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Estimating Surface Currents Using Dyes and Drogues

by Steven A. Hughes

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) described herein provides information about simple, inexpensive field techniques for quantifying current patterns in the vicinity of coastal structures such as breakwaters, jetties, and groins. Although these techniques cannot produce a complete picture of the flow regime, they do provide reliable information that can be included with other analyses to understand and solve coastal engineering problems. The techniques are illustrated by application to Aguadilla Harbor, Puerto Rico.

BACKGROUND: There are two categories of postconstruction monitoring of completed coastal navigation projects:

a. Project condition monitoring consists of periodic inspections and measurements conducted as part of project maintenance. Information from condition monitoring is used to assess the project state and make decisions about repair and rehabilitation.

b. Project performance monitoring consists of observations and measurements used to assess the actual project performance relative to design objectives.

Onsite observation of environmental conditions (waves, currents, winds, etc.), along with project response, are essential components of both categories of monitoring. However, project performance monitoring typically requires more quantification of environmental parameters to assess how well the project is fulfilling its intended function.

Techniques for estimating water current magnitude and direction at a navigation project range from very simple methods, such as dye and drogue releases, to very sophisticated methods, such as suites of in situ instruments or complex numerical models. This CHETN illustrates how simple dye and drogue studies can provide useful information about surface currents that can then be used to infer sediment pathways in the vicinity of a harbor or other coastal project.

Dye and drogue studies have several advantages:

a. Inexpensive (minimum equipment requirements)

b. Low manpower requirements

c. Minimum preparation (no calibration or equipment testing)

d. Flexibility (study plan can be altered or expanded as necessary)

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The major disadvantages of dye and drogue studies include the following:

a. Limited scope and spatial coverage

b. Results apply only to conditions at the time of the study (i.e., no long-term records)

c. Care must be taken to assure that personnel are not at risk when they are on coastal structures during heavy wave conditions

d. Only surface currents are estimated

e. Estimation techniques are crude; and consequently, accuracy is less than optimal

Despite the shortcomings, dye and drogue studies can substantially augment other sources of information, thus providing a broader base on which to make engineering decisions.

NOTIFYING LOCAL AUTHORITIES AND ENVIRONMENTAL SENSITIVITY: Dye and drogue studies are highly visible activities, particularly around navigation structures, harbors, and marinas. Local inhabitants and users of the project might become alarmed when they see patches of water turning bright green, or when they observe strangers throwing objects into the water, and they might call the local police agency to report this suspicious behavior. If the local authorities are aware of the study, they will be able to reassure the concerned citizens and explain what is happening.

Be sure to inform the appropriate local authorities of a planned dye or drogue study via official U.S. Army Corps of Engineers letter. Such authorities might include harbor/marine police, harbor master, local police agencies, and local municipalities. The letter should be brief and explain in simple terms what is being done, when the study is to occur, and who to contact if there are any questions. The letter needs to state that any dye used in the study is safe for humans and the marine environment. It is a good idea to attach a data sheet giving details about the chemical nature of the dye. Hand delivering the letter and giving an oral summary just before commencing the study is much better than sending a letter several weeks in advance.

ESTIMATING CURRENTS FROM DYE RELEASE: Dyes suitable for use in a marine environment are available in liquid, powder, and pellet form. Pellets dissolve in water resulting in a continuous dye source which is beneficial for showing flow trajectories. Because the pellets usually sink to the bottom, best results for surface currents are obtained where the pellets are affixed to an anchored float so the dye is released on the water surface. Multiple buoy positions give a series of pathlines revealing the principle flow patterns in the vicinity of the structure. Estimating current speed from a fixed dye source is done by tracking the position of the head of the pathline as it moves with the current flow. Figure 1 shows an aerial view of a continuous source dye release at Shinnecock Inlet, NY.

Powdered or liquid dye is usually deployed as a single release at a selected location. At initial release the dye is concentrated into a small patch that begins to grow in area as it migrates with

Figure 1. Dye release at Shinnecock Inlet (photograph courtesy of Aram Techunian, First Coastal Corp.)

the flow. The shape of the dye patch can elongate over time, indicating stronger flow on one side of the patch; or it may retain a circular shape, indicating a more uniform surface current. Current magnitude and direction are estimated by roughly plotting the position of the dye patch centroid as in migrates in time.

Dye Deployment. Dye studies achieve the best results outside of regions where strong turbulence occurs. For example, dye placed inside the breaker zone quickly dissipates without giving much information about current magnitude. Where vessels can safely navigate, the dye can be deployed from a small boat such as a Zodiac. A small vessel can sequentially inject dye at multiple locations with minimal time lapse between injections. Hand signals, radios, or cell phones are used to notify the shore observers when each dye packet is released so that timing can begin. Number and location of dye injection points is subjective, and depends to a great extent on the particular project site and the goals of the study.

Launching dye packets from a coastal structure is also a possibility, but placement is much more haphazard. One suggested technique is to wrap about two tablespoons of powered dye in tissue paper, shape it into a ball, and secure it with rubber bands. A powerful slingshot is then used to cast the dye packet into the water. The tissue is supposed to dissolve and release the dye as a point injection. This presumes the release occurs near the surface and not after the packet settles to the bottom. Accurate placement of dye packets using this technique requires practice and some experimentation to get the right amount of tissue paper (strong enough to withstand launch forces, but breaks on impact). Tossing packets by hand is another option.

Dye Tracking. Most often, movement of the dye patch(es) is tracked by shore-based observers who estimate the location of the dye patch centroid and note the time. Estimating distances over water is very difficult, and this can introduce significant errors in current speed estimation. Depending on the situation, it may be possible to use fixed landmarks in conjunction with dye location estimates. For example, if a dye release is moving along a coastal structure, the observer can note the time when the leading edge of the patch passes through a line perpendicular to a fixed (known) location on the structure. The observer then moves to the next fixed location (if another observer is not already stationed there).

An observer at a fixed location might be able to track the dye movement using a simple compass or surveying instrument to record angle or direction to the dye patch at a given time. This also requires a reasonable estimate of distance along the direction radial which becomes more critical as the observation angle becomes more acute. If conditions are favorable, photography is an excellent means for recording dye positions in time. Photography works best if photographs can be shot from an elevated perspective such as a nearby building, or other accessible structure. Reasonable estimates of dye travel distance should be possible without photo rectification provided there is some feature on the photograph from which to estimate the length scale, and the camera lens is not wide-angled.

With Global Positing System (GPS) resolution now at about 5 m, another viable option is to track the dye patch using a small vessel situated within the dye patch or adjacent to the leading edge of the patch. Position of the GPS unit is recorded along with the time of the reading. The accuracy of this method increases with the speed of the dye movement. The GPS resolution is not sufficient for tracking slow moving dye patches.

Each estimate of the location of the dye patch centroid (or leading edge) must be accompanied by the time of observation. Estimates of average dye migration are calculated as the distance traveled between two adjacent observations divided by the time between the two observations. Field recording of dye patch location and time of observation can be made on a notepad showing a planform sketch of the experiment area along with identifiable landmarks for reference. Sketching the shape of the dye pattern as it evolves may give additional insight into the flow regime. Pencil or indelible ball-point pens are recommended because they are less likely to run or smear if the notepad gets wet from sea spray. A small voice recorder can be used to give more detailed descriptions of the dye patch movement between estimates of location, but voice recording should not supplant sketches of the dye movement.

Dye Recommendations. One of the safest dyes for use in the marine environment is Uranine (Sodium Fluorescein). In powder form Uranine is rusty colored, but when put in water it turns a bright green-yellow color that is easy to see and track. Uranine dye is sensitive to sunlight, and it loses its color over a relatively short time. Several hours after deployment there will be little trace of the dye due to sunlight and dispersion. Uranine dye has no known health effects for humans or marine life.

Rhodamine B is the other recommended dye for marine studies. Because of its distinct red hue, Rhodamine B was also used in the cosmetics industry. However, the Food and Drug

Administration now regulates its use in cosmetics because at certain levels it is a known carcinogen. For this reason, Rhodamine B is not recommended for field use.

One source in the United States for Uranine dye is:

Keystone Aniline Corporation
2501 W. Fulton Street
Chicago, IL 60612

Phone: 1-800-522-4393
Web: *www.dyes.com*

The product is referred to as: Uranine concentrate dye, and it costs approximately $25 per pound. Normally the dye is sold in barrels, but it is possible to purchase as little as 22.68 kg (50 lb).

About 250 ml (8 oz) of powdered Uranine concentrate is used for each dye injection point. Prepare for the dye study by pouring about 250 ml (8 oz) of powdered dye into small plastic bottles or other containers that have a good screw-on lid. Latex gloves are recommended for this task. During dye injection, one bottle containing the premeasured amount of dye is opened and poured into the water at each injection location.

Suggested Equipment. The following is a list of recommended and optional equipment needed to perform a simple dye study.

a. Essential…
(1) Dye and containers
(2) Watch or timing device
(3) Notepad and pens/pencils
(4) Map of study area with dye injection points identified
(5) Deployment equipment (vessel, slingshot, etc.)
(6) Corps of Engineers identification
(7) Letter describing the study

b. Optional…
(1) Survey tape to measure distances on land or coastal structures
(2) Communication devices for study team members
(3) Voice recorder
(4) Latex gloves for handling dye

DYE STUDY AT AGUADILLA HARBOR, PUERTO RICO: Since its construction in 1995, the Corps' harbor project at Aguadilla, Puerto Rico, has suffered from shoaling by littoral sediment thought to be moving through the more porous sections of the breakwater and around the southern tip of the structure. The project was selected for monitoring under the Monitoring Completed Navigation Projects (MCNP) Program. One aspect of the monitoring program was to investigate the physical mechanisms that result in harbor shoaling and to determine the local sediment pathways that are active during storms.

A dye study was performed as part of a site visit by a team from the U.S. Army Engineer Research and Development Center (ERDC) in November 2001. Waves were estimated to have a breaking wave height of 3 m (10 ft) with periods in the range of 7-10 sec. The plunging breakers were mobilizing large quantities of sand along the seaward toe of the breakwater, and as the waves curled over it was evident that sand was suspended throughout the water column. Sand appeared to be moving from north to south (see Figure 2 for reference) along the breakwater. At the southern tip of the breakwater, the waves broke across the structure head, and significant quantities of sand were carried by the breaking wave around the head and into the harbor mouth by the diffracted waves.

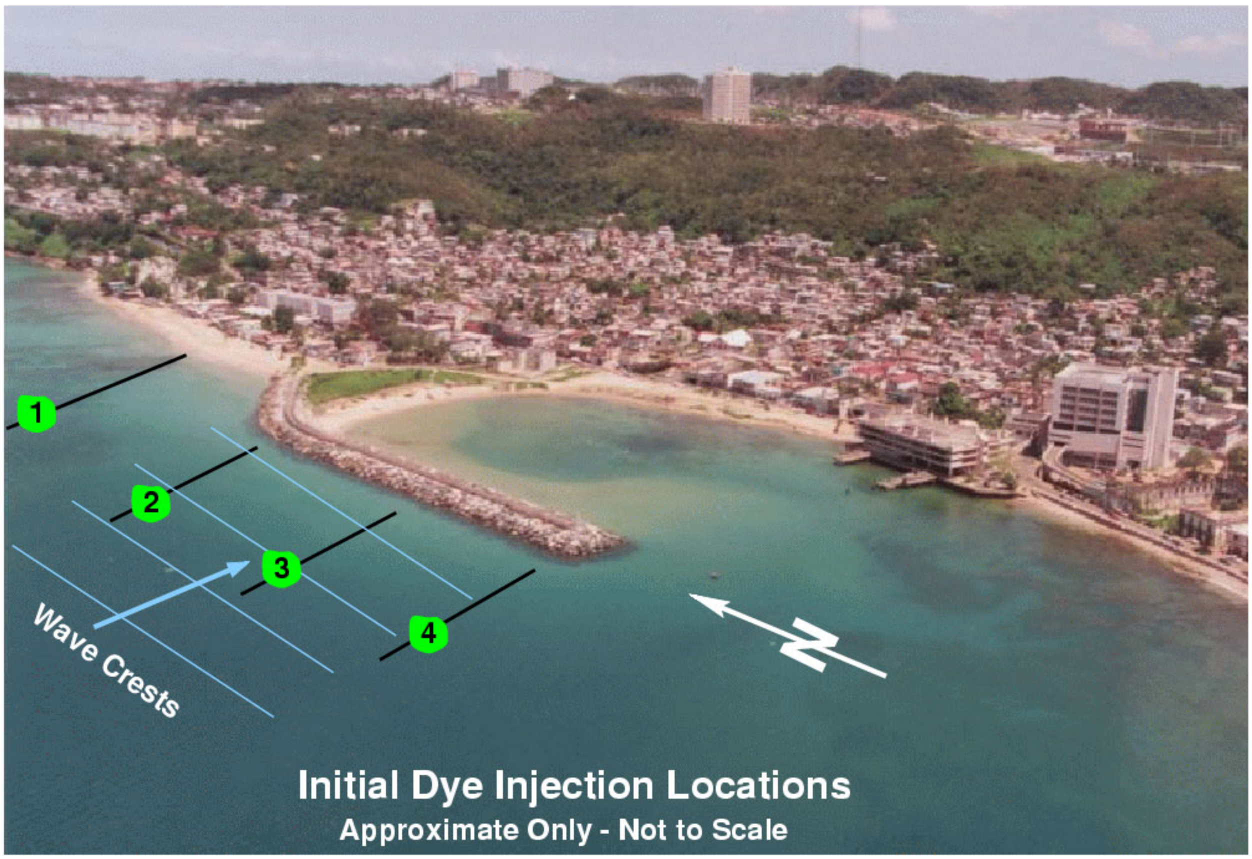

Figure 2. Approximate dye release locations

Four dye releases were made offshore of the Aguadilla Harbor in the approximate locations shown in Figure 2. At each location a volume of approximately 250 ml (8 oz) of Uranine powered dye was released on the water surface. The release was made from an inflatable Zodiac. Release times were 10:05, 10:08, 10:09, and 10:11 a.m. local time for locations 1, 2, 3, and 4, respectively. The four release points were aligned parallel to the breakwater at an estimated distance 100 m (330 ft) seaward of the breakwater. Large waves breaking seaward of the breakwater and a wide surf zone at the north beach prevented any dye deployments closer to the breakwater.

Sketches illustrating evolution of the dye patterns on the water surface are presented in the following sections. These sketches are based on ground-level qualitative observations, and thus the dye patterns shown on the sketches are not drawn to scale. However, the figures do represent the general trends of surface currents during the study period.

Dye Release No. 1 - North Beach. The dye released seaward of the beach immediately north of the harbor breakwater moved generally south and elongated during the first 20 min as illustrated in Figure 3. The centroid of the dye pattern moved about 100 m (330 ft) during that time giving an estimated average surface current speed of about 0.08 m/s (0.3 ft/s).

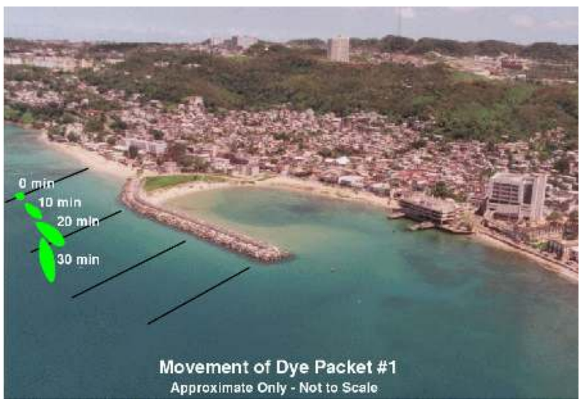

Figure 3. Approximate path of dye release No. 1

Figure 4. Approximate path of dye release No. 2

During the last 10 min of observation the dye pattern seemed to move further offshore into a position that was noticeably seaward of the release location for dye packet No. 2. This seaward drift might have been caused by waves reflected off the breakwater elbow.

Dye Release No. 2 - Breakwater Elbow. The second dye packet was released seaward of the breakwater elbow where the shore-connected portion of the structure transitions to the main breakwater leg aligned in the north-south direction. Over the span of 35 min the dye pattern enlarged slightly and moved south along a line generally parallel to the breakwater as illustrated in Figure 4. Less elongation of the dye pattern was observed compared to dye packet No. 1.

The average speed of the dye centroid as it covered the 100-m distance between the two black lines shown on Figure 4 was estimated to be 0.05 m/s (0.16 ft/s). In other words, dye packet No. 2 moved at about half the average speed of dye packet No. 1.

Dye Release No. 3 - Breakwater Midpoint. The most intriguing dye deployment occurred at a location directly seaward of the midpoint of the breakwater's straight section. Figure 5 illustrates the general evolution of this dye deployment. Rather than moving parallel to the breakwater, the dye pattern elongated in a shoreward direction with the shoreward end moving south at a faster rate than the seaward end. The packet also moved at a higher average speed with the centroid moving at an estimated rate of 0.09 m/s (0.3 ft/s) and the shoreward edge moving at about 0.13 m/s (0.4 ft/s). The stronger current closer to the breakwater had created a shearing effect that seemed to entrain the dye and elongate the pattern. Eventually, the pattern moved beyond the southern end of the breakwater and dissipated.

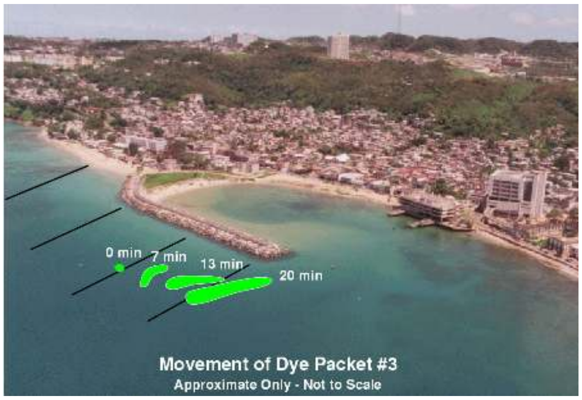

Figure 5. Approximate path of dye release No. 3

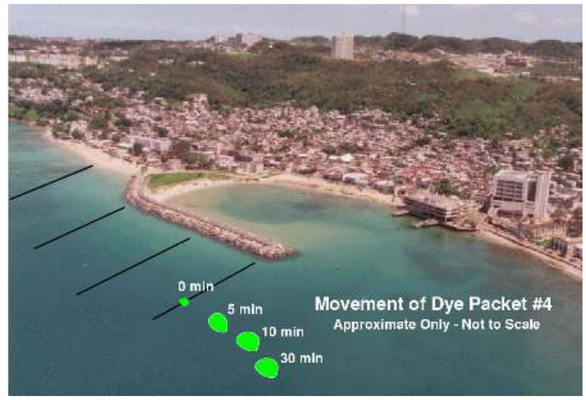

Figure 6. Approximate path of dye release No. 4

Dye Release No. 4 - Breakwater South End. The final dye release was directly offshore of the breakwater's southern tip. As shown in Figure 6, the dye pattern initially moved south as a compact area at an estimated speed of about 0.15 m/s (0.5 ft/s). Little elongation or expansion of the pattern was observed. After about 10 min the southerly migration of the dye pattern slowed until it seemed to become stationary at the location labeled “30 min” in Figure 6.

Apparently, the wave-generated alongshore current had a nodal point to the south of the breakwater. This may be an indication that the influence of the breakwater on the alongshore current does not have an effect south of the breakwater. With this decrease in southerly flow as illustrated by dye release No. 4, it is hard to conclude that any littoral sand is moving to the beach region south of the harbor project. In other words, sand in the littoral system is not bypassing the harbor.

ESTIMATING CURRENTS FROM DROGUE RELEASE: Drogues are objects that float on the surface and move with the surface current. The major assumption is that the drogue moves at nearly the same speed as the current. Drogues with only slightly positive buoyancy are more likely to move at the current speed than lighter drogues. Very light drogues such as plastic floats will have a significant freeboard and could be pushed along by wind in addition to water currents.

Drogues can be sophisticated devices complete with electronic instrumentation such as “pingers” that can be tracked from shore stations. These types of drogues are used in more involved studies that cover large areas or studies where the drogues cannot be tracked visually from shore. Typically, deployment and recovery of instrumented drogues requires a vessel. The expense of instrumented drogues is not warranted for estimating currents near coastal structures.

Oranges are a favorite low-cost drogue for estimating currents adjacent to coastal structures. Besides being biodegradable and perfectly safe for the environment, oranges are quite easy to see, and they usually float low in the water. (There is always the possibility that a particular variety of orange will not float in fresh water, so testing should be conducted prior to the experiment.) Oranges are locally available at a reasonable cost. Tennis balls also work well as drogues because they are readily seen and do not float too high in the water. The major drawback to using tennis balls as drogues relates to the environment. Some means for recovering the tennis balls needs to be incorporated into the study plan. Brightly painted wooden blocks are also suitable drogues.

Drogue Deployment. In most cases the drogues (oranges) are thrown into the water from atop a coastal structure. This limits the deployment distance to the capability of the person throwing the orange. But on a positive note, deployment distance can be estimated reasonably well for each individual by measurement of a few land-based tosses prior to the study. Greater deployment distances can be achieved via vessel deployment or use of some type of "drogue launcher." Homemade devices such as slingshots, air cannons, or catapults have potential, but testing and safety are important considerations before using these devices in the field. If a launching device is constructed, it should be calibrated for launch distance on dry land.

Drogue Tracking. Tracking drogues is similar to tracking dye deployments discussed earlier in this CHETN. A watch is used to time the movement of the drogue between two locations. Distance traveled over the time span needs to be estimated by the observer. This is most easily done where currents are flowing parallel to a coastal structure that can be safely accessed. In this case, simply mark the starting, intermediate, and final positions and step off (or measure) the distances between the positions. Establishing and marking timing locations prior to drogue deployment allows the observer to move along the structure with the drogue, and note the times when the drogue is perpendicular to the structure at each location.

Estimating travel distances for drogues moving along paths that are neither linear nor structure-parallel is more difficult. Consequently, current speed measurements calculated for this situation must be viewed more qualitatively. Use of photography shot from a good vantage point can be used to estimate more precise travel distances provided the drogues can be easily seen and some object of known dimensions is in the image for scale reference. The example drogue study in the next section illustrates drogue movement parallel to a structure and drogue movement inside a harbor.

Suggested Equipment. The following is a list of recommended and optional equipment needed to perform a simple drogue study.

a. Essential…
   (1) Bag of oranges (or similar drogue)
   (2) Watch or timing device
   (3) Notepad and pens/pencils
   (4) Map of study area with drogue insertion points identified
   (5) Corps of Engineers identification
   (6) Letter describing the study

b. Optional…
   (1) Survey tape to measure distances on land or coastal structures
   (2) Drogue launcher (and liability insurance?)
   (3) Deployment vessel
   (4) Communication devices for study team members
   (5) Voice recorder

DROGUE STUDY AT AGUADILLA HARBOR, PUERTO RICO: An impromptu drogue study was devised with the purpose of observing and measuring currents near to the breakwater and in the harbor during the high-energy wave conditions. Equipment consisted of a bag of 20 small oranges, a stop watch, and a notepad. Oranges were thrown into the water, and the drift progress was timed between two known points. When possible, the distance between the points was estimated by pacing the distance along the breakwater and assuming each pace was about 0.85 m (2.8 ft). Average surface current was obtained as the distance traveled divided by the time of travel. In all, about 15 oranges were thrown into the water over the course of the study; the rest were eaten by the field crew. Some oranges were immediately lost in the white water of the surf zone and could not be tracked. Other oranges were swept onto the rocks of the breakwater by large waves before they traveled any significant lateral distance.

Seaward of Breakwater. The first oranges were thrown into the water from the beach north of the harbor. Here the surf zone was wide, and the oranges could not be thrown far enough offshore to be outside of the breaker zone. When the next wave broke and turned the sea surface white with foam, visual contact with the oranges was lost. However, the oranges did reappear to the south where the beach meets the north leg of the breakwater. The oranges were swept into the swash zone and were unable to move further south. (See Figure 7 for reference.)

Successful deployments were obtained over the entire length of the breakwater. Oranges were thrown into the sea a distance estimated to range between 20 and 30 m (65 and 100 ft). Usually, this location was just seaward of the wave breaking point so the onshore/offshore movement of the drogue was primarily oscillatory with most of the translation movement in the longshore direction.

Figure 7 shows the approximate locations of the drogues along the seaward side of the breakwater when times were recorded. Estimated average surface current between the adjacent points is listed for each reach. The measurements are detailed in Table 1. The measurements indicate a relatively constant longshore current of about 0.3 m/s (1 ft/s) moving south along the breakwater. Current speed at the seabed would probably be less, but still strong enough to move sediment mobilized into the water column by the breaking waves. Without wave breaking, these current speeds are close to the sediment incipient motion criterion for fine-grained sand. The coarser grain sizes (approximately 0.3 mm) found on the beach north of the breakwater would probably not be transported by this current if the mobilizing action of the waves was absent.

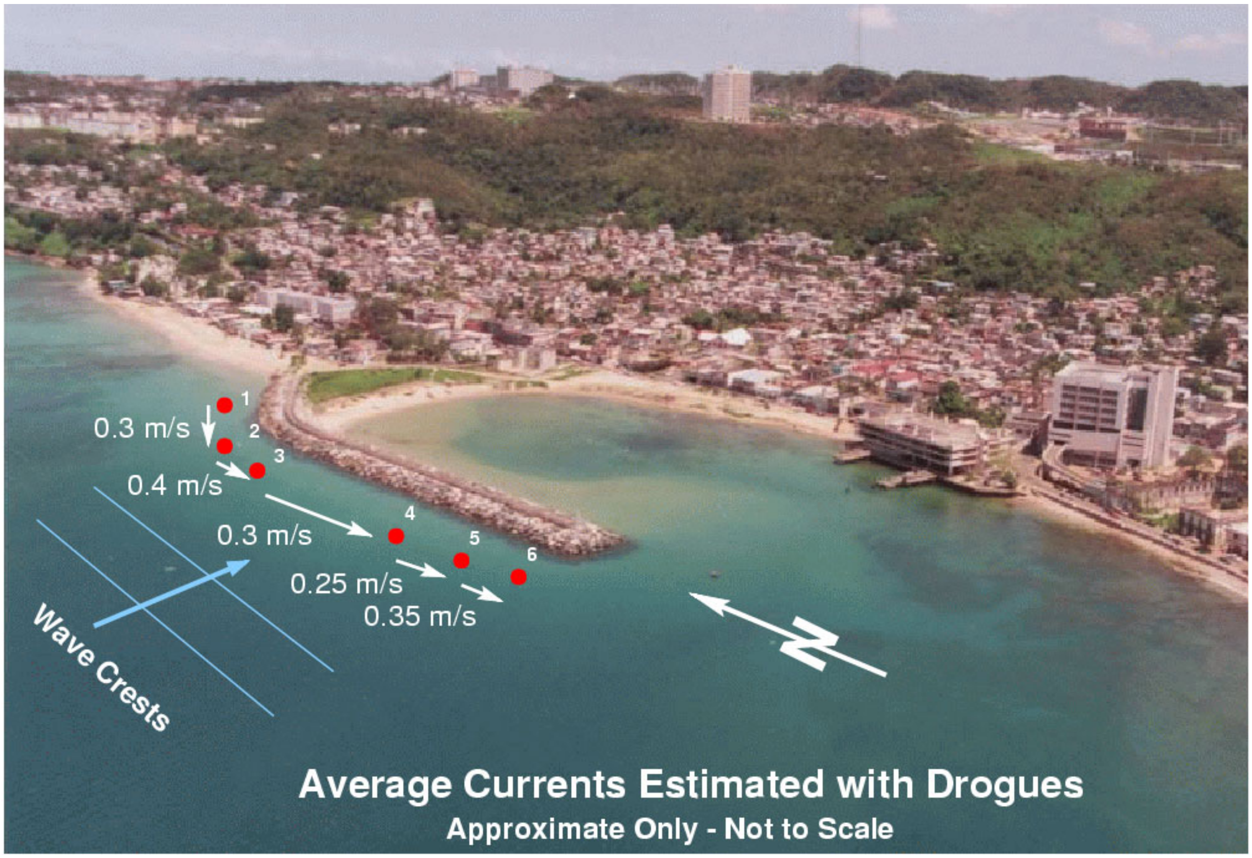

Figure 7. Measurement locations and average currents along breakwater

Table 1
Drogue Measurements

Range	Paces	Distance (m)	Time (s)	Average Speed (m/s)
1-2	36	30.6	98	0.3
2-3	35	30.0	73	0.4
3-4	100	85.0	287	0.3
4-5	35	30.0	120	0.25
5-6	30	25.5	73	0.35

Landward of Breakwater. Current patterns in the harbor and at the harbor entrance were examined qualitatively. Because of the drogue movements and difficulty in estimating distance traveled using known reference points, it was not possible to estimate current speeds with any confidence. Five drogues were deployed, and their approximate paths are shown in Figure 8.

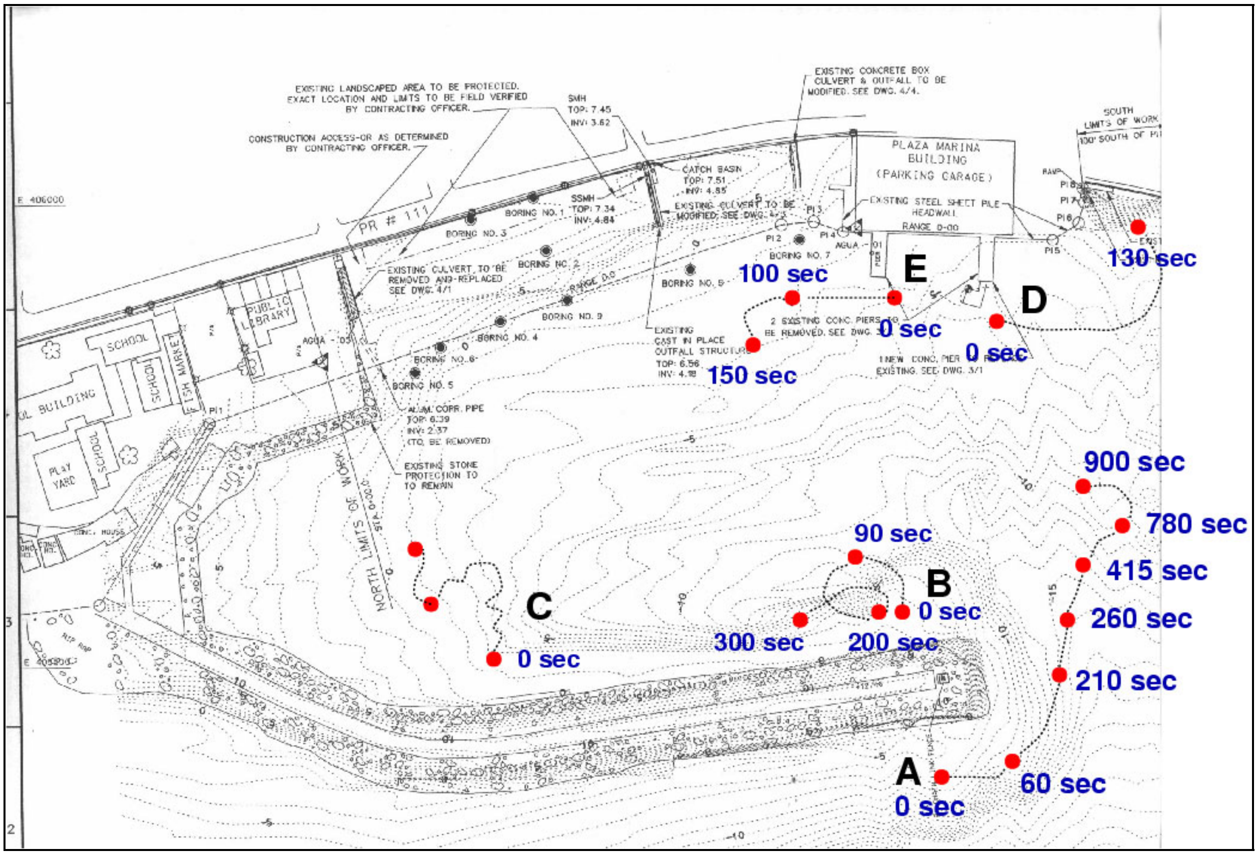

Figure 8. Drogue paths within harbor

Drogue A. This orange was tossed from the southern end of the walking platform on the breakwater into the water about 20 m (65 ft) seaward of the breakwater. The current moved it rapidly past the end of the breakwater in the first minute. The drogue then traveled landward toward the harbor entrance until it moved past the breaking wave point at about 260 sec. Shoreward progress then slowed until it seemed the drogue reached an equilibrium position at the harbor entrance. The drogue maintained this position for the remainder of the observation.

The track of Drogue A, and eventual stalling, indicated a current nodal point just outside the harbor entrance. This implies that sand moving into the harbor enters very close to the breakwater head, and then is carried in by the diffracted waves. Drogue A stayed outside of the diffracted wave influence. This was confirmed by dropping a second orange (not shown) into the water directly south of the breakwater head at the wave breaking point. This drogue was immediately swept well into the harbor by the next breaking wave and was lost from view.

Drogue B. Drogue B was tossed near the leeward breakwater toe from the southern end of the breakwater as shown in Figure 8. From observation of a surfer wading out to the end of the breakwater, water depth at this location was about waist deep. The drogue fell into a circular path resembling a stagnation area in the lee of a flow separation point. This observation is consistent with the accumulation of sand in this area.

Drogue C. This drogue was placed into the northern end of the harbor in shallow water near the beach as illustrated in Figure 8. The drogue stayed in the immediate vicinity of the beach as the small waves traveled up the beach face. Because of the general meandering movement, no times were recorded. A member of the dive team spotted an orange at this location 2 days later, and it was most likely the same orange.

Drogue D. Visual observation indicated that water was flowing out of the harbor in the region near the parking garage. Drogue D confirmed this observation by moving southward until the orange was trapped in the small pocket beach just to the south of the parking garage. It appeared that the wave pattern would keep the orange in this location indefinitely. A second orange from one of the previous experiments also showed up on this pocket beach. The failure of Drogues A and D to progress any further south provides additional evidence that sand may not be bypassing the harbor project and moving to beaches south of the harbor.

Drogue E. This drogue moved slowly into the harbor along the path sketched on Figure 8 by the small spilling waves that had diffracted into the harbor.

SUMMARY: Much can be learned about currents in the vicinity of coastal structures using the simple dye and drogue techniques discussed in this CHETN. Dye and drogue studies are inexpensive, have minimal manpower requirements, and cause no environmental impact or disruption of navigation. Although the current speed and direction estimates obtained from these studies are not highly accurate, the information is useful when added to other knowledge of the local physical processes at the project site. The main disadvantage of dye and drogue studies is that the acquired information pertains only to the conditions at the time of the study and may not be representative of the average conditions. This is less of a concern where the currents are predominantly tidal and cyclic.

The relative simplicity of performing dye and drogue studies should not overshadow safety concerns. Walking on coastal structures during energetic wave conditions is hazardous because of the possibility of strong wave overtopping. Always apply common sense on the conservative side when deciding whether or not to venture onto a coastal structure. Finally, when reporting observations and estimates obtained from simple dye and drogue studies, be sure to note sources of potential errors, particularly if travel distances were difficult to ascertain .

ADDITIONAL INFORMATION: This CHETN is a product of the Aguadilla Harbor, Puerto Rico, Monitoring Work Unit of the Monitoring Completed Navigation Projects (MCNP) Program being conducted at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. For additional information on the CHETN, contact Ms. Jackie Pettway, Jackie.S.Pettway@usace.army.mil of the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. For information about the Monitoring Completed Navigation Projects (MCNP) Program, please contact the MCNP Program Manager, Dr. Lynn Hales, Lyndell.Z.Hales@usace.army.mil . Beneficial reviews were provided by Dr. Andrew Garcia, Mr. Dennis Markle, and Mr. Carl Miller, Coastal and Hydraulics Laboratory.

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