

**Analyzing Drifter Designs and Data Gathering Methods in Complex Estuarine  
Environments**

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## **Abstract**

The ability to accurately and consistently map ocean circulation is important for understanding marine processes like sediment transport, pollution distribution, and plankton migration. My study compares three distinct drifter designs and evaluates the effectiveness of each design in terms of build-ability, ease of deployment, collecting data, and accuracy in observations. Two of the designs, the Davis design and the sock design, are industry standards. The other was a novel design consisting of, one surface and one drogue. The drogue drifters were designed to drift at a depth of 7 meters. All of the drifters were deployed off of Edward's Point, near Edmonds, WA and all drifters experienced a flood and ebb tide allowing this study to look at the differences in current between the two stages of tide. All drifters were successfully deployed with only one facing technical difficulties. The drifter's average speed and sinuosity of their path were calculated using information from the drifter mounted GPS units. From these calculations, both surface drifters had comparable results, but the sock drifter performed significantly better than the Morgan designed drogue drifter. This study also confirms the ability to study current using individual drifters in a complex environment.

## **Introduction**

Littoral environments provide complicated modeling challenges for scientists when attempting to quantitatively describe circulation and surface currents. These challenges become even greater in estuarine environments where shear is created with the input of freshwater into the saline oceanic water. Modeling estuarine circulation is made difficult by the combination of the ongoing variable input of the freshwater into the systems with often-complex bathymetry. To get an accurate measure of surface circulation in estuarine environments, especially near coastlines, direct physical observations of circulation are required. This calls for the use of drifters equipped with GPS for mapping purposes as an applied tool in shallow water research.

This paper explores if drifters can measure estuarine circulation at various depths in areas of high shear, as well as if different designs of drifters respond better to the shifts in current and gather more accurate current data. The study gathered and mapped the circulation in a marine estuary of the Puget Sound. This data provided the means to determine the speed of the currents at various depths. The study also compared alternative designs of these drifters and their responsiveness during changes from ebb to flood tide at different depths and under conditions of shear within the estuary. The track data was plotted in the ESRI ArcGIS ver. 10.1 Geographic Information System to examine the overall path of each drifter and calculate their path sinuosity. Path sinuosity provided a quantitative measure of the drifter meandering from release to recovery relative to a straight-line path between the start and end points. All of these parameters were used to compare the various drifter designs and make recommendations on which designs to use in future data collections of littoral circulation patterns.

This study investigates the responsiveness of different drifter designs in a complex estuary environment. The research will specifically look at the performance between the Star

drifter design and that of the more traditional Davis drifter at the surface (1 meter) and the difference in the circulation observed between those designs and the drogue designs at depth (7 meters).

Ocean drifters are divided into two categories, surface and drogue. A surface drifter sits at the water level and measures current over the 1-meter depth. A drogue drifter is tethered to a buoy on the surface and hangs to a specific depth that is being measured. This allows the speed of the water at that depth to be the force that moves the tethered buoy. In this study, four drifters were used; two surface and two drogue. One of the surface drifters is the Davis design, which is the industry standard for measuring ocean circulation. It features four large sails that are positioned ninety degrees from each other and are attached to a mast, which protrudes out of the water. One of the drogue drifters is known in the industry as the “sock.” It is a 5-meter long cloth tube with holes cut in it to create a dimple effect. It has a massive surface area, which helps with getting pushed along by the weaker currents at depth. It is also an industry standard. The other surface and drogue drifters are this author’s own design and will be discussed in detail in the methods section.

Basic drifter design is focalized around the concept of symmetry, a key factor that allows the drifter to not have a bias when being pushed by a current. Drifters require neutral buoyancy, or as close too as possible, and enough surface area that allows the drifters to have enough force acted upon the sails by the current to drift at the same speed as the current. The Davis drifter, which has a fixed mast, is neutrally buoyant and naturally floats on the surface. The “sock” and Morgan drifters were slightly negatively buoyant in order maintain tension in the line connecting the drifters to the buoys they were tethered to. That tension insured that the drifter was underneath the buoy, allowing the buoy’s GPS to accurately portray the position of the drifter.

The surface area is an important feature as it determines the speed of the drifter. Too much surface area makes the drifter hard to deploy and not enough could result in an inaccurate measurement.

For years, ocean drifters have been used to model circulation patterns in both open ocean environments and littoral environments (Gründlingh 1999). Drifters have also been deployed to collect data on surface wave height in areas of high mixing. Using technology to obtain a GPS transmitter's Doppler shift has allowed observers to make detailed calculations in the physical properties of waves and surface movement in the ocean (Herbers, et al. 2012). Herbers, et al. deployed surface drifters at the mouth of the San Francisco Bay, an area of high mixing and complex currents. Drifters have been proven to be a valuable tool in coastal environments where other forms of predicting and gathering data simply are not possible. In estuarial environments drifters are a technology that can be utilized and optimized to achieve understanding about the circulation within the estuary.

Understanding circulation in estuaries has been an ongoing scientific process. Hess, in 1974, attempted three-dimensional modeling of estuary circulation and salinity (Hess 1976). He observed that gravitational circulation was driven by salinity gradients, but complication in circulation came from factors such as topography, Coriolis acceleration, and lateral density variations, as well as variable wind-driven currents. These additional factors are the first major obstacle in modeling estuarine circulation. In 1975, Bowden and Hamilton (Bowden and Hamilton (1975) experimented with modeling circulation and mixing in a tidal estuary with variations in both internal and external parameters. They were studying how those parameters affected velocity and salinity distribution. Some of their observations were that vertical mixing was more intense during the flood than it was during the ebb, signaling that the shear was greater

in the flood. Bowdon (Bowden 1980) did another study on turbulent mixing in estuaries. He observes that the pattern of flow in a tidal estuary is dominated by the salinity gradient. This gradient is formed from the fresh water input, and extends from the river mouth all the way to the mouth of the estuary. Fresh seaward flow is on the top layer and the saline upstream flow is below the seaward flow. In estuaries with strong tidal currents, additional mixing between the top layer of river water and the bottom layer of saline water can be caused by bottom friction. Bowdon concludes by writing that creating model for estuarine flow and vertical circulation it is imperative that there is an understanding of the various physical processes affecting circulation and a way to quantify them.

Byer (1989) studied the physical processes of estuaries since those processes are such a large control system for biological and chemical systems in the estuarine environment. Byer notes that variable discharge from rivers, especially during spring melt, creates unique circulation within the estuary. This further complicates the model since river discharge is varies from year to year and seasonally. It was also observed that in narrow estuaries, more intense flood tide carries the saline water inland on the surface.

Estuaries are unique environments that are difficult to model. In order to meet those modeling demands, drifters can be used to physically gather data on circulation and currents and that information can be paired with environmental data to look at patterns. Those patterns and correlations could then be translated into quantitative variables to further help scientists model estuaries around the globe.

My design concerns for the drifter were based off of size, ease of construction, and cost to build. The Star drifter design was very cheap to produce. The total cost of construction of the body was approximately \$80, not including the GPS unit. Due to its lightweight construction, a

single person can easily build and deploy the finished product. The 12 sail design allowed me to get the same amount of surface area as the Davis drifter, in a smaller and lighter package. The mast was also detectable and interchangeable allowing for easier storage and deployment from a research vessel. I rejected the idea of trying to make a star drifter that had the same surface area as the sock drifter. The dimensions calculated would have been too big and cumbersome for a small research vessel. Instead, I opted have the drogue star drifter have the same surface area as the surface star drifter and the Davis drifter.

## **Methods**

For this study, I designed my drifters to have twelve separate sails and to have identical surface area as the Davis drifters. My design initially started with a .75" diameter 6-way PVC fitting to which I attached 24" PVC pipes and attached them with glue. I then capped the ends of the pipes with PVC caps. At the end of one cap, I attached a metal ring that was the attachment point for the buoy. I then attached the 22"x22"x32" sails to the frame. I used diamond rip stop tenting material and brass grommets so the sails could be zip tied to the PVC.

The buoy I used as the drifter mast was a crabbing pot float. It consisted of a foam float with a PVC pipe running through and an orange flag sticking up at the top. The GPS units were Garmin eTrexes and were placed in waterproof otter boxes and attached to the crabbing pot float.

The design goals of the star drifter were to create a smaller, accurate, cheap, and easily deployable float that would be easy to fix or repair underway. Early in the design process, I used a large buoy with a PVC pipe through it was my drifter tether and GPS mount. This proved to be detrimental as it had too large of an above water profile and the drifter was pushed around by the wind. I then attached small crabbing floats that allowed the above water profile to become much smaller and not as influenced by the wind. The second biggest change was that I drilled holes

into the PVC pipe to better fasten the sails. This did not affect the ability of the drifter to be deployed as I had already drilled holes in the supporting arms to allow them to fill with water. The additional holes did not make a noticeable difference with how the drifter interacted with the water.

I deployed the drifters off of Edwards Point, near Edmonds, WA just after 1030. That was during peak flood tide, with a slack tide scheduled at 1200. This time was chosen because it allowed me to analyze the responsiveness of the drifters during a tide change as well as gather tide data about both the flood and ebb tides. Gathering data for both of the tides would allow me to compare the drifters behavior and course, and observe unique characteristics about each part of the tidal cycle.

The drifters were deployed off the R/V Weelander. They were deployed by hand and the deployment location was marked by shipboard GPS as well as the individual GPS units located on the drifters themselves. Monitoring the drifters was done visually, requiring the Weelander to maintain a presence within the deployment area. The recovery was also done by hand with the location of the recovery being logged by ship board GPS as well as the individual GPS on each drifter. All times were recorded in a log book, allowing for confirmation of times when analyzing the GPS data later on.

The first set of deployments occurred during flood tide between 1037 and 1042. Each drifter was picked up, and redeployed in order to avoid interfering with the ferry lanes. The two deployments are referred to a “Deployment 1” and “Deployment 2”, respectively throughout the paper. All the drifters were picked up between 1148 and 1233 and were redeployed between 1159 and 1234. It should be noted that the Morgan Drogue drifters redeployment was more of a status check and less of a physical redeployment. All the drifters we picked up by 1400.

The data from the GPS units was downloaded and organized using ArcGIS. In ArcGIS, all data points were looked at and a line connecting these points was drawn for each individual drifter. This line gave the distance travelled by the drifter allowing for average velocity calculations. The distance between the start and the end point was used in conjunction with the actual distance travelled to calculate the sinuosity of each drifter. The formula used for sinuosity was:

$$\text{Sinuosity} = \frac{\text{Actual Path Distance (m)}}{\text{Shortest Path Distance (m)}}$$

## Results

The Morgan surface drifter was deployed at 10:42:28 (Table 1) and drifted with the flood current, in a northbound direction until it was picked up to avoid the ferry traffic. During that first deployment, the drifter travelled for 01:06:22. In that time it traveled 899.73 meters according to the Garmin eTrex 10 GPS unit attached to it. It had an average velocity through the top meter of water of 0.23 m/s, comparable to the sock drifter's speed during the flood. The Morgan surface drifter was displaced 885.08 meters, which gave it a displayed sinuosity of 1.02. That value is very close to a straight line and the smallest sinuosity displayed in the study.

The Morgan surface drifter was again deployed at 11:59:55, right at Ebb tide. It floated for 01:55:45, and was picked up at 13:55:40. It floated out away from the shore, and not in a due south direction as anticipated. During this period the drifter traveled 713.25 meters at a rate of 0.10 meters per second. It was displaced 460.80 meters during that time, giving it a sinuosity of 1.58. During the ebb tide, the drifter experienced half the speed and significantly more sinuosity than flood tide.

The Davis surface drifter was deployed at 10:43:16 with the north bound flood tide and was recovered to avoid possible ferry traffic. The Davis drifter was deployed for 1:08:34 and recovered at 11:51:50. In that time traveled 1343.70 meters, an average of 0.33 meters per second, the fastest recorded speed of any of the drifters. It experienced a true displacement of 1217.32 meters, giving it a sinuosity of 1.10.

The Davis drifter was again deployed at 11:59:45, at the beginning of the ebb tide. Similarly to the Morgan surface drifter it went out away from the shore instead of going south as predicted. It was deployed for 1:54:45 and was eventually recovered at 13:54:30. During this deployment the drifter travelled 1011.50 meters and had an average speed of 0.15 meters per second. It experienced a displacement of 681.02 meters, which gives it a sinuosity of 1.49.

The Morgan drogue drifter was deployed at 10:39:43 and went north with the flood tide. It drifted for 1:54:00 until it was picked up at 12:33:43. Within that time it had travelled 459.63 meters at a velocity of 0.07 meters per second. This is significantly slower than the Morgan surface drifter over the same time interval. It experienced a displacement of 324.40 meters, which led it to have a sinuosity of 1.42.

When the Morgan drogue drifter was redeployed at 12:34:50, it drifted in the ebb tide until 13:00:20, for a duration of 01:25:30. In that interval, the drifter travelled 579.82 meters at a velocity of 0.11 meters per second. The displacement it experienced was 506.56 meters from its deployment location, giving it a sinuosity of 1.14. The Morgan drifter experienced greater speed and straighter path during the ebb than the flood, opposite that the Morgan surface drifter recorded.

The sock drifter was deployed at 10:37:39 and floated for 1:14:28 until it was retrieved at 11:54:07. During that time it travelled north with the flood tide for 929.76 meters with an

average speed of 0.21 meters per second. That speed is very comparable to the recorded flood speed observed by the Morgan surface drifter. It experienced a displacement of 904.94 meters, giving it a calculated sinuosity of 1.03, which is very close to the same sinuosity that the Morgan surface drifter recorded during the flood tide.

The sock drifter was redeployed at 12:00:21 and drifted for 00:29:58. It was picked up at 12:30:17 due to a snap in the shackle that attached the buoy to the GPS, allowing the drifter to be lost. Over the time interval, the sock experienced major turbulence, only drifting 55.16 meters at a rate of 0.03 meters per second. Its total displacement was only 10.91 meters and the sinuosity was calculated as 5.06.

NOAA listed the tide 2.7 miles WSW of Edmonds to be 0.2 knot flood and a 0.5 knot ebb. The speed of the drifters has been converted from meters per second to knots in Table 2 in order to gauge the accuracy of the drifters. The drifter's velocity ranged from -0.44 knots to 0.44 knots faster than the estimated current.

## **Discussion**

The observed results and collected data revealed interesting patterns in tidal cycles off Edward's Point, along with challenges for using drifters to collect surface current data.

The data the drifters gathered show the nuance and difficulties in gathering surface circulation in complex environments. Across the board, the drifters experienced faster speeds during the flood tide, before noon, than during the ebb tide, after noon. This is interesting from a variety of perspectives. In an estuary environment, it would intuitively make sense that ebb tides would be stronger than flood tides on the surface. There is a constant flow of water, especially in the spring tide due to snowmelt, from the fresh water source. This less dense fresh water would

flow away from the river mouth on the surface of the estuary. However, that is not what was observed.

Both the Davis drifter and the Morgan surface drifter both had very little sinuosity while going with the flood tide and the wind. However, they both experienced increased sinuosity when drifting with the ebb tide and against the wind. The increased turbulence in their path could have both been caused by wind drag on their masts. The Davis drifter recorded significantly faster average speeds compared to the Morgan drifter. During the flood tide the Davis drifter average 0.10 meters/second more than the Morgan surface drifter, however the Morgan surface drifter experienced less sinuosity. During the ebb tide, the Davis drifter averaged 0.05 meters/second faster than the Morgan surface drifter and also experienced less sinuosity. This observed increase in speed going both into the wind and with the wind possibly indicates that the mast had little to do with the mast interacting with the wind and more to do with the design of the drifter below the water line.

The drogue drifters had significant differences in their performance. The sock drifter recorded a velocity during the flood tide about equal to the velocity of the surface drifters. This indicates that the surface layer was well mixed and shear was not great enough to result in a speed decrease 7 meters below the waterline. However, the Morgan drogue drifter had significant performance deficiencies compared to the sock drifter. This can be attributed to the sock drifter having significantly more surface area than the Morgan drifter. The Morgan drogue drifter failed in accurately measuring the current and it would be safe to conclude that Morgan drogue drifter does not meet expectations to accurately get depth current data.

The same pattern was seen in the sock drogue drifter as the two surface drifters. Similar flood velocities were recorded with a similar drop in velocity during the ebb tide. The sinuosity

of the drogue drifter was also very high during the flood tide. It should be noted that the sock drifter broke off from its buoy at 1237. After 1237, the GPS recorded an increased speed as the buoy was being pushed around by the wind. This gives credibility to the sock drifter design, that it was portraying current speed at 7 meters in depth and was not being overwhelmed by the strong southerly wind present the day of testing.

Through out the entire day, there was a strong southerly breeze. This could have factored into the speed of the drifters. As the drifters went north in the flood tide they had the wind working with them, while during the ebb tide the wind was working against them. This could explain the difference in speed. Although the drifters did not have the same velocity against the wind, they still were drifting with the current, giving credibility to the design of the drifters. According to the NOAA predictions, the drifters exceed the estimated current speed during flood tide and are under the estimated speed during the ebb tide (Table 2). This data proves reasonable evidence that the wind adversely affected the performance of the drifters, causing the drifters to go faster than the current when going with the wind, and causing the drifters to go slower when facing the wind.

A success of this testing was the positive outcome that it is very feasible to go out and measure surface currents in complex estuarine environments. This testing, can be recreated in various locations in order for scientists to gain understanding of how water moves in environments that experience shear.

Going forward I would set a test criteria for calibrating the speed of the drifters. Picking a place that is well studied and has ample amounts of current data will help with time of deployment. The current observations can give estimates on whether the drifter is accurately recording the speed of the current. Ideally it would occur on a non-windy day minimizing the

non-current forces acting on the drifter. Once a baseline has been identified, the drifters can be deployed in windy conditions to see how the data gathered differs, allowing for an understanding of data accuracy under windy conditions.

Based on this study, I recommend that further studying be conducted on the Star surface drifter. It performed similarly to the Davis drifter. The Star drifter was slower through the water but both drifters did not accurately measure the speed of the current. However, its ease of construction and deployment make it a good option for future design studies. The Sock greatly performed the Star drogue drifter, which went under the estimated current speed even when drifting with the wind. The Star drifter design was not adequate for the 7 meter depth due to its minimal surface area compared to the sock. From this study, the sock should continue to be used as a drogue drifter in future studies.

**Table 1**

	Start Time	Finish Time	Elapsed Time	Distance Travelled (m)	V (m/s)	Displacement (m)	Sinuosity
Star Drouge Drifter 1	17:39:43	19:33:43	1:54:00	459.6341	0.0672	324.3996	1.4169
Star Drouge Drifter 2	19:34:50	21:00:20	1:25:30	579.8232	0.1130	506.5588	1.1446
Sock Drifter 1	17:37:39	18:54:07	1:14:28	929.7565	0.2081	904.9437	1.0274
Sock Drifter 2	19:00:21	19:30:17	0:29:58	55.1627	0.0307	10.9097	5.0563
Star Surface Drifter 1	17:42:28	18:48:50	1:06:22	899.7302	0.2259	885.0830	1.0165
Star Surface Drifter 2	18:59:55	20:55:40	1:55:45	713.2491	0.1027	460.7992	1.5479
Davis Drifter 1	17:43:16	18:51:50	1:08:34	1343.7015	0.3266	1217.3205	1.1038
Davis Drifter 2	18:59:45	20:54:30	1:54:45	1011.4987	0.1469	681.0211	1.4853

Table 1. The start and finish times for the deployed drifters, as well as the calculated elapsed

time, distance, velocity, displacement and sinuosity. The distance and displacement were found by using ArcGIS and measuring the length of the GPS track and the distance between the start and finish points. Velocity and sinuosity were calculated with the times recorded and the

distances measured. The first deployment (marked by the number 1) took place during the flood tide. The second deployment (marked by the number 2) took place during the ebb tide.

**Table 2**

	V (m/s)	V (knots)	Est. Tidal Speed (NOAA)	Difference (knots)
Star Drogue Drifter 1	0.0672	0.1306	0.2000	-0.0694
Star Drogue Drifter 2	0.1130	0.2197	0.5000	-0.2803
Sock Drifter 1	0.2081	0.4045	0.2000	0.2045
Sock Drifter 2	0.0307	0.0596	0.5000	-0.4404
Star Surface Drifter 1	0.2259	0.4392	0.2000	0.2392
Star Surface Drifter 2	0.1027	0.1996	0.5000	-0.3004
Davis Drifter 1	0.3266	0.6349	0.2000	0.4349
Davis Drifter 2	0.1469	0.2856	0.5000	-0.2144

Table 2. The speeds of the drifter, in meters per second, converted to knots in order for a clear representation of the accuracy of the drifters. The 0.20 knot speed is associated with the flood tide and the 0.50 knot speed is the ebb tide.

## Literature Review

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