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Staff Papers Series

Staff Paper P85-14 March 1985

UPPER MISSISSIPPI RIVER BARGE AND TOWING
INDUSTRY FUEL USE ANALYSIS

by

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Introduction

During 1976-79, as a result of the Water Resources Act of 1976, the Great River Environmental Action Team was active in Mississippi River management planning. The Great River Environmental Action Team (GREAT) was a Federal and State interagency task force established to develop a comprehensive river management plan for the navigable sections of the Upper Mississippi river. One of the major programs coming out of the GREAT planning effort and other governmental actions provided for reduction of dredge materials. As a result of this, the Corps of Engineers - St. Paul District developed a program of reduced depth dredging for channel maintenance.

Consequently, a reduced amount of under-hull water is now available under the current channel maintenance program when compared to that of the early 1970's. This translates into increased drag for operating vessels. This increase in drag alters performance, increases operating costs and increases consumption of non-renewable energy resources. The impacts of reduced depth dredging on transportation cost and energy consumption is of concern to Minnesota because of the major impact barge transportation has on the State of Minnesota's economy. For example, agricultural prosperity depends on accessible export markets for both the raw and processed products. As agriculture has become more specialized, the imputs needed to produce our goods must increasingly come from outside of Minnesota. Thus, the cost of transportation has a direct impact on both the cost and marketing margins of Minnesota products. Liquid and solid fuel movements also depend heavily on barge transportation, as do a number of other industries. Consequently an efficient and reliable transportation system is vital to Minnesota and the Upper Midwest.

The barge and towing industry accounts for major movements of many commodities both to and from Minnesota. Tables 1-3 illustrate the magnitude of barge movements in 1982 for the Twin Cities (above mile 830) and the St. Croix, Black and Minnesota Rivers (additional movements occur from lower pool 2, Red Wing and Winona that are not included here). Table 1 gives the volume of outbound commodities in short tons while Table 2 and 3 follow the same format for inbound commodities and total tonnage respectively. Over sixteen million tons of goods were transported by barge in 1982 in this portion of the St. Paul District of the Corps of Engineers. Figure 1 offers additional insight as to the role the barge and towing industry plays. It shows the transportation modes used for shipments from Mississippi River Twin Cities terminal elevators as reported to the Minneapolis Grain Exchange for various years.

This study addresses the physical relationships between fuel use in the barge industry and reduced depth dredging. However, it should be remembered that reduced depth dredging has changed the operating environment for barging in Minnesota in other ways besides increased fuel costs. These include safety considerations, increased transit times, and a perception within the barge industry that Minnesota is indifferent to the problems of commercial navigation.

Table 1

Freight Traffic: Outbound Commodities - 1982 (Short Tons)

COMMODITY	St.Croix River	% of total	Minnesota River	% of total	Black River	% of total	MPLS.	% of total	St. Paul	% of total	DISTRICT TOTAL	% of TOTAL
GRAINS & MILL PRODUCTS:												
CORN		.00	1372970	35.93	31116	17.97	180268	12.56	1273808	13.32	2858162	17.80
WHEAT		.00	835441	21.86		.00	251471	17.52	1273290	13.32	2360202	14.70
SOYBEANS		.00	773534	20.24	3029	1.75	171718	11.96	1000284	10.46	1948565	12.14
OATS		.00	51333	1.34	1440	.83	17862	1.24	29139	.30	99774	.62
BARLEY		.00		.00		.00	4473	.31	5702	.06	10175	.06
OILSEEDS,NEC		.00	2119	.06		.00	4058	.28	31161	.33	37338	.23
ANIMAL FEEDS		.00	8260	.22		.00	47400	3.30	261973	2.74	317633	1.98
MILL PRODUCTS,NEC		.00	18499	.48		.00	38954	2.71	47707	.50	105160	.65
subtotal	0	.00	3062156	80.13	35585	20.55	716204	49.89	3923064	41.03	7737009	48.19
FERTILIZERS:												
NITROGENOUS		.00	32165	.84		.00	2909	.20	4425	.05	39499	.25
POTASSIC		.00	1639	.04		.00	41014	2.86	202114	2.11	244767	1.52
PHOSPHATIC		.00	2951	.08		.00	3107	.22	7392	.08	13450	.08
OTHER,NEC		.00	147699	3.86		.00	1567	.11	118983	1.24	268249	1.67
subtotal	0	.00	184454	4.83	0	.00	48597	3.38	332914	3.48	565965	3.52
COAL	1064305	100.00	348935	9.13	6985	4.03	111547	7.77	2634737	27.56	4166509	25.95
SAND,GRAVEL,ROCK		.00	1486	.04		.00	306867	21.37	1347006	14.09	1655359	10.31
NON-METALLIC MINERALS		.00	98000	2.56	15466	8.93	15891	1.11	226077	2.36	355434	2.21
CEMENT		.00		.00		.00	134695	9.38	136195	1.42	270890	1.69
PETROLEUM & PRODUCTS		.00		.00	59645	34.44	6697	.47	526087	5.50	592429	3.69
COKE,PITCH,ASPHALT		.00	65943	1.73	41829	24.15	20710	1.44	226559	2.37	355041	2.21
LUMBER,PULP,PAPER		.00		.00		.00	2455	.17	6910	.07	9365	.06
ALL OTHERS,NEC		.00	60666	1.59	13691	7.90	71974	5.01	201674	2.11	348005	2.17
TOTAL	1064305	100.00	3821648	100.00	173201	100.00	1435687	100.00	9561223	100.00	16056006	100.00

Source: Waterborne Commerce of the United States 1982

Table 2

Freight Traffic: Inbound Commodities - 1982 (Short Tons)

COMMODITY	St.Croix River	% of total	Minnesota River	% of total	Black River	% of total	MPLS.	% of total	St. Paul	% of total	DISTRICT TOTAL	% of TOTAL
GRAINS & MILL PRODUCTS:												
CORN		.00		.00		.00		.00		.00	0	.00
WHEAT		.00	4496	.62		.00		.00		.00	4496	.09
SOYBEANS		.00		.00		.00		.00	3083	.13	3083	.06
OATS		.00		.00		.00		.00		.00	0	.00
BARLEY		.00		.00		.00		.00		.00	0	.00
OILSEEDS,NEC		.00		.00		.00		.00		.00	0	.00
ANIMAL FEEDS		.00		.00		.00		.00	16074	.66	16074	.33
MILL PRODUCTS,NEC		.00		.00		.00		.00	6134	.25	6134	.13
subtotal	0	.00	4496	.62	0	.00	0	.00	25291	1.04	29787	.62
FERTILIZERS:												
NITROGENOUS		.00	32165	4.43		.00	2909	.46	4425	.18	39499	.82
POTASSIC		.00	1639	.23		.00		.00		.00	1639	.03
PHOSPHATIC		.00	2951	.41		.00	3107	.49	2885	.12	8943	.18
OTHER,NEC		.00	147699	20.34		.00	1567	.25	118983	4.91	268249	5.54
subtotal	0	.00	184454	25.40	0	.00	7583	1.20	126293	5.22	318330	6.57
COAL	1064305	100.00	348935	48.06		.00	111597	17.66	348914	14.41	1873751	38.69
SAND,GRAVEL,ROCK		.00	1486	.20		.00	306867	48.55	1038653	42.90	1347006	27.81
NON-METALLIC MINERALS		.00	98000	13.50		.00	15891	2.51	184751	7.63	298642	6.17
CEMENT		.00		.00		.00	134695	21.31	1500	.06	136195	2.81
PETROLEUM & PRODUCTS		.00		.00		.00		.00	507236	20.95	507236	10.47
COKE,PITCH,ASPHALT		.00	65943	9.08		.00	2487	.39	40525	1.67	108955	2.25
LUMBER,PULP,PAPER		.00		.00		.00	2455	.39	2532	.10	4987	.10
ALL OTHERS,NEC		.00	22767	3.14		.00	50507	7.99	145166	6.00	218440	4.51
TOTAL	1064305	100.00	726089	100.00			632082	100.00	2420861	100.00	4843337.0	100.00

Source: Waterborne Commerce of the United States 1982

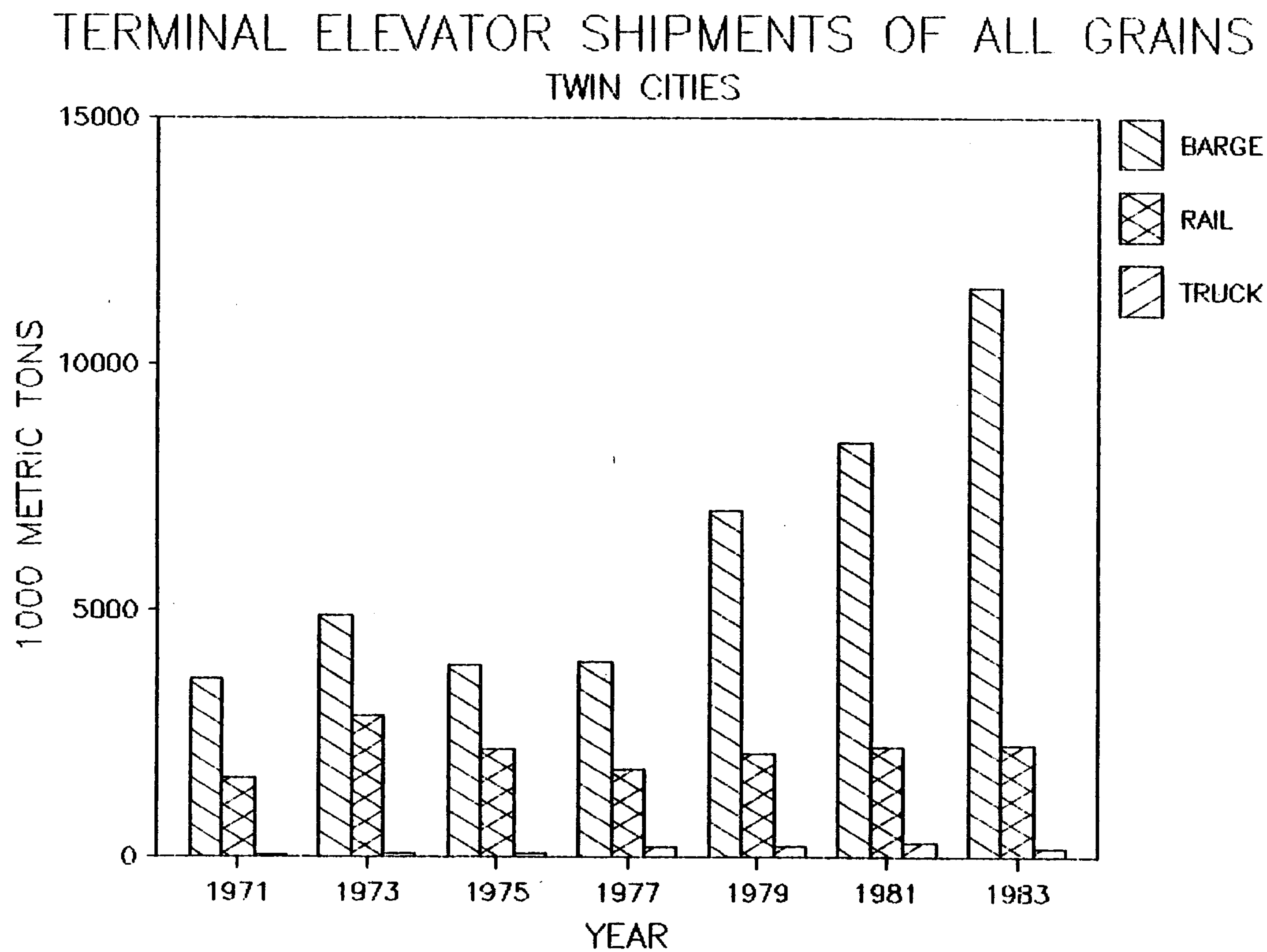
Table 3

Freight Traffic: Total Tonnage - 1982 (Short Tons)

COMMODITY	St.Croix River	% of total	Minnesota River	% of total	Black River	% of total	MPLS.	% of total	St. Paul	% of total	DISTRICT TOTAL	% of TOTAL
GRAINS & MILL PRODUCTS:												
CORN		.00	1372970	44.35		.00	180268	22.43	1273808	19.39	2827046	27.01
WHEAT		.00	830945	26.84		.00	251471	31.29	1273290	19.38	2355706	22.50
SOYBEANS		.00	773534	24.99		.00	171718	21.37	997201	15.18	1942453	18.56
OATS		.00	51333	1.66		.00	17862	2.22	29139	.44	98334	.94
BARLEY		.00		.00		.00	4473	.56	5702	.09	10175	.10
OILSEEDS,NEC		.00	2119	.07		.00	4058	.50	31161	.47	37338	.36
ANIMAL FEEDS		.00	8260	.27		.00	47400	5.90	245899	3.74	301559	2.88
MILL PRODUCTS,NEC		.00	18499	.60		.00	38954	4.85	41573	.63	99026	.95
subtotal	0	.00	3057660	98.78	0	.00	716204	89.12	3897773	59.33	7671637	73.28
FERTILIZERS:												
NITROGENOUS		.00		.00		.00		.00		.00	0	.00
POTASSIC		.00		.00		.00	41014	5.10	202114	3.08	243128	2.32
PHOSPHATIC		.00	0	.00		.00		.00	4507	.07	4507	.04
OTHER,NEC		.00	0	.00		.00	0	.00		.00	0	.00
subtotal	0	.00	0	.00	0	.00	41014	5.10	206621	3.15	247635	2.37
COAL		.00		.00		.00		.00	2285823	34.80	2285823	21.84
SAND,GRAVEL,ROCK		.00		.00		.00		.00		.00	0	.00
NON-METALLIC MINERALS		.00		.00		.00		.00		.00	0	.00
CEMENT		.00		.00		.00		.00		.00	0	.00
PETROLEUM & PRODUCTS		.00		.00		.00	6697	.83	18851	.29	25548	.24
COKE,PITCH,ASPHALT		.00		.00		.00	18223	2.27	99381	1.51	117604	1.12
LUMBER,PULP,PAPER		.00		.00		.00		.00	4378	.07	4378	.04
ALL OTHERS,NEC		.00	37899	1.22		.00	21467	2.67	56508	.86	115874	1.11
TOTAL			3095559	100.00			803605	100.00	6569335	100.00	10468499	100.00

Source: Waterborne Commerce of the United States 1982

FIGURE 1


TERMINAL ELEVATOR SHIPMENTS OF ALL GRAINS
TWIN CITIES
15000
10000
5000
0
1000 METRIC TONS
1971
1973
1975
1977
1979
1981
1983
YEAR
BARGE
RAIL
TRUCK

Methodolodgy

The method of analysis consisted of :

1) A literature review of fuel and power requirements for various channel configurations.

2) Interviews with marine engineers, marine diesel experts, and barge industry line-haul personnel.

3) A series of computer simulations using various tow and channel configurations.

4) Analysis of the computer simulations.

A comparison of barge industry fuel use prior to the reduced depth dredging with current fuel use was not appropriate for the following reasons.

1) The effect of major fuel conservation efforts by barge operators in response to significantly higher fuel cost in the late 1970's and early 1980's as opposed to the early 1970's.

2) The lack of complete and reliable fuel records for different river segments.

It was originally hypothesized that an acceptable comparison to make would be that of actual fuel use on segments of the Upper Mississippi with actual fuel use on similar segments of the Ohio River. If Ohio River segments could be adequately matched in characteristics to Upper Mississippi segments and fuel use data was reported for each of these segments, the differences in fuel use could be attributed to the respective dredging programs. Review of the data from industry sources indicate that comparable fuel use data by river segments (from FMS i.e. fuel monitoring systems) is not yet available. A further difficulty is that major carriers on the Ohio River went to heavier fuels than used on the Upper Mississippi in response to the higher energy cost of recent years. The Ohio River emphasis was not on developing FMS so comparable data on fuel consumption is not available.

Literature Review

A number of computer data bases were accessed to identify work relating to fuel/power requirements and channel configuration on the inland waterways. Although numerous related articles were identified and reviewed, literature on the direct measurement of tow fuel use on various segments of the inland waterway was not available; additionally the bulk of engineering data does not address a channel depth to draft ratio of less than 1.5 (see Velednitsky, "Determination of Resistance of Displacement Ships in Shallow Water", Translated by R. Latorre). Highlights from the reviewed literature address both of these findings along with other pertinent facts .

Baumel et al. (1) addressed fuel consumption by mode for grain export, using physical measurements collected from on-vehicle metering for truck and rail but not for barges. The study cited these problems with fuel metering on towboats.

> " Vibrations created when one or both propellers are in full reverse make on-board metering impossible. Daily fuel tank measurements obtained from calibrated steel tape measures were the only available method of obtaining towboat fuel consumption. "

Baumel reported fuel consumption characteristics with the data split as to Upper and Lower Mississippi and upbound and downbound movements. The values presented for barges are in Table 4.

Table 4

Comparison of Net Ton-Miles on Upper and Lower Mississippi

	Net ton-miles/gal. southbound	Net ton-miles/gal. northbound	Net ton-miles/gal. round-trip
Upper Mississippi	952.7	627.1	756.5
Lower Mississippi	1289.9	516.1	737.3

The study also noted that there was more variation in fuel use on Upper Mississippi tows than on those that operated on the Lower Mississippi.

A mathematical formula based on engineering and technological relationships was used by Howe, et al. (11) to develop a production function for tows. This formula takes into account both channel depth and width.

Resistance of a barge tow was given as:

$$R = 0.07289\, e^{(1.46/D-H)}\, S^{2.0}\, H^{0.6+(50/W-B)}\, L^{0.38}\, B^{1.19}$$

Notation used:

- B = width of barge tow, in feet
- D = depth of channel, in feet
- H = draft of barge tow, in feet
- L = length of barge tow, in feet
- R = resistance of barge tow, in pounds force
- S = speed, in miles per hour
- W = width of channel, in feet

To assist in understanding the relationships presented in the above equation Table 5, Table 6 and Table 7 are displayed. Table 5 defines the dimensions of a typical 15 barge tow and the channel depth and width values used. Table 6 displays the resistance of a barge tow under various channel configurations. The tow speed and dimensions were held constant while channel depth and width were changed. Table 7 contains values for each combination of depth and width as a percentage of a 15 by 300 foot channel. Figure 2 graphs how resistance increases for a barge tow as channel depth is reduced from 20 feet to 11 feet while maintaining channel width at 300 feet. A major conclusion of Howe et al. on technology and production functions for barge tows was :

> " The effects of channel width and depth on the rate of output of the tow and on operating cost are dramatic when width and depth approach the breadth and draft of the barge flotilla. However, the favorable effects of increased channel width and depth appear to be largely exhausted at depths four times flotilla draft and at widths twice that of the flotilla."

Table 5

Values used in Resistance Equation

B = 105 ft. H = 9 ft. L = 1200 ft. S = 4.0 mph

While D = 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

and W = 250, 300, 350, 400, 450, 500, 550

The GREAT I Dredging Requirements Work Group (6) reviewed the literature on navigational safety. They cite a study on vessel safety by the Delft Hydraulics Laboratory (7) that determined that a channel depth to vessel draft ratio of less than 1.5 reduced directional stability. Also reported in GREAT I was a study from the University of Michigan, Department of Naval Architecture and Marine Engineering on effects of channel width and depth on barges. The findings of this study which incorporated tow-tank data are found in Table 8.

TABLE 6

JOINT EFFECTS OF CHANNEL WIDTH AND DEPTH ON RESISTANCE OF A BARGE TOW
15 Barge Tow @ 4.0 MPH

RESISTANCE IN POUNDS OF FORCE

Depths (Feet)	Widths (Feet) 250	300	350	400	450	500	550
11	72564	59752	53262	49364	46770	44922	43540
12	56891	46846	41758	38702	36668	35220	34136
13	50374	41479	36974	34268	32468	31185	30225
14	46827	38559	34371	31856	30182	28990	28098
15	44603	36728	32739	30343	28748	27613	26763
16	43079	35473	31620	29306	27766	26669	25849
17	41971	34560	30806	28552	27052	25983	25183
18	41128	33866	30188	27979	26509	25461	24678
19	40466	33321	29702	27528	26082	25052	24281
20	39933	32882	29311	27165	25738	24721	23961

TABLE 7

As a Percent of a 15 by 300 Foot Channel

Depths (Feet)	Widths (Feet) 250	300	350	400	450	500	550
11	198%	163%	145%	134%	127%	122%	119%
12	155%	128%	114%	105%	100%	96%	93%
13	137%	113%	101%	93%	88%	85%	82%
14	127%	105%	94%	87%	82%	79%	77%
15	121%	100%	89%	83%	78%	75%	73%
16	117%	97%	86%	80%	76%	73%	70%
17	114%	94%	84%	78%	74%	71%	69%
18	112%	92%	82%	76%	72%	69%	67%
19	110%	91%	81%	75%	71%	68%	66%
20	109%	90%	80%	74%	70%	67%	65%

FIGURE 2

EFFECTS OF CHANNEL DEPTH ON RESISTANCE

15 Barge Tow @ 4.0 MPH (300 foot width)

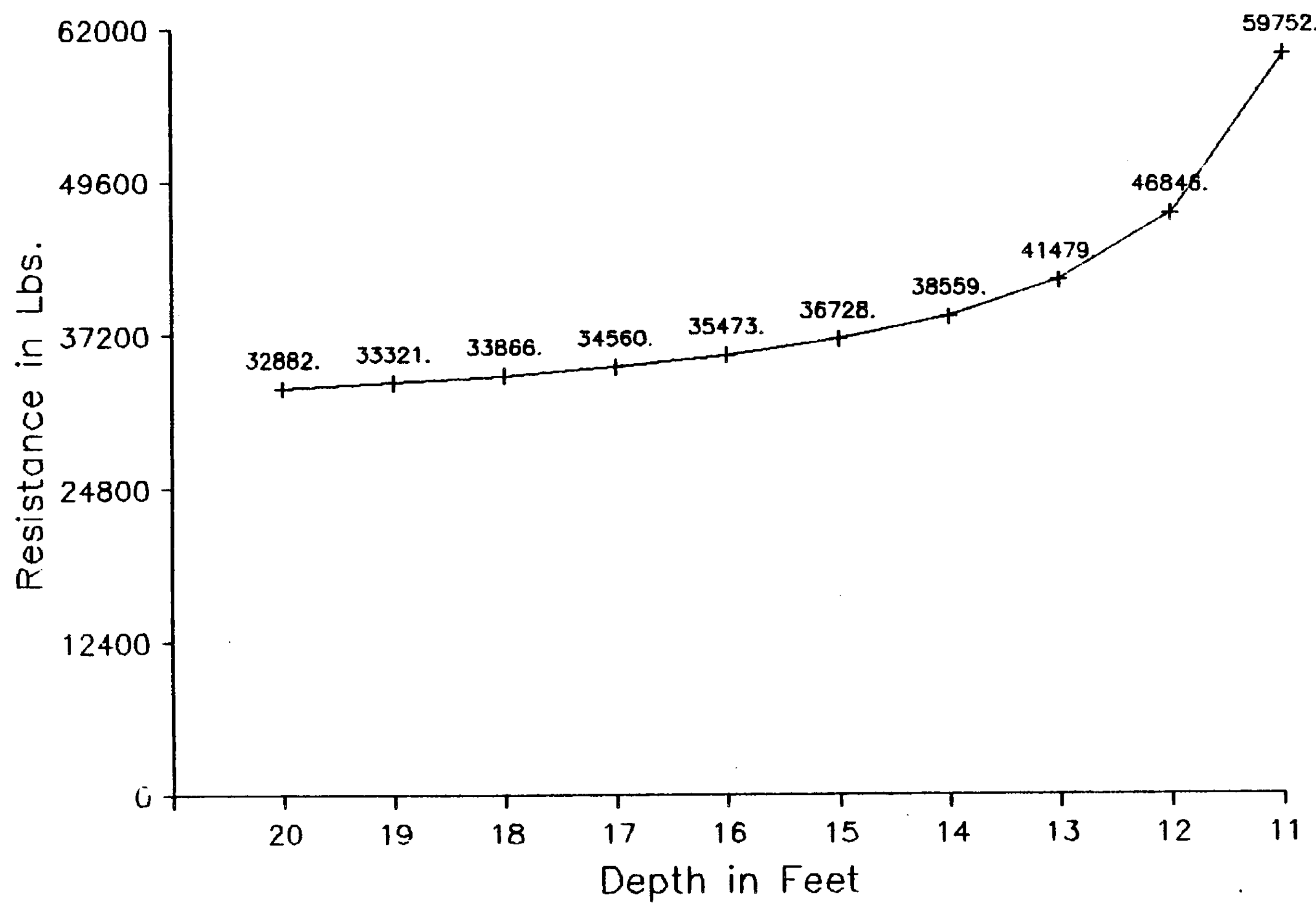


Table 8

Joint Effects of Channel Width and Depth on Speed of Tows
3 by 2 Barge tow, 8.5 ft. draft

Channel Width	Channel Depths		
	11 ft.	13 ft.	18 ft.
125 ft.	3.70 knots	4.10 knots	5.02 knots
225 ft.	4.55 knots	5.30 knots	6.38 knots
300 ft.	4.95 knots	5.67 knots	6.64 knots

Marbury (17) states that a barge first "feels" bottom at a channel depth of about 67 feet (for a tow three barges wide at a nine foot draft). A channel depth to draft ratio for a 67 foot channel and a nine foot draft tow is 7.44. This makes it clear that a tow operating on the Inland Waterway is in " shallow " water and subject to bottom resistance.

Interviews

Barge line-haul personnel and a number of experts in the fields of marine engineering, naval architecture, and marine diesel engines were interviewed on current developments during February and March, 1985. These interviews confirmed that the data required for a detailed fuel use analysis are not available at this time. However, it was also apparent that the ability to collect detailed fuel data is rapidly becoming available in the barge and towing industry. A number of line-haul firms are turning to fuel monitoring systems for more complete information with the intention of increasing operating efficiency. Information about individual firm programs is frequently confidential, but some generalizations about this industry development can be made. The initial work on developing a FMS was done on the Lower Mississippi.

Major work on the FMS began in 1982 and 1983. The reason for this is that a major part of all fuel burned on the Inland Waterways takes place on this part of the Mississippi. Thus, the greatest potential saving of fuel is on the Lower Mississippi. FMS on the Upper Mississippi began during the end of the 1984 shipping season. We did not find FMS with any history on the Ohio River.

Fuel Monitoring Systems (FMS)

In the last two years, major breakthroughs in hardware and software have led to a means of collecting the type of data required for comprehensive study of barge fuel use. Equipment installations are now exiting the experimental research and development stage. The systems are now at the point of reliable operation and are being incorporated in the decision making process of barge firms. Unlike tow-tank studies and studies based on engineering relationships, data collected on a continuous basis during actual movements allows the complex set of forces that effect the operation and the efficiency of the tow to become components of the model. The simultaneous factors acting on a tow at one time that must be measured or otherwise considered, include:

1) Depth of Channel
2) Width of Channel
3) Direction of Tow
4) Speed of Current
5) Wind Speed
6) Wind Direction
7) Traffic Levels
8) Individual Pilot Methods
9) Other

Empirical data collection allows these factors to be considered for actual operational adjustments. Although equipment, configuration and level of implementation differ, the systems generally include :

1) A microprocessor to coordinate equipment recording and reporting.
2) A fuel meter to measure fuel as it is taken on board.

3) A fuel meter on each engine to measure fuel burned.
4) A tachometer for each engine.
5) A tachometer for each shaft.
6) A clock and calendar.
7) A receiver to determine position and speed over land.
8) A depth sounder.
9) A speed though water sensor.
10) An interactive terminal to enter position, draft, and type of barge in tow.

Computer Simulation

The most effective means available to quantify the increase in fuel use due to the reduced channel dimensions caused by reduced dredging is with computer programs developed with the data from the FMS. The computer model used here is one that is currently being used on the river system. Operational decisions are based in part on reports generated with this program. This type of decision making tool that uses the information collected by the fuel monitoring system is quickly being incorporated into the barge industry. The computer model is based on engineering relationships and empirical data is added to the information base after each actual run. This incorporation of actual data will improve the performance of the computer modeling as the data-base of empirical observation increases over time.

A number of runs using the simulation model were made for different tow sizes, draft, barge placement in tow, speed, and channel depth. The three tow sizes used were 15 barges, 12 barges, and 9 barges. These are tow sizes prevalent on the Upper Mississippi. Drafts of 9 ft, 8 ft and 1.6 ft (empty) were used. Speed of tow was either 4.0 mph or 6.0 mph. Channel depths of 11 thru 15 feet or 11 thru 20 feet are used. The relative position of barges in the tow, their draft, speed, and if the barge is a rake or box is found in a figure preceding the table for each run. These 12 configurations used can be found in figures 3, 6, 10, 13A, 13B, 16, 19, 22, 25, 28, 32, and 35.

Analysis of Computer Runs

For every configuration run, a reduction in channel depth while holding the other variables constant caused an increase in gallons per hour (GPH) of fuel burned. This is expected due to the increased drag that must be overcome. The magnitude of this increase is the major information that the computer program offers.

A 15 barge tow with a 9 ft. draft @ 4.0 mph (configuration 1, Figure 3) in a 20 ft. channel burns 37.86 GPH of fuel. The increase in fuel use, with a reduction of channel depth from 20 ft. to 11 ft., was 31.76 GPH or an 83.9% increase. The increase was 1.68 GPH for the reduction of the channel depth from 20 ft. to 19 ft. while the last one foot reduction in depth increased fuel use by over 6.8 GPH. The change in channel depth from 15 ft. to 11 ft., for the 12 tow configurations analyzed, caused a range of increases from 7.93 GPH for configuration 7 to 28.38 GPH for configuration 5. The percentage increase ranged from 20.42% for configuration 8 to 41.39% for configuration 9.

The importance of barge placement in a tow with a mix of empty and full barges is illustrated by the difference in the GPH for configuration 3 and configuration 4 with 37.49 GPH and 28.66 GPH respectively in a 15 ft. channel. Both of these tows have a total of 15 barges (11 empty and 4 loaded to a 9 ft. draft) moving @ 4.0 MPH. Only placement differs, with configuration 3 having its loaded barges in a box while configuration 4 locates them in a row (see figure 10 & 13A). This type of tow would almost exclusively be upbound tow due the predominance of the downbound grain move. The increase due to a change from a 15 ft. to a 11 ft. channel also is very dependent on barge placement. Configuration 3 increased 13.79 GPH (36.78%) while configuration 4 increased 8.67 GPH (30.25%). Configurations 6 and 7 have the similar specifications with only the draft parameter changed to 8 ft. for the loaded barges. In a 15 ft. channel these tows burn fuel at 34.77 GPH and 27.12 GPH and the change from a 15 ft. to an 11 ft. channel increases them 12.19 GPH (35%) and 7.93 GPH (29.24%) respectively.

The draft of the tows become important for efficiency. A barge loaded to a 9 foot draft carries about 200 tons more cargo than the same barge loaded only to an 8 foot draft (see Appendix B). This is important when looking at the GPH per 100 tons of cargo. A 15 barge tow loaded to a 9 ft. draft carries about 22,500 tons. When loaded to only an 8 ft. draft the tow carries 19,500 tons or 3,000 tons less. With a channel depth of 15 ft., the 9 ft. draft tow uses 49.28 GPH and the 8 ft. draft tow uses 44.51 GPH. The 9 ft. draft tow burns .219 GPH per 100 tons while the 8 ft. draft tow uses .228 GPH per 100 tons. With the channel depth changed to 11 ft. the 9 ft. draft barge uses 69.62 GPH and the 8 ft. draft tow burns 62.09 GPH. This gives .309 GPH per 100 tons and .318 GPH per 100 tons for the 9 ft. and 8 ft. draft tows. Even with a lower GPH of fuel used, the tow at an 8 ft. draft burns more fuel per 100 tons of cargo than the tow at 9 ft.

FINDINGS AND RECOMMENDATIONS

Commercial navigation is of major importance to a number of Minnesota's industries including agriculture. However, at this time, many firms in the barge industry are in financial difficulty. The current dredging practices on the Upper Mississippi add to the cost problems of the industry.

The reduced depth dredging program on the Upper Mississippi River has resulted in increased fuel consumption and in an increase in the trip times required by the commercial navigation industry. The increase in fuel consumption is due to reduced channel depth and width. The increase in trip time results from slower speeds due to increased drag, navigational adjustments due to the decreased stability associated with shallow channel depths and requirements for additional maneuvering at bends and when meeting due to narrower channels. Consequently, barge industry operating costs are higher because of increased fuel consumption and the additional operating and capital costs caused by increased trip times.

The goal of the reduced dredging program recommended by GREAT I was to reduce the amount of dredge spoil because of environmental concerns. Because of this single objective of GREAT I, nonrenewable energy consumption was not considered nor were alternative solutions adequately explored which might have been more cost effective. For example, the costs of alternative dredging techniques such as riverine disposal were not considered nor were the positive environmental effects of dredging and channel maintenance analyzed. In fact, riverine disposal may present the least-cost and most environmentally desirable method of disposing of much of the dredge material (6). In addition to reduced non-renewable energy consumption and improved navigational safety for both barge traffic and small boats, wider and/or deeper channels will reduce or eliminate bank erosion and have other positive impacts on the aquatic environment.

In view of these facts and the current national priorities stressing transportation user fees and energy conservation, The current dredging practices and philosophy should be reevaluated. It may be possible to improve fuel utilization, lower barge operating costs, and reduce channel maintenance costs with little or no environmental degradation. It should be determined if the stress on reducing the volume of dredge material with its corresponding increases in energy consumption and higher transportation costs for agriculture and other industries is appropriate given current economic conditions.

FIGURE 3

15 Barge Tow

4.0 MPH

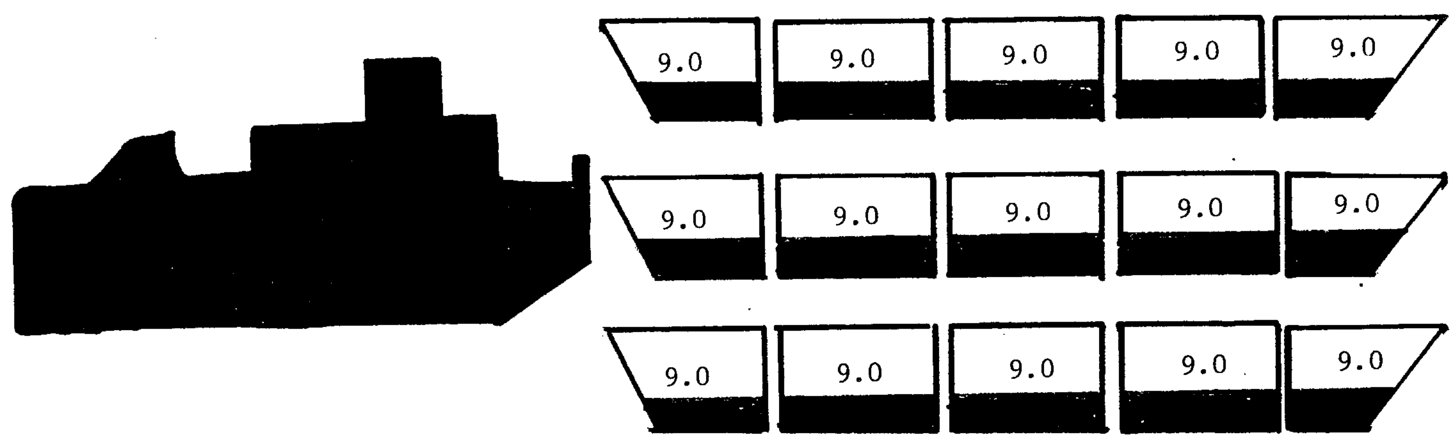


TABLE 9

15 BARGE TOW WITH A 9 FOOT DRAFT @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	20	252.40	37.86	
A 15 BARGE TOW LOADED	19	263.60	39.54	1.68
TO A 9 FOOT DRAFT	18	276.30	41.45	1.91
	17	291.10	43.66	2.21
SPEED 4.0 MPH	16	308.30	46.24	2.58
	15	328.50	49.28	3.04
	14	352.80	52.92	3.64
	13	382.20	57.32	4.40
	12	418.40	62.76	5.44
	11	464.00	69.62	6.86

INCREASE IN FUEL USE IN GALS. / HOUR

TO	19 FT	18 FT	17 FT	16 FT	15 FT	14 FT	13 FT	12 FT	11 FT
FROM 20 FT	1.68	3.59	5.80	8.38	11.42	15.06	19.46	24.90	31.76
19 FT		1.91	4.12	6.70	9.74	13.38	17.78	23.22	30.08
18 FT			2.21	4.79	7.83	11.47	15.87	21.31	28.17
17 FT				2.58	5.62	9.26	13.66	19.10	25.96
16 FT					3.04	6.68	11.08	16.52	23.38
15 FT						3.64	8.04	13.48	20.34
14 FT							4.40	9.84	16.70
13 FT								5.44	12.30
12 FT									6.86

INCREASE IN FUEL USE AS A PERCENTAGE

TO	19 FT	18 FT	17 FT	16 FT	15 FT	14 FT	13 FT	12 FT	11 FT
FROM 20 FT	4.44	9.48	15.32	22.13	30.16	39.78	51.40	65.77	83.89
19 FT		4.83	10.42	16.94	24.63	33.84	44.97	58.73	76.07
18 FT			5.33	11.56	18.89	27.67	38.29	51.41	67.96
17 FT				5.91	12.87	21.21	31.29	43.75	59.46
16 FT					6.57	14.45	23.96	35.73	50.56
15 FT						7.39	16.31	27.35	41.27
14 FT							8.31	18.59	31.56
13 FT								9.49	21.46
12 FT									10.93

FIGURE 4

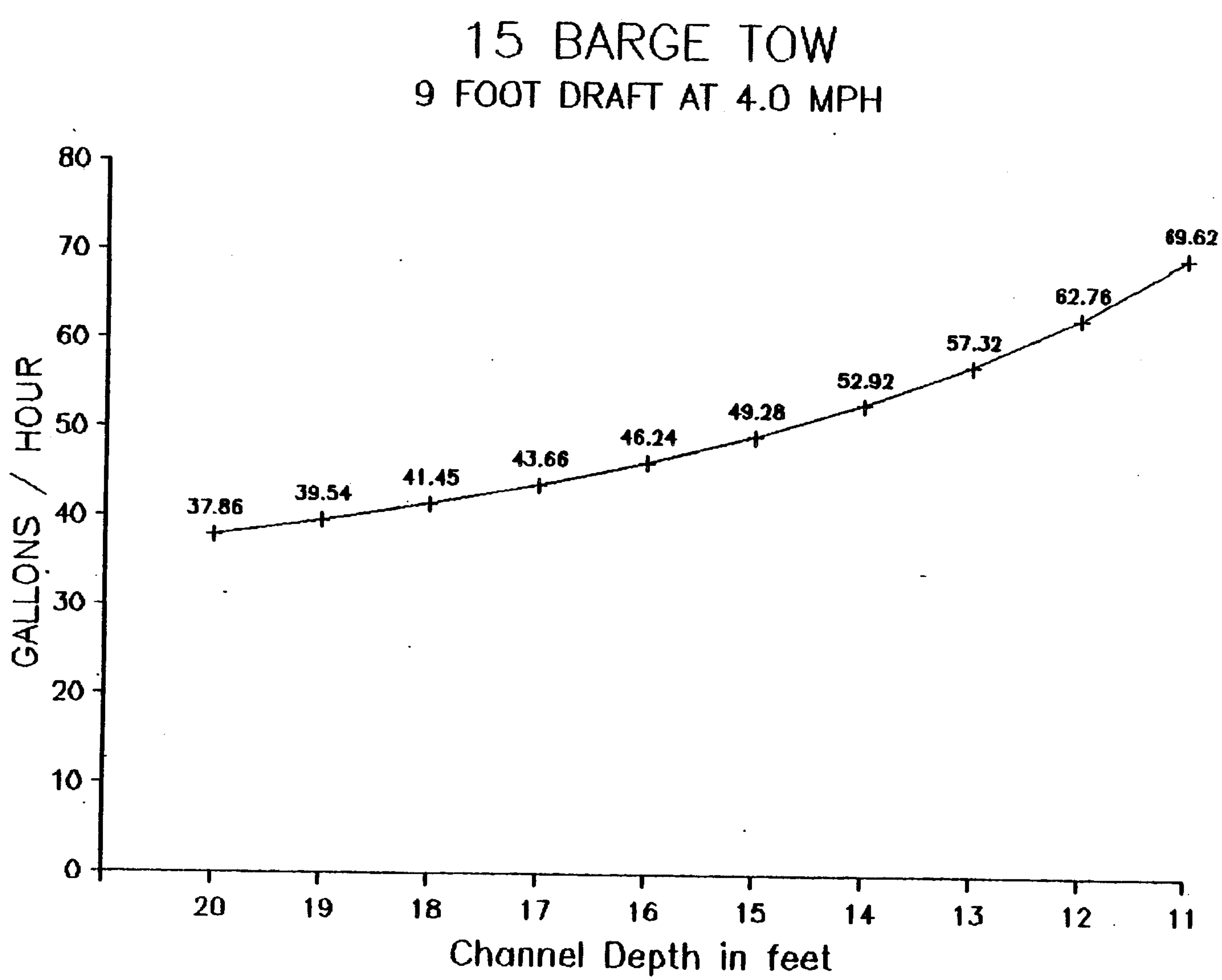

15 BARGE TOW
9 FOOT DRAFT AT 4.0 MPH
GALLONS / HOUR
80
70
60
50
40
30
20
10
0
37.86
39.54
41.45
43.66
46.24
49.28
52.92
57.32
62.76
69.62
20
19
18
17
16
15
14
13
12
11
Channel Depth in feet

FIGURE 5

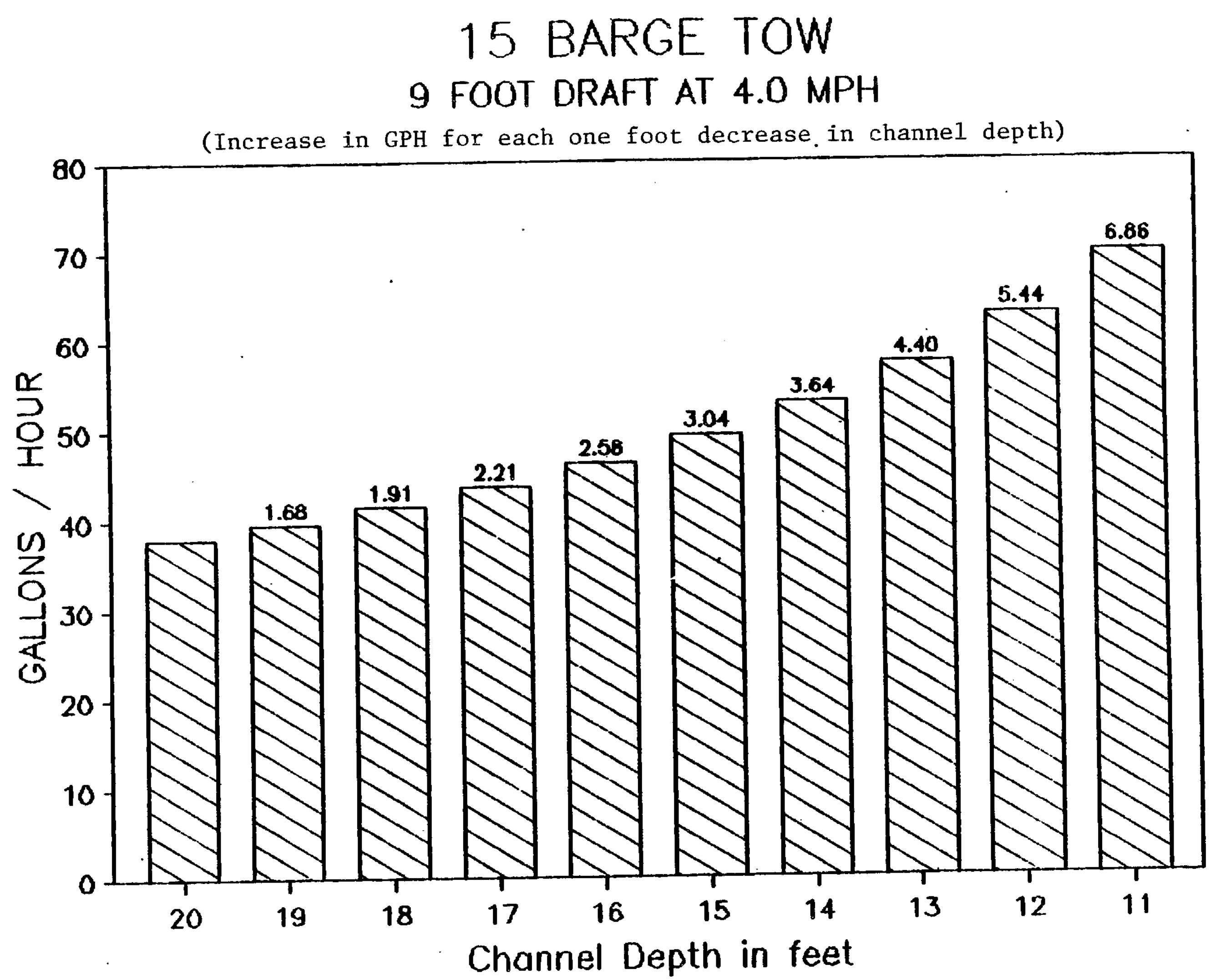

15 BARGE TOW
9 FOOT DRAFT AT 4.0 MPH
(Increase in GPH for each one foot decrease in channel depth)
GALLONS / HOUR
0
10
20
30
40
50
60
70
80
1.68
1.91
2.21
2.58
3.04
3.64
4.40
5.44
6.86
20
19
18
17
16
15
14
13
12
11
Channel Depth in feet

FIGURE 6

15 Barge Tow

4.0 MPH

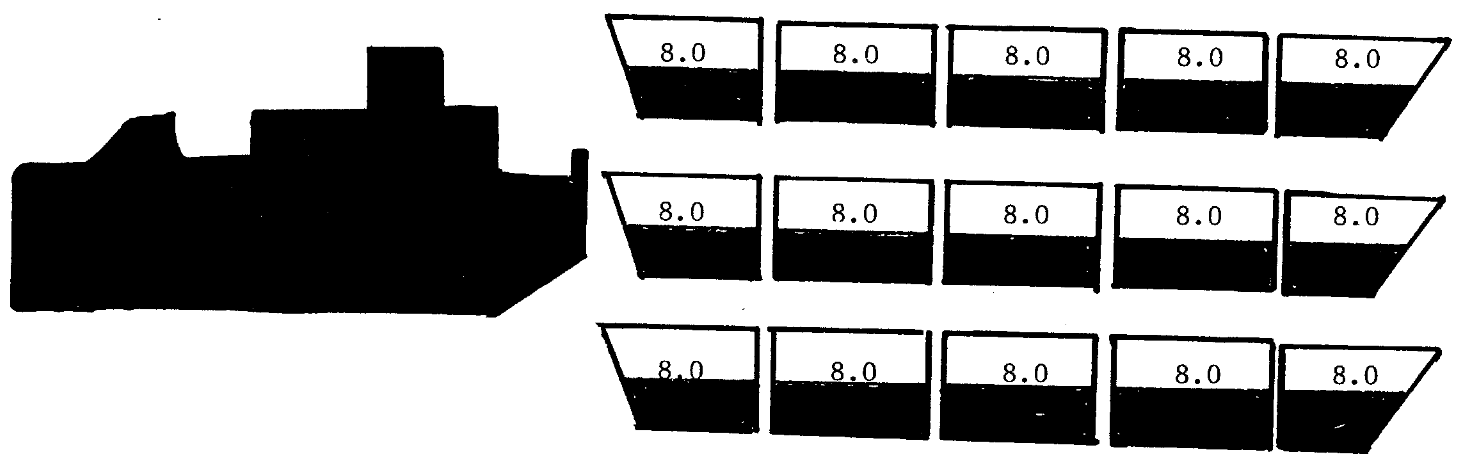


TABLE 10

15 BARGE TOW WITH A 8 FOOT DRAFT @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	296.80	44.51	
A 15 BARGE TOW LOADED	14	317.80	47.67	3.16
TO A 8 FOOT DRAFT	13	343.20	51.48	3.81
	12	374.50	56.18	4.70
SPEED 4.0	11	413.90	62.09	5.91

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	3.16	6.97	11.67	17.58
14 FT		3.81	8.51	14.42
13 FT			4.70	10.61
12 FT				5.91

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	7.1	15.66	26.22	39.5
14 FT		7.99	17.85	30.25
13 FT			9.13	20.61
12 FT				10.52

FIGURE 7

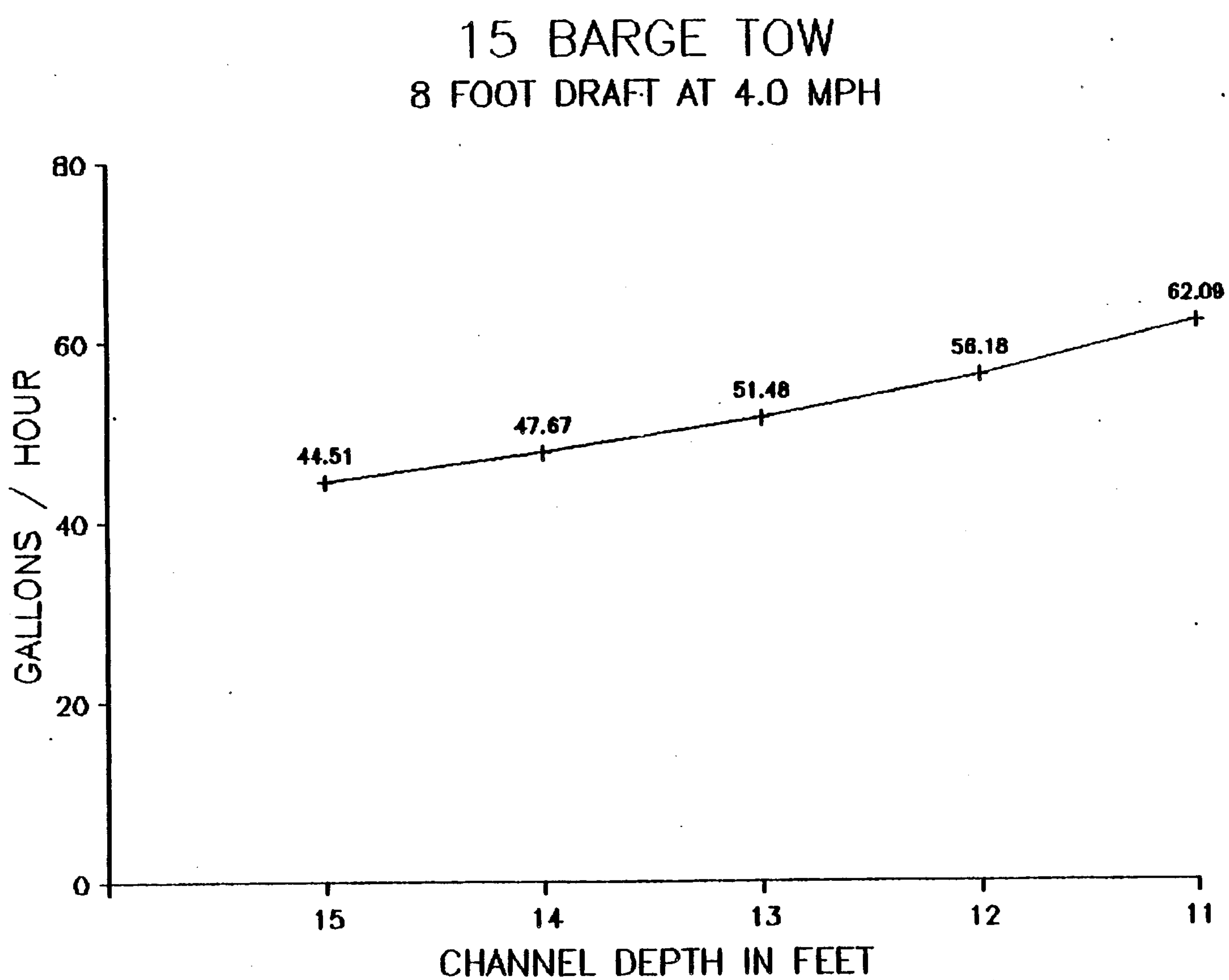

15 BARGE TOW
8 FOOT DRAFT AT 4.0 MPH
GALLONS / HOUR
80
60
40
20
0
44.51
47.67
51.48
56.18
62.09
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 8

15 BARGE TOW

8 FOOT DRAFT AT 4.0 MPH

(Increase in GPH for each one foot decrease in channel depth)

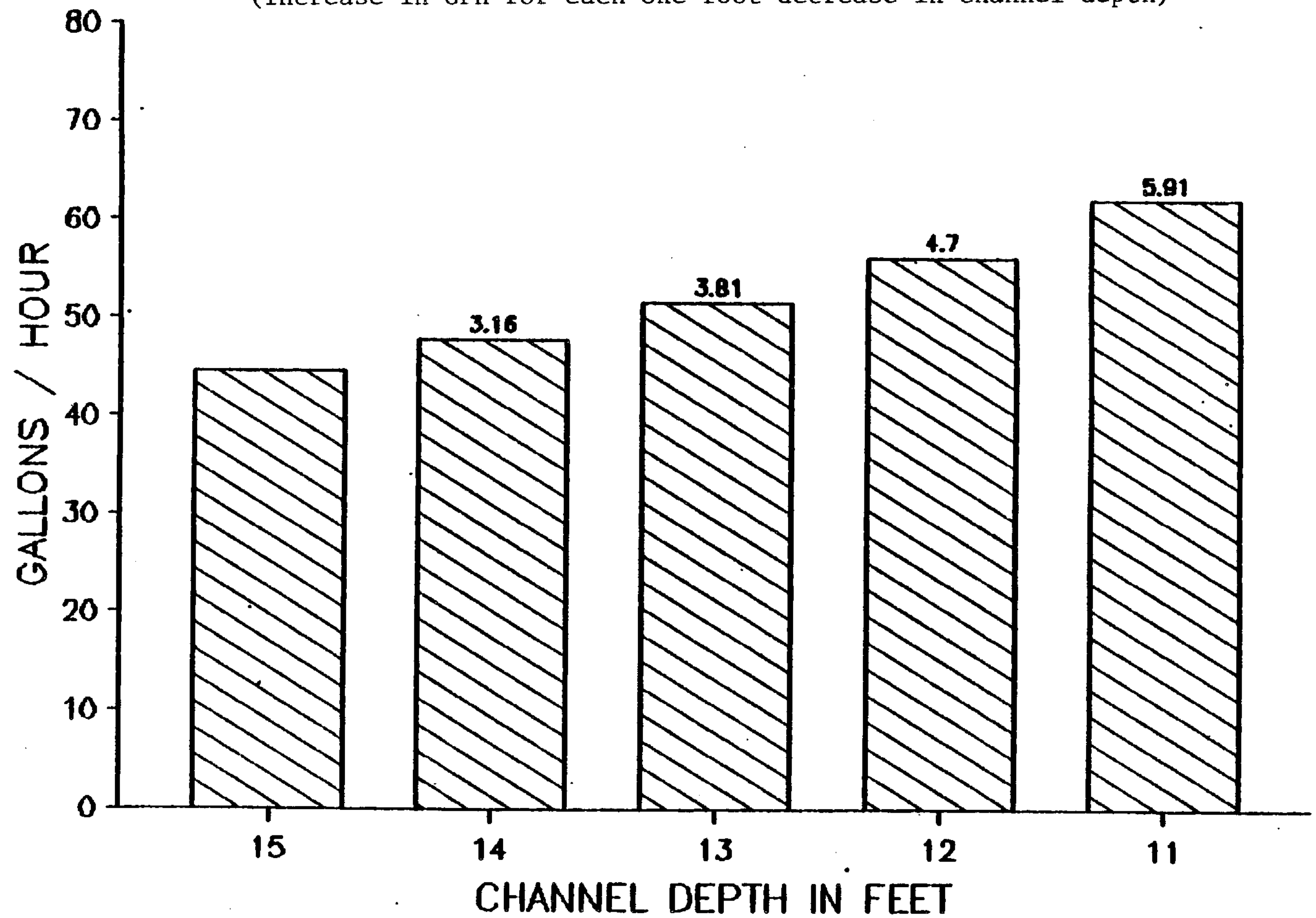


FIGURE 9

15 BARGE TOW

4.0 MPH

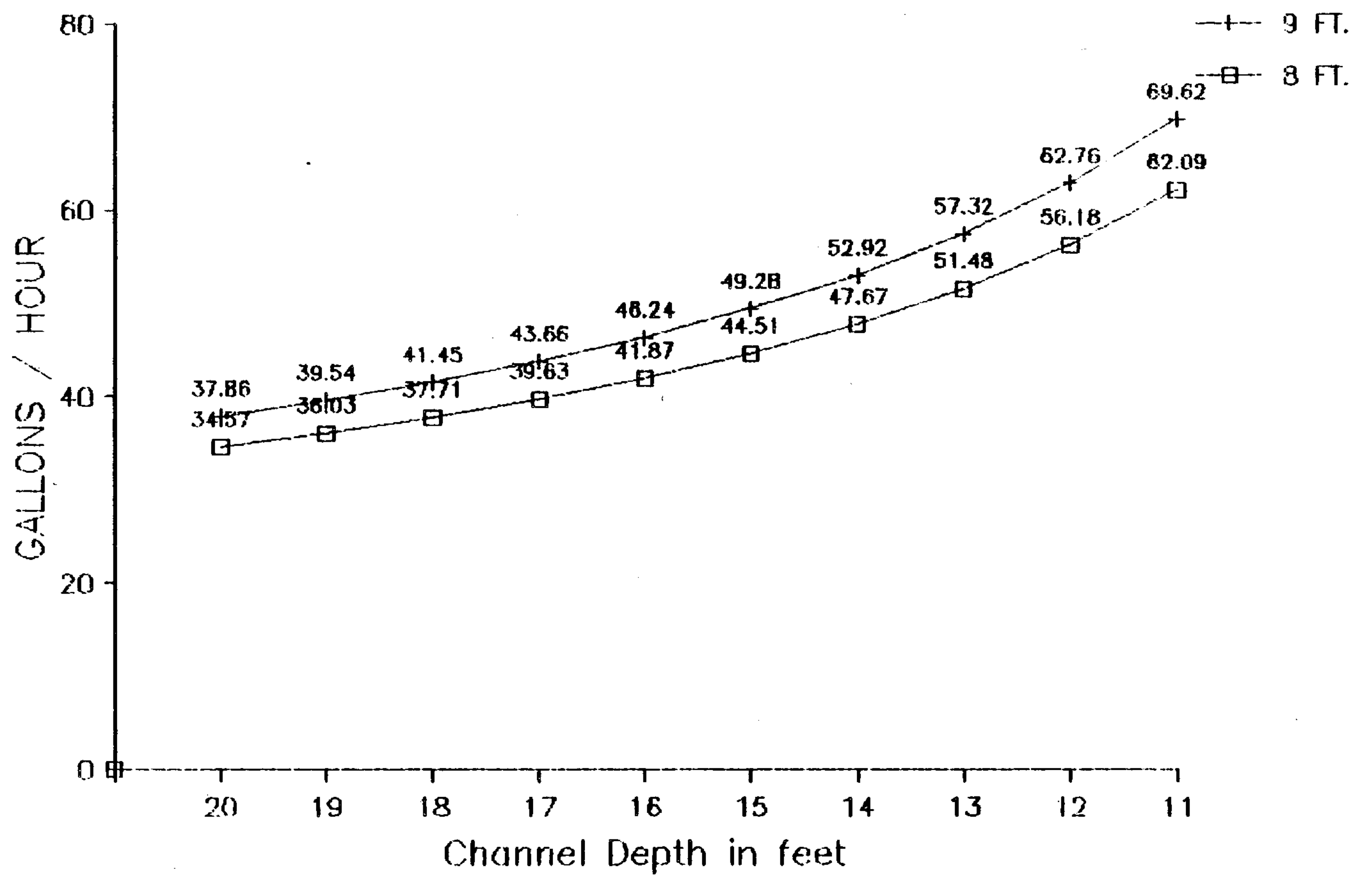


FIGURE 10

15 Barge Tow

4.0 MPH

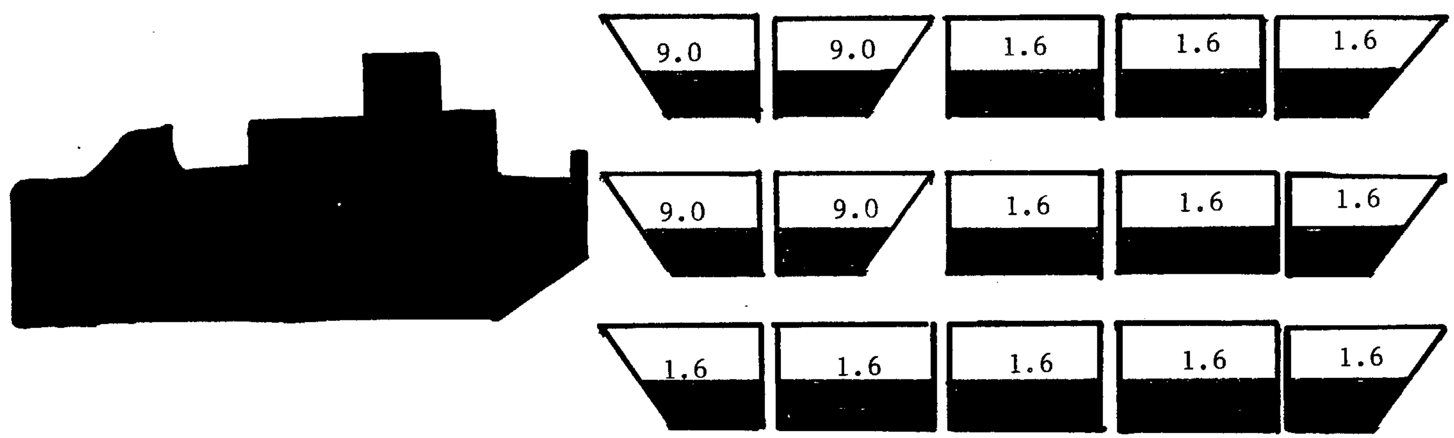


TABLE 11

15 BARGE TOW WITH 4 AT A 9 FOOT DRAFT AND 11 AT A 1.6 FOOT DRAFT
THE 4 LOADED BARGES ARE CONFIGURED AS A BOX @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	249.9	37.49	
A 15 BARGE TOW LOADED	14	266.4	39.96	2.47
WITH 4 IN A BOX AT 9	13	286.3	42.95	2.99
11 AT 1.6 FT.	12	310.7	46.64	3.69
SPEED 4.0 MPH	11	341.3	51.26	4.62

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	2.47	5.48	9.17	13.79
14 FT		2.99	6.68	11.30
13 FT			3.69	8.33
12 FT				4.62

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	6.59	14.62	24.46	36.78
14 FT		7.48	16.72	28.28
13 FT			8.59	19.39
12 FT				9.91

FIGURE 11

15 BARGE TOW (4 LOADED 11 EMPTY)

9 FOOT DRAFT AT 4.0 MPH (BOX)

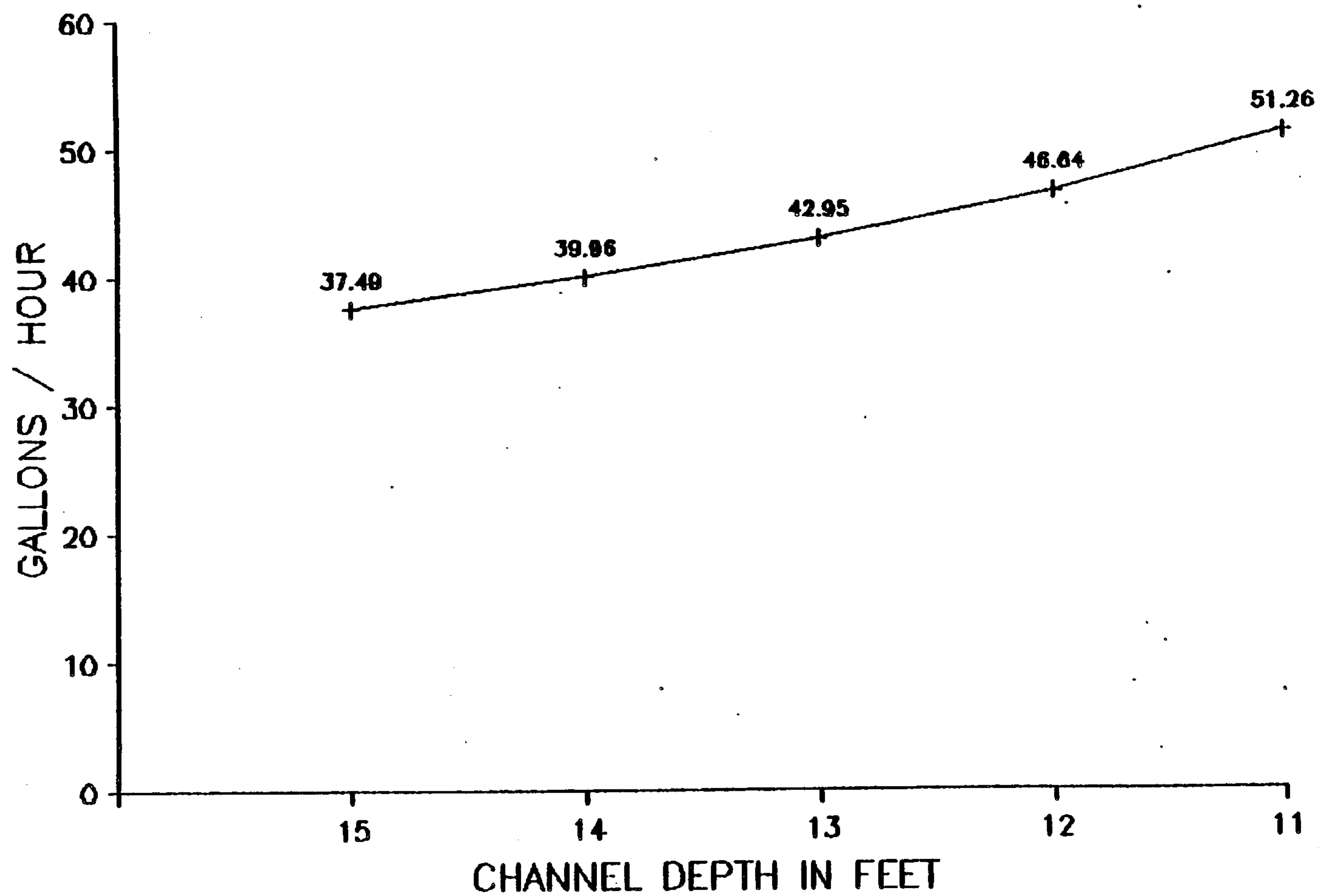


FIGURE 12

15 BARGE TOW (4 LOADED 11 EMPTY)

9 FOOT DRAFT AT 4.0 MPH (BOX)

(Increase in GPH for each one foot decrease in channel depth)

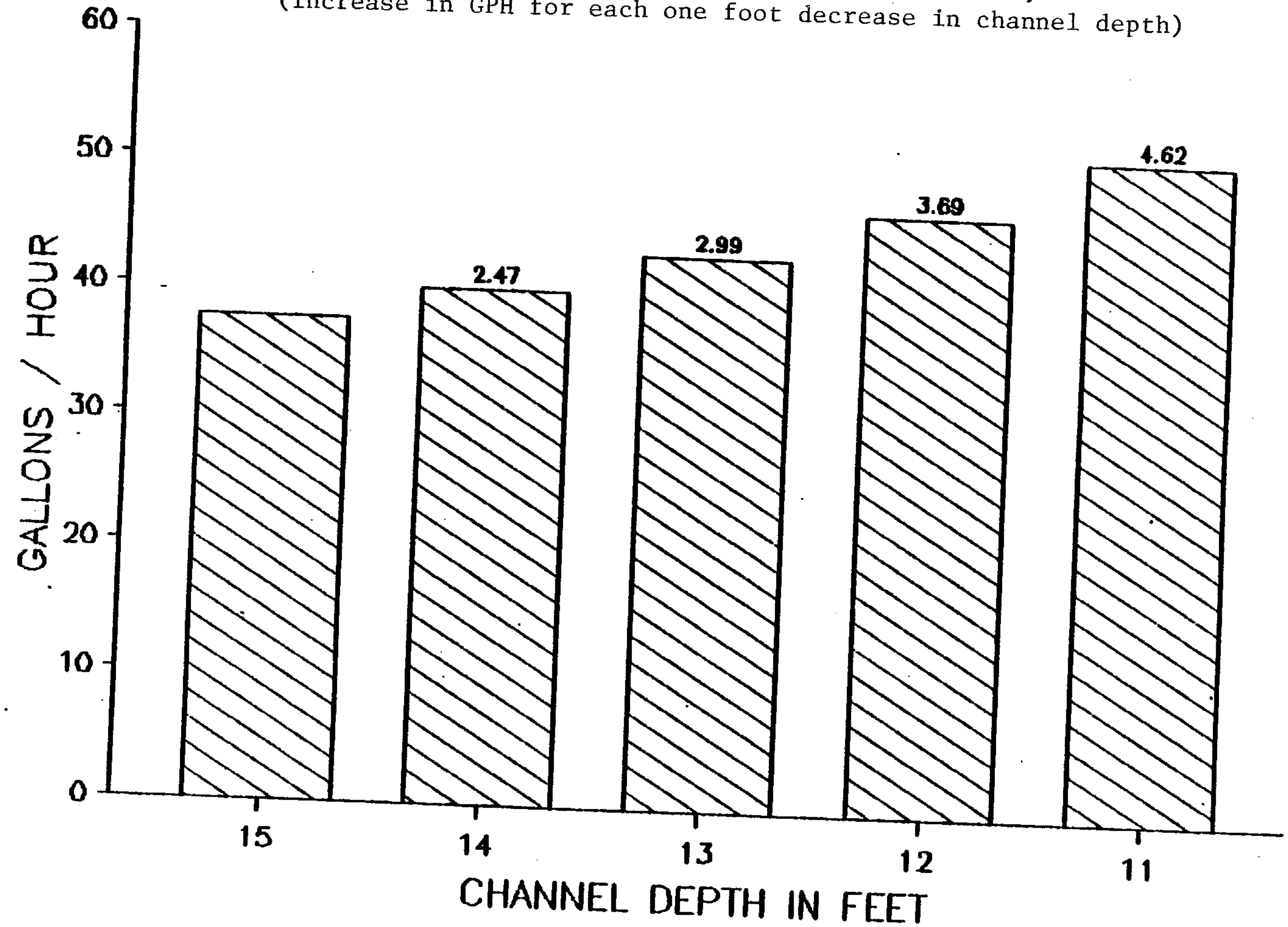


FIGURE 13A

15 Barge Tow

4.0 MPH

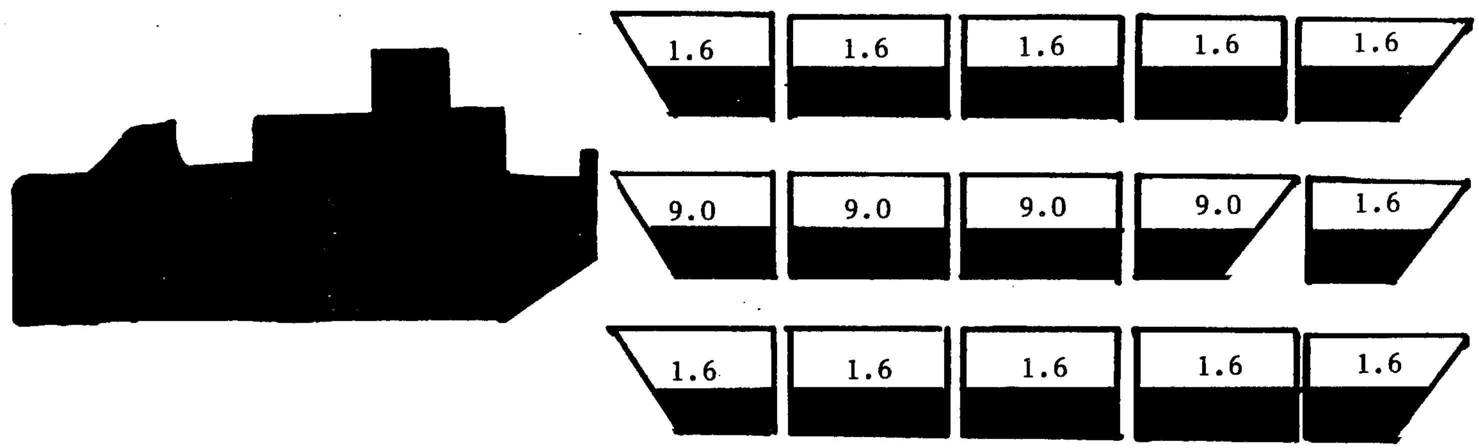


TABLE 12A

15 BARGE TOW WITH 4 AT A 9 FOOT DRAFT AND 11 AT A 1.6 FOOT DRAFT
THE 4 LOADED BARGES ARE CONFIGURED AS A ROW @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	191.1	28.66	
A 15 BARGE TOW LOADED	14	201.6	30.24	1.58
WITH 4 IN A ROW AT 9	13	214.3	32.14	1.90
11 AT 1.6 FT.	12	229.7	34.46	2.32
SPEED 4.0 MPH	11	248.9	37.33	2.87

INCREASE IN FUEL USE IN GALS. / HOUR

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	1.58	3.48	5.80	8.67
14 FT		1.90	4.22	7.09
13 FT			2.32	5.19
12 FT				2.87

INCREASE IN FUEL USE AS A PERCENTAGE

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	5.51	12.14	20.24	30.25
14 FT		6.28	13.96	23.85
13 FT			7.23	16.15
12 FT				8.33

FIGURE 14A

15 BARGE TOW (4 LOADED 11 EMPTY)

9 FOOT DRAFT AT 4.0 MPH (ROW)

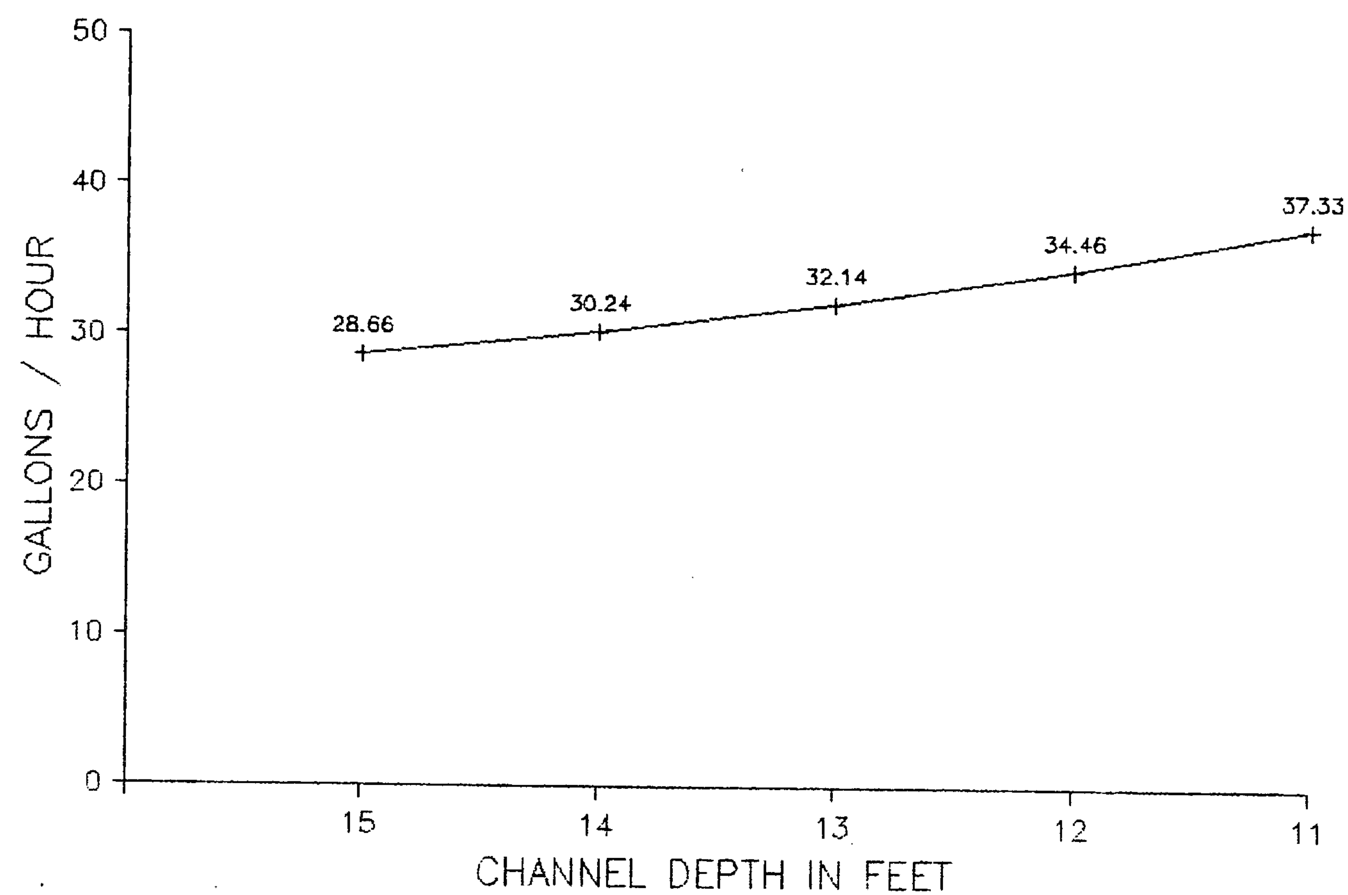


FIGURE 15A

15 BARGE TOW (4 LOADED 11 EMPTY)

9 FOOT DRAFT AT 4.0 MPH (ROW)

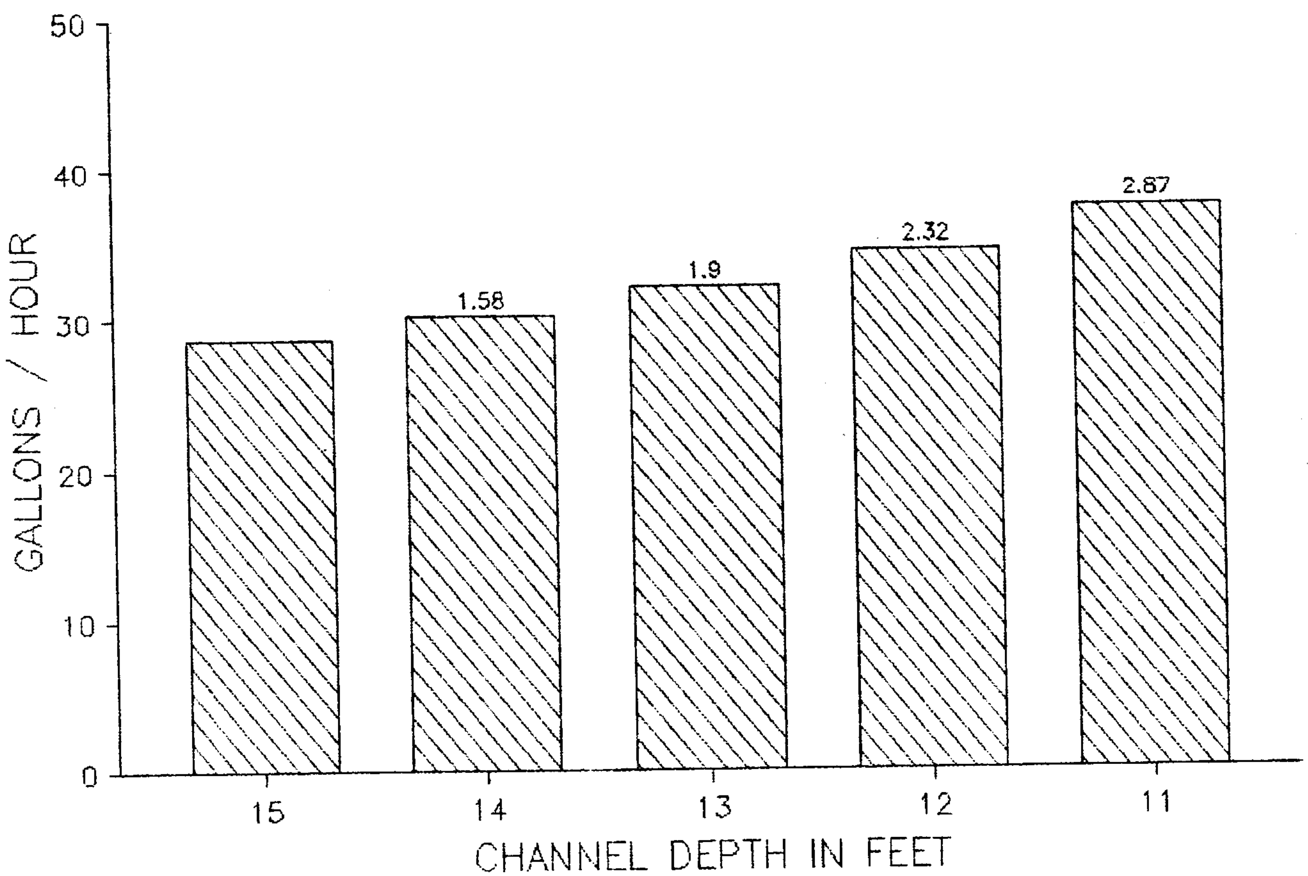


FIGURE 13B

15 Barge Tow

6.0 MPH

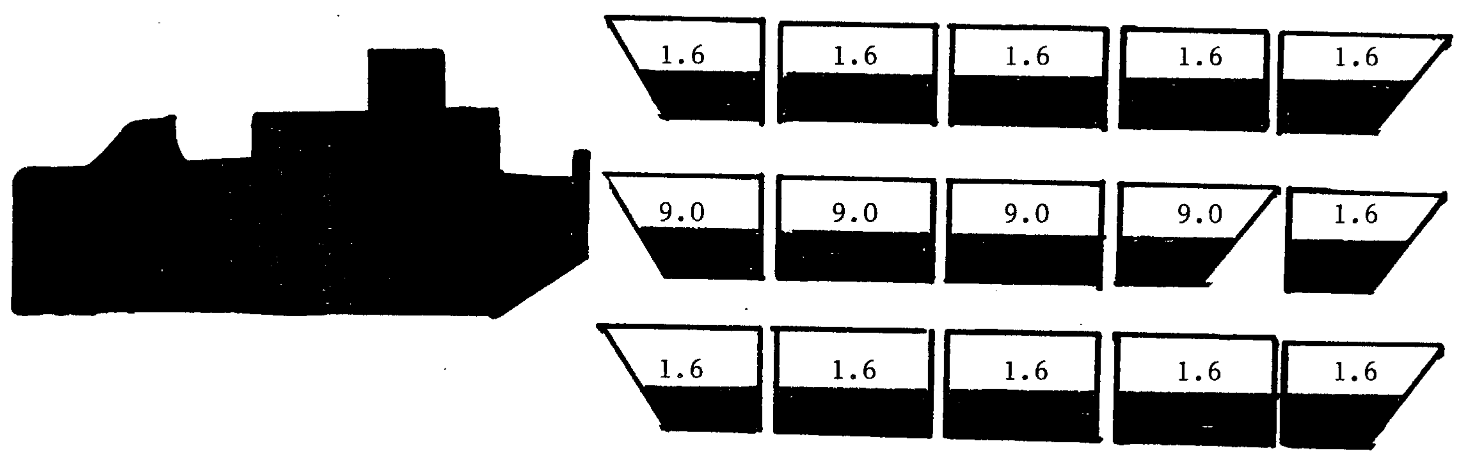


TABLE 12B

15 BARGE TOW WITH 4 AT A 9 FOOT DRAFT AND 11 AT A 1.6 FOOT DRAFT
THE 4 LOADED BARGES ARE CONFIGURED AS A ROW @ 6.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	624.4	93.66	
A 15 BARGE TOW LOADED	14	659	98.85	5.19
WITH 4 IN A ROW AT 9	13	700.4	105.07	6.22
11 AT 1.6 FT.	12	750.9	112.64	7.57
SPEED 6.0 MPH	11	813.6	122.04	9.4

INCREASE IN FUEL USE IN GALS. / HOUR

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	5.19	11.41	18.98	28.38
14 FT		6.22	13.79	23.19
13 FT			7.57	16.97
12 FT				9.4

INCREASE IN FUEL USE AS A PERCENTAGE

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	5.54	12.18	20.67	30.31
14 FT		6.29	13.95	23.46
13 FT			7.21	16.15
12 FT				8.35

FIGURE 14B

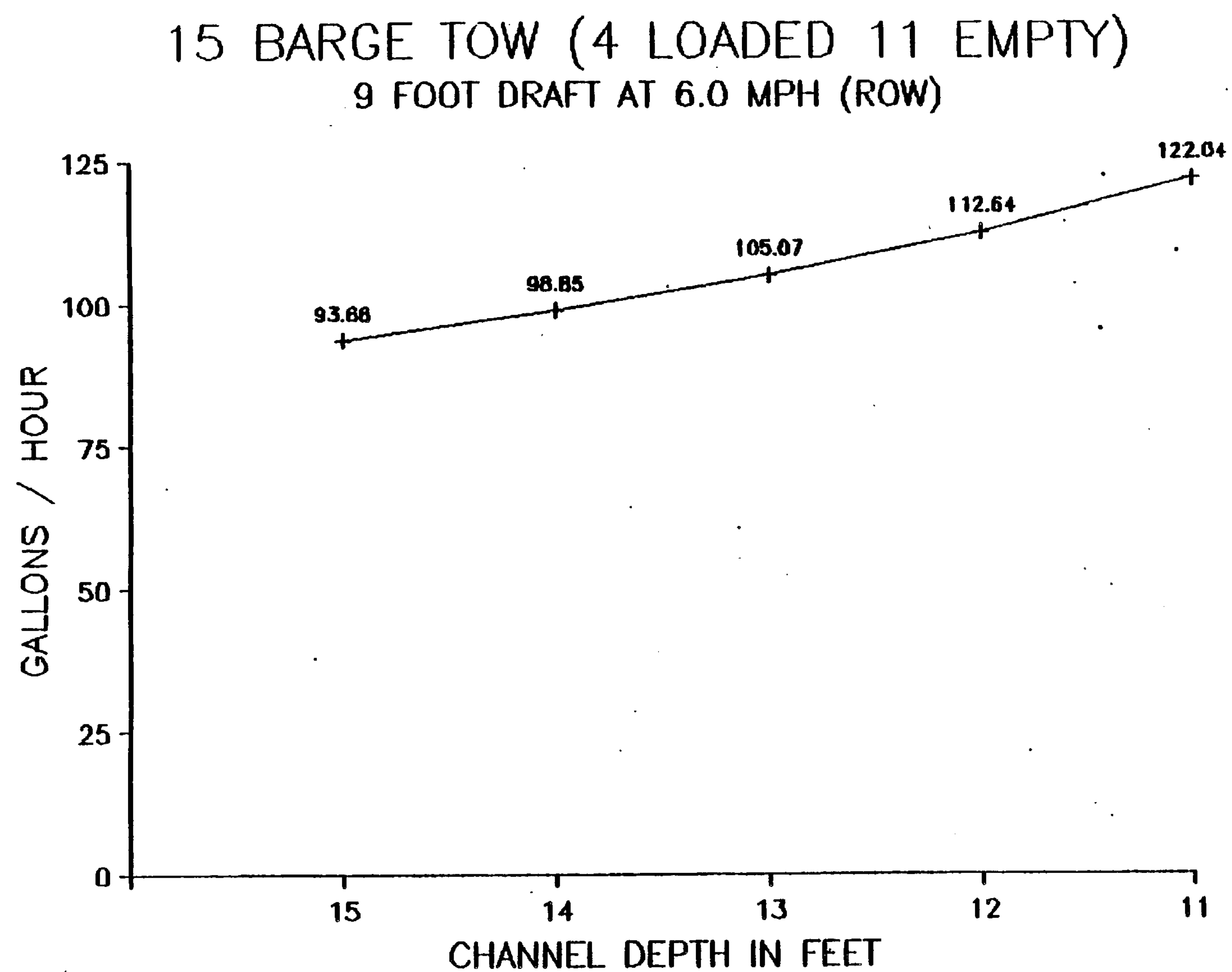

15 BARGE TOW (4 LOADED 11 EMPTY)
9 FOOT DRAFT AT 6.0 MPH (ROW)
GALLONS / HOUR
125
100
75
50
25
0
93.66
98.85
105.07
112.64
122.04
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 15B

15 BARGE TOW (4 LOADED 11 EMPTY)

9 FOOT DRAFT AT 6.0 MPH (ROW)

(Increase in GPH for each one foot decrease in channel depth)

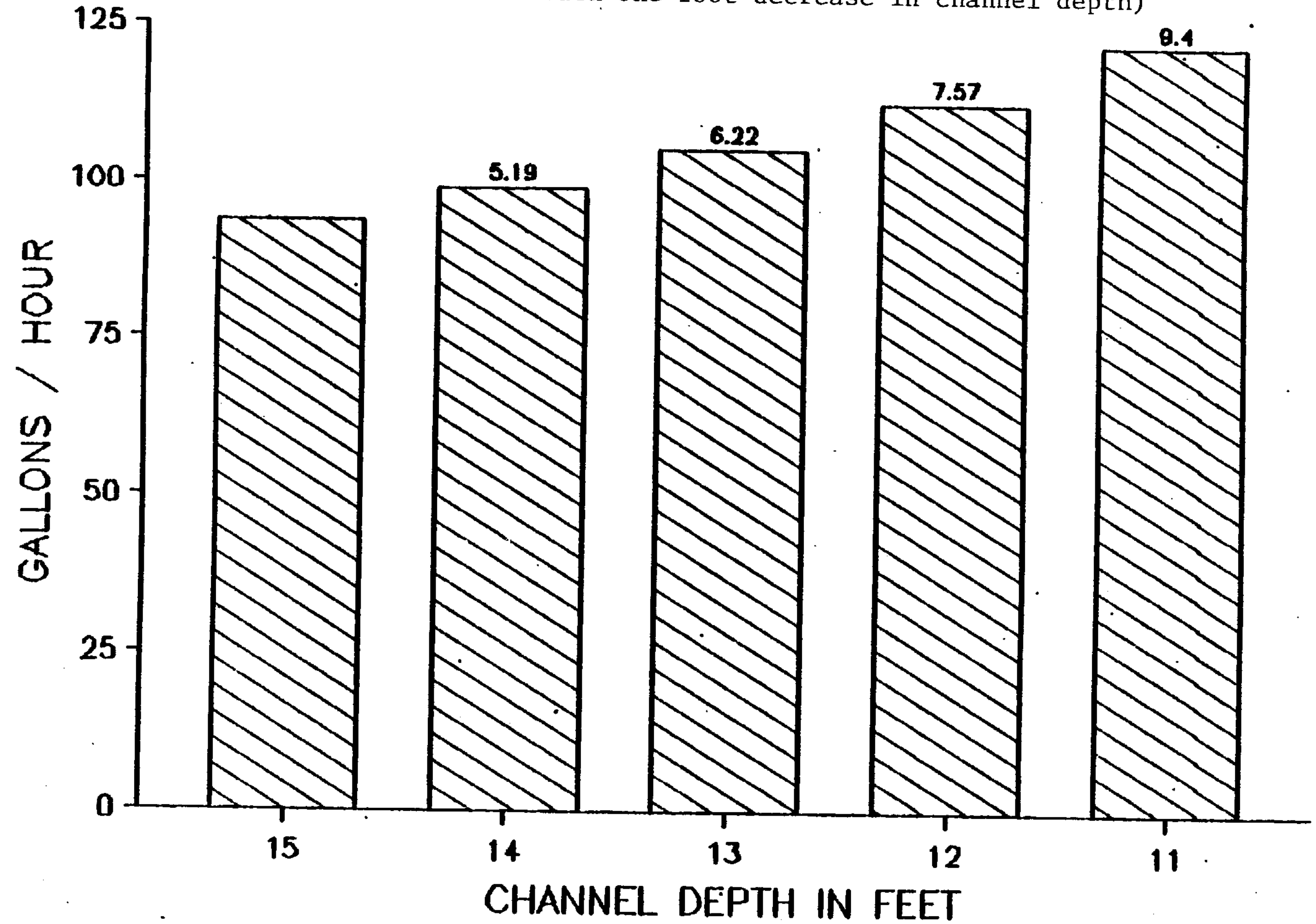


FIGURE 16

15 Barge Tow

4.0 MPH

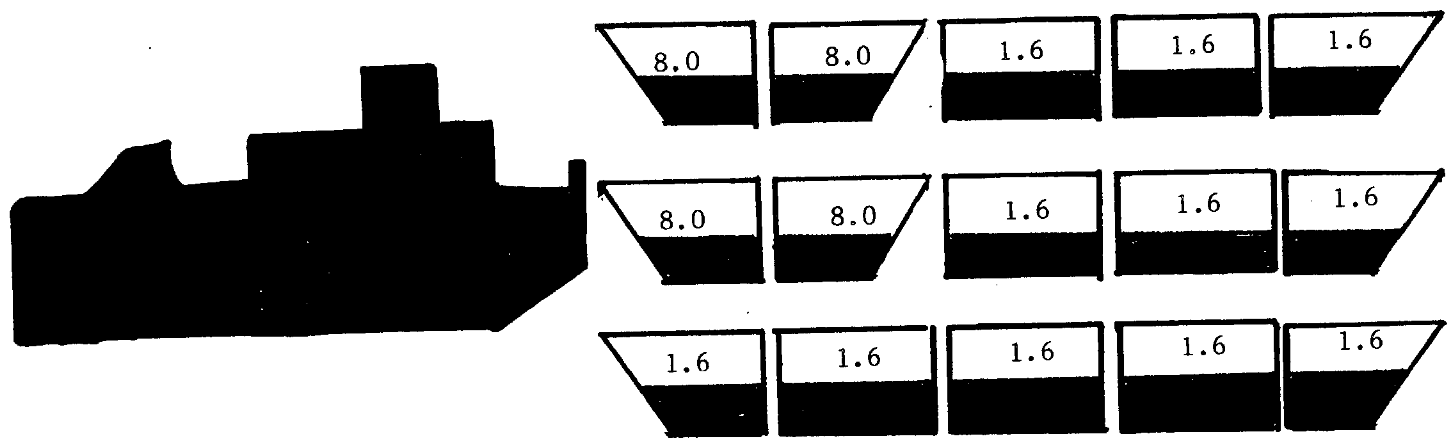


TABLE 13

15 BARGE TOW WITH 4 AT A 8 FOOT DRAFT AND 11 AT A 1.6 FOOT DRAFT
THE 4 LOADED BARGES ARE CONFIGURED AS A BOX @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	231.8	34.77	
A 15 BARGE TOW LOADED	14	246.5	36.97	2.20
WITH 4 IN A BOX AT 8	13	264.2	39.63	2.66
11 AT 1.6 FT.	12	285.9	42.89	3.26
SPEED 4.0 MPH	11	313.1	46.96	4.07

INCREASE IN FUEL USE IN GALS. / HOUR

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	2.20	4.86	8.12	12.19
14 FT		2.66	5.92	9.99
13 FT			3.26	7.33
12 FT				4.07

INCREASE IN FUEL USE AS A PERCENTAGE

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	6.33	13.98	23.35	35.06
14 FT		7.20	16.01	27.02
13 FT			8.23	18.49
12 FT				9.49

FIGURE 17

15 BARGE TOW (4 LOADED 11 EMPTY)

8 FOOT DRAFT AT 4.0 MPH (BOX)

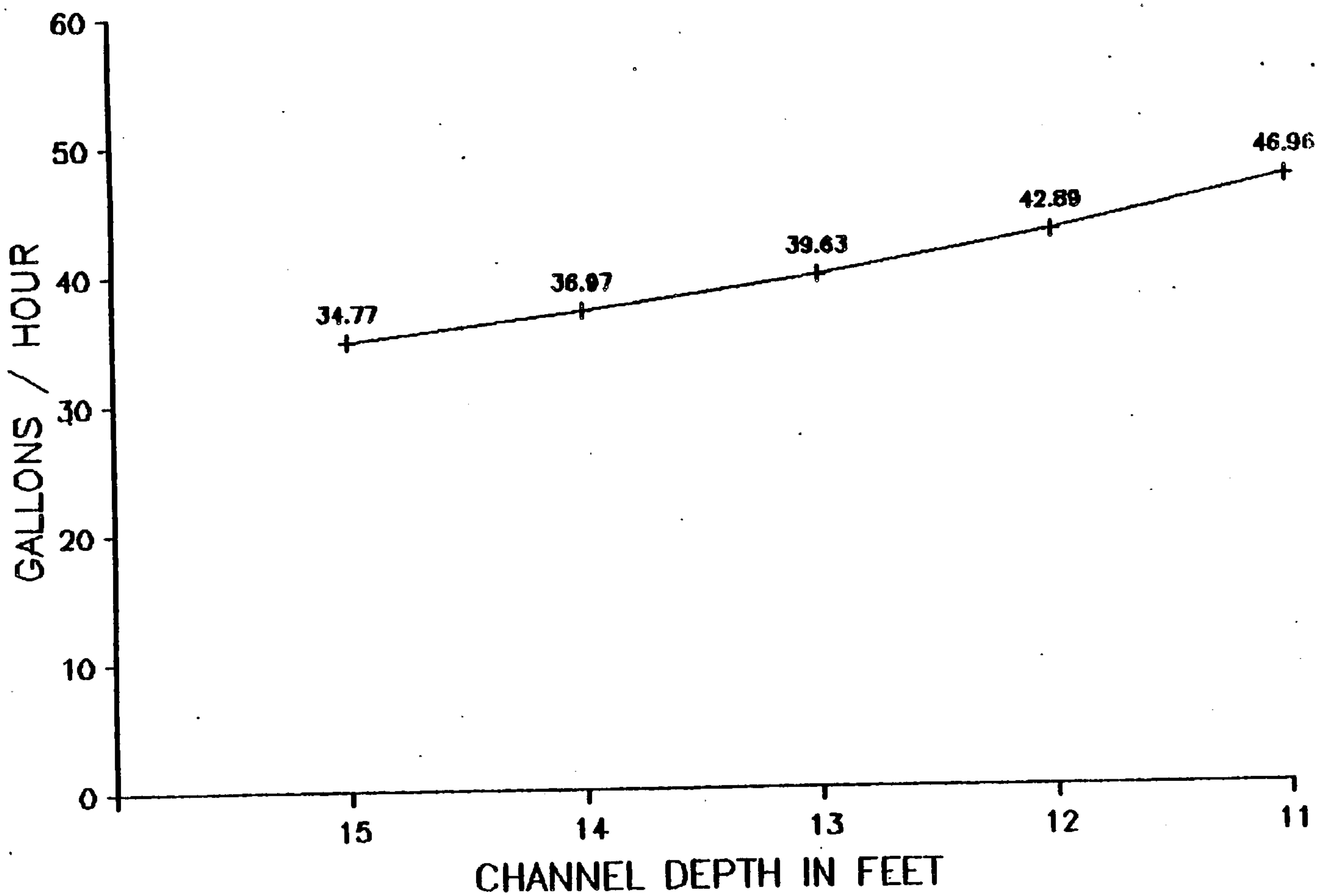


FIGURE 18

15 BARGE TOW (4 LOADED 11 EMPTY)

8 FOOT DRAFT AT 4.0 MPH (BOX)

(Increase in GPH for each one foot decrease in channel depth)

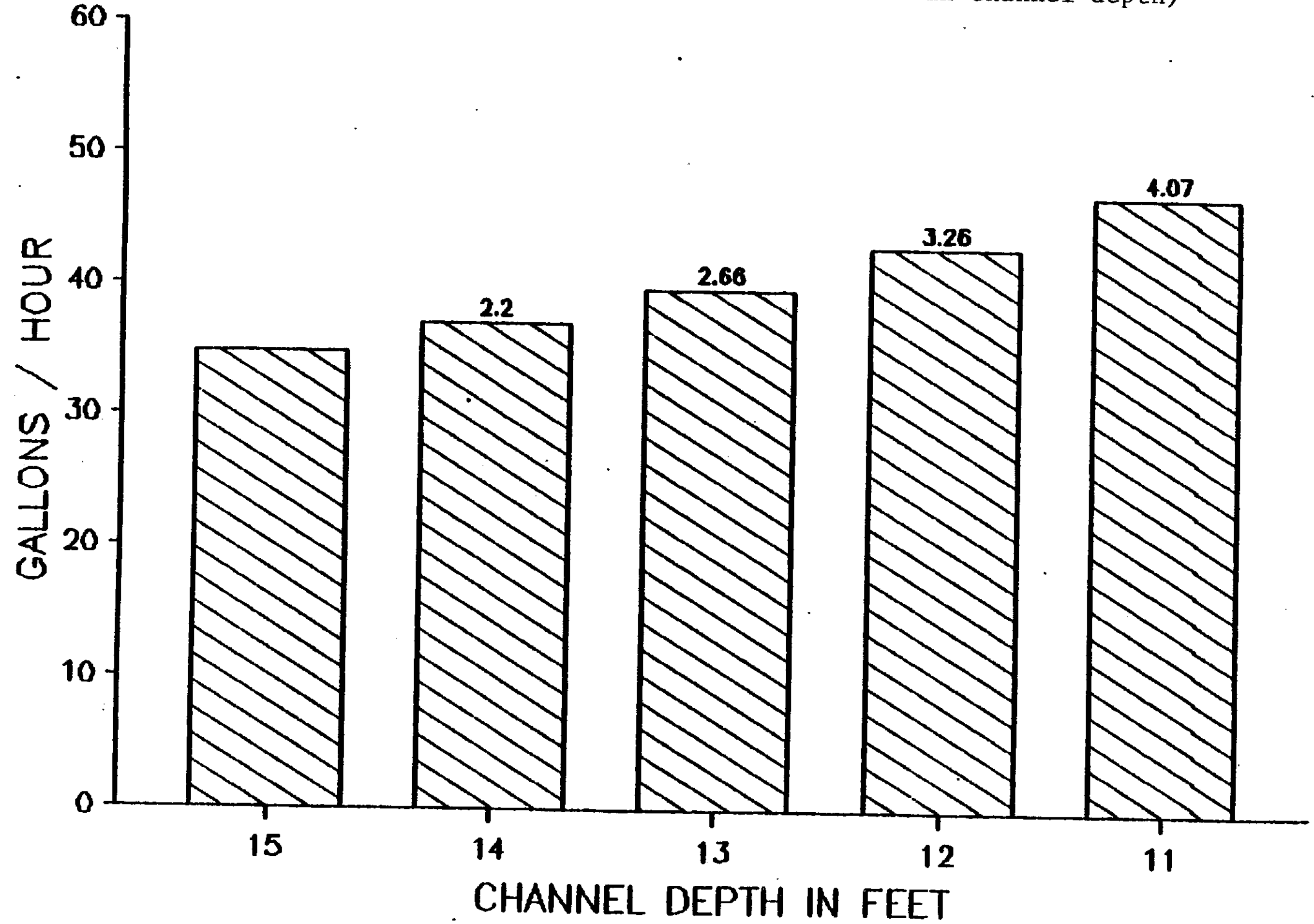


FIGURE 19

15 Barge Tow

4.0 MPH

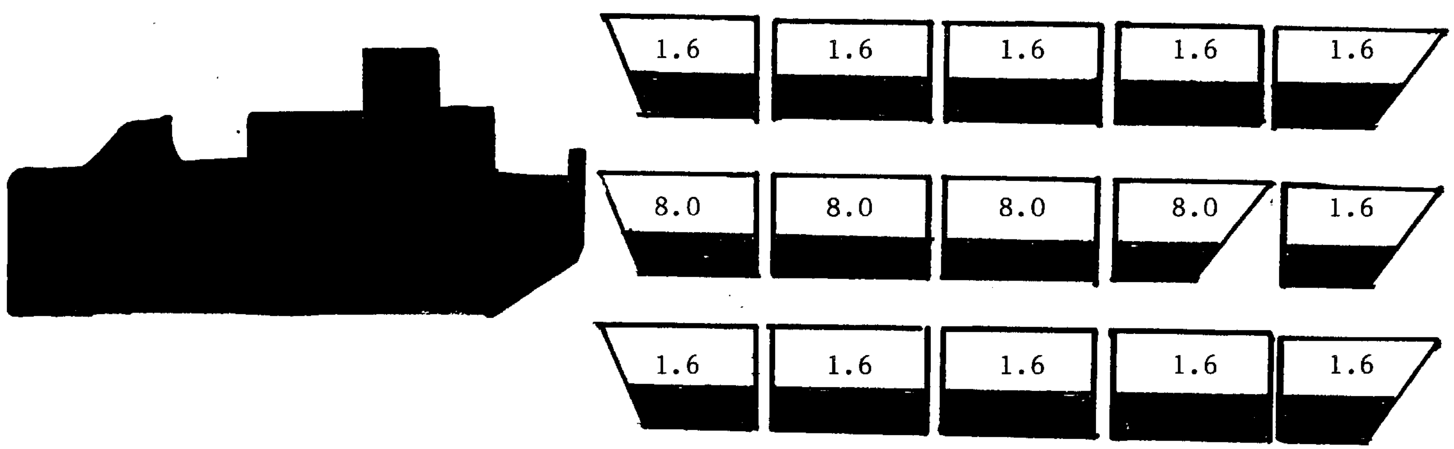


TABLE 14

15 BARGE TOW WITH 4 AT A 8 FOOT DRAFT AND 11 AT A 1.6 FOOT DRAFT
THE 4 LOADED BARGES ARE CONFIGURED AS A ROW @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	180.8	27.12	
A 15 BARGE TOW LOADED	14	190.5	28.57	1.45
WITH 4 IN A ROW AT 8	13	202.1	30.31	1.74
11 AT 1.6 FT.	12	216.2	32.43	2.12
SPEED 4.0 MPH	11	233.7	35.05	2.62

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	1.45	3.19	5.31	7.93
14 FT		1.74	3.86	6.48
13 FT			2.12	4.74
12 FT				2.62

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	5.35	11.76	19.58	29.24
14 FT		6.09	13.51	22.68
13 FT			6.99	15.64
12 FT				8.08

FIGURE 20

15 BARGE TOW (4 LOADED 11 EMPTY)
8 FOOT DRAFT AT 4.0 MPH (ROW)

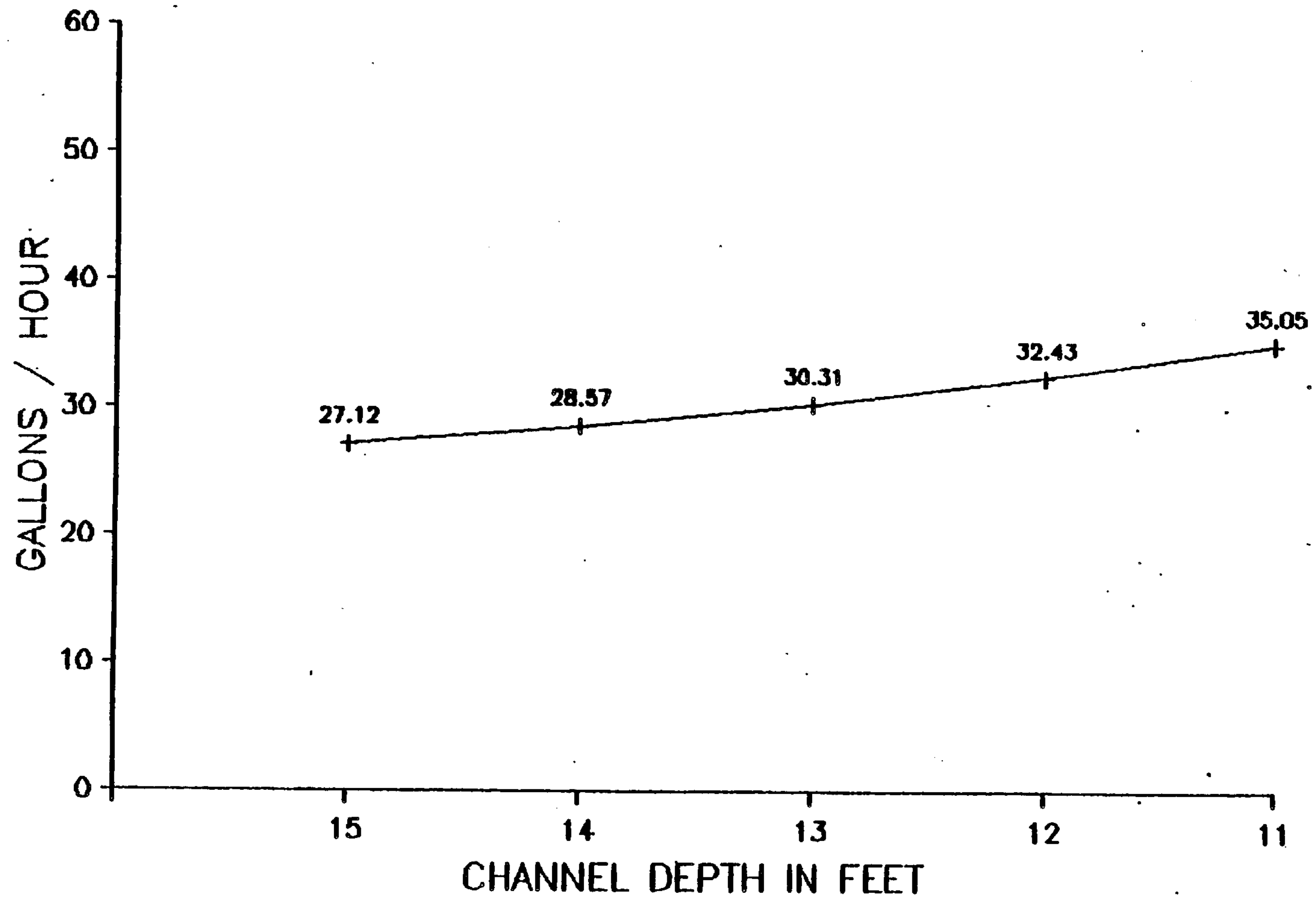


FIGURE 21

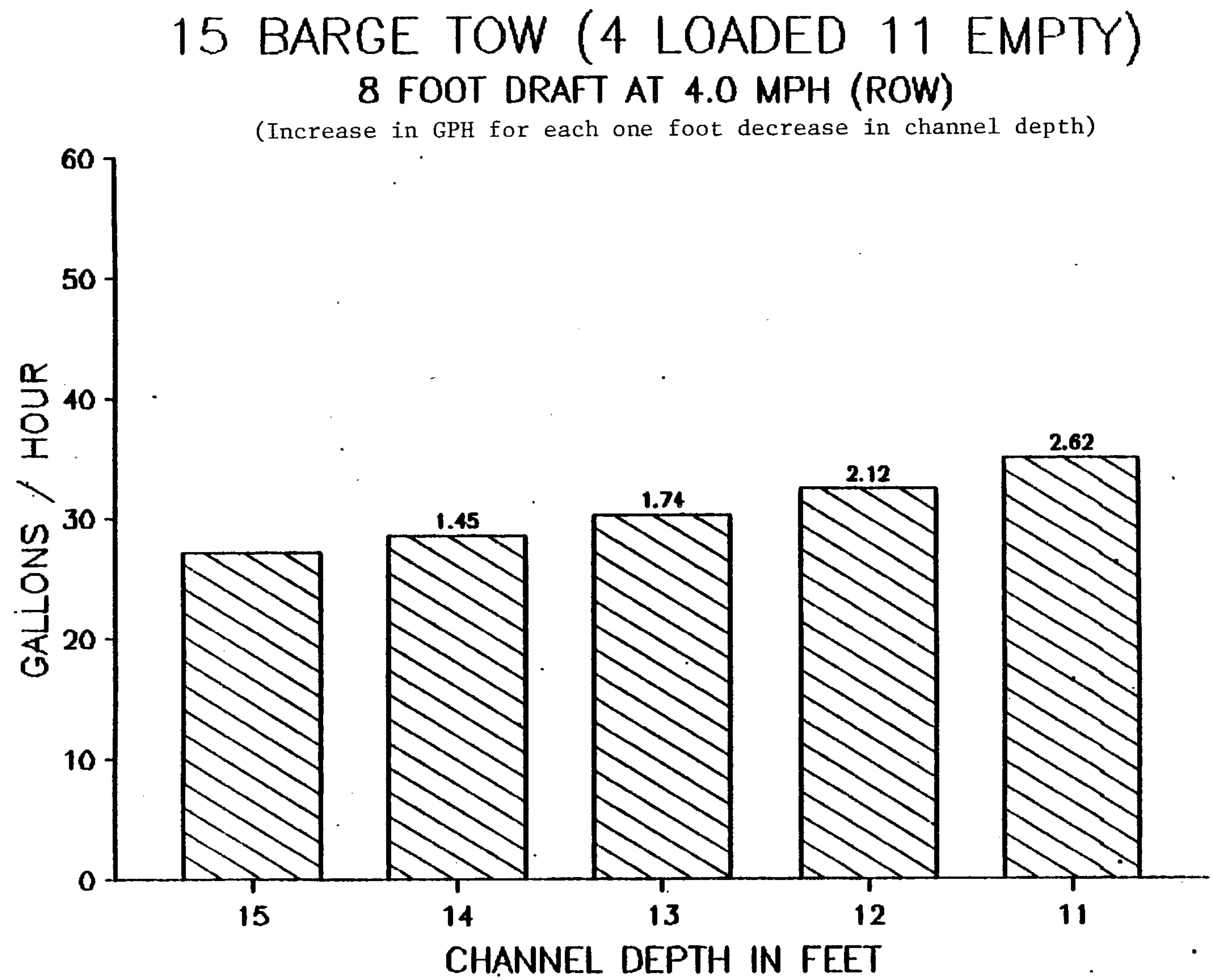

15 BARGE TOW (4 LOADED 11 EMPTY)
8 FOOT DRAFT AT 4.0 MPH (ROW)
(Increase in GPH for each one foot decrease in channel depth)
GALLONS / HOUR
60
50
40
30
20
10
0
1.45
1.74
2.12
2.62
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 22

15 Barge Tow

6.0 MPH

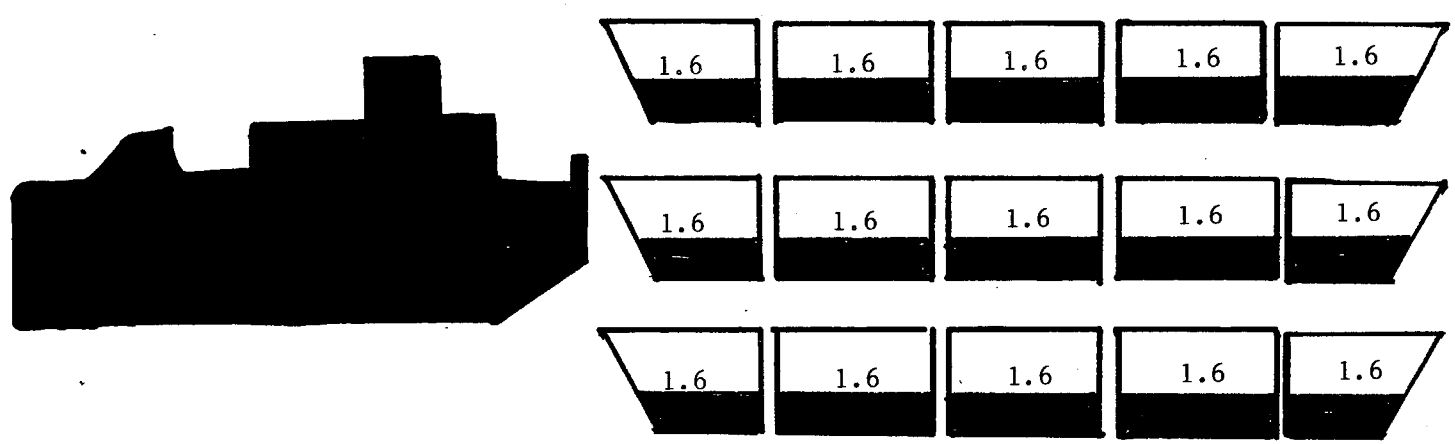


TABLE 15

15 BARGE TOW WITH A 1.6 FOOT DRAFT @ 6.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	384.2	57.63	
A 15 BARGE TOW	14	398.7	59.83	2.2
WITH A 1.6 FOOT DRAFT	13	416.2	62.43	2.6
	12	437.1	65.57	3.14
SPEED 6.0 MPH	11	462.7	69.4	3.83

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	2.2	4.8	7.94	11.77
14 FT		2.6	5.94	9.77
13 FT			3.14	6.97
12 FT				3.83

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	3.82	8.33	13.78	20.42
14 FT		4.35	9.93	16.33
13 FT			5.03	11.17
12 FT				5.84

FIGURE 23

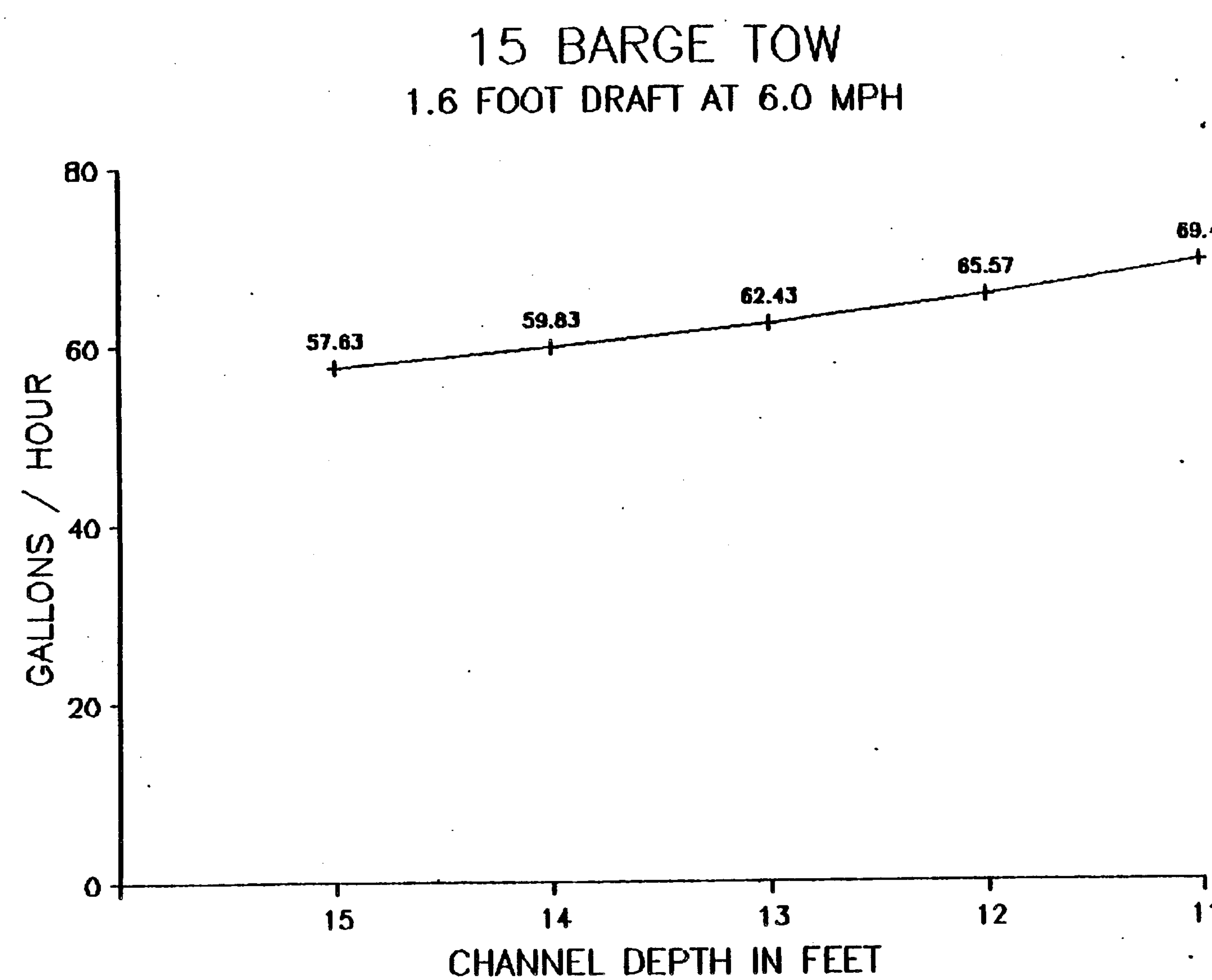
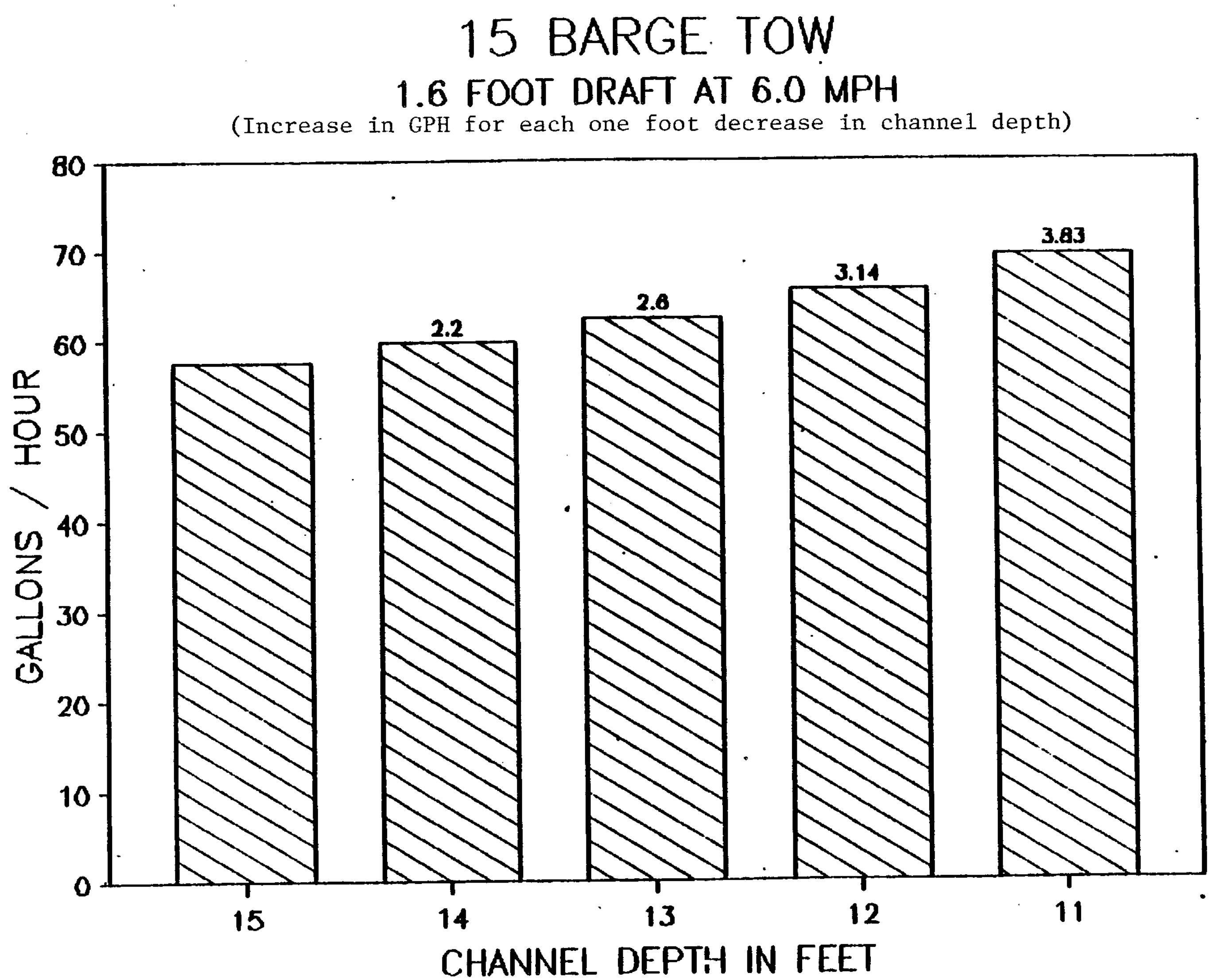

15 BARGE TOW
1.6 FOOT DRAFT AT 6.0 MPH
GALLONS / HOUR
80
60
40
20
0
57.63
59.83
62.43
65.57
69.4
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 24



15 BARGE TOW
1.6 FOOT DRAFT AT 6.0 MPH
(Increase in GPH for each one foot decrease in channel depth)
GALLONS / HOUR
0
10
20
30
40
50
60
70
80
2.2
2.6
3.14
3.83
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 25

12 Barge Tow

4.0 MPH

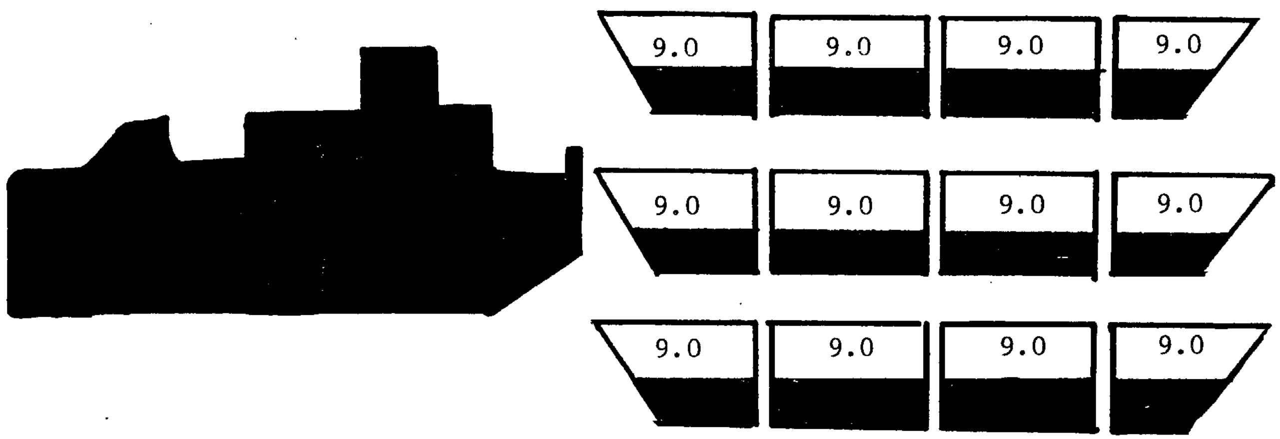


TABLE 16

12 BARGE TOW WITH A 9 FOOT DRAFT @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	283.8	42.57	
A 12 BARGE TOW LOADED	14	304.8	45.72	3.15
TO A 9 FOOT DRAFT	13	330.2	49.53	3.81
	12	361.6	54.23	4.70
SPEED 4.0	11	401.1	60.19	5.96

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	3.15	6.96	11.66	17.62
14 FT		3.81	8.51	14.47
13 FT			4.70	10.66
12 FT				5.96

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	7.4	16.35	27.39	41.39
14 FT		8.33	18.61	31.65
13 FT			9.49	21.52
12 FT				10.99

FIGURE 26

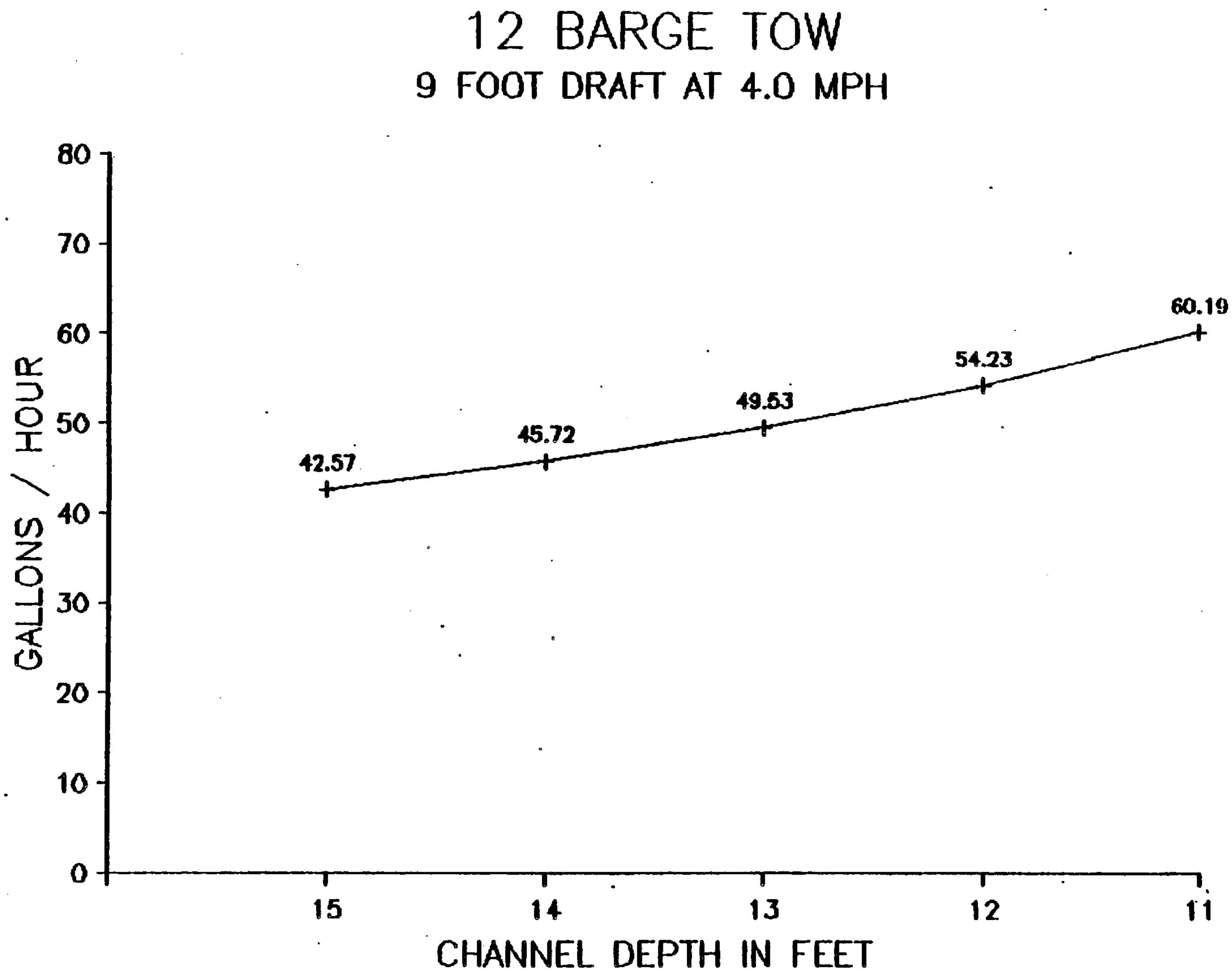

12 BARGE TOW
9 FOOT DRAFT AT 4.0 MPH
GALLONS / HOUR
80
70
60
50
40
30
20
10
0
42.57
45.72
49.53
54.23
60.19
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 27

12 BARGE TOW

9 FOOT DRAFT AT 4.0 MPH

(Increase in GPH for each one foot decrease in channel depth)

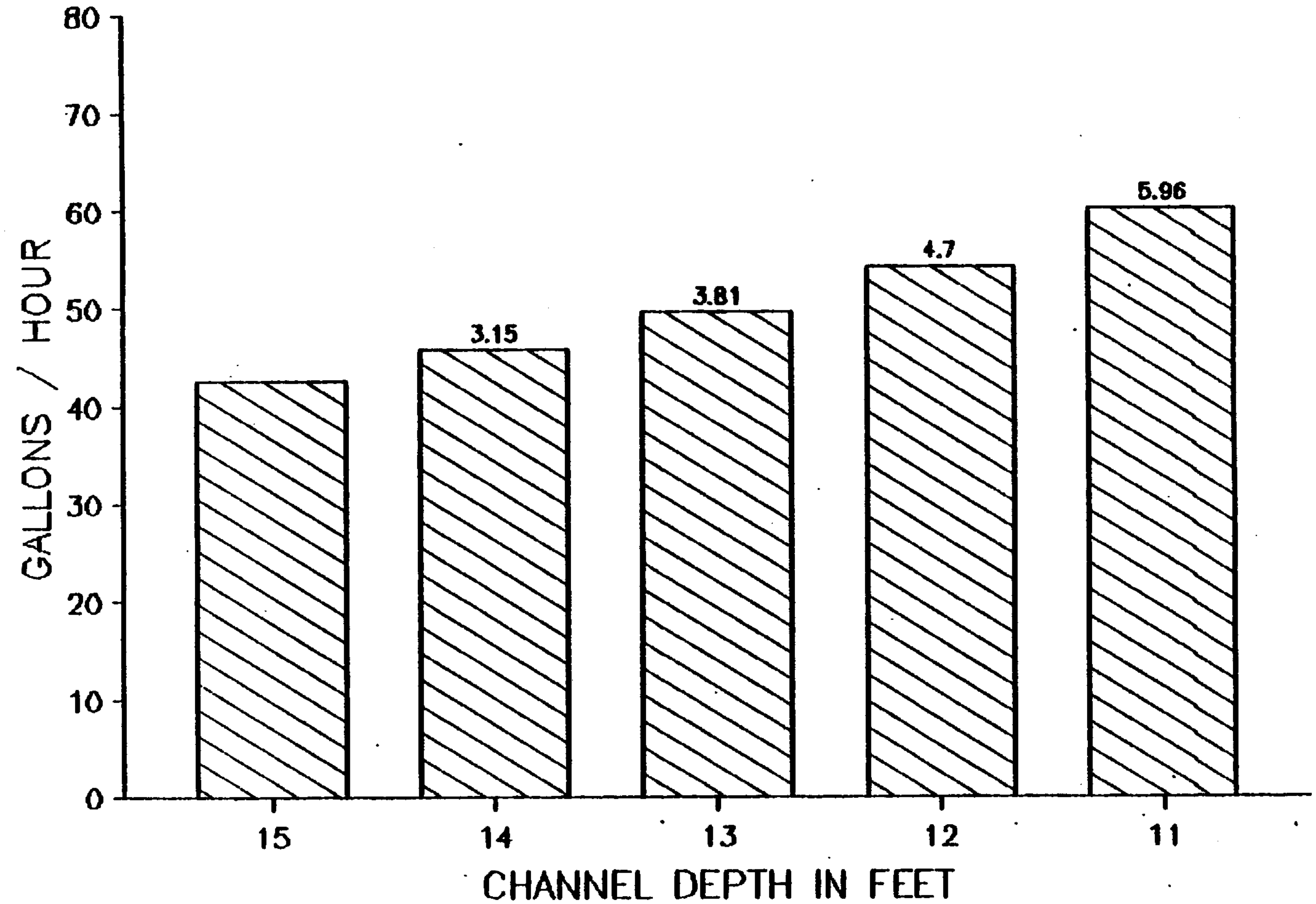


FIGURE 28

12 Barge Tow

4.0 MPH

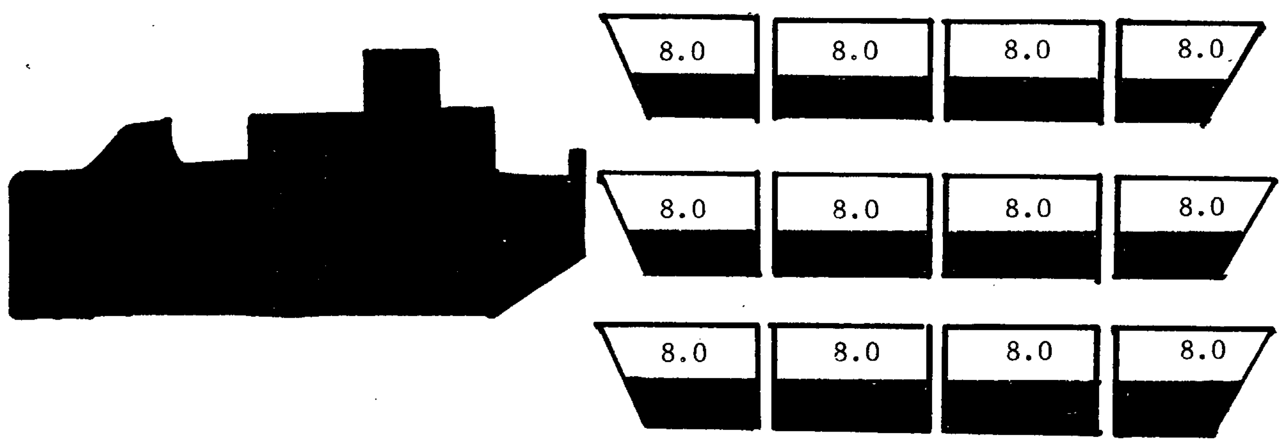


TABLE 17

12 BARGE TOW WITH A 8 FOOT DRAFT @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	255.4	38.31	
A 12 BARGE TOW LOADED	14	273.5	41.02	2.71
TO A 8 FOOT DRAFT	13	295.4	44.31	3.29
	12	322.4	48.35	4.04
SPEED 4.0	11	256.3	53.44	5.09

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	2.71	6.00	10.04	15.13
14 FT		3.29	7.33	12.42
13 FT			4.04	9.13
12 FT				5.09

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	7.07	15.66	26.21	39.49
14 FT		8.02	17.87	30.28
13 FT			9.12	20.61
12 FT				10.53

FIGURE 29

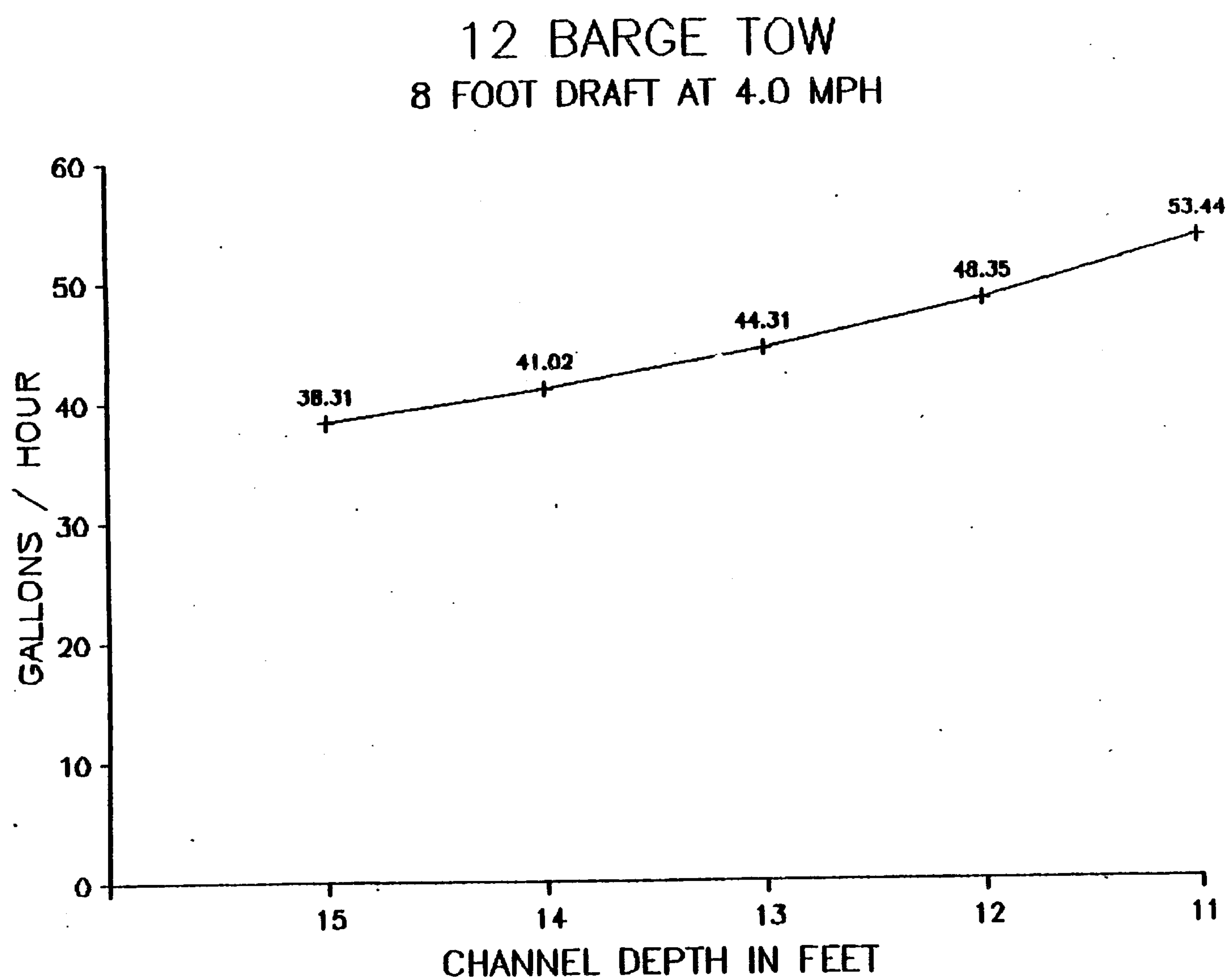

12 BARGE TOW
8 FOOT DRAFT AT 4.0 MPH
GALLONS / HOUR
60
50
40
30
20
10
0
38.31
41.02
44.31
48.35
53.44
15
14
13
12
11
CHANNEL DEPTH IN FEET

FIGURE 30

12 BARGE TOW

8 FOOT DRAFT AT 4.0 MPH

(Increase in GPH for each one foot decrease in channel depth)

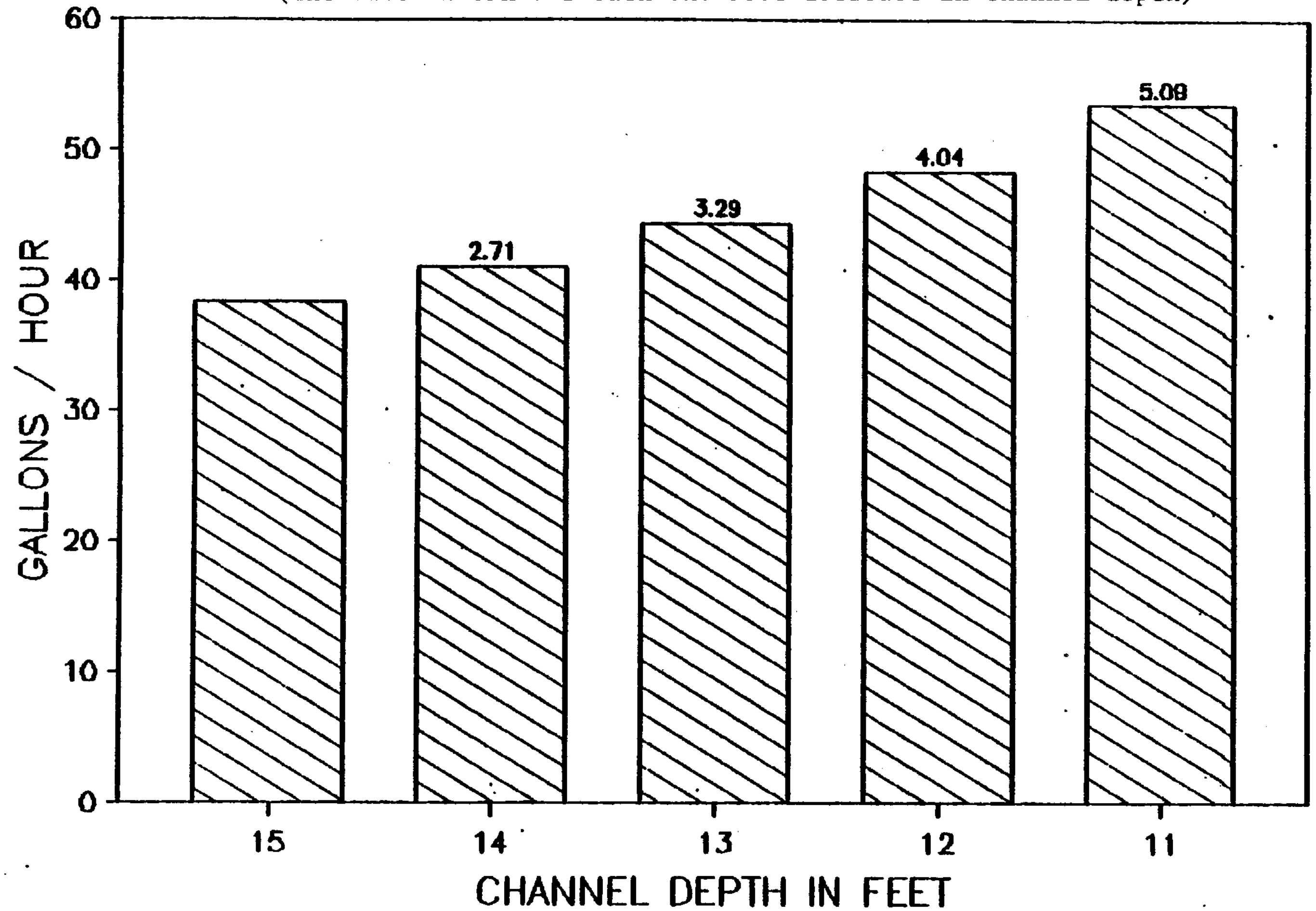


FIGURE 31

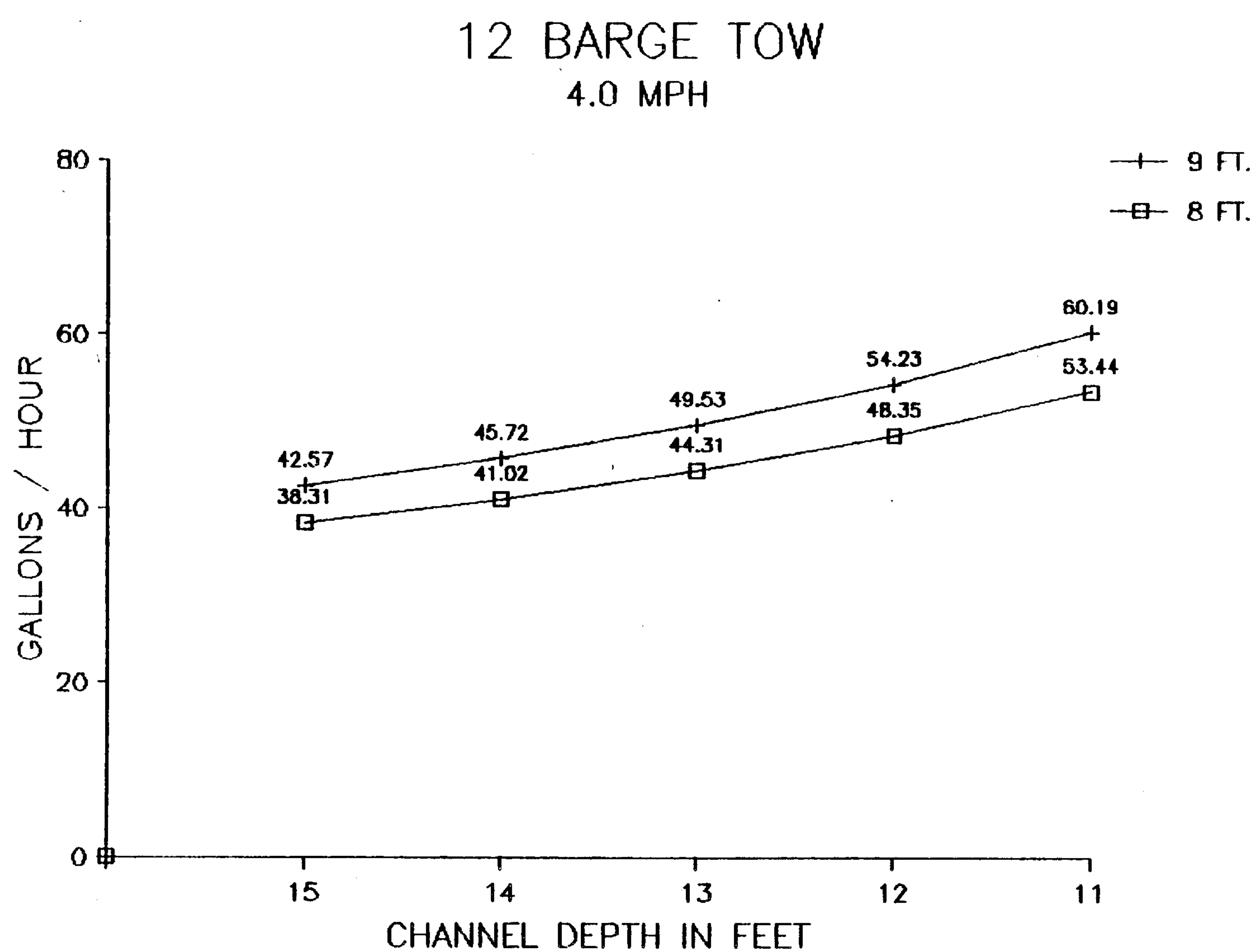

12 BARGE TOW
4.0 MPH
9 FT.
8 FT.
GALLONS / HOUR
0
20
40
60
80
CHANNEL DEPTH IN FEET
15
14
13
12
11
42.57
38.31
45.72
41.02
49.53
44.31
54.23
48.35
60.19
53.44

FIGURE 32

9 Barge Tow

4.0 MPH

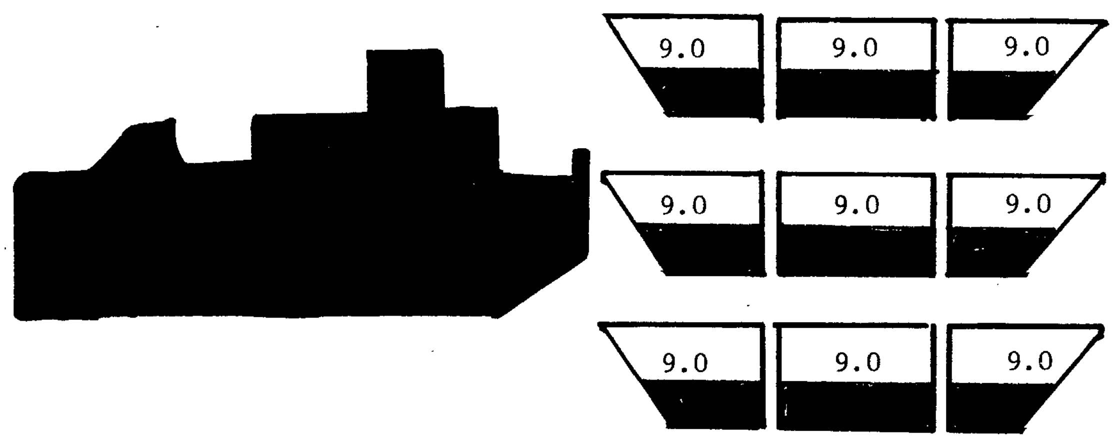


TABLE 18

9 BARGE TOW WITH A 9 FOOT DRAFT @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	238.2	35.72	
A 9 BARGE TOW LOADED	14	255.8	38.36	2.64
TO AN 9 FOOT DRAFT	13	277.1	41.57	3.21
	12	303.5	45.52	3.95
SPEED 4.0 MPH	11	336.7	50.5	4.98

INCREASE IN FUEL USE IN GALS. / HOUR

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	2.64	5.85	9.80	14.78
14 FT		3.21	7.16	12.14
13 FT			3.95	8.93
12 FT				4.98

INCREASE IN FUEL USE AS A PERCENTAGE

TO	14 FT	13FT	12 FT	11 FT
FROM 15 FT	7.39	16.38	27.44	41.37
14 FT		8.37	18.66	31.65
13 FT			9.51	21.48
12 FT				10.94

FIGURE 33

9 BARGE TOW

9 FOOT DRAFT AT 4.0 MPH

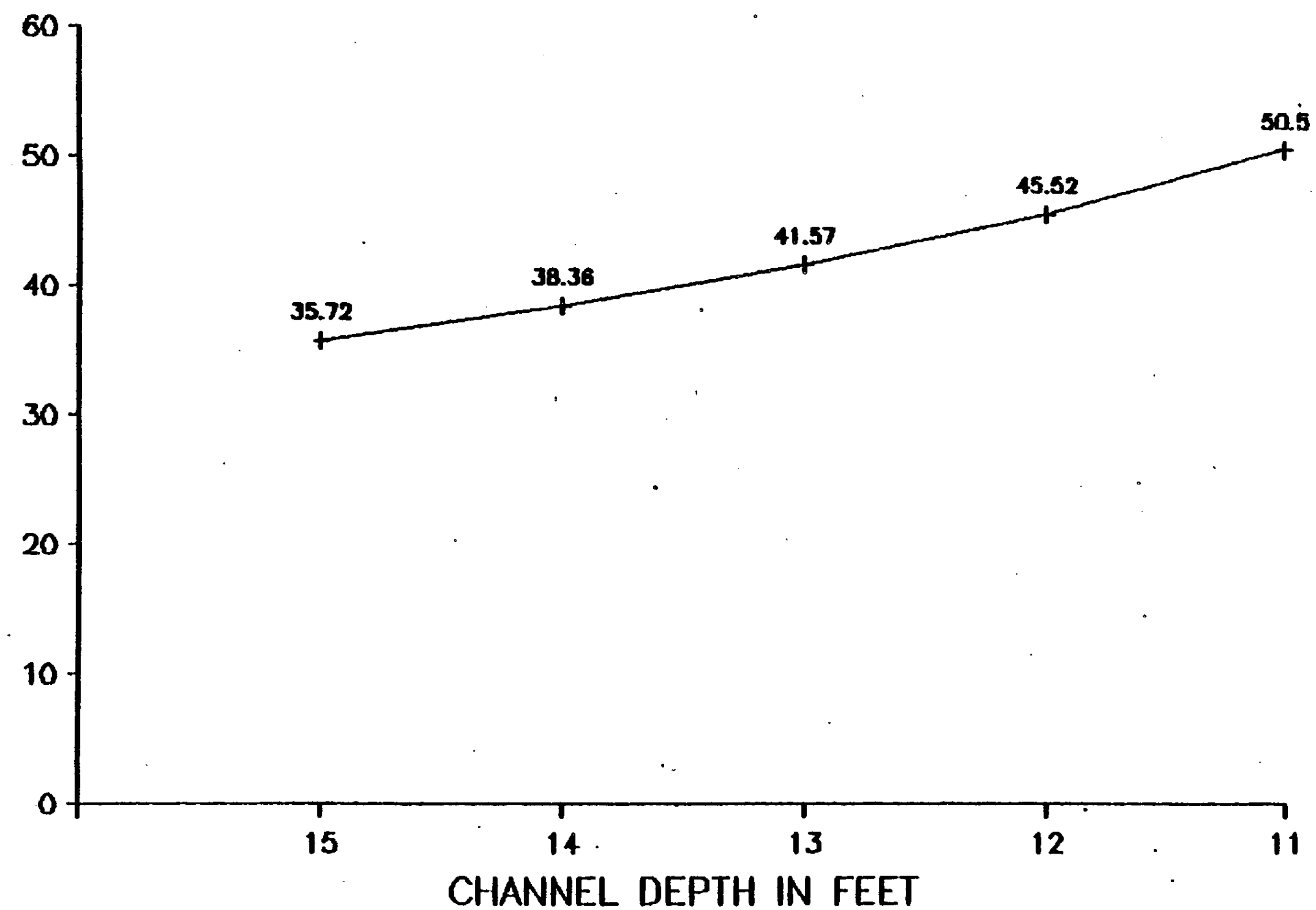


FIGURE 34

9 BARGE TOW

9 FOOT DRAFT AT 4.0 MPH

(Increase in GPH for each one foot decrease in channel depth)

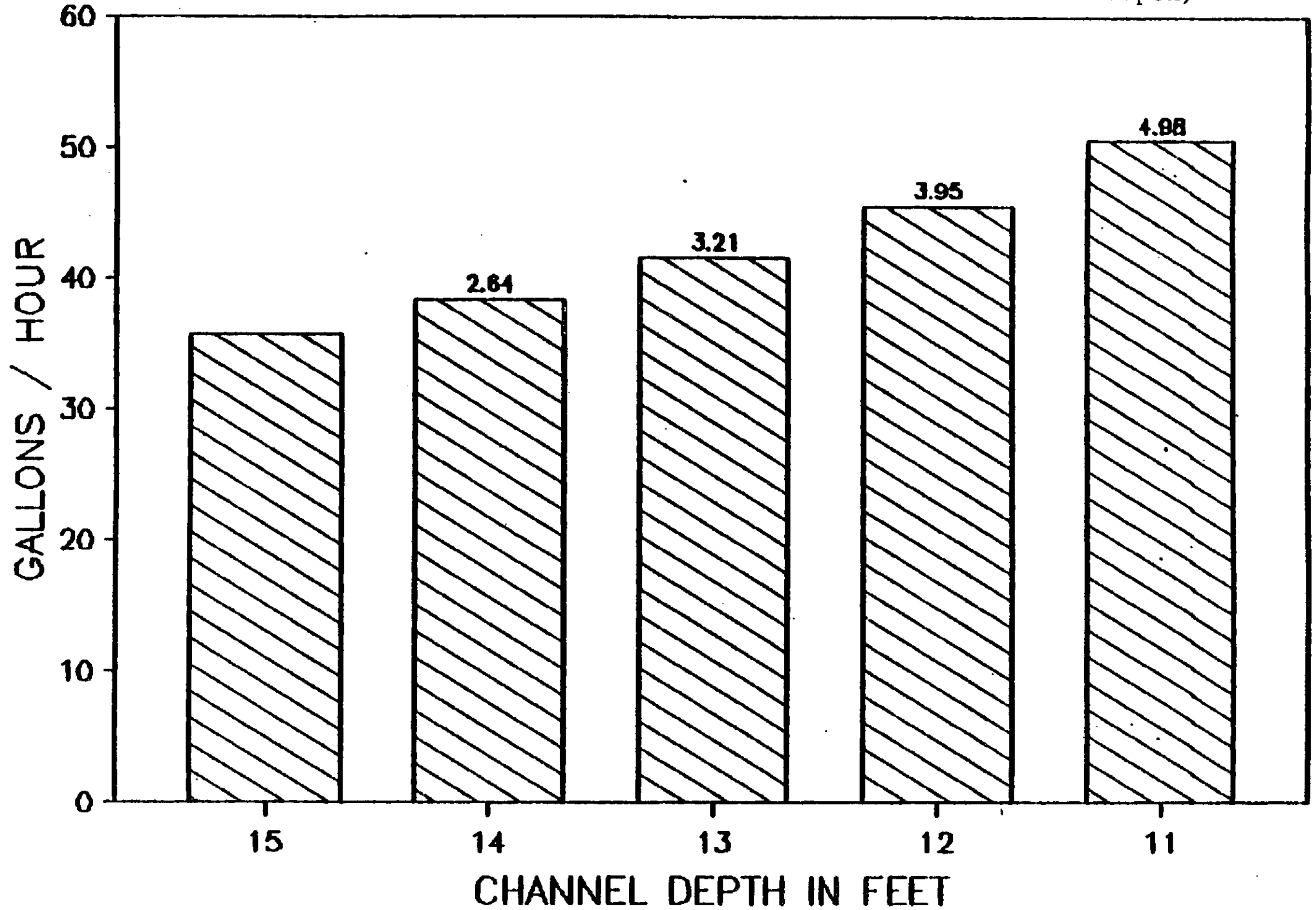


FIGURE 35

9 Barge Tow

4.0 MPH

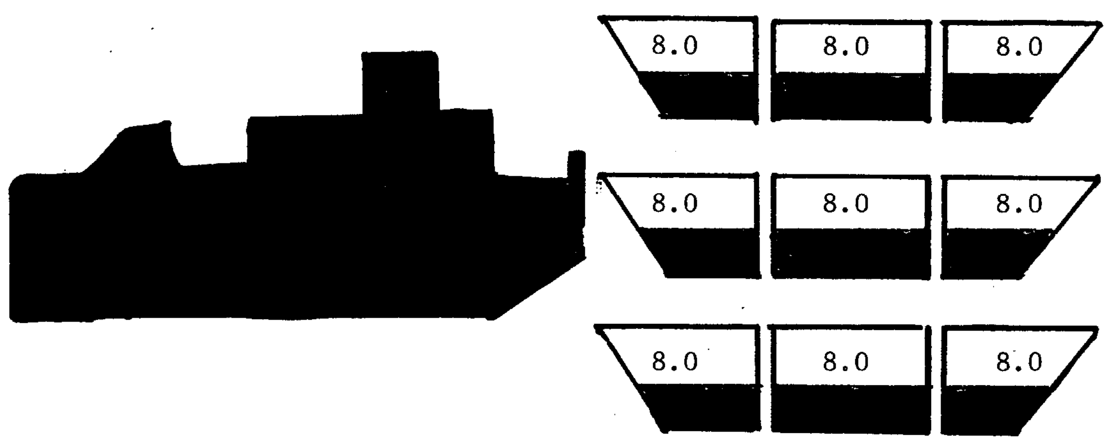


TABLE 19

9 BARGE TOW WITH A 8 FOOT DRAFT @ 4.0 MPH

	CHANNEL DEPTH IN FEET	REQUIRED HORSEPOWER FOR TOW	GAL. FUEL BURNED PER HOUR	INCREASE IN GAL./HR PER 1FT LESS DEPTH
THIS TABLE IS FOR	15	213.1	31.96	
A 9 BARGE TOW LOADED	14	228.2	34.23	2.27
TO AN 8 FOOT DRAFT	13	246.5	36.98	2.75
	12	269.1	40.36	3.38
SPEED 4.0 MPH	11	297.4	44.61	4.25

INCREASE IN FUEL USE IN GALS. / HOUR

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	2.27	5.02	8.40	12.65
14 FT		2.75	6.13	10.38
13 FT			3.38	7.63
12 FT				4.25

INCREASE IN FUEL USE AS A PERCENTAGE

	TO 14 FT	13FT	12 FT	11 FT
FROM 15 FT	7.1	15.71	26.28	39.58
14 FT		8.03	17.91	30.32
13 FT			9.14	20.63
12 FT				10.53

FIGURE 36

9 BARGE TOW

8 FOOT DRAFT AT 4.0 MPH

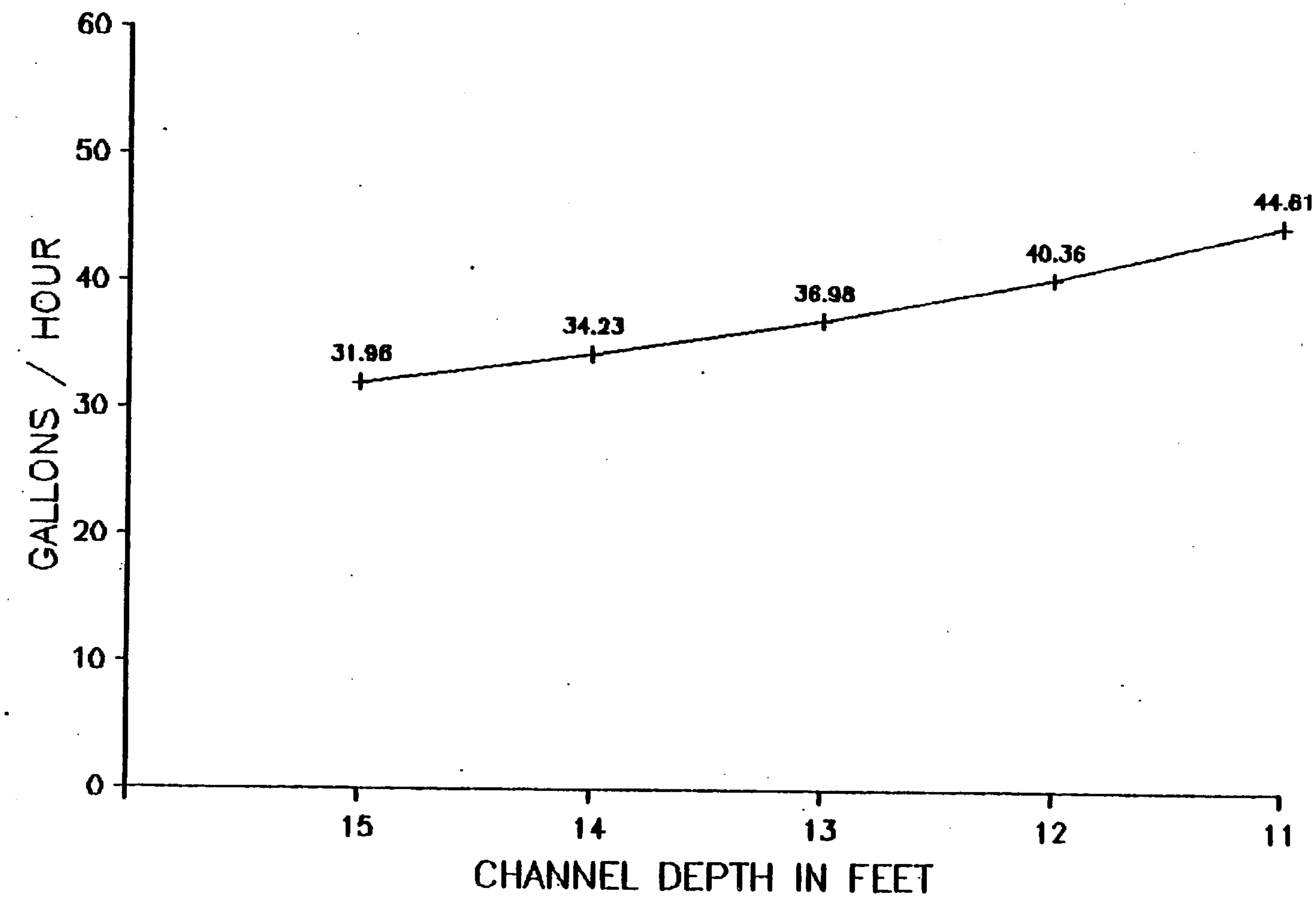


FIGURE 37

9 BARGE TOW

8 FOOT DRAFT AT 4.0 MPH

(Increase in GPH for each one foot decrease in channel depth)

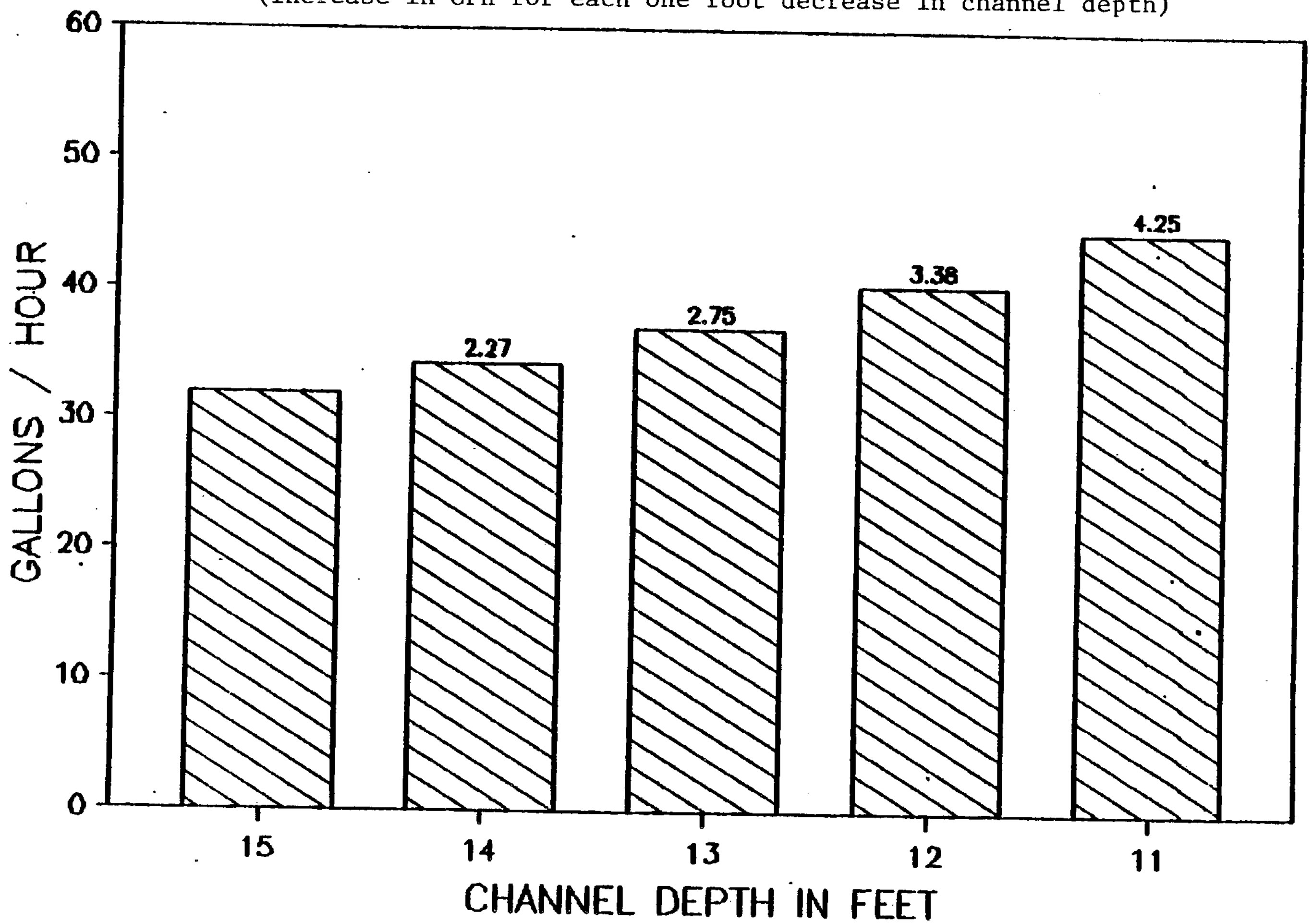
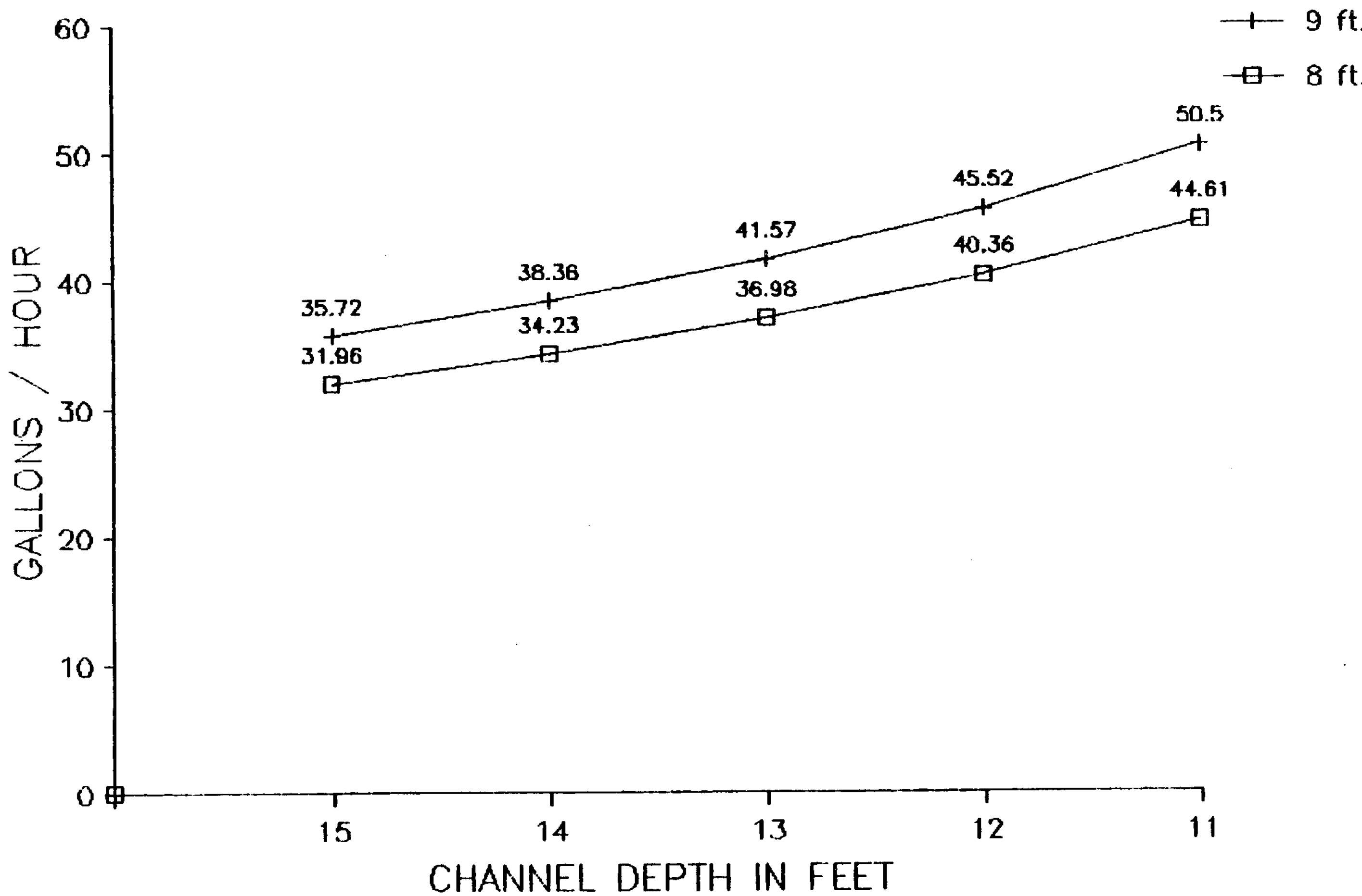


FIGURE 38

9 BARGE TOW

4.0 mph



Appendix A

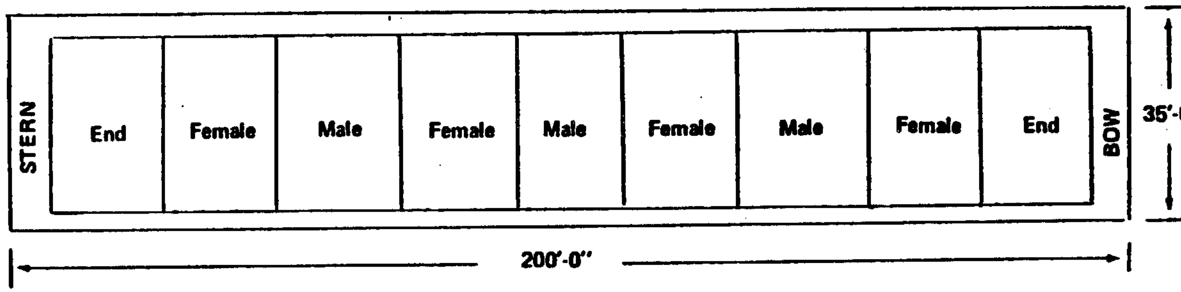
Several organizations have contributed data and insight for this report. Contacts included:

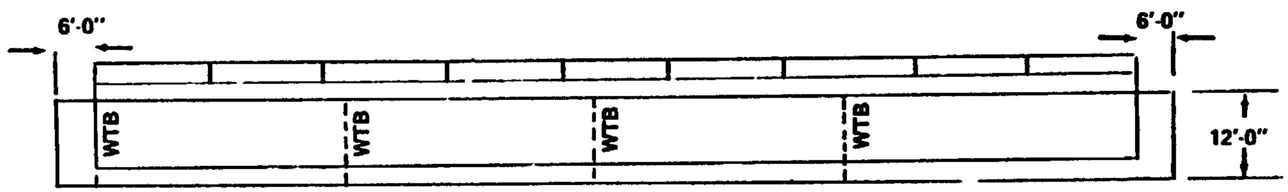
Agri-Trans Corporation	St. Louis, MO
American Barge and Towing	St. Louis, MO
The American Waterways Operators, Inc.	Arlington, VA
Cargo Carriers, Incorporated	Minneaploi[, MN
Caterpillar Tractor Company - Industrial Division Marine	Peoria, Ill
Conagra Transportation, Inc.	Alton, Ill
Conticarriers and Terminals, Inc.	Des Planes, Ill
Federal Barge Line	St. Louis, MO
General Motors Corporation - Electro-Motive Division	Hazelwood, MO
Iowa State University	Ames, IA
John Fabick Tractor Company	St. Louis, MO
Louisiana State University - Ports and Waterways Institute	Baton Rouge, LA
Merrill Marine Services, Inc.	St. Louis,MO
Minnesota Department of Energy	St. Paul, MN
Minnesota Department of Transportation	St. Paul, MN
Resources For the Future	Washington D.C.
Riverway Company	Minneapolis, MN
Riverway Harbor Services	St. Louis, MO
Spartan Transportation Corporation	St. Louis, MO
University of Illinois - Agricultural Economics Department	Urbana, Ill
University of Michigan - Department of Navel Architecture and Marine Engineering	Ann Arbor, MI
University of New Orleans - School of Navel Architecture and Marine Engineering	New Orlean, LA
University of Wisconsin - Agricultural Economics Department	Madison, WI
Upper Mississippi Waterway Association	Amery, WI
The Valley Line Company	St. louis, MO
Twin City Barge and Towing Company, Inc.	St. Paul, MN
Wisconsin Barge Line, Inc.	St. Louis, MO
U.S. Army Corps of Engineers - St. Paul District	St. Paul, MN
U.S. Army Corps of Engineers - St. Louis District	St. Louis, MO

DESCRIPTION: Semi-integrated hopperbarges fitted with nine (9) fiberglass lift-off hatch covers. Construction is welded steel with seven (7) watertight compartments. Barges were built by Jeffboat in 1981.

CARGO CAPACITY IN SHORT TONS

DRAFT	CARGO T	DRAFT	CARGO T	DRAFT	CARGO T	DRAFT	CARGO T	DRAFT	CARGO T
1'-5"	0	3'-3"	401	5'-1"	802	6'-11"	1203	8'-9"	1604
1'-6"	18	3'-4"	419	5'-2"	820	7'-0"	1221	8'-10"	1622
1'-7"	36	3'-5"	437	5'-3"	839	7'-1"	1239	8'-11"	1641
1'-8"	54	3'-6"	455	5'-4"	857	7'-2"	1258	9'-0"	1659
1'-9"	72	3'-7"	473	5'-5"	875	7'-3"	1276	9'-1"	1677
1'-10"	91	3'-8"	492	5'-6"	893	7'-4"	1294	9'-2"	1695
1'-11"	109	3'-9"	510	5'-7"	911	7'-5"	1313	9'-3"	1714
2'-0"	128	3'-10"	528	5'-8"	929	7'-6"	1331	9'-4"	1732
2'-1"	146	3'-11"	547	5'-9"	948	7'-7"	1349	9'-5"	1750
2'-2"	164	4'-0"	565	5'-10"	966	7'-8"	1367	9'-6"	1768
2'-3"	182	4'-1"	583	5'-11"	985	7'-9"	1386	9'-7"	1786
2'-4"	201	4'-2"	601	6'-0"	1003	7'-10"	1404	9'-8"	1804
2'-5"	219	4'-3"	620	6'-1"	1021	7'-11"	1422	9'-9"	1823
2'-6"	237	4'-4"	638	6'-2"	1039	8'-0"	1440	9'-10"	1841
2'-7"	255	4'-5"	656	6'-3"	1058	8'-1"	1458	9'-11"	1859
2'-8"	273	4'-6"	674	6'-4"	1076	8'-2"	1476	10'-0"	1878
2'-9"	292	4'-7"	692	6'-5"	1094	8'-3"	1495		
2'-10"	310	4'-8"	711	6'-6"	1112	8'-4"	1513		
2'-11"	328	4'-9"	729	6'-7"	1130	8'-5"	1531		
3'-0"	346	4'-10"	748	6'-8"	1148	8'-6"	1549		
3'-1"	364	4'-11"	766	6'-9"	1167	8'-7"	1567		
3'-2"	382	5'-0"	784	6'-10"	1185	8'-8"	1586		

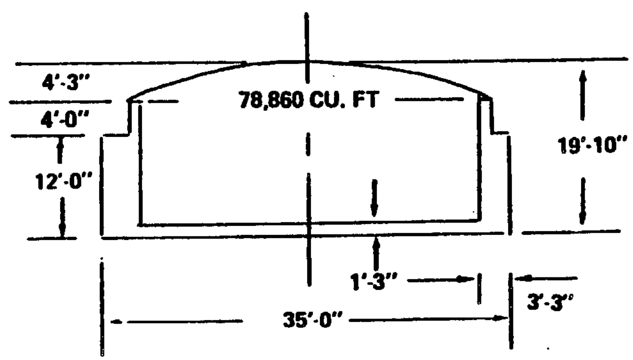


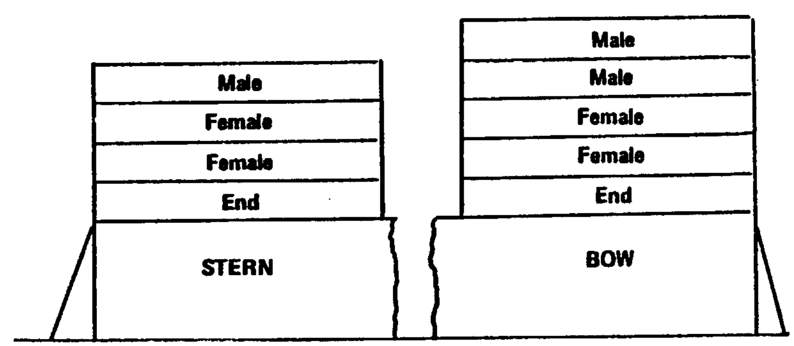


Hopper Length:
Top: 188'-0"
Bottom: 188'-0"
Hopper Depth: 14'-8½"

Hopper Width:
Top: 28'-6"
Bottom: 28'-6"

Weight of Hull	299 Short Tons
Weight of Covers	11 Short Tons
Total Weight	310 Short Tons

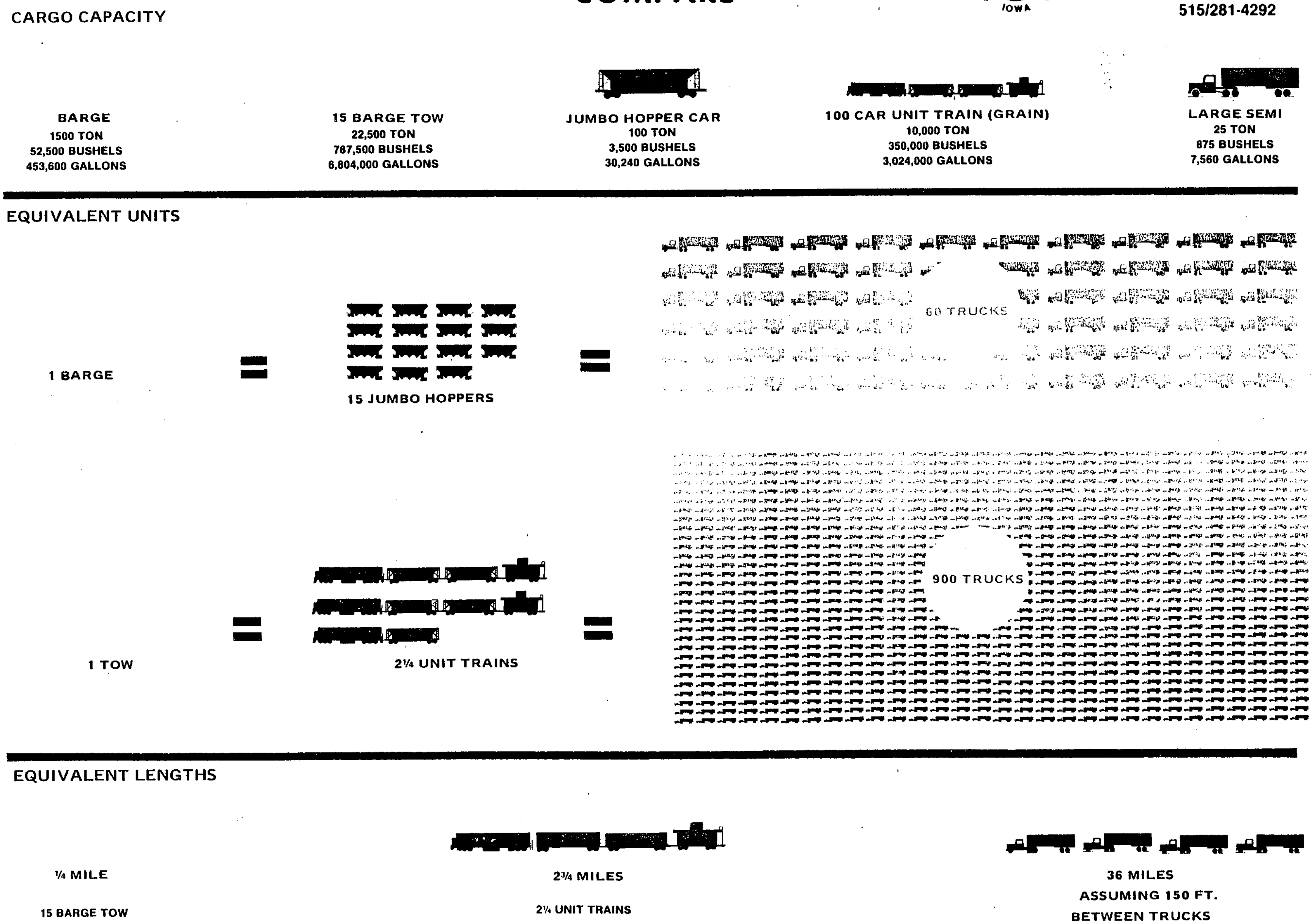




21.2

COMPARE

River Transportation Division
Iowa Department of Transportation
State Capitol
Des Moines, Iowa 50319
515/281-4292



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