3.1.2 Physical Oceanography

Oceanographic currents are distinguished by wind-driven surface currents in the upper portion of the water column and thermohaline currents in the intermediate and bottom layers of the oceans. Surface currents consist predominantly of the horizontal movement of water whereas vertical movement (e.g., upwelling or downwelling) resulting from density differences is characteristic of deeper waters.

Surface currents in the vicinity of Guam are dominated by the North Pacific Equatorial Current (NPEC), though coastal eddies may develop in the lee (westward side) of the island as a result of the NPEC flowing past Guam. The NPEC flows westward at an average speed of 0.33 to 0.66 ft/s (0.1 to 0.2 m/s, 0.2 to 0.4 kt; DON 2005) and reaching a maximum speed of approximately 0.98 ft/s (0.3 m/s, 0.6 kt; Wolanski et al. 2003) in response to tradewinds typically occurring between 10° N and 15° N (Reid 1997). Seasonal differences were identified with respect to the direction of the tradewinds. The direction of the tradewinds tend to be more uniform during the dry season (winter months) with more directional variability during the wet season (summer months) (NOAA 2009a). The strength and location of coastal eddies west of Guam are dependent on the angle at which the NPEC approaches and subsequently bifurcates around the island mass. These eddies are capable of producing eastward moving currents on the lee (westward side) of Guam (Wolanski et al. 2003).

The Pacific El Nino/Southern Oscillation (ENSO) is an important coupled ocean-atmosphere phenomenon that can cause climate variability. During El Niño, tradewind activity is weakened or in a strong El Nino even reversed due to higher-than-average air pressure covering Indonesia and the western tropical Pacific and below-average air pressure covering the eastern tropical Pacific. During La Niña, the tradewinds become stronger than normal due to below-average air pressure covering Indonesia and the western tropical Pacific and above-average air pressure covering the eastern tropical Pacific (PEAC 2006).

Deep water currents in this region are dominated by the North Pacific Deep Water (NPDW) and the Lower Circumpolar Water (LCPW). The NPDW flows westward from the northeastern Pacific Ocean and the LCPW, after flowing northwestward across the equator east of Guam, branches into two limbs, a northward flow into the Pacific Basin and a westward flow towards the West Marianas Basin (Siedler et al. 2004).

The following sections describe the regional and ODMDS specific surface, intermediate layer and bottom currents from both modeled (satellite-derived) data and *in situ* (instrument-measured) data collection. The ROI for the following sections on oceanic currents is the water column within the ODMDS study areas.

3.1.2.1 Modeled Currents

Data generated from the global Navy Coastal Ocean Model (NCOM) was first used to evaluate currents surrounding the vicinity of the ODMDS alternative sites to determine consistency of regional current patterns and to understand the currents that dredged material may be subject to as a consequence of horizontal dispersion after the initial placement of material. The NCOM is an assimilative ocean model nowcast/forecast system developed and administered by the Naval Oceanographic Office (NAVO). Barron et al. (2007) discusses model validation using both observational data and other global ocean models for comparison. Detailed results of the modeled current data assessment are presented in the *Ocean Current Study, Ocean Dredged Material Disposal Site, Apra Harbor, Guam* (Weston Solutions and Belt Collins 2007b) and summarized briefly below.

Resolution of the model is 1/8°, or 7.5 x 7.5 nm. Input parameters for the model are satellite-measured sea surface temperature (SST) and sea surface height (SSH; altimetry) derived from the Modular Ocean Data Assimilation System (MODAS) and Navy Layered Ocean Model (NLOM), respectively. SST and SSH measurements are then used to project a vertical profile of temperature and density, from which thermohaline currents are derived. Thermohaline currents occur at depth and are driven by differences in density rather than wind patterns, which derive surface currents. Surface currents are derived from atmospheric conditions provided by the Navy Operational Global Atmospheric Prediction System (NOGAPS) which force NCOM predictions. Ocean depth and coastline boundaries used in the NCOM are based on a global dataset of two minute (1/30°) bathymetry data. Tidal currents were not incorporated in the model results.

Current data were provided for the entire 2005 calendar year. Data were provided for a 1° x 1° square area bounded by 14° N and 13° N latitude in the north and south, respectively and 145° E and 144° E longitude in the east and west, respectively. Thus, at the resolution of the model (1/8°), data were provided at 81 discrete locations. At each of these stations, data were provided for 17 separate depths. Currents were provided at finer (shorter) intervals near the surface with increasingly coarse (longer) intervals at deeper depths. At each station and depth, current data were provided for each six hour increment. Current data were provided as u (east-west) and v (north-south) vectors.

During processing of the text files, the individual vector data were used to calculate speed and direction for each location and depth. Rose diagrams representing the frequency distribution of current directions and speed for each depth at a single location and vector plots representing daily averaged current velocities at each location by month and depth were created. These plots provided a cursory review of the spatial (both horizontal and vertical) as well as temporal patterns in the data. Once patterns were identified, more quantitative statistical analyses were conducted using SAS software to identify significant trends or differences in the currents.

3.1.2.2 Regional Current Patterns

<u>Surface Currents</u>

During the fall and winter months (predominantly the dry season; Figure 3-2), surface currents tend to be quite uniform, having a significant west-northwesterly component across much of the study area. As the surface current approaches and bifurcates around Guam from the east, the currents in the southern portion of the study area tend to be more westerly, while currents in the northern portion of the study area tend to be towards the west-northwest. Once past Guam and beyond the site-specific study areas, these currents converge, with the currents in the southern portion of the study area trending more northwesterly and currents in the northern portion of the study area trending more westerly. This pattern creates an area of variable current patterns directly in the lee of the island, with surface currents capable of flowing back towards Guam on occasion. This pattern is most evident in February and March when the surface currents are highly uniform, however, it is also observed in the three preceding months (November through January) and one succeeding month (April).

In the summer months (predominantly the wet season; Figure 3-2), surface currents are slightly more variable on a month to month basis and the net current direction tends to flow in more southwesterly direction. During this time, the currents approaching Guam in the southern portion of the study area continue to be predominantly to the west, but having an increasingly greater southwesterly component through time such that currents approaching Guam in September are primarily trending to the southwest. The currents approaching Guam in the northern portion of the study typically trend towards the west-southwest, with directional variability being greater than those observed in the south during the same time period. In the lee of the island, the area of variable current patterns continued to persist.

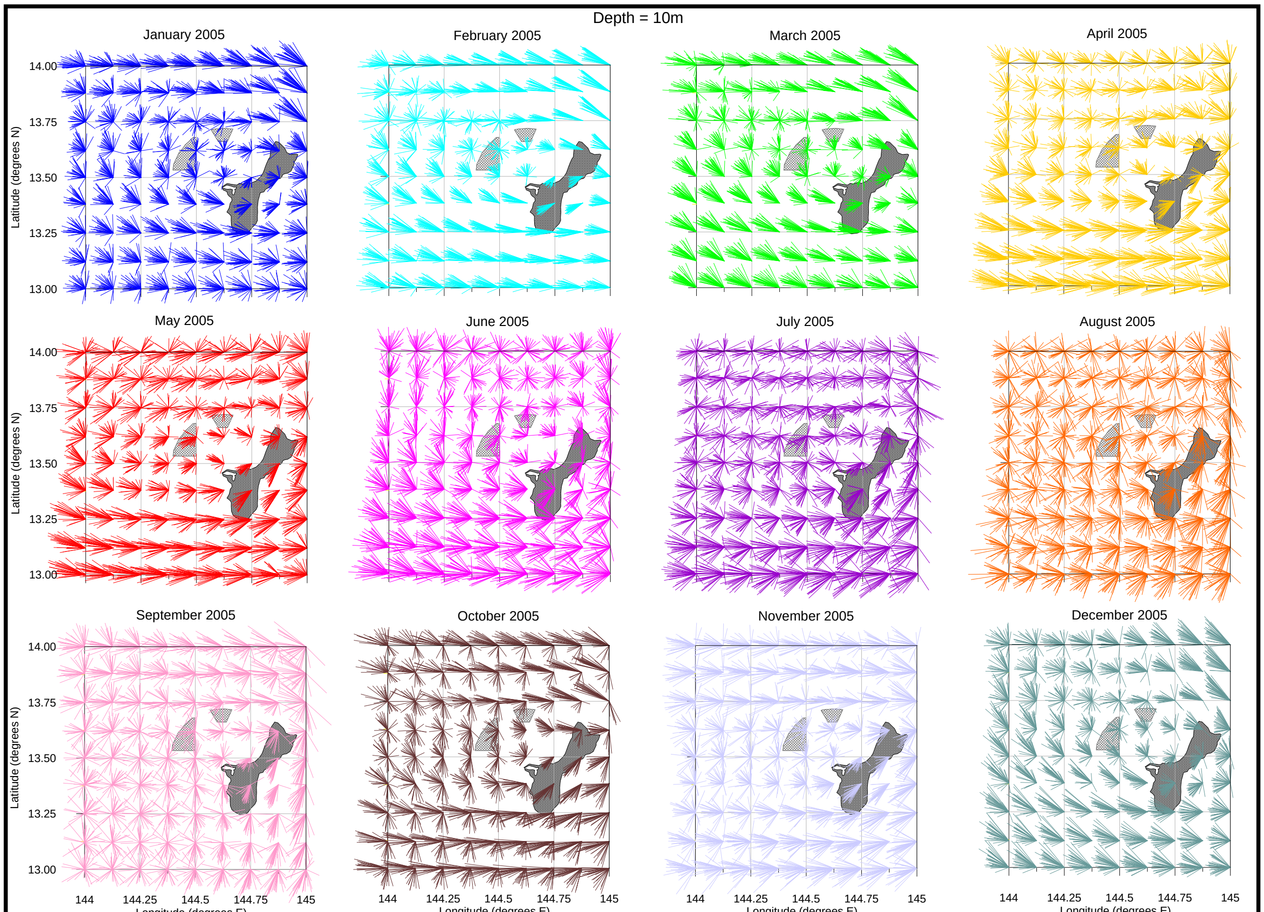


Figure 3-2.
Vector Plots of Daily Averaged Current Velocities by Month for Each Location at 33 ft (10 m) Depth

Note: Vectors indicate the current direction and relative speed for each day at each station.

<u>Intermediate Layer Currents</u>

Figure 3-3 and Figure 3-4 illustrate the intermediate layer currents on a regional scale. Figure 3-3 shows the upper portion of this layer at 1,300 ft (400 m) and Figure 3-4 shows the lower portion of this layer at 4,900 ft (1,500 m). At 1,300 ft (400 m), seasonal differences in the current pattern are apparent, but negligible. Throughout most of the year, the currents approach Guam from the east, similar to the currents at the surface. At this intermediate depth, the currents begin to show evidence of flowing along the isobaths, with the structure of the Marianas Ridge influencing current patterns. Directly east and southeast of Guam, the currents trend in a southwesterly direction, then once past the southern part of the island, the currents uniformly turn towards the northwest. Along the western boundary of the regional study area, the currents are strong and towards the north. Directly on the west side of Guam, the currents wrapping around the southern tip of the island turn further, trending northeast and eventually returning to the eastern side of the island as they cross the Rota Banks, just north of Guam.

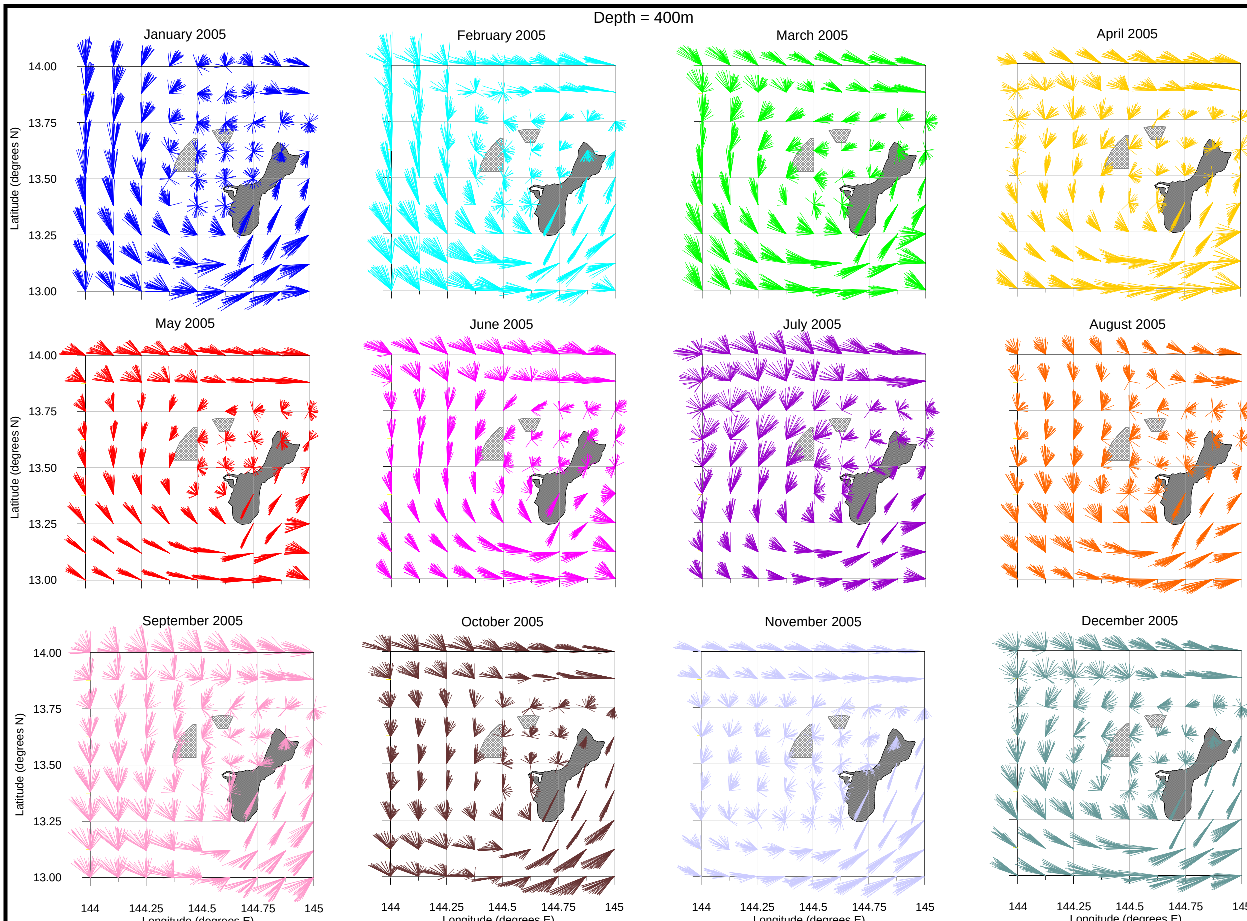


Figure 3-3.
Vector Plots of Daily Averaged Current Velocities by Month for Each Location at 1,300 ft (400 m) Depth

Note: Vectors indicate the current direction and relative speed for each day at each station.

Currents approaching northeast of Guam, north of the Rota Banks, flow in a uniform westerly direction.

At 4,900 ft (1,500 m), there is no evidence of seasonal patterns. The Marianas Ridge, which trends from the southwest of Guam and continues towards the northeast is apparent and strongly influences the current patterns. On the east side of the Marianas Ridge, currents are highly uniform, trending in a southwesterly direction along isobaths at an average speed of 0.16 ft/s (0.05 m/s, 0.09 kt). It is not evident if the currents at this depth, approaching Guam from the Eastern Marianas Basin, flow through a gap in the ridge or if another water body is responsible for the currents on the west side of the Marianas Ridge; however, on the west side of Guam, currents at 4,900 ft (1,500 m) are also highly uniform, though flowing counter to the currents on the east side of the ridge, in a north-northeast direction along isobaths at an average speed of about 0.07 to 0.16 ft/s (0.02 to 0.05 m/s, 0.04 to 0.09 kt).

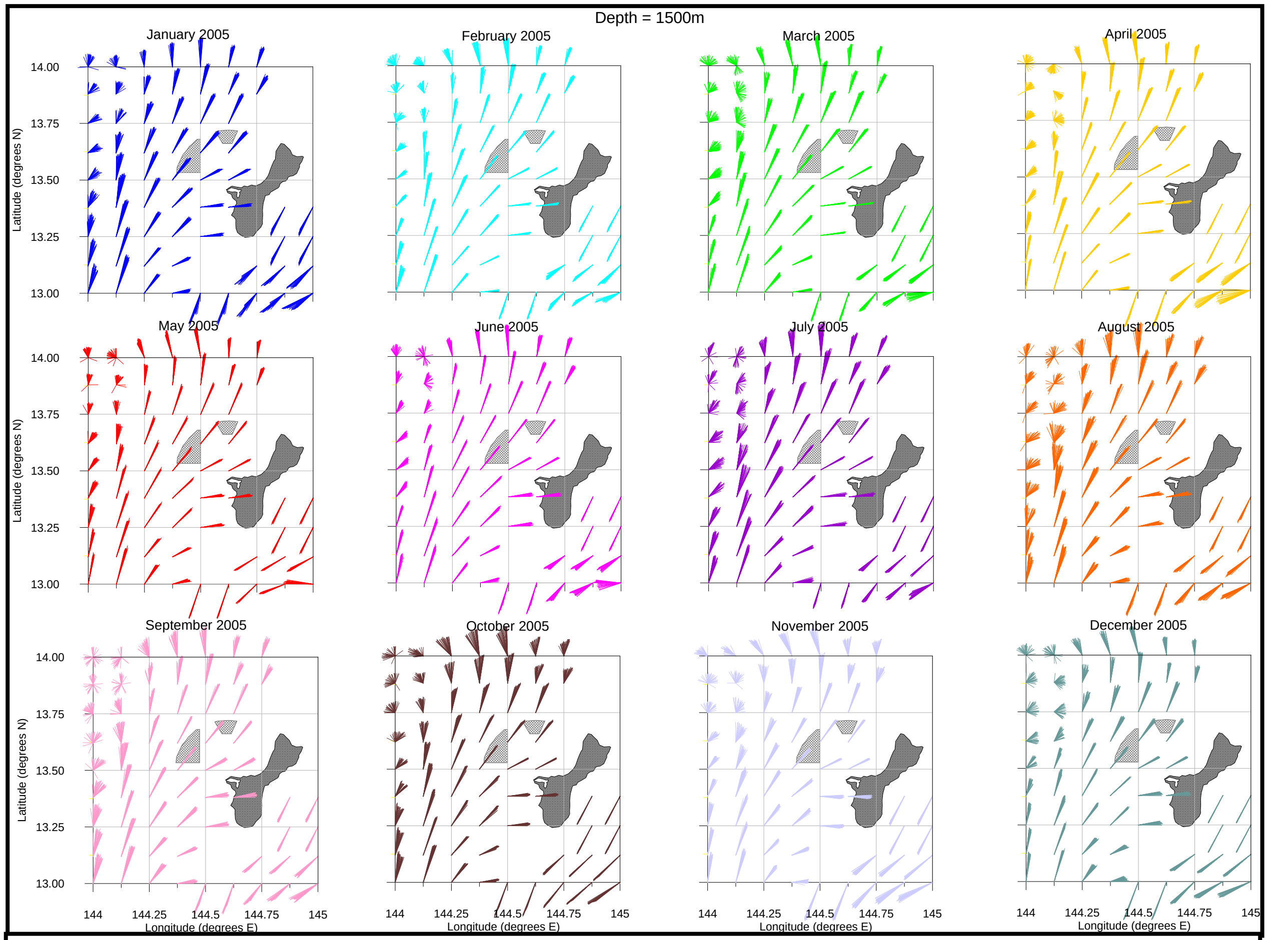


Figure 3-4.
Vector Plots of Daily Averaged Current Velocities by Month for Each Location at 4,900 ft (1,500 m) Depth

Note: Vectors indicate the current direction and relative speed for each day at each station.

Bottom Currents

Figure 3-5 illustrates the bottom layer currents on a regional scale. Two distinct bottom currents are evident, depending on the relation to the Marianas Ridge. East of the Marianas Ridge, the bottom current below 8,200 ft (2,500 m) continued to be very uniform and trends in a southwesterly direction at an average speed of about 0.10 to 0.13 ft/s (0.03 to 0.04 m/s, 0.06 to 0.07 kt), flowing along isobaths, similar to the currents in the intermediate layer. West of the Marianas Ridge, there appears to be a poorly developed countercurrent relative to the intermediate layer with erratic currents, ranging from a north-northwesterly direction to a south-southwesterly direction, though areas with a predominant easterly component occur. Current speeds average about 0.03 to 0.07 ft/s (0.01 to 0.02 m/s, 0.02 to 0.04 kt).

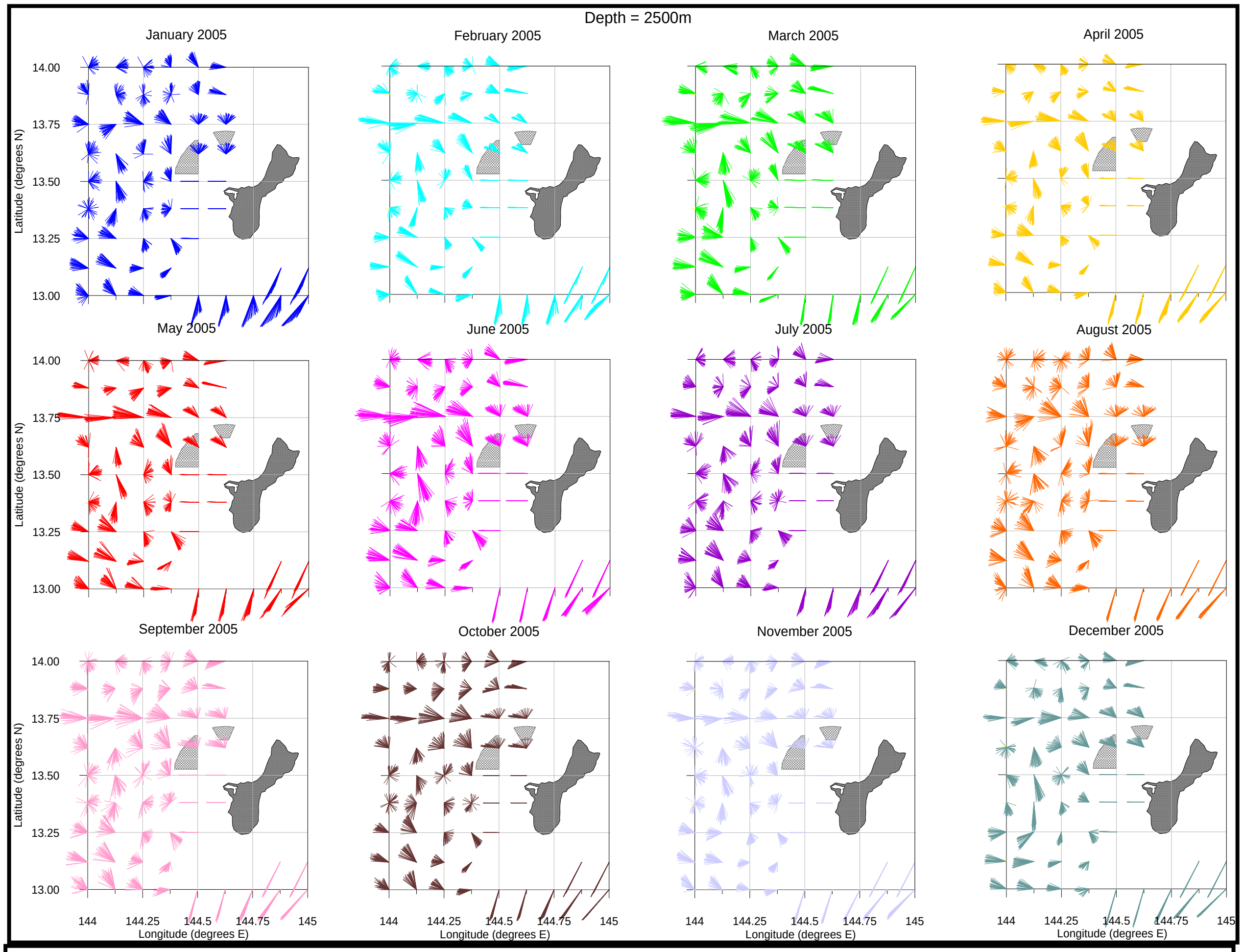


Figure 3-5.
Vector Plots of Daily Averaged Current Velocities by Month for Each Location at 8,200 ft (2,500 m) Depth

Note: Vectors indicate the current direction and relative speed for each day at each station.

<u>North Alternative Study Area (Modeled) Current Patterns</u>

Surface currents at the North Alternative Study Area exhibit a more consistent pattern than those at the Northwest Alternative, having a stronger and more westerly component ranging from 0.08 to 0.30 ft/s (0.03 to 0.1 m/s, 0.05 to 0.18 kt). This is likely a result of its closer proximity to the uniform westward flows around the north side of the island. However, two to three week periods consisting of irregular, poorly developed currents occurred at this site. The southern portion of this site experiences greater variability than the northern portion. Intermediate layer currents (1,300 ft [400 m] to 6,550 ft [2,000 m]) at the North Alternative area trend towards the northeast with decreasing variability with increasing depth. Current speeds are about 0.10 to 0.16 ft/s (0.03 to 0.05 m/s, 0.06 to 0.09 kt) in the intermediate layer. The bottom currents (below 8,200 ft [2,500 m]) in the North Alternative area were fairly consistent, trending in a north-northwesterly direction at a speed of approximately 0.07 ft/s (0.02 m/s, 0.04 kt).

Northwest Alternative Study Area (Modeled) Current Patterns

Surface currents at the Northwest Alternative Study Area tend to be highly variable during most of the year, with periods of strong and consistent southward flowing pulses during the wet weather season. Intermediate layer and bottom currents at the Northwest Alternative area are similar to those modeled in the North Alternative area.

3.1.2.3 *In Situ* Currents

Arrays of four in-line current meters and one upward-looking current profiler were moored at two sites, CM1 and CM2 (Figure 3-6), for the purpose of recording surface, midwater, and bottom currents over a period of one year in the vicinity of the proposed ODMDS. In-line current meters were positioned at depths of approximately 1,000 ft (305 m), 3,281 ft (1,000 m), 5,702 ft (1,738 m), and at a depth of 328 ft (100 m) above the ocean floor (7,497 ft [2,285 m] at CM1 and 6,982 ft [2,128 m] at CM2). Current direction and velocity were logged by the current meters in 1-hour intervals. For determining the speed and direction of surface currents, a current profiler was located in-line with the current meters at a depth of approximately 492 ft (150 m) below the surface at each location. The current profiler logged surface current data (current velocity and direction) in 16.4 ft (5 m) intervals every 1 hour from the water's surface to a depth of 492 ft (150 m). Due to electrical problems in the current profiler installed at CM1, surface current data was not obtained at this site. Upper surface currents at CM1, to a depth of approximately 82 ft (25 m), appeared to be predominantly wind driven and therefore were assumed to be similar to those measured at CM2. For ease in interpretation and discussion, vector speeds were averaged for each day of the year and plotted as speed and direction in vector plots. Vector plots of average daily mid-water and bottom currents at CM1 are provided in Figure 3-7 while vector plots of surface water, mid-water and bottom currents at CM2 are provided in Figure 3-8 and Figure 3-9.

CM1 Currents

Surface Currents- Depths of 0-82 ft (0-25 m)

It was assumed that sites CM1 and CM2 experienced similar current speeds and directions in their upper surface waters as a result of their close proximity to one another and as a result of the wind-driven nature of upper surface currents. Because surface current data were not collected at CM1, as previously mentioned, CM2 data were used to represent the uppermost surface conditions (82 ft (25 m) at both sites. During the months of January, February, March, and April 2008, the average daily currents measured at 82 ft (25 m) trended almost exclusively in a west, southwesterly direction with maximum velocities of 1.3 ft/s (0.40 m/s, 0.77 kt) (Figure 3-7). The upper surface currents then ran in a predominantly westerly direction in May and in a west, southwesterly direction in June. The months of July and August showed the greatest variability in current direction at 82 ft (25 m) depth, trending from northeast to northwest to southwest and also had the highest measured current velocities (1.7 ft/s [0.54 m/s, 1.0 kt]). In September, the current direction ranged from northeast to southwest but trend predominantly in a southwest direction. In October through early December the upper surface currents returned to trending almost exclusively in a west, southwesterly direction. Speeds of the upper surface currents were slightly lower during the mid-summer (June and July) and mid-winter months (January and February) (average velocity= 0.89 ft/s [0.27 m/s, 0.53 kt]) than at other times of the year (average velocity = 1.1 ft/s [0.33 m/s, 0.65 kt]).

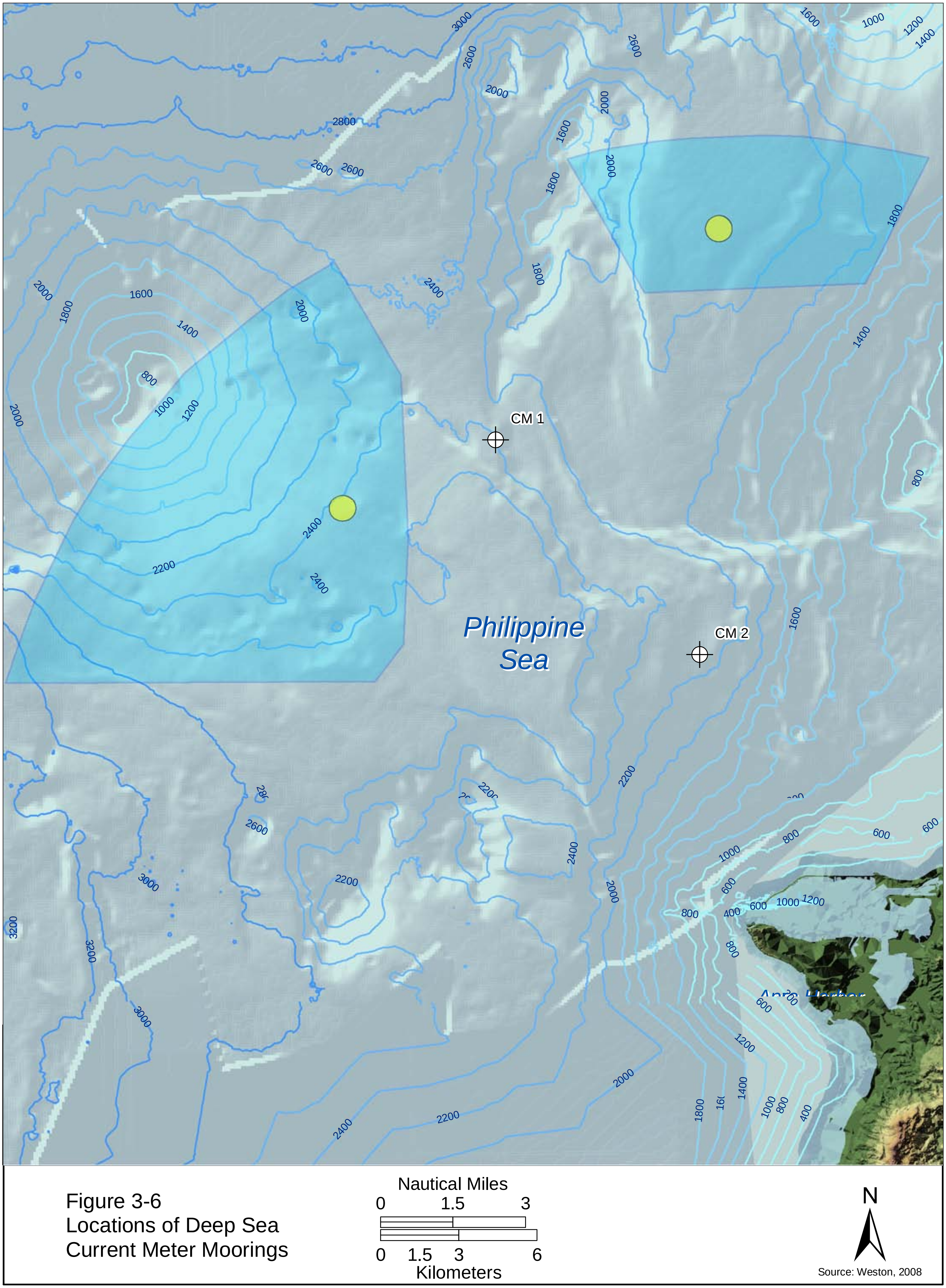


Figure 3-6
Locations of Deep Sea
Current Meter Moorings

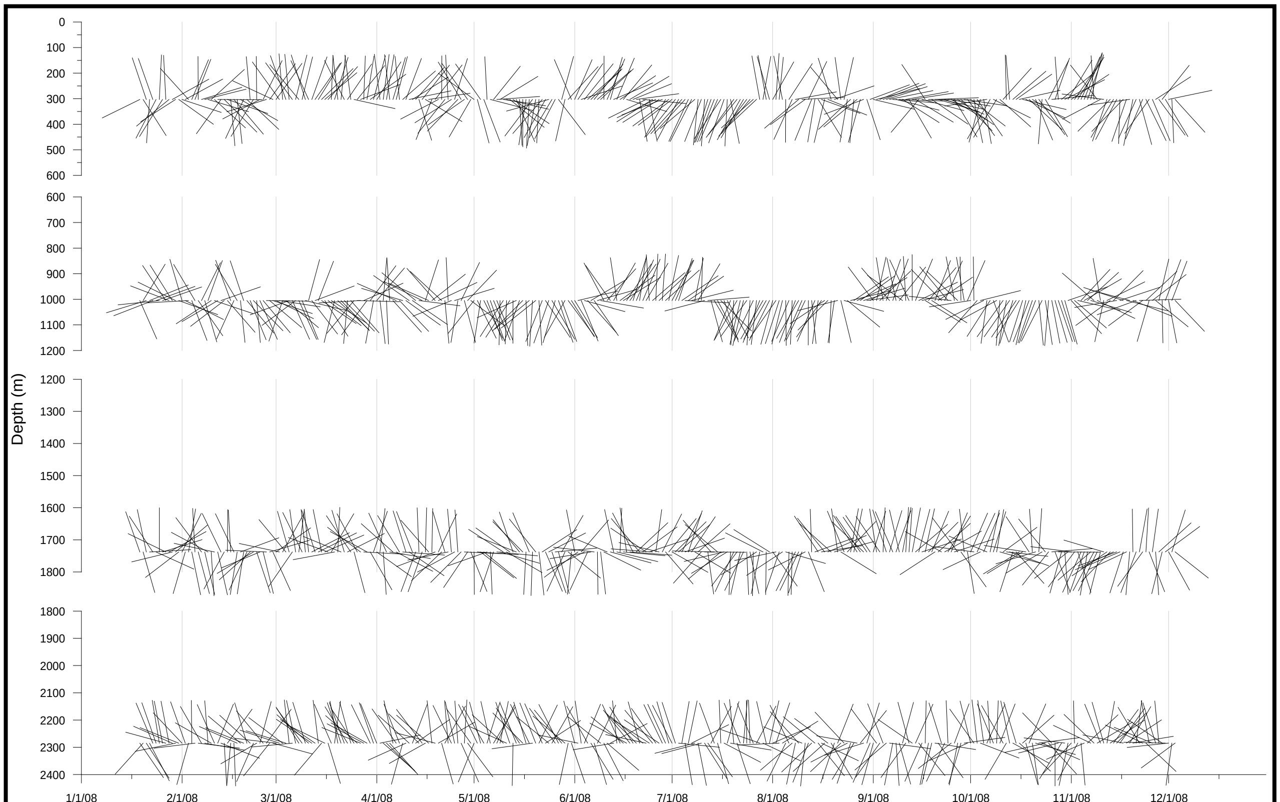


Figure 3-7.
Vector Plots of Average Daily Current Direction in 303 m, 1005 m, 1,738 m, and 2,285 m Depths at CM1

Mid-water Currents- Depths of 995 ft-5,702 ft (303m-1,738m)

Currents in 995 ft (303 m) of depth at CM1 flowed predominantly in a northerly direction during the first half of the year and in a southerly direction during the second half of the year (see Figure 3-7). The current direction at 995 ft (3,035 m) in depth was erratic during large periods of January, April, August, and October, when no persistent directional pattern was observed. From mid-February through the beginning of April, the current trended in a north/northeasterly direction, before becoming erratic in the latter portion of April and the beginning of May. A southerly shift in current direction occurred in May and was followed by a northeasterly current flow throughout most of June. Currents at CM1 in 995 ft (303 m) depth were the most highly organized in late June through July when they flowed consistently in a southeasterly direction and again in September when they flowed consistently in an easterly direction. In November, currents were somewhat disorganized, initially flowing in a northeasterly direction before shifting and flowing in a predominantly southwesterly direction.

The CM1 yearly average current speed at 995 ft (303 m) depth was 0.20 ft/s (0.06 m/s, 0.12 kt). Daily average current speeds ranged from 0.007 to 0.65 ft/s (0.002 to 0.197 m/s, 0.004 to 0.385 kt). Periods in which erratic current directions were observed over several days generally corresponded with weaker than average current speeds. Disorganized and erratic currents observed throughout the months of January and August were correlated to the weakest average monthly current speeds (0.13 ft/s [0.04 m/s, 0.08 kt]). Similarly, periods which had consistent and organized current directions over the course of 1 week or more corresponded with higher than average current speeds. July and November had the strongest average monthly current speeds (0.30 ft/s and 0.26 ft/s [0.091 m/s and 0.080 m/s, 0.178 kt and 0.154 kt], respectively). Currents in 3,297 ft (1,005 m) of depth at CM1 flowed predominantly in a southeasterly to southwesterly direction throughout the majority of the year (Figure 3-7). The current direction was erratic during the months of January, February, March, April, and November and corresponded to periods in which below average current velocities were recorded. During the months of May, August, October, and most of July, the CM1 currents at 3,297 ft (1,005 m) consistently flowed in a southerly or southwesterly direction. Throughout the months of June and September the currents trended in a northeasterly to northwesterly direction.

CM1 average current speeds at 3,297 ft (1,005 m) depth (0.13 ft/s [0.040 m/s, 0.078 kt]) were approximately 40 percent slower than the average yearly velocities measured at 995 ft (303m) in depth (0.20 ft/s [0.060 m/s, 0.118 kt]). The months of January and February had the weakest current velocities (0.06 ft/s and 0.07 ft/s [0.017 m/s and 0.020 m/s, 0.036 kt and 0.041 kt], respectively) while the months of June, July, and October had the strongest average current velocities (0.25 ft/s, 0.19 ft/s, and 0.19 ft/s [0.076 m/s, 0.057 m/s, and 0.057 m/s; 0.148 kt, 0.112 kt, and 0.112 kt], respectively).

Currents in 5,702 ft (1,738 m) at CM1 were generally less organized than those observed at other depths, flowing predominantly in either a northerly, northwesterly or southwesterly direction for the majority of the year (Figure 3-7). The currents at 5,702 ft (1,738 m) flowed consistently in a southwesterly direction from mid-July through the first week of August and the end of October through the second week of November. In contrast, currents ran consistently in a northerly direction throughout March and from mid-August through mid-October. During all other times of the year, current flow at 5,702 ft (1,738 m) was disorganized and erratic, rarely flowing in the same direction for longer than two or three days at a time.

CM1 average yearly current velocities (0.09 ft/s [0.027m/s, 0.053 kt]) at 5,702 ft (1,738 m) were 33% slower than those (0.13 ft/s [0.040 m/s, 0.078 kt]) measured at 3,297 ft (1,005 m). The seamounts located to the west and north of CM1 likely alter the flow of these deepwater currents. Average monthly current velocities were relatively stable throughout the year, ranging from 0.06 ft/s (0.017 m/s, 0.035 kt) in May to 0.12 ft/s (0.037 m/s, 0.071 kt) in September.

Bottom Currents- Depth of 7,497 ft (2,285 m)

In general, bottom currents at CM1 (7,497 ft [2,285 m] in depth) were somewhat organized, flowing in a northwesterly direction approximately 60% of the year (Figure 3-7). As stated previously, deep water currents in this region are typically dominated by the NPDW and the LCPW. Bathymetrically, CM1 is located in a sloping valley between two seamounts. The northeasterly flow of the measured current at 7,497 ft (2,285 m) in depth is likely attributed to the LCPW, which after being split by the island of Guam, deflects in a northward trajectory over the study area as it flows past CM1 into the Pacific Basin (Siedler et al. 2004). Bottom currents in this region flowed in a northward direction from February through June and in a mixed direction (primarily northerly or southerly) between the months of July through October. The currents returned to trending in a northerly direction in November.

CM1 average yearly current velocities (0.06 ft/s [0.018 m/s, 0.035 kt]) at 7,497 ft (2,285 m in depth) were less than those (0.09 ft/s [0.027 m/s, 0.053 kt]) measured at CM1 at 5,702 ft (1,738 m) and similar to those (0.07 ft/s [0.021 m/s, 0.041 kt]) measured at CM2 at a depth of 6,982 ft (2,128 m). The month of March had the highest average current velocity (0.08 ft/s [0.024 m/s, 0.047 kt]) while the months of August and September had the lowest average current velocities (0.04 ft/s [0.013 m/s, 0.024 kt]). During all other months, the average monthly current velocity varied little, ranging from 0.05 to 0.07 ft/s (0.015 to 0.022 m/s, 0.029 to 0.041 kt).

CM2 Currents

Surface Currents – Depth of 0 to 492 ft (0 to 150 m)

During the months of January, February, March, and April 2008, the average daily currents measured at 82 ft (25 m) trended almost exclusively in a west, southwesterly direction with maximum speeds of 1.3 ft/s (0.4 m/s, 0.77 kt) (Figure 3-8). The upper surface currents ran in a predominantly westerly direction in May and in a west, southwesterly direction in June. July and August had the greatest variability in current direction at 82 ft (25 m) depth, trending from northeast to northwest to southwest and also had the highest measured current speeds (1.8 ft/s [0.54 m/s, 1.07 kt]). In September, the current direction ranged from northeast to southwest but ran predominantly in a southwest direction. In October through early December the upper surface currents returned to running almost exclusively in a west, southwesterly direction. Velocities of the upper surface current were slightly lower during the mid-summer (June and July) and mid-winter months (January and February) (average velocity= 0.9 ft/s [0.27 m/s, 0.53 kt]) than at other times of the year (average velocity = 1.1 ft/s [0.33 m/s, 0.65 kt]).

The direction of surface currents at 164 ft (50 m) in depth was well-correlated with currents at 328 ft (100 m) and 492 ft (150 m) throughout most of the year (Figure 3-8). Average surface current speeds declined slightly with increasing depth, slowing appreciably below 82 ft (25 m) in depth. While the yearly average current speed at 82 ft (25 m) was 1.0 ft/s (0.31 m/s, 0.592 kt), the average yearly current speeds at 164 ft (50 m), 328 ft (100 m), and 492 ft (150 m) were 0.46 ft/s, 0.43 ft/s, and 0.33 ft/s (0.14 m/s, 0.13 m/s and 0.10 m/s; 0.27 kt, 0.25 kt, and 0.20 kt), respectively.

Surface current directions at 164 ft (50 m) to 492 ft (150 m) in depth often ran counter to directions of currents measured at 82 ft (25 m) in depth (Figure 3-8). In January, currents at 164 ft (50 m), 328 ft (100 m), and 492 ft (150 m) were erratic and not well correlated among the surface depths. In February, March, and April, the surface currents at 164 ft (50 m), 328 ft (100 m), and 492 ft (150 m) were well correlated, and ranged from flowing in a north, northeasterly direction to a south, southeasterly direction. In May and June, the currents predominantly flowed in an easterly direction (ranging from east northeast to southwest) while from July through September the currents changed direction regularly, with no prevailing directional pattern observed. In October, the currents at 164 ft (50 m) and 328 ft (100 m) in depth flowed primarily in a northeasterly direction at the beginning of the month and in a south-southwesterly direction in the middle of the month while at 492 ft (150 m) in depth, the current flowed a predominantly in a northerly direction at the beginning of the month and in a southerly direction at the end of the month. November currents at 164 ft (50 m), 328 ft (100 m), and 492 ft (150 m) flowed predominantly easterly, trending in a northeasterly direction at the end of November and beginning of December.

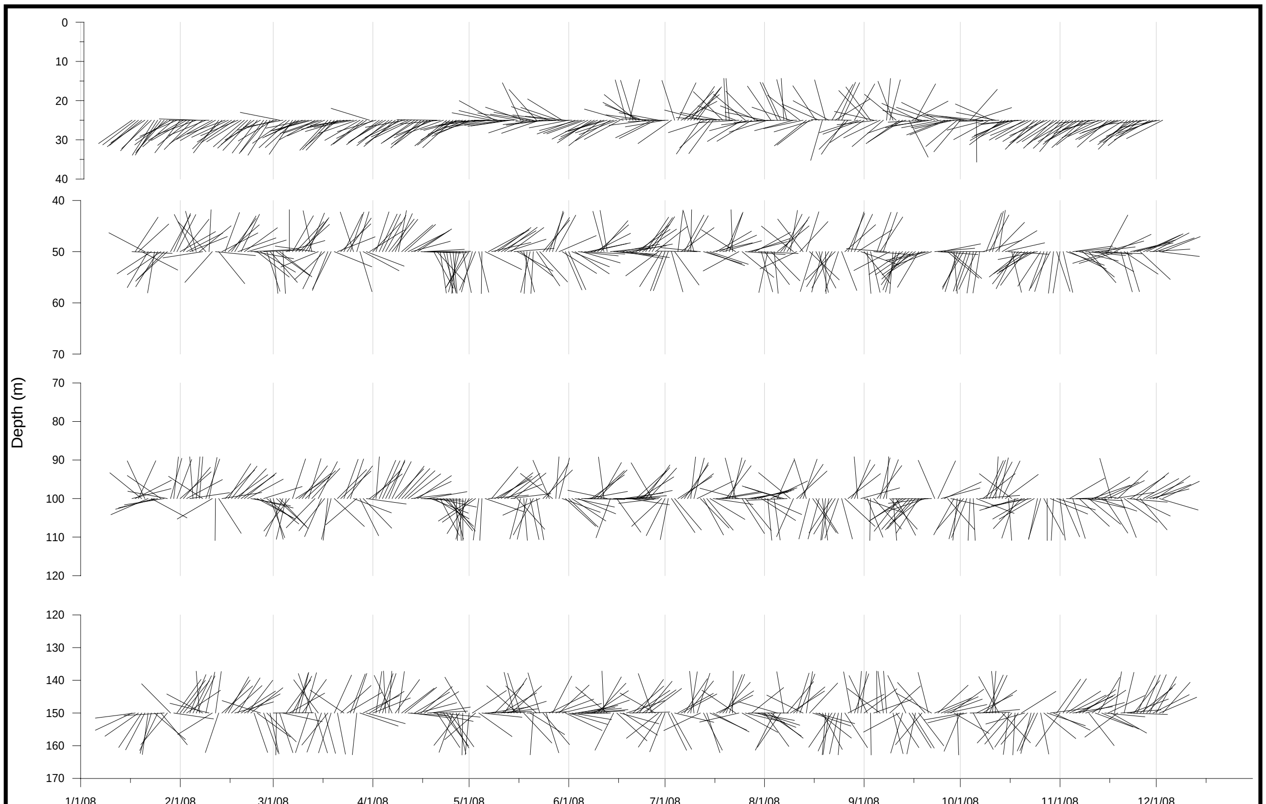


Figure 3-8.
Vector Plots of Average Daily Current Direction in 25 m, 50 m, 100 m, and 150 m Depths at CM2

Mid-water Currents- Depths of 984 ft-5,630 ft (303 m-1,716m)

Currents in 984 ft (300 m) of depth at CM2 flowed in a northeasterly direction throughout the majority of the year (Figure 3-9). The current direction at 984 ft (300 m) in depth was erratic in January and during a portion of the middle of February when no persistent directional pattern was observed. From mid-February through the beginning of April, the current trended in a north/northeasterly direction, before shifting direction and flowing predominantly southwesterly through mid-May. From mid-May through mid-June and from mid-July through the end of October, the current flowed in a northeasterly direction. Current flow from mid-June through mid-July and from mid-November through the end of November was predominantly in a southerly direction.

CM2 average current velocities at 984 ft (300 m) in depth (0.20 ft/s [0.06 m/s, 0.12 kt]) were approximately 40% slower than the averaged velocities measured at 492 ft (150 m) in depth (0.33 ft/s [0.10 m/s, 0.20 kt]). Disorganized and erratic currents observed in January corresponded with the weakest average current velocity (0.07 ft/s [0.02 m/s, 0.04 kt]) measured for a given month. Periods in which erratic current directions were observed over several days often corresponded with weaker than average current velocities. The highest current velocities were observed from mid-July through mid-November.

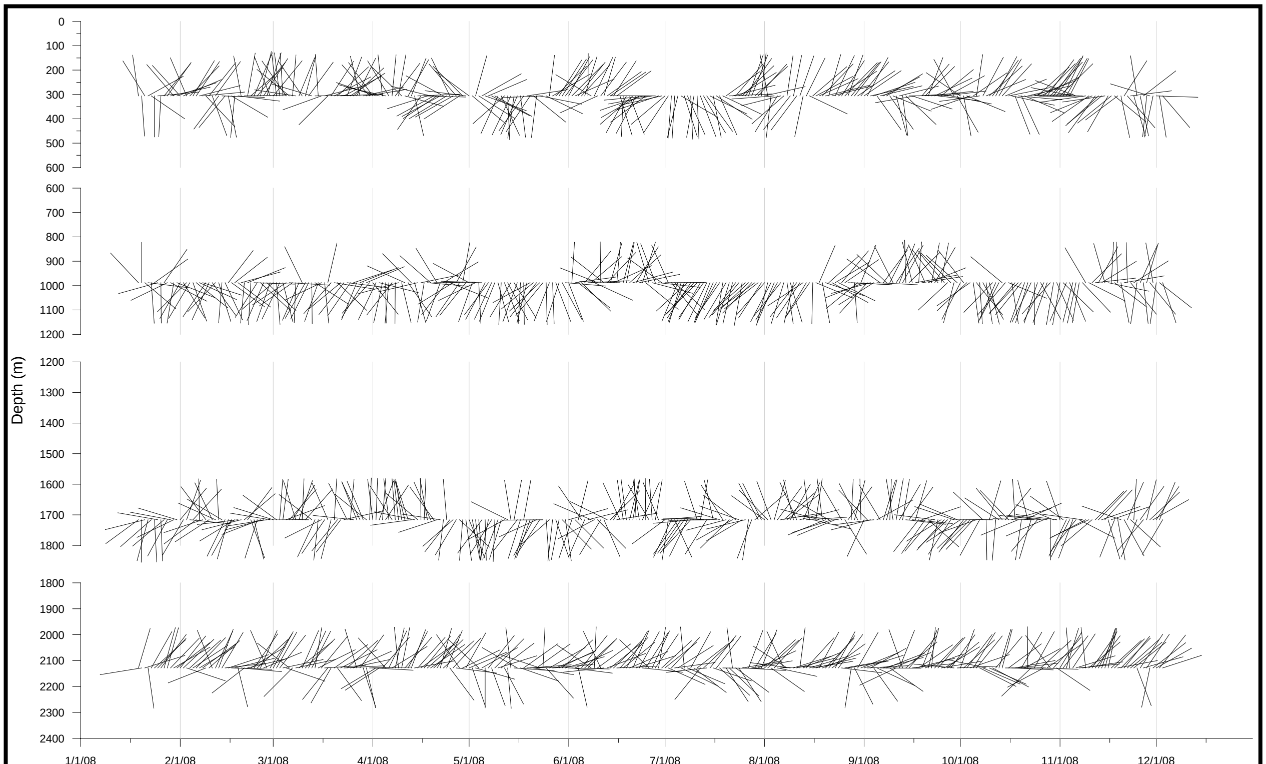


Figure 3-9.
Vector Plots of Average Daily Current Direction in 306 m, 988 m, 1716 m, and 2128 m Depths at CM2

Currents in 3,281 ft (1,000 m) of depth at CM2 flowed in a southerly or southwesterly direction throughout the majority of the year. The current direction at 3,281 ft (1,000 m) in depth was erratic during the months of January, April, and November. These months corresponded to periods in which below average current velocities were recorded. During the months of February, March, May, July, October, and portions of August, the CM2 currents at 3,281 ft (1,000 m) flowed in a predominantly southerly or southwesterly direction. Throughout June, September, and for several days at the end of August, the currents trended in a northeasterly to northwesterly direction.

CM2 average current velocities at 3,281 ft (1,000 m) in depth (0.10 ft/s [0.03 m/s, 0.06 kt]) were approximately 50% slower than the average yearly velocities measured at 984 ft (300 m) in depth (0.33 ft/s [0.10 m/s, 0.20 kt]). Periods of weak current velocities were generally correlated with disorganized and erratic current directions. The months of January and March had the weakest current velocities (0.05 ft/s and 0.06 ft/s [0.014 m/s and 0.017 m/s, 0.029 kt and 0.035 kt], respectively) while the months of July, October, and August had the strongest average current velocities (0.19 ft/s, 0.14 ft/s, and 0.13 ft/s [0.059 m/s, 0.042 m/s, and 0.040 m/s; 0.112 kt, 0.083 kt, and 0.077 kt], respectively).

Currents in 5,630 ft (1,716 m) of depth at CM2 were generally less organized than those observed at other depths, flowing predominantly in either a northerly or southwesterly direction for most of the year (see Figure 3-9). During the months of March, April, June, August, and the first two weeks of September, the current flowed mostly in a northerly or northwesterly direction. The current direction was erratic during the months of February, and March, the first two weeks of June, and the months of October and November. These months corresponded to periods in which below average current velocities were recorded. During the months of January and May, the first week of July, and the last two weeks in September, the currents at 5,630 ft (1,716 m) flowed in a predominantly southerly or southwesterly direction.

CM2 average yearly current velocities (0.07 ft/s [0.020 m/s, 0.041 kt]) at 5,630 ft (1,716 m) were slightly less than those (0.10 ft/s [0.032 m/s, 0.059 kt]) measured at 3,281 ft (1,000 m). Periods of weak current velocities at 5,630 ft (1,716 m) in depth were generally correlated with erratic current directions. In contrast to trends observed in upper waters, the month of January had the highest average current velocity (0.1 ft/s [0.029 m/s, 0.059 kt]). The months of June, October, and November had the weakest average current velocities (0.05 ft/s, 0.05 ft/s, and 0.06 ft/s [0.016 m/s, 0.16 m/s, and 0.017 m/s; 0.029 kt, 0.029 kt, and 0.035 kt], respectively) while the months of January, April, and May had the strongest average current velocities (0.1 ft/s, 0.08 ft/s, and 0.07 ft/s [0.029 m/s, 0.024 m/s, and 0.022 m/s; 0.059 kt, 0.047 kt, and 0.041 kt], respectively).

Bottom Currents- Depth of 6,928 ft (2,128 m) depth

In general, bottom currents at CM2 were highly organized, flowing in a northeasterly direction over 70 percent of the year (see Figure 3-9). As stated previously, deep water currents in this region are typically dominated by the NPDW and the LCPW. The northeasterly flow of the measured current at 6,928 ft (2,128 m) in depth is likely attributed to the LCPW, which after being split by the island, deflects in a northward trajectory over the study area as it flows into the Pacific Basin (Siedler et al. 2004). During the months of May and July, bottom currents flowed in a southerly to southwesterly direction for one to two-week periods of time. The remainder of the year, the bottom currents ran almost exclusively in a northeasterly direction.

CM2 average yearly current velocities (0.07 ft/s [0.021 m/s, 0.041 kt]) at 6,928 ft (2,128 m) in depth were nearly identical to those (0.07 ft/s [0.020 m/s, 0.041 kt]) measured at 5,577 ft (1,700 m). The month of January had the highest average current velocity (0.13 ft/s [0.039 m/s, 0.077 kt]). During all other months, the average monthly current velocity varied little, ranging from 0.06 ft/s (0.017 m/s, 0.035 kt) in May to 0.08 ft/s (0.024 m/s, 0.047 kt) in February.

3.1.2.4 Comparison between Modeled Currents and *In Situ* Current Measurements

Current data modeled by the NAVO for use in predicting the transport and deposition of dredged material at the proposed ODMDS offshore from Guam were compared to *in situ* current measurements collected to determine if modeled currents accurately predicted localized currents within the study area. The two closest sites for which NCOM results were available were used for comparison to sites CM1 and CM2.

The local features of the offshore environment surrounding Guam significantly affect current flows. Coastal eddy development in the lee of the island as a result of the NPEC flowing past Guam was predicted by Wolanski et al. (2003) and is also represented in the NCOM data. Wolanski's findings indicated that the strength and locations of coastal eddies were dependent upon the angle at which the NPEC approaches Guam and were affected significantly by storm systems. During seasons when tropical storms are most prevalent, vector plots of currents derived from NCOM data show greater variability.

The ENSO phenomenon was considered for the modeled current data and *in situ* measurements based on observations and forecasts provided by the Pacific ENSO Applications Center (PEAC) and a comparison to the Multivariate ENSO Index (MEI) developed by NOAA's Earth System Research Laboratory. Based on the results of this comparison, it was determined the NCOM current data appropriately reflected what is known about the regional current patterns around Guam and were representative of near-normal conditions with respect to ENSO (Weston 2007b). With respect to the ENSO phenomenon during the *in situ* measurements, May through June of 2008 were classified as near-normal conditions. January through April, and July through December, were classified as weak La Niña events with the exception of February and March, which were classified as moderate or stronger La Nina events (NOAA 2009b). The PEAC observed that while the prevailing state of the climate was ENSO-neutral, climatic effects typical of La Niña were noted for much of 2008 and included abnormally strong and widespread easterly surface winds in the low latitudes (PEAC 2009).

Surface Currents - Site CM1

Surface currents at 984 ft (300 m) in depth were predicted by NCOM to flow most frequently in either a westerly (19% of the time) or southwesterly direction (18% of the time) and to flow least frequently in a southerly direction (7% of the time) (Table 3-2). *In situ* measurements of currents in 994 ft (303 m) of depth at CM1 determined that currents flowed most frequently in either a southwesterly (19% of the time) or northerly direction (18% of the time) and least frequently in a westerly direction (2% of the time; Table 3-3). In general, the current direction frequencies predicted by NCOM for surface currents at 984 ft (300 m) in depth were not well-correlated to observed currents at CM1 (Figure 3-10).

Midwater Currents - Site CM1

Modeled currents at depths of 3,281 ft (1,000 m), 4,921 ft (1,500 m), and 6,561 ft (2,000 m) were largely uniform in direction. NCOM predicted currents at midwater depths to flow predominantly in a northeasterly direction at depths of 3,281 ft (1,000 m), 4,921 ft (1,500 m), and 6,561 ft (2,000 m). At 3,281 ft (1,000 m) the model predicted currents to flow northeasterly 99% of the time and northerly 1% of the time, while at 4,921 ft (1,500 m) and 6,561 ft (2,000 m) the currents were predicted to flow northerly 32% and 18% of the time, respectively, and to flow in a northeasterly direction 68% and 82% of the time, respectively (Table 3-2). *In situ* current readings indicated that currents flowed predominantly in a southerly or southeasterly direction (22% and 17% of the time, respectively) at 3,281 ft (1,000 m) and in a predominantly northerly or southerly direction (19% and 17% of the time, respectively) at 5,577 ft (1700 m; Table 3-3). Northeasterly flows that were predicted to comprise the majority of the flow direction according to NCOM data accounted for less than 15% of the measured current direction frequency at 3,281 ft (1,000 m) and 5,702 ft (1,738 m). The variable current direction measured *in situ* at CM1 suggests that eddy currents in the lee of the island and/or local bathymetric features or weather patterns may be affecting the nearshore current flow around Guam significantly more than is predicted by NCOM data. Additionally, tidal fluctuations which are not accounted for in NCOM results also likely impact current direction to some extent.

Bottom Currents - Site CM1

Currents at 2,500 m in depth were predicted by NCOM data to flow in northwesterly, westerly, or northerly directions 61%, 16% and 14% of the time, respectively (Table 3-2). Currents measured approximately 328 ft (100 m) above the ocean floor at CM1 flowed mainly in a northwesterly direction 25% of the time and in a northerly direction 24% of the time. Southerly and westerly flows were recorded 11% and 9% of the time, respectively (Table 3-3). With the exception of the predominant northerly and northwesterly flow direction frequencies, all other compass headings had relatively similar current direction frequencies.

Current Speed - Site CM1

Current speeds were predicted by NCOM data to be below 0.7 ft/s (0.2 m/s, 0.4 kt) in all but the uppermost surface waters (Table 3-4). In 164 ft (50 m) of depth, current speeds were modeled to be below at 0.7 ft/s (0.2 m/s, 0.4 kt) 80% of the time and between 0.7 and 1.0 ft/s (0.2 and 0.3 m/s, 0.4 and 0.6 kt) 16% of the time, while at 328 ft (100 m) in depth, currents were modeled to flow at speeds below 0.7 ft/s (0.2 m/s, 0.4 kt) 73% of the time and at 0.7-1.0 ft/s (0.2-0.3 m/s, 0.4-0.6 kt) 19% of the time. Currents were modeled to flow at speeds below 0.7 ft/s (0.2 m/s, 0.4 kt) 100% of the time below 984 ft (300 m) in depth. *In situ* current measurements at 984 ft (300 m) in depth and below were less than 0.7 ft/s (0.2 m/s, 0.4 kt) over 99% of the time and were well correlated to the current speeds predicted by NCOM (Figure 3-10 and Table 3-5).

Table 3-2. Relative Frequencies for Modeled Current Direction at Navy Site 1

	Relative Percent Frequency of Current Direction at Navy Site 1 (13.750º N, 144.500º E)							
Depth (m)	**North**	**North east**	**East**	**South east**	**South**	**South west**	**West**	**North west**
20	2%	4%	10%	9%	13%	17%	36%	9%
50	3%	3%	6%	13%	16%	22%	33%	4%
100	2%	1%	2%	3%	11%	28%	47%	6%
300	16%	10%	8%	9%	7%	18%	19%	15%
1000	1%	99%	0%	0%	0%	0%	0%	0%
1500	32%	68%	0%	0%	0%	0%	0%	0%
2000	18%	82%	0%	0%	0%	0%	0%	0%
2500	14%	10%	0%	0%	0%	0%	16%	61%
Frequency Total	8%	24%	6%	5%	6%	12%	30%	8%

Table 3-3. Relative Frequencies for *In Situ* Current Direction at CM1

	Relative Percent Frequency of Current Direction at CM1							
Depth (m)	**North**	**North east**	**East**	**South east**	**South**	**South west**	**West**	**North west**
303	18%	17%	15%	12%	13%	19%	2%	5%
1005	11%	14%	11%	17%	22%	13%	5%	7%
1738	19%	12%	9%	7%	17%	13%	9%	14%
2285	24%	10%	4%	8%	11%	9%	9%	25%
Frequency Total	18%	13%	10%	11%	16%	14%	6%	13%

Table 3-4. Modeled Current Speeds at Navy Site 1

Depth (m)	Directions							
	North	North east	East	South east	South	South west	West	North west
	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)
20	0.06	0.06	0.09	0.08	0.10	0.13	0.19	0.09
50	0.07	0.06	0.08	0.08	0.09	0.13	0.19	0.08
100	0.06	0.05	0.05	0.04	0.06	0.14	0.19	0.08
300	0.04	0.02	0.02	0.02	0.02	0.03	0.03	0.03
1000	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.08
1500	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
2000	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2500	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02

Table 3-5. Measured Current Speeds at CM1

Depth (m)	Directions							
	North	North east	East	South east	South	South west	West	North west
	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)
303	0.06	0.06	0.05	0.06	0.07	0.07	0.04	0.06
1005	0.04	0.04	0.03	0.03	0.05	0.05	0.02	0.04
1738	0.04	0.03	0.02	0.02	0.02	0.03	0.02	0.03
2285	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02

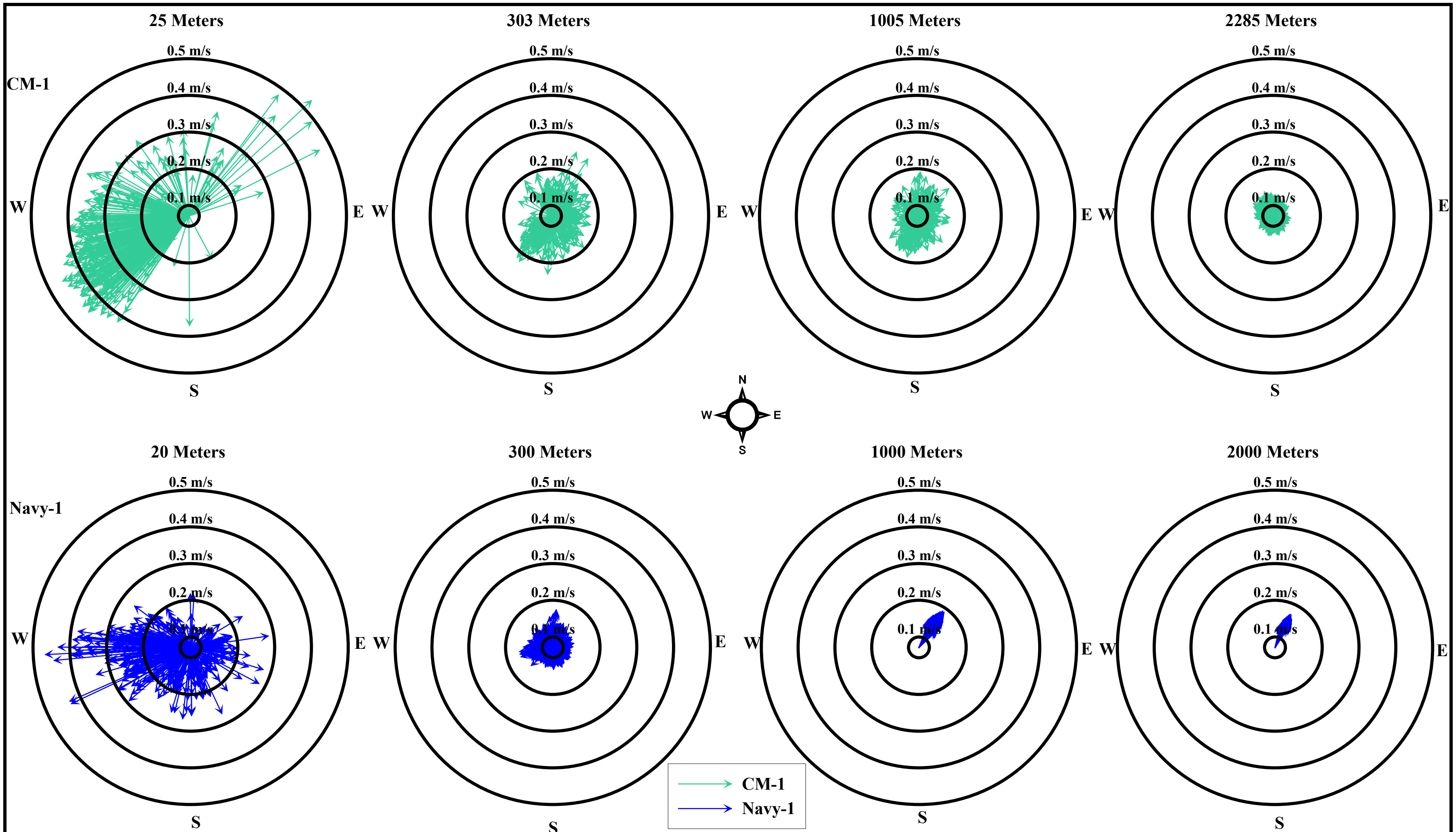


Figure 3-10.
Rose Diagram Plots of Daily Average Current Direction and Speed Over 1 Year Period, Comparing Modeled Navy Currents and *in situ* Currents at CM1

Surface Currents - Site CM2

Modeled surface currents at 66 ft (20 m) in depth were somewhat accurate in predicting upper surface current direction frequencies. NCOM predicted currents to flow in a westerly direction 34% of the time, a northwesterly direction 21% of the time and in a northerly direction 15% of the time (Table 3-6). In 2008, *in situ* currents in 66 ft (20 m) of depth at CM2 were observed flowing in a westerly direction 49% of the time, a northwesterly direction 4% of the time, and in a northerly direction 33% of the time (Table 3-7). However, as depth increased, the model became increasingly less accurate with respect to current direction. At 164 ft (50 m) in depth, although the model predicted that currents would flow predominantly westerly (37% of the time) or southwesterly (21% of the time), actual flow at CM2 in 164 ft (50 m) of depth was mainly northwesterly (25% of the time), easterly (21% of the time) and southeasterly (16% of the time).

Current direction frequencies were predicted to remain consistent between depths of 328 ft (100 m) and 984 ft (300 m) at CM2. The model predicted currents to flow primarily westerly (51% and 53% of the time, respectively), southerly (10% and 16% of the time, respectively), or northwesterly (18% and 15% of the time, respectively) (Table 3-6). Measured current direction frequencies at CM2 in 328 ft (100 m) and 984 ft (300 m) of depth however, did not correlate well with the model's predicted current directions and were not consistent between the two depths (Figure 3-11). Currents flowed in a northwesterly direction 27% and 6% of the time at 328 ft (100 m) and 984 ft (300 m) in depth, respectively, while flowing in a northeasterly direction 9% and 29% of the time, at 328 ft (100 m) and 984 ft (300 m) in depth, respectively (Table 3-7). The westerly current direction predicted by the model was observed only 5% and 9% of the time, respectively in 328 ft (100 m) and 984 ft (300 m) at CM2.

Midwater Currents - Site CM2

Modeled currents at depths of 3,281 ft (1000 m), 4,921ft (1,500 m), and 6,562 ft (2,000 m) were largely uniform in direction. NCOM predicted currents at midwater depths to flow almost exclusively in a northwesterly direction (Table 3-6). At 3,281 ft (1000 m) in depth, the model predicted currents to flow easterly 12% of the time and northwesterly 88% of the time, while at 4,921ft (1,500 m) and 6,562 ft (2,000 m) in depth, the currents were predicted to flow northwesterly 100% of the time. *In situ* current readings indicated that currents flowed in a southwesterly direction the majority of the time (27% and 21% at 3,281 ft (1,000 m) and 5,557 ft (1,700 m; Table 3-7), respectively) while flowing only a small fraction of the time in a northwesterly direction (7% and 12% of the time at 3,281 ft (1,000 m) and 5,630 ft (1,716 m), respectively). The variable current direction measured *in situ* at CM2 suggests that eddy currents in the lee of the island or local bathymetric features may be affecting the nearshore current flow around Guam significantly more than is predicted by NCOM data. Additionally, tidal fluctuations are not accounted for in NCOM results and may impact current directions.

Bottom Currents - Site CM2

Bottom currents in 8,202 ft (2,500 m) of depth were predicted by NCOM data to flow mainly northwesterly, westerly, or northerly directions 61%, 16% and 14% of the time, respectively (Table 3-6). Currents measured approximately 328 ft (100 m) above the ocean floor at CM2 flowed in a northeasterly direction 45% of the time and in an easterly direction 24% of the time (Table 3-7). Westerly and northerly flows were recorded 3% and 11% of the time, respectively.

Table 3-6. Relative Frequencies for Modeled Current Direction at Navy Site 2

Depth (m)	Relative Frequency of Direction at Navy Site 2 (13.625º N, 144.625ºE)							
	North	Northeast	East	Southeast	South	Southwest	West	Northwest
20	15%	10%	2%	2%	3%	13%	34%	21%
50	7%	13%	5%	2%	2%	21%	37%	13%
100	3%	5%	4%	1%	2%	10%	56%	18%
300	8%	5%	1%	1%	1%	16%	53%	15%
1000	0%	88%	12%	0%	0%	0%	0%	0%
1500	0%	100%	0%	0%	0%	0%	0%	0%
2000	0%	100%	0%	0%	0%	0%	0%	0%
2500	14%	10%	0%	0%	0%	0%	16%	61%
Frequency Total	6%	29%	6%	1%	1%	8%	34%	15%

Table 3-7. Relative Frequencies for *In Situ* Current Direction at CM2

Depth (m)	Relative Frequency of Direction at Site CM2							
	North	Northeast	East	Southeast	South	Southwest	West	Northwest
20	33%	4%	1%	1%	9%	0%	49%	4%
50	13%	8%	21%	16%	2%	10%	4%	25%
100	10%	9%	18%	15%	3%	14%	5%	27%
306	11%	29%	14%	9%	11%	11%	9%	6%
988	8%	9%	11%	12%	24%	27%	3%	7%
1716	20%	10%	5%	3%	14%	21%	14%	12%
2128	11%	45%	24%	7%	4%	3%	3%	4%
Frequency Total	14%	11%	17%	12%	5%	12%	7%	21%

<u>Current Speed - Site CM2</u>

Current speeds were predicted by NCOM data to below 0.7 ft/s (0.2 m/s, 0.4 kt) in all but the uppermost surface waters (Table 3-8). At 66 ft (20 m) in depth, currents were modeled to flow at speeds below 0.7 ft/s (0.2 m/s, 0.4 kt) 98% of the time and at speeds between 0.7 and 1.0 ft/s (0.2 and 0.3 m/s, 0.4 and 0.6 kt) 2% of the time, while at 164 ft (50 m) in depth, currents were modeled to flow at speeds below 0.7 ft/s (0.2 m/s, 0.4 kt) 99% of the time and at speeds of 0.7-1.0 ft/s (0.2-0.3 m/s, 0.4-0.6 kt) 1% of the time. For all other depths, modeled current speeds were less than 0.7 ft/s (0.2 m/s, 0.4 kt) 100% of the time. The *in situ* current profiler at CM2 detected current speeds that were greater than 1.3 ft/s (0.4 m/s, 0.8 kt) 94% of the time at 66 ft (20 m) in depth and detected current speeds below 0.7 ft/s (0.2 m/s, 0.4 kt) only 1% of the time (Table 3-9). Current speeds diminished markedly with increasing depth and were measured below 0.7 ft/s (0.2 m/s, 0.4 kt) 82% of the time at 164 ft (50 m) in depth. Only 1 percent of the measured current speeds at 164 ft (50 m) were above 1.3 ft/s (0.4 m/s, 0.8 kt). At 328 ft (100 m) depth, 89% of the measured currents were below 0.7 ft/s (0.2 m/s, 0.4 kt) and at 984 ft (300 m) or greater, the current speed was less than 0.7 ft/s (0.2 m/s, 0.4 kt) 99% of the time. Although upper surface current speeds were underestimated by the modeled data, the measured speed below 328 ft (100 m) was well correlated with the current speed predicted by NCOM (Figure 3-11 and Table 3-8).

3.1.2.5 Summary

Modeled NCOM current data and *in situ* measurements of regional oceanographic currents were consistent with respect to average speeds; however, *in situ* measurements showed greater variability in current direction. The NCOM model does not account for tidal fluctuations and this is the main source of spatial disparity between actual *in situ* measurement locations and NCOM model locations. With these differences noted, it is likely that the fate and transport of dredged material modeled using NCOM data is conservative (predicts a maximum possible scenario of a larger area of deposits) due to the uniformity of in NCOM current data. Dredged material disposed at the Guam ODMDS will likely settle within a smaller area due to the more variable current directions as measured at the site during the 2008 survey.

3.1.3 Water Column Characteristics and Chemical Analysis

The ROI for all water column characteristics is the water column within the ODMDS study areas. Water column characteristics include temperature, salinity, turbidity, light transmittance and dissolved oxygen. These characteristics were evaluated within the study region using a Seabird Electronics (SBE) 9*plus* conductivity/temperature/depth (CTD) instrumentation package as well as collecting water samples for ammonia-N, dissolved orthophosphate-P, nitrate-N, nitrite-N, total organic carbon (TOC), trace metals, polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides and polychlorinated biphenyls (PCBs) (both Aroclors and individual congeners). Results of the CTD casts and water sampling tests are described below for both study areas, and approximate sampling locations are displayed in Figure 3-12.

Table 3-8. Modeled Current Speeds at Navy Site 2

Depth (m)	Directions							
	North	North east	East	South east	South	South west	West	North west
	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)
20	0.07	0.08	0.07	0.08	0.09	0.08	0.07	0.09
50	0.08	0.07	0.06	0.05	0.07	0.07	0.07	0.07
100	0.06	0.07	0.08	0.03	0.03	0.08	0.07	0.07
300	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03
1000	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1500	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
2000	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2500	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01

Table 3-9. Measured Current Speeds at CM2

Depth (m)	Directions							
	North	North east	East	South east	South	South west	West	North west
	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)	Speed (m/s)
303	0.06	0.06	0.05	0.06	0.07	0.07	0.04	0.06
1005	0.04	0.04	0.03	0.03	0.05	0.05	0.02	0.04
1738	0.04	0.03	0.02	0.02	0.02	0.03	0.02	0.03
2285	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02

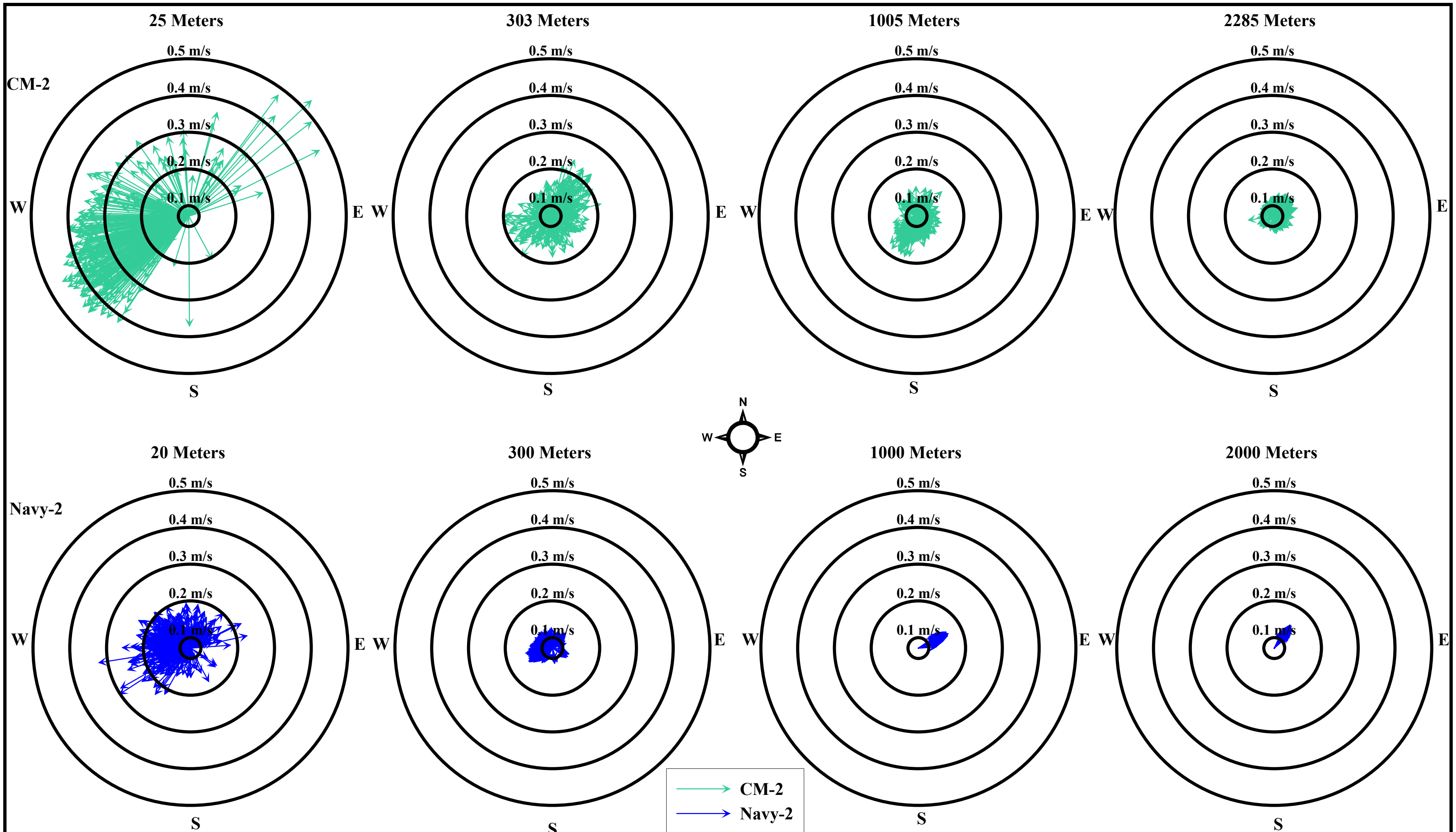


Figure 3-11.
Rose Diagram Plots of Daily Average Current Direction and Speed Over 1 Year Period, Comparing Modeled Navy Currents and *in situ* Currents at CM2

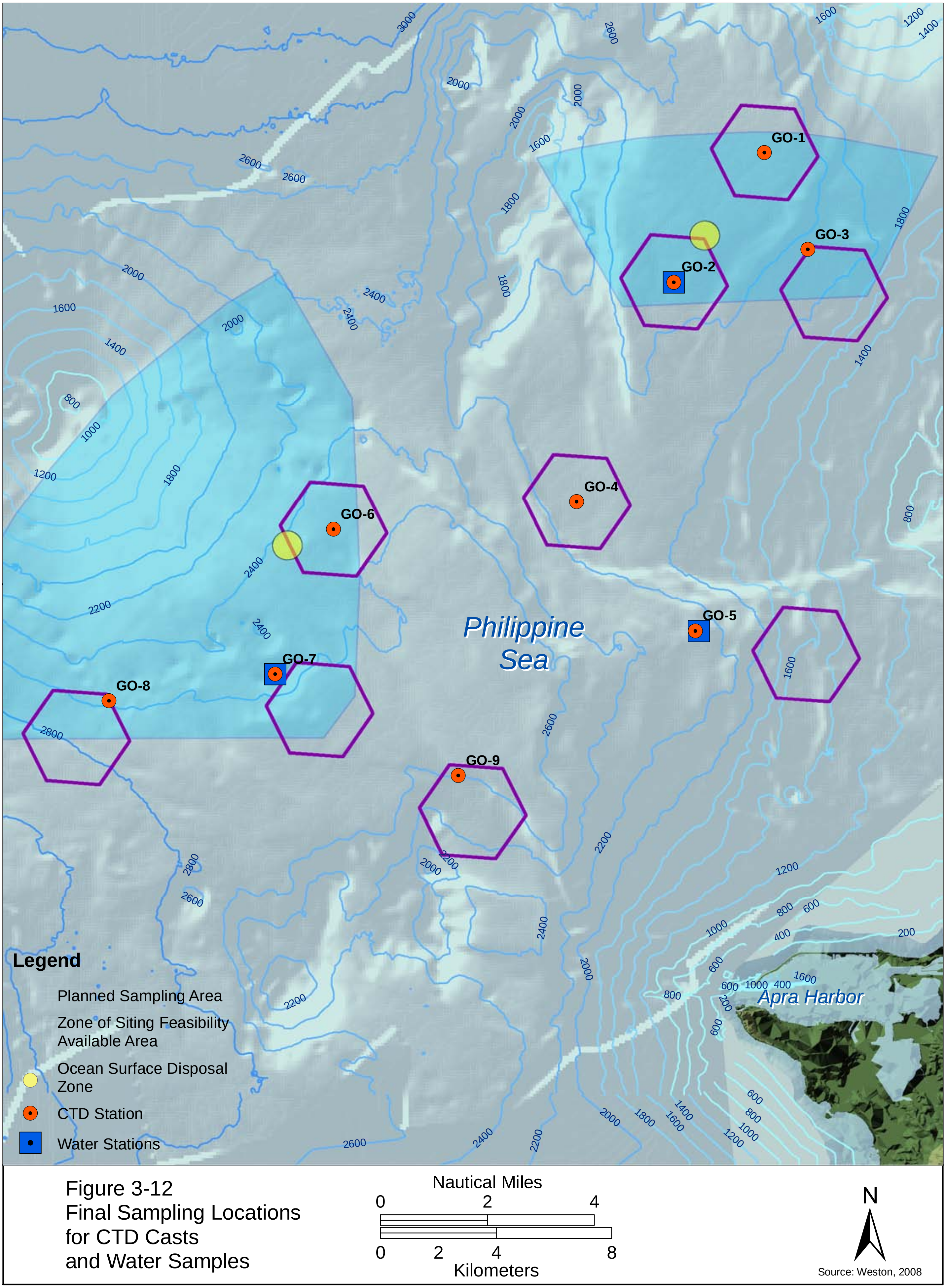


Figure 3-12
Final Sampling Locations for CTD Casts and Water Samples

3.1.3.1 Temperature

Temperature profiles in the open oceans typically have a well mixed surface layer in the upper 330 to 660 ft (100 to 200 m) underlain by a region of rapid temperature decline, known as the thermocline, which may be several hundreds of meters thick. Below the thermocline, temperature gradually decreases until temperatures of approximately 34 to 37°F (1 to 3°C) are reached at the seafloor. The maximum water temperatures, as expected, are located in the surface layer, where energy from direct sunlight is present but is rapidly dissipated with increasing depth.

Historical sea surface temperatures (January 2001 through June 2008) measured offshore of the southwest corner of Guam range from a winter-time low of 80.2°F (26.8°C) to a summer-time high of 86.7°F (30.4°C), with an annual average temperature of 83.7°F (28.7°C) (NOAA 2008a).

North Study Area

During the Site Characterization Survey conducted in the Guam ODMDS study region in April 2008, the average sea surface temperature (measured at 50 ft [15 m]) for the North Study Area (Stations 1-3) averaged 83.7°F (28.7°C), which is consistent with historical data. Temperatures within the upper water column were fairly uniform, averaging 82.8°F (28.2°C) from the surface down to the top of the thermocline. The top of the thermocline was located between approximately 425 and 525 ft (130 and 160 m), with an average temperature of 81.1°F (27.3°C). The thermocline was approximately 820 ft (250 m) thick, extending to depths of approximately 1,310 ft (400 m). Below the thermocline, temperatures gradually decreased from an average of 48.0°F (8.9°C) to an average of 35.6°F (2.0°C) near the ocean floor.

Northwest Study Area

During the Site Characterization Survey conducted in the Guam ODMDS study region in April 2008, the average sea surface temperature (measured at 50 ft [15 m]) for the Northwest Study Area (Stations 6-8) averaged 83.7°F (28.7°C), which is consistent with historical data. Similar to conditions in the North Alterative Study Area, temperatures within the upper water column were fairly uniform, averaging 82.8°F (28.2°C) from the surface down to the top of the thermocline. The top of the thermocline was located between approximately 410 and 490 ft (125 and 150 m), with an average temperature of 81.0°F (27.2°C). The thermocline was approximately 790 ft (240 m) thick, extending to depths of approximately 1,250 ft (380 m). Below the thermocline, temperatures gradually decreased from an average of 50.9°F (10.5°C) to an average of 35.2°F (1.8°C) near the ocean floor.

Inshore/Proposed Reference Site

In addition to collecting data from three stations within the North and Northwest Study Areas, three other stations were surveyed to gain a more comprehensive understanding of the regional marine biology, geology and physical oceanographic characteristics. These stations were located inshore of the two study areas and one of these stations was identified as a potential reference location for future Tier III testing. Tier III testing is required under the MPRSA and is described in the Ocean Testing Manual (USEPA and USACE 1991). Tier III testing includes the chemical, bioassay and bioaccumulation testing of project-specific proposed dredged materials to determine their suitability for ocean disposal. Results of Tier III tests are compared to similar tests conducted on reference material. Reference material is collected from a predetermined reference site having similar characteristics of the study area. Therefore, the surveys conducted in April 2008, included the collection of data from a location close to, but beyond the range of possible impacts of a potential ODMDS, to determine its suitability as a possible reference site.

During the Site Characterization Survey conducted in the Guam ODMDS study region in April 2008, the average sea surface temperature (measured at 50 ft [15 m]) measured at sites inshore of the two study areas, including the proposed reference location for future Tier III testing (Stations 4, 5 and 9) averaged 83.7°F (28.7°C), which is consistent with historical data. Similar to conditions in the North and Northwest Alterative Study Areas, temperatures within the upper water column were fairly uniform, averaging 82.9°F (28.3°C) from the surface down to the top of the thermocline. The top of the thermocline was located between approximately 401 and 460 ft (125 and 140 m), with an average temperature of 81.3°F (27.4°C). The thermocline was approximately 900 ft (275 m) thick, extending to depths of approximately 1,400 ft (425 m). Below the thermocline, temperatures gradually decreased from an average of 48.7°F (9.3°C) to an average of 35.6°F (2.0°C) near the ocean floor.

3.1.3.2 Salinity

Salinity is the measure of the amount of dissolved salts (predominantly chloride and sodium) in seawater. Salinity tends to remain relatively constant through the water column, but may vary slightly near the surface due to evaporation and precipitation, and at depth due to mixing of surface and deep waters. A feature called a halocline is a significant, vertical salinity gradient that may be found in seawater and affects the density of seawater. Typically located near thermoclines, haloclines interact with the thermocline and may result in the development of a pronounced pycnocline (e.g., strong density gradient).

North Study Area

During the Site Characterization Survey conducted in the Guam ODMDS study region in April 2008, the average salinity in the surface waters (measured at 50 ft [15 m]) for the North Study Area (Stations 1-3) averaged 34.4 parts per thousand (ppth). At the base of the surface water and just above the thermocline, salinity increased rapidly to a maximum average value of 35.0 ppth at approximately 575 ft (175 m) depth. Salinity then decreased to a minimum average value of 34.2 ppth near the base of the thermocline. Below the thermocline, the salinity remained relatively constant, with an average concentration of 34.6 ppth near the seafloor.

Northwest Study Area

In the Northwest Study Area (Stations 6-8), salinity in the surface waters averaged 34.5 ppth across the three stations. Similar to the salinity profile observed at stations in the North Study Area, the salinity was consistent in the upper surface waters, then rapidly increased to a maximum concentration of 35.1 ppth at approximately 560 ft (170 m) depth. Salinity then decreased to a minimum concentration of 34.3 ppth near the bottom of the thermocline (1,400 ft [425 m]). Below the thermocline, salinity remained constant, with an average concentration of 34.6 ppth near the seafloor.

Inshore/Proposed Reference Site

Water column salinity profiles at the inshore and proposed reference sites were similar to the North and Northwest Study Areas. The average salinity in the surface water was 34.5 ppth. Below the surface layer, salinity rapidly increased to a maximum concentration of 35.1 ppth at approximately 560 ft (170 m) depth. The minimum salinity concentration occurred at approximately 1,410 ft (430 m) depth with a concentration of 34.3 ppth. Below the thermocline, salinity remained constant, having an average concentration of 34.6 ppth near the seafloor.

3.1.3.3 Transmissivity and Turbidity

Transmissivity and turbidity are measures of the visual water quality. Transmissivity refers to the amount of light that passes through a sample (high transmissivity values suggest clearer water) whereas turbidity is a measure of the amount of light scattered by a sample (high turbidity values suggest turbid or cloudy water). The presence of sediments, excessive algal growth and plankton may result in lower transmissivity or higher turbidity values. Water clarity tends to be higher in oceanic regions due to the absence of suspended sediments from freshwater discharge or resuspension by waves and tides. Transmissivity and turbidity of seawater near Guam is not likely to be effected by seasonal changes due to the consistently warm climate.

<u>North Study Area</u>

Transmissivity was slightly lower in surface waters of the North Study Area (Stations 1-3) than in the middle and lower water column. At the surface, the average transmissivity value was 84.5%, while in the mid-water column transmissivity values were higher at 85.5%.

Turbidity measured in the North Study Area (Stations 1-3) was relatively constant through the water column; however, slight changes in the turbidity measurements did have a discernable trend. Turbidity in the surface waters averaged 44.9 nephelometric turbidity units (NTU). Minimum turbidity values were measured just below the thermocline, averaging approximately 43.3 NTU. Turbidity increased slightly through the remainder of the water column, with an average value of 44.5 NTU near the seafloor.

<u>Northwest Study Area</u>

Similar to the findings in the North Study Area, the Northwest Study Area (Stations 6-8) had fairly consistent transmissivity values throughout the water column, with slightly increased values when approaching the middle water column and elevated values down to the bottom water in comparison to surface waters. Transmissivity measurements in the surface waters were 85.2%, and increased slightly to 85.7% approaching the mid-water column.

Turbidity measured in the Northwest Study Area (Stations 6-8) followed the same pattern as in the North Study Area. Turbidity in the surface waters averaged 43.9 NTU. Minimum turbidity values were measured just below the thermocline, averaging approximately 42.2 NTU. Turbidity increased slightly through the remainder of the water column, having an average value of 44.9 NTU near the seafloor.

<u>Inshore/Propose Reference Site</u>

The sites inshore of the two study areas, including the proposed reference location for future Tier III testing (Stations 4, 5 and 9) had fairly consistent transmissivity values throughout the water column, with a slight increase approaching the middle water column and remaining elevated to the bottom water when compared to surface waters. Transmissivity measurements at the inshore and reference sites were 84.8% and increased slightly to 85.8% approaching the mid-water column.

Turbidity measured in inshore of the two study areas and at the proposed reference site (Stations 4, 5 and 9) followed the same pattern as in the North and Northwest Study Areas. Turbidity in the surface waters averaged 43.5 NTU. Minimum turbidity values were measured just below the thermocline, averaging approximately 42.1 NTU. Turbidity increased slightly through the remainder of the water column, with an average value of 44.9 NTU near the seafloor. It should be noted that turbidity values measured at Station 9 in the upper 130 ft (40 m) of the water column were inconsistent with measurements made at all other stations visited during the Site Characterization Surveys in April 2008. Measured values at this station were up to 10 NTU lower than other stations. These lower measurements were likely a result of incorrect sensor readings rather than greater water clarity, since a corresponding signature was not evident in transmissivity measurements.

3.1.3.4 Dissolved Oxygen

Sufficient oxygen levels are critical because significant decreases in dissolved oxygen may cause mortality of some organisms, leading to decreases in overall species diversity. In areas such as the North Pacific Ocean, seawater generally has higher oxygen content relative to its low rate of consumption near the surface. Below the surface layer, dissolved oxygen tends to decrease, having a minimum concentration near the bottom of the light or photic zone. This is likely due to greater rates of oxygen consumption by the processes of respiration of animals and plants and microbial decomposition of organic matter or detritus than is being generated by photosynthesis. At greater depths, dissolved oxygen concentrations tend to increase due to the capacity for denser and colder seawater to contain more oxygen.

<u>North Study Area</u>

Dissolved oxygen concentrations in the surface waters of the North Study Area (Stations 1-3) averaged approximately 6.00 milligrams per liter (mg/L). Dissolved oxygen concentrations slowly increased through the surface layer to an average 6.19 mg/L at 260 ft (80 m) depth. Concentrations then decreased to 2.19 mg/L at approximately 600 m depth. From 1,970 ft (600 m) to the bottom of the water column, dissolved oxygen concentrations slowly increased to 3.66 mg/L.

<u>Northwest Study Area</u>

The average sea surface dissolved oxygen concentration (measured at 50 ft [15 m]) for the Northwest Study Area (Stations 6-8) was 5.98 mg/L. The maximum dissolved oxygen concentration occurred at approximately 260 ft (80 m) depth with a value of 6.16 mg/L, and the minimum dissolved oxygen concentration occurred at approximately 1,800 ft (550 m) with a value of 2.21 mg/L. Below 1,800 ft (550 m), dissolved oxygen concentrations slowly increased until nearly reaching 3.92 mg/L the seafloor.

<u>Inshore/Proposed Reference Site</u>

Dissolved oxygen concentrations in the surface waters measured at sites inshore of the two study areas, including the proposed reference location for future Tier III testing (Stations 4, 5 and 9), averaged 5.98 mg/L. Similar to the dissolved oxygen profiles for the North and Northwest Study Areas, the dissolved oxygen concentration slowly increased to 6.16 mg/L at approximately 260 ft (80 m) depth, then decreased to a concentration of 2.21 mg/L at approximately 1,800 ft (550 m) depth. Below the photic zone, concentrations of dissolved oxygen increased to an average of 3.76 mg/L.

3.1.3.5 Regional Summary

As expected, water quality parameters, including temperature, salinity, transmissivity, turbidity and dissolved oxygen, measured across the entire study region were consistent with each other and followed oceanographic trends typical for tropical latitudes. Temperature remained relatively constant in the surface layer, decreased rapidly through a thermocline layer between water depths of approximately 490 to 1,310 ft (150 to 400 m), and then steadily decreased to minimum values observed near the seafloor. Salinity concentrations also remained constant in the mixed surface layer, increased sharply near the top of the thermocline, decreased to a minimum value near the base of the thermocline, and remained relatively constant through the remainder of the water column. Transmissivity and turbidity values were relatively constant throughout the entire water column with minor changes. Dissolved oxygen concentrations were greatest near the surface, decreasing to a minimum near the base of the photic zone. Below the photic zone, dissolved oxygen concentrations steadily increased towards the bottom of the water column. These trends are evident in Figures 3-13 through 3-16, which depict a representative station from each study area (Station 2 for the North Study Area and Station 7 for the Northwest Study Area), the proposed reference site (Station 5) and an average of the remaining six study stations. These figures further illustrate the similarity between study areas (e.g., there were no significant differences between the North and Northwest Study Areas).

3.1.4 Water Column Chemical Analyses

Conventional and chemical analyses were performed on water samples from four discrete depths at each of three locations: one in the North Study Area, one in the Northwest Study Area and one at the proposed reference site. Analyses included nitrogen (ammonia, nitrate, nitrite), dissolved orthophosphate, TOC, dissolved trace metals and organic pollutants (PAHs, chlorinated pesticides/PCBs). The results of these analyses are presented in Table 14 of the Field Report Baseline Studies Conducted for the Designation of an Ocean Dredged Material Disposal Site, Apra Harbor, Guam (Weston Solutions and TEC 2008b) and described in the following sections.

3.1.4.1 Conventional Parameters

Ammonia, dissolved orthophosphate, nitrate, nitrite, and TOC were measured to determine typical nutrient levels in samples collected offshore of Guam. Seasonal current patterns, uptake by marine plants (phytoplankton), and upwelling may alter nutrient levels in marine ecosystems. However, these changes are also caused by biogeochemical processes and regeneration due to decomposition of sinking particulate matter.

<u>North Study Area</u>

With the exception of nitrite, which was not detected in any of the depth specific samples at Station 2, nutrients generally increased with depth; whereas TOC generally decreased with depth (Figure 3-17 and Figure 3-18). Ammonia ranged from non-detectable levels at the surface to 0.03 mg/L in the near bottom sample (Figure 3-17). Dissolved orthophosphate concentrations ranged from non-detectable levels at the surface to 0.08 mg/L in the near bottom sample. Nitrate concentrations ranged from non-detectable levels in the surface sample to 0.5 mg/L in the near bottom sample, with a maximum concentration in the mid-water column sample of 0.84 mg/L. TOC concentrations ranged from 0.6 mg/L in the surface sample to an estimated value of 0.1 mg/L in the near bottom sample (Figure 3-18). The Dixon’s Test for extreme values was utilized to determine the homogeneity of nutrient values throughout the water column. There were no significant differences in nutrient levels among samples collected at each of the four different water depths at Station 2 in the North Study Area.

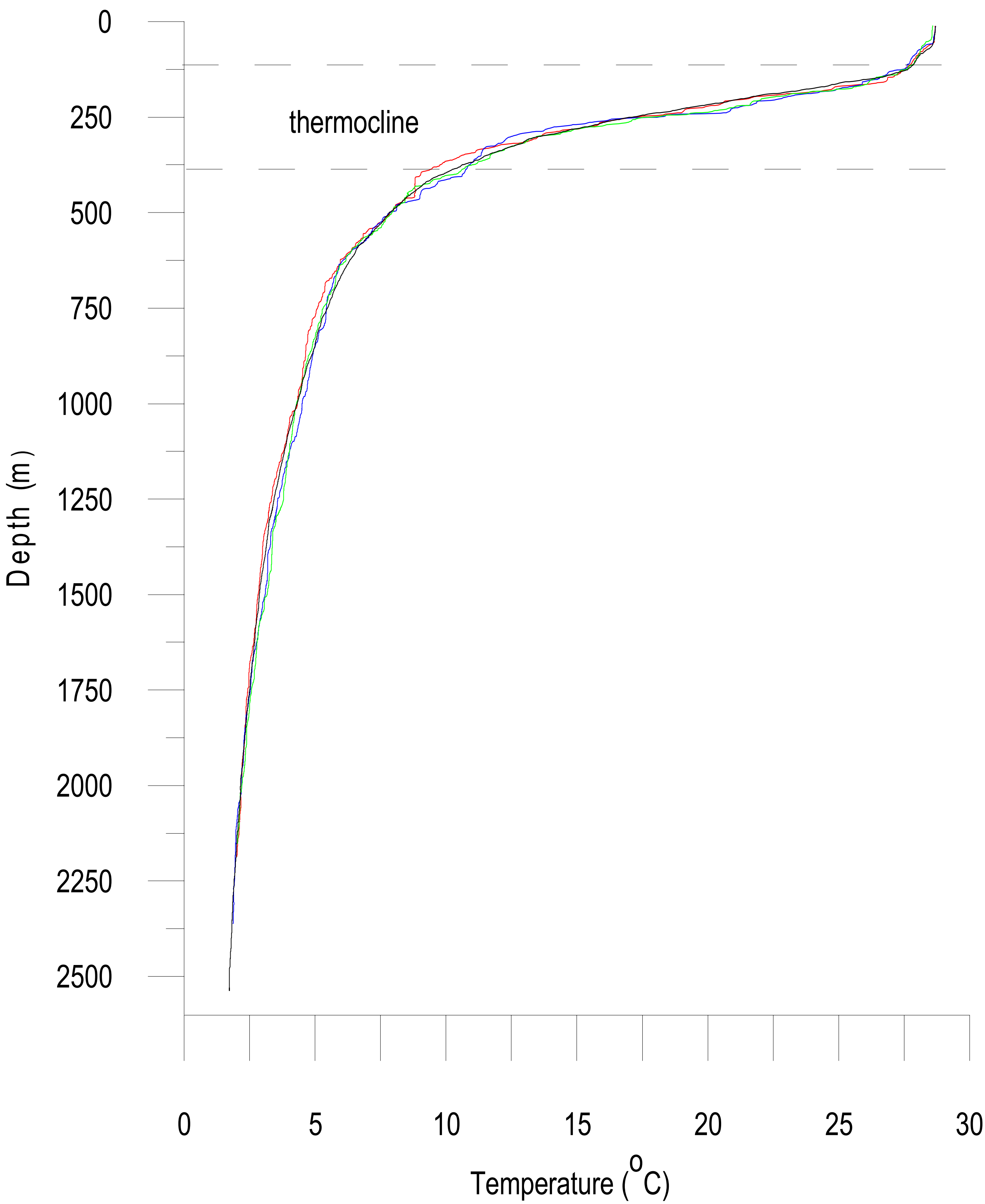


Figure 3-13.
Comparison of Temperature Profiles between Representative Stations in the North Study Area, Northwest Study Area and Proposed Reference Site

Source: Weston, 2008

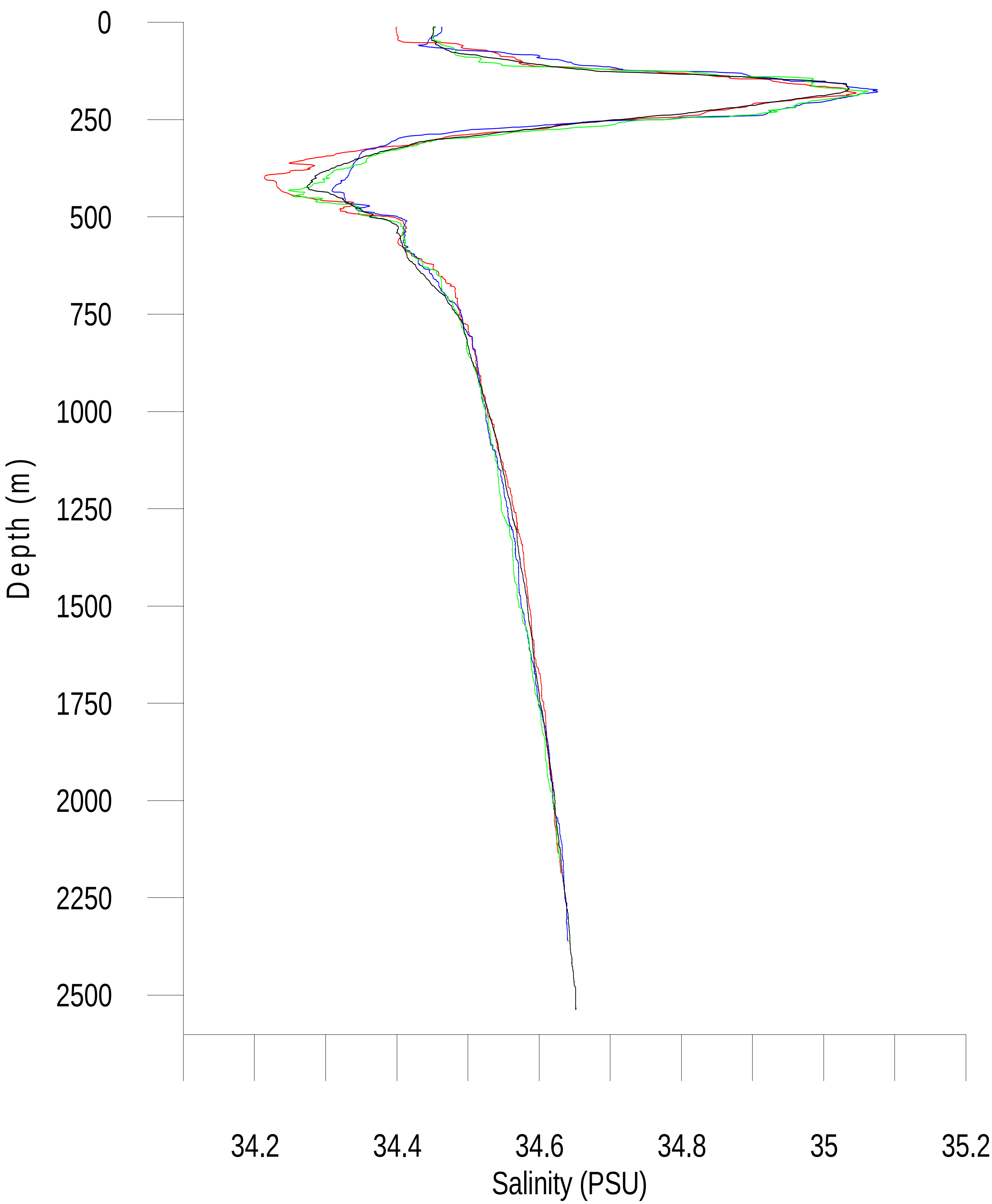


Figure 3-14.
Comparison of Salinity Profiles between Representative Stations in the North Study Area, Northwest Study Area and Proposed Reference Site

Source: Weston, 2008

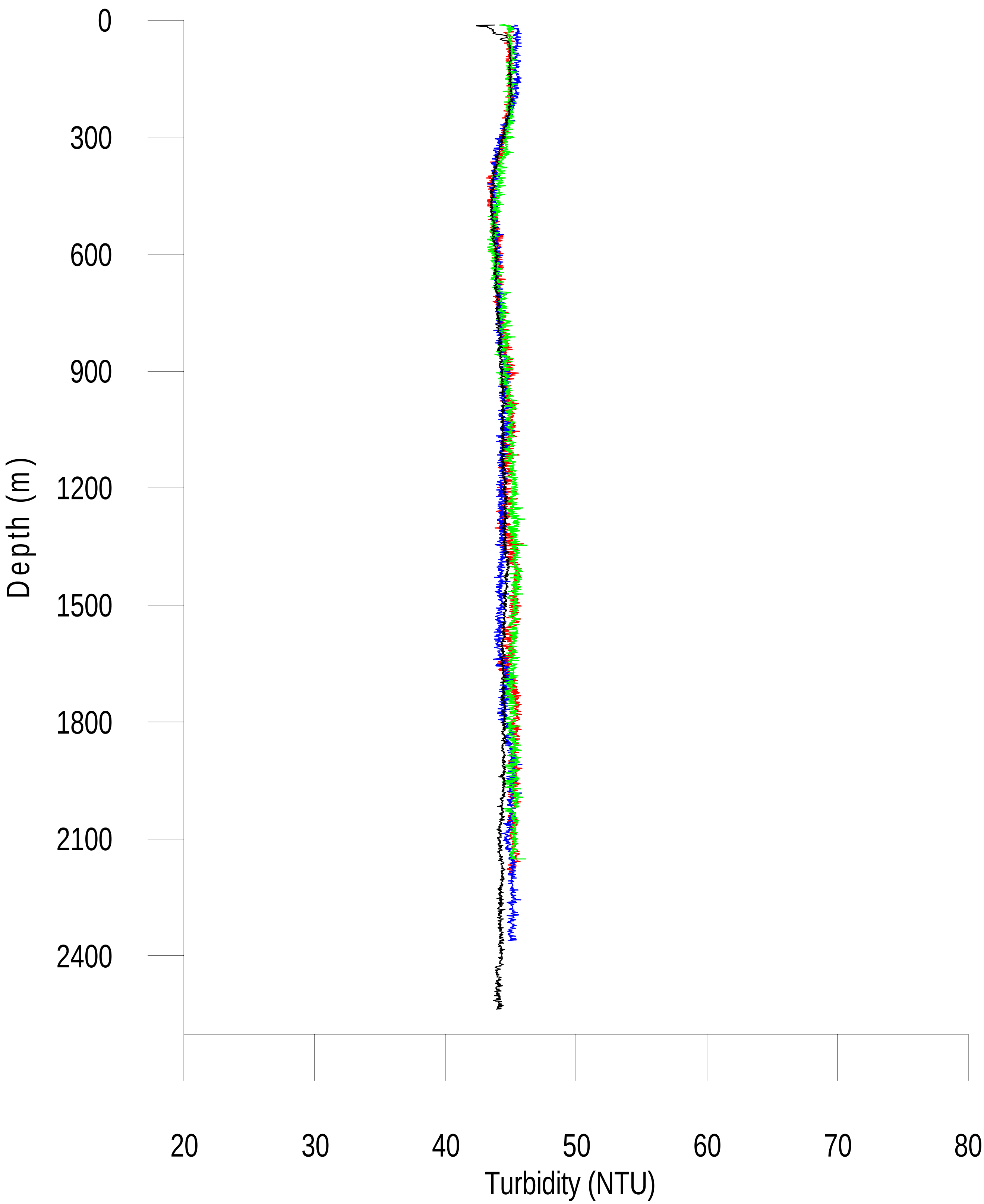


Figure 3-15.
Comparison of Turbidity Profiles between Representative Stations in the North Study Area, Northwest Study Area and Proposed Reference Site

Source: Weston, 2008

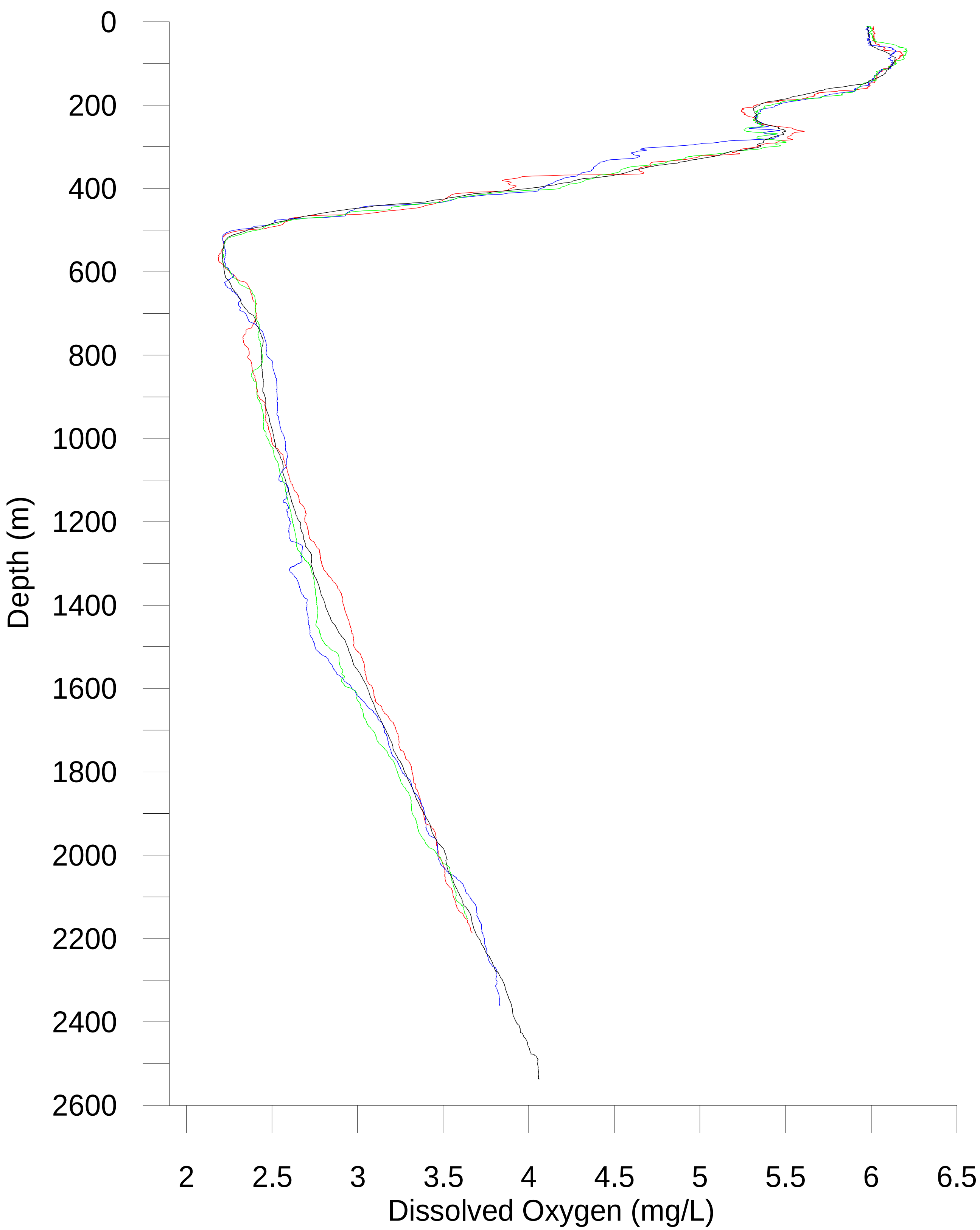


Figure 3-16.
Comparison of Dissolved Oxygen Profiles between Representative Stations in the North Study Area, Northwest Study Area and Proposed Reference Site

Source: Weston, 2008

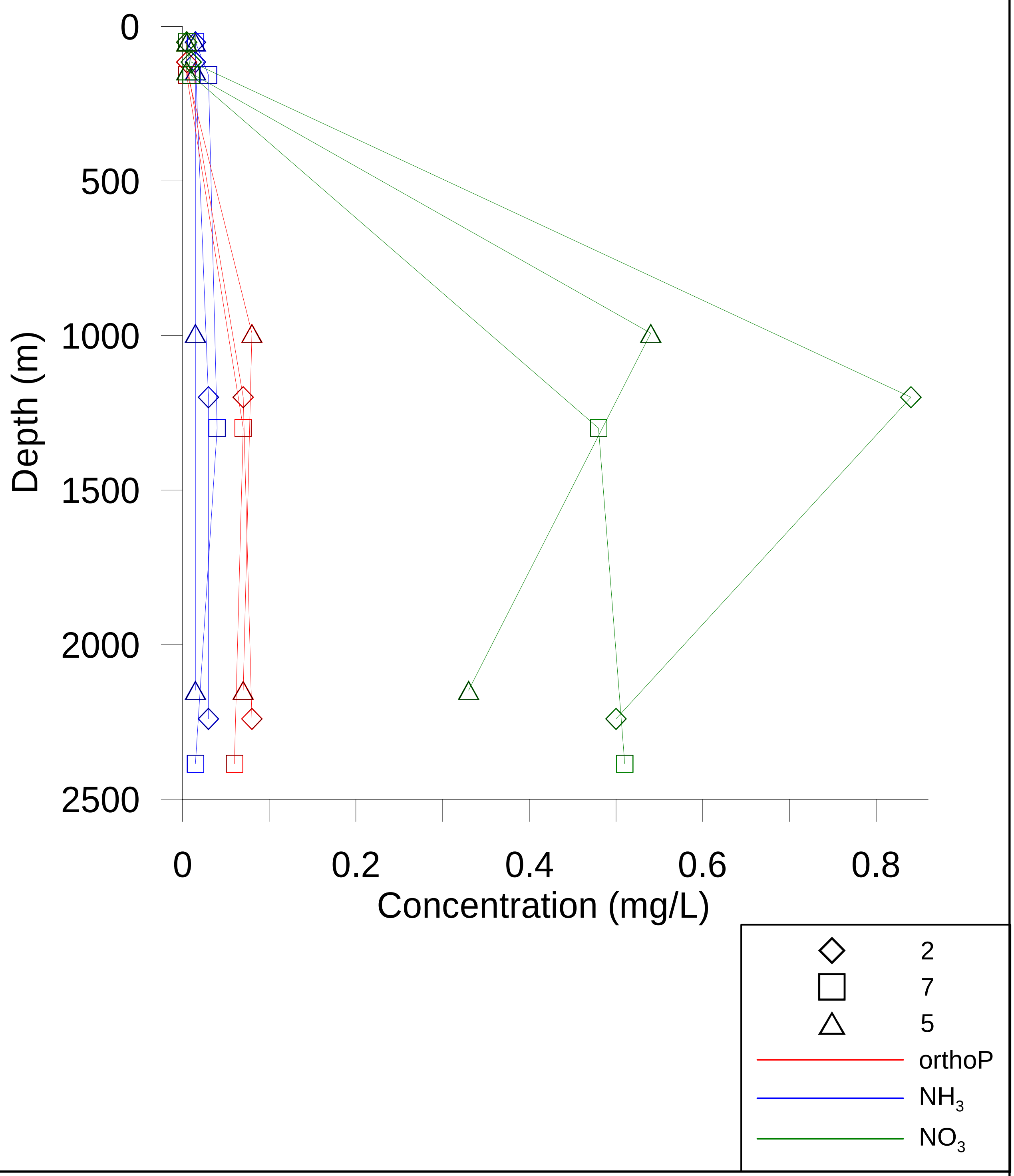


Figure 3-17.
Nutrient Concentrations with Depth in the North Study Area, Northwest Study Area and Proposed Reference Site

Source: Weston, 2008

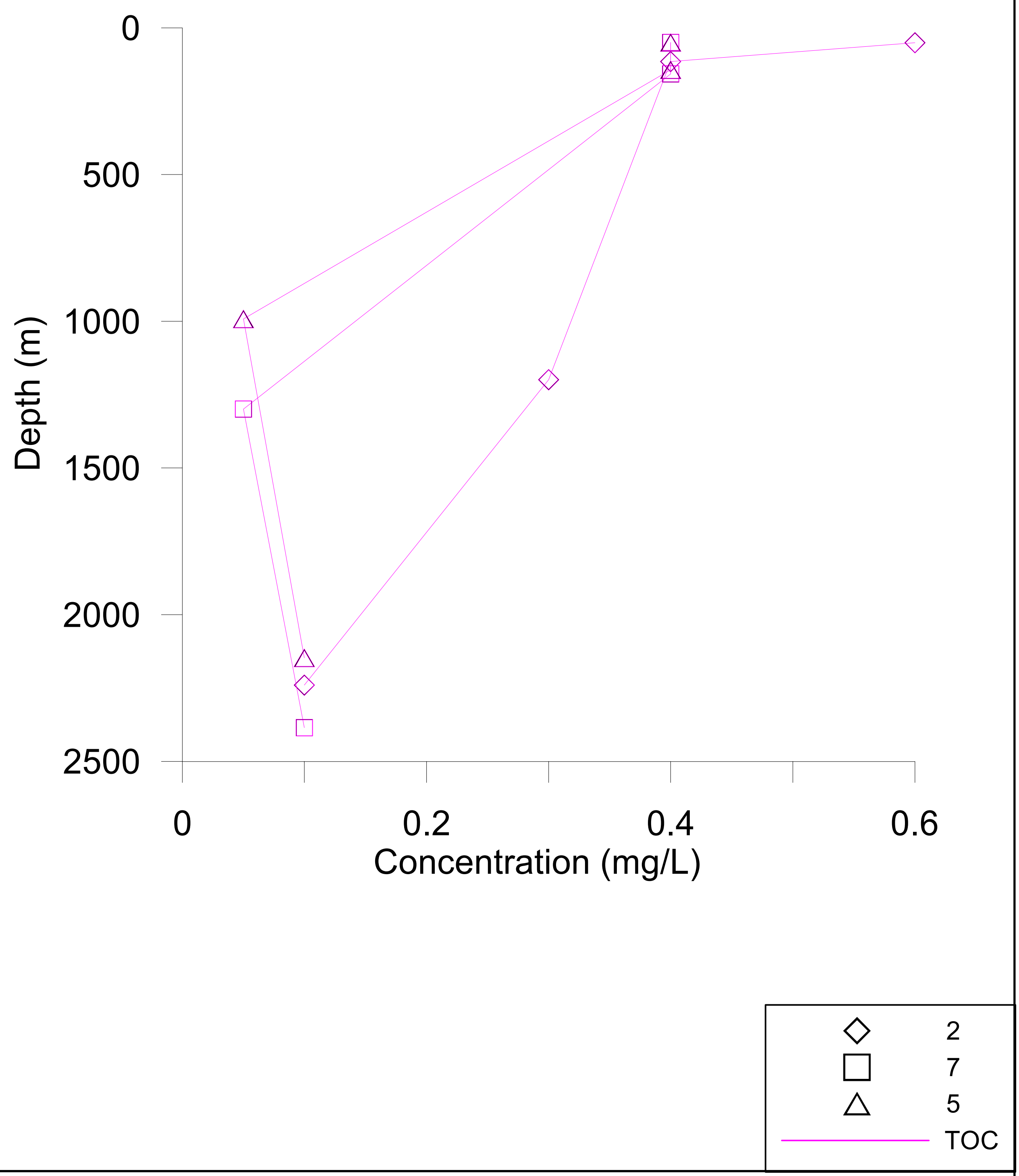


Figure 3-18.
Total Organic Carbon (TOC) Concentrations with Depth in the North Study Area, Northwest Study Area, and Proposed Reference Site

Source: Weston, 2008

Northwest Study Area

With the exception of nitrite which was not detected in any of the depth specific samples at Station 7, nutrients tended to have an increasing trend with depth, whereas TOC tended to have a decreasing trend with depth (see Figure 3-17 and Figure 3-18). Ammonia ranged from non-detectable levels at the surface to 0.04 mg/L in the mid-water column sample; ammonia was not detected in the near bottom sample (see Figure 3-17 and Figure 3-18). Dissolved orthophosphate concentrations ranged from non-detectable levels at the surface to 0.06 mg/L in the near bottom sample. Nitrate concentrations ranged from non-detectable levels in the surface sample to 0.51 mg/L in the near bottom sample. TOC concentrations ranged from 0.4 mg/L in the surface sample to an estimated value of 0.1 mg/L in the near bottom sample. The Dixon's Test for extreme values was utilized to determine the homogeneity of nutrient values throughout the water column. There were no significant differences in nutrient levels between samples collected at each of the four different water depths at Station 7 in the Northwest Study Area.

Inshore/Proposed Reference Site

At the proposed reference site, ammonia and nitrite were not detected in any of the depth specific samples. Contrary to the trends identified in nutrient levels at the North and Northwest Study Areas, dissolved orthophosphate, nitrate and TOC did not exhibit a trend with depth (see Figure 3-17 and Figure 3-18). Dissolved orthophosphate concentrations ranged from non-detect at the surface and mid-column water samples to 0.08 and 0.07 mg/L in the thermocline and near bottom samples, respectively. Nitrate concentrations ranged from non-detectable levels in the surface and mid-column water samples to 0.54 and 0.33 mg/L in the thermocline and near bottom samples, respectively. TOC concentrations ranged from 0.4 mg/L in the surface and mid-column water samples to non-detectable levels in the thermocline sample; TOC had an estimated concentration of 0.1 mg/L in the near bottom sample. The Dixon's Test for extreme values was utilized to determine the homogeneity of nutrient values throughout the water column. There were no significant differences in nutrient levels between samples collected at each of the four different water depths at Station 5, the proposed reference site.

3.1.4.2 Trace Metals

North Study Area

In the North Study Area, samples were collected from four distinct depths at Station 2. In the dissolved form, all trace metals were detected in the four samples with the exception of aluminum, beryllium, iron, mercury and tin (Table 14 of Weston Solutions and TEC 2008b). Throughout the water column, dissolved metals concentrations were consistent with other deep ocean reference samples (Brown et al. 1989a) and had the ranges listed in Table 3-10.

Table 3-10. Upper and Lower Trace Metal Concentration Values at the North Study Area

Trace Metal	Lower Value (µg/L)	Upper Value (µg/L)
Antimony	0.11	0.17
Arsenic	1.63	2.04
Cadmium	0.007 (estimated)	0.073
Chromium	0.179	0.273
Cobalt	0.114	0.258
Copper	0.25	2.09
Lead	0.005 (estimated)	0.03
Manganese	0.12	0.22
Molybdenum	5.79	6.45
Nickel	0.243	0.608
Selenium	Non-detectable levels	0.07
Silver	0.04	0.06
Thallium	0.008 (estimated)	0.01
Titanium	Non-detectable levels	0.063
Vanadium	1.93	2.23
Zinc	7.11	10.7

All of the dissolved metals concentrations were one to three orders below their respective Criterion Continuous Concentration (CCC) values. Figure 3-19 illustrates metals concentrations with depth for those analytes having corresponding CCC and Criterion Maximum Concentration (CMC) values.

Using the Dixon's Test for detecting extreme values, it was determined that all four depths had similar concentrations for each metal with the exception of manganese and zinc. The dissolved manganese concentration was slightly higher in the bottom sample compared to the other three depths and the dissolved zinc concentration was slightly lower in the sample collected from the thermocline than the other three depths. Although these outliers were identified, due to the relatively low concentrations of these metals in the water samples, the metals concentrations were averaged across depths for subsequent comparison between alternative study areas.

Northwest Study Area

In the Northwest Study Area, samples were collected from four distinct depths at Station 7. In the dissolved form, all trace metals were detected in the four samples with the exception of aluminum, beryllium, iron, mercury and tin (Table 14 of Weston Solutions and TEC 2008b).

Throughout the water column, dissolved metals concentrations were consistent with other deep ocean reference samples (Brown et al. 1989a) and had the ranges listed in Table 3-11.

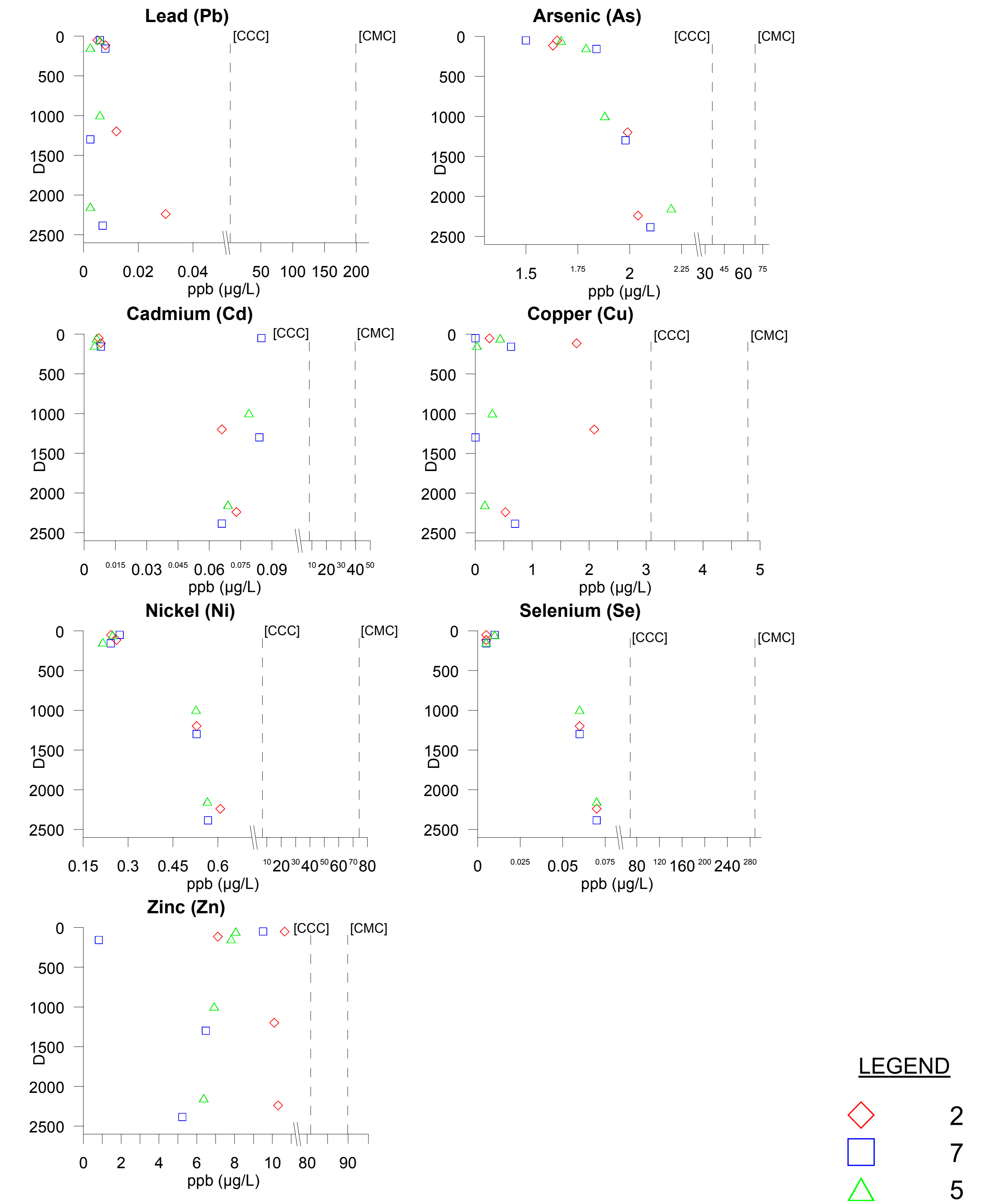


Figure 3-19.
Dissolved Metals Concentrations with Depth in the North Study Area, Northwest Study Area and Proposed Reference Site

Source: Weston, 2008

Table 3-11. Upper and Lower Trace Metal Concentration Values at the Northwest Study Area

Trace Metal	Lower Value (µg/L)	Upper Value (µg/L)
Antimony	0.13	0.15
Arsenic	1.50	2.10
Cadmium	0.008 (estimated)	0.085
Chromium	0.181	0.253
Cobalt	0.103	0.126
Copper	Non-detectable levels	0.70
Lead	Non-detectable levels	0.008 (estimated)
Manganese	0.11	0.28
Molybdenum	6.08	6.37
Nickel	0.242	0.567
Selenium	Non-detectable levels	0.07
Silver	0.03 (estimated)	0.04
Thallium	0.009 (estimated)	0.01
Titanium	Non-detectable levels	0.04
Vanadium	1.94	2.20
Zinc	0.819	9.51

All of the dissolved metals concentrations were one to three orders below their respective CCC values. Figure 3-19 illustrates metals concentrations with depth for those analytes having corresponding CCC and CMC values.

Using the Dixon's Test for detecting extreme values, it was determined that all four depths had similar concentrations for each metal with the exception of manganese and molybdenum. The dissolved manganese concentration was slightly higher in the bottom sample compared to the other three depths and the dissolved molybdenum concentration was slightly higher in the sample collected from the surface than the other three depths. Although these outliers were identified and due to the relatively low concentrations of these metals in the water samples, the metals concentrations were averaged across depths for subsequent comparison between study areas.

Inshore/Proposed Reference Site

At the proposed reference site, samples were collected from four distinct depths at Station 5. In the dissolved form, all trace metals were detected in the four samples with the exception of beryllium, iron, mercury and tin (Table 14 of Weston Solutions and TEC 2008b). Throughout the water column, dissolved metals concentrations were consistent with other deep ocean reference samples (Brown et al. 1989a) and had the ranges listed in Table 3-12.

Table 3-12. Upper and Lower Trace Metal Concentration Values at the Proposed Reference Site

Trace Metal	Lower Value (µg/L)	Upper Value (µg/L)
Aluminum	Non- detectable levels	3.3 (estimated)
Antimony	0.13	0.16
Arsenic	1.67	2.20
Cadmium	0.005 (estimated)	0.079
Chromium	0.175	0.263
Cobalt	0.089	0.101
Copper	0.03	0.44
Lead	Non-detectable levels	0.006 (estimated)
Manganese	0.08	0.16
Molybdenum	5.90	6.20
Nickel	0.216	0.565
Selenium	Non-detectable levels	0.07
Silver	0.03 (estimated)	0.04
Thallium	0.009 (estimated)	0.01
Titanium	Non-detectable levels	0.049
Vanadium	2.00	2.23
Zinc	6.37	8.06

All of the dissolved metals concentrations were one to three orders below their respective CCC values. Figure 3-19 illustrates metal concentrations with depth for those analytes having corresponding CCC and CMC values.

Using the Dixon's Test for detecting extreme values, it was determined that all four depths had similar concentrations for each metal; therefore, the metals concentrations were averaged across depths for subsequent comparison between study areas.

3.1.4.3 Polycyclic Aromatic Hydrocarbons (PAHs)

North Study Area

At Station 2 in the North Study Area, PAHs analyzed from water samples collected at four distinct depths were not detected with the exception of 1-methynaphthalene, 2-methylnaphthalene and naphthalene (Table 14 of Weston Solutions and TEC 2008b). The analyte 1-methynapthalene was estimated at a concentration of 1.5 ng/L in the surface sample (taken at 170 ft [51 m] depth) and 2-methylnapthalene was estimated at a concentration of 1.9 ng/L in the bottom sample (taken at 2,240 m depth). Napthalene was detected in all four water samples collected at Station 2, ranging in concentration from 5.6 to 10.8 ng/L, five orders of magnitude below the CMC for naphthalene. The presence of 1-methylnaphthalene, 2-methylnaphthalene and naphthalene in these samples may have been attributable to the proximity of the designated smoking area on board the *R/V Melville* to the deployment and retrieval area of the water samplers. Regardless, the concentrations observed in samples from Station 2 were well below CMC values and considered biologically insignificant. There were no significant differences in PAH concentrations between samples collected at each of the four different water depths at Station 2 in the North Study Area.

Northwest Study Area

At Station 7 in the Northwest Study Area, PAHs analyzed from water samples collected at four distinct depths were not detected with the exception of 2-methylnaphthalene, naphthalene and perylene (Table 14 of Weston Solutions and TEC 2008b). The analyte 2-methylnapthalene was estimated at a concentration of 1.3 ng/L in the sample collected at the top of the thermocline (taken at 515 ft [157 m] depth). Napthalene was detected in three water samples collected at Station 7, ranging in concentration from 5.1 to 14.4 ng/L, five orders of magnitude below the CMC for naphthalene; naphthalene was not detected in the bottom sample. Perylene was estimated at a concentration (3.6 ng/L) below the MRL (5 ng/L) in the sample collected at the top of the thermocline. Similar to the North Study Area samples cross-contamination of the sample may have caused the 2-methylnaphthalene and naphthalene detections. There were no significant differences in PAH concentrations between samples collected at each of the four different water depths at Station 7 in the Northwest Study Area.

Inshore/Proposed Reference Site

At Station 5, the proposed reference site, PAHs analyzed from water samples collected at four distinct depths were not detected with the exception of naphthalene and perylene (Table 14 of Weston Solutions and TEC 2008b). Napthalene was detected in all four water samples collected at Station 5, ranging in concentration from 4.5 ng/L in the surface sample to 8.5 ng/L in the mid-column and near bottom samples, six orders of magnitude below the CMC for naphthalene. Perylene was estimated at a concentration of 3.4 ng/L in the sample collected at the top of the thermocline. Similar to the North and Northwest Study Area samples cross-contamination of the sample may have caused the naphthalene detections. There were no significant differences in PAH concentrations between samples collected at each of the four different water depths at Station 5 at the proposed reference site.

3.1.4.4 Organochlorine Pesticides/PCBs

North Study Area

Concentrations of all chlorinated pesticides, including PCBs (both Aroclors and individual congeners), were not detected at each depth interval at each of the three stations in the North Study Area (Stations 1-3) (Table 14 of Weston Solutions and TEC 2008b). There were no significant differences in chlorinated pesticide concentrations between samples collected at each of the four different water depths at Station 2 in the North Study Area.

Northwest Study Area

Concentrations of all chlorinated pesticides, including PCBs (both Aroclors and individual congeners), were not detected at each depth interval at each of the three stations in the Northwest Study Area (Stations 6-8) with the exception of 4,4'-DDT (estimated at a concentration of 4.8 ng/L in the bottom water sample (7,825 ft [2,385 m] depth) collected at Station 7 (Table 14 of Weston Solutions and TEC 2008b). There were no significant differences in chlorinated pesticide concentrations between samples collected at each of the four different water depths at Station 7 in the Northwest Study Area.

Inshore/Proposed Reference Site

Concentrations of all chlorinated pesticides, including PCBs (both Aroclors and individual congeners), were not detected at each depth interval at each of the three stations inshore of the two alternative areas (Stations 4, 5 and 9) (Table 14 of Weston Solutions and TEC 2008b). There were no significant differences in chlorinated pesticide concentrations between samples collected at each of the four different water depths at Station 5 at the proposed reference site.

3.1.4.5 Regional Summary

The conventional and chemical characteristics of water collected from stations located in the North and Northwest Study Areas were similar. Overall, nutrients tended to increase in concentration with increasing water depth, whereas TOC tended to decrease in concentration with increasing water depth. Metals concentrations were relatively low compared to CCC and CMC values and were within the same order of magnitude of other deep ocean reference site water samples. Very few PAH or chlorinated pesticides were detected in any of the water samples.

As mentioned previously, a few metals were identified as outliers using the Dixon's Test for extreme values. However, due to the relatively low concentrations of these metals in the water samples, averages values were calculated for these metals concentrations at each station in order to compare results from the North and Northwest Study Areas to each other and to the proposed reference site. Figure 3-20 and Figure 3-21 show that the mean value for each analyte at a particular station falls within one standard deviation of the mean for that analyte at another station. Consequently, no significant differences were observed in water quality between the North and Northwest Study Areas as well.

3.1.5 Regional Geology

The ROI for regional geology is the general region of Guam, which includes the ODMDS study areas, the Island of Guam, and the offshore area between them. Guam is the largest and southernmost of the Mariana Islands, located at 13° 28' North latitude, 144° 45' East longitude in the western Pacific Ocean. The Marianas Islands are part of the Marianas Ridge, a complex island-arc system which is located west and on the concave side of the Mariana Trench (Figure 3-22). The Marianas Ridge was formed from the subduction of the oceanic Pacific Plate under the oceanic Philippine Plate. To the east, generally uniform underwater slopes descend from Guam at a rate of approximately 4° into the subduction zone area known as the Mariana Trench, located approximately 70 mi (113 km) away from Guam (Emery 1962) with depths greater than 36,000 ft (11,000 m). To the west, more complex underwater slopes descend rapidly from Guam at a rate up to 14° to approximately 6,000 ft (1,830 m) into two depressions, interpreted by Tracey et al. (1964) as collapse or graben-like features, and identified as the northwest and southwest collapse areas. These depressions are bounded by normal faults with two seamounts, likely underwater volcanoes, occurring to their west, approximately 15 nm (28 km) from the island of Guam. Further west, water depths increase to over 12,000 ft (3,600 m) in the East Mariana Basin of the Philippine Sea (Emery 1962; Tracey et al. 1964).

The island of Guam was formed through a combination of geologic processes; two volcanoes (identified in Tracey et al. [1964] as the Eocene and Miocene volcanoes) to the west of present day Guam collapsed and the related faulting with this event resulted in uplift of submerged areas, eventually creating the island of Guam. Today, the island is characterized by two distinct terrain features, a limestone plateau in the northern half and volcanic uplands in the southern half. The northern plateau, bounded by steep cliffs, is approximately 600 ft (183 m) in elevation in the north and gently slopes to approximately 200 ft (60 m) in the central portion of Guam. The southern uplands are distinguished by a ridge of mountains trending parallel to the long axis of the island with elevations above 1,000 ft (305 m) and a maximum of 1,334 ft (406 m) at Mount Lamlam. An interior basin area characterized by rolling lowlands and karst occurs in the south central portion of Guam. Coastal lowland features are predominant along the coast in the southern half and sporadic in the north. Fringing reefs occur around the majority of the island. Guam is approximately 30 mi (48.3 km) in length, trending northeast-southwest in the northern half and trending north-south in the southern half. Guam ranges from 4 to 11 mi (6.4 to 17.7 km) wide and has a total land area of approximately 212 sq. mi (549 square km) (Tracey et al. 1964).

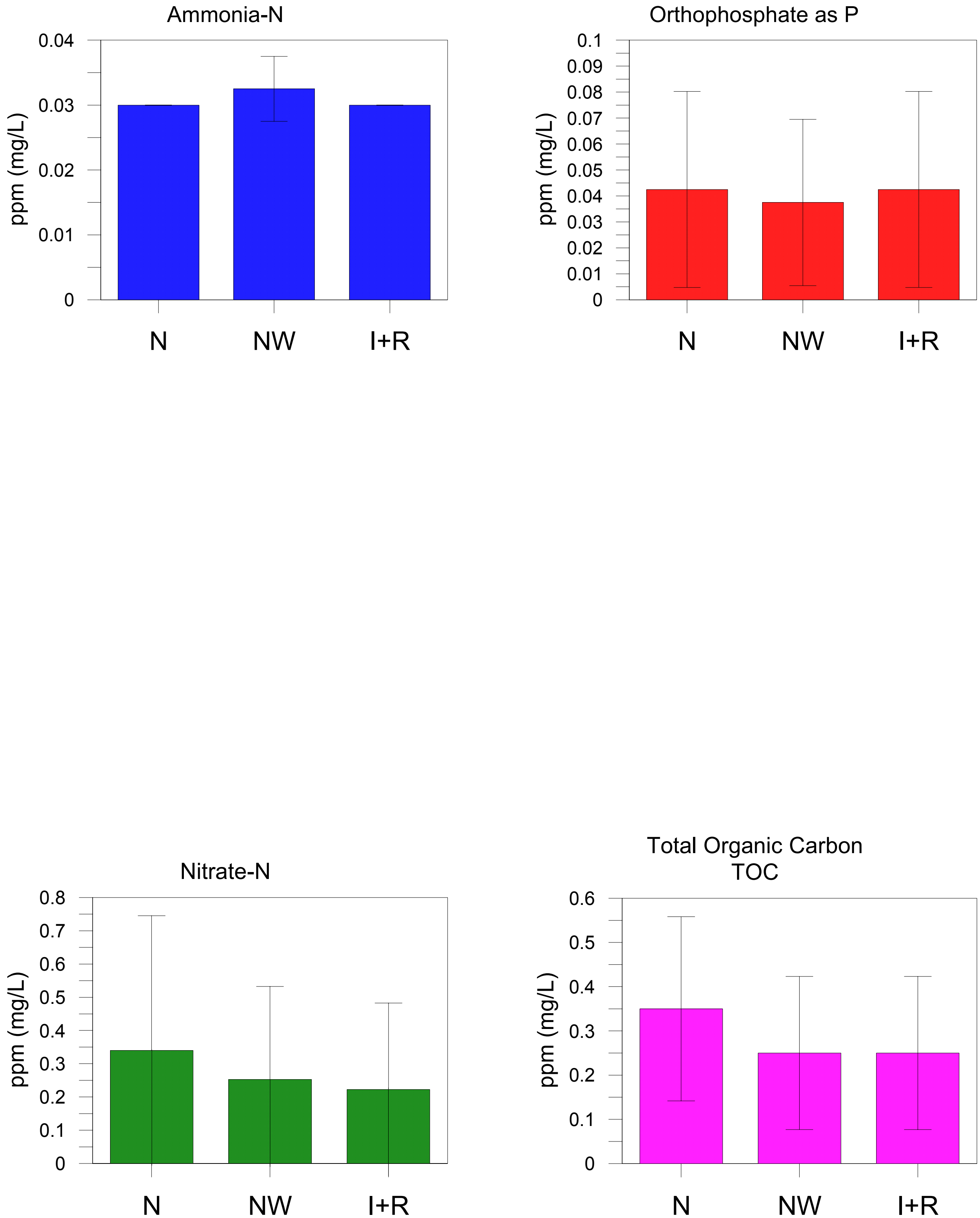


Figure 3-20. Mean and Standard Deviation of Selected Conventional Chemistry Constituents of Water Samples Collected Offshore of Guam, Showing Comparison of Study Areas (N and NW) to Each Other and Proposed Reference (I+R)

Source: Weston, 2008

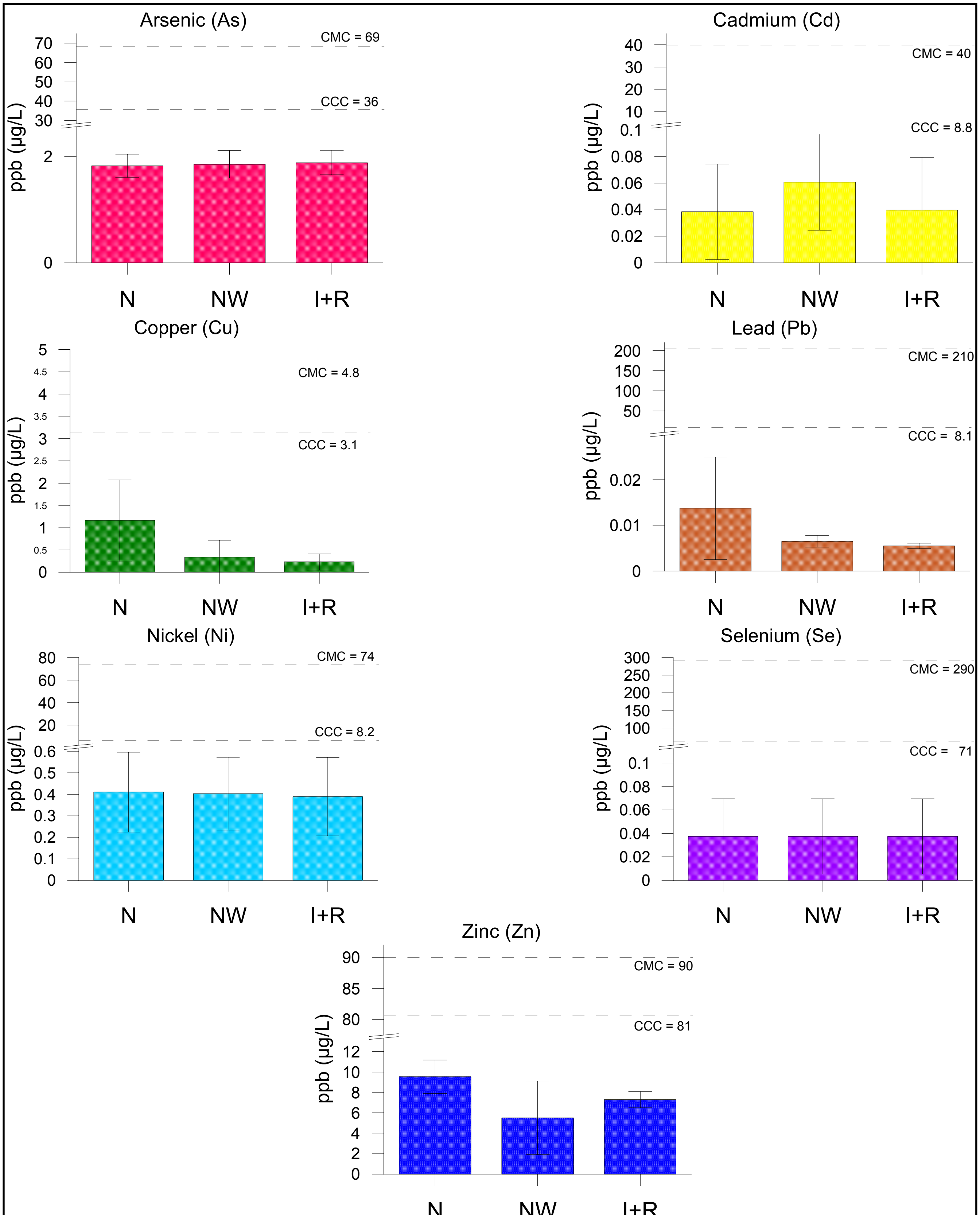


Figure 3-21.

Source: Weston, 2008

Mean and Standard Deviation of Selected Metals Showing Comparison of Study Areas (N and NW) to Each Other, Proposed Reference (I+R) and CMC and CCC Values

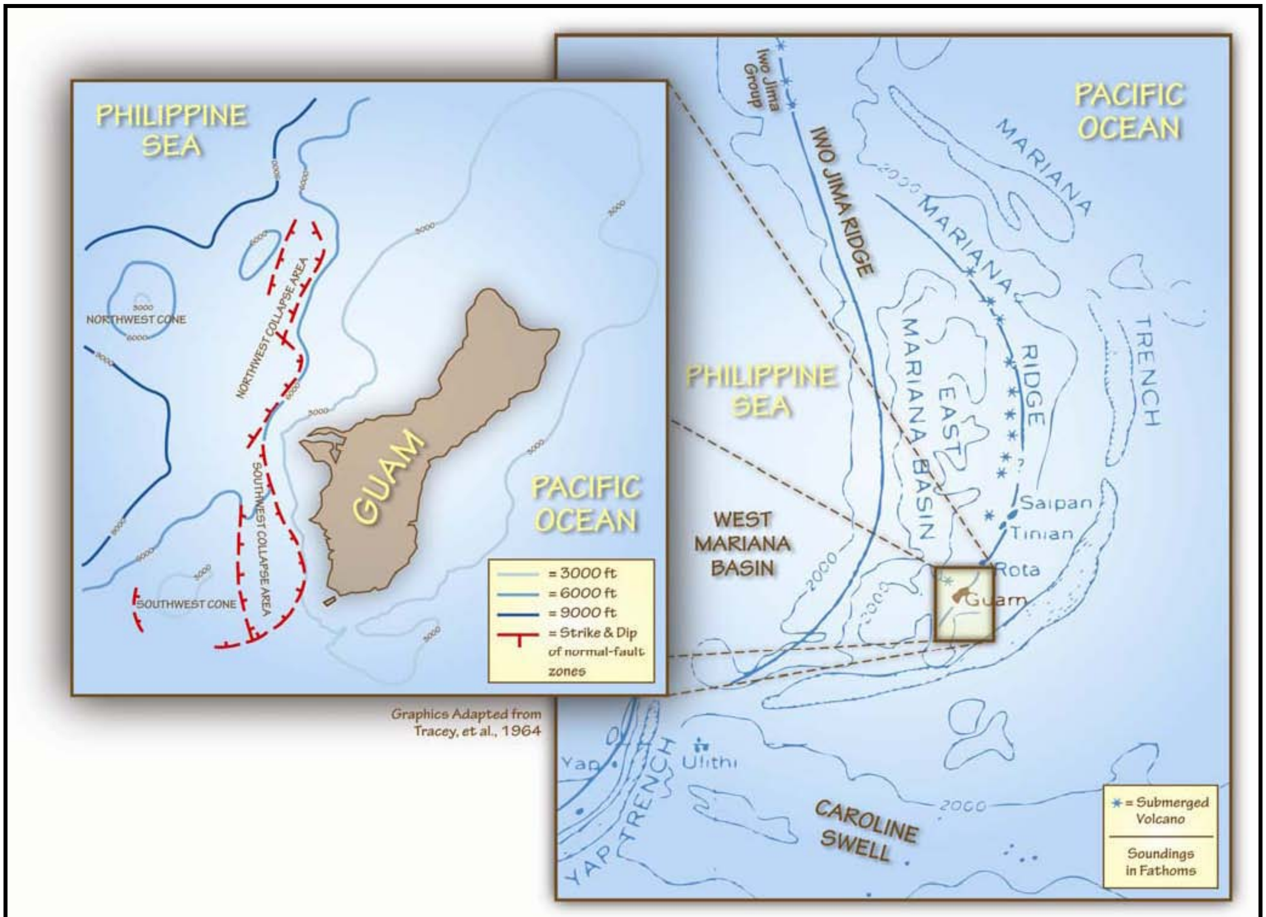


Figure 3-22.
Marine Geology Offshore of Guam and Surrounding Vicinity

Several underwater terraces have been observed around Guam and adjacent underwater banks such as Santa Rosa Reef and Galvez Bank. These terraces occur in relatively shallow water, with mean depths of 55 ft (17 m), 105 ft (32 m), 195 ft (59 m) and 315 ft (96 m). These terraces may likely be indicative of historical sea levels (Emery 1962).

3.1.5.1 Proximity to Continental Shelf

The island of Guam is volcanic and not part of a continental land mass, and therefore does not have a continental shelf. In the absence of a shelf break, continental shelf can be defined as submerged land between shoreline and a depth of 656 ft (200 m). On Guam, this typically occurs within 1 nm (1.9 km) of shore. The slope tends to increase rapidly offshore of Guam and depths can reach 6,000 ft (1.829 km) within 3 nm (5.6 km) (Weston Solutions and Belt Collins 2006). The study areas that contain both ODMDS alternative sites are well beyond the continental shelf, with the closest center point being 11.1 nm (20.6 km) from the shoreline.

3.1.5.2 Study Region Bathymetry

The Guam ODMDS study region is located northwest of the island of Guam, approximately 5 nm (9.2 km) to 15 nm (28 km) offshore. During the 2008 Site Characterization Survey, a bathymetric survey of the region and surrounding area was conducted using by multibeam hydrographic survey system. Figures 3-23 through 3-25 show the results of this survey. Water depths increase rapidly offshore of Orote Point, Guam, to 6,550 ft (2,000 m). Several underwater canyons are apparent in the slope. The center of the study region is bisected by a broad shelf extending west from the base of the slope at depths of approximately 7,220 ft (2,200 m). South and southwest of this shelf, water depths continue to increase to 12,470 ft (3,800 m) into the East Mariana Basin. To the west, the shelf connects with Perez Bank, a large conical seamount (identified in Figure 3-22 as the Northwest Cone), which rises to depths of only 2,625 ft (800 m). A ridge extends from the northeast to the shelf, separating the northern half of the study region into two sections. The eastern section consists of a depression between the island slope to the east, the shelf-like feature to the south and ridge to the west. The western section consists of increasing water depths to 11,150 ft (3,400 m) into the East Mariana Basin.

Seamounts are large bathymetric features on the seafloor, which can interact with oceanic currents and create variability in the physical flow field. Seamount effects, which can include internal wave generation, eddy formation, local upwelling and closed circulation patterns have the potential to impact pelagic and benthic ecosystems over seamounts (Boehlert and Genin 1987). However, not all seamounts generate the same effects, due to different shapes, sizes, summit depths, and distance from other bathymetric features (Porteiro and Sutton 2007). Shallow seamounts reach into the euphotic zone, intermediate seamounts have summits below the euphotic zone but within approximately 1,315 ft (400 m) of the sea surface, and deep seamounts have peaks below approximately 1,315 ft (400 m) depth (Genin 2004). The conical Tracey Seamount (e.g., Perez Bank) west of Guam, is considered a deep seamount, which rises from bottom depths of approximately 9,840 ft (3000 m) up to a summit at approximately 2,625 ft (800 m) below the sea surface. The euphotic zone, or surface water shallow enough to receive sufficient light to support photosynthesis, extends to a depth of approximately 495 ft (150 m) in tropical waters (Lalli and Parsons 1993), well above the summit of Perez Bank. Figure 3-26 shows the plan and profile views of both study areas, their distance from Guam and local seamounts, and the relationship to ocean depth at the seafloor disposal boundary.

North Study Area

The North Study Area, as determined through the ZSF process, is trapezoidal in shape and is predominantly located across a depression, identified in the previous section as the northwest collapse area of an ancient volcano (Figure 3-24). This depression is bounded by increasing slopes on all sides except to the north. The eastern portion of the North Study Area is located over slopes declining towards the northwest at 9°. The easternmost boundary is located in approximately 5,900 ft (1,800 m). A narrow canyon bisects this slope. The central and western portion of this area is located over a relatively flat region, with a <1° slope slightly declining towards the north. A ridge of seamounts bounds the extreme western portion of this region, with depths rising to approximately 6,550 ft (2,000 m) in the southwest and 5,575 ft (1,700 m) in the northwest corner. To the north of the North Study Area, a canyon trending towards the northwest bisects the ridge of seamounts including Spoon Bank, extending to depths of 11,150 ft (3,400 m).

Northwest Study Area

The Northwest Study Area, as determined through the ZSF process, is triangular in shape and is predominantly located across the southeastern flank of Perez Bank, a conical seamount approximately 15 nm (28 km) northwest of Apra Harbor, Guam (Figure 3-25). The northwest extent of this alternative area arcs across the tip of the seamount at only 2,625 ft (800 m) depth. The bathymetry slopes down off the seamount at approximately 7° to depths of approximately 8,200 ft (2,500 m) in the eastern portion of this area and 8,860 ft (2,700 m) in the southern portion.

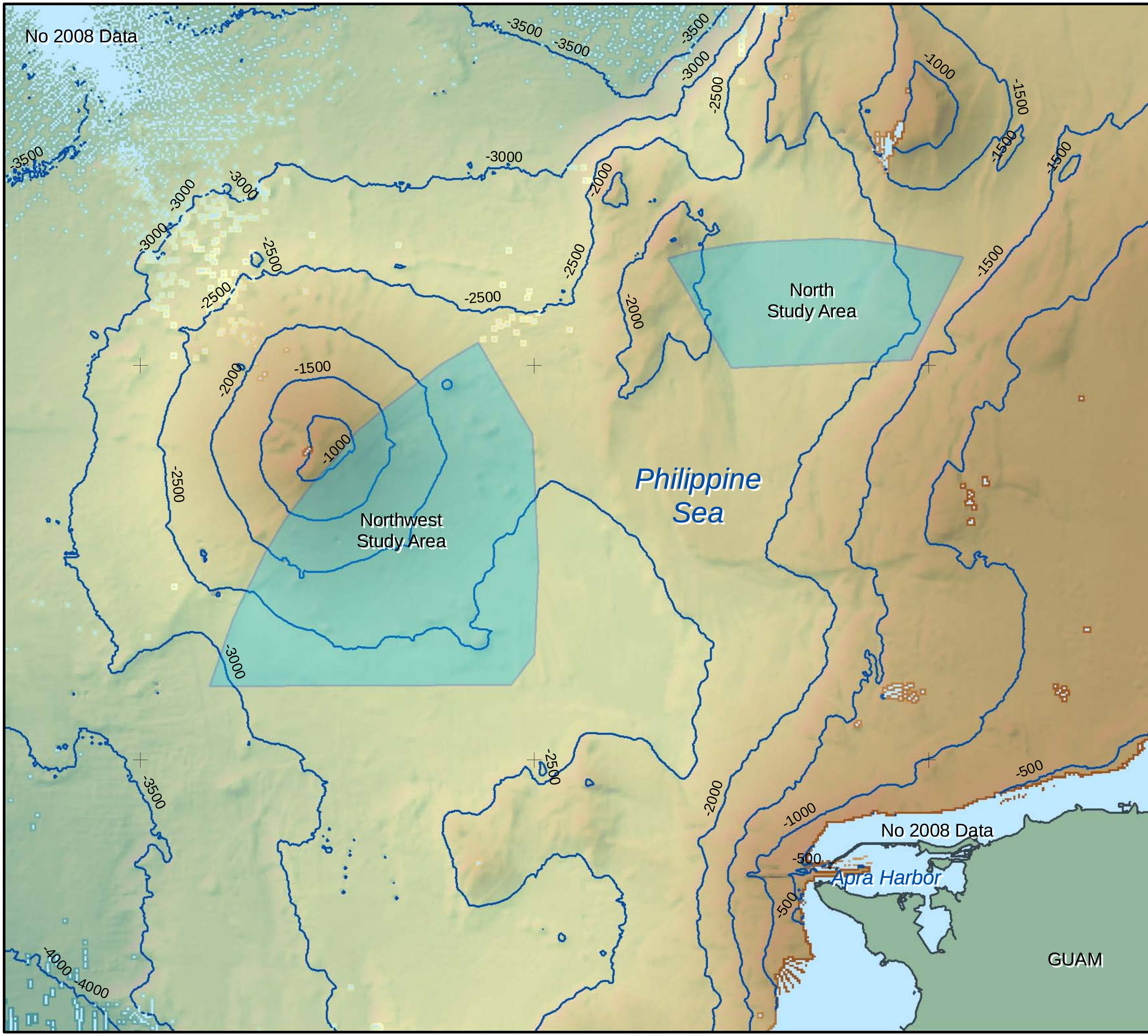
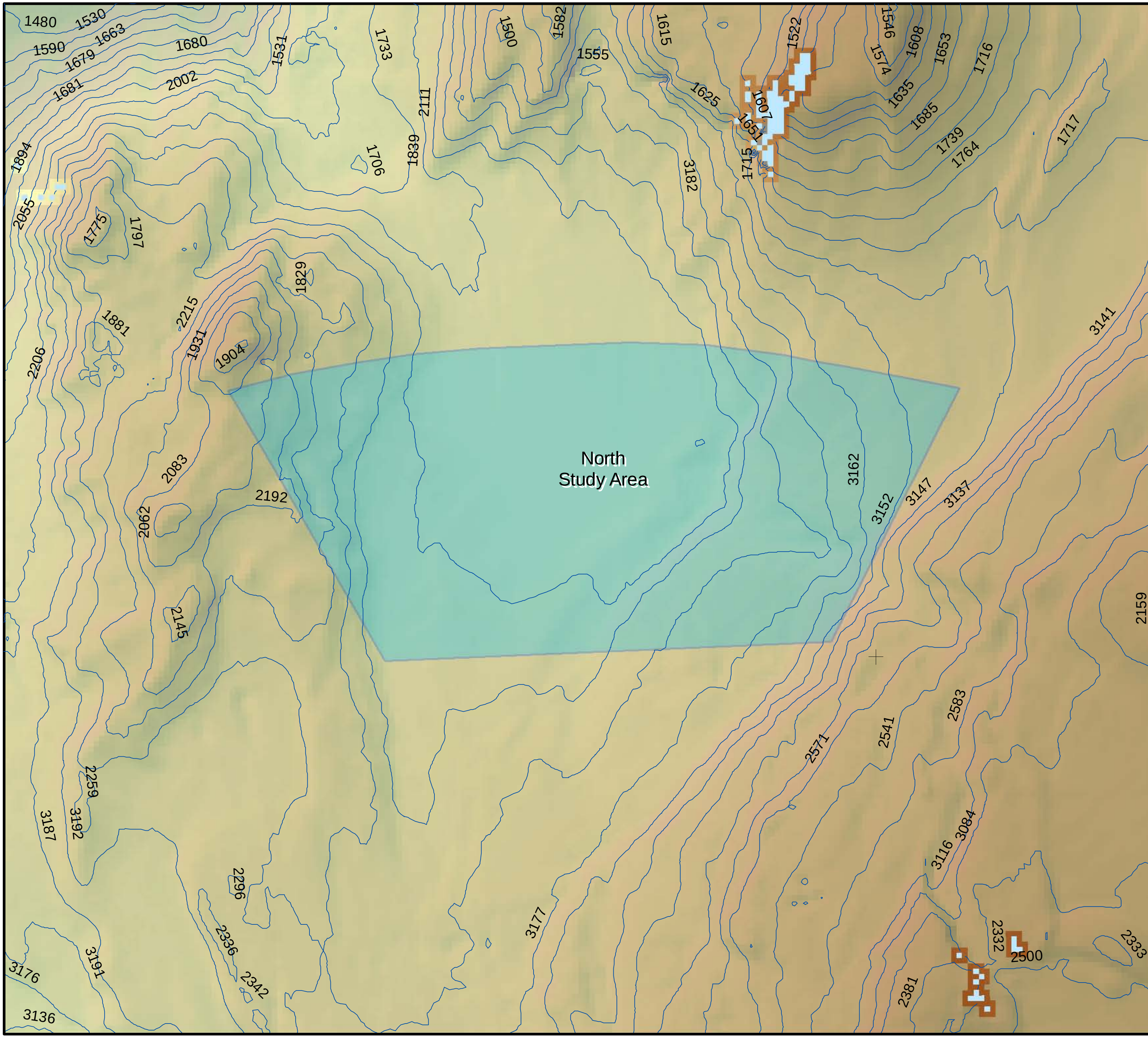


Figure 3-23
Regional Bathymetry

Figure 3-24
North Study Area Bathymetry



Legend

Zone of Siting Feasibility Available Area

2008 Bathymetry Data Depth (m)

Contours (100 m)

High : -34

Low : -4045

N

Nautical Miles
0 0.5 1

0 0.5 1 2
Kilometers

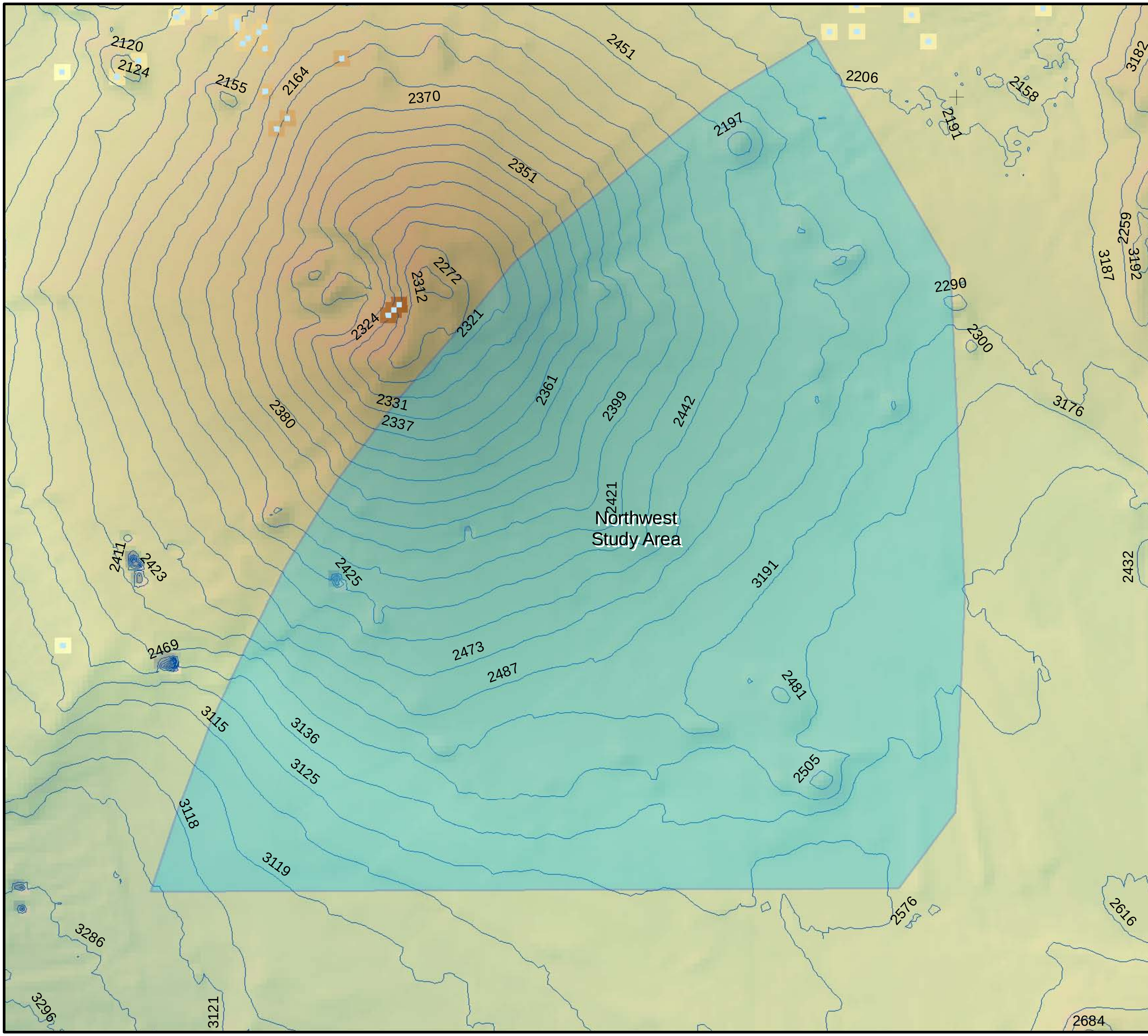


Figure 3-25
Northwest Study Area Bathymetry

Legend

Zone of Siting Feasibility Available Area

2008 Bathymetry Data Depth (m)

Contours (100 m)

High : -34

Low : -4045

Nautical Miles
0 0.5 1

0 0.5 1 2
Kilometers

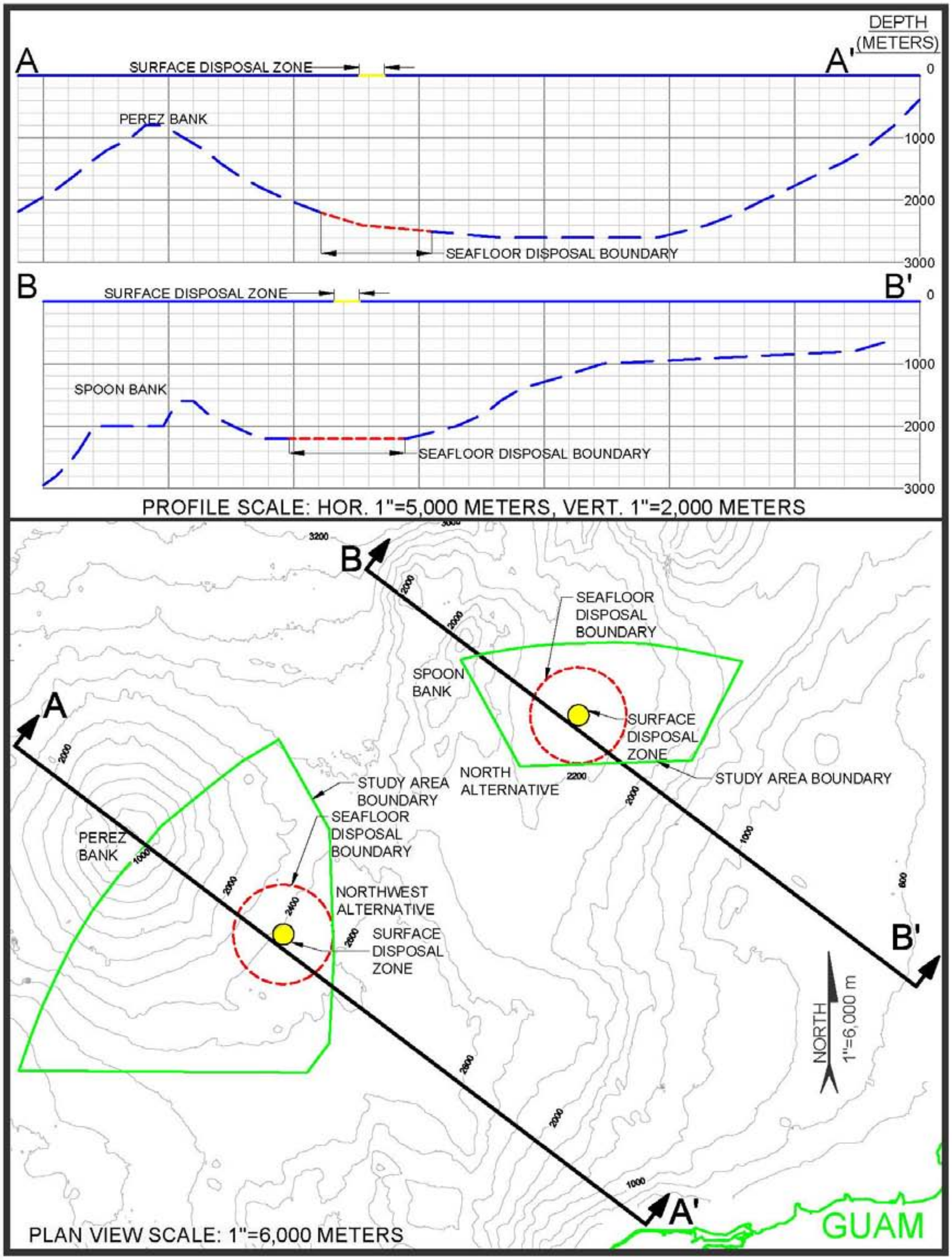


Figure 3-26.
Plan and Profile Views of Upper Water Column Sediment Dispersion in the North and Northwest Study Areas During La Niña Conditions