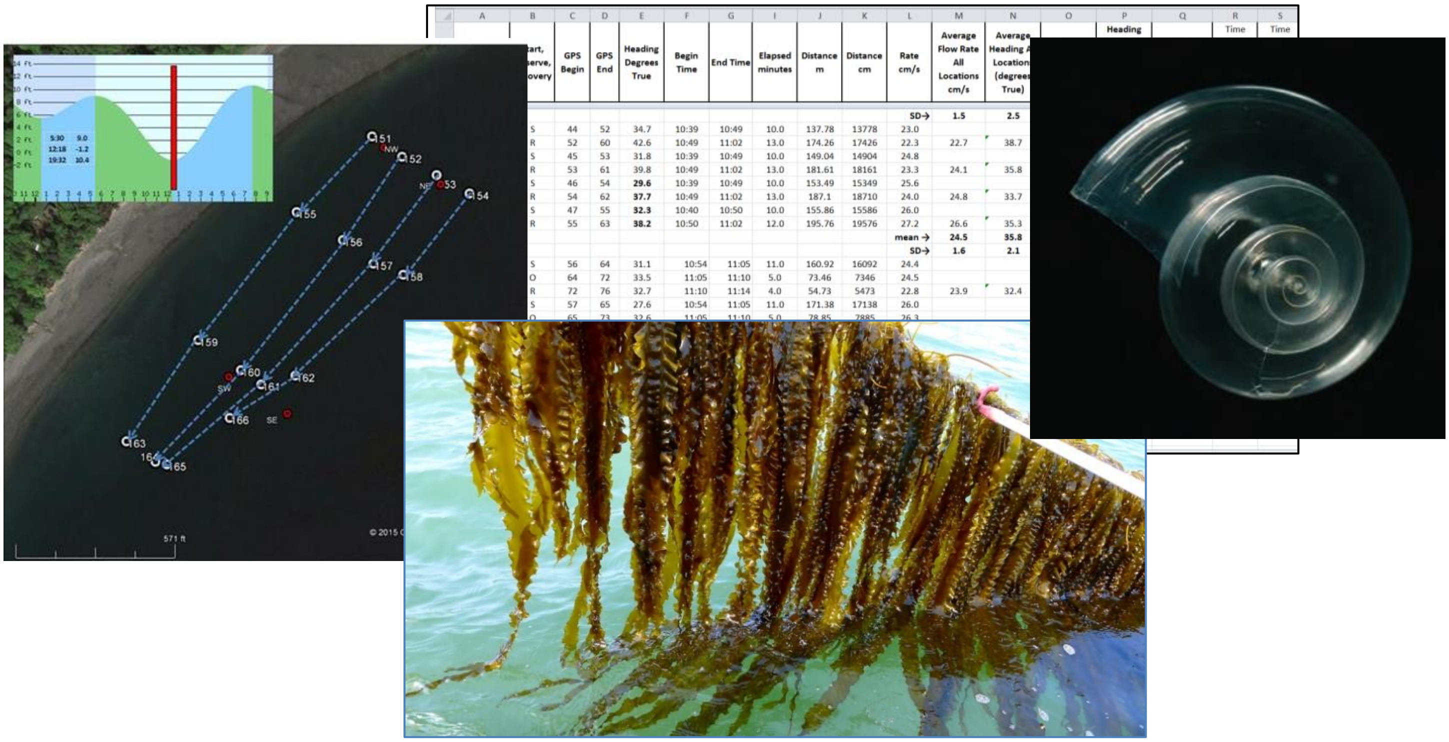
Preliminary Assessment of Seawater Circulation near Hood Head, Hood Canal, Washington for Seaweed Cultivation – Ocean Acidification Refugium Evaluation



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Dr. Joth Davis provided the assistance in completing the field work at the Hood Head site including provision of the sampling vessel.

Cover photos from this report except:

Pteropod photo from: Washington State Blue Ribbon Panel on Ocean Acidification (2012): *Ocean Acidification:From Knowledge to Action, Washington State's Strategic Response*. H. Adelsman and L. Whitely Binder (eds). Washington Department of Ecology, Olympia, Washington.Publication no. 12-01-015.
Seaweed photo credit: Thimble Island Oyster Company

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Introduction

Background

Seaweed cultivation known as “marine agronomy” and wild seaweed harvest occurs in many countries for human food and animal feed. In Japan and Asia alone, the production is worth many billions of US dollars.

Increasingly there is interest in seaweed cultivation for concurrent other purposes too. These include removal of excess nutrients such as dissolved inorganic nitrogen from coastal areas with eutrophication issues, as fuel stock for alternative energy production, for aquatic habitat conservation or restoration and for pharmaceutical and chemical extraction.

The subject of a project spearheaded by the Puget Sound Restoration Fund (PSRF) is another purpose: seaweed for creation of ocean acidification (OA) refugia for sensitive species being adversely affected by the increasingly acidic waters. The concept is simple; seaweed removes carbonates from seawater and results in less acidity. PSRF and their partners propose creation and documentation of economically self-sustaining refugia where seaweed is harvested to cover the costs of production while providing the benefit of sweetening the water, i.e., increasing pH and aragonite saturation, an important factor in maintaining shell-forming marine species that are now becoming threatened.

However, adequate data or validated models of marine agronomy as a means to mitigate OA are scarce or non-existent, although they are the subject of publications, discussion and theoretical modeling. OA mitigation is sometimes considered a qualitative side-benefit of marine agronomy and it may be modeled in terms of theoretical carbon removal and effects on carbonate chemistry. However, ocean acidification in coastal areas remains difficult to measure versus background variation related to mixing and transport. OA determination in coastal areas especially requires the use of sensitive and accurate measuring equipment for pH and the related parameters of carbonate chemistry that are only now being developed. The PSRF project will include use of state-of-the-art seawater chemical measurement moorings that will be arrayed up and downstream of a large seaweed farm. By estimating seaweed biomass and growth and comparing the water chemistry effects, a real-world evaluation of such a system can be quantitatively measured and compared to existing models and projections commonly used.

This report includes preliminary data and analysis of water circulation at a seaweed project in Washington State that is intended to provide proof of concept for creation of ocean acidification refugia. This report is a minor step in the process of planning, building and operating the seaweed-OA refugium but necessary to begin to understand how to place carbonate chemistry, current meters and other moorings around the facility.

The approach to be taken with the refugium planning involves measuring background conditions upstream of the seaweed array and the effects of the seaweed downstream after the water passes through all of the seaweed. When the tide changes, the downstream becomes upstream but the problem is that flows are often in different directions so the fixed moorings downstream will sometimes only be measuring part of the effect of the entire seaweed array. Determining about how often that sometimes occurs was a goal of this small study.

Upstream/downstream aquatic measurements are commonly used in marine ecology studies and regulatory monitoring. I have used it to measure fecal coliform production of gull in the Dungeness River and nutrient production by aquaculture facilities on numerous occasions. It has been used for Washington Departments of Fish and Wildlife, Natural Resources and Ecology for required monitoring of floating aquaculture in the past. Its use yielded reasonably accurate results compared to widely accepted laboratory data when conducted appropriately, as I reported in the State's programmatic EIS for marine fish culture (Parametrix et al. 1990). I also used the approach for stable isotope studies of aquaculture effects in Puget Sound and the mid-Columbia River.

When seaweed production is underway at the Hood Head facility, current meters will be positioned up and downstream of the seaweed and possibly within the culture area to provide physical transport velocity and direction (vector) data. However, it is very difficult to estimate the actual rates of the seaweed effects unless the water is flowing like a pipeline through the facility, i.e., straight through and parallel with the long axis of the facility. This will not occur regularly, but should several times daily for long enough periods to collect reasonably accurate data. When the water flows tangentially, some unknown amount of the effect will escape monitoring. All of this assumes a uniform downstream effects field unless several downstream instrument moorings can be use. Some minor variation of flow direction will have to be accepted, say five compass degrees, or 2.8% of the possible 180 compass degrees of a 360-degree compass rose. Elapsed time of flow through must also be considered to measure the effects of the entire facility.

Objectives

In order to measure the effects of the seaweed array upon water carbonate chemistry, it is essential that the hydrodynamics of the site be understood before final design of the sampling strategy and monitoring equipment placement. The process initiated with this survey will involve additional study and planning by the project team that includes many other participants.

The primary objective of the drogue (i.e., drifter) studies reported herein was to document the frequency with which water flows directly through the project site. This is the first step in a process of deciding where the water chemistry moorings will be placed and how it is to be operated. A companion objective was to collect concurrent drogue velocity information. More accurate effects measurements will likely occur when flows are modestly slow and dilution of effect is minimized. Velocity measurement can more accurately be done by current meters and will commence in the winter of 2015-2016. However, the drogue data gives some first insight into the range of expected velocity that will be found as this study was conducted on both large and small tidal exchange days.

Although perhaps obvious to some readers, drogue tracking provides valuable wide-area information not provided by current meter moorings that focus on a single point (i.e., Lagrangian vs. Eulerian measurements). The drogues follow the pathway of water movement throughout a monitored area and several can be set at once and followed concurrently.

By repeatedly placing, tracking with GPS, recapturing and replacing the drogues upstream of the project area an estimate of the pathways taken and variation from straight through flow was made in this survey. Such data could also be made by placing current meters at both ends of the facility, but directional transport in the area between them would remain unknown and speculative. Drogue data may also be useful to determine if there is a need to build a seaweed array within the aquatic lease area that is angled to match some dominant flow direction, although this may be technically difficult.

A third intangible but important objective I have found with all drogue surveys is to simply be on the site of a marine project or study area to observe conditions, birds and marine mammals, use by humans, wind waves, etc. In the present case, we had discussions with several local boaters including residents of Hood Head and we felt these contacts to be valuable and all those who came by voiced strong support for the project. Remote sensing is a wonderful thing, but on-site human observation and contact with local residents is an important factor in the success of any project.

Site Location and General Characteristics

The study site is located in Western Washington State near the entry to a long, narrow and deep fjord known as Hood Canal northwest of Seattle (Figure 1). Located in the North Hood Canal region, the general area is known for a long floating bridge (Figure 2) and is just north of the U.S. Navy's Trident submarine base.

Figure 1. Project vicinity map

Seawater from Admiralty Inlet in the main basin of Puget Sound flows into the area during mixed semidiurnal tidal flows. The orientation of Hood Canal from southwest to northeast and surrounding topography allows for orographic channeling of prevailing southwest winter winds to northerly winds in the summer. Hood Canal's southern and central regions have been the subject of increasing concern due to seasonal deep-water hypoxia and vertical stratification-turnover events that cause marine fish and invertebrate kills and other adverse conditions. However, the project site is within the northern Hood Canal area that is much more well-mixed and less prone to such problems.

North Hood Canal is relatively deep with depths to approximately 175 meters, but the project is located nearshore adjacent to Hood Head in less than 20 m depth. Hood Head is an island along the west shore of Hood Canal that is lightly populated with residential or seasonal occupied cabins.

The seaweed project site has previously been leased for longline shellfish aquaculture from the Washington Department of Natural Resources and is presently having a permit modification to allow for seaweed aquaculture. As shown in Figure 2, the lease area is located on the west side of Hood Canal and the east side of Hood Head Island (or peninsula, depending on tidal height). It is protected from north winds by a sand spit (Hannon Point) to the north and to some extent by the Hood Canal floating bridge to the south.

Figure 2. Project near-vicinity map.

The Hood Head aquatic lease area corners are located as follows:

NE Corner: 47°52'58.7" N; 122°36'54.3" W

NW Corner: 47°52’57.6” N; 122° 36’ 51.0” W

SE Corner: 47°53’ 07.4” N; 122 ° 36’ 47.3” W

SW Corner: 47°53’ 06.3” N; 122° 36’ 44.1” W

The project lease area measures 1000’ (304.9 m) north to south and 250’ (76.2 m) east to west. The lease area is 5.74 acres (250,000 ft^2 or 2.32 hectares). The seaweed array final size and orientation is not yet determined but may be approximately 500 ft. long by 250 ft. wide (152.4 m x 76.2 m) or 125,000 ft^2 (11,612 m^2 or 0.0116 km^2). An example layout with the seaweed longlines oriented longitudinally is shown as Figure 3. Small yellow dots indicate possible current meter locations, although more than one current meter may be placed at each end to provide a more accurate measure of flow direction and velocity.

Figure 3. Example possible seaweed array as yellow colored lines within the aquatic lease area in green background color.

Source: Puget Sound Restoration Fund unpublished proposal.

Methods

Water circulation studies were conducted using "windowshade drogues" that were nylon, underwater sails attached by a 1/16th inch line to a surface float (Figure 4). The underwater sails were 1 x 0.75 meter dimension (0.75 m^2) and set to operate at an average depth of 2.0 m below the surface. The surface floats were 10" bullet shaped commercial trawl buoys with a ¾-inch diameter schedule 90 PVC conduit of 1.5 m length placed through them. The conduit provides enhanced visibility for locating and as a means to attach the thin line to the underwater windowshade sail. Each drogue was numbered on the float as well as having stripes on the pole for distant identification.

Figure 4. Windowshade drogue and marker float as described in the text.

Windowshade drogues were deployed in various locations and patterns depending on conditions and tidal stage but mostly in an array of four drogues, spaced in equal distances and a perpendicular array in relation to the shoreline. During northward flowing conditions, the drogues were placed along such a transect parallel to south end of the array. During southward flows, the drogues were placed along the north end of the lease area.

GPS locations of the drogues were logged by use of a Garmin GPSmap 60CSx geographic positioning unit operated with WAAS enabled. The GPS antenna was held immediately over each drogue as the boat navigated by and the location recorded. Given the short distances involved in this survey, at least three locations were logged for each drogue within the lease area, with more recorded if the flows were slow. As the drogues passed the midway north to south part of the lease area, their location was recorded and another set of drogues were placed upstream. In this manner, usually eight drogues were deployed at any given time. Winds were not a factor in these surveys (Table 1) and GPS accuracy was acceptable, but not as good as normally experienced in Puget Sound.

Table 1. Field survey timing and concurrent predicted tidal and wind conditions.

Date	Time	Predicted Tidal Height(ft)	Predicted Tidal Change (ft)	High/Low Tide	Wind Velocity Range (mph)	Wind Velocity Average (mph)	GPS 95% confidence Interval
7/17/2015	5:30 AM	9.0’	3.4’	H	--	--	
7/17/2015	12:18 PM	-1.2’	**10.2’**	**L**	0 – 7	4.0	3.2 m
7/17/2015	19:32 PM	10.4’	**11.6’**	**H**	2 - 10	6.0	3.4 m
8/21/2015	10:13AM	7.7	5.7’	H	--	--	
8/21/2015	15:45 PM	4.9	**2.8’**	**L**	0 - 2	1.0	3.6 m
8/21/2015	21:55 PM	9.2	**4.3’**	**H**	0 - 2	0.5	3.4 m

The first survey day had both a large ebb and flood tidal exchange (10.2 and 11.6 ft respectively), while the second survey day was picked to be modestly low (2.8 and 4.3 respectively). These predictions were for the tidal station in Hood Canal near the entry to Port Gamble that is across the water body to the east.

For comparison, the mean tidal range at this station is 6.7’ and spring tides for this station are defined as 10.3’ elevation change. Thus, we sampled nearly matched large ebb and flood tides on the first sampling day and small ebb and flood tides on the second sampling day and bracketed the mean tidal amplitude values.

Results

Visual Drogue Distribution Plots

Detailed drogue tracks from both days surveys are included in this report's appendix. Figures 5 through 14 below condense and summarize the results for the general direction of most drogues during each indicated tidal period. Raw data with some data reduction are shown in Table 2 and 3 after the generalized drogue path charts.

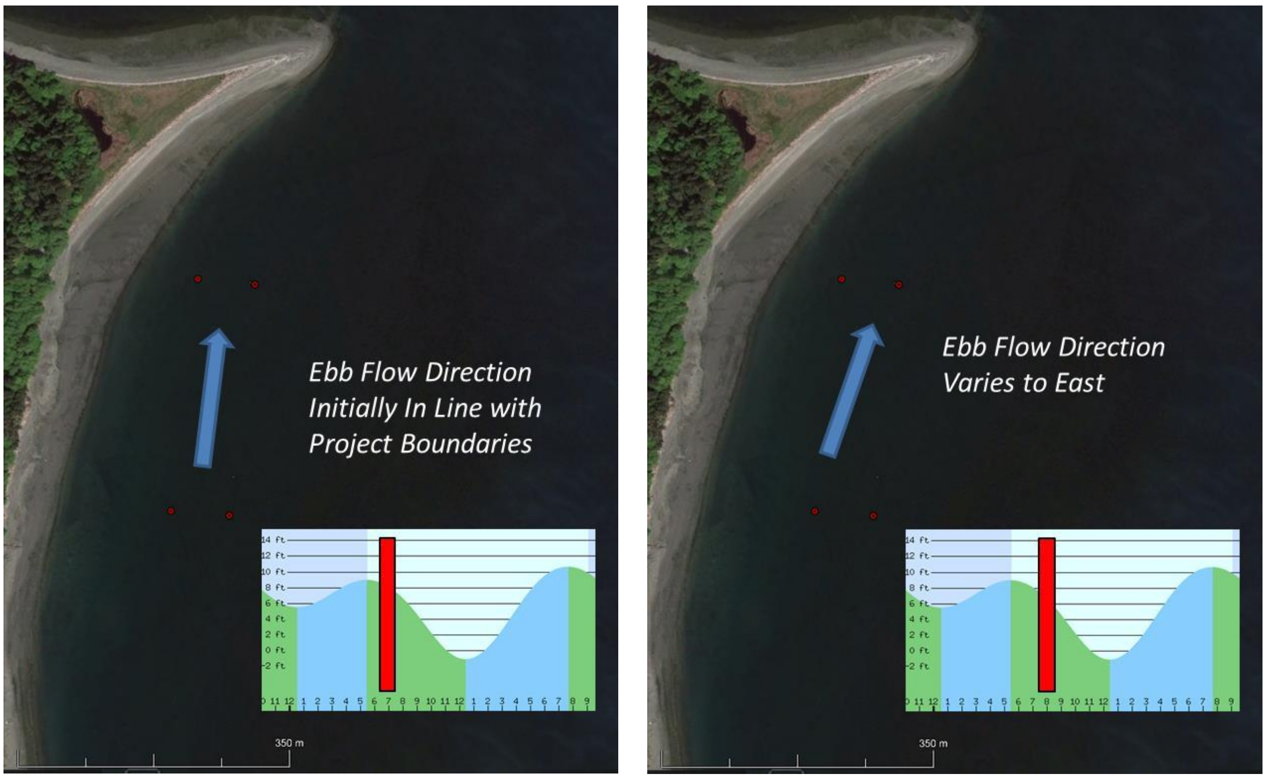


Figure 5. Generalized summary of flow directions for daytime ebb and flood of July 17, 2015.

Small red circles represent the four corners of the WDNR lease area for this project. Predicted tidal chart for Port Gamble Entry Tidal Station shown in lower right of each figure. Time of drogue monitoring represented for each figure indicated by the red vertical bar in the tidal chart. See appendix for more detailed plots of each drogue path used to make these generalized plots.

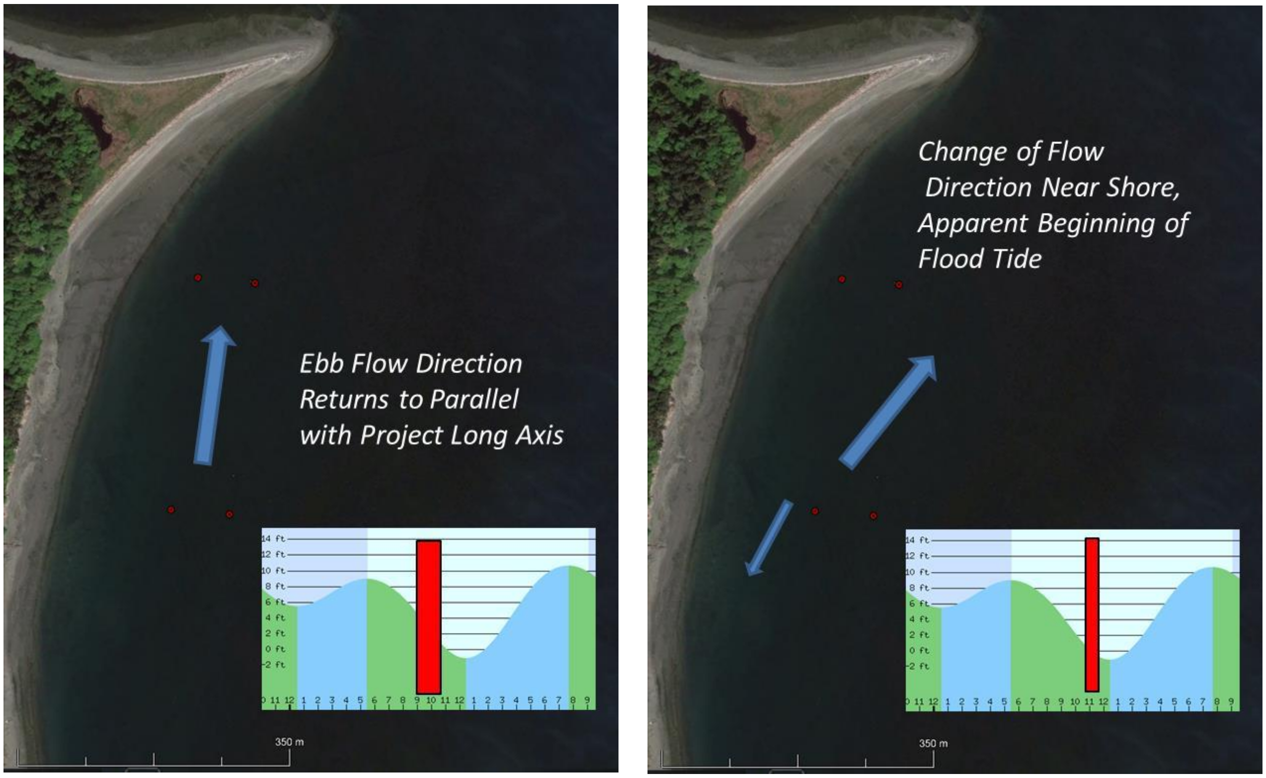


Figure 6. Generalized summary of flow directions for daytime ebb and flood of July 17, 2015.

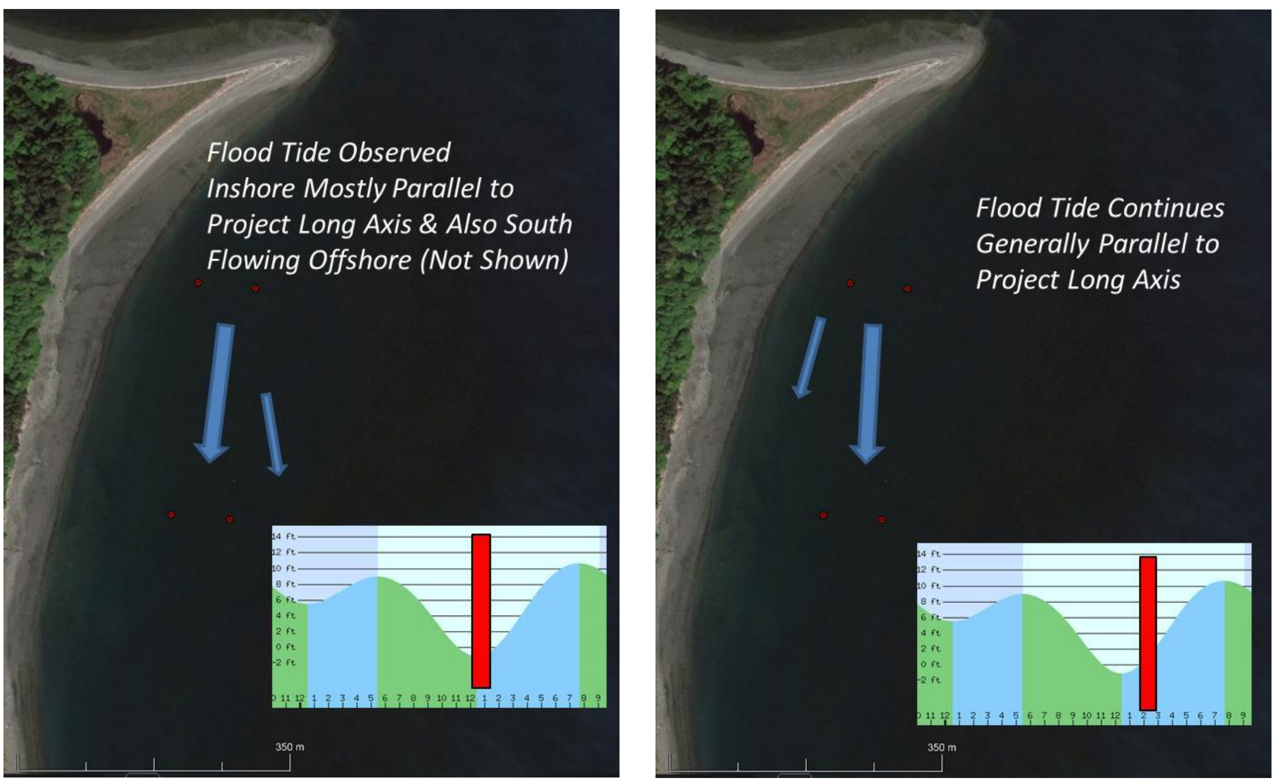


Figure 7. Generalized summary of flow directions for daytime ebb and flood of July 17, 2015.

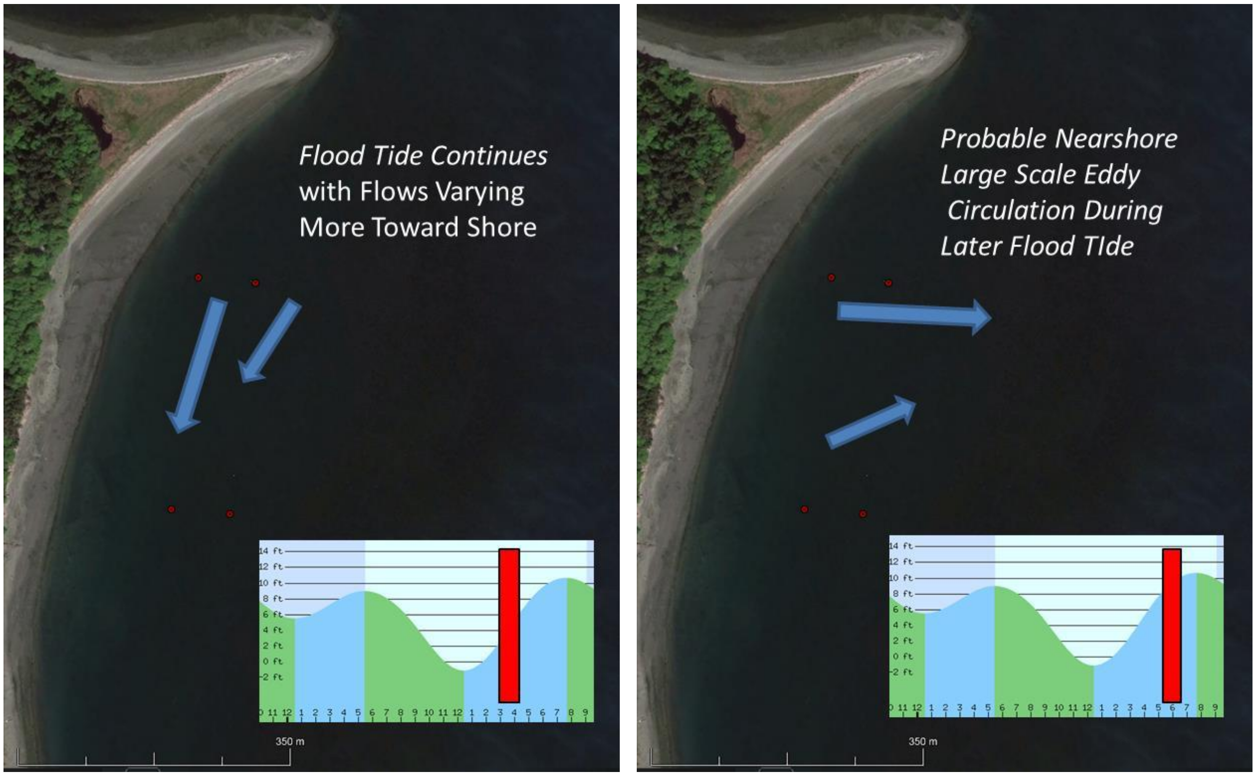


Figure 8. Generalized summary of flow directions for daytime ebb and flood of July 17, 2015.

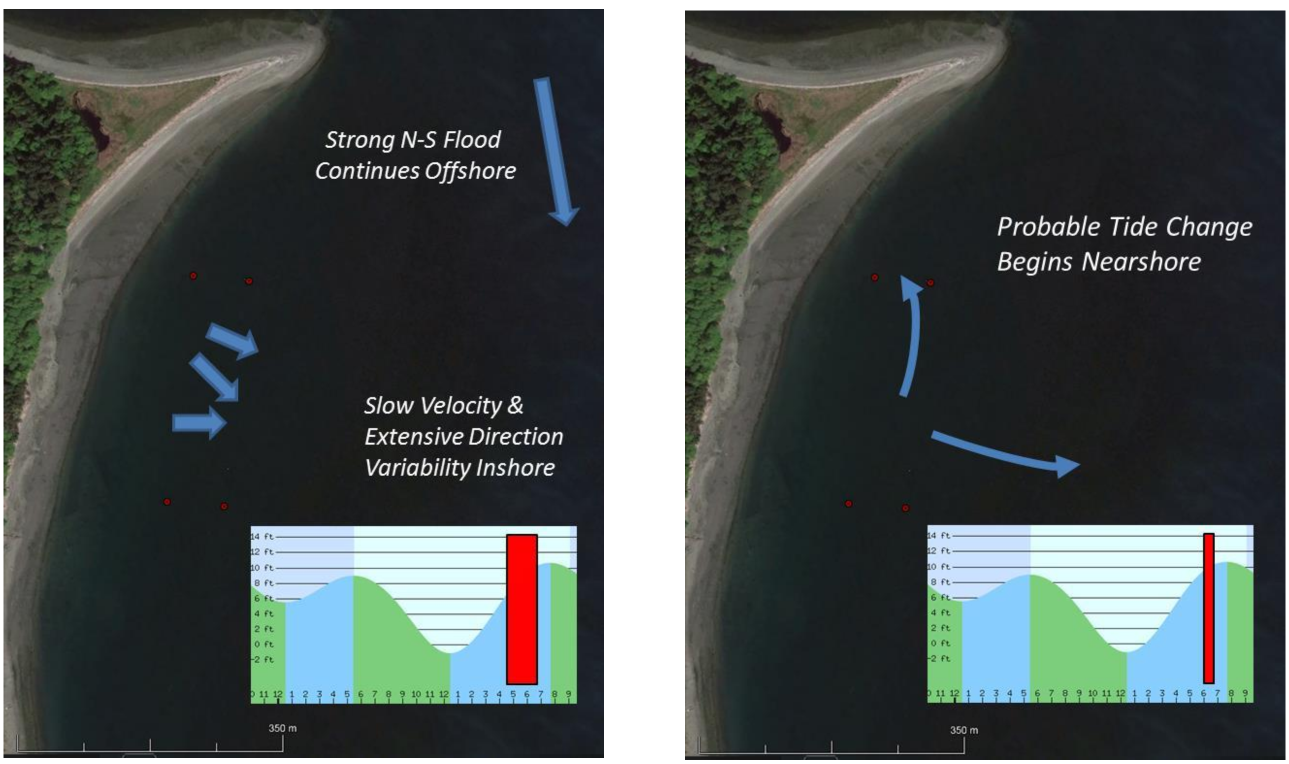


Figure 9. Generalized summary of flow directions for daytime ebb and flood of July 17, 2015.

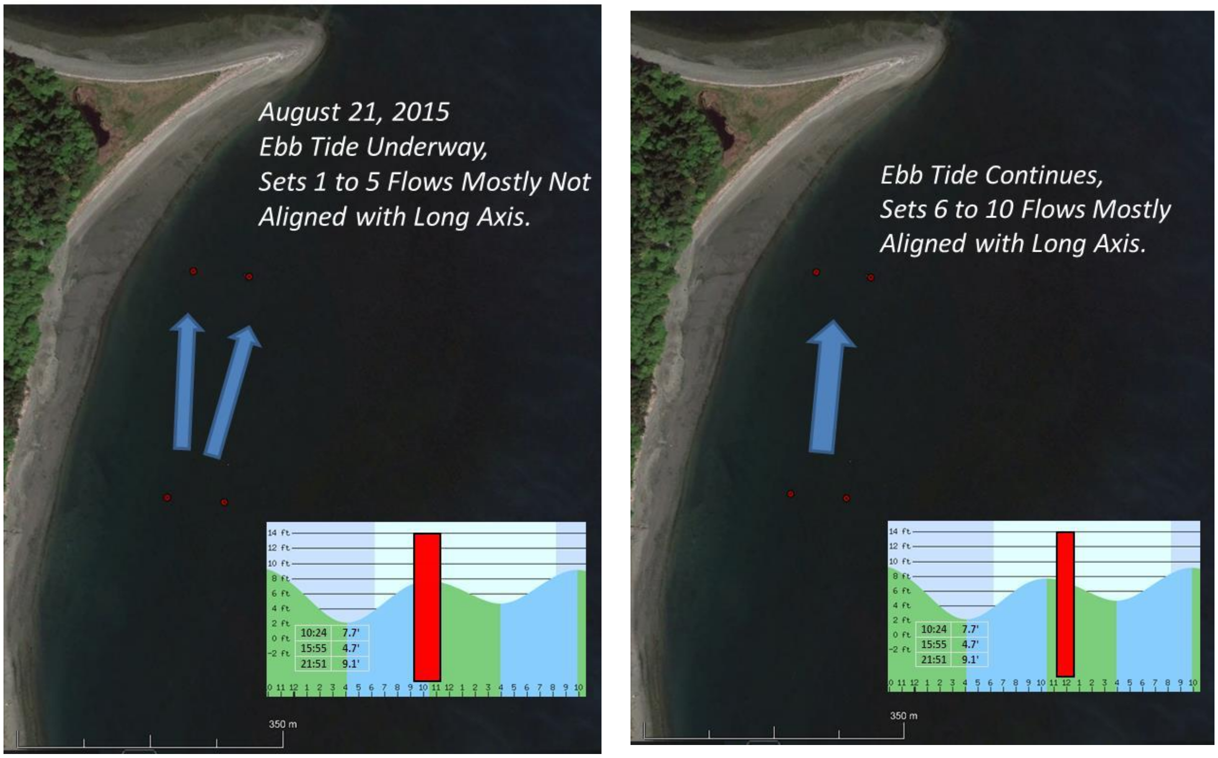


Figure 10. Generalized summary of flow directions for daytime ebb and flood of August 21, 2015, sets 1-5 left and sets 6-10 right.

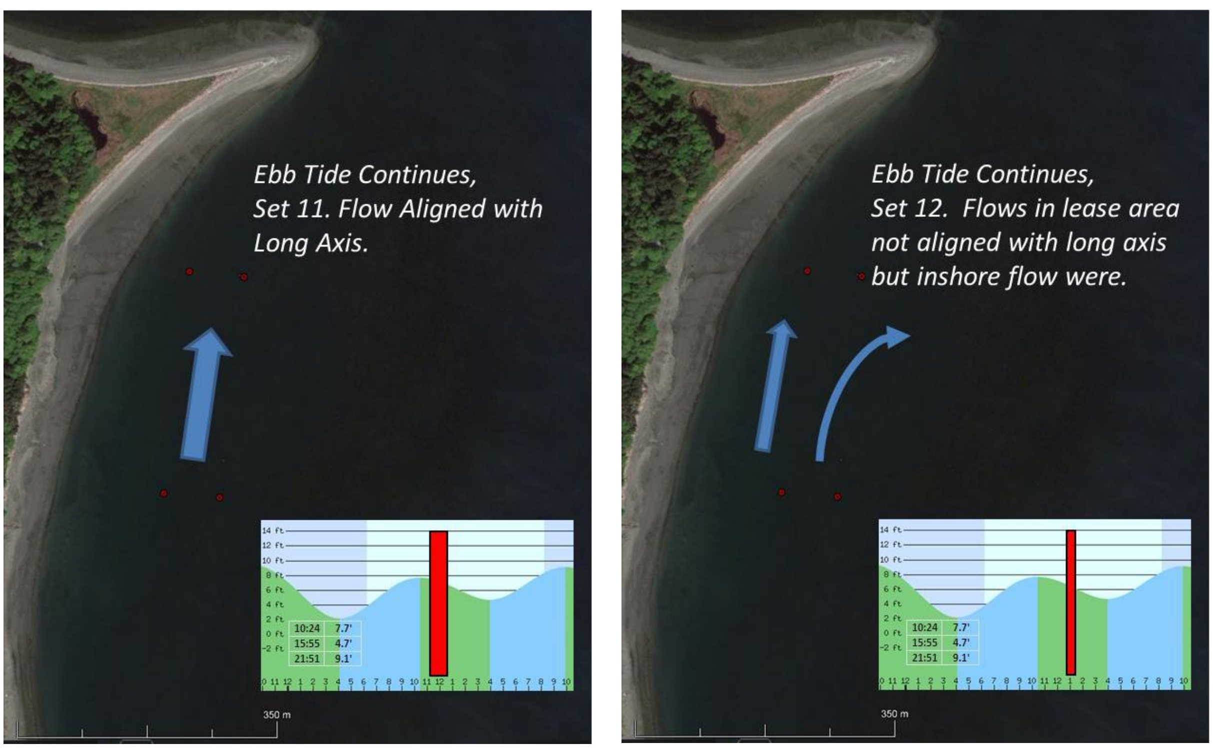


Figure 11. Generalized summary of flow directions for daytime ebb and flood of August 21, 2015, set 11 left and set 12 right.

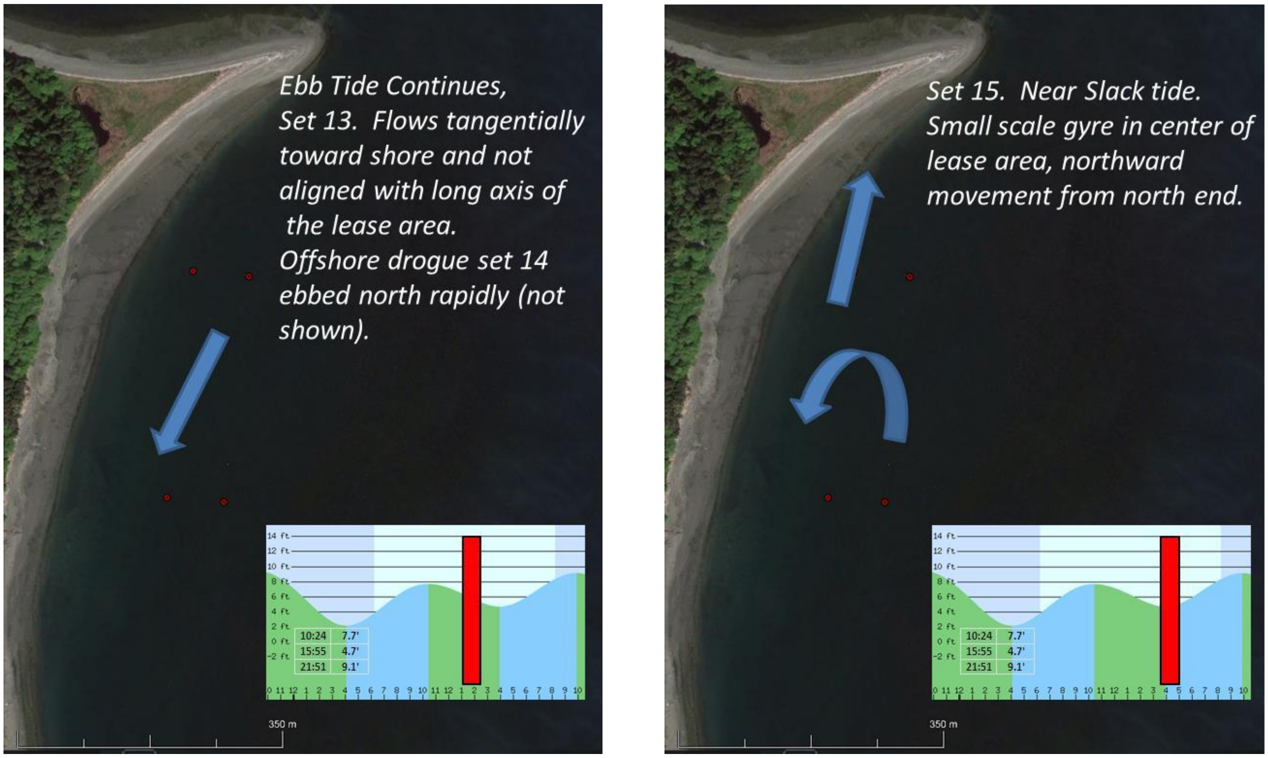


Figure 12. Generalized summary of flow directions for daytime ebb and flood of August 21, 2015, set 13 left and set 15 right. Sets 14 and 16 not shown for brevity.

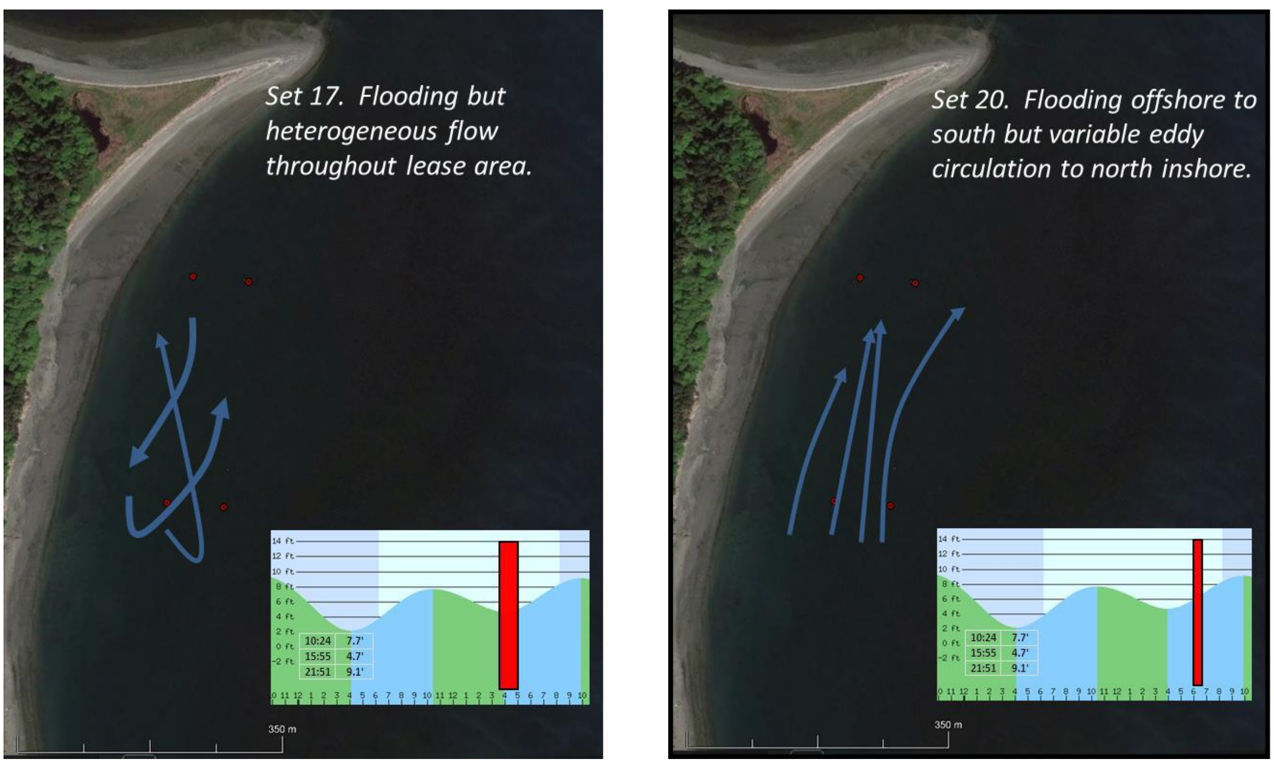


Figure 13. Generalized summary of flow directions for daytime ebb and flood of August 21, 2015, set 17 left and set 20 right.

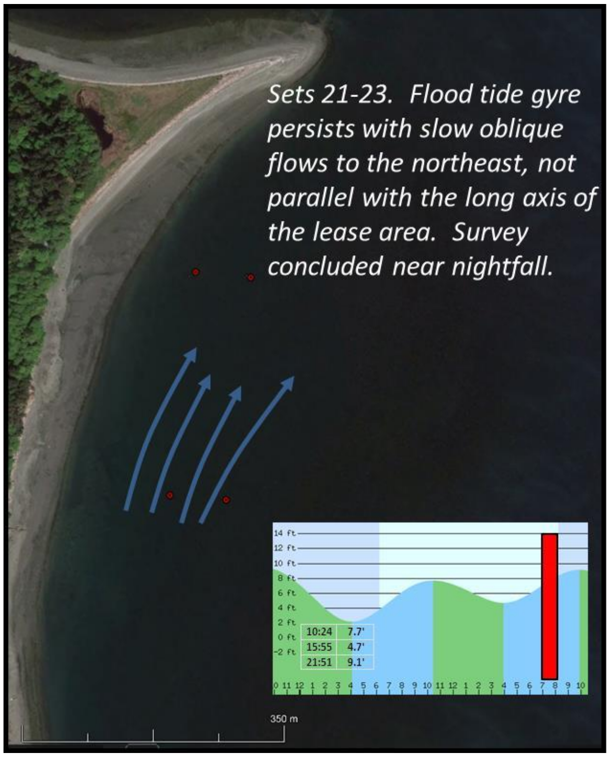


Figure 14. Generalized summary of flow directions for daytime ebb and flood of August 21, 2015, sets 21-23.

Tabular Data and Calculations

In this section data tables for all observations, inside and outside the lease area are reported in spreadsheet form. Several pages of this table follow. Important results are the five right columns indicating conditions in within the lease area only and periods of minimal direction variation from "straight through" the lease area flow. Bold entries in the "heading degrees True) column indicate measurements completely within the lease area only. These data are addressed in the next section of this report. These data are available to project team members in Excel format.

With regard to quality assurance: I inspected for outliers and improbable results and in two drogue tracks, I found to contain an error that were based on 10-minute time recording errors from my entries in the field. These errors were apparent by checking immediately prior and later entries in clusters of drogues released or measured at the same time so the corrections were obvious. In addition, a technician coded some of the first day's compass direction in either direction, inducing 180-degree errors. Every one of those data entries was replotted and checked by a separate worker to insure accuracy. All of the original data were correct, but some entries were 180 degrees incorrect by using the measuring tool in Google Earth in the wrong direction.

Table 2. Drogue survey data and calculations 27 July 2015.

27 July 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation	Elapsed Time < 5 degrees Variation
Set No. 1 Ebb																
1	S	21	25	39.4	6:49	6:59	10.0	233.1	38.9							
1	R	25	32	51.5	6:59	7:12	13.0	197.0	25.3	32.1	45.5					
2	S	22	26	40.0	6:49	7:00	11.0	276.8	41.9			41.9	12.0	11		
2	R	26	31	51.0	7:00	7:12	12.0	251.5	34.9	38.4	45.5					
3	S	23	27	36.4	6:52	7:00	10.0	321.2	53.5							
3	R	27	30	44.4	7:00	7:11	11.0	312.5	47.3	50.4	40.4					
4	S	24	28	39.2	6:52	7:01	11.0	348.6	52.8							
4	R	28	29	41.7	7:01	7:10	9.0	356.6	66.0	59.4	40.5					
									mean →	45.1	43.0	41.9	12.0			
									SD→	12.2	2.9	NA	NA			
Set No.2 Ebb																
3	S	33	38	**33.4**	7:15	7:23	8.0	227.8	47.5			47.5	5.4	8	8	
3	R	38	43	52.9	7:23	7:41	18.0	488.3	45.2	46.3	43.2					
4	S	34	39	**33.3**	7:15	7:23	8.0	249.4	52.0			52.0	5.3	8	8	
4	R	39	42	44.4	7:23	7:40	17.0	532.5	52.2	52.1	38.9					
5	S	35	40	40.1	7:15	7:24	9.0	265.1	49.1							
5	O	40	41	40.4	7:24	7:39	15.0	568.6	63.2	56.1	40.3					
									mean →	51.5	40.8	49.7	5.4			
									SD→	4.9	2.2	3.2	0.1			
Set No.3 Ebb																
1	S	47	51	**33.9**	8:10	8:19	9.0	148.8	27.6			27.6	28.0	9		
1	R	51	55	**48.7**	8:19	8:30	11.0	209.7	31.8	29.7	41.3	31.8	5.9	11	11	
2	S	48	52	**39.1**	8:11	8:19	8.0	173.0	36.0			36.0	20.7	8		
2	O	52	56	44.6	8:19	8:30	11.0	231.1	35.0							
2	R	56	61	31.9	8:30	8:47	17.0	471.3	46.2	39.1	38.5					
3	S	49	53	38.6	8:11	8:20	9.0	183.2	33.9							
3	O	53	57	43.2	8:20	8:31	11.0	252.6	38.3							
3	R	57	60	29.0	8:31	8:46	15.0	525.9	58.4	43.5	36.9					
4	S	52	54	34.2	8:12	8:20	8.0	199.7	41.6							
4	O	54	58	39.9	8:20	8:31	11.0	279.3	42.3							
4	R	58	59	14.3	8:31	8:45	14.0	483.4	57.6	47.2	29.5					
									mean →	39.9	36.6	31.8	18.2			
									SD→	7.6	5.1	4.2	11.3			
Set No.4 Ebb																
1	S	63	67	343.3	8:53	9:07	14.0	48.0	5.7							
1	R	67	82	201.9	9:07	9:31	24.0	38.5	2.7	4.2	272.6					
2	S	64	68	7.8	8:54	9:08	14.0	106.7	12.7							
2	R	68	81	298.6	9:08	9:30	22.0	52.3	4.0	8.3	153.2					
3	S	65	69	19.4	8:55	9:09	14.0	365.0	43.5							
3	O	69	80	**32.8**	9:09	9:28	19.0	407.2	35.7			35.71	4.8	19	19	19
3	R	80	83	32.2	9:28	9:36	8.0	92.3	19.2	32.8	28.1					
4	S	66	70	25.4	8:55	9:10	15.0	518.6	57.6							
4	R	70	79	34.7	9:10	9:26	16.0	660.9	68.8	63.2	30.1					
									mean →	27.1	121.0	20.0	8.0			
									SD→	27.2	116.8	22.3	4.6			
Set No.5 Ebb																
5	S	71	75	**29.8**	9:14	9:24	10.0	191.3	31.9				1.8	10	10	10
5	R	75	84	44.9	9:24	9:37	13.0	297.9	38.2	35.0	37.4					
6	S	72	76	**30.0**	9:15	9:24	9.0	287.6	53.3				2.0	9	9	9
6	R	76	85	45.7	9:24	9:38	14.0	264.3	31.5	42.4	37.9					
7	S	73	77	**27.3**	9:15	9:25	10.0	309.6	51.6				0.7	10	10	10
7	R	77	86	42.3	9:25	9:40	15.0	466.8	51.9	51.7	34.8					
8	S	74	78	28.6	9:15	9:25	10.0	339.0	56.5							
8	R	78	87	29.6	9:25	9:41	16.0	620.0	64.6	60.5	29.1					
									mean →	47.4	34.8	21.1	3.4			
									SD→	11.1	4.0	1.6	2.9			
Set No.6 Ebb																
1	S	88	92	**22.2**	9:53	10:00	7.0	77.3	18.4			18.4	5.8	7	7	
1	O	92	96	**41.5**	10:00	10:11	11.0	75.5	11.4			11.4	13.5	11		
1	O	96	103	**79.2**	10:11	10:27	16.0	131.7	13.7			13.7	51.2	16		
1	R	103	105	28.7	10:27	10:42	15.0	255.3	28.4	18.0	42.9					
2	S	89	93	**25.1**	9:53	10:01	8.0	147.3	30.7			30.7	2.9	8	8	8
2	O	93	97	49.5	10:01	10:12	11.0	152.8	23.2							
2	O	97	102	20.8	10:12	10:26	14.0	115.3	13.7							
2	R	102	104	230.1	10:26	10:40	14.0	98.0	11.7	19.8	81.4					
3	S	90	94	26.3	9:54	10:01	7.0	184.7	44.0							
3	O	94	98	30.3	10:01	10:12	11.0	189.3	28.7							
3	O	98	101	44.1	10:12	10:25	13.0	101.6	13.0							
3	R	101	106	27.8	10:25	10:43	18.0	11.4	1.1	21.7	32.1					
4	S	91	95	**30.0**	9:54	10:02	8.0	221.5	46.1			46.1	2.0	8	8	8
4	O	95	99	38.4	10:02	10:13	11.0	277.9	42.1							
4	R	99	100	19.6	10:13	10:24	11.0	344.7	52.2	46.8	29.3					
									mean →	26.6	46.4	38.4	2.5			
									SD→	13.6	24.0	10.9	0.6			

27 July 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation	Elapsed Time < 5 degrees Variation
Set No.7 Ebb																
1	S	107	114	211.2	10:48	11:02	14.0	6.7	0.8							
1	R	114	118	217.9	11:02	11:17	15.0	144.0	16.0	8.4	214.5					
2	S	108	113	**49.5**	10:49	11:01	12.0	101.5	14.1			14.1	21.5	12		
2	R	113	117	53.0	11:01	11:15	14.0	336.0	40.0	27.0	51.3					
3	S	109	112	**46.4**	10:52	11:00	10.0	230.5	38.4			38.4	18.4	10		
3	R	112	116	12.9	11:00	11:14	14.0	212.9	25.3	31.9	29.7					
4	S	110	111	37.9	10:52	10:59	9.0	284.2	52.6							
4	R	111	115	28.8	10:59	11:13	14.0	259.3	30.9	41.7	33.4					
									mean →	27.3	82.2	25.5	10.7			
									SD→	14.0	88.7	15.0	10.7			
Set No.8 Near Slack																
1	S	119	123	208.9	11:20	11:23	3.0	40.0	22.2							
1	O	123	127	232.4	11:23	11:29	6.0	56.2	15.6							
1	O	127	131	244.3	11:29	11:35	6.0	44.9	12.5							
1	R	131	135	218.2	11:35	11:47	12.0	154.4	21.4	17.9	226.0					
2	S	120	124	**172.3**	11:20	11:24	4.0	37.2	15.5			15.5	35.7	4		
2	O	124	128	85.8	11:24	11:29	5.0	48.9	16.3							
2	O	128	132	52.2	11:29	11:36	7.0	67.2	16.0							
2	R	132	136	41.5	11:36	11:52	14.0	56.3	6.7	13.6	88.0					
3	S	121	125	106.7	11:21	11:24	3.0	32.9	18.3							
3	O	125	129	47.9	11:24	11:30	6.0	95.0	26.4							
3	O	129	133	23.6	11:30	11:36	6.0	52.8	14.7							
3	R	133	137	302.3	11:36	11:51	15.0	25.8	2.9	15.6	120.1					
4	S	122	126	23.7	11:21	11:25	4.0	94.7	39.5							
4	O	126	130	344.6	11:25	11:30	5.0	37.3	12.4							
4	O	130	134	216.4	11:30	11:37	7.0	78.4	18.7							
4	R	134	138	198.7	11:37	11:51	14.0	92.8	11.0	20.4	195.8					
									mean →	16.9	157.5	15.5	35.7			
									SD→	2.9	64.3	NA	NA			
Set No.9 Flood Begins																
1	S	139	143	**206.6**	11:53	12:03	10.0	152.1	25.4			25.4	1.4	10	10	
1	R	143	147	212.4	12:03	12:11	8.0	136.4	28.4	26.9	209.5					
2	S	140	144	**202.4**	11:54	12:04	10.0	146.4	24.4			24.4	5.6	10	10	
2	R	144	148	218.0	12:04	12:12	8.0	65.4	13.6	19.0	210.2					
3	S	141	145	**215.0**	11:54	12:04	10.0	104.4	17.4			17.4	7.0	10	10	
3	R	145	149	229.2	12:04	12:13	9.0	105.3	19.5	18.5	222.1					
4	S	142	146	170.0	11:55	12:05	10.0	27.1	4.5							
4	R	146	152	145.9	12:05	12:14	9.0	12.1	2.2	3.4	158.0					
									mean →	16.9	199.9	20.7	12.4			
									SD→	9.8	28.6	4.9	15.7			
Set No.10 Begin Flood																
1	S	151	155	219.4	12:21	12:29	8.0	116.7	24.3							
1	O	155	159	212.0	12:29	12:41	12.0	178.3	24.8							
1	R	159	163	214.5	12:41	12:48	7.0	136.6	32.5	27.2	215.3					
2	S	152	156	**209.9**	12:22	12:30	8.0	113.0	23.6			23.6	1.9	8	8	8
2	O	156	160	**212.3**	12:30	12:41	11.0	182.3	27.6			27.6	4.3	11		11
2	R	160	164	212.2	12:41	12:48	7.0	138.9	33.1	28.1	211.5					
3	S	153	157	**209.8**	12:22	12:31	9.0	120.1	22.2			22.2	1.8	9	9	9
3	O	157	161	**217.3**	12:31	12:41	10.0	182.4	30.4			30.4	9.3	10	10	
3	R	161	165	223.8	12:41	12:48	7.0	136.5	32.5	28.4	217.0					
4	S	154	158	213.7	12:22	12:31	9.0	115.7	21.4							
4	O	158	162	221.0	12:31	12:42	11.0	163.0	24.7							
4	R	162	166	231.4	12:42	12:49	7.0	86.4	20.6	22.2	222.0					
									mean →	26.5	216.4	26.0	4.3			
									SD→	2.9	4.4	3.7	3.5			
Set No.11 Flood																
1	S	167	171	224.2	13:03	13:12	9.0	137.1	25.4							
1	R	171	175	216.1	13:12	13:20	8.0	124.2	25.9	25.6	220.2					
2	S	168	172	**217.5**	13:03	13:13	10.0	196.1	32.7			32.7	9.5	10	10	
2	R	172	176	**208.1**	13:13	13:21	8.0	209.1	43.6	38.1	212.8	43.6	0.1	8	8	8
3	S	169	173	**217.9**	13:04	13:13	9.0	220.2	40.8			40.8	9.9	9	9	
3	R	173	177	**218.5**	13:13	13:21	8.0	191.7	39.9	40.4	218.2	39.9	10.5	8		
4	S	170	174	221.2	13:04	13:14	10.0	199.2	33.2							
4	R	174	178	223.7	13:14	13:22	8.0	160.7	33.5	33.3	222.5					
									mean →	34.4	218.4	39.2	7.5			
									SD→	6.5	4.1	4.6	5.0			
Set No.12 Flood																
1	S	179	183	205.7	13:32	13:43	11.0	207.5	31.4							
1	R	183	187	233.7	13:43	13:51	8.0	130.3	27.2	29.3	219.7					
2	S	180	184	**214.8**	13:32	13:44	12.0	214.3	29.8			29.8	6.8	12	12	
2	R	184	188	**210.9**	13:44	13:52	8.0	164.9	34.3	32.1	212.9	34.3	2.9	8	8	8
3	S	181	185	**208.4**	13:32	13:44	12.0	232.9	32.3			32.3	0.4	12	12	12
3	R	185	189	**210.3**	13:44	13:52	8.0	155.8	43.0	34.8	189.5	43.0	8.2	7	7	7
4	S	182	186	**123.0**	13:33	13:45	12.0	151.2	21.0			21.0	85.0	12		
4	R	186	190	216.2	13:45	13:52	7.0	180.4	43.0	32.0	169.6					
									mean →	32.0	197.9	32.1	20.7			
									SD→	2.3	22.9	7.9	36.1			

27 July 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area
Set No.13 Flood														
1	S	191	195	216.0	14:07	14:15	8.0	64.1	13.4					
1	O	195	199	219.5	14:15	14:24	9.0	35.3	6.5					
1	R	199	203	258.0	14:24	14:33	9.0	11.4	2.1	7.3	231.2			
2	S	192	196	**217.5**	14:07	14:16	9.0	72.1	13.3			13.3	9.5	9
2	O	196	200	**235.2**	14:16	14:24	8.0	58.7	12.2			12.2	27.2	8
2	R	200	204	277.6	14:24	14:34	10.0	26.6	4.4	10.0	243.4			
3	S	193	197	**228.1**	14:07	14:16	9.0	58.7	10.9			10.9	20.1	9
3	O	197	201	**246.6**	14:16	14:26	10.0	66.0	11.0			11.0	38.6	10
3	R	201	205	271.5	14:26	14:34	8.0	42.8	8.9	10.3	248.7			
4	S	194	198	242.6	14:07	14:16	9.0	92.0	17.0					
4	O	198	202	253.4	14:16	14:26	10.0	94.1	15.7					
4	R	202	206	261.6	14:26	14:35	9.0	47.4	8.8	13.8	252.5			
									mean →	10.4	244.0	11.9	23.9	
									SD→	2.7	9.3	1.2	12.2	
Set No.14 Flood														
1	S	207	211	212.5	14:52	14:59	9.0	16.7	3.1					
1	O	211	215	218.1	14:59	15:13	14.0	222.8	26.5					
1	R	215	219	214.3	15:13	15:20	7.0	105.7	25.2	18.9	215.0			
2	S	208	212	**180.0**	14:52	14:59	9.0	26.4	4.9			4.9	28.0	9
2	O	212	216	**209.8**	14:59	15:14	15.0	225.0	25.0			25.0	1.8	15
2	R	216	220	**213.8**	15:14	15:21	7.0	123.2	29.3	21.3	201.2	29.3	5.8	7
3	S	209	213	**189.5**	14:51	15:00	9.0	52.1	9.6			9.6	18.5	9
3	O	213	217	**212.0**	15:00	15:14	14.0	210.9	25.1			25.1	4.0	14
3	R	217	221	**220.8**	15:14	15:22	8.0	122.3	25.5	22.0	207.4	25.5	12.8	8
4	S	210	214	205.7	14:51	15:00	9.0	83.9	15.5					
4	O	214	218	215.4	15:00	15:14	14.0	216.4	25.8					
4	R	218	222	223.4	15:14	15:22	8.0	117.2	24.4	25.1	214.8			
									mean →	21.8	209.6	19.9	11.8	
									SD→	2.6	6.6	10.0	10.1	
Set No.15 Ebb														
1	S	223	227	21.2	15:29	15:40	11.0	29.0	4.4					
1	R	227	235	74.4	15:40	15:56	16.0	90.4	9.4	6.9	47.8			
2	S	224	228	**81.9**	15:30	15:41	11.0	31.4	4.8			4.8	53.9	11
2	R	228	236	97.1	15:41	15:57	16.0	130.5	13.6	9.2	89.5			
3	S	225	229	**89.0**	15:30	15:41	11.0	30.8	4.7			4.7	61.0	11
3	R	229	237	103.0	15:41	15:57	16.0	137.3	14.3	9.5	96.0			
									mean →	8.5	77.8	4.7	57.5	
									SD→	1.4	26.2	0.1	5.0	
Set No.16 Ebb														
5	S	226	231	93.1	15:38	15:43	5.0	10.1	3.4					
5	R	231	240	65.5	15:43	16:03	20.0	129.1	10.8	7.1	79.3			
6	S/R	232	239	**96.3**	15:45	16:01	16.0	155.2	16.2	16.2	85.0	16.2	68.3	16
7	S/R	233	241	**77.7**	15:45	16:04	19.0	120.5	10.6	10.6	83.2	10.6	49.7	19
8	S/R	234	241*	**48.9**	15:46	16:05	19.0	98.0	8.6	8.6	72.1	8.6	20.9	19
									mean →	10.6	79.9	11.8	46.3	
									SD→	4.0	5.7	3.9	23.9	
Set No.17 Ebb														
1	S	242	251	**48.7**	16:06	16:28	22.0	176.9	13.4			13.4	20.7	22
1	R	251	256	**73.7**	16:28	16:33	5.0	46.1	15.4	14.4	61.2	15.4	45.7	5
2	S	243	252	**56.5**	16:07	16:29	22.0	208.4	15.8			15.8	28.5	22
2	R	252	257	**74.1**	16:29	16:33	4.0	26.6	11.1	13.4	65.3	11.1	46.1	4
3	S	244	247	**53.4**	16:08	16:17	9.0	92.3	17.1			17.1	25.4	9
3	O	247	253	67.0	16:17	16:29	12.0	127.1	17.7					
3	R	253	258	167.4	16:29	16:34	5.0	5.0	1.7	11.8	95.9			
4	S	245	254	60.1	16:08	16:29	21.0	202.2	16.0					
4	R	254	259	213.3	16:29	16:34	5.0	15.2	5.1	10.6	136.7			
7	S/R	249	252	208.3	16:21	16:26	5.0	59.1	19.7	19.7	162.3			
8	S	246	248	49.3	16:11	16:19	8.0	65.8	13.7					
8	R	248	255	112.3	16:19	16:30	11.0	74.9	11.3	12.5	80.8			
									mean →	13.7	100.4	14.5	33.3	
									SD→	3.2	40.8	2.3	11.9	

27 July 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation	Elapsed Time < 5 degrees Variation
Set No.18 Ebb																
1	S	260	264	**66.4**	16:43	16:53	10.0	63.1	10.5			10.5	38.4	10		
1	O	264	269	184.6	16:53	17:03	10.0	54.5	9.1							
1	O	269	274	169.1	17:03	17:20	17.0	30.8	3.0							
1	R	274	283	132.9	17:20	17:34	14.0	56.4	6.7	7.3	138.3					
2	S	261	265	**98.5**	16:43	16:53	10.0	47.7	8.0			8.0	70.5	10		
2	O	265	270	169.3	16:53	17:03	10.0	30.2	5.0							
2	O	270	275	149.4	17:03	17:20	17.0	72.1	7.1							
2	R	275	284	129.2	17:20	17:35	15.0	93.4	10.4	7.6	136.6					
3	S	262	266	**135.1**	16:44	16:54	10.0	23.4	3.9			3.9	72.9	10		
3	O	266	271	229.8	16:54	17:04	10.0	32.7	5.4							
3	O	271	276	181.4	17:04	17:21	17.0	52.3	5.1							
3	R	276	285	92.5	17:21	17:35	14.0	73.0	8.7	5.8	159.7					
4	S	263	267	**193.5**	16:44	16:54	10.0	42.9	7.1			7.1	14.5	10		
4	O	267	272	201.1	16:54	17:04	10.0	47.1	7.8							
4	O	272	277	207.9	17:04	17:21	17.0	75.5	7.4							
4	R	277	286	72.9	17:21	17:36	15.0	80.5	8.9	7.8	168.8					
8	S	268	273	157.2	16:59	17:06	7.0	110.8	26.4							
8	O	273	278	163.5	17:06	17:23	17.0	327.1	32.1							
8	R	278	291	170.0	17:23	17:45	22.0	316.7	24.0	28.0	163.6					
									mean →	11.3	153.4	7.4	49.1			
									SD→	9.4	14.9	2.7	27.9			
Set No.19 Ebb																
1	S	287	292	**116.7**	17:41	17:55	14.0	29.8	3.5			3.5	88.7	14		
1	R	292	296	84.5	17:55	18:10	15.0	28.3	3.1	3.3	100.6					
2	S	288	293	**110.0**	17:41	17:55	14.0	39.8	4.7			4.7	82.0	14		
2	R	293	297	78.9	17:55	18:11	16.0	7.5	0.8	2.8	94.5					
3	S	289	294	**141.8**	17:41	17:56	15.0	46.5	5.2			5.2	113.8	15		
3	R	294	298	14.0	17:56	18:11	15.0	13.1	1.5	3.3	77.9					
4	S	290	295	166.1	17:42	17:56	14.0	52.3	6.2							
4	R	295	299	140.1	17:56	18:12	16.0	39.5	4.1	5.2	153.1					
									mean →	3.6	106.5	4.5	94.8			
									SD→	1.1	32.5	0.8	16.8			
Set No.19 Ebb																
1	S	300	304	**43.4**	18:14	18:25	11.0	33.1	5.0			5.0	15.4	11		
1	O	304	309	**18.5**	18:25	18:29	4.0	42.4	17.7			17.7	9.5	4	4	
1	R	309	315	**77.5**	18:29	18:53	24.0	16.1	1.1	8.5	46.5	1.1	49.5	24		
2	S	301	305	**86.0**	18:14	18:26	12.0	47.2	6.6			6.6	58.0	12		
2	O	305	310	**8.8**	18:26	18:40	14.0	79.3	9.4			9.4	19.2	14		
2	R	310	316	178.5	18:40	18:54	14.0	64.3	7.7	7.3	91.1					
3	S	302	306	**78.3**	18:15	18:27	12.0	33.8	4.7			4.7	50.3	12		
3	O	306	311	47.5	18:27	18:40	13.0	57.9	7.4							
3	R	311	314	18.3	18:40	18:52	12.0	46.4	6.4	6.4	48.0					
4	S	303	307	127.7	18:15	18:27	12.0	39.4	5.5							
4	O	307	308	97.2	18:27	18:34	7.0	35.3	8.4							
4	O	308	312	93.6	18:34	18:41	7.0	72.4	17.2							
4	R	312	313	94.7	18:41	18:52	9.0	127.1	23.5	13.7	103.3					
									mean →	9.0	72.2	7.4	33.7			
									SD→	3.2	29.3	5.7	21.2			

Table 3. Drogue survey data and calculations 21 August 2015

21 Aug. 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation	Elapsed Time < 5 degrees Variation
Set No. 1 Ebb																
1	S	1	5	30.2	9:18	9:27	9.0	61.92	11.5							
1	R	5	15	28.8	9:27	9:52	25.0	234.89	15.7	13.6	29.5					
2	S	2	6	22.5	9:18	9:27	9.0	79.98	14.8							
2	R	6	16	26.3	9:27	9:53	26.0	225.64	14.5	14.6	24.4					
3	S	3	7	23.7	9:19	9:28	9.0	97.33	18.0							
3	R	7	17	25.4	9:28	9:54	26.0	241.72	15.5	16.8	24.6					
4	S	4	8	**18.0**	9:19	9:28	9.0	101.82	18.9			18.9	10.0	9	9	
4	R	8	18	**24.1**	9:28	9:54	26.0	246.89	15.8	17.3	21.0	24.1	3.91	26	26	26
									mean →	**15.6**	**24.9**	**21.5**	**7.0**			
									SD→	**1.8**	**3.5**	**3.7**	**4.3**			
Set No. 2 Ebb																
5	S	11	23	37.8	9:50	10:14	24.0	226.24	15.7							
5	R	23	35	44.8	10:14	10:29	15.0	155.24	17.2	16.5	41.3					
6	S	12	24	42.9	9:50	10:15	25.0	264.51	17.6							
6	R	24	40	46.2	10:15	10:30	15.0	181.93	20.2	18.9	44.5					
7	S	13	25	**41.5**	9:50	10:15	25.0	282.14	18.8			9.2	13.5	25		
7	R	25	37	**44.3**	10:15	10:31	16.0	171.3	17.8	18.3	42.9	10.2	16.3	16		
8	S	14	26	**41.2**	9:51	10:15	24.0	294.94	20.5			7.5	13.2	24		
8	R	26	38	**43.8**	10:15	10:31	16.0	202.13	21.1	20.8	42.5	6.9	15.8	16		
									mean →	**18.6**	**42.8**	**8.5**	**14.7**			
									SD→	**1.8**	**1.3**	**1.5**	**1.6**			
Set No. 3 Ebb																
1	S	27	31	40.3	10:18	10:27	9.0	119.82	22.2							
1	O	31	39	41.4	10:27	10:33	6.0	78.91	21.9							
1	R	39	48	47.2	10:33	10:44	11.0	112.33	17.0	20.4	43.0					
2	S	28	32	40.6	10:18	10:27	9.0	114.31	21.2							
2	O	32	40	40.4	10:27	10:34	7.0	79.71	19.0							
2	R	40	49	43.4	10:34	10:44	10.0	146.85	24.5	21.5	41.5					
3	S	29	33	**35.3**	10:19	10:27	8.0	119.83	25.0			3.0	7.3	8	8	
3	O	33	41	**38.4**	10:27	10:34	7.0	84.42	20.1			7.9	10.4	7		
3	R	41	50	**42.9**	10:34	10:45	11.0	147.81	22.4	22.5	38.9	5.6	14.9	11		
4	S	30	34	**31.1**	10:19	10:27	8.0	128.32	26.7			1.3	3.1	8	8	
4	O	34	42	**38.3**	10:27	10:34	10.0	89.45	23.0			5.0	6.7	10	10	
4	R	42	51	**42.9**	10:34	10:45	11.0	145	22.0	23.9	37.4	6.0	14.9	11		
									mean →	**22.1**	**40.2**	**4.8**	**9.6**			
									SD→	**1.5**	**2.5**	**2.3**	**4.7**			
Set No.4 Ebb																
5	S	44	52	34.7	10:39	10:49	10.0	137.78	23.0							
5	R	52	60	42.6	10:49	11:02	13.0	174.26	22.3	22.7	38.7					
6	S	45	53	31.8	10:39	10:49	10.0	149.04	24.8							
6	R	53	61	39.8	10:49	11:02	13.0	181.61	23.3	24.1	35.8					
7	S	46	54	**29.6**	10:39	10:49	10.0	153.49	25.6			2.4	1.6	10	10	10
7	R	54	62	**37.7**	10:49	11:02	13.0	187.1	24.0	24.8	33.7	4.0	9.7	13	13	
8	S	47	55	**32.3**	10:40	10:50	10.0	155.86	26.0			2.0	4.3	10	10	10
8	R	55	63	**38.2**	10:50	11:02	12.0	195.76	27.2	26.6	35.3	0.8	10.2	12		
									mean →	**24.5**	**35.8**	**2.3**	**6.5**			
									SD→	**1.6**	**2.1**	**1.3**	**4.2**			
Set No. 5 Ebb																
1	S	56	64	31.1	10:54	11:05	11.0	160.92	24.4							
1	O	64	72	33.5	11:05	11:10	5.0	73.46	24.5							
1	R	72	76	32.7	11:10	11:14	4.0	54.73	22.8	23.9	32.4					
2	S	57	65	27.6	10:54	11:05	11.0	171.38	26.0							
2	O	65	73	32.6	11:05	11:10	5.0	78.85	26.3							
2	R	73	77	35.1	11:10	11:14	4.0	58.73	24.5	25.6	31.8					
3	S	58	66	**27.7**	10:54	11:06	12.0	185.44	25.8			2.2	0.3	12	12	12
3	O	66	74	**31.1**	11:06	11:11	5.0	78.7	26.2			1.8	3.1	5	5	5
3	R	74	78	**40.5**	11:11	11:15	4.0	66.91	27.9	26.6	33.1	0.1	12.5	4		
4	S	59	67	**29.7**	10:55	11:06	11.0	199.3	30.2			2.2	1.7	11	11	11
4	O	67	75	**33.7**	11:06	11:11	5.0	89.03	29.7			1.7	5.7	5	5	
4	R	75	79	**35.7**	11:11	11:15	4.0	70.97	29.6	29.8	33.0	1.6	7.7	4	4	4
									mean →	**26.5**	**32.6**	**1.6**	**5.2**			
									SD→	**2.5**	**0.6**	**0.8**	**4.5**			

21 Aug. 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation	Elapsed Time < 5 degrees Variation
Set no. 6 Ebb																
5	S	68	80	30.5	11:07	11:18	11.0	170.91	25.9							
5	R	80	88	30.1	11:18	11:24	6.0	111.86	31.1	28.5	30.3					
6	S	69	81	26.2	11:08	11:18	10.0	177.11	29.5							
6	R	81	89	27.2	11:18	11:25	7.0	124.83	29.7	29.6	26.7					
7	S	70	82	**25.9**	11:08	11:18	10.0	196.95	32.8			4.8	2.1	10	10	10
7	R	82	90	**35.8**	11:18	11:25	7.0	120.51	28.7	30.8	30.8	0.7	7.8	7	7	
8	S	71	83	**26.5**	11:08	11:18	10.0	207.8	34.6			6.6	1.5	10	10	10
8	R	83	91	**30.3**	11:18	11:25	7.0	131.87	31.4	33.0	28.4	3.4	2.3	7	7	7
									mean →	**30.5**	**29.1**	**3.9**	**3.4**			
									SD→	**1.9**	**1.9**	**2.5**	**2.9**			
Set No.7 Ebb																
1	S	84	92	28.0	11:20	11:30	10.0	182.9	30.5							
1	R	92	100	32.9	11:30	11:40	10.0	106.39	17.7	24.1	30.4					
2	S	85	93	23.3	11:20	11:30	10.0	190.28	31.7							
2	R	93	101	31.5	11:30	11:37	7.0	111.76	26.6	29.2	27.4					
3	S	86	94	**25.7**	11:21	11:31	10.0	206.57	34.4			6.4	2.3	10	10	10
3	R	94	102	**34.3**	11:31	11:37	6.0	129.71	36.0	35.2	30.0	8.0	6.3	6	6	
4	S	87	95	**30.5**	11:21	11:31	10.0	218.34	36.4			8.4	2.5	10	10	10
4	R	95	103	**33.3**	11:31	11:37	6.0	128.21	35.6	36.0	31.9	7.6	5.3	6	10	
									mean →	**31.1**	**29.9**	**7.6**	**4.1**			
									SD→	**5.6**	**1.9**	**0.9**	**2.0**			
Set No. 8 Ebb																
5	S	96	104	20.3	11:33	11:40	7.0	150.31	35.8							
5	R	104	112	27.6	11:40	11:47	7.0	100.34	23.9	29.8	23.9					
6	S	97	105	22.5	11:34	11:41	7.0	160.63	38.2							
6	R	105	113	29.0	11:41	11:47	6.0	105.74	29.4	33.8	25.7					
7	S	98	106	21.7	11:34	11:42	8.0	181.57	37.8							
7	R	106	114	32.2	11:42	11:47	5.0	118.07	39.4	38.6	26.9					
8	S	99	107	**25.5**	11:34	11:42	8.0	189.11	39.4			11.4	2.5	8	8	8
8	R	107	115	**30.3**	11:42	11:48	6.0	110.41	30.7	35.0	27.9	2.7	2.3	6	6	6
									mean →	**34.3**	**26.1**	**7.0**	**2.4**			
									SD→	**3.6**	**1.7**	**6.2**	**0.2**			
Set No.9 Ebb																
1	S	108	116	24.1	11:44	11:59	15.0	258.35	28.7							
1	R	116	120	26.6	11:59	12:04	5.0	67.79	22.6	25.7	25.3					
2	S	109	117	26.5	11:45	11:59	14.0	256.85	30.6							
2	R	117	121	30.6	11:59	12:04	5.0	63.19	21.1	25.8	28.5					
3	S	110	118	**29.6**	11:45	12:00	15.0	289.54	32.2			4.2	1.6	15	15	15
3	R	118	122	**35.2**	12:00	12:05	5.0	81.92	27.3	29.7	32.4	0.7	7.2	5	5	
4	S	111	119	**29.4**	11:45	12:00	15.0	302.5	33.6			5.6	1.4	15	15	15
4	R	119	123	**42.2**	12:00	12:05	5.0	90.33	30.1	31.9	35.8	2.1				
									mean →	**28.3**	**30.5**	**3.1**	**3.4**			
									SD→	**3.1**	**4.6**	**2.2**	**3.3**			
Set No. 10 Ebb																
1	S	124	128	30.3	12:09	12:12	12.5	173	23.1							
1	R	128	146	31.0	12:12	12:27	15.0	72.49	8.1	15.6	30.6					
2	S	125	129	27.5	12:10	12:22	12.0	198.7	27.6							
2	R	129	137	26.5	12:22	12:27	5.0	79.31	26.4	27.0	27.0					
3	S	124	130	24.3	12:10	12:22	12.0	223.95	31.1							
3	R	130	138	27.7	12:22	12:27	5.0	75.58	25.2	28.1	26.0					
4	S	127	131	**27.6**	12:10	12:23	13.0	232.56	29.8			1.8	0.4	13	13	13
4	R	131	139	**32.4**	12:23	12:27	4.0	78.29	32.6	31.2	30.0	4.6	4.4	4	4	4
									mean →	**25.5**	**28.4**	**3.2**	**2.4**			
									SD→	**6.9**	**2.2**	**2.0**	**2.8**			
Set No.11 Ebb																
5	S	132	146	24.6	12:25	12:39	14.0	144.63	17.2							
5	R	146	148	43.2	12:39	12:50	11.0	76.51	11.6	14.4	33.9					
6	S	133	141	26.0	12:25	12:39	14.0	158.98	18.9							
6	R	141	149	40.4	12:39	12:51	12.0	97.05	13.5	16.2	33.2					
7	S	136	142	**27.2**	12:25	12:39	14.0	185.02	22.0			6.0	0.8	14	14	14
7	R	142	150	**31.9**	12:39	12:51	12.0	115.33	16.0	19.0	29.5	12.0	3.9	12	12	12
8	S	135	143	**28.4**	12:26	12:40	14.0	201.1	23.9			4.1	0.4	14	14	14
8	R	143	151	**37.1**	12:40	12:51	11.0	151.28	22.9	23.4	32.8	5.1	9.1	11	11	
									mean →	**18.3**	**32.4**	**6.8**	**3.6**			
									SD→	**3.9**	**1.9**	**3.6**	**4.0**			

21 Aug. 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation	Elapsed Time < 5 degrees Variation
Set No.12 Ebb																
1	S	144	152	20.3	12:41	12:57	16.0	96.43	10.0							
1	R	152	156	38.7	12:57	13:09	12.0	181.08	25.1	17.6	29.5					
2	S	145	153	31.7	12:42	12:57	16.0	132.34	10.0							
2	R	153	157	32.8	12:57	13:09	12.0	176.47	24.5	17.4	30.9					
3	S	146	154	**32.4**	12:42	12:58	16.0	169.09	17.6			10.4	4.4	16	16	6
3	O	154	160	**52.5**	12:53	13:12	19.0	95.46	8.4			19.6	24.5	19		
3	R	160	164	**74.3**	13:12	13:23	11.0	52.1	7.9	11.3	53.1	20.1	46.3	11		
4	S	147	155	**40.5**	12:42	12:58	16.0	197.17	20.5			7.5	12.5	16		
4	O	155	161	**57.6**	12:58	13:12	14.0	128.25	15.3			12.7	29.6	14		
4	R	161	165	79.8	13:12	13:23	11.0	79.5	12.0	16.0	59.3					
									mean →	**15.6**	**43.2**	**14.1**	**23.4**			
									SD→	**2.9**	**15.2**	**5.6**	**16.1**			
Set No. 13 Ebb																
1	S	158	162	168.5	13:11	13:22	11.0	19.15	23.9							
1	O	162	168	247.4	13:22	13:37	15.0	25.57	2.8							
1	O	168	171	217.9	13:37	14:25	48.0	89.8	3.1							
1	R	171	174	**142.5**	14:25	15:15	50.0	155.84	5.2	11.7	176.5	22.8	65.6	50		
2	S	159	163	180.1	13:11	13:22	11.0	12.81	23.9							
2	O	163	167	239.4	13:22	13:40	18.0	25.17	2.3							
2	O	167	170	241.2	13:40	14:23	43.0	171.76	6.7							
2	R	170	173	216.3	14:23	15:14	51.0	245.93	8.0	16.0	127.9					
									mean →	**13.8**	**152.2**	**22.8**	**65.6**			
									SD→	**3.0**	**34.3**	**NA**	**NA**			
Set No. 14 Ebb																
3	S	166	169	39.6	13:29	13:40	11.0	157.86	23.9							
3	R	169	172	25.1	13:40	14:40	60.0	842.52	23.4	23.7	32.3					
									mean →	**23.7**	**32.3**	**NA**	**NA**			
									SD→	**NA**	**NA**	**NA**	**NA**			
Set No. 15 Near Slack																
1	S	175	181	324.5	15:17	15:30	13.0	11.07	1.4							
1	O	181	181	261.2	15:30	15:45	15.0	20.46	2.3							
1	R	181	184	198.5	15:45	15:51	6.0	7.71	2.1	1.9	261.4					
2	S	176	179	**19.3**	15:18	15:31	13.0	73.91	9.5			18.5	8.7	13	13	
2	O	179	182	17.9	15:31	15:46	15.0	52.69	5.9							
2	O	182	187	**295.7**	15:46	16:07	21.0	48.57	3.9			24.1	87.7	21		
2	R	187	192	240.1	16:07	16:30	23.0	146.52	10.6	7.5	143.2					
3	S	177	180	28.5	15:18	15:32	14.0	84.77	10.1							
3	R	180	183	29.1	15:32	15:47	15.0	64.85	7.2	8.6	28.8					
									mean →	**6.0**	**144.5**	**21.3**	**48.2**			
									SD→	**3.6**	**116.3**	**4.0**	**55.8**			
Set No. 16 Flood																
1	S	185	189	308.1	15:52	16:05	13.0	20.1	2.6							
1	R	189	193	248.4	16:05	16:31	26.0	4.07	0.3	1.4	278.2					
3	R	188	191	23.1	16:10	16:29	19.0	240.6	21.1	21.1	23.1					
4	R	189	190	33.3	16:21	16:26	5.0	11.6	3.9	3.9	33.3					
									mean →	**8.8**	**111.5**	**NA**	**NA**			
									SD→	**10.7**	**144.5**	**NA**	**NA**			
Set No. 17 Flood																
1	S	194	198	165.3	16:53	16:58	5.0	35.11	11.7							
1	O	198	203	138.9	16:58	17:17	19.0	33.42	2.9							
1	O	203	211	355.2	17:17	17:32	15.0	91.78	10.2							
1	R	211	221	2.2	17:32	17:57	25.0	189.14	12.6	9.4	165.4					
2	S	195	199	**200.3**	16:53	16:59	6.0	29.45	8.2			19.8	7.7	6	6	
2	O	199	205	**205.6**	16:59	17:10	11.0	110.38	16.7			11.3	2.4	11	11	11
2	O	205	213	267.9	17:10	17:33	23.0	29.88	2.2							
2	R	213	218	332.1	17:33	17:54	21.0	46.62	3.7	7.7	251.5					
3	S	197	200	**223.5**	16:54	16:59	5.0	13	4.3			23.7	15.5	5		
3	O	200	207	212.4	16:59	17:20	21.0	76.38	6.1							
3	O	207	210	231.7	17:20	17:31	11.0	56.45	8.6							
3	R	210	219	240.1	17:31	17:55	15.0	80.43	10.3	7.9	218.5					
									mean →	**8.3**	**211.8**	**18.3**	**8.6**			
									SD→	**0.9**	**43.4**	**6.3**	**6.6**			
Set No. 18 Flood																
4	S	201	204	184.7	17:03	17:18	15.0	92.4	10.3							
4	O	204	212	331.9	17:18	17:32	14.0	30.98	3.7							
4	R	212	222	30.0	17:32	17:57	25.0	280.4	18.7	10.9	182.2					
5	S	202	206	**209.9**	17:04	17:19	15.0	75.7	8.4			19.6	1.9	15	15	15
5	O	206	214	221.9	17:19	17:34	15.0	63.83	7.1							
5	R	214	217	272.1	17:34	17:54	10.0	26.1	6.8	7.3	236.0					
									mean →	**9.1**	**209.1**	**19.6**	**1.9**			
									SD→	**2.6**	**38.0**	**NA**	**NA**			

21 Aug. 15 Drogue No.	Start, Observe, Recovery	GPS Begin	GPS End	Heading Degrees True*	Begin Time	End Time	Elapsed minutes	Distance m	Rate cm/s	Average Flow Rate All Locations cm/s	Average Heading All Locations (Degrees T)	Observed Flow in Lease Area cm/s	Heading Deviation from Straight Through (Degrees T)	Minutes Sampled Within Lease Area	Elapsed Time < 10 degrees Variation
Set No. 19 Flood															
6	S	208	209	240.0	17:20	17:30	10.0	40.52	6.8						
6	R	209	220	260.6	17:30	17:56	26.0	116.04	7.4	7.1	250.3				
7	R	215	216	11.7	17:46	17:50	4.0	70.32	29.3	29.3	11.7				
									mean →	**18.2**	**131.0**	**NA**	**NA**		
									SD→	**15.7**	**168.7**	**NA**	**NA**		
Set No.20 Flood															
1	S	223	227	38.4	18:00	18:10	10.0	88.45	14.7						
1	R	227	235	49.8	18:10	18:21	11.0	146.42	22.2	18.5	44.1				
2	S	224	228	39.6	18:00	18:10	10.0	129.6	21.6						
2	R	228	240	39.5	18:10	18:22	12.0	152.92	21.2	21.4	39.6				
3	S	225	229	**34.3**	18:01	18:11	10.0	138.72	23.1			4.9	6.3	10	10
3	R	229	237	**31.5**	18:11	18:22	11.0	155.28	23.5	23.3	32.9	4.5	3.5	11	11
4	S	226	230	**40.4**	18:01	18:11	10.0	151.76	25.3			2.7	12.4	10	
4	R	230	238	**48.6**	18:11	18:22	11.0	162.62	24.6	25.0	44.5	3.4	20.6	11	
									mean →	**22.0**	**40.3**	**3.9**	**10.7**		
									SD→	**2.8**	**5.4**	**1.0**	**7.6**		
Set No. 21 Flood															
5	S	231	239	38.6	18:18	18:30	12.0	88.1	12.2						
5	O	239	247	65.3	18:30	18:40	10.0	96.68	16.1						
5	R	247	255	65.2	18:40	18:56	16.0	125.29	13.1	13.8	56.4				
6	S	232	240	40.5	18:18	18:30	12.0	98.64	13.7						
6	O	240	248	52.1	18:30	18:41	11.0	98.25	14.9						
6	R	248	256	60.3	18:41	18:57	16.0	155.04	16.2	14.9	51.0				
7	S	233	241	**56.9**	18:18	18:30	12.0	100.89	14.0			14.0	28.9	12	
7	O	241	249	**57.3**	18:30	18:41	11.0	91.61	13.9			14.1	29.3	11	
7	R	249	257	63.8	18:41	18:57	16.0	108.77	11.3	13.1	59.4				
8	S	234	242	**49.7**	18:19	18:31	12.0	113.24	15.7			12.3	21.7	12	
8	O	242	250	**56.9**	18:31	18:42	11.0	103.34	15.7			12.3	28.9	11	
8	R	250	258	63.3	18:42	18:58	16.0	125.71	13.1	14.8	56.6				
									mean →	**14.2**	**55.8**	**13.2**	**27.2**		
									SD→	**0.9**	**3.5**	**1.0**	**3.7**		
Set No. 22 Flood															
1	S	243	251	38.7	18:37	18:54	17.0	130.13	12.8						
1	R	251	267	55.7	18:54	19:16	22.0	151.81	11.5	12.1	47.2				
2	S	244	252	42.7	18:38	18:54	16.0	102.6	10.7						
2	R	252	268	56.1	18:54	19:16	22.0	130.9	9.9	10.3	49.4				
3	S	245	253	**44.5**	18:38	18:54	16.0	122.5	12.8			15.2	16.5	16	
3	R	253	269	**55.8**	18:54	19:16	22.0	119.4	9.0	10.9	50.1	19.0	27.8	22	
4	S	246	254	**56.6**	18:38	18:55	17.0	135.68	13.3			14.7	28.6	17	
4	R	254	270	**61.3**	18:55	19:17	22.0	163.6	12.4	12.8	59.0	15.6	33.3	22	
									mean →	**11.5**	**51.4**	**16.1**	**26.5**		
									SD→	**1.2**	**5.2**	**1.9**	**7.2**		
Set No. 23 Flood															
5	S	259	263	39.1	19:04	19:14	10.0	72.29	12.0						
5	R	263	271	51.2	19:14	19:37	23.0	127.4	9.2	10.6	45.1				
6	S	260	264	35.7	19:04	19:14	10.0	61.67	10.3						
6	R	264	272	45.6	19:14	19:38	24.0	121.85	8.5	9.4	40.7				
7	S	261	265	44.0	19:04	19:14	10.0	70.93	11.8						
7	R	265	273	**42.9**	19:14	19:38	24.0	135.79	9.4	10.6	43.5	18.6	14.9	24	
8	S	262	266	47.0	19:05	19:15	10.0	73.48	12.2						
8	R	266	274	**43.5**	19:15	19:40	25.0	143.46	9.6	10.9	45.3	18.4	15.5		
									mean →	**10.4**	**43.6**	**18.5**	**15.2**		
									SD→	**0.7**	**2.1**	**0.1**	**0.4**		

Flow Direction and Velocity

Flow direction determination was a primary goal of this brief study. Summary statistics (Table 4) and a more detailed data parsing into components (Table 5) are presented here.

Approximately equal sampling time occurred on both sampling days (Table 4). Day one had less ebb tide sampling by a 16% margin compared to day two. Drogues remained in the lease area at nearly the same fraction (32% and 33% of each day respectively). In these regards, the sampling was fairly balanced between days.

Table 4. Summary statistics for sampling times by location and tide.

Day 1 July 27, 2015	Minutes	Percent
Total drogue sampling time	2293	100%
All ebb tide sampling	997	43%
All flood tide sampling	1190	52%
All slack tide sampling	106	5%
Drogue sampling in lease area	729	32%
Drogue sampling outside lease area	1564	68%
Day 2 August 21, 2015	**Minutes**	**Percent**
Total drogue sampling time	2529	100%
All ebb tide sampling	1490	59%
All flood tide sampling	904	36%
All slack tide sampling	135	5%
Drogue sampling in lease area	826	33%
Drogue sampling outside lease area	1703	67%

Table 5 illustrates the breakout of results by tidal period and consistency of flow through that was parallel to the long axis of the lease area to within > 10 and >5 degree variations. Some data from Table 4 are intentionally repeated in Table 5.

Slack tide in terms of no water motion was actually not observed at any time during these surveys, Drogue kept moving at all times but the slowest movement period on day one was designated as slack tide. On day two, a very long period of minimal motion occurred in the middle of the predicted afternoon flood tide period while water motion offshore remained robust. Offshore motion was determined by occasionally setting drogues offshore and quickly recovering them once direction and velocity were determined.

As an important aside, the water flooded southward offshore while this sluggish northward inshore circulation occurred. Drogue movement slowed to a very slow rate as they reached shallow region north of the lease area and just south of Hannon Point, but they did not contact the sea bottom. I speculate that at such times when the seaweed is present, the refuge effect of the seaweed project may become greatest, as dilution of the seaweed effects will be minimal. However, straight through flow occurred infrequently on the small flood of day two (4% of the entire ebb, Table 5) thus measurement of the effect may often be qualitative as flux calculations or algorithms may not be useful a large percentage of the time. Nevertheless, this may be an important goal to measure.

The ebb tide was marginally best for day one versus the flood and much better than the flood for day two in terms of consistency of flow parallel to the lease long axis. Fully 16% of the entire ebb tide sampled was within 5 degrees of parallel to lease area long axis on day two.

Table 5. Parsing of summary data into tidal stage for sampling times and variation from straight through flow within the lease area.

	Ebb		Flood		"Slack"	
Day 1 July 27, 2015	**Minutes**	**Percent of Ebb**	**Minutes**	**Percent of Flood**	**Minutes**	**Percent of Slack**
Total drogue sampling time	997	43%	1190	52%	106	5%
Drogue sampling time in lease area	209	29%	482	66%	38	5%
> 10 degree variation from long axis for total sampling time by tide	128	13%	115	10%	38	36%
> 5 degree variation from long axis for total sampling time by time	64	6%	64	5%	28	26%
	Ebb		**Flood**		**"Slack"**	
Day 2 August 21, 2015	**Minutes**	**Percent of Ebb**	**Minutes**	**Percent of Flood**	**Minutes**	**Percent of Slack**
Total drogue sampling time	1490	59%	904	36%	135	5%
Drogue sampling time in lease area	566	38%	226	25%	34	25%
> 10 degree variation from long axis for total sampling time by tide	334	22%	53	6%	13	10%
> 5 degree variation from long axis for total sampling time by time	232	16%	37	4%	0	0%

Flow velocity and its interrelation with direction are also important to this project. Due to time limitations for preparing this report, only the basic velocity data are reported here. Table 6 illustrates that overall stronger flows occurred for both tides on the Day one, large tidal amplitude day in July 2015 for all drogue locations. That is not surprising but the small tidal amplitude day was relatively strong too, only 17% (3.8 cm/s) less average velocity. This was obvious when at the site and making these measurements.

Within the lease area only mean ebb velocity exceeded mean flood velocity on day one. On day two, the flood was approximately twice as strong despite the long quiescent period mentioned above. To some extent, the data are biased because of increased monitoring during active periods of drogue movement and this was evident in the velocity data.

Large standard deviations relative to the means indicate large variation in flow. Maximum calculated velocities within the lease area were 52 cm/s on day one for all locations and 24.1 cm/s on day two. Maximum velocity was not much different on ebb versus flood on both days. Larger tides will occur at this site during seaweed production. Current meters will provide a better view of velocity at the site and will be scrutinized for several factors including peak velocity and percentile velocity distribution. The observed velocities from this survey are not known to be destructive to sugar kelp (*Saccharina latissima*) or bull kelp (*Nereocystis luetkeana*) survival and in fact, these grow in much higher velocity conditions in the Strait of Juan de Fuca and the San Juan Islands. High rates of flow will reduce the seawater chemistry signal produced by the seaweed culture array. The data herein could be further used to estimate the probable seawater effects once seaweed biomass and timing projects are made.

Table 6. Summary of flow velocity statistics from Hood Head drogue survey.

All Drogue Locations	Velocity cm/s	Ebb only cm/s	Flood Only cm/s
Day 1 Mean	**22.4**	**30.9**	**14.6**
Day 1 SD	16.2	17.8	11.0
Day 2 Mean	**18.6**	**23.0**	**12.2**
Day 2 SD	9.4	8.2	6.2
Inside lease area only	**Velocity cm/s**	**Ebb only cm/s**	**Flood Only cm/s**
Day 1 Mean	**18.6**	**25.9**	**14.5**
Day 1 SD	13.5	14.0	12.1
Day 2 Mean	**8.2**	**6.3**	**11.8**
Day 2 SD	6.9	5.9	7.0

Summary and Conclusions

Shallow seawater circulation surveys were conducted near Hood Head in Northern Hood Canal, Washington State using drift objects (drogues) tracked with a GPS receiver during warm weather with light winds. An existing Washington Department of Natural Resources aquatic land leased area in this location will be the site to study the effects of a seaweed aquaculture on ocean acidification. The concept being tested is creation of seawater habitat and refugia for aquatic species such as wild and cultured shell-forming organisms that are especially sensitive to increasing ocean acidification (OA). The growth and timely harvest of seaweed will remove excess carbon and nutrients from surrounding seawater and the PAFF project is being designed to document these benefits quantitatively.

The main objective of the brief field surveys reported herein was to begin to understand the flow patterns through the seaweed project area and near vicinity. Extensive and high quality instrumentation will be located “upstream and downstream” of the seaweed and this survey by the University of Washington Applied Physics Laboratory and NOAA Pacific Marine Environmental Laboratory staff and others. This preliminary survey was intended to help inform on optimum location of the moorings and the suitability of the site for calculating net change of seawater carbonate chemistry, dissolved oxygen and dissolved nutrients conditions. At this point, the site appears to be suitable for the task but more study with current meters and other approaches are planned.

A probable sampling strategy for quantifying seawater effect of the seaweed will involve measuring results when water passes directly through the seaweed array, in line with the long axis of the seaweed longlines like a pipeline effect. Models of seaweed physiology and growth can be applied or adapted to the region, but without quality field data, validation of models is not possible and the chance for error in estimating effects high.

The study days included daylight ebb and flood tides that were much larger and smaller than the mean tidal amplitude for the subject area. As expected from the bathymetry and surrounding shoreline topography, ebb tide in a northerly direction produced the optimum conditions for measurement with 16% of the observations within 5 degrees of straight through. This occurred on day two of sampling is especially good as flow velocity was less that day than on the large tidal day one. Lower flow rates allow better signal to background noise determination as dilution is less. Evidence of gyre circulation was apparent during much of the flood tide due to the presence of Hannon Point just north of the lease area. Nevertheless, reverse flow patterns resulting from gyre circulation during flood tide approximated “straight through” flow that could be useful for monitoring, particularly as flow velocity at such times was also reduced.

References Cited

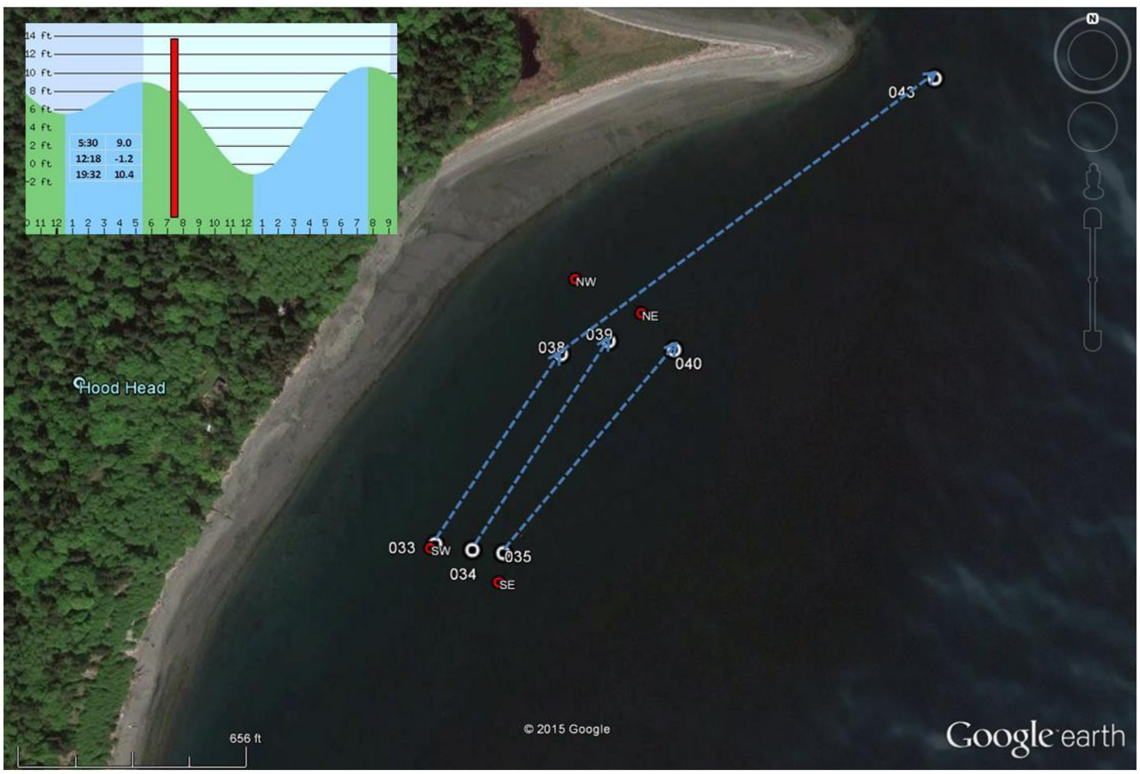
Parametrix, Battelle Northwest Laboratories and Rensel Associates. 1990. **Programmatic Environmental Impact Statement: Fish culture in floating net-pens.** Prepared for the Washington Department of Fisheries and other resource agencies. 161 pp.

Washington State Blue Ribbon Panel on Ocean Acidification (2012): *Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response*. H. Adelsman and L. Whitely Binder (eds). Washington Department of Ecology, Olympia, Washington. Publication no. 12-01-015

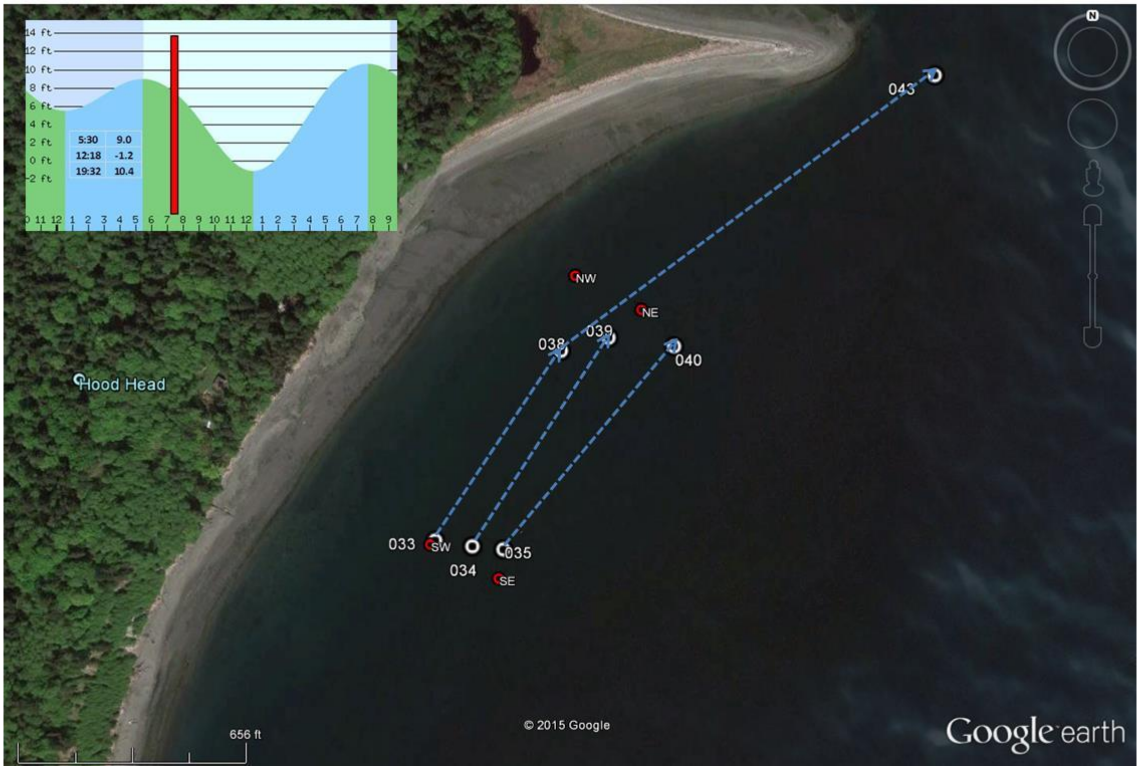
Appendix

The following images indicate the aquatic lease area corners (small red circles with NW, NE, SW or SE corner labels. Plots of all of the drogue tracks collected nearshore near and within the lease area are indicated by the blue dotted line drawn to connect measured GPS locations indicated as white circles and associated GPS codes.

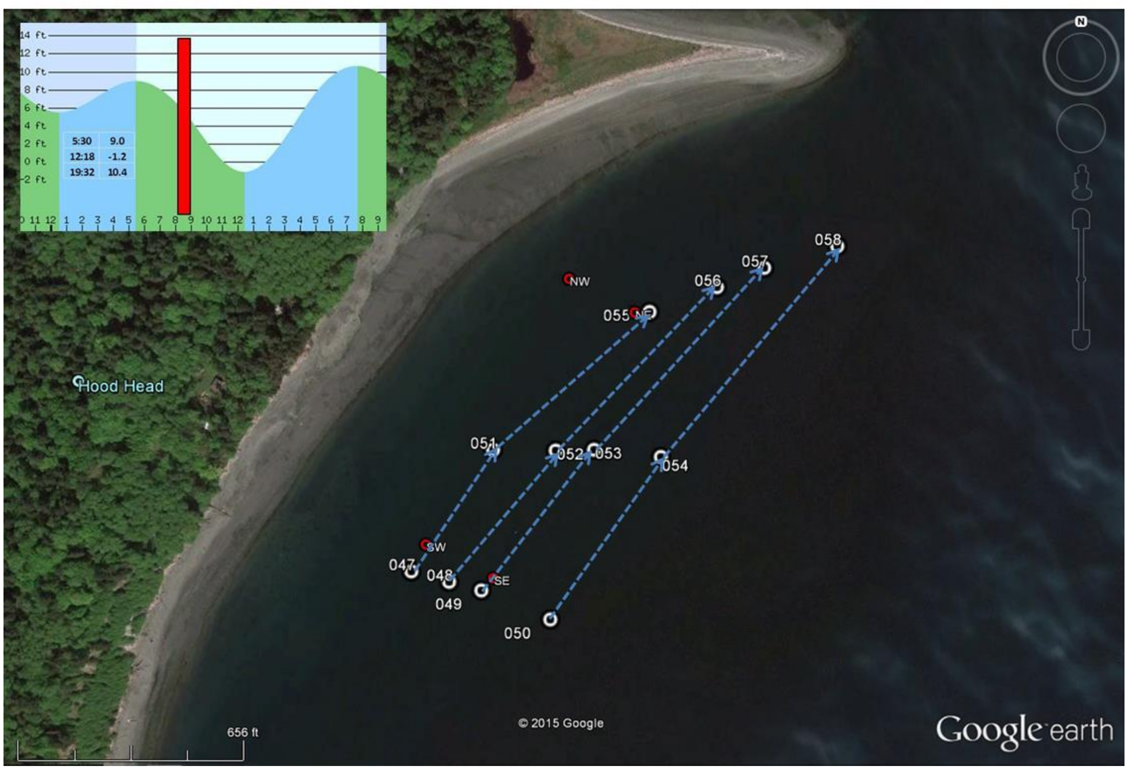
Some drogue surveys use attached GPS recorders, but this was not necessary for this survey, as the distance between recordings was very small and the time intervals short. Thus, it is highly unlikely that any of the drogues deviated significantly from the reported pathways herein.



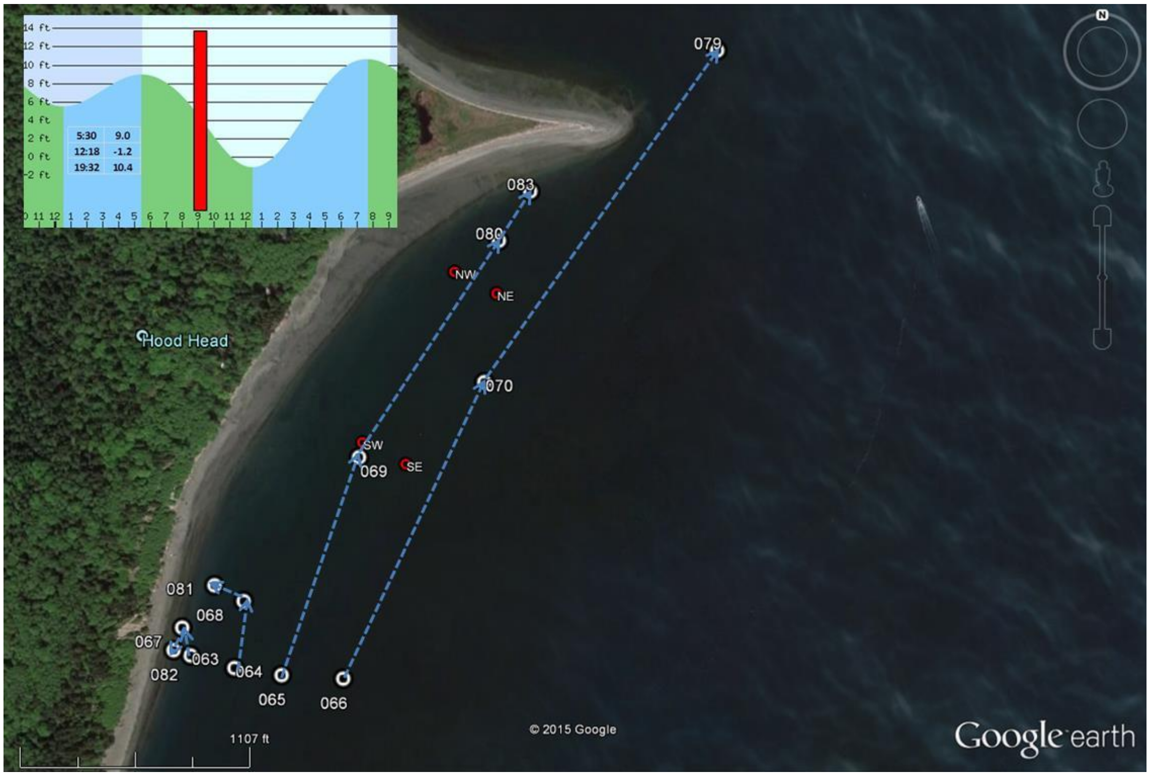
Appendix Figure 15. Ebb tide July 17, 2015.



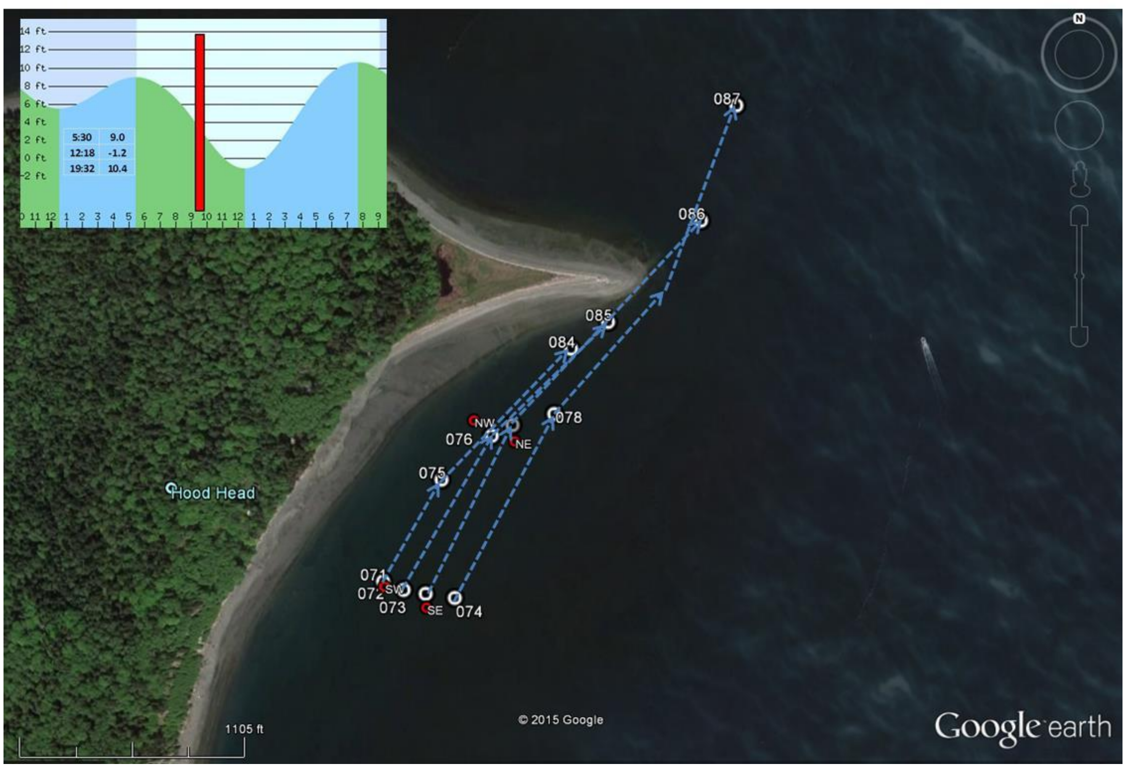
Appendix Figure 16. Ebb tide July 17, 2015



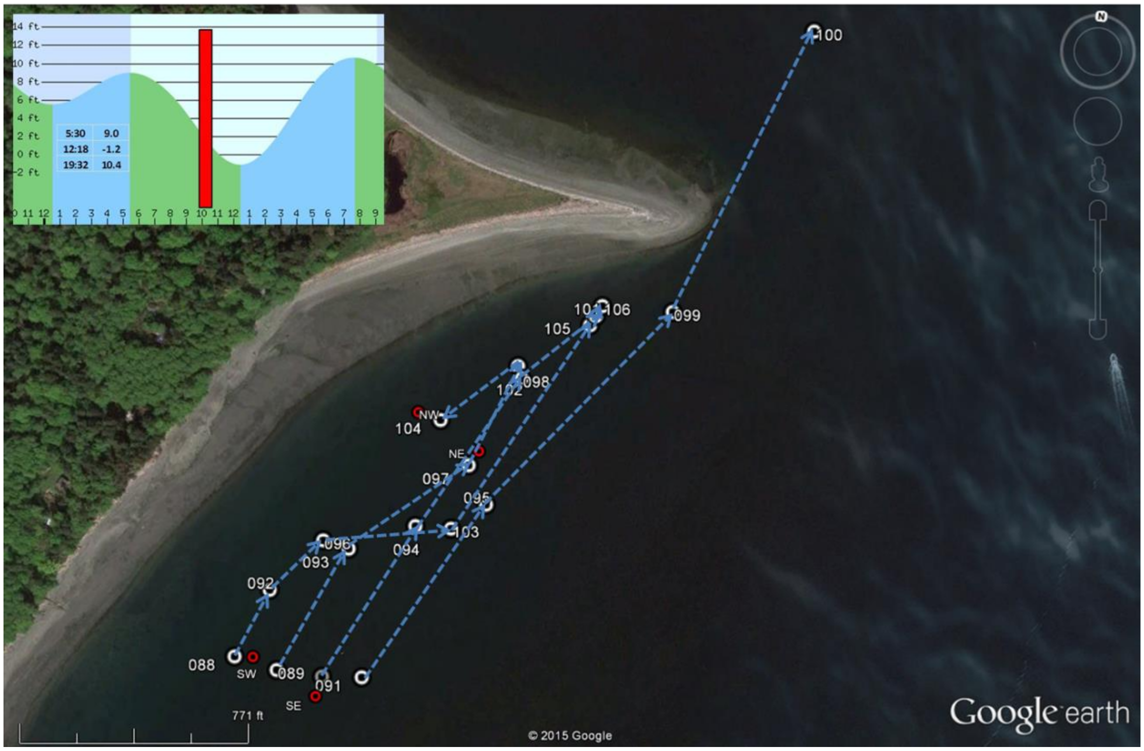
Appendix Figure 17 Ebb tide July 17, 2015



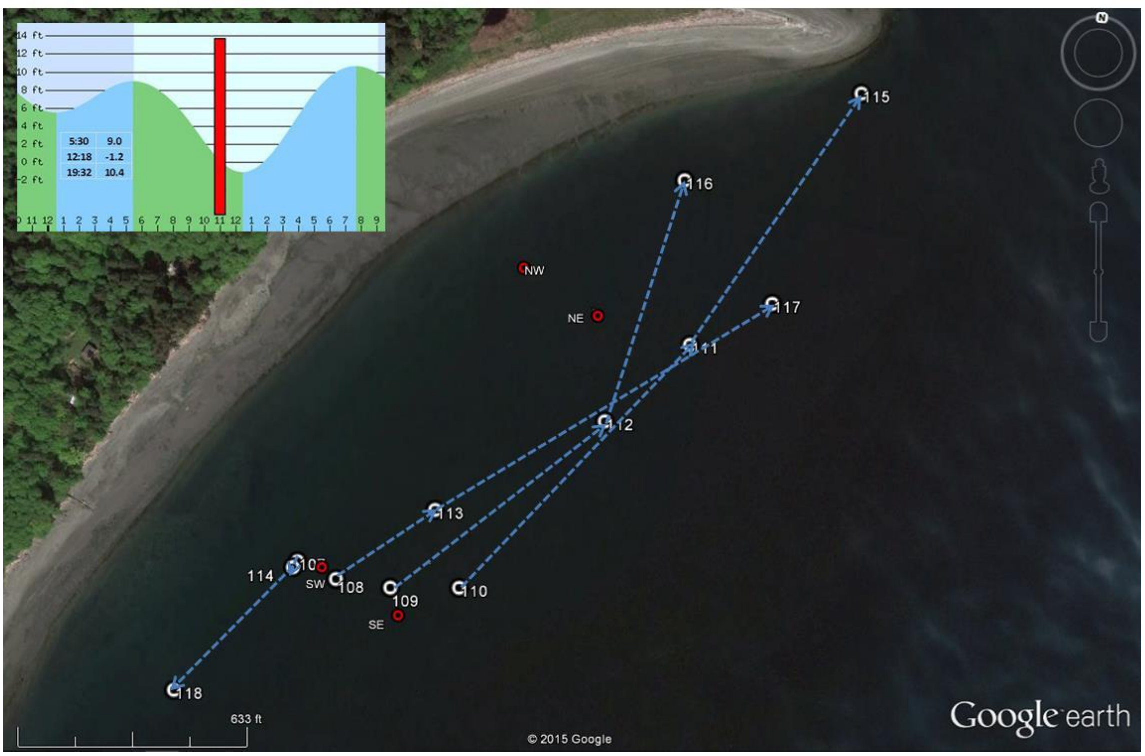
Appendix Figure 18 Ebb tide July 17, 2015



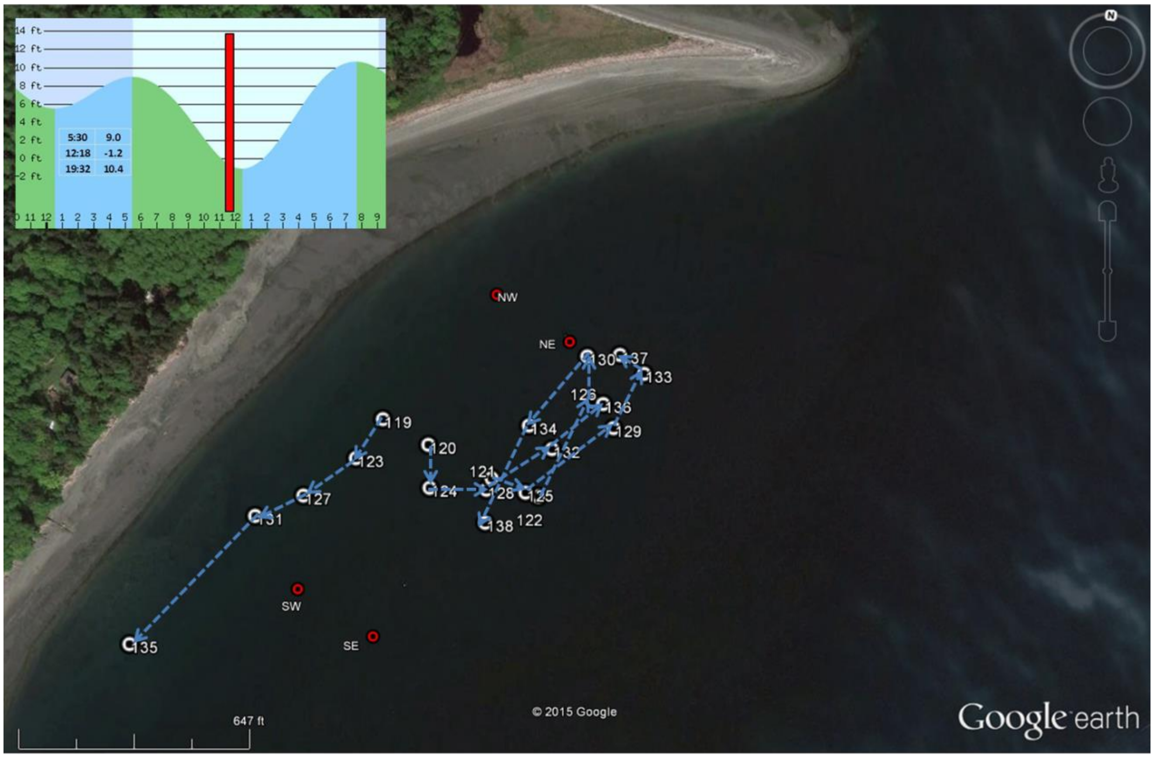
Appendix Figure 19 Ebb tide July 17, 2015



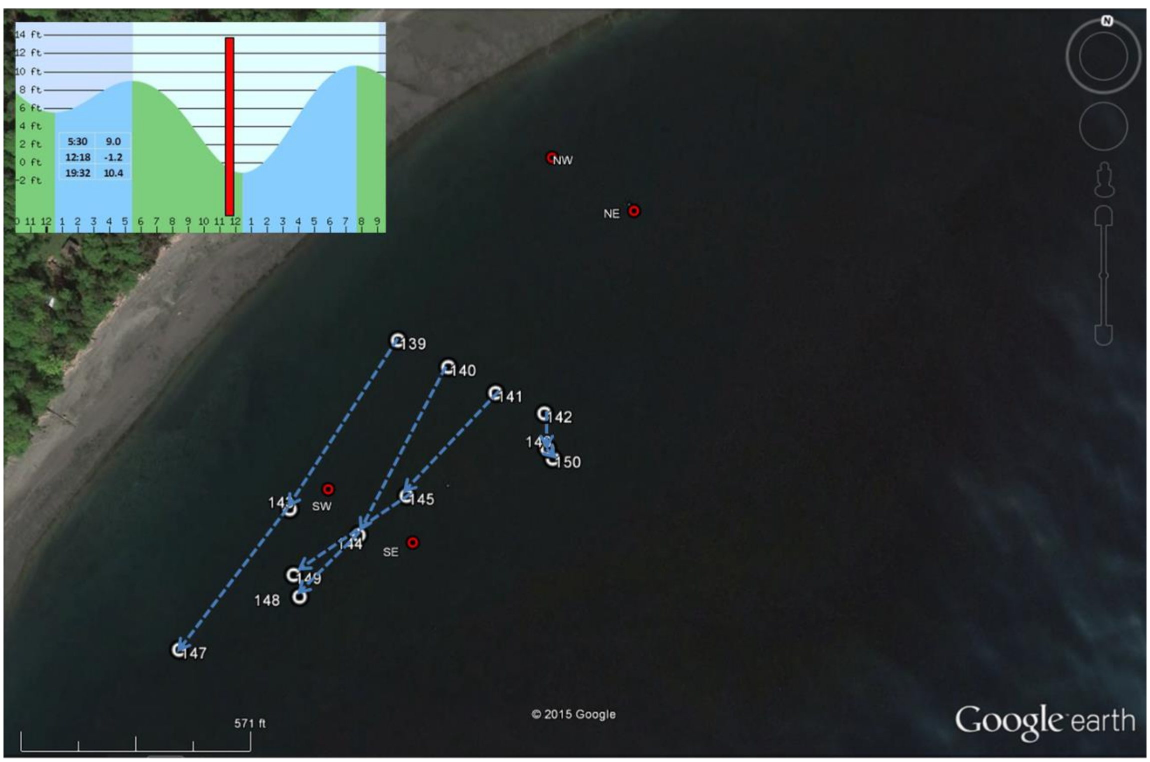
Appendix Figure 20. Ebb tide July 17, 2015



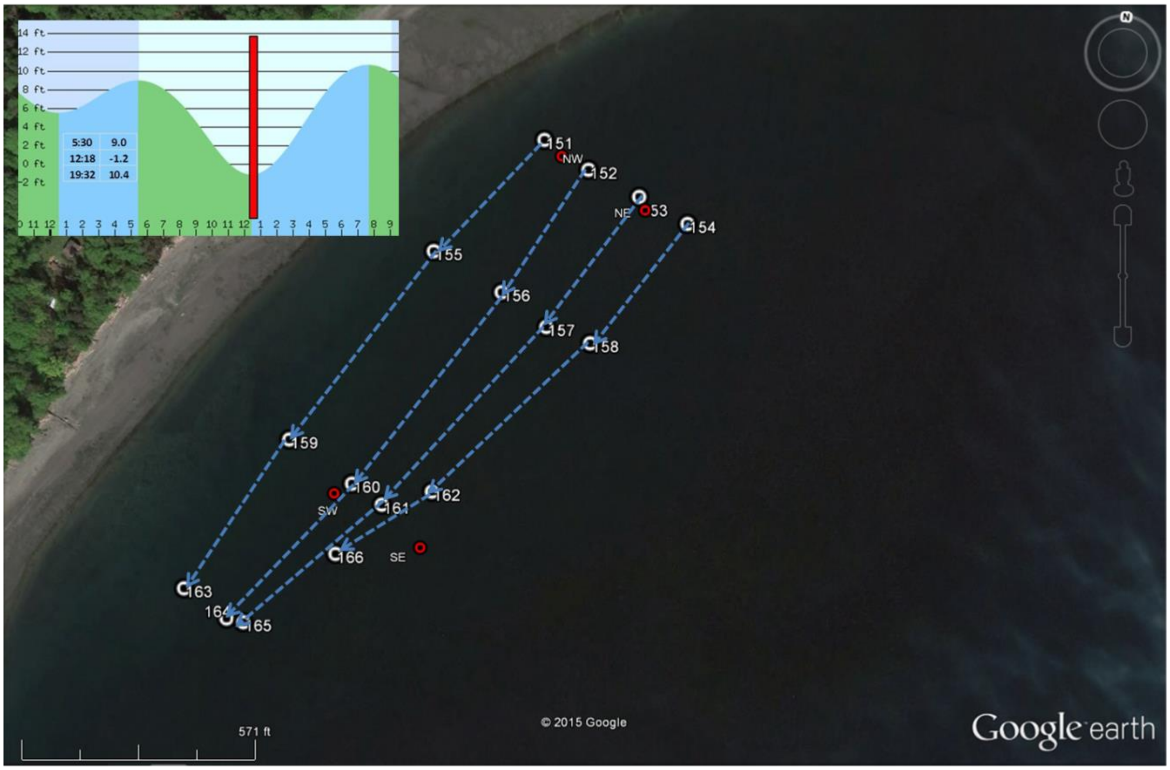
Appendix Figure 21. Ebb tide July 17, 2015



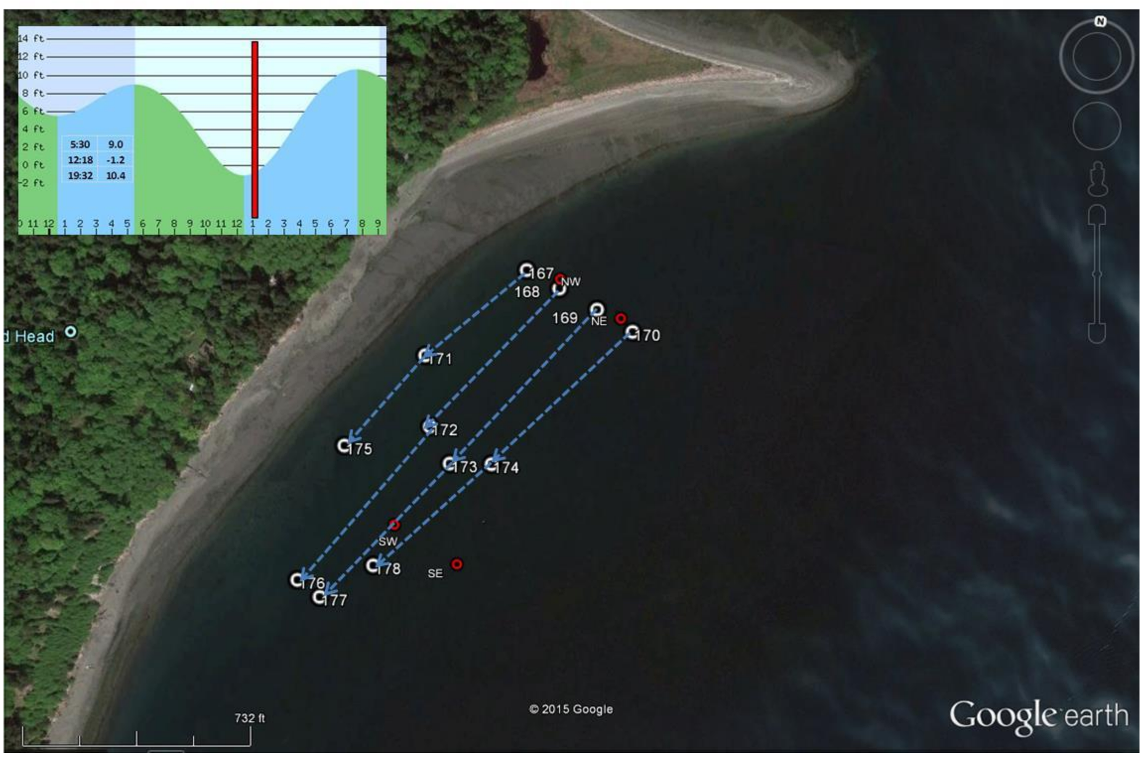
Appendix Figure 22. Change of tide, July 17, 2015



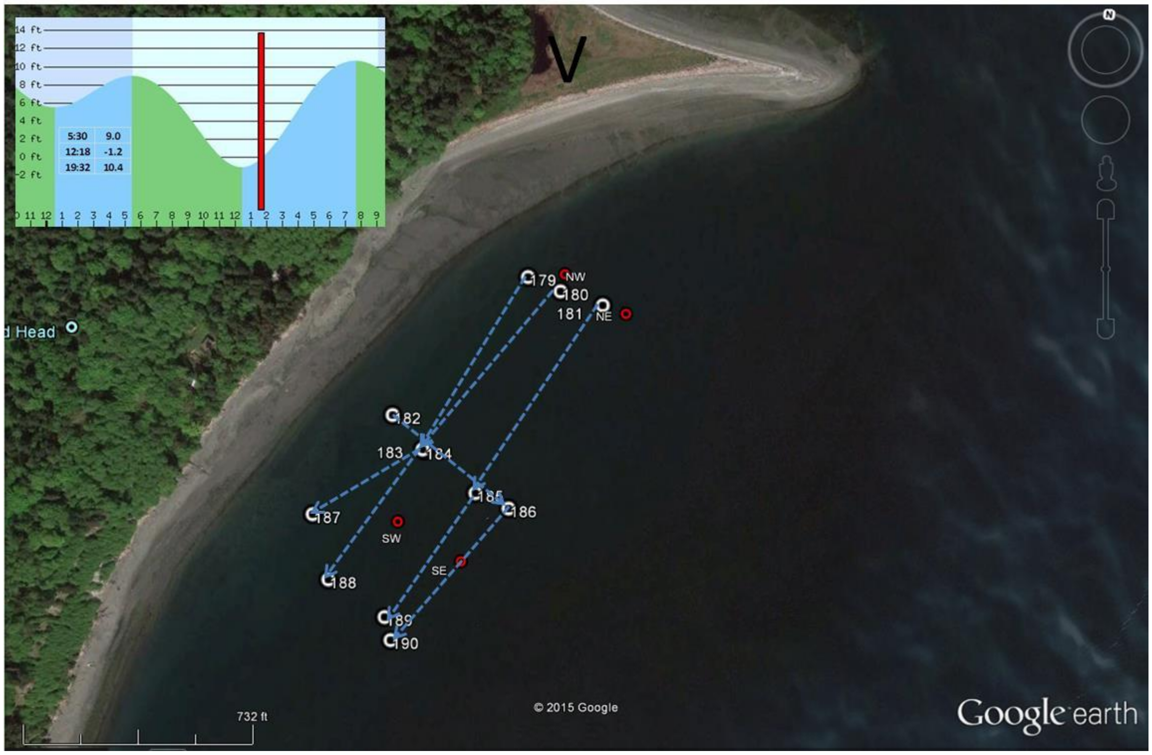
Appendix Figure 23. Flood tide July 17, 2015



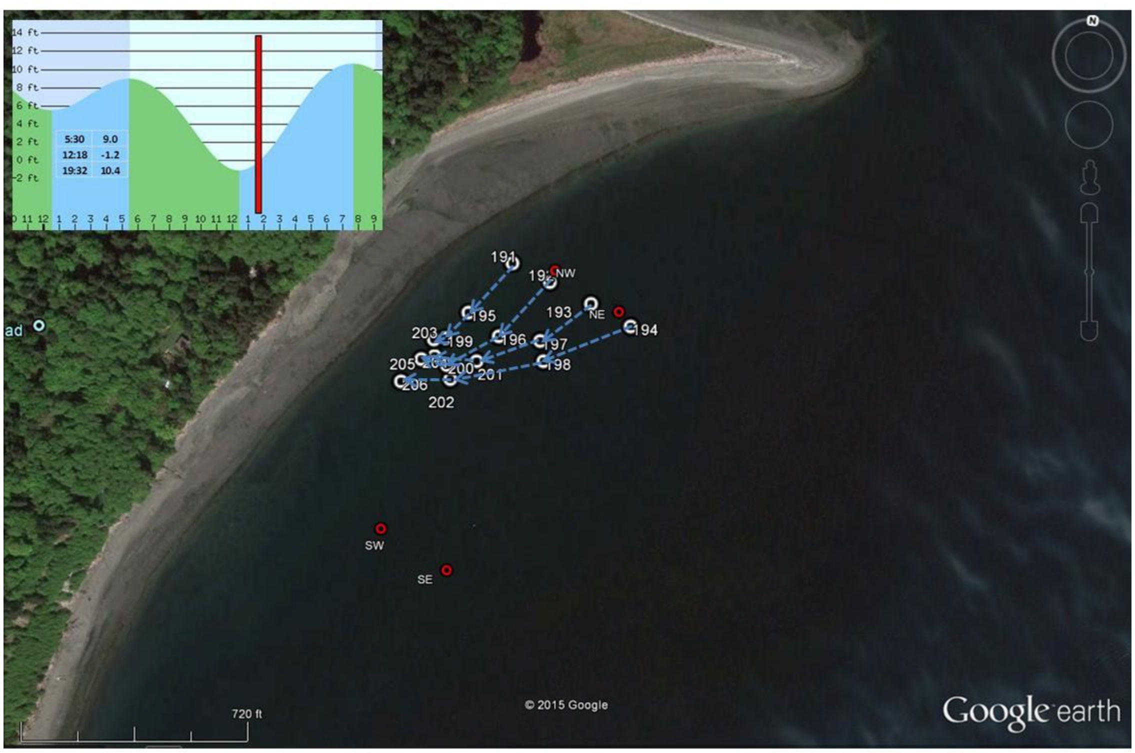
Appendix Figure 24. Flood tide July 17, 2015



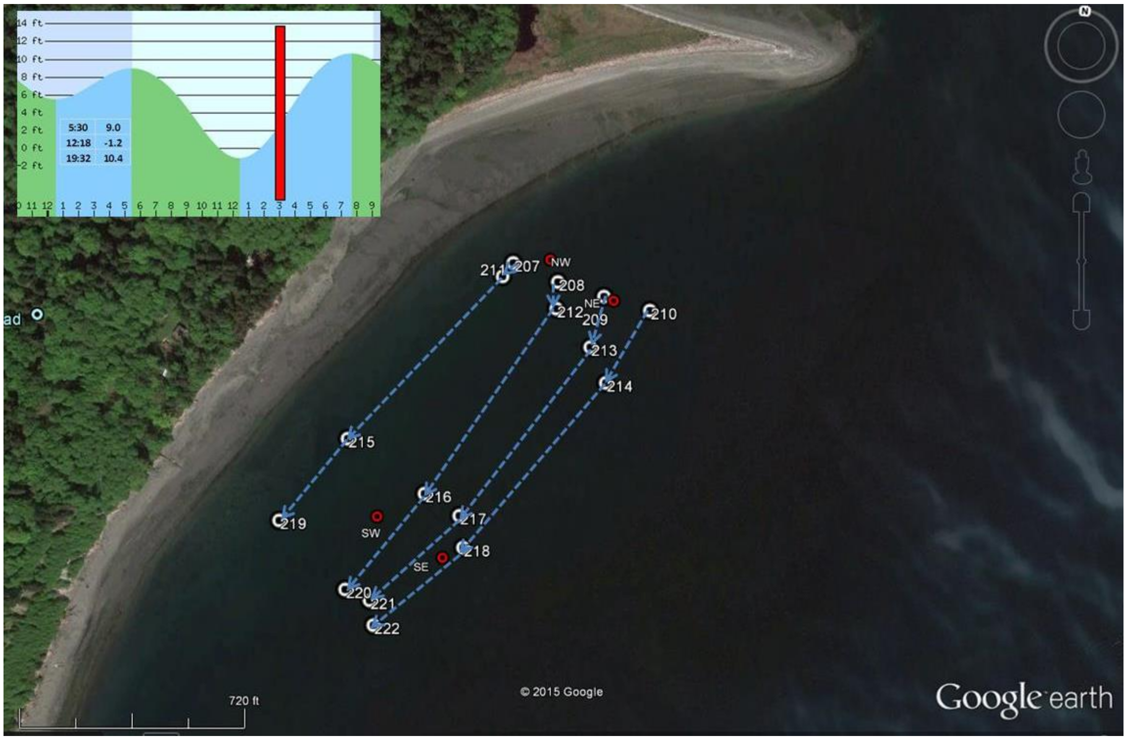
Appendix Figure 25. Flood tide July 17, 2015



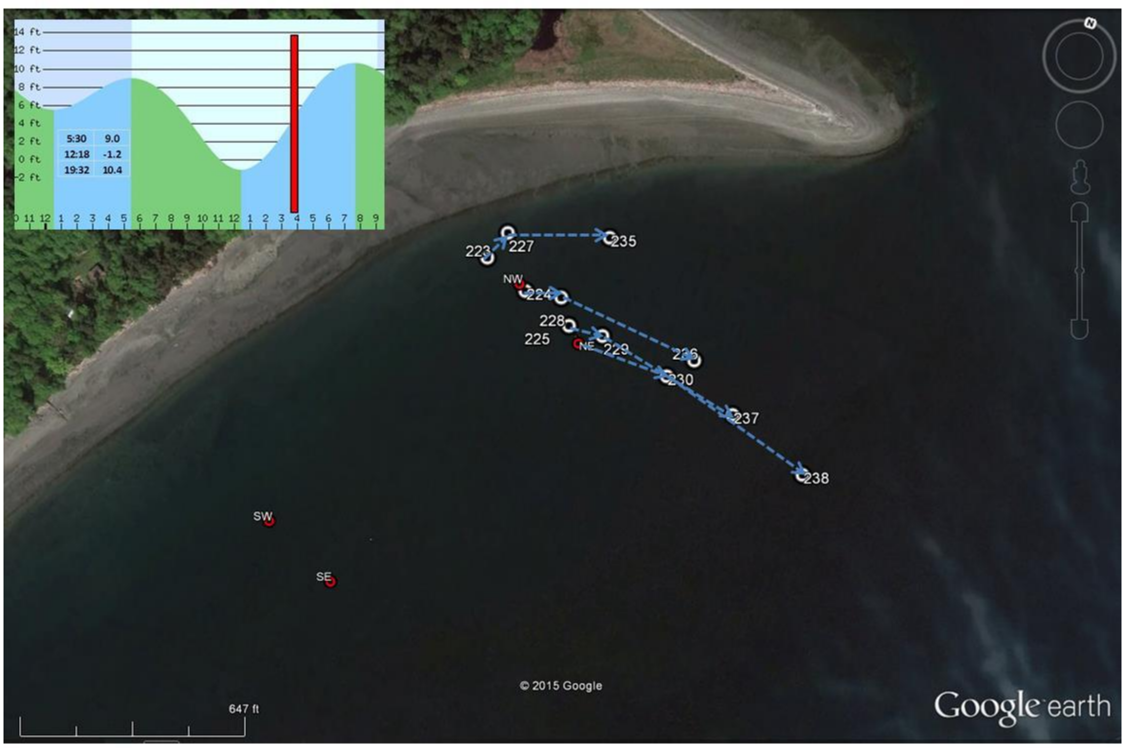
Appendix Figure 26. Flood tide July 17, 2015



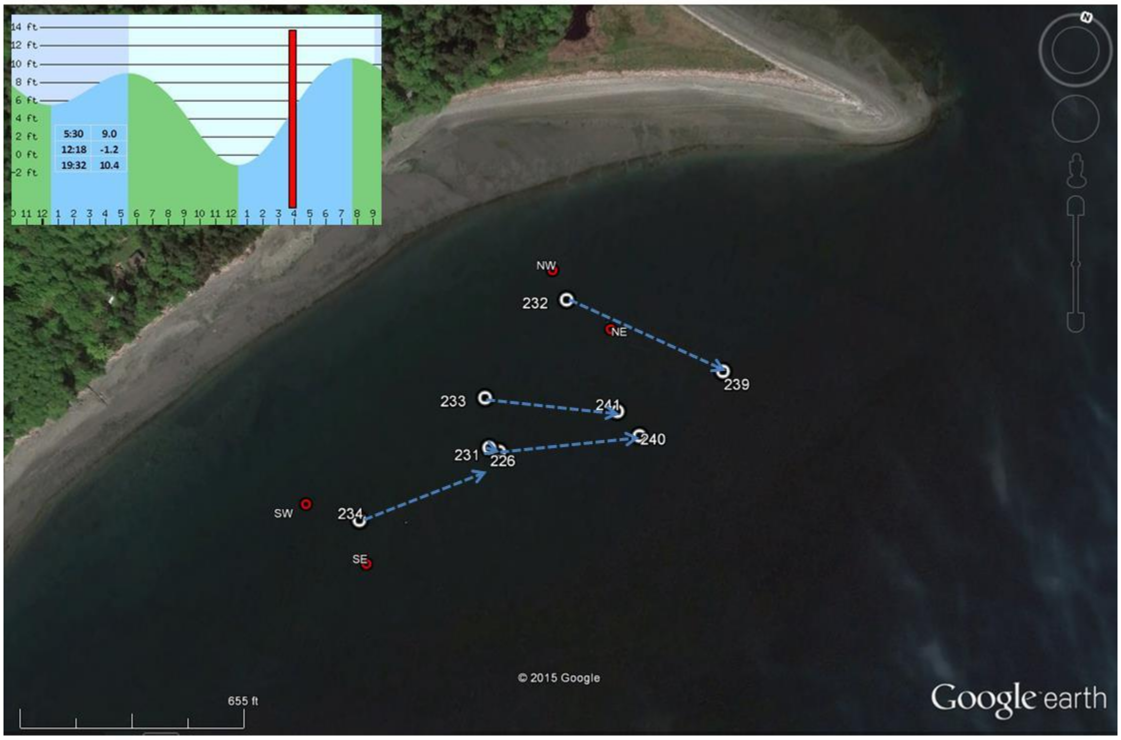
Appendix Figure 27. Flood tide July 17, 2015



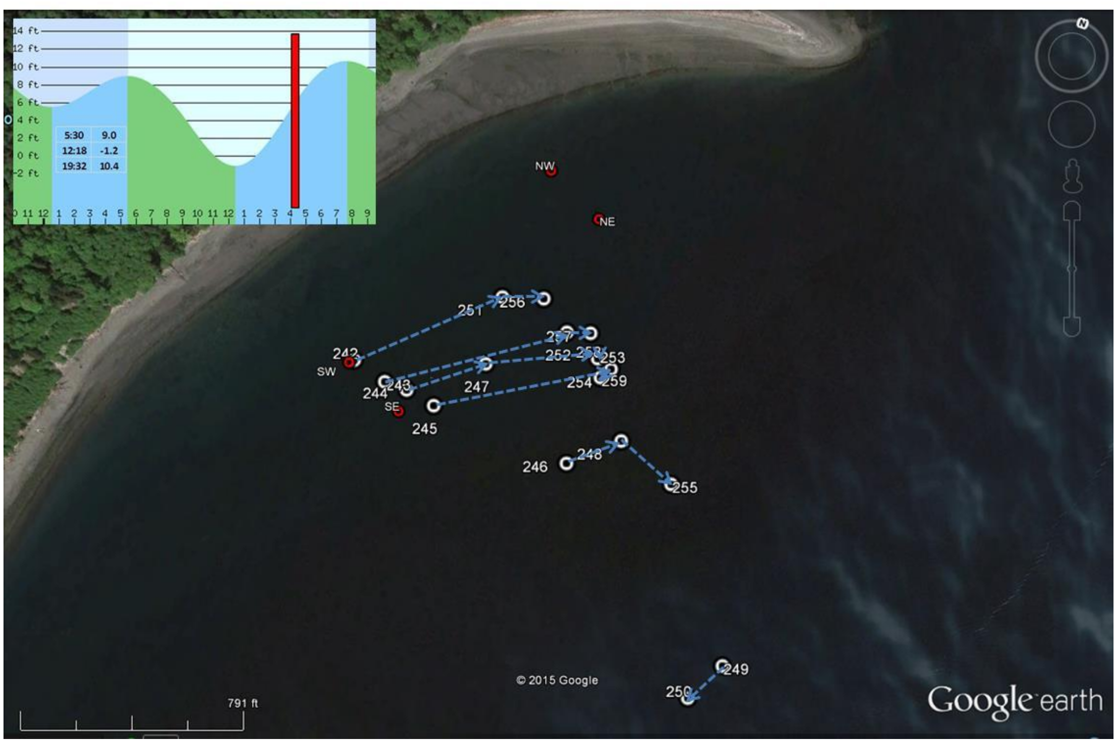
Appendix Figure 28. Flood tide July 17, 2015



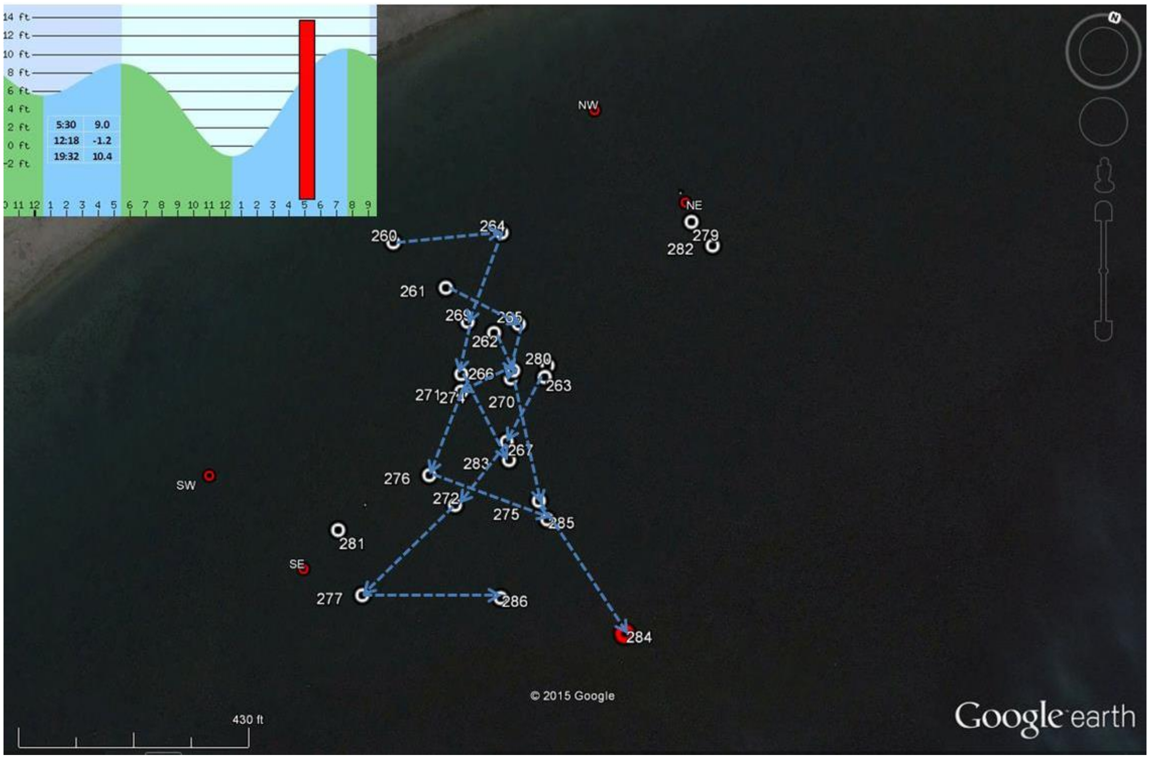
Appendix Figure 29. Flood tide July 17, 2015



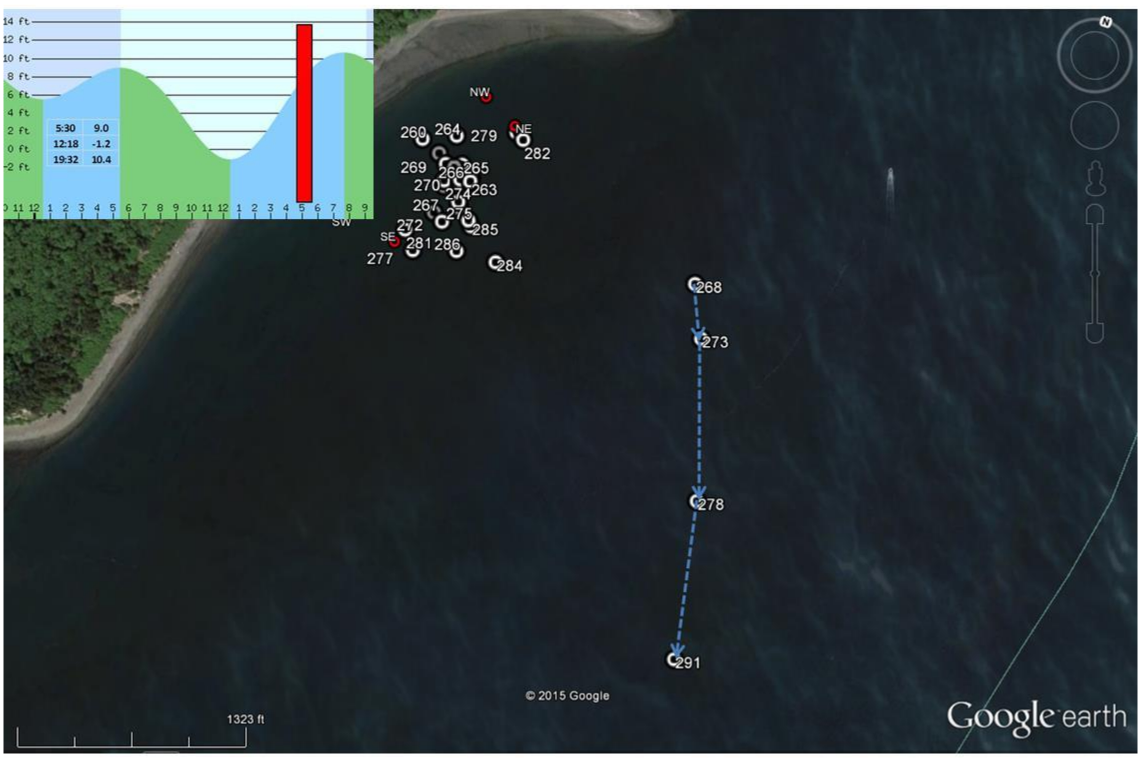
Appendix Figure 30. Flood tide July 17, 2015



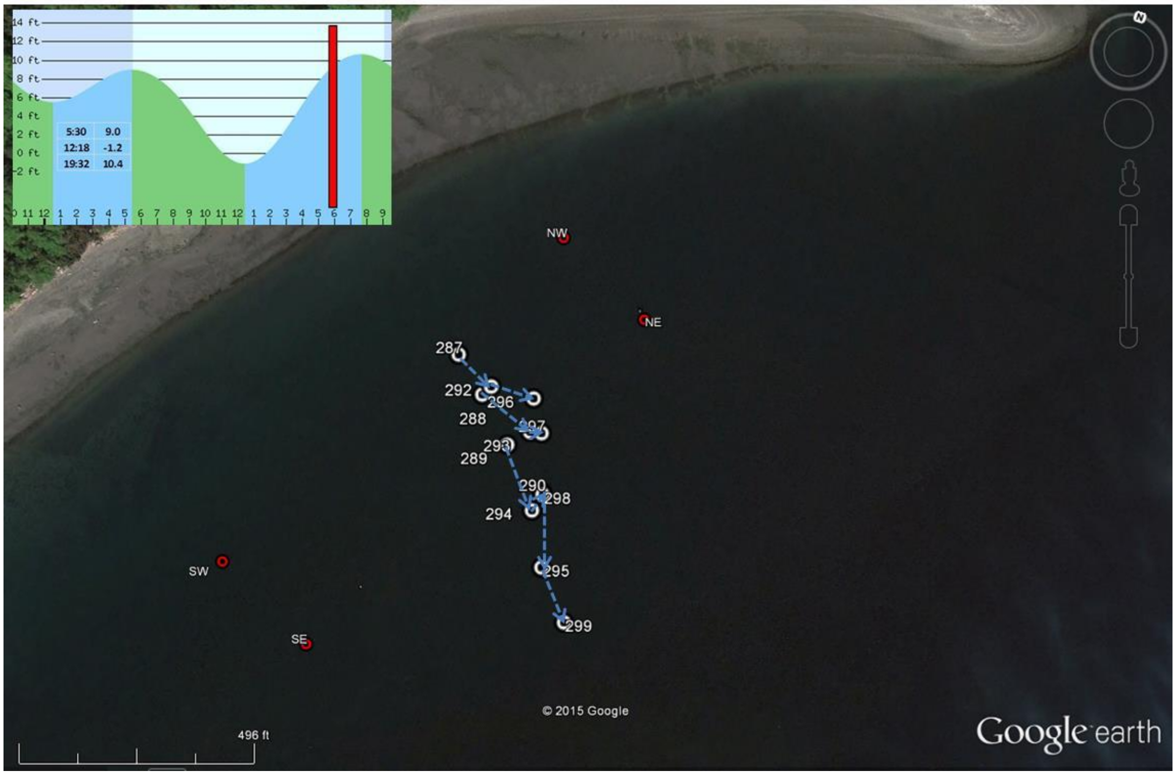
Appendix Figure 31. Flood tide July 17, 2015



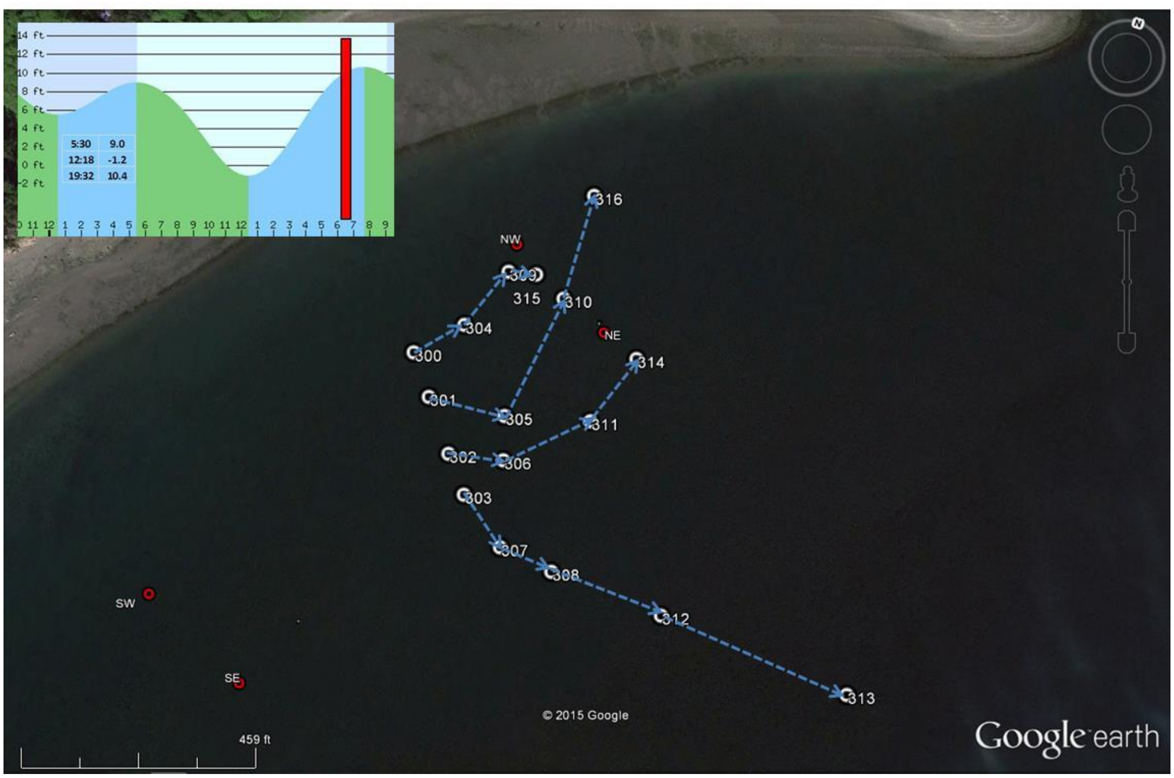
Appendix Figure 32. Flood tide July 17, 2015



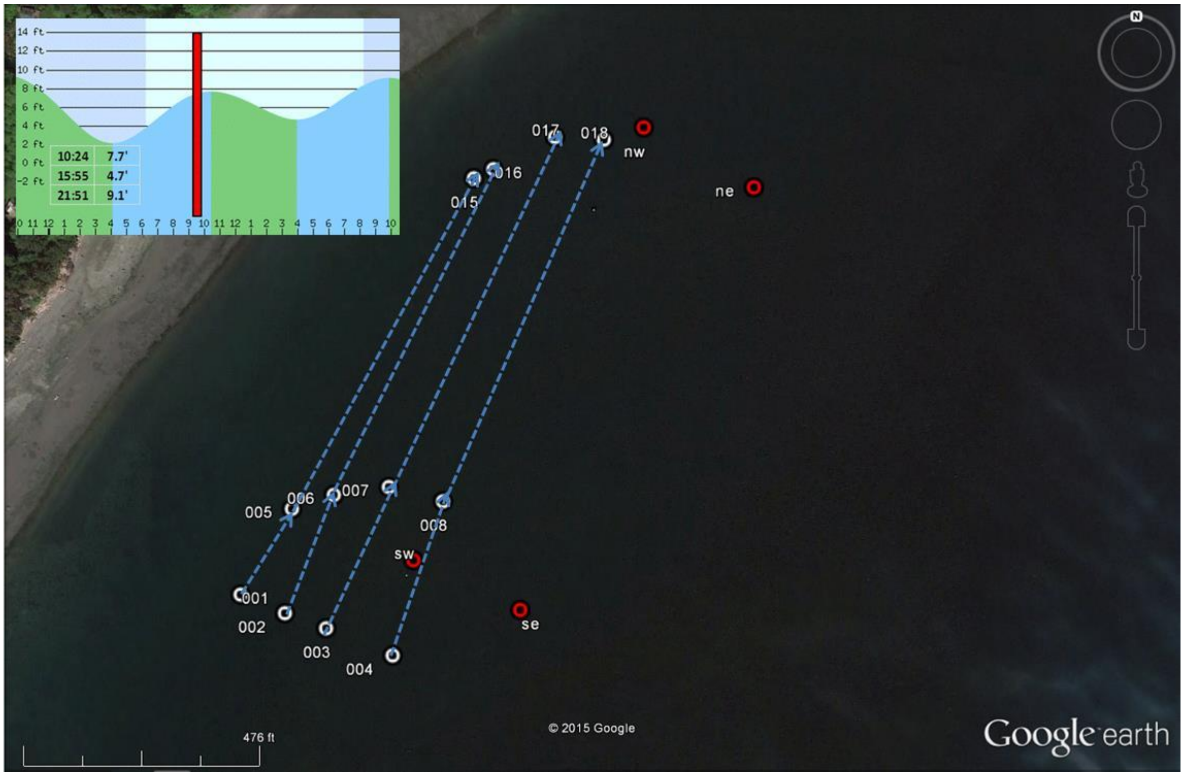
Appendix Figure 33. Flood tide July 17, 2015



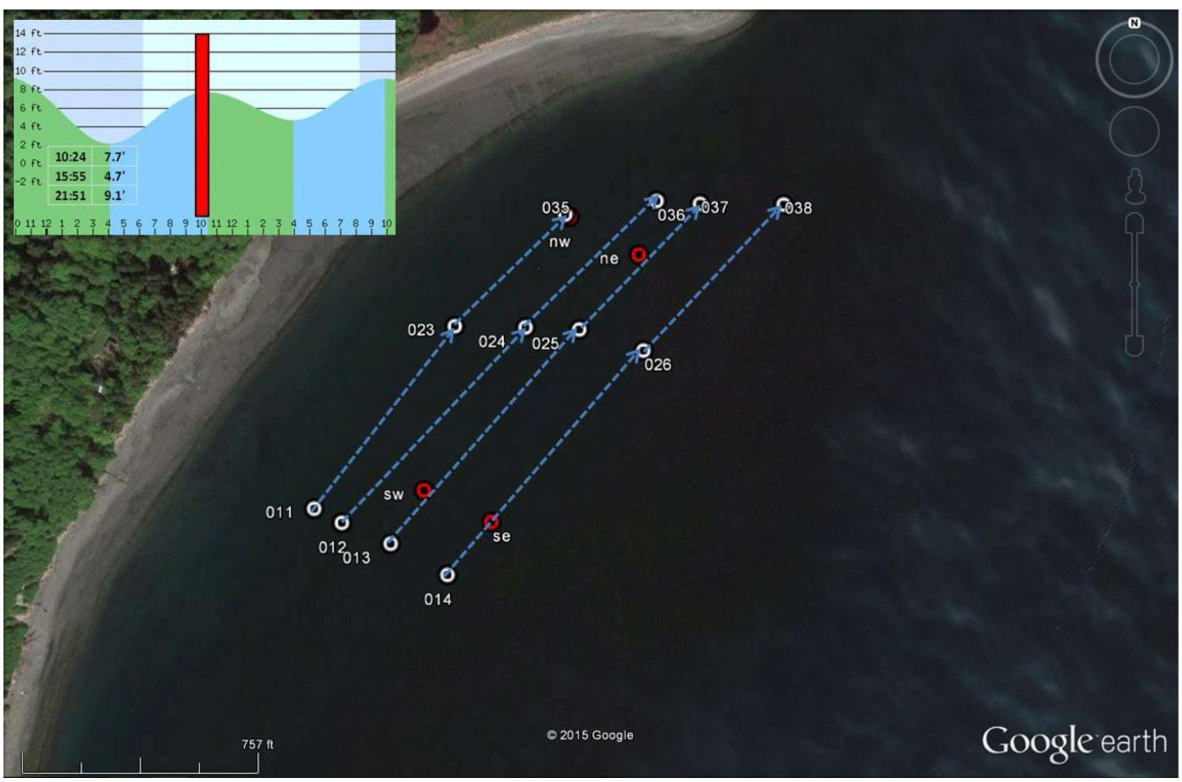
Appendix Figure 34. Flood tide July 17, 2015



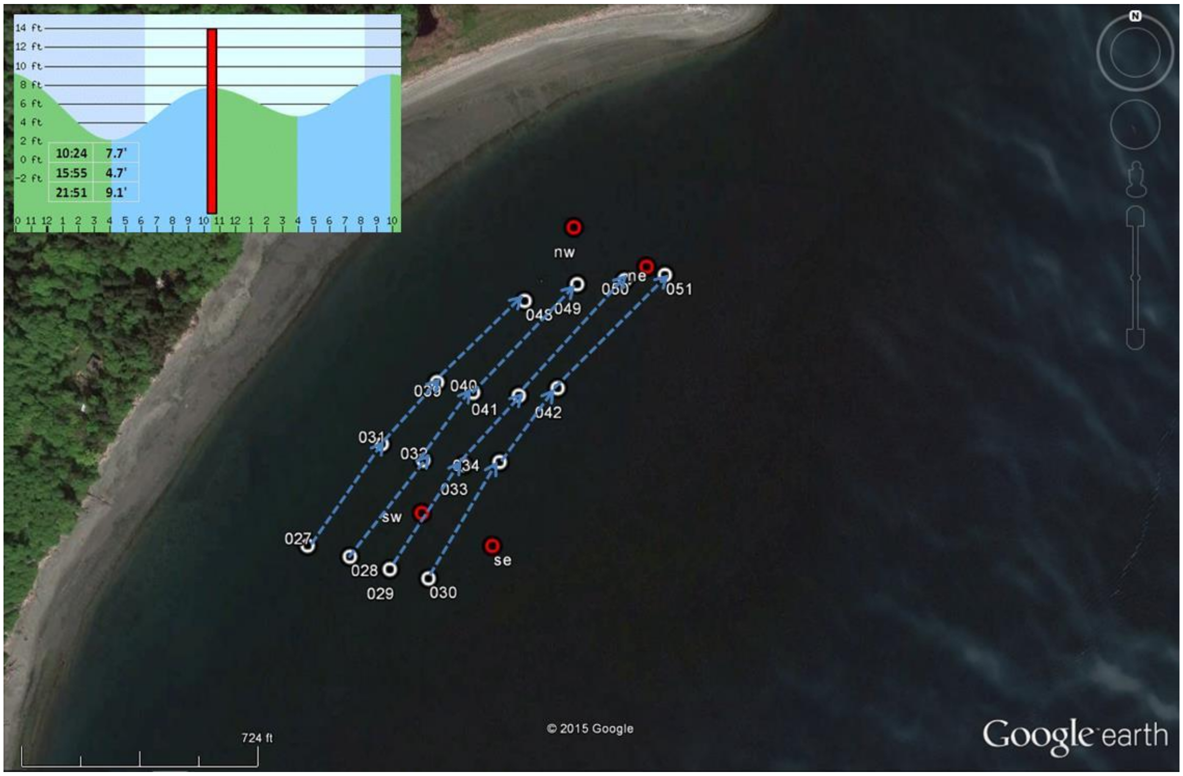
Appendix Figure 35. Last plot for July 17, 2015 survey.



Appendix Figure 36. Begin August 21, 2015 ebb tide.



Appendix Figure 37. August 21, 2015 ebb tide



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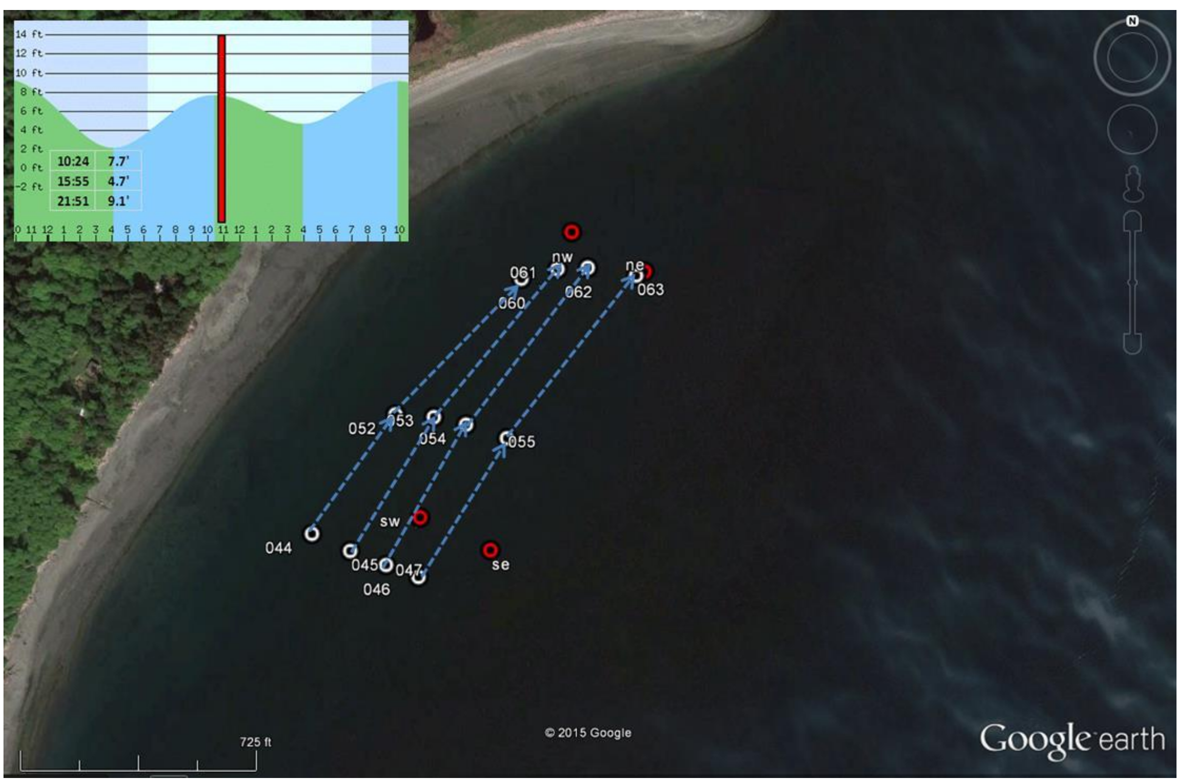
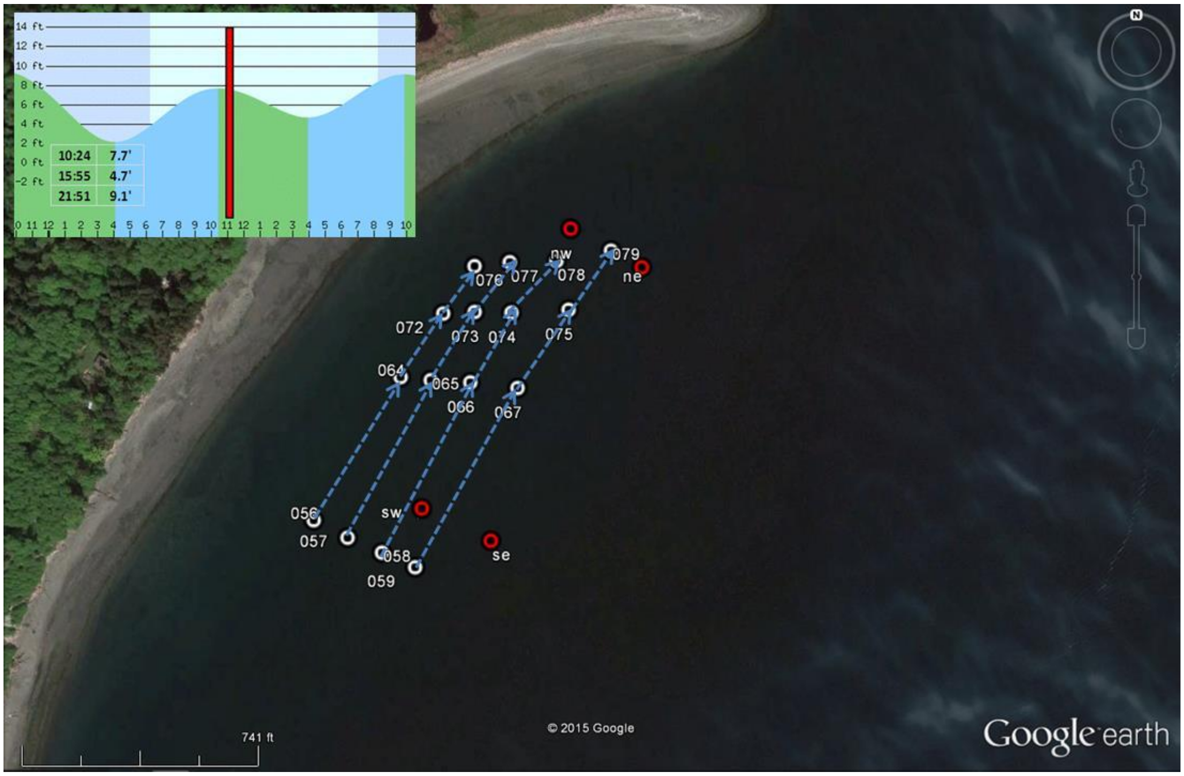


Appendix Figure 39. August 21, 2015 ebb tide



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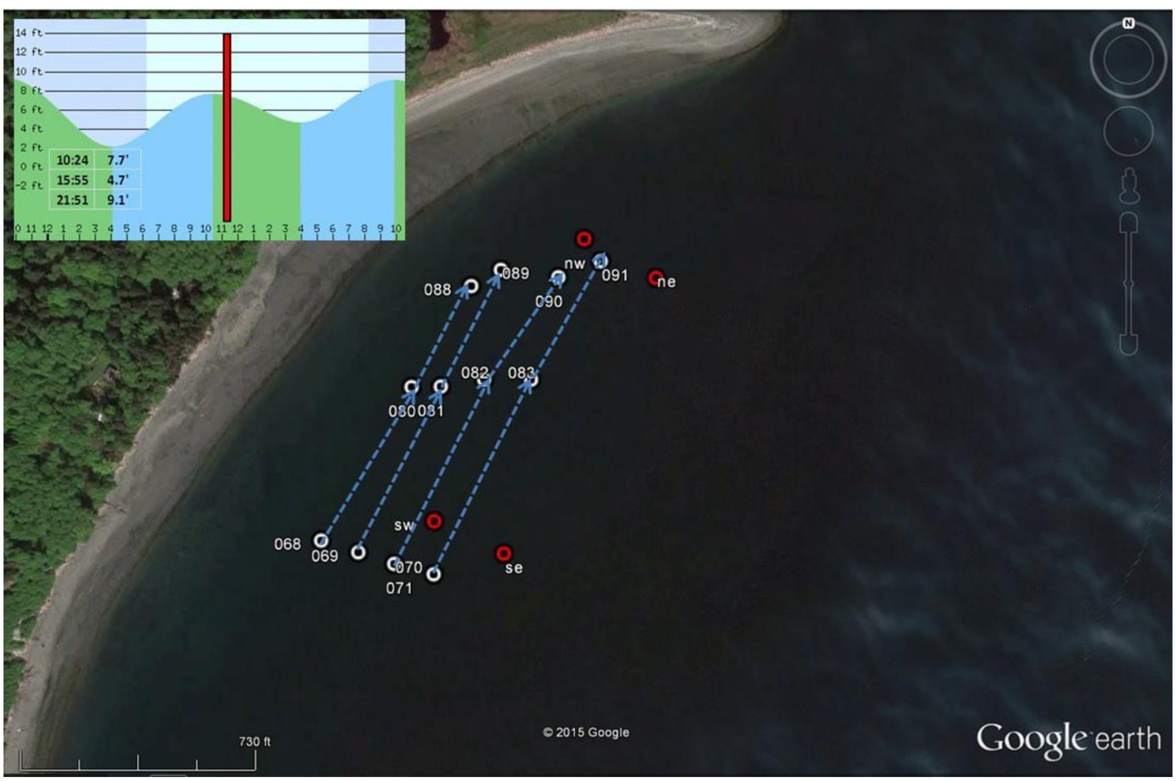

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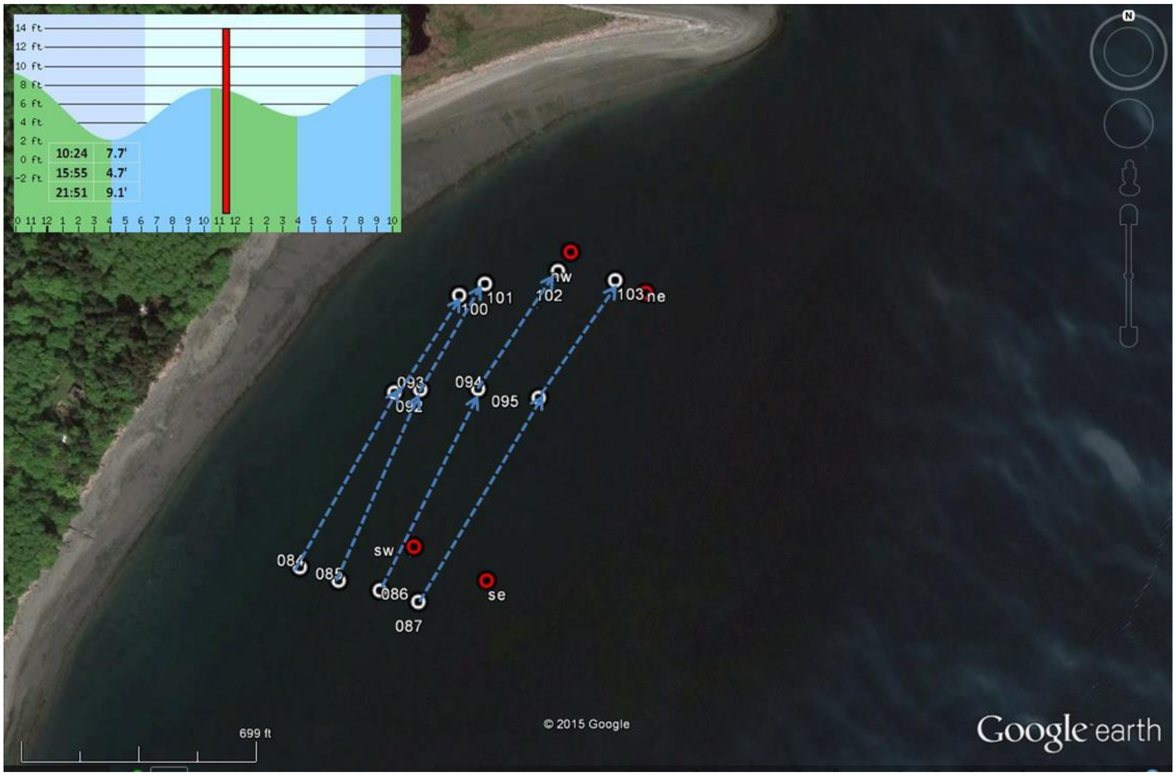
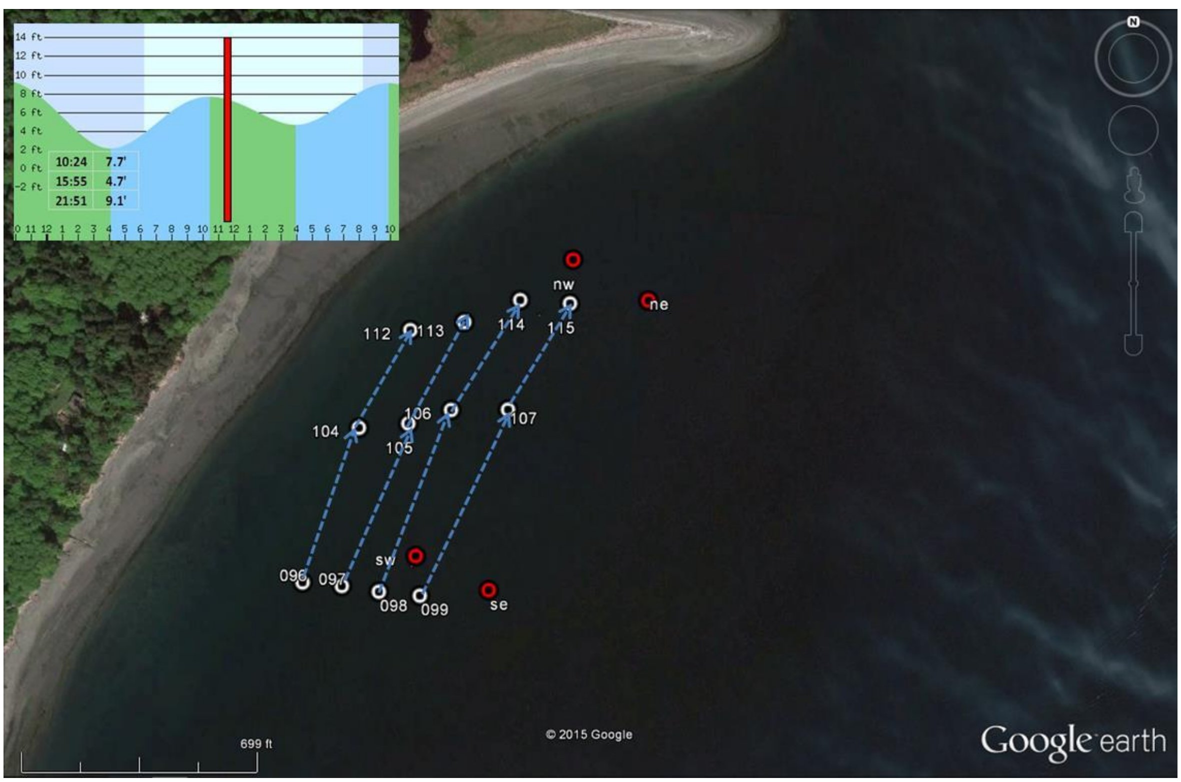
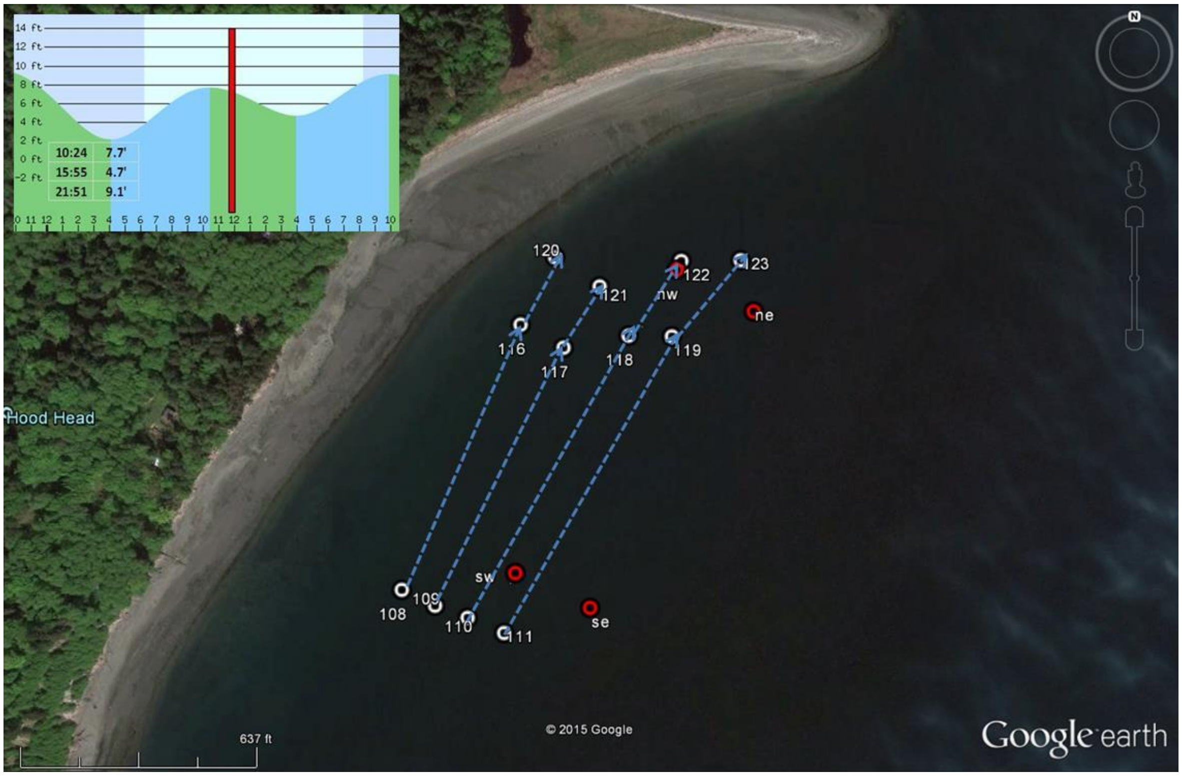


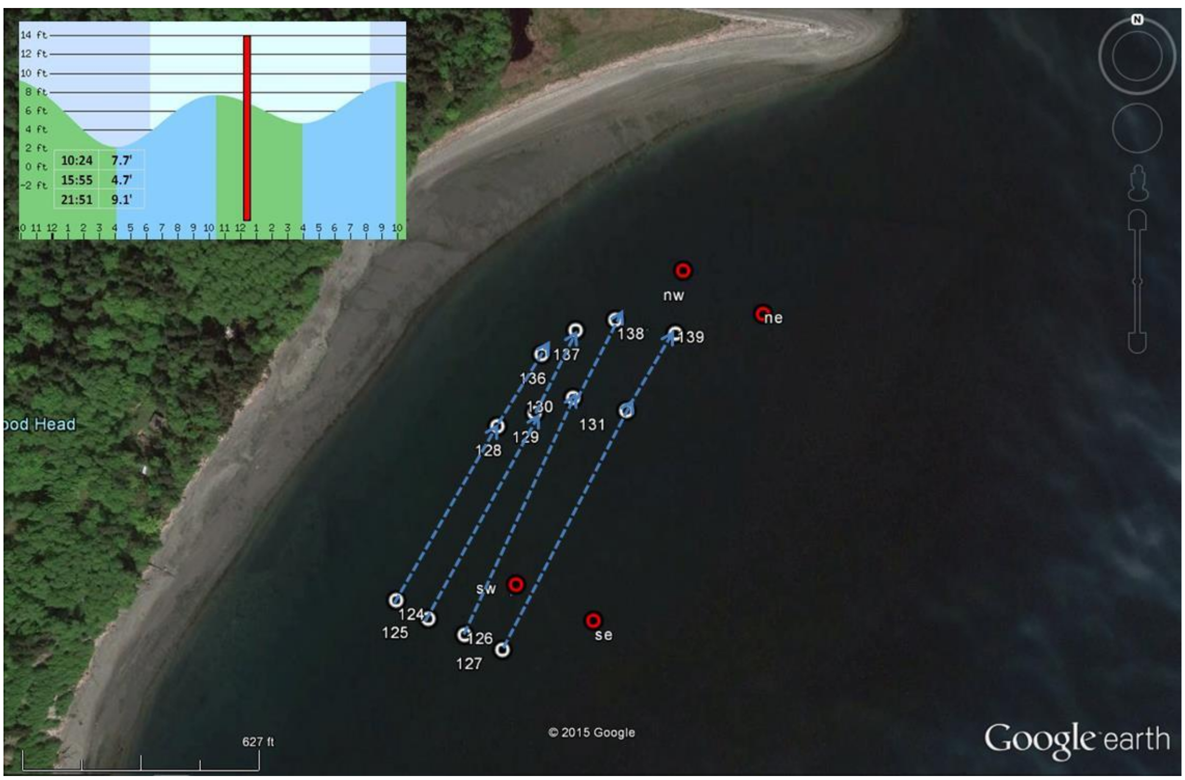
Appendix Figure 42. August 21, 2015 ebb tide



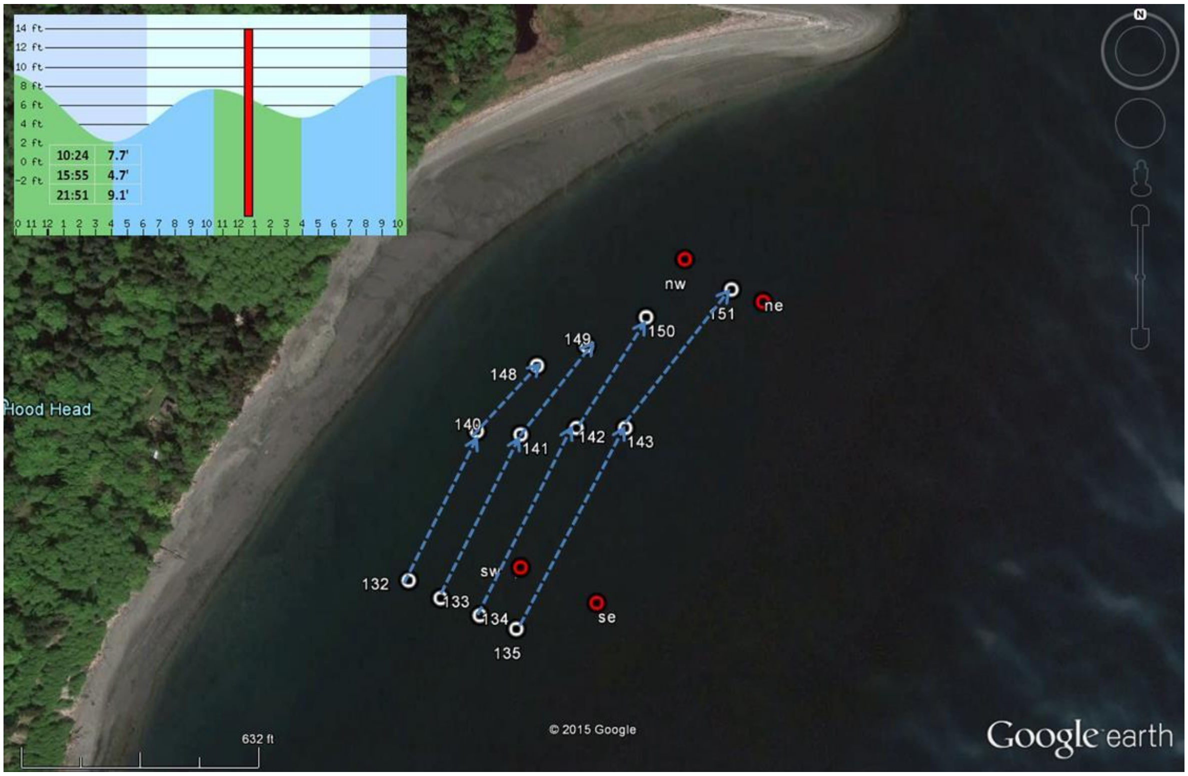
Appendix Figure 43. August 21, 2015 ebb tide



Appendix Figure 44. August 21, 2015 ebb tide



Appendix Figure 45. August 21, 2015 ebb tide



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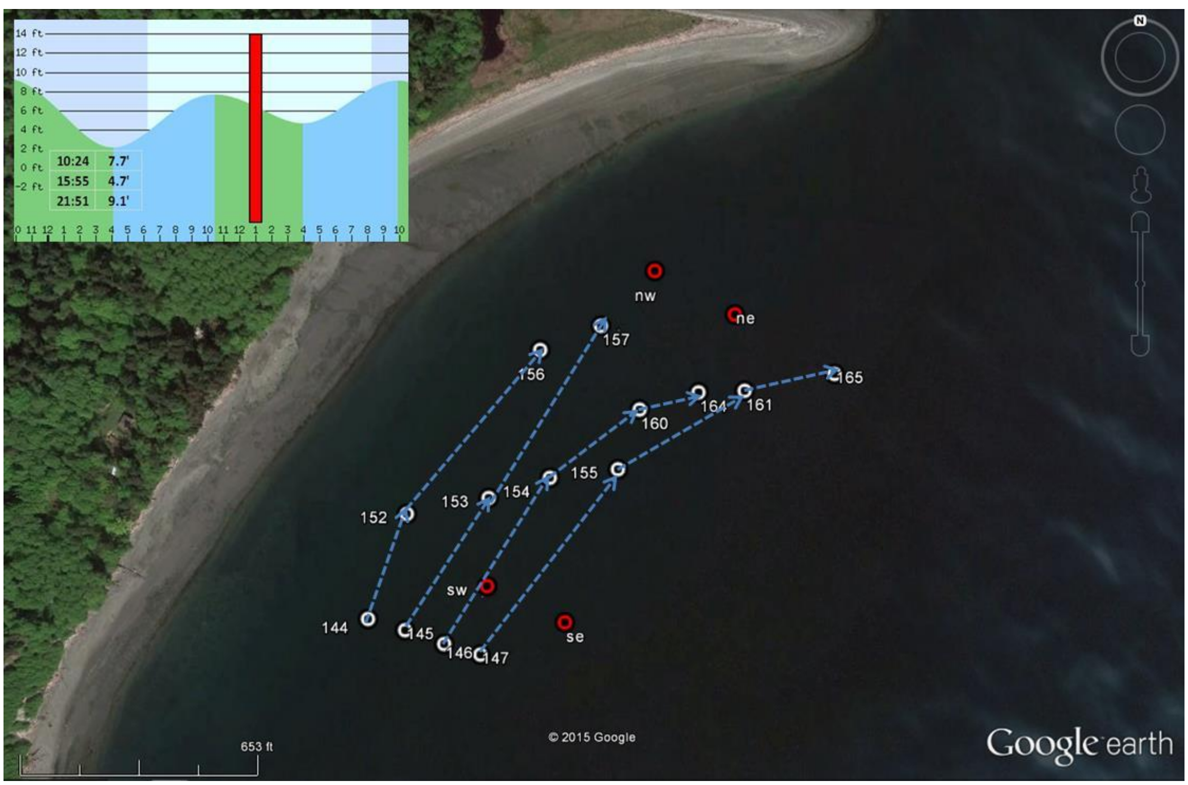

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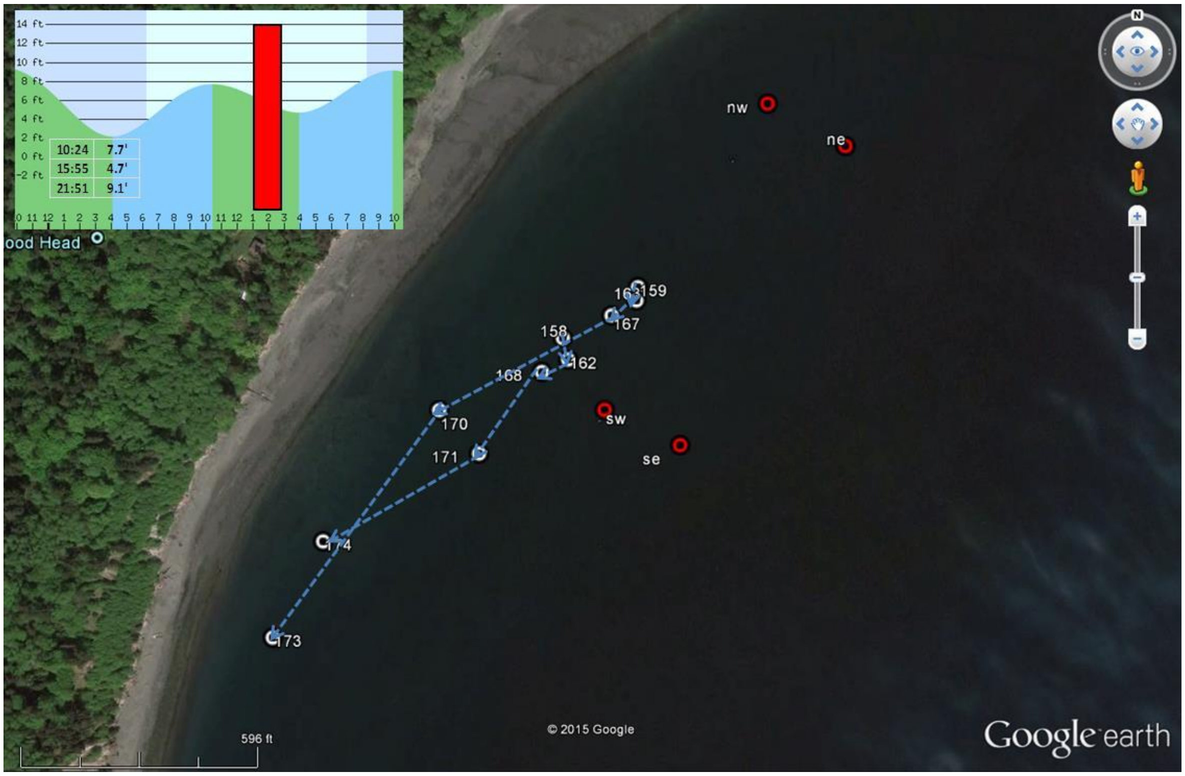

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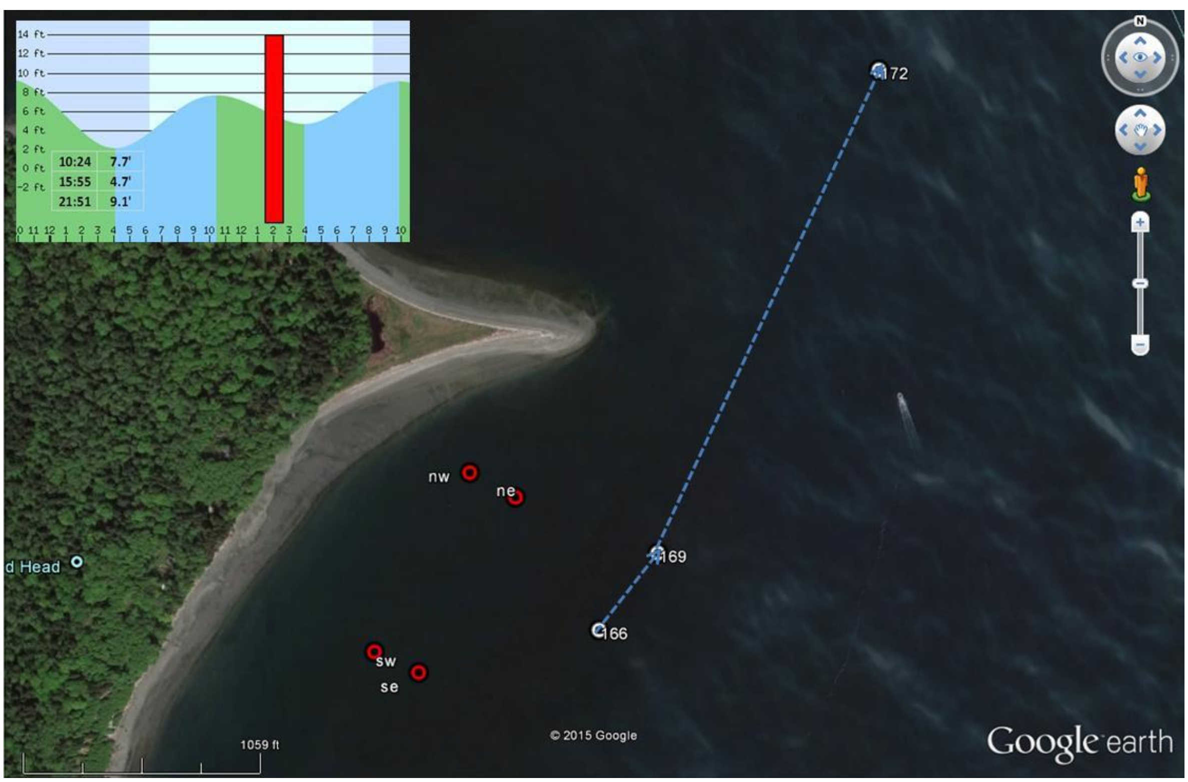

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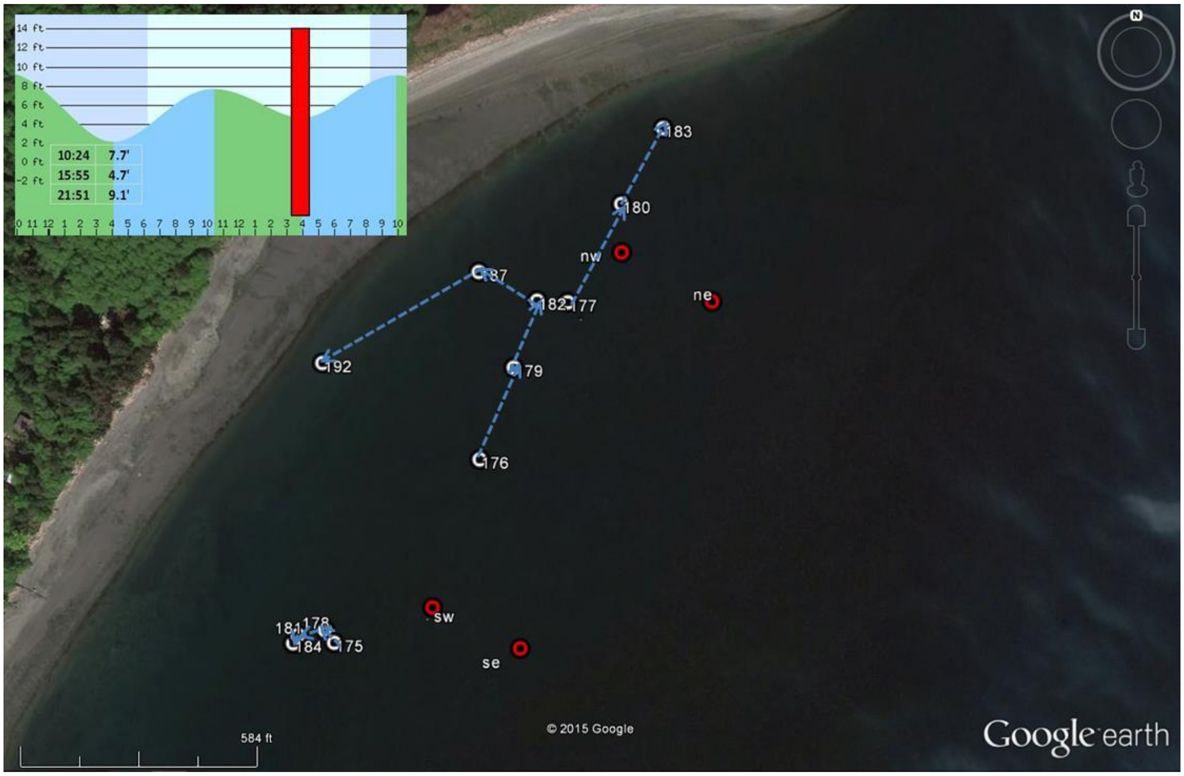
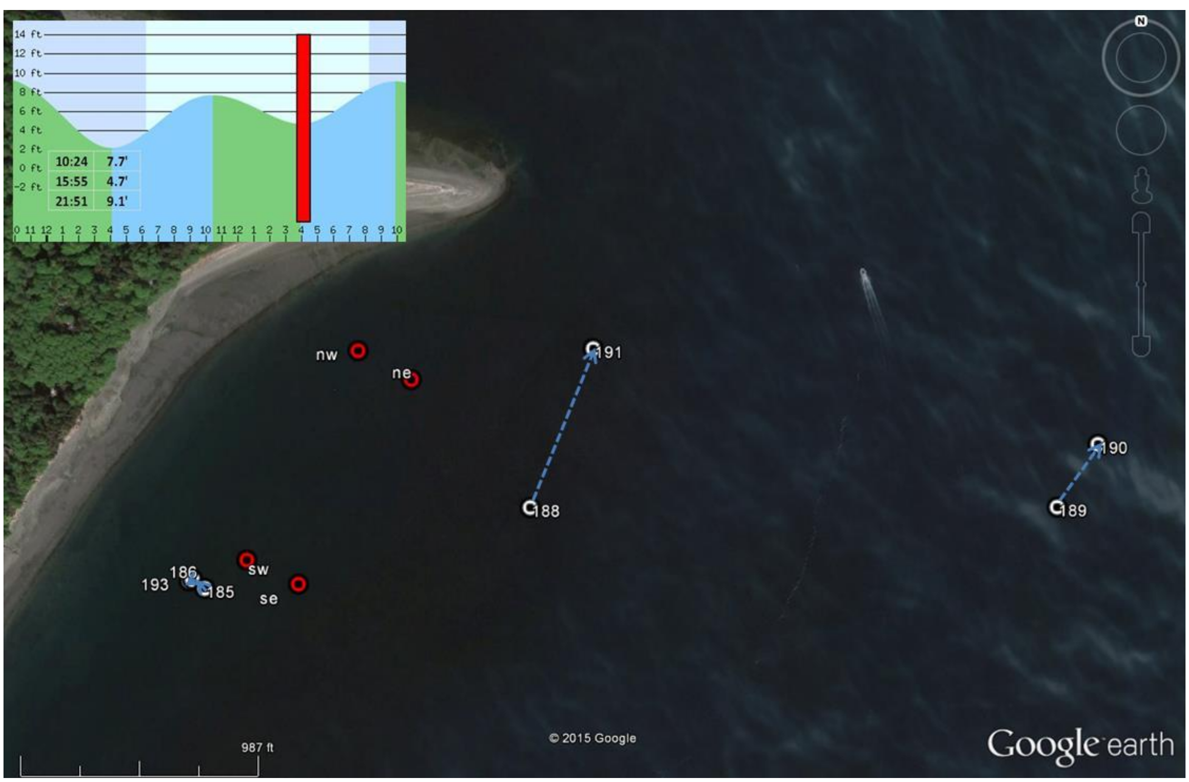
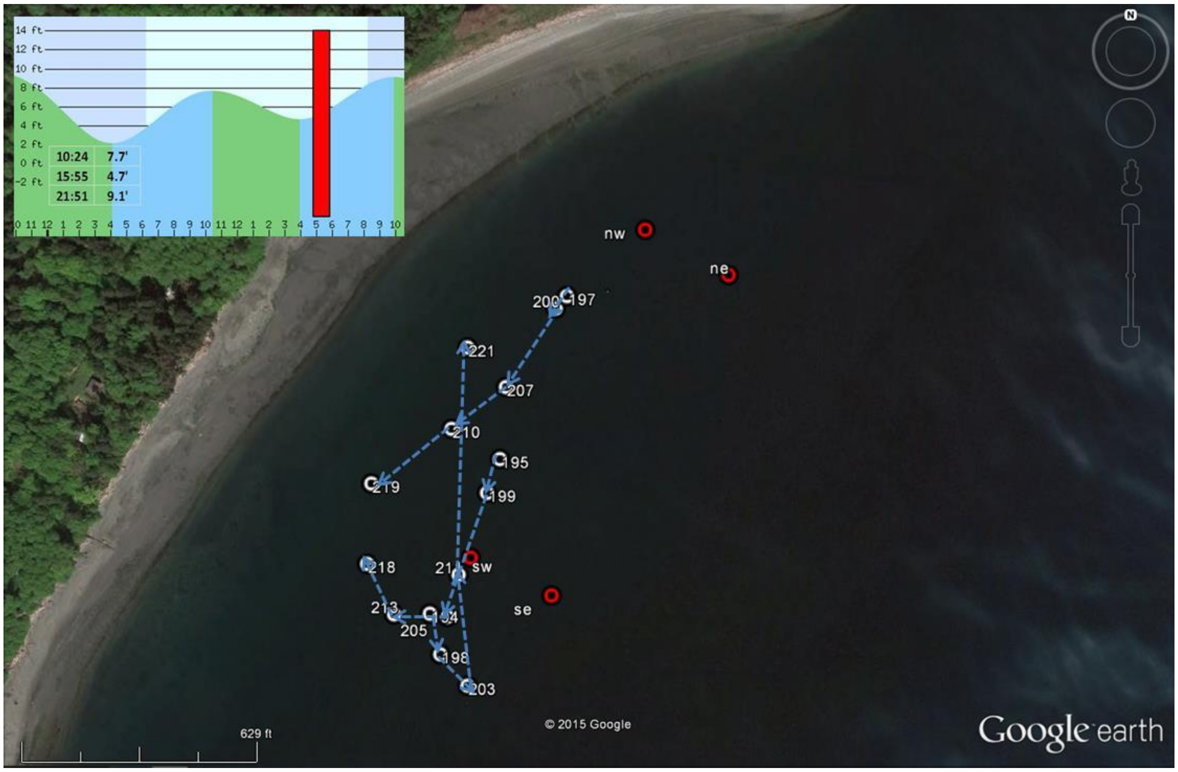


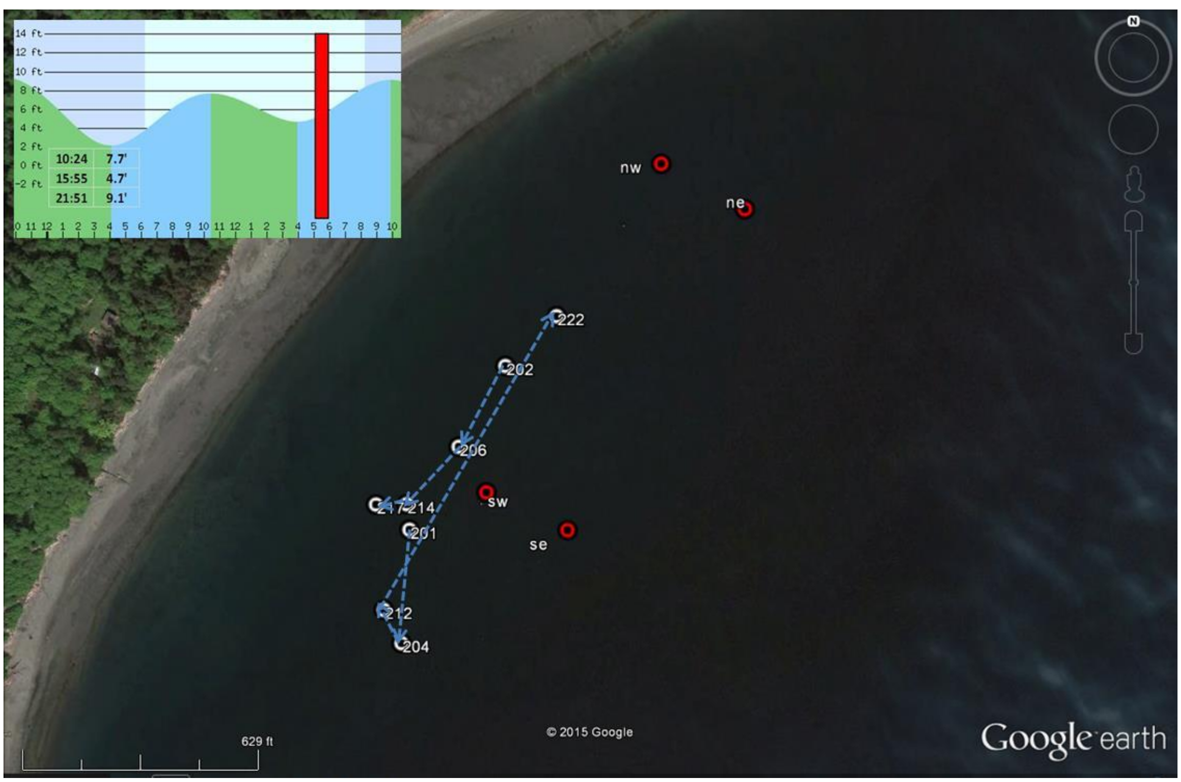
Appendix Figure 50. August 21, 2015 ebb tide



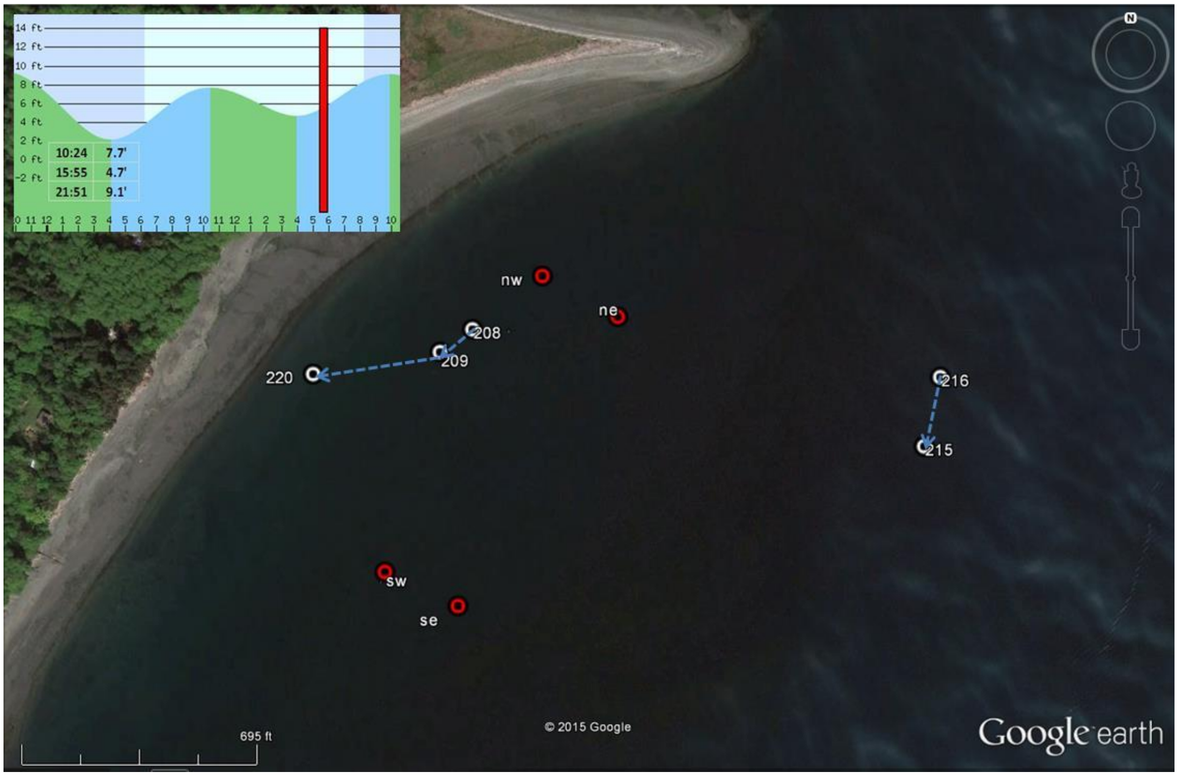
Appendix Figure 51. August 21, 2015 ebb tide



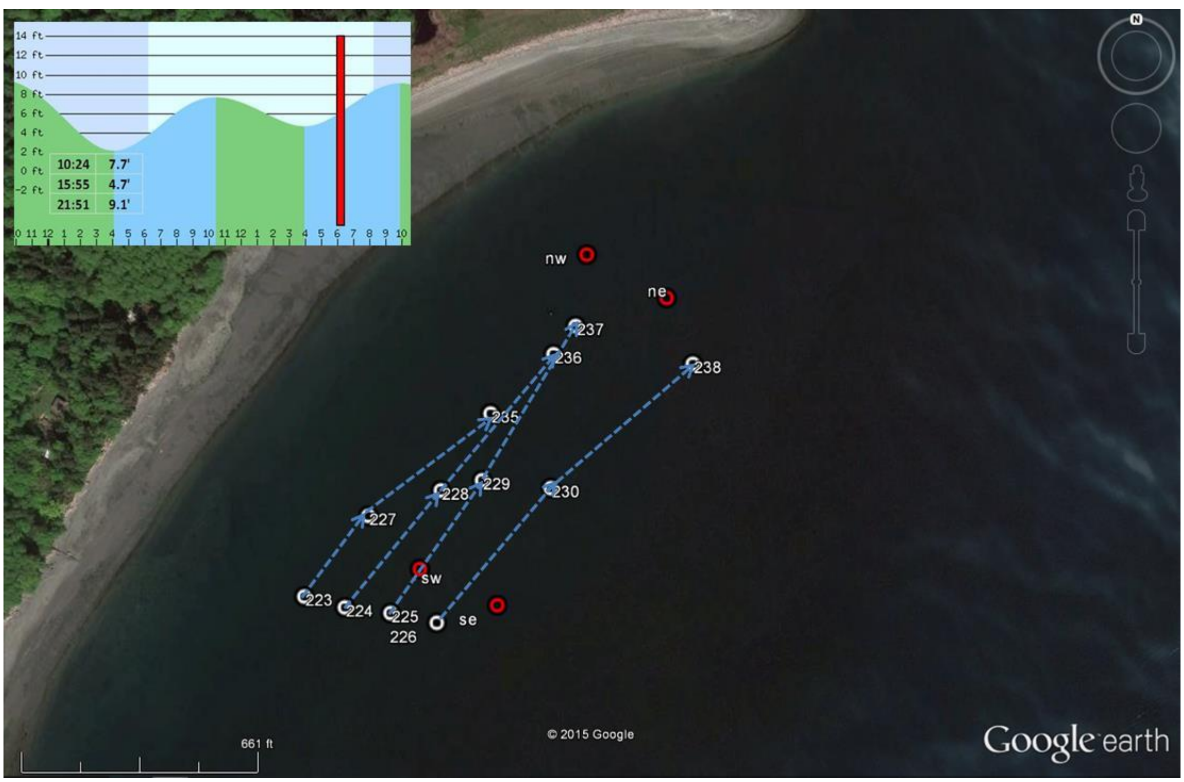
Appendix Figure 52. August 21, 2015 flood tide



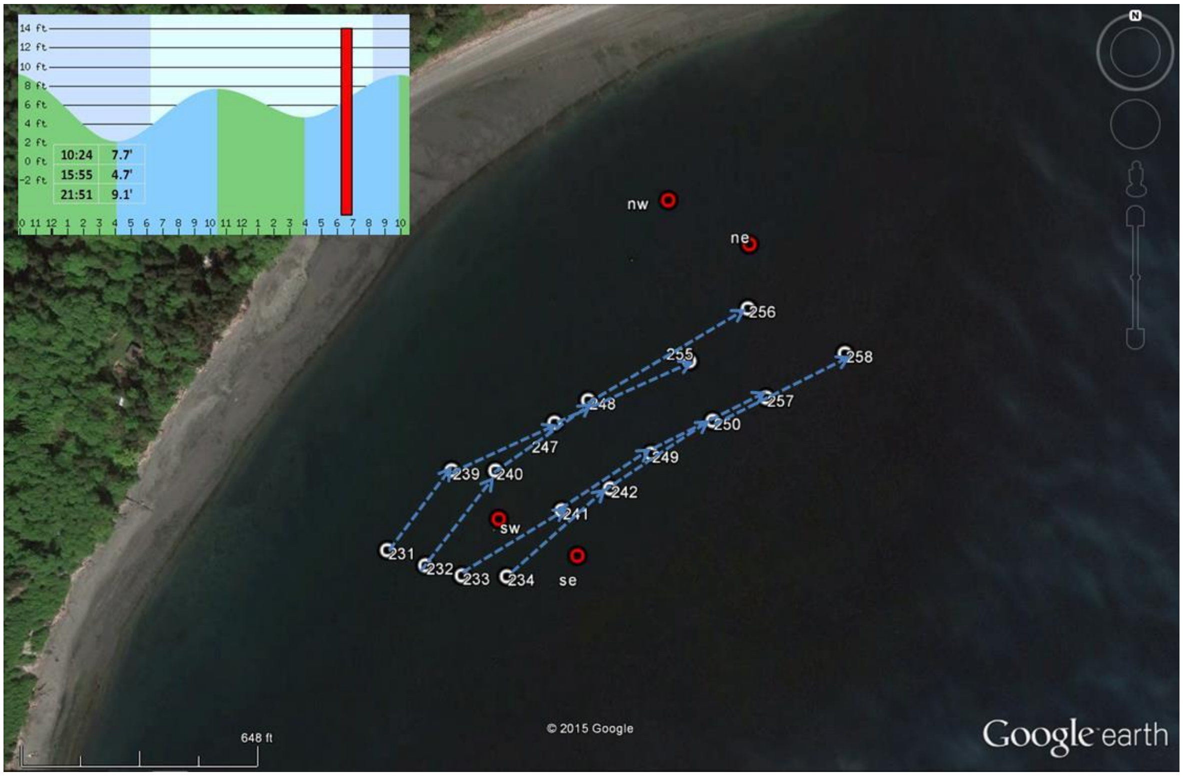
Appendix Figure 53. August 21, 2015 flood tide



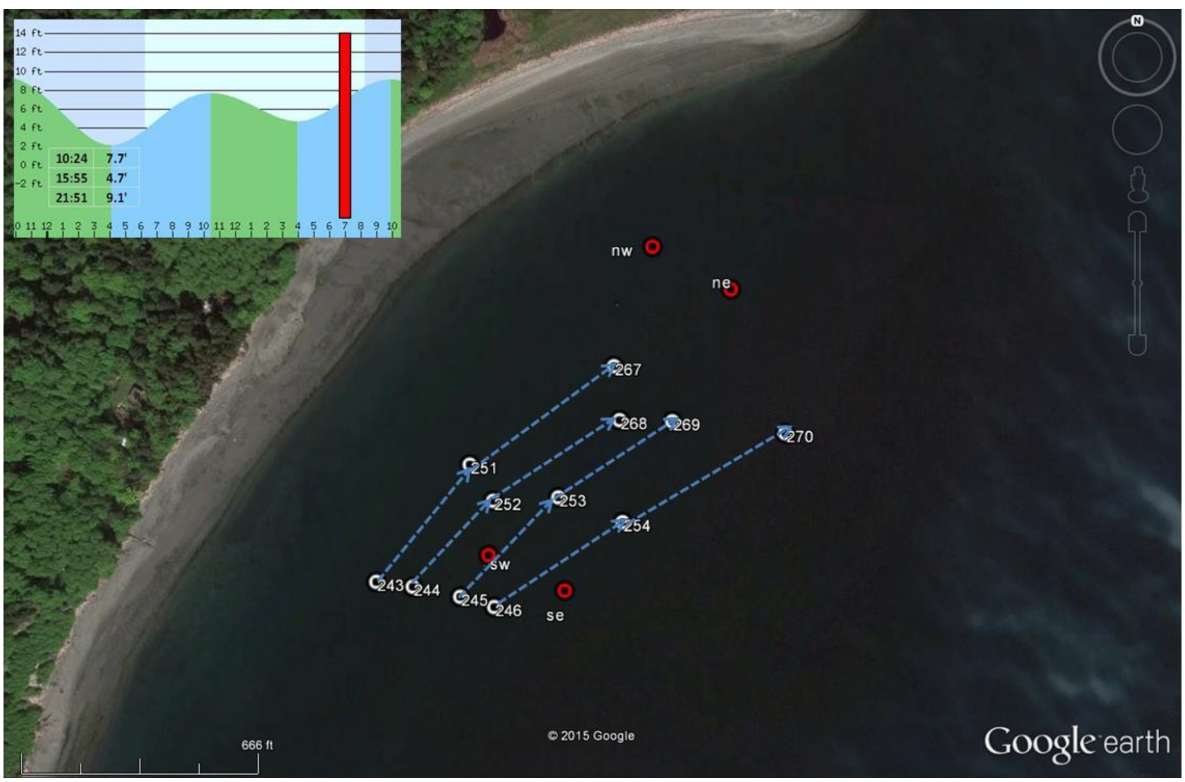
Appendix Figure 54. August 21, 2015 flood tide



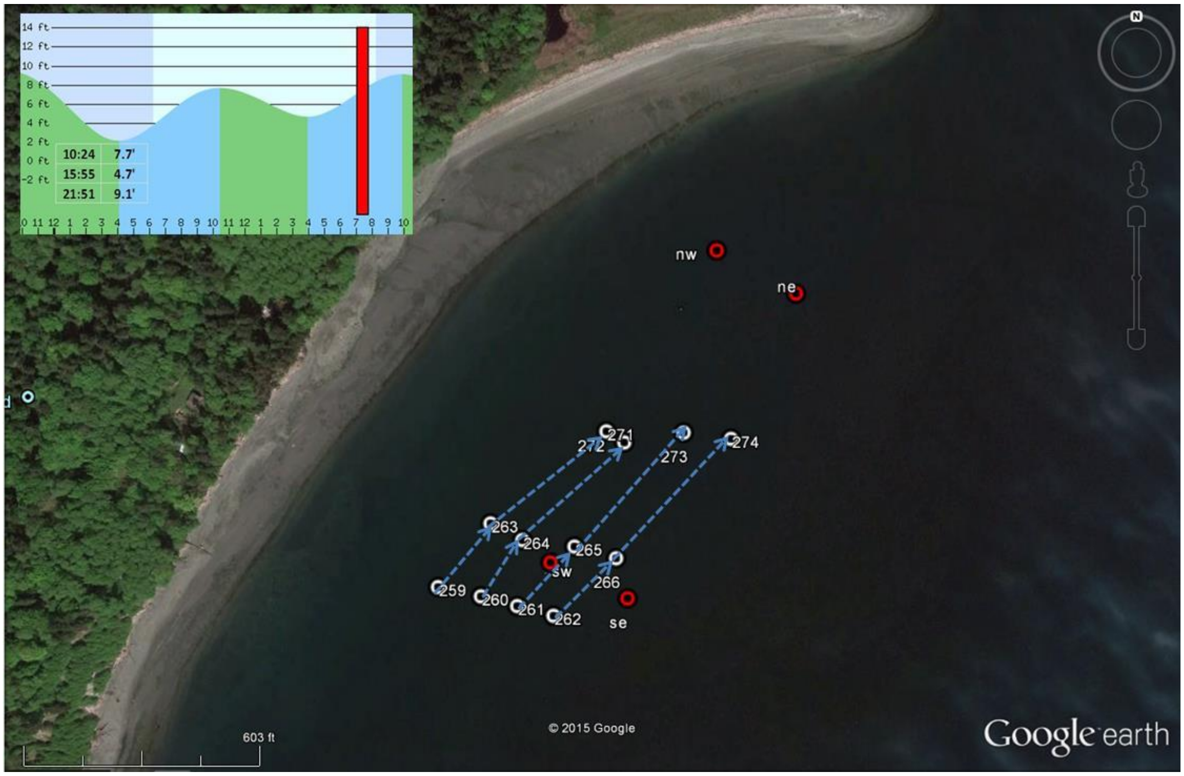
Appendix Figure 55. August 21, 2015 flood tide



Appendix Figure 56. August 21, 2015 flood tide



Appendix Figure 57. August 21, 2015 flood tide



Appendix Figure 58. End August 21 2015 survey.