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Scale Modeling of Fixed-Fishing Gear to Compare and Quantify Differently Configured Buoyline and Groundline Profiles: An Investigation of Entanglement Threat

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Massachusetts Division of Marine Fisheries, working with the Marine Institute's Centre for Sustainable Aquatic Resources and the National Marine Fisheries Service's Gear Research Team, used scale models of fixed-fishing gear to compare, quantify and investigate buoyline and groundline profiles in order to address the entanglement threat they may pose. Scaled-model buoylines were configured with a variety of line types, surface and subsurface buoys, and scopes. A scaled-model groundline was also configured entirely as buoyant line. Models were subjected to scaled-currents up to 3.0 kts, and modeled at 1:10 and 1:5 scales at the Centre for Sustainable Aquatic Resources' 22 M long and 4 M deep flume tank located at the Marine Institute of Memorial University, St. Johns Newfoundland. The flume tank provided full-scale depths of 40 M (131 ft.) and 20 M (65 ft.), or that comparable to depths found in Cape Cod Bay. Twenty- one (21) different configurations were tested during one hundred and twenty (120) modeled test runs. The results showed that buoyline configurations and scope affected buoyline profiles, and that different current loads (speeds) affected both buoyline and groundline profiles throughout the water column. Furthermore, the use of float line at the bottom 1/3 of a buoyline showed a similar profile to that of 100% sink and 100% neutral-buoyant configured lines over all but the slowest current speeds (< 0.5 kts.). Modeling did not account for any surface influences, such as wind and sea state. Independent, full-scale field-tests comparing buoylines and groundlines showed similar results. Modeling also showed that the amount of scope in the buoyline was the most significant variable in reducing a buoyline profile. While shortening the scope of the buoyline may be the best means of reducing the profile, replacing the bottom 1/3 of an all sink line with float line appears not to change the profile appreciably, especially given temporal and spatial considerations surrounding low current loads (0.5 kts. or less) in much of the Gulf of Maine, and thus may not pose an additional entanglement risk.

Introduction

The interaction between marine harvesting efforts and non-targeted species is a growing concern for all maritime nations. This is of particular concern where the non-targeted species is a highly endangered species as is the case for the North Atlantic right whale, *Eubalaena glacialis*. Entanglement in fishing gear has been listed as a significant threat to the North Atlantic right whale (Clapham, 2003; Knowlton, *et al*, 2002; Kraus, 1999; NMFS, 1991). Between 1970 and 2001, there have been at least 5 confirmed right whale deaths due to entanglement (Knowlton and Kraus, 2001). The actual number is almost certainly higher. Scar studies have shown that 67% of the population has been entangled at some point in their life (Knowlton *et al*, 2002). Fixed-fishing gear (e.g. trap gear and gillnets), have been implicated in many entanglement cases. For lobster gear, the two primary components are the buoyline, which connects a trap or set of traps to a surface buoy, and the "groundline" (or "mainline"), which connects consecutive trap together in a "trawl". Both components have been documented as entanglement threats to right whales (Clapham, 2001; Johnson *et al*, 2004 in press).

The risk of entanglement in lobster gear is perceived to exist in part because many lobstermen prefer to use floating line, entirely or in part, for rigging their groundlines and buoylines. Floating line, typically comprised of polypropylene, is less expensive than sinking line, and more importantly, remains off the bottom thereby reducing abrasion and the potential to foul with the substrate and the traps themselves. However, the use of floating line, or other means to keep lines off the bottom, increases the risk of entanglement by increasing the amount of line in the water column that the animal can encounter.

While right whales have a broad distribution along the east coast of North America, a large portion of the population aggregates seasonally off Massachusetts (Brown and Marx, 1999; CeTAP, 1982; Kenney *et al*, 1995; Kenney and Kraus, 1991; Mayo and Marx, 1990; Weinrich *et al*, 2000; Winn *et al* 1986). In fact, two of the three Critical Habitats - Cape Cod Bay (CCB) and the Great South Channel (GSC), designated off the US coast for these animals, are found in or adjacent to Massachusetts waters.

The Massachusetts Division of Marine Fisheries (*MarineFisheries*) has investigated the entanglement threat posed by fixed-fishing gear. In 1998, the agency showed that groundlines rigged with floating line rose consistently at least 10 feet off of the sea floor (Carr, 1998). During the winter of 2001/ 2002 the documentation of lobster trawls set with floating line in CCB showed that the groundlines arced on average 16 feet, and as much as 25 feet off the bottom

(McKiernan *et al*, 2002). Both studies demonstrated the increased risk of entanglement posed by floating groundlines.

Since 1997, *MarineFisheries* has aggressively regulated fixed-gear fisheries, especially groundlines, in one of these Critical Habitats - Cape Cod Bay - during winter and early spring when right whales aggregate there. Starting in 1997, lobstermen fishing CCB Critical Habitat were required to use sinking groundline between traps during this time, and beginning in 2003 lobstermen were required to use sinking groundline year-round. In 2004, the requirement for sinking groundline was extended beyond CCB Critical Habitat to encompass all of Cape Cod Bay.

The agency continues to investigate the entanglement threat posed by fixed-fishing gear. This study attempts to better understand the physics of rigging design for both the groundline and buoyline (the "standing tackle" of trap gear), the relationship of the rigging design, and layout of "trap" gear to entanglement of whales.

Statement of the Problem

In recent years, groundline profiles in the lobster industry have been well documented by use of Remote Operated Vehicles (ROVs) and SCUBA. These studies have shown that floating groundlines arc as much as 25 feet off the bottom (Carr, 1998; McKiernan *et al*, 2002; Maine Division of Marine Resources, in progress). Efforts to reduce the threat that these arcs provide focus on lowering the height of groundline and thereby reducing the probability that the animal will come in contact with the line. Whereas the lowering of groundlines by prohibiting the use of buoyant line will almost certainly reduce the entanglement threat, some fishermen argue against such regulations. They allege that the use of non-buoyant lines, in contact with the substrate, increases abrasion, and results in more fouling, which shortens the lifespan of the line and may result in gear loss. This along with the higher price for non-buoyant line equates to increased costs for the fisherman.

Buoyline profiles, however, have not been as well documented, nor is it well understood how these profiles might affect entanglement risk beyond the fact that line is in the water column where an animal can come in contact with it. One of the reasons for the lack of knowledge is that there are a large number of buoyline configurations. The surface marker system may include a single foam buoy, a "high-flyer" (multiple close-cell foam buoys with spar), or large inflated poly balls, all of which may have surface toggle buoys, and under some circumstances, subsurface toggles attached. The buoylines themselves may consist of varying proportions of floating, sinking, or near "neutral" buoyant lines; each comprised of different materials, braids, lays, diameters, drag characteristics, and breaking strengths. One of these configurations involves the use of float line at the bottom portion of the buoyline to keep the line off the bottom. Regulators have restricted the use of float line in buoylines perceiving that its use in the buoyline will result in loops and arcs of line in the water column that will increase the entanglement threat. In fact, NOAA Fisheries had suggested eliminating the use of float line in the buoylines all together. As was the case for groundlines, some fishermen argued against the effectiveness of such actions.

While the study of fixed-gear has increased with the intent of minimizing the risk of entanglement for whales, there remains limited, *in situ,* documentation of the gear, especially the buoylines and their diverse configurations. To gain the required level of quantification and the necessary understanding of buoyline behavior under varying environmental conditions would be both difficult and costly at full-scale. Moreover there are technical and logistical challenges presented by surface conditions, depth and the associated lack of light for filming. Alternative means are required to provide state and federal fishery managers with quantitative information on differently configured fixed-fishing gear to allow effective entanglement risk reduction.

Study Objectives

The primary objective was to provide realistic demonstrations and quantification of clear static and quasi-static buoyline and groundline profiles (i.e. under some current load) under controlled conditionsthrough use of scaled-models supported by full-scale comparisons in order to assess their relative risk of entanglement and practicality of use. One specific objective was to assess whether or not the use of buoyant line in the bottom portion of otherwise sink buoyline would pose a greater entanglement risk.

Methods

Modeling

Twenty (20) different buoyline configurations and one (1) groundline configuration were modeled to include: 1) line types comprised of negatively, neutrally* and positively buoyant rope, and/or different proportions of each; 2) buoy types and arrangements (single/dual floats, surface/ sub-surface configurations); and 3) line scope (ratio of line length to depth). Table 1 shows the different configurations tested. The scale(s) for the modeling was determined primarily from the desired full-scale depth range, the size of the accommodating test facility, and the ability to scale down current effects and gear.

Although northern right whales range throughout the entire northwest Atlantic, this initial study addresses habitats similar to Cape Cod Bay (CCB) and other inshore trap fisheries within the lower/ western Gulf of Maine. Right whales have been routinely observed throughout CCB and in nearly all depths within the Bay (Brown and Marx, 1998; Brown and Marx, 1999, Brown and Marx, 2000; Brown *et al*, 2002; Brown *et al*, 2003; Mayo *et al* 1999). These depths range from approximately 30 feet up to the Bay's maximum depth of 200 feet. The Flume Tank at the Centre for Sustainable Aquatic Resources at the Marine Institute in St. Johns, Newfoundland was an ideal test facility in that it has a working depth of 4M (~13 ft) and a 22M(~72 ft) long viewing gallery encompassing one entire side of the tank for documenting subsurface behavior of the gear. Given this depth and the desired range of depths to target for full-scale comparison to CCB and surrounding waters, a linear scale of 1:10 was decided on. This scale provided a full-scale depth value of approximately 131 feet, which is quite comparable to that in Cape Cod Bay. All tests were conducted at the single fixed depth for the scale identified.

The only environmental variable considered (tested) in the study was current load (speed) and this was froude-scaled to represent full-scale speeds between 0 and 3 kts, which is within the range of currents typically found within CCB Critical Habitat (personal observation). Currents were typically

Table 1: Modeling Configurations

Configurations	Scale	Scope	% Float Line	% Sink Line	% "Neutral" Line	Buoy rig	Buoy Code
1	1:10	1.75	10	90	0	Bullet Buoy	A
2	1:10	1.75	33	67	0	Bullet Buoy	A
3	1:10	1.75	67	33	0	Bullet Buoy	A
4	1:10	1.75	100	0	0	Bullet Buoy	A
5	1:10	1.75	0	100	0	Bullet Buoy	A
6	1:10	1.75	0	0	100	Bullet Buoy	A
7	1:05	1.75	33	67	0	Bullet Buoy	A
8	1:10	1.25	10	90	0	Bullet Buoy	A
9	1:10	1.25	33	67	0	Bullet Buoy	A
10	1:10	1.25	67	33	0	Bullet Buoy	A
11	1:10	1.25	100	0	0	Bullet Buoy	A
12	1:10	1.25	0	100	0	Bullet Buoy	A
13	1:10	1.5	33	67	0	Bullet Buoy	A
14	1:10	1.5	67	0	0	Bullet Buoy	A
15	1:10	1.5	100	0	0	Bullet Buoy	A
16	1:10	1.5	0	100	0	Bullet Buoy	A
17	1:10	1.75	0	100	0	Subsurf. Toggles	B
18	1:10	1.75	0	100	0	Surface Toggles	C
19	1:10	1.75	0	100	0	Polyball	D
20	1:10	1.5	100	0	0	Groundline arc	A
21	1:1	1.5	0	100	0	Full scale Buoy	E

* Neutrally buoyant refers to those lines with a specific gravity near that of seawater. However, since the specific gravity of seawater depends upon temperature and salinity among other things and the line itself may vary over time, there really is no such thing as neutrally buoyant line. In fact, neutrally buoyant line tends to be negatively buoyant.

generated in the flume tank by use of impellers; however, at speeds of 0.25 kts. or less at the 1:10 scale, use of the impellers proved impractical and inconsistent. For these slower speed runs the moving ground-plane in the tank was used to create a 'current' relative to the trap by moving the gear through the water column. As an alternative to using the ground-plane, a 1:5 scaled model (~65 ft full-scale depth) was used allowing for less scale-down effect in current. This scale generated current from the impellers down to 0.125 kts. before having to switch to the ground-plane technique. In either case, currents tended to be more uniform throughout the water column than they would have been in the field. Differences in bottom topography, surface effects (sea state, windage), diurnal tidal effects on current direction, and depth differences (other than between the two scales) were not accounted for in this study.

Because of the large amount of variability among fishermen in rigging of trap gear, especially in the buoyline, the modeling was limited to constant-diameter line. However, varying proportions of sinking (including neutral-buoyant line) and floating line segments were included in configuring the models. For this study 7/16" line was modeled as the buoyline, which is quite common in the inshore lobster fishery (Hoffman *et al*, 2002; Lyman, 2004). At the 1:10 scale, 1.25mm twine was used, which at full-scale is off by only .055 inch. This is well within the margin of error in the manufacturing of the line. The various model lines were selected for buoyancy based on their values of specific gravity (S.G.). However, since full-scale lines are set in seawater with a S.G. of about 1.025, as opposed to model lines set in freshwater with a S.G. of 1.00, the model lines appeared to be slightly "heavier". This difference is small and was considered acceptable, especially when one considers the variability in S.G. found in the field (at full-scale) in different water masses and within the different line types. For the corresponding line types, polypropylene was used for float line (S.G. = 0.91), polyamide for sink line (S.G. = 1.17), and Dyneema™ for neutral buoyant line (S.G. = 0.97).

Buoy modeling accounted for weight and buoyancy forces. Buoy models were fabricated from closed-cell foam and rigid plastic spheres with dimensions based on their full-scale counterparts. Buoys modeled were the standard 7" x 15" bullet buoy, the 9" diameter trawl buoy, the A3 polyball, and a pair of bullet buoys acting as toggle buoys. Accuracy of the models was ± 2.5 mm in diameter and within 6% error of buoyancy compared to full-scale counterparts. Buoyline buoy configurations included: (A) single bullet buoy, (B) surface bullet buoy with trawl buoy as a subsurface toggle 30 feet from the bottom, (C) two surface bullet buoys spaced 12 feet apart, (D) A3 Polyball with bullet buoy as a toggle, and (E) a full-scale buoy (buoyancy equal to that of a 7" x 15" bullet buoy). A more detailed description of modeled buoys and evaluation of modeling accuracy can be found in the *Buoyline Rigging Evaluation Report,* prepared by Centre for Sustainable Aquatic Resources' engineers and is included as Appendix A.

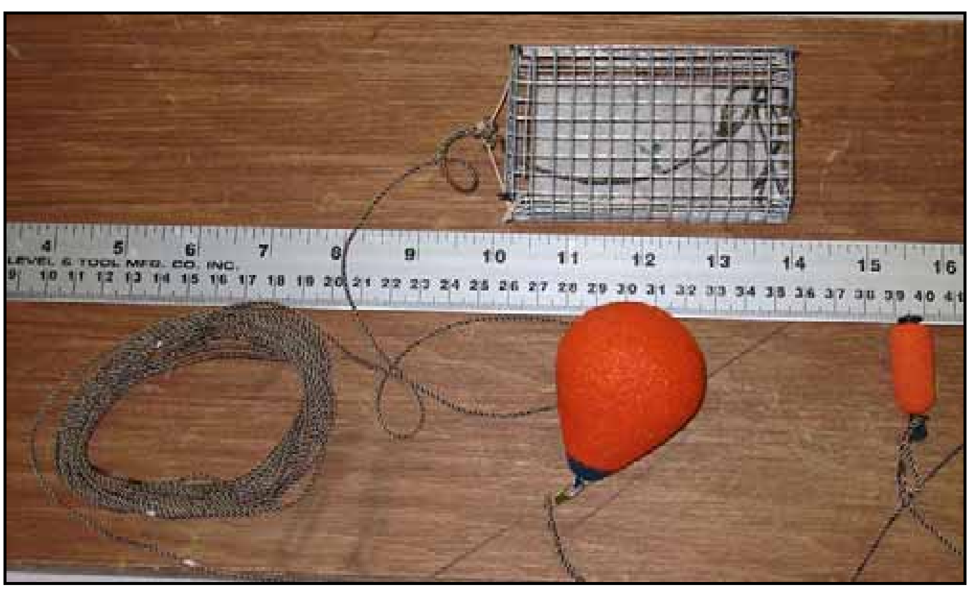

Figure 1: 1:10 scaled model with A3 polyball and 100% sink line.

A "single" rigging design (i.e. one buoyline per trap) was done for all the buoyline tests with a bridle connecting the buoyline to the trap as done in the industry. Trap models were scaled to their proper dimensions for both 1:10 and 1:5 scales. However, the weight of the modeled traps was not scaled. In order to avoid disturbing the traps between consecutive runs, and so maintain a common (spatial) base point, the modeled weight of the traps was increased to approximately 120 kg (320 lbs) full-scale. The focus of this study was not trap – bottom interactions, but the profile of the different buoyline configurations.

Two separate checks of scale effect were conducted. The first was a set of eight (8) runs done on a separate model scaled to 1:5 on a buoyline configuration of 1.75 scope and rigged with 33% float line at the bottom terminus. The 1:5 scale models was subjected to currents between .063 and 1.5 kts. The second was a full-scale buoyline (buoy code E). The full-scale buoyline was dropped into the tank and subjected to increasing current until the buoy submerged. A 1:10 model of this scenario was then created and the value of speed at buoy submergence noted. For all of these conditions, the value of current speed required for buoy submergence differed only by a few tenths of a knot, which was considered quite good and entirely adequate for the purposes of this work.

One set of multi-trap tests were performed in order to look at groundline profiles. Traps and line configurations were modeled, as above, to a 1:10 scale. The model, comprising two traps, was rigged with scaled 7/16", float line (polypropylene) mainline with traps set 2.72 M (~9 ft) apart, which is equivalent to traps being 90 feet apart at full-scale. Traps were oriented perpendicular to the current flow or across the flume tank, and subject to currents between 0 and 1 kts. The above configuration was modeled based on full-scale rigs documented in CCB during the winter of 2002 (McKiernan *et al*, 2002).

Test Protocol

One hundred and twenty (120) modeled test runs were performed on the various configurations and under different current loads. Tests were performed between March 18 and March 21, 2003 (Table 2 shows the particulars of each test run). Tests procedures were carried out as follows:

1. Test lines were placed in a pressure chamber for 30 minutes at 1500 psi to remove air entrapment prior to any testing. The only exception was with neutral-buoyant line, which did not follow this procedure (see section 4.4 of *Buoyline Rigging Evaluation* in Appendix A for detailed explanation). For all other line configurations, after pressurization and between tests, test lines were stored immersed in water.

2. The modeled trap with test line was typically set midway along the flume tank, approximately 3M (10 ft) away from the observation window, as to provide the best view of the line profile. Due to time constraints, there were several runs in which two or more models were run simultaneously in the tank.

3. Test line profiles were subjected to different current loads. In addition to a baseline condition of "no current" (0 kts), most configurations were subjected to four discrete current speeds. These were 1, 0.75, 0.5, and 0.25 kts. Current loads sometimes ran as low as .063 kts and as high as 3 kts. For current loads of 0.25 and 0.125 kts at the 1:10 scale, current relative to the trap and line configurations was provided by moving the ground-plane track at the bottom of the tank (impeller-induced currents were lowered to .25 kts for the 1:5 scale testing).

4. Test line configurations were videotaped while they underwent current loads. However, once the line profile had reached equilibrium, the "static" condition of the line at that current was documented using a camera on a xy coordinate system to digitize 3 to 10 node/inflection points along the line's profile. Digitized points were then used to create a spline curve in AutoCAD. In cases where the automatically generated spline did not show good agreement with the model, additional "control" points were added. Due to the use of the ground-plane track at slower current speeds, digitized points of the test line profiles could not be obtained. The xy coordinate camera was also used to quantify the maximum height of the gangions and groundline between traps. In addition to being videotaped as in the buoyline runs, groundline arcs were videotaped from within the tank by use of submersible video cameras.

Tests were observed and directed on-site by Ed Lyman of the Massachusetts Division of Marine Fisheries, and Glenn Salvador and John Kenney of NMFS Gear Research Team.

Table 2: Test Run Configurations

Test Run	Scale	Scope	Speed Kts	% Float	% Sink	% Neutral	Buoy Type	Test Run	Scale	Scope	Speed Kts	% Float	% Sink	% Neutral	Buoy Type
1	10	1.75	0.000	0	100	0	A	63	10	1.25	0.125	10	90	0	A
2	10	1.75	1.000	0	100	0	A	64	10	1.25	0.125	33	67	0	A
3	10	1.75	0.500	0	100	0	A	65	10	1.25	0.125	67	33	0	A
4	10	1.75	0.750	0	100	0	A	66	10	1.75	0.000	0	0	100	A
5	10	1.75	0.250	0	100	0	A	67	10	1.75	0.000	0	0	100	A
11	10	1.75	0.000	33	67	0	A	68	10	1.75	1.000	0	0	100	A
12	10	1.75	1.000	33	67	0	A	69	10	1.75	1.000	0	0	100	A
13	10	1.75	0.750	33	67	0	A	70	10	1.75	1.500	0	0	100	A
14	10	1.75	0.500	33	67	0	A	71	10	1.75	0.750	0	0	100	A
15	10	1.75	0.250	33	67	0	A	72	10	1.75	0.500	0	0	100	A
16	10	1.75	0.000	67	33	0	A	73	10	1.75	0.250	0	0	100	A
17	10	1.75	1.000	67	33	0	A	74	10	1.75	0.125	0	0	100	A
18	10	1.75	0.500	67	33	0	A	75	10	1.75	0.000	0	100	0	D
19	10	1.75	0.750	67	33	0	A	76	10	1.75	1.000	0	100	0	D
20	10	1.75	0.250	67	33	0	A	77	10	1.75	2.000	0	100	0	D
20A	10	1.75	0.125	67	33	0	A	78	10	1.75	3.000	0	100	0	D
21	10	1.75	0.000	100	0	0	A	79	10	1.75	0.500	0	100	0	D
22	10	1.75	1.000	100	0	0	A	80	10	1.75	0.250	0	100	0	D
23	10	1.75	1.500	100	0	0	A	81	10	1.75	0.125	0	100	0	D
24	10	1.75	0.500	100	0	0	A	82	10	1.75	0.000	100	0	0	A
24A	10	1.75	0.250	100	0	0	A	83	10	1.75	1.000	100	0	0	A
25	10	1.75	0.750	100	0	0	A	84	10	1.75	0.750	100	0	0	A
26	5	1.75	0.000	33	67	0	A	85	10	1.75	0.500	100	0	0	A
27	5	1.75	1.000	33	67	0	A	86	10	1.75	0.250	100	0	0	A
28	5	1.75	1.500	33	67	0	A	87	10	1.75	0.125	100	0	0	A
29	5	1.75	0.750	33	67	0	A	88	10	1.5	0.000	33	67	0	A
30	5	1.75	0.500	33	67	0	A	89	10	1.5	0.000	67	33	0	A
31	5	1.75	0.250	33	67	0	A	90	10	1.5	1.000	33	67	0	A
32	5	1.75	0.125	33	67	0	A	91	10	1.5	1.000	67	33	0	A
33	5	1.75	0.063	33	67	0	A	92	10	1.5	0.750	33	67	0	A
34	10	1.75	0.000	0	100	0	B	93	10	1.5	0.750	67	33	0	A
35	10	1.75	1.000	0	100	0	B	94	10	1.5	0.500	33	67	0	A
36	10	1.75	1.500	0	100	0	B	95	10	1.5	0.500	67	33	0	A
37	10	1.75	0.750	0	100	0	B	96	10	1.5	0.250	33	67	0	A
38	10	1.75	0.500	0	100	0	B	97	10	1.5	0.250	67	33	0	A
39	10	1.75	0.250	0	100	0	B	98	10	1.5	0.125	33	67	0	A
40	10	1.75	0.125	0	100	0	B	99	10	1.5	0.125	67	33	0	A
41	10	1.75	0.000	0	100	0	C	100	10	1.25	0.000	0	100	0	A
42	10	1.75	1.000	0	100	0	C	101	10	1.25	0.000	100	0	0	A
43	10	1.75	1.500	0	100	0	C	102	10	1.25	0.750	0	100	0	A
44	10	1.75	0.750	0	100	0	C	103	10	1.25	0.750	100	0	0	A
45	10	1.75	0.500	0	100	0	C	104	10	1.25	1.000	100	0	0	A
46	10	1.75	0.250	0	100	0	C	105	10	1.25	0.500	0	100	0	A
47	10	1.75	0.125	0	100	0	C	106	10	1.25	0.500	100	0	0	A
47A	10	1.75	1.500	0	100	0	E	107	10	1.25	0.250	0	100	0	A
48	10	1.25	0.000	10	90	0	A	108	10	1.25	0.250	100	0	0	A
49	10	1.25	0.000	33	67	0	A	109	10	1.25	0.125	0	100	0	A
50	10	1.25	0.000	67	33	0	A	110	10	1.25	0.125	100	0	0	A
51	10	1.25	1.000	10	90	0	A	111	10	1.50	0.000	0	100	0	A
52	10	1.25	1.000	33	67	0	A	112	10	1.50	0.000	100	0	0	A
53	10	1.25	1.000	67	33	0	A	113	10	1.50	1.000	0	100	0	A
54	10	1.25	0.750	10	90	0	A	114	10	1.50	1.000	100	0	0	A
55	10	1.25	0.750	33	67	0	A	115	10	1.50	0.750	0	100	0	A
56	10	1.25	0.750	67	33	0	A	116	10	1.50	0.750	100	0	0	A
57	10	1.25	0.500	10	90	0	A	117	10	1.50	0.500	0	100	0	A
58	10	1.25	0.500	33	67	0	A	118	10	1.50	0.500	100	0	0	A
59	10	1.25	0.500	67	33	0	A	119	10	1.50	0.250	0	100	0	A
60	10	1.25	0.250	10	90	0	A	120	10	1.50	0.250	100	0	0	A
61	10	1.25	0.250	33	67	0	A	121	10	1.50	0.125	0	100	0	A
62	10	1.25	0.250	67	33	0	A	122	10	1.50	0.125	100	0	0	A

* Buoy symbols: A = 7” x 15” bullet buoy, B = bullet buoy with subsurface toggle, C = bullet buoy with surface toggle, D = polyball buoy with toggle, E = full-scale bullet buoy. See *Buoyline Rigging Evaluation Report* in Appendix A).

Measurement and Analysis

Qualitative measures were obtained from video footage, while most quantitative measures were obtained from analysis of AutoCAD "layered" profiles allowing for comparison of profiles between configurations and/or current speeds. Qualitative measures included noting whether line was in contact with the bottom or the surface; whether buoys were submerged; the number, location, and shape of loops of line, and mid-water arcs; or whether line was fouled around the trap. Quantitative measures included current speed, scope, straight-line distance between trap and surface buoy, horizontal component of the profile (the greatest horizontal distance covered by the line's profile relative to the depth at which it was set), and if possible, the amount of line in contact with the bottom and/or surface.

Full-scale, *in situ*, Field Comparison

Several full-scale comparisons of modeled test configurations of buoyline profiles were carried out in the field. The study site was off the west side of Appledore Island, Isles of Shoals, ME. The site was offshore providing good visibility required to document buoyline profiles at full-scale. While the site was protected, it was subject to currents of at least 0.5 kts. Physical conditions at the site were a tidal depth ranging between 40 to 50 feet, a level, sandy bottom, a southwest through northern exposure, and a fetch as great as 12 nm.

Two full-scale test configurations were set; comprising 100% nylon, sink line, and 33% polypropylene float line at the bottom terminus of otherwise sink line. Both configurations were made up of 7/16" line, rigged with 7"x15" bullet buoys, complete with weaklinks, and secured to a dummy trap (see Appendix B for images of full-scale configurations). Test lines were set on July 13, 2003. SCUBA divers documented test line profiles by use of an underwater Nikonos camera equipped with a 15 mm wide-angle lens. Test line profiles were documented on 7/13, 7/26, 9/1, and 9/20, 2003. Buoyline profiles were documented at several currents and tidal states, including slack water. Currents were measured on site by use of a General Oceanics mechanical, rotor, flowmeter (.020– 5 kts. or 10 cm/sec— 7.9 m/sec).

Results

One hundred and twenty (120) modeled test runs covering twenty-one (21) different rigging configurations of buoylines and groundlines were performed under different current loads ranging from zero to approximately 1.5 kts. full-scale for the majority of tests, to a maximum of about 3 kts. for the larger float configurations. Tests were performed between March 18 and March 21, 2003. Table 2 outlines the test runs, their configurations and subjected current loads.

AutoCAD plots showing line profiles for all configurations that were measured are shown in Appendix C. Several test runs were not quantified due to the fact that slower current speeds were modeled through the use of the ground-plane track on the bottom of the flume tank, and as such, the determination of points along the profile of a moving line was not possible. In some tests, lines fouled and equilibrium was not reached, thus not allowing for quantification. However, for those line profiles that were quantified a suite of measures outlined in the methods were taken from the AutoCAD profiles. These measures along with some simple observations are also shown in Table 3 in Appendix D.

Much of the results and discussion that pertains to the evaluation of modeling in this study can be found in more detail in the *Buoyline Rigging Evaluation Report* in Appendix A. In addition to looking at physical parameters in order to evaluate model accuracy, scale comparisons were made both in the tank and in the field at full-scale.

Comparisons of profiles at the two scales (1:10 and 1:5) show very similar results (Figure 2). There was somewhat more variability in the profiles at the smaller scale (1:10). Most of this was seen in the upper water column where the line was more influenced by weight and drag effects from the greater amount of line in the water column. Also noted was that the larger amount of line resulted in surface buoys submerging earlier at given current loads.

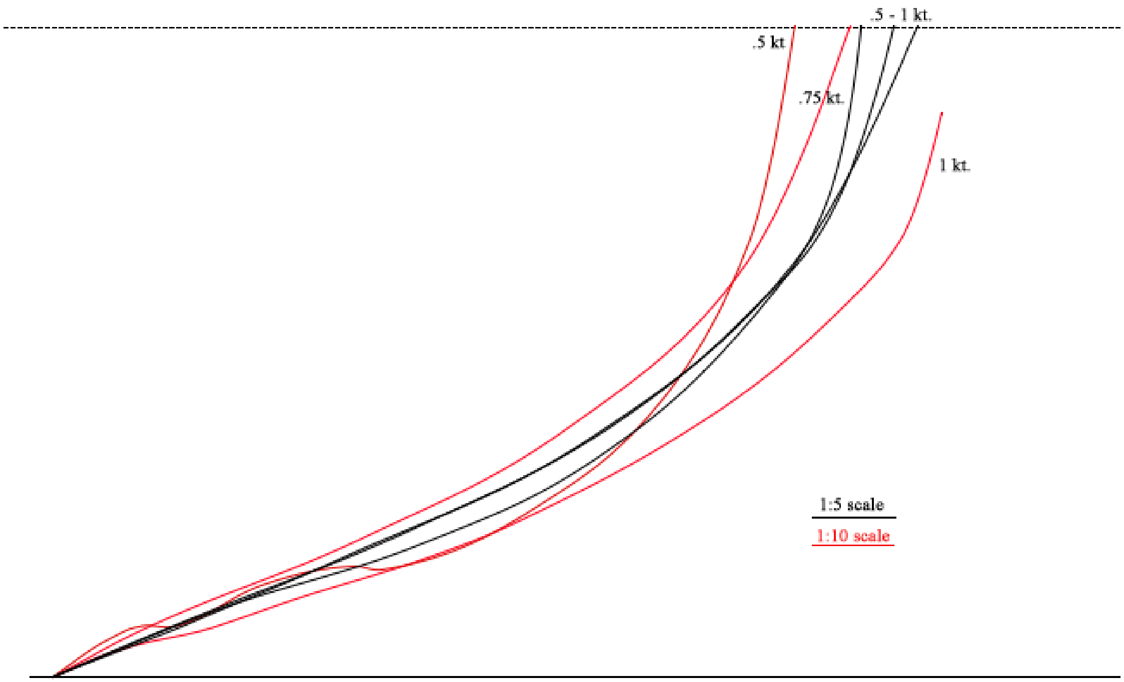

Figure 2: Comparison of 1:5 and 1:10 scales on 33% float line profiles at 1.75 scope at different currents.

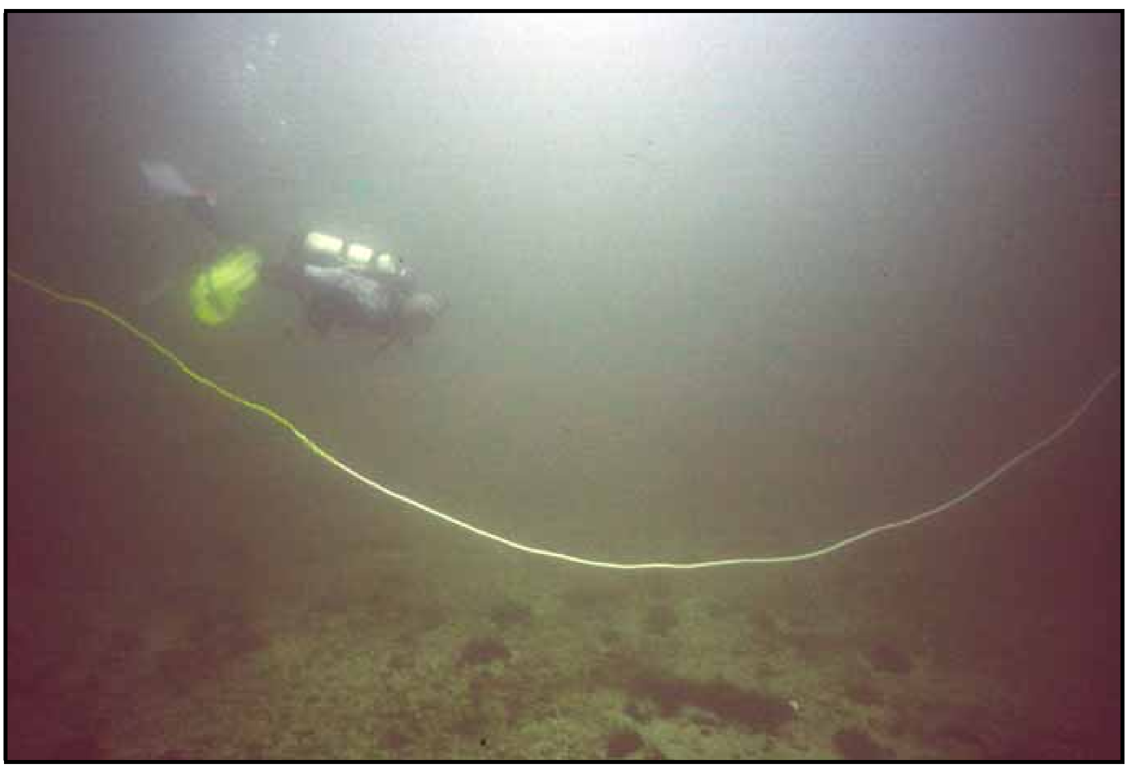

Figure 3: Portion of full-scale profile of 33% float line at 1.75 scope during short interval of slack water.

While full-scale field tests of buoyline profiles were not quantified, qualitative comparison to modeled buoylines (some of which were also not quantified) showed similar results, thus lending validity to the accuracy and use of modeled buoylines. Unfortunately, due to the inherit difficulties of documenting line profiles *in situ*, profiles were only documented under the influence of 0 kts. current (slack tide) and approximately 0.5 kts. current. Figure 3 shows a full-scale, 33% float line rig at slack tide. Note that the line remains off the bottom, by forming a sinusoidal curve in the water column.

As mentioned in the methods, not all variables affecting the full-scale version of the gear in the field could be accounted for in the modeling. These variables included deployment from the vessel, changes in bottom topography and obstructions, current variation throughout the water column, tidal influences, and surface influences, such as sea state and wind. It is difficult to determine how a buoyline's profile might have been affected by lack of surface effects.

The inability to scale down line in regard to its subtleness (stiffness) was exemplified as kinks in line profiles, especially for those runs performed under low current loads (See AutoCAD profiles in Appendix C for examples). In order to model for this variable, lines would have had to be as thin as a spider web, which if possible, would have then affected drag coefficients (See *Buoyline Rigging Evaluation Report*, prepared by Centre for Sustainable Resources' engineers, included as Appendix A for more detail).

One means of quantifying a line's profile was by looking at its horizontal component (HC), or the maximum distance the line covered in the horizontal plane relative to the depth (Y axis). Comparison of HCs using the AutoCAD - derived profiles showed that scope was the greatest contributor to reducing HC in line profiles. Figure 4 shows the line profiles of one configuration (33% float line) for the three scopes tested (1.25, 1.5, 1.75) at different current loads. In addition, Figure 5, comparing the actual HC values for the above configuration, demonstrates how the reduction in scope results in a corresponding reduction in HC over various current speeds.

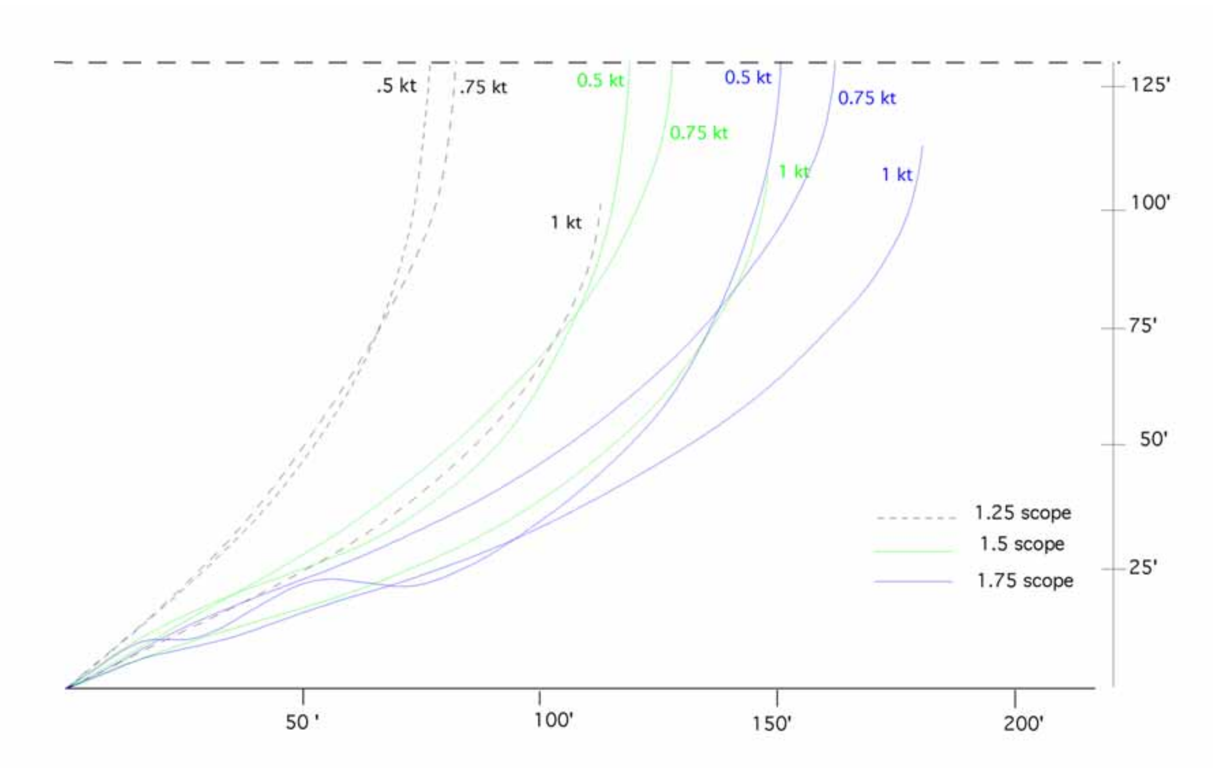

Figure 4: Comparison of scopes of 33% float line.

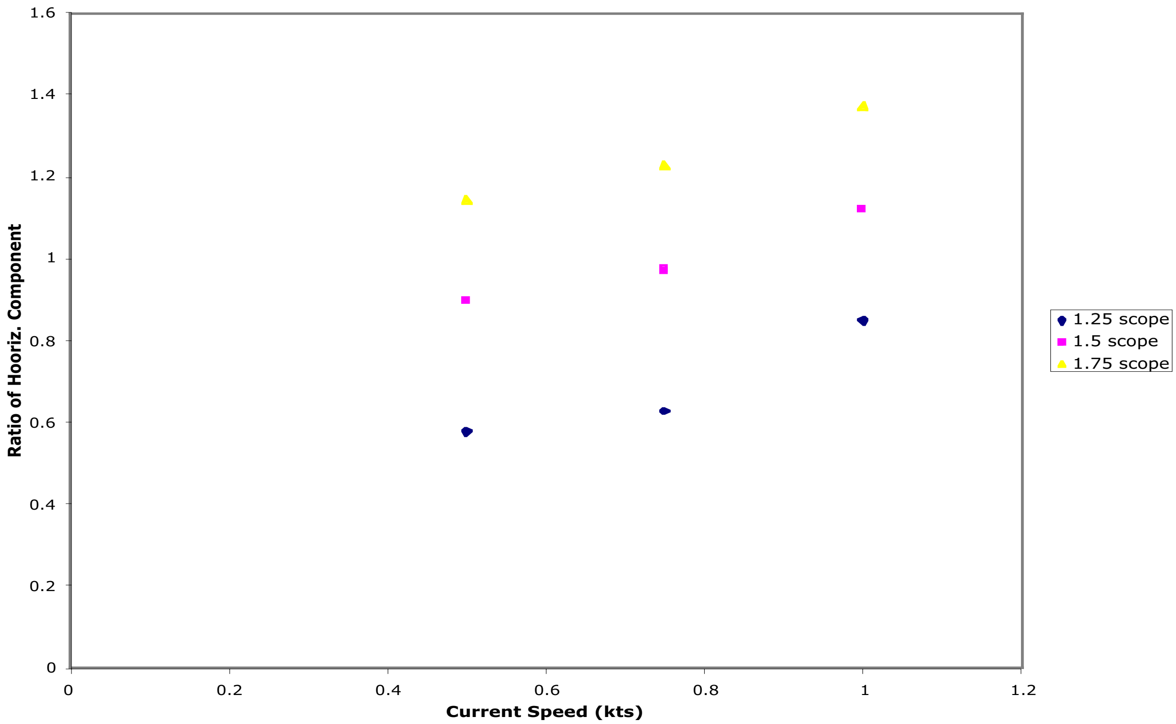

Figure 5: Comparison of HC (maximum distance in horizontal plane of line profile relative to depth) for 33% float line rig at different scopes and current speeds.

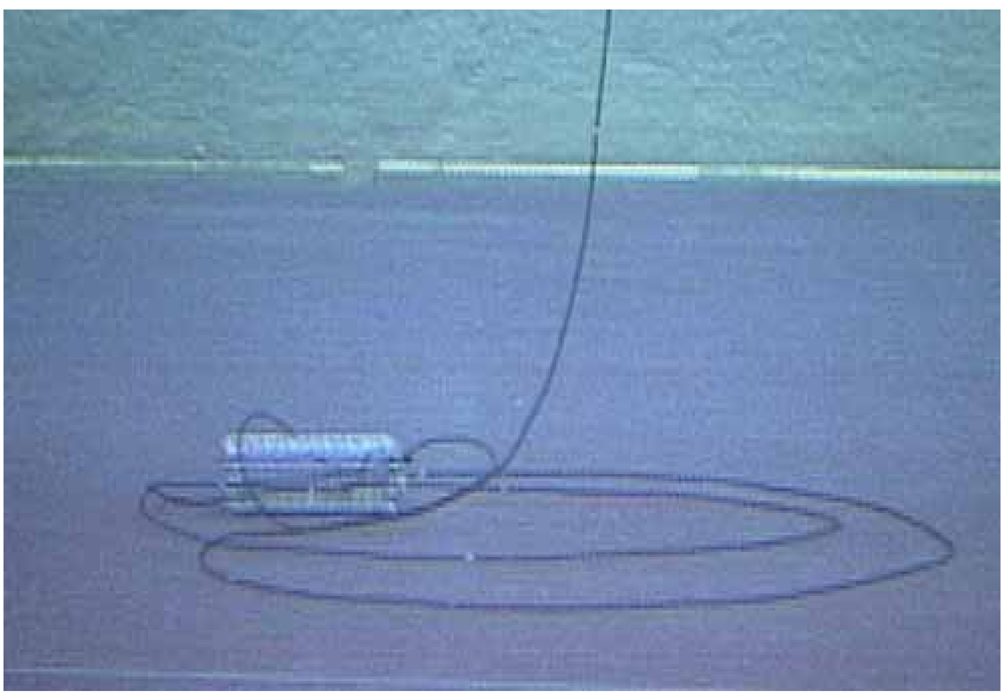

Figure 6: Image showing model with 100% sink line at 0 kts.

Another parameter noted, and in some cases quantified, was the amount of line at the surface and/or in contact with the bottom. Table 3, providing both qualitative and quantitative indications of line at the surface and on the bottom, shows not surprisingly, that for buoyline profiles lacking subsurface toggles and made up off mostly non-buoyant line there is a greater likelihood of line coming in contact with the bottom at slower current speeds. Conversely, for those configurations made up of entirely buoyant line there was a greater likelihood of line being found at the surface under similarly slow current speeds. As Figure 6 demonstrates, negative buoyant line tended to lie around the trap (the only obstruction modeled in this study), and in fact fouled on the trap on several occasions when current was applied.

Review of AutoCAD profiles and Table 3, shows that the use of subsurface toggles did keep line off the bottom at slower current speeds. However, buoyline profiles configured with subsurface toggles also exhibited loops and arcs of line in the water column and in some instances a greater HC than non-toggled line configurations. Another attribute of buoyline profiles configured with either surface or subsurface toggles is that surface buoys tended to remain at the surface under greater current loads. Of course this was also the case with the buoyline rigged with the A3 Polyball. In all three examples there exists a significant increase in buoyancy over the standard bullet buoy. In addition, these rigs representing increased buoyancy, also tended to exhibit a greater HC, especially with the increased drag once the surface buoy submerged (See Appendix C for examples).

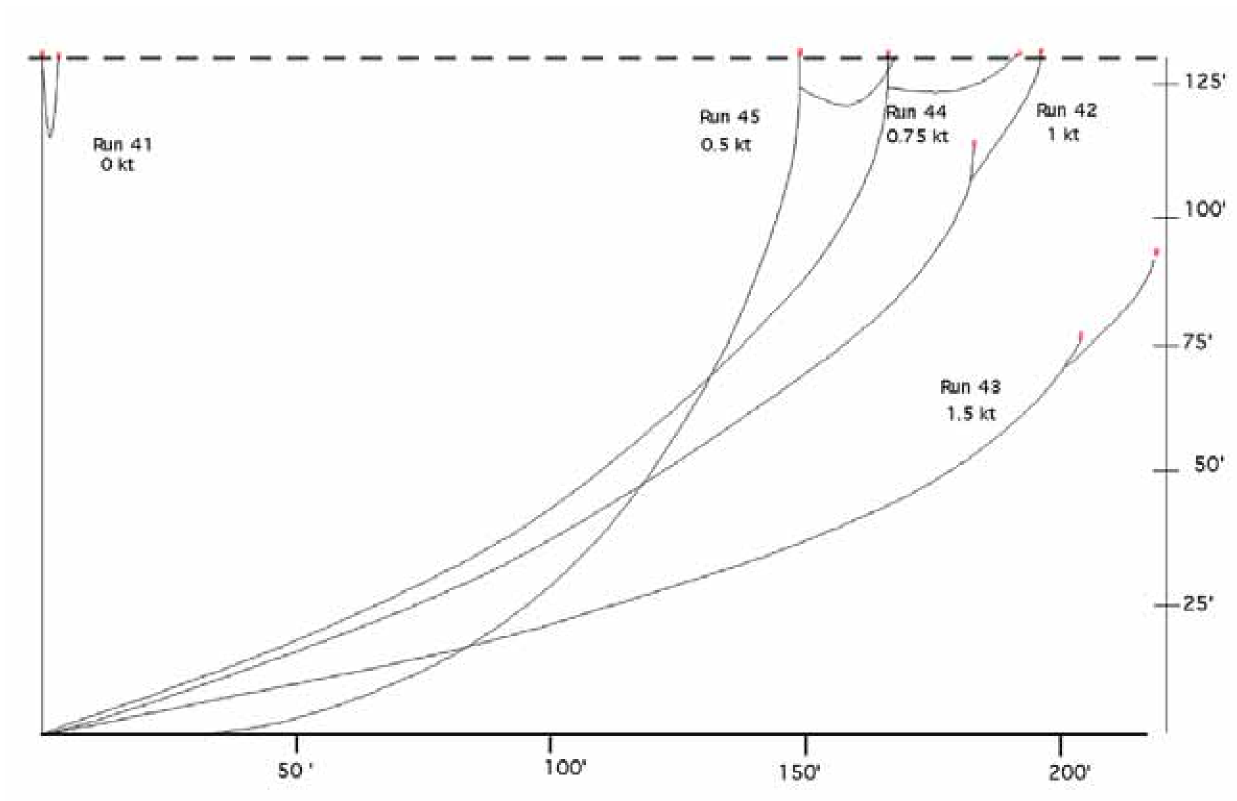

Figure 7: Comparison of AutoCAD profiles of surface toggle-rigged buoylines.

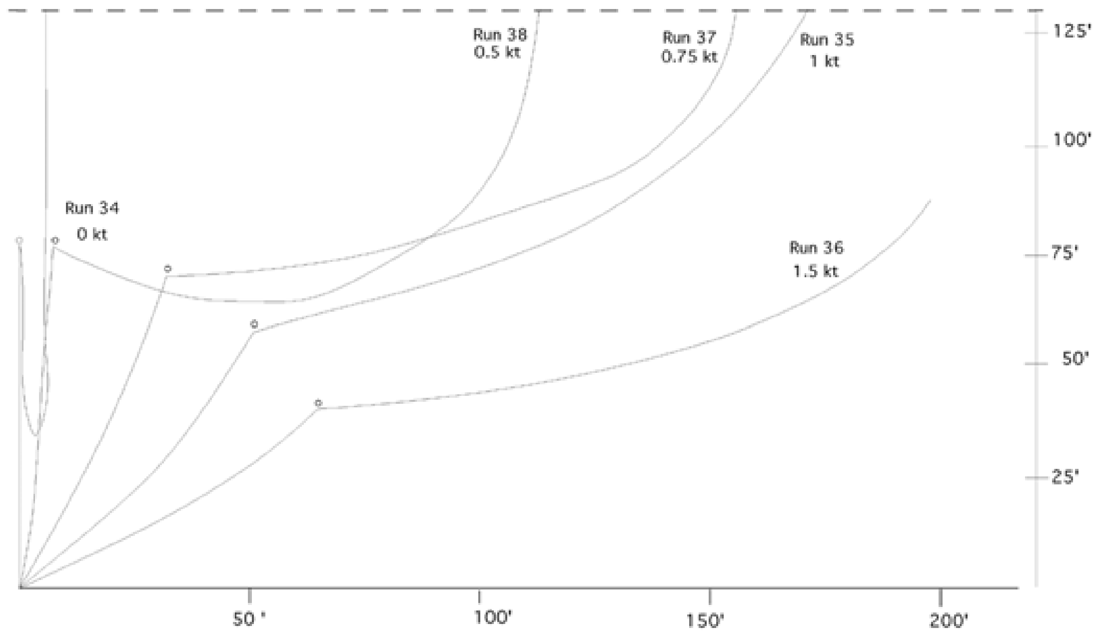

Figure 8: Comparison of AutoCAD profiles of subsurface toggle-rigged buoylines.

Modeled buoylines rigged with various amounts of float and sink line also demonstrated that the line was kept away from the surface, and other than making contact at a single point under some of the test runs, remained off the bottom under low current loads. In reducing contact at surface and bottom, while at the same time maintaining scope, the profiles of these configurations did produce loops or horizontal arcs of line in the water column at low current test runs (see Figure 9). However, as comparison of these profiles under increasing current load demonstrate (see Figure 10 and Appendix C for more examples), these loops and arcs disappear under the influence of very little current. In fact, as Figure 10 shows, at 0.5 kts the profiles of these rigs configured with both float and sink line look quite similar to those profiles of lines comprised entirely of non-buoyant line (sink and neutral buoyant).

Current data was obtained from the Gulf of Maine Ocean Observing System (GOMOOS). Surface current data obtained from the GOMOOS Massachusetts Bay buoy (42º 31.66' N/ 070º 33.99'W), located SE of Gloucester, MA in 65M (213 ft) of water, and the Western Maine buoy (43º 10.84'N/ 070º 25,67'W) located off Cape Neddick, ME in 62 M (203 ft) of water, between January and November 2003, indicated that surface currents in these southern Gulf of Maine coastal regions are generally 0.3 kts or greater 53% and 55% of the time respectively. Surface current data from the same two buoys and time frame indicate surface currents of 0.5 kts. or greater 22% and 23% of the time respectively. However, current varies throughout the water column. A detailed look at the Massachusetts Bay GOMOOS buoy shows that the average greatest hourly difference in current over the water column was 0.45 kts, and that the average difference in current between the surface and the bottom was 0.17 kts (January– November, 2003). The buoy data also indicated that bottom currents were typically less than surface currents and that the direction of current over the water column differed by as much as 90º.

It was not just the combination float and sink line configurations that had similar profiles at higher currents. Many modeled line configurations at currents approaching 0.5 kts. had similar profiles attesting that at greater currents, drag forces are more a factor than weight and buoyancy in determining a buoyline's profile.

It should be noted that the increased amount of buoyant line in the buoyline, as was the case for toggles and the A3 polyball, provided extra buoyancy. This allowed the surface buoy to remain at the surface under greater current loads.

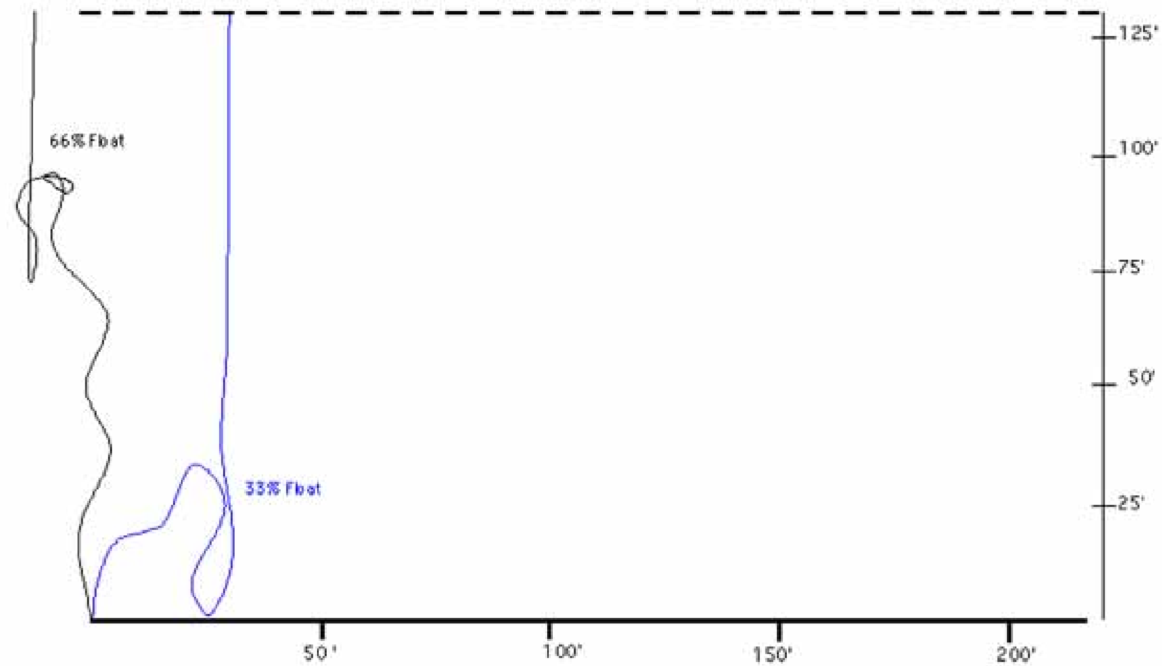

Figure 9: Comparison of 33% and 67% float line rigs at "no current".

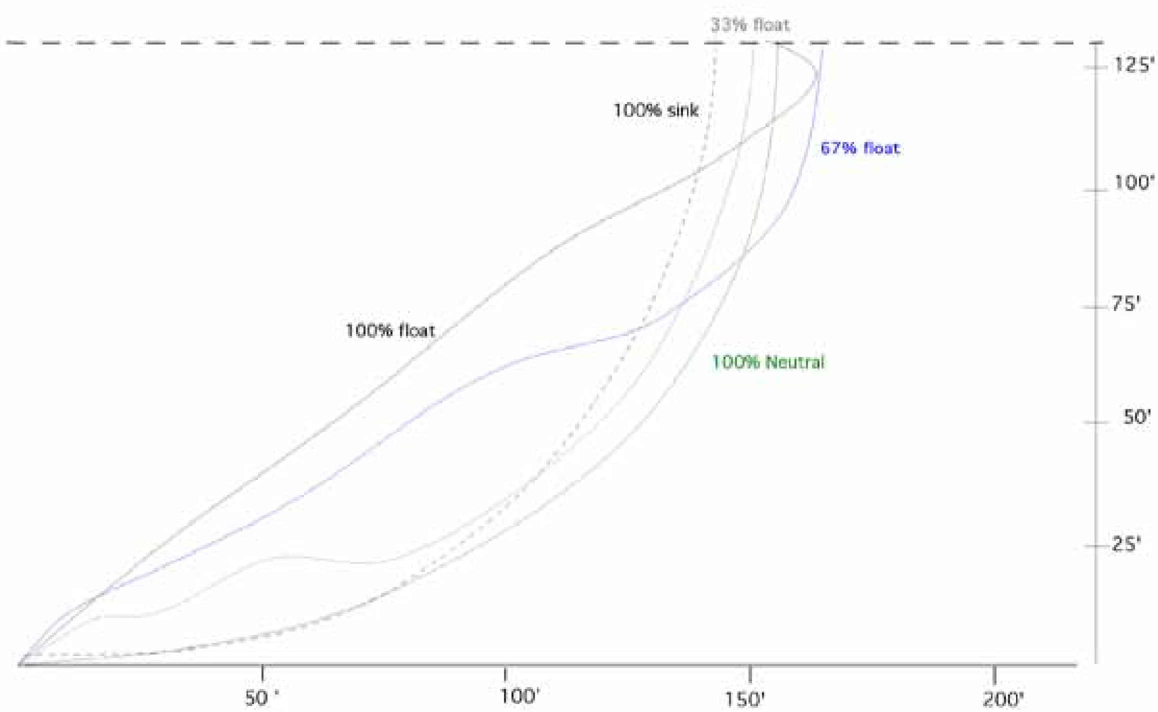

Figure 10: Comparison of differently configured buoylines at 0.5 kts of current.

Figure 11: Images of groundline model at 0 and .75 kts.

Analysis of modeled groundline profiles showed that at current speeds of 0.75 kts and greater the groundline was very close to the bottom. In fact at 1 kt, the belly of the groundline was less than 2 feet off the bottom. On the other hand, at 0 kts. (slack water) the profile of the groundline was just over 18 feet off the bottom. This is comparable to full-scale studies done in Cape Cod Bay by *MarineFisheries* during the winter of 2002 (McKiernan *et al*, 2002). In that study floating groundline height was found to average 16 feet off the bottom. Figure 11 shows the groundline models at slack water and 0.75 kts of current. Figure 12 depicts the modeled groundline profiles between the two test traps at various currents.

Inspection of bottom currents from the Massachusetts Bay GOMOOS buoy indicates that the average current on the bottom over the past year was 0.21 kts. Data suggests that bottom currents at this buoy were greater than or equal to 0.3 kts approximately 7.5% of the time, greater than or equal to 0.5 kts approximately 1.5% of the time, and greater than or equal to 1 kt. less than 1% of the time. However, there is a great deal of variation in bottom currents throughout the Gulf of Maine.

In regard to test runs of modeled neutral-buoyant line, it should be noted that the Dyneema™ twine, used to represent neutrally buoyant line, exhibited a time-dependant behavior that was not observable in either of the other two line types (floating or sinking). When subjected to pressure to remove entrapped air, the Dyneema™ twine immediately sank to the bottom. As purchased, the line initially floated and then over a period of 20-30 minutes gradually sank to the bottom of the tank as surface tension was overcome and any reserve buoyancy was lost. In the end, when given enough time, lines configured with neutral-buoyant line showed very similar profiles to that of lines configured with negative buoyant line. The only apparent difference between the neutral buoyant and sink line was that even though the neutral buoyant line eventually sank, it did have more inherent buoyancy than the 100% sink line, since its surface buoys were typically able to remain at the surface over a greater current load.

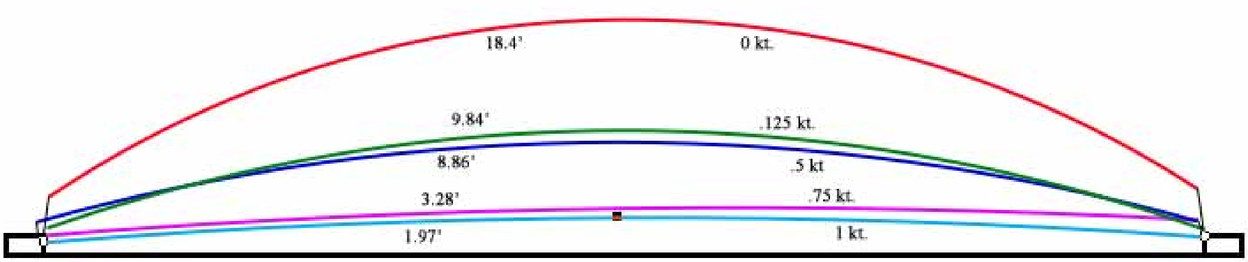

Figure 12: Comparison of modeled groundline profiles for various current speeds.

Discussion and Conclusions

Use of Scale Modeling to Understand Entanglement Threat

Scaled models have been used to test commercial fishing gear and obtain a better understanding of its operation (Ward 1992). The Massachusetts Division of Marine Fisheries, as part of their Conservation Engineering Program, has modeled mobile commercial fishing gear in order to minimize the impact on non-targeted species (Carr and Caruso, 1993; McKiernan *et al*, 1998, Pol, 2003; Pol *et al*, 2003). In a first of its kind, groundbreaking effort, this study modeled fixed-gear to elucidate the entanglement threats potentially posed by different gear configurations, and at the same time maintain practical use in the fishing industry.

The study, focusing on different buoyline and groundline configurations under the effects of different currents, used controlled comparisons at different scales to evaluate the use of modeling and then evaluate the modeling to better understand the physics of line profiles. Many variables affecting the full-scale versions in the field were accounted for in the modeling. Those that were not, and the limitations this imposed on model interpretations, are detailed in a modeling evaluation report submitted by engineers at the Centre of Sustainable Resources, and evaluated later in the discussion. After careful review, Centre of Sustainable Resources' engineers concluded that scale modeling performed in this study were for the most part representative of their full-scale counterparts.

Scope

In this study, a decrease in the scope of the buoyline was the greatest contributor to a reduced profile as indicated by the amount of line in the water column and the line's horizontal component. While reducing the scope of buoylines may reduce the threat of entanglement by reducing the amount of line that an animal can come in contact with and the overall profile, it can pose significant disadvantages to the fisherman and may contribute to entanglement threat in other ways. For instance, reduced scope may contribute to gear loss (surface buoys submerged at lower currents), the fisherman's inability to set the gear at different depths, and a more difficult (perhaps dangerous) retrieveal of gear.

In several cases the modeling of buoylines demonstrated some obvious results. For instance, during slack water and low current, the use of 100 % float line resulted in a significant amount of line at the surface, while the use of 100% sink line and so-called "neutrally buoyant" line, resulted in significant amounts of line in contact with the bottom. Line at the surface may pose an additional entanglement threat, as well as, increase the likelihood of gear loss for the fisherman. Line on the bottom, may reduce the threat of entanglement directly, but because it is more likely to chafe and foul, it may result in increased gear loss, which in itself may contribute to the entanglement threat. In addition, increase chafe shortens the lifespan of the line and results in increased investment for the fisherman.

Buoys and Toggles

The use of the larger surface buoys, along with toggles, added buoyancy, which allowed surface markers to stay at the surface over greater currents. However, the use of surface toggles also created horizontal arcs of line at the surface that may increase entanglement risk. The profile of the buoyline between trap and surface marker configured with toggles was similar to the profiles of lines configured with standard bullet buoys without toggles.

The use of subsurface toggles also added buoyancy, allowing the buoyline to stay off the bottom, and as in surface toggles, for marker buoys to remain at the surface under greater currents. However, subsurface toggles also created greater horizontal arcs midway in the water column possibly increasing the risk of entanglement. These arcs remained even for the higher currents so that in the case of buoylines rigged with subsurface toggles profiles did not mirror that of alternately rigged buoylines. Here the buoyancy of the subsurface buoy outweighed the effects of drag on the line's profile. In addition, it is likely that surface influences would have little effect on the arc of line created between the surface and subsurface buoys during slack and reduced current times.

Neutral Buoyant Line Configurations

For some tests a "neutrally buoyant" line, line at or near the specific gravity of seawater, was used. It has already been mentioned that "neutral buoyancy" is in truth more a theoretical concept than a realistic target. Attempts were made to achieve neutral buoyancy in the tank at model scale, but like its full-scale counterpart it was determined that "neutrally buoyant" line ended up being "negatively buoyant". In fact, the nomenclature of this line has been recently changed to "non-buoyant line" by *MarineFisheries* in the Code of Massachusetts Regulations (322CMR 1200). Thus, caution should be exercised when predicting the behavior of full-scale buoyline profiles configured with "neutrally-buoyant" lines using the results from this study. A more detailed discussion of the full-scale behavior of so-called neutral buoyant line can be found in the *Buoy-line Rigging Evaluation Report* found in Appendix A.

Float – Sink Buoyline Combinations

In Massachusetts coastal waters the use of float line at the bottom of the buoyline is very popular among lobstermen. A *MarineFisheries* survey conducted in 2002 indicated that 42% of Massachusetts' inshore lobstermen used a combination of float and sink line in their buoylines to keep the slack line off the bottom and thus reduce abrasion and fouling (Hoffman *et al*, 2002).

In this study, the use of varying amounts of float line at the bottom of the buoyline did indeed keep slack line off the bottom during low current situations. In addition, the greater the amount of float line used, the greater the buoyancy effect on the buoyline. However, the incorporation of float line in the buoyline also produced loops and arcs in the modeled lines' profiles, though, albeit at slack tide or low current. It is these loops and arcs that are perceived as an increased threat of entanglement. Starting in 2003, lobstermen fishing in state waters of Maine, New Hampshire, Massachusetts and Rhode Island were required to incorporate at least one option from a Lobster Take Reduction Technology List (50 CFR 229.32). The first option on this list was, "All buoylines must be composed entirely of sinking and/or neutrally-buoyant line".

For the configuration comprising 67% float line these arcs and loops were well up in the water column. This may indeed pose a greater risk of entanglement compared to the arcs and loops formed deeper in the water column by the 33% float line configuration. However the results showed that the use of 33% float line at the bottom terminus of the buoyline actually provided a similar profile to buoylines configured with 100% non-buoyant line once the scaled current load approached 0.5 kts. The comparison float line length to scope indicates that only 33% float line is required to keep a 1.5- scoped buoyline off the bottom, while approximately 43% is needed for a 1.75-scoped buoyline.

While it would be extremely difficult to obtain current values (actual or modeled) for the entire Gulf of Maine at a spatial and temporal resolution that would discern the effects of current on any given set of gear, the data from the Massachusetts Bay GOMOOS buoy, along with current data from other coastal stations may at least provide an indication of what to expect for Massachusetts coastal waters. This data, in addition to showing the variability in current along the Massachusetts coast, suggests that for many areas, currents are great enough to remove loops and arcs in float/sink combination buoylines represented by 33% float line or less, over a majority of the time. This percentage increases in areas right along the coast, and for areas such as the backside of Cape Cod, Nantucket Shoals, and Race Point at the north end of Cape Cod. Furthermore, considering the added influence of surface effects, which may also act to reduce loops and strong sinusoidal profiles in some configurations, there is most likely little additional risk of entanglement from float/sink line combination buoylines, especially in regard to the 33% (or less) bottom-rigged float line configuration at a 1.5 scope (or less), when compared to a buoyline rigged entirely of non- buoyant line.

Groundline Profile

One of the advantages of floating groundline is to keep the line off the bottom and thus reduce line fouling and abrasion. It has long been suggested that current affects the profile of the groundline such that with greater current the groundline eventually lies over and comes in contact with the bottom. Many previous studies have looked at the arcs that floating groundline form between traps, but ignore the dynamic nature of these arcs by documenting them at a single moment in time, typically in low current situations (by area or time). This study looked at the dynamic nature of floating groundlines, though admittedly not at full-scale. While this study did not provide a current load great enough to cause the groundline to lie on the bottom, it did show that at currents approaching 1 kt, the groundline profile modeled had gone from 18 feet to less than 2 feet off the bottom. Interestingly, the 18-foot maximum height and overall shape of the profile found in the modeling were comparable to similarly rigged full-scale groundlines studied in Cape Cod Bay (McKiernan *et al*, 2002). In that study maximum groundline heights averaged 16 feet off the bottom.

Current data from the Massachusetts Bay GOMOOS buoy and other surface stations indicate that currents exist to lower groundline profiles, but that for many areas the amount of time that the groundline is subjected to these stronger currents is rather limited. The exceptions perhaps would be those areas that experience higher currents, such as Nantucket Shoals, and extreme Down East Maine. In these areas modeling suggests that groundlines, if set across current, would be lowered right to the substrate for a significant amount of time. However, in high current areas, gear is typically set along the current, not across it. It has yet to be determined how this orientation would affect the groundline's profile.

No one argues that having groundlines floating in the water column increases the possibility of entanglement, but how low must it be before the threat is diminished? Certain whale behavior experts have suggested that groundline heights would have to be less than 2 feet in order to reduce the threat of mouth entanglements in rights whales feeding along the bottom (Kraus and Mayo, 2003 Take Reduction Team meeting). Past studies have indicated near-bottom usage by right whales in the Bay of Fundy and in Cape Cod Bay (Baumgartner and Mate, 2003; Wiley and Goodyear, 1998). Do right whales dive to the bottom in other parts of the Gulf of Maine and at other times? This we do not know.

Many fishermen already use non-buoyant groundlines in their trawls (NMFS; Hoffman *et al*, 2002; Lyman, 2004). However, not all bottom types and environments may be favorable to fishing non-buoyant groundlines. In some of these other areas there may be a lower probability of bottom feeding right whales or the existence of strong currents lowering floating groundline profiles. Both may equate to a reduced threat of entanglement. With the possible exception of these aforeto-mentioned areas, steps should be taken to lower groundline profiles where ever and when ever possible, or in other words, as broadly as possible, as to reduce the entanglement threat to right whales and other species.

Buoyline Profile

While the threat posed by floating groundlines is quite evident, it is not so clear what threat the buoyline profile actually poses other than the fact that it represents line in the water column. Is the vertical component or the horizontal component of the profile the greater threat? What is worse - a loop of line, or a sinusoidal curve? What part of the profile - nearer to the surface or nearer to the bottom – is more of a threat? In part, the answer(s) may depend on what part of the water column the animal is using and at what frequency, the animal's orientation in the water column, what it is doing when it comes in contact with the gear (i.e. feeding), and how it behaves after contact. Many of these questions have yet to be answered. Telemetry studies have provided information on how deep whales go in the water column and their orientation (Baumgartner and Mate 2003; Goodyear, 1993; Mate *et al*, 1992; Mate *et al*, 1997; Wiley and Goodyear, 1998). However, the data is sparse. Documentation and assessment of entangled whales has provided some information on how and where on the animal the entanglement may occur (Clapham, 2001; Johnson *et al*, in press; Morin *et al* - CCS disentanglement Database, 2004; Whittingham *et al*, 2003). Direct observations of entanglements, though few, suggest that animals may react violently on initial contact with the gear, thus increasing the risk that the contact will result in an entanglement and the parting of the gear (Weinrich personal communication; Lyman, personal observation).

Modeling Robustness

While not all variables affecting the full-scale versions in the field were accounted for in the modeling, many were. Deployment from a vessel, changes in bottom topography, current variation throughout the water column, tidal influences, and surface influences, were the few variables that were not accounted for in the modeling.

While deployment of gear may influence groundline profiles (Carr, 1998), it should have little influence on buoyline profiles and modeling comparisons. However, bottom topography and obstructions, not considered in the modeled test runs, along with a uniform current across the water column, would almost certainly provide a different current load than experienced in the field. In the field, and as an example, different water masses and/or changes in bottom topography may affect current load over the vertical dimension. GOMOOS buoys provide data illustrating the difference between surface and bottom currents at given locations, that in themselves are also quite variable. In areas where there exist great changes in bottom topography, such as banks and ledges, there would be a greater influence and lack of accountability in the modeling; while, for many inshore areas off the coast of Massachusetts, like Cape Cod Bay, that are represented by a rather uniform bottom, the influence of bottom topography and obstructions may be minimal, and thus the modeling more accurate.

In addition, for those tests done at low current speed in which current was provided by moving the models through the water column by use of the moving ground-plane, there were no bottom drag effects at all. Under these circumstances flow would have been higher along the bottom. This was exemplified by the fact that non-buoyant line configurations under a current load generated by moving the model through the water column, tended to have less line laying on the bottom, than those same configurations under the same current load as generated by the impellers. This is a direct result of less frictional forces along the bottom and thus greater flow.

In regard to tidal difference, to a limited degree, this was accounted for by the modeling of different scales, and scopes in the buoylines. Though not accounted for in the modeling, surface influences on the profile of the buoyline are probably minimal. It has been shown that wave action primarily affects buoys and attached gear in the vertical plane rather than the horizontal plane. In addition, wind effects on the buoy(s) modeled here, compared to the current effects on the submerged portion of the gear would be much less in all cases other than slack water. At slack water or periods of low current, windage on the surface system may act on the buoyline and cause it to stretch out more along the horizontal plane.

Summary

In summary, this modeling exercise demonstrated that both buoyline and groundline profiles are very dynamic in nature. Their profiles are affected by the way they are rigged and the environment they are set in. The question of how they may affect the risk of entanglement, and more importantly, how that risk can be decreased, is a challenging one. Solutions towards reducing the threat may work for one configuration, in one environment and at one particular time, but may not work for another configuration, subjected to other environmental influences at another time. The answer may be to either work with the existing complexity or simplify where one can. In many ways modeling does both. By scaling the gear down and observing it in a controlled environment, one is able to simplify and at the same time address the complexities of many different configurations under different influences. While comparisons can be made using full-scale rigs, as was done in this study, it has been difficult to do so quantitatively because of the inherent challenges of quantifying buoyline and groundline profiles in the field. Some effort has been put forth through the use of ROVs and SCUBA divers attempting to document the profiles, but again, these have remained for the most part qualitative. In addition, such techniques do not account for the dynamic nature of line profiles over time.

Scale models of fixed-fishing gear were used here to compare, quantify and investigate buoyline and groundline profiles to assess the entanglement threat they may pose. Scaled-models were configured with a variety of line types, surface and subsurface buoys, scopes, and were subject to scaled-currents. In addition to showing the dynamic nature of line in the water column, the results showed that that the amount of scope in the buoyline was the most significant variable looked at in changing the buoyline profile, namely its horizontal component and the amount of line available for the animal to come in contact with. Furthermore, while the use of float line at the bottom 1/3 terminus of the buoyline exhibited loops and arcs at lower currents (<0.5 kts), it otherwise appeared similar in profile to that of buoyline rigged entirely of non-buoyant line. These finding were backed up by observations made on full-scale field-tests comparing the same configurations. Thus, replacing the bottom 1/3 of an all sink buoyline with floating line appears to not change the buoyline profile appreciably in those areas with moderate current. The value of these findings are that the greatest possible reduction of scope may be the most significant variable reducing a buoyline's profile and thus entanglement threat; and that the use of float line at the bottom of the buoyline may not pose an additional risk of entanglement and at the same time provide advantages to the fisherman by keeping line off the bottom where it may foul and chafe.

While modeling may help answer these questions, there is still need to look at full-scale rigs in the field. However, to date, full-scale field studies have relied on SCUBA and ROVs. Both of which document line profiles as snapshots in time and thus do not account for the dynamic nature of line profiles. There needs to be a better way to quantify groundline and buoyline profiles over time, and one possibility is the use of mini-loggers, hermetically, sealed archival depth sensors that record depth at a user-defined time interval. *MarineFisheries* has begun deploying mini-loggers on fishing gear to document the overall profiles of both groundlines and buoylines *in situ* and over time.

Acknowledgements

Thanks to NOAA Fisheries for financial support towards this research. In addition, much of the study was carried out in collaboration with John Kenney, Glenn Salvador, and John Higgins of the NMFS Northeast Region Protected Resource Gear Research Team.

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Appendix A

Buoyline Rigging Evaluation Report

Submitted to Massachusetts Division of Marine Fisheries

by

Centre for Substainable Resources
Marine Institute
Memorial University
St. Johns, Newfoundland
Canada

Buoy-Line Rigging Evaluation Rope type, Floats and Scope

1.0 Introduction

Using scaled models is an accepted way to support the development of different marine systems, and to investigate potential problems in operation. The design and rigging of mooring tackle is one such area. Of particular interest for this project was the quasi-static condition, i.e. shape in the water column, of different rigging scenarios for lobster-pot buoy–lines. The experimental (rigging) variables were;

a) Line type (sinking/floating/neutral) and proportions of each
b) Buoy type and arrangement (single/dual floats, surface/sub-surface configurations)
c) Line scope (ratio of line length/water depth).

The ‘environmental’ variables were limited to current speed only. No effort was made in these tests to consider explicitly any effect (on the mooring system) of wind or waves

The client group for these tests was the State of Massachusetts (MA), with observers from the National Oceanic and Atmospheric Administration (NOAA) present to witness the tests and help focus the direction of the individual sets of experiments.

A total of 122 individual experiments covering 15 different rigging designs were tested over a range of current speeds from zero to approximately 1 to 1.5 knots full scale for the majority of tests, to a maximum of about 3 knots for the larger float.

Video records were made of each model at each (current) speed, including where possible the transition from speed to speed. The resulting shape was drawn in AutoCad with a splined curve fit through the individual data points, and ‘referenced’ to the model in cases where the automatically computed spline-shape deviated from the physical reality in the tank. Locations of mid-water arches and straight-line distances (pot to buoy) were computed/identified from these representations. These drawings form the basis of the quantitative data for this project and are include with this report as a non-editable file on CD-ROM.’

2.0 Models and Experimental Set-up

A geometric scale, based on Froude modelling laws, of 1:10 was used for these tests. This approach was taken because;

a) Working from a typical full-scale pot-size and the range of water-depths in the area of interest, it provided a satisfactory level of visual realism of the tests without compromising the technical/ practical considerations. Figure 1 shows a 1:10 model of a pot with mooring line and buoys attached.

b) The dominant forces to be considered in the full-scale scenario were primarily those related to the balance between gravitational force and buoyancy force. The scale error introduced by not accurately modelling the current-induced viscous drag on the mooring lines and floats (which would require matching the full-scale Reynolds' number for the line) was considered acceptable. Figure 2 shows the different buoy-types used in this study, models were based on typical full-scale components used in the MA pot fishery.

In order to avoid disturbing the pots between consecutive runs, and so maintain a common (spatial) base point, the models of the pots were increased to an unrealistic weight (approx 120 kg full scale). Pot/bottom interaction could NOT be examined by these tests, so by 'fixing' the pot in space this variable was removed from the study.

There were two separate checks on the effect of scale; one using a 1:5 scale model (to check arch-shape), and one using a full-scale buoy/rope to check on the likely value of current speed on 'submergence; of the buoy. The results of these efforts are discussed in Section 4.3.

Table 1 shows the target full-scale values and model-scale equivalents as used for this program.

The experimental set up and procedure for this work was (nominally) as follows;

a) The model mooring lines were prepared as indicated in Table 1. To remove air-entrapment (in the lines) as a test variable, all model lines were subjected to a pressure of 1500psi for a minimum of 30 minutes prior to testing. Note that the final test set for the'Neutrally Buoyant' lines did NOT follow this procedure'– see Section 4.4 for discussion on 'Neutral Buoyancy'. For all other line types, after pressurizing, and between tests, the models were stored immersed in water.

b) The pot was''set' at a point in the tank that offered good visibility from the Viewing Gallery over the entire speed range. This was nominally located at mid-tank-length and about 6 meters away from the observation windows in the Gallery. Because of time constraints, for certain groups of runs there were 2 or more line configurations in the tank simultaneously.

c) The'static' condition of the line at zero current was defined using the Gallery x-z camera to digitise node/inflection points and then using that data to create a spline curve in AutoCAD. This formed the baseline condition. In cases where the automatically generated spline did not show good agreement with the model, additional 'control' points were added. A sample plot of the data, comparing line shapes for different speeds can be seen in Figure 3.

d) For each current speed tested the buoy line was allowed to reach an equilibrium condition, and then step (c) was repeated. For speeds greater than 0.25 knots the tank impellers were used to generate the required current. At speeds of 0.25 knots and less using the impeller proved impractical/inconsistent. For these slower speed runs the moving ground-plane in the tank was used to create a 'current' relative to the pot. Geometry measurements of the tackle were not possible for these slower speed runs.

Tests were also conducted using multiple pots arranged orthogonal across the flow (and connected by ground-lines and gangions). For these tests the buoy lines (pot to buoy) were 100% 'sinking' (nylon) and the ground lines and gangions were 100% floating (polypropylene). These tests were primarily qualitative in nature and were included mostly to observe the behaviour of the ground-line under a current load and the likelihood of bottom 'entanglement' as a result of tide reversals.

3.0 Critical Measurements

The AutoCAD files represent the definitive source for geometry measurements and condition comparisons for this work. However the Run Log in Table 2 does include selected critical values of distance, speed etc..

4.0 Discussion of Results

The following sections address those areas of the model work that could be expected to have some effect on extrapolation of the data to full scale. Aside from measurement (equipment) accuracy, these are predominantly scale effects.

4.1 Buoyancy and Displacement

The significant buoyant forces in this work were limited to those represented by the various lines and by the different buoy shapes. The various model lines were selected based on the values of specific gravity for the line material, as compared to the fresh water in the tank (s.g.=1.0). The full-scale line of course would be immersed in sea-water with a specific gravity of about 1.025, thus the model lines appear to be 'lighter' than what would be expected from a straight (linear) scale-conversion based on diameter.

The float models were typically fabricated from closed-cell foam, with dimensions based on commercially available units as indicated in Figure 2 (client-supplied image(s)). From normal machine-shop practice, but given the nature of the material, the dimensional accuracy of the models could be expected to be about 0.25 mm on diameter, or approximately +/- 2.5 mm on full-scale diameter. For the 'toggle' type buoy, this level of accuracy on diameter corresponds to a potential error in buoyancy of about 3.5 % - 4 %.

The spherical trawl buoy (trawl 'can') was modelled by a rigid plastic sphere 22.7mm in diameter and pierced with a central rope-hole. This model represented a full-scale diameter of 8.9", very closely representing an industry-standard nine-inch float.

Exact ratios of weight/buoyancy were impractical given the small size of many of the models, as well as the possible variation on commercially available marker buoys. However, for the larger A3 float the reserve buoyancy of the model was measured at 59.4 grams in tank water, which scales to 60.9Kgf or 134 pounds in saltwater. The published value of reserve buoyancy for this float type ("Polyform" from Saeplast – Ref [3]) is 143 pounds. While the model thus apparently represents a 6% error in reserve buoyancy, the actual amount of reserve buoyancy in an inflatable float varies with internal air pressure – and air-pressure in marker buoys is NOT carefully controlled in actual practice.

4.2 Line Stiffness

Using Froude Scaling, the ratio of the bending stiffness (E*I) between model and full-scale varies with the scale factor raised to the fifth power (i.e. a^5). In this case, with 'full-scale' material being used for the model lines, then strictly speaking the lines themselves were much too stiff to represent a true hydro-elastic model. This error is mostly visibly manifested in the tests with the polypropylene (floating) line, wherein the line revealed localized 'kinks' and short 'straight-line' segments as a result of this excessive stiffness. While the global shapes of the line(s) are believable, localized distortion should be ignored. This phenomenon was much less noticeable for the 'softer' nylon twine.

4.3 Scale Checks

Two separate checks were conducted, as part of this work, to establish a 'comfort level' for the modelling realism.

1) a separate model at a scale of 1:5 was constructed and tested for one line/buoy combination.

2) A full-scale buoy/rope combination was installed in the tank and the flow speed adjusted until the buoy submerged. A 1:10 model of this scenario was then created and the value of speed at buoy submergence noted.

For all of these conditions, the value of current speed required for buoy submergence differed only by a few tenths of a knot. Given the lack of wave action and windage effects, this level of agreement was considered quite good and entirely adequate for the purposes of this work.

4.4 Neutral Buoyancy

For some tests a 'neutrally buoyant' line was required, as line of this type is available to industry. Attempts were made to achieve neutral buoyancy in the tank at model scale, but these efforts had limited success and tests containing this line would perhaps be better referred to as 'reduced buoyancy' tests.

Perfect 'neutral buoyancy' is in truth more a theoretical concept than a realistic target, and thus the sale of a 'neutrally buoyant' rope is more a marketing ploy then a reality. Every line type is neutrally buoyant in the correct fluid, but (fluid) density varies with salinity and with temperature, and thus a 'perfectly neutral' line can become one that will either float (positive buoyancy) or sink (negative buoyancy). Also, in practice, the effective specific gravity of the line itsel changes with air-entrapment (see notes Runs# 66 – 80) as well as with any level of the bio fouling which can be expected in the field. Based solely on the ratio of specific gravities (rope material to fluid), full-scale neutrally buoyant rope should always sink in ocean water, and the model scale equivalent should always float (in the tank). A discussion of full-scale behaviour is beyond the scope of this report, but it should be noted that the Dyneema twine used to represent a neutrally buoyant mooring line exhibited a time-dependant behaviour that was not observable in either of the other two line types. When subjected to pressure to remove entrapped air, the Dyneema twine immediately sank to the bottom. As purchased, the line initially floated and then over a period of 20-30 minutes gradually sank to the bottom of the tank as surface tension was overcome and any reserve buoyancy was lost. A contribution to the practical knowledge here is just how easy it is to change, even under 'best laboratory' conditions, a line that is nominally 'neutrally buoyant' into one that has a definite 'bias'. Caution should thus be taken when predicting the behaviour of full-scale moorings based on the 'neutrally-buoyant' properties of the lines.

References

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[2] Personal Communication (e-mail) Kenney/Harris 06/03/03 re: typical buoy types.

[3] Saeplast Website http://www.saeplast.com/servlet/Saeplast/getProduct?productid=A-3&segmentid=C accessed 05/05/03.

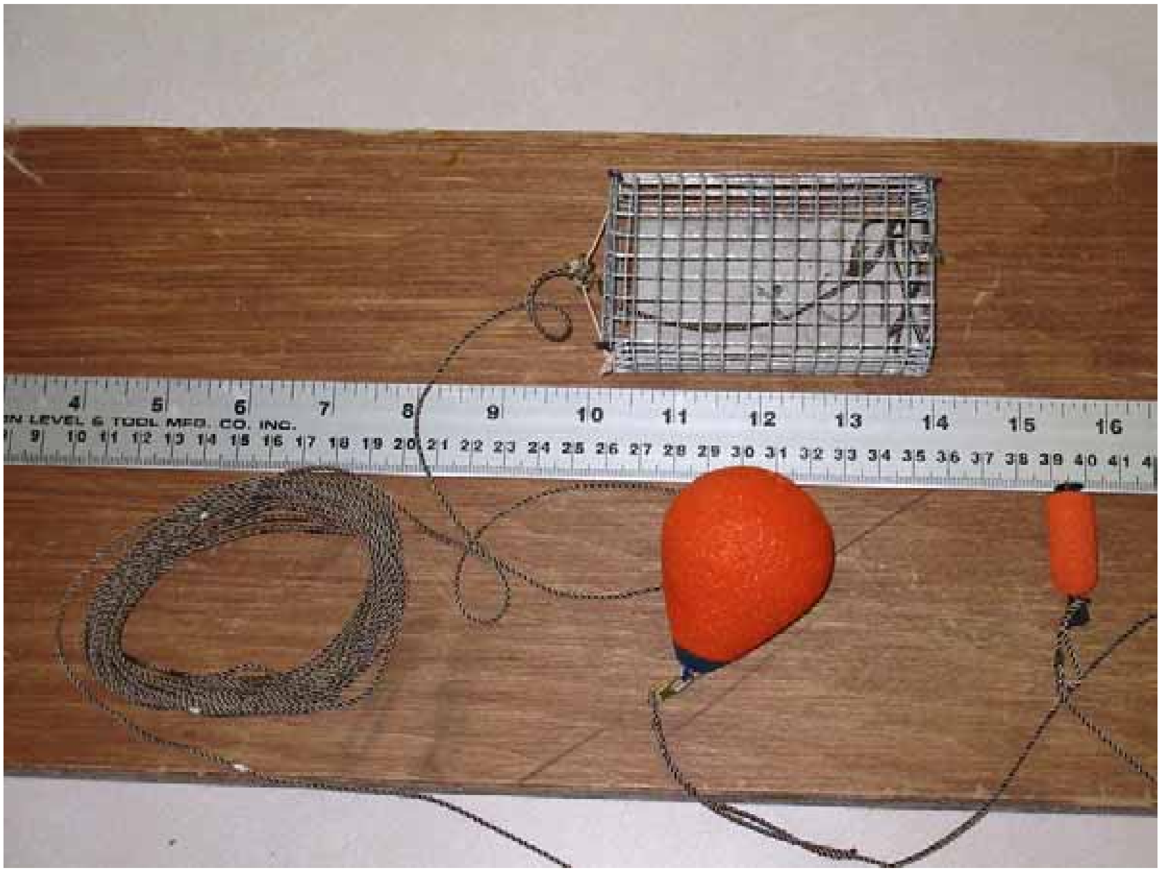


Figure 1 – 1:10 Test Model with Line and Typical Float(s)

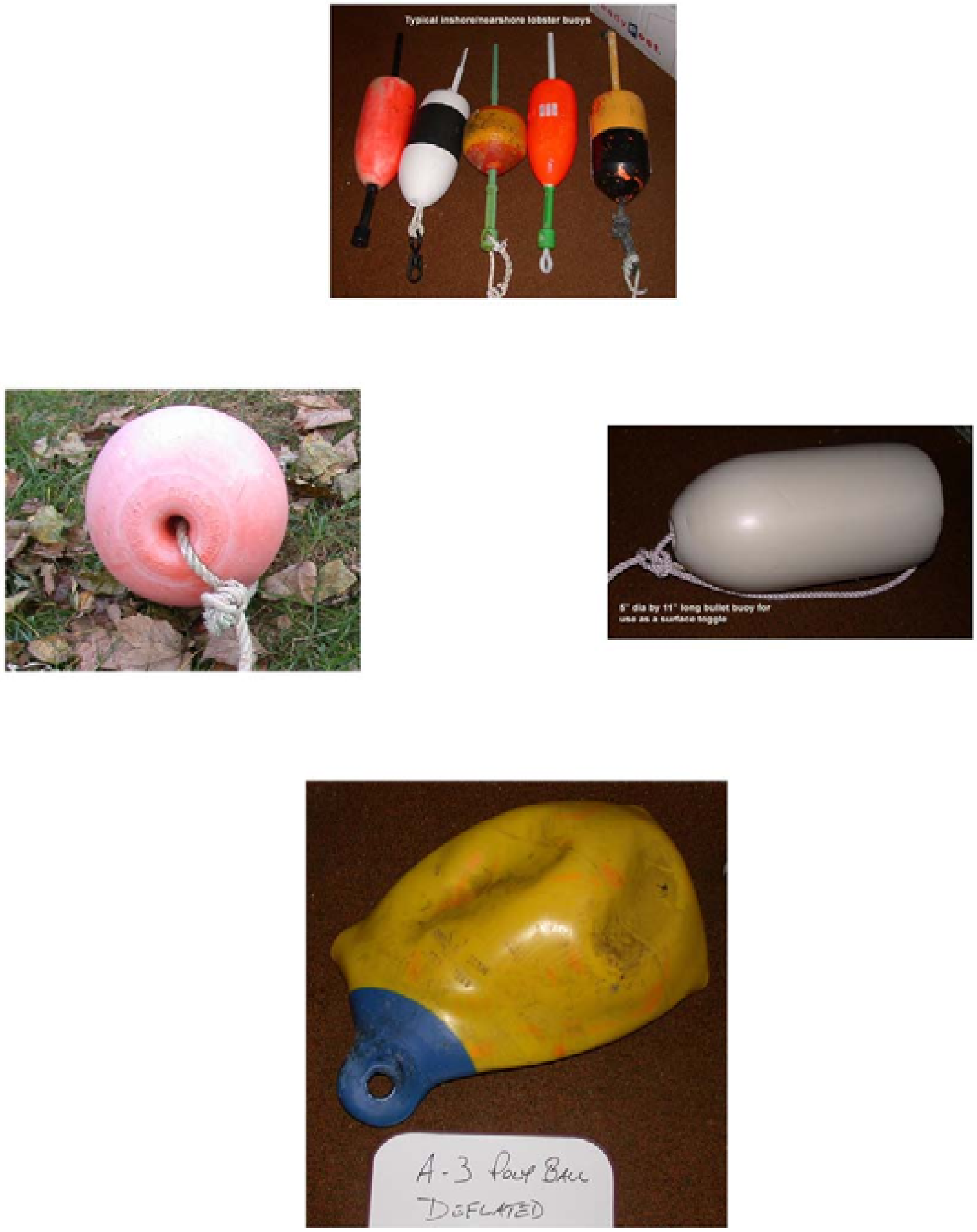


Figure 2– Typical Full-Scale Buoys (Client Supplied Images)

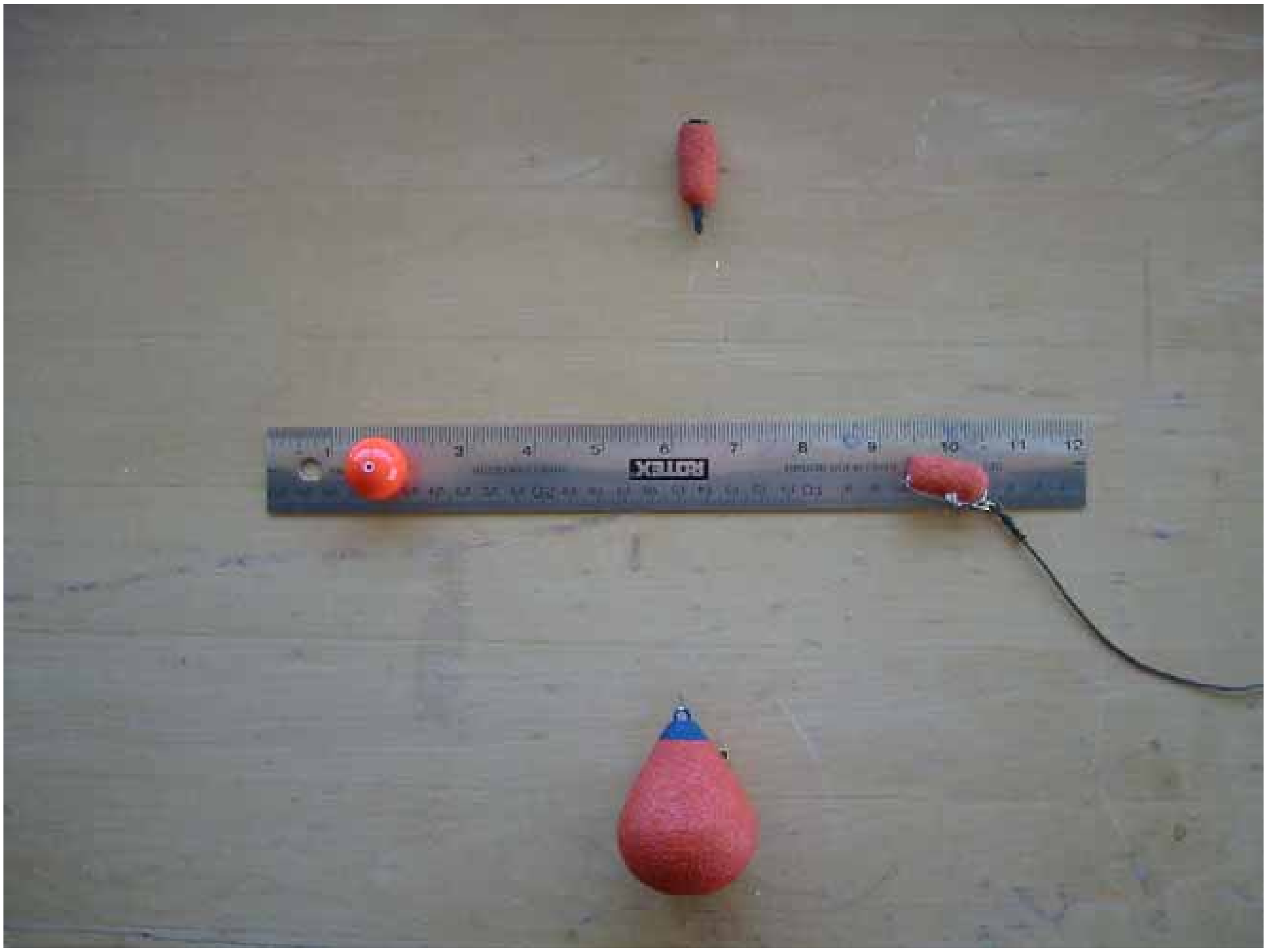


Figure 3 –Buoy Models Used in These Tests

			Full-Scale Target values					Model-Scale Values as Tested				
Config.	% floating	% sinking	water depth (m)	rope ratio	total rope length (m)	floating length (m)	sinking length (m)	water depth (m)	rope ratio	total rope length (m)	floating length (m)	sinking length (m)
1	0	100	40	1.75	70	0.0	70.0	4	1.75	7	0.000	4.900
2	10	90	40	1.75	70	7.0	63.0	4	1.75	7	0.490	4.410
3	33	67	40	1.75	70	23.1	46.9	4	1.75	7	1.617	3.283
4	67	33	40	1.75	70	46.9	23.1	4	1.75	7	3.283	1.617
5	100	0	40	1.75	70	70.0	0.0	4	1.75	7	4.900	0.000

	Full-Scale Target values (s.g. SW = 1.025)					Model-Scale Values as Tested (s.g. FW=1.00)					
Rope Type	Diameter [in]	Diameter [mm]	Rope Const.	Specific Gravity	Effective Ratio	Diameter and Construction at 1:10		Diameter and Construction at 1:5		Specific Gravity	Effective Ratio
Floating (Polypropylene)	0.4375	11.1	3-strand	0.91	0.89	1.25 mm	braid	2.3 mm	3-strand	0.91	0.91
Sinking (Nylon)	0.4375	11.1	3-strand	1.18	1.15	1.25 mm	3-strand	2.6 mm	3-strand	1.17	1.17
Neutral (Dyneema)	0.375	9.5	3-strand	1.08	1.05	1.25 mm	braid	N/A	N/A	0.97	0.97

Notes:

1 .Fullscale 'sinking' line is 60% Polyester (s.g.=1.36) and 40% Polypropylene (s.g.=0.91) - average Specific Gravity =1.18

2. Commercial available 'Neutral' line has values of s.g. of 1.06 to 1.09 - Above Table uses 'mean' value of Specific Gravity

Table 1 - Target and Achieved Values for Model Components

Appendix B: Full-scale Images of Buoyline

Image 1: 7/16" 3-strand buoyline configured
with 33% float line at a 1.75 scope.

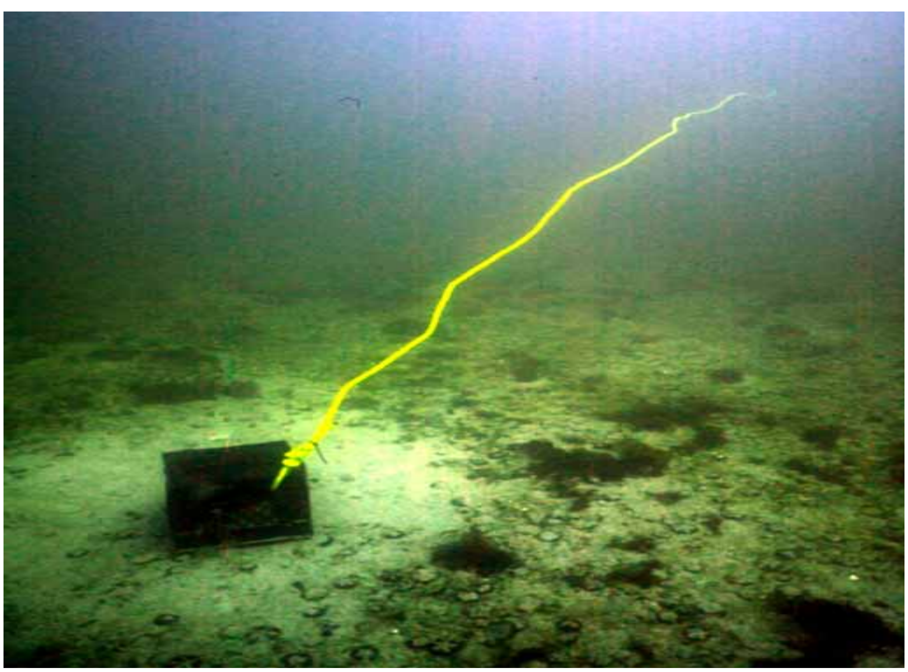


Image 2: Full-scale image showing profile of 1.75 scoped buoyline configured with
1/3 float line arcing off seafloor and away from the dummy trap.

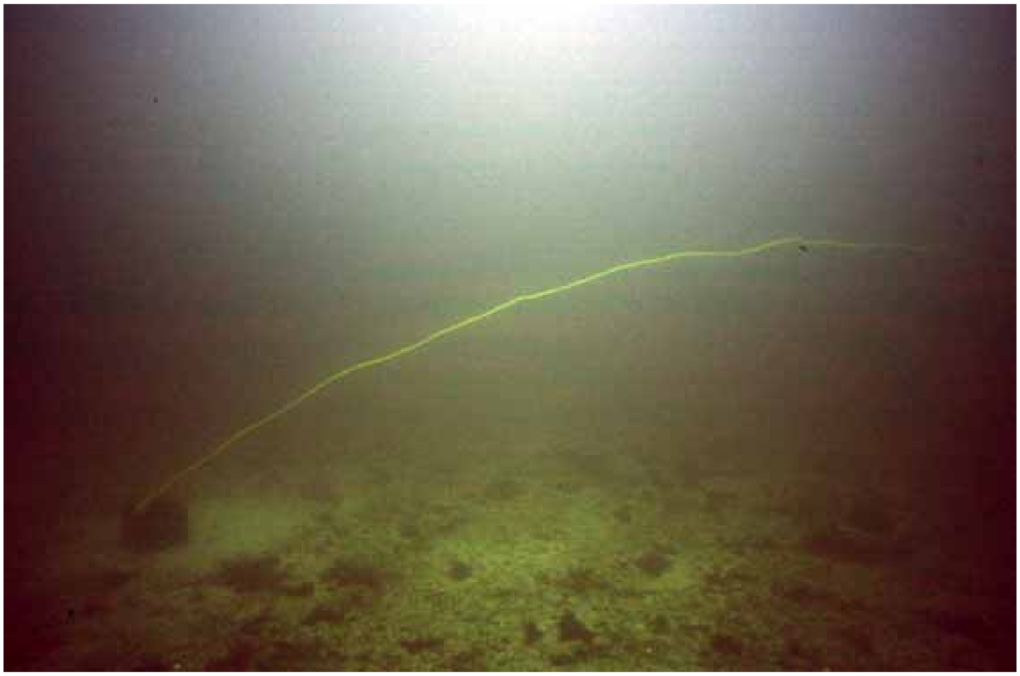


Image 3: Full-scale image showing profile of 1.75 scoped, 7/16" float line configured at bottom terminus of buoyline at slack current.

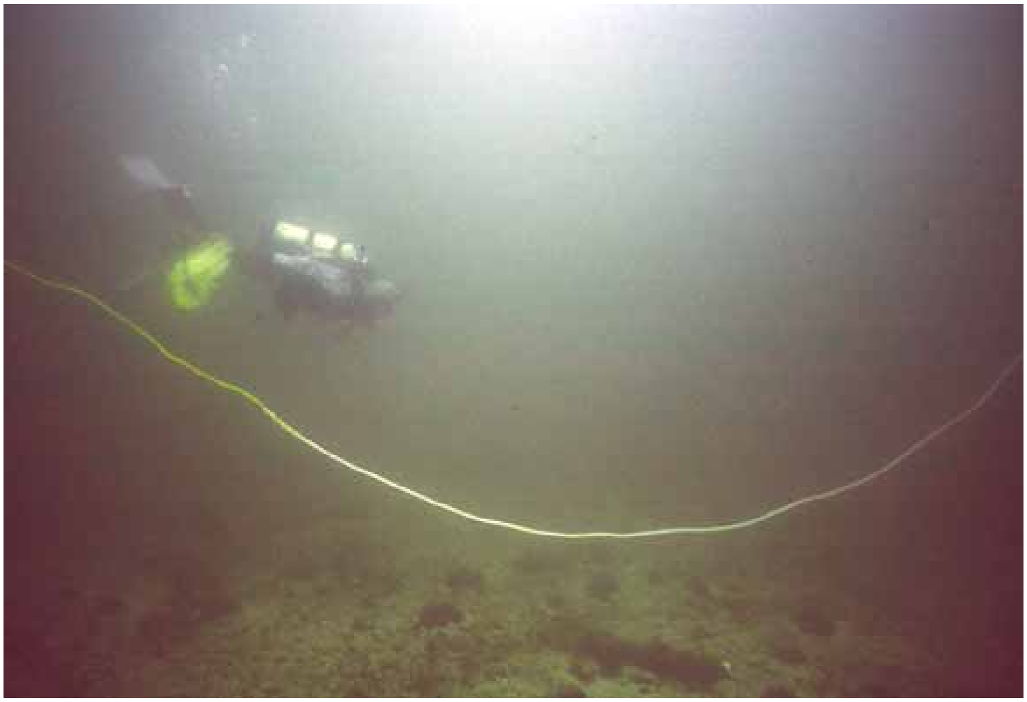


Image 4: Full-scale image showing profile of 1.75 scoped, buoyline rigged with 1/3 float line at point of transition between float and sink line at time of slack tide. Note that profile remains off bottom.

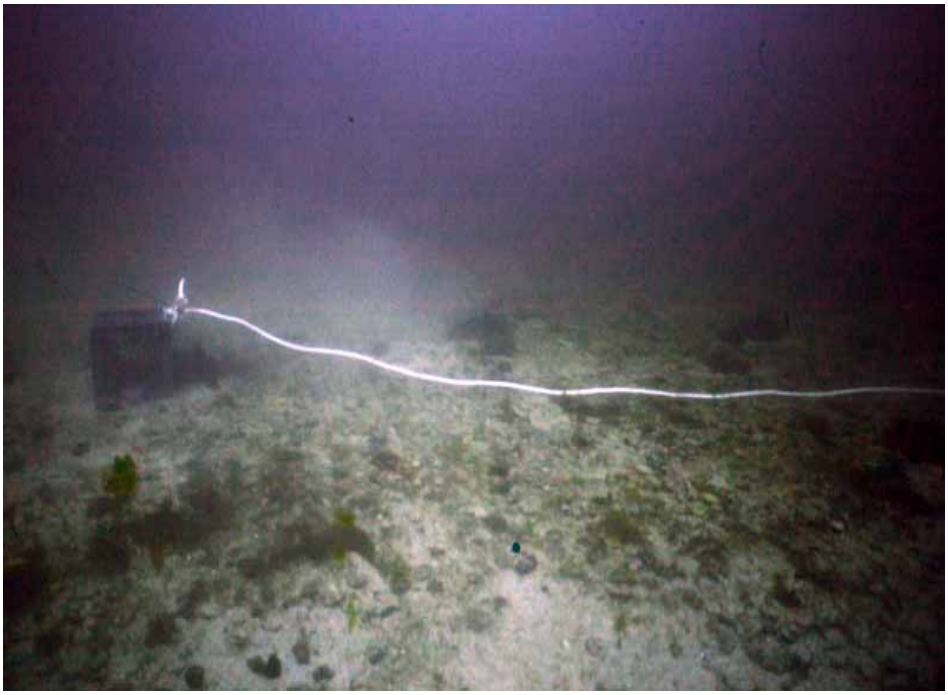
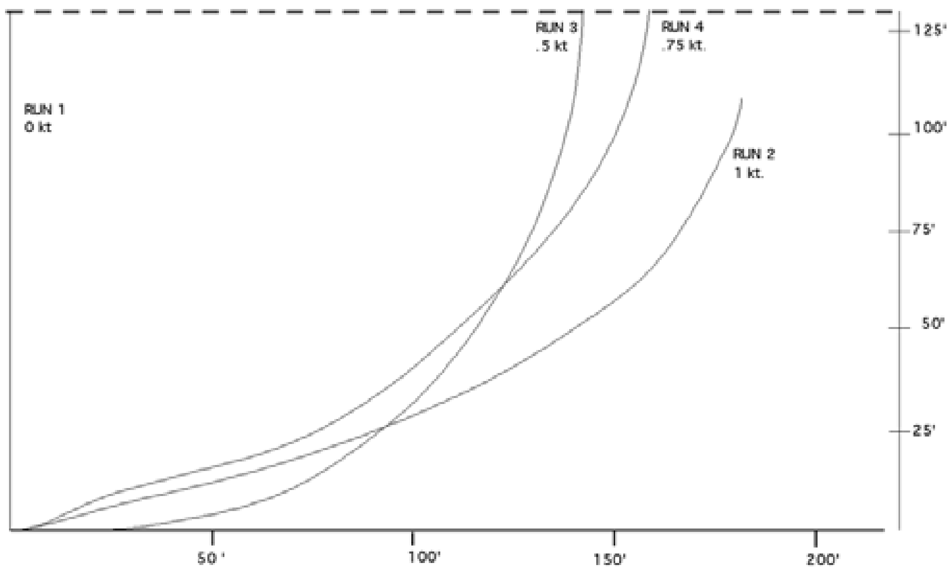


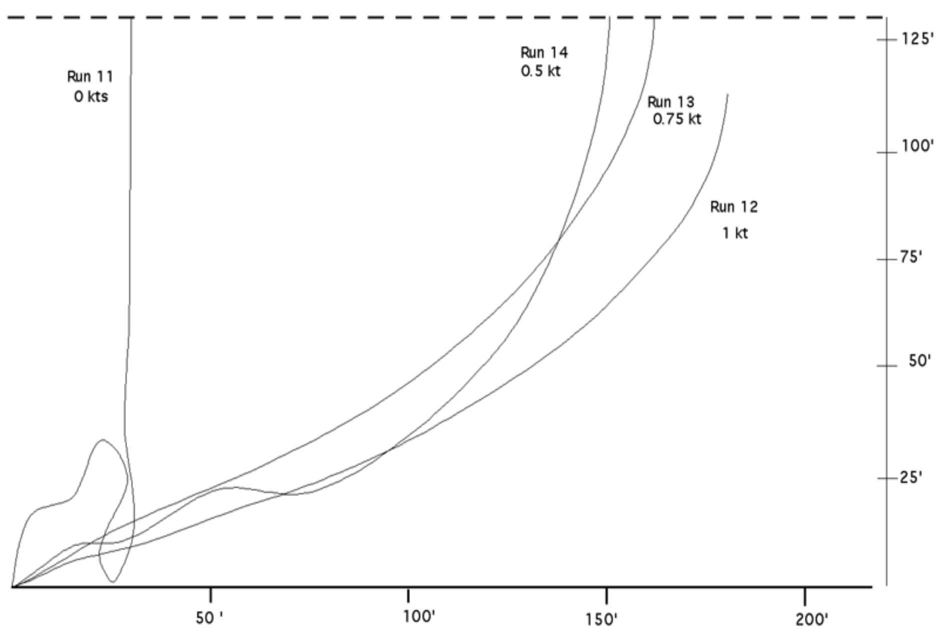
Image 5: Full-scale image showing profile of 1.75 scoped, buoyline rigged entirely with sinking line at time of slack tide. Note that a great deal of line is in contact with the bottom.

APPENDIX C: AutoCAD Profiles

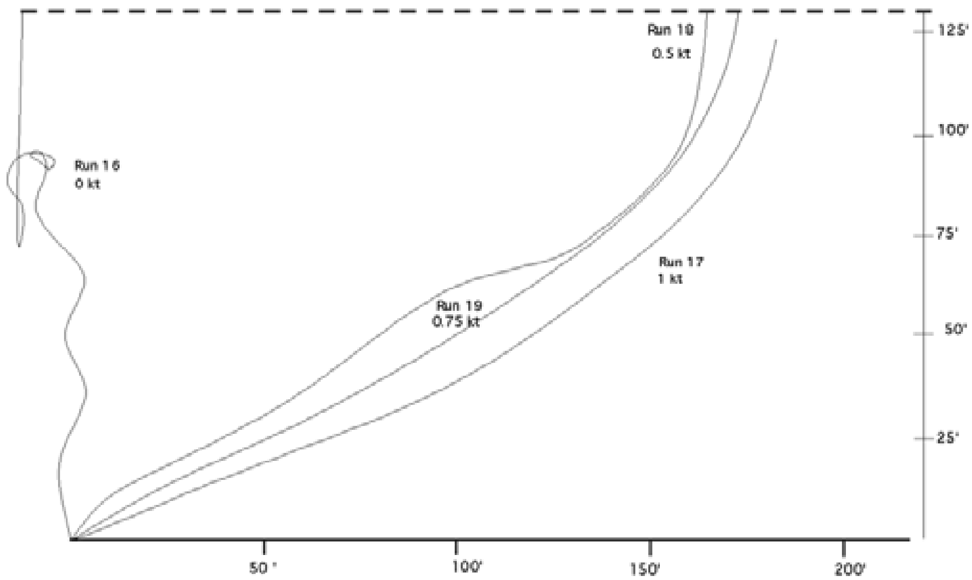
Runs 1 - 4:
1:10 scale, 1.75 scope, 100% sink line, buoy type A



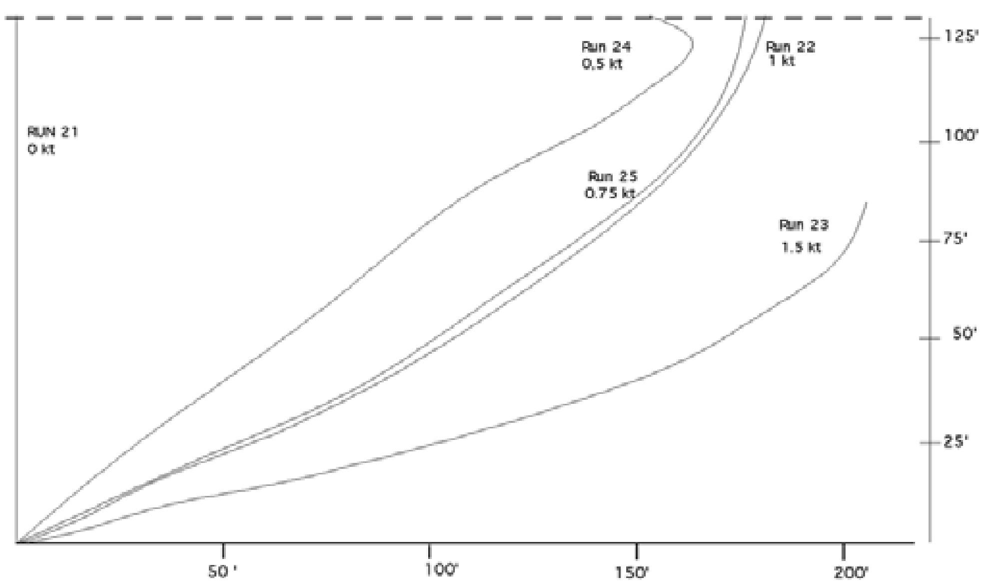
Runs 11 - 14:
1:10 scale, 1.75 scope, 33% float line, buoy type A



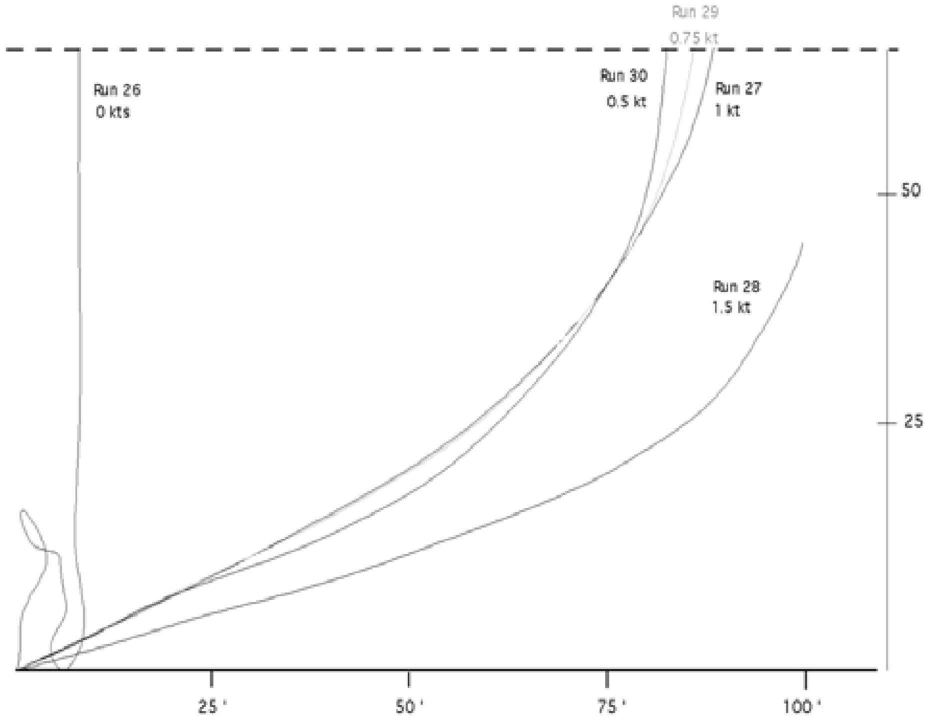
Runs 16 - 19:
1:10 scale, 1.75 scope, 67% float line, buoy type A



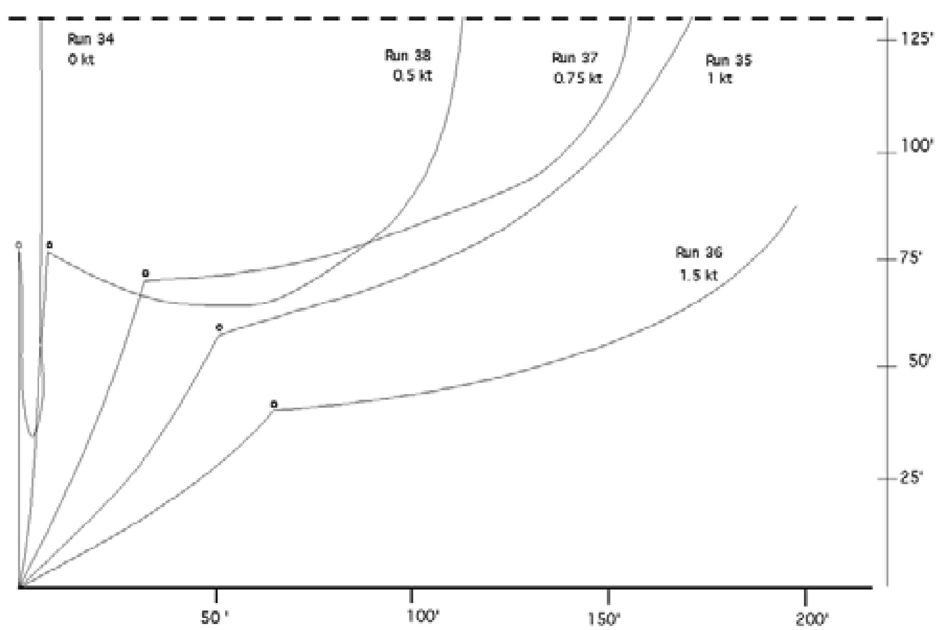
Runs 21 - 25:
1:10 scale, 1.75 scope, 100% float line, buoy type A



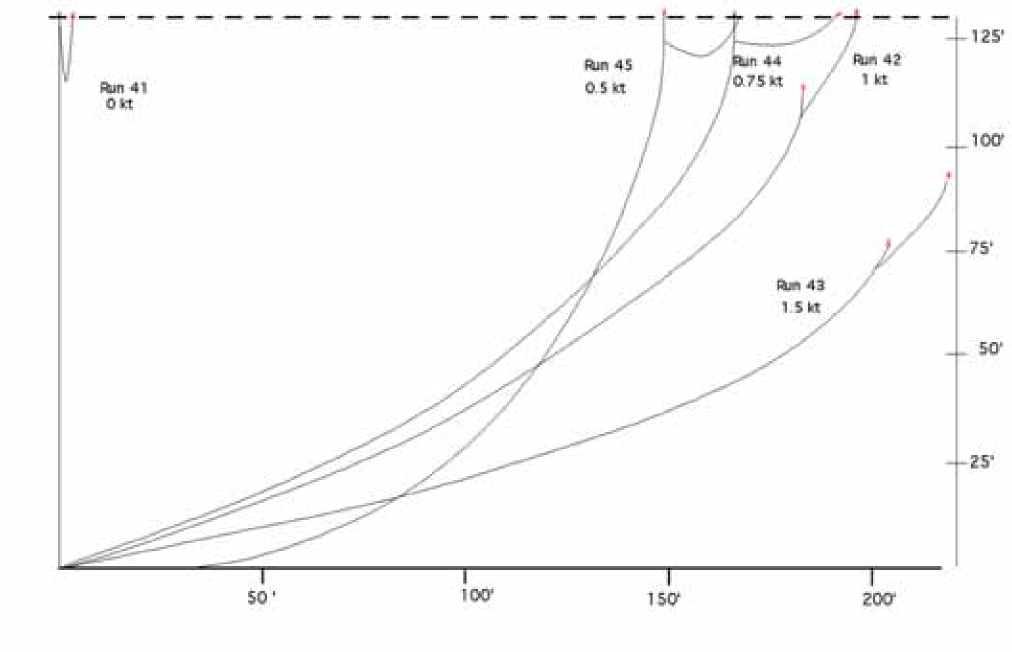
Runs 26 - 30:
1:5 scale, 1.75 scope, 33% float line, buoy type A



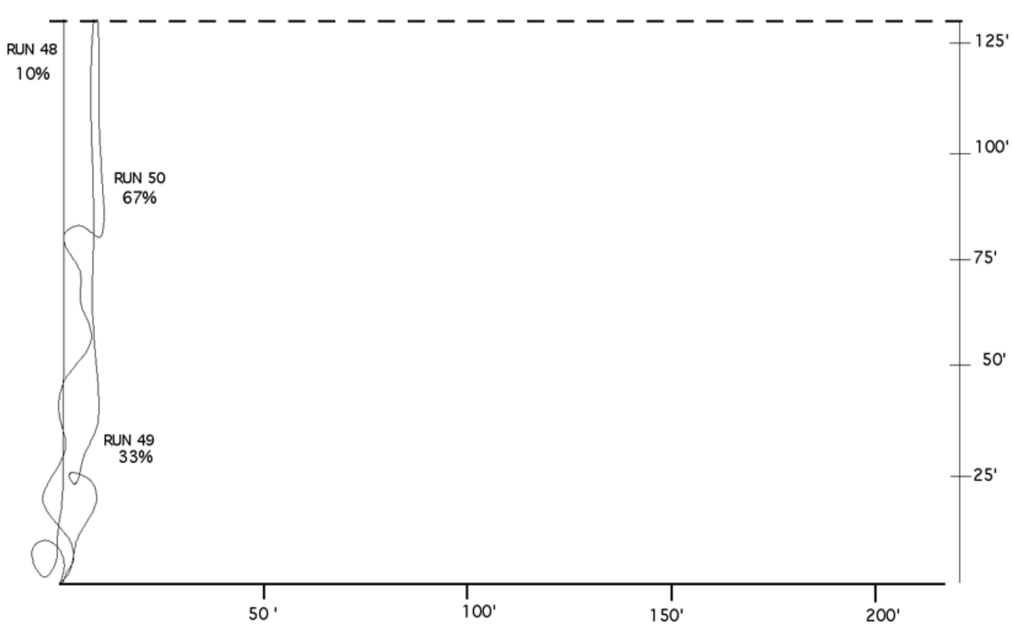
Runs 34 - 38:
1:10 scale, 1.75 scope, 100% sink line, buoy type B



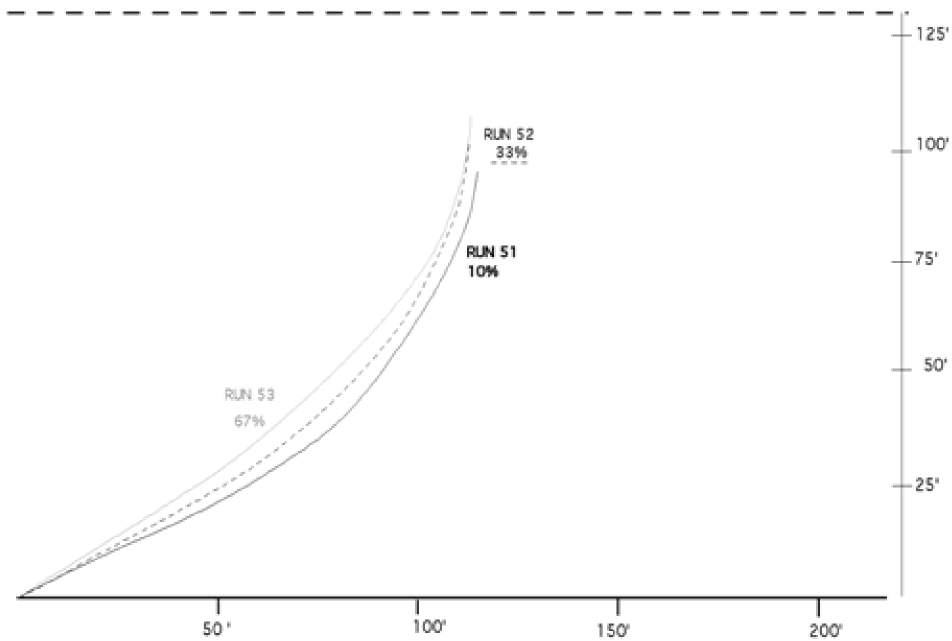
Runs 41 - 45:
1:10 scale, 1.75 scope, 100% sink line, buoy type C



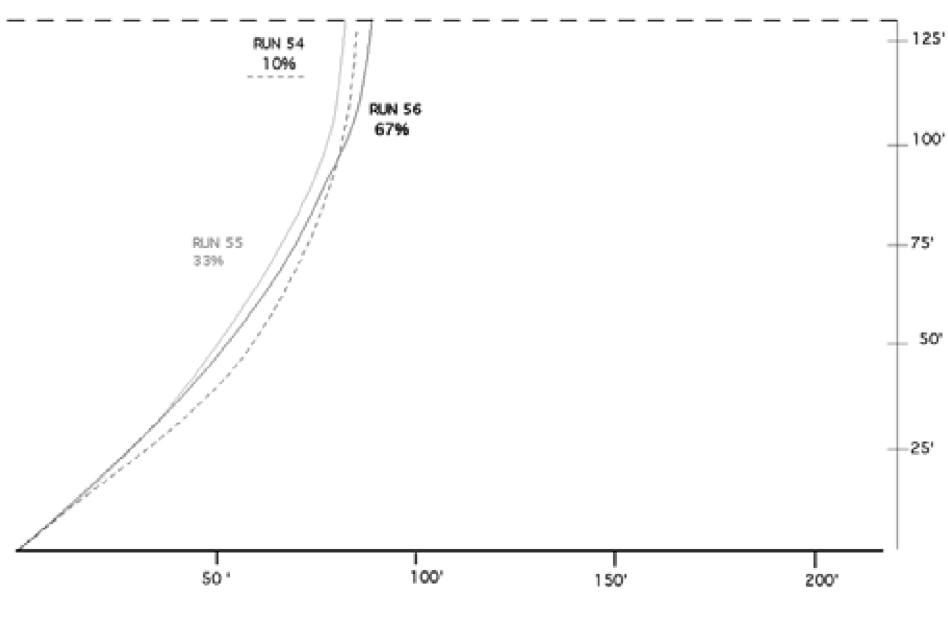
Runs 48 - 50:
1:10 scale, 1.25 scope, 10%, 33% and 67% float line, 0 knots, buoy type A



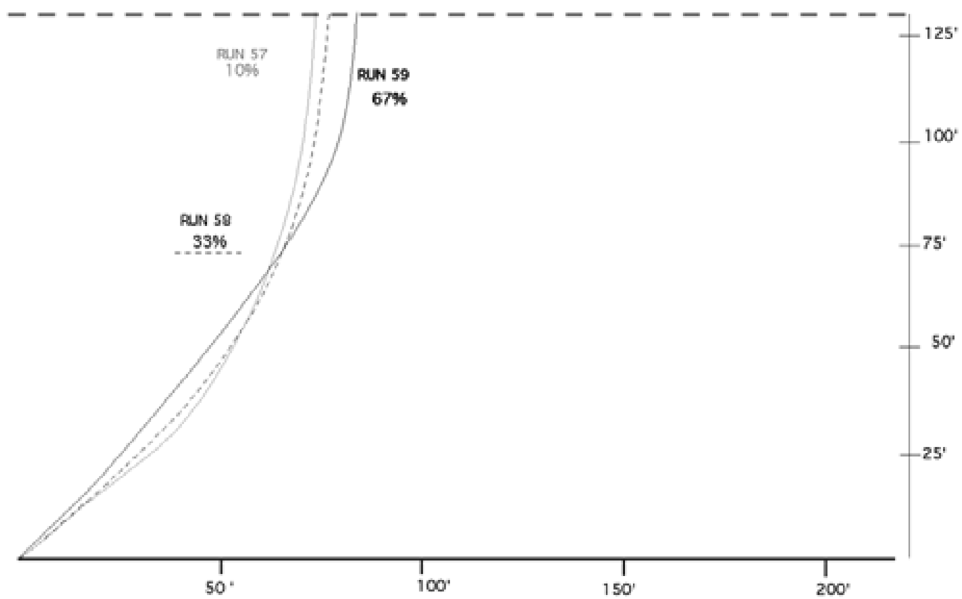
Runs 51- 53:
1:10 scale, 1.25 scope, 10%, 33%, and 67% float line, 1 kt, buoy type A



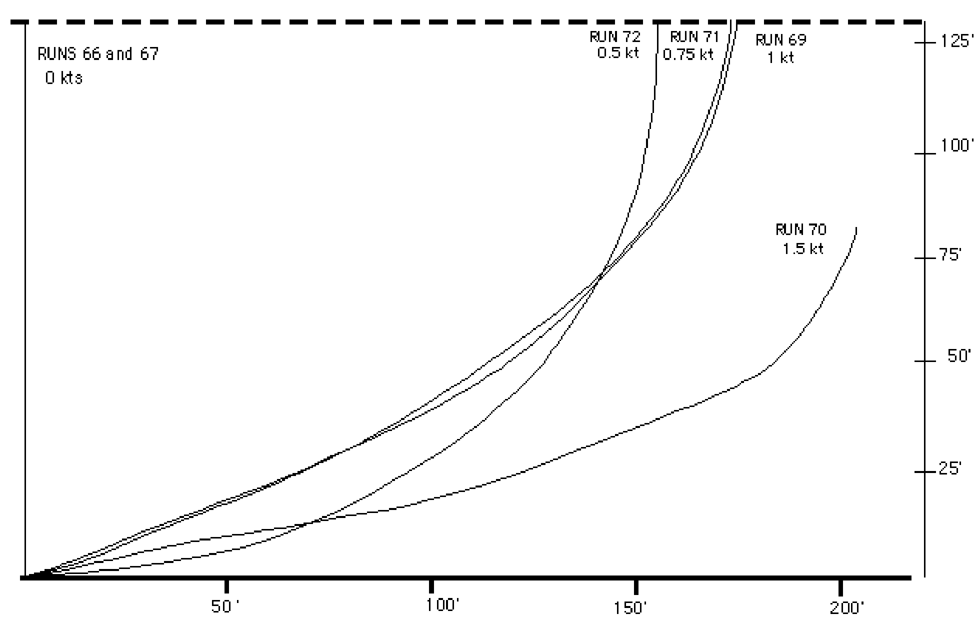
Runs 54 - 56:
1:10 scale, 1.25 scope, 10%, 33%, and 67% float line, .75 kt, buoy type A



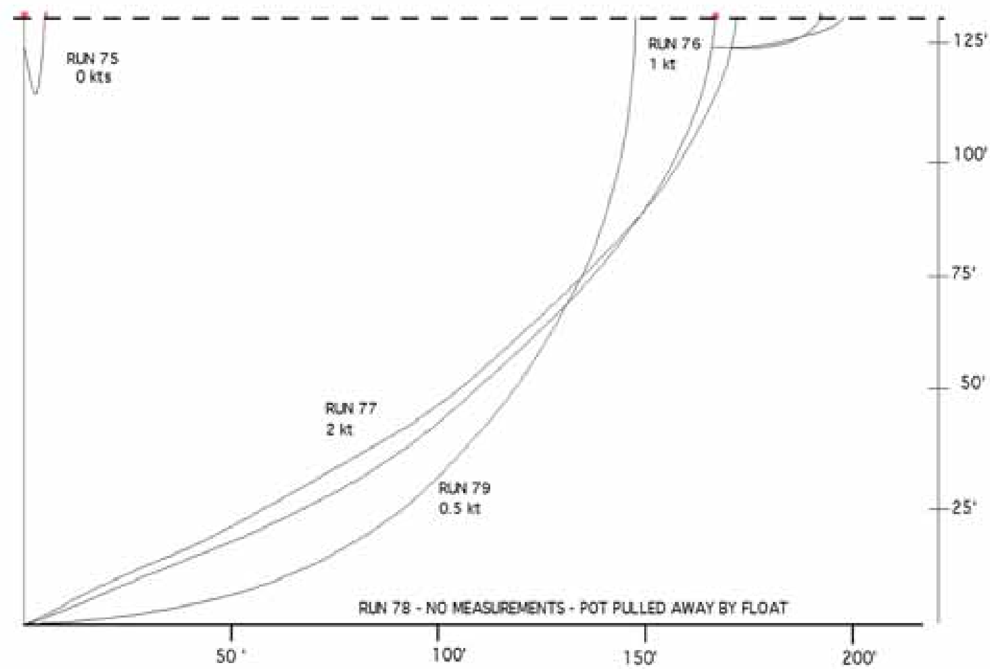
Runs 57 - 59:
1:10 scale, 1.25 scope, 10%, 33%, and 67% float line, .5 kt, buoy type A



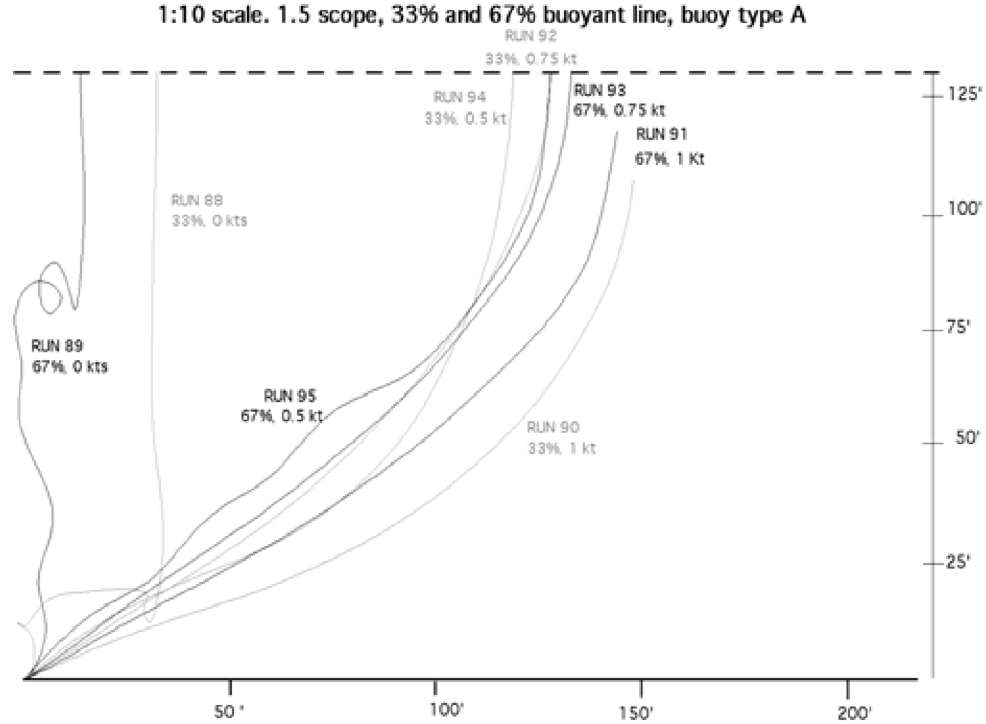
Runs 66, 67, 69 - 72:
1:10 scale, 1.75 scope, 100% neutral buoyant line, buoy type A



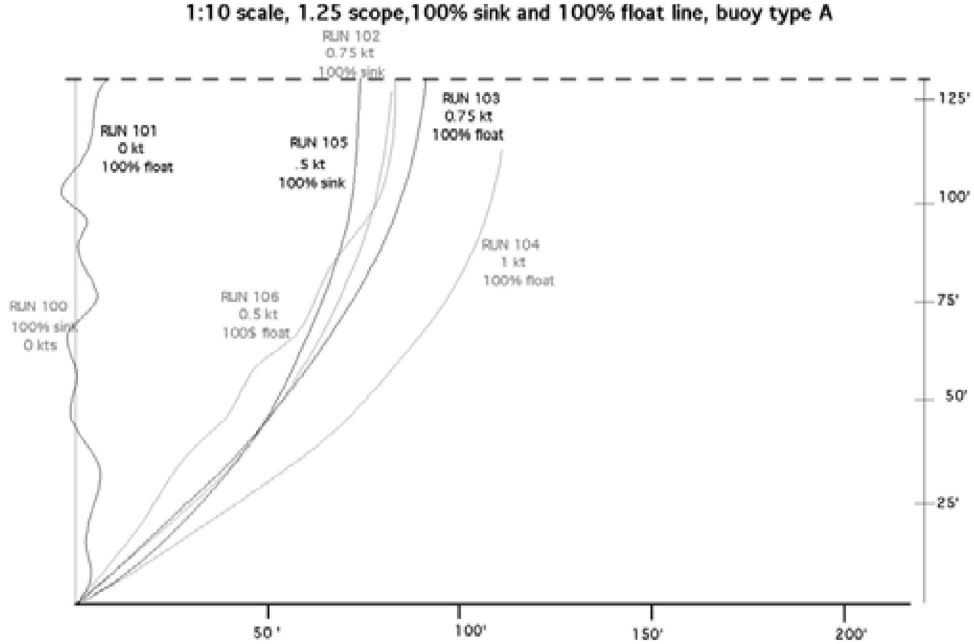
Runs 75 - 79:
1:10 scale, 1.75 scope, 100% sink line, buoy type D



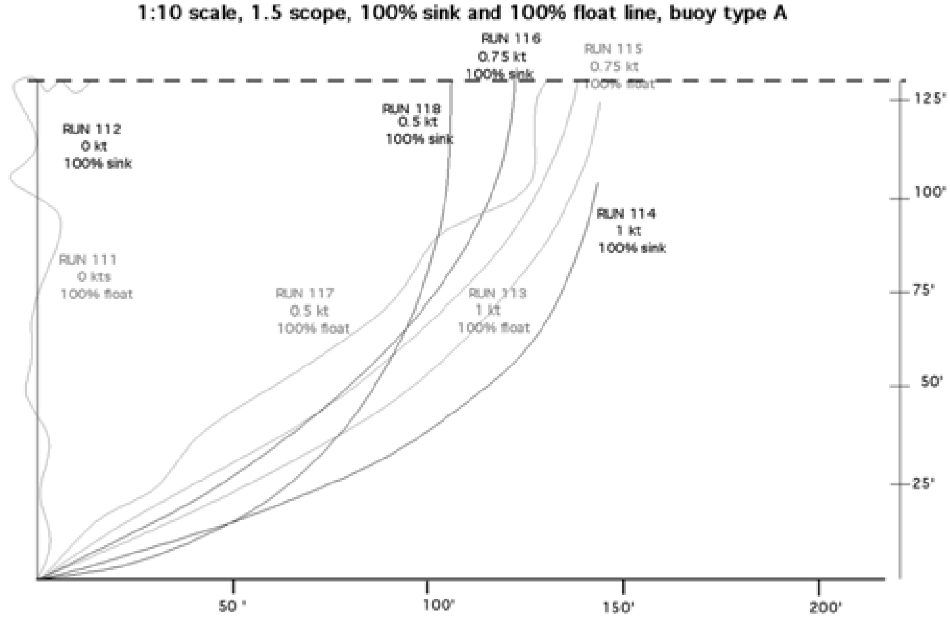
Runs 88 - 95:
1:10 scale. 1.5 scope, 33% and 67% buoyant line, buoy type A



Runs 100 - 106:
1:10 scale, 1.25 scope,100% sink and 100% float line, buoy type A



Runs 111-118:
1:10 scale, 1.5 scope, 100% sink and 100% float line, buoy type A



APPENDIX D
TABLE 3:

Qualitative and Quantitative Results from Modeled Line Profiles

Test Run	Scale	Scope	Current (kts)	% sink	% Float	% Neutral	Buoy Type	Line on Bottom	Line at Surface	Buoy at Surface	Y Max(ft)	X Max.(ft)	Horiz. Comp.	Line Surf.(ft)	Line Bott.(ft)	Buoy-Pot Dist. (ft)
1	10	1.75	0.000	100	0	0	A	Yes	No	Yes	131.2	0.0	0.00	0.0	98.4	131.2
2	10	1.75	1.000	100	0	0	A	No	No	No	109.0	181.3	1.38	0.0	0.0	211.6
3	10	1.75	0.500	100	0	0	A	Yes	No	Yes	131.2	141.1	1.08	0.0	24.0	192.7
4	10	1.75	0.750	100	0	0	A	No	No	Yes	131.2	157.9	1.20	0.0	0.0	205.3
5	10	1.75	0.250	100	0	0	A	Yes	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
11	10	1.75	0.000	67	33	0	A	No	No	Yes	131.2	30.4	0.23	0.0	0.0	134.7
12	10	1.75	1.000	67	33	0	A	No	No	No	113.6	180.2	1.37	0.0	0.0	213.1
13	10	1.75	0.750	67	33	0	A	No	No	Yes	131.2	161.4	1.23	0.0	0.0	208.0
14	10	1.75	0.500	67	33	0	A	No	No	Yes	131.2	150.3	1.15	0.0	0.0	199.6
15	10	1.75	0.250	67	33	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
16	10	1.75	0.000	33	67	0	A	No	No	Yes	131.2	18.0	0.14	0.0	0.0	132.5
17	10	1.75	1.000	33	67	0	A	No	No	No	124.0	181.8	1.39	0.0	0.0	220.1
18	10	1.75	0.500	33	67	0	A	No	No	Yes	131.2	164.5	1.25	0.0	0.0	210.4
19	10	1.75	0.750	33	67	0	A	No	No	Yes	131.2	172.2	1.31	0.0	0.0	216.5
20	10	1.75	0.250	33	67	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
20A	10	1.75	0.125	33	67	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
21	10	1.75	0.000	0	100	0	A	No	Yes	Yes	131.2	0.0	0.00	98.4	0.0	131.2
22	10	1.75	1.000	0	100	0	A	No	No	Yes	131.2	180.2	1.37	0.0	0.0	223.0
23	10	1.75	1.500	0	100	0	A	No	No	No	85.0	205.1	1.56	0.0	0.0	222.0
24	10	1.75	0.500	0	100	0	A	No	Yes	Yes	131.2	162.6	1.24	5.3	0.0	209.0
24A	10	1.75	0.250	0	100	0	A	No	Yes	Yes	131.2	N/A	N/A	N/A	N/A	N/A
25	10	1.75	0.750	0	100	0	A	No	No	Yes	131.2	176.0	1.34	0.0	0.0	219.5
26	5	1.75	0.000	67	33	0	A	Yes	No	Yes	65.6	84.0	1.28	0.0	1.0	106.6
27	5	1.75	1.000	67	33	0	A	No	No	Yes	65.6	87.4	1.33	0.0	0.0	109.3
28	5	1.75	1.500	67	33	0	A	No	No	No	44.9	99.1	1.51	0.0	0.0	108.8
29	5	1.75	0.750	67	33	0	A	No	No	Yes	65.6	85.1	1.30	0.0	0.0	107.5
30	5	1.75	0.500	67	33	0	A	No	No	Yes	65.6	82.0	1.25	0.0	0.0	105.0
31	5	1.75	0.250	67	33	0	A	No	No	Yes	65.6	N/A	N/A	N/A	N/A	N/A
32	5	1.75	0.125	67	33	0	A	No	No	Yes	65.6	N/A	N/A	N/A	N/A	N/A
33	5	1.75	0.063	67	33	0	A	Yes	No	Yes	65.6	N/A	N/A	N/A	N/A	N/A

Table 3 (continued)

Test Run	Scale	Scope	Current (kts)	% sink	% Float	% Neutral	Buoy Type	Line on Bottom	Line at Surface	Buoy at Surface	Y Max (ft)	X Max. (ft)	Horiz. Comp.	Line Surf.(ft)	Line Bottom(ft)	Buoy-Pot Dist. (ft)
34	10	1.75	0.000	100	0	0	B	Yes	No	Yes	131.2	6.7	0.05	0.0	98.4	131.4
35	10	1.75	1.000	100	0	0	B	No	No	Yes	131.2	170.6	1.30	0.0	0.0	215.2
36	10	1.75	1.500	100	0	0	B	No	No	No	87.7	197.3	1.50	0.0	0.0	216.0
37	10	1.75	0.750	100	0	0	B	No	No	Yes	131.2	154.9	1.18	0.0	0.0	203.0
38	10	1.75	0.500	100	0	0	B	No	No	Yes	131.2	112.4	0.86	0.0	0.0	172.8
39	10	1.75	0.250	100	0	0	B	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
40	10	1.75	0.125	100	0	0	B	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
41	10	1.75	0.000	100	0	0	C	Yes	No	Yes	131.2	3.4	0.03	0.0	98.4	131.3
42	10	1.75	1.000	100	0	0	C	No	No	Yes	131.2	195.9	1.49	0.0	0.0	235.8
43	10	1.75	1.500	100	0	0	C	No	No	No	93.5	218.9	1.67	0.0	0.0	238.0
44	10	1.75	0.750	100	0	0	C	No	No	Yes	131.2	165.8	1.26	0.0	0.0	211.5
45	10	1.75	0.500	100	0	0	C	Yes	No	Yes	131.2	148.7	1.13	0.0	2.0	198.3
46	10	1.75	0.250	100	0	0	C	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
47	10	1.75	0.125	100	0	0	C	Yes	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
47A	10	1.75	1.500	100	0	0	E	No	No	No	0.0	0.0	0.00	0.0	0.0	0.0
48	10	1.25	0.000	90	10	0	A	No	No	Yes	131.2	0.0	0.00	0.0	0.0	131.2
49	10	1.25	0.000	67	33	0	A	No	No	Yes	131.2	0.0	0.00	0.0	0.0	131.2
50	10	1.25	0.000	33	67	0	A	No	No	Yes	131.2	0.0	0.00	0.0	0.0	131.2
51	10	1.25	1.000	90	10	0	A	No	No	No	0.0	0.0	0.00	0.0	0.0	0.0
52	10	1.25	1.000	67	33	0	A	No	No	No	100.7	112.0	0.85	0.0	0.0	150.6
53	10	1.25	1.000	33	67	0	A	No	No	No	108.4	113.4	0.86	0.0	0.0	156.9
54	10	1.25	0.750	90	10	0	A	No	No	No	0.0	0.0	0.00	0.0	0.0	0.0
55	10	1.25	0.750	67	33	0	A	No	No	Yes	131.2	82.3	0.63	0.0	0.0	154.9
56	10	1.25	0.750	33	67	0	A	No	No	Yes	131.2	89.0	0.68	0.0	0.0	158.6
57	10	1.25	0.500	90	10	0	A	No	No	Yes	131.2	0.0	0.00	0.0	0.0	131.2
58	10	1.25	0.500	67	33	0	A	No	No	Yes	131.2	76.5	0.58	0.0	0.0	151.9
59	10	1.25	0.500	33	67	0	A	No	No	Yes	131.2	83.0	0.63	0.0	0.0	155.3
60	10	1.25	0.250	90	10	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
61	10	1.25	0.250	67	33	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
62	10	1.25	0.250	33	67	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
63	10	1.25	0.125	90	10	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
64	10	1.25	0.125	67	33	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A

Table 3 (continued)

Test Run	Scale	Scope	Current (kts)	% sink	% Float	% Neutral	Buoy Type	Line on Bottom	Line at Surface	Buoy at Surface	Y Max (ft)	X Max. (ft)	Horiz. Comp.	Line Surf.(ft)	Line Bottom(ft)	Buoy-Pot Dist. (ft)
65	10	1.25	0.125	33	67		A	No	No	Yes	131.2	N/A	N/A			N/A
66	10	1.75	0.000	0	0	100	A	Yes	No	Yes	131.2	0.0	0.00	0.0	98.4	131.2
67	10	1.75	0.000	0	0	100	A	Yes	No	Yes	131.2	0.0	0.00	0.0	98.4	131.2
68	10	1.75	1.000	0	0	100	A	No	No	No	0.0	0.0	0.00	0.0	0.0	0.0
69	10	1.75	1.000	0	0	100	A	No	No	Yes	131.2	174.6	1.33	0.0	0.0	218.4
70	10	1.75	1.500	0	0	100	A	No	No	No	82.5	203.3	1.55	0.0	0.0	219.4
71	10	1.75	0.750	0	0	100	A	No	No	Yes	131.2	173.1	1.32	0.0	0.0	217.2
72	10	1.75	0.500	0	0	100	A	No	No	Yes	131.2	155.7	1.19	0.0	0.0	203.7
73	10	1.75	0.250	0	0	100	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
74	10	1.75	0.125	0	0	100	A	Yes	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
75	10	1.75	0.000	100	0	0	D	Yes	No	Yes	131.2	0.0	0.00	0.0	98.4	131.2
76	10	1.75	1.000	100	0	0	D	No	No	Yes	131.2	167.0	1.27	0.0	0.0	212.4
77	10	1.75	2.000	100	0	0	D	No	No	Yes	131.2	171.8	1.31	0.0	0.0	216.2
78	10	1.75	3.000	100	0	0	D	N/A	N/A	N/A	0.0	N/A	N/A	N/A	N/A	0.0
79	10	1.75	0.500	100	0	0	D	Yes	No	Yes	131.2	147.9	1.13	0.0	2.0	197.7
80	10	1.75	0.250	100	0	0	D	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
81	10	1.75	0.125	100	0	0	D	Yes	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
82	10	1.75	0.000	0	100	0	MP	Yes	No	Yes	131.2	0.0	0.00	N/A	N/A	131.2
83	10	1.75	1.000	0	100	0	MP	No	No	No	0.0	0.0	0.00	N/A	N/A	0.0
84	10	1.75	0.750	0	100	0	MP	No	No	Yes	0.0	0.0	0.00	N/A	N/A	0.0
85	10	1.75	0.500	0	100	0	MP	Yes	No	Yes	0.0	0.0	0.00	N/A	N/A	0.0
86	10	1.75	0.250	0	100	0	MP	No	No	Yes	0.0	N/A	N/A	N/A	N/A	N/A
87	10	1.75	0.125	0	100	0	MP	No	No	Yes	0.0	N/A	N/A	N/A	N/A	N/A
88	10	1.5	0.000	67	33	0	A	No	No	Yes	131.2	35.1	0.27	0.0	0.0	135.9
89	10	1.5	0.000	33	67	0	A	No	No	Yes	131.2	15.9	0.12	0.0	0.0	132.2
90	10	1.5	1.000	67	33	0	A	No	No	No	107.8	147.3	1.12	0.0	0.0	182.5
91	10	1.5	1.000	33	67	0	A	No	No	No	116.8	143.6	1.09	0.0	0.0	185.1
92	10	1.5	0.750	67	33	0	A	No	No	Yes	131.2	127.9	0.97	0.0	0.0	183.3
93	10	1.5	0.750	33	67	0	A	No	No	Yes	131.2	132.1	1.01	0.0	0.0	186.2
94	10	1.5	0.500	67	33	0	A	No	No	Yes	131.2	117.8	0.90	0.0	0.0	176.4
95	10	1.5	0.500	33	67	0	A	No	No	Yes	131.2	127.6	0.97	0.0	0.0	183.0
96	10	1.5	0.250	67	33	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A

Table 3 (continued)

Test Run	Scale	Scope	Current (kts)	% sink	% Float	% Neutral	Buoy Type	Line on Bottom	Line at Surface	Buoy at Surface	Y Max (ft)	X Max. (ft)	Horiz. Comp.	Line Surf.(ft)	Line Bottom(ft)	Buoy-Pot Dist. (ft)
97	10	1.5	0.250	33	67	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
98	10	1.5	0.125	67	33	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
99	10	1.5	0.125	33	67	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
100	10	1.25	0.000	100	0	0	A	Yes	No	Yes	131.2	12.3	0.09	0.0	32.8	131.8
101	10	1.25	0.000	0	100	0	A	No	No	Yes	127.9	82.0	0.62	32.8	0.0	151.9
102	10	1.25	0.750	100	0	0	A	No	No	No	0.0	90.9	0.69	0.0	0.0	90.9
103	10	1.25	0.750	0	100	0	A	No	No	Yes	112.9	110.0	0.84	0.0	0.0	157.6
104	10	1.25	1.000	0	100	0	A	No	No	No	0.0	73.9	0.56	0.0	0.0	73.9
105	10	1.25	0.500	100	0	0	A	No	No	Yes	131.2	83.3	0.63	0.0	0.0	155.4
106	10	1.25	0.500	0	100	0	A	No	No	Yes	131.2	0.0	0.00	0.0	0.0	131.2
107	10	1.25	0.250	100	0	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
108	10	1.25	0.250	0	100	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
109	10	1.25	0.125	100	0	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
110	10	1.25	0.125	0	100	0	A	No	No	Yes	131.2	N/A	N/A	N/A	N/A	N/A
111	10	1.50	0.000	0	100	0	A	No	Yes	Yes	131.2	20.8	0.16	65.6	0.0	132.9
112	10	1.50	0.000	100	0	0	A	yes	No	Yes	131.2	0.0	0.00	0.0	65.6	131.2
113	10	1.50	1.000	0	100	0	A	No	No	No	124.5	142.9	1.09	0.0	0.0	189.6
114	10	1.50	1.000	100	0	0	A	No	No	No	103.7	142.1	1.08	0.0	0.0	175.9
115	10	1.50	0.750	0	100	0	A	No	No	Yes	131.2	137.5	1.05	0.0	0.0	190.1
116	10	1.50	0.750	100	0	0	A	No	No	Yes	131.2	121.8	0.93	0.0	0.0	179.1
117	10	1.50	0.500	0	100	0	A	No	No	Yes	131.2	131.0	1.00	0.0	0.0	185.4
118	10	1.50	0.500	100	0	0	A	No	No	Yes	131.2	105.4	0.80	0.0	0.0	168.3
119	10	1.50	0.250	0	100	0	A	No	Yes	Yes	0.0	N/A	N/A	N/A	N/A	N/A
120	10	1.50	0.250	100	0	0	A	Yes	No	Yes	0.0	N/A	N/A	N/A	N/A	N/A
121	10	1.50	0.125	0	100	0	A	No	Yes	Yes	0.0	N/A	N/A	N/A	N/A	N/A
122	10	1.50	0.125	100	0	0	A	Yes	No	Yes	0.0	N/A	N/A	N/A	N/A	N/A