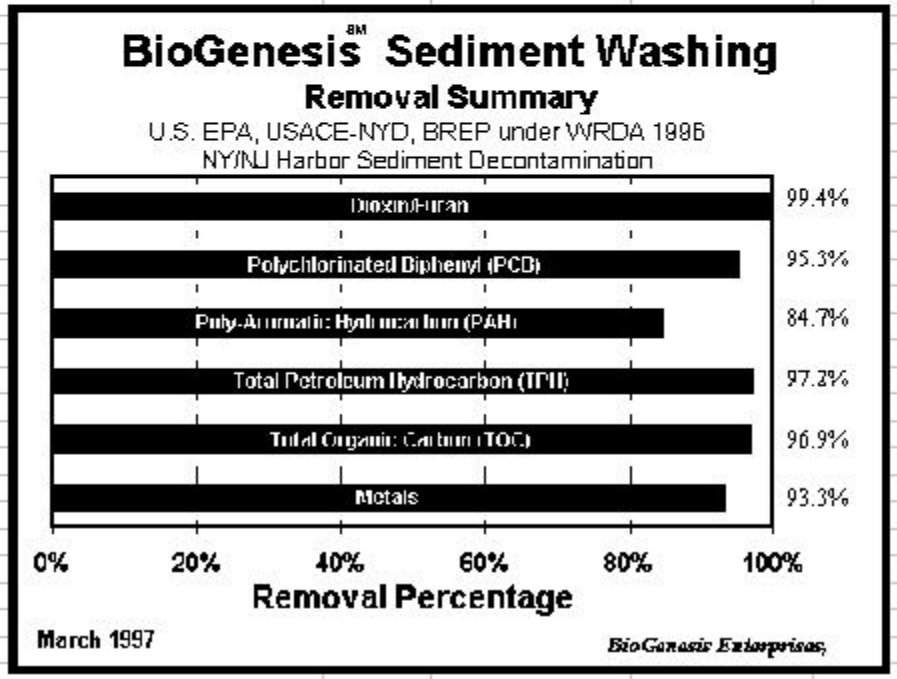


Figure 25. Removal summary, WRDA testing, 2/28/97

4.3.5 *Conclusions and Recommendations*

4.3.5.1 Conclusions

The conclusions from this round of bench testing were as follows:

a.1. Organic contaminant removal efficiencies are validated for grain sizes larger than 400 mesh, or a medium silt.

a.2. Inorganic contaminants for grain sizes larger than 400 mesh can be chelated into the liquid phase during the treatment process. The cleaned sediment may require a subsequent rinse to remove the chelating agent if the sediment is intended for reuse in an extremely sensitive environment such as the ocean. Future toxicity testing will define the treatment requirements in this regard.

a.3. Extraction rates for individual congeners of PCBs and dioxin/furan are highly correlated with little variation among congeners. Variation among different PAHs is somewhat greater.

a.4. Organic contaminant removal rates are highly correlated among the different contaminant types: PAHs, PCB, and dioxin/furan. That is, if one set of contaminants extracts at 90%, other organic contaminants will also be extracted in that range. The importance of this is that it points at full scale to the possibility of using an indicator test for quality control testing.

a.5. The use of vacuum filter technology for separation of extremely fine particles is feasible with some modifications. These are the subsequent treatment of contaminated filter material (diatomaceous earth) either by reprocessing through the sediment/cavitation system, or by using slurry biodegradation technology.

a.6. The core technology for removal of organic and inorganic contaminants is validated. Additional work is required to select the optimum means of performing liquid/solid separation and water treatment. Such work is difficult at the bench scale because of inability to produce sufficient material for practical testing under controlled conditions.

4.3.5.2 Recommendations

b.1. Proceed to pilot scale at 8 - 10 CY per hour on a batch basis using existing equipments.

b.2. Conduct an additional abbreviated round of sediment testing to further investigate system capabilities for grain sizes less than 400 mesh.

b.3. Investigate and test different methods of liquid-solid separation that can be applied using little or no polymer or coagulating chemicals.

4.4 WRDA Bench Study, August 1997 (BNL 3)

4.4.1 *Project Description*

4.4.1.1 Purpose and Objectives

Review of results obtained from the February 1997 bench testing showed excellent removal efficiency for particle sizes greater than 38 micrometers (400 mesh). Previous testing (SEDTECH) had shown good cleaning for particles smaller than 38 micrometers. However the degree of cleaning of the clay fraction of New York/New Jersey harbor sediment had not been demonstrated.

Therefore, the principal objective of August 1997 bench testing was to determine removal efficiencies for the grain size fraction smaller than 38 micrometers.

4.4.1.2 Sample source

Sediment for the August 1997 testing was dredged in late June 1997 from Newtown Creek. Dredging was by the Army Corps of Engineers, Brookhaven, and U.S. EPA Region II. To provide the opportunity for good discrimination in the testing, efforts were made to obtain sediment from areas of higher contamination.

4.4.1.3 Particle size distribution and untreated contamination levels

The distribution of particle sizes is shown in figure 26. Over 52% was clay and 33% was silt. The high silt and clay percentage was designed to allow evaluation of cleaning silt and clay particles.

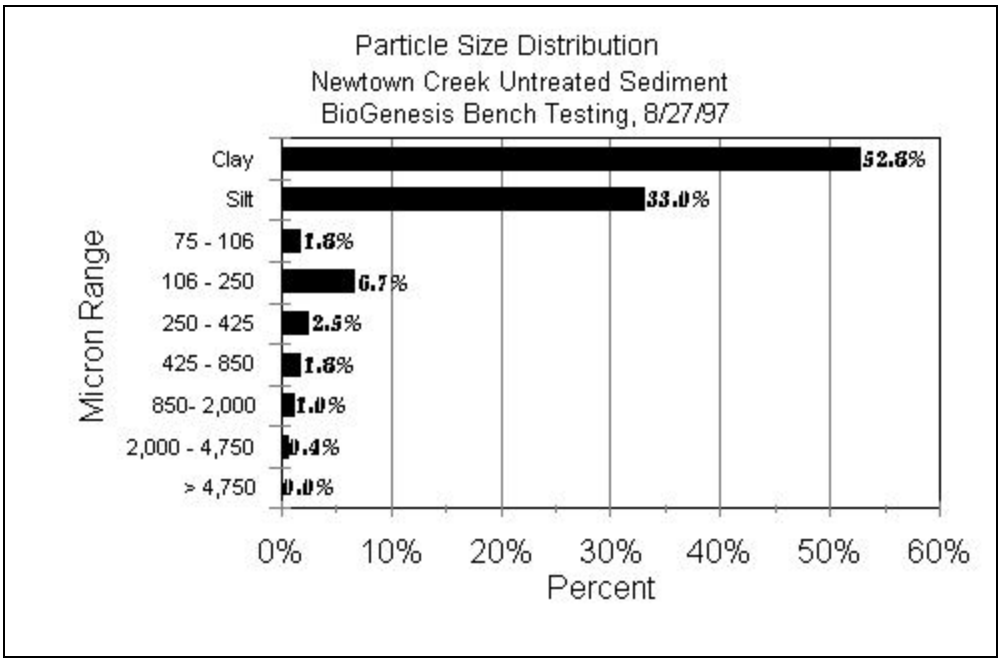


Figure 26. Particle size distribution, Newtown Creek sediment, 8/27/97 bench testing

Untreated contamination levels are depicted in table 13. BioGenesis submitted a pretreatment sample to ANAlab in order to have contaminant information on which to base the cleaning chemical formulation. Brookhaven submitted untreated samples to Triangle Laboratory at the same time as treated samples were submitted, on 9/17/97. Review of ANAlab and Triangle Laboratory analyses for untreated sediment shows variations between the two laboratories for PAHs that may be due to sample variation, sample storage, or instrument variation. The metal results are fairly well correlated with each other.

Table 13. Newtown Creek Untreated Sediment, August 1997 Bench Testing

	ANAlab	Triangle		ANAlab	Triangle
Total Organic Carbon (%)			**Polychlorinated Biphenyl (PCB)(ug/kg)**		
TOC	9.2	n/a	Total MonoCB	n/a	175 EMPC
			Total DiCB	n/a	191 EMPC
Polyaromatic Hydrocarbon (PAH)(ug/kg)			Total TriCB	n/a	429
			Total TetraCB	n/a	718
naphthalene	540	269	Total PentaCB	n/a	487
acenaphthylene	u	114	Total HexaCB	n/a	456
acenaphthene	460	300	Total HeptaCB	n/a	165
fluorene	u	191	Total OctaCB	n/a	39
phenanthrene	1,200	858	Total NonaCB	n/a	13
anthracene	450	771	Total PCB		2,320
fluoranthene	2,200	2,815			
pyrene	2,200	4,567	**Dioxin (ng/kg)**		
benzo(a) anthracene	u	1,793			
chrysene	7,120	1,994	2378 TCDD	n/a	26
benzo(b)fluoranthene	1,100	1,835	Total TCDD	n/a	543
benzo(k)fluoranthene	u	648	Total PeCDD	n/a	823
benzo(a)pyrene	880	1,471	Total HxCDD	n/a	2,240
indeno(1,2,3-cd) pyrene	410	875	Total HpCDD	n/a	4,080
dibenzo(a,h)anthracene	u	n/a	Total TCDF	n/a	1,870
benzo(ghi)perylene	650	1,001	Total PeCDF	n/a	2,450
Total PAH	17,210	19,502	Total HxCDF	n/a	2,820
			Total HpCDF	n/a	3,170
Metals (mg/kg)					
As	28.6	22.2	Pb	384	454
Cd	20.4	18.2	Hg	1.66	n/a
Cr	195	226	Ni	111	119

n/a = not analyzed

EMPC = Estimated Maximum Possible Concentration

u = undetected

4.4.2 *Experimental Design and Procedures*

4.4.2.1 Treatment system description and process flow

Table 14 describes the components used in bench testing on August 27, 1997. The functional flow diagram, figure 27, showing processing flow follows the table.

Table 14. Functional Description of Bench System Equipment

Equipment	Functional Description
E-1 Sediment Preprocessor	Physically separates sediment particles to prepare the particles for subsequent extraction.
T-1 Buffer Tank #1	Allows extraction chemical to wet each sediment particle and prevent the particles from re-adhering to each other. Sediment is circulated. EDTA for metals chelation is added here. Sample point 2, preprocessor output.
E-2 Sediment Collision Chamber	Physically separates contaminant and particles.
T-2 Buffer Tank #2	Buffer and holding tank, 225 gal. Prevents particles from re-adhering to each other. Sample point 4, first pass output from collision chamber.
T-3 Buffer Tank #3	Holding tank for Collision Chamber output, 400 gallon capacity. Sodium carbonate peroxyhydrate is added here to prepare for cavitation/oxidation.
E-3 Cavitation Oxidation Unit	Oxidizes organic contamination
T-3 Buffer Tank #3	Holding tank for Cavitation Oxidation output, 400 gallon capacity. Samples points 6 (solids) and 7 (supernatant).
E-7 Blaster	Provides water & chemical mixture to the E-1 Sediment Preprocessor and the E-2 Collision Chamber at 680 bar (10,000 psi). Not shown on process flow diagram.

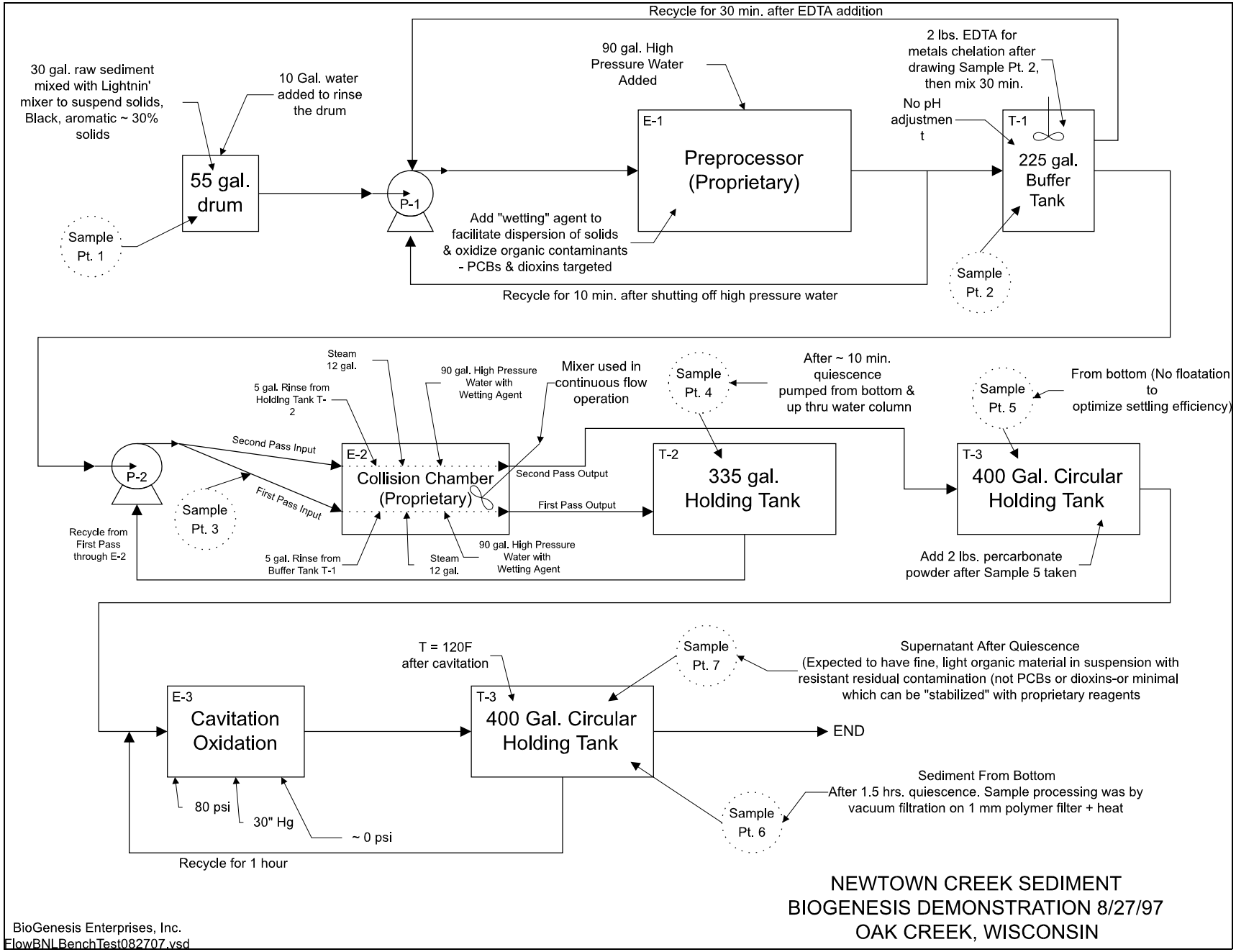


Figure 27. BioGenesis K system process flow, WRDA testing, 8/27/97.

4.4.2.2 Processing plan

The processing plan consisted of the following steps:

- Feed sediment through the preprocessor E-1 in order to finely divide all particles and create a uniform slurry. Simultaneously add cleaning chemical to begin the desorption process and to prevent readherence of the fine particles after separation. Recycle for 10 to 15 minutes.

- Chelate inorganic contaminants for one-half hour in Buffer/Mixing tank T-2.

- Process the sediment through the collision chamber E-2 to desorb organic contaminants.

- Process the sediment through the collision chamber E-2 a second time.

- Collect collision chamber output in Tank T-3. Add percarbonate oxidizing chemical to prepare the sediment for processing in the cavitation/oxidation unit.

- Process the sediment slurry through Cavitation/Oxidation E-3 to oxidize as much organic contamination as possible. Recirculate the slurry through the unit for one hour.

- Allow the cavitation/oxidation output to settle approximately two hours. Then sample the settled solids and supernatant.

4.4.3 *Sampling and Analysis*

4.4.3.1 Sample points

Table 15 depicts the sample points selected for monitoring. These points were agreed on by BioGenesis and the BNL representative prior to the testing. The points were selected to give highest priority to defining untreated conditions (sample point 1) and the decontamination of the treated solids (sample point 6).

Table 15. BioGenesis K Bench System Sample Point

	Sample Point			
Analysis Test	1	4	6	7
Sieve	X		X	
Total Suspended Solids (TSS)	X	X	X	
Sulfides	X	X	X	
TOC	X	X	X	
PAH	X	X	X	X
PCB	X	X	X	X

Table 15. BioGenesis K Bench System Sample Point				
	Sample Point			
Analysis Test	1	4	6	7
Metals	X	X	X	X

4.4.3.2 Analysis methods

Analysis methods were selected to identify and quantify the most important organic and inorganic contaminants. Previous testing (SEDTECH, BNL2, and internal testing) had shown that organic contaminants (TRPH, PAH, PCB, and dioxin) all were removed in parallel with each other, that is, if PAH removal was 90%, then TRPH, PCB, and dioxin would also be removed approximately to the same degree. For purposes of this testing, PAH, PCB, and metals were deemed to provide the desired data on system cleaning of the fines. The tests selected for each parameter were:

Grain Size	- ASTM Method D422 Modified
TOC	- ASTM Method D4129-82M, Total Organic Carbon, to measure overall removal of organic material
PAH	- EPA Method 8270A to measure semi-volatile hydrocarbons by high resolution gas chromatography / low resolution mass spectrometry, principally Poly-Aromatic Hydrocarbons
PCB	- EPA Method 680 Modified to measure polychlorinated biphenyls by high resolution chromatography / high resolution mass spectrometry
Metals	- EPA Methods 6010A and 7471 to measure inorganic contaminants

Samples were taken as indicated in table 14 on August 27, 1997 and BioGenesis shipped them by Federal Express to Brookhaven National Laboratory on August 28th. Due to fiscal resource limitations, samples were held at Brookhaven until September 16 when they were shipped to Triangle Laboratory for analysis. Triangle conducted extractions for PCB and PAH testing between September 25 and October 9, 1997. Extractions occurred between 29 and 43 days after processing in Milwaukee. The EPA maximum analysis method holding time until extraction for both PAH and PCB is 7 days. *For reasons discussed in following sections, the organic contaminant testing results must be cautiously treated due to the extended holding times for the samples*. Inorganic analysis, which occurred between October 8 and 13, was not affected since the holding time for metals testing is 45 days, according to the relevant methods.

4.4.4 *Data Management, Analysis, and Interpretation*

4.4.4.1 Data Summary, Untreated and Treated

Table 16 compares the analytical results for untreated and treated material from the BNL3 testing.

Table 16. Untreated/Treated Comparison, August 1997 Bench Testing					
	Untreated	**Treated**		**Untreated**	**Treated**
		Sample Pt. 6			**Sample Pt. 6**
Total Organic Carbon			Polychlorinated Biphenyl (PCB)*(See Note 1)*		
	Percent			ppb	
TOC	9.2 (ANAlab)	n/a	Total MonoCB	175 EMPC	15.1 EMPC
			Total DiCB	191 EMPC	23
Polyaromatic Hydrocarbon (PAH) *(See Note 1)*			Total TriCB	429	199
	ug/kg		Total TetraCB	718	283
naphthalene	269	913	Total PentaCB	487	232
acenaphthylene	114	326	Total HexaCB	456	253
acenaphthene	300	434	Total HeptaCB	165	83
fluorene	191	533	Total OctaCB	39	19
phenanthrene	858	2,243	Total NonaCB	13	4
anthracene	771	1,612	Total PCB	2,320	1,100
fluoranthene	2,815	7,358			
pyrene	4,567	6,767	METALS		
benzo(a)anthracene	1,793	3,563		mg/kg	
chrysene	1,994	3,781	As	22.2	13
benzo(b)fluoranthene	1,835	3,496	Cd	18.2	4
benzo(k)fluoranthene	648	1,155	Cr	226	124
benzo(a)pyrene	1,471	2,666	Pb	454	239
indeno(1,2,3-cd) pyrene	875	1,595	Hg	n/a	6
dibenzo(a,h)anthracene	n/a	669	Ni	119	63
benzo(ghi)perylene	1,001	1,453	n/a = not analyzed		
Total PAH	19,502	36,891	EMPC = Estimated Max. Possible Concentration		
			u = undetected		
Note 1: PAH and PCB analyses conducted after 29 - 43 days holding time until extraction.					

4.4.4.2 Interpretation of Results

Analysis results indicated that TOC, PCB, and metals decreased in the treated material as compared to the untreated, while PAH results of treated material were twice that of untreated. All previous BioGenesis experience and testing indicates that the PAH result is impossible because organic results always move together. It is not possible to selectively extract one organic contaminant without extracting others. *Therefore it is highly likely that the "treated" test results and the "untreated" test results for PAH were reversed at some time during sample processing, analysis, or reporting.* It has not been possible to validate this hypothesis, but there is no other logical explanation. Subsequent testing after 70 days by R. E. Lee Laboratory, Green Bay, Wisconsin, an environmental laboratory certified by Wisconsin, of additional "treated" samples shows a reasonable close correlation of results with the "untreated" results reported by Triangle. See table 16 for the tabulation. This gives considerable confidence that a switch occurred and may have been as simple as a name or label reversal.

Review of the test results plus subsequent in-house testing indicates the strong probability that the results for PAH, PCB, and dioxin are understated due to reabsorption of contamination by the solids in connection with extended holding times prior to analysis.

Mean extraction of metals was 52% for As, Cd, Cr, Pb, Hg, and Ni. This is less than the 90% extraction achieved during BNL 2 in February 1997. The major factor changing between the two tests was that BNL 2 test consisted of silt that did not pass 400 mesh. See paragraph 4.3.4 and following.

4.4.5 *Conclusions and Recommendations*

4.4.5.1 Conclusions

a.1. For organic contaminants–analysis results are inconclusive due to extended holding times of 43 - 70 days prior to extraction.

a.2. For metals–smaller grain sizes may require an increased concentration of chelating chemical or a longer residence time, or both.

4.4.5.2 Recommendations

b.1. Reprocess the sediment, about 30 kg, that was the solids output from the test. Increase the chemical concentrations and run the process for additional cycles.

b.2. Ensure that extractions for analyses are processed by the laboratory within EPA established holding time of 7 days for organic contaminants.

b.3. Analyze the reprocessed sediment for TOC, PAH, metals, and PCBs.

4.5 WRDA Bench Study Nov 97 (BNL 4)

4.5.1 *Project Description*

Analysis reports on Newtown Creek samples processed using BioGenesis K Sediment Washing on August 27, 1997, during the third BNL bench testing, showed organic contaminant removal efficiencies on the order of 50%. This was significantly lower than anticipated, since results of the February 28, 1997 testing had shown removal efficiencies in the 85 to 95% range, and also since previous testing on the same sediment during July 1997 had shown removal efficiencies in the 90% range, albeit without fine grained material. Review of the analysis reports for the August 27, 1997 processing showed that extractions of the organic contaminants had not occurred for 29 to 43 days after the processing. This holding time was 4 to 6 times longer than the 7 day holding time required by the EPA test procedures. Thus, the results could not be relied on for comparison with previous testing and for prediction of future removal efficiencies.

After review of the results and performance of bench top tests to validate the line of thinking, BioGenesis reported to Brookhaven its belief that the extended holding time before extraction

had allowed contaminants, which had been removed from organic and solid material to the water phase during processing, to be reabsorbed onto organic and inorganic material in the sediment matrix.

BioGenesis took two approaches to investigate the circumstances connected with the unexpectedly low results of BNL3 testing. The first approach was to reprocess sediment that had been retained from the August testing. This testing is referred to as the fourth Brookhaven test, BNL 4, and the results are presented in this section 4.5. The second approach was to perform a study of transfer of contaminants from the water phase to sediment solids and organic material. That study is reported in section 4.6.

4.5.1.1 Purpose and objectives

The purpose of reprocessing sediment retained from the previous BNL3 test on August 27, 1997 was twofold–first, to explore the effect of successive treatments on inorganic contaminants and second, to remove organic contaminants reported by Triangle testing to be still present in the sediment. Removal of the organic contaminants would show that the contaminants were not resistant to decontamination by BioGenesis K washing and would support the theory that reabsorption of contaminants had occurred following BNL3. Further, successful decontamination would verify that the small grain sizes below 400 mesh were cleanable with BioGenesis K washing.

4.5.1.2 Sample Source

The source of sediment for BNL4 was the Newtown Creek sediment solids that had been washed during BNL3. These solids had been allowed to settle from August 27, 1997 to November 13, 1997, or 77 days.

4.5.1.3 Particle Size Distribution and Untreated Contamination Levels

Substantially all of the fines had settled from the supematant during 77 days. Thus for practical purposes, the grain size is the same as BNL3. Figure 26 shows the distribution to be 54% clay, 33% silt, and 13% larger particles.

There are three baselines for untreated contamination levels. These are:

- Tests results reported by Triangle as the “untreated” sediment for BNL3.
- Test results reported by Triangle as the “treated” sediment for BNL3.
- Test results reported by R.E. Lee laboratory on a sample submitted 70 days following BNL3 testing.

The latter test is referred to as the “interim” result. Table 17 tabulates the three levels. The values in boldface are believed to be most representative of the BNL4 baseline. For PAH, the Triangle “Treated” and “Untreated” are believed reversed during the reporting process. Since there is reasonable correlation between the R. E. Lee “Interim” and the Triangle “Untreated”, the

later result from R. E. Lee is accepted. For PCB and metals, the Triangle "Treated" is believed valid and is thus accepted as the BNL4 baseline.

Table 17. Untreated Test Results, BNL4 Reprocessing			
Contaminant	**Triangle "Untreated"**	**Triangle "Treated**	**R. E. Lee "Interim"**
TOC (%)			
Organic Content	9.2	9.2	**3.3**
PAH (mg/kg)			
naphthalene	269	913	**286**
acenaphthylene	114	326	**367**
acenaphthene	300	434	**168**
fluorene	191	533	**195**
phenanthrene	858	2243	**1250**
anthracene	771	1612	**812**
fluoranthene	2815	7358	**3200**
pyrene	4567	6767	**3400**
benzo(a) anthracene	1793	3563	**1440**
chrysene	1994	3781	**1550**
benzo(b)fluoranthene	1835	3496	**830**
benzo(k)fluoranthene	648	1155	**818**
benzo(a)pyrene	1471	2666	**951**
indeno(1,2,3-cd) pyrene	875	1595	**576**
dibenzo(a,h)anthracene	NP	NP	**267**
benzo(ghi)perylene	1001	1453	**634**
Total PAH	19502	37895	**16744**
PCB (ppb)			
Total MonoCB	175 EMPC	**15 EMPC**	NP
Total DiCB	191 EMPC	**23**	NP
Total TriCB	429	**199**	NP
Total TetraCB	718	**283**	NP
Total PentaCB	487	**232**	NP
Total HexaCB	456	**253**	NP
Total HeptaCB	165	**83**	NP
Total OctaCB	39	**19**	NP
Total NonaCB	13	**4**	NP
Total PCB	2320	**1111**	NP
METALS (mg/kg)			
As	22	**13**	NP
Cd	18	**4**	NP
Cr	226	**124**	NP
Pb	454	**239**	NP
Hg	13	**6**	NP
Ni	119	**63**	NP
Total Metals	852	**449**	NP
Notes:			
1. EMPC = Estimated Maximum Possible Concentration			
2. TOC test results by ANAlab on untreated sediment			
3. Triangle "Untreated" and "Treated" results for PAH are believed to be reversed			
4. NP = Not performed			

4.5.2 *Experimental Design and Procedures*

4.5.2.1 Treatment system description and process flow

Table 18 describes the components used in bench testing on November 14, 1997. The process flow diagram, figure 28, follows table 18.

Table 18. Functional Description of BNL 4 Bench System Equipment

Equipment	Functional Description
E-1 Sediment Preprocessor	Physically separates sediment particles to prepare the particles for subsequent extraction.
T-1 Buffer Tank #1	Allows extraction chemical to wet each sediment particle and prevent the particles from re-adhering to each other. Sediment is circulated. EDTA for metals chelation is added here.
E-2 Sediment Collision Chamber	Physically separates contaminant and particles.
T-3 Buffer Tank #3	Holding tank for Collision Chamber output, 400 gallon capacity. Percarbonate is added here to prepare for cavitation/oxidation.
E-4 Processor	Finely fractionates organic biomass particles.
E-3 Cavitation Oxidation Unit	Oxidizes organic contamination
T-3 Buffer Tank #3	Holding tank for Cavitation Oxidation output, 400 gallon capacity. Samples point 6 (solids).
E-7 Blaster	Provides water & chemical mixture to the E-1 Sediment Preprocessor and the E-2 Collision Chamber at 680 bar (10,000 psi). Not shown on process flow diagram.

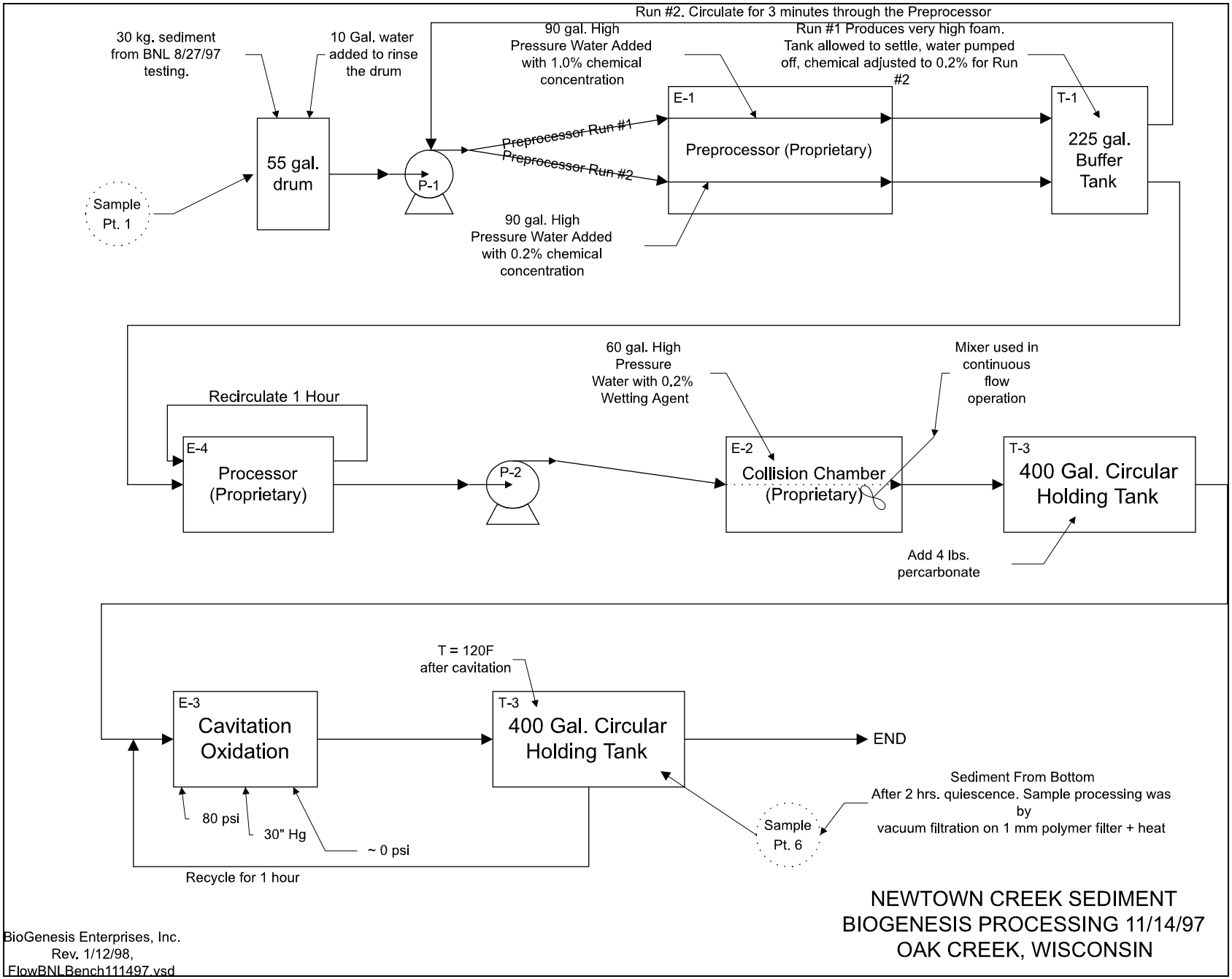


Figure 28. BioGenesis K system flow, BNL bench testing, 11/14/97

4.5.2.2 Processing plan

The processing plan consisted of the following steps:

- Thoroughly mix 2 pounds chelating chemical into the sediment supply tank.
- Feed sediment through the Preprocessor for 3 minutes, Run #1. Use a chemical concentration of 1%.
- Allow sediment to settle; then re-input sediment to the Preprocessor, Run #2.
- Circulate sediment through the Processor for 1 hour.
- Process the sediment through the collision chamber E-2 to desorb organic contaminants.
- Collect collision chamber output in Tank T-3. Add 4 pounds percarbonate oxidizing chemical to prepare the sediment for processing in the cavitation/oxidation unit.
- Process the sediment slurry through Cavitation/Oxidation E-3 to oxidize as much organic contamination as possible. Recirculate the slurry for one hour.
- Allow the cavitation/oxidation output to settle at least two hours. Then sample the settled solids and supernatant.

4.5.3 *Sampling and Analysis*

4.5.3.1 Sample points

Table 19 depicts the sample points selected for monitoring. The points were selected to define starting conditions (sample point 1) and the decontamination of the treated solids (sample point 6).

Table 19. BioGenesis K Bench System Sample Point

	Sample Point	
Analysis Test	1, Starting Conditions	6, Treated Solids
TOC	X	X
PAH	X	X
PCB	X	X
Metals	X	X

4.5.3.2 Analysis methods

Analysis methods were selected to identify and quantify the most important organic and inorganic contaminants - TOC, PAH, PCB, and metals. Dioxin was not tested because removals on PAH and PCB have been demonstrated to predict removal rates on dioxin. The tests selected for each parameter were:

TOC	ASTM Method D4129-82M, Total Organic Carbon, to measure overall removal of organic material
PAH	EPA Method 8270A to measure semi-volatile hydrocarbons by high resolution gas chromatography / low resolution mass spectrometry, principally Poly-Aromatic Hydrocarbons
PCB	EPA Method 8082 to measure polychlorinated biphenyls by high resolution chromatography / electron capture detection
Metals	EPA Methods 6010A and 7471 to measure inorganic contaminants

Samples were taken as indicated in the matrix on November 14, 1997 and BioGenesis shipped them by overnight delivery to Robert E. Lee & Associates, Inc., Green Bay, Wisconsin. Extractions occurred on November 17, 1997, which was well within the allowed holding time until extraction of 7 days. Inorganic analysis was conducted between November 26 and December 4, 1997, within the allowed time of 45 days.

4.5.4 *Data Management, Analysis, and Interpretation*

4.5.4.1 Data summary and comparison to starting analysis

Table 20 summarizes the test results for BNL4 reprocessing taking the results of BNL3 as a baseline.

Table 20. Treated Test Results, BNL4 Reprocessing

Contaminant	Treated Baseline from BNL 3 Triangle	Treated BNL 4 Robert E. Lee	BNL 4 Removal Percent
TOC (%)			
Organic Content	3.3	2.0	39
PAH (ug/kg)			
naphthalene	286	138	52
acenaphthylene	367	34	91
acenaphthene	168	34	80
fluorene	195	51	74
phenanthrene	1,250	743	41
anthracene	812	177	78
fluoranthene	3,200	537	83
pyrene	3,400	177	95
benzo(a) anthracene	1,440	234	84
chrysene	1,550	286	82
benzo(b)fluoranthene	830	158	81

Table 20. Treated Test Results, BNL4 Reprocessing			
Contaminant	Treated Baseline from BNL 3 Triangle	Treated BNL 4 Robert E. Lee	BNL 4 Removal Percent
benzo(k)fluoranthene	818	204	75
benzo(a)pyrene	951	236	75
indeno(1,2,3-cd) pyrene	576	ND (MDL 26)	95
dibenzo(a,h)anthracene	267	ND(MDL 30)	89
benzo(ghi)perylene	634	ND (MDL 27)	96
Total PAH	**16,744**	**3,175**	**81**
PCB (ppb)			
Total MonoCB	15 EMPC	ND (MDL 7.5)	Not determined
Total DiCB	23	ND (MDL 8.2)	Not determined
Total TriCB	199	ND (MDL 8.8)	96
Total TetraCB	283	ND (MDL 6)	98
Total PentaCB	232	ND (MDL 6.2)	97
Total HexaCB	253	ND (MDL 8)	97
Total HeptaCB	83	ND (MDL 10)	88
Total OctaCB	19	ND (MDL 14)	Not determined
Total NonaCB	4	ND (MDL 25)	Not determined
Total PCB	**1,111**	**93.7**	**92**
METALS (mg/kg)			
As	13.3	12.8	4
Cd	3.85	1.4	64
Cr	124	63	49
Pb	239	60	75
Hg	1.1	.3	73
Notes:			
1. EMPC = Estimated Possible Maximum Concentration			
2. ND = Not Detected			
3. MDLs used to compute removal efficiencies for non-detects			

4.5.4.2 Interpretation of results

Table 21 shows the results of two treatment operations. Results for organic contaminant removal during the first treatment, BNL 3, are difficult to interpret because of the extended holding times which most probably allowed recontamination of cleaned solids (see section 4.6.). The removal rates for organic contaminants during BNL 3 were probably higher than indicated by the test results. Removal rates for metals during BNL 3 are considered valid.

Table 21. Summary of Successive Treatments				
Contaminant	BNL 3 Untreated Triangle	BNL 3 Treated Triangle	BNL4 Treated Robert E. Lee	Overall Removal Percent
TOC (%)				
Organic Content	**9.2**	**3.3**	**2.0**	**78%**
PAH (ug/kg)				
naphthalene	913	286	138	85%
acenaphthylene	326	367	34	90%
acenaphthene	434	168	34	92%
fluorene	533	195	51	90%
phenanthrene	2,243	1,250	743	67%

Table 21. Summary of Successive Treatments				
Contaminant	BNL 3 Untreated Triangle	BNL 3 Treated Triangle	BNL4 Treated Robert E. Lee	Overall Removal Percent
anthracene	1,612	812	177	89%
fluoranthene	7,358	3,200	537	93%
pyrene	6,767	3,400	177	97%
benzo(a) anthracene	3,563	1,440	234	93%
chrysene	3,781	1,550	286	92%
benzo(b)fluoranthene	3,496	830	158	95%
benzo(k)fluoranthene	1,155	818	204	82%
benzo(a)pyrene	2,666	951	236	91%
indeno(1,2,3-cd) pyrene	1,595	576	ND (MDL 26)	98%
dibenzo(a,h)anthracene	Not Determined	267	ND(MDL 30)	89%
benzo(ghi)perylene	1,453	634	ND (MDL 27)	98%
Total PAH	**37,895**	**16,744**	**3,175**	**92%**
PCB (ppb)				
Total MonoCB	175 EMPC	15 EMPC	ND (MDL 7.5)	96%
Total DiCB	191 EMPC	23	ND (MDL 8.2)	96%
Total TriCB	429	199	ND (MDL 8.8)	98%
Total TetraCB	718	283	ND (MDL 6)	99%
Total PentaCB	487	232	ND (MDL 6.2)	99%
Total HexaCB	456	253	ND (MDL 8)	98%
Total HeptaCB	165	83	ND (MDL 10)	94%
Total OctaCB	39	19	ND (MDL 14)	Not Determined**
Total NonaCB	13	4	ND (MDL 25)	Not Determined**
Total PCB	**2,673**	**1,111**	**93.7**	**96%**
METALS (mg/kg)				
As	22.2	13.3	12.8	42%
Cd	18.2	3.85	1.4	92%
Cr	226	124	63	72%
Pb	454	239	60	87%
Hg	2.1	1.1	0.3	86%
Notes:				
1. EMPC = Estimated Maximum Possible Concentration				
2. ND = Not Detected				
3. MDLs used to compute removal efficiencies for non-detects				
** Removal percentage not computed using MDL due to low untreated level				
compared to MDL.				

Since higher extractions on organic contaminants were probably achieved in BNL 3 than the results show, it is not valid to compute removal efficiencies for BNL 4 using BNL 3 as a baseline. The better approach is to compare the results from BNL 4 to untreated results from BNL 3. This computation is shown in the right-hand column of table 20. Overall removal rates for organic contaminants range from a low of 67% to a high of 98%. The mean removal for the contaminants tested was 92%, with grain size distribution of 54% clay and 33% silt. The result is consistent with results achieved during BNL 2 testing in February 1997 that confirmed decontamination of particles larger than 400 mesh (38 micrometers).

Inorganic results are consistent with previous testing that shows successive removal with successive processing. Plotting the removal amounts on a logarithmic scale (figure 29) shows

that the removal rate has linear characteristics, and that removal percentages range from one-half to one order of magnitude for each processing.

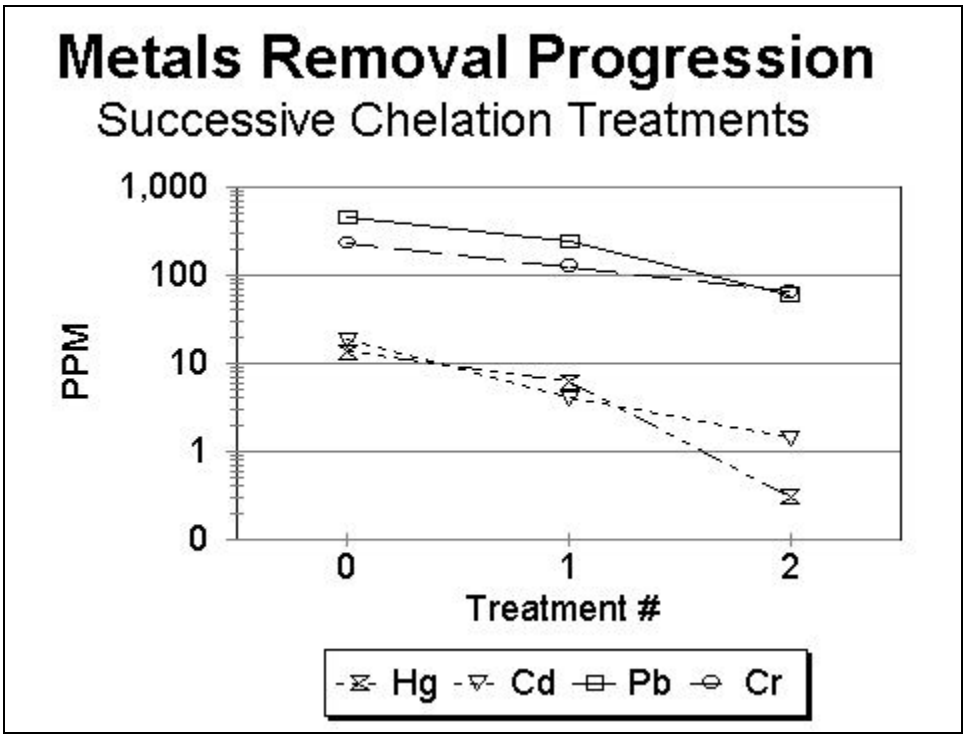


Figure 29. Metals removal progression, successive chelation treatments

To date, metals removal has been tested as an adjunct to primary treatment of organic contaminants. These results should therefore be considered a baseline. By adjusting chemical concentrations and residence times, BioGenesis estimates that extraction rates per treatment should improved by 10 to 30%.

4.5.5 *Conclusions and Recommendations*

4.5.5.1 <u>Conclusions</u>

a.1. The ability of the BioGenesis K washing process to treat sediment with high proportions of clay is established at the bench scale.

a.2. Within the precision of the tests conducted, the extraction rates for PAH, PCB, and metals that were achieved during BNL 3/4 testing on clays are comparable to those achieved during BNL 2 testing on silt.

a.3. Due to size mismatches in the bench equipment, more water was used than necessary. Pilot scale operations are expected to use approximately 50% less water.

a.4. Actual processing time in the preprocessor, processor, and collision chamber totaled approximately 3 minutes, this short time did not allow for iterative adjustments to operating

parameters to optimize processing. Higher extraction efficiencies are believed achievable under steady state operating conditions.

a.5. Additional bench scale testing could be expected to provide only incremental additions to technical knowledge that would be useful prior to piloting the technology. No additional technical knowledge is required prior to pilot scale operations.

4.5.5.2 Recommendations

b.1. Proceed to pilot scale operations.

b.2. Carefully structure the sampling and analysis plan to explore the capabilities of the technology.

b.3. Establish close liaison with the analysis laboratory prior to submitting samples to ensure that sample processing is timely, and that the procedures used consider the nature of both sediment with high organic content and the chemicals used in processing.

b.4. Evaluate alternative methods of liquid-solid separation and water treatment using output from the pilot scale washing equipment.

b.5. Ensure that the sediment that is treated during the pilot has a sufficiently wide range of contamination, both as to type and amounts, that good discrimination can be obtained as a basis for projecting future use of the technology.

4.6 Contaminant Transfer Study, October - December 1997

4.6.1 *Background*

Section 4.4 presented the results BioGenesis K Sediment Washing on August 27, 1997, during the third BNL bench testing and section 4.5. presented the results of reprocessing the output from the August 27, 1997 BNL3 testing. Section 4.5.1. identified the rationale for conducting a study of contaminant transfer in sediment. Subsequent sections report the results of that study.

The relationship between contaminants, organic material, and inorganic solids in sediment is absolutely essential to understanding how to decontaminate sediment. Because of this, BioGenesis undertook an experiment to validate the absorption/partitioning line of thinking. The experiment's outcome was intended to expand knowledge of the role played in BioGenesis K processing by removal of organic content, and to give further insights that could reduce the operating and capital costs of processing.

4.6.2 *Purpose*

The purpose of the study was to enhance understanding of the nature, extent, and timing associated with organic contaminants being absorbed from the water phase to inorganic particles and organic material in sediment. A further purpose was to explore the timing and extent of partitioning of contamination from organic material to inorganic material. This knowledge was needed to validate empirically derived understanding of the washing mechanisms being used to decontaminate sediment, give understanding of the relative importance in treatment of organic material removal, and identify the relative importance of dewatering sediment immediately after BioGenesisK treatment. All of these would potentially have an impact on system costs, both capital and operating, and on the equipment configuration and testing in the forthcoming demonstration.

4.6.3 *Procedure*

The study examined two types of sediment: one with a very low (< 1%) organic material content, and one with a 3% organic material content. The base sediment material was a dried, greyish/brown, sandy/silt. 70% of the mixture passed 400 mesh.

Low organic material procedure (<1%)

1. Weigh out two aliquots, each of 200g of the dried sandy/silt material.

2. Dissolve 0.1 g each of pyrene, fluorene, phenanthrene, acenaphthylene, and anthracene in 5 ml of surfactant, and 0.1 g each of naphthalene and 2-methyl naphthalene into 5 ml of surfactant.

3. Add the two dissolved mixtures of surfactant and contaminants to two aliquots of 1,000 ml water and mix thoroughly. The resulting contamination level of the water mixture is 1,000 ppm of each contaminant, a total of 5,000 ppm in one aliquot and 2,000 in the second.

4. Add the contaminated water mixtures to the sandy/silt and mix thoroughly.

5. Store the samples undisturbed at room temperature.

6. Follow the sampling procedure outline below.

High organic material content (3%)

7. Follow steps 1 - 6 as above, except that 25 ml of a natural organic material was dissolved in each container of the 1,000 ml containers in addition to the contaminants.

Sampling and analysis

8. Sample the four mixtures each week for the first 2 to 6 weeks. Thereafter, decrease frequency to every two weeks when the rate of change decreases. Sample both liquid and solids, a total of 8 samples for each period.

9. Prior to withdrawing each sample, mix the sediment thoroughly and allow to settle.

10. For the solids samples, withdraw 10 g from the container. Gravity drain the sample. Then rinse the sample gently with water and gravity drain. Reserve the solids.

11. For the liquid, withdraw 25 ml from the container. Vacuum filter the water using a 1 micrometer filter. Reserve the liquid, discarding the filtered solids.

12. For both solid and liquid samples, extract each sample, and perform GC analysis.

Reporting

13. For each solid and liquid sample, report the level of contamination in ppm.

4.6.4 *Results*

Data collected in the testing is presented in tables 22, 23, and 24. Table 22 shows data derived from the low (<1%) organic material test series, while table 23 shows data derived from the high (3%) organic material test series. Table 24 tabulates water and sediment appearance changes during the testing.

BioGenesis Contaminant Transference Study

October 6, 1997 to December 29, 1997

(all quantities in parts per million)

LOW ORGANIC CONTENT TEST SERIES								
End of Week	0	1	2	4	6	8	10	12
acenaphthylene								
Contaminant Qty in Liquid	1000	980	860	720	662	539	380	230
Qty Transferred to Organic & Inorganic Solids	0	0	180	230	288	353	430	511
Sum	1000	980	1040	950	950	892	810	741
Assumed Qty of Degradation	0	-20	40	-50	-50	-108	-190	-259
Change in solids from previous period		0	180	50	58	65	77	81
Percent Solids Gain From Previous Period as a Base				28%	25%	23%	22%	19%
Change in liquid from previous period		-20	-120	-140	-58	-123	-159	-150
Percent Liquid Loss from Previous Period as a Base		-2%	-12%	-16%	-8%	-19%	-29%	-39%
fluorene								
Contaminant Qty in Liquid	1000	1000	960	830	790	709	586	478
Qty Transferred to Organic & Inorganic Solids	0	0	30	124	154	211	288	457
Sum	1000	1000	990	954	944	920	874	935
Assumed Qty of Degradation	0	0	-10	-46	-56	-80	-126	-65
Change in solids from previous period		0	30	94	30	57	77	169
Percent Solids Gain From Previous Period as a Base				313%	24%	37%	36%	59%
Change in liquid from previous period		0	-40	-130	-40	-81	-123	-108
Percent Liquid Loss from Previous Period as a Base		0%	-4%	-14%	-5%	-10%	-17%	-18%
anthracene								
Contaminant Qty in Liquid	1000	950	810	700	673	566	448	346
Qty Transferred to Organic & Inorganic Solids	0	39	170	254	293	408	479	568
Sum	1000	989	980	954	966	974	927	914
Assumed Qty of Degradation	0	-11	-20	-46	-34	-26	-73	-86
Change in solids from previous period		39	131	84	39	115	71	89
Percent Solids Gain From Previous Period as a Base			336%	49%	15%	39%	17%	19%
Change in liquid from previous period		-50	-140	-110	-27	-107	-118	-102
Percent Liquid Loss from Previous Period as a Base		-5%	-15%	-14%	-4%	-16%	-21%	-23%
pyrene								
Contaminant Qty in Liquid	1000	948	850	735	752	639	498	362
Qty Transferred to Organic & Inorganic Solids	0	48	135	199	198	269	321	419
Sum	1000	996	985	934	950	908	819	781
Assumed Qty of Degradation	0	-4	-15	-66	-50	-92	-181	-219
Change in solids from previous period		48	87	64	-1	71	52	98
Percent Solids Gain From Previous Period as a Base			181%	47%	-1%	36%	19%	31%
Change in liquid from previous period		-52	-98	-115	17	-113	-141	-136
Percent Liquid Loss from Previous Period as a Base		-5%	-10%	-14%	2%	-15%	-22%	-27%
phenanthrene								
Contaminant Qty in Liquid	1000	929	820	746	706	509	396	224
Qty Transferred to Organic & Inorganic Solids	0	67	135	156	200	305	404	510
Sum	1000	996	955	902	906	814	800	734
Assumed Qty of Degradation	0	-4	-45	-98	-94	-186	-200	-266
Change in solids from previous period		67	68	21	44	105	99	106
Percent Solids Gain From Previous Period as a Base			101%	16%	28%	53%	32%	26%
Change in liquid from previous period		-71	-109	-74	-40	-197	-113	-172
Percent Liquid Loss from Previous Period as a Base		-7%	-12%	-9%	-5%	-28%	-22%	-43%
naphthalene								
Contaminant Qty in Liquid	1000	960	899	810	660	506	326	198
Qty Transferred to Organic & Inorganic Solids	0	28	97	138	231	310	447	522
Sum	1000	988	996	948	891	816	773	720
Assumed Qty of Degradation	0	-12	-4	-52	-109	-184	-227	-280
Change in solids from previous period		28	69	41	93	79	137	75
Percent Solids Gain From Previous Period as a Base			246%	42%	67%	34%	44%	17%
Change in liquid from previous period		-40	-61	-89	-150	-154	-180	-128
Percent Liquid Loss from Previous Period as a Base		-4%	-6%	-10%	-19%	-23%	-36%	-39%
2-methylnaphthalene								
Contaminant Qty in Liquid	1000	982	910	870	730	548	359	266
Qty Transferred to Organic & Inorganic Solids	0	12	76	118	236	302	504	628
Sum	1000	994	986	988	966	850	863	894
Assumed Qty of Degradation	0	-6	-14	-12	-34	-150	-137	-106
Change in solids from previous period		12	64	42	118	66	202	124
Percent Solids Gain From Previous Period as a Base			533%	55%	100%	28%	67%	25%
Change in liquid from previous period		-18	-72	-40	-140	-182	-189	-93
Percent Liquid Loss from Previous Period as a Base		-2%	-7%	-4%	-16%	-25%	-34%	-26%

Table 22. Contaminant transfer study, low organic content case

BioGenesis Contaminant Transference Study

October 6, 1997 to December 29, 1997

(all quantities in parts per million)

HIGH ORGANIC CONTENT TEST SERIES										
End of Week	0	1	2	3	4	5	6	8	10	12
acenaphthylene										
Contaminant Qty in Liquid	1000	880	698	465	334	231	199	178	155	118
Qty Transferred to Inorganic Solids	0	26	86	186	296	352	401	426	462	456
Sum	1000	906	784	651	630	583	600	604	617	574
Qty Transferred to Organic Solids & Degradation	0	-94	-216	-349	-370	-417	-400	-396	-383	-426
Change in solids from previous period		26	60	100	110	56	49	25	36	-6
Percent Solids Gain From Previous Period as a Base				116%	59%	19%	14%	6%	8%	-1%
Change in liquid from previous period		-120	-182	-233	-131	-103	-32	-21	-23	-37
Percent Liquid Loss from Previous Period as a Base		-12%	-21%	-33%	-28%	-31%	-14%	-11%	-13%	-24%
fluorene										
Contaminant Qty in Liquid	1000	930	739	526	463	294	251	236	173	126
Qty Transferred to Inorganic Solids	0	16	69	161	236	287	362	396	460	471
Sum	1000	946	808	687	699	581	613	632	633	597
Qty Transferred to Organic Solids & Degradation	0	-54	-192	-313	-301	-419	-387	-368	-367	-403
Change in solids from previous period		16	53	92	75	51	75	34	64	11
Percent Solids Gain From Previous Period as a Base				133%	47%	22%	26%	9%	16%	2%
Change in liquid from previous period		-70	-191	-213	-63	-169	-43	-15	-63	-47
Percent Liquid Loss from Previous Period as a Base		-7%	-21%	-29%	-12%	-37%	-15%	-6%	-27%	-27%
anthracene										
Contaminant Qty in Liquid	1000	890	726	496	409	306	233	213	154	121
Qty Transferred to Inorganic Solids	0	52	75	111	152	209	281	337	359	356
Sum	1000	942	801	607	561	515	514	550	513	477
Qty Transferred to Organic Solids & Degradation	0	-58	-199	-393	-439	-485	-486	-450	-487	-523
Change in solids from previous period		52	23	36	41	57	72	56	22	-3
Percent Solids Gain From Previous Period as a Base			44%	48%	37%	38%	34%	20%	7%	-1%
Change in liquid from previous period		-110	-164	-230	-87	-103	-73	-20	-59	-33
Percent Liquid Loss from Previous Period as a Base		-11%	-18%	-32%	-18%	-25%	-24%	-9%	-28%	-21%
pyrene										
Contaminant Qty in Liquid	1000	906	709	506	391	292	212	192	136	109
Qty Transferred to Inorganic Solids	0	33	102	194	301	362	402	467	516	543
Sum	1000	939	811	700	692	654	614	659	652	652
Qty Transferred to Organic Solids & Degradation	0	-61	-189	-300	-308	-346	-386	-341	-348	-348
Change in solids from previous period		33	69	92	107	61	40	65	49	27
Percent Solids Gain From Previous Period as a Base			209%	90%	55%	20%	11%	16%	10%	5%
Change in liquid from previous period		-94	-197	-203	-115	-99	-80	-20	-56	-27
Percent Liquid Loss from Previous Period as a Base		-9%	-22%	-29%	-23%	-25%	-27%	-9%	-29%	-20%
phenanthrene										
Contaminant Qty in Liquid	1000	896	711	530	376	248	186	178	141	105
Qty Transferred to Inorganic Solids	0	25	91	108	168	214	291	336	396	411
Sum	1000	921	802	638	544	462	477	514	537	516
Qty Transferred to Organic Solids & Degradation	0	-79	-198	-362	-456	-538	-523	-486	-463	-484
Change in solids from previous period		25	66	17	60	46	77	45	60	15
Percent Solids Gain From Previous Period as a Base			264%	19%	56%	27%	36%	15%	18%	4%
Change in liquid from previous period		-104	-185	-181	-154	-128	-62	-8	-37	-36
Percent Liquid Loss from Previous Period as a Base		-10%	-21%	-25%	-29%	-34%	-25%	-4%	-21%	-26%
naphthalene										
Contaminant Qty in Liquid	1000	720	609	581	394	271	234	206	181	168
Qty Transferred to Inorganic Solids	0	67	116	122	201	232	311	432	452	496
Sum	1000	787	725	703	595	503	545	638	633	664
Qty Transferred to Organic Solids & Degradation	0	-213	-275	-297	-405	-497	-455	-362	-367	-336
Change in solids from previous period		67	49	6	79	31	79	121	20	44
Percent Solids Gain From Previous Period as a Base			73%	5%	65%	15%	34%	39%	5%	10%
Change in liquid from previous period		-280	-111	-28	-187	-123	-37	-28	-25	-13
Percent Liquid Loss from Previous Period as a Base		-28%	-15%	-5%	-32%	-31%	-14%	-12%	-12%	-7%
2-methylnaphthalene										
Contaminant Qty in Liquid	1000	748	692	563	451	293	262	202	196	192
Qty Transferred to Inorganic Solids	0	23	74	96	172	197	244	313	367	401
Sum	1000	771	766	659	623	490	506	515	563	593
Qty Transferred to Organic Solids & Degradation	0	-229	-234	-341	-377	-510	-494	-485	-437	-407
Change in solids from previous period		23	51	22	76	25	47	69	54	34
Percent Solids Gain From Previous Period as a Base			222%	30%	79%	15%	24%	28%	17%	9%
Change in liquid from previous period		-252	-56	-129	-112	-158	-31	-60	-6	-4
Percent Liquid Loss from Previous Period as a Base		-25%	-7%	-19%	-20%	-35%	-11%	-23%	-3%	-2%

Table 23. Contaminant transfer study, high organic content case

Observed Appearance Changes		
Week	**Low Organic Content**	**Higher Organic Content**
0	Water is clear with slight straw color	Water is clear with slight straw color
1	No change from previous	No change in color, slightly cloudy
2	Water slightly cloudy; no change in solids	Water is cloudy
4	Water light gray; stronger brown tone to solids	Water is cloudy and gray
6	Water light gray, cloudy & with increased viscosity; solids much stronger gray with brownish tone	Water is cloudy and gray; slightly viscous
8	Water is gray, less cloudy, viscosity slightly less	Water is gray and lightly gelatinous
10	Water is a darker gray, but clear	Water is still gray, but clearing
12	Water is gray and clear; solids are dark gray	No observation

Table 24. Observed appearance changes

For the low organic content test series, the only organic material in the mixture was the

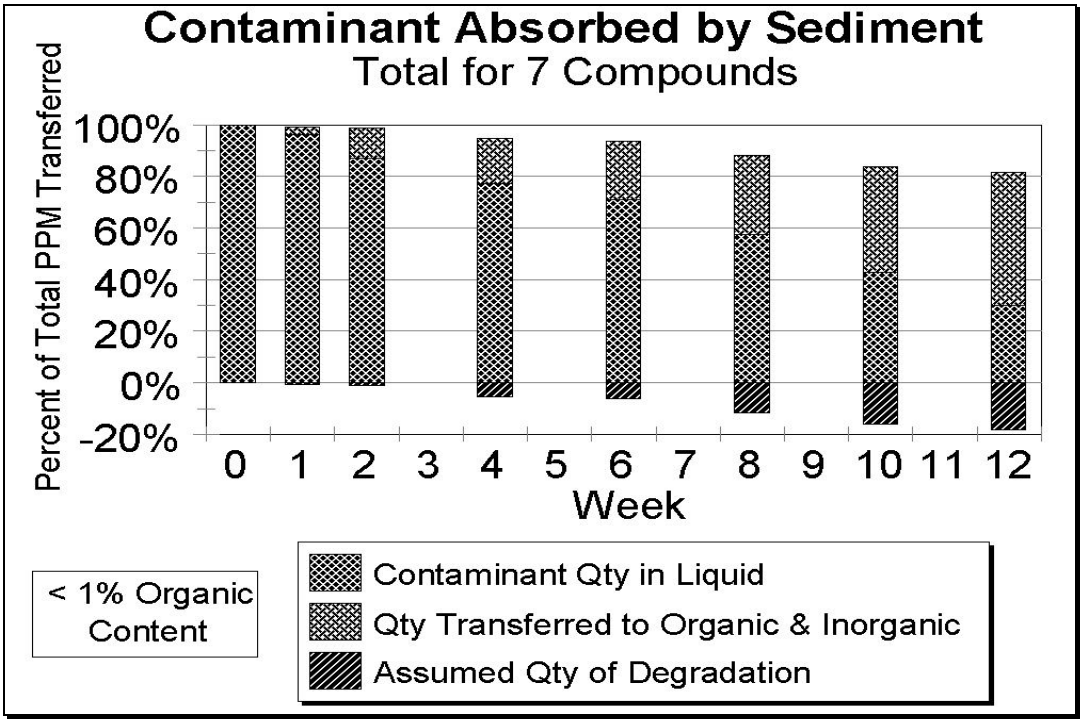


Figure 30. Contaminant absorption and partitioning, total for 7 compounds, low organic content case

contaminant, surfactant it was dissolved in, and organic material generated by degradation of the contaminant and surfactant during the test. Periodic testing determined the contamination in the solid phase and the contamination in the liquid phase. The difference between the sum of those two factors and the beginning quantity of 1,000 ppm for each contaminant was *assumed to be biodegraded*. The contamination of organic and inorganic solids were treated as one value for this testing. Note: See remarks about future tests.

Figure 30, Contaminant absorption by sediment, total for 7 compounds, gives an overview of how the contaminants were transferred from the liquid phase to the solid phase, and by inference, to biodegradation. For absorption, it shows a fairly steady transfer rate that results in about 50% of the beginning quantity of contaminants having been transferred to the solid phase by week 12. Note, however that the apparently linear transfer rate is a combination of non-linear factors as discussed below. Degradation shows a period of 2 - 3 weeks with little activity, followed by increasing inferred degradation. Typically, the first period of any new system is a microbial adaptation phase, and this interpretation is consistent with that view.

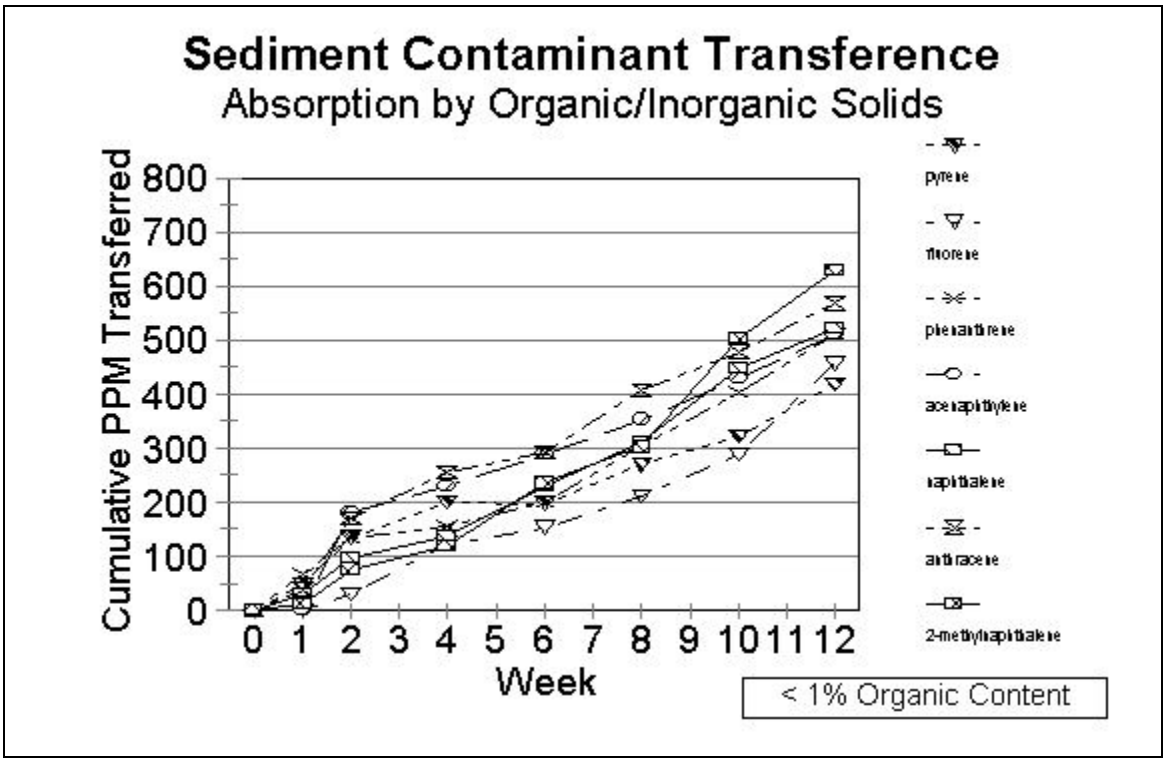


Figure 31. Sediment contaminant transfer, absorption by organic/inorganic solids, low organics case

Figure 31, Sediment Contaminant Transfer, Absorption by Organic/Inorganic Solids, shows two distinct periods. These are the first two weeks, and thereafter. During the first two weeks, the increase in contamination of the solids is believed due almost entirely to absorption. Subsequently, the transfer is a combination of two factors. First, absorption is continuing from the contaminants in the water. Second, organic material that has been formed through biodegradation of surfactants (and possibly some contaminant) is being transferred to the solids. At the end of 12 weeks, a mean of 52% of the beginning contamination had been absorbed by the organic and inorganic solids, and a total of 70% had been transferred from the water.

Figure 32, Sediment Contaminant Transfer, Liquid to Organic Solids and Degradation, shows very low activity for the first two weeks. This period is associated with the adaptation phase of microbes in the water and those contained in the biodegradable surfactants used to solubilize the contaminants. From about week three onward, biological activity increases. The total mean transfer by the end of the 12 week period is 18%.

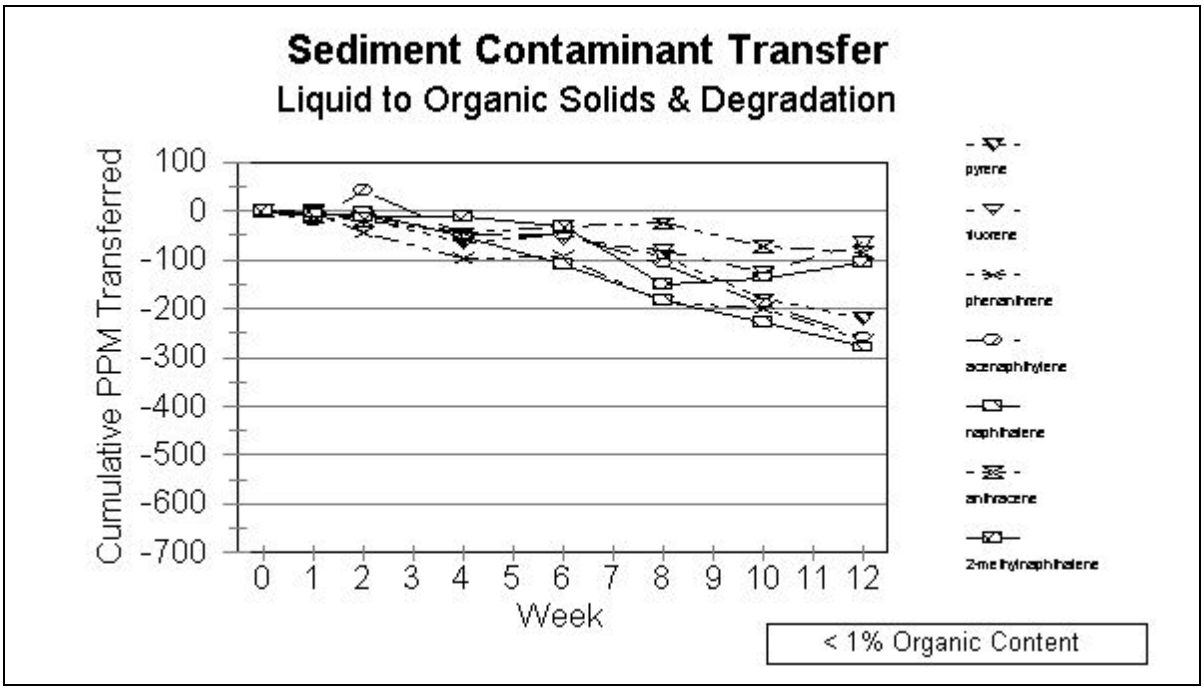


Figure 32. Sediment contaminant transfer, liquid to organic solids and degradation

For the high organic content test series, the periodic testing determined the contamination transferred to inorganic solids, and the contamination that remained in the liquid. The difference between the sum of these two items and the beginning quantity of 1,000 ppm per contaminant was *assumed to be either absorbed by the organic material added initially or biodegraded.*

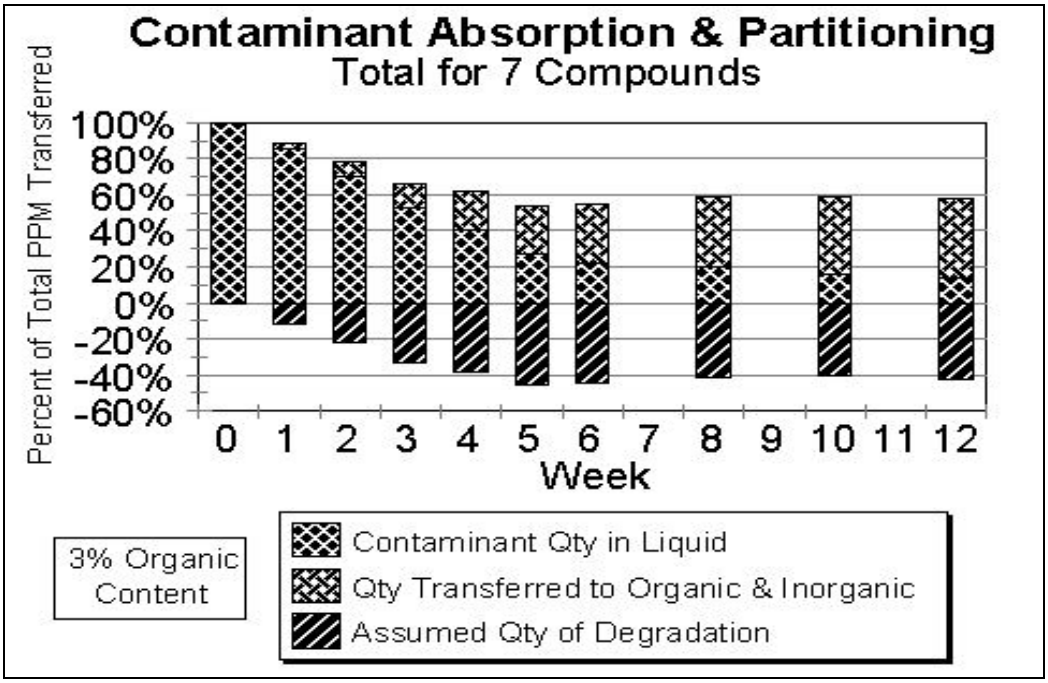


Figure 33. Contaminant absorption and partitioning, total for 7 compounds, high organic content case

Figure 33, Contaminant Absorption and Partitioning, Total for 7 Compounds, gives an overview of the overall transfer and partitioning for the high organic content test. When compared to figure 30, the differences are striking. At the end of 12 weeks, the total contamination of the solids is slightly less than for the low organic case. However there is significantly less contaminant remaining in the water. The inference is that substantial contamination has been absorbed by the organic solids. Biodegradation has also occurred and may have been increased by the ready availability of nutrition from the organic material added for the test.

For the high organics case, figure 34 and figure 35 illustrate both transfer by absorption and

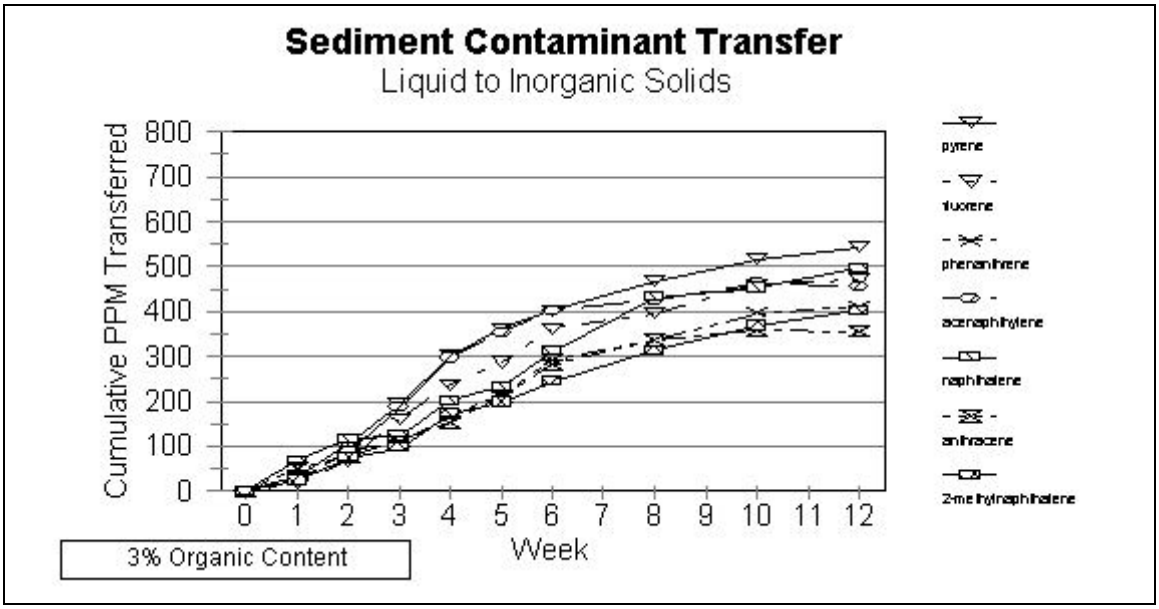


Figure 34. Sediment contaminant transfer, liquid to inorganic solids

partitioning. In figure 34, the first three weeks show a gradual increase in contamination of the solids. This is due to absorption from the water. From about week 3 to week 8, absorption from the water continues, but it is augmented by the beginning of partitioning from the organics that have absorbed contamination. Finally from about week 8 onward, both partitioning from the organics and absorption continue.

Figure 35 shows rapid absorption by the organic material during the first 2 weeks. This is much higher that observed for the low organic case. From weeks 2 to 7 there is continued absorption, but the slope of the curve decreases. Partitioning appears to be beginning and contaminant that has been absorbed by the organic material is now being transferred to the inorganic solids. This is also seen in the increasing slope of the curve in figure 35 during the same period. The period from week 7 onward appears to be the high partitioning phase wherein the absorption rate is matched by the partitioning rate. The result is a slope of zero and no further net transfer of contaminant to organic solids. Degradation also is happening in this phase, but its effect cannot be assessed in the current test. The total contamination transferred to the inorganic solids is 45%, and the total contamination removed from the water is 86%. For the high organic case, both a greater total amount of contaminant is being removed, and it is being removed in a shorter period of time.

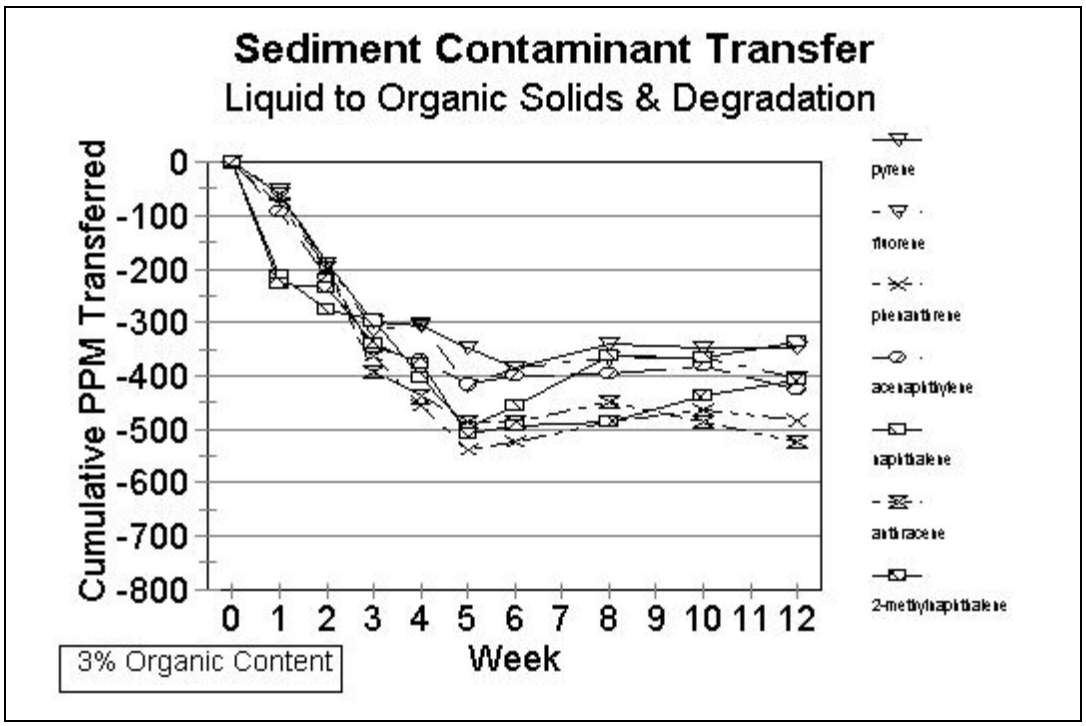


Figure 35. Sediment contaminant transfer, liquid to organic solids & degradation

4.6.5 *Conclusions and Recommendations*

4.6.5.1 <u>Conclusions</u>

This test provides insight to the role of absorption and partitioning as mechanisms that transfer contaminants from liquids to solid sediment particles. In particular, it shows the role that organic material in natural aquatic systems plays in absorbing contaminants and transferring them through partitioning to solids. Several conclusions emerge that directly affect the BioGenesis K Sediment Washing Process.

a.1. Desorption of organic material from the sediment is even more important than previously believed. Removal of organic material, in and of itself, takes with it a large amount of contamination. What remains is the contaminant coating on the sediment particles themselves.

a.2. With the desorption of the organic material from solids, the contaminants remaining on the sediment particles are now more directly exposed to the impact forces in the collision chamber. This means that a more thorough cleaning will be possible.

4.6.5.2 <u>Recommendations</u>

b.1. An additional study should be performed to discriminate and quantify factors that were aggregated during this test. These are the amount of degradation, the amount of contaminant absorbed by the organic material, and the amount of contaminant partitioned from the organic

material to the inorganic solids after initial absorption from the water. The follow-on experiment is outlined as follows:

Step1: Produce contaminated organic material and model the absorption process

- Contaminate water with known types/amounts of contaminants.
- Add organic material, mix, and allow to settle.
- Monitor changes in the water on a weekly basis for 8 weeks.
- Then separate and reserve the organic material.
- Analyze the organic material to establish contamination level.

Step 2: Model the partitioning process.

- Prepare clean solid and liquid mixture simulating clean sediment.
- Add the reserved organic material from Part 1.
- Monitor contamination transferred from the organic material weekly for up to 12 weeks.
- Separate, rinse, and analyze the solids.
- Separate the organic material in the liquid and analyze.
- Analyze the liquid.
- Check the mass balance.

Step 3: Compare observations to predicted results.

- Water would show an increase in contamination in the first week.
- Thereafter, water contamination would slowly decrease due to absorption by solids.
- Solids would show a slow increase due both to absorption from the water and to partitioning from the contaminated organic material.

The result would be improved insight to the mechanism of contamination absorption and partitioning so it can be reversed or interfered with during sediment decontamination.

b.2. Separate the multiple functions now being performed by the *Sediment Preprocessor*. Two of these are adding chemical to the sediment and thoroughly homogenizing the slurry. Continue to call this preprocessing. Rename the part of the equipment that fractionates organic material into the smallest possible pieces the *Sediment Processor*. The function of this equipment is to

expose the organic contamination on the particles for desorption in the collision chamber and subsequent oxidation by cavitation oxidation. The separation is important because it gives the ability to adjust the cleaning system to match the amount of organic material in the sediment to be cleaned. Low organic content material may not need treatment in the Sediment Processor. This would lower costs. On the other hand, high organic content material may need extended residence times in the Processor. Increased residence times would increase effectiveness on high organic content material. Variation in employment of the Sediment Processor should be examined during the forthcoming demonstration.

5 STATUS OF BIOGENESIS K TECHNOLOGY AS OF MARCH 1998

The BioGenesis K Sediment Washing System consists of five main subsystems. These are surfactant chemicals, preprocessing, processing, collision, and cavitation. The current status of each will be summarized in turn. Figures 36 and 37 show the process flow of the core processing equipment.

5.1 Surfactant Chemicals

The sediment system uses proprietary mixtures of ionic and non-ionic surfactants to mobilize contamination. These mixtures are tailored by BioGenesis to address the contamination type, sediment type and organic content, and prospective end use of the sediment. The chemical mixtures have been used throughout BioGenesis K system testing since 1991 and, after formulation and test on a particular sediment, are considered capable of being produced on-demand in any quantity required.

5.2 Sediment Preprocessor Subsystem

The Sediment Preprocessor separates sediment particles and mixes cleaning chemicals with the sediment. The pilot unit has been extensively tested and is highly reliable. One unit is capable of processing up to 2,000 gallons per hour of sediment having a 30% solids content. The Preprocessor has no scale-up limitations and can be replicated and produced on demand with 45-60 day lead times.

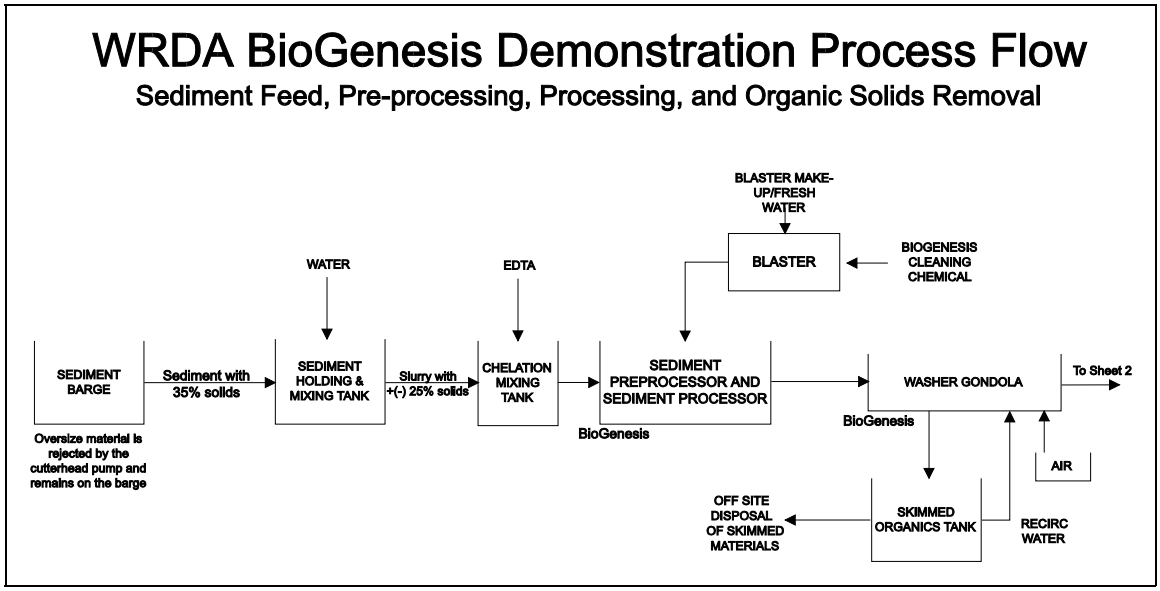


Figure 36. BioGenesis K process flow (feed, processing, organic solids removal)

5.3 Sediment Processor Subsystem

The Sediment Processor micro-fractionalizes organic material in the sediment. The pilot unit has been extensively tested and is highly reliable. A single unit is capable of processing up to

2,000 gallons per hour of sediment having a 30% solids content. The Processor has no scale-up limitations and can be replicated and produced on demand with 45 to 60 day lead times.

5.4 Collision Chamber Subsystem

The Collision Subsystem is at pilot scale of 8 to10 CY per hour. The Collision Subsystem been extensively tested and functions as designed with high reliability. The subsystem can be duplicated with 90-120 days lead time. Larger units are conceived, but have not been engineered pending incorporation of lessons learned from pilot project processing. The current estimate is that the first scale-up unit will have a capacity of 35 to 70 CY per hour. Estimated production time for the first scale-up unit is 150 days after completion of engineering.

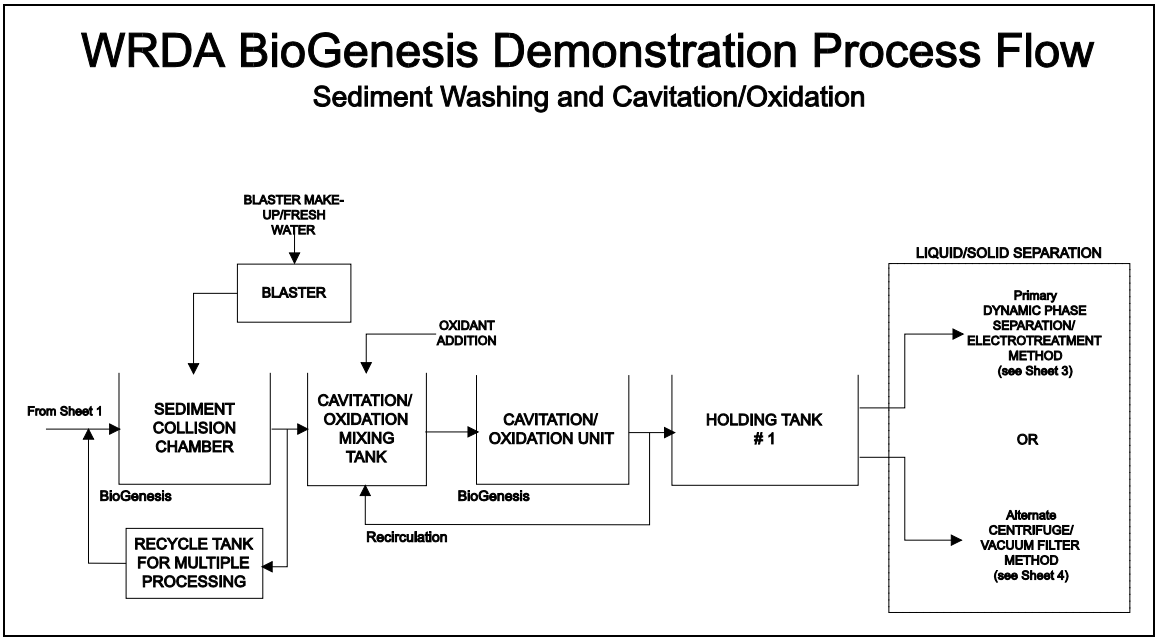


Figure 37. BioGenesis K process flow (washing, cavitation)

5.5 Cavitation Subsystem

The Cavitation Subsystem currently processes 30 to 50 gallons per minute. Scale-up of the equipment to 500 gallons per minute has been completed, and the higher capacity equipment will be utilized and its performance tested during the initial stage of the pilot project. Production lead time on additional units is 60-90 days. Larger units will be engineered to incorporate lessons from the pilot project.

6 SEDIMENT HANDLING, PREPARATION, AND FEED; LIQUID-SOLID SEPARATION; AND WATER TREATMENT

Treatment of contaminated sediment in the core decontamination equipment requires that sediment be received, prepared, and delivered to the core equipment, that output from core equipment be dewatered, and that the water be subsequently treated to remove contamination. Three subsystems are required: sediment materials handling, liquid-solid separation, and water treatment.

Sediment materials handling uses off-the-shelf, conventional equipment to receive, prepare, and feed sediment to the core processing equipment. This subsystem must deliver a slurry with approximately 15% solids that are less than 1/4" in size. Three equipment options have been selected to meet this requirement, each of which is suitable for use at sites with different physical arrangements of barge access and distance from sediment offload to processing location. The options (cutter-head pump, eddy pump, and trucking) are described below.

Liquid-solid separation technology has been surveyed to identify technology capable of meeting project needs. Conventional methods of dewatering fine particles employ hydrocarbon polymers to coagulate and agglomerate fines into larger particles that can then be removed from the water using centrifuge and filter press technology. The primary goal of this approach is to remove the suspended solids from the water. This technology is well-known, but cannot be used. The reason is that before dewatering, some organic contaminants and all inorganic contaminants, remain in the liquid phase with the suspended solids. Addition of polymer to agglomerate particles during primary liquid-solid separation would trap contaminants along with the fine particles, and recontaminate fines that had been treated. So primary liquid solid separation must be accomplished without polymer or with extremely small amounts. Two options (centrifuge/vacuum filter and electro-coagulation/screw press) have been developed for evaluation during the pilot project, and are described below.

The water treatment sub-system will use conventional technology including clarification, precipitation, flocculation, oxidation, and settling. These technologies are industry standard, and no unusual problems are anticipated.

6.1 Sediment Handling and Feed Subsystem

As-dredged sediment is expected to be delivered to the processing site by barge. The sediment is expected to contain 30 to 35% solids, to have some natural solid particles larger than 1/4", and to also contain various trash and oversized man-made materials. The sediment handling and feed subsystem must screen the trash and solids larger than 1/4", move the sediment to the processing site from the barge, and adjust the solids content to 15 -20%.

Three methods have been identified to handle the sediment. Each will meet project requirements, although at different costs. Two primary, site-specific criteria will govern the selection of handling method. These are the availability of mooring space for the sediment barge and the distance of the barge mooring from the processing site.

6.1.1 *Processing site within 400 - 800 feet of barge mooring*

If the processing site is within 400 to 800 feet of the barge mooring, the barge will be used as the contaminated sediment reservoir. Sediment will be pumped from the barge using a cutter-head pump suspended from a mobile crane mounted on the barge or on the bulkhead if available. The cutter-head pump will shred solids down to 1/4 inch, which is the maximum size able to be accepted by the BioGenesis pilot equipment. The pump will reject gross oversize material which will remain on the barge for subsequent processing/disposal. The cutter-head pump processes at 200 gallons per minute.

The sediment stream from the barge will contain particle sizes of less than 1/4 inch. This stream will be pumped up to 400 feet to the BioGenesis preprocessor feed tank. If the processing area is more than 400 feet from the barge, then portable tankage will be positioned at the 400 foot point to receive the sediment. From that point, slurry pumps will move the sediment to the feed tank for the preprocessor unit. Every attempt will be made to keep the pumping distance to the minimum in order to minimize handling and expense, however this transfer technique could be employed for an extended distance, if necessary. The overall technique of pumping directly from barge to feed tanks can be scaled-up as necessary for full and commercial scale processing. All equipment is off-the-shelf and commercially available.

This option is preferred over succeeding methods because trash screening and material sizing is accomplished on the barge in one step, thus minimizing off-barge sediment handling before input to the BioGenesis preprocessor. It also minimizes input storage and tankage requirements because the sediment can be processed off the barge as needed in a controlled manner to meet processing requirements that will fluctuate from day-to-day.

6.1.2 *Processing site within 800 to 1,500 feet of barge mooring*

If the processing site is located more than about 800 feet from the processing site, sediment will be moved from the barge to the site using more powerful eddy pump equipment. This equipment is capable of moving 200 gallons per minute a distance of 1,500 feet or more without intermediate boost stages. The eddy pump is a recessed impeller centrifugal pump with open throat and vertical configuration designed for sediment movement. It is positioned at the barge by a mobile crane, and is capable of drawing in sufficient water with the solids to keep a free-flowing slurry in the feed lines to the slurry receiving tank. The pump has a screened inlet to screen out materials greater than 1 inch in diameter.

The sediment arriving at the processing site will contain particles and debris that is between 1 inch and 1/4 inch, that is, larger than the 1/4 inch maximum specification for input to the BioGenesis preprocessor. This oversize material will be removed by screening, after which the sediment will be transferred to the preprocessor feed tank

Although this handling technique is able to move the sediment stream farther, it has the disadvantage of needing a screening step after arrival of the sediment at the processing site. It may also require additional holding tankage and an additional storage location for oversize material. (Recall that the cutter-head pump accomplished transfer and sizing in one step, and that all oversize material remained on the barge.) Nonetheless this method is completely feasible and

is an acceptable alternative. All equipment in this option is off-the-shelf and commercially available.

6.1.3 *Processing site outside pumping distance from the barge mooring*

If the processing site is located outside of pumping distance from the barge mooring, then sediment must be moved from the barge location to the processing site via truck. A cutter-head pump and mobile crane will be located at the barge, sediment will be pumped into trucks, and the trucks will then be offloaded into slurry tankage at the processing site. This option has the advantage that it does not depend on the proximity of a suitable barge mooring to the processing site. However, it has the disadvantages of requiring over-the-road sediment movement and permitting, and introduces an additional on-load/off-load step in processing. Costs will also be higher with the combination of cutter-head pump and truck transportation.

This method is feasible for the pilot demonstration, and provides location flexibility. It uses off-the-shelf, commercially available equipment.

6.2 Liquid-Solid Separation Subsystem

Sediment will be delivered to the Liquid-Solid Separation Subsystem from the output of the Cavitation Subsystem, the final step in BioGenesis core decontamination processing. This sediment is a slurry with a solids content of about 8 to 10%. The slurry contains solid organic and inorganic particles that are suspended in water, inorganic contaminants that were desorbed during processing and solubilized by chelation, and organic contaminants that resisted oxidation during cavitation processing.

Existing liquid-solid separation technologies have been evaluated against the criteria of using no polymer, having high throughput capacity, and being able to handle the full range of silt and clay particle sizes. Additional evaluation factors were cost, complexity, and maintainability. The overall objective is to produce dewatered solids with a solids content of 70% and water with a suspended solids content that would be acceptable in a publicly owned treatment works (POTW).

During WRDA work to date, hydrocyclones and vacuum filtration have been used and centrifugation has been tested. Assessment of these three technologies is as follows:

- Hydrocyclone banks have difficulty achieving high volumes on extremely fine materials, but can effectively be used for separation of particles not passing 200-300 mesh.

- Centrifugation is a good candidate for silt and larger clay particles. Testing with Brandt Corporation has identified an equipment configuration consisting of hydrocyclones, wet screen, and centrifuge that is believed capable of removing particles down to 3 micrometers. Testing of this equipment on pilot system output is required during the demonstration.

- Vacuum filter technology using diatomaceous earth as the filter material is an effective solids filter, and may be usable as a final polishing stage for the smallest 1-15

micrometer size particles. It has the disadvantage that organic contaminants are trapped along with the fines by the very active surface of the diatomaceous earth. This contaminated filter material would then need to be reprocessed through cavitation oxidation to destroy the organic contaminants and avoid creating an additional contaminated waste stream. Such reprocessing must be tested during the pilot demonstration.

Figure 38 shows the configuration of equipment and processing flow for the centrifuge-vacuum filter configuration. This system is feasible and appears able to meet technical goals at pilot scale operations. It has the disadvantage of using sophisticated, expensive equipment and being manpower intensive. These factors dictate that alternatives to reduce complexity and cost must be evaluated during the pilot demonstration.

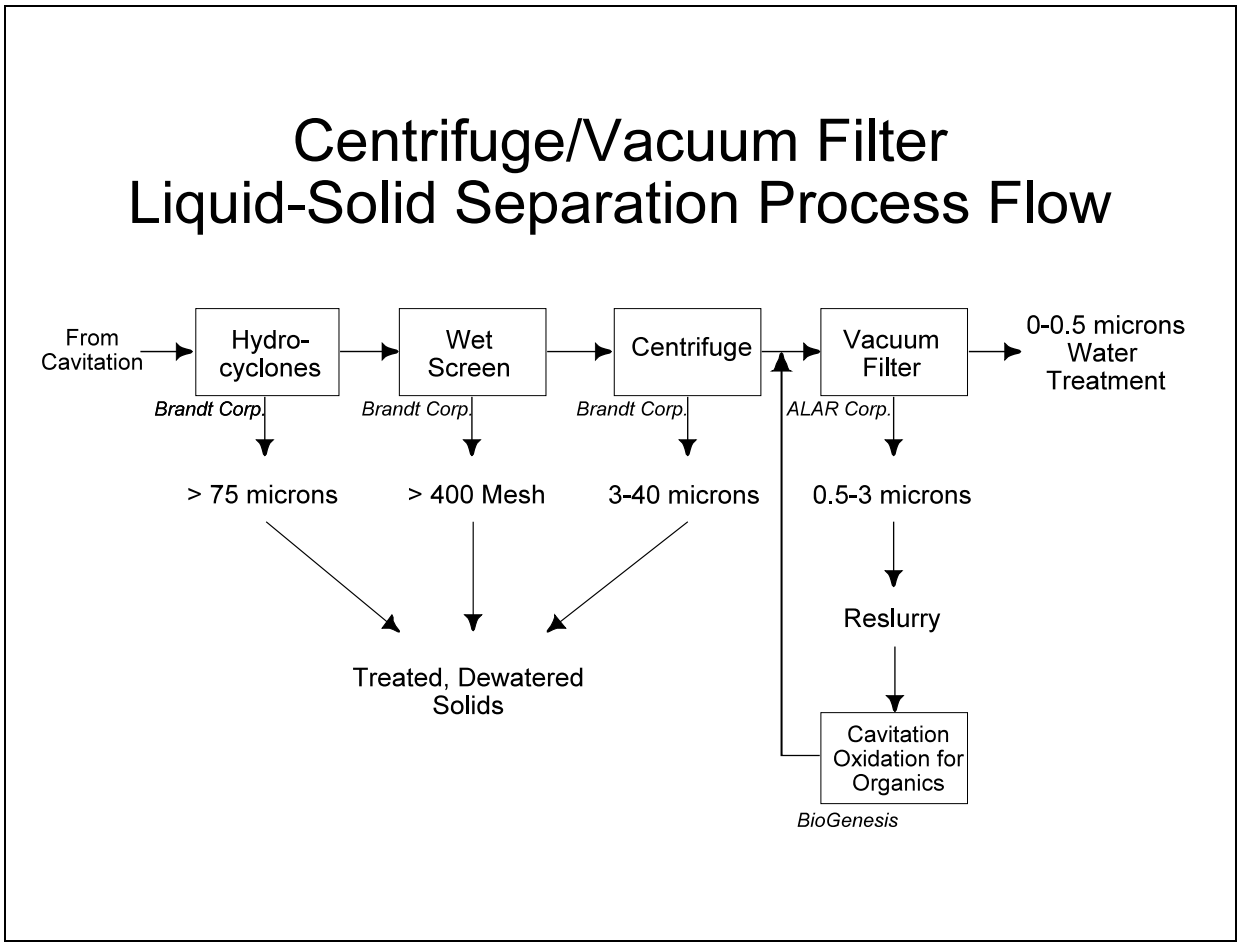


Figure 38. Liquid-solids separation flow using centrifugation and vacuum filtration.

Two technologies have been identified that, in combination, show promise of being simpler, more reliable, and less costly than the centrifugation-vacuum filtration option. These are electro-coagulation combined with plate separation and a screw press. Figure 39 shows the process flow for this option.

- Electro-coagulation: Clean Stream Technology, Inc. has been identified as having developed a new technique for separating fines based on the principle of agglomeration

of charged particles that are subsequently separated using lamella clarifiers. This technology is just now ready for testing. If it is effective on output from the washing system, it will decrease the cost and complexity of liquid-solid separation.

- Screw press: FKC Company, Ltd., has been identified with equipment able to de-water fines using no, or very low levels of polymer. Testing has shown that this equipment is a candidate for dewatering provided it can be fed input with a solids content of approximately 40% or greater.

Both the centrifugation/vacuum filter and electro-coagulation/screw press technologies will be evaluated during the pilot demonstration. It could well be that the best solution may be to select parts of both systems. This will become apparent only after empirical evaluation.

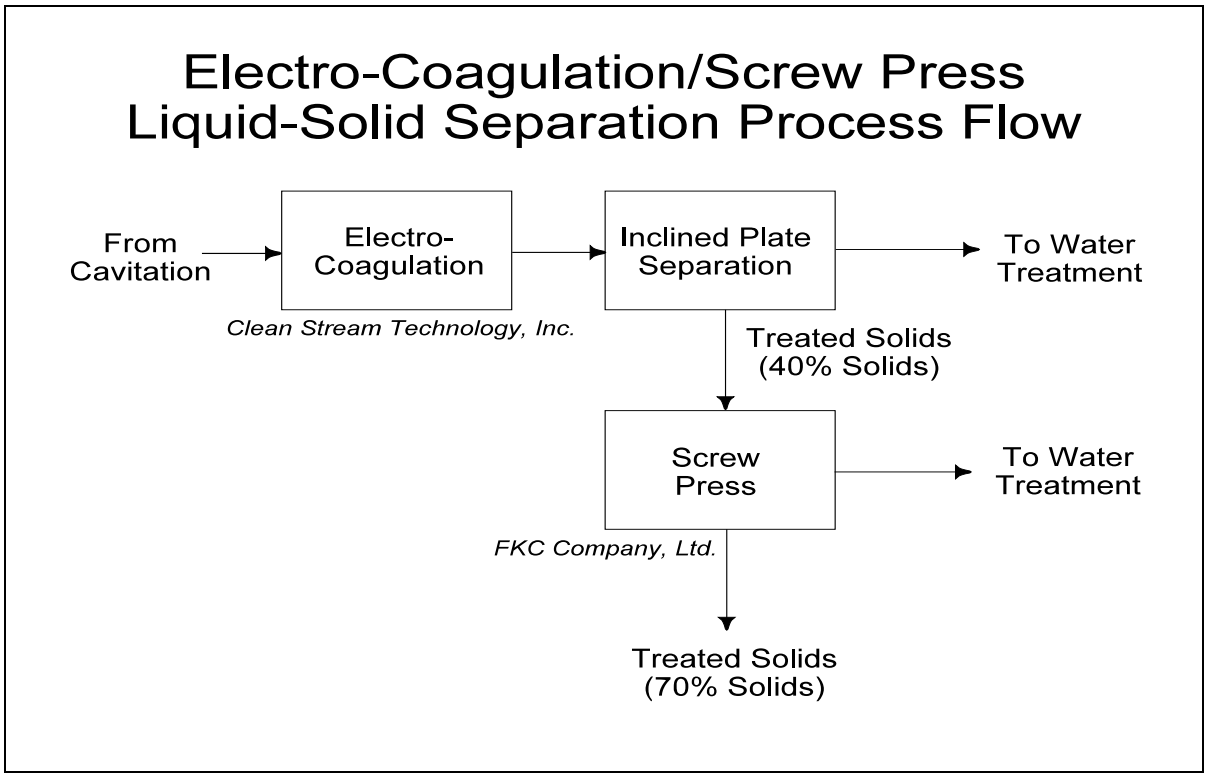


Figure 39. Liquid-solid separation process flow using electro-coagulation and screw press technology.

6.3 Water Treatment Subsystem

The output from the Liquid-Solid Separation Subsystem is the input to the Water Treatment Subsystem. The water stream will contain dissolved inorganic contaminants that were previously chelated, and possibly low levels of organic contaminants and suspended solids. Until output from the pilot system–that is sediment which has been BioGenesis processed and dewatered–is available, exact specification of the water treatment train components is not possible. However this is not seen as a problem since the water treatment processes that will be used are all proven, industry standard technologies. These processes include precipitation, clarification, pH adjustment, flocculation, and settling. If soluble organic contaminants are

present, advanced oxidation, activated carbon, and biological treatment will be evaluated. Laboratory evaluation of the liquid-solid separation subsystem outputs will allow definitive, high confidence specification of suitable equipment. Once a combination of unit process has been specified, a pilot scale test using field scale equipment can be conducted. Note that design data

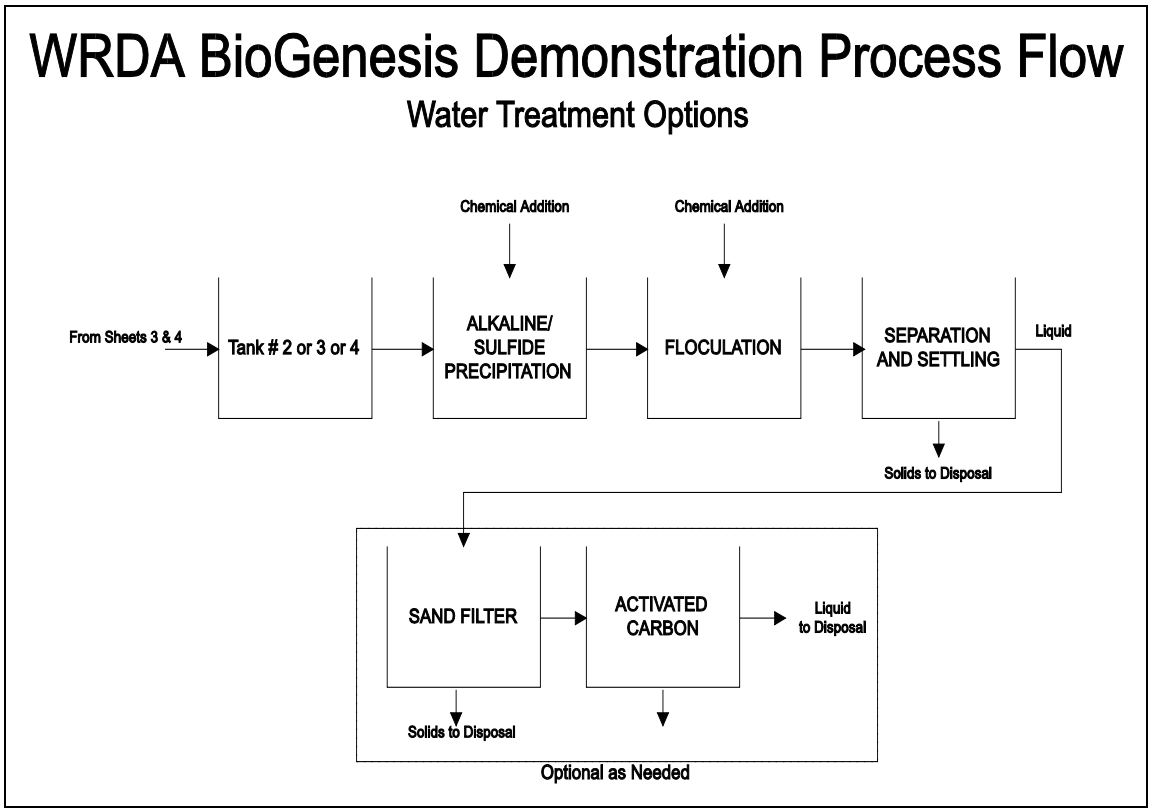


Figure 40. BioGenesis K process flow (water treatment options)

to be obtained from the laboratory testing are anticipated to be sufficient to design scale-up equipment without a need for full piloting of water treatment. This area has been identified as a potential cost avoidance area that will be discussed further in the pilot demonstration operations concept in Section 7. Figure 40 has been included to show the process flow of one configuration of water treatment equipment . The final configuration will be determined by the results of water laboratory testing during the pilot demonstration.

7 PILOT DEMONSTRATION PLANNING

7.1 Transition from Bench to Pilot Scale

Original planning in the statement of work for 1997 envisioned that the BNL2 Bench Study would lead directly to scale-up of the technology to pilot scale, which was selected to be 15,000 cubic yards. Two events occurred that led project management to defer implementation of pilot work at larger scale to a succeeding phase. These were, primarily, the need for additional validation of the technology's ability to decontaminate fines and secondarily, the requirement to locate and permit a satisfactory operating site.

Section 4.3 discusses the results of the BNL2 Bench Study. These results were highly satisfactory for grain sizes greater that 38 micrometers (400 mesh). However due to equipment limitations during the test, the study did not address decontamination capability for the entire range of fine material typical of New York and New Jersey sediments. As a result, project management decided to reallocate efforts to more definitively show the ability to decontaminate fine material prior to proceeding to pilot scale. This was done in the BNL3 and BNL4 bench studies.

Also during 1997, BioGenesis, with the assistance of BNL and EPA Region 2, conducted an extensive search for a satisfactory operating location for scale-up operations. This search did not succeed during 1997 due to the practical matters of finding a suitably sized property for sale which was in an accessible location, could be obtained at an affordable price, and was acceptable to local governmental bodies in conformance with public policy.

7.2 Objectives

7.2.1 *Demonstrate BioGenesis K technology at pilot scale*

- Show that NY/NJ sediment can be decontaminated using BioGenesis K washing technology at pilot scale
- Quantify the nature and extent of process side streams at pilot scale. Show that side streams are environmentally and economically acceptable as part of the decontamination process
- Test and optimize materials handling, liquid-solid separation, and water treatment technology to complement the core washing technology
- Collect operating and cost information that can support scale-up cost calculations.

7.2.2 *Obtain design information for scale-up*

Operation of the demonstration scale system will provide essential information on unit process performance that is required to design scale-up equipment. To obtain this information, key unit processes must be operated in different modes so that the system is optimized, and a careful

evaluation of the mass flow balance for the entire process must be calculated. For each unit operation the demonstration project will provide information including:

- whether the equipment modeled is correct for the intended use
- whether design loading rates for each unit operation can accommodate process variability
- whether and how much surge capacity is needed
- whether variations in chemical usage, residence time, repeat processing, processing rates, and equipment settings have an effect on product quality.

The data collected will be the basis of the design of a scale-up facility. The result will be full-scale facility that begins operation with fewer problems, and with defined chemical usage, utilities, and on-line performance. Since full-scale design will be based to the maximum possible extent on commercially available equipment to minimize costs and maintain on-line reliability, scale-up will involve matching and adapting available equipment to the process needs. The information developed during the pilot is the essential basis for scale-up.

7.2.2.1 BioGenesis core processing equipment

7.2.2.1.1 *Preprocessor*

Process flow rates are the primary information needed to size the Preprocessor. Additionally, grain size analysis should be performed on before and after samples from the preprocessor to assess change.

7.2.2.1.2 *Processor*

Process flow rates are the primary information needed to size the Processor to match both the Preprocessor and the Collision Chamber unit.

7.2.2.1.3 *Collision Chamber*

The variables associated with the Collision Chamber that affect processing efficiency include throughput rate, blasting pressure, and number of collision cycles. Collection of data on these factors is required for scale-up design. Samples should be taken before and after the collision chamber to quantify the extraction efficiency for both single and multiple passes through the unit.

7.2.2.1.4 *Cavitation unit*

Scale-up of the Cavitation unit to 500 gallons per minute was completed in November 1997. The primary data that is needed for scale-up is the destruction efficiency as related to processing time and oxidation chemical quantity.

7.2.2.2 Materials handling

Full scale treatment of dredged sediments requires a reliable materials handling system to convey contaminated sediments into the treatment train, mix them with water and additives as necessary for the washing steps, and convey the product fractions to their appropriate end uses. Since the equipment and procedures for materials handling derive from conventional practices in the mineral processing industries, this task is one of appropriate equipment selection and specification based on pilot demonstration experience, rather than development of any new equipment.

7.2.2.3 Liquid-solid separation equipment

Liquid-solid separation technology has been particularly difficult to specify during bench operations because, as previously discussed, conventional methods using polymer as a separation aid are not suitable. Also the position of the liquid-solid separation process in the treatment train makes separation equipment specification dependent on the nature of the output from the pilot-scale BioGenesis equipment.

WRDA testing in August 1997 identified that the bench scale equipment was producing a liquid-solid ration of 4 to 5:1 as compared to a reduced ratio of 2 to 3:1 expected for the pilot scale equipment. To obtain high-confidence data for scale-up design, sufficient material from the pilot core processing unit must be processed through the two proposed liquid-solid separation equipment configurations, and any variants of these, to ensure understanding of capabilities and constraints.

7.2.2.4 Water treatment equipment

Together with liquid-solid separation, exact specification of water treatment equipment has been hindered by not being able to analyze output from the BioGenesis pilot equipment that has been processed through liquid-solid separation equipment and provided as input to water treatment. Fortunately, water treatment technology will be straightforward to specify following analysis of the pilot-scale system outputs.

The water treatment analysis will provide the following information for scale-up design:

- the types of equipment required to meet overall process requirements.
- the identity and dosage of required chemicals, if any
- process design criteria including loading rates and retention times
- water recycle rates, and off-site wastewater and sludge disposal quantities.

Due to the well-developed nature of water treatment technology, there is good confidence that the required scale-up information can be obtained. Based on the laboratory testing that is envisioned, it may be possible to obtain all required scale-up data without extensive field-scale

water treatment. This is a potential cost avoidance area for consideration during the pilot demonstration.

7.2.3 *Produce treated material for beneficial reuse evaluation*

Numerous potential uses have been identified for the beneficial use of decontaminated dredged materials. These include:

- Manufactured soil - High-end growth use (potting soil)
- Manufactured soil - Low-end growth use (top soil)
- Nonstructural fill material (daily/intermediate landfill cover)
- Shoreline stabilization
- Restoration/fill for underwater areas
- Wetlands/habitat restoration
- Brownfield redevelopment
- Fill for strip-mine reclamation
- Development of natural resource, agriculture, horticulture, forestry, parks and recreation areas since the material is considered to be "clean".

BioGenesis independently has conducted its own research on developing a manufactured soil recipe that converts the sediment into a growing medium (SeaSoil™) that provides a highly fertile product, stabilizes residual inorganics and breaks down organic components.

In order to move from the concept/bench development phase to products that can be successfully marketed, the following information is needed:

- Product recipes must be developed for specific, economically viable end uses.
- Equipment for mixing the products with decontaminated sediment must be identified and tested.
- Greenhouse/field testing must be conducted to demonstrate the practicality of using sediment as a component of manufactured soil and to document that plant composition is not affected by residual contaminants that may remain in the decontaminated sediment.
- The structural and physical characteristics of the decontaminated sediment need to be identified for use in products such as fill material and daily/intermediate landfill cover.

The following analytical/geotechnical testing should be performed on decontaminated sediment from the pilot demonstration, and, as applicable, on the manufactured soil produced:

- physical structure
- soil contaminants
- soil elemental analysis
- earthworm bioassay
- growth tests
- metal and organic root/plant uptake tests
- leachate tests.

7.3 Pilot Demonstration Overview and Schedule

The operating concept for the pilot demonstration is structured into four phases. These are Planning, Preparation, and Permitting; Core System Operation; Liquid-Solid Separation and Water Treatment Evaluation; and Integrated Operation. Project execution will start following selection and approval of the demonstration site and direction from Brookhaven to proceed.

Mr. Brad Carpenter, P.E., of Roy F. Weston, Inc. has been designated as the Project Manager for the pilot demonstration. The BioGenesis Operations Manager for the pilot demonstration is Mr. Michael Dubey. Technical oversight of decontamination operations will be provided by Dr. Mohsen Amiran of BioGenesis and Mr. James Dougherty, P.E., of Weston.

7.3.1 *Planning, Preparation, and Permitting*

Three major planning documents are required in order to execute the demonstration. These are the Work Plan (WP), Health and Safety Plan (HASP), and Quality Control and Analysis Program Plan (QAPP). The WP and HASP are approximately 60% complete and await the integration of site specific information following approval of the demonstration site location. Initial drafts of the QAPP have been completed by Brookhaven and await integration of site specific information and the Sampling and Analysis information. It is estimated that finalization and coordination of these documents will take approximately three weeks following site approval and direction to proceed. Since these documents will be for part of the permit submission, it is paramount that they be completed as rapidly as possible.

At the same time as the WP, HASP, and QAPP are being completed, permit applications will be prepared with the objective of submitting them as soon as the planning documents are completed. Prior to permit application, a pre-permit review meeting will be held with state representatives. This will help to ensure that the permit applications are complete and address all matters of importance to reviewing authorities. Weston personnel will prepare the permit applications and be assisted as necessary by BioGenesis.

7.3.2 *Core System Operation*

The second phase of the pilot demonstration will operate the core processing equipment to process 50 to 100 CY of treated sediment. From two to four batches of sediment (8 to 10 CY per batch) will be required in order to optimize chemical concentrations and equipment operating parameters. The next series of batches (i.e. the first "production" batches will be designed primarily to produce test slurry for use in evaluating liquid-solid separation equipment. Only as much material will be processed as is required for liquid-solid separation testing. For planning purposes this is estimated to be three to four batches.

7.3.3 *Liquid-Solid Separation and Water Treatment Evaluation*

The initial batches of sediment produced from the core system will be used to test the centrifuge-vacuum filter and electro-coagulation-screw press equipments. Different configurations of the equipments will tested on the different slurry batches to determine the best operating settings. Then, sufficient slurry will be de-watered to provide representative outputs for water treatment evaluation.

Water treatment testing will be conducted initially in the laboratory. Here the water treatment train will be designed using industry standard types of equipment. Following the treatability calculations, selected water treatment equipment will be assembled and tested on outputs from liquid-solid separation.

7.3.4 *Integrated Operation*

When the previous three phases have been completed, sufficient information will have been obtained to satisfy project all project objectives to validate effectiveness at pilot scale and to support scale-up design calculations. The equipment will then be operated to process the balance of the available untreated material, which could be up to 900 CY. This will be done at the direction of the project sponsor to meet needs for beneficial reuse testing or to evaluate other multiple types of sediment.

Assuming authorization to proceed is given by Brookhaven, the following pages give a schedule of events. This schedule will slip day-for-day depending on program direction.

WRDA Sediment Decontamination NY/NJ Harbor
BioGenesis℠ Pilot Project Schedule

ID	Task Name	Duration
1	Authorization to Proceed	0 days
2	Task 1 Planning	45 days
3	Develop Health & Safety Plan	21 days
4	Complete HASP	5 days
5	Client Review HASP	10 days
6	Incorp. Comments; Submit Final HASP	3 days
7	Client Approve HASP	3 days
8	PFD/Mass Balance	10 days
9	Develop PFD/Mass Balance	5 days
10	Client Review PFD/Mass Balance	3 days
11	Incorp.Cmnts/Submit Final PFD/Mass Balance	1 day
12	Client Review & Approve PFD/Mass Balance	1 day
13	Work Plan/Sampling & Analysis Plan	27 days
14	Complete Work Plan	15 days
15	Client Review Work Plan	5 days
16	Incorp.Cmnts/Submit Final Work Plan	5 days
17	Client Review & Approve Work Plan	2 days
18	Equip Layout, Site Plan/Specs	25 days
19	Develop Site Plan	15 days
20	Site Owner Review Site Plan	5 days
21	Finalize Site Plan	5 days
22	P & ID, Elect, Mech Plans/Specs	15 days
23	Develop P&ID & Electrical Drwgs	10 days
24	Site Owner Review P & ID & Electrical	3 days
25	Finalize P&ID and Electrical	2 days
26	Local Permiting	20 days
27	Task 2 Operations	95 days
28	Equipment Procurement	10 days
29	Procure Mechanical Contractor	10 days
30	Procure Electrical Contractor	10 days
31	Site Preparation/Mobilization	20 days
32	Mobilization/Setup	5 days
33	Construct Secocdary Containment	5 days

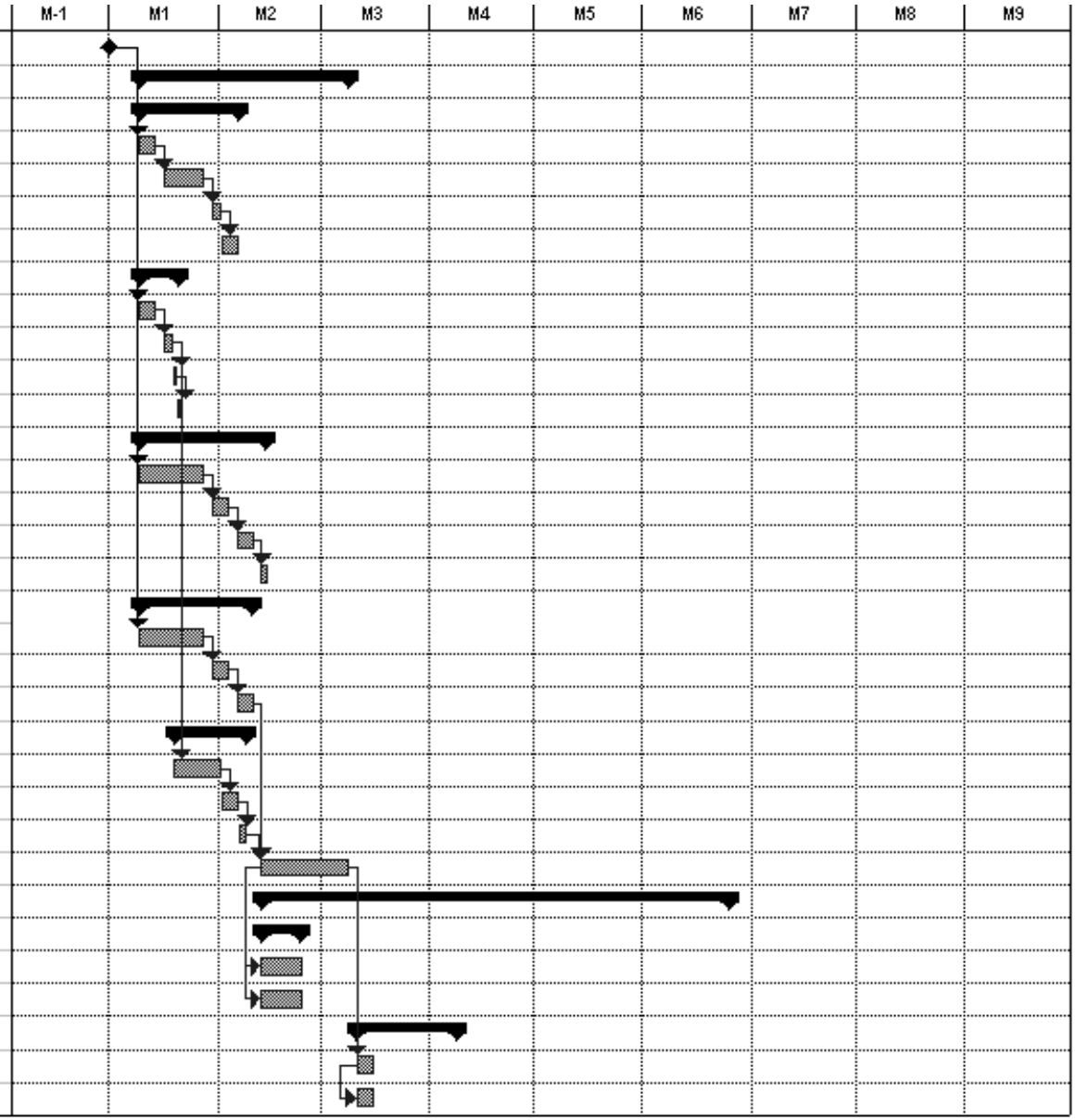


Figure 41. BioGenesis℠ sediment decontamination pilot project schedule

WRDA Sediment Decontamination NY/NJ Harbor
BioGenesis℠ Pilot Project Schedule

ID	Task Name	Duration
34	Core Process Equipment Delivery	5 days
35	Mechanical/Piping Installation	10 days
36	Electrical Installation	10 days
37	Check-out & Commissioning (clean soil)	5 days
38	Core Operations	10 days
39	Startup Runs	10 days
40	Evaluation Period	25 days
41	Bench-Scale Testing - Liquid/Solid Sep.	10 days
42	Evaluate Data	5 days
43	Deliver Liquid/Solid Sep Equipment	5 days
44	Deliver Water Treatment Equipment	5 days
45	Mechanical Piping Installation	5 days
46	Electrical Installation	5 days
47	Full Operations	10 days
48	BioGenesis Operations	10 days
49	Liquid/Solid Separation Operations	10 days
50	Water Treatment Pilot Operations	10 days
51	Sampling	45 days
52	Startup Testing	10 days
53	Full Operations Testing	10 days
54	Demobilization/Site Restoration	10 days
55	Decon of Equipment	5 days
56	Demobilization of Equipment	5 days
57	Site Restoration	5 days
58	Task 3 Final Report	115 days
59	Laboratory Analysis	65 days
60	Prepare Draft Final Report	25 days
61	Submit Draft Final Report to Client	0 days
62	Client Review Draft Final Report	15 days
63	Prepare Final Report	10 days
64	Submit Final Report to Client	0 days

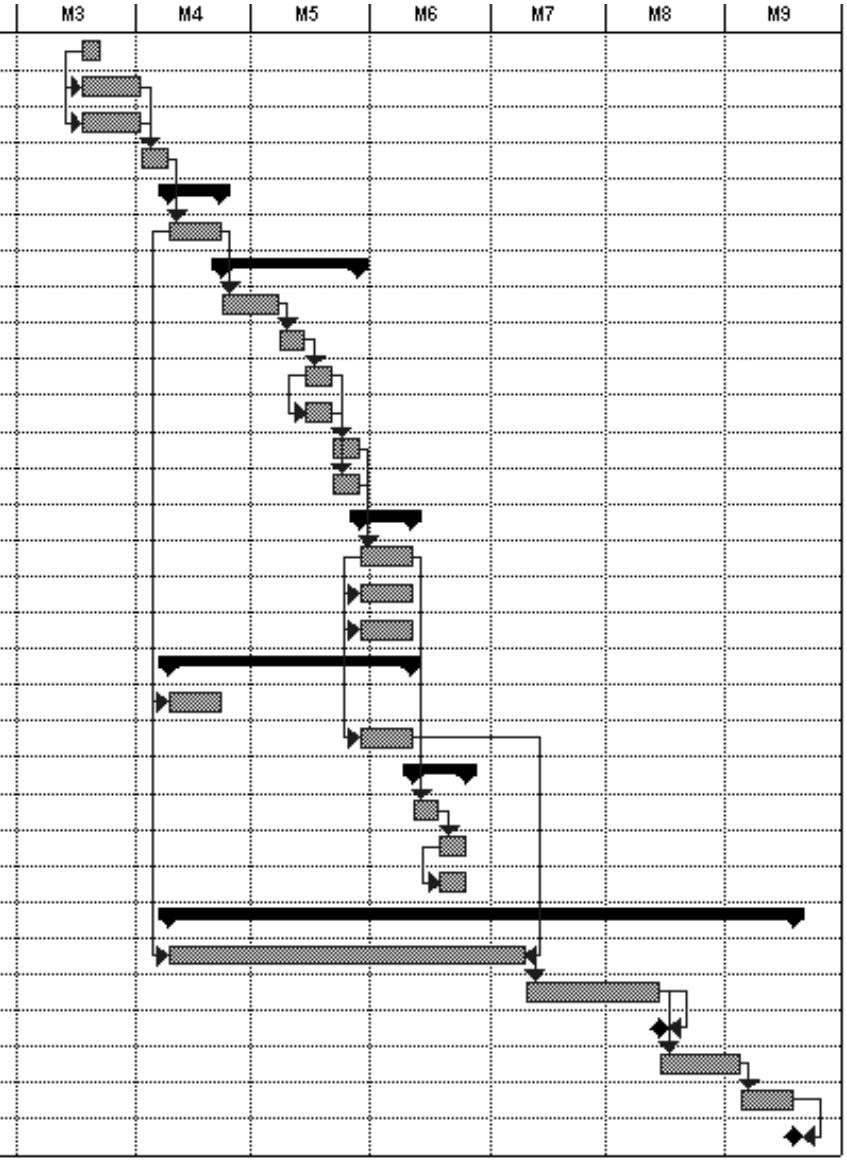


Figure 41 continued. BioGenesis℠ sediment decontamination pilot project schedule

7.4 Permitting Considerations

Federal, state, and municipal permits will be required for sediment decontamination processing. These permits will vary depending on the location, jurisdiction, geography, and attributes of the processing site. Assuming that the pilot demonstration is performed in New Jersey, the following permits may be required. Similar permits will be required if the chosen site is in New York.

- Wetlands permits from NJDEP or USACE for impacts to wetlands or any dredging work required
- Waterfront development permits from NJDEP if a facility is used that presently does not have barge or waterfront access, or if access requires approval
- Section 401 water quality certificate
- NJDEP water allocation permit
- NPDES permit for storm water and/or wastewater discharges, or local sewerage authority approval to discharge to a local POTW owned by the municipality.

Municipal site plan approval may also be required, and, from a public relations viewpoint, consideration should be given to municipal input. This would include a presentation to the local planning board (open to the public). Municipal site plan approval generally requires:

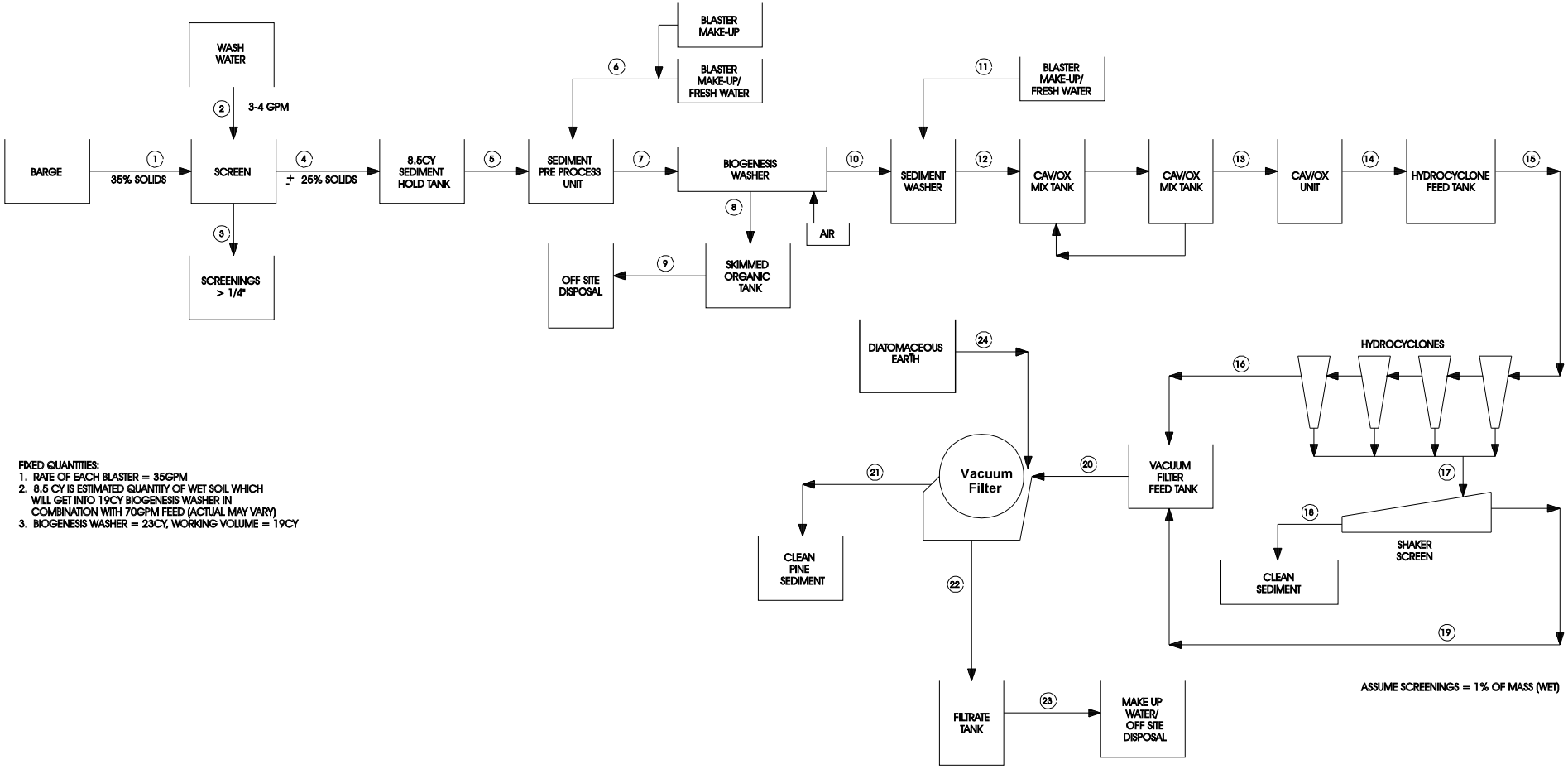
- Project engineering plans
- Zoning approval
- Building commission approval (architectural, electric, plumbing, and fire permits)
- Soil erosion and sediment control plans.

In addition to permits for actual decontamination operations, the beneficial reuse of decontaminated sediment may require permits depending on the specific use. NJDEP guidelines for beneficial reuse of dredged material take into consideration the degree of contamination of the waste, the quantity, and the site where the waste will be disposed of. Applications are reviewed on a case-by-case basis by NJDEP. Except for landfill cover, the NJDEP goal would be to meet criteria for residential use.

7.5 Process Flow Overview

The process flow diagram and mass balance calculation in Figure 42 gives an overview of the BioGenesis K Washing Process flow. It also presents mass balance calculations based on known parameters and best available estimates where definitive data for pilot scale operations is not available. The mass balance data and equipment configuration will be finalized during finalization of the Work Plan that is scheduled for spring 1998.

BioGenesis℠ Process Flow Diagram and Mass Balance



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	STREAM
# SLURRY	11469	-	158	15836	15836	0	25844	-	-	25804	-	30812	30812	30812	30812	30077	735	588	-	30224	# SLURRY
SPEC. GRAV.	1.15	-		1.11	1.11		1.06	-	-	1.06	-	1.05	1.05	1.05	1.05	1.04	1.43	-	-	1.04	SPEC. GRAV.
#H_2O	7455	4524	102	11877	11877	70	21885	-	-	21884	5008	26893	26893	26893	26893	26746	147	-	147	26893	#H_2O
#SOLIDS	4014	0	56	3959	3959	0	3959	40	40	3919	0	3919	3919	3919	3919	3331	588	588	-	3331	#SOLIDS

Figure 42. BioGenesis K process flow diagram and mass balance.

7.6 Site Requirements

7.6.1 *Pilot Demonstration Site*

The requirements for the pilot demonstration site are as follows:

Area	3 to 5 acres
Waterfront access	Serviceable bulkhead/dock area within 400 ft. of process area
Ingress/Egress	Tractor trailer required
Process area	50,000 SF, preferred all in a building with 24 feet clear height. Alternatively, a minimum building of 10,000 SF and outside adjacent 40,000 SF area is needed.
Water supply	200 gpm.
Power supply	1,000 amp, 480V, 3 phase service
Nominal output	24 yd^3/day

7.6.2 *Full-scale Site*

Estimated requirements for a full-scale site capable of processing 100,000 CY sediment per year are as follows. These requirements will be refined following the pilot demonstration.

Area	15-20 acres Waterfront with serviceable bulkhead/dock area within 400 ft. of process area
Building	To be determined
Ingress/Egress	Tractor trailer required
Process area	To be determined
Rail	Required (ultimately)
Water supply	To be determined
Power supply	To be determined
POTW	Located close to a POTW tie-in
Nominal output	100,000 yd^3/yr

7.7 Site and Equipment Configuration

Using the requirements for a full-scale facility outlined in paragraph 7.6.2, an example of equipment layout is provided in Figure 43. The facility has several key requirements which are being given priority in the search for a suitable operating location. These are:

- Water access for receiving sediment by barge. This is the most economical and efficient method and is mandatory in order to mesh smoothly with dredging operations and have minimum impacts of local communities.
- Enough overall space to allow storage of incoming sediment before it is processed, together with space to store both ingredients for and finished product associated with the production of manufactured soil.

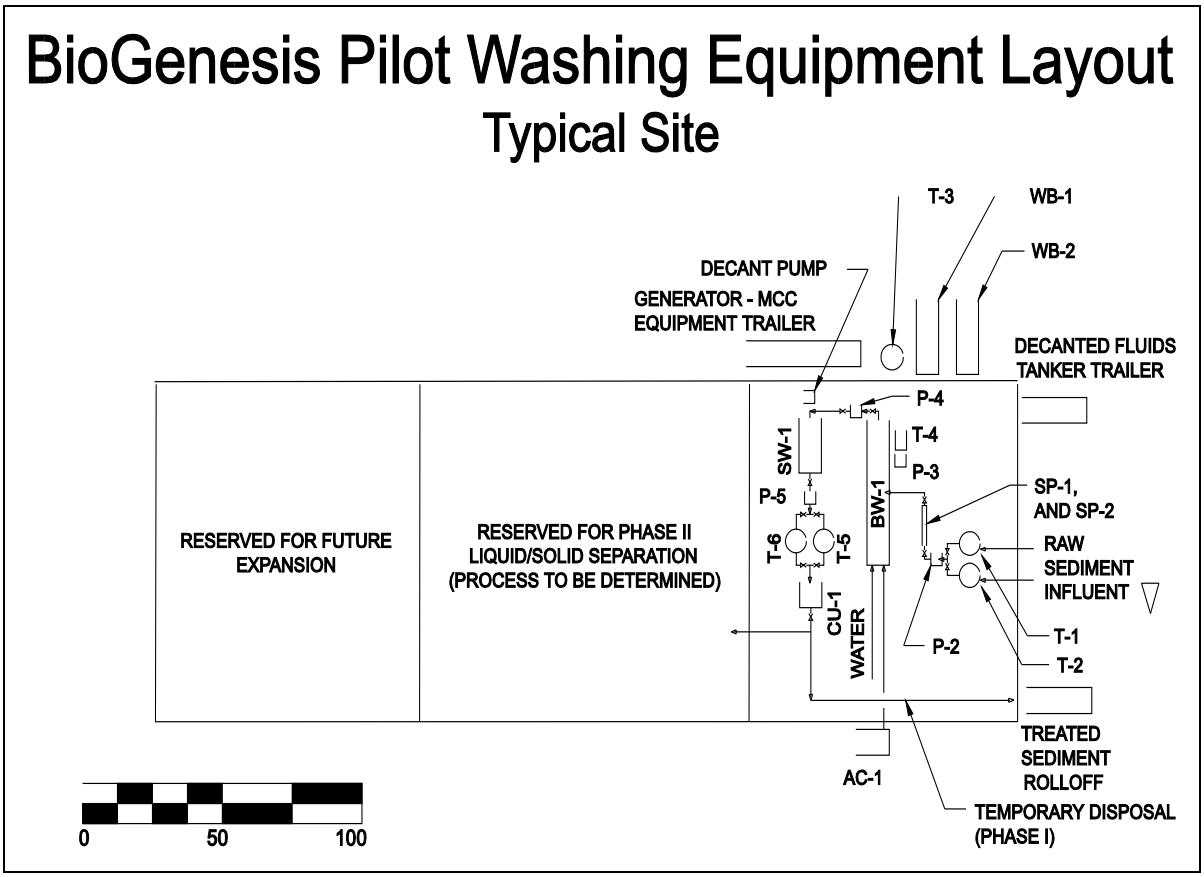


Figure 43. Typical washing equipment and site layout

Table 25. BioGenesis Pilot Plant Equipment List

ITEM NO.	DESCRIPTION	SIZE	DIMENSIONS	VOLUME/RATE	PROVIDED BY	POWERED BY	ELECTRICAL/AIR REQUIREMENTS	COMMENTS
AC-1	AIR COMPRESSOR			375scfm + Weston	Weston	Diesel Fuel		100psi
BW-1	BIOGENESIS WASHER		8' x 45' x 13'high		BioGenesis	Gen/MCC		
CU-1	CAVITATION UNIT		8' x 8'	100gpm	BioGenesis	Weston's Gen	480V 50A	
GEN-1	ELECTRIC GENERATOR				Weston	Diesel Fuel		
M-1	SEDIMENT HOLDING TANK MIXER	77 rpm	6 blade, 42" paddle	15:1 gear ratio	Weston	Electric	120/208V,10HP, 1160rpm	Provided with Tank T-1
M-2	SEDIMENT HOLDING TANK MIXER	77 rpm	6 blade, 42" paddle	15:1 gear ratio	Weston	Electric	120/208V,10HP, 1160rpm	Provided with Tank T-2
M-3	CAVITATION OXIDATION TANK MIXER	71 rpm	6 blade, 42" paddle	24:1 gear ratio	Weston	Electric	120/208V,30HP, 1750rpm	Provided with Tank T-5
M-4	CAVITATION OXIDATION TANK MIXER	71 rpm	6 blade, 42" paddle	24:1 gear ratio	Weston	Electric	120/208V,30HP, 1750rpm	Provided with Tank T-6
P-1	RAW SEDIMENT TRANSPORT PUMP @ BARGE	Model DP-7.5		100gpm	Weston	Electric	Generator needed	TOYO Pump Operated w/Excavator
P-2	BIOGENESIS WASHER FEED PUMP	Model W15-3	45" x 22"	110gpm	Weston	AIR	20 CFM	Warren Rupp Sandpiper Diaphragm Pump
P-3	FILTERED CONTAINER WATER RETURN PUMP			100gpm	BioGenesis	Electric		Centrifugal Pump
P-4	SEDIMENT WASHER FEED PUMP	Model W15-3	45" x 22"	170gpm	Weston	AIR	40 CFM	Warren Rupp Sandpiper Diaphragm Pump
P-5	CAVITATION TANKS FEED PUMP	Model W15-3	45" x 22"	200gpm	Weston	AIR	70 CFM	Warren Rupp Sandpiper Diaphragm Pump
P-6	DECANT PUMP			100gpm	Weston	Electric		Trash Pump
S-1	SCREEN - 1/4" solids				Weston	n/a		*hold*
S-2	SCREEN - 1/4" solids				Weston	n/a		*hold*
SP-1	SEDIMENT PREPROCESSOR		4"dia x 6' long		BioGenesis	n/a	none	
SP-2	SEDIMENT PREPROCESSOR		4"dia x 6' long		BioGenesis	n/a	none	
SW-1	SEDIMENT WASHER		8' x 17' x 15'high		BioGenesis	Weston's Gen	480V 60A	
T-1	RAW SEDIMENT HOLDING TANK	2300gal	7'6"dia x 7'high	1/4" SS w/Bridge	Weston	n/a		UPE No. 0091112 w/mixer
T-2	RAW SEDIMENT HOLDING TANK	2300gal	7'6"dia x 7'high	1/4" SS w/Bridge	Weston	n/a	none	UPE No. 0091113 w/mixer
T-3	WATER BLASTER SUPPLY TANK	4000gal	8'dia x 13.5'high	Polyethylene	Weston	n/a	none	BAKER RENTAL
T-4	SKIMMED ORGANIC MATERIALS TANK	700gal			Weston	n/a	none	BAKER RENTAL
T-5	CAVITATION OXIDATION MIX TANK	3000gal	7'6"dia x 9'high	1/4" SS w/Bridge	Weston	n/a	none	UPE No. 0036700 w/mixer
T-6	CAVITATION OXIDATION MIX TANK	3000gal	7'6"dia x 9'high	1/4" SS w/Bridge	Weston	n/a	none	UPE No. 0036701 w/mixer
T-7	SEDIMENT HOLDING CONTAINER TANK	10,000gal	8' x 35' x 13'high	Steel	Weston	n/a	none	BAKER EZ ACCESS TANK
T-8	DECANTED FLUIDS TANKER TRUCK	4000 gal	8' x 25' x 10'high	Polyethylene	Weston	n/a	none	BAKER POLY TANK TRAILER
WB-1	WATER BLASTER	10,000 psi	8' x 12'	70gpm	BioGenesis	Diesel Engine		
WB-2	WATER BLASTER	10,000 psi	8' x 12'	30gpm	BioGenesis	Diesel Engine		
BW-1	BIOGENESIS WASHER		8' x 45' x 13'high		BioGenesis	Gen/MCC		
CU-1	CAVITATION UNIT		8' x 8'	100gpm	BioGenesis	Weston's Gen	480V 50A	
P-3	FILTERED CONTAINER WATER RETURN PUMP			100gpm	BioGenesis	Electric		Centrifugal Pump
SP-1	SEDIMENT PREPROCESSOR		4"dia x 6' long		BioGenesis	n/a	none	
SP-2	SEDIMENT PREPROCESSOR		4"dia x 6' long		BioGenesis	n/a	none	
SW-1	SEDIMENT WASHER		8' x 17' x 15'high		BioGenesis	Weston's Gen	480V 60A	
WB-1	WATER BLASTER	10,000 psi	8' x 12'	70gpm	BioGenesis	Diesel Engine		
WB-2	WATER BLASTER	10,000 psi	8' x 12'	30gpm	BioGenesis	Diesel Engine		
AC-1	AIR COMPRESSOR			375scfm + Weston	Weston	Diesel Fuel		100psi

Table 25. BioGenesis Pilot Plant Equipment List

ITEM NO.	DESCRIPTION	SIZE	DIMENSIONS	VOLUME/RATE	PROVIDED BY	POWERED BY	ELECTRICAL/AIR REQUIREMENTS	COMMENTS
GEN-1	ELECTRIC GENERATOR				Weston	Diesel Fuel		
M-1	SEDIMENT HOLDING TANK MIXER	77 rpm	6 blade, 42" paddle	15:1 gear ratio	Weston	Electric	120/208V,10HP, 1160rpm	Provided with Tank T-1
M-2	SEDIMENT HOLDING TANK MIXER	77 rpm	6 blade, 42" paddle	15:1 gear ratio	Weston	Electric	120/208V,10HP, 1160rpm	Provided with Tank T-2
M-3	CAVITATION OXIDATION TANK MIXER	71 rpm	6 blade, 42" paddle	24:1 gear ratio	Weston	Electric	120/208V,30HP, 1750rpm	Provided with Tank T-5
M-4	CAVITATION OXIDATION TANK MIXER	71 rpm	6 blade, 42" paddle	24:1 gear ratio	Weston	Electric	120/208V,30HP, 1750rpm	Provided with Tank T-6
P-1	RAW SEDIMENT TRANSPORT PUMP @ BARGE	Model DP-7.5		100gpm	Weston	Electric	Generator needed	TOYO Pump Operated w/Excavator
P-2	BIOGENESIS WASHER FEED PUMP	Model W15-3	45" x 22"	110gpm	Weston	AIR	20 CFM	Warren Rupp Sandpiper Diaphragm Pump
P-4	SEDIMENT WASHER FEED PUMP	Model W15-3	45" x 22"	170gpm	Weston	AIR	40 CFM	Warren Rupp Sandpiper Diaphragm Pump
P-5	CAVITATION TANKS FEED PUMP	Model W15-3	45" x 22"	200gpm	Weston	AIR	70 CFM	Warren Rupp Sandpiper Diaphragm Pump
P-6	DECANT PUMP			100gpm	Weston	Electric		Trash Pump
S-1	SCREEN - 1/4" solids				Weston	n/a		*hold*
S-2	SCREEN - 1/4" solids				Weston	n/a		*hold*
T-1	RAW SEDIMENT HOLDING TANK	2300gal	7'6"dia x 7'high	1/4" SS w/Bridge	Weston	n/a		UPE No. 0091112 w/mixer
T-2	RAW SEDIMENT HOLDING TANK	2300gal	7'6"dia x 7'high	1/4" SS w/Bridge	Weston	n/a	none	UPE No. 0091113 w/mixer
T-3	WATER BLASTER SUPPLY TANK	4000gal	8'dia x 13.5'high	Polyethylene	Weston	n/a	none	BAKER RENTAL
T-4	SKIMMED ORGANIC MATERIALS TANK	700gal			Weston	n/a	none	BAKER RENTAL
T-5	CAVITATION OXIDATION MIX TANK	3000gal	7'6"dia x 9'high	1/4" SS w/Bridge	Weston	n/a	none	UPE No. 0036700 w/mixer
T-6	CAVITATION OXIDATION MIX TANK	3000gal	7'6"dia x 9'high	1/4" SS w/Bridge	Weston	n/a	none	UPE No. 0036701 w/mixer
T-7	SEDIMENT HOLDING CONTAINER TANK	10,000gal	8' x 35' x 13'high	Steel	Weston	n/a	none	BAKER EZ ACCESS TANK
T-8	DECANTED FLUIDS TANKER TRUCK	4000 gal	8' x 25' x 10'high	Polyethylene	Weston	n/a	none	BAKER POLY TANK TRAILER