SAND TRACER MOVEMENT MEASURED IN A STRONG RIP CURRENT

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Abstract

On August 21, 1980, the author and colleagues performed a trial sand tracer experiment in a strong rip current on Ajigaura Beach, Japan, a sandy beach facing the Pacific Ocean. Synoptic observations were made of the flow and sand-movement patterns associated with the rip current. Significant wave height was about 1 m, and current meters recorded average speeds exceeding 50 cm/sec in areas where instruments could be placed. Three colors of sand tracer were injected, and ten fixed stations were sampled at intervals for 180 min. The sand cores were split into segments and tracer grains counted under ultraviolet light. Depth of tracer mixing and tracer movement could then be determined. The greatest depth of disturbance was found at the root of the rip, where the feeder currents turned to flow offshore. Pulsations in tracer movement were observed with 45-60 min interval period, and the measurements indicate that the dominant mode of transport was suspended load. Although not completely successful because of equipment failure, the experiment demonstrates that such measurements are possible.

Introduction

As part of a series of intensive field data collection studies in Japan (Horikawa and Hattori 1987), the author and colleagues conducted several short- and long-term florescent tracer measurements of longshore sand transport in the surf zone (Kraus, Farinato, and Horikawa 1981, Kraus et al. 1982, Kraus 1988). Prior to making longshore tracer experiments, it was our standard procedure to reconnoiter the nearshore to avoid rip currents. In early afternoon, on August 21, 1980, a strong and persistent rip current was identified in the planned experiment area at Ajigaura Beach, Japan, facing the Pacific Ocean, and it was decided to perform a trial sand tracer experiment in the rip current. In this trial experiment, which occurred around mid tide, simultaneous measurements were attempted of the current and sand movement. Although this experiment is

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14. ABSTRACT **On August 21, 1980, the author and colleagues performed a trial sand tracer experiment in a strong rip current on Ajigaura Beach, Japan, a sandy beach facing the Pacific Ocean. Synoptic observations were made of the flow and sand-movement patterns associated with the rip current. Significant wave height was about 1 m, and current meters recorded average speeds exceeding 50 cm/sec in areas where instruments could be placed. Three colors of sand tracer were injected, and ten fixed stations were sampled at intervals for 180 min. The sand cores were split into segments and tracer grains counted under ultraviolet light. Depth of tracer mixing and tracer movement could then be determined. The greatest depth of disturbance was found at the root of the rip, where the feeder currents turned to flow offshore. Pulsations in tracer movement were observed with 45-60 min interval period, and the measurements indicate that the dominant mode of transport was suspended load. Although not completely successful because of equipment failure, the experiment demonstrates that such measurements are possible.**						
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more than 30 years old, it has not been published in the open literature and still offers insights into the dynamics of rip currents and field measurement techniques. It may also have been the first experiment that attempted to measure sand movement synoptically in a rip current in the field.

The reconnaissance surveys of the water circulation pattern were accomplished by hand-tethered floats (Sasaki and Horikawa 1978) and indicated a persistent rip current throughout the day. The tethered float or drogue procedure is illustrated in Figure 1. The measurement procedure was as follows. Upon the diver's signal, a float tied to the diver's wrist was released and allowed to flow with the current. Once the cord reached its 2-m extension, the diver signaled the timekeeper-recorder on shore, who noted the time for extension and direction according to diver's hand signals. One or two stand-by divers accompanied the timekeeper as a safety precaution and backup. The timekeeper moved alongshore at a spacing marked by a chain or rope upon which a weight was attached to fix the initial position, pulling the weight to the present position. The drogues were designed to sample the current about 0.3-0.6 m under the water surface by attaching fins (Figure 2) or by the shape of the drogue to minimize motion induced by wind and surface waves.

Divers (professional salvage divers) and the author, all in complete wet suits because of the cold water, placed instruments, injected the tracer, and sampled the bottom with ropes tied around their waists tied to screw (auger) anchors on shore (Figure 3). The ropes prevented divers from being swept to sea by the rip, which would eliminate that person from participating until he could swim around and back to the site. A bathymetry survey was also made the same manner, with rod holders tied to shore by lines.

Eight electromagnetic current meters were deployed, of which five returned usable records. A capacitance wave gauge placed in the breakers malfunctioned, but an 8-mm memo-motion movie camera (camera triggered by an electric timer at fixed intervals) gave some quantitative indication of wave height. Three colors of sand tracer were injected, and ten fixed stations were sampled at 15-min intervals for 180 min. The sand cores were split into segments and tracer grains counted under ultraviolet light. Depth of disturbance as calculated according to the method of Kraus (1985), and tracer movement could then be determined. The greatest depth of disturbance was found at the root of the rip, where the feeder currents turned to flow offshore. Apparent pulsations in tracer movement were observed at 45-60 min intervals, and interpretations were made concerning mode of transport as bed load or suspended load.

Short Review on Rip Currents

A rip current is a strong and narrow seaward-directed flow of water in or penetrating through the surf zone. Rip currents are recognized as being significant mechanisms for offshore sand transport of sediment and associated beach erosion (Komar 1998, pp. 470-472), and they are also a significant safety concern for bathers. According to the heuristic model of Sasaki (1980), the dominant mode of offshore transport in rip currents is suspended load. However, no quantitative field study is known for the evaluation of the mode and amount of sediment transported by a rip current, or for relating the rip current properties with the sediment movement This lack of information of rips obviously owes to the challenge and danger of operating in and around such a powerful current. Nevertheless, through experience gained in working in the surf zone as described here, it is possible to take a quantitative approach in the study of the hydrodynamics and sediment transport associated with rip currents.

The pattern of water flow associated with rip currents has been studied both theoretically and through field and laboratory observations. The basic phenomenon was described in the pioneering field studies of rip currents and nearshore circulation made by Shepard and coworkers (Shepard 1936, Shepard, Emery and La Fond 1941, Shepard and Inman 1950). Harris (1967) and Sonu (1972) classified rip currents within the context of various observed nearshore flow patterns and the direction of wave incidence. Seminal sources for the numerical modeling of rip currents are the works of Arthur (1962) and Bowen (1969). One of the interesting features of rip currents is the long-period fluctuation in current velocity and direction. Dalrymple (1978) reviews the generating mechanisms of rip currents. MacMahan, Thornton, and Reniers (2006) give a comprehensive review of rip current processes, and Yu and Slinn (2003) present a modern numerical model of the wave-current interaction associated with rip currents.

On a long natural beach, rip currents may be considered a transient perturbation of the surf zone longshore flow pattern and magnitude. Their influence can be neglected in determining the long-term longshore sediment transport rate. In contrast, near structures such as groins or jetties, the presence of rip currents is almost independent of the angle of wave approach. In such cases, the rip current is not a perturbation but, rather, the major mechanism controlling sediment movement in the area. Sediment carried offshore by such a rip current is then available for further transport by any coastal current. This material may then be reintroduced to the littoral system on the other side of the structure, deposited in adjacent harbor basins, or lost offshore. Sasaki (1980) hypothesized that on beaches for which normally incident waves and, hence, rip currents, are dominant (see Harris ,1967; Sonu, 1972), the short-term net longshore transport rate may be less than expected because of the interruption through offshore transport of sediment by the rips. This sediment is returned to the surf zone during times of calmer weather.

The study of sediment movement by rip currents and the required field data collection techniques are thus necessary for improving both long- and short-term quantitative models of beach change, as well as for making prediction about the genesis, persistence, location, strength, and dimensions of rips for promoting beach bathing safety. The complex environment of the rip current, with coexistence of strong currents both parallel and perpendicular to wave incidence, will also yield valuable information for three-dimensional modeling of the nearshore circulation and resultant sediment transport. Finally, it is mentioned that even after a rip current ceases to be active, relic features in the bathymetry, especially the rip channel, will continue to influence the circulation pattern and sediment transport until the bottom is molded into a state compatible with the existing wave and flow conditions.

Experiment Procedure and Layout

After locating the rip by tethered float, the circulation pattern was observed by injecting a small amount of rhodamine dye near the shoreline. With the position of the rip current established, eight electromagnetic current meters were deployed in a symmetric array to record the rip feeder currents from both sides, rip current through the channel, and the current offshore. The instruments were ultimately set with a southward bias as shown in Figure 4, because of the strong current in that direction. Meter heads were positioned approximately 20 cm from the bottom. The current pattern was periodically observed with injected dye.

It was also planned to install several capacitance type wave gages at the site. Rough wave conditions limited the number of wave gages to one. Unfortunately, this gauge failed. A calibration check of the wave gauge was made in intervals by filming it with a 16 mm memo-motion camera (Hotta, Mizuguchi, and Isobe 1982). Wave height (significant wave height of 1 m) was obtained from these films.

Sand movement was observed by injection of fluorescent tracer and periodic sampling. Because of the acute difficulty for divers to move about in a rip current, the usual spatial-type sampling method was infeasible. A temporal sampling method (Kraus et al. 1982), requiring relatively few sampling points, remained viable. Strictly speaking, tracer techniques are limited to situations where no erosion or accretion takes place. This is certainly not the case in a rip current. However, by taking large numbers of core samples, it is believed that the temporal sampling method might be capable of yielding an estimate of the average transport, because, for example, a layer of fresh sand is distinguishable if it is observed over a layer of tracer.

Rapid sampling under such adverse conditions was made possible by a specially designed core sampler (Kraus, Farinato, and Horikawa 1981) that does not require diving. Unfortunately, because instrument setting took a significant amount of time, the suitability of the tracer method could not be fully tested because the tracer portion of the experiment had to be shortened. Fading daylight halted tracer sampling after 2-1/2 hr of a scheduled 4-hr experiment. Temporal sampling designed around the one-time injection of tracer requires several hours. Duane and James (1980) have presented evidence through example that a continuous injection method can reduce the sampling time to less than 1 hr. Such experiments seem suited to the rapidly changing conditions of the surf zone and rip currents, but are not explored further here.

Tracer of three colors in amounts of 15 kg each was injected as three separate point sources on a line parallel to the shoreline and approximately perpendicular to the axis of the rip channel, as shown in Figure 4. The procedure called for burial of the tracer at the injection sites so as not to spread the tracer over a wide area and artificially introduce it into the water column. Three colors were placed in an attempt to correlate the tracer movement with local current strength. Stations J, A, B, C, and K formed the principal measurement line on which samples were taken every 15 min. Stations E, F, G, H, and I, sampled at 30-min intervals, served as a check for the general containment and movement of the tracer onshore and alongshore. Samples from station D, taken at 15-min intervals, gave further indication of the movement of tracer offshore.

Sampling stations were not marked by poles because of the strong current and scour that would be induced around the poles. Divers located their sites by moving offshore to the full extension of a line of fixed length. These lines were anchored on the beach and also served as safety lines. All stations were sampled simultaneously. The tracer was not injected symmetrically with respect to the sampling grid because the rip current had shifted slightly northward after the sampling stations were set, as observed from the movement of dye. The injection points were thus shifted northward. A bottom topography survey proceeded simultaneously with the tracer experiment.

In the laboratory, the core samples were cut into either 2-cm segments up to 14 cm (Stations A, B, C, D, and F), or into 4-cm segments up to 12 cm (Stations E, G, H, I, J, and K). The segments were dried and weighed, and the number of tagged grains counted for each color. The result was then expressed as a concentration (tracer grains of a particular color/100 g of sample).

Results

Current

The data from the operational current meters are given in Figure 5. Current meters 5 and 6 failed completely. The cross-shore u components of meter Nos. 1 and 7, and the longshore v component of meter No. 2 were also not available due to instrument malfunction.

The current meter data (and spectra not shown here) indicate the existence of a long-period fluctuation in the cross-shore current velocity. To interpret the time change in the overall current pattern, averages were computed for eight intervals of approximately 20-min length. Figure 6 summarizes results for the current at the approximate 20-min intervals.

Tracer concentration

The tracer concentrations found at the sampling stations are displayed in Figures 7-12, in which the concentrations (y-axis) are displayed with log scale. Plots on the right side give the concentration averaged over all segments in a core, and plots on the left give the concentration found in the top segment only, of either 2- or 4-cm thickness. Comparison shows that the tracer found in the top 2 cm is not always sufficient to represent the total concentration at the site. A sample consisting of the upper 4 cm more closely coincides with the total.

The most apparent feature in the Figures 7-12 is the long-period fluctuation in concentration. This fluctuation, comprising order of magnitude differences, is found for both the green and orange tracer. Peaks are approximately 45 to 60 min apart. The first strong peak occurred earliest at stations J and K. Station D had an early arrival of a small amount of tracer. The next and larger two pulses in tracer at station D arrived about 15 min later than the corresponding pulse at other stations, which is compatible with the difference in distance between the stations and injection point. Because of the consistency in peaks among all stations and time lag in peaks at the most distant station from the injection line, it is concluded that the pulses are actual and not random deviations. A similar pulsation in longshore transport was reported by Kraus, Farinato, and Horikawa (1980). These fluctuations correspond to the long-period fluctuations in the waves and current passing over the bed. Also noted is that the peak in concentration observed at Station B at 90 min that was apparently transported to Station D, in the throat of the rip, appearing 30 min later (120 min).

The centrally placed green colored tracer was injected directly at the base of the rip neck, as judged by the offshore movement of dye. Green tracer dominated transported tracers and appeared in relatively large amount at all sampling stations. The movement of the total sediment load can be estimated by reference to longshore transport experiments. A typical tracer advection velocity alongshore is 0.5 cm/sec (Kraus et al. 1982), which includes movement by bedload and suspended load (a sediment particle may experience both). Taking this value as an estimate, the time needed for green tracer to reach Station J, a distance 15 m from the injection site, would be 50 min. Assuming that the fastest tracer grains move with double the above advection velocity would imply that small amounts of tracer might be expected to be found up-wave at sampling site J approximately 25 min after injection. Figure 12 shows that a substantial amount of green tracer was found at Station J in the first sampling, 15 min after injection, implying an advection velocity exceeding 100 cm/sec. The suspended load should move with approximately the velocity of the current (Figure 6), and Figure 5 indicates a short-term sediment transport velocity of 50 cm/sec. Figure 6 implies possibly 54 cm/sec offshore-directed flow in the region of Stations A and J, and it is noted again that current meters could not be placed in areas of strongest flow. This analysis of tracer movement indicates that suspended load mode was probably dominant over bed load transport.

Depth of tracer mixing

It was assumed that the tracer is homogeneously distributed within each core segment. This model gives a parameter, the percentage cutoff, which can be varied to examine the depth of mixing as a function of concentration (Kraus, 1985). Two criteria were applied to define the depth of mixing. The first is that a minimum concentration must exist in at least one segment of a core. This minimum was set at 20 grains/100 g. A minimum-number criterion eliminates noise. The second criterion applies the assumption that most tracer should be in the upper slices. If not, then presumably accretion took place. If less than 10% of the total concentration was not contained in an upper segment starting from the top, then that segment was not counted in the defining procedure. The mixing depth "zero" was then reset below the void segment. Both criteria serve to define a depth of mixing in regions where substantial tracer was found. Finally, the average over all samplings at a given station was concentration weighted.

With certain exceptions, most of the tracer was found to reside in the upper 4 cm of the bed. An interesting exception appeared at station A (Figure 13). At the fourth sampling (T = 4), a large amount of tracer seems to have been buried by 10 cm of sand. In the fifth sampling, the large discontinuity in concentration disappeared, and tracer was found to a depth of 12 cm. A similar departure was not evident at stations B and C for the same samplings. Therefore, the large accretion at station A could have been a local process caused by, for example, a collapse in the rip channel bank.

Conclusions

This trial experiment was designed (with great haste) to simultaneously measure the waves, flow, and sand movement in a rip current. The main problem encountered was the physical limitation of working in a strong offshore-directed current, but this was to a large extent overcome through use of safety lines anchored on shore. With improvements in instrument reliability and decrease in their size, it appears possible to make long-term point measurements of the current and waves in a large-sized rip current. It was found useful to supplement the eulerian current measurements with an overall view of the current as given by the motion of dye.

A significant result is that sand sampling could be performed accurately and systematically in such a challenging environment. The key factors to accomplish this were the introduction of a long, metallic core sampler and sampling in a temporal-type arrangement. There is some doubt if a single injection tracer experiment can yield the transport rate in a reasonable time span. Temporal sampling with continuous introduction of tracer might be more applicable (Duane and James 1980).

The greatest sand movement occurred for the (green colored) tracer centered on the rip current axis, in contrast to the movement in the feeder currents. Tracer injected closer to the feeder currents showed markedly less movement. The rapid spread of green tracer to all sampling stations indicates that suspended load was dominant in the rip. Suspended particles can be easily carried onshore by the wave bore, in addition to the rip current directed offshore.

Pulsations with a period of 45 to 60 min were found in the tracer motion. The pulsations are attributed to long-period fluctuations in the incident waves and resulting current. Experimenters should be aware of this phenomenon when making short-term measurements of sediment transport.

The depth of mixing varied from approximately 4 to 7 cm, greater than those found in longshore sand transport experiments (Kraus et al. 1982). The greatest depth was found at the root of the rip where the feeder currents turn to flow offshore. Coupled with the reduced tracer movement found at the feeder currents, the offshore movement of tracer by the rip current was primarily localized to the removal of sand along the rip channel.

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FIGURES

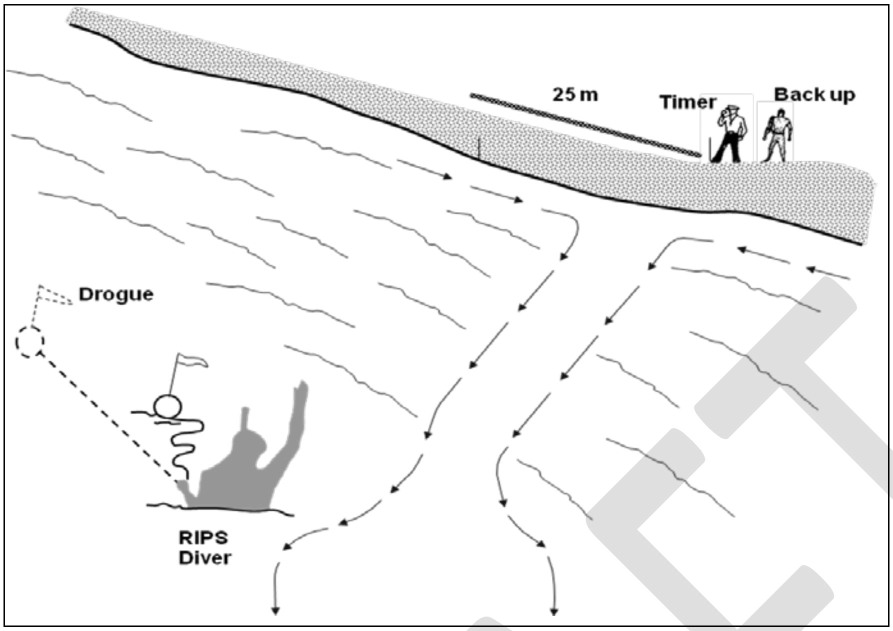

Figure 1. Reconnaissance survey of nearshore circulation by tethered float.

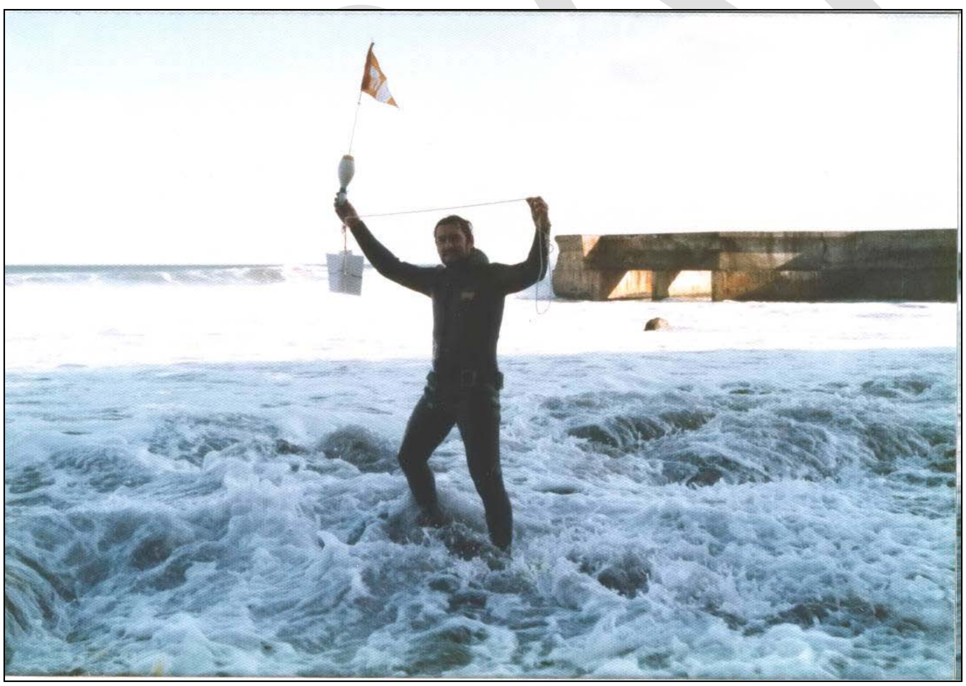

Figure 2. Drogue with fins to sample the current below the water surface.

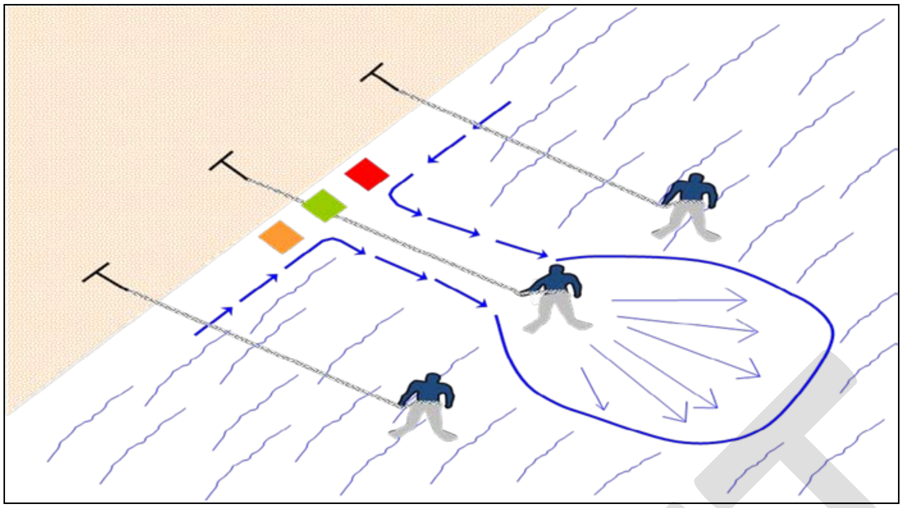

Figure 3. Divers tethered to shore for sediment sampling after tracer injection.

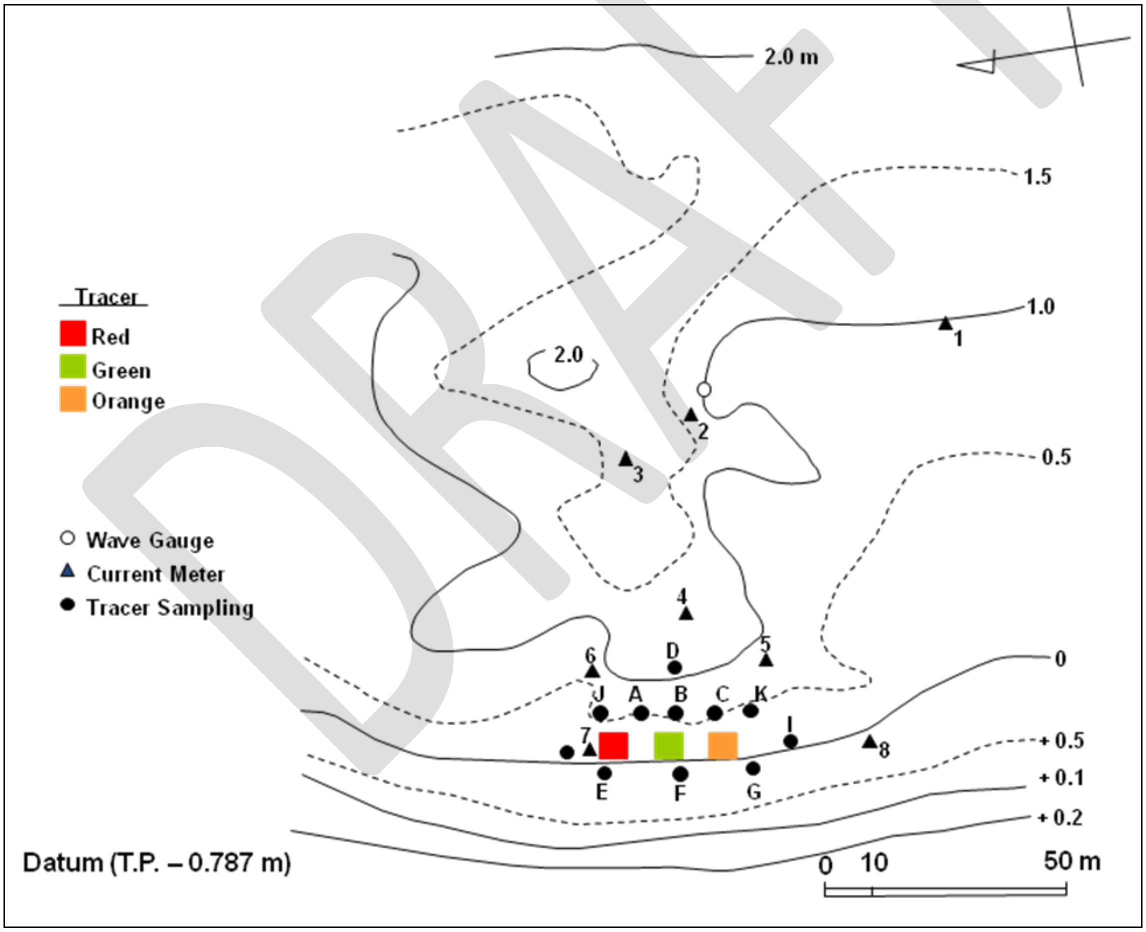

Figure 4. Instrument layout, tracer injection points, and tracer sampling stations around the rip channel. The vertical datum is local mean sea level, where "T.P." (Tokyo Piel) refers to the standard vertical water level datum in Japan (Tokyo Bay).

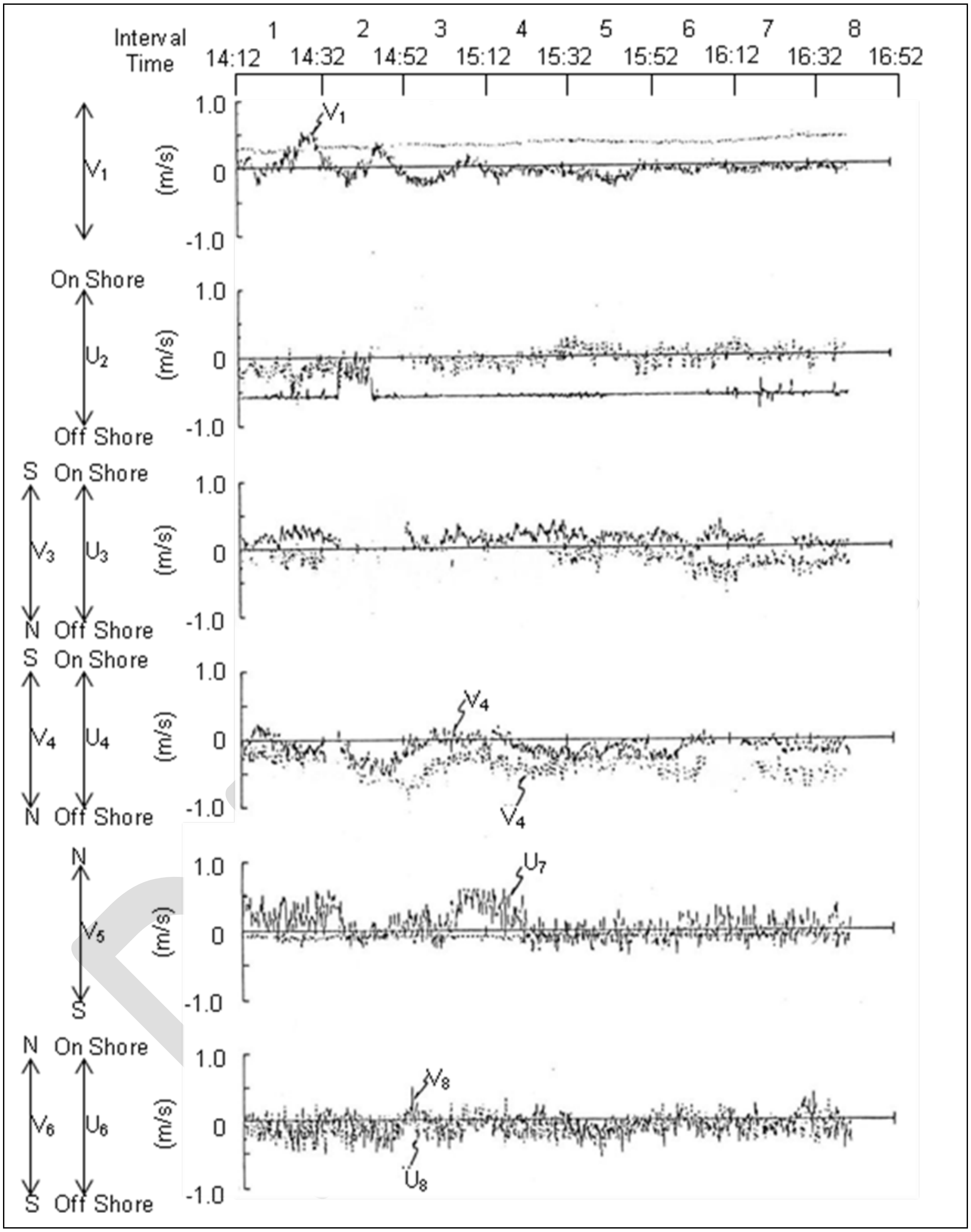

Figure 5. Raw current meter records.

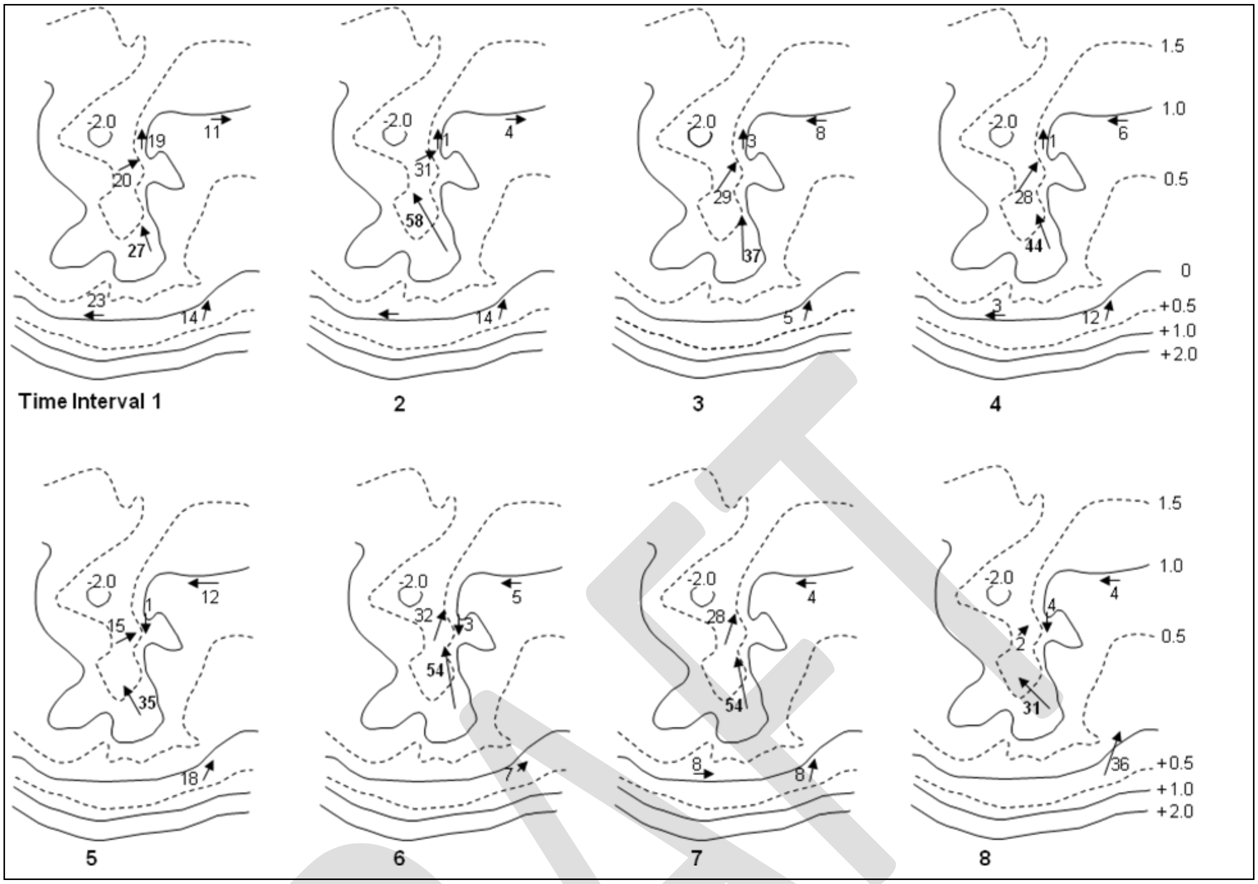

Figure 6. Available current averaged over approximately 20-min intervals for eight time segments. Values of current velocity given in cm/sec, and depth in m to approximate MSL.

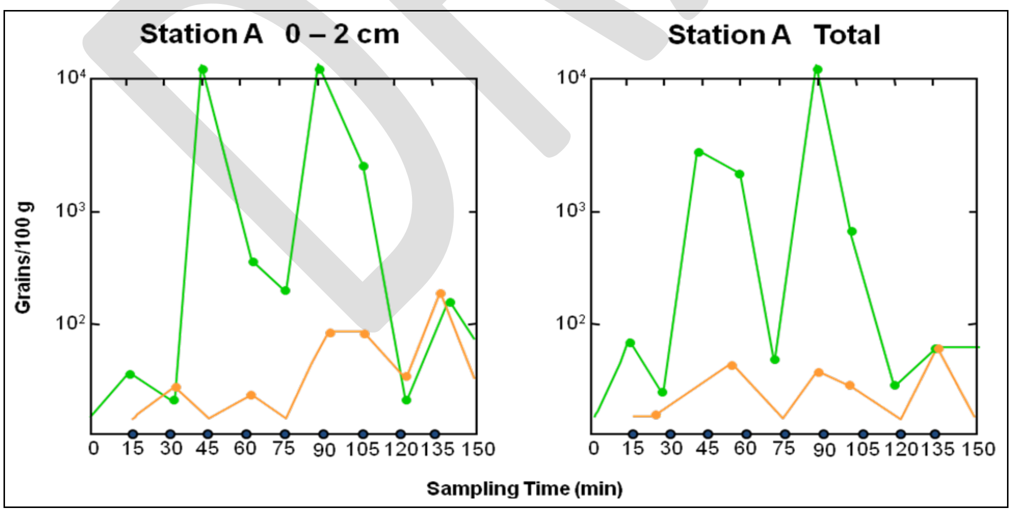

Figure 7. Tracer concentration through time slightly north and seaward of rip channel. Colors correspond to tracer colors shown in Figure 4. No red tracer was observed at Station A.

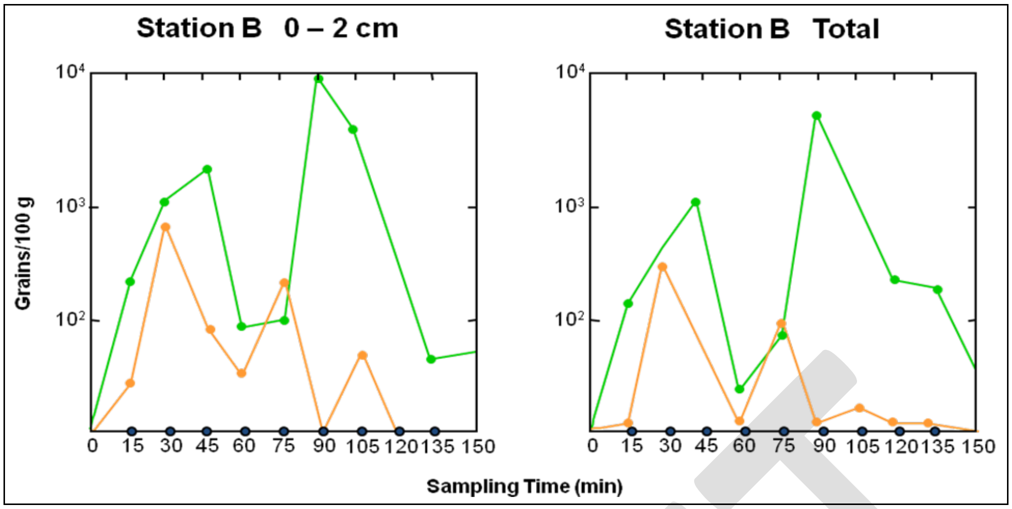

Figure 8. Tracer concentration through time seaward of rip channel. Colors correspond to tracer colors shown in Figure 4. No red tracer was observed at Station B.

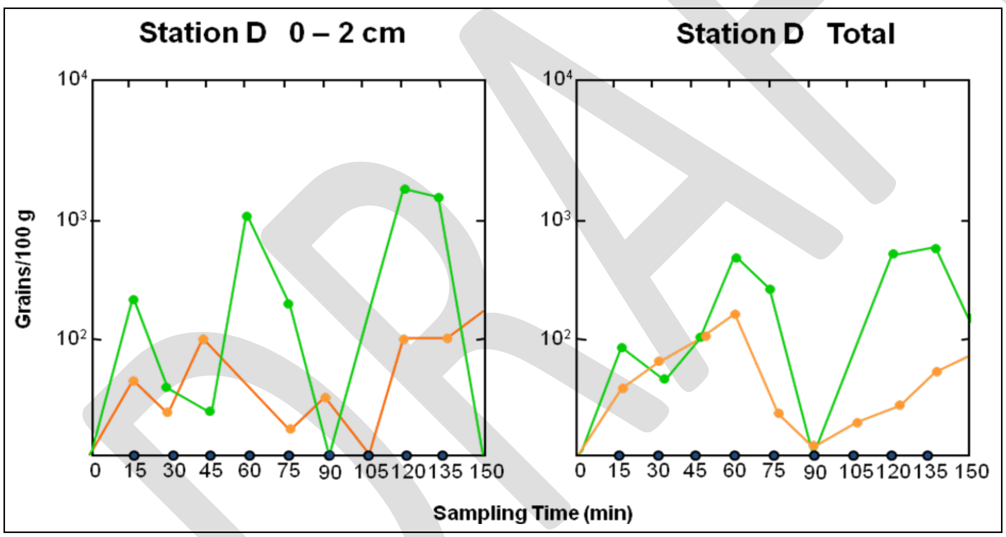

Figure 9. Tracer concentration through time offshore of the injection area. Colors correspond to tracer colors shown in Figure 4. No red tracer was observed at Station D.

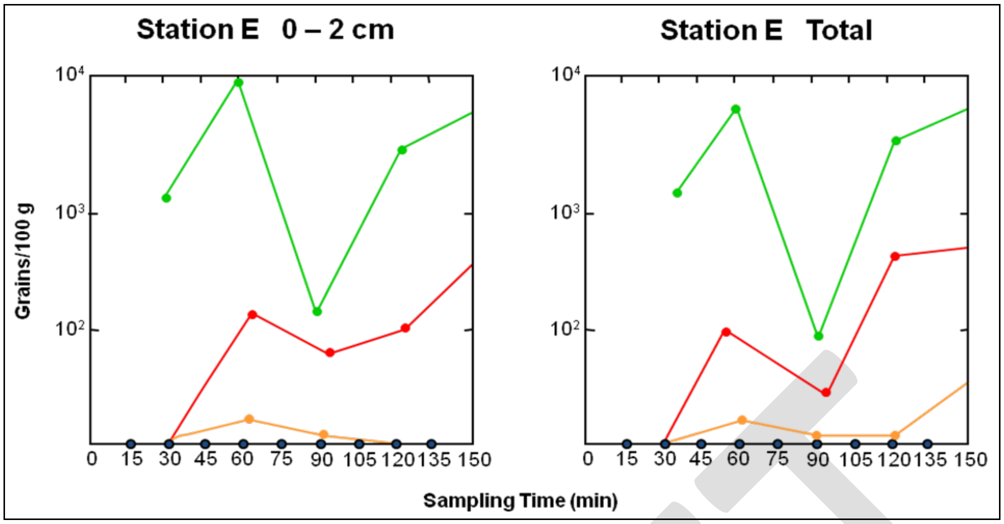

Figure 10. Tracer concentration through time north and shoreward of injection site. Colors correspond to tracer colors shown in Figure 4.

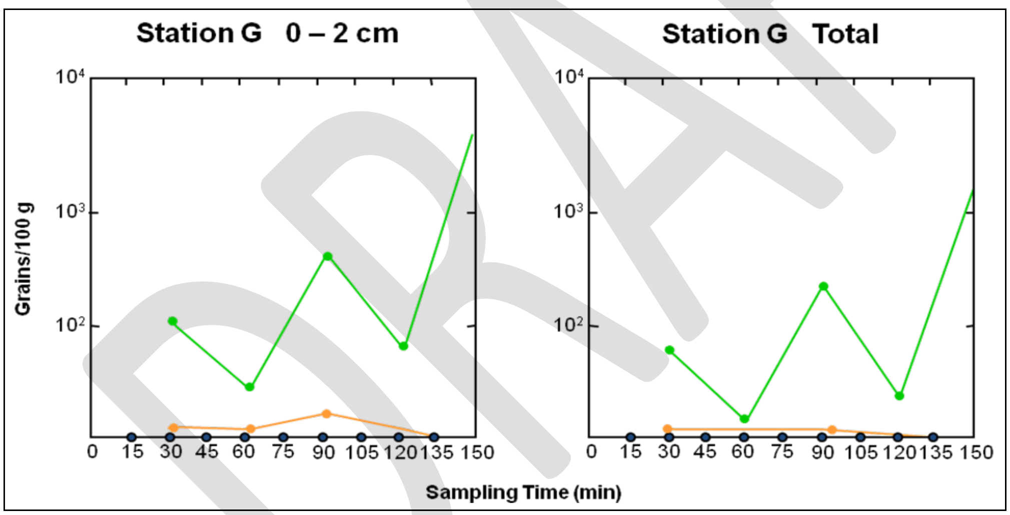

Figure 11. Tracer concentration through time south and shoreward of injection site. Colors correspond to tracer colors shown in Figure 4. No red tracer was observed at Station G.

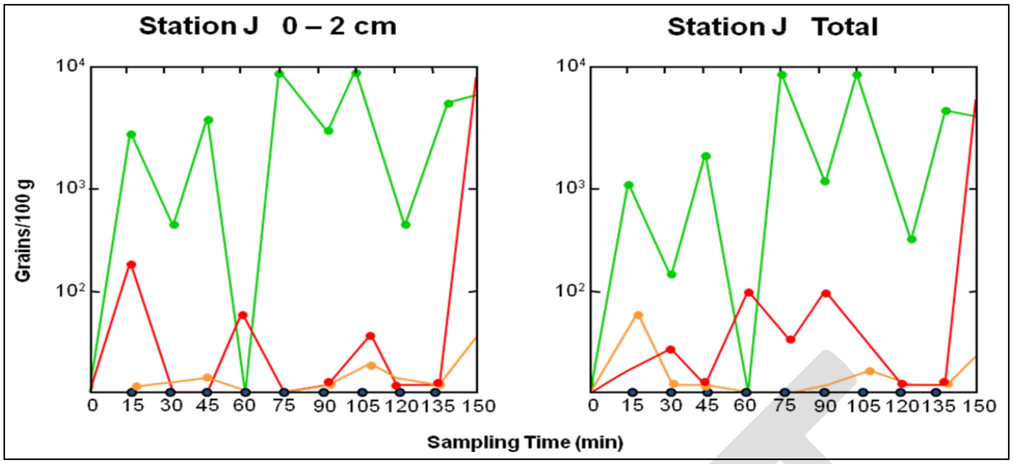

Figure 12. Tracer concentration through time, located north and seaward of injection site.

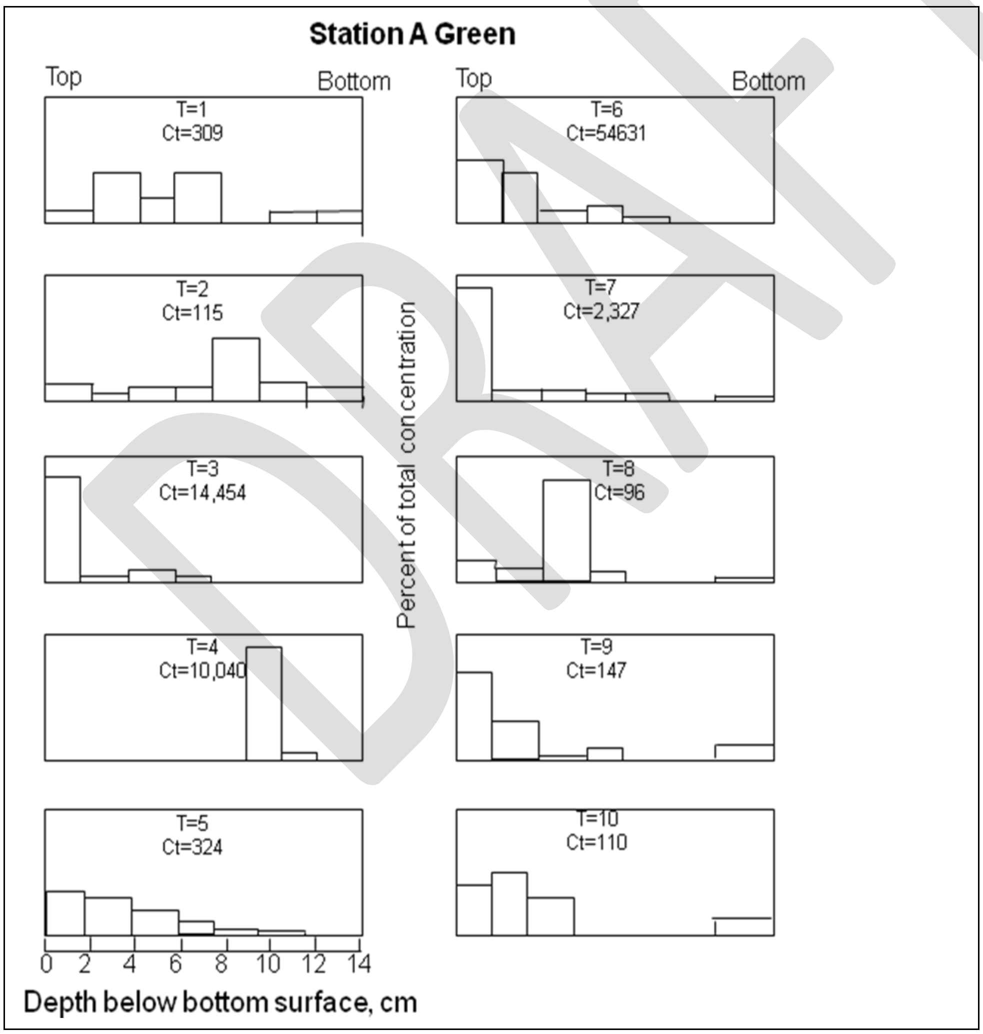

Figure 13. Example of depth of tracer mixing in the bed (Ct = total tracer count in the core).