The Design of an Electrohydraulic Dredge for Clam Surveys

RONALD JOEL SMOLOWITZ and VERNON E. NULK

ABSTRACT—A clam dredge system, using an electrically driven submersible pump, was designed for surf clam, Spisula solidissima, *and ocean quahog,* Arctica islandica, *surveys along the northeast coast of the United States in water depths to 100 m. The 3,200 kg, 5.2 m long dredge has a 1.52 m cutting knife and pumps 7,570 l per minute through the cutting jet manifold. The pump power requirement is 100 amps of 460 V AC 3-phase current provided via a special cable by the ship's 150 kW generators. This paper describes the design of the dredge and the operating experiences to date.*

Introduction

The Northeast Fisheries Center (NEFC) of the National Marine Fisheries Service, formerly the Bureau of Commercial Fisheries, has been conducting clam surveys off the northeastern United States since 1963. Initially these were exploratory surveys mostly concerned with determining the distribution and potential for commercial utilization of the Atlantic surf clam, *Spisula solidissima.* A variety of vessels, gears, and methods were used. These surveys also revealed that a large ocean quahog, *Arctica islandica,* resource existed in the Middle Atlantic region between depths of 40 and 60 m (Murawski and Serchuk, 1979).

In 1977 two important trends forced a change in clam survey procedure. The first was the decline in the surf clam populations due to intense fishing pressure and a massive natural kill in 1976. These factors increased the pressure on the deeper ocean quahog beds. The second trend, the direct result of the Magnuson Fishery Management and Conservation Act, was the need for more consistent and reliable resource data for management purposes. These two trends strengthened the need for an improved standard survey to measure distribution and production potential of both the surf clam and ocean quahog stocks.

The experimental design for the new standard survey consists of performing tows of 5 minutes duration at about 350 depth-stratified but randomly selected stations in depths from 18 to 110 m. A towing speed of 1.5 knots is constantly maintained with the aid of a shipboard doppler speed log.

One of the key requirements of the new survey was to insure that the dredge used could be operated in a consistent and efficacious manner. This was no simple task considering the various depths and substrates the survey sampled.

Existing commercial and survey hydraulic clam dredges operate using a deck-mounted pump to supply water to the dredge via a hose (Fig. 1). The hose, which is 6-10 inches (15.2-25.4 cm) in diameter, is assembled in sections, and the overall length is a function of the depth being worked. Commercial fishermen have found that the dredge efficiency is significantly affected by supply pressure and volume as well as substrate type. Variations in hose length should then also affect dredge operation.

Basic Concept Development

The dredge system in use at the time the choice was made to go to a new survey was a 48-inch (122 cm) surface-supplied hydraulic dredge (Fig. 2). The dredge was of two-piece construction as it was originally built to be handled over the side. Water was supplied by a 6-inch

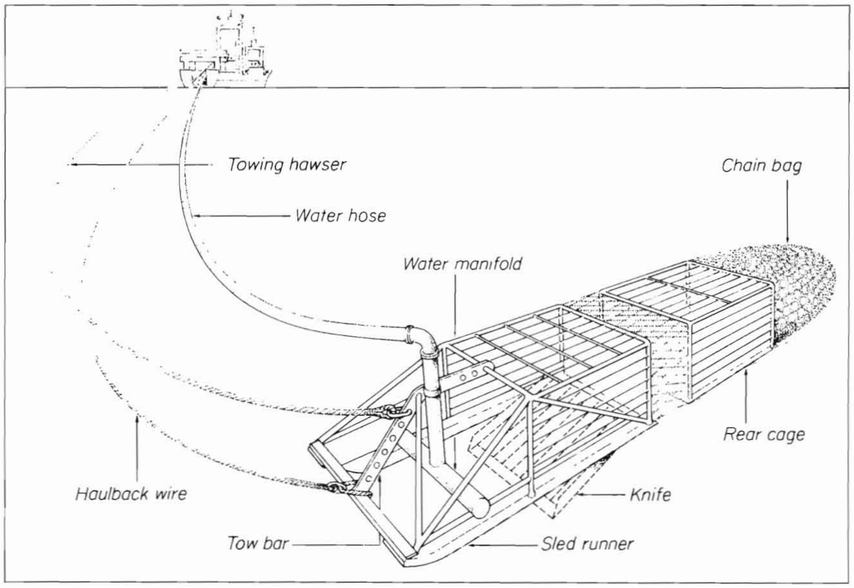


Figure 1.—The older commercial-type dredge was usually of two-piece construction as clammers felt it tended bottom better. It was also easier to handle over the side.

The authors are with the Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

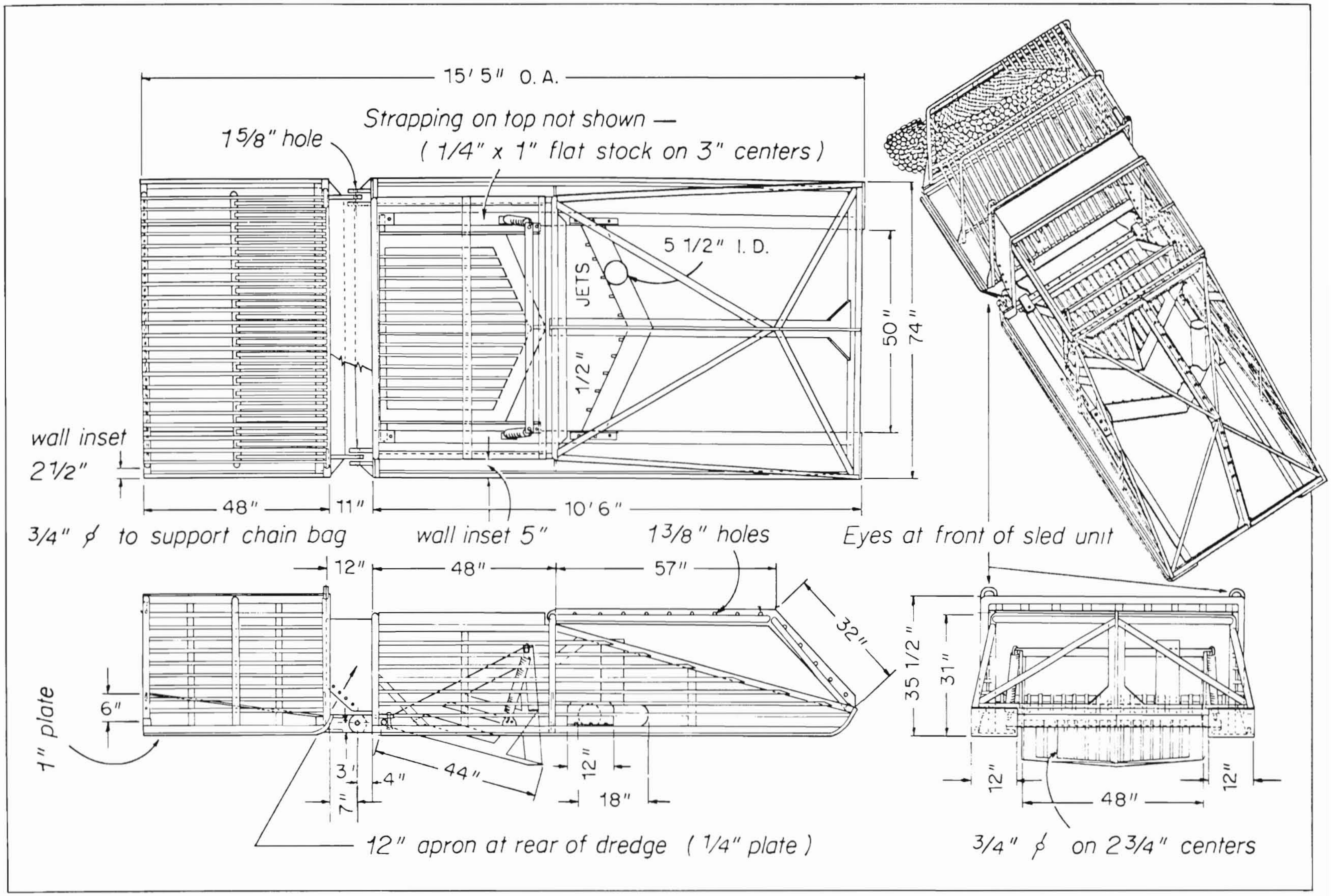


Figure 2.—An early version of the 48-inch (1.22 m) survey dredge with a V-knife and manifold. Later modifications included a straight blade and manifold and eliminated the chain bag.

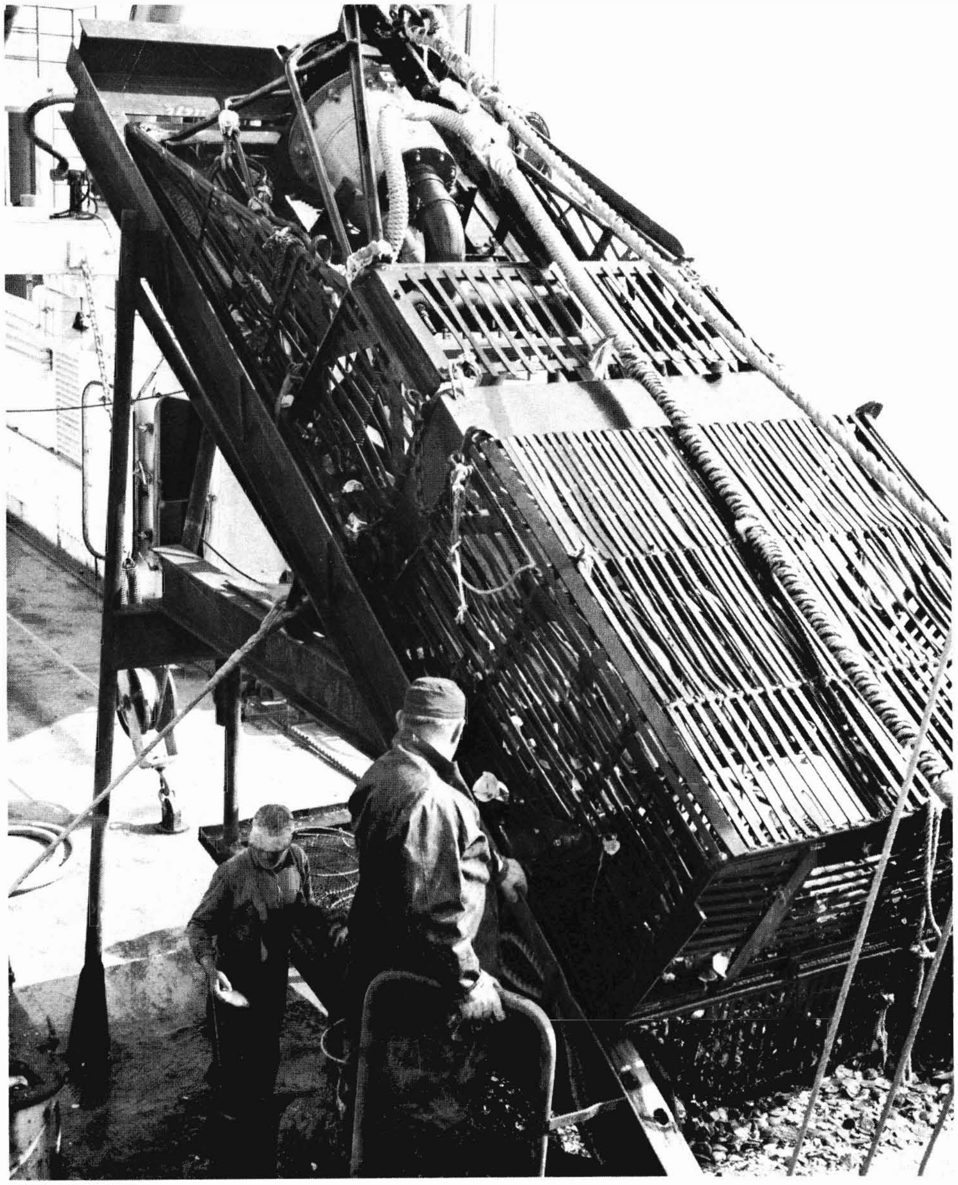


Figure 3.—The 48-inch (1.22 m) survey dredge modified for electrohydraulic operation. The electric cable to the submersible pump is wrapped with rope for protection from cuts and abrasion.

(15.2 cm) centrifugal pump powered by a 100-horsepower diesel engine mounted on the main deck of the NOAA ship *Delaware II*.

There were several major operational problems with this system. The first was that the dredge was depth limited to about 55 m since its efficiency, due to pressure drop in the hose, was decreased considerably at greater depths. Handling the long and bulky hose was difficult, especially at the greater depths. The dredge itself was apparently too light, 1,360 kg, to fish "hard on the bottom" (never leaving contact with the bottom) when towed by the *Delaware II* under certain conditions of sea, tide, and depth as evidenced by many "water-hauls" (hauled up completely empty).

The most important consideration was that the scientists wanted to sample to 110 m, the maximum known extent of the commercially important clam beds. The deepest the commercial fleet was fishing was 55 m and to do that they were using double hoses attached to massive pumps and engines built into the vessels. There was no way this size equipment could be added to the *Delaware II*.

The NEFC had experience with another method of clamming: Electrohydraulic dredging. The first system was built in 1965 (Standley and Parker, 1967) and was used over the course of the next 7 years (Fig. 3). The *Delaware II*, built in 1968, was designed with ample electric power available to operate the new system. The electrohydraulic dredging method was abandoned when the prototype system began to experience excessive reliability problems. In 1977, after reviewing these problems, it was decided they could be resolved. Since much of the electrohydraulic system was usable, and there were significant time and money constraints, it was decided to build a second generation system putting the emphasis on a new dredge design as opposed to a completely new approach.

Meetings were held with clam industry representatives and it was agreed that a survey dredge would not have to be as efficient as a commercial dredge for each set of fishing factors (depth, bottom type, etc.) but that it should be roughly based on an industry-type design that could be related to the industry as far as catching efficiency. Ideally, the dredge needed to be a consistent sampler. The operational design problem was stated as follows: To insure the dredge rides squarely on the bottom with blade fully cutting over a known distance and to have the entire catch within the desired size-selection range retained.

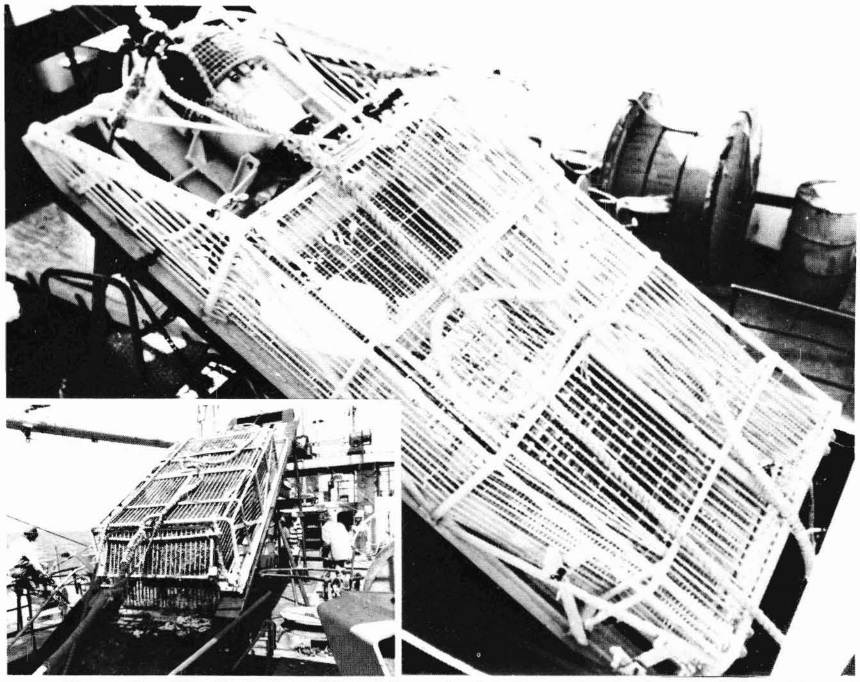


Figure 4.—The 60-inch (1.52 m) electrohydraulic dredge in the "dump" position on the ramp.

Dredge Design

This paper is primarily concerned with the mechanical design of the electrohydraulic dredge. Details of the electrical system can be found in Crossen and Smolowitz (1980).

The first decision made on the dredge design was to increase its size, compared with the old dredge, to increase the sample size collected and dredge weight. A choice of a 152.4 cm (60-inch) wide cutting blade was made, since anything wider would not fit up the stern ramp of the *Delaware II* and this size was common commercially in the event that comparison fishing experiments would be conducted. For the same reason other dredge characteristics, such as bar spacing, were kept similar to industry designs.

It was decided to construct the dredge as one piece to aid in midwater stability and stern docking and undocking (some dredges still are of two-piece construction). The forward section of the dredge was designed to contain the electrically driven submersible pump. Manifold to blade edge distance and cage volume followed industry practice. However, the dredge structure was built extra strong because of rough bottom encountered during random survey tows. The above factors evolved into a dredge length of 5.2 m, width of 2.13 m, and weight of 3,182 kg (Fig. 4).

Blade Design

One major problem with the old dredge was the high frequency of cut clams in the catch. Fishermen have traditionally found that their best surf clam catch rates, with minimum cut clams, was with blade depth (distance between bottom of dredge runner and bottom of blade) set between 5 and 6 inches (12.7 and 15.2 cm). Blade depth for ocean quahogs is usually less, about 4 inches (10.2 cm). The blade depth on the survey dredges was set at 8 inches (20.3 cm) to be able to assume complete sampling free of a depth-related bias.

Over the years, two observations were made relating to the high incidence of cut clams. In heavy weather or when towing down current the dredge, as judged by how the ship handled, was bouncing along on the bottom; thus the blade was passing in and out of the layer of clams in the substrate, resulting in damaged animals. This problem was remedied in the new dredge by making it heavier and by better controlling the speed over bottom by using a doppler speed log.

The other cause of cut clams was the blade mounting method. New Jersey commercial surf clammers had found that by keeping the blade depressed by the use of a spring device, this "floating-knife" would ride over the dense deposits of clay substrate found in that region. The spring usually consists of a steel spring or a number of rubber bands cut from old tire inner tubes. A commercial clammer usually works one geographic region for a period of time. Thus, he adjusts the spring tension to compensate for different bottom types by continuously observing his catch rate and incidence of cut clams. Due to the nature of the clam surveys, the latter feedback process cannot exist, and thus the blade tension is usually too low or too high. In the case of being too low, the blade rides up in hard compact sands, in many instances cutting right through the clam bearing layer, causing cuts. When the blade tension is too high, the consequence is filling the dredge with clay and/or heavy sediments, thus clogging the dredge early in the tow. It was found during clam surveys that, in general, the higher the spring tension the better the catch rate.

To eliminate any doubt about variations in cutting depth due to blade movement, it was decided to fish the new survey dredge normally with the blade fixed securely 20 cm below the runners. The capability to "float" the blade was still retained. During a routine survey, consisting of about 300 random stations, the blade gets badly "rim-racked" several times due to large rocks or obstructions. A door was provided on the top of the dredge to facilitate removal and replacement of the blade assembly and manifold; the whole job requires about an hour. During exploratory fishing on known "hard" bottom the blade has been spring mounted and has sustained virtually no damage.

Many fishermen feel that keeping the blade edge or "knife" sharp improves the efficiency of the dredge. During the normal course of towing the knife edge gets considerably dented by small rocks. On the new dredge, as with many industry dredges, the knife edge is a separate piece of plow steel bolted onto the blade assembly and is readily replaceable.

One other design consideration was the location of the blade assembly. The blade was located close to the midpoint of the longitudinal axis, as many commercial fishermen feel this placement improves bottom-tending characteristics.

Cage Design

The cage of the old survey dredge, which was built by a commercial dredge maker in 1965, was constructed of 1-inch wide (2.54 cm) flat bar welded between ½-inch (1.27 cm) diameter rods leaving ¾-inch (1.9 cm) spacing between. Without the flat bar the dredge would have had the 2.5-inch (6.35 cm) spacing, almost standard throughout the commercial surf clam fleet.

While the commercial fisherman is primarily interested in retaining surf clams greater than 5 inches (12.7 cm), the scientist needs a complete sample of clams down to 2 inches (5.1 cm). The catch of "prerecruit" clams is used to assess the overall clam population as an aid in determining future harvest.

The problem with decreasing the spacing in the dredge cage is that the dredge tends to clog up rapidly in most substrates. If the dredge does clog before the tow is completed, it effectively stops fishing, thus giving a biased sample.

One of the first considerations in designing the cage was to build it similar to a commercial dredge but with large scantlings to increase weight and ruggedness. The top and sides of the cage were constructed of ⅝-inch (1.6 cm) diameter round stock placed 2⅝-inches (6.7 cm) on center. The bottom of the cage was constructed sloping upwards towards the aft end, the entire bottom being higher than the runners. The ¾-inch (1.9 cm) round stock forming the bottom was alternately staggered in two layers spaced 2¾-inches (7.0 cm) apart on centers when measured diagonally. Commercial fishermen claim this method of construction allows the trash and sediment to wash out more efficiently. In addition, round vs. flat construction materials are believed to provide better flushing action.

The next step was to line the entire cage with a removable liner. The commercial boats fishing for ocean quahogs, a smaller clam than the surf clam, line their surf clam dredges with wire mesh, with anywhere from 1.5- to 2.5-inch (3.8-6.4 cm) openings, usually square mesh. The new survey dredge was first lined with 1×1-inch (2.54 cm^2) vinyl coated wire (14-gauge) mesh because that would give 100 percent retention of 2-inch (5.1 cm) clams. However, subsequent field tests, described later in this paper, indicated rapid clogging, so the liner was enlarged to 2×2-inch (5.1 cm^2) 11-gauge mesh.

The cage is also equipped with several hatches or doors. The entire aft end of the dredge cage is hinged to swing open and dump the entire contents over the ship's stern. This "trash door" is usually used if the dredge is filled with rocks or clay.

The rearmost section of the cage bottom is a catch removal door hinged at its aftermost end. The door is opened by means of a lever mounted on the dredge side. The aft end of the cage, with the trash door, is tapered at an angle so that when the dredge is sitting in the stern ramp the aft end is vertical. This facilitates dumping the catch.

Manifold Assembly

The manifold on the new survey dredge is a bolt-on unit capable of being positioned at different distances from the blade. There are 14 cutting nozzles made of ¾-inch (1.90 cm) diameter, 6-inch (15.2 cm) long pipe nipples angled at 45° to the vertical facing aft. In addition there are two "blowbacks" connected by hose to the blade assembly. The 6-inch (15.2 cm) diameter inlet to the manifold can either be connected to the dredge-mounted submersible pump or to a hose from a surface supply.

Submersible Pump Mount

The submersible pump is mounted onto the dredge with the suction end facing forward. It is bolted into a cradle along the dredge centerline and protected on the bottom by a 1-inch (2.54 cm) thick steel plate. The suction is surrounded by steel plate except for the top section which is covered by a screen. The openings in the screen (12 mm) are smaller than the inside nozzle diameter to prevent gravel from entering and blocking the nozzles. A guard made of steel bar is bolted on over the pump.

To enable the pump to be located in this position, it was necessary to tow the dredge using a bridle arrangement. A heavy steel bar is incorporated into the dredge frame on both sides of the forward part of the dredge with holes for bridle attachment. There are also accommodations made to mount an odometer and counterweight in this part of the dredge.

Operation

The dredge is set and hauled from a stern ramp using a 1-inch (2.54 cm) steel wire rope from the main trawl winch. Once the dredge is on the bottom, a 2-inch (5.1 cm) polypropylene rope connected between the dredge and the ship takes over the load to pull the dredge

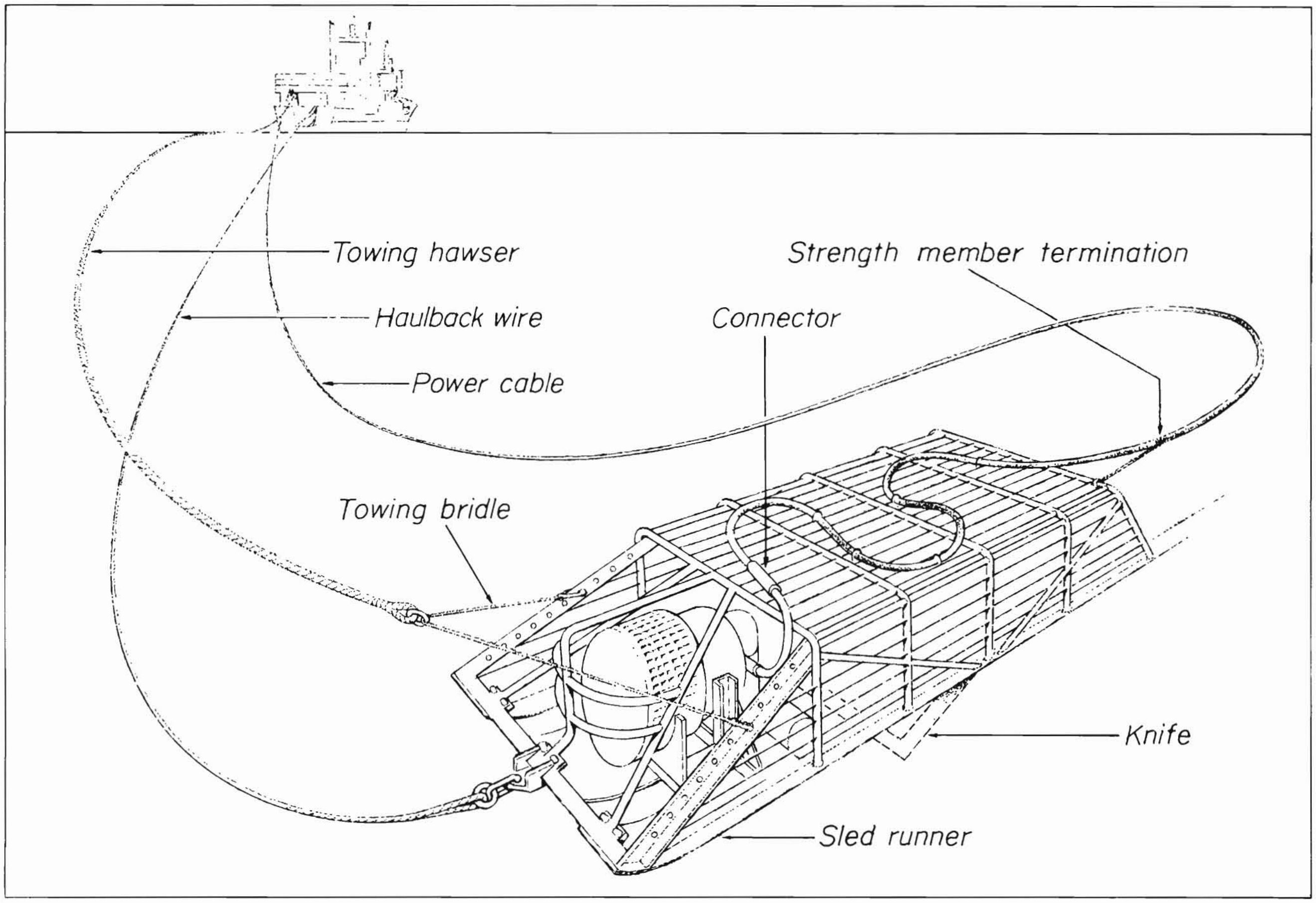


Figure 5.—The dredge is towed by the towing hawser, the hauling wire is kept slack, and the power cable has about 1,500 pounds tension.

along the bottom for the tow duration (Fig. 5). The elasticity of the polypropylene provides a built-in shock absorber. Also, both the steel cable and the plastic rope act as backups for each other. At the same time the dredge is set or hauled, an operator at the electric cable winch is controlling the amount of cable out. During the tow the winch maintains a preset tension on the cable, generally on the order of 1,500 pounds.

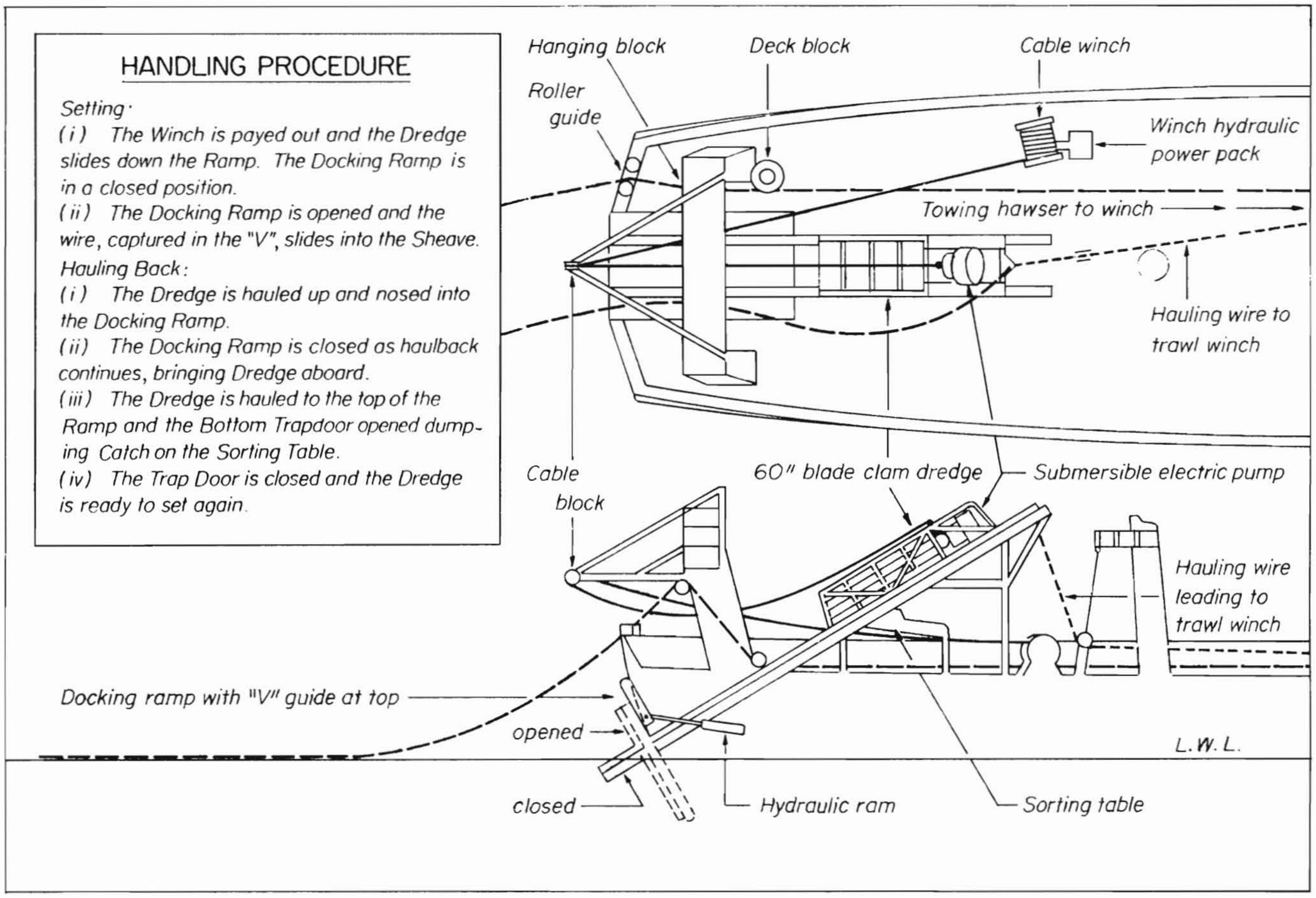
The ramp assembly used to carry the dredge aboard the vessel is a 43-foot (13.1 m) long, 8,700-pound (3,955 kg) structure primarily of 10-inch (25.4 cm) vertical "H" beams forming rails 6 feet (1.8 m) apart. Its lower end is set into the stern ramp of the vessel and rises forward at a 30° incline to a height of 15 feet (4.6 m). The lower section of the ramp, 13 feet (4.0 m) long, pivots at water level to enable docking and alignment of the dredge prior to retrieval. Once the dredge is properly aligned, it is hauled to the top of the incline, at which time the catch door in the rear underside of the dredge is opened, allowing the catch to be emptied into a sorting table beneath the ramp (Fig. 6).

Extensive use is made of a doppler speed log to maintain a constant towing speed over the bottom of 1.5 knots throughout the 5-minute standard survey tow. Comparisons made using a loran-C plotter and actual diver measurements of the dredge path confirm that the actual tow lengths are standardized within the confidence limits required for assessment purposes.

Diver observations indicate that the dredge fishes "hard" on the bottom, cutting a uniform trench for the full length of the tow. This is confirmed by catch analysis showing few cut clams.

Clam Dredge Testing

The *Delaware II* was outfitted with the electrohydraulic clam system during a cruise from 13 to 22 August 1979. One of the main objectives of the trip was to collect data on the efficiency and selectivity of the system in catching clams when it was fished in a research survey mode. A similar cruise had been con-



HANDLING PROCEDURE

Setting:

(i) The Winch is payed out and the Dredge slides down the Ramp. The Docking Ramp is in a closed position.

(ii) The Docking Ramp is opened and the wire, captured in the "V", slides into the Sheave.

Hauling Back:

(i) The Dredge is hauled up and nosed into the Docking Ramp.

(ii) The Docking Ramp is closed as haulback continues, bringing Dredge aboard.

(iii) The Dredge is hauled to the top of the Ramp and the Bottom Trapdoor opened dumping Catch on the Sorting Table.

(iv) The Trap Door is closed and the Dredge is ready to set again.

Figure 6.—Stern chute clam dredge ramp used aboard the *Delaware II*.

ducted in the past using the old survey dredge, some of the results of which are described in Meyer et al. (1981).

Seventy-seven tows were made, 10 of them observed by divers, along the south coast of long Island, N.Y., and along the New Jersey coast south to Atlantic City (Table 1).

Table 1.—Tow summary for *Delaware II* Cruise 79-08, 13-22 August 1979.

Tow no.	Position Lat.	Position Long.	Depth (m)	Remarks
1	40°53'N	72°09.5'W	27	
2-17	40°25'N	72°23.6'W	55	Marked clam area
18	40°45.6'N	72°39.6'W	18	
19	40°46.9'N	72°36.2'W	18	
20	40°50.1'N	72°25.2'W	18	
21	40°50.5'N	72°23.1'W	18	
22	40°50.5'N	72°23.1'W	18	Divers' survey path
23	40°51.7'N	72°21.5'W	16	Divers' film dredge
24	40°44.9'N	72°40.1'W	24	
25	39°16.2'N	74°20.4'W	16	
26	39°19.0'N	74°20.7'W	15	
27	39°19.3'N	74°16.2'W	15	
28	39°17.2'N	74°28.5'W	13	
29	39°25.8'N	74°12.0'W	18	
30	39°25.4'N	74°11.9'W	16	Divers' survey path
31	39°25.5'N	74°11.8'W	18	"
32	39°23.7'N	74°11.0'W	18	
33	39°25.5'N	74°11.8'W	18	"
34	39°25.5'N	74°11.8'W	18	"
35	39°25.5'N	74°11.8'W	18	
36	39°23.3'N	74°18.0'W	11	
37	39°34.5'N	74°12.5'W	9	
38	39°35.0'N	74°12.8'W	7	
39	39°37.4'N	74°10.5'W	11	Packed w/clay
40	40°33.0'N	73°50.0'W	9	Divers' survey path
41	40°33.5'N	73°51.0'W	7	
42	40°33.3'N	73°51.0'W	7	Divers' ride dredge
43	40°33.0'N	73°50.0'W	9	Divers' survey path
44	40°33.0'N	73°50.0'W	9	
45	40°33.8'N	73°43.0'W	11	
46	40°34.3'N	73°41.7'W	9	
47	40°34.6'N	73°31.8'W	9	
48	40°36.9'N	73°15.9'W	9	
49	40°36.9'N	73°13.9'W	13	
50	40°37.1'N	73°10.9'W	16	
51-77	40°25'N	72°23.6'W	55	Marked clam area
78	40°56.0'N	72°11.0'W	16	Divers' film dredge

Diver Dredge Observations

The following is a summary of some of the information provided by diver observation:

1) There was more than sufficient water flow from the pump for proper digging action of the nozzles. At slow speeds, up to 1 knot, the jets dug deeper

than the blade. However, path surveys didn't show any clams being blown under the blade or deep into the cut path. Cutting depth was in inverse function of dredge speed.

2) In abnormally dense clam beds off Rockaway Beach, N.Y. many small clams were found in the first 15 m of each tow path. This may indicate selection through the blade assembly.

3) The 2.5 cm square lined dredge tended to fill rapidly, in most test areas before the first 75 m of the tow. Upon filling, the dredge still dug, but blew everything to the sides and no longer sampled properly.

4) No flushing was observed out of the top or sides of the dredge. Flushing took place through the bottom and rear panels.

5) The dredge towed much easier (lower engine rpm required) with the pump on.

Video Taping

A Sub-sea Systems CM-40[1] underwater color television camera was used to document the dredge in operation. The camera was used in three modes: Diver held, dredge mounted, and surface lowered. Lighting was provided by two 250-watt lights mounted on the camera housing. A 150 m long multiconductor cable provided for the video signals, camera power, lighting, and diver communications. The cable was handled on deck using a hand-powered winch with 14 sliprings.

The video and audio signals were monitored on the surface with a JVC 33 cm color TV monitor (Model No. 4280 m) and recorded on video tape with a JVC color portable video cassette recorder (Model No. HR-410DA).

Five hours of video tape were made on the operation of the cutting nozzles and the blade and of the flushing action of the dredge cage at various speeds. The lowering of a camera in areas previously dredged enabled inspections of the dredged trenches.

Substrate Testing

It is generally believed that bottom type significantly affects clam dredge operations. During this cruise a preliminary attempt was made to classify the different substrates. To this end, the following test equipment (manufactured by Soiltest, Inc.) was used:

1) Pocket penetrometer (CL-7000) with 2.54 cm diameter adapter foot (CL-701),

2) Torvane torsional vane shear device (CL-600 with sensitive vane adapter (CL-602, 0.0-0.2 TSF range),

3) Sand grading chart (A-17).

The hardest sand encountered by the divers was on tow station 33. The divers collected a sample using a large coffee can as a corer and brought it up to the surface for analysis. The sample was classified as coarse sand, subrounded with granules having a penetration of 0.047 kg/cm^2 and a shear of 0.008 kg/cm^2. The dredge had no trouble cutting through this substrate.

Main Winch Tension Test

A hydraulic load cell was attached to the deck haulback block to provide a direct reading of the tension on the main wire.

Maximum tensions during haulbacks averaged about 10,000-13,000 pounds with brief peak loads up to 17,000 pounds. At tow station 39, when the dredge was fully on board, the winch stalled at about 18,000 pounds of tension. After the dredge was flushed of some of its catch, it was able to be hauled aboard.

Operating Parameters

Of the 77 tows, 43 were made primarily in an attempt to recover previously marked clams in a small area that seemed to have a relatively uniform distribution of ocean quahogs. We took advantage of this by varying operating parameters to determine what effects, if any, they had on catch rate (Table 2).

Table 2.—Catch data (number of clams) from test tows.

Tow no.	Catch	Tow no.	Catch	Tow no.	Catch	Tow no.	Catch	Tow no.	Catch
2	131	51	169	58	456	63	144	70	571
3	120	52	104	59	316	64	392	71	513
4	145	53	231	60	354	65	489	72	518
5	403	54	261	61	400	66	272	73	414
6	129	55	178	62	109	67	550	74	523
7	198	56	215			68	343	75	564
8	362	57	255			69	357	76	898
9	152							77	513
10	352								
11	307								
12	293								
13	353								
14	378								
15	280								
16	176								
17	155								
$\bar{X}$ =	245.88		201.86		327.00		363.86		564.25
SD=	104.12		55.63		132.61		134.39		142.98
SE=	26.03		21.03		59.30		50.79		50.25
±2SE=	193.82		159.80		208.40		262.28		462.67
	297.94		243.92		445.60		465.44		665.83

Tow Stations 2-17

Scope was varied from 1.6:1 to 3:1 with no apparent effect. The length of tow was also varied from 3 to 15 minutes with no apparent effect on catch rates. These observations were probably due to the dredge filling rapidly and then just acting as a plow. Catches from tows 2-17 varied from 120 to 403 clams, the average being 246 clams. During tow 16 the dredge was operated with the pump off and caught 176 clams. The mesh size throughout these stations was 2.54 cm^2.

Tow Stations 51-77

Tow stations 51-77 were all fished at a constant speed (1.5 knots), scope (2:1), and duration (5 minutes).

On tows 51-57 the pump was not

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[1] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

turned on until the dredge was on the bottom and strain was placed on the towing hawser. The average catch was 202 clams. On tows 58-62 the pump was turned on before the dredge hit the bottom. The average catch increased to 327 clams. This technique probably allowed the dredge to fish a little longer before filling up and thus was used on all subsequent tows.

On tows 63-69 the rear mesh panel was changed to 5.1 cm square mesh. The average catch for these tows increased to 364 clams. On tows 70-77 the rear bottom panel mesh was also changed to 5.1 cm^2 mesh and the average catch increased to 564 clams per tow. This indicates, along with diver observations, that most of the washing action, and probably selection, occurs on the dredge's bottom.

Throughout the above tests, despite the mesh size modifications, the size distribution of the clams retained did not appreciably change. A possible explanation for the lack of differential selectivity is that shell, sand, and live invertebrates may have clogged the dredge at the beginning of the tows, negating further filtering ability (Murawski et al., 1980). Actually, as seen by the overall change in catch rates, there apparently was a change in filtering ability but not enough to influence selectivity in this test area and for the population size/structure present.

Path Surveys

Divers conducted detailed surveys on six dredge paths. The procedure used was as follows: The ship set the dredge, with a buoy attached, heading down current and anchored up on the dredge. The divers, tended from a Zodiac rubber boat, descended to the dredge and marked the starting point with an anchor and buoy. In addition, they placed a reel of marked (leaded) line on the bottom and attached one end to the rear of the dredge. When they were ready they moved clear of the dredge and signaled the surface to start the tow. The ship turned the pump on and commenced towing. Using a Northstar loran-C/EPSCO plotter, a doppler speed log, and an estimate of the distance between the dredge buoy and anchor buoy, the ship towed long enough to make a 50 m path. Upon completion of the tow, the pump was stopped and the ship anchored-up on the dredge.

After the pump was shut off, the divers read the lead line to get the path length. They then proceeded down the path collecting any clams on the surface in the dredge area.

Using 0.25 m^2 grid squares, they took random samples both inside and outside the path.

Table 3 presents the results from three path surveys made in the same area off the coast of Brigantine, N.J., in 18 m of water.

Due to the small number of clams found during tow number 31 by diver sampling, we increased the sampling in tows 33 and 34 to 30 grid samples inside and 30 grid samples outside the paths. The data from tows 33 and 34 were then combined and the standard error of the grid samples was calculated to find the 95 percent confidence limits. Using these limits, the efficiency based on the dredge catch divided by the total clams found in the path (*E*) was calculated to lie between 74.9 and 87.9 percent of $\overline{X} = 83.1$ percent, which is reasonable. However, in a similar manner, the efficiency based on outside the path grid densities (*D*), lies between 100.1 and 529.7 percent or $\overline{X} = 168.3$ percent, which is too high. These results make both efficiency calculations suspect, possibly indicating insufficient sampling or diver undersampling. One other possibility is that clam distributions are spotty in nature and the assumption that clam density to either side of the path is similar to that within the path, is wrong within our limited sampling regime.

Discussion

Clamming, regardless of the species, area, or method, simply involves digging through substrate and gathering clams. Research on soft-shell clams, *Mya arenaria,* has shown that efficiency (percent removals) and breakage (mortality on clams remaining) using hand-harvesting techniques is a function of the fisherman's skill and method (Medcof and MacPhail, 1952, 1967; Dow et al., 1954; Glude, 1954). Improvements in efficiency, nearing 100 percent, and reductions in breakage came about with the introduction of hydraulic escalator dredges into this fishery (Dickie and MacPhail, 1957; Manning, 1957, 1960; MacPhail, 1961; Medcof, 1961). As with hand methods, the efficiency and effects of hydraulic dredging are highly variable depending on location, bottom type, clam density, gear design, weather, and operator skill. The long-term effects of an indirect nature, such as sediment clouds covering the bottom or sand particles damaging the animals, have been hard to observe and document.

Hand methods of clamming, such as

Table 3.—Path survey results from three stations in the same area occupied on *Delaware II* Cruise 79-08, 13-22 August 1979.

	Tow no.			Tows 33 and 34 combined
Observation or measurement	31	33	34	
Path length	61 m	58 m	56 m	—
Width	1.52 m	1.52 m	1.52 m	—
Path area	92.72 m^2	83.16 m^2	85.12 m^2	173.28 m^2
Dredge catch (A)	106	93	82	175
Surface catch (B)	12 (9 damaged)	20 (9 damaged)	4 (3 damaged)	24
Path samples catch (0.25 m^2)	1,0,0,0,0,0	1, 29-0's	30-0's	1, 59-0's
Density of pathg clams remaining	0.66 clams/m^2	0.13 clams/m^2	0	0.067 clams/m^2
Total patch clams remaining (C)	61	12	0	11.55
Outside samples catch (0.25 m^2)	2,1,1,1, 8-0's	1,1,1,1,1, 25-0's	2,1,1, 27-0's	2,7-1's 52-0's
Density of outside clams	1.66 clams/m^2	0.66 clams/m^2	0.53 clams/m^2	0.60 clams/m^2
Total clams in patch before tow based on grid densities (D)	154	58	45	104
Total clams found in path (A+B+C=E)	179	125	86	210.5
Efficiency based on (D)	68.8%	160.0%	182.2%	168.3%
Efficiency based on (E)	59.2%	74.4%	95.3%	83.1%

raking and tonging, were used in the surf clam fishery (Parker, 1971) and are still used in the inshore quahog, *Mercenaria mercenaria,* fishery. In the 1920's, towed nonhydraulic dredges, or "dry" dredging, came into use in these fisheries but not without controversy which still exists today. Glude and Landers (1953) compared the effects of hand raking and power dredging and found no biological basis for restricting either method of fishing.

In the surf clam fishery, development continued on into hydraulic dredging due to the increased efficiency (Parker, 1971) and the fact that dry dredging crushed surf clams (Ruggiero, 1961). Medcof and Caddy (1971) found that a skillfully controlled hydraulic dredge was close to 100 percent efficient in catching ocean quahogs. In comparison they found a dry dredge less than 1 percent efficient and broke the shells of 80 percent of the uncaught clams.

Experiments conducted with the old NEFC hydraulic survey dredge gave results similar to those reported above: Efficiency that could approach 100 percent (Meyer et al., 1981). Efficiency, in both studies, was found to be a function of towing speed, scope, and the relationship between cutting blade and hydraulic nozzles. Observations of the survey dredge proved that, once the dredge filled, efficiency dropped to zero and the dredge became a tool of destruction along the bottom.

Testing of the new electrohydraulic survey dredge, some of which has been reported in this paper, indicates that this dredge can also be highly efficient. An analysis of 10 tows in the marked quahog area indicates that less than 3 percent of the catch suffered cuts due to dredging action. The question arises about how a dredge can be fine-tuned to maximize its efficiency and minimize destructive effects. To answer this question requires an understanding of the exact mechanism, or functional principle, of dredge operation.

One of the first clues on how a hydraulic dredge works was observed by Medcof and MacPhail (1964) during development of a hydraulic rake to harvest soft-shell clams. Using laboratory aquaria and field tests, they determined that the hydraulic nozzles, or water jets, were converting the clam-bearing substrate from a solid to a fluid state: A slurry. The clams, being less dense that the slurry, become buoyant and pop up to the slurry surface. Based on this observation they presumed there was a large amount of tolerance in the design of the hydraulic system as long as the fluidizing function was maintained.

The slurring action is a function of water jet volume, pressure, and flow, as well as dredge speed. Diver observations by Medcof and Caddy (1971), confirmed by our divers during field tests, show that when the dredge is towed too slowly for a given set of hydraulic parameters, the slurring action becomes an excavating action, digging a trench deeper than the "cutting" blade of the dredge. Correspondingly, when the dredge is towed too fast, it either comes out of the bottom or rapidly fills with substrate and performs a "plowing" action.

During the efficiency tests conducted with the new survey dredge, the divers made some general observations of bottom hardness using their hands. On hard sand bottom before the dredge made a pass they could barely get their fingers to penetrate, but after the dredge passed they could stick their entire arm up to the elbows into the substrate in the dredge track.

Robert Frost, of the clammer *Wando River* out of Warren, R.I., heard of this observation and realized the clams would tend to float up out of the fluidized bottom. He decided to modify his 60-inch (1.52 m) hydraulic ocean quahog dredge to make use of this principle. He increased his hydraulic manifold-to-blade-distance to 48 inches (1.2 m), increased the water flow, and decreased the blade depth to 3 cm. Towing between 2 and 3 knots he almost doubled his catch rate. Making use of a flow meter and remote pressure gauge, Frost found that at his towing speeds his greatest catch rates occurred at 50 gpm (190 lpm) per inch (2.54 cm) of blade width. Realizing that speed is a critical factor, Frost plans to purchase a $14,000 doppler speed log to improve his operation.

Frost's increased catch rate does not mean that his dredge efficiency, as measured by percent removal, has increased. What may be happening is that clogging due to substrate filling the dredge has decreased, and that with the increase in speed the dredge is effectively fishing a greater area of bottom before it fills and plows. This may be economically efficient for a commercial operation, but is not desirable for a survey mode.

Knowing that there is a relationship between towing speed and water volume that can change and still permit 100 percent dredge efficiency, allows for new design considerations. In the electrohydraulic dredge operation, if the water volume requirement can be cut significantly, at whatever sacrifice in towing speed, the initial system cost would drop considerably and reliability would be greatly enhanced.

A better understanding of the "bed fluidization" requirements of the clam harvesting process is needed. This, in turn, could be used to improve manifold/nozzle design, an area of high fluid "losses" in both commercial surface-supplied dredges and the electrohydraulic dredge. Improvements in this area alone probably would result in significant energy savings to the commercial clam industry.

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Appendix A

Dredge Hydraulics

If the new information available indicates that water volume requirements can be decreased, then the use of a surface supply to the new survey dredge needs to be reconsidered. At the same time it would be interesting to theoretically examine the head losses due to the manifold/nozzle design and see if this arrangement can be improved. In this section we are going to compare a surface to a submersible-supplied system under today's operating conditions, to provide a starting point for future work in the above areas.

Standley and Parker (1967), during the development of the first electrohydraulic dredge, instrumented for pressure and flow both surface-supplied and submersible pump operations. They presented the following data for the surface pump:

Length of hose (L) = 250 ft
Diameter of hose (D) = 0.5 ft

	Flow (Q) gpm
Case I	1,475
Case II	1,825

	Pressure difference (Δp) psi
Case I	17
Case II	27

Using this data we can calculate the roughness height (ϵ) for the clam hose.

Case I

$$\text{Discharge } Q = 1{,}475 \text{ gal/min} \times \frac{1 \text{ min}}{60 \text{ sec}} \times \frac{1 \text{ ft}^3}{7.46 \text{ gal}} = 3.295 \text{ ft}^3/\text{sec}$$

$$\text{Velocity } V = \frac{Q}{A}$$

$$A = \pi r^2 = \pi\left(\frac{1}{4}\right)^2 0.19636 \text{ ft}^2$$

$$V = \frac{3.295}{0.19636} = 16.7812 \text{ ft/sec}$$

Using the Darcy-Weisbach equation

$$h_f = f\frac{L}{D}\,\frac{V^2}{2g}\ ,$$

$$h_f = \text{head loss} = \Delta p = 17 \text{ lb/in}^2 \times \frac{144 \text{ in}^2}{1 \text{ ft}^2} \times \frac{1 \text{ ft}^3}{64 \text{ lb}} = 38.25 \text{ ft}_{\text{water}}$$

substituting to solve for friction factor f

$$\frac{(38.25)\ (32.2)}{(250)\ (281.608)} = f = 0.0175.$$

Using the Moody diagram from Streeter (1966),
$f = 0.0175$, $VD'' = 100.68$, and

$$\frac{\epsilon}{D} = 0.0005,$$

roughness height ϵ is 0.00025 foot.

Case II

$$Q = 1{,}825 \text{ gal/min} = 4.077 \text{ ft}^3/\text{sec}$$

$$V = \frac{Q}{A} = \frac{4.077}{0.19636} = 20.76 \text{ ft/sec}$$

$$h_f = 27 \text{ lb/in}^2 = 60.75 \text{ ft}_{\text{water}}$$

substituting into the Darcy-Weisbach equation,

$$60.75 = f\frac{(250)\ (20.76)^2}{(0.5)\ (2)\ (32.2)}$$

$$f = 0.0182$$

$$VD'' = 124.58$$

from Moody diagram $\frac{\epsilon}{D} = 0.006$

thus $\epsilon = 0.0003$ ft.

From the results of these two cases we will assume that the roughness height for the clam hose is 0.00028 foot. This is a composite roughness height which takes into account minor losses created by hose fittings, etc.

Goodyear Rubber Company, one of the manufacturers of rubber clam hose, has standard loss charts that give the head loss for 6-inch diameter rubber hose as 8.8 psi per 100 feet of hose at 1,800 gpm. This works out to a roughness height of 0.00015 foot.
Thus 8.8 lb/in^2 × 2.5 = 22.0 lb/in^2 head loss for 250 ft,

$$\text{or } h_f = 22.00 \text{ lb/in}^2 \times \frac{144 \text{ in}^2}{1 \text{ ft}^2} \times \frac{1 \text{ ft}^3}{64 \text{ lb}} = 49.5 \text{ ft}_{\text{water}}.$$

As expected this theoretical head loss of 49.5 feet is lower than the Case II head loss of 60.75 feet. The difference is possibly due to "minor losses" caused by the catenary the hose takes while being towed as well as the hose fittings. Actually the so-called minor losses can be highly significant in the clamming operation.

For the comparison of the surface vs. submersible supply systems we chose to look at an operating depth of 300 feet; the maximum limit of the commercial-size clam populations now known. Using two to one scope this will involve hose lengths of 600 feet. We chose 2,000 gpm as the flow rate as this is about the lower industry limit for 60-inch dredges.

Specific gravity is about 1.025 for seawater, but for the purposes of this discussion we will neglect it, as it will have little significance on these calculations.

Surface Supply Loss Calculations

Suction losses (see Fig. A-1):

$V_s = \frac{Q}{A}$

$Q = 2{,}000$ gpm $= 4.47$ ft^3/sec, $D_s = 8''$, $r = 4'' = 0.33'$

$A = \pi r^2 = 0.342$ ft^2

$V_s = 13.07$ ft/sec

H_{ss} = static head loss = 15 ft

H_{sv} = velocity head loss $= \frac{V^2}{2g}$

$= \frac{13.07^2}{64} = 2.67$ ft

H_{sf} = frictional losses $= f\frac{(L_s + L_e)}{D_s}\frac{(V_s)^2}{(2g)}$

L_s = suction line length = 21 ft

D_s = inside diameter = 0.66 ft

L_e = equivalent length due to "minor losses"

f = friction factor = 0.018

$L_e = \frac{KD}{f}$ K = 2 elbows = 1.90

1 swing check = 2.50

K_{total} = 4.40

$L_e = \frac{4.4\,(0.66)}{0.018} = 161.33$ ft

$H_{sf} = \frac{(0.018)\,(182.3)\,(13.07)^2}{0.66(64)} = 13.27$ ft

H_{se} = entrance head loss $= \frac{0.5V^2}{2g} = 1.33$ ft

Total suction losses = 32.27 ft$_{\text{water}}$ (14.2 psi)

Discharge losses:

$V_d = \frac{4.47}{0.19636} = 22.76$ ft/sec

$H_{dv} = \frac{(V_d^2 - V_s^2)}{2g} = \frac{22.76^2 - 13.07^2}{64}$

$= 5.42$ ft

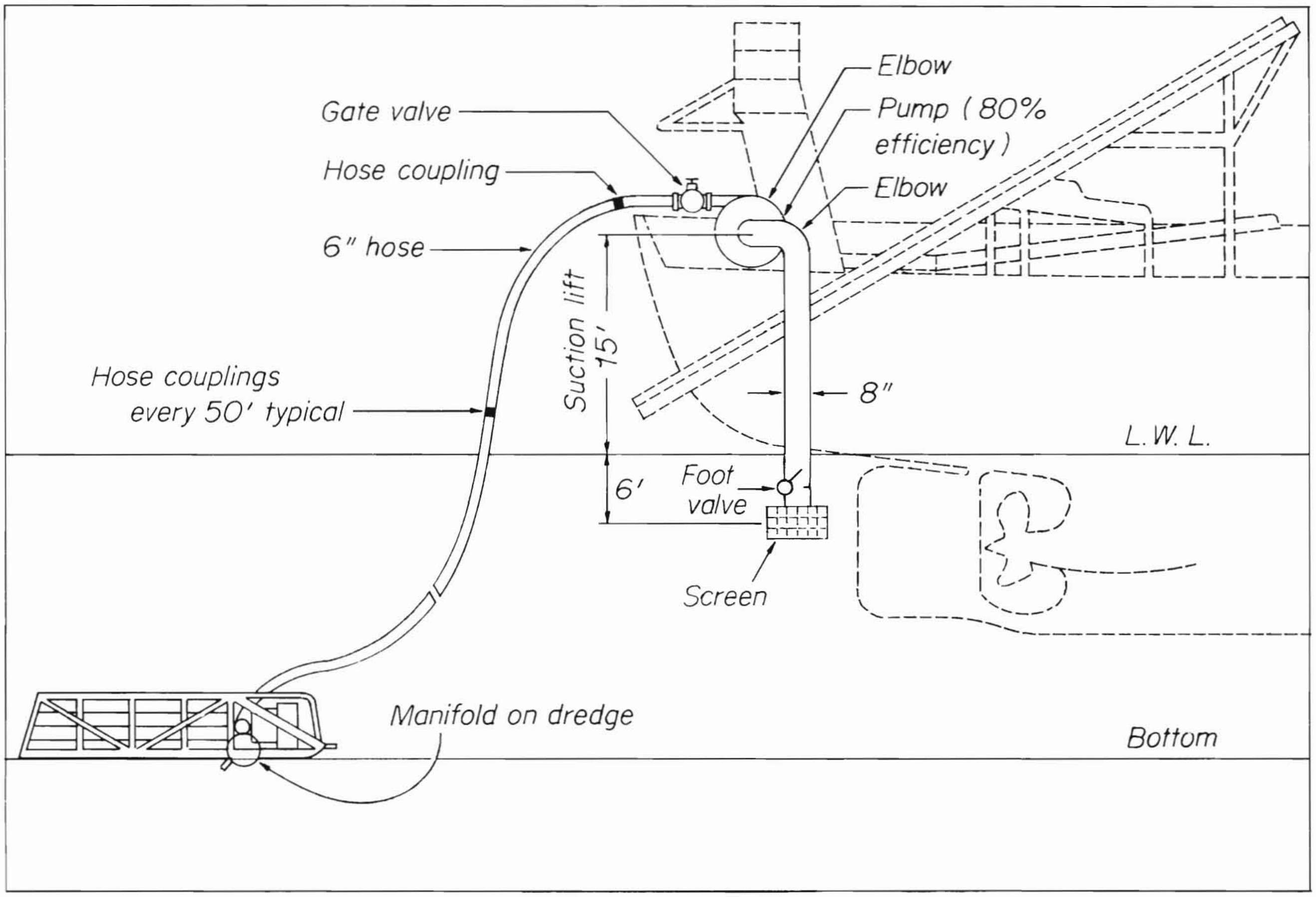

Figure A-1.—Schematic of surface-supplied clam dredge system.

$f = 0.018$
$L_d = 600$ ft
$D_d = 0.5$

$$H_{df} = \frac{f(L_d + L_e)\,V_d^2}{D_d(2g)}$$

K = 1 elbow = 0.90
gate valve = 0.19
$K = 1.1$

$$L_e = \frac{(1.1)(0.5)}{0.018} = 30.5 \text{ ft}$$

$$H_{df} = \frac{(0.018)(630.5)(22.76)^2}{(0.5)(64)} = 183.7 \text{ ft}$$

Total discharge losses =
189.12 ft_{water} (83.2 psi)

Horsepower (water) required to overcome losses:

$$HP_w = \frac{Q\,H_{\text{total}}}{3{,}960}$$
$$= \frac{(2{,}000)\,(189.12 + 32.27)}{3{,}960}$$
$$= 111.8 \text{ HP.}$$

Assume requirements entering dredge manifold are 2,000 gpm at 100 feet of head (44 psi):

$$HP_w = \frac{(2{,}000)\,(100)}{3{,}960} = 50.50$$

Total water horsepower required = 162.3. Brake horsepower required using 80 percent efficiency of a high head, high capacity end suction centrifugal pump

$$= \frac{162.3}{0.8} = 202.9 \text{ brake horsepower}$$

required to drive a surface pumping system using 6-inch discharge hose.

There is a simple method to decrease the horsepower requirements: Use a larger diameter discharge hose. The following information was extracted from the standard loss tables found in the Goodyear Technical Information Bulletin (821-947-850; 3/77):

Hose dia. (I.D.)	Flow (gpm)	psi per 100′	psi per 600′	HP_w
6-inch	2,000	16.5	99.0	112.5
	3,000	—[1]	—[1]	—
8-inch	2,000	2.2	13.2	15.0
	3,000	4.5	27.0	46.0

Eight-inch hose is very attractive from an hydraulic efficiency standpoint but presents a handling problem. Advances in hose technology in the area of strong, lightweight flat-reeling hose may solve this problem.

Submersible Supply (Gorman-Rupp Model S8A1) Loss Calculations

$$\text{Three-phase kilowatts} = \frac{\text{Volts} \times \text{Amps} \times \text{Power factor} \times 1.732}{1{,}000}$$

Readings from operations: Volts = 460
Amps = 100
From Power curves: Kilowatts = 70
Substituting and solving for Power factor:
Power factor = 0.88.

$$\text{Motor efficiency} = \frac{746 \times \text{Horsepower}}{1.732 \times \text{Volts} \times \text{Three-phase amps} \times \text{Power factor}}$$

From motor performance curves
at 70 kw input, hp at 460V = 85,
amps = 103.
Substituting and solving for efficiency,
Motor efficiency = 87.8 percent.

$$\text{Pump efficiency} = \frac{\text{gpm} \times \text{head in feet}}{3{,}960 \times \text{hp (to pump)}}$$

From curves gpm = 2,200 at 90′ head,
hp = 85.

Substituting, pump efficiency = 60%.

From the above analysis and the pump manufacturer's pump and motor performance curves it takes about 85 horsepower to maintain 2,000 gpm at 100 feet of head at the manifold using our submersible pump system. Since the water horsepower requirement, as shown previously, is 50.5 hp, the losses are about 35 hp. This is far better then the 112.5 hp losses for the 600 feet of 6-inch hose but not as good as the 15 hp for the 600 feet of 8-inch hose.

Most of the submersible system losses are due to the low pump efficiency of 60 percent. The particular pump used was designed for other purposes, where tradeoffs were made against efficiency. If we placed a high efficiency (80 percent) centrifugal pump, similar to the surface supply system, on the dredge and powered it by a submersible electric motor, we would cut the losses to 17 horsepower, which is comparable to the losses in 600 feet of 8-inch hose.

There are some losses in the electrical cable but they are not very significant, as the following calculation for the voltage drop in 1,000 feet of GGC (#1AWG) cable demonstrates:

Resistance of #1AWG per 1,000 feet at 25°C copper stranded = 0.134 ohms
Voltage drop (E) = $IR \times 0.865$
(for 3 phase) using 100 amps
$E = 11.59$ volts.

If voltage at the controller is 460, at the pump it will be 448.41 or a 2.5 percent *IR* drop. For most electric motors this will result in a 1-2 percent drop in efficiency.

One other area of loss in the electrohydraulic dredge system is the generator. Most generators operate at about 90 percent efficiency. The 10 percent losses here can be roughly equated to the suction losses of a surface-supplied system.

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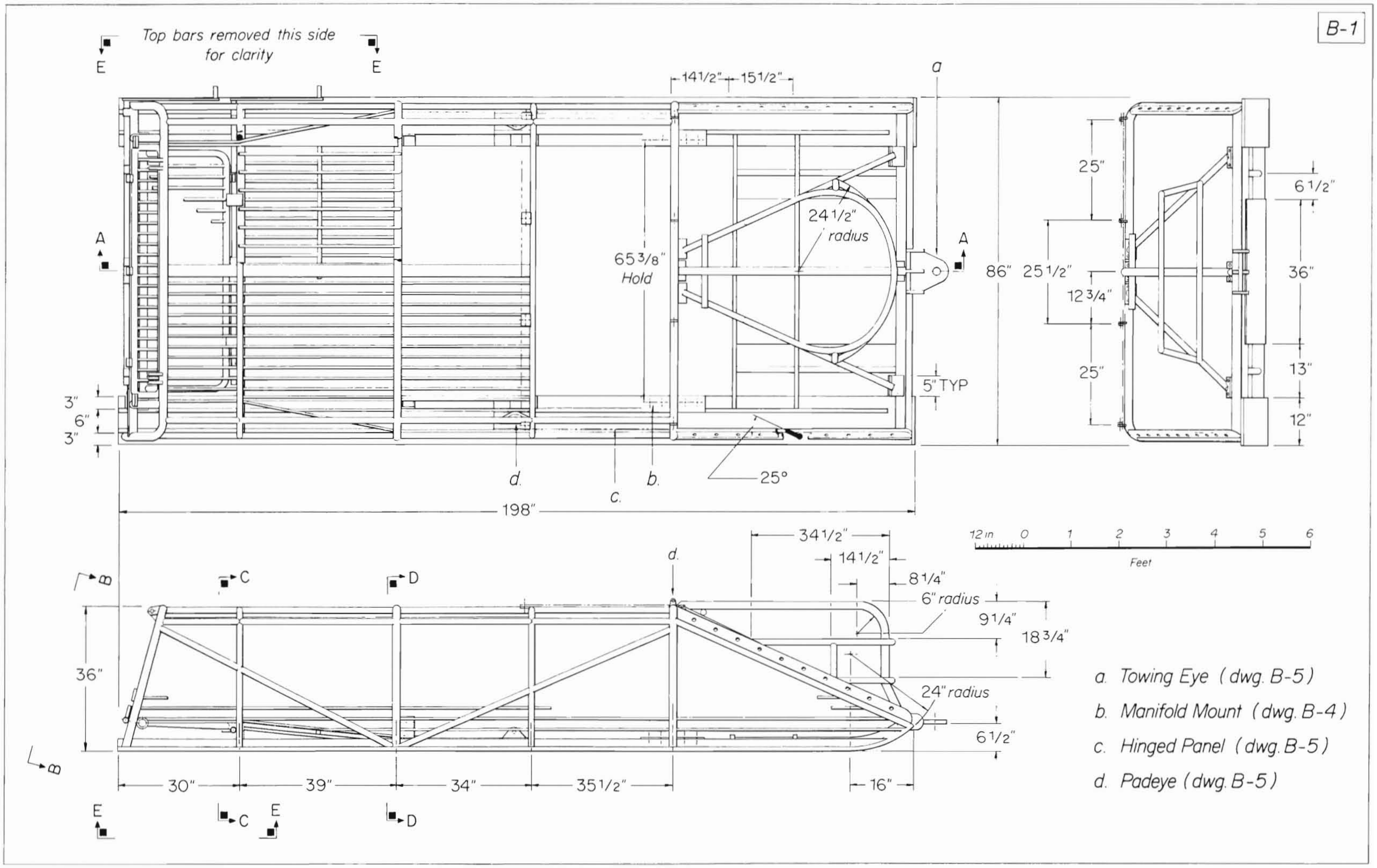
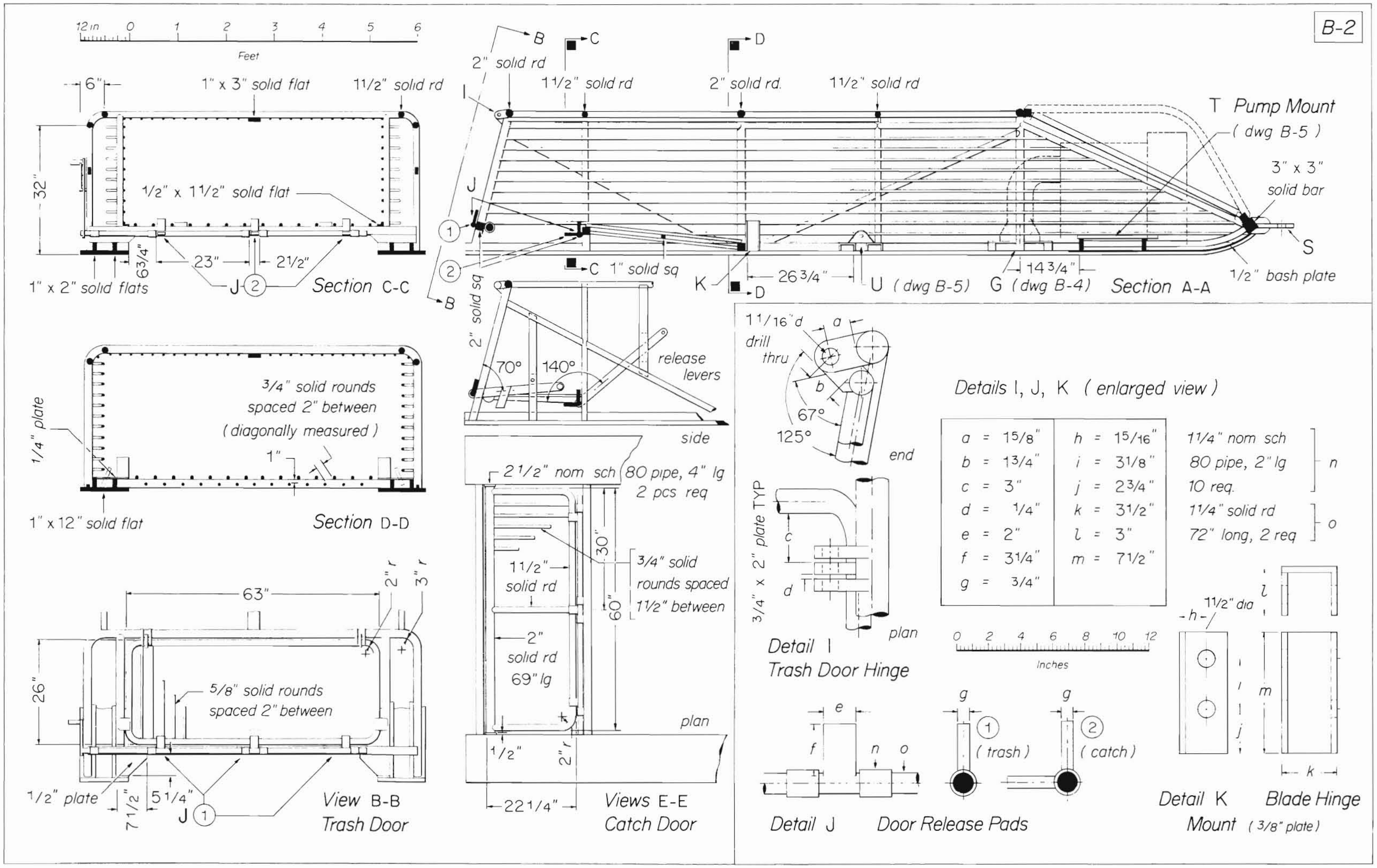
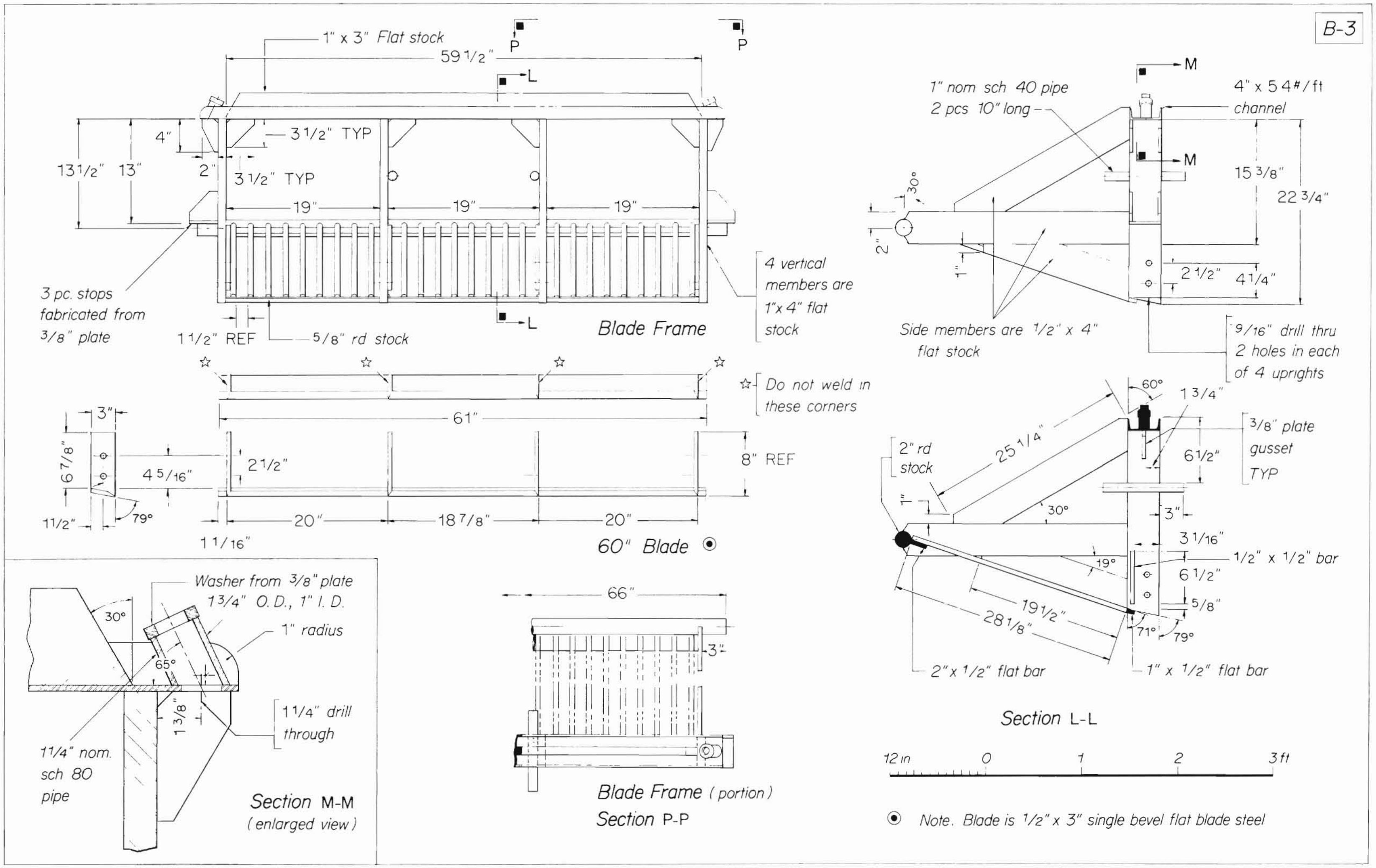
[1] Note that the pressure required to drive 3,000 gpm through the 6-inch hose exceeds the bursting strength.

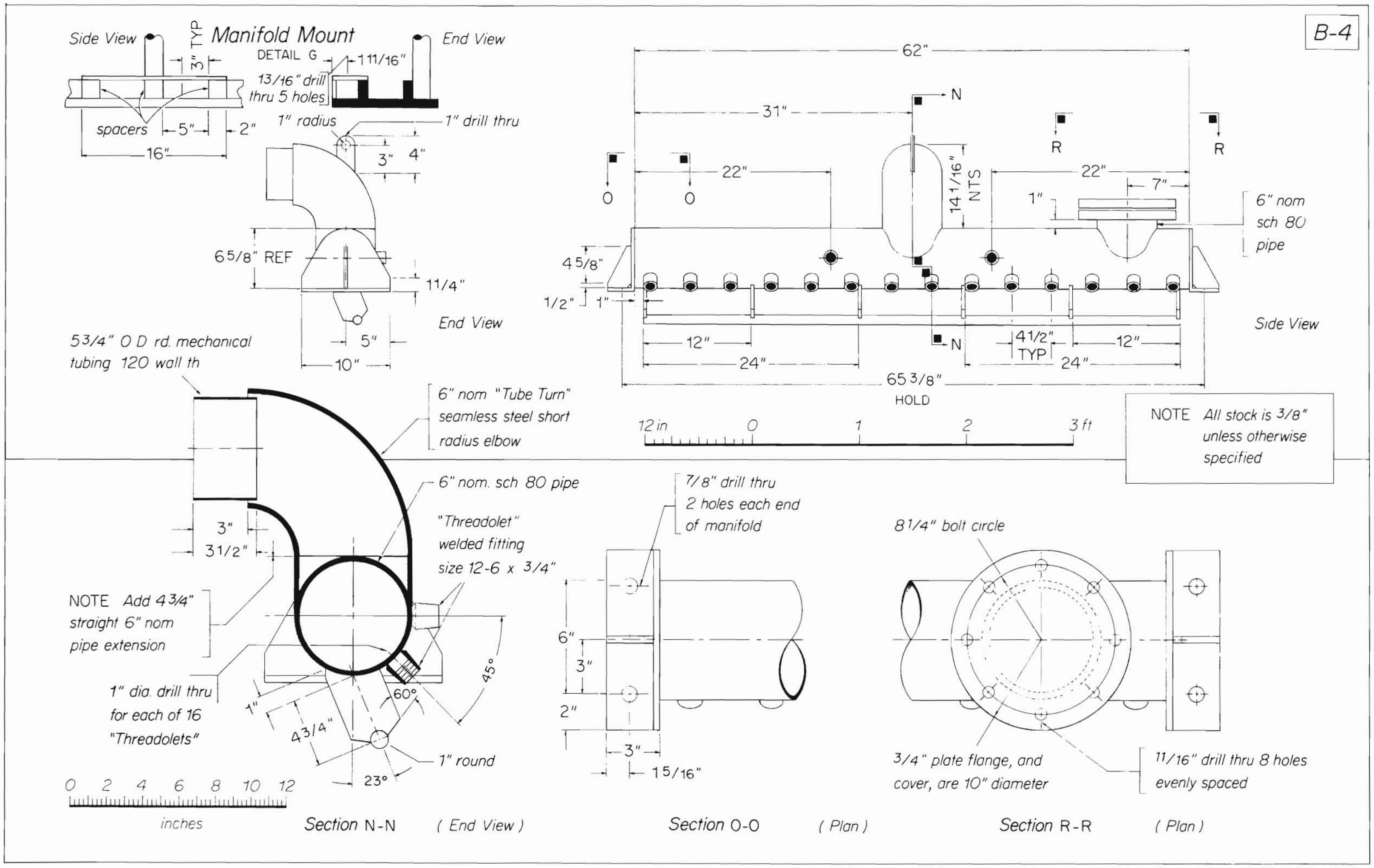
Appendix B

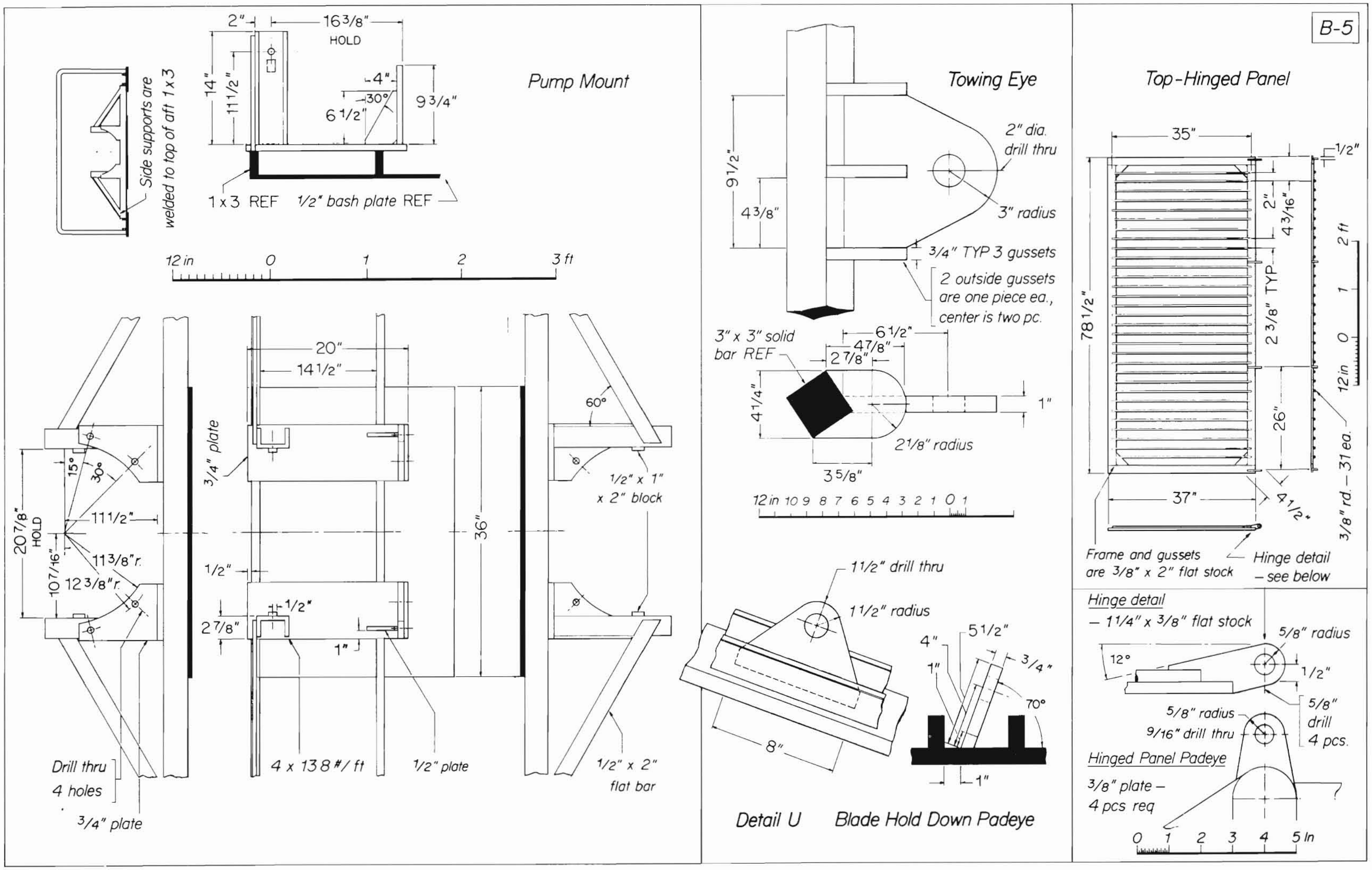

B-1
Top bars removed this side for clarity
E
E
A
A
a
14 1/2"
15 1/2"
24 1/2" radius
65 3/8" Hold
86"
5" TYP
3"
6"
3"
d.
b.
c.
25°
198"
25"
25 1/2"
12 3/4"
25"
6 1/2"
36"
13"
12"
12 in 0 1 2 3 4 5 6
Feet
B
B
C
D
d.
34 1/2"
14 1/2"
8 1/4"
6" radius
9 1/4"
18 3/4"
24" radius
6 1/2"
36"
30"
39"
34"
35 1/2"
16"
E
C
E
D
a. Towing Eye (dwg. B-5)
b. Manifold Mount (dwg. B-4)
c. Hinged Panel (dwg. B-5)
d. Padeye (dwg. B-5)


B-2
12 in 0 1 2 3 4 5 6
Feet
6"
1" x 3" solid flat
1 1/2" solid rd
32"
1/2" x 1 1/2" solid flat
6 3/4"
23"
2 1/2"
1" x 2" solid flats
J ②
Section C-C
B
2" solid rd
I
C
1 1/2" solid rd
D
2" solid rd.
1 1/2" solid rd
T Pump Mount
(dwg B-5)
3" x 3"
solid bar
S
J
①
②
C 1" solid sq
K
D
26 3/4"
U (dwg B-5)
14 3/4"
G (dwg B-4)
Section A-A
1/2" bash plate
B
1/4" plate
3/4" solid rounds
spaced 2" between
(diagonally measured)
1"
1" x 12" solid flat
Section D-D
2" solid sq
70°
140°
release
levers
side
2 1/2" nom sch 80 pipe, 4" lg
2 pcs req
30"
60"
1 1/2"
solid rd
3/4" solid
rounds spaced
1 1/2" between
2"
solid rd
69" lg
plan
1/2"
2" r
22 1/4"
Views E-E
Catch Door
63"
2" r
3" r
26"
5/8" solid rounds
spaced 2" between
1/2" plate
7 1/2
5 1/4"
J ①
View B-B
Trash Door
1 1/16" d
drill
thru
a
b
67°
125°
end
3/4" x 2" plate TYP
c
d
plan
Detail I
Trash Door Hinge
Details I, J, K (enlarged view)
a = 15/8"
b = 13/4"
c = 3"
d = 1/4"
e = 2"
f = 31/4"
g = 3/4"
h = 15/16"
i = 31/8"
j = 23/4"
k = 31/2"
l = 3"
m = 71/2"
11/4" nom sch 80 pipe, 2" lg 10 req. n
11/4" solid rd 72" long, 2 req o
0 2 4 6 8 10 12
Inches
e
f
n o
Detail J
g
① (trash)
g
② (catch)
Door Release Pads
11/2" dia
h
i
j
l
m
k
Detail K Blade Hinge
Mount (3/8" plate)



⦿ Note. Blade is 1/2" x 3" single bevel flat blade steel


B-4
Side View
Manifold Mount
DETAIL G
End View
3" TYP
1 11/16"
13/16" drill thru 5 holes
spacers
5"
2"
16"
1" radius
1" drill thru
3"
4"
6 5/8" REF
1 1/4"
End View
5"
10"
5 3/4" O D rd. mechanical tubing 120 wall th
6" nom "Tube Turn" seamless steel short radius elbow
6" nom. sch 80 pipe
"Threadolet" welded fitting size 12-6 x 3/4"
3"
3 1/2"
NOTE Add 4 3/4" straight 6" nom pipe extension
1" dia. drill thru for each of 16 "Threadolets"
1"
4 3/4"
60°
45°
1" round
23°
0 2 4 6 8 10 12
inches
Section N-N (End View)
62"
31"
N
R
R
O
O
22"
22"
7"
14 1/16" NTS
1"
6" nom sch 80 pipe
4 5/8"
1/2"
1"
12"
24"
4 1/2" TYP
12"
24"
65 3/8" HOLD
Side View
12 in 0 1 2 3 ft
NOTE All stock is 3/8" unless otherwise specified
7/8" drill thru 2 holes each end of manifold
6"
3"
2"
3"
1 5/16"
Section O-O (Plan)
8 1/4" bolt circle
3/4" plate flange, and cover, are 10" diameter
11/16" drill thru 8 holes evenly spaced
Section R-R (Plan)


B-5
Pump Mount
2"
16 3/8"
HOLD
14"
11 1/2"
4"
30°
6 1/2"
9 3/4"
Side supports are welded to top of aft 1 x 3
1 x 3 REF
1/2" bash plate REF
12 in
0
1
2
3 ft
20"
14 1/2"
3/4" plate
36"
60°
1/2" x 1" x 2" block
15°
30°
20 7/8" HOLD
10 7/16"
11 1/2"
11 3/8" r.
12 3/8" r.
1/2"
1/2"
2 7/8"
1"
Drill thru 4 holes
3/4" plate
4 x 13.8 #/ft
1/2" plate
1/2" x 2" flat bar
Towing Eye
2" dia. drill thru
3" radius
9 1/2"
4 3/8"
3/4" TYP 3 gussets
2 outside gussets are one piece ea., center is two pc.
3" x 3" solid bar REF
6 1/2"
4 7/8"
2 7/8"
4 1/4"
1"
2 1/8" radius
3 5/8"
12 in 10 9 8 7 6 5 4 3 2 1 0 1
1 1/2" drill thru
1 1/2" radius
4"
5 1/2"
3/4"
1"
70°
8"
1"
Detail U
Blade Hold Down Padeye
Top-Hinged Panel
35"
1/2"
2"
4 3/16"
2 3/8" TYP
78 1/2"
26"
37"
4 1/2"
3/8" rd. – 31 ea.
2 ft
1
0
12 in
Frame and gussets are 3/8" x 2" flat stock
Hinge detail – see below
Hinge detail
– 1 1/4" x 3/8" flat stock
5/8" radius
12°
1/2"
5/8" drill 4 pcs.
5/8" radius
9/16" drill thru
Hinged Panel Padeye
3/8" plate – 4 pcs req
0 1 2 3 4 5 In