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Biopraxis™ Inc.
Redefining the Quantum Leap

SHIPYARD STORMWATER MOP-UP®

Final Report

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between
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and
Biopraxis, Inc.

Biopraxis, Inc.
P.O. Box 910078
San Diego, CA 92191-0078

Executive Summary

Government agencies are imposing increasingly stringent regulations to prevent surface water pollution. The complex and highly variable nature of stormwater – which is responsible for one-third of all surface water contamination – makes it extremely difficult to meet current or projected regulatory requirements for stormwater runoff. Shipyard stormwater runoff typically contains a variety of heavy metals, toxic organics, oils and greases, and high levels of total suspended solids (TSS). The heavy metals are particularly difficult to treat; yet many shipyards are now facing NPDES permitting requirements that require the treated stormwater to pass acute/chronic toxicity testing, or even meet drinking water levels, before it can be discharged into receiving waters.

Biopraxis proposed to evaluate MOP-UP®, a new technology under development for groundwater remediation, for use in treating stormwater runoff for direct discharge to receiving waters. MOP-UP® is based on a new family of particulate reagents, prepared by a proprietary new process, that are remarkably effective at treating heavy metal contamination. Biopraxis is teamed with USFilter to couple MOP-UP® reagents with commercial separation technologies for rapid development and deployment of a system that can treat the full range of stormwater contaminants. The resulting Shipyard Stormwater MOP-UP® system is expected to not only enable shipyards to meet the most stringent environmental regulations for stormwater treatment and discharge, but to enable the design of a simple, reliable treatment system that has a small footprint, requires little training to operate, needs minimal maintenance, generates far less sludge than conventional wastewater treatment technologies, and has very low life cycle costs.

Six shipyards supported the Biopraxis/USFilter team, providing details on stormwater runoff composition and variability, and providing samples of stormwater runoff for use in treatability testing.

Under the MARITECH ASE program, studies showed that MOP-UP® reagents are capable of taking copper, zinc, and lead to nondetectable levels (0.002, 0.010, and 0.002ppm, respectively), even in highly complex shipyard stormwater samples provided by four shipyards at the four corners of the country. The reagents were also shown to have exceptionally high loading capacities, taking up many times their own weight in copper, zinc, lead, or nickel during tests with excess metal ion concentrations; and taking up half again their own weight while removing all detectable metal ions from dilute solutions representative of shipyard stormwater concentrations, while doing so in the short periods of time needed to meet treatment system requirements. If the reagents are recycled, their loading capacities can be even higher, and the amount of sludge produced even lower.

Chester Engineers, a wholly-owned subsidiary of USFilter, evaluated a wide range of commercial treatment systems that could be coupled with MOP-UP® reagents to treat all the diverse contaminants found in shipyard stormwater runoff, simultaneously. The most promising options, for which life cycle cost estimates were developed, were based on ACTIFLO® and Memtek microfiltration. ACTIFLO®, a sand ballasted coagulation-sedimentation system designed for treating highly-variable waters/wastewaters (e.g., stormwater runoff and sewer overflows), whereas Memtek is a crossflow tubular membrane separator that removes particulate contaminants at a high fluid velocity from diverse industrial wastewaters, including highly corrosive saline solutions. Both of these technologies currently enjoy widespread use for a variety of industrial applications, and both offer substantial advantages in comparison with competing separation technologies for treating highly complex and variable wastewaters.

Each approach offers its own advantages. ACTIFLO® is a compact clarification system that utilizes microsand as a seed for floc formation. The high surface area of the microsand enhances flocculation, while its density acts as a ballast or weight to enhance settling. The rapid settling

allows the design of clarifiers with high overflow rates and short retention times; i.e., system footprints 5 to 20 times smaller than conventional clarification systems of similar capacity, with significantly lower total capital costs. The microsand also permits the treatment system to perform well under dramatically changing flow rates without impacting the quality of the final effluent. ACTIFLO® can go from zero to millions of gallons per day, achieving steady-state conditions within minutes; has a very low backpressure and therefore consumes little power; and is robust and easily maintained. The intense mixing and contact time leads to significant chemical savings as compared to conventional clarification processes. Memtek, on the other hand, produces an exceptionally high quality effluent, since the microfiltration membranes provide an absolute barrier to particle passage. The rugged membranes are designed for operation in hostile environments, and have an expected life of 5-7 years. The proprietary crossflow tubular design permits the wastewater to be pumped continuously through the membranes at a high fluid velocity. Clean water is forced through the pores of the membrane while the particulate contaminants remain suspended in the recirculated stream. The turbulence of the recirculated slurry prevents the contaminants from accumulating on the membrane surface, thereby maintaining high and continuous filtration rates. Because filtration rather than sedimentation is used to separate particulates, fewer chemicals are needed; the system produces a concentrated, suspended solid slurry. The use of the recirculated slurry dampens fluctuations in the wastewater chemistry and permits efficient performance of the MOP-UP® reagents and the membranes.

When combined with MOP-UP® reagents, both systems are expected to treat all the contaminants in shipyard stormwater runoff very effectively, meeting current discharge limitations. For more stringent NPDES permitting requirements that are anticipated at some shipyards, Memtek may be the clear choice. However, pilot plant studies are required to confirm the predicted performance, as well as develop design parameters such as the necessary dosage rate of the reagent, retention time, and overflow rate.

Both systems were sized for treating three different storm scenarios, ranging from a total runoff volume of 250,000gal with a peak flow of 2,000gpm for a 2-year storm event (the baseline scenario, developed for the pilot-scale test bed being installed at NASSCO under another MARITECH program) to a total runoff volume of 1,000,000gal with a peak flow of 8,000gpm for a 2-year storm event. The analyses showed that the availability of stormwater storage facilities will drive the choice between the two technologies. Since ACTIFLO® can handle very high flow rates, stormwater storage is not needed; however, the capital and operating costs of this treatment system are higher than those of Memtek. Therefore, when storage facilities are already available, Memtek, even with its superior effluent quality, will have significantly lower life cycle costs. Memtek systems capable of meeting the requirements for the three storm scenarios at shipyards with storage facilities already available were estimated to range from $430,000 in capital costs (including equipment, freight, site preparation, and installation) and $5,100 in annual operating and maintenance costs for the baseline scenario, to $676,000 in capital costs and $9,500 in annual operating and maintenance costs for the 1,000,000gal scenario.

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Section II – Chester Engineers Report

1.0 Introduction

Government agencies are imposing increasingly stringent regulations to prevent surface water pollution. The complex and highly variable nature of stormwater – which is responsible for one-third of all surface water contamination – makes it extremely difficult to meet current or projected regulatory requirements for stormwater runoff. Shipyard stormwater runoff typically contains a variety of heavy metals, toxic organics, oils and greases, and high levels of total suspended solids (TSS). The heavy metals are particularly difficult to treat; yet many shipyards are now facing NPDES permitting requirements that require the treated stormwater to pass acute/chronic toxicity testing, or even meet drinking water levels, before it can be discharged into receiving waters. Even in relatively arid regions of the country, a two-year storm event at a major shipyard can produce 1.5 million gallons of stormwater runoff within 24 hours; therefore, treatment systems must be capable of treating a wide range of flow rates, reaching steady-state performance at very high flow rates quickly, and treating very large volumes economically. Due to the very limited space at most shipyards, a treatment system that can process the stormwater while it is generated, without storage, is highly desirable. Moreover, the system should be a subsurface installation, to minimize interference with normal shipyard activities.

Under the MARITECH ASE program, Biopraxis proposed to evaluate MOP-UP®, a new technology under development for groundwater remediation, for use in treating stormwater runoff for direct discharge to receiving waters. MOP-UP® is based on a new family of particulate reagents, prepared by a proprietary new process, that are remarkably effective at treating heavy metal contamination. Biopraxis is teamed with ***USFilter*** to couple MOP-UP® reagents with commercial separation technologies for rapid development and deployment of a system that can treat the full range of stormwater contaminants. The resulting Shipyard Stormwater MOP-UP® system is expected to not only enable shipyards to meet the most stringent environmental regulations for stormwater treatment and discharge, but to enable the design of a simple, reliable treatment system that has a small footprint, requires little training to operate, needs minimal maintenance, generates far less sludge than conventional wastewater treatment technologies, and has very low life cycle costs.

Studies on using MOP-UP® for groundwater remediation, conducted under the auspices of the Department of Energy (DOE), have shown that MOP-UP® reagents have extraordinary properties:

- MOP-UP® reagents can have extremely high affinities for heavy metals and radionuclides, making it possible to remove all detectable traces of these contaminants.
- In radiotracer screening tests, MOP-UP® reagents have readily taken diverse heavy metals and radionuclides to ***sub-parts per billion*** and even ***sub-parts per trillion*** levels, even at pH extremes.
- Complex mixtures of heavy metals and/or radionuclides have been readily treated in the presence of organic pollutants, chelating agents, and/or high concentrations of iron, sulfate, calcium, potassium, sodium, magnesium, and nitrate.
- The reagents have ***extremely high loading capacities***, typically being capable of taking up several times their own weight in metals. Therefore, far less reagent is needed, and far less secondary waste is produced, than when conventional metal treatment technologies are used.

MOP-UP® is not only effective, but is also expected to be ***economical***. Because the reagents can be prepared in high yields from inexpensive precursors using environmentally-friendly processes, they are projected to be very low-cost when produced in bulk. Because MOP-UP® reagents have extraordinarily high capacities, whether in very dilute or heavily contaminated wastewaters, very little reagent will be needed. And because the MOP-UP® reagents have such high capacities and can treat dissolved metals ***without pH adjustment***, very little sludge will be produced.

According to a recent study conducted under the auspices of NSRP, stormwater runoff from shipbuilding and repair facilities typically contains metals (primarily Cu and Zn, with some yards also reporting Pb, Cr, Cd, Hg, Ni, Ag, and/or Sn); oil and grease; toxic organics [polyaromatic hydrocarbons (PAHs), petroleum hydrocarbons, and total organic carbon (TOC)]; and total suspended solids (TSS). Cu and Zn not only tend to be the most prevalent contaminants, but also tend to be the constituents most toxic to indicator organisms used in monitoring stormwater runoff contamination and treatment efficacy.

Contaminated groundwaters have properties that are similar in many ways to stormwater runoff – they tend to be extremely variable, with constituents and flow rates changing dramatically due to seasonal fluctuations in rainfall, temperature, and groundcover; and they are typically very complex, often containing mixtures of metals, other inorganics, and a variety of organics. And, as with stormwater runoff, the groundwater pollutants that are the most difficult by far to treat are heavy metals. Nevertheless, MOP-UP® reagents have already been shown to be highly effective in tests conducted with simulated and real groundwater samples from diverse sites throughout the U.S. (e.g., Table 1.)

Table 1 – Treatability Test with S-3 Ponds Area groundwater contaminants

Metal	*Initial ppm*	*Final ppm*	*% Metal Removed*
Al	81.0	< 0.05	>99.93
Ba	19.1	0.30	98
Cd	4.0	< 0.002	>99.7
Cu	0.32	< 0.002	>96.9
U	0.36	0.000179	>99.95
Zn	0.50	< 0.010	>97.9
Hg	1.1	< 0.000100	>99.95

Results from the first MOP-UP® reagent treatability test with S-3 Ponds Area groundwater contaminants; treatment had not yet been optimized. Initial sample constituents included 360ppm total metals (including Fe, Mn, and Mg, which were not analyzed for removal efficiency), 1700ppm nitrate, 3.8ppm trichloroethylene, 5.0ppm 2-butanone, 51.8ppm acetone, 7.0ppm chloroform, 3.2ppm toluene, 17.3ppm methylene chloride, parts per thousand chlorine, and high parts per million levels of sodium, potassium, and sulfate. Treatment was done at the native pH of 4.1, without pretreatment or pH adjustment.

The overall objective of the MARITECH ASE program was to evaluate MOP-UP® for use in practical, economical stormwater runoff treatment systems for use at shipyards. Under the MARITECH program, Biopraxis and US Filter proposed to:

(1) Obtain historical data on stormwater runoff composition from participating shipyards;

(2) Conduct treatability studies with 'clean' solutions and simulated stormwater samples to identify the reagents most promising for treating copper and zinc;

(3) Conduct treatability studies with samples of stormwater runoff provided by shipyards located throughout the U.S., to confirm that both metals can be taken below the targeted residual levels in complex and highly variable 'real world' samples;

(4) Evaluate commercial wastewater systems for their ability to meet shipyard stormwater treatment requirements for removing oils and greases and TSS, as well as achieving desired flow rates, footprint limitations, minimal maintenance, and economical life cycle costs;

(5) Evaluate MOP-UP® reagents for their compatibility with the chosen treatment systems; and

(6) Develop life cycle cost estimates for the chosen Shipyard Stormwater MOP-UP® system.

The National Steel and Shipbuilding Company (NASSCO) offered to serve as a 'model' shipyard for establishing pass/fail performance criteria, and treatment system requirements for use in developing the life cycle cost estimates. NASSCO provided information about its site, six years' of historical data on stormwater composition at each outfall, and engineering analyses that had previously been conducted on applicable stormwater runoff regulations and treatment system requirements.

2.0 Shipyard Stormwater Composition

During contract negotiations, Biopraxis was asked to include additional shipyards in the program. Four additional shipyards were contacted and all agreed to support the program; a fifth subsequently learned about the program and asked to participate as well. These six shipyards are located throughout the U.S.; i.e., in the northeast, on the middle Eastern coast, in the southeast, on the Gulf, in the southwest, and in the northwest (Fig. 1). Some – such as NASSCO – already face

Figure 1. Participating shipyards

extremely stringent NPDES permitting requirements; others do not yet have even monitoring requirements.

Four of the six participating shipyards were able to provide detailed information on the constituents found in their stormwater runoff. One participating shipyard does not yet have any monitoring requirements; and the sixth shipyard is just beginning to put a monitoring program in place and does not yet have any historical data. Both of these, however, provided their "best guess" as to the contaminants that might be present in their stormwater runoff and would be of concern.

Two of the shipyards had problems with Cu and Zn only. Three are concerned about potential permitting requirements for Pb in the stormwater as well as the Cu and Zn. The sixth was concerned about Ni as well as Pb, Cu, and Zn. Data assembled during literature searches on shipyard stormwater indicate that Pb is a fairly widespread contaminant of concern throughout the shipbuilding and repair industry. Therefore, tests with Pb treatment, and a few with Ni, were included in some of the studies.

Not only is stormwater at any given facility highly variable, but the stormwater characteristics vary sharply from facility to facility (Table 2.) In addition to differences in the presence and concentrations of various contaminants, the average pH of the water varies from yard to yard. Of the three shipyards providing details on the pH of the stormwater runoff, one typically finds its stormwater at pH 5.0 - 6.0, with some samples as acidic as pH 4.2, and others as alkaline as pH 10.64; one at 6.5 - 7.5; and one at 7.5 - 8.5.

	Shipyard			
	W 1997-1999	*X 1996-1999*	*Y 1992-1999*	*Z 1995-1999*
pH	5.99 – 8.73	6.6 – 8.5	4.20 – 10.64	–
TSS mg/L	< 5 – 478	7 – 99	0.74 – 155	2.9 – 90
O/G mg/L	< 1 – 137	< 1 – 29	< 0.5 – 8.0	0.4 – 14.3
Cu ppb	< 50 – 6,100	42 – 1,300	20 – 2,500	4 – 1,290
Pb ppb	< 50 – 1,100	3 – 400	< 6 – 170	4 – 100
Zn ppb	1,100 – 16,500	100 – 5,100	120 – 7,100	8 – 2,220

Table 2. Range of major contaminants in shipyard stormwater

The conditions found at these shipyards were used to develop screening tests for identifying the MOP-UP® reagents most promising for use in stormwater runoff treatment.

As noted earlier, NASSCO, as the lead shipyard, was the basis for establishing pass/fail criteria and developing the life cycle cost estimates. The NPDES permitting requirements for shipyards to discharge stormwater directly to the San Diego harbor are based on acute and chronic toxicity tests involving *Mysidopsis bahia* shrimp as the indicator organism. Studies funded by the yard indicate that copper and zinc are the two stormwater constituents that cause the shrimp to die, with lethal concentrations being approximately 200ppb Cu and 400ppb zinc. Therefore, 200ppb Cu and 400ppb zinc were established as the '***pass/fail***' criteria for the MARITECH program.

However, shipyards in other parts of the country are facing the possibility even more stringent permitting requirements, e.g., drinking water levels for toxic metals. The ***goal*** of the Shipyard Stormwater MOP-UP® program was to develop a stormwater runoff treatment technology capable of meeting the requirements of shipbuilding and repair facilities facing the most stringent permitting requirements, i.e., 2ppb Cu and 10ppb zinc.

Since copper and zinc are the stormwater constituents that are the most difficult to treat by far, the Shipyard Stormwater MOP-UP® laboratory studies focused on evaluating MOP-UP® reagents for their removal. However, the analyses of the available commercial separation systems took into account the need to treat ***all*** of the contaminants found in shipyard stormwater runoff.

3.0 Treatability Studies

The MOP-UP® technology can be used to produce a variety of reagents with diverse properties. Some reagents are relatively specific for certain heavy metals; others take up a broad range of inorganic contaminants. Some are fine particles that are readily suspended in wastewater for prolonged periods with very light mixing; others are larger and/or more dense, and settle rapidly – especially after taking up several times their own weight in heavy metals. Some are highly effective at separating metal ions from organic contaminants; others tend to treat organics as well as inorganics. Because the reagents are particulates, they do not interact with each other. Therefore, a formulation comprising two or more reagents can be used for exceptionally complex wastewaters.

Two properties are especially important for developing a user-friendly, economical stormwater runoff treatment system; i.e., (1) the ability to take heavy metals to nondetectable levels under the range of conditions found in shipyard stormwater runoff; and (2) the ability to take up high loadings of heavy metals. The former is essential for meeting NPDES permitting requirements, whereas the latter will result in minimal reagent consumption and minimal sludge production, both of which translate into low operating costs.

Therefore, under the Shipyard Stormwater MOP-UP® program, a series of tests were used to screen a number of MOP-UP® reagents. Candidate reagents were first screened for their ability to take copper and zinc to nondetectable levels (< 0.002ppm and < 0.010ppm, respectively) from concentrations typically found in shipyard stormwater runoff. Some were also screened for their ability to take lead and/or nickel to nondetectable levels, as well. The most promising candidates were then examined for their loading capacities for copper, zinc, and lead. And, finally a few of the reagents were then tested in samples of stormwater runoff, provided by participating shipyards, to confirm that the reagents can, indeed, treat real-world samples as predicted.

3.1. Screening Studies

The first tests involved samples containing a single heavy metal; subsequent studies contained mixtures of two or more metals, sometimes mixed with oils and greases. The concentrations of the contaminants were chosen on the basis of the pollutants found in shipyard stormwater runoff. These tests were designed to identify the reagents that were most promising for taking contaminants in the polluted stormwater to nondetectable levels (0.002ppm for copper and lead, and 0.010 for zinc). As expected, most of the candidates readily passed these tests, even when the metals were in solutions containing high concentrations (120-170ppm) of oils/greases.

Additional tests were conducted with the more promising reagents, to evaluate their relative metal loading capacities. It should be noted that the test protocol did not measure the 'true' loading capacities of the reagents. Typically, such a test is conducted in a very large excess of the dissolved metal ion, at the pH that is optimum for metal ion removal (typically alkaline when cations such as copper, zinc, and lead are tested) and is taken to equilibrium – which can take several days to reach. The MOP-UP® reagent tests, on the other hand, comprised a simple static batch incubation; i.e., the reagents were added to the solutions and allowed to sit, without agitation or mixing, for 2 or 4 hours, then removed, and the residual metal concentrations were measured. The pH of the test solution was very acidic, rather than alkaline, often as low as pH 3-4.

The loading capacities of conventional adsorbents are typically on the order of 10 - 50mg/g, in a very large excess of metal ion, at optimum pH, and measured at equilibrium. With the protocol used on the MARITECH program, the maximum metal ion available to the MOP-UP® reagents would achieve a loading capacity of 1,000mg/g. However, the metal ion concentration proved to be considerably less than a very large excess. All twelve of the MOP-UP® reagents tested against copper removed ≥90%, i.e., exhibited loading capacities in excess of 900mg/g. Two of the reagents removed > 99%, i.e., exhibited loading capacities in excess of 990mg/g. Since all of the reagents were rapidly approaching total removal of the copper and were still taking up metal at a high rate, it is highly likely that the capacities were actually far in excess of the measured amount; and a test in which a significant excess of copper is present would show the reagents to have even better capabilities (see below). Similarly, ten reagents tested against zinc removed >96% of the zinc and two removed > 95%; i.e., all twelve exhibited loading capacities for zinc well in excess of 950mg/g. The pH of the lead solutions was considerably more acidic than that of the copper or zinc. Nevertheless, eleven of the reagents took up at least 500mg/g within the short static incubation; one of the reagents took up 945mg/g, and the final reagent took up all detectable lead, i.e., 1,000mg/g.

Although the tests did not demonstrate the true loading capacities of the MOP-UP® reagents, they more than demonstrated that the reagents have significantly higher loading capacities than conventional adsorbents.

The MOP-UP® reagent production process produces particles that cover a range of sizes, with some reagents being in the 3-5μm range and others in the 80-100μm range (before metal uptake.) Many of the separation technologies of interest rely on density and/or particle size to remove particles from contaminated water. Therefore, in subsequent studies, MOP-UP® reagents were fractionated, and the 'loading capacities' of the dense fraction or the large particle fraction were evaluated. Because the earlier tests did not begin to measure true loading capacities, a much higher ratio of metal ion to reagent was used.

Typically, smaller particles have higher loading capacities because they have higher surface areas; therefore, it was originally assumed that the smaller particles would account for more of the metal removal. However, this did not turn out to be the case for the MOP-UP® reagents (Table 3.) Instead, in general, the most dense fraction out-performed the lighter fractions. These findings were extremely promising, since the dense fraction will be separated from the treated stormwater more easily than the lighter fractions. In addition, the dense fraction typically constituted the bulk of the reagent, e.g., comprised 85-95% of the total reagent produced, by weight. Therefore, using density to recover the most readily separated reagent fraction will not only enhance performance, but will have little impact on cost.

It should be noted that the results are affected by pH; some of the reagents tend to buffer the pH very well, some raise it as they interact with the metals, and some lower the pH, depending on reaction kinetics and the initial pH of the water. Generally speaking, the higher the pH, the higher the loadings of the heavy metal cations that the MOP-UP® reagents can remove. The results should therefore be considered to be general trends/capabilities of the individual reagents, with some differences in loading capacities to be expected in waters with different pH ranges. Nevertheless, the affinities of the MOP-UP® reagents for heavy metal pollutants are substantially higher than originally anticipated.

Table 3 – Preliminary Loading Capacity Test Results

Reagent	4-Hour Loading Capacities (in mg metal/g reagent) Copper	Lead	Zinc	Nickel
Reagent M08f				
'Whole' fraction	36,200	30,000	4,300	4,400
Dense fraction	34,300	41,000	8,600	4,000
Large particle	23,300	58,800	17,300	4,600
Reagent M09f				
'Whole' fraction	44,900	38,500	13,000	6,900
Dense fraction	50,100	31,400	11,300	4,000
Large particle	44,600	52,800	2,700	7,100
Reagent T10f				
'Whole' fraction	38,700	30,600	5,900	18,400
Dense fraction	45,100	40,200	6,800	9,100
Large particle	11,100	7,500	6,000	55,200
Reagent T10m				
'Whole' fraction	28,700	31,100	8,100	7,400
Dense fraction	41,300	26,100	8,400	9,200
Large particle	44,800	40,600	12,200	3,000

It should also be emphasized that no adsorbent will actually take up its maximum loading capacity when used to treat a complex wastewater such as stormwater, since (1) a variety of wastewater constituents will compete for binding sites on the adsorbent; (2) the metal ion will not present be in substantial excess (the objective being to remove as much of the metal as possible); and (3) the adsorbent is not exposed to the contaminated water for prolonged periods of time. The loadings that are typically seen in a treatment system are therefore significantly lower than those seen in capacity tests. Capacity tests are simply used to identify adsorbents with superior overall properties, rather than to measure the amount of metal that will be taken up in the treatment system. The actual loadings that will be achieved will depend on the properties of the contaminated waste-water.

However, MOP-UP® reagents clearly have substantially higher capacities than conventional adsorbents – by orders of magnitude. In addition, tests with heavily contaminated samples such as acid mine drainage from the Berkeley Pit have shown that the reagents can take up several times their own weight in metals in such complex wastewaters, even at an unfavorable pH (in the case of the acid mine drainage, at the native pH of 3.8).

<u>3.2. Stormwater Runoff Treatability Studies</u>

Four of the shipyards participating in the Shipyard Stormwater MOP-UP® project provided samples of stormwater runoff for use in treatability tests to confirm that MOP-UP® reagents can, indeed, take toxic heavy metals to nondetectable levels in stormwater runoff (Table 4.) Two reagents were selected for testing in a given sample. The tests were performed as a static batch incubation, i.e., without any stirring or agitation, in 500mL of stormwater. The spent reagent was removed by filtering. Aliquots of the original stormwater sample and the treated samples (the tests were run in triplicate) were sent to an independent laboratory for analysis. Both of the reagents chosen for testing in stormwater from Shipyard One and Shipyard Four took the heavy metals of concern to nondetectable levels. One of the reagents took zinc and lead to nondetectable levels, and copper to 0.005ppm, in the stormwater from Shipyard Three. This same reagent took copper to nondetectable levels, zinc to 0.013ppm, and lead to 0.007ppm in the stormwater from Shipyard Two.

	Shipyard							
	One		***Two***		***Three***		***Four***	
	Initial ppb	***Final ppb***	***Initial ppb***	***Final ppb***	***Initial ppb***	***Final ppb***	***Initial ppb***	***Final ppb***
T10m								
Copper	13	ND	200	ND	515	5	97	ND
Zinc	130	ND	1,200	13	450	ND	840	ND
Lead	20	ND	20	7	10	ND		
T06f								
Copper	13	ND	200	ND	515	13		
Zinc	130	ND	1,200	123	450	63		
Lead	20	ND	20	8	10	ND		
M09f								
Copper							97	ND
Zinc							840	ND

Table 4. Treatability tests with stormwater from four major shipyards

It should be emphasized that the metal ion removal efficiency is likely to be even better if the samples are stirred. In kinetics studies with the stormwater sample from Shipyard Two (see below), copper, zinc, and lead were all readily taken below the targeted levels.

3.3. MOP-UP® Reagent Compatibility with Commercial Treatment Systems

Finally, MOP-UP® reagents were evaluate for their potential compatibility with the two most promising treatment technologies, i.e.:

(1) ACTIFLO®, a sand ballasted coagulation-sedimentation system designed for treating highly-variable waters/wastewaters (e.g., stormwater runoff and sewer overflows); and

(2) Memtek Microfiltration, a crossflow tubular membrane separator that removes particulate

contaminants at a high fluid velocity from diverse industrial wastewaters, including highly corrosive saline solutions.

Both of these technologies currently enjoy widespread use for a variety of industrial applications, and both offer substantial advantages in comparison with competing separation technologies for treating highly complex and variable wastewaters. Both are very effective at removing fine particulates. Highly efficient removal of ***dissolved*** inorganics such as copper and zinc cations, however, will require the use of MOP-UP®.

Each approach offers its own advantages. ACTIFLO® is a compact clarification system that utilizes microsand as a seed for floc formation. The high surface area of the microsand enhances flocculation, while its density acts as a ballast or weight to enhance settling. The rapid settling allows the design of clarifiers with high overflow rates and short retention times; i.e., system footprints 5 to 20 times smaller than conventional clarification systems of similar capacity, with significantly lower total capital costs. The microsand also permits the treatment system to perform well under dramatically changing flow rates without impacting the quality of the final effluent. ACTIFLO® can go from zero to millions of gallons per day, achieving steady-state conditions within minutes; has a very low backpressure and therefore consumes little power; and is robust and easily maintained. Memtek, on the other hand, produces an exceptionally high quality effluent, since the microfiltration membranes provide an absolute barrier to particle passage. The rugged membranes are designed for operation in hostile environments, and have an expected life of 5-7 years. The proprietary crossflow tubular design permits the wastewater to be pumped continuously through the membranes at a high fluid velocity. Clean water is forced through the pores of the membrane while the particulate contaminants remain suspended in the recirculated stream. The turbulence of the recirculated slurry prevents the contaminants from accumulating on the membrane surface, thereby maintaining high and continuous filtration rates. Because filtration rather than sedimentation is used to separate particulates, fewer chemicals are needed; the system produces a concentrated, suspended solid slurry.

Because ACTIFLO® and Memtek operate on very different principles, the conditions under which MOP-UP® reagents would interact with the heavy metal contaminants in each of these systems will differ significantly.

- In an ACTIFLO® system, residence time is very short (10-12 minutes); and, aside from the microsand ballast material, chemicals used to treat contaminants are typically not recycled. For the MOP-UP® reagents to take heavy metals to undetectable levels within a short residence time, the reaction kinetics must be extremely rapid or the reagents must be fairly concentrated. For treatment to be economical, it should involve minimal consumables; therefore, for a MOP-UP® reagent to be compatible with ACTIFLO®, it must achieve very rapid metal removal even when added to the contaminated water in very dilute concentrations. It is possible to design the system to recycle the MOP-UP® reagents a few times; and this may even improve flocculation/precipitation and separation. However, the reagents are unlikely to achieve their full loading capacities in this treatment system. Finally, since ACTIFLO® separation is based on settling, the reagents should be relatively large, dense particles with rapid settling characteristics for metal removal to be effective. Therefore, reagent compatibility with ACTIFLO® will be based more on metal removal kinetics and settling properties, than on metal loading 'capacities'.

- In a Memtek Microfiltration system, the particulate contaminants remain suspended in a recirculated stream. The residence time for the MOP-UP® reagents, therefore, will be far longer than in the ACTIFLO® system; the reagents will, in effect, be recycled continuously. This will permit the MOP-UP® reagents to be added at very high concentrations, which will (a) significantly improve metal removal kinetics; and (b) maximize their metal loadings before they are discarded. This will, in turn minimize the costs for consumables, and minimize even further the amount of sludge that is produced. Therefore, loading 'capacities' become more important than reaction kinetics in the Memtek approach.

Accordingly, MOP-UP® reagent candidates were tested for their ability to perform efficiently under the conditions that would be experienced in these promising commercial treatment systems.

The stormwater sample from Shipyard Two were used to evaluate the metal removal capabilities of four MOP-UP® reagent candidates under conditions relevant to Memtek (Table 5). Three different

Shipyard Two Stormwater Initial ppb			Cu *200ppb*	Zn *1,200ppb*	Pb *20ppb*
				Final ppb	
T03f	0.3 mg	5 min	ND	35	0.004
		8	ND	35	0.004
		12	ND	32	0.003
	1.0	5 min	ND	30	0.003
		8	ND	29	0.003
		12	ND	25	0.003
	4.0	5 min	ND	ND	0.001
		8	ND	ND	0.0008
		12	ND	ND	0.0007
T06f	0.3 mg	5 min	54	ND	0.003
		8	40	ND	0.003
		12	40	ND	0.002
	1.0	5 min	ND	ND	0.003
		8	ND	ND	0.003
		12	ND	ND	0.003
	4.0	5 min	ND	ND	0.002
		8	ND	ND	0.002
		12	ND	ND	0.001
T10f	0.3 mg	5 min	40	ND	0.003
		8	40	ND	0.003
		12	26	ND	0.003
	1.0	5 min	ND	ND	0.002
		8	ND	ND	0.002
		12	ND	ND	0.001
	4.0	5 min	ND	ND	0.002
		8	ND	ND	0.002
		12	ND	ND	0.002
T10m	0.3 mg	5 min	ND	ND	0.0002
		8	ND	ND	0.0002
		12	ND	ND	0.0003
	1.0	5 min	ND	ND	0.0003
		8	ND	ND	0.0003
		12	ND	ND	0.0003
	4.0	5 min	ND	ND	0.0003
		8	ND	ND	0.0003
		12	ND	ND	0.0003

Table 5 – Kinetics studies in stormwater

Conditions relevant to Memtek-based treatment system concentrations of each reagent were used. The samples were gently swirled during treatment, the reagents were separated from the water by microfiltration, and the amounts of metal remaining after 5, 8, and 12min were measured. As can be seen from the results, the reagents readily take dissolved metal ions to nondetectable levels in this stormwater when the sample is mildly agitated. (Radiotracers were used to determine the actual residual levels that could be achieved, since ICP-MS is not sensitive enough to measure sub-ppb concentrations.)

Since ACTIFLO® uses a high-agitation environment to maximize contact between the contaminated wastewater and the chemicals/microsand, a new protocol was developed, in which excess metal ion solution was continuously stirred in a large beaker, reagent was added, and triplicate samples were taken periodically for analysis. Three different metal ion concentrations and two different reagent concentrations were chosen. The metal concentrations ranged from the highest concentration seen at any of the participating shipyards in the last two years to five times the maximum concentration seen at any participating shipyard. The reagent concentrations were 0.005g/L and 0.05g/L. The lower reagent concentration was chosen to help evaluate the loading capacities that would be reached in the different copper ion solutions[1], while the higher reagent concentration was chosen to evaluate the length of time that would be needed and/or the number of times the MOP-UP® reagents would have to be recycled for the metal to be taken to nondetectable levels. Samples were pulled for analysis at 10min (i.e., within the 12min residence time of a standard Actiflo® system); 20min (i.e., within the 20-24min residence time of an Actiflo® system modified with additional tankage); 40min (to simulate the MOP-UP® reagents recycled once in the added-tankage system); and 60min (to simulate the MOP-UP® reagents recycled three times.)

An example of the results obtained for zinc are shown in Table 6. As can be seen, the higher concentration readily removed the zinc within 20min, i.e., a system with an additional tank or one in which the reagents are recycled once.

	2ppm		5ppm		10ppm	
	%	mg/g	%	mg/g	%	mg/g
0.005mg						
10min	49	198	21	207	11	211
20min	64	256	26	259	13	268
40min	75	302	33	329	17	331
60min	80	320	35	355	20	401
0.05mg						
10min	98	39	> 99.9	≥ 100	87	174
20min	99	40	> 99.9	≥ 100	> 99.9	≥ 200
40min	> 99	≥ 40	> 99.9	≥ 100	> 99.9	≥ 200
60min	> 99	≥ 40	> 99.9	≥ 100	> 99.9	≥ 200

Table 6 – Metal removal kinetics

Conditions relevant to ACTIFLO®; treatment done at pH 6.0

1 Loadings depend on the relative concentrations of the metal ions and the reagents, as well as pH and the presence of other sample constituents. The reagents take up much higher loadings when very low concentrations are incubated in very heavily contaminated wastewaters than when high reagent concentrations are incubated in lightly contaminated wastewaters.

Similar results were obtained for copper. At the lower reagent concentration, the loading capacities continued to rise steadily throughout the incubation period (e.g., Fig. 2), with 200mg/g being taken up by the reagent at all initial copper concentrations within the first 10min, and 400mg/g taken at the highest copper concentration within the test period. Therefore, while low reagent concentrations can be used to remove all detectable copper economically in a single 'pass' through the

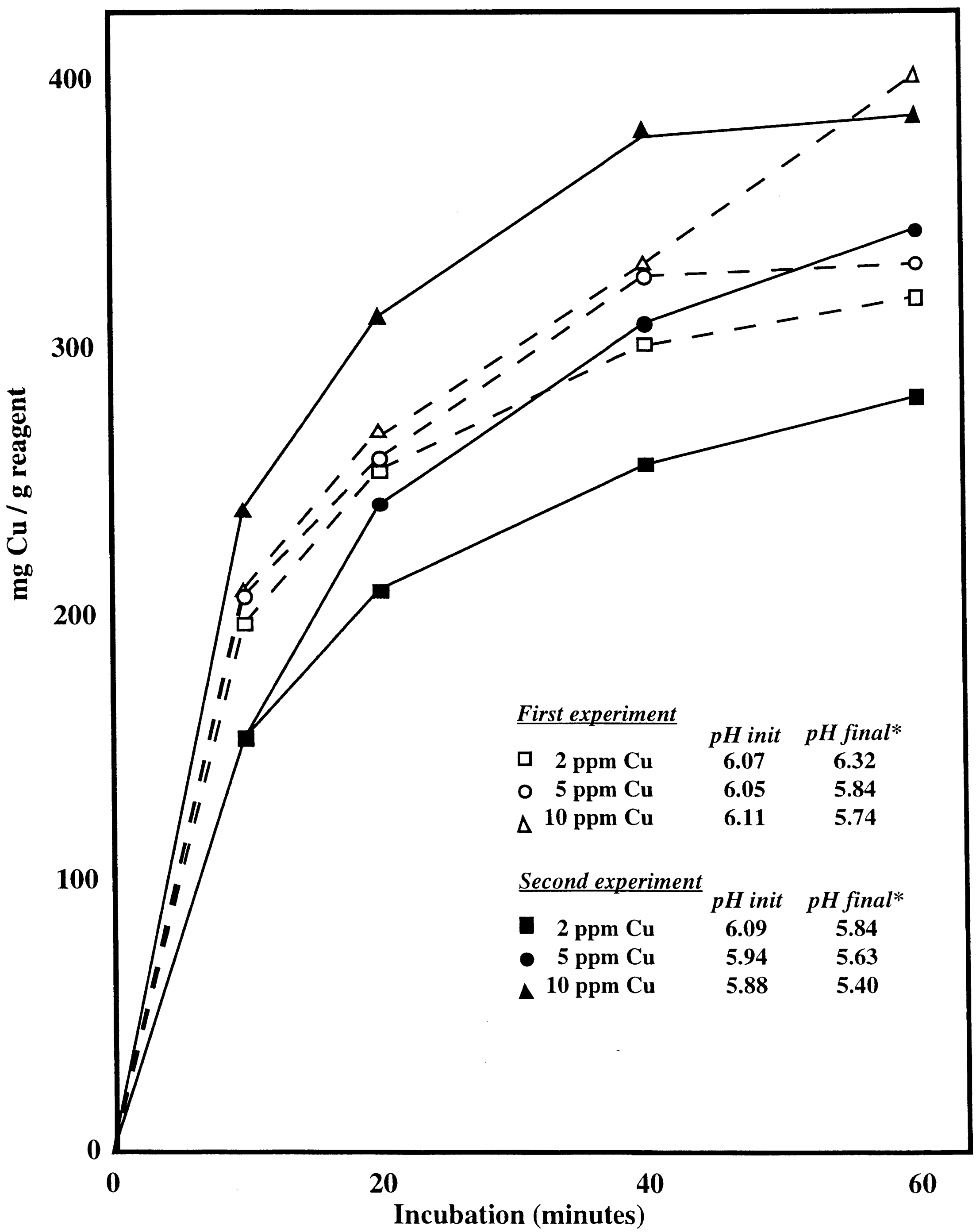

Figure 2. Kinetics tests with T10m, added to MilliQ solutions of Cu at 0.005 mg/mL

Actiflo® system, recycling the reagent once or twice can increase the metal loadings and minimize operating costs even further.

Other reagents also performed efficiently under the ACTIFLO® treatment conditions.

In analyzing these data, it must be remembered that at least four sample properties will affect the loadings that can be achieved, i.e., contact time, pH, initial metal ion : reagent concentration ratio, and sample composition. Generally speaking, the longer the contact time, the higher the pH, the higher the metal : reagent ratio, and/or the more complex the sample, the higher the loading of metal that is taken up. For example, Table 7 shows the impact of pH on Pb and Cd loadings at a set initial metal : reagent ratio; and Table 8 shows the impact of both initial Cd concentration and pH at a set reagent ratio.

pH	*mg Pb / g reagent*	*pH*	*mg Cd / g reagent*
2.11	232	2.00	321
2.95	252	2.06	323
3.47	237	2.29	323
3.60	342	2.43	324
3.65	481	2.80	362
4.23	700	5.30	384
5.80	878	7.40	548
6.51	2800	9.40	1538
7.00	3451	10.15	1746
7.56	3558	10.38	1865
9.08	3563	11.35	1924
10.43	3541		

20.7 ppm initial Pb concentration — *11.24 ppm initial Cd concentration*

0.0058 mg reagent / mL

Table 7. Impact of pH on metal loadings

Initial mM Cd	*mg Cd / g reagent pH 2.7*	*pH 6.5*	*pH 10.3*
0.005	44	97	96
0.01	63	189	186
0.03	189	310	523
0.1	281	364	1777
0.2	320	389	3574
0.4	394		4732
0.5		448	
0.6	390		4953
0.8	394		4694
1.0	391	533	4849

0.0058 mg reagent / mL

Table 8. Impact of initial metal ion concentration and pH on metal loadings

As can readily be seen in Table 7, the loadings increase as the pH rises; and as can be seen in Table 8, the loadings increase as either the initial pH or the initial metal concentration rises. It would be interesting to run the metal removal kinetics experiments while titrating the sample with an alkaline solution, to determine the actual loadings that could be achieved; and determine whether pH adjustment during stormwater treatment can be even more economical if, e.g., a small amount of crushed lime is mixed with the contaminated stormwater after the reagents are added.

4.0 Life Cycle Cost Estimates

MOP-UP® reagents are currently produced in high yield, under ambient conditions, from low-cost precursors, using very simple techniques. Attempts to scale up from very small to small production batches showed that the reagents were easier to produce in the larger lots. However, trade-off studies will be needed to optimize production efficiency while ensuring that the properties of the resulting reagents are not affected adversely. Commercial equipment can readily be used for bulk production. Therefore, the primary costs associated with scaling up will be those associated with conducting the tradeoff studies and acquiring the requisite equipment. Alternatively, contract houses that already have the appropriate equipment may be licensed to produce the reagents.

Preliminary rough cost estimates indicate MOP-UP® reagents will cost ~$0.50 - $1.00 per pound when produced in bulk.

ACTIFLO® and Memtek Microfiltration treatment systems that utilize MOP-UP® reagents are expected to offer significant cost savings over other technologies. One of the most important benefits will be the simplicity of the treatment system. Rather than an elaborate treatment train with multiple polishing steps to take metals down to extremely low residual levels by conventional technologies, a MOP-UP® based system will take the metals down to the desired levels simply by mixing the contaminated wastewater with the MOP-UP® reagents and then separating the reagents from the treated water. Significant cost savings will therefore be realized in terms of operator training, operator hours, maintenance and repair, and ordering/stockpiling the myriad parts and consumables associated with multi-stage conventional treatment systems.

Because MOP-UP® reagents have such high capacities for metals, little reagent will be consumed. Memtek will not require any chemicals to separate the reagents from the treated wastewater, while ACTIFLO® will require a modest amount of polymer coagulant. However, even when ACTIFLO® relies on more conventional chemicals for treating wastewater contaminants, the intense mixing and microsand contact leads to very efficient use of chemicals, allowing significant chemicals savings (typically 20% - 50%) compared to other clarification processes, without negative impact on effluent quality. By substituting MOP-UP® for some of these more conventional chemicals, ACTIFLO® promises to be even more attractive from the standpoint of very low costs for consumables.

Because MOP-UP® reagents have high metal capacities and because they will be separated from the treated water with very few, if any, chemical additives, the amount of sludge that will be produced will be exceptionally low. This, in turn, will minimize sludge handling, transport, and disposal costs.

Chester Engineers evaluated a variety of different approaches for treating all of the contaminants typically found in shipyard stormwater MOP-UP®. As noted above, the two most promising are based on ACTIFLO® and Memtek Microfiltration. Capital, operating, and maintenance cost estimates were developed for both the ACTIFLO® and Memtek Microfiltration treatment system concepts. The Chester Engineers studies are presented in detail in the following sections.

Biopraxis

San Diego, California

Evaluation of Shipyard Storm Water MOP-UP® Project

March 2001

CHESTER ENGINEERS

Biopraxis
San Diego, California

Evaluation of Shipyard Storm Water MOP-UP® Project

March 2001

Prepared by: Andrea Henderson
Kashi Banerjee, Ph.D.

Approved by: Charles D. Blumenschein, P.E., DEE

Project No. 5372-02

CHESTER ENGINEERS

600 Clubhouse Drive · Pittsburgh, PA 15108
412-269-5700 · Fax 412-269-5749

BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP®
PROJECT
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BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP®
PROJECT
EXECUTIVE SUMMARY

MOP-UP®, an innovative method for reducing heavy metal concentrations in complex aqueous media below parts per billion (ppb) levels, has a potential application for the treatment of storm water prior to discharge. Biopraxis contracted Chester Engineers to evaluate the potential application of its proprietary MOP-UP® reagents in conjunction with conventional and state-of-the-art water treatment equipment to develop a system capable of meeting the storm water treatment requirements faced by the shipbuilding industry.

The National Steel and Shipbuilding Company (NASSCO) site in San Diego, California, was chosen as the model site for this evaluation; however, the evaluation was to consider various flow scenarios to assess the potential application of the recommended technology to other shipbuilding sites. The regulatory requirements for storm water discharges from shipyards are becoming very stringent, utilizing toxicity limits rather than chemical concentrations or loads. NASSCO's discharge permit specifies essentially no acute toxicity at the end of the pipe.

The primary objectives of this project were:

- To assess technologies that would incorporate the proprietary MOP-UP® reagents for metals removal from the NASSCO shipyard storm water,
- To provide estimated costs for the most promising alternatives,
- To develop criteria for selection of a preferred alternative, and
- To discuss the applicability of the recommended system to storm water at other shipyards.

The parameters of concern in the shipyard storm water included metals, suspended solids, and oil and grease. Conventional and state-of the-art treatment technologies for control of these contaminants were evaluated, and nine potential treatment options were developed. Of these nine options, two conceptual designs were chosen for their superior ability to control suspended solids. The most promising options proposed for further evaluation were: 1) the MOP-UP® reagent used in combination with an ActiFlo system followed by a Mycelx product (Option 8) and 2) the MOP-UP® reagent used with a Memtek microfiltration system and an Ametek filter (Option 9). Option 8 is capable of

removing suspended solids greater than 3 microns in size, while Option 9 removes suspended solids larger than 0.2 micron in size.

In order to evaluate the cost of these technologies as they would be applied to shipyard sites, the size of the proposed systems had to be considered. Both systems were sized based on six different flow management options. Data from a Hart Crowser report dated July 2000 were used to determine design storm criteria for the San Diego area and to develop three different storm scenarios for our evaluation. The storm characteristics used to size the proposed treatment system are as follows:

- A total runoff volume of 250,000 with a peak flow of 2,000 gpm (Case 1)
- A total runoff volume of 500,000 with a peak flow of 4,000 gpm (Case 2)
- A total runoff volume of 1,000,000 with a peak flow of 8,000 gpm (Case 3)

For each of these storm scenarios, the treatment systems were sized to treat the full flow of runoff as it was generated, based on the assumption that no existing facilities were available for storage of the storm water. In addition, the same storm characteristics were evaluated under the assumption that the site would have facilities available for the storage of storm water for subsequent treatment over a period of days (Cases 4, 5, and 6).

The estimated costs for the proposed treatment systems are as follows:

	Option 8 MOP-UP® Reagent & ActiFlo System followed by Mycelx Product		**Option 9 MOP-UP® Reagent & Microfiltration System followed by Ametek Filter**	
Flow Scenarios	**Capital Cost**	**Annual Operating Cost**	**Capital Cost**	**Annual Operating Cost**
Case 1	$1,041,000	$11,800	$1,068,000	$12,700
Case 2	$1,115,000	$16,200	$1,428,000	$17,300
Case 3	$1,725,000	$20,600	$2,651,000	$30,900
Case 4	$797,000	$9,400	$430,000	$5,100
Case 5	$814,000	$10,400	$481,000	$6,600
Case 6	$846,000	$11,600	$676,000	$9,500

On the basis of our evaluations, the following conclusions were developed:

1. The design storm event for the San Diego area corresponds to a storm with 1.17 inches of rainfall in a 24-hour period with a total runoff volume of 291,000 gallons. The peak flow rate is 1,900 gpm, occurring for a duration of fifteen minutes. The base flow rate is 135 gpm.

2. Additional sampling and analyses should be conducted during storm events to determine the necessity of treating the entire volume of storm water generated, as the toxicity of the storm water discharge is expected to decrease over the duration of the storm event. Available data from other publications and reference materials indicate that the bulk of the contaminants would be present in the "first flush" of the storm. Data should be collected to determine whether after a prescribed period or set amount of flow the storm water still exhibits toxic characteristics. This information could then be used to reduce the total amount of storm water that requires treatment.
3. Two potential treatment methods for the storm water runoff from shipbuilding operations include Option 8 (MOP-UP® reagent utilized in an ActiFlo system followed by Mycelx media) and Option 9 (MOP-UP® reagent utilized with a microfiltration system followed by an Ametek filter). However, pilot plant studies are required to confirm the predicted performance of these systems with the MOP-UP® reagent as well as design parameters such as the necessary dosage rate of the reagent, retention time, and overflow rate.
4. Option 9 is expected to achieve a better effluent quality than Option 8 because of the ability of the system to remove suspended solids >0.2 micron. Extremely stringent discharge conditions at some locations may require the use of Option 9 to achieve the desired effluent quality.
5. The availability of existing storm water storage capacity will be a critical factor in choosing the most cost-effective treatment option for each shipbuilding site.
6. When applying these technologies to other sites, the size and intensity of typical storm events for the area must be carefully considered.
7. The cost estimates developed in this report compare the two treatment alternatives for different flow conditions and in consideration of available on-site storage facilities. These data can be used to develop a general assessment of the potential cost of treating the storm water under various site conditions.

Based on the above conclusions and the estimated costs presented in this report, the following criteria were developed for determining the most appropriate, cost-effective storm water treatment system for any particular shipbuilding site:

- **Performance**

At sites where the discharge conditions are extremely stringent, Option 9 would be recommended due to the superior ability of the Memtek microfiltration system to remove particles greater than 0.2 micron. At sites where the discharge limits are less stringent, the choice between the microfiltration system and the ActiFlo system is then driven by cost.

- **Cost**

The costs for the proposed treatment systems are largely driven by the availability of storm water storage capacity. Our guidelines for recommending treatment systems at sites with and without existing storage capacity are as follows:

- ***Sites With Existing Storage Capacity***

  For sites with existing storm water storage capacity (as in Cases 4, 5, and 6), the Option 9 (MOP-UP® reagent utilized with a microfiltration system followed by an Ametek filter is clearly the preferred alternative. Not only are the capital and operating costs lower than those for Option 8, but the effluent quality will be superior.

- ***Sites Without Existing Storage Capacity***

  For sites without existing storm water storage capacity, Option 9 would still be recommended for facilities where the typical storm event does not exceed a total of 250,000 gallons, as in Case 1. The costs for Options 8 and 9 are fairly comparable under these conditions. However, for sites where larger storm events are expected, Option 8 (MOP-UP® reagent utilized in an ActiFlo system followed by a Mycelx product) would become the preferred alternative because of the high capital cost of installing large storm water storage basins. The cost for an Option 8 treatment system that can handle a total volume of 500,000 gallons and a peak flow of 4,000 gpm is $1,115,000, while the Option 9 system would cost $1,428,000 (Case 2). Similarly, the cost of Option 8 sized to treat a 1,000,000-gallon storm with a peak flow of 8,000 gpm is $1,725,000, while the Option 9 treatment system increases to $2,651,000 (Case 3). Clearly, the characteristics of the storm events expected at the site must be considered when determining the most cost-effective treatment option.

BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP®
PROJECT
SECTION 1
INTRODUCTION

Biopraxis is developing MOP-UP®, a unique family of reagents capable of reducing heavy metal concentrations in complex aqueous media below parts per billion (ppb) levels. This technology has a potential application for the treatment of stormwater prior to discharge. Biopraxis contracted Chester Engineers to evaluate the potential application of its proprietary chemical reagent in conjunction with conventional and state-of-the-art water treatment equipment to develop a system capable of meeting the storm water treatment requirements faced by for the shipbuilding industry. The National Steel and Shipbuilding Company (NASSCO) site in San Diego, California, was chosen as the model site for this evaluation.

NASSCO is one of the ten largest shipbuilding firms in the United States. The shipyard is located on the San Diego Bay and encompasses 79 acres of land and 47 acres of water. The complex and highly variable nature of stormwater associated with shipbuilding operations makes compliance with current and projected regulatory requirements for stormwater runoff extremely difficult. In general, storm water runoff tends to be highly variable, with constituents and flow rates changing dramatically due to seasonal fluctuations in rainfall, temperature, and surface characteristics. Runoff water quality is typically very complex, often containing mixtures of metals, other inorganics, and a variety of organics. In addition, runoff water quality changes throughout the storm event.

Biopraxis' MOP-UP® applies a much simpler approach to storm water treatment than conventional metal pollution treatment technologies. It is capable of achieving superior performance with fewer steps, less hardware, and lower costs. MOP-UP® is based on a new family of particulate reagents that have extraordinary properties, synthesized by a proprietary new process. Because the constituents are particulate rather than soluble, reagents with otherwise incompatible chemistries can be mixed with impunity and the resulting formulation used to treat complex pollutant mixtures. For these reasons, MOP-UP® is expected to be particularly well suited for treatment of the shipyard storm water.

PROJECT OBJECTIVES

The primary objectives of this project were:

- To assess technologies that would incorporate the proprietary MOP-UP® reagents for metals removal from the NASSCO shipyard storm water,
- To provide estimated costs for the most promising alternatives,
- To develop criteria for selection of a preferred alternative, and
- To discuss the applicability of the recommended system to storm water at other shipyards.

The cost estimates were developed based on evaluating specific site conditions at the NASSCO shipyard in San Diego, as described in a report that was previously prepared for NASSCO by Hart Crowser in July 2000. Using this site as a model, additional cost estimates were prepared to present the impact that changing the flow and available on-site storage conditions would have on the costs. Based on a preliminary screening of available technologies, the most promising technologies that can meet the treatment criteria are assessed in greater detail.

MODEL SITE CONDITIONS

Physical Characteristics of the Model Area

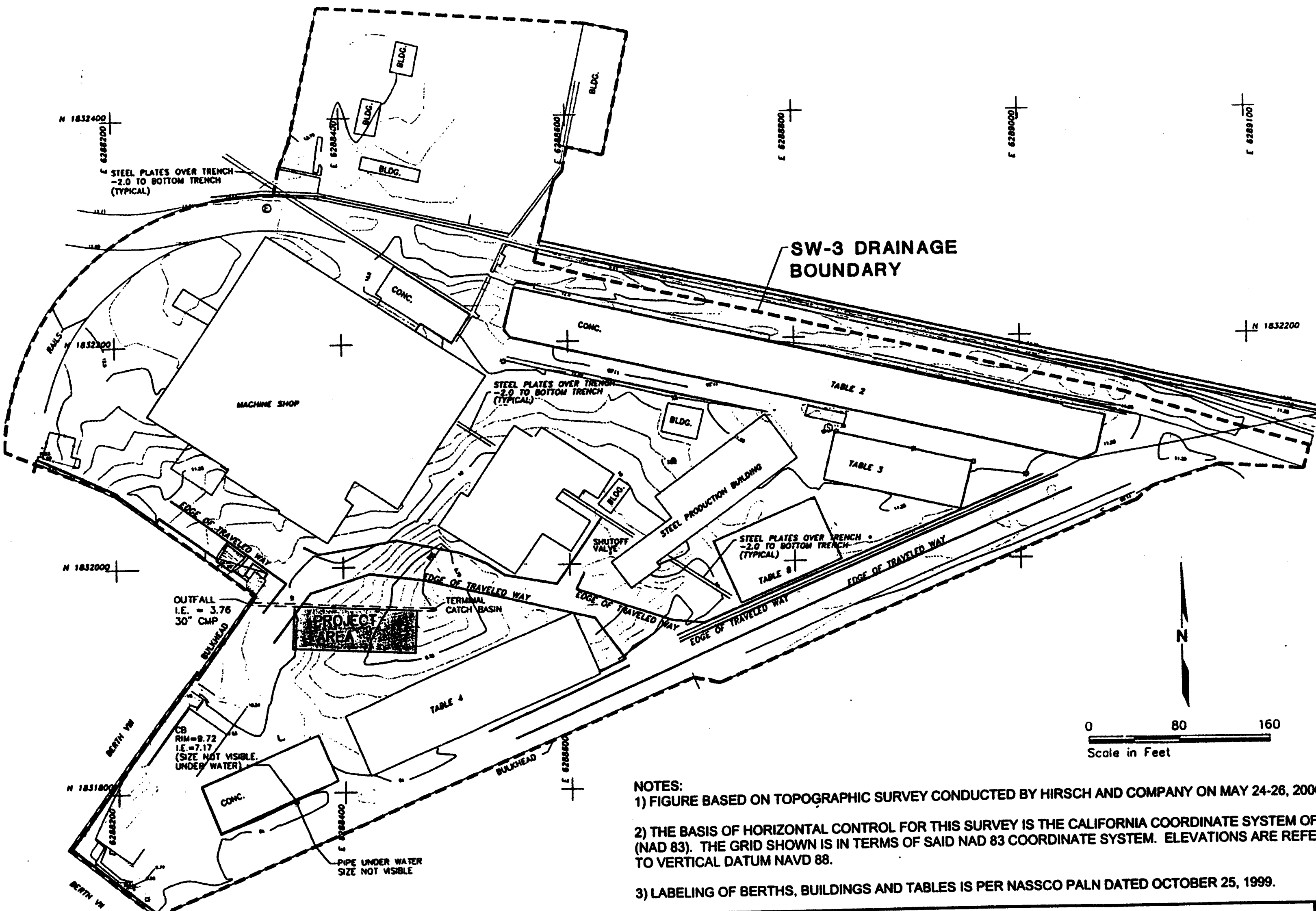
The Hart Crowser report presents storm water data and design storm characteristics for a particular area of the NASSCO shipyard, designated as SW-3. Based on meetings with NASSCO, it was decided to develop the model storm water treatment system based on treating runoff from the SW-3 area, encompassing 9.25 acres (see Figure 1-1). This area is used generally for machining and parts storage. A machine shop and metal production building are located in this area of the shipyard. This area also contains numerous flat concrete tables, which are fabrication areas for large sections of vessels. The surface of this area has fairly flat slopes and is mainly impermeable. The storm water generated in this area is expected to be typical of storm water at other facilities with similar shipbuilding operations since the rainwater becomes contaminated as it comes into contact with these industrial activities.

Regulatory Requirements

NASSCO's NPDES permit regulates the quality of storm water by using toxicity limits rather than chemical concentrations or loads, which is a typical approach seen in the permits for other shipyards and Naval facilities in San Diego. NASSCO's permit limitation for stormwater is extremely stringent and specifies essentially no acute toxicity at the end of the pipe. The permit includes the following specific requirements:

- Storm water discharges shall produce greater than 70 percent survival of laboratory test species 90 percent of the time in acute effluent bioassay tests.
- Storm water discharges shall produce greater than 90 percent survival of laboratory test species 50 percent of the time in acute bioassay tests.
- The discharge of the first flush (defined as the first 0.25 inch of rainfall) of stormwater from high risk areas shall be terminated (diverted to sanitary sewer) to reduce the discharge of pollutants into the San Diego Bay, or an alternative that achieves the same pollutant reduction in the discharge shall be implemented.

Further details of the shipyard storm water characteristics and the target effluent concentrations for the proposed treatment systems are provided in the following section.



NOTES:

1) FIGURE BASED ON TOPOGRAPHIC SURVEY CONDUCTED BY HIRSCH AND COMPANY ON MAY 24-26, 2000.

2) THE BASIS OF HORIZONTAL CONTROL FOR THIS SURVEY IS THE CALIFORNIA COORDINATE SYSTEM OF 1983 (NAD 83). THE GRID SHOWN IS IN TERMS OF SAID NAD 83 COORDINATE SYSTEM. ELEVATIONS ARE REFERENCED TO VERTICAL DATUM NAVD 88.

3) LABELING OF BERTHS, BUILDINGS AND TABLES IS PER NASSCO PALN DATED OCTOBER 25, 1999.

DWN BY:	CHK'D BY:	APPR BY:			DWG NO.:
FILE NAME: usfsw-3.dsf	SCALE: As Shown	DATE: 1/9/01	CHESTER ENGINEERS	SW-3 SITE PLAN (HARTCROWSLER DWG. 7374009.DWG PLOT DATE 7/27/00)	FIGURE 1-1

BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP® PROJECT
SECTION 2
STORM WATER FLOW AND CHARACTERIZATION

DESIGN STORM

Our estimates for sizing a model treatment system for the NASSCO storm water and developing the capital costs are based on the design storm conditions found in the report prepared by Hart Crowser for NASSCO in July 2000. It was assumed that the methodology used by Hart Crowser for determining the design storm and the calculated peak flow rate were accurate.

As indicated earlier, area designated as SW-3 in the Hart Crowser report was selected for our evaluation. The Santa Barbara Urban Hydrograph (SBUH) Method was used by Hart Crowser to determine the design storm conditions. Based on this, the design peak flow for area SW-3 is 4.28 cubic feet per second (cfs) or 1900 gallons per minute (gpm), and lasts for a duration of 15 minutes. The design storm consists of 1.17 inches of rainfall in a 24-hour period. The total volume of runoff generated by this storm event is 291,045 gallons. As can be seen from the SBUH, the base flow is approximately 0.3 cfs or 135 gpm (see the hydrograph included as Figure 2-1 at the end of this section).

Using the Hart Crowser data, we based our model treatment system on two criteria: 1) the total volume of water generated by the storm event and 2) the peak flow rate during the storm. By using these criteria, we have assumed that the system will collect 100 percent of the design storm runoff. The purpose of this assumption is to minimize the potential for events that would result in an exceedance of the permit conditions. However, storm events could occur that would exceed the design storm both in intensity and in total precipitation, which could overwhelm the treatment system. All of these criteria drive the decision-making on the applicability of treatment systems. Some systems can handle higher flow rates and fluctuating flows within design conditions better than other systems. For some systems, it may not be practical to design for the peak flow; therefore, storage of some portion of the storm event for treatment at a later time may be required.

Another important consideration in determining appropriate storm water management options is the variability of the water quality over time. The quality of the storm water generated within the first portion of a rainfall event typically exhibits higher levels of contaminants and possible toxicity as compared to the storm water later in an event. This is because the water initially comes in contact with and washes away particulate contaminants on the surfaces of rooftops, materials stored outdoors, and paved areas within the industrial facility. The U.S. EPA recognizes this variation in storm water quality by the more stringent requirements frequently placed on the "first flush" of a rainfall event. Storm water discharge permit applications generally include a requirement for grab sampling of the "first flush" followed by composite sampling throughout the storm event. Because the water quality improves during the duration of a storm, additional sampling and analysis should be conducted at the NASSCO site during storm events to determine the necessity of treating the entire volume of water generated by the storm. If the toxicity decreases sufficiently during the rainfall event, collection and/or treatment of the total volume generated may not be necessary. The extent of variation in storm water quality therefore could be a significant factor in the selection and sizing of a treatment system.

STORM WATER FLOW SOURCES

As mentioned previously, the total area of the NASSCO shipyard is 79 acres. Using the design storm conditions of 1.17 inches of rainfall over a 24-hour period, the total volume of runoff per storm event was estimated to be 2.5 million gallons for the entire shipyard. The NASSCO shipyard site contains nine storm water outfalls. A brief description of each outfall follows. Information about the various storm water outfalls was obtained from a report prepared for NASSCO by CH2MHILL in March 1997.

Storm Water Outfall No. 1

SW-1 is a surface outfall with no tributary catch basins. All storm runoff is conveyed as sheet flow to a drainage swale along the NASSCO property line. Potential sources of storm water pollution within the drainage area of this outfall include roadways, a small portion of the plate storage area, and roof drainage from the adjacent property's warehouse.

Storm Water Outfall No. 2

SW-2 has four tributary catch basins. A steel plate covers two of the catch basins. A plate storage area, primer line, hazardous waste storage yard, and coating storage locker are located in this area of the shipyard. The area also includes an enclosed building where rust is blasted off of metal plates prior to painting.

Storm Water Outfall No. 3

SW-3 has one tributary catch basin. This area includes a plating shop, electric shop, machine shop, miscellaneous outdoor storage areas, roadways, and yard utility trenches.

Storm Water Outfall No. 4

SW-4 has three catch basins and a trench system to collect storm water. A diversion system collects the first flush from the area. This drainage area includes a one-block area that is used for the construction of new shipbuilding components. Materials contained in this area include paints, oil, and grease.

Storm Water Outfall No. 5

SW-5 has two tributary catch basins. The drainage area includes a sheet metal shop, electrical shop, metal storage areas, and the northeastern half of Berth 1, which contains roadways and some material storage.

Storm Water Outfall No. 6

The SW-6 drainage area has no tributary catch basins other than a roof drain on Building 7. The drainage area includes a label shop, various material storage areas, and dock roadways.

Storm Water Outfall No. 7

SW-7 has one tributary catch basin. Sources within the drainage area to this outfall include an electrical shop and associated storage, and Berths 3 and 4, which contain roadways and various material storage areas.

Storm Water Outfall No. 8

SW-8 has one tributary catch basin, which has a control valve kept closed at all times. The only source area within the drainage area of this outfall includes an unpaved grinding and welding area.

Storm Water Outfall No. 9

SW-9 has 13 tributary catch basins that drain into a major municipal storm drain. This drain carries large volumes of urban runoff from off-site areas north of the NASSCO property. The NASSCO property areas that drain to SW-9 are major fabrication, painting, and welding areas, including numerous storage areas.

STORM WATER CHARACTERIZATION

NASSCO monitors storm water from the nine storm water outfalls described above. The data collected at NASSCO are summarized on Table 2.1. This table presents the average, minimum, and maximum water quality from various storm events both for the entire site and for the SW-3 drainage area considered in this report. For the purposes of this report, we have assumed that the treatment system will be required to control TSS, O&G, and dissolved metals in order to comply with the NPDES permit requirements. TSS and O&G would be expected to have technology-based limitations, and dissolved metals would be the likely source of acute toxicity in the storm water. Furthermore, the NPDES permit emphasizes that copper and zinc are the storm water contaminants of concern.

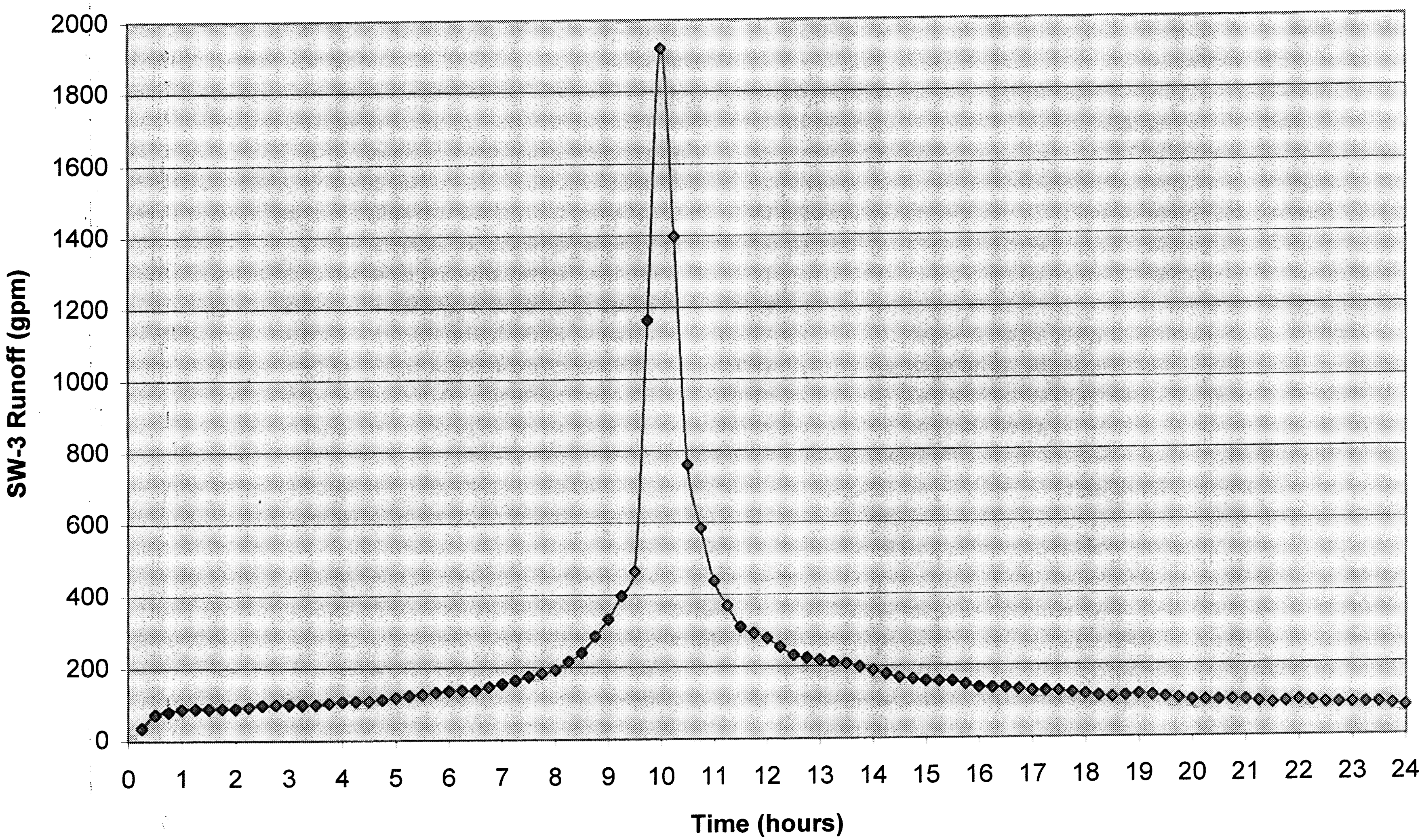
Table 2.1 – Summary of NASSCO Storm Water Data

	O&G mg/L	TPH mg/L	TSS mg/L	Cu mg/L	Pb mg/L	Ni mg/L	Zn mg/L	Acute Toxicity % survival
NASSCO Site-Wide Storm Water Quality								
Average	7	1.5	41	0.49	0.11	0.26	2.40	39
Minimum	1	0.5	1	0.03	0.00	0.01	0.26	95
Maximum	57	22	552	2.20	0.92	1.00	9.90	0
SW-3 Drainage Area Storm Water Quality								
Average	8	1.6	26	0.34	0.09	0.28	1.45	56
Minimum	2	0.5	5	0.16	0.02	0.02	0.79	68
Maximum	22	6.2	49	0.76	0.17	0.57	3.30	35

STORM WATER MANAGEMENT ALTERNATIVES

Two general options exist for treating the shipyard storm water runoff. One option would be to treat the storm water runoff during each storm event as it occurs. The other option would be to collect the storm water runoff in a storage tank and then feed it to a treatment system over time. This option could significantly reduce the size, and therefore the cost, of the system necessary to treat the storm water if the facility already has on-site storage capacity available to contain and store the storm water. Both of these options assume that the entire volume of storm water runoff would require treatment. As discussed previously in this section, additional sampling and analyses should be conducted during storm events to determine the necessity of treating the total volume of storm water generated. The impacts of the storm water management options on the selection of a treatment system are addressed in Section 6 of this report.

Figure 2-1: SW-3 Drainage Area Hydrograph for a 24-Hour Storm Event



BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP®
PROJECT
SECTION 3
TREATMENT TECHNOLOGIES FOR METALS, SUSPENDED SOLIDS, AND OIL AND GREASE

As discussed in Section 2, the parameters of concern in shipyard storm water discharge are dissolved metals, suspended solids, and oil and grease. A literature search was conducted to review the treatment processes available for removal of these constituents from water. General descriptions of the proven treatment techniques revealed through Chester Engineers' experience and the literature search are provided below. These processes are combined into potential treatment system options for shipyard storm water in Section 4 of this report.

METALS TREATMENT

The common treatment technologies that are used to remove dissolved metal ions from contaminated water include chemical precipitation, coprecipitation/adsorption with iron or aluminum salt, ion exchange, and reverse osmosis. Brief descriptions of these technologies are presented below, followed by a description of Biopraxis' innovative MOP-UP® technology for metals removal.

Chemical Precipitation

Chemical precipitation involves the removal of metallic contaminants from aqueous solutions by converting soluble, heavy metals to insoluble salts. The precipitated solids are then removed from solution by coagulation/flocculation followed by sedimentation and/or filtration. Precipitation is caused by the addition of chemical reagents that alter the physical state of the dissolved metals. The standard reagents include the following:

- Lime,
- Caustic,
- Magnesium hydroxide,
- Sodium carbonate,
- Phosphate, and
- Sulfide.

These reagents precipitate metals as hydroxides, carbonates, phosphates, and sulfides.

Figure 3-1 presents a flow diagram of a typical precipitation process for metals removal. A chemical precipitant is added to the metal-containing water in a stirred reaction vessel. The dissolved metals are converted to an insoluble form by a chemical reaction between the soluble metal and the precipitant. The suspended particles are then coagulated and flocculated, and are either settled in the batch tank or passed through a membrane filter. Granular media filtration can be used to polish any suspended metal precipitates that do not settle in the clarification tank.

Hydroxide precipitation is the prevalent type of chemical precipitation. Hydroxide precipitation normally involves the use of calcium hydroxide (lime), sodium hydroxide (caustic), or magnesium hydroxide as a precipitant to remove metals as insoluble metal hydroxides. The effluent metals concentration attained by hydroxide precipitation is dependent on the metals present, precipitant used, the reaction conditions (especially pH), and the presence of other materials that may inhibit precipitation. Effluent metal concentrations as low as 0.5 mg/L are achievable by hydroxide precipitation. (Preliminary studies indicate that copper must be below 0.2 mg/L and zinc below 0.4 mg/L for NASSCO storm water to pass the acute toxicity test. Other shipyards are facing even more stringent requirements; e.g., copper below 0.002 mg/L and zinc below 0.010 mg/L.)

Precipitation of metals as metal-carbonate is another method of removing heavy metals from water. Carbonate salt, usually sodium carbonate, is added to the water and reacts with the metals and to form insoluble metal-carbonate. Low solubility product (Ksp) values of zinc, lead, and nickel as their carbonate salts indicate that concentrations of these heavy metals can be reduced to 0.5 mg/L by treating water with sodium carbonate with proper pH control, clarification, and filtration.

Phosphate complexing of heavy metals is another alternative to hydroxide precipitation. Trisodium phosphate, dicalcium phosphate, and triple super phosphate are common sources of phosphate material used to form complexes with heavy metals. The insoluble complexed salt of heavy metal then precipitates. The heavy metal removal efficiency of this process varies between 85 and 95%; however, the efficiency of the treatment process depends on the pH condition, phosphate source, reaction time, and wastewater characteristics.

Sulfide precipitation is also an effective alternative to hydroxide precipitation for heavy metals removal. This process, with a filtration device, is capable of reducing the concentrations of heavy metals to less than 0.1 mg/L. However, the potential for hydrogen sulfide gas evolution, sulfide toxicity, and odor frequently makes the inorganic sulfide precipitation process less attractive than other alternatives.

Coprecipitation/Adsorption

Iron coprecipitation/adsorption is a well-accepted process for removal of heavy metals from contaminated water. In this process, ferric salt (e.g., ferric chloride or ferric sulfate) is added to water and forms a precipitate of iron oxyhydroxide. Freshly prepared oxides of iron are quite amorphous and have significant binding capacity for dissolved metals. The trace elements (both dissolved and suspended) are adsorbed onto and trapped within the precipitate. The settled precipitate is then separated from the water, leaving a purified effluent. The reactive hydroxyl surface sites and the high surface area (250 to 350 m^2/g) of iron oxyhydroxide make the iron coprecipitation/adsorption process very effective. Binding of a contaminant is a function of reaction pH, adsorbent (iron) concentration, adsorbate (metal) concentration, and the presence of competing cations and anions. Depending upon the pH condition, this process is also capable of removing oxyanions of metals (such as arsenate, chromate, selenite, etc.) from water. With a properly designed solid/liquid separation system, the iron coprecipitation/adsorption process is capable of removing more than 95% of dissolved metals from wastewater. This technology is less expensive than ion exchange and reverse osmosis.

Ion Exchange

Ion exchange is primarily a volume reduction process. The metal ions are removed from contaminated water and concentrated on the exchange resin. Because electroneutrality must be maintained in the system, the resin releases replacement ions back into the solution. During regeneration, the metal ions are released from the resin and are solubilized in the regenerant solution. Treatment of this concentrated waste is required prior to discharge. Ion exchange is capable of reducing the concentrations of heavy metals to non-detectable levels; however, high capital and operating costs sometimes make this process economically unfeasible.

Reverse Osmosis

Reverse osmosis (RO) is a pressure driven process that retains virtually all ions and passes water. The pressure applied exceeds the osmotic pressure of the salt solution against a semi-permeable membrane, thereby forcing pure water through the membrane and leaving salts behind. The RO process can remove more than 99% of all dissolved salts including heavy metals, such as copper, lead, nickel, zinc, etc. The operating transmembrane pressure in RO system varies between 200 and 1500 psi. Depending on the water quality and the discharge limitations, a low-volume concentrated RO reject is treated prior to disposal. RO is capable of reducing the concentrations of heavy metals to non-detectable levels; however, high capital and operating costs make this process economically unfeasible in this application.

Biopraxis' Innovative MOP-UP® Technology

The use of Biopraxis MOP-UP® reagents will eliminate the need for conventional metals removal methods. MOP-UP® reagents range in size between 3 to 5 microns for the smaller-sized reagents and between 15 to 20 microns for reagents with larger particle sizes. (These particle sizes are before metals have been adsorbed; the reagents not only grow larger as higher metal loadings are adsorbed, but also begin to stick together in clumps, making them easier to remove.) The MOP-UP® reagents adsorb dissolved metals onto the reagent matrix, thereby creating a particulate that can be removed with subsequent treatment. This process has a number of advantages over conventional metals precipitation, including:

1. a reduction of the amount of sludge generated;
2. a relatively fast reaction time;
3. elimination of the need for additional chemicals that would alter the total dissolved solids of the storm water and potentially impact toxicity tests;
4. elimination of the need to adjust the pH of the storm water, which adds costs, increases dissolved solids, and generates additional sludge; and
5. the regents have a high capacity for metals, thereby minimizing the amount of reagent consumed and simultaneously binding the majority of the dissolved metal into a stable particulate matrix.

SUSPENDED SOLIDS REMOVAL

Regardless of the approach used for treating dissolved metals, total suspended solids (TSS) must be removed from the storm water run-off. If chemical precipitation, coprecipitation/adsorption, or MOP-UP® is used to treat dissolved heavy metals, then the solids removal technology can serve the dual purpose of removing the metals as well as the TSS from the storm water.

Clarification

Gravity sedimentation is a common method for removal of metal particulate and other solids. To improve the performance of clarifiers, coagulants such as polymeric flocculants are added. These coagulant aids enhance solids removal by aiding in the formation of larger, more readily settleable floc. Two important design parameters for clarifiers include the clarification area and solids loading rate.

The clarification area is designed based on the surface loading rate, expressed as gpd/ft^2. The surface loading rate of a clarifier ranges between 700 and 1,400 gpd/ft^2. The solids loading rate ranges between 20 and 30 lb/ft^2. Typically, effluent from the clarifier contains suspended solids concentrations ranging between 20 and 30 mg/L. Usually, particle sizes greater than 50 to 75 microns are removed with conventional clarification.

ActiFlo Process

The ActiFlo process is a compact water clarification system that utilizes microsand as a seed for floc formation. The microsand provides surface area that enhances flocculation and acts as a ballast or weight. The resulting sand-ballasted floc displays improved settling characteristics, which allow for clarifier designs with high overflow rates and short retention times. These designs result in system footprints that are between 5 and 20 times smaller than conventional clarification systems of similar capacity. The use of microsand also permits the unit to perform well under dramatically changing flow rates without impacting final effluent quality. The surface overflow rate (SOR) varies from 10 gpm/ft^2 to as high as 60 gpm/ft^2. The ActiFlo system is capable of removing particle sizes greater than 3 microns.

Filtration

Filtration is a solid-liquid separation process in which the liquid passes through a porous medium or other porous material to remove as many fine suspended solids as possible. As indicated above, the effluent from a conventional clarifier contains about 20 to 30 mg/L of suspended solids that can be further reduced to less than 5 mg/L by filtration. The common types of medium used in granular bed filters are silica, sand, anthracite coal, and garnet. These may be used alone, in dual, or mixed-media configuration. The hydraulic loading rate to a standard gravity filter varies between 2 and 5 gpm/ft^2, and that for the high-rate filter is typically between 10 and 12 gpm/ft^2. Usually, particle sizes greater than 25 to 30 microns are removed by granular media filtration. The media is cleaned by backwashing at the rate of 15 to 20 gpm/ft^2 for 15 minutes. The backwash water is collected in a sludge holding tank/thickener, where solids are separated from the liquid. The separated solids are dewatered prior to off-site disposal.

Microfiltration

Microfiltration is a pressure-driven membrane process used to separate solids from liquid, based on particle size. Using an applied pressure difference across a membrane, solvent and small solute species pass through the membrane and are collected as permeate, while larger sub-micron range particles (>0.2 micron) are retained by the membrane and are recovered as concentrate.

Microfiltration results in a concentrated, suspended solid slurry that is typically discharged to dewatering equipment, such as a sludge thickener followed by a filter press. The microfiltration system includes a number of components, such as pumps and feed vessels; piping; monitoring and control units for temperature, pressure, and flow rate;

process and cleaning tanks; and membranes. Membranes are specifically designed to handle various waste stream parameters, including temperature, pH, and chemical withstanding capability. Membranes are available in several different configurations, including hollow fiber, tubular, flat plate, and spiral wound. The configuration selected for each application depends on the type of application.

OIL AND GREASE TREATMENT

Oil-water mixtures may contain oil present as free oil, dispersed oil, emulsified oil, or soluble oil. Free oil is usually characterized by droplet sizes greater than 150 microns. Dispersed oil has a droplet size ranging between 20 and 150 microns. The droplet size of emulsified oil varies between 5 and 20 microns. Soluble oil is not present in the form of droplets in water, as the oil particle size is typically less than 5 microns. The following discussion presents common approaches for oil and grease removal technology.

Gravity Oil-Water Separator

The primary function of an oil-water separator, such as an API separator, is to separate free oil from contaminated water. Such gravity separators will not separate oil droplets smaller than the size of free oil, nor will they break down the emulsions. When the water containing free oil is brought to a relatively quiescent state and given sufficient time, the oil droplets will coalesce and eventually separate from the water. The separated layer of oil will float and may be skimmed off. Usually, gravity separators are designed by following the criteria specified in the API design manual on Disposal of Refinery Wastes. A significant reduction (more than 95 percent) of free oil can be achieved within one hour, and no appreciable improvement in oil removal results after two hours of detention time.

Dissolved Air Flotation Separator

Dissolved Air Flotation (DAF) devices utilize the gravity separation concept for the removal of oil and grease from contaminated water, but are more effective than API separators in removing dispersed oil mixtures because the buoyancy differential is enhanced by inducing small air bubbles. Coagulant aids, such as iron or aluminum salts, activated silica, polyelectrolytes, etc., are added to promote agglomeration of the oil-bearing matter into large floc that is more easily removed. Emulsified oil is treated by breaking the emulsion through physical/chemical processes and sending the oil-water mixture to a DAF unit for phase separation. A properly designed DAF device is effective in producing an effluent containing between 10 and 15 mg/L of total oil and grease.

Polishing Techniques for Oil Removal

The oil and grease removal methods discussed above are typically used for the treatment of oily wastes and will result in the removal of more than 95% of the oil present in the water. However, surface water discharge permits often contain conditions that prohibit oil sheen on the surface of the water, which may require effluent concentrations less than 2 mg/L. For this reason, polishing techniques have been developed to further remove oil as an effort to ensure the elimination of oil sheen. These devices often contain proprietary chemicals that enhance the capability of the media to remove oil. Examples of such devices include the Ametek system, which is a pressure filtration system, and "Terraguard," which is sheen control media that is infused with a Mycelx chemical compound (see Appendix A for copies of related information).

SOLIDS HANDLING TECHNOLOGIES

The following paragraphs describe the solids handling technologies that can be used to reduce the volume of sludge generated by wastewater treatment processes. Volume reduction is necessary to reduce sludge disposal costs.

Gravity Thickening

Gravity thickening is a physical liquid-solid separation technology used to concentrate the raw sludge. Sludge is fed from a primary settling tank or clarifier to a thickening tank, where gravity separates the supernatant liquid from the sludge, increasing the sludge density. The thickened sludge that collects on the bottom of the tank is pumped to additional dewatering equipment or is hauled away for disposal.

Increasing the solids content in the thickener substantially reduces capital and operating costs of the subsequent dewatering device and also reduces the hauling cost. Typically, gravity thickeners achieve sludge with 4 to 10 percent solids by weight.

Rotary Vacuum Filtration of Sludge

The rotary vacuum precoat filter consists of a perforated plate steel drum deck covered with a filter cloth. A diatomaceous earth precoat is used to prevent small, suspended particles from passing through the filter and into the center of the drum where filtrate is removed. A knife blade is used to shave filter cake from the surface of the diatomaceous earth precoat filter, preventing the filter cake from reaching a thickness that would not adhere to the filter. Rotary drum filters typically rotate between 0.25 and 6.5 revolutions per minute (RPM), depending on the concentration of suspended solids in the wastewater. Rotary vacuum filtration typically achieves sludge with 20 to 25 percent solids by weight.

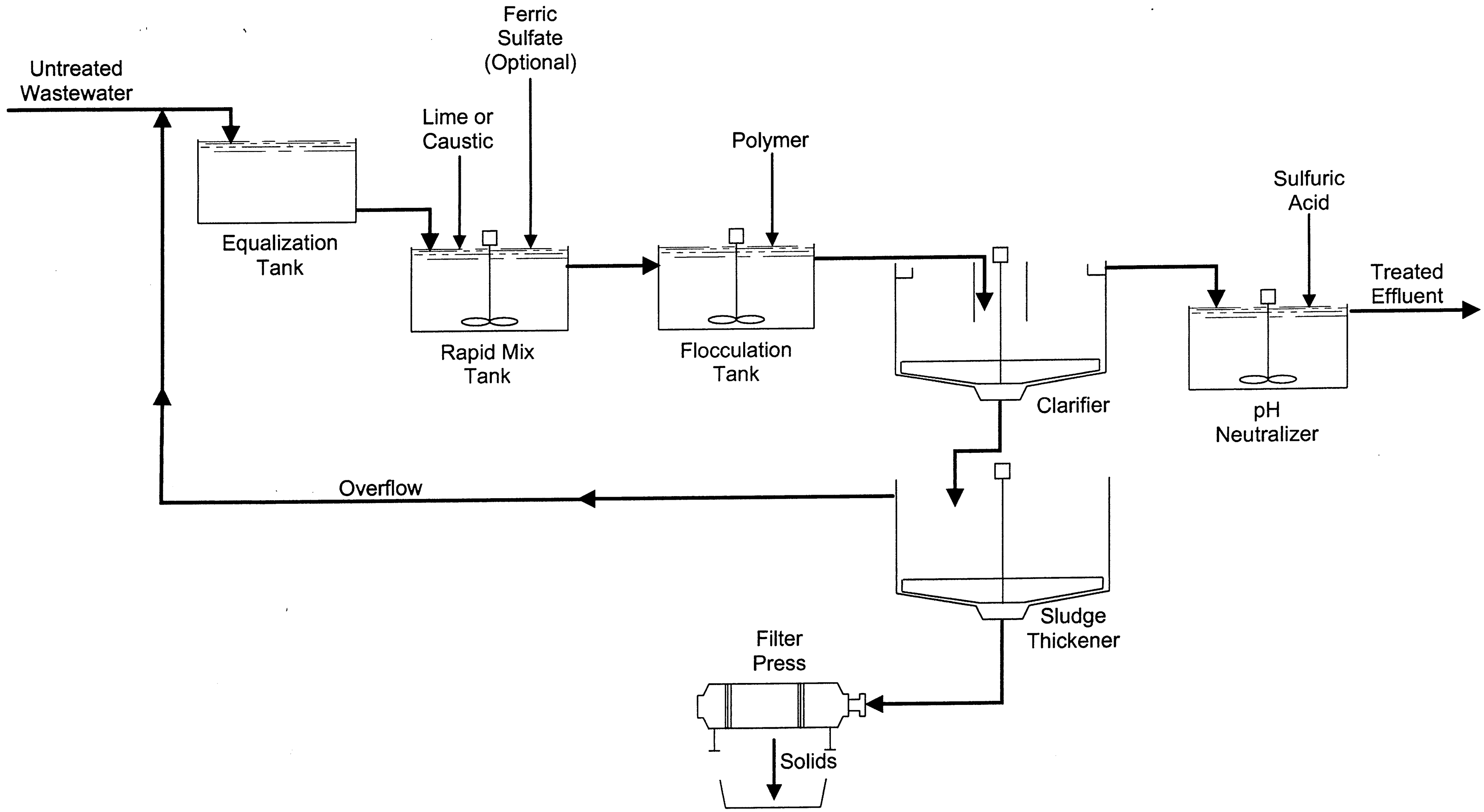
Pressure Filtration of Sludge

The plate-and-frame filter press is most commonly used for sludge dewatering. A filter press consists of a series of parallel plates pressed together by a hydraulic ram with cavities between the plates. The filter press plates are covered with a filter cloth and are concave on each side to form cavities. At the start of a cycle, a hydraulic pump clamps the plates tightly together and a feed pump forces sludge slurry into the cavities of the plates. The liquid (filtrate) escapes through the filter cloth and grooves molded into the plates and is transported by the pressure of the feed pump (typically around 100 psi) to a discharge port. The solids are retained by the cloth and remain in the cavities. This process continues until the cavities are packed with sludge solids. An air blow-down manifold is used on some units at the end of the filtration cycle to drain remaining liquid from the system, thereby improving sludge dryness and aiding in the release of the cake. The pressure is then released and the plates are separated.

The sludge solids or cake is loosened from the cavities and falls into a hopper or drum. A plate filter press can produce a sludge cake with a dryness of approximately 25 to 55 percent solids for metal hydroxide sludge.

Centrifugation of Sludge

This sludge dewatering device collects wet sludge in a cone-shaped drum. The drum is rotated to generate centrifugal forces to concentrate solids to the walls of the drum. These solids are continually removed from the centrifuge by an auger, screw conveyor, or similar device. Centrifugation dewaters sludge, reducing the volume and creating a semi-solid cake. Centrifugation of sludge can typically achieve a sludge of 20 to 35 percent solids.



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cpsmr	None	1/9/01

DWG NO.: Figure 3-1

Process Flow Diagram of a Typical Chemical Precipitation System for Metals Removal

CHESTER ENGINEERS

DWN BY: JS | CHK'D BY: | APPR BY:

BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP®
PROJECT
SECTION 4
TREATMENT ALTERNATIVES

As discussed in the Introduction of this report, a primary objective of this project was to develop treatment alternatives that would incorporate Biopraxis' proprietary MOP-UP® reagents for metals removal from shipyard storm water, using NASSCO as a model site. MOP-UP® reagents can reduce residual concentrations of dissolved heavy metals in the contaminated water to ppb levels. The reagents can be added into a completely mixed reactor system, a fixed bed system, or a fluidized bed system. Because the reagents are not soluble, they can be utilized with other chemical processes to treat complex pollutant mixtures. Utilizing the unit processes described in Section 3, the following treatment options were developed, incorporating the MOP-UP® reagent to enhance metals removal. Section 5 presents an evaluation of these alternatives.

OPTION 1. CONTACT TANK AND DAF UNIT FOLLOWED BY DUAL MEDIA FILTER

Storm water will flow to a contact tank where the MOP-UP® reagent will be added. The water will then be pumped to a DAF unit. In this unit, free oils will be separated from the treated water and heavy solids, and the oily scum will float at the top. If the storm water contains emulsified oil, addition of an emulsion breaking chemical will be required prior to the DAF unit. The fine particles of the exhausted reagents will be removed at the DAF unit with the floating scum. The separated oily waste will be transferred to a storage tank prior to off-site disposal.

A DAF system with an average bubble size of 75 microns is capable of removing about 65 to 80% of the oil present in the storm water. The treated water from the DAF unit will be filtered through a dual media filtration unit prior to discharge. It is expected that the particles greater than 25 to 30 microns in size will be removed in this process. Oil and grease removal is expected to be in the range of 90%, with an effluent of less than 5.0 mg/L oil and grease.

Literature search information and our experience indicate that a properly designed dual media filter with an average hydraulic loading rate of 4 gpm/ft^2 generates an effluent containing between 2 and 5 mg/L of suspended solids. Typically, a dual media filter removes more than 95% of particles greater than 30 microns in size. It is expected that the treated water will contain suspended solids ranging between 2 and 5 mg/L.

The filter backwash will be collected in a sludge holding tank where solids/liquid separation will occur. The solids will be combined with solids from the bottom of the DAF for dewatering prior to off-site disposal.

OPTION 2. CONTACT/SETTLING TANK FOLLOWED BY DUAL MEDIA FILTER

In this configuration, storm water will be pumped to a contact tank where MOP-UP® reagents will be added. The contact tank will be equipped with a baffle and will be designed in such a way that a portion of this tank could be used as a solids settling chamber. Floating free oil will be skimmed off the top of the settling chamber. The clarified effluent from this tank will be passed through a dual media filter prior to discharge. This process should be capable of removing particles greater than 25 to 30 microns. Oil and grease removal is expected to be in the range of 90%, with an effluent of less than 5 mg/L oil and grease. The filter backwash will be collected in a sludge holding tank where solids/liquid separation will occur. The solids from the contact tank as well as from the sludge holding tank will be dewatered prior to off-site disposal.

OPTION 3. CONTACT TANK FOLLOWED BY CENTRIFUGE

As described in the previous options, MOP-UP® reagents will be added to the contact tank. After the reaction, suspended solids present in the storm water as well as the exhausted MOP-UP® reagents will be separated from the water using a centrifuge. A properly designed centrifuge is expected to produce clear water containing between 10 to 15 mg/L of suspended solids. Usually, a centrifuge removes more than 95% of particles larger than 500 microns. A separate oil removal system will be required to remove oil from the centrate prior to discharge.

OPTION 4. CONTACT TANK FOLLOWED BY HYDROCYCLONE

As described above, reagents will be mixed with storm water in the contact tank. The resultant mixture will then be pumped into a hydrocyclone, where solid/liquid separation will take place. It is anticipated that this treatment system will remove particles greater than 100 microns in size. The water quality produced by the hydrocyclone is expected to be worse than that produced by a dual media filter. A separate oil removal system will be required to remove oil from the hydrocyclone effluent.

OPTION 5. DAF FOLLOWED BY HIGH RATE FILTER

Using a DAF unit, oil will be removed from the storm water and hauled away for off-site disposal. The clarified effluent will then flow through a high rate filter containing a mixture of the MOP-UP® reagent and filter media. The filter will be operated at a hydraulic loading rate of 10 to 12 gpm/ft^2. Filter backwash will be collected in a sludge holding tank where solids/liquid separation will occur. The solids will be dewatered prior to off-site disposal along with dewatered solids from the DAF unit. When the MOP-UP® reagent is exhausted, the filter media will be separated from the reagent for reuse. The spent reagent will be disposed off site. This system is expected to remove particles greater than 100 microns in size; however, particle size removal will depend on the type of filter media used. Oil and grease removal is expected to be in the range of 85 to 90%, with an effluent oil and grease concentration of approximately 5.0 mg/L.

OPTION 6. DAF FOLLOWED BY FIXED BED MOP-UP® SYSTEM

Oil will be removed from storm water using a DAF unit. Floating oil and heavy solids will be removed from the top and bottom of the DAF. The clear water from this unit will be pumped to an adsorption column containing the MOP-UP® reagent. An inert media will be used to hold the reagent. In order to avoid excessive pressure drop within the column, the system will be operated in an upflow mode. The exhausted media from the column will be sent off-site for disposal. Oil and grease removal is expected to be in the range of 85 to 90%, with an effluent oil and grease concentration of approximately 5.0 mg/L.

OPTION 7. DAF FOLLOWED BY FLUIDIZED BED SYSTEM

This option is similar to Option 6, except that the inert media containing the MOP-UP® reagents will be in a fluidized state during the reaction. As in Option 6, the oil and grease concentration in the treated effluent is expected to be about 5.0 mg/L.

OPTION 8. CONTACT TANK FOLLOWED BY ACTIFLO SYSTEM

In this option, contaminated storm water will be mixed with the MOP-UP® reagents in a contact tank. Using an ActiFlo unit, suspended solids and the exhausted reagents will be separated from the treated water. It is anticipated that this treatment system would remove more than 99% of the particles greater than 3 microns in size. Oil and grease removal is expected to be in the range of 80 to 85%, with an effluent oil and grease concentration of approximately 5.0 mg/L. A Terraguard sheen control medium infused with Mycelx will remove the remaining oil and grease to <2 mg/L. Solids from the hydrocyclone will be dewatered prior to off-site disposal.

OPTION 9. MICROFILTRATION

A microfiltration system would be equipped with two reaction tanks and a concentration tank. Contaminated storm water will be directed to the first reaction tank, where the water will be mixed with the MOP-UP® reagents. After thorough mixing, the water will then flow to the second reaction tank. In this tank, chemical coagulants, anti-scaling agents, and other required chemicals will be added. The mixture will then pass through a microfilter where suspended solids including the MOP-UP® reagents will be separated from the water. It is anticipated that 99% of the particles larger than 0.2 microns will be removed by this treatment system. The effluent from the microfiltration unit will be fed to an Ametek filter for removal of the residual oil prior to discharge. The Ametek oil removal system contains a proprietary filtration media, known as Clerify, that is capable of holding 300% of its own weight in removed oil. Solids from the microfilter will be dewatered prior to off-site disposal.

BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP® PROJECT
SECTION 5
EVALUATION OF ALTERNATIVES

Based upon the available information, our preliminary evaluation reveals that Options 1 through 7, as presented in the previous section, will generate treated water that would contain particles smaller than 30 microns. MOP-UP® reagents are typically smaller than this, unless the reagent production process is modified. Options 1 through 7 therefore are not expected to be capable of separating the exhausted MOP-UP® reagents from the treated water. As a result, the concentrations of metals (as total metal) may not be reduced to ppb levels. While studies have shown that MOP-UP® reagents can be produced as much larger particles, the process used to modify production will add somewhat to the production costs, and the larger particles will have overall lower capacities. Therefore, detailed evaluation of these options was not pursued further.

As indicated in Section 4, a contact tank followed by an ActiFlo system (Option 8) is expected to remove more than 99% of particles greater than 3 microns in size. In other words, this option is expected to remove more than 99% of the exhausted MOP-UP® reagents. In addition, Option 9, the microfiltration system, is expected to generate treated water that would not contain more than 1% of particles larger than 0.2 microns. This option would produce an even better quality of water than Option 8. However, additional treatment to ensure effective oil and grease removal from the contaminated storm water would be required for each of these options. A more detailed evaluation of these two options is presented in this section of the report along with the design criteria for a model treatment system based on the design storm characteristics discussed in Section 2 (250,000 gallons per storm with a peak flow of 2,000 gpm).

ACTIFLO SYSTEM (OPTION 8)

Process Concept

Fundamentally, the ActiFlo process is very similar to conventional (coagulation, flocculation, and sedimentation) water treatment technology. Both ActiFlo and conventional technology use coagulants and polymeric flocculant for the aggregation of suspended materials. These materials are then subsequently removed by settling and disposed. The primary advance made in the ActiFlo process is the addition of microsand as a "seed" and ballast for the formation of high density floc. The resulting floc has a relatively high density microsand nucleus and is easily removed by settling. With these factors in mind, a brief overview of the physiochemical processes involved in conventional water treatment is beneficial in understanding the advantages of the ActiFlo process.

Conventional water clarification processes primarily involve the destabilization and subsequent removal of colloidal suspended solid materials that are not readily removed by gravitation alone. These suspended materials can be natural or synthetic organic or inorganic compounds, microorganisms, and/or viruses that typically range in size from 10^{-3} μm to 1,000 μm. In most natural systems, the stability of colloidal suspended materials is attributed to a net negative surface charge that causes individual particles to repel each other and remain in suspension. To counteract these repulsive forces, a chemical coagulant such as alum ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), poly-aluminum chloride (PACl), lime (CaO or $Ca(OH)_2$) or any other highly charged ionic chemical species is added to bring about a net reduction in the repulsive force between the suspended materials. This process results in the destabilization and/or attraction of the suspended solids to form chemical floc.

Although destabilized, the chemical floc may remain in suspension due to its extremely low mass. Removal of these particles is most easily achieved by aggregating the smaller particles together into larger, more settleable floc. Floc formation is typically accomplished by forming inter-particle polyelectrolyte bridges using chemical (flocculant aid) polymeric flocculant. This process provides larger, more settleable floc that is more readily removed by gravitational settling.

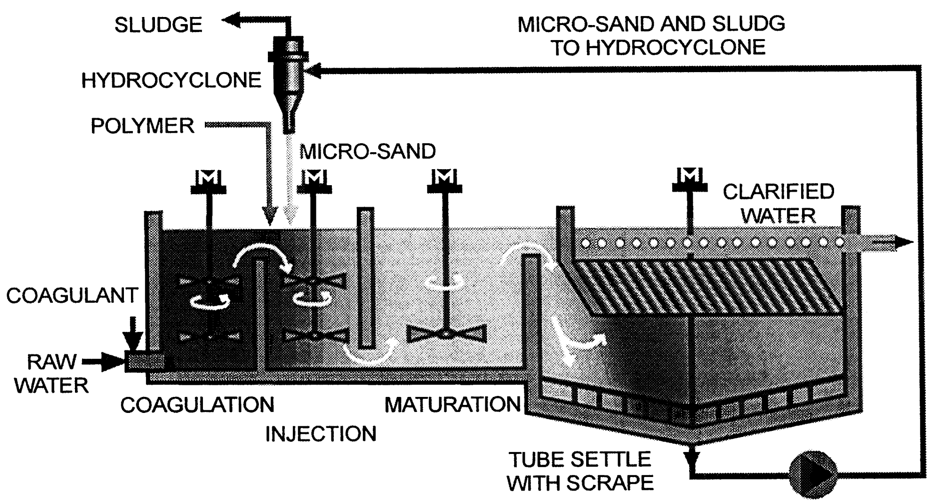
ActiFlo differs from conventional clarification in that it provides microsand as a ballasting agent in the flocculation step. The microsand serves several important roles in the ActiFlo process:

- The high surface area to volume ratio of the microsand particles serves as a "seed" for floc formation.
- The microsand and polymer "seed" promote the enmeshment of suspended materials and result in the formation of large stable floc.
- The relatively high specific gravity of the microsand (~2.65) serves as a ballast for the formation of high density floc.
- The high microsand concentration within the ActiFlo process effectively dampens the effects of changes in the raw water quality.
- The chemically inert microsand does not react with the process chemistry, allowing it to be effectively removed from chemical sludge and reused in the process.

Together, these factors provide a process that is extremely efficient in the treatment of "difficult" waters, stable with changes in raw water quality, and relatively easy to operate and optimize.

Overall, the use of microsand results in the development of chemical floc that is significantly denser and more durable than floc from conventional clarification processes. The ActiFlo floc will have a considerably higher settling velocity than conventional floc and will allow a significantly higher clarifier overflow rate. The higher overflow rate possible with ActiFlo translates directly into reduced process volume, reduced system footprint, and significant reductions in total capital cost. Additional information about the proposed ActiFlo system is included in Appendix B.

System Operation with MOP-UP® Reagent



Raw water enters the ActiFlo system in the first flash mix tank (coagulation tank). Here, chemical coagulant (alum, ferric salt, etc.) is typically added to destabilize suspended solids and colloidal matter in the influent stream. Typical hydraulic retention time in the coagulation tank is around two minutes.

The use of the Biopraxis MOP-UP® reagent presents a unique opportunity to enhance the ActiFlo process for metals removal. The concept is to add the MOP-UP® reagent in the initial reactor of the ActiFlo system. The MOP-UP® reagent will be mixed with the storm water in a flow-proportional feed system using equipment similar to that provided with the ActiFlo system for the addition of coagulants and polymers. After mixing, the reagents would have an opportunity to continue reacting with the storm water in mix and maturation tanks prior to separation in the clarification unit.

After initial mixing, the water passes into the second flash mix tank (injection tank) where flocculant aid polymer and microsand are added to initiate floc formation. These serve as a "seed" for floc formation and development in the next process step.

ActiFlo treatment continues as water passes through the underflow passage from the injection tank into the maturation tank. In the maturation tank, relatively gentler mixing provides ideal conditions for the formation of polymer bridges between the microsand and the destabilized suspended solids. This process is further augmented by the large specific surface area of the microsand, which provides enhanced opportunity for polymer bridging and enmeshment of microsand and floc already in suspension.

The fully formed ballasted flocs leave the maturation tank and enter the settling tank. Here, laminar upflow through the lamella settling zone provides rapid and effective removal of the microsand/sludge flocs. Clarified water exits the ActiFlo system via a series of collection troughs or weirs.

The ballasted floc sand-sludge-reagent mixture is collected at the bottom of the settling tank and withdrawn using a rubber-lined centrifugal slurry pump. The sand-sludge-reagent mixture is then pumped to the hydrocyclone for separation. Energy from pumping is effectively converted to centrifugal forces within the body of the hydrocyclone causing chemical sludge containing the MOP-UP® reagents to be separated from the higher density microsand. Once separated, the microsand is concentrated and discharged from the bottom of the hydrocyclone and reinjected into the ActiFlo process for reuse. The lighter density sludge is discharged out of the top of the hydrocyclone and sent for thickening or final disposal. Alternatively, the sludge may be re-injected into the mixing tank to allow the MOP-UP® reagents to adsorb higher loadings of dissolved metals. Sludge re-injection is also expected to improve flocculation and solids separation.

Performance Data from Other Studies (without MOP-UP® Reagent)

Several ActiFlo systems have been installed in pilot- as well as full-scale systems. Data collected from ActiFlo systems treating river water for use as drinking water as well as from systems treating combined sewer overflows were reviewed and evaluated. Table 5-1 summarizes the performance of the ActiFlo system.

Table 5-1
Performance Data for ActiFlo from Other Studies

Parameter	Influent Concentration (mg/L)	Effluent Concentration (mg/L)
Oil & Grease	60	<5
TSS	290	6
Copper	0.15	<0.01 – 0.05
Lead	0.025	<0.005 – 0.01
Nickel	0.36	<0.02 – 0.05
Zinc	0.27	<0.03 – 0.5

As the table illustrates, chemical treatment followed by an ActiFlo system is capable of reducing the metal concentrations to the sub-ppb level. Data collected from a pilot study that was conducted in an industrial wastewater treatment plant indicate that the ActiFlo system is capable of removing about 85 to 90% of the oil present in the wastewater. Data also reveal that the ActiFlo system, at design conditions, can remove more than 99% of particles greater than 3 microns in size.

Application to NASSCO Stormwater Treatment

A conceptual schematic of the proposed treatment system for the NASSCO storm water is shown in Figure 5-1 at the end of this section.

Raw water entering the ActiFlo system should not contain any particles greater than 5 mm in size. A bar screen and automatic backwashing screen are included in the system to remove these particles. The ActiFlo system could be placed in the ground and connected directly to a storm sewer collection system. There is very little head loss through the ActiFlo system, less than 2 feet. Depending on site conditions, pumping of storm water to the ActiFlo system would not be required.

The ActiFlo system, sized to treat the shipyard storm water flow at NASSCO site SW-3, is a one-train system with a total nominal flow of 2,000 gallons per minute. The system is sized based on an overflow rate of 50 gpm/ft^2. The maximum capacity of the system is estimated at 3,000 gallons per minute (gpm), based on an overflow rate of 60 gpm/ft^2. However, at this flow rate, it is anticipated that performance of the system would decline slightly. At the base flow of 135 gpm, the units would operate at an overflow rate of 3.4 gpm/ft^2.

The preliminary design for the standard 2,000-gpm concrete basin plant includes all of the equipment necessary for a fully functional ActiFlo system, including:

- Inlet control valves and flow meters
- A screening device to control solids greater than 3 mm
- ActiFlo process trains complete with tanks and all mechanical equipment
- Metering pumps
- Manual dry polymer preparation system, including mixing and aging tanks.
- Process instrumentation
- PLC control panel

Figure 5-2 shows a typical flow diagram for an ActiFlo Package Plant, and Figure 5-3 shows the layout of the system.

The following table summarizes the preliminary design information for the ActiFlo system. The actual size of the ActiFlo system needed at any given shipyard would be determined based on treatability study results and the chosen storm water management option, as discussed in Section 6.

Table 5-2
Design Specifications for Option 8

System Design	
Number of Trains	1
Nominal Flow per Train, gpm	2,000
Total Maximum Flow, gpm	2,000
Overall Dimensions for 2,000-gpm concrete basin plant	
Total Length, ft	26'4"
Total Width, ft	9'
Total Process Tank Height, ft	16'
ActiFlo Design Parameters @ Nominal Flow (2,000 gpm)	
Coagulation Tank HRT, min	1
Injection Tank HRT, min	1
Maturation Tank HRT, min	3
Settler Rise Rate at Nominal Flow, gpm/ft^2	50

At the design peak flow of 2,000 gpm, the available detention time in the reaction tanks of the ActiFlo system prior to settling is 5 minutes. Presently, the required detention time for the complete reaction of the Biopraxis MOP-UP® reagents is not precisely known. While the metals uptake rate of the MOP-UP® reagents has been shown to be extremely fast, it is a function of the concentrations of the reagents and the dissolved metals; *i.e.*, with a very short retention time, a higher reagent concentration will be needed to reduce the heavy metals to non-detectable levels. During this phase of evaluation, it is assumed that a 2- to 5-minute reaction time would be adequate to adsorb the dissolved metals from the contaminated storm water. An upstream mixing tank may be used to lengthen the contact time and minimize reagent consumption without any significant cost penalty. It may be possible to enhance the capacity of the MOP-UP® reagents by recycling a portion of the sludge that settles in the clarifier to the front end of the treatment system. This sludge may contain MOP-UP® reagents that have not completely reacted. We do not anticipate that sludge recycling will have a significant impact on the system performance or overall effluent quality; however, pilot testing should be conducted to determine the effectiveness of this option.

The spent reagent would be separated from the microsand in the hydrocyclone process included in the ActiFlo system. The microsand will be recycled to the process, and the spent reagent and other solids will be diverted to a 2,000-gallon sludge holding tank for further solids separation and dewatering in a 4-ft^3 filter press prior to off-site disposal.

Although we anticipate oil and grease removal to about 5 mg/L with the ActiFlo unit, we have included a Mycelx product for control of potential oil sheen. The treated effluent from the ActiFlo system will flow through a "Terraguard" sheen control media that is infused with a Mycelx chemical compound. The Mycelx product has a claimed capacity of 360 grams of oil per gram of media. The effective surface area of the media is maximized by the Mycelx chemical, enhancing the oil removal capability. The final effluent therefore is expected to contain <2 mg/L oil.

Projected Performance
Based on Design Influent Conditions

Using the available influent data, Chester calculated the expected effluent concentrations from Option 8 (MOP-UP® reagent and ActiFlo system followed by Mycelx media), based on the following assumptions:

- MOP-UP® reagents are capable of removing >99.9% of dissolved metals.
- The MOP-UP® reagent is greater than 5 microns in size.
- The ActiFlo system would remove approximately 99% of particles greater than 3 microns in size.
- The ActiFlo system would conservatively remove about 80% to 90% of the oil.
- The Mycelx media would remove any residual floating oil.

The projected performance of Option 8 is summarized in Table 5-3.

Table 5-3
Projected Performance of Option 8
(MOP-UP® Reagents and ActiFlo System followed by a Mycelx Media)

Parameter	Average Influent Concentration (mg/L)	Projected Effluent Concentration (mg/L)
Oil & Grease	8	<2.0
TSS	26	5
Copper	0.34	0.004
Lead	0.09	<0.002
Nickel	0.28	0.003
Zinc	1.45	0.016

Note: Projected effluent concentrations are calculated assuming that MOP-UP® reagent would remove 99% dissolved metals and that 90% of the MOP-UP® reagent is greater than 3 microns in size.

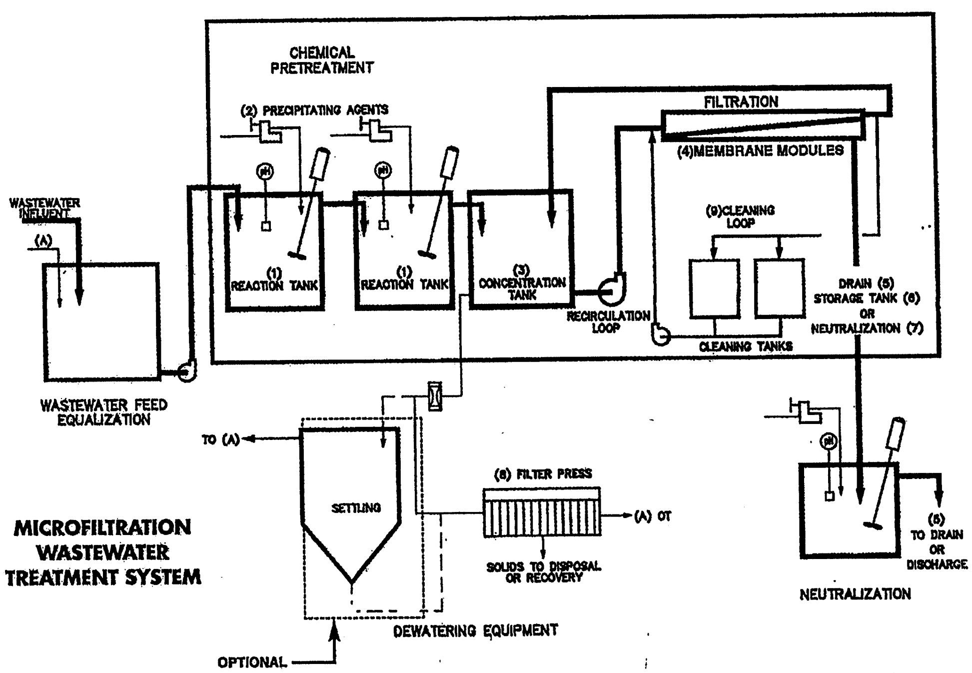
As the table illustrates, the treated effluent is expected to contain approximately 4 µg/L copper, <0.002 µg/L lead, 3 µg/L nickel, 16 µg/L zinc, and less than 2 mg/L oil. However, an on-site pilot-scale study is required to verify the projected performance data. Additionally, aquatic toxicity data are needed to determine the acceptable concentration levels.

MICROFILTRATION SYSTEM (OPTION 9)

Process Concept

A cross-flow membrane microfilter is often used in place of a conventional clarifier for a superior effluent quality. The microfilter utilizes a polymeric tubular membrane to separate precipitated particles from the wastewater. The Memtek Microfiltration system offers many advantages (see brochure included in Appendix B). The membranes are designed for rugged conditions, are compact, and are easily transportable with a small footprint. The expected membrane life is 5 to 7 years. Microfiltration results in excellent effluent quality because the membranes provide a barrier to particle passage.

The membranes of the microfiltration system are designed to act as a positive barrier to particles greater that 0.2 microns. In the operation of the microfiltration system, solids are retained on the interior of the tubular membrane and recirculated back to the feed (concentration) tank. The solids continue to recycle in this manner until the solids concentration increases to the point of restricting the flux rate across the membrane, typically in the range of 2 to 5 percent. At this point, the solids are automatically discharged from the system and transported to a sludge holding tank.



MICROFILTRATION WASTEWATER TREATMENT SYSTEM

System Operation with MOP-UP® Reagent

Following bar screens for removal of debris and grit, the storm water will be directed to two "flash mix" tanks for mixing with the MOP-UP® reagents. The mixing time will allow for the adsorption of the dissolved heavy metals onto the reagent matrix. Use of the Biopraxis MOP-UP® reagents in this system will eliminate the need for pH adjustment and the associated increases in sludge generation. (However, the pH may need to be adjusted just prior to discharge if the storm water is exceptionally acidic or basic, as is seen at some shipyard outfalls.) Following these tanks, the mixture would be permitted to continue to react in a concentration tank. A polymer may be added to enhance the flocculation of the solids formed with the MOP-UP® reagents. The wastewater would then be pumped to the Memtek Microfiltration process.

The Memtek Microfiltration process incorporates a proprietary crossflow tubular membrane that removes particulate contaminants and produces a high quality effluent. The wastewater is pumped continuously through the tubular membranes at a high fluid velocity. At the normal operating pressure, clean water is forced through the pores of the membrane while the particulate contaminants remain suspended in the recirculated stream. These particulates are recirculated back to the concentration tank. This allows for additional adsorption of heavy metals onto the MOP-UP® reagents and enhances the formation of larger solid particles. The slurry concentration is typically maintained between 2 to 5% solids. The turbulence of the recirculated slurry prevents the contaminants from accumulating on the membrane surface, thereby maintaining high and continuous filtration rates. The clean water flows by gravity from the membrane modules to the discharge.

Performance Data from Other Studies (without MOP-UP® Reagent)

Data collected from the use of microfiltration for treatment of industrial wastewater were reviewed and evaluated. After chemical precipitation, solids were separated from the liquid using a Memtek Microfiltration system. The performance data are summarized in Table 5-4.

Table 5-4
Performance Data for Microfiltration from Other Studies

Parameter	Influent Concentration (mg/L)	Effluent Concentration (mg/L)
Aluminum	157.5	0.8
Arsenic	1.2	0.05
Cadmium	28.2	0.05
Chromium	16.4	0.1
Copper	133.2	0.1
Fluoride	105.6	5.0
Gold	10.0	0.15
Iron	116.0	0.02
Lead	25.7	0.05
Mercury	15.0	0.007
Nickel	60.0	0.1
Rhodium	24.6	0.1
Silver	91.6	0.1
Tin	34.0	1.0
Zinc	340.0	0.09
TSS	975.0	<1.0

As the table illustrates, the suspended solids were reduced to less than 1 mg/L. Chemical precipitation followed by microfiltration removed more than 99.9% of copper lead, nickel, and zinc. The effluent oil and grease is expected to be less than 2.0 mg/L. The data also indicate that this treatment system consistently produced an effluent free of particles greater than 0.2 microns. The slurry concentration is typically maintained between 2 to 5% solids.

Application to NASSCO Stormwater Treatment

An assessment of the design storm conditions indicated that installation of a microfiltration system large enough to handle the high flows that would occur during the peak flow periods of a storm event would not be economical. To minimize the size of the system needed, a storage tank is required to collect the storm water runoff for treatment with the microfiltration system over a longer period of time. A conceptual schematic of the proposed system is included as Figure 5-4.

As in Option 8, raw water entering the treatment system should not contain any particles greater than 5 mm in size. A bar screen and automatic backwashing screen are included in the system to remove these particles. The storm water will flow through the screens and enter a sump. A transfer pump system, including a sump and variable speed pumps with controls, feeds the collected storm water to a storage tank and from the tank to the treatment system. Based on the hydrograph for the design storm event, a 120,000-gallon storage tank would be necessary. The storage tank would be equipped with an oil skimmer to remove floating oils.

The proposed microfiltration system is a dual-train system capable of treating flows up to 320 gpm. Within the microfiltration system, solids are retained on the interior of the tubular membrane and recirculated back to the feed (concentration) tank until the solids concentration restricts the flux rate across the membrane and the solids are automatically discharged to a sludge holding tank. Settled solids in the sludge holding tank are removed and dewatered prior to off-site disposal. Filtrate from the filter press and water from the sludge holding tank are recycled to the microfiltration system. The effluent from the microfiltration unit will be fed to an Ametek filter for removal of the residual oil prior to discharge. The Ametek oil removal system contains a proprietary filtration media known as Clerify™, which has excellent oil removal capacity. The media is capable of holding 300% of its own weight in removed oil.

The preliminary design for the microfiltration system includes the following equipment:

- Feed Pump
- Recirculation Pump
- Cleaning Pump
- Concentration Tank – 12,000 gallons
- Cleaning Tank – 600 gallons
- Water Flush Tank – 600 gallons

Figure 5-5 shows a typical process flow diagram for the Memtek Microfiltration system, and Figure 5-6 shows the layout of the system. The following table summarizes the preliminary design for the system.

Table 5-5
Memtek Microfiltration Design Criteria

Design Capacity	
Number of Trains	2
Nominal Flow per Train, GPM	160
Total Maximum Flow, GPM	320
Overall Dimensions for High-Flow Microfiltration System	
Total Length, ft	40'5"
Total Width, ft	13'6"
Total Process Height, ft	13'11 5/8"
Equipment Dimensions	
Concentration Tank, ft (Diameter x Height)	12'6" D x 13'9" H
Cleaning Tank, ft (Length x Width x Height)	6'10" L x 4' W x 3' H
Water Flush Tank, ft (Length x Width x Height)	6'10" L x 4' W x 3' H

Projected Performance
Based on Design Influent Conditions

Using the available influent data, the expected effluent concentrations from Option 9 (MOP-UP® reagents and microfiltration followed by Ametek filter) were calculated, based on the following assumptions:

- Dissolved metal removal by the MOP-UP® reagents will be at least as good as has already been demonstrated in treatability tests with shipyard storm water runoff samples, using microfiltration (0.4 micron filters).
- The MOP-UP® reagents are greater than 5 microns in size.
- Microfiltration is capable of removing about 99% of particles greater than 0.2 micron.
- The free oil removal efficiency of the Ametek filter is about 95%.

The projected performance of Option 9 is summarized in Table 5-6.

Table 5-6
Projected Performance Data of Option 9
(MOP-UP® Reagent and Microfiltration followed by Ametek Filter)

Parameter	Average Influent Concentration (mg/L)	Projected Effluent Concentration (mg/L)
Oil & Grease	8	<1.0
TSS	26	1
Copper	0.34	< 0.002
Lead	0.09	<0.002
Nickel	0.28	<0.01
Zinc	1.45	<0.01

As the table illustrates, the treated effluent is expected to contain < 2 μg/L copper, <2 μg/L lead, <10 μg/L nickel, <10 μg/L zinc, and <1 mg/L oil and grease. However, an on-site pilot-scale study is required to verify the projected performance data.

PILOT-SCALE TESTING

The performance evaluation of Options 8 and 9, as presented above, is based on limited data for the storm water quality from SW-3, as well as on information provided by the manufacturers of the proposed treatment systems and our experience with those treatment options. However, because the available data were limited and the MOP-UP® reagent has not been previously tested with proposed treatment options, pilot-scale tests are recommended to confirm the performance predictions presented in this report.

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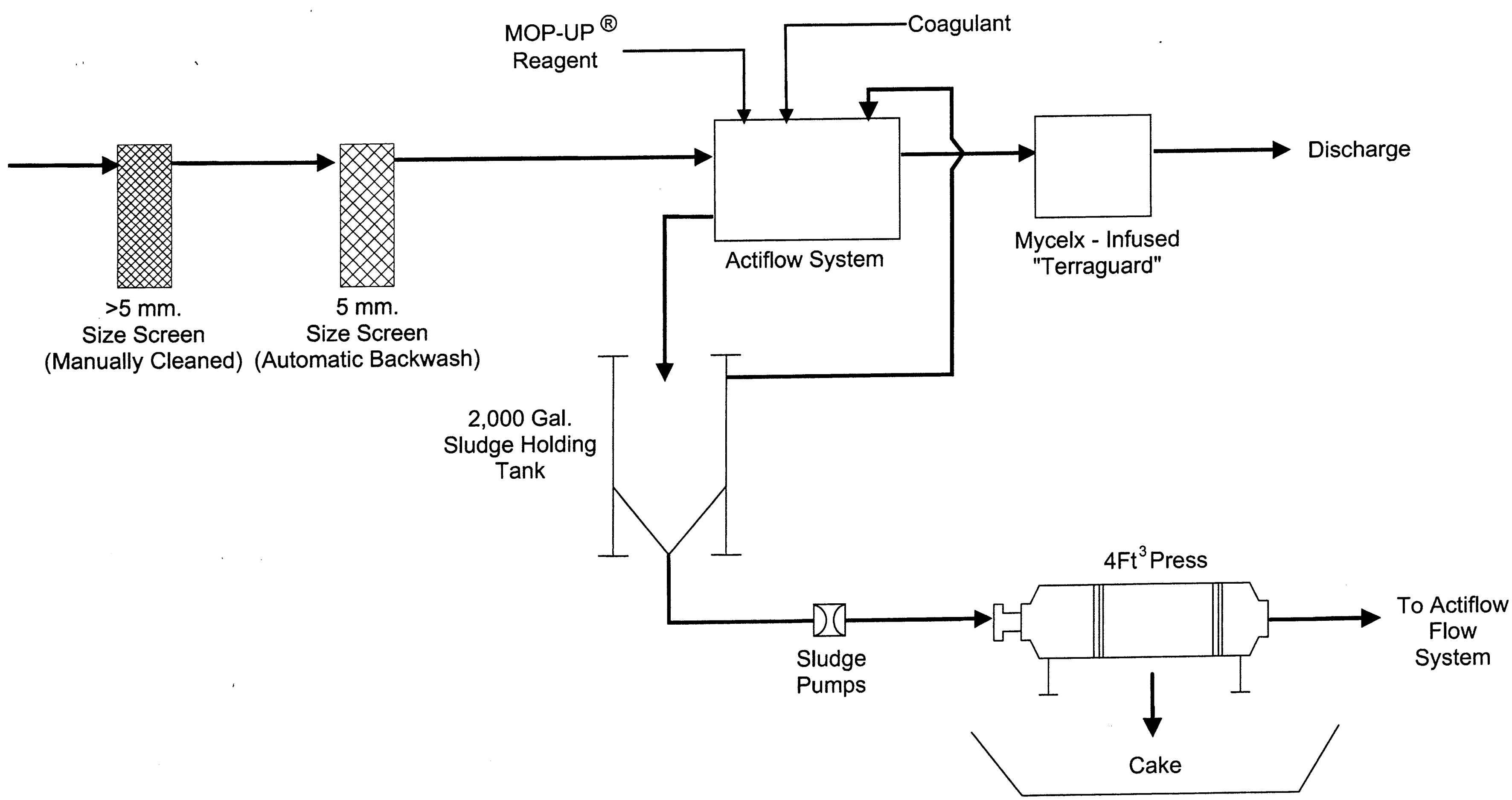

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SCALE: None	

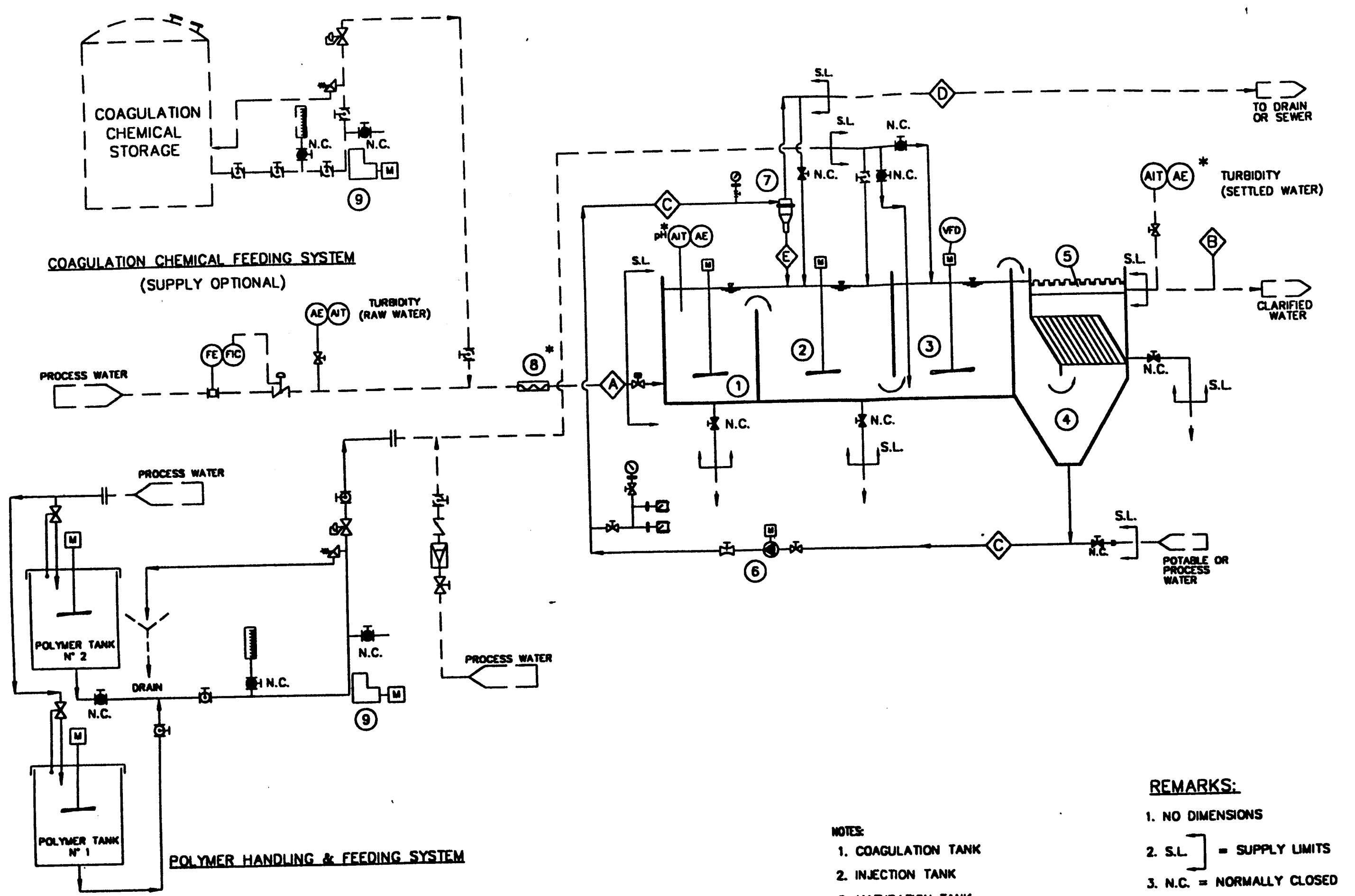
TITLE: CONCEPTUAL SCHEMATIC FOR STORMWATER TREATMENT OPTION 8 (Actiflow SYSTEM; MODEL UNIT) Flow = 2000 Gpm

CLIENT: NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

USFilter

USFOS ENGINEERING AND CONSTRUCTION
600 CLUBHOUSE DRIVE, MOON TOWNSHIP, PA
412-269-5700

PROJECT	CODE	DRAWING	SHEET	REV
		Figure 5-1	OF	



NOTES:

1. COAGULATION TANK
2. INJECTION TANK
3. MATURATION TANK
4. SETTLING TANK
5. SETTLED WATER TROUGH
6. MICROSAND RECIRCULATION PUMP
7. HYDROCYCLONE
8. STATIC IN-LINE MIXER
9. METERING PUMP

REMARKS:

1. NO DIMENSIONS
2. S.L.] = SUPPLY LIMITS
3. N.C. = NORMALLY CLOSED
4. * = INCLUDED IN SCOPE

LEGEND:

- SOLENOID VALVE
- MODULATING VALVE
- ON-OFF VALVE
- TWO POSITION VALVE
- VALVE (NON SPECIFIC)
- CHEMICAL VALVE
- PINCH VALVE

DESCRIPTION	UNITS	FLOW DIAGRAM NUMBER A	B	C	D	E
NAME		Raw water	Settled water	Recirculated microsand	Sludge waste	Injection return
STATE		Liquid	Liquid	Liquid	Liquid	Liquid
COMPOSITION		Water	Water	Sludge and Sand	Sludge	Sand
SERVICE		Continued	Continued	Continued	Continued	Continued
TEMPERATURE	°F	32–75	32–75	35–75	35–75	35–75
PRESSURE	PSI	Gravity	Gravity	10–15	Gravity	Gravity
ACP-XXX NOMINAL FLOW	GPM	REFER TO TECHNICAL DATA SHEET				

REV		DESCRIPTION	DATE	BY	APPV
3	B2	ADDED MECHANICAL MIXER IN COAGULATION TANK			TAP
2	C3	UPDATED			MLG
1	C1	REVISED SCOPE OF POLYMER HANDLING & FEED			MLG
0	N/A	PRIMARY RELEASE			

USFilter

Figure 5-2

ACTIFLO PACKAGE PLANT FLOW DIAGRAM (ACP-XXX)

NTS | 04/30/98 | 1 OF 1

650PK-010-1

REF. No. 74198010

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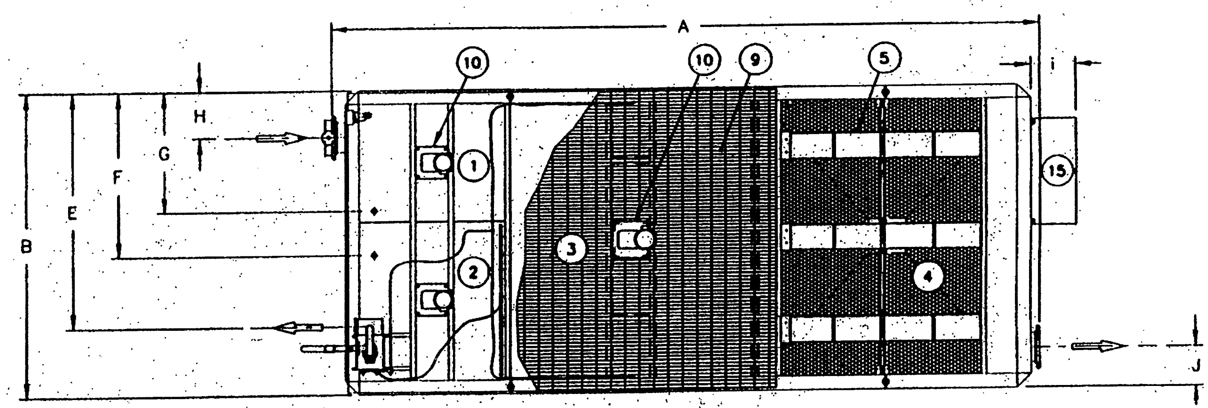
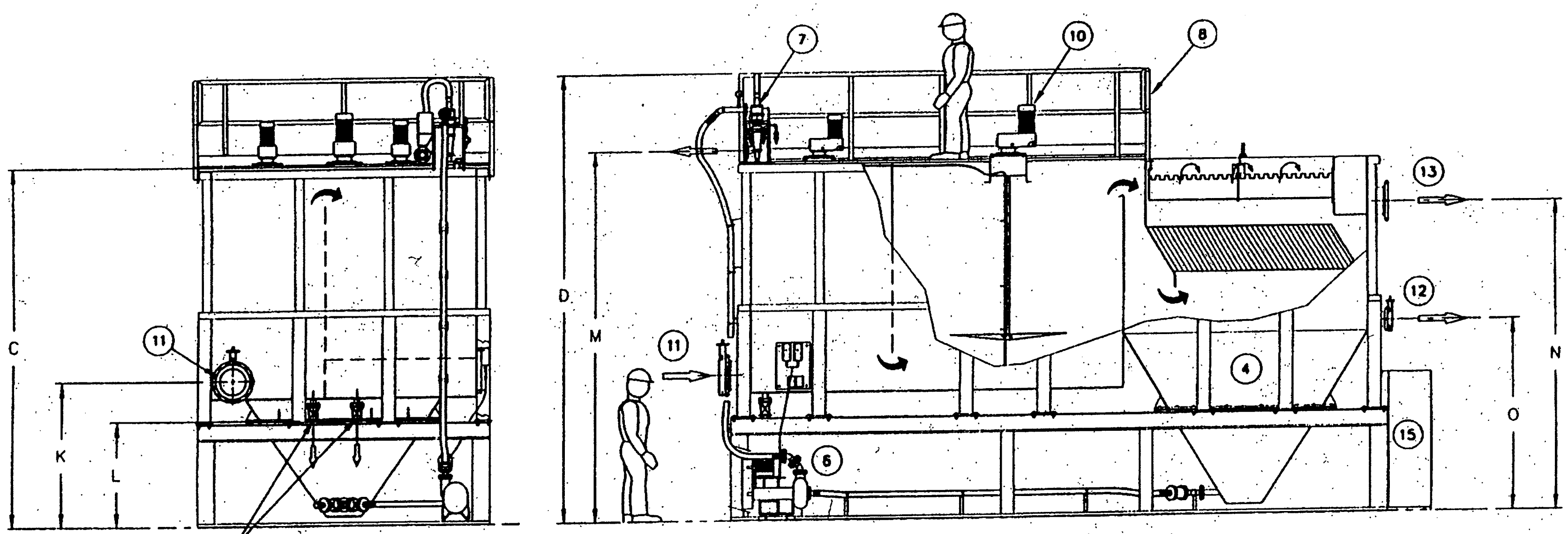
STD: 3-0600-8X11A | INTL REF: | BAR = 1" AT PLOT SCALE

1. COAGULATION TANK
2. INJECTION TANK
3. MATURATION TANK
4. SETTLING TANK
5. CLARIFIED WATER TROUGH
6. MICROSAND RECIRCULATION PUMP
7. HYDROCYCLONE
8. HANDRAIL
9. GRATING
10. MIXER
11. RAW WATER INLET
12. DRAIN
13. CLARIFIED WATER OUTLET
14. LADDER (NOT SHOWN)
15. CONTROL PANEL



PLAN VIEW

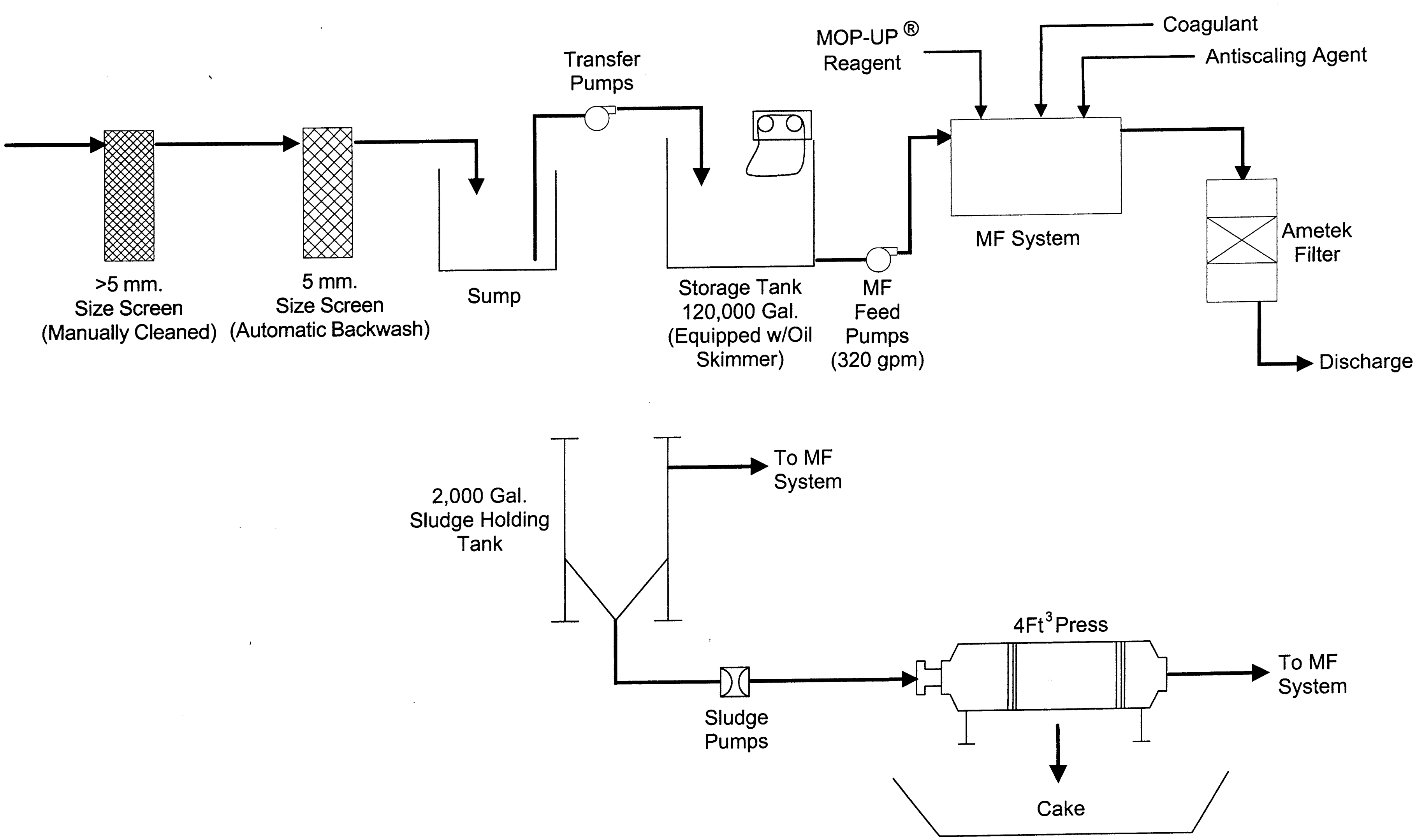


LEFT SIDE VIEW

ELEVATION

DESIGNER LAM	DATE 1-9-01	TITLE ACTIFLO PACKAGE PLANT LAYOUT
CHECKER	DATE	CLIENT
ENGINEER	DATE	
MANAGER	DATE	USFilter — USFOS ENGINEERING AND CONSTRUCTION, 600 CLUBHOUSE DRIVE, MOON TOWNSHIP, PA, 412-269-5700
FILE: USFact.dsf		PROJECT / CODE / DRAWING FIGURE 5-3 / SHEET OF / REV
SCALE: NTS		

STD: 3-0600-8X11A | INTL REF: | BAR = 1" AT PLOT SCALE



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CHECKER:	DATE:
ENGINEER: KB	DATE: 02/01/01
MANAGER:	DATE:
FILE: swt1.dsf	
SCALE: None	

TITLE: CONCEPTUAL SCHEMATIC FOR STORMWATER TREATMENT OPTION 9 (MF SYSTEM; MODEL UNIT)

CLIENT: NATIONAL STEEL AND SHIPBUILDING COMPANY SAN DIEGO, CALIFORNIA

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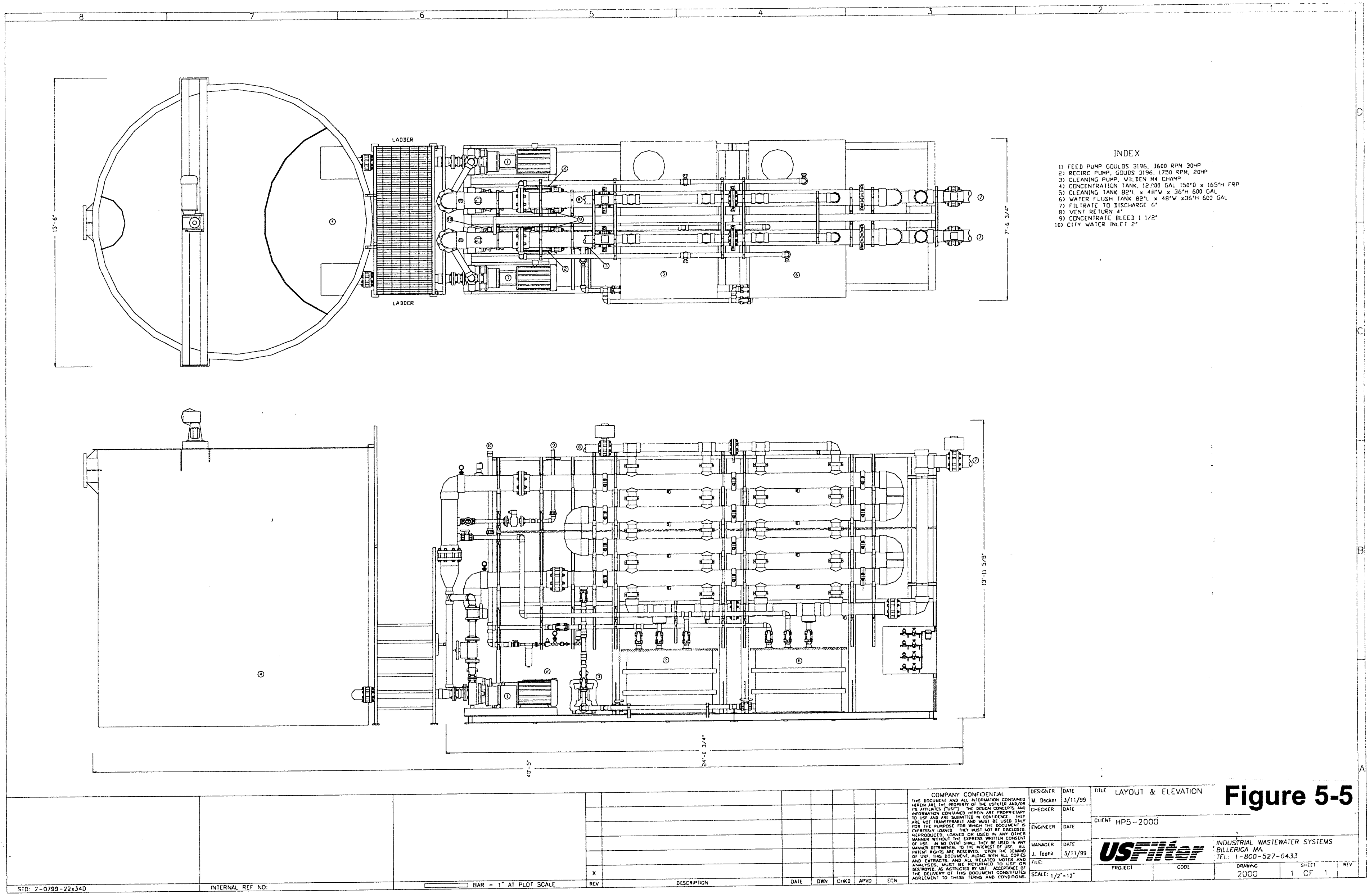
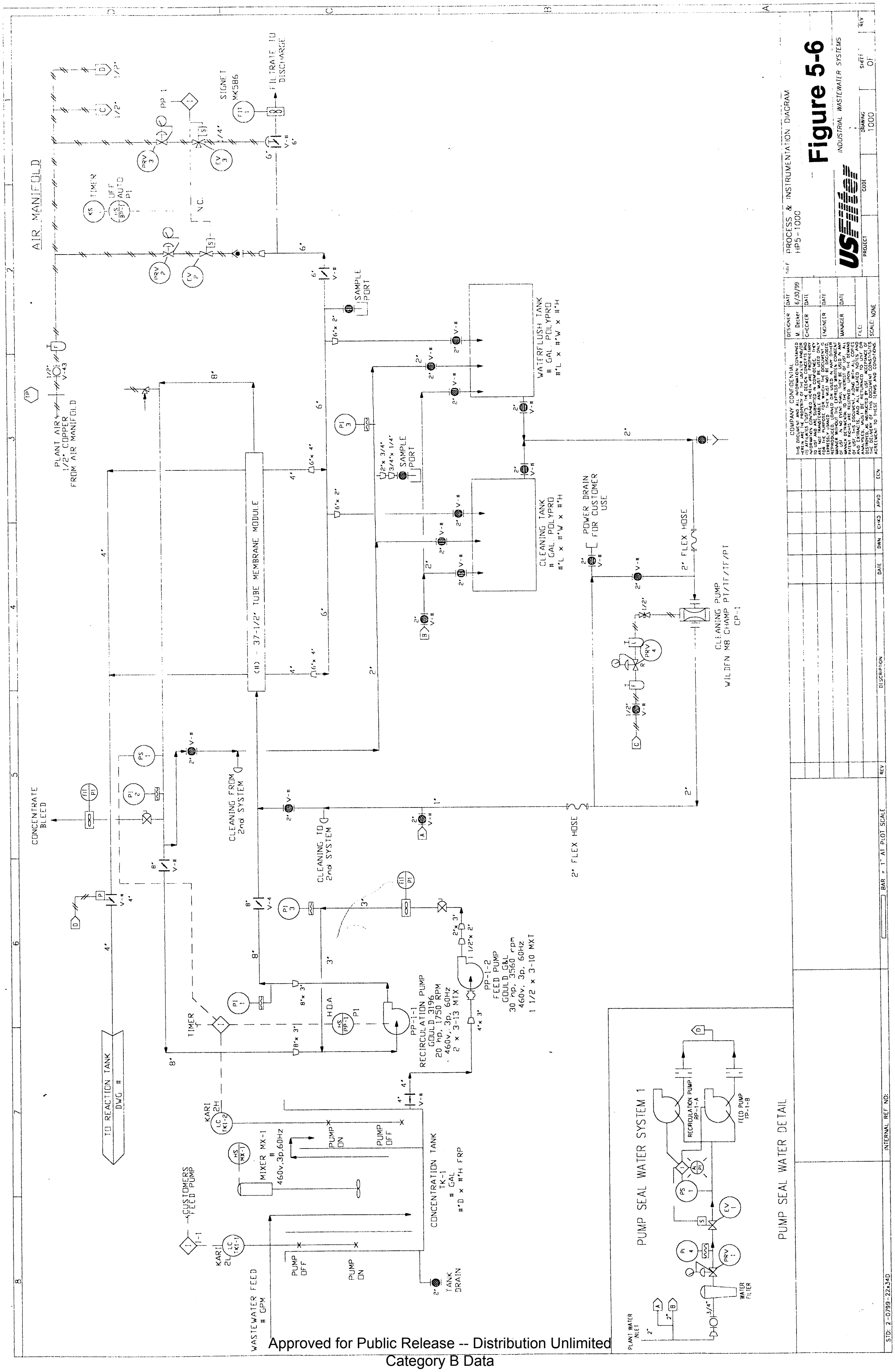
USFOS ENGINEERING AND CONSTRUCTION
600 CLUBHOUSE DRIVE, MOON TOWNSHIP, PA
412-269-5700

PROJECT	CODE	DRAWING	SHEET	REV
		Figure 5-4	OF	



INDEX
1) FEED PUMP GOULDS 3196, 3600 RPM 30HP
2) RECIRC PUMP, GOUDS 3196, 1750 RPM, 20HP
3) CLEANING PUMP, WILDEN M4 CHAMP
4) CONCENTRATION TANK, 12,000 GAL 150"D x 165"H FRP
5) CLEANING TANK 82"L x 48"W x 36"H 600 GAL
6) WATER FLUSH TANK 82"L x 48"W x36"H 600 GAL
7) FILTRATE TO DISCHARGE 6"
8) VENT RETURN 4"
9) CONCENTRATE BLEED 1 1/2"
10) CITY WATER INLET 2"
LADDER
LADDER
13'-6"
7'-6 3/4"
13'-11 5/8"
24'-0 3/4"
40'-5"
COMPANY CONFIDENTIAL
DESIGNER M. Decker DATE 3/11/99
CHECKER
ENGINEER
MANAGER J. Toohil DATE 3/11/99
SCALE: 1/2"=12"
TITLE LAYOUT & ELEVATION
CLIENT HP5-2000
USFilter
INDUSTRIAL WASTEWATER SYSTEMS
BILLERICA MA.
TEL: 1-800-527-0433
DRAWING 2000
SHEET 1 OF 1
STD: 2-0799-22x34D
INTERNAL REF NO:
BAR = 1" AT PLOT SCALE

Figure 5-5



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BIOPRAXIS
SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORM WATER MOP-UP®
PROJECT
SECTION 6
STORM WATER MANAGEMENT OPTIONS

Our evaluation of treatment options was based on treatment of storm water characteristics generated from Area SW-3 at the NASSCO shipyards. However, the scope of this project was to include consideration of the applicability of a recommended alternative to other areas of the shipyard as well as to other shipyards with similar operations. As with any treatment system design, the influent water quality and the required effluent quality will dictate the treatment technologies to be considered. Other significant factors include flow volume and variability. As discussed in Section 2 of this report, additional storm water data are required to determine the necessity of treating the entire volume of storm water runoff generated during a rainfall event. In the absence of these data, we have assumed that treatment of the entire storm water volume generated would be necessary.

To evaluate storm water management options, the model treatment systems developed as Options 8 and 9 were considered for two flow management scenarios. In the first scenario, the storm water is from a facility that has no available on-site storage for the storm water. Three storm water conditions were selected:

- Case 1- Total flow of 250,000 gallons per storm with a peak flow of 2,000 gpm (Model System),
- Case 2 – Total flow of 500,000 gallons per storm with a peak flow of 4,000 gpm, and
- Case 3 – Total flow of 1,000,000 gallons per storm with a peak flow of 8,000 gpm.

In the second scenario, the storm water is from a facility that has existing on-site storage capacity for storm water. We assumed that adequate pumping systems would be in place to transfer the stormwater to the storage facilities. Additionally, we assumed that the stored stormwater could be treated over a longer period, up to five days. Peak flow rate of the storm event would not be an issue since any flow in excess of the proposed system capacity would be retained in the storage tank. The treatment flow rate for each of the following cases would be determined by the capability of the proposed system. The same three storm water conditions were used, *i.e.*:

- Case 4 – Total flow of 250,000 gallons per storm event,

- Case 5 – Total flow of 500,000 gallons per storm event, and
- Case 6 – Total flow of 1,000,000 gallons per storm event.

The ActiFlo and Memtek microfiltration treatment options were applied to each of the flow management cases described above to further develop conceptual designs for treatment systems appropriate to storm water runoff from shipbuilding operations. This step was necessary in order to determine the potential costs for treatment systems with the various flow management options. Our conceptual designs of the treatment options for each flow management case are described below.

APPLICATION OF THE TREATMENT OPTIONS IN SIX FLOW MANAGEMENT CASES

Case 1

Case 1 considers treatment of a total flow of 250,000 gallons per storm with a peak flow of 2,000 gpm, assuming that no existing facilities are available for storm water storage on site. In this case, Option 8 (MOP-UP® reagent and ActiFlo followed by a Mycelx product) is sized to handle the peak flow of this storm as it enters the treatment system. However, the microfiltration system proposed for Option 9 (MOP-UP® and microfiltration followed by an Ametek filter) is limited to a treatment capacity of 325 gpm. Therefore, sufficient storage to contain the specified storm is required as part of the treatment system. The Option 8 system would treat the storm water as it is generated, but the Option 9 system would treat the water over approximately 13 hours.

Case 2

Case 2 considers treatment of the total flow of 500,000 gallons per storm with a peak flow of 4,000 gpm. This case assumes that no existing facilities are available for storm water storage on site. As in Case 1, Option 8 is sized to handle the peak flow of this storm as it enters the treatment system, but sufficient storage had to be included in the design of the treatment system for Option 9. The Option 8 system would treat the storm water as it is generated; however, the Option 9 system would treat the water over approximately 26 hours.

Case 3

Case 3 considers treatment of the total flow of 1,000,000 gallons per storm with a peak flow of 8,000 gpm. This case assumes that no existing facilities are available for storm water storage on site. As in Cases 1 and 2, Option 8 is sized to handle the peak flow of this storm as it enters the treatment system, but sufficient storage had to be included in the design of the treatment system for Option 9. The Option 8 system would treat the storm water as it is generated; however, the Option 9 system would treat the water over a 2-day period (approximately 52 hours).

Case 4

Case 4 assumes that the facility has the on-site storage capacity to contain and store storm water, along with adequate pumping systems to transfer the storm water to the storage facilities and from the storage facilities to the treatment system. The Case 4 storm would produce 250,000 gallons of storm water for treatment. The flow rate of the storm water runoff is not an issue since this scenario assumes that adequate pumping and storage exists for the total volume of the storm water.

In this case, the ActiFlo system specified for Option 8 would be a pre-packaged steel construction unit capable of treating 500 gpm, rather than the concrete basin plants considered in Cases 1, 2, and 3. This unit is the smallest size ActiFlo system produced. At the flow rate of 500 gpm, treatment of the storm water would occur over approximately an 8-hour period.

The influent sump and storage tank included in the design of Option 9 for Cases 1, 2, and 3 would not be required because this case assumes that the storm water storage capacity is pre-existing. In addition, because of the readily available storage, the microfiltration system was sized to treat the water over a five-day period. The resulting treatment flow through the system is 35 gpm. The smaller system capacity will significantly lower the cost.

Case 5

Case 5 also assumes that the facility has the on-site storage capacity to contain and store storm water, along with adequate pumping systems to transfer the storm water to the storage facilities and from the storage facilities to the treatment system. The Case 4 storm would produce 500,000 gallons of storm water for treatment. As in Case 4, the flow rate of the storm water runoff is not an issue since this scenario assumes that adequate pumping and storage exists for the total volume of the storm water.

In this case, the ActiFlo system specified for Option 8 would be the pre-packaged steel construction unit specified for Case 4. At the flow rate of 500 gpm, treatment of the storm water would occur over approximately a 17-hour period.

As in Case 4, the influent storage would not be required in Option 9 because this case assumes that the storm water storage capacity is pre-existing. Similarly, the microfiltration system was sized to treat the water over a five-day period; however, because of the higher storm water volume assumed in this case, the resulting treatment flow through the system is 70 gpm.

Case 6

As in Cases 4 and 5, this case assumes that the facility has the on-site storage capacity to contain and store storm water, along with adequate pumping systems to transfer the storm water to the storage facilities and from the storage facilities to the treatment system. The Case 6 storm would produce 1,000,000 gallons of storm water for treatment. Again, the flow rate of the storm water runoff is not an issue since this scenario assumes that adequate storage exists for the total volume of the storm water.

In this case, the ActiFlo system specified for Option 8 is the pre-packaged steel construction unit with the treatment capacity of 500 gpm. At this flow rate, storm water treatment would occur over approximately a 2-day period.

As in Cases 4 and 5, the influent storage would not be required in Option 9 because the storm water storage capacity is pre-existing. The microfiltration system was again sized to treat the water over a five-day period, resulting a treatment flow through the system of 140 gpm.

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EVALUATION OF SHIPYARD STORM WATER MOP-UP® PROJECT
SECTION 7
ESTIMATED COSTS

The principal criteria for selecting a preferred treatment alternative are performance and cost. Section 5 evaluated the performance of Options 8 and 9 based on the storm water quality for SW-3 at the NASSCO shipyard, and Section 6 described potential flow management options which will affect the sizing and cost of a proposed treatment system. Capital and operating costs were developed for Options 8 and 9 based on each of the six flow management cases described in Section 6, resulting in 12 sets of capital and operating costs. Those costs are summarized in Table 7-1, and the detailed cost estimates for each case are included in Appendix C.

Table 7-1
Summary of Estimated Capital and Annual Operating Costs for Options 8 and 9

Flow Scenarios	Option 8 MOP-UP® Reagent & ActiFlo System followed by Mycelx Product		Option 9 MOP-UP® Reagent & Microfiltration System followed by Ametek Filter	
	Capital Cost	**Annual Operating Cost**	**Capital Cost**	**Annual Operating Cost**
Case 1	$1,041,000	$11,800	$1,068,000	$12,700
Case 2	$1,115,000	$16,200	$1,428,000	$17,300
Case 3	$1,725,000	$20,600	$2,651,000	$30,900
Case 4	$797,000	$9,400	$430,000	$5,100
Case 5	$814,000	$10,400	$481,000	$6,600
Case 6	$846,000	$11,600	$676,000	$9,500

Note that the estimated costs provided in this report do not include the cost for the MOP-UP® reagent. The dosage and cost of this proprietary reagent will depend on the metals found at the shipyard site, their typical concentrations, and factors such as pH and temperature. (While the reagents can remove heavy metal ions such as copper to non-detectable levels at very low pH, the loading capacities are not as high. And, as with any chemical reaction, the reagent metal removal kinetics are affected by temperature, and so a higher reagent concentration may be needed at lower temperatures to achieve the same effluent quality seen at higher temperatures.) However, MOP-UP® reagents are expected to be very economical; current projections are in the range of approximately $1 per pound when produced in bulk. Since the reagents can achieve very high loadings, operating costs will be low. Pilot-scale tests are recommended to determine the required dosage rates and to confirm the predicted performance of the proposed systems.

The estimated capital costs include the cost of major equipment items and estimates for freight, installation, site preparation, electrical, piping, and a contingency. The annual operating and maintenance costs were developed based on the assumption that treatment would be required for four significant storm events (>1 inch of rainfall) per year. The O&M costs for Option 8 (ActiFlo) include the costs for treatment chemicals (excluding the MOP-UP® reagent), microsand, Mycelx media, power consumption, sludge disposal, and labor. The O&M costs for Option 9 (Microfiltration) include the costs for the Clerify filter media, power consumption, sludge disposal, and labor.

Utilizing these costs, the conclusions and recommendations presented in Section 8 present guidelines for selecting the preferred treatment system for storm water generated from shipbuilding operations, based on site-specific conditions.

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SAN DIEGO, CALIFORNIA
EVALUATION OF SHIPYARD STORMWATER MOP-UP® PROJECT
SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The technical and economic feasibility of the potential treatment options for the stormwater runoff generated at the SW-3 drainage area of the NASSCO shipyard were evaluated, and the following conclusions were developed:

1. The design storm event for the San Diego area corresponds to a storm with 1.17 inches of rainfall in a 24-hour period with a total runoff volume of 291,000 gallons. The peak flow rate is 1,900 gpm, occurring for a duration of fifteen minutes. The base flow rate is 135 gpm.

2. Additional sampling and analyses should be conducted during storm events to determine the necessity of treating the entire volume of storm water generated, as the toxicity of the storm water discharge is expected to decrease over the duration of the storm event. Available data from other publications and reference materials indicate that the bulk of the contaminants would be present in the "first flush" of the storm. Data should be collected to determine whether after a prescribed period or set amount of flow the storm water still exhibits toxic characteristics. This information could then be used to reduce the total amount of storm water that requires treatment.

3. Two potential treatment methods for the storm water runoff from shipbuilding operations include Option 8 (MOP-UP® reagent utilized in an ActiFlo system followed by Mycelx media) and Option 9 (MOP-UP® reagent utilized with a microfiltration system followed by an Ametek filter). However, pilot plant studies are required to confirm the predicted performance of these systems with the MOP-UP® reagent as well as design parameters such as the necessary dosage rate of the reagent, retention time, and overflow rate.

4. Option 9 is expected to achieve a better effluent quality than Option 8 because of the ability of the system to remove suspended solids >0.2 micron. Extremely stringent discharge conditions at some locations may require the use of Option 9 to achieve the desired effluent quality.

5. The availability of existing storm water storage capacity will be a critical factor in choosing the most cost-effective treatment option for each shipbuilding site.
6. When applying these technologies to other sites, the size and intensity of typical storm events for the area must be carefully considered.
7. The cost estimates developed in this report compare the two treatment alternatives for different flow conditions and in consideration of available on-site storage facilities. These data can be used to develop a general assessment of the potential cost of treating the storm water under various site conditions.

RECOMMENDATIONS

Based on the above conclusions and the costs presented in Section 7, the following criteria were developed for determining the most appropriate, cost-effective storm water treatment system for any particular shipbuilding site:

Performance

At sites where the discharge conditions are extremely stringent, Option 9 would be recommended due to the superior ability of the Memtek microfiltration system to remove particles greater than 0.2 micron. At sites where the discharge limits are less stringent, the choice between the microfiltration system and the ActiFlo system is then driven by cost.

Cost

As discussed in Section 7, the costs for the proposed treatment systems are largely driven by the size of the storm event and the availability of storm water storage capacity. Our guidelines for recommending treatment systems at sites with and without existing storage capacity are as follows:

Sites With Existing Storage Capacity

For sites with existing storm water storage capacity (as in Cases 4, 5, and 6), the Option 9 (MOP-UP® reagent utilized with a microfiltration system followed by an Ametek filter) is clearly the preferred alternative. Not only are the capital costs lower than those for Option 8, but the effluent quality will be superior. Operating costs will be significantly lower than those for Option 8, since the MOP-UP® reagents will be able to achieve higher loadings; less reagent will be consumed, and less sludge produced.

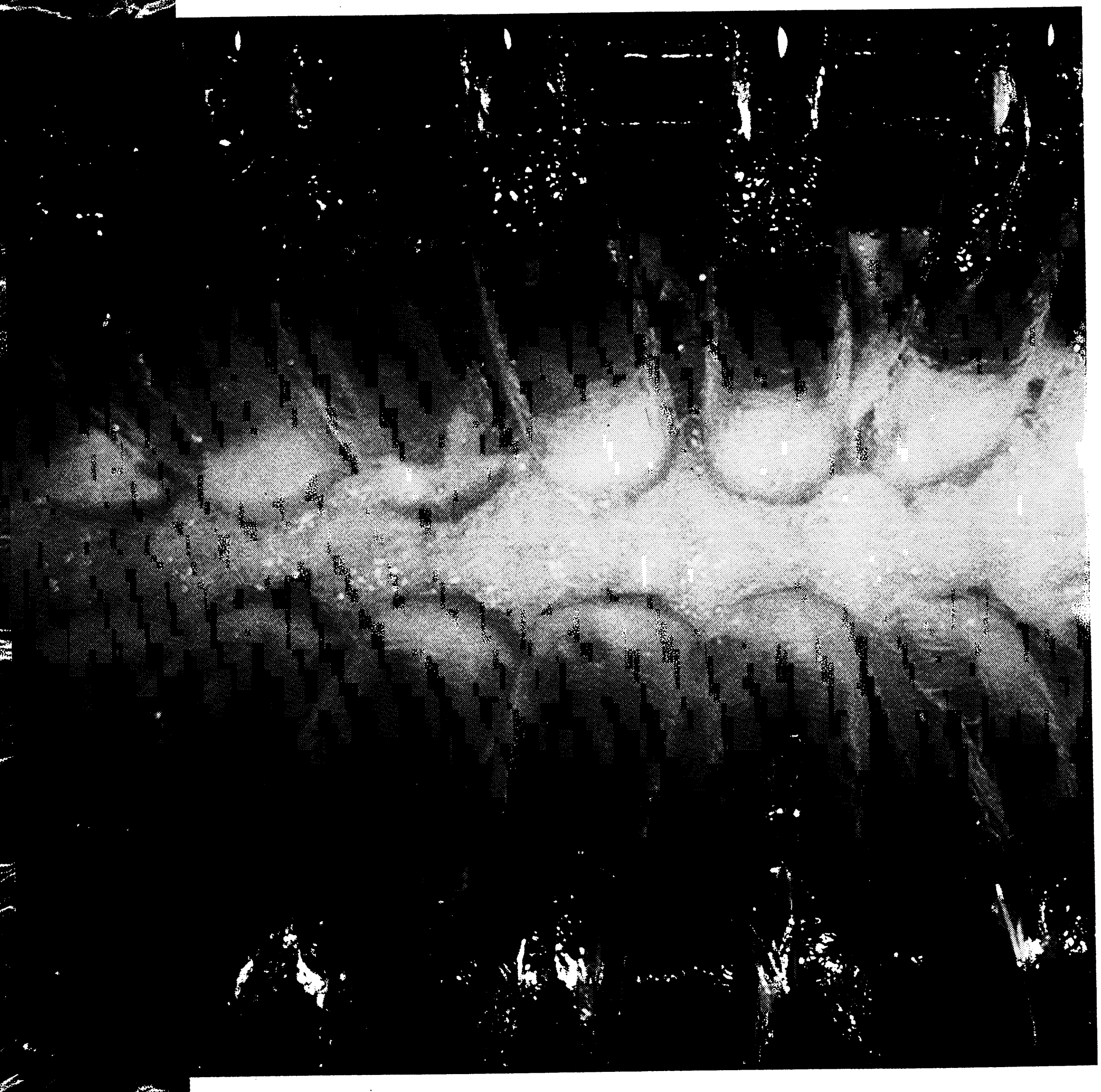
Sites Without Existing Storage Capacity

For sites without existing storm water storage capacity, Option 9 would be recommended for facilities where the typical storm event does not exceed a total of 250,000 gallons, as in Case 1. The costs for Options 8 and 9 are fairly comparable under these conditions, at $1,041,000 and $1,068,000, respectively. However, for sites where larger storm events are expected, Option 8 (MOP-UP® reagent utilized in an ActiFlo system followed by the Mycelx media) would become the preferred alternative because of the capital cost of installing large storm water storage basins. As shown in Table 7-1, the cost for an Option 8 treatment system that can handle a total volume of 500,000 gallons and a peak flow of 4,000 gpm is $1,115,000, while the Option 9 system would cost $1,428,000 (Case 5). Similarly, the cost of Option 8 sized to treat a 1,000,000-gallon storm with a peak flow of 8,000 gpm is $1,725,000, while the Option 9 treatment system increases to $2,651,000 (Case 6). Clearly, the characteristics of the storm events expected at the site must be considered when determining the most cost-effective treatment option.

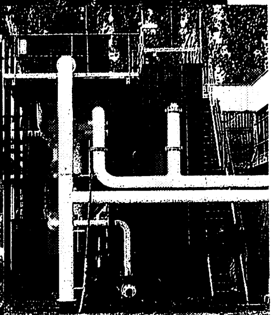
ACTIFLO®

PROCESS

SEWAGE WATER - STORM WATER

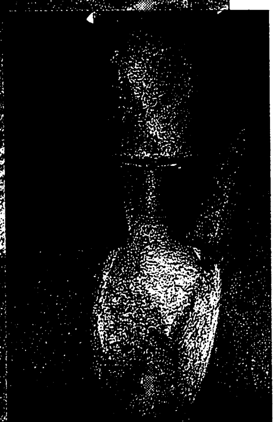


Krüger



The ACTIFLO® process in sewage treatment is a physicochemical process combining the benefits of weighted flocculation and lamella settling. It is installed immediately after the fine screening and degritting stage. Downstream of ACTIFLO®, the treated water can be discharged into the river or sent to additional biological treatment.

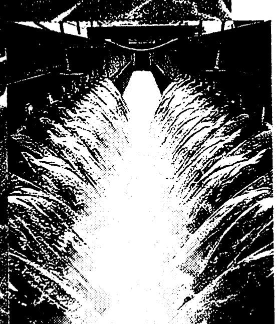
For compactness and quick start-up, ACTIFLO® is particularly well-suited for storm water peak-shaving in combined sewer systems



Following fine screening and grit removal, the raw water flows through:

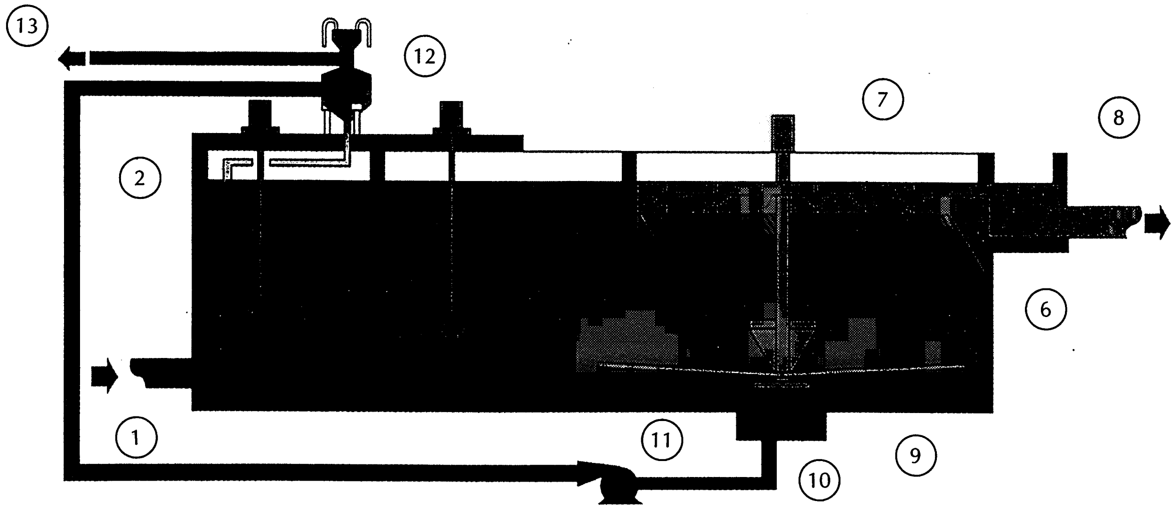
- A coagulation stage where chemical coagulant is injected;
- A flocculation stage through an injection tank and then through a maturation tank. In the injection tank (also called a flash mixing tank) the suspended solids and microsand (both conditioned by the polyelectrolyte) attach themselves to each other following induced collisions. The newly formed floc is ballasted by the dense sand. The floc thickens and matures in the maturation tank. Both tanks are fitted with dynamic mixers designed to produce the optimum velocity gradients;
- A decantation stage where the flocculated water enters the counter-current lamella settler. The treated water is then drawn of at the top of the lamella via a system of collectors to ensure an equal distribution of flow.

The sludge and microsand are precipitated at the bottom of the settler and collected by a scraper or hoppers prior to being pumped to the hydrocyclones. The hydrocyclones separate the sludge from the microsand. The microsand is recirculated into the flocculation stage. Typical sand loss with the sludge is 2 mg/l of treated water.



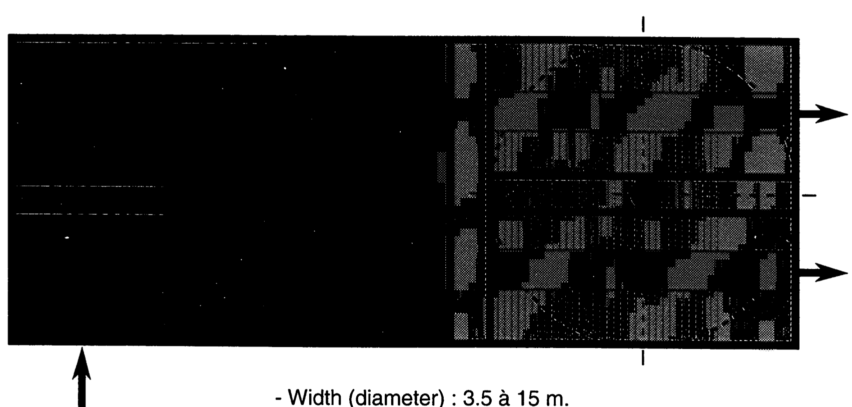
The ACTIFLO® process removes more than 80% of the suspended solids levels -- as low as 30 mg/l can be achieved. In addition, iron or aluminum coagulants will remove phosphorus below 2 mg/l. BOD removal is greater than 50%, often in the range of 60% to 70%.

LONGITUDINAL SECTION



1 - Raw water inlet	*8 - Treated water outlet*
2 - Injection of microsand	*9 - Sludge scraper and trough*
3 - Flash mixing zone (coagulation)	*10 - Sludge and sand outlet sump*
4 - Gentle mixing zone (flocculation)	*11 - Recycling pump*
5 - Inlet to settling zone	*12 - Hydrocyclones for microsand recovery*
6 - Lamella modules	*13 - Sludge outlet*
7 - Collecting troughs or pipes	

PLAN VIEW



- Width (diameter) : 3.5 à 15 m.
- Flows : 500 à 23 000 m^3/h.

C - Flash mixing zone *I - Injection* *M - Maturation*

The ACTIFLO® process offers many advantages:

- Compactness
  Weighted flocculation permits a total retention time of less than 15 minutes. The upflow velocity can reach >53 gpm/ft^2 (130 meters per hour) based on the area of the water surface at the top of the lamella.
- Response time
  The inert microsand remains in the flocculation tanks and is available to respond immediately once the reactants are added and the mixers and flow are started. It is therefore the ideal treatment system for dealing with storm flows, which by their nature occur suddenly.
- Flexibility
  ACTIFLO® can process flows between 10% and 100% of its nominal design capacity--the reactant rates being set on the inlet flow.
- Consistency of effluent
  Whatever inlet conditions, the concentration of suspended matter in the effluent remains almost constant.
- Sludge treatability
  The good decantability of th sludge allows it to be thickened and dewatered easily.

FOR MORE INFORMATION

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CARY, NORTH CAROLINA 27513

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FACSIMILE 919-677-0082

ACTIFLO REFERENCES

Potable Water

UNITED STATES

#	Plant	Start-Up	Total Capacity MGD	No. of Trains
1.	N. Table Mountain, CO	1998	11	2
2.	Montezuma, CO	1999	4	2
3.	Casper, WY	1999	27	2
4.	Newport, KY	1999	15	2
5.	Cass County, MO	1999	1	1
6.	Southeast Regional, UT	2000	20	2
7.	Sharon, PA	2000	16	3
8.	Spotsylvania, VA	2000	12	4
9.	Statham, GA	2000	1	1
10.	Lincolnton, NC	2000	9	1
11.	Rawlins, WY	2000	4	1
12.	Bardstown, KY	2000	8	2
13.	London, KY	2000	6	2
14.	Foothill, CA	2001	40	2
15.	Fresno, CA	2001	20	2
16.	Tampa, FL	2001	40	2
17.	Tampa Bay, FL	2001	60	2
18.	Melbourne, FL	2001	20	2
19.	West Plains, MO	2001	8	2
20.	Princeton, KY	2001	3	2
21.	Rattlesnake, KY	2001	2	2
22.	Wilsonville, OR	2001	22	2

FRANCE

#	Plant	Start-Up	Total Capacity MGD	No. of Trains
1.	Neuilly S. Marne	1991	55.5	3
2.	Vitre	1991	2	1
3.	Ancenis	1992	4.5	1
4.	Nord Mayenne	1992	4.5	2
5.	Annet S. Marne	1992	12	1
6.	La Bultiere	1994	7	1
7.	Le Pornic	1995	4	1
8.	Picotalen	1995	7	1
9.	Mery S. Oise	1998	48	2
10.	Nice Super Rimiez	1998	18	1
11.	Troheir (Quimper)	1998	4	2
12.	St. Pierre & Miquelon	1999	2	2

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ACTIFLO REFERENCES

Potable Water

CANADA

#	Plant	Start-Up	Total Capacity MGD	No. of Trains
1.	Kahnawake, QC	1993	2	1
2.	Roberval, QC	1994	4	1
3.	Montmagny, QC	1996	4	2
4.	St. Jovite, QC	1996	2	2
5.	St. Anselme, QC	1996	1	1
6.	Gatineau, QC	1997	29	2
7.	Wemotaci, QC	1997	0.2	1
8.	St. Jerome, QC	1997	10	2
9.	St. Lambert, QC	1997	37	3
10.	Quebec City, QC	1998	63	2
11.	Lindsay, ON	1998	6	2
12.	Mont-Carmel, QC	1998	0.2	1
13.	Brantford, ON	1999	26	2
14.	L'Assomption, QC	1999	6	2
15.	Lakefield, ON	2000	1.2	2
16.	Carleton Place, ON	2000	3.2	2
17.	Saint-Pascal, QC	2000	1.5	2
18.	Windsor, QC	2000	1.7	2
19.	Port Cartier, QC	2000	1.7	2
20.	St. Damase, QC	2001	2	2
21.	Sept-Iles, QC	2001	13	2
22.	St. Damase, QC	2001	2	2

GREAT BRITAIN

#	Plant	Start-Up	Total Capacity MGD	No. of Trains
1.	Llyswen	1995	2	1
2.	Broomy Hill	1995	14	2
3.	Irton	1996	8	4
4.	ECCUP	1997	32	2
5.	Elvington	1998	71	4+1

OTHER COUNTRIES

#	Plant	Start-Up	Total Capacity MGD	No. of Trains
1.	Omerli , Turkey	1995	83	5
2.	Balikesir, Turkey	1998	63	4
3.	Kuala Lumpur I, Malaysia	1998	150	5
4.	Kuala Lumpur II, Malaysia	2000	150	5

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ACTIFLO REFERENCES

Municipal Wastewater & CSO

#	Plant	Country	Start-Up	Total Capacity MGD	No. of Trains	Application
1.	Herford	Germany	1997	36	2	Tertiary
2.	Colombier	Switzerland	1998	17	1	CSO & Tertiary
3.	Lindsay	Canada	1999	8	2	Tertiary
4.	Emdrup So	Denmark	1999	2.4	1	Tertiary
5.	Massey, ON	Canada	1999	0.4	1	Tertiary
6.	Deseronto, ON	Canada	1999	1.3	1	Tertiary
7.	Acheres I	France	2000	513	5+1	CSO & Tertiary
8.	MCA – Mabeuge	France	2000	0.5	1	CSO
9.	Shepparton	Australia	2000	7	2	Lagoons
10.	Fleetwood	Great Britian	2000	28	3	Primary
11.	Boras	Sweden	2000	17	1	Tertiary
12.	Delta Diablo, CA	USA	2000	14	2	Tertiary
13.	Roros	Norway	2000	1	1	Tertiary
14.	Skreia	Norway	2000	2	1	Tertiary
15.	Strathroy, ON	Canada	2000	6	3	Tertiary
16.	Boisbriand, QC	Canada	2000	4	1	Secondary
17.	Aurillac	France	2000	5	1	Tertiary
18.	Reims	France	2001	63	3	Tertiary
19.	Houplain	France	2001	10	1	Tertiary
20.	Cap d'Agde	France	2001	8	1	Primary
21.	Geneva	Switzerland	2001	137	4	Primary & CSO
22.	Beenleigh	Australia	2001	8	1	CSO
23.	St. Bernard, LA	USA	2001	10	1	Primary & CSO
24.	Onondaga, NY	USA	2002	126	4	Tertiary
25.	Le Mans	France	2003	29	1	Tertiary
26.	Le Mans	France	2003	11	1	Biofilter Backwash
27.	Valenton	France	2003	228	3+1	CSO
28.	Valenton	France	2003	118	2+1	Tertiary
29.	Bern	Switzerland	2004	23	2	Biofilter Backwash
30.	Boulogne Sur Mer	France	2004	7	1	Biofilter Backwash
31.	Acheres II	France	2004	513	5+1	CSO & Tertiary

9/11/00

a VIVENDI water company

USFilter

KRÜGER PRODUCTS
401 HARRISON OAKS BOULEVARD- SUITE 100
CARY, NORTH CAROLINA 27513

TELEPHONE 919-677-8310
FACSIMILE 919-677-0082

ACTIFLO REFERENCES

Industrial Process Water & Wastewater

#	Plant	Country	Start-Up	Total Capacity MGD	No. of Trains	Application
1.	Scott Paper	Canada	1997	1	1	Process
2.	Olymel-1, QC	Canada	1998	0.2	1	Process
3.	Lainage Victor, QC	Canada	1998	1	1	Process
4.	Lactel, QC	Canada	1998	0.2	1	Process
5.	Troilus, QC	Canada	1998	6	1	Tertiary
6.	Krüger, QC	Canada	1998	8	1	Pulp & Paper
7.	Olymel-2, QC	Canada	1999	0.2	1	Process
8.	Papier Masson, QC	Canada	1999	0.3	1	Process
9.	Cascades Industries, NC	USA	1999	0.3	1	Process
10.	LSP Energy, MS	USA	2000	5.5	1	Process
11.	DOW Chemical, MI	USA	2000	22.5	2	Tertiary
12.	Jose	Venezuela	2000	14	2	Process
13.	Poudres Metalliques, QC	Candada	2000	2	1	Process
14.	HUISH Detergents, TX	USA	2001	1	1	Process

9/11/00

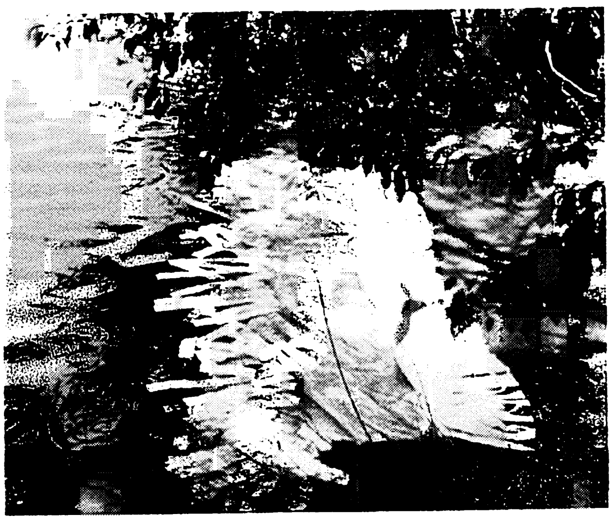
MOTHER environmental systems, inc.

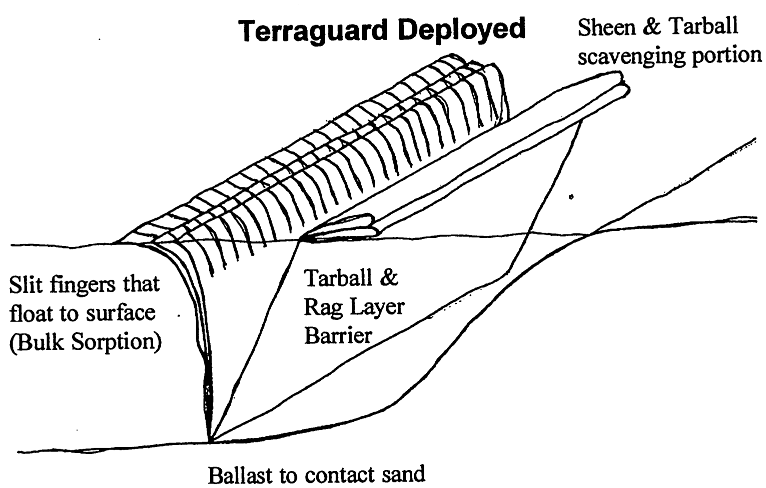
terraguard™

SHORE LINE PROTECTION SYSTEM

ALL **MOTHER** PRODUCTS ARE INFUSED WITH OUR PATENTED **MYCELX** CHEMISTRY

Designed For Protection of Bird Estuaries, Environmentally Sensitive Wetlands and Shore Lines





Terraguard is the complete shore line protection system. **Terraguard's** dual material composition enables it to protect the shore from the complete range of oil spill generated pollution. **Terraguard** extends from above the air water interface down to sand level and will protect the shore line from surface film, tarballs and emulsification products. The slit fingers and sheen/tarball portions always float above the oil/water interface to provide continuous protection during rough weather or tidal swings. **Terraguard** is engineered for rapid deployment and is available in 10 ft. interconnectable units.

Will Not Entrap or Entangle Wildlife

Benefits

terraguard™ instantly attaches to oil
terraguard™ will never sink or become ineffective
terraguard™ prevents weathering and separation on contact
terraguard™ is triboelectrically inactive and will not generate static charge
terraguard™ is environmentally safe

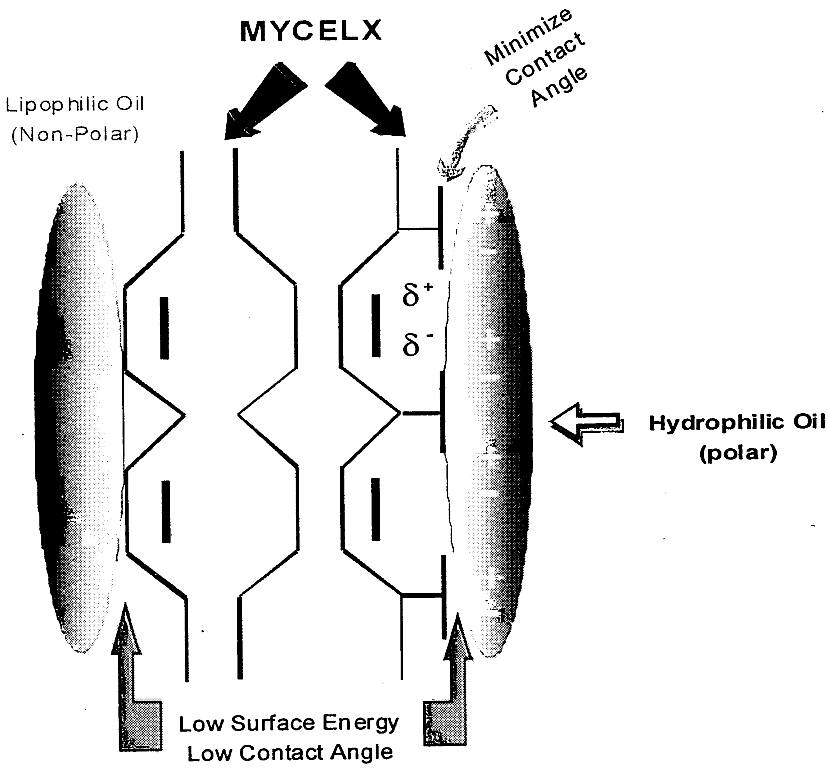
1124 Purina Drive, Gainesville, Georgia 30501, 1-888-306-6843
Email: mother@mycelx.com Website: mycelx.com

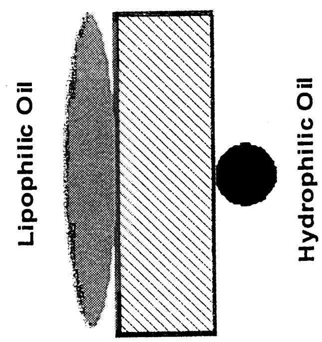
31799

MYCELX REMOVES ALL HYDROCARBONS FROM WATER

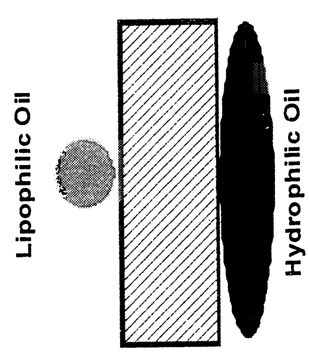
MYCELX filters are engineered to remove semi-soluble and insoluble molecules from many types of liquids, but its primary application is for water remediation. Unlike activated carbon which relies upon physiochemically entrapping water insoluble organic compounds, MYCELX actually solubilizes both water soluble and insoluble organic compounds, bonds them to its surface and keeps them from separating and emulsifying. MYCELX can remove mixed emulsions, both oil/water & water/oil along with lipophilic and hydrophilic organic compounds. MYCELX also is able to remove many chelated and nonchelated metals from the process stream.

Why couldn't you use a polymer other than MYCELX to solubilize organics from solutions? Because organics are lipophilic or hydrophilic. Only MYCELX removes both. Conventional polymers will attract one and repel the other. MYCELX dissolves both. That's why MYCELX can remove oil/water, water/oil emulsions and other materials cannot.





Standard Polymer for Lipophilics



Standard Polymer for Hydrophilics

MOTHER
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systems, inc.

TECHNICAL BULLETIN

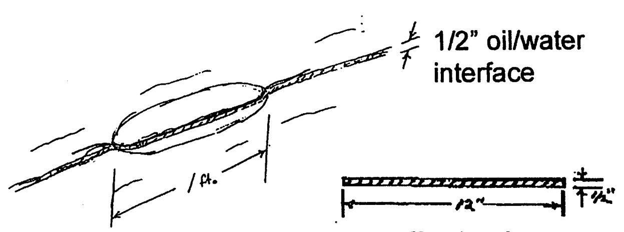
WHY **MOTHER** PRODUCTS WORK BETTER

All **MOTHER** products are infused with our patented **MYCELX** chemistry which renders all component materials highly absorbent to oil and repellent to water (U.S. Patent 5,437,793). Chemistry coupled with innovations made by identifying key physiochemical observables allows application specific substrate selections to be made, thus allowing product designs which maximize field effectiveness.

As an example, let's consider effectively removing and containing a film of oil on water. We have determined that oil is only removed where the substrate material makes contact with the surface. Effectiveness of oil pickup is directly a function of area exposed to the oil-water interface, and not a function of mass or volume. Extra mass only causes the material to drag-out more water. This is verified by the fact that the standard MBPP (melt blown polypropylene) boom or pad only picks up seven percent of its total oil sorption capacity, while dragging out up to ten times its weight in water.

Our **MYCELX** infused products have been designed to maximize effective surface area and minimize weight. This maximizes performance while reducing water drag and waste disposal costs. On that basis, our products are fifty to one-hundred times less costly to use per unit of oil removed while maintaining a much higher degree of performance. What one actually pays for is effective contact area. (Please refer to drawings)

8" dia. 3M MBPP Boom



Effective Area
$100/sq. ft.

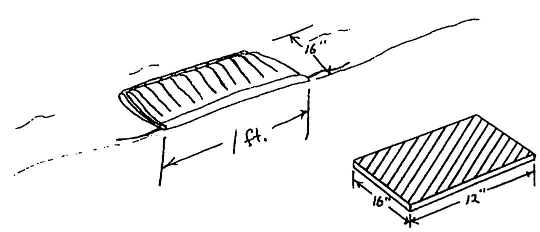
Weight of 1ft section: 1.0 lb
Cost per 1 ft section: Approximately $4.00
Effective Area: 12"x1/2" = 6 in^2/(144 in^2/ft) = 0.04 ft^2

Calculations for 10 ft Sections

Length: 10 ft
Weight: 10 lb
Cost/ft^2: $100.00
Water Drag-out: 100 lb

Cost/Effective Area: $100/ft^2

Sheen Devil™



Effective Area
$3.10/sq. ft.

Weight of 1 ft section: 0.10 lb
Cost per 1 ft section: $4.00
Effective Area: 12"x16"/(144 in^2/ft^2) = 1.3 ft^2

Calculations for 10 ft Sections

Length: 10 ft
Weight: 1 lb
Cost/ft^2: $3.10
Water Drag-out: 0 lb

Cost/Effective Area: $3.10/ft^2

1124 Purina Drive Gainesville, Georgia 30501 1-888-306-6843

31799

MYCELX®

PERFORMANCE DATA

30" 5 micron **MYCELX** infused spunbond filter cartridge

Category	Affinity	Capacity / Filter (g)
Oil and Grease	E	360
Polyaromatic Hydrocarbons (PCB, insecticides etc..)	E	360
Surface Active Agents (Surfactants) *1 HLB < 8 HLB 8 -18 HLB > 18	 E F G	30 - 300
*2 C_1 - C_6 aliphatics and aromatics with functional groups	P *3	30 - 100
*2 C_6 - C_{10} aliphatics and aromatics with functional groups	F - G	100 - 300
*4 Aromatic Hydrocarbons	G - E	360
Halogenated Hydrocarbons	G - E	200 - 360
Heavy Chelated and Organically Bound Metals	F - E	100 - 300

Affinity Scale single pass efficiency

E (excellent) > 90%
G (good) > 50%
F (fair) > 30%
P (poor) < 10%

*1 HLB = Hydrophilic Lipophilic Balance
*2 alcohols, aldehydes, ketones, ethers, esters, glycols, carboxylic acids etc..
*3 F to G for compounds with K_B values > 80
*4 Benzene, Toluene, Ethylbenzene, Xylenes

MOTHER environmental systems, inc.

1124 Purina Drive • Gainesville, GA 30501
770-534-3118 • Fax: 770-534-3117 • Email: mother@mycelx.com • Website: mycelx.com

MYCELX®

Filter Technology

After years of research, Mother Environmental Systems has synthesized and patented a revolutionary new class of compounds which have the ability to instantly remove the entire range of organic chemicals from water. This class of compounds is known as MYCELX.

MYCELX has the ability to remove volatile and non-volatile, water soluble and water insoluble organic compounds. MYCELX is able to solubilize and remove from solution mixed emulsions (oil/water, water/oil) and lipophilic and hydrophilic organic compounds in addition to many chelated and nonchelated metals. Simply stated, all organic compounds regardless of size, shape and degree of water solubility are much more soluble in MYCELX than they are in water and other media, including other organic solvents. By reducing the problem to one of differential solubility, MYCELX technology has eliminated limiting factors such as vapor pressure and water solubility associated with today's technology and propelled water treatment into the 21st century.

MYCELX can completely remove all types of organic compounds ranging in size and solubility from very large and relatively water insoluble, such as PCB's, to small and water soluble, such as benzene, without regard for any property other than the extreme differential affinity these compounds exhibit in relation to MYCELX.

Mother Environmental Systems has developed proprietary and patented processing technology which enables us to infuse the MYCELX chemistry into a variety of substrate materials. This gives us the ability to address specific pollutants and applications by utilizing the optimal substrate for a particular application.

MYCELX®

Materials able to be removed from water by MYCELX

Alkanes
Alkenes
Cycloalkanes
Aromatic Hydrocarbons
Crude Oils
Tallow and other animal fats
Vegetable Oils
Complex Organics, Monomers & Polymers
Heavy Metals
PCBs
MTBE
Chlorinated Organics
Emulsions

MOTHER
environmental
systems, inc.

TECHNICAL BULLETIN

APPLICATION SPECIFIC SUBSTRATES

All **MOTHER** absorbent products are infused with our patented **MYCELX** chemistry which renders component materials highly absorbent to oil and repellent to water (U.S. Patent 5,437,793). **MYCELX** chemistry coupled with innovations made by identifying key physiochemical observables allows application specific substrate selections to be made, thus allowing product designs which maximize field effectiveness.

Based on observations of actual oil spills, our products have been designed to optimize the following parameters:

1. **Weight**
   We use the lightest weight materials to allow easy handling and keep disposal costs down

2. **Buoyancy**
   MOTHER uses materials that will stay buoyant for extended periods of time to maximize product life and to keep heavy oils from sinking

3. **Effective Area**
   Our products have been designed to maximize the area that is in contact with the contaminated surface thus maximizing containment and removal

4. **Water Drag out**
   A minimum of water attaches to our products to keep disposal weight low and BTU values high (if incineration is required)

5. **Substrate Selection**
   Due to our versatility we do not depend on one single material such as melt blown polypropylene (MBPP). We are able to make many materials perform oil absorbing tasks with our patented **MYCELX** chemistry. Substrate selections are based on appropriate properties for the given application. We use materials ranging from wood shavings to polyethylene and other polymeric substrates to make the most effective products available.

Specific Applications

Substrates are selected according to the tasks they are to perform; for example, sheen requires a material that is very buoyant and stays at the oil/water interface. Heavy oils require materials that prevent sinking and weathering.
Each **MOTHER** product has been designed for specific applications by using a substrate that closely matches the properties required.

MOTHER environmental systems, inc.

MYCELX®

Application Matrix

	WATER APPLICATIONS								LAND APPLICATIONS				
	Light Oil	Medium Oil	Heavy Oil	Boom or Sweep Deployment	Shoreline Protection	Spotty Water	Sheen Removal	Rheology Modification (All Oils)	Absorbent Spill Dike or Berm	Spill Absorption	Puddle, Pond And Drainage Ditch	Surface Protection	Crude Oil & Asphalt Solvent
versipad™	●	●				●	●			●	●		
versimat™	●	●		●		●	●					●	
smartpad™	●	●	●							●	●	●	
terraguard™	●	●	●	●	●	●	●						
superbuoyant RD™			●	●		●							
superbuoyant roll™			●	●	●	●	●				●	●	
viscochips™								●	●	●			
sheen devil™	●	●	●	●	●	●	●				●		
powersolve™													●

AFL
FILTRATION

TEL: +44 (0) 1642 370 616
FAX: +44 (0) 1642 564 70

DAIMLER DRIVE, COWPEN LANE INDUSTRIAL ESTATE, BILLINGHAM. TS23 4JD

Clerify™ LR Trace Oil Removal System.

Reduce operating costs and comply with discharge regulations. Clerify™ thoroughly removes the *dissolved, dispersed and emulsified oil* from water in a single pass. The Clerify™ trace oil removal system delivers superior oil removal performance downstream of primary separation.

Clerify™ is a filtration media which is a **barrier** to trace oil contamination often present in produced, feed, waste or process water. Thorough removal of trace oil contamination is becoming a vital requirement to ensure compliance with discharge regulations or to reduce water supply or disposal charges. Clerify™ is the ideal solution, it provides exceptional oil removal performance, typically removing up to 95% of **total hydrocarbons** in a single pass. The media has the capacity to hold 300% of it's own weight of removed oil. Clerify™ is so effective because it **chemically bonds** with the removed hydrocarbon. This also means removed oil cannot leach out, even when the media is fully saturated, a major problem with alternative oil removal technologies. The unique **adsorption** technique that Clerify™ utilises facilitates high flow rates. The system is convenient to use and the pressure differential through the media remains constant irrespective of the hydrocarbon loading. Clerify™ media rolls are placed inside carbon steel housings which have been designed for ease of installation and operation. Where appropriate housings can be used in multiples, skid mounted and offshore specification systems are also available, consult AFL for details.

Technical specification of media housing:

Part number:		AXR51C60
Height:		3.50M
Diameter:		1.35M
Weight (empty)		2180Kg
Weight (operating)		6190Kg
Material:		Carbon Steel
Design code:		ASME VIII Div. 1
Mounting:		3 X Partial skirts (seismic loading)
Gross volume:		3.3M3
Operating pressure:		0-5BARG
Design pressure:		7.5BARG
Maximum flow rate:		50M3/hr (220 US gpm)
Media loading and removal:		Via removable top.
Temperature range:		1-50C
Nozzle sizes	Inlet:	6" 150#SORF
	Outlet:	6" 150#SORF
	Vent	2" 150#SORF
	Drain	2" 150#SORF
	Relief valve	3" 150#SORF
	Inlet monitor	1" NPT 3000#coupling
	Outlet monitor	1" NPT 3000#coupling

Weight & capacity of Clerify™ media:

Clerify™ media required:	A2R1000-60AN126
Typical gross weight (dry):	250Kg (550Lbs)
Typical net weight of media (dry)	225Kg (495Lbs)
Removed hydrocarbon capacity:	Three times net dry weight of media.

Specification subject to amendment, details should be verified at time of order.

Superior filtration performance.

Water to be treated enters the vessel at a nozzle located on the side of the housing. Diffusion plates ensure that the untreated water circulates evenly around the circumference of the housing.

The Clerify™ media in the form of a cylindrical roll is located centrally inside the housing. Under system pressure, the oily water passes through the media. The Clerify™ reacts when in contact with the hydrocarbon forming an instant, permanent chemical bond.

The treated water exits the media through a perforated polypropylene center core and is discharged from the housing through a nozzle at the base of the housing.

Renewal of the Clerify™ media is simple and rapid once it has become fully saturated with removed oil. After release of the domed top plate, the cylinder of media is lifted out by hooking the provided lifting straps fixed through the media onto a suitable lifting device. The replacement media is then lowered into the housing and secured using the clamp-down arrangement installed to ensure a positive gasket seal. Disposal of the spent media should be in accordance with local regulations.

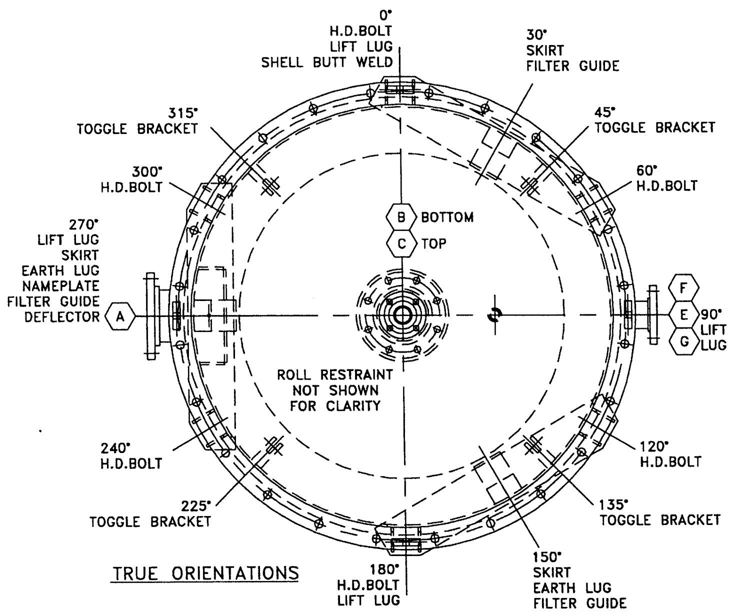
Provision has been made at the inlet and outlet nozzles for the connection of monitoring equipment to measure the inlet and outlet oil content levels.

Special features.

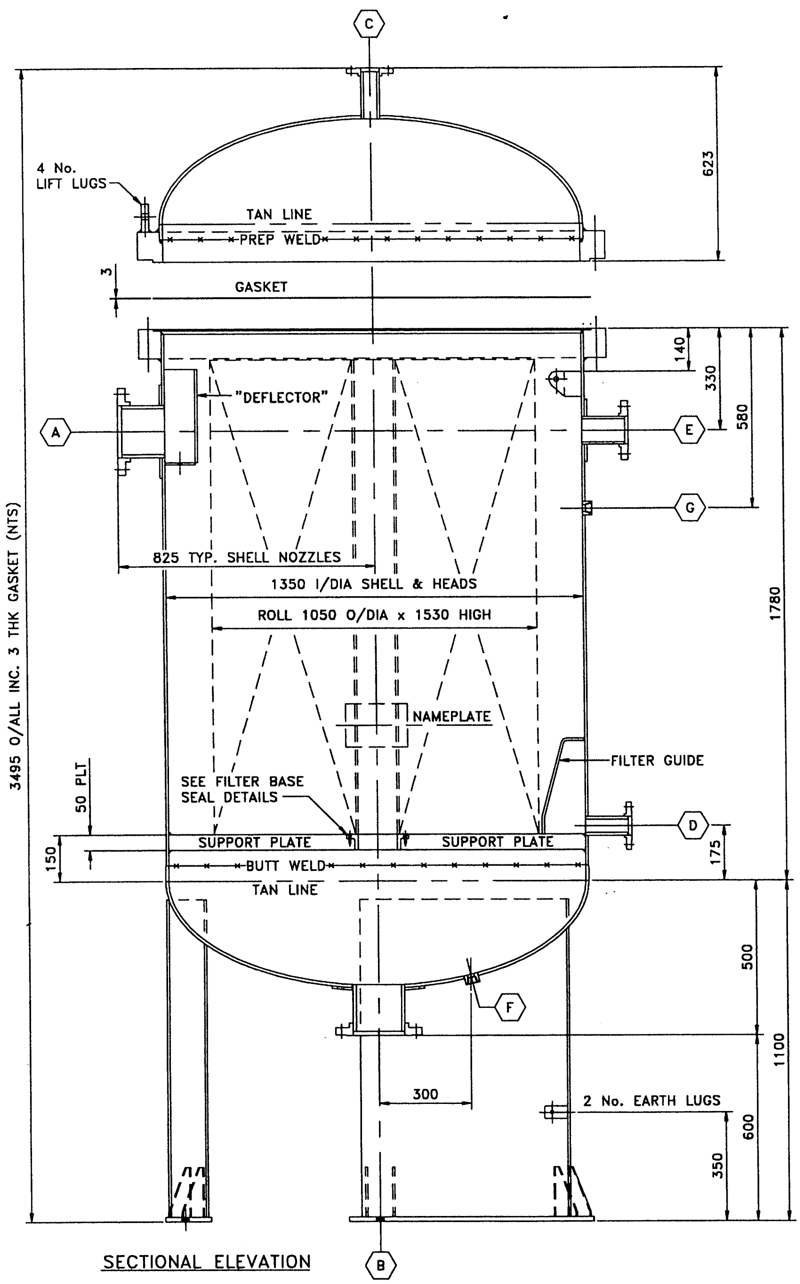
- Clerify™ adsorbs up to 300% of its dry weight of hydrocarbon.
- Chemically bonds with the removed hydrocarbon.
- Will not leach out removed oil, even when fully saturated.
- Typically adsorbs up to 95% of total hydrocarbons in water.
- Removes dissolved, dispersed and emulsified oil from water.
- Does not require regeneration, is rapidly changed minimizing interruption.
- Can achieve extremely low oil contamination levels if required.
- Operating temperature range 1 - 50 degrees Centigrade.
- No chemicals, electricity supply or instrumentation required .
- Proven in-service performance offshore & onshore.
- Packages available to match any flow rate with consistent oil removal performance.
- Easy operation, no adjustments required.
- No sensitivity to platform or vessel motion in offshore applications.

Applications.

Clerify™ is widely used in a great many diverse applications. The following additional publications are available from AFL on request which contain case studies of applications in the following sectors, Offshore Oil & Gas, Industrial Applications, Marine uses, RO Membrane protection.



TRUE ORIENTATIONS



SECTIONAL ELEVATION

USFilter

Taking care of the world's water.

ADVANCED MEMBRANE FILTRATION

A MAJOR ADVANTAGE FOR RELIABLE WASTEWATER TREATMENT OR PROCESS FILTRATION

SYSTEMS THAT GIVE YOU GREATER FLEXIBILITY AND BETTER PERFORMANCE

USFilter's Memtek® E-Series systems incorporate proprietary crossflow tubular membranes which remove precipitated contaminants and produce a high quality filtrate suitable for discharge or further treatment. The modular components stand alone, work together or work with existing equipment. The stand alone units are ideally suited for integrating with existing reaction tanks or settlers for effluent polishing. Membrane filtrate from an E-Series system can be discharged from the plant or reused directly in non-critical rinses. The filtrate is also suitable as a feed to reverse osmosis where from 75-90% of the water can be recycled and reused within the plant. Standard E-Series systems accommodate flow rates up to 400 gpm while custom designed systems are available to handle larger flow capacities. These Memtek systems are easy to operate and provide for continuous solid/liquid separation with minimal operator attention.

EF ADVANCED MEMBRANE FILTRATION UNITS

The basic EF unit is a skid-mounted package consisting of membrane modules, recirculation pump, in-place cleaning loop, backpulse mechanism, instrumentation and controls. The skid-mounted design is compact and requires minimal floor space.

EFC ADVANCED MEMBRANE FILTRATION SYSTEMS

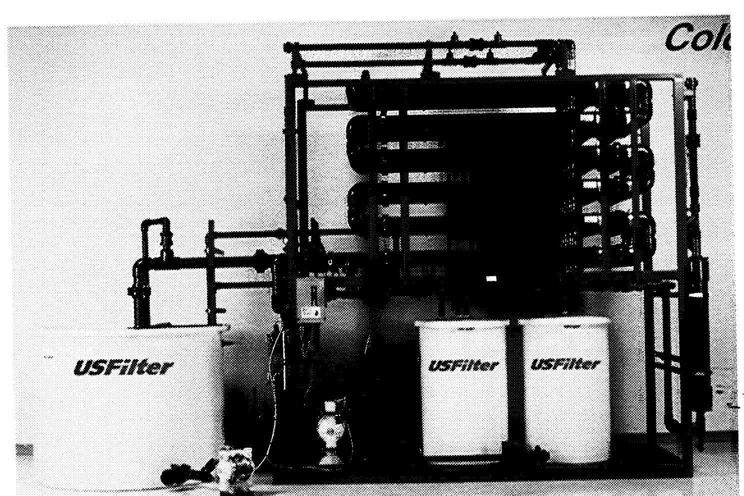
The EFC system includes the EF unit equipment plus a recirculation tank with level controls, anti-swirl baffles and slurry transfer pump.

RX AND RXP REACTION UNITS

These units are rugged, corrosion resistant tanks equipped with heavy duty mixers; metering pumps; chemical reaction monitors and controllers; level controls and alarms; inlet, overflow and drain ports; control panel; access platform and covers.

MATERIALS OF CONSTRUCTION

The rugged fluorocarbon membranes are non-plugging and abrasion and chlorine resistant. The process tanks are fabricated from heavy duty fiberglass reinforced epoxy resins or high density polyethylene. All components in contact with wastewater are PVC, polypropylene, nylon, stainless steel or other corrosion resistant material.



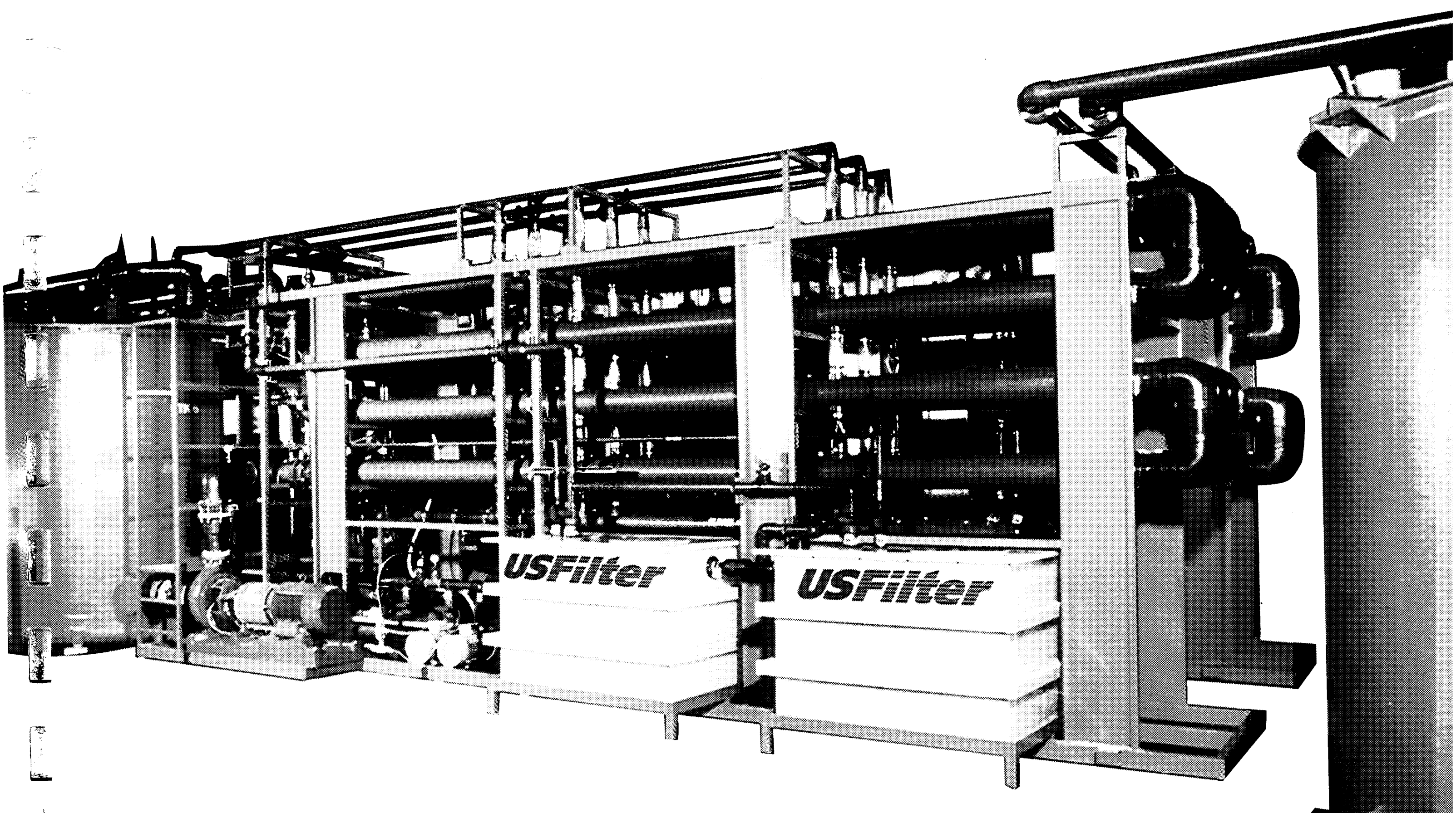
EFC Model 424

Market	Application
Metal Finishing	Removal of heavy metals to less than 0.1 ppm
Printed Circuit Board	Removal of heavy metals to less than 0.1 ppm
Semiconductor	Arsenic removal to less than 0.1 ppm Fluoride removal to below 5 ppm Cutting fluid recycle from silica grinding and slicing operations Deionized water recycle from wet blast and back grinding processes Heavy metals removal from tin/lead plating onto lead frames
Groundwater Remediation	Removal of heavy metals to less than 0.1 ppm
Battery Manufacturing	Removal of lead and cadmium from wastewater
Automotive	Removal of zinc and phosphate from phosphatizing operations
General Industry	Removal of heavy metals from incinerator scrubber water Pretreatment for reverse osmosis water recycling Lime softening of cooling tower blowdown for water recycling General heavy metals removal to less than 0.1 ppm Replacement of clarifier or a clarifier followed by a sand filter

E-SERIES SYSTEM CAPABILITY*

Contaminant	Wastewater Conc. (mg/l)	Memtek Effluent (mg/l)
Aluminum	10-1000	0.5
Arsenic	1-50	0.005
Cadmium	25-115	0.05
Chromium	3-275	0.1
Copper	1-1500	0.1
Cyanide	5-300	0.1
Gallium	4-20	0.5
Germanium	20-110	0.5
Gold	1-12	0.15
Iron	2-1500	0.02
Lead	2-100	0.05
Manganese	1-10	0.02
Mercury	3-30	0.005
Nickel	4-300	0.1
Rhodium	20-500	0.1
Silver	10-200	0.1
Tin	20-75	0.1
Uranium	1-15	0.01
Zinc	2-400	0.1

*Typical values achieved in practice may vary depending on equipment configuration and pretreatment chemistry



Memtek EFC-Series Microfitration System

Pretreatment in RX and RXP Units

The process begins with the transfer of wastewater to one or more reaction tanks (1) followed by controlled addition of pretreatment chemicals to precipitate the contaminants to filterable particles. Pretreatment chemistry (2) is selected considering the nature of the wastewater, the desired contaminant removal efficiency and minimization of solids volume. Reactions are monitored and controlled automatically and continuously.

Filtration in EF and EFC Units

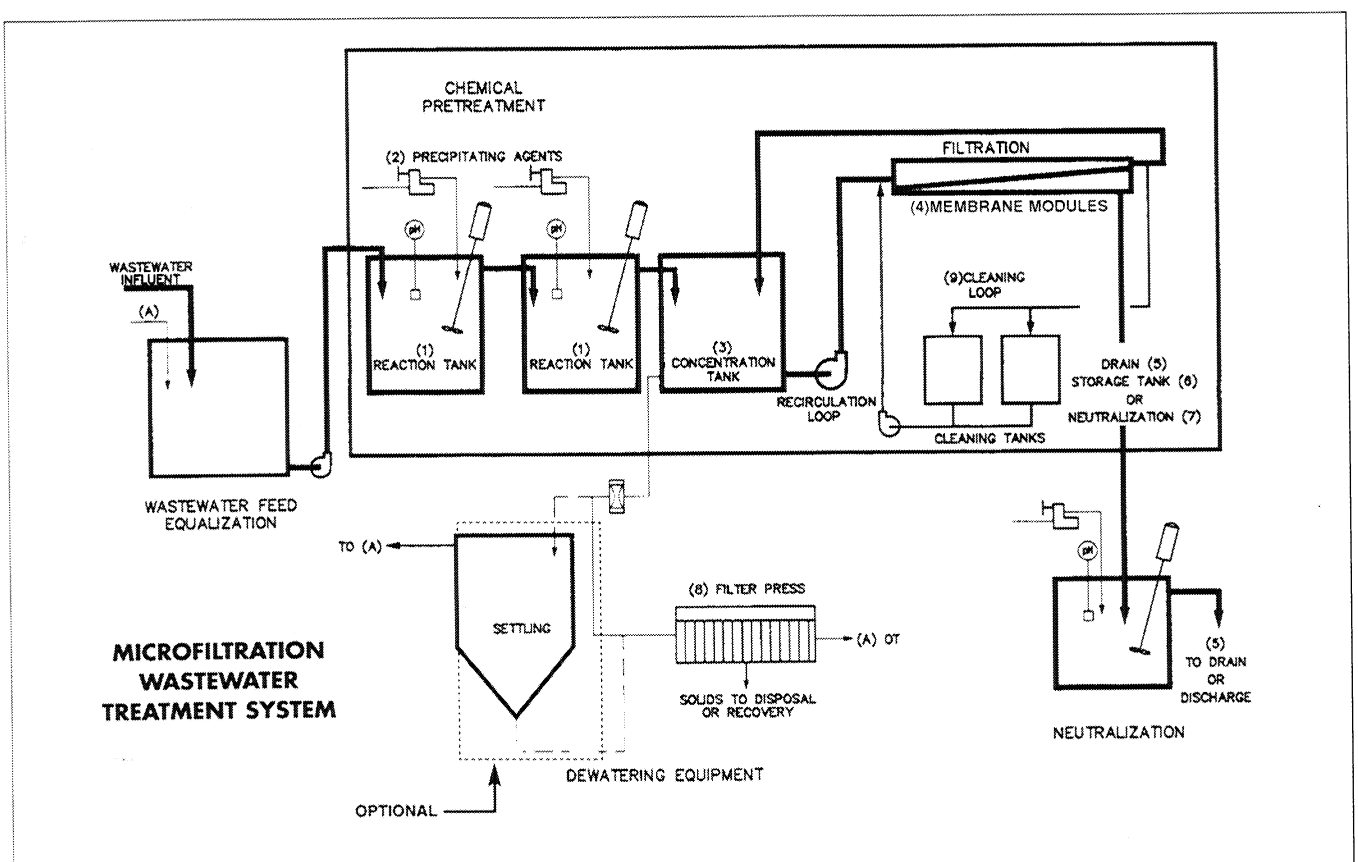
The chemically pretreated wastewater then flows to the concentration tank (3). From there, the water is pumped continuously through the tubular membrane filtration modules (4) at a high fluid velocity. At the normal operating pressure (20-40 psi), clean water is forced through the pores of the membrane while the particulate contaminants remain suspended in the recirculated stream. The turbulence of the recirculated slurry prevents the contaminants from accumulating on the membrane surface, thereby maintaining high and continuous filtration rates. The filtration piping also includes a backpulse mechanism which reverses the flow of filtrate to maintain higher flow rates and extend the time between cleaning cycles.

The clean water (membrane filtrate) flows by gravity from the membrane modules to a drain (5), storage tank (6) or the final neutralization tank (7). Clean, neutralized filtrate is often used as recycled water for non-critical rinses and applications.

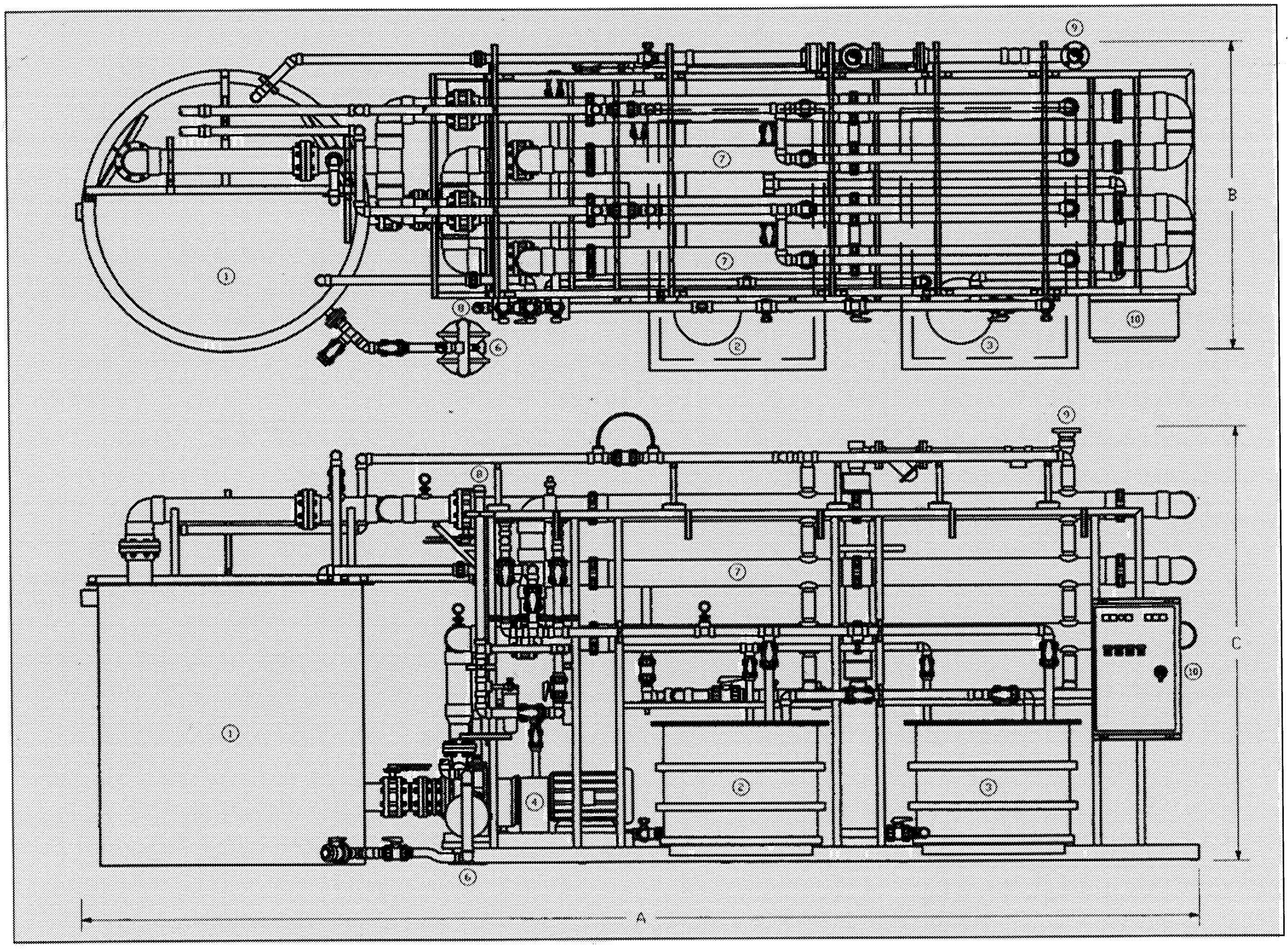
The filtrate is ideally suited for further processing by reverse osmosis (RO) for water recycle.

The concentration of the wastewater slurry recirculated in the membrane modules is typically maintained between 2-5% solids. Under normal operating conditions, a portion of the slurry is periodically removed from the system, usually to a filter press (8) which produces a dry (30-40%) solids cake for disposal. Filtrate from the press is returned to the feed system for reprocessing.

Every E-Series filtration system includes a convenient integral cleaning loop (9) consisting of a pump, two tanks and the necessary piping and valving to permit in-place cleaning of the membrane modules. No disassembly is required and cleaning normally requires < 2 hours after 60-100 hours of operation.



MICROFILTRATION WASTEWATER TREATMENT SYSTEM



SPECIFICATIONS		EFC 400	EFC 424	EFC 1200	EFC 2400	EFC 3600	EFC 4800	EFC 7200	EFC 10800
Capacity (nominal)	gpm	4-24	8-48	8-48	20-96	36-144	42-192	72-288	108-432
	m^3/hr.	1-5.5	2-11	1.8-11	4.5-22	8-33	9-43	16-65	24-98
Membrane Modules	Tubes/Module	4	4	10	10	10	10	10	10
	Quantity (min-max)	4-12	8-24	6-12	12-24	18-36	24-48	36-72	54-108
Concentration Tank Volume	Gallons	275	550	660	1375	1700	2600	4280	5000
	Cubic Meters	1.1	2.1	2.5	4.5	6.4	9.8	16.2	18.9
Process Pumps	Quantity	1	1	1	1	1	2	2	3
	Horsepower (each)	7.5	15	20	30	50	30	50	50
Electrical	Operating (kw)	4-8	8-16	12-23	16-32	26-52	32-63	50-101	76-152
Dimensions (ft.–in.)	Length A	11′10″	18′3″	24′7″	25′5″	33′	26′9″	37′10″	39′4″
	Length B	4′10″	5′4″	5′10″	7′1″	8′1″	9′6″	17′1″	25′3″
	Length C	8′11″	11′7″	9′10″	10′	11′10″	11′3″	11′11″	11′11″
Dimensions (mm)	Length A	3601	5560	7493	7747	10,058	8153	11,532	11,989
	Length B	1473	1625	1778	2159	2464	2896	5207	7696
	Length C	2718	3530	2997	3048	3607	3429	3632	3632
Weight (lbs.)	Wet	4000	8000	18,000	26,000	34,000	52,000	73,000	98,000
	Dry	1000	2000	7500	10,000	15,000	18,000	29,000	43,000
Weight (kg.)	Wet	1818	3636	8182	11,818	15,455	23,636	33,182	44,545
	Dry	455	910	3409	4545	6818	8182	13,182	19,545

FEATURES

- Rugged, long life tubular membranes
- Continuous removal of suspended solids and precipitates
- Compact, skid-mounted, accessible design
- Piped-in-place cleaning system
- Auto-clean available as an option
- Backpulse mechanism for optimum flux and cleaning cycle
- Automatic, trouble-free operation
- Supported by options and auxiliary process modules
- PLC controlled

BENEFITS

- Absolute barrier to particle passage
- Proven membrane performance backed by guarantees and warranties
- Membranes produce high quality effluents, eliminating the need for polymer
- Less sludge generation than conventional systems
- System integrates easily with existing chemical treatment systems
- Modular design allows for expansion

SYSTEM OPTIONS AVAILABLE

Cyanide Destruction Modules
Chrome Reduction Systems
pH Neutralization Modules
Reverse Osmosis Systems for Water Recycling

OTHER TREATMENT EQUIPMENT

Electrolytic Recovery
Ion Exchange Systems
Acid Recovery
Ion Exchange Water Recycling
Acid Purification
Sand Filters
Atmospheric Evaporators
Clarifiers
Caustic Etch Recovery
Alkaline Cleaner Recycle
Filter Presses
Belt Presses
Gravity Belt Thickeners
Sludge Dryers

E-SERIES UNITS ARE KEY ELEMENTS OF TREATMENT SYSTEM UPGRADES

Wire and Cable Manufacturer, Jacksonville, FL

A manufacturer of high carbon steel wire products is using the E-Series system to treat rinsewaters from the acid cleaning and descaling of wire rod and processed wire. The E-Series system consistently produces effluent at less than half the discharge limits for all metals. The management staff wanted assurance that the waste treatment system would operate in compliance. USFilter Memtek Products demonstrated detailed knowledge of the company's wastewater and confirmed their design concept with treatability testing on actual samples of the wastewater. USFilter Memtek Products provided turnkey installation, startup and operator training. The system provides the customer with the confidence that the effluent is consistently well below discharge limits.

Parts Manufacturer, New Haven, IN

A leading manufacturer of industrial, automotive, aerospace and defense fluid connectors, and automotive and commercial custom engineered molded and extruded plastic products is using the USFilter Memtek E-Series microfiltration system to treat metal bearing wastewaters. Since startup, the treatment system has consistently met the required effluent limitations at operating costs that are lower than conventional technologies.

Printed Circuit Board Manufacturer, Raleigh, NC

A major manufacturer of printed circuit boards, recently upgraded their wet processing operations with new, state-of-the-art equipment. The customer also replaced their wastewater treatment system, which was based on ion exchange, with a USFilter Memtek E-Series microfiltration system. The customer needed a reliable waste treatment system to meet very low compliance limits. The E-Series microfiltration system has reduced operating costs and generated sludge with high copper content. As a result, sludge disposal costs are significantly lower than expected.

USFilter
Taking care of the world's water.

Memtek Products
28 Cook Street
Billerica, MA 01821
978.667.2828 *phone*
800.527.0433 *toll-free phone*
978.667.1731 *fax*

http://www.usfilter.com

Bulletin No. MEM-AMF-6/99

Option 8 - MOP-UP Reagent ActiFlo System Followed by Mycelx Media

Capital Cost Estimate - Case 1 Peak Flow = 2,000 gpm	
1 x 2,000 gpm ACTIFLO Concrete Basin Plant	$432,000
Sludge Holding Tank (2,000 gallon)	$6,000
Filter Press (4 cubic feet)	$16,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$542,000**
Freight (3% of Equipment Cost)	$16,000
Installation (10% of Equipment Cost)	$54,000
Site preparation (5% of Equipment Cost + Concrete)	$59,000
Electrical (10% of Equipment Cost)	$54,000
Piping (20% of Equipment Cost)	$108,000
Total	$833,000
Contingency @ 25%	$208,000
Total with Contingency	**$1,041,000**

Operating Cost Estimate - Case 1
Design Storm = 250,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Polymer	0.20 mg/L (0.42 lb)	$3,500/ton	$0.73
Sand	1.0 g/m3	$80/ton	$0.08
Coagulant Fe2(SO4)3)	100 mg/L (209 lbs)	$350/ton	$36.51
Biopraxis Reagent			
Power Consumption	15.0 HP	$0.114/KWh	$30.60
Sludge Disposal	260 lbs	$40/ton	$5.20
Labor	4 hrs	$35/hr	$140.00
Total Estimated Operating Cost Per Design Storm Event			$213.13
Mycelx Media	10 ft/year	$100/10 ft	$100.00
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$952.51
Estimated Maintenance Per Year (2% of Equipment Cost)			$10,800.00
Total Estimated Operating and Maintenance Cost Per Year			**$11,752.51**

Option 8 - MOP-UP Reagent ActiFlo System Followed by Mycelx Media

Capital Cost Estimate - Case 2 Peak Flow = 4,000 gpm	
1 x 4,000 gpm ACTIFLO Concrete Basin Plant	$601,000
Sludge Holding Tank (3,000 gallon)	$8,000
Filter Press (8 cubic feet)	$24,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$721,000**
Freight (3% of Equipment Cost)	$22,000
Installation (10% of Equipment Cost)	$72,000
Site preparation (5% of Equipment Cost + Concrete)	$77,000
Electrical (10% of Equipment Cost)	$72,000
Piping (20% of Equipment Cost)	$144,000
Total	$892,000
Contingency @ 25%	$223,000
Total with Contingency	**$1,115,000**

Operating Cost Estimate - Case 2
Design Storm = 500,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Polymer	0.20 mg/L (0.83 lb)	$3,500/ton	$1.46
Sand	1.0 g/m3	$80/ton	$0.17
Coagulant Fe2(SO4)3)	100 mg/L (417 lbs)	$350/ton	$73.02
Biopraxis Reagent			
Power Consumption	30.0 HP	$0.114/KWh	$61.21
Sludge Disposal	520 lbs	$40/ton	$10.40
Labor	8 hrs	$35/hr	$280.00
Total Estimated Operating Cost Per Design Storm Event			$426.25
Mycelx Media	10 ft/yr	$100/10 ft	$100.00
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$1,805.01
Estimated Maintenance Per Year (2% of Equipment Cost)			$14,400.00
Total Estimated Operating and Maintenance Cost Per Year			**$16,205.01**

Option 8 - MOP-UP Reagent ActiFlo System Followed by Mycelx Media

Capital Cost Estimate - Case 3 Peak Flow = 8,000 gpm	
1 x 8,000 gpm ACTIFLO Concrete Basin Plant	$747,000
Sludge Holding Tank (6,000 gallon)	$12,000
Filter Press (16 cubic feet)	$37,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$884,000**
Freight (3% of Equipment Cost)	$27,000
Installation (10% of Equipment Cost)	$88,000
Site preparation (5% of Equipment Cost + Concrete)	$116,000
Electrical (10% of Equipment Cost)	$88,000
Piping (20% of Equipment Cost)	$177,000
Total	$1,380,000
Contingency @ 25%	$345,000
Total with Contingency	**$1,725,000**

Operating Cost Estimate - Case 3
Design Storm = 1,000,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Polymer	0.20 mg/L (1.67)	$3,500/ton	$2.92
Sand	1.0 g/m3	$80/ton	$0.33
Coagulant Fe2(SO4)3)	100 mg/L (835 lbs)	$350/ton	$146.04
Biopraxis Reagent			
Power Consumption	60.0 HP	$0.114/KWh	$122.41
Labor	12 hrs	$35/hr	$420.00
Total Estimated Operating Cost Per Design Storm Event			$691.71
Mycelx Media	10 ft/yr	$100/10 ft	$100.00
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$2,866.82
Estimated Maintenance Per Year (2% of Equipment Cost)			$17,700.00
Total Estimated Operating and Maintenance Cost Per Year			**$20,566.82**

Option 8 - MOP-UP Reagent ActiFlo System Followed by Mycelx Media

Capital Cost Estimate - Case 4 Peak Flow = 35 gpm	
500 GPM Actiflo Prefabricated Steel Package Plant	$320,000
Sludge Holding Tank (2,000 gallon)	$6,000
Filter Press (8 cubic feet)	$16,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$430,000**
Freight (3% of Equipment Cost)	$13,000
Installation (10% of Equipment Cost)	$43,000
Site preparation (5% of Equipment Cost)	$22,000
Electrical (10% of Equipment Cost)	$43,000
Piping (20% of Equipment Cost)	$86,000
Total	$637,000
Contingency @ 25%	$160,000
Total with Contingency	**$797,000**

Operating Cost Estimate - Case 4
Design Storm = 250,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Polymer	0.20 mg/L (0.42 lb)	$3,500/ton	$0.73
Sand	1.0 g/m3	$80/ton	$0.08
Coagulant Fe2(SO4)3)	100 mg/L (209 lbs)	$350/ton	$36.51
Biopraxis Reagent			
Power Consumption	4.0 HP	$0.114/KWh	$2.83
Sludge Disposal	260 lbs	$40/ton	$5.20
Labor	4 hrs	$35/hr	$140.00
Total Estimated Operating Cost Per Design Storm Event			$185.36
Mycelx Media	10 ft/yr	$100/10 ft	$100.00
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$841.42
Estimated Maintenance Per Year (2% of Equipment Cost)			$8,600.00
Total Estimated Operating and Maintenance Cost Per Year			**$9,441.42**

Option 8 - MOP-UP Reagent ActiFlo System Followed by Mycelx Media

Capital Cost Estimate - Case 5 Peak Flow = 70 gpm	
500 GPM Actiflo Prefabricated Steel Package Plant	$320,000
Sludge Holding Tank (3,000 gallon)	$8,000
Filter Press (8 cubic feet)	$24,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$440,000**
Freight (3% of Equipment Cost)	$13,000
Installation (10% of Equipment Cost)	$44,000
Site preparation (5% of Equipment Cost)	$22,000
Electrical (10% of Equipment Cost)	$44,000
Piping (20% of Equipment Cost)	$88,000
Total	$651,000
Contingency @ 25%	$163,000
Total with Contingency	**$814,000**

Operating Cost Estimate - Case 5 Design Storm = 500,000 gallons			
Item	**Estimated Average Per Design Storm Event**	**Estimated Unit Cost**	**Estimated Operating Cost Per Design Storm Event**
Polymer	0.20 mg/L (0.83 lb)	$3,500/ton	$1.46
Sand	1.0 g/m3	$80/ton	$0.17
Coagulant Fe2(SO4)3)	100 mg/L (417 lbs)	$350/ton	$73.02
Biopraxis Reagent			
Power Consumption	4.0 HP	$0.114/KWh	$5.67
Sludge Disposal	520 lbs	$40/ton	$10.40
Labor	8 hrs	$35/hr	$280.00
Total Estimated Operating Cost Per Design Storm Event			$370.71
Mycelx Media	10 ft/yr	$100/10 ft	$100.00
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$1,582.86
Estimated Maintenance Per Year (2% of Equipment Cost)			$8,800.00
Total Estimated Operating and Maintenance Cost Per Year			**$10,382.86**

Option 8 - MOP-UP Reagent ActiFlo System Followed by Mycelx Media

Capital Cost Estimate - Case 6 Peak Flow = 140 gpm	
500 GPM Actiflo Prefabricated Steel Package Plant	$320,000
Sludge Holding Tank (6,000 gallon)	$12,000
Filter Press (16 cubic feet)	$37,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$457,000**
Freight (3% of Equipment Cost)	$14,000
Installation (10% of Equipment Cost)	$46,000
Site preparation (5% of Equipment Cost)	$23,000
Electrical (10% of Equipment Cost)	$46,000
Piping (20% of Equipment Cost)	$91,000
Total	$677,000
Contingency @ 25%	$169,000
Total with Contingency	**$846,000**

Operating Cost Estimate - Case 6 Design Storm = 1,000,000 gallons			
Item	**Estimated Average Per Design Storm Event**	**Estimated Unit Cost**	**Estimated Operating Cost Per Design Storm Event**
Polymer	0.20 mg/L (1.67)	$3,500/ton	$2.92
Sand	1.0 g/m3	$80/ton	$0.33
Coagulant Fe2(SO4)3)	100 mg/L (835 lbs)	$350/ton	$146.04
Biopraxis Reagent			
Power Consumption	4.0 HP	$0.114/KWh	$11.33
Sludge Disposal	1040 lbs	$40/ton	$20.80
Labor	12 hrs	$35/hr	$420.00
Total Estimated Operating Cost Per Design Storm Event			$601.43
Mycelx Media	10 ft/yr	$100/10 ft	$100.00
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$2,505.70
Estimated Maintenance Per Year (2% of Equipment Cost)			$9,100.00
Total Estimated Operating and Maintenance Cost Per Year			**$11,605.70**

Option 9 - MOP-UP Reagent Microfiltration System followed by Ametek

Capital Cost Estimate - Case 1 Peak Flow = 2,000 gpm	
High Flow Microfiltration System	$244,000
120,000 Gallon Equalization Tank	$96,000
Oil Skimmer	$5,000
Transfer Sump	$25,000
Pumps with controls (2000 gpm)	$55,000
Sludge Holding Tank (2,000 gallons)	$6,000
Filter Press (4 cubic feet)	$16,000
Oil Adsorbing Media Filter Assembly	$6,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$541,000**
Freight (3% of Equipment Cost)	$16,000
Installation (10% of Equipment Cost)	$54,000
Site Preparation (5% of Equipment Cost)	$27,000
Electrical (10% of Equipment Cost)	$54,000
Piping (20% of Equipment Cost)	$162,000
Total	$854,000
Contingency @ 25%	$214,000
Total with Contingency	**$1,068,000**

Operating Cost Estimate - Case 1 Design Storm = 250,000 gallons			
Item	**Estimated Average Per Design Storm Event**	**Estimated Unit Cost**	**Estimated Operating Cost Per Design Storm Event**
Biopraxis Reagent			
Power Consumption	100 HP	$0.114/KWh	$204.02
Clerify Filter Cartridges	1 cartridge	$40 each`	$40.00
Transfer Pumps	40 HP	$0.114/KWh	$81.61
Sludge Disposal	260 lbs	$40/ton	$5.20
Labor	4 hrs	$35/hr	$140.00
Total Estimated Operating Cost Per Design Storm Event			$470.83
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$1,883.33
Estimated Maintenance Per Year (2% of Equipment Cost)			$10,800.00
Total Estimated Operating and Maintenance Cost Per Year			**$12,683.33**

Option 9 - MOP-UP Reagent Microfiltration System followed by Ametek

Capital Cost Estimate - Case 2 Peak Flow = 4,000 gpm	
High Flow Microfiltration System	$244,000
300,000 Gallon Equalization Tank	$240,000
Oil Skimmer	$5,000
Transfer Sump	$25,000
Pumps with controls (4000 gpm)	$83,000
Sludge Holding Tank (3,000 gallons)	$8,000
Filter Press (8 cubic feet)	$24,000
Oil Adsorbing Media Filter Assembly	$6,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$723,000**
Freight (3% of Equipment Cost)	$22,000
Installation (10% of Equipment Cost)	$72,000
Site Preparation (5% of Equipment Cost)	$36,000
Electrical (10% of Equipment Cost)	$72,000
Piping (20% of Equipment Cost)	$217,000
Total	$1,142,000
Contingency @ 25%	$286,000
Total with Contingency	**$1,428,000**

Operating Cost Estimate - Case 2
Design Storm = 500,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Biopraxis Reagent			
Power Consumption	100 HP	$0.114/KWh	$204.02
Clerify Filter Cartridges	2 cartridges	$40 each	$80.00
Transfer Pumps	60 HP	$0.114/KWh	$122.41
Sludge Disposal	520 lbs	$40/ton	$10.40
Labor	8 hrs	$35/hr	$280.00
Total Estimated Operating Cost Per Design Storm Event			$696.84
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$2,787.35
Estimated Maintenance Per Year (2% of Equipment Cost)			$14,500.00
Total Estimated Operating and Maintenance Cost Per Year			**$17,287.35**

Option 9 - MOP-UP Reagent Microfiltration System followed by Ametek

Capital Cost Estimate - Case 3 Peak Flow = 8,000 gpm	
High Flow Microfiltration System	$244,000
1,000,000 Gallon Equalization Tank	$800,000
Oil Skimmer	$5,000
Transfer Sump	$25,000
Pumps with controls (4000 gpm)	$126,000
Sludge Holding Tank (6,000 gallons)	$12,000
Filter Press (16 cubic feet)	$37,000
Oil Adsorbing Media Filter Assembly	$6,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$1,343,000**
Freight (3% of Equipment Cost)	$40,000
Installation (10% of Equipment Cost)	$134,000
Site Preparation (5% of Equipment Cost)	$67,000
Electrical (10% of Equipment Cost)	$134,000
Piping (20% of Equipment Cost)	$403,000
Total	$2,121,000
Contingency @ 25%	$530,000
Total with Contingency	**$2,651,000**

Operating Cost Estimate - Case 3
Design Storm = 1,000,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Biopraxis Reagent			
Power Consumption	100 HP	$0.114/KWh	$204.02
Clerify Filter Cartridges	3 cartridges	$40 each	$120.00
Transfer Pumps	120 HP	$0.114/KWh	$244.83
Sludge Disposal	1040 lbs	$40/ton	$20.80
Labor	12 hrs	$35/hr	$420.00
Total Estimated Operating Cost Per Design Storm Event			$1,009.65
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$4,038.61
Estimated Maintenance Per Year (2% of Equipment Cost)			$26,900.00
Total Estimated Operating and Maintenance Cost Per Year			**$30,938.61**

Option 9 - MOP-UP Reagent Microfiltration System followed by Ametek

Capital Cost Estimate - Case 4 Peak Flow = 35 gpm	
Microfiltration System	$104,000
Sludge Holding Tank (2,000 gallons)	$6,000
Filter Press (4 cubic feet)	$16,000
Oil Adsorbing Media Filter Assembly	$3,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$217,000**
Freight (3% of Equipment Cost)	$7,000
Installation (10% of Equipment Cost)	$22,000
Site Preparation (5% of Equipment Cost)	$11,000
Electrical (10% of Equipment Cost)	$22,000
Piping (20% of Equipment Cost)	$65,000
Total	$344,000
Contingency @ 25%	$86,000
Total with Contingency	**$430,000**

Operating Cost Estimate - Case 4
Design Storm = 250,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Biopraxis Reagent			
Power Consumption	11 HP	$0.114/KWh	$22.44
Clerify Filter Cartridges	1 cartridge	$40 each	$40.00
Sludge Disposal	260 lbs	$40/ton	$5.20
Labor	4 hrs	$35/hr	$140.00
Total Estimated Operating Cost Per Design Storm Event			$207.64
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$830.57
Estimated Maintenance Per Year (2% of Equipment Cost)			$4,300.00
Total Estimated Operating and Maintenance Cost Per Year			**$5,130.57**

Option 9 - MOP-UP Reagent Microfiltration System followed by Ametek

Capital Cost Estimate - 5 Peak Flow = 70 gpm	
Microfiltration System	$122,000
Sludge Holding Tank (3,000 gallons)	$8,000
Filter Press (8 cubic feet)	$24,000
Oil Adsorbing Media Filter Assembly	$3,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$245,000**
Freight (3% of Equipment Cost)	$7,000
Installation (10% of Equipment Cost)	$24,000
Site Preparation (5% of Equipment Cost)	$12,000
Electrical (10% of Equipment Cost)	$24,000
Piping (20% of Equipment Cost)	$73,000
Total	$385,000
Contingency @ 25%	$96,000
Total with Contingency	**$481,000**

Operating Cost Estimate - Case 5
Design Storm = 500,000 gallons

Item	Estimated Average Per Design Storm Event	Estimated Unit Cost	Estimated Operating Cost Per Design Storm Event
Biopraxis Reagent			
Clerify Filter Cartridges	2 cartridges	$40 each	$80.00
Power Consumption	22 HP	$0.114/KWh	$44.89
Sludge Disposal	520 lbs	$40/ton	$10.40
Labor	8 hrs	$35/hr	$280.00
Total Estimated Operating Cost Per Design Storm Event			$415.29
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$1,661.14
Estimated Maintenance Per Year (2% of Equipment Cost)			$4,900.00
Total Estimated Operating and Maintenance Cost Per Year			**$6,561.14**

Option 9 - MOP-UP Reagent Microfiltration System followed by Ametek

Capital Cost Estimate - Case 6 Peak Flow = 140 gpm	
Microfiltration System	$203,000
Sludge Holding Tank (6,000 gallons)	$12,000
Filter Press (16 cubic feet)	$37,000
Oil Adsorbing Media Filter Assembly	$3,000
Centerflow Screen with compactor	$88,000
Total Estimated Equipment Cost	**$343,000**
Freight (3% of Equipment Cost)	$10,000
Installation (10% of Equipment Cost)	$34,000
Site Preparation (5% of Equipment Cost)	$17,000
Electrical (10% of Equipment Cost)	$34,000
Piping (20% of Equipment Cost)	$103,000
Total	$541,000
Contingency @ 25%	$135,000
Total with Contingency	**$676,000**

Operating Cost Estimate - Case 6 Design Storm = 1,000,000 gallons			
Item	**Estimated Average Per Design Storm Event**	**Estimated Unit Cost**	**Estimated Operating Cost Per Design Storm Event**
Biopraxis Reagent			
Clerify Filter Cartridges	3 cartridges	$40 each	$120.00
Power Consumption	44 HP	$0.114/KWh	$89.77
Sludge Disposal	1040 lbs	$40/ton	$20.80
Labor	12 hrs	$35/hr	$420.00
Total Estimated Operating Cost Per Design Storm Event			$650.57
Total Estimated Operating Cost Per Year (Based on 4 Storm Events per year)			$2,602.28
Estimated Maintenance Per Year (2% of Equipment Cost)			$6,900.00
Total Estimated Operating and Maintenance Cost Per Year			**$9,502.28**