Controlling Oil Spills in Fast Currents - the Flow~Diverter Approach

by

Tom Coe
CSC Advanced Marine Center
1201 M Street SE, Suite 300
Washington, DC 20003
202 675-6824
tcoe@csc.com
Web www.amc.csc.com

Jim Mackey
Hyde Marine
28045 Ranney Parkway
Cleveland, OH 44145
440 871-8000
jmackey@hydemarine.com
Web www.hydemarine.com

Abstract

Sixty nine percent (645 million tons) of oil is transported on United States waterways annually where currents routinely exceed one knot. Conventional skimmers and booming methods quickly lose effectiveness as current speed increases above 1 knot. The US Coast Guard recognized that this threat could not be easily controlled, and so they initiated a project that led to the successful development of a novel spill control device, the Oil Spill Flow~Diverter™.

The Flow~Diverter system is effective at diverting and converging oil at speeds up to 5+ knots. In more moderate currents it can also be used in place of an anchor, towboat or outrigger arm to deploy and position the outboard end of a deflection boom. It can also be used to disperse oil and assist with in-situ burn operations.

The diverter is a unique stable catamaran design that consists of two hulls. Each hull is comprised of symmetrical foils with integral buoyancy. The foils are pinned to a rigid connecting structure such that they can pivot but always remain parallel to each other. Two or more diverter catamarans can be connected together with cables to increase the total sweep width of the system. Two control lines are anchored to shore or secured to a boat and are used to deploy the system by adjusting the foils' angle to the oncoming water.

With the control lines securely anchored, the system is launched into the current and "flies out" into a stable operating position. It remains in equilibrium, balanced by the hydrodynamic lift forces of the passing water and the tension in the lines. The foils create a strong transverse surface current downstream to achieve the desired diversion and consolidation affect on floating oil. Unlike most skimmers and deflection boom, the diverters are not adversely affected as currents increase. The oil is diverted by the same amount irrespective of the current or speed of advance.

The Flow~Diverter development, testing and product improvements are presented. Several applications of the diverter technology are shown and various response tactics are discussed in this paper.

Problem:

Containment and removal of oil spilled in inland rivers and coastal tidal regions where currents exceed one knot is very difficult because many skimmers and conventional booming methods are not effective in fast currents. The oil will generally entrain and follow the water path under the boom or skimmer when currents exceed one knot unless it is prevented by a deflection, containment or the recovery device. This can be accomplished using specialized equipment and tactics; however, good equipment and properly trained response personnel are essential for ultimate success. Some fast-water skimmers collect the oil as it goes by the recovery device through various means such as surface slicing, sorbent properties and quiescent zones. Other high-speed containment systems slow down the surface water to prevent oil entrainment through the use of baffles, inclined planes or expanding chambers. The oil can also be redirected and concentrated if a flow diversion device influences the surface current direction, which is the subject of this paper.

Fast water creates large drag forces on equipment making them difficult to anchor or maneuver, and often causing equipment failure (submergence, planing and breakage). Maneuvering boats and equipment in fast water is dangerous. Fast water accelerates many spill processes, necessitating quicker and more efficient responses compared to stagnant water or slow-moving current conditions. Timely response efforts are required in order to minimize environmental damage, economic losses and associated cleanup costs.

Sixty nine percent (645 million tons) of oil is transported on United States waterways annually where currents routinely exceed one knot.[1] Another spill source are the thousands of facilities that are located on the banks of fast-current waterways that store millions of gallons of oil. Thousands of oil pipelines traverse fast-water rivers and bays, which also poses oil spill threats. Between 1992 and 1998 fifty eight percent of all oil spilled in the US occurred in fast-current waterways. This figure represents 4.5 million gallons of oil spilled in swift flowing rivers, harbors and coastal areas where conventional boom and skimmers are often ineffective[1].

Background:

The USCG Research and Development Center initiated a request for proposal for the development of innovative fast-water spill response equipment to address this critical gap in the industry. CSC Advanced Marine Center won a $50K contract to develop and demonstrate the Oil Spill Flow~Diverter™ (patent pending) concept.

Technical Approach:

Concept and Previous Work

Flow~diverters are floating deflectors comprised of a series of parallel foils positioned in a vertical orientation. The interaction of the hydrodynamic lift and drag forces on the foils due to the passing water are balanced by tension in the control lines. The flow~diverters thus fly out into the current and attain a steady state angle to the current. Their attack angle to the oncoming water changes the surface current direction down stream and thus diverts oil to shore. This diversion process can move the oil away from a sensitive area or to a shore-side inlet or shallow area where the current slows down and the oil can be collected by conventional means. The concept transforms the natural energy in the river or tidal current flow into a secondary or transverse surface current to achieve the desired oil diversion effects. The flow~diverters can be easily deployed and retrieved from shore without the use of a boat by controlling the angle of attack of the foils with two control lines. The flow~diverters can be quickly retrieved to shore by one person to allow vessels or large debris to pass. Moderate size debris will flow through the system. The foils influence the surface current down stream and direct it and the oil toward the mooring location. In shallow water, the diverters set up a spiral circulation pattern in the water column accentuating the diversion effect. In the 1970's, field tests conducted with large deflectors in the St. Lawrence River proved successful to divert 90 percent of plastic pellets simulating oil into a low current tributary when only 40 percent were naturally diverted there.[2] Oil diversion in navigable rivers and coastal areas can also be achieved by using several sets of diverters in a cascade manner as seen in Figure 1.

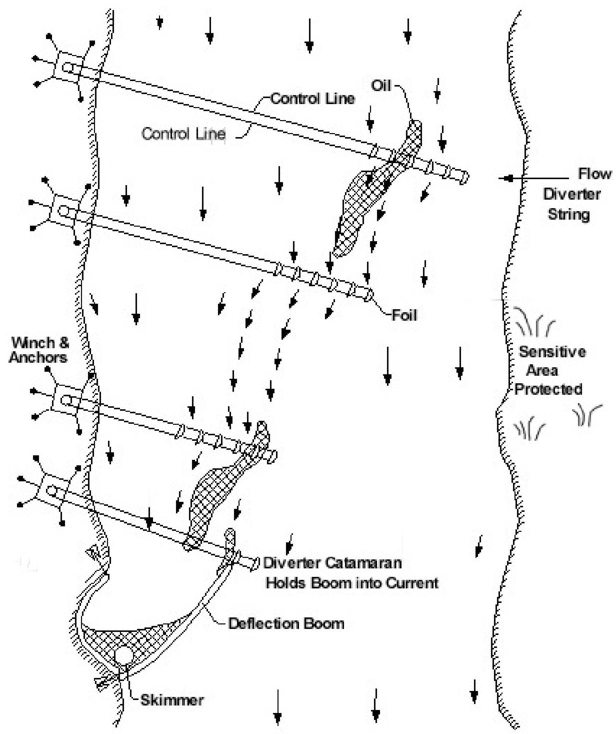

Figure 1. Flow Diverters in a Cascade Tactic

The oil is herded to shore where currents are slower and conventional booms and skimmers can collect and remove the oil. Flow~diverters can also be used as an advancing system from a boat. One tactic is to concentrate oil into narrow rows for skimmer collection. This is accomplished by towing a flow diverter system off both sides of a vessel. The oil will be directed by the diverters into the wake of the vessel where a trailing skimmer can collect it. This can also be accomplished by mooring two opposing diverter systems in a river or tidal current.

Flow~diverters will continue to divert oil in currents well above the speeds at which conventional deflection boom and skimmers loose their effectiveness. The Flow~Diverter system's effective sweep width and diversion capabilities are not degraded in faster currents as conventional deflection boom tactics and skimmers are degraded.

They were successfully demonstrated in the mid-1970's in Canada but were not commercially developed because the foils were too heavy and big and hard to deploy. Initial flume testing showed that diverters with a height 1/3rd the depth of the test channel were most effective because they produced a spiral circulation pattern in the water column down stream of the deflectors. The transverse current decayed at an exponential rate down stream. We believe this height to depth ratio concept was incorrectly applied to the field tests in the 45-foot deep St. Lawrence River field tests. The deflectors for these tests were huge, 16.4-foot height and 34-foot length with 34-foot spacing between them, in order to achieve that same 1/3rd height to channel depth ratio. In deep water, it is not necessary to influence the circulation pattern in the entire water column to be effective. Only the current direction in the top layer has to be changed to divert the oil. This approach will allow flow~diverters be a reasonable size that can be quickly transported and deployed by two people at the water's edge without a requirement for lifting equipment or boats. Under the USCG contract our goal was to design, fabricate and test flow diverters that will be effective at diverting oil in shallow as well as deep water.

Design

The oil spill flow diverters were developed with the following operational requirements.

- Deflect oil in currents up to 7 knots
- Deployable from the shore or by boat with no additional resources
- Transportable to the spill scene in a pickup truck or boat
- Setup quickly by two people.

The design team consisted of Tom Coe, an Ocean Engineer and retired Coast Guard Officer, and Otto Scherer, a senior Naval Architect, both CSC Advanced Marine Center employees. Stability calculations showed that at above 3 knots a typical foil design would dive and submerge with expected roll angles of 15 degrees due to the downward lift component exceeding reserve buoyancy. The control lines alone were not considered adequate to prevent this problem. A catamaran design was selected to maintain roll stability and prevent subsequent diving and planing associated with excessive rolling or heel. This configuration also facilitated foil control during deployments. The catamaran design makes it easier to open the foils with the control lines and it also prevents the foils from getting tangled in the lines by keeping them parallel and separated. As seen in Figure 2, there are two upper and two lower pipes and control attachment pad-eyes on each end of the foil pair. The lower pipes are covered with plastic vinyl Zipper-tube fairings to reduce drag and turbulence. These one-inch diameter lower pipes were eventually

Figure 2. Two Prototype Diverter Catamarans

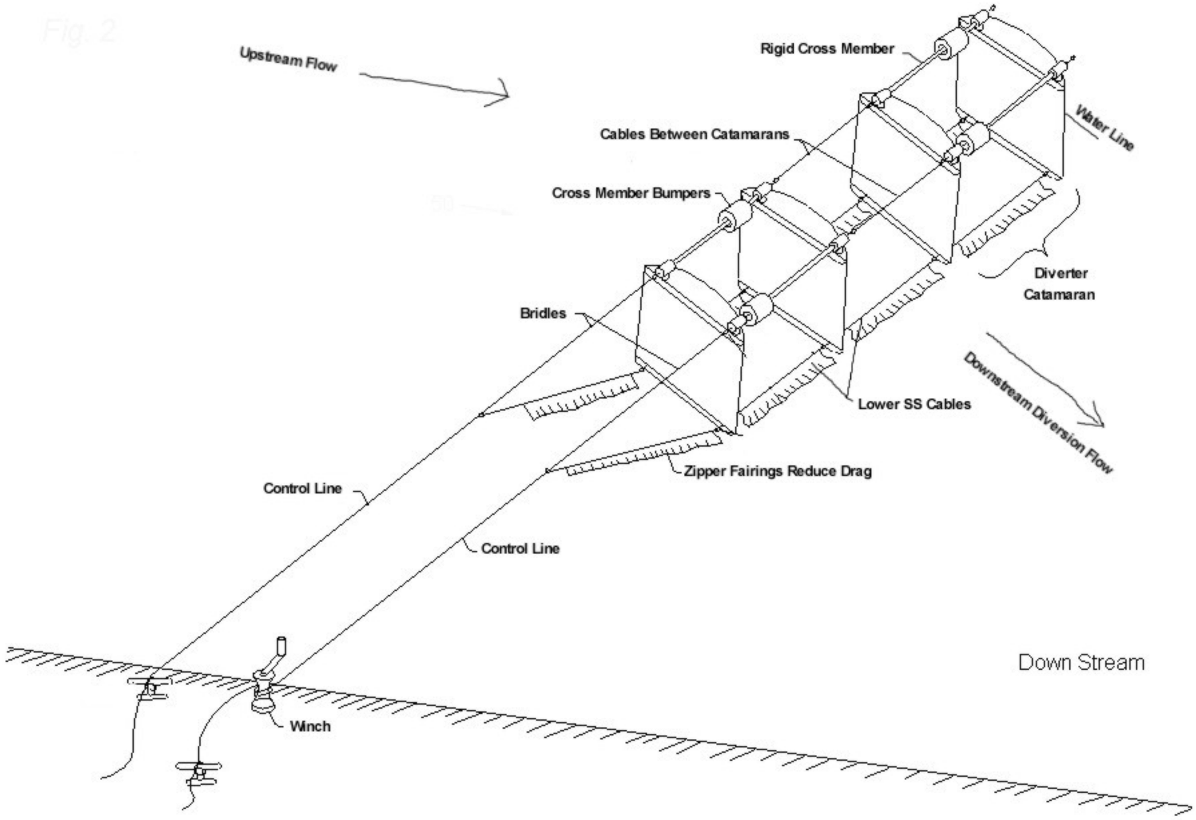

Figure 3. Two Diverter Catamarans in an Array

replaced with 5/16th-inch stainless steel cables to further reduce drag and weight as seen in Figure 3. Tests at OHMSETT showed that the catamarans rode at a more level trim angle and had less splashover at high speeds with lower cables in lieu of the higher diameter pipes. Roll stability is attained by using two upper cross pipes and two lower cables that also function as control points that are pinned into the vertical axis of the foils. This allows for the two foils to pivot on the cross members parallel to each other. The angle of attack is adjusted by control lines to fly them out into the current and back into shore.

Circulating Water Channel Tests

Tests were conducted in May 2000 at the Naval Surface Warfare Center Carderock Division (NSWCCD) Bethesda, MD in a circulating water channel (CWC). The channel, Figure 4, has a test section open to the atmosphere and a closed recirculating water circuit with variable speed. The working section dimensions are 60 ft length, 22 ft width and 9ft depth with 3.3 ft of freeboard above the free water surface. This channel was large enough to test full-scale response equipment and thus eliminate scaling effects in the development process. This test configuration simulates a river under controlled conditions.

The initial prototype catamaran when collapsed with the foils in line with each other, had a heel angle which made it difficult to open when adjusting the control lines. This problem was corrected by adding additional foam to the inboard side of the prototype foil hulls. The curved foils are formed from 3/16-inch thick aluminum plate with 1/4-inch thick end caps. The end

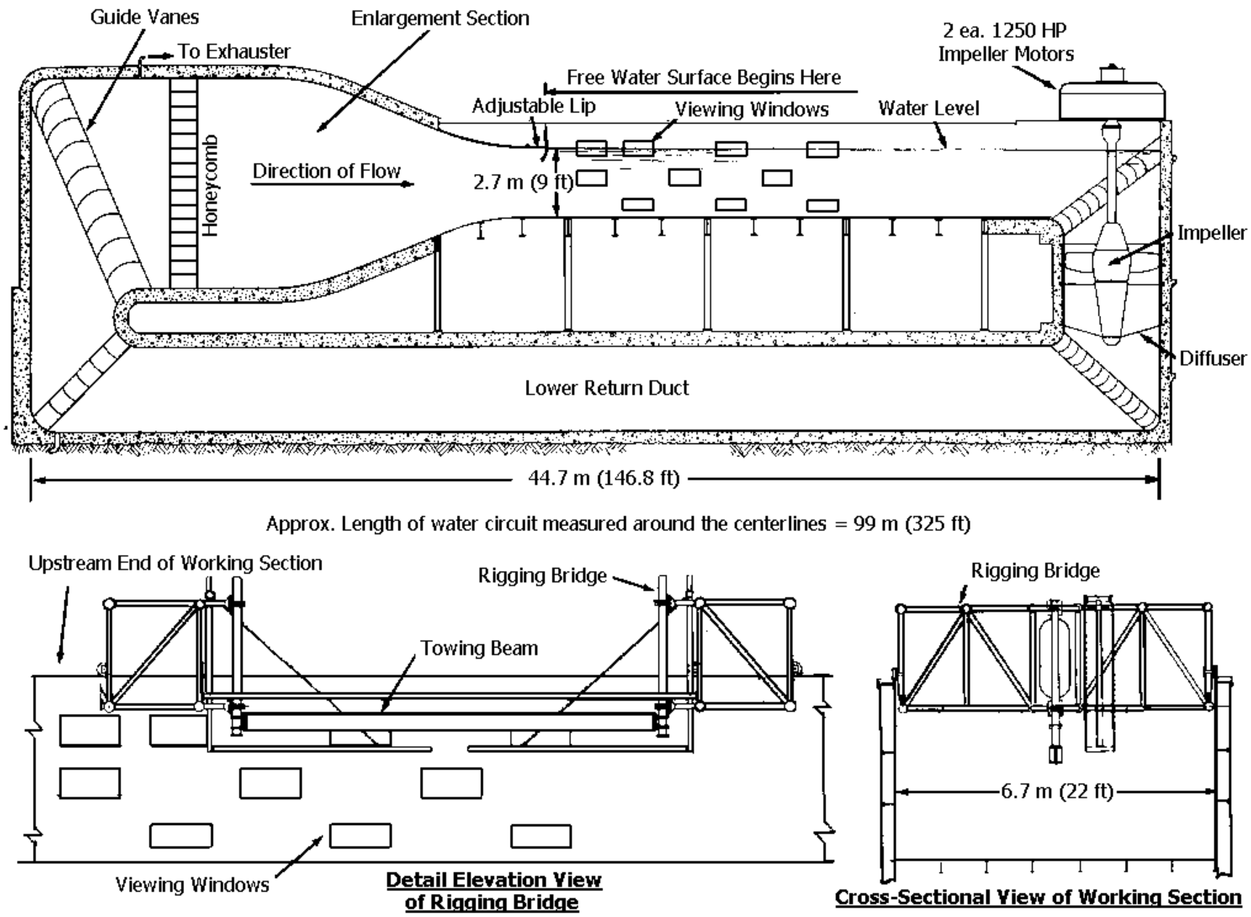

Figure 4. NSWCCD Circulating Water Channel

caps add rigidity to the foils and allow cross members to be inserted and pinned in place through reinforced holes. The hull consists of closed-cell foam 16-inches high that was cut with a hot wire using templates that matched the curvature of the foil. They were then epoxied to the each side of the foil top. The foam is covered with 6-ounce fiberglass cloth and epoxy coated for improved durability. The final prototype catamaran is shown in Figure 5 in the CWC. The diverters have 2-foot draft, 9-inch freeboard and are connected across the top with two 54-inch rigid pipe cross structures. The foils are 3.5 foot long with maximum open cord depth of 6-inches. The 3.5-foot long hull has a maximum enclosed cord depth of 15.5 inches. The foil and integral hull are completely symmetrical which enables them to be operated in a current coming from either direction without making any changes to the anchoring system or rigging. This is especially beneficial in tidal currents where the diverters can be used on both flood and ebb tides to divert oil toward the shore for containment. It also allows deployment from either side of a river or boat without any changes to the catamarans or rigging. Additional diverter catamarans are added to the system to increase the sweep width as required by attaching them with 54-inch long cables and alloy shackles, Figure 3.

One diverter catamaran was tested in the CWC at discrete currents from 1 to 7 knots. Tension was measured in each of the four bridles using a computer data acquisition system. Two bridles (top and bottom) connect to each of the two control lines. As we predicted, tension was higher on the forward control line. The aft control line with less tension is therefore best suited for adjusting the foils' angle of attack. The catamaran foils created a lift that is proportional to the transverse diversion current produced. The tension in the bridle cables increased substantially as the current and associated foil lift increased as seen in Table I. Lift forces and thus tensions in the bridles and control lines are proportional to the square of the current velocity.

Two of the four data sets evaluated two foils attached by cables in lieu of the rigid cross members. As anticipated, this made it very difficult to keep the foils upright. The first attempt resulted in an inboard heel of 10 degrees toward the mooring location. This caused the foils to rise partly out of the water in higher speed runs. Lengthening the top bridles eliminated this heel. The foils tended to get tangled in the cables when collapsed. It was difficult to deploy the foils in this configuration and the heel angle could not be easily controlled.

Oil deflection was measured using foam peanuts that simulated oil. The oil diversion effect was the same at all velocities. The diversion effect was limited due to side-wall effects. Diversion of the simulated oil was 8.3 feet over from the most inboard foil at 30 feet down stream. A 15-inch extension piece was bolted on the bottom of the foil to determine if oil diversion would be greater down stream, but this could not be determined due to the limited width of the channel. The extension piece, however, made the diverter more sensitive to control line changes and at high speed the catamaran became somewhat unstable with significant pitch down by the bow. Both foil configurations had flow separation at the back of the foils in currents of 4 knots and higher. Turbulence and waves were excessive above 5 knots. This may have been accentuated due the shallow water effect of the channel at 9-feet and probable side-wall effects. Cross member spacing was varied to determine if diversion would be improved and to see if hull wake could be minimized. The optimum spacing was determined to be 54-inches or 1.5 times the foil length. At four knots and above some simulated oil blockage occurred due to bow wave interference with hull spacing of 42 inches, a spacing that is equal to the hull length. Oil blockage did not occur with the wider 54-inch spacing at any speed up to 7 knots.

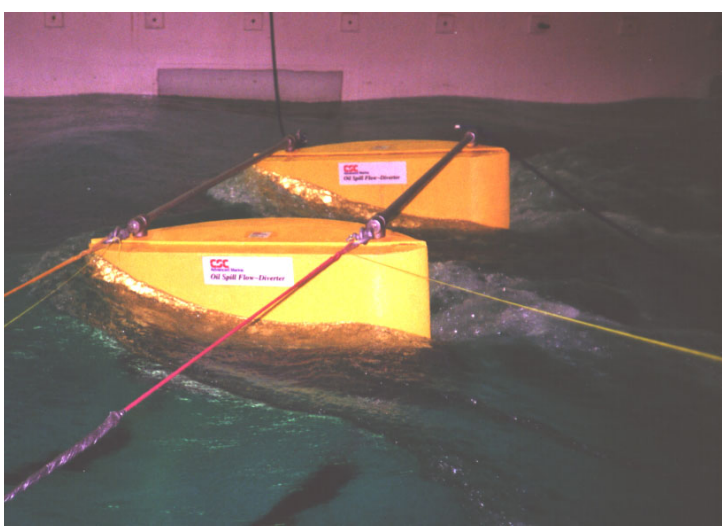

Figure 5. Final Design Tested at NSWCCD CWC 3 Knots – 54-inch Cross-Pipe Spacing

Table I. Tension Loads on a Catamaran Diverter

CSC Advanced Marine Oil Spill Flow~Diverter Tests at the NSWCCD Circulating Water Channel, May 2000

Tension Loads Measured on Two Diverter Foils (one Diverter Catamaran)

Run No. M/D/Time	Speed	Tension, Aft Bottom				Tension, Aft Top				Tension, Fwd Bottom				Tension, Fwd Top				Foil* Attack Angle	Array** Trail Angle	Diverter Configuration and Comments
		Avg	Min	Max	Std	Avg	Min	Max	Std	Avg	Min	Max	Std	Avg	Min	Max	Std			
	(kt)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(deg)	(deg)	
51514244	1.0	-20	-22	-18	1	3	-24	42	17	14	9	20	2	27	24	30	1.0	22.5	58.6	Catamaran 54-inch Pipe Spacing
51514312	2.0	9	2	19	2	45	4	90	21	64	50	77	5	68	58	80	3.5			
51514405	3.0	52	33	74	6	131	53	157	22	139	123	157	6	132	114	153	6.4	26.2	55.2	
51514540	4.0	153	127	179	8	282	190	337	33	293	260	320	9	295	264	335	9.8	26.2		
51515004	5.0	267	228	307	15	417	376	458	14	416	370	457	15	466	400	531	19.5	25.7	52.9	
51515054	6.0	354	260	442	27	495	420	560	22	564	463	670	34	624	502	750	38.9			
51515124	7.0	215	123	335	32	465	375	553	30	670	516	783	41	483	302	653	47.6	34.5		
51609194	1.0	-27	-31	-23	2	6	-26	45	19	40	33	46	3	14	11	17	0.9	32.2	53.8	54-inch Cable Spacing. No pipes used
51609235	2.0	15	8	20	2	53	18	96	21	134	121	148	4	48	42	52	1.6	34.5		
51609335	3.0	56	24	87	16	130	64	153	22	228	212	243	5	76	68	83	2.6	36.7	46.5	
51609400	4.0	105	81	132	7	206	184	242	9	360	325	410	12	110	94	133	6.0	39.3		Foils started to lift out due to inboard roll
51609455	5.0	158	136	184	6	206	157	225	6	347	309	387	12	96	81	113	5.0	44.4		10 degree heel caused by bridle lengths.
51610311	3.0	82	71	94	5	118	51	135	19	213	204	228	5	96	87	104	4	31.7	55.0	Increase top bridles length by two inches
51601344	4.0	231	206	264	9	237	214	254	6	383	346	417	9	204	180	228	6	31.7	53.6	each to obtain level trim (Cables Only)
51610400	5.0	390	346	425	12	304	275	340	9	522	470	580	16	293	261	333	11	31.1	54.6	
51610492	6.0	425	357	488	19	307	249	377	21	565	472	669	29	264	218	329	19	32.2		
51611041	7.3	376	256	610	88	325	202	453	47	618	410	845	84	289	155	528	92			
51614175	2.0	14	2	29	5	88	32	130	27	149	122	179	9	184	147	214	11	31.1	48.6	Catamaran with 15-inch extension
51614315	3.0	141	108	164	8	221	152	241	7	349	310	376	10	371	336	403	10	28.9	45.0	Adjust aft control line to even loading.
51614422	4.0	266	229	297	10	368	332	407	11	685	630	736	17	603	548	665	18	36.9	47.5	
51614500	5.0	398	325	474	20	431	358	524	21	875	772	985	35	738	618	885	34	39.3	45.5	
51615094	7.0	462	397	547	20	483	421	554	21	1025	909	1140	36	829	723	976	39	39.3	43.7	

Notes: * Foil angle of attack to the oncoming undisturbed flow stream
** Array angle is measured from the side of the tank to the forward control line.
Bridles are 9-foot long and attached to the catamaran upper and lower control points at a 3-foot vertical separation and respective control line at their apex

Operational field-testing was conducted on the Mississippi River in New Orleans in early June 2000. The current in the river varied between 1.3 and 3 knots during the tests. Tests were conducted off a barge moored to the side of the riverbank, Figure 6. Rice hulls were used to simulate oil. The diversion effect produced with only two catamarans is dramatic as shown in Figure 7. All oil going inboard and through the foils is diverted toward the shore by the transverse current that they create which is visible in Figure 7. Catamarans are attached to each other using stainless steel cables and alloy shackles. The foil attachment points, cables and control lines can take loads in excess of 9,000 pounds. This affords deployment of up nine diverter catamarans in an array in a 4-knot current and three in a 7-knot current. The orange pipe bumpers were added to keep the foils partially open when collapsed, Figure 6. This makes it easier to open the catamaran foils with the control lines.

Figure 6. Two Catamarans Deployed from a Stationary Barge, Mississippi River 1.5 knots

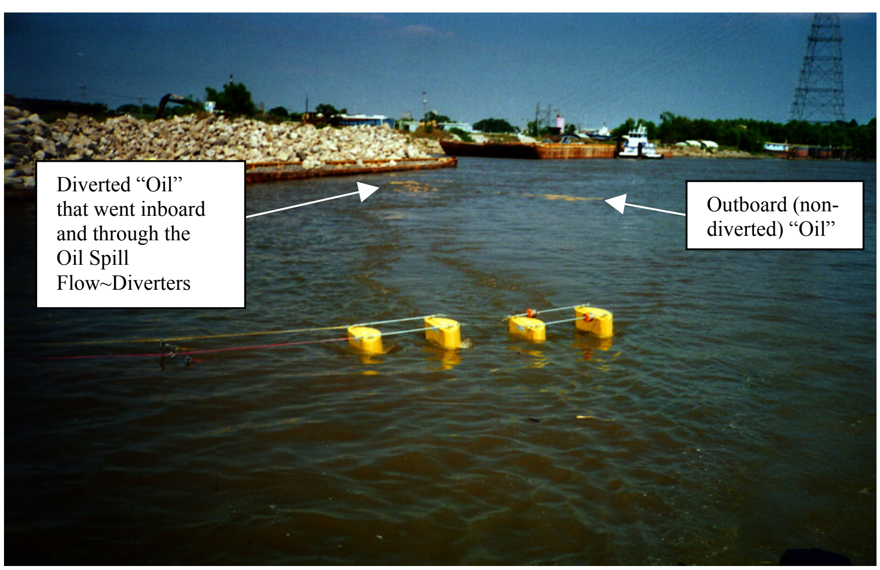

Figure 7. Rice Hulls (Simulated Oil) Down Stream; Show Separation and Diversion Effect.

The aft control line is pulled in to open the foils and they fly out into the current. Control lines and bridles are 5/16th-inch Spectra that is easy to handle. The angle of attack of the foils to the oncoming current is approximately 25-35 degrees under optimum conditions. The control line is adjusted until the diverter-array moves as far forward into the current as it can. This is the optimum diversion condition that is easily determined visually by the operator. At that point, the array attains a steady state 55-degree angle to the shoreline. The force required to adjust the length of the aft control line is reduced to a level easily handled by one operator when using a three-shive block and tackle or a winch, if available. The array is retrieved to shore by letting out the aft control line until the catamarans collapse or by pulling in on the aft control line until the foils stall. The diverter array performed well even in three-foot waves that were produced by passing tugs. When in the collapsed mode the two catamarans were towed at 9 knots behind the boat to simulate a fast transit situation.

The flow diverters were towed off a 24-foot boat proceeding up stream in the Mississippi River with a relative current up to 6.5 knots. That was the maximum speed the boat could attain towing the diverters with two 150-HP outboards. The boat had to crab into the current due to the large lift and diversion force "drag" of the diverters off the port stern. Oil would be diverted across the wake of the boat in the diversion line depicted in Figure 8. The diverters also performed well while being towed across and down stream as long as a relative velocity to the current was maintained at one knot or greater. This scenario could be used to dynamically divert oil away from a sensitive area in swift currents or to move it toward a recovery point. Another tactic is to tow one catamaran off each side of a boat, diverting oil into its wake for a trailing skimmer to retrieve it or to facilitate more efficient application of oil dispersants.

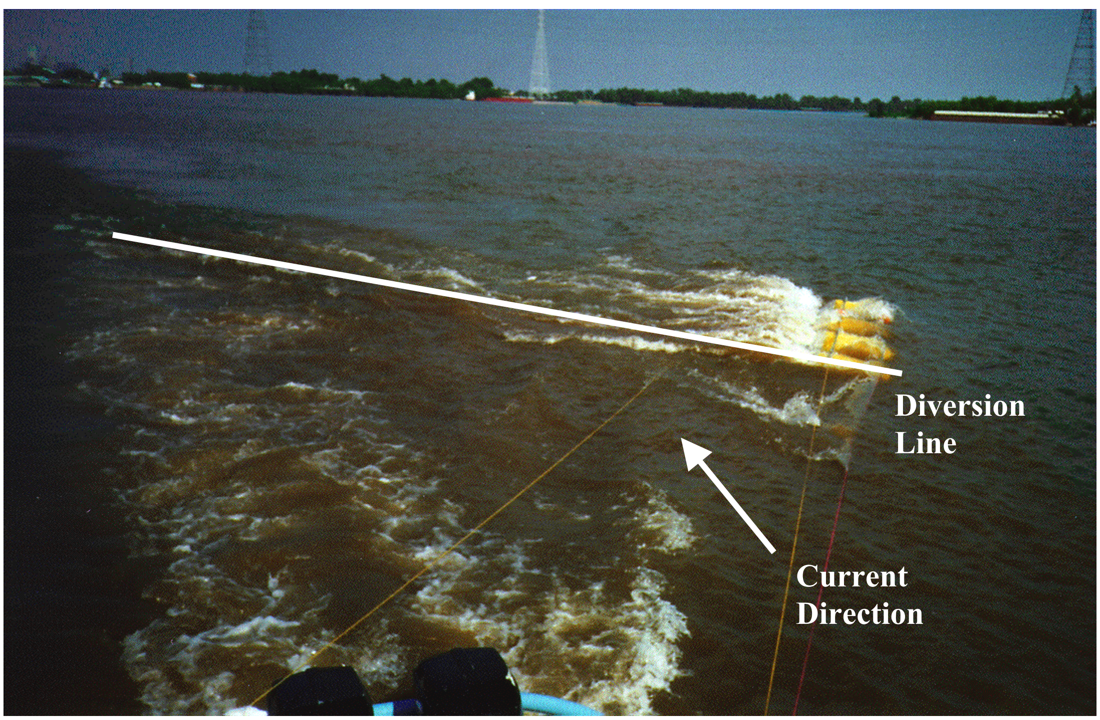

Figure 8. Diverter Catamarans Towed into Current (6 knots relative current)

When the diverters are collapsed they can be easily lifted by two people and quickly transported by a pickup truck or a boat to the scene, Figure 9. One Diverter Catamaran weighs 150 pounds and in the closed position is 8-feet long, 3.2-feet high with a depth of 1.3-feet. Since the draft is only two feet, they can be deployed from shore without the use of a boat.

Figure 9. Flow Diverter Catamaran Closed for Quick Transport or Storage

Tests completed in June 2000 at the OHMSETT tow tank in Leonardo, NJ demonstrated that the oil spill flow~diverters successfully controlled both light diesel and viscous Sundex 790 (20,000 cSt) oil in tests at 1 to 5 knots. With only two diverter catamarans, the diesel oil was diverted approximately 15-feet downstream from the most inboard diversion foil, as seen in Figures 10 and 11. The oil that went through the outboard catamaran hulls was also diverted to that inboard position resulting in a maximum diversion and consolidation oil of approximately 24 feet from the outermost hull of the array, Figure 11. Some oil was temporarily dispersed due to waves and turbulence at speeds of 4 knots and higher, however, the oil resurfaced within minutes in the same diverted position down stream which occurred in lower speed non-turbulent runs. Tension loads were substantial on the two catamarans at 5 knots, with an average of 1,362 lbs. on the forward control line and 11% less on the aft control line at 1,211 lbs. Average tension loads at

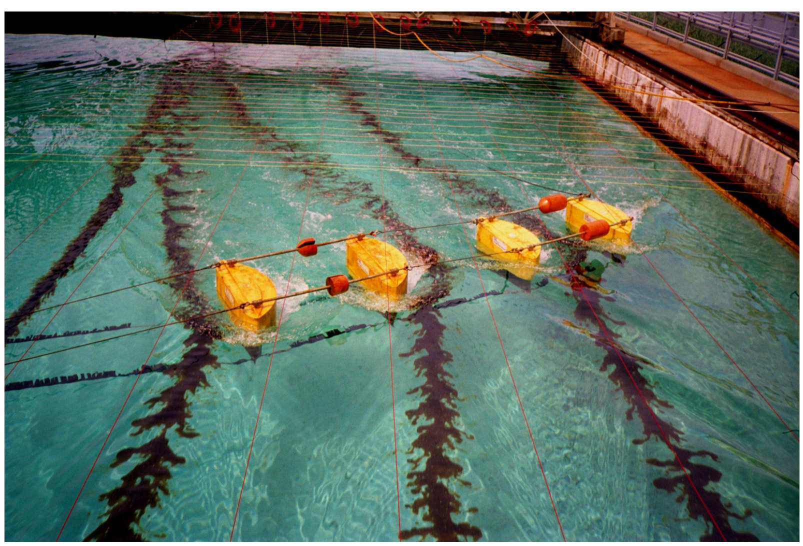

Figure 10. Oil Diverted at OHMSETT Test, 3 Knots

2 knots were, as expected much lower with 288 lbs. on the forward line and 30% less on the aft control line at 203 lbs. This demonstrates the need for high strength design and components in high-speed currents along with an effective anchoring system to handle the high loads. Spectra line of 5/16th inch diameter was selected as the control lines and bridles for its strength, ease of handling and low-drag characteristics. It can withstand loads in excess of 9,000 lbs., and it has insignificant stretch under load which minimizes the danger of snap back.

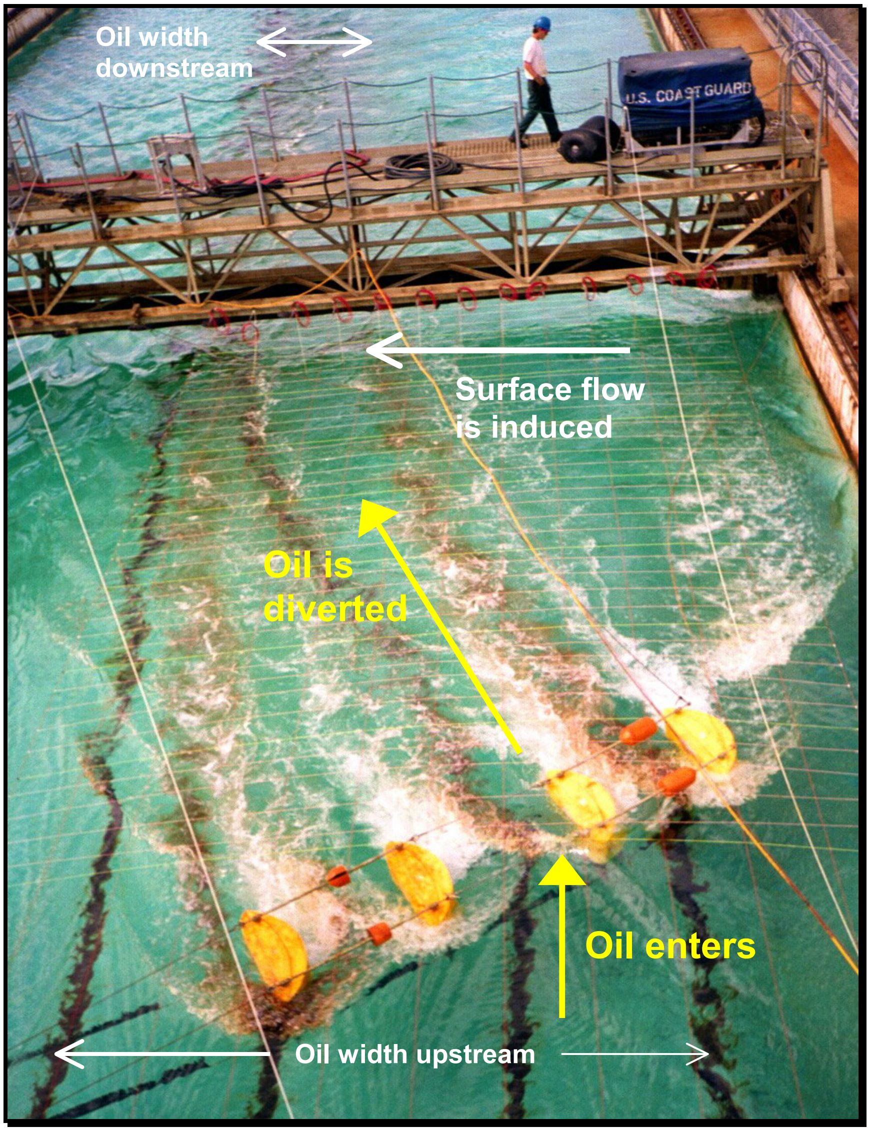

Figure 11. Diversion of Diesel Fuel at 4 knots in OHMSETT Tank

Production Product Improvements are jointly under way by CSC Advanced Marine Center and the Hyde Marine of Cleveland, Ohio. Improvements include: higher speed capabilities (7+ knots), lighter weight, variable draft (for shallow rivers) and tapered centerboard foils that are more debris tolerant. The new hull and centerboard foil design is shown in Figure 12. The two hulls will be attached in a diverter catamaran configuration in a manner similar to the prototype design. The draft is 24 inches, and this can be reduced as the river conditions dictate by raising and pinning the centerboard to lower drafts of 18-inches and 12-inches. Some oil diversion is also anticipated without the centerboard for very shallow or rocky conditions since the hulls also have a symmetrical foil shape and will have a draft of approximately 4 inches. Lower submerged support cables will not be required in the low-draft configuration. Higher speed performance is achieved with a more streamlined, 8-foot long hull. The longer hull and a higher length to beam ratio reduces the wave-making drag and turbulence. The hulls, just shy of 8 feet long, will fit into a pickup truck four abreast when they are disassembled from the rigid cross members. This design also affords longer cross members and will result in twice the diversion effect per catamaran compared to the initial prototype. This is accomplished by spacing the foils further apart, approximately 8-feet, within and between the catamarans. An array of four new-style catamarans will have a sweep width diversion effect of approximately 60 feet. Use of only one diverter catamaran will still divert and consolidate oil approximately 21 feet down stream. Sweep width of the improved design is calculated by the following formula:

$$SW(feet)=[(\text{number of catamarans in array}) \times 13] + 8.$$

The formula accounts for the nominal 55-degree angle of the diverter array and includes the diversion effect inboard of the innermost catamaran of 15 feet. We are in the process of looking for opportunities to demonstrate the prototype and the improved production model flow~diverters when available later this year in demanding fast-water conditions.

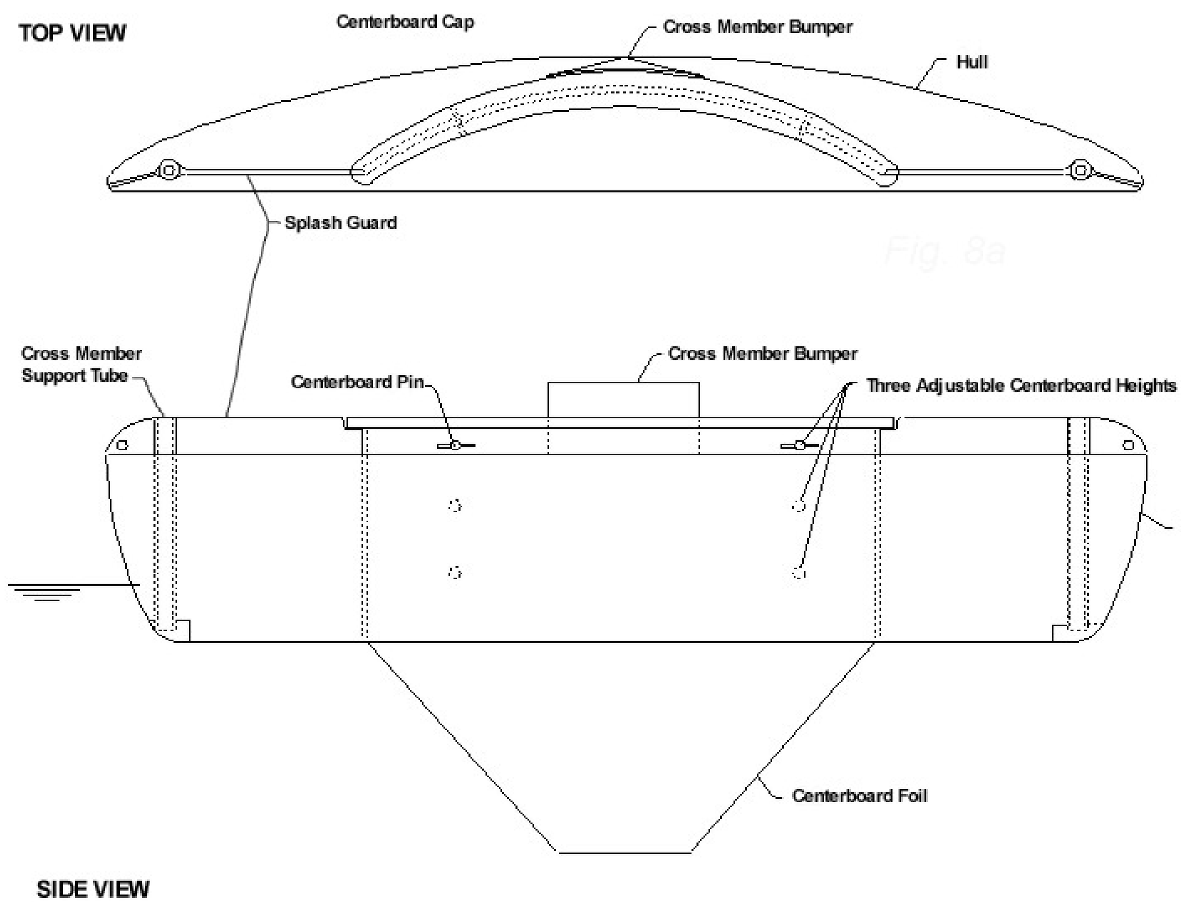

Figure 12. Centerboard Hull Configuration

Flow Diverter Vs Deflection Boom

In order to divert oil with deflection boom, the boom must be angled into the current to prevent oil entrainment. A faster current requires a steeper angle and thus more boom is needed to attain the same sweep width than in slower currents. Longer boom requires more anchors to keep it in shape and prevent oil entrainment. Boats are required to deploy the boom and associated mid-channel anchors.

Flow~diverters do not degrade in performance as the current increases. The diversion effect down stream remains the same as the current increases. The angle of the diverter array will decrease a bit due to added drag on the foil system in currents above five knots. Tests conducted in the circulating water channel with one diverter catamaran showed that the array steady-state control-line angle to the side of the tank was 55 degrees at five knots and this decreased to 44 degrees at 7 knots. There was no appreciable change in the control-line array angle between 1 and 5 knots. Therefore, a slightly longer array of diverters (16% longer) is required to attain the same sweep width at currents above 5 knots. Table II compares the two diversion methods to attain a 100-foot diversion sweep-width at various current speeds. Ten times the amount of deflection boom (1,071 feet) is required to divert oil with the same 100 feet sweep width at 7.5 knots, when compared to a 0.75 knot current where100 feet of boom is needed. This is due to the deflection angle required at higher speeds. The flow-diverter requirement barely changes over the same speed range, 8 diverter catamarans at 7.5 knots compared to 7 diverter catamarans at 1 knot to obtain the same 100-feet sweep width. Diverters require fewer anchors (all on shore) than deflection boom (most in the water) in currents above 1.5 knots.

Table II. Comparison of Deflection Boom with Flow~Diverter at 100-foot Sweep Width

	Deflection Boom			Flow~Diverter	
Velocity (knots)	Max Boom Deflection Angle (degrees)	Boom Required for 100-foot Profile to Current (feet)	Anchors if Placed every 50 ft (number)	Flow Diverter Catamarans (number)	Flow Diverter Anchors (number)
7.5	5	1,071	22	8	8
6.0	7	857	18	8	8
5.0	8	714	15	7	8
4.3	9	612	13	7	6
3.5	11	504	11	7	6
3.0	14	429	10	7	4
2.5	16	357	8	7	4
2.0	21	286	7	7	4
1.5	28	214	5	7	4
1.0	44	143	4	7	4
≤0.75	90	100+	3	NA	NA

Other Flow-Diverter Applications

One diverter catamaran develops enough lift to deploy and position a deflection boom or other equipment out into a current from shore, Figure 1. They eliminate the need for support boats and difficult to deploy mid channel anchors. A vessel can deploy boom and other equipment without the need for heavy and bulky outriggers by using the flow~diverter at speeds above one knot.

Other floating material such as foam and debris can also be controlled by the system. It may also have some applications in the fishing industry such as herding and collection of brine shrimp.

Oil can be dispersed by another embodiment of the flow~diverter system. Towing the diverter array at high speeds (above normal diversion velocities) will mechanically mix the oil without the use of dispersant chemicals. Waves and turbulence produced by the foils thus disperse the oil in the water column. The effectiveness of this action can be improved with the use of dispersant chemicals. These are distributed through the use of a pump, distribution hose and nozzles mounted on the leading cross structures and connection cables of the diverter array, Figure 13. Impellers are towed off the trailing cross members to further improve the oil dispersion and effectiveness of the applied dispersant if it is used. This system has an advantage over arial spraying and ship outrigger spraying techniques. Arial spraying is hit or miss since the droplets do not always reach the water and droplet size is difficult to control. Both arial and ship outrigger dispersant systems require proper wave-induced mixing for it to be effective. The Diverter~Disperser allows for effective dispersion in calm (no wind) conditions when other techniques require a minimum 15-knot wind. This opens the window-of-opportunity for dispersant response. The diverter foils are also lighter weight and more easily transported than standard dispersant outriggers. When fabricated from fire resistant materials or outfitted with water-spray nozzles the diverter system can also be used to control burning oil.

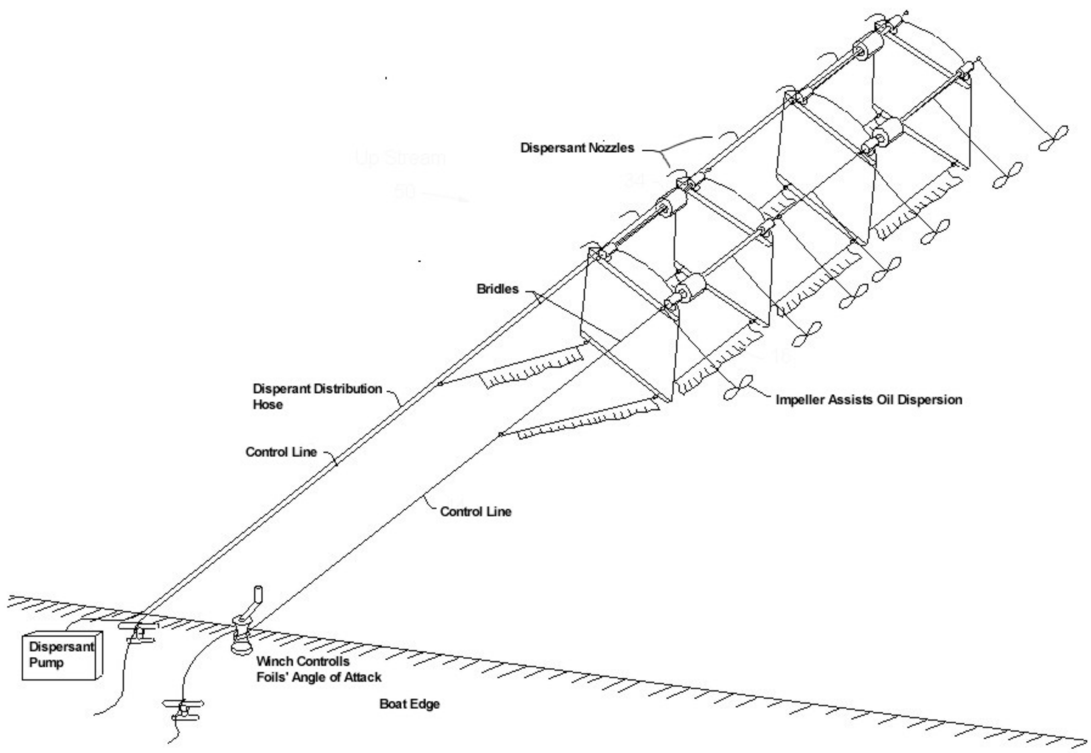

Figure 13. Oil Dispersant Deployed and Mixed by the Diverter System

Conclusions

The Flow~Diverter™ system and method (patent pending) is a promising new tool for timely response to spills in fast moving water and as an effective high-speed advancing system. It can be used to divert oil away from sensitive areas or effectively herd and concentrate oil for recovery in currents up to 5+ knots. The foils of one catamaran develop enough lift that allows it to also be used to deploy and position a diversion boom. Other embodiments of the invention disperse oil and assist with insitu burning. Fast currents and shallow water do not degrade it's performance.

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