

Areas of Special Biological Significance

BIGHT'08



Southern California Bight
2008 Regional Monitoring
Program
Vol. II

Southern California Bight 2008 Regional Monitoring Program: II. Areas of Special Biological Significance

February 2011

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FOREWORD

The Southern California Bight 2008 Regional Monitoring Program (Bight'08) is part of an effort to provide an integrated assessment of environmental condition through cooperative regional-scale monitoring. The Bight'08 program is a continuation of regional surveys conducted in 1994, 1998 and 2003, and represents the joint efforts of more than 90 participating organizations. The Bight'08 program consists of several elements including: Sediment Toxicity, Sediment Chemistry, Areas of Special Biological Significance (ASBS), Demersal Fishes and Megabenthic Invertebrates, Benthic Macrofauna, Offshore Water Quality, Rocky Reefs, Shoreline Microbiology, and Bioaccumulation. Bight'08 workplans, quality assurance plans, as well as the data described in this report and assessment reports for other elements are available at www.sccwrp.org.

The proper citation for this report is: Schiff, K.C., B. Luk, D. Gregorio and S. Gruber. 2011. Southern California Bight 2008 Regional Monitoring Program: II. Areas of Special Biological Significance. Southern California Coastal Water Research Project. Costa Mesa, CA.

ACKNOWLEDGEMENTS

This project was only possible with the collaboration of the ASBS Planning Committee of Southern California Bight Regional Marine Monitoring Program. Sampling was performed by ABC Laboratories, AMEC Environmental, Mactech Environmental, and Weston Solutions. Laboratory analysis was performed by ABC Laboratories, CRG Marine Laboratories, Nautilus Environmental, and Weston Solutions. Partial funding was provided by the State of California Water Resources Control Board Surface Water Ambient Monitoring Program.

EXECUTIVE SUMMARY

Over 280 km of shoreline have been designated as marine water quality protected areas, termed Areas of Special Biological Significance (ASBS), in southern California, USA. While the standard for water quality protection in an ASBS is “natural water quality”, there are at least 271 documented coastal discharges that potentially threaten this important ecological resource. The goal of this study was to assess the water quality status of ASBS by answering two questions: 1) What is the range of natural water quality near reference drainage locations? and 2) How does water quality near ASBS discharges compare to the natural water quality near reference drainage locations? The sample design focused exclusively on receiving water (not effluents) and wet weather, which are the locations and times where natural and anthropogenic contributions can mix making pollutants difficult to identify and control. Sixteen locations encompassing 35 site-events were sampled immediately prior to (<48 hours), then immediately following (<24 hours) storm events ranging from 0.1 to 9.8 cm rainfall. Geometric mean concentrations of total suspended solids (TSS), nutrients (ammonia, nitrate, nitrite, total nitrogen, total phosphorus), total and dissolved trace metals (arsenic, cadmium, chromium, copper, nickel, lead, silver, and zinc), and polycyclic aromatic hydrocarbons (PAH) from post-storm samples were similar at reference drainage and ASBS discharge sites. The average concentration difference between post-storm geometric mean concentrations at reference drainage vs. ASBS discharge sites across all parameters (except chlorinated hydrocarbons) was 3%. Concentrations of chlorinated hydrocarbons were almost entirely nondetectable and no post-storm sample exhibited significant toxicity to the purple sea urchin *Strongylocentrotus purpuratus*. In addition, there was no consistent increase from pre- to post-storm concentrations at either reference drainage or ASBS discharge locations. Most post-storm concentrations did not correlate well with storm parameters (i.e., rainfall quantity, antecedent dry period) or stormwater tracers (i.e., salinity, dissolved organic carbon), decreasing the utility of these tools for predicting impacts. A reference based threshold was used as a proxy for distinguishing differences from natural water quality. The reference based threshold included a two-step process: 1) was the individual chemical post-storm discharge concentration greater than the 85th percentile of the reference drainage site post-storm concentrations; and then 2) was the individual post-storm discharge concentration greater than the pre-storm concentration for the same storm event. While the concentrations near ASBS discharges were on average similar to reference site concentrations, there were some individual ASBS discharge sites that were greater than the reference site based threshold. Cumulatively across all ASBS, the constituents that were most frequently greater than the reference site based threshold were nutrients and general constituents, followed by dissolved or total trace metals.

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I. INTRODUCTION

Coastal municipalities and other agencies subjected to nearshore water quality regulation face a difficult task. The public demands equal access to the shoreline and, at the same time, mandates protection of water quality to maintain the integrity of marine ecosystems. Public access, especially in highly populated urban centers is almost always to the detriment of coastal marine life. This is routinely observed in terms of habitat loss (Boesch *et al.* 2001), harvesting of seafood and other marine resources (Cohen 1997), and the introduction of pollutants (Daskalakis and O'Connor 1995, Schiff *et al.* 2000). Almost by definition, natural water quality is in the absence of coastal development and public access (Halpern *et al.* 2008).

Southern California epitomizes this conundrum. Approximately 17.5 million people live within an hour's automobile drive to the beach and is home to the sprawling urban centers of Los Angeles and San Diego, two of the nation's eight largest cities (US Census Bureau 2009). Over 1.5 billion gallons of treated wastewater are discharged to the ocean every day (Lyon and Stein 2009). In a typical rainy season, over double this volume is discharged via surface runoff (Ackerman and Schiff 2003). Surface runoff following storm events will carry the accumulated anthropogenic pollutants from urban activities such as residential application of fertilizers and pesticides (Schiff and Sutula 2004), trace metals from brake and tire wear (Davis *et al.* 2001), and atmospheric fallout from mobile and non-mobile sources (Sabin *et al.* 2006). Exacerbating these potential threats to the environment, sanitary and stormwater systems are separate in southern California. Therefore, stormwater runoff receives virtually no treatment prior to entering the ocean (Lyon and Stein 2009).

The dilemma between water quality protection and urbanization reaches a climax in southern California at areas of special biological significance (ASBS). The ASBS are marine water quality protected areas whose standard is "no discharge of waste" and maintenance of "natural water quality" (SWRCB 2005). Over 2800 km of shoreline in southern California are designated as ASBS. While state regulatory agencies have been effective at minimizing point source discharges, there are at least 271 storm drain outfalls (SCCWRP 2003). These storm drains can discharge urban runoff, but also natural runoff from undeveloped portions of their respective watersheds. Nutrients, trace metals, and some organic constituents found in urban runoff are also natural components of the ecosystem (Yoon and Stein 2008). The dichotomy between natural versus anthropogenic inputs ultimately clashes because the state regulatory structure does not numerically define natural water quality.

In order to address the dilemma between water quality protected areas and development in the coastal zone, the goal of this study was to assess the water quality in southern California ASBS. Specifically, the study was designed to answer two questions: 1) what is the range of natural water quality near reference drainage locations? and 2) how does water quality near ASBS discharges compare to the natural water quality at reference drainage locations? These two questions address the primary lack of information faced by both ASBS dischargers and regulators that stymies management actions, if they are necessary. The first question aims to quantify what is meant by "natural water quality" by visiting locations presumptively free of anthropogenic contributions. The second question compares the natural water quality levels derived from the first question to water quality near ASBS discharges to determine the level of existing water quality protection.

II. METHODS

There are 34 ASBS in California, 14 of which occur in southern California (Figure 1). The majority (78%) of ASBS shoreline in southern California surrounds the offshore Channel Islands, but a significant fraction (35 km) occur along the six mainland ASBS.

This study had two primary design elements. The first design element was a focus on receiving water. All samples were collected in receiving waters near reference drainage or ASBS discharges; no effluent discharge samples were collected as part of this study. The second design element was a focus on wet weather. Dry weather was not addressed in this study.

Sampling

Sixteen sites were selected for wet weather sampling in this study (Table 1). Six of the sampling locations were reference drainage sites (representing natural water quality) and 10 were ASBS discharge sites. Reference site selection followed five criteria: 1) the site must be an open beach with breaking waves (i.e., no embayments); 2) the beach must have drainage from a watershed that produces flowing surface waters during storm events; 3) the reference watershed should be similar in size to the watersheds that discharge to ASBS; 4) the watershed must be comprised of primarily (>90%) open space; and 5) neither the shoreline nor any segment within the contributing watershed can be on the State's 2006 list of impaired waterbodies (e.g., §303d list). All but one of the reference drainage sites was located within an ASBS.

A total of 35 site-events were sampled (Table 1). Twelve site-events were sampled near reference drainage locations, and another 23 site-events were sampled near ASBS discharge locations. Up to three storm events were sampled per site. A storm was defined as any wet weather event that resulted in surface flow across the beach into the ocean receiving water. Rainfall during sampled events ranged from 0.1 to 9.8 cm. Pre-storm samples were collected prior to (<48 hours) rainfall, and post-storm samples were collected immediately following (<24 hours) rainfall, with most post-storm samples collected less than 6 hours after rainfall cessation. Approximately 89% of all post-storm samples also had a pre-storm sample collected. Samples were collected in the ocean at the initial mixing location in the receiving water. Both pre- and post-storm samples were collected by direct filling of pre-cleaned sample containers just below the water surface.

Laboratory Analysis

All water samples were analyzed for 93 parameters: 1) general constituents including total suspended solids (TSS), dissolved organic carbon (DOC), and salinity; 2) nutrients including nitrate (NO₃-N), nitrite (NO₂-N), ammonia (NH₃-N), total nitrogen (TN), total phosphorus (TP), and ortho-phosphate (PO₄-P); 3) dissolved and total trace metals (arsenic, cadmium, chromium, copper, nickel, lead, silver, zinc); 4) chlorinated hydrocarbons including total PCB (sum of congeners 18, 28, 37, 44, 49, 52, 66, 70, 74, 77, 81, 87, 99, 101, 105, 110, 114, 118, 119, 123, 126, 128, 138, 149, 151, 153, 156, 157, 158, 167, 168, 169, 170, 177, 180, 183, 187, 189, 194, 201, 206) and total DDT (sum of o,p'- and p,p'-DDT, DDE, and DDD); 5) total polycyclic aromatic hydrocarbons (28 PAHs); and 5) short-term chronic toxicity. All sample analysis followed standard methods and/or EPA approved procedures (APHA 2006). Trace metals were prepared for analysis using ammonium pyrrolidine dithiocarbamate (APDC), a chelation method that concentrates trace metals and removes matrix interferences (USEPA 1996). Toxicity of the receiving water was evaluated by performing an egg fertilization test using the endemic purple sea urchin *Strongylocentrotus purpuratus* (USEPA 1995).

The project focused on performance-based measures of quality assurance. In general, laboratory data quality was quite good: no laboratory blank samples greater than the method detection limit; 96% success meeting data quality objectives (DQOs) for precision using laboratory duplicates; 91% success meeting DQOs for accuracy using spiked samples. The lowest accuracy success rate was for cadmium (12 of 15 batches) and zinc (8 of 16 batches) where the requirement of 75 to 125% recovery from seawater was not met. This was due, in part, to the APDC chelation method that has lower affinities for extracting cadmium and zinc.

Data Analysis

Data analysis followed four steps. The first step was determining the validity of reference drainage site selection. This was achieved by examining the data for known anthropogenic contamination (i.e., chlorinated hydrocarbons such as DDTs and PCBs), testing for outlier samples in the reference drainage data set, and the presence of toxicity. The second data analysis step compared the average concentration of post-storm ambient concentrations at reference drainage sites to ASBS discharge sites. Differences between these concentrations were evaluated using a studentized T-test. The third data analysis step examined potential relationships among parameters looking for explanatory variables that derive differences both within reference drainage sites and between reference drainage and ASBS discharge sites. Rainfall quantity, antecedent dry period, TSS and DOC concentrations were correlated with all of the post-storm chemical concentrations and with the relative change in concentration between pre- and post-storm concentrations after log-transformation for data normalization. For the final data analysis, a reference based threshold was used as a proxy for distinguishing differences from natural water quality. The reference based threshold included a two-step process: 1) was the individual chemical post-storm discharge concentration greater than the 85th percentile of the reference drainage site post-storm concentrations; and then 2) was the individual post-storm discharge concentration greater than the pre-storm concentration for the same storm event. For ASBS discharge sites that did not have a matching pre-storm concentration, the pre-storm concentration from the previous storm at that site for which data was available was used.

III. RESULTS

Post-storm reference drainage site concentrations were similar to post-storm ASBS discharge site concentrations (Figure 2). For 13 parameters (including TSS, nutrients, total PAH and total trace metals), none were significantly different between reference drainage and discharge sites following storm events ($p < 0.05$). Of the minor differences between reference drainage and ASBS discharge site results, post-storm geometric mean concentrations were greater for nine of 13 constituents at reference drainage sites. No detectable concentrations of total DDT or total PCB were observed at reference drainage sites. However, detectable quantities of chlorinated hydrocarbons (p,p'-DDE), while extremely rare, did occur at certain ASBS discharge sites. The average difference between geometric mean concentrations at reference drainage vs. ASBS discharge sites across all parameters (except chlorinated hydrocarbons) was 3%; no parameter differed by more than a factor of 70%.

In general, there was no consistent increase or decrease in concentrations pre- to post-storm at reference drainage or ASBS discharge sites (Figure 3). Pre:Post-storm concentration ratios were not significantly different between reference drainage and ASBS discharge sites for any of the trace metals. Nearly every trace metal, whether from reference drainage or ASBS discharge sites, encompassed unity within its interquartile distribution indicating that pre- and post-storm concentrations were similar. The only exception was copper that, despite having similar reference drainage and discharge site concentrations, had roughly 75% of their respective distributions greater than unity. This would indicate that receiving water concentrations of copper increased following storm events.

Most relationships of discharge post-storm concentrations with storm characteristics were poor (Table 2). Correlation coefficients with storm size ranged from -0.2 to 0.25 across all constituents, none of which were significant. Correlation coefficients with antecedent dry days were marginally better, ranging from -0.45 to 0.34 across all constituents; only salinity and total P were statistically significant. Other potential explanatory variables such as salinity, TSS, or DOC concentrations provided limited insight. Salinity was negatively correlated with most of the total trace metals; cadmium, chromium, and copper were statistically significant. In contrast, TSS was positively correlated with most of the total trace metals; arsenic, chromium, lead and nickel were statistically significant. Despite the statistically significant correlation for a subset of metals for both salinity and TSS, no correlation explained more than 45% of the variability in parameter concentrations observed in ASBS receiving waters. In fact, roughly one-third of the parameters had correlation coefficients less than 0.30.

Differences from natural water quality were relatively infrequent at ASBS discharge sites (Table 3, Figure 4). ASBS 25 (Northwest Santa Catalina Island) had the greatest proportion of analyses that were greater than reference site based thresholds (35% of all analyses). ASBS 29 (La Jolla) had the smallest proportion of analyses that were greater than reference site based thresholds (5% of all analyses). Cumulatively across all ASBS, 15% of all analyses were greater than reference site based thresholds. Nutrients (24% of all analyses) and general constituents (23% of all analyses) were greater than reference site based thresholds most frequently (Table 3, Figure 5). For both total and dissolved metals, approximately 19% of all samples were greater than reference site based thresholds. Total PAH were greater than reference site based thresholds least frequently (2% of all analyses).

Significant toxicity was not observed during this study. Sea urchin fertilization in all post-storm samples ranged from 88 to 100% of laboratory control responses, indicating a lack of statistically significant effect in both the reference drainage and ASBS discharge samples. However, samples from ASBS 25, the site that differed most from natural water quality, had no toxicity data.

IV. DISCUSSION

Based on the data collected during this study, ASBS in southern California are consistently protective of natural water quality following storm events. On average, the range of post-storm pollutant concentrations in receiving waters sampled near ASBS discharge sites were not significantly different from post-storm concentrations at reference drainage sites, which included stormwater inputs free of (or minimally influenced by) anthropogenic sources. No conservative tracer could be used to track natural constituents such as salinity, TSS, or DOC, in large part because pollutant concentrations were so low. Furthermore, synthetic anthropogenic contaminants such as total DDT or total PCB were not detectable across the wide variety of reference drainage sample locations in ASBS, and were rarely detectable at discharge sites in ASBS. Moreover, no post-storm samples collected near ASBS discharges exhibited toxicity.

Although ASBS on average were maintaining natural water quality, there were some individual ASBS sites that appeared to have anthropogenic contributions. ASBS 25 (Catalina Island) had an unusually large proportion of analyses that were greater than reference site based thresholds. This is not wholly unexpected as this site is subject to pollutant inputs via stormwater runoff from a developed community as well as a vessel mooring field. ASBS 21 (San Nicolas Island), 32 (Newport Coast), and 33 (Heisler Park), all of which receive discharges from municipal and/or industrial (military) stormwater runoff, were the next three water quality protected areas to exceed reference site based thresholds. While no stormwater discharge information was collected just upstream of the ASBS during our storm events, other studies have identified pollutants such as nutrients and trace metals widespread in municipal (Tiefenthaler *et al.* 2008) and industrial (Lee *et al.* 2007) stormwater. Trace metals and nutrients were also two groups of constituents that had the greatest proportion of samples greater than the reference site based thresholds in this study.

The reference drainage sites in this study were used to as a proxy for establishing natural water quality thresholds. The algorithm selected for this natural water quality threshold, while not arbitrary, is not an exclusive approach to utilizing the reference drainage site information. In this case, the 85th percentile of the reference site distribution was selected as a primary threshold. Because of the similarities to the reference site data, approximately 15 percent of the ASBS discharge data distribution also exceeded this threshold. As a test of sensitivity, differing reference thresholds were used to assess the ASBS discharge site information. Regardless of whether the thresholds were empirically based (i.e., 95th percentile) or statistically based (i.e., 95th prediction interval), a concomitant decrease in ASBS discharge site difference from natural water quality followed (i.e., 5%). This once again emphasizes that, despite a few samples with high magnitude concentrations that exceeded reference site maxima, the reference and discharge data were similar in their distribution.

Turbulent mixing and advection associated with breaking waves likely plays a large role in reducing concentrations in coastal stormwater plumes. Mixing and advection were the primary forces associated with shoreline dilution of dye and bacteria near flowing storm drains in Santa Monica Bay (Clarke *et al.* 2007). In these examples, dilution factors of 10^3 to 10^6 were observed at distances of 25 m from the discharge mixing zone during dry weather. While the increased flows from dry to wet weather could overwhelm nearshore mixing and advection, wave energy also increases during storm events. Similarly detailed studies at the shoreline during wet weather have not been conducted.

The data in this study represent some of the first near-shore seawater concentrations at reference drainage sites located on the Pacific coast of the United States that are influenced by stormwater inputs. The concentrations were generally low overall with many parameters very close to, or less than, method detection limits (i.e., DDTs, PCBs, PAHs). The trace metal concentrations measured in these nearshore waters were in the same range as concentrations measured from reference freshwater streams in the

southern California coastal range (Yoon and Stein 2008). However, the trace metal concentrations measured in this study were greater than typical open ocean concentrations cited by the State of California as reference conditions (Klapow and Lewis 1979) suggesting that these open ocean concentrations are not representative of near-coastal conditions.

Despite this new source of information, many data gaps remain in regards to natural water quality and these data gaps limit our ability to definitively assess water quality in ASBS. The data gaps fall into five categories. First, the reference data set that was used to derive natural water quality is limited. While this study produced one of the most complete data sets to date on ambient seawater concentrations near reference drainages during wet weather, it was only comprised of 12 site-events. Undoubtedly, this is insufficient to capture the wide range of natural conditions associated with watershed size and composition, storm size and intensity, or receiving water dynamics associated with waves and currents. Without a good grasp of natural water quality following storm events, it will be uncertain whether those ASBS discharges that were similar to reference drainage conditions actually lacked measurable anthropogenic enhancements. The second data gap is associated with those ASBS discharges that were dissimilar from reference drainage sites. While it appeared clear, even from our limited reference data set, that some ASBS discharge sites contained anthropogenic contributions, the thresholds we evaluated are not currently regulatory compliance measures. Additional information on the magnitude and duration of anthropogenic contributions is crucial before state regulators or regulated ASBS managers can rank or prioritize discharges for remediation. The third data gap addresses sources of anthropogenic inputs to ASBS discharges. Sites that appeared dissimilar from natural water quality may be attributable to non-anthropogenic site-specific causes (i.e., marine mammal defecation of nutrients). This gap is best addressed through follow-on site-specific investigations. The fourth data gap addresses all of the non-sampled ASBS discharges. Only 10 ASBS discharges were targeted in this study and, while these may have been the largest and perceived greatest risk to the ASBS, they are only a small fraction of the 271 discharges to the southern California ASBS. The last data gap to evaluate for natural water quality is non-water quality threats. Risks posed by poaching, trampling, or invasive species are equally, or perhaps even more, threatening to the health of ASBS. To compliment this chemical and toxicity testing effort, the State of California and stakeholders are currently addressing this data gap by conducting intertidal and subtidal biological surveys of ASBS.

Table 1. Reference drainage and ASBS discharge sites, and their respective sampling effort, collected immediately prior to and immediately following storm events in southern California.

| ASBS Number | ASBS Name | SiteName | Latitude | Longitude | Reference or Discharge | Number Pre-Storm Samples | Number Post-Storm Samples | |
|-------------|--------------------------|------------------------------|----------|------------|------------------------|--------------------------|---------------------------|----|
| ASBS 21 | San Nicolas Island | Barge Landing | 33.21967 | -119.44728 | Discharge | 2 | 2 | |
| ASBS 21 | San Nicolas Island | Cissy Cove | 33.21448 | -119.48459 | Discharge | 1 | 1 | |
| ASBS 21 | San Nicolas Island | Reference Site | 37.26600 | -119.49828 | Reference | 2 | 2 | |
| ASBS 21 | San Nicolas Island | Reverse Osmosis site | 33.24281 | -119.44433 | Discharge | 1 | 1 | |
| ASBS 24 | Malibu | Solstice Beach | 34.03255 | -118.74216 | Reference | 1 | 1 | |
| ASBS 24 | Malibu | Arroyo Sequit | 34.04441 | -118.93393 | Reference | 1 | 1 | |
| ASBS 24 | Malibu | Broad Beach | 34.03339 | -118.85090 | Discharge | 3 | 3 | |
| ASBS 24 | Malibu | Nicholas Canyon | 34.04172 | -118.91574 | Reference | 3 | 3 | |
| ASBS 24 | Malibu | Westward Beach | 34.01030 | -118.81721 | Discharge | 2 | 2 | |
| ASBS 25 | Santa Catalina Island | Two Harbors Pier | 33.44194 | -118.49821 | Discharge | 1 | 2 | |
| - | - | Italian gardens | 33.41011 | -118.38176 | Reference | 1 | 2 | |
| ASBS 29 | San Diego | Avienda de la Playa | 32.85466 | -117.25899 | Discharge | 3 | 3 | |
| ASBS 31 | La Jolla | San Diego Marine Life Refuge | 32.86632 | -117.25469 | Discharge | 1 | 3 | |
| ASBS 32 | NewportCoast/CrystalCove | NewportCoast/CrystalCove | 33.58867 | -117.86759 | Discharge | 3 | 3 | |
| ASBS 33 | Heisler Park | El Moro Canyon | 33.56033 | -117.82205 | Reference | 3 | 3 | |
| ASBS 33 | Heisler Park | Heisler Park | 33.54301 | -117.78958 | Discharge | 3 | 3 | |
| | | | | | | Discharge | 20 | 23 |
| | | | | | | Reference | 11 | 12 |
| | | | | | | Total | 31 | 35 |

Table 2. Correlation coefficients between storm characteristics: rainfall quantity, antecedent dry days (Ant Dry); or conservative tracers: total suspended solids (TSS), salinity, dissolved organic carbon (DOC) and chemical parameters of interest. Bold numbers are statistically significant at $p < 0.05$.

| | Rainfall | Ant Dry | Salinity | TSS | DOC |
|-----------|----------|--------------|--------------|-------------|-------------|
| Salinity | 0.20 | -0.43 | | | |
| TSS | 0.19 | 0.23 | 0.02 | | |
| DOC | 0.08 | -0.11 | 0.50 | 0.05 | |
| Ammonia-N | 0.08 | 0.29 | -0.34 | -0.11 | 0.26 |
| Nitrate-N | -0.05 | 0.05 | 0.00 | -0.08 | 0.41 |
| Total N | -0.20 | 0.22 | -0.07 | 0.15 | 0.09 |
| Total P | -0.07 | 0.34 | 0.03 | 0.07 | -0.21 |
| Arsenic | -0.04 | -0.04 | 0.13 | 0.46 | 0.17 |
| Cadmium | -0.01 | -0.01 | -0.34 | -0.09 | 0.03 |
| Chromium | 0.25 | 0.25 | -0.34 | 0.67 | 0.21 |
| Copper | 0.07 | 0.07 | 0.02 | 0.27 | 0.24 |
| Lead | 0.13 | 0.13 | -0.06 | 0.37 | 0.15 |
| Nickel | 0.14 | 0.14 | -0.19 | 0.55 | 0.32 |
| Zinc | 0.02 | 0.02 | -0.44 | 0.31 | -0.10 |
| Total PAH | 0.16 | 0.16 | -0.03 | 0.03 | 0.11 |

Table 3. Reference site based threshold exceedence frequency near discharges into Areas of Special Biological Significance (ASBS) following storm events in southern California.

| Parameter | Reference Site Based Threshold | | Discharge Site Comparison | | |
|--------------------------|-----------------------------------|-------|------------------------------|---|---|
| | 85th Percentile of Reference Data | Units | Total No. Post-Storm Samples | Pct Samples > Reference 85th Percentile | Pct of Samples > Reference 85th Percentile and greater than Pre-Storm Concentration |
| Total Suspended Solids | 16.5 | mg/L | 23 | 35 | 22 |
| Dissolved Organic Carbon | 0.80 | mg/L | 21 | 24 | 19 |
| Ammonia-N | 0.03 | mg/L | 23 | 30 | 26 |
| Nitrate-N | 0.05 | mg/L | 23 | 26 | 13 |
| Nitrite-N | 0.01 | mg/L | 23 | 0 | 0 |
| Total Nitrogen | 4.0 | mg/L | 21 | 10 | 5 |
| Total Phosphorus | 0.10 | mg/L | 23 | 9 | 9 |
| Arsenic-Dissolved | 1.48 | ug/L | 19 | 32 | 32 |
| Arsenic-Total | 1.9 | ug/L | 23 | 13 | 4 |
| Cadmium-Dissolved | 0.05 | ug/L | 19 | 21 | 16 |
| Cadmium-Total | 0.14 | ug/L | 23 | 26 | 17 |
| Chromium-Dissolved | 0.21 | ug/L | 19 | 5 | 5 |
| Chromium-Total | 1.6 | ug/L | 23 | 17 | 13 |
| Copper-Dissolved | 0.45 | ug/L | 19 | 47 | 42 |
| Copper-Total | 2.2 | ug/L | 23 | 26 | 26 |
| Iron-Dissolved | 1.7 | ug/L | 19 | 11 | 11 |
| Iron-Total | 813 | ug/L | 23 | 13 | 13 |
| Lead-Dissolved | 0.02 | ug/L | 19 | 26 | 21 |
| Lead-Total | 1.1 | ug/L | 23 | 13 | 17 |
| Nickel-Dissolved | 0.32 | ug/L | 19 | 32 | 26 |
| Nickel-Total | 1.5 | ug/L | 23 | 17 | 17 |
| Silver-Dissolved | ND | ug/L | 19 | 0 | 0 |
| Silver-Total | 0.0 | ug/L | 23 | 13 | 9 |
| Zinc-Dissolved | 2.88 | ug/L | 19 | 5 | 5 |
| Zinc-Total | 8.6 | ug/L | 23 | 30 | 30 |
| TotalPAH | 19.6 | ug/L | 23 | 9 | 9 |

Figure 1. Map of Areas of Special Biological Significance (ASBS) in Southern California.



Figure 2. Comparison of geometric mean (\pm 95% confidence interval) concentrations in ambient near-shore receiving waters following storm events at reference drainage and ASBS discharge sites. Total suspended solids (TSS) and nutrients in mg/L; Total Polycyclic Aromatic Hydrocarbons (Total PAHs), and total trace metals in $\mu\text{g/L}$.

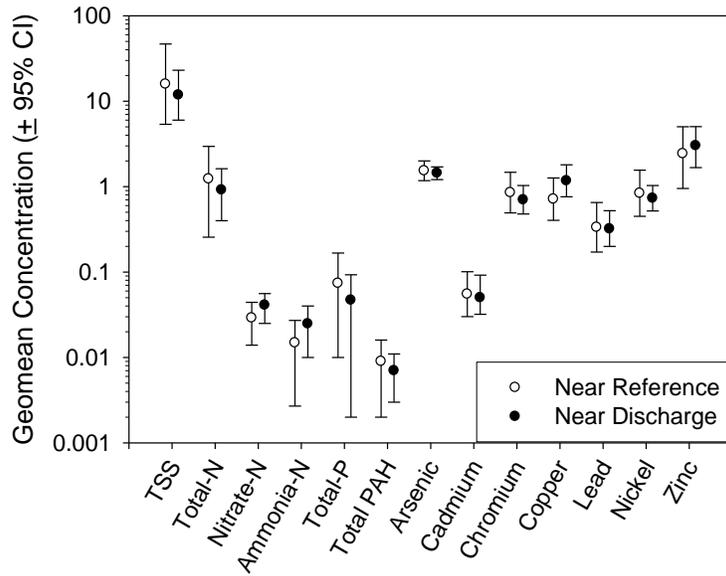


Figure 3. Distribution of post-storm relative to pre-storm trace metal concentrations in ambient near-coastal waters at reference drainage (in white) and ASBS discharge (in grey) sites. Box plots include the 5th, 25th, 50th, 75th, and 95th percentile of the data distribution.

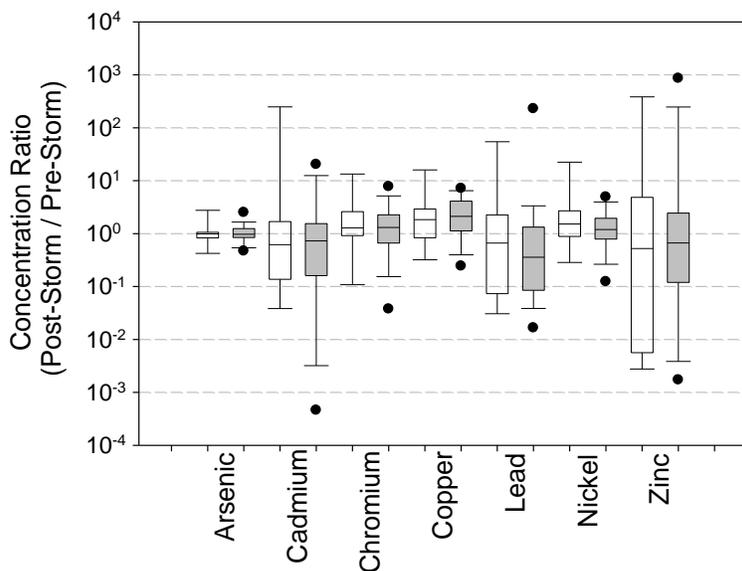


Figure 4. Frequency of reference site based threshold exceedences for all parameters during all storm events at each Area of Special Biological Significance (ASBS) in southern California. Number above bar is total sample size.

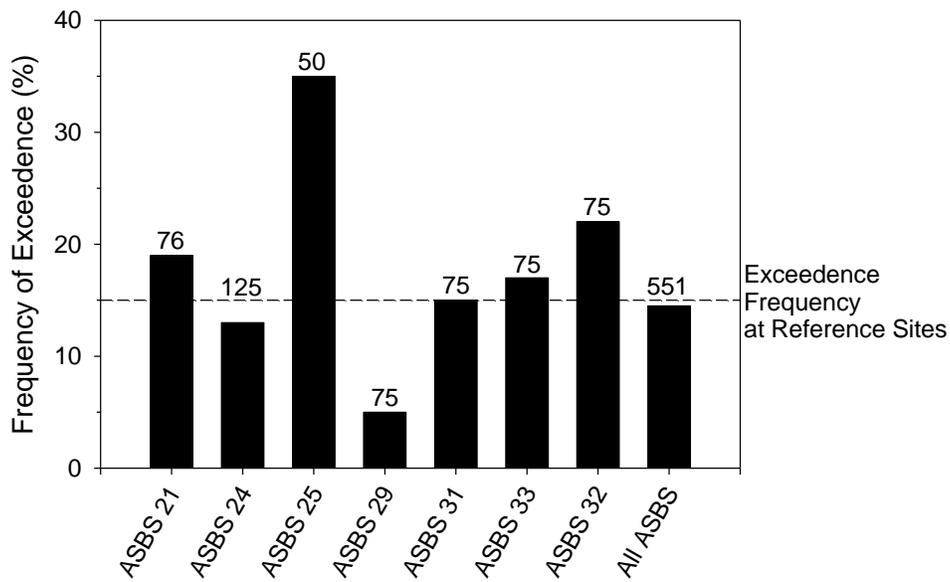
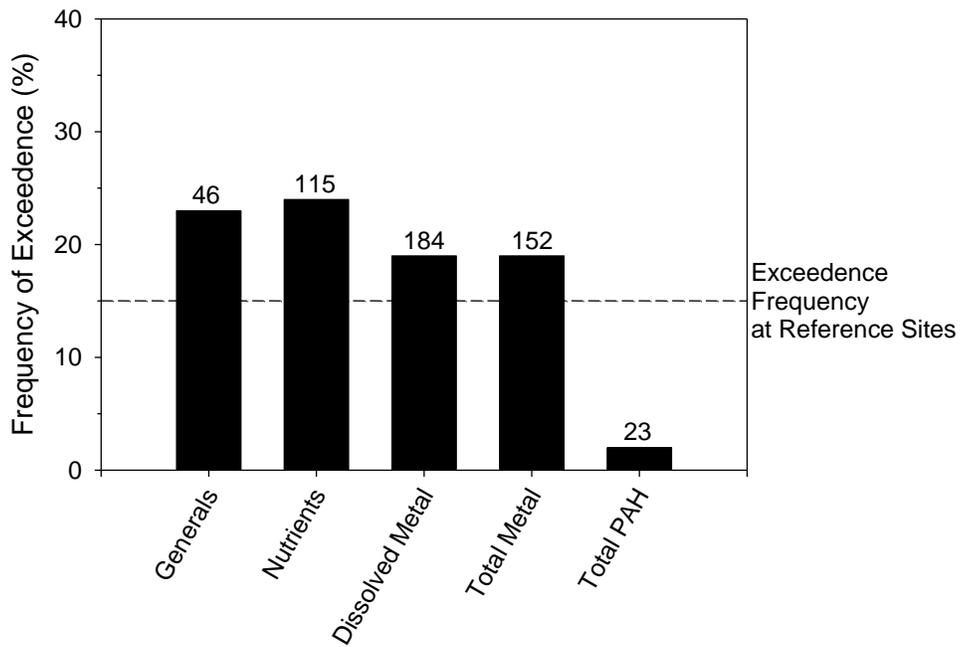


Figure 5. Frequency of reference site based threshold exceedences by parameter group for all storm events and all Areas of Special Biological Significance (ASBS) in southern California. Number above bar is total sample size.



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APPENDIX A: PARTICIPANTS IN THE BIGHT'08 REGIONAL MONITORING PROGRAM

| Organization | Coastal Ecology | Microbiology | Water Quality | Rocky Reefs | Areas of Special Biological Significance | Coastal Wetlands and Estuaries | Bioaccumulation |
|--|-----------------|--------------|---------------|-------------|--|--------------------------------|-----------------|
| AMEC Incorporated | | | | | X | | |
| Aquatic Bioassay and Consulting Laboratories | X | | X | | X | | |
| Associated Laboratories | | X | | | | | |
| California Polytechnic University | | | X | | | | |
| California State Parks | | | | | X | X | |
| California State University Channel Islands | | | | | | X | |
| California State University Long Beach | X | | | | | | |
| California Dept. of Fish and Game | X | | | | | X | X |
| California Department of Public Health | | | X | | | | |
| Camp Pendleton Marine Corps Base | | | | | | X | |
| Channel Islands National Marine Sanctuary | X | | | | | | |
| Chevron USA Products Company | X | | | | | | |
| City of Carlsbad | | | | | | X | |
| City of Coronado | | | | | | X | |
| City of Del Mar | | | | | | X | |
| City of El Cajon | | | | | | X | |
| City of Encinitas | | X | | | | X | |
| City of Escondido | | | | | | X | |
| City of Imperial Beach | | | | | | X | |
| City of La Mesa | | | | | | X | |
| City of Laguna Beach | | | | | X | | |
| City of Lemon Grove | | | | | | X | |

| Organization | Coastal Ecology | Microbiology | Water Quality | Rocky Reefs | Areas of Special Biological Significance | Coastal Wetlands and Estuaries | Bioaccumulation |
|---|-----------------|--------------|---------------|-------------|--|--------------------------------|-----------------|
| City of Long Beach | | | X | | | | |
| City of Los Angeles Environmental Monitoring Division | X | X | X | | | X | |
| City of Poway | | | | | | X | |
| City of San Marcos | | | | | | X | |
| City of Santee | | | | | | X | |
| City of Solana Beach | | | | | | X | |
| City of Vista | | | | | | X | |
| City of Chula Vista | | | | | | X | |
| City of Malibu | | | | | X | | |
| City of Newport Beach | | | | | X | X | |
| City of Oceanside | | | X | | | X | |
| City of Oxnard | X | | X | | | | X |
| City of San Diego | X | X | X | | X | | X |
| City of Ventura | | | X | | | X | |
| Coastal Conservancy | | | X | | | X | |
| CRG Marine Laboratories | X | | X | | X | | X |
| Encina Wastewater Authority | X | X | X | | | | |
| Jet Propulsion Laboratory | | | X | | | | |
| Los Angeles County Dept. of Beaches & Harbors | X | | | | | | |
| Los Angeles County Dept. of Health Services | | X | | | | | |
| Los Angeles County Dept. of Public Works | | X | | | X | | |
| Los Angeles County Sanitation Districts | X | X | X | X | | | X |
| Los Angeles Department of Water and Power | X | | | | | | |
| Los Angeles Regional Water Quality Control Board | | | | | X | X | X |
| Loyola Marymount University | | X | | | | | X |
| Marine Pollution Studies Laboratory - Granite | X | | | | | | |

| Organization | Coastal Ecology | Microbiology | Water Quality | Rocky Reefs | Areas of Special Biological Significance | Coastal Wetlands and Estuaries | Bioaccumulation |
|--|-----------------|--------------|---------------|-------------|--|--------------------------------|-----------------|
| Canyon | | | | | | | |
| Marine Pollution Studies Laboratory - Rancho Cordova | X | | | | | | X |
| MBC Applied Environmental Sciences | X | | | | | | |
| Monterey Bay Aquarium Research Institute | | | X | | | | |
| Natural History Museum of Los Angeles County | X | | | | | | |
| National City | | | | | | X | |
| National Parks Service | | | | X | | | |
| Nautilus Environmental | X | | | | X | | |
| NES Energy, Inc. | X | | | | | | |
| National Oceanic and Atmospheric Administration | X | X | X | | | X | |
| NRG Energy, Inc. | X | | | | | | |
| Orange County Environmental Health Division | | X | | | | | |
| Orange County Public Facilities and Resources | | | | | X | X | |
| Orange County Sanitation District | X | X | X | | | | X |
| Port of Long Beach | X | | | | | | |
| Port of Los Angeles | X | | X | X | | | |
| Port of San Diego | X | | | | | X | X |
| Reliant Corporation | X | | | | | | |
| Resource Conservation District | | | | | | X | |
| Riverside County Flood Control District | | | X | | | | |
| San Bernardino Flood Control District | | | X | | | | |
| San Diego County | | | | | | X | |
| San Diego County Dept. of Environmental Health | | | | | | X | |

| Organization | Coastal Ecology | Microbiology | Water Quality | Rocky Reefs | Areas of Special Biological Significance | Coastal Wetlands and Estuaries | Bioaccumulation |
|--|-----------------|--------------|---------------|-------------|--|--------------------------------|-----------------|
| San Diego Regional Water Quality Control Board | | | | | X | X | |
| San Diego State University | | | | X | | | |
| San Elijo Joint Powers Authority | X | | | | | | |
| San Elijo Lagoon Conservancy | | | | | | X | |
| San Francisco Estuary Institute | | | | | | | X |
| Santa Ana Regional Water Quality Control Board | | | X | | | X | |
| Santa Ana River Watershed Management Authority | | | | | | X | |
| Santa Monica Bay Restoration Commission | | | | | | X | |
| Scripps Institution of Oceanography Sea Ventures | | | X | | | | |
| South Orange County Water Authority | | | | | | | |
| Southern California Coastal Water Research Project Stanford University | X | X | X | X | X | X | X |
| State Water Resources Control Board | X | X | X | X | X | X | X |
| Tijuana Estuary National Estuarine Research Reserve University of California, Los Angeles | | X | X | | | X | |
| University of California, San Diego | | | | X | X | | |
| University of California, Santa Barbara | | X | X | X | | X | |
| University of California, Santa Cruz | | | | | X | | |
| University of South Carolina | | | | | | X | |
| University of Southern California | | | X | | X | | |
| US EPA Region IX | | | | | | X | X |

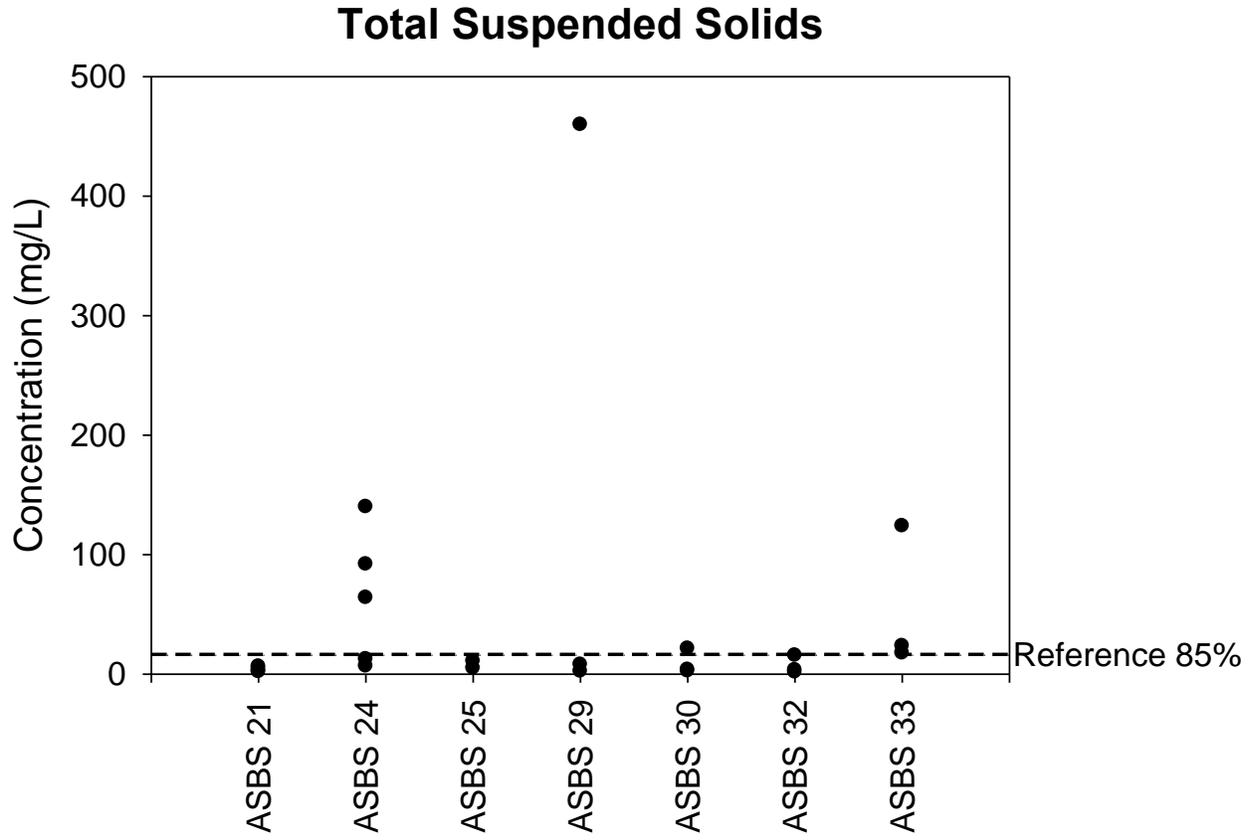
| Organization | Coastal Ecology | Microbiology | Water Quality | Rocky Reefs | Areas of Special Biological Significance | Coastal Wetlands and Estuaries | Bioaccumulation |
|--|-----------------|--------------|---------------|-------------|--|--------------------------------|-----------------|
| US EPA Office of Research and Development | X | | | | | | |
| US Fish and Wildlife Service | | | | | | X | |
| US Geological Survey | X | | | | | | |
| US Navy | | | | | X | | |
| Vantuna Research Group, Occidental College | X | | | X | X | | |
| Ventura County Public Health Laboratory | | X | | | | | |
| Ventura County Watershed Protection Division | | | X | | | X | |
| Weston Solutions | X | X | X | | X | X | |

APPENDIX B: SUMMARY TABLES OF REFERENCE AND DISCHARGE SITE PRE- AND POST-STORM CONCENTRATIONS

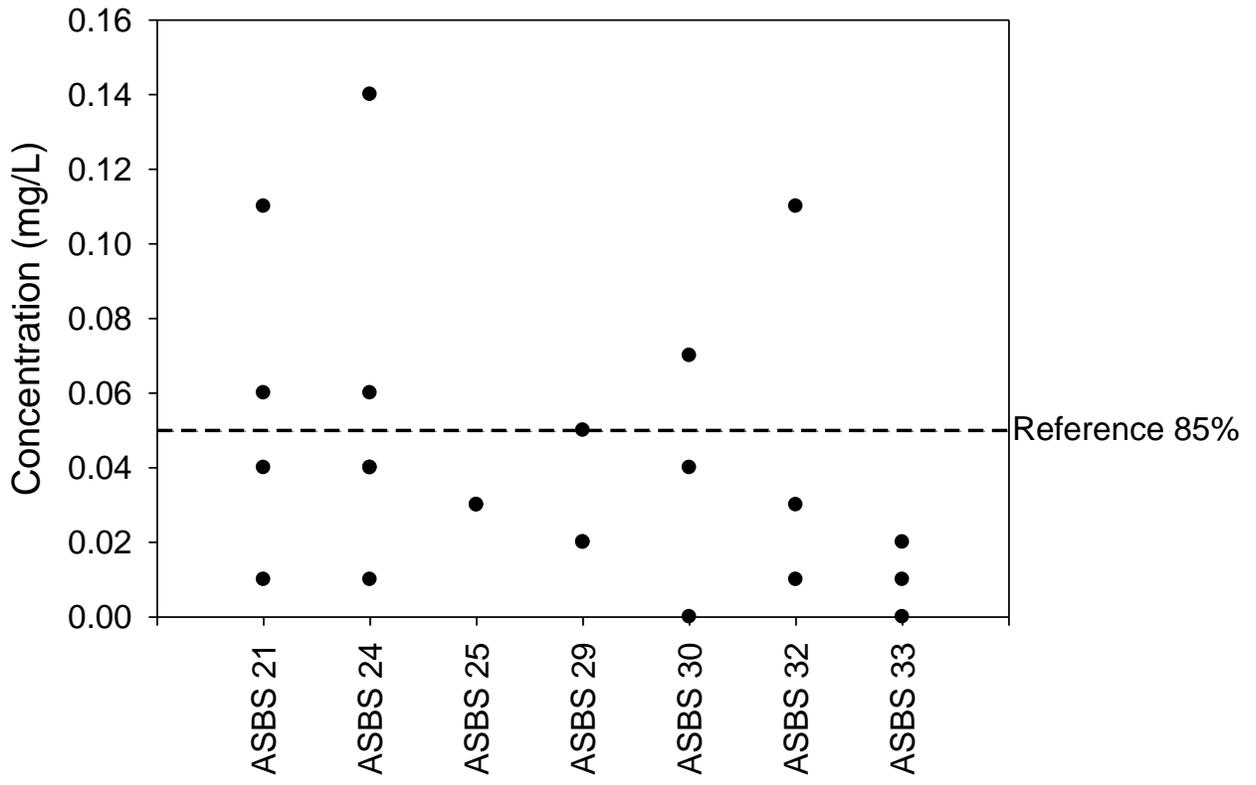
| Reference Sample Summary Concentrations | | | | | | | | | | | | |
|---|-------|-----------------|---------------------|------|-------|---------|---------------|----------------------|------|-------|---------|---------------|
| | | | Reference Pre-Storm | | | | | Reference Post-Storm | | | | |
| Parameter | Units | Detection Limit | %ND | Min | Max | GeoMean | (+) 95% CI | %ND | Min | Max | GeoMean | (+) 95% CI |
| Ammonia-N | mg/L | 0.03 | 55 | 0.00 | 0.04 | 0.01 | (0.003, 0.03) | 58 | 0.00 | 0.05 | 0.01 | (0.003, 0.03) |
| Arsenic-Dissolved | ug/L | 0.01 | 0 | 1.10 | 1.58 | 1.34 | (1.23, 1.45) | 0 | 0.41 | 1.53 | 1.25 | (0.94, 1.65) |
| Arsenic-Total | ug/L | 0.01 | 0 | 1.16 | 5.02 | 1.64 | (1.25, 2.17) | 0 | 0.53 | 4.53 | 1.53 | (1.17, 2.0) |
| Cadmium-Dissolved | ug/L | 0.005 | 11 | 0.00 | 0.04 | 0.02 | (0.01, 0.03) | 0 | 0.02 | 0.12 | 0.04 | (0.02, 0.06) |
| Cadmium-Total | ug/L | 0.005 | 9 | 0.00 | 0.92 | 0.09 | (0, 0.23) | 0 | 0.02 | 0.47 | 0.06 | (0.03, 0.10) |
| Chromium-Dissolved | ug/L | 0.025 | 0 | 0.14 | 0.23 | 0.17 | (0.15, 0.19) | 0 | 0.14 | 0.30 | 0.18 | (0.16, 0.22) |
| Chromium-Total | ug/L | 0.025 | 0 | 0.04 | 16.93 | 0.46 | (0.17, 1.27) | 0 | 0.29 | 8.34 | 0.85 | (0.49, 1.47) |
| Copper-Dissolved | ug/L | 0.01 | 0 | 0.02 | 0.73 | 0.16 | (0.07, 0.35) | 0 | 0.08 | 0.99 | 0.23 | (0.13, 0.42) |
| Copper-Total | ug/L | 0.01 | 0 | 0.05 | 6.08 | 0.46 | (0.21, 1.04) | 0 | 0.27 | 5.88 | 0.71 | (0.4, 1.26) |
| DOC | mg/L | 0.10 | 60 | 0.00 | 1.40 | 0.23 | (0.01, 0.53) | 45 | 0.00 | 3.60 | 0.55 | (0.07, 1.26) |
| Iron-Dissolved | ug/L | 0.50 | 78 | 0.00 | 0.80 | 0.12 | (0, 0.33) | 20 | 0.00 | 8.91 | 1.15 | (0.32, 2.49) |
| Iron-Total | ug/L | 0.50 | 0 | 1.00 | 10680 | 77 | (15, 403) | 0 | 18 | 7874 | 259 | (105, 635) |
| Lead-Dissolved | ug/L | 0.005 | 11 | 0.00 | 0.05 | 0.02 | (0.01, 0.03) | 10 | 0.00 | 0.06 | 0.02 | (0.01, 0.03) |
| Lead-Total | ug/L | 0.005 | 0 | 0.02 | 6.93 | 0.13 | (0.05, 0.38) | 0 | 0.07 | 7.02 | 0.33 | (0.17, 0.65) |
| Nickel-Dissolved | ug/L | 0.005 | 0 | 0.17 | 0.40 | 0.23 | (0.19, 0.27) | 0 | 0.15 | 0.49 | 0.25 | (0.20, 0.31) |
| Nickel-Total | ug/L | 0.005 | 9 | 0.00 | 19 | 0.79 | (0.02, 2.15) | 0 | 0.25 | 15 | 0.84 | (0.45, 1.56) |
| Nitrate-N | mg/L | 0.01 | 27 | 0.00 | 0.08 | 0.03 | (0.01, 0.05) | 83 | 0.00 | 0.07 | 0.03 | (0.01, 0.04) |
| Nitrite-N | mg/L | 0.01 | 91 | 0.00 | 0.01 | 0.001 | (0, 0.003) | 67 | 0.00 | 0.01 | 0.003 | (0, 0.01) |
| Silver-Dissolved | ug/L | 0.02 | 100 | -- | -- | -- | -- | 100 | -- | -- | -- | -- |
| Silver-Total | ug/L | 0.02 | 64 | 0.00 | 0.18 | 0.03 | (0, 0.06) | 86 | 0.00 | 0.06 | 0.01 | (0, 0.02) |
| TN | mg/L | 2.00 | 55 | 0.00 | 1.86 | 0.22 | (0, 0.55) | 42 | 0.00 | 11.00 | 1.23 | (0.26, 3.0) |
| TotalPAH* | ng/L | 1.00 | 18 | 0.00 | 318 | 33 | (0, 91) | 25 | 0.00 | 32 | 9 | (2, 16) |
| TP-Total | mg/L | 0.02 | 45 | 0.00 | 0.33 | 0.07 | (0.01, 0.14) | 50 | 0.00 | 0.59 | 0.07 | (0, 0.17) |
| TSS | mg/L | 0.50 | 9 | 0.00 | 1472 | 10 | (2, 44) | 0 | 2.30 | 1692 | 16 | (5, 47) |
| Zinc-Dissolved | ug/L | 0.005 | 44 | 0.00 | 5.55 | 0.71 | (0, 2.05) | 40 | 0.00 | 5.62 | 0.92 | (0.13, 2.27) |
| Zinc-Total | ug/L | 0.005 | 18 | 0.00 | 29 | 3.08 | (0.97, 7.47) | 21 | 0.00 | 19 | 2.43 | (0.95, 5.03) |

| ASBS Discharge Sample Summary Concentrations | | | | | | | | | | | | |
|--|-------|-----------------|---------------------|------|-------|---------|-------------|----------------------|------|-------|---------|--------------|
| Parameter | Units | Detection Limit | Discharge Pre-Storm | | | | | Discharge Post-Storm | | | | |
| | | | %ND | Min | Max | GeoMean | (±) 95% CI | %ND | Min | Max | GeoMean | (±) 95% CI |
| Ammonia-N | mg/L | 0.03 | 60 | 0.00 | 0.06 | 0.02 | (0.01,0.03) | 48 | 0.00 | 0.11 | 0.02 | (0.01,0.04) |
| Arsenic-Dissolved | ug/L | 0.01 | 0 | 0.89 | 1.58 | 1.29 | (1.18,1.40) | 0 | 0.47 | 1.82 | 1.29 | (1.10,1.50) |
| Arsenic-Total | ug/L | 0.01 | 0 | 0.98 | 3.16 | 1.53 | (1.34,1.78) | 0 | 0.57 | 3.37 | 1.44 | (1.21,1.70) |
| Cadmium-Dissolved | ug/L | 0.005 | 13 | 0.00 | 0.85 | 0.08 | (0.00,0.17) | 5 | 0.00 | 1.18 | 0.08 | (0.00,0.17) |
| Cadmium-Total | ug/L | 0.005 | 5 | 0.00 | 0.31 | 0.07 | (0.04,.010) | 0 | 0.01 | 1.07 | 0.05 | (0.03,0.09) |
| Chromium-Dissolved | ug/L | 0.025 | 0 | 0.12 | 0.20 | 0.16 | (0.15,0.17) | 0 | 0.12 | 0.21 | 0.17 | (0.16,0.18) |
| Chromium-Total | ug/L | 0.025 | 0 | 0.06 | 5.53 | 0.41 | (0.24,0.72) | 0 | 0.16 | 5.48 | 0.70 | (0.48,1.03) |
| Copper-Dissolved | ug/L | 0.01 | 0 | 0.05 | 1.06 | 0.24 | (0.16,0.36) | 0 | 0.08 | 3.16 | 0.36 | (0.22,0.60) |
| Copper-Total | ug/L | 0.01 | 0 | 0.16 | 5.41 | 0.58 | (0.39,0.86) | 0 | 0.26 | 10.09 | 1.17 | (0.76,1.80) |
| DOC | mg/L | 0.10 | 56 | 0.00 | 1.40 | 0.28 | (0.10,0.50) | 48 | 0.00 | 3.60 | 0.39 | (0.14,0.07) |
| Iron-Dissolved | ug/L | 0.50 | 38 | 0.00 | 3.90 | 0.64 | (0.27,1.12) | 26 | 0.00 | 4.10 | 0.68 | (0.47,0.90) |
| Iron-Total | ug/L | 0.50 | 0 | 6.40 | 2415 | 80 | (33,195) | 0 | 46 | 3863 | 187 | (108,322) |
| Lead-Dissolved | ug/L | 0.005 | 13 | 0.00 | 4.50 | 0.02 | (0.01,0.03) | 26 | 0.00 | 0.09 | 0.02 | (0.01,0.30) |
| Lead-Total | ug/L | 0.005 | 0 | 0.02 | 2.08 | 0.14 | (0.07,0.26) | 0 | 0.05 | 3.10 | 0.32 | (0.20,0.52) |
| Nickel-Dissolved | ug/L | 0.005 | 0 | 0.16 | 0.55 | 0.24 | (0.20,0.29) | 0 | 0.15 | 2.17 | 0.28 | (0.21,0.37) |
| Nickel-Total | ug/L | 0.005 | 0 | 0.20 | 4.78 | 0.53 | (0.34,0.83) | 0 | 0.24 | 4.31 | 0.73 | (0.52,1.03) |
| Nitrate-N | mg/L | 0.01 | 32 | 0.00 | 396 | 0.38 | (0.00,1.60) | 9 | 0.00 | 0.14 | 0.04 | (0.03,0.06) |
| Nitrite-N | mg/L | 0.01 | 100 | -- | -- | -- | -- | 83 | 0.00 | 0.01 | 0.002 | (0.00,0.004) |
| Silver-Dissolved | ug/L | 0.02 | 100 | -- | -- | -- | -- | 100 | -- | -- | -- | -- |
| Silver-Total | ug/L | 0.02 | 80 | 0.00 | 0.06 | 0.01 | (0.00,0.01) | 87 | 0.00 | 0.06 | 0.01 | (0.00,0.02) |
| Total CHC | ng/L | 1.00 | 100 | -- | -- | -- | -- | 100 | -- | -- | -- | -- |
| Total PAH | ng/L | 1.00 | 24 | 0.00 | 121 | 11 | (0.00,23) | 30 | 0.00 | 32 | 7 | (3,11) |
| Total PCB | ng/L | 1.00 | 100 | -- | -- | -- | -- | 100 | -- | -- | -- | -- |
| Total-N | mg/L | 2.00 | 47 | 0.00 | 555 | 0.99 | (0.00,3.0) | 38 | 0.00 | 5.99 | 0.91 | (0.40,1.62) |
| Total-P | mg/L | 0.02 | 35 | 0.00 | 0.46 | 0.08 | (0.03,0.14) | 57 | 0.00 | 0.59 | 0.05 | (0.002,0.09) |
| TSS | mg/L | 0.50 | 5 | 0.00 | 104 | 5 | (2,11) | 0 | 1.70 | 460 | 12 | (6,23) |
| Zinc-Dissolved | ug/L | 0.005 | 50 | 0.00 | 10.35 | 0.92 | (0.26,1.93) | 58 | 0.00 | 5.15 | 0.61 | (0.20,1.17) |
| Zinc-Total | ug/L | 0.005 | 10 | 0.00 | 12 | 3 | (2,5) | 13 | 0.00 | 16 | 3.02 | (2,5) |

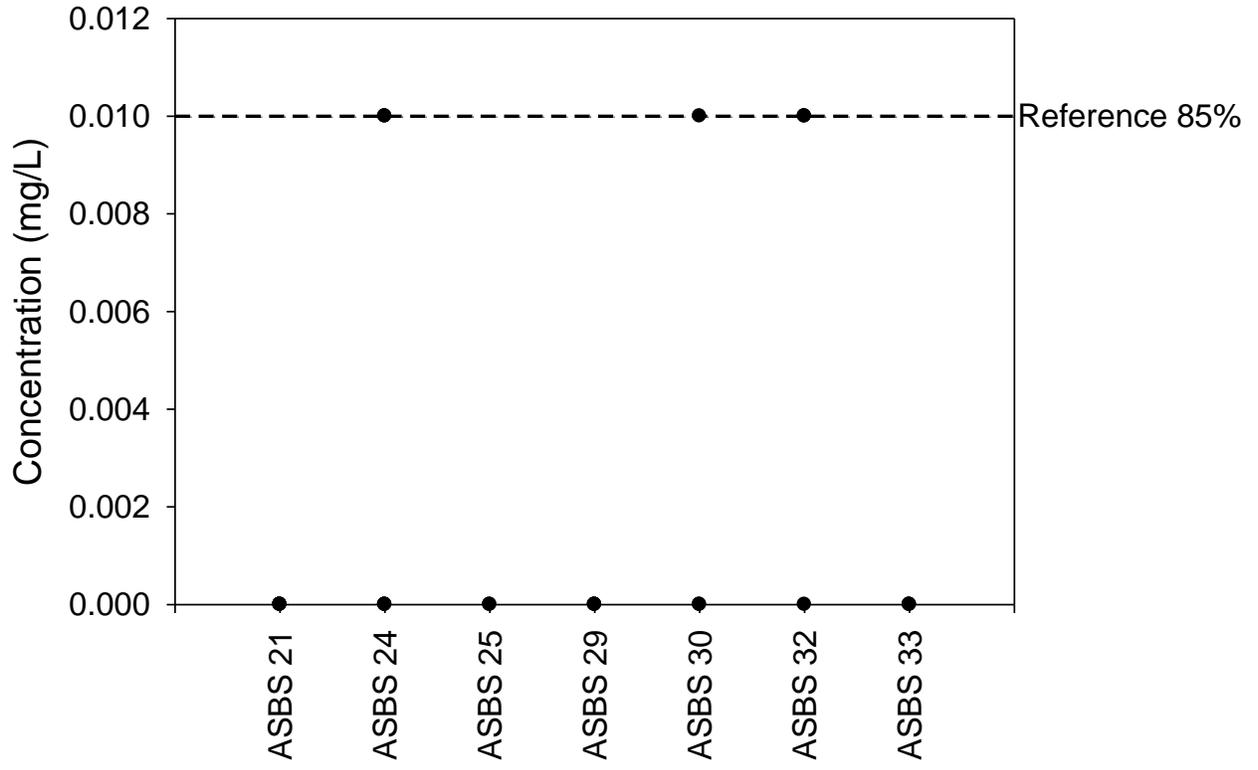
**APPENDIX C: INDIVIDUAL GRAPHS OF POST-STORM
DISCHARGE CONCENTRATIONS BY ASBS**



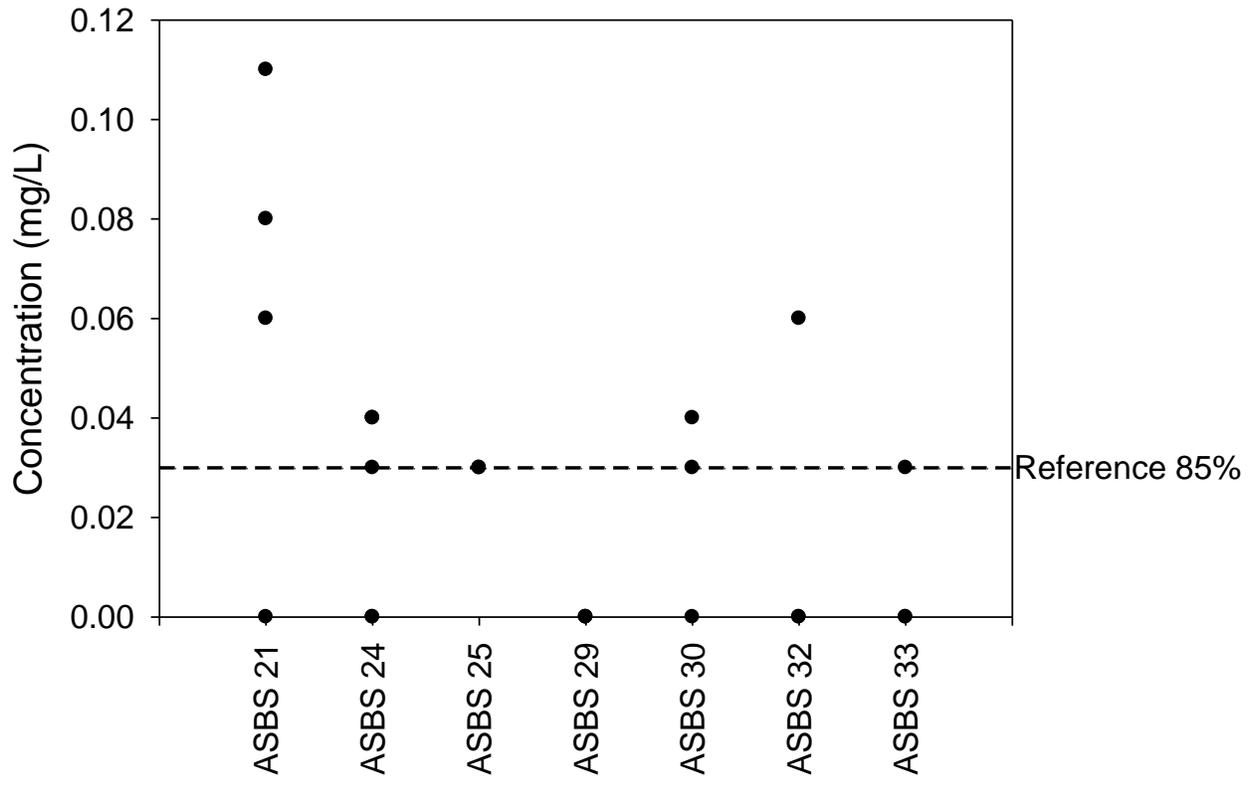
Nitrate-N



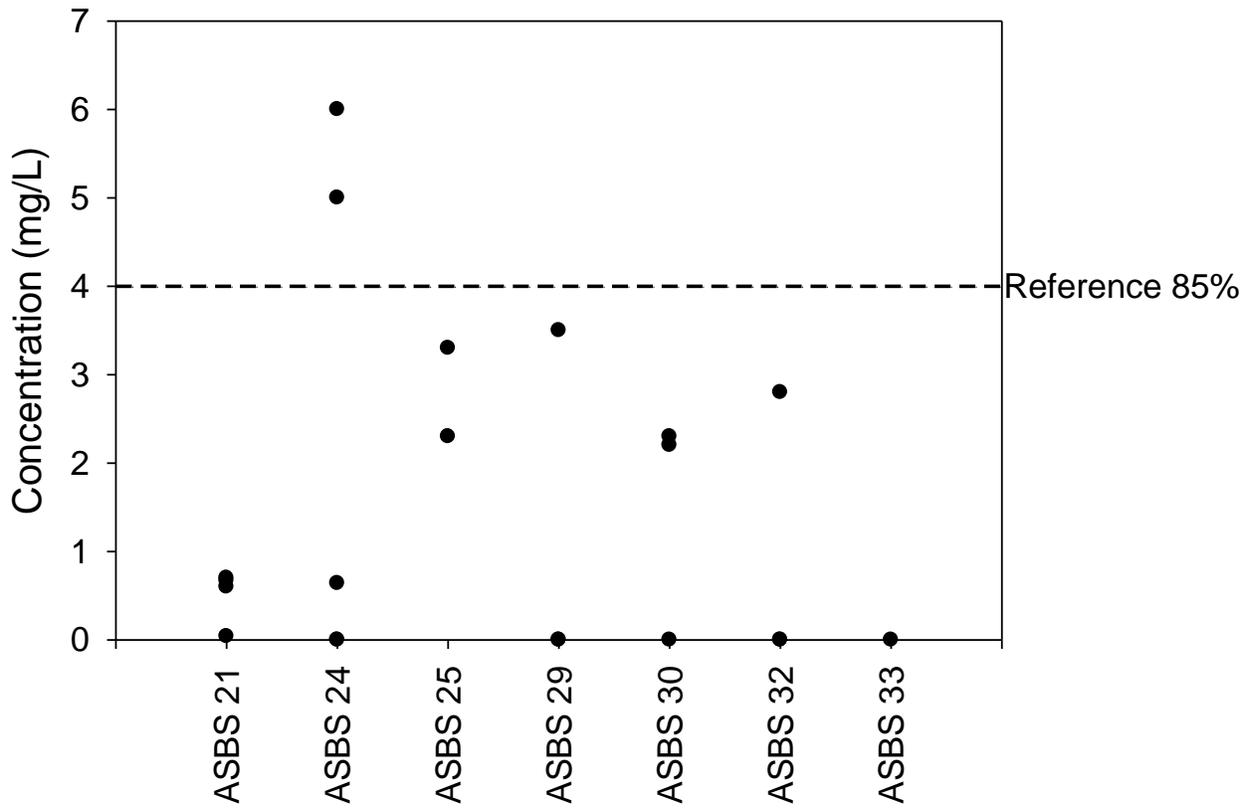
Nitrite-N



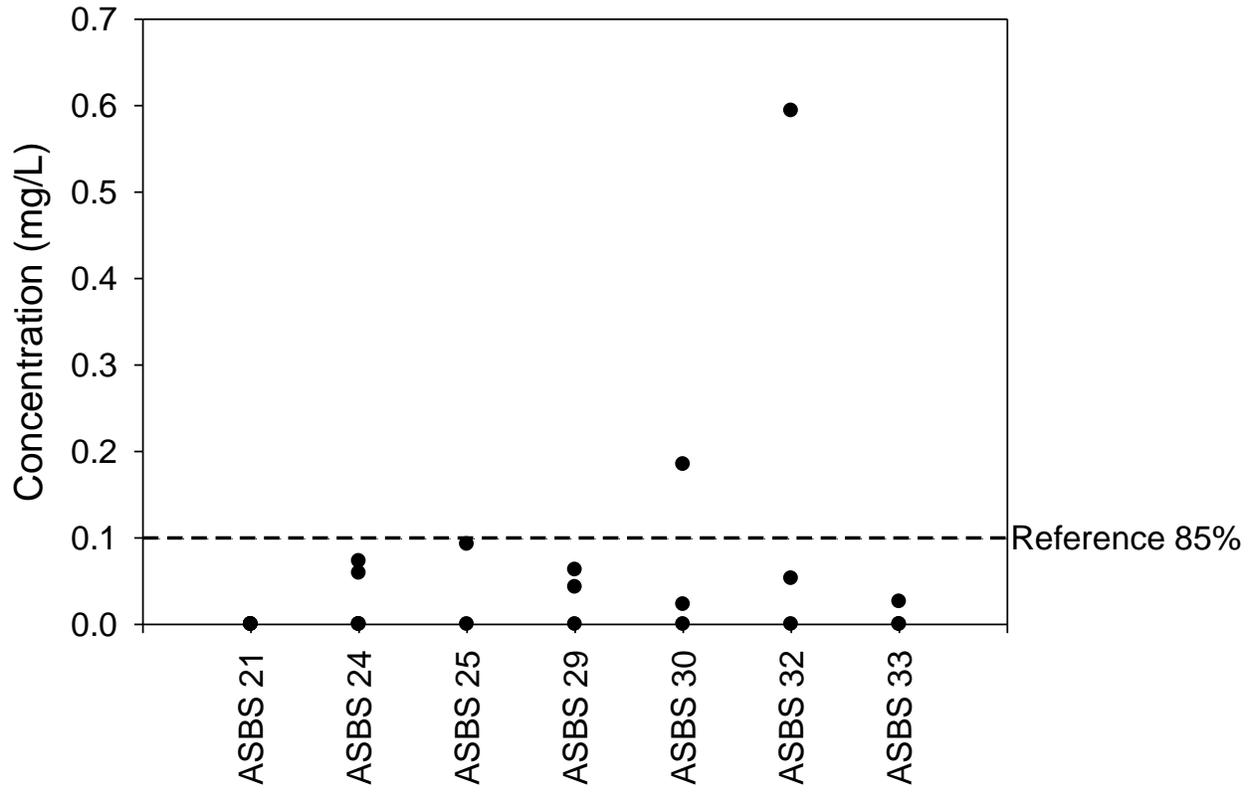
Ammonia-N



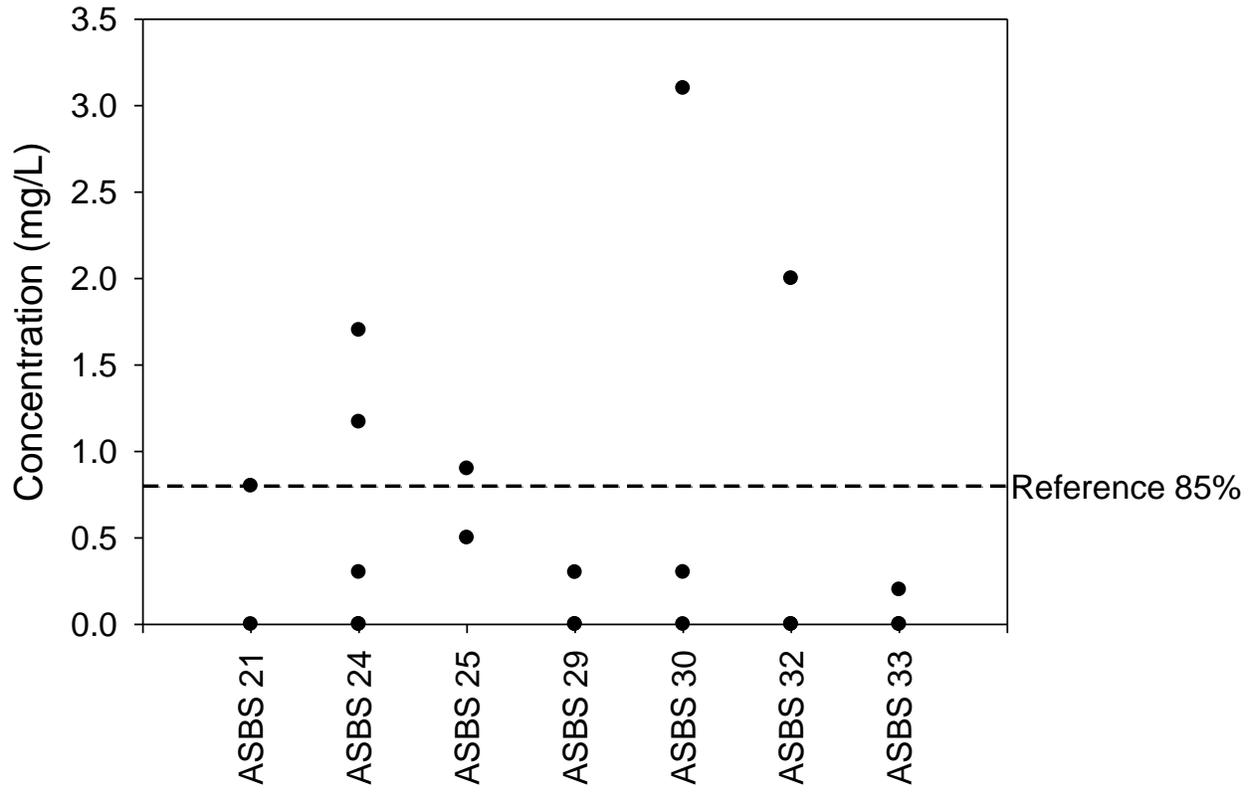
Total Nitrogen



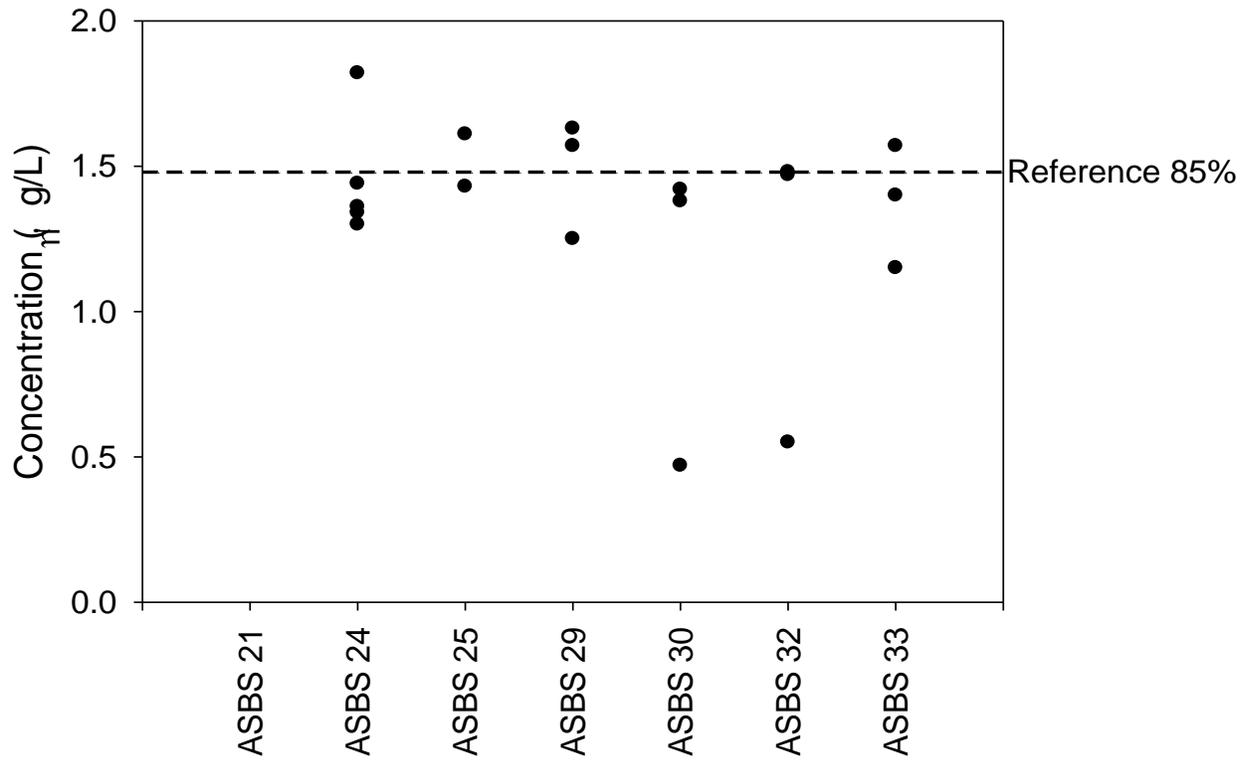
Total Phosphorus



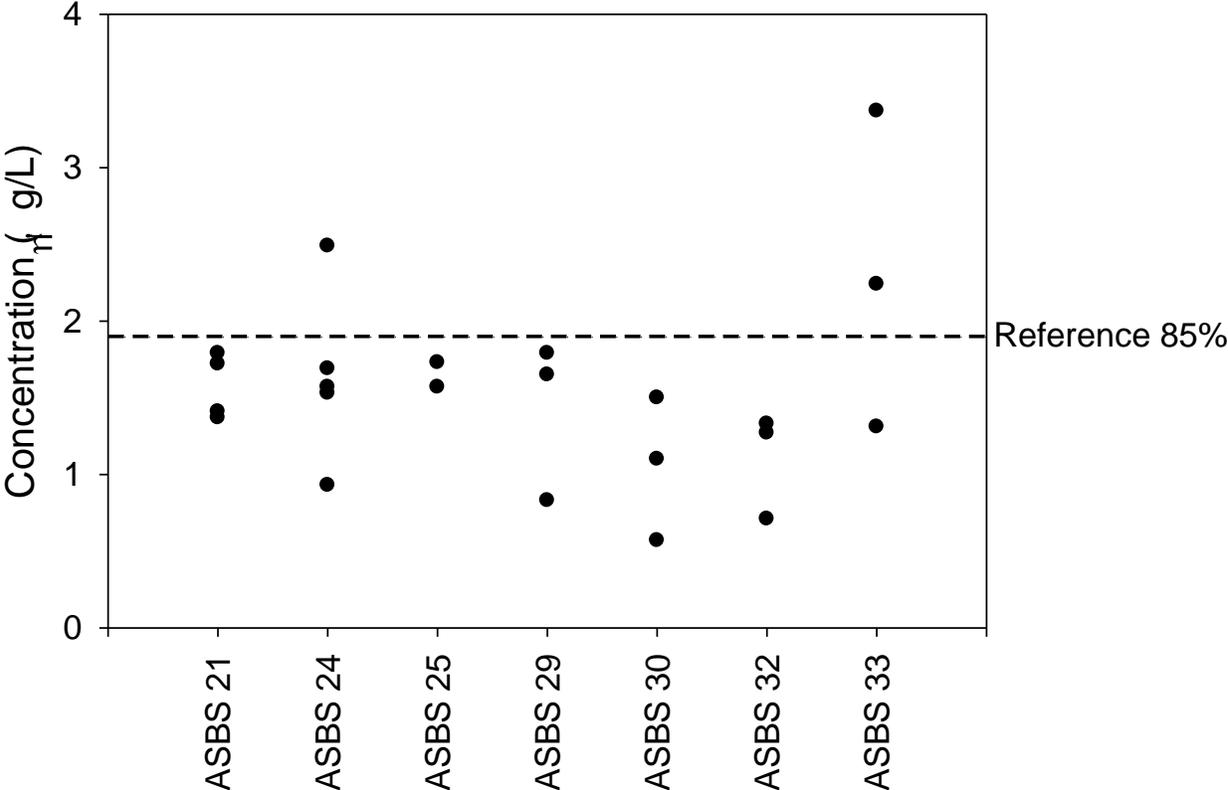
Dissolved Organic Carbon



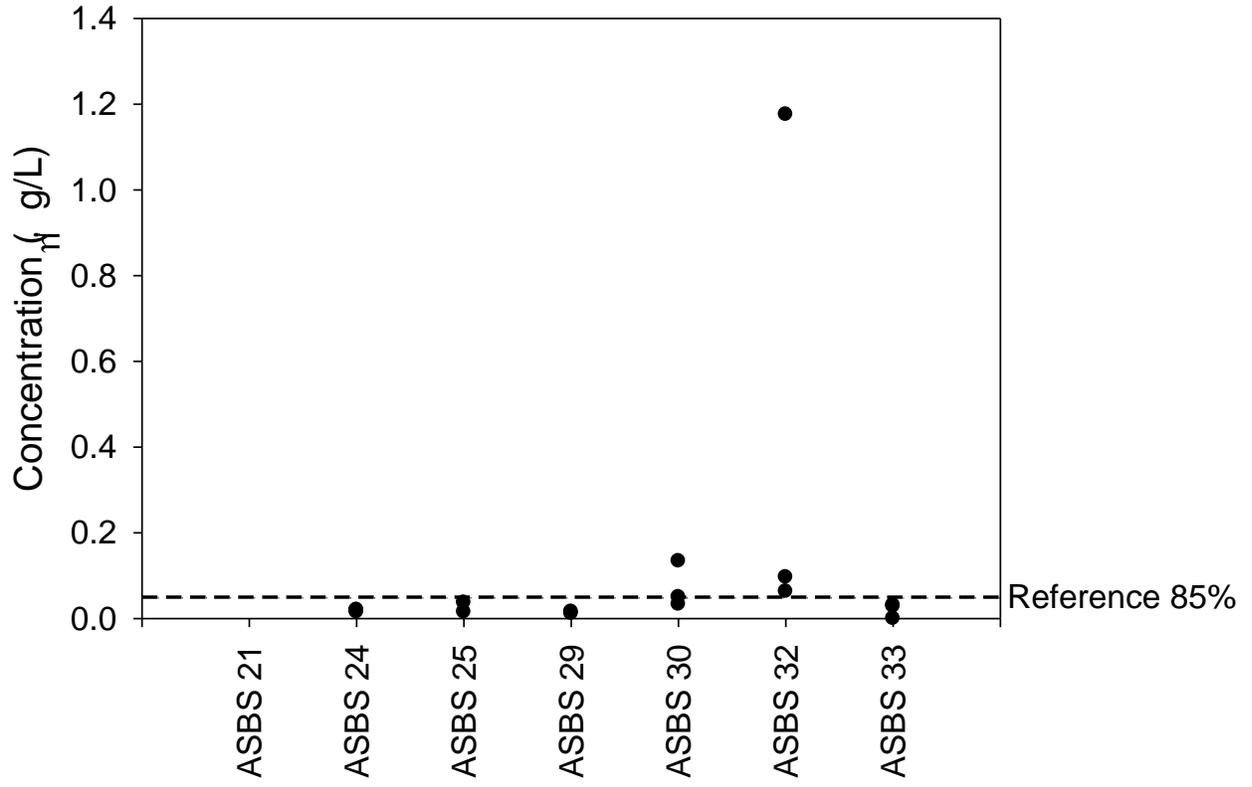
Arsenic-Dissolved



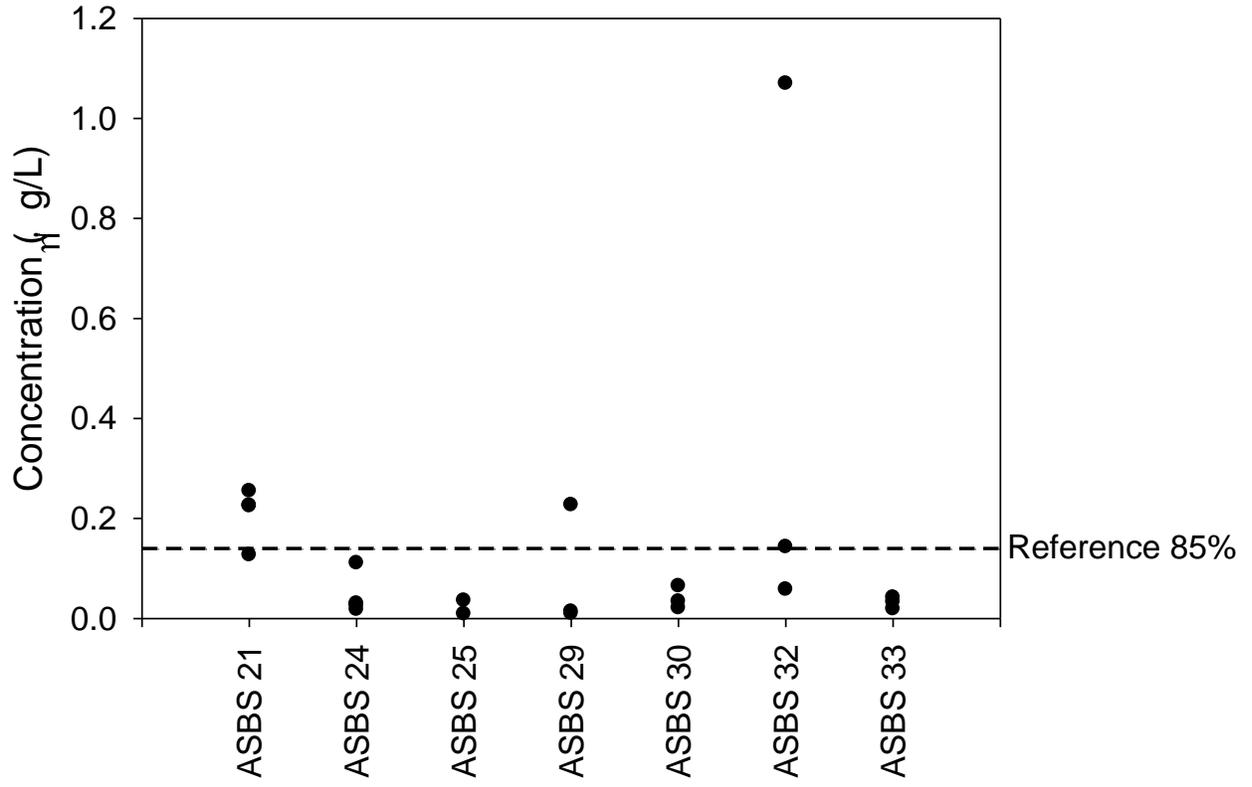
Arsenic-Total



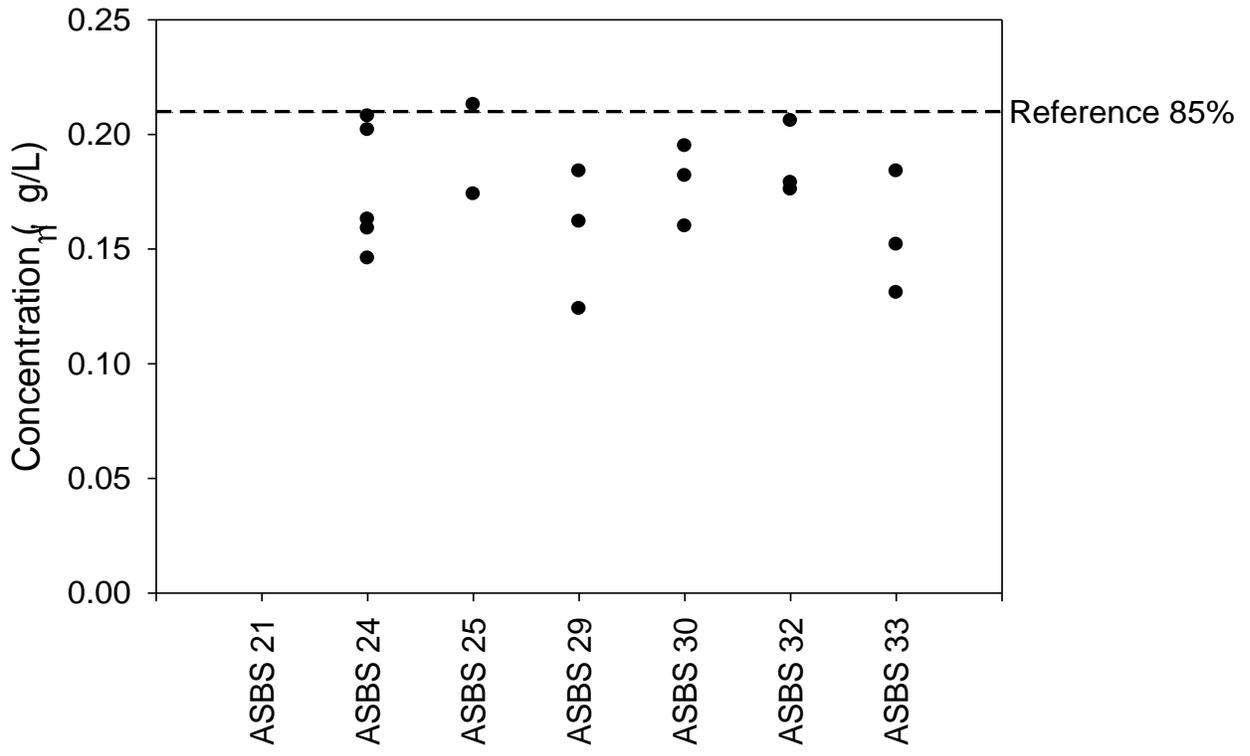
Cadmium-Dissolved



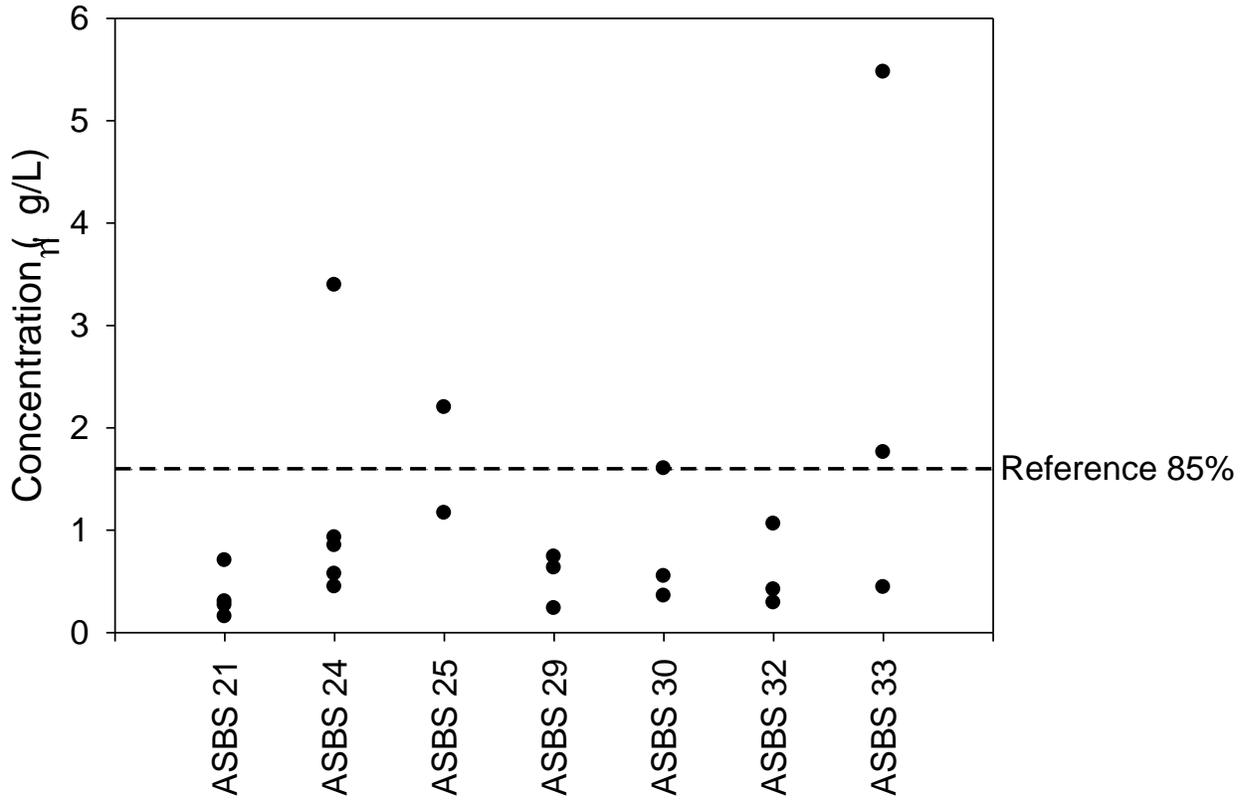
Cadmium-Total



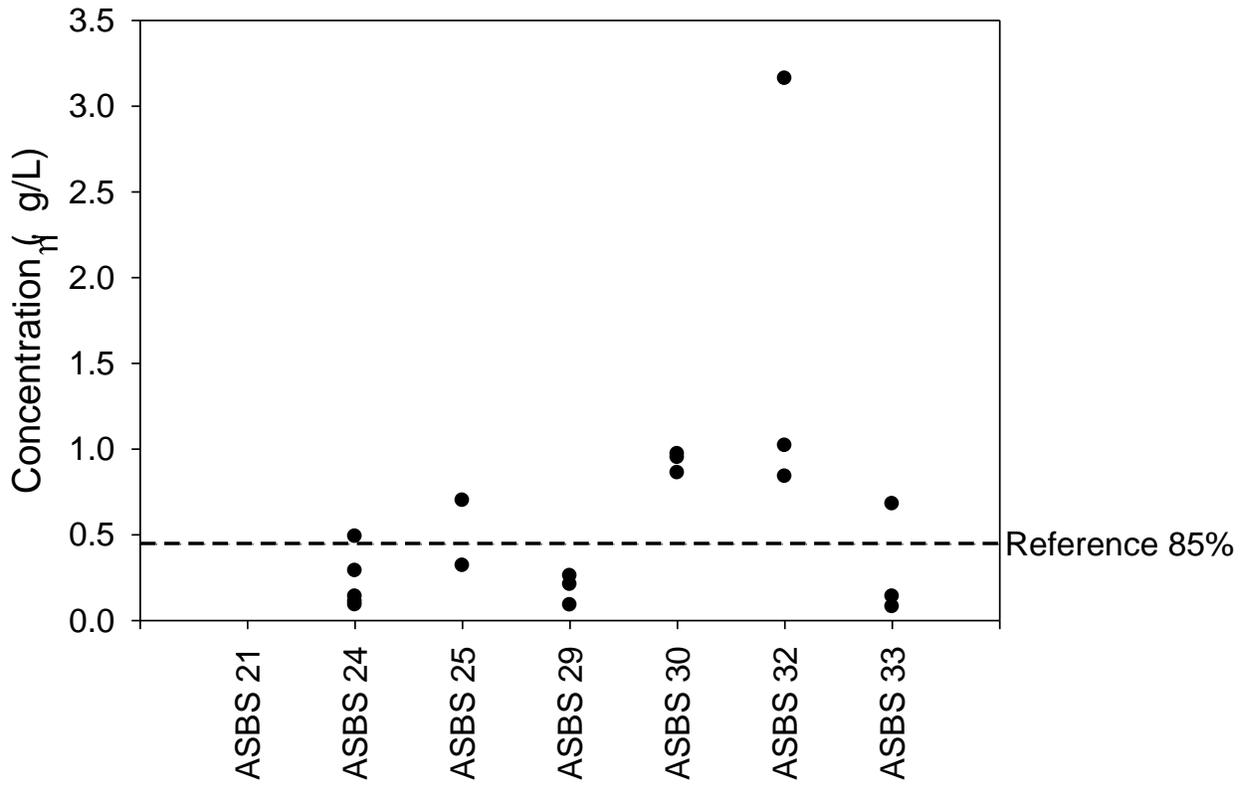
Chromium - Dissolved



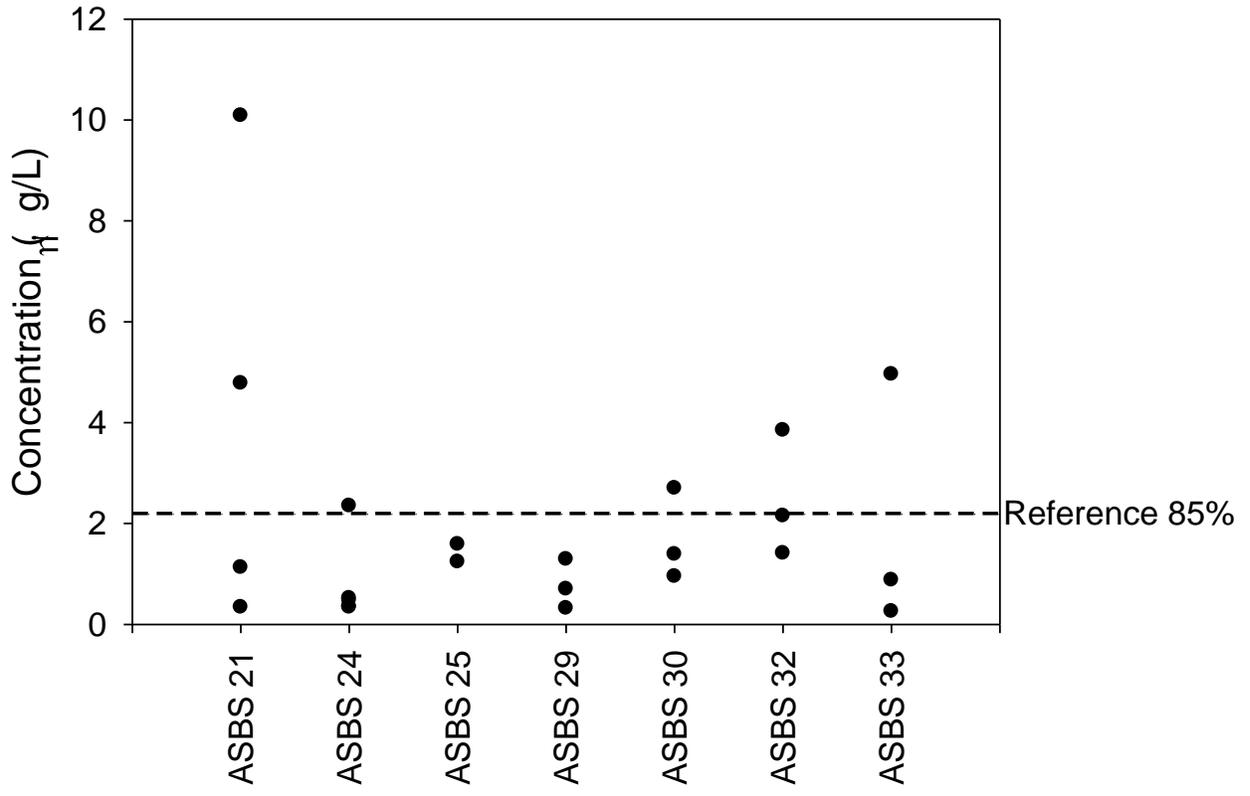
Chromium - Total



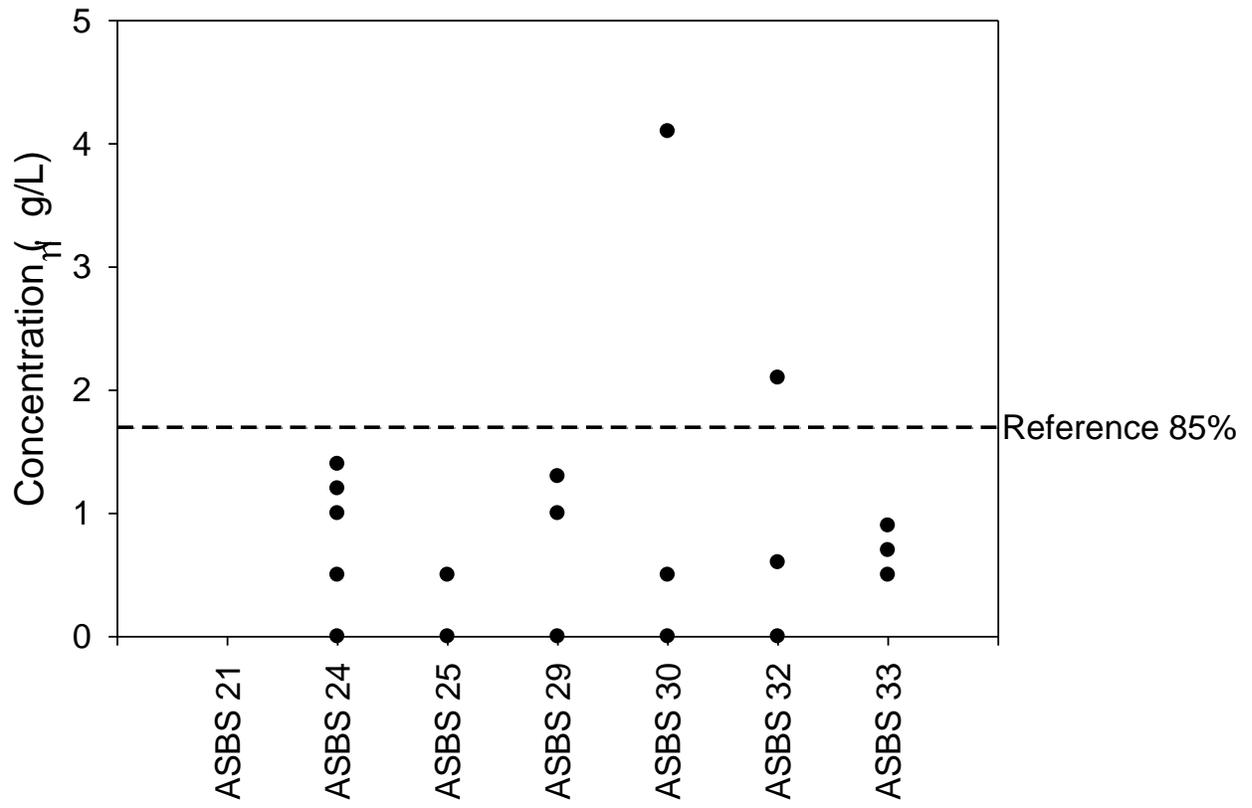
Copper - Dissolved



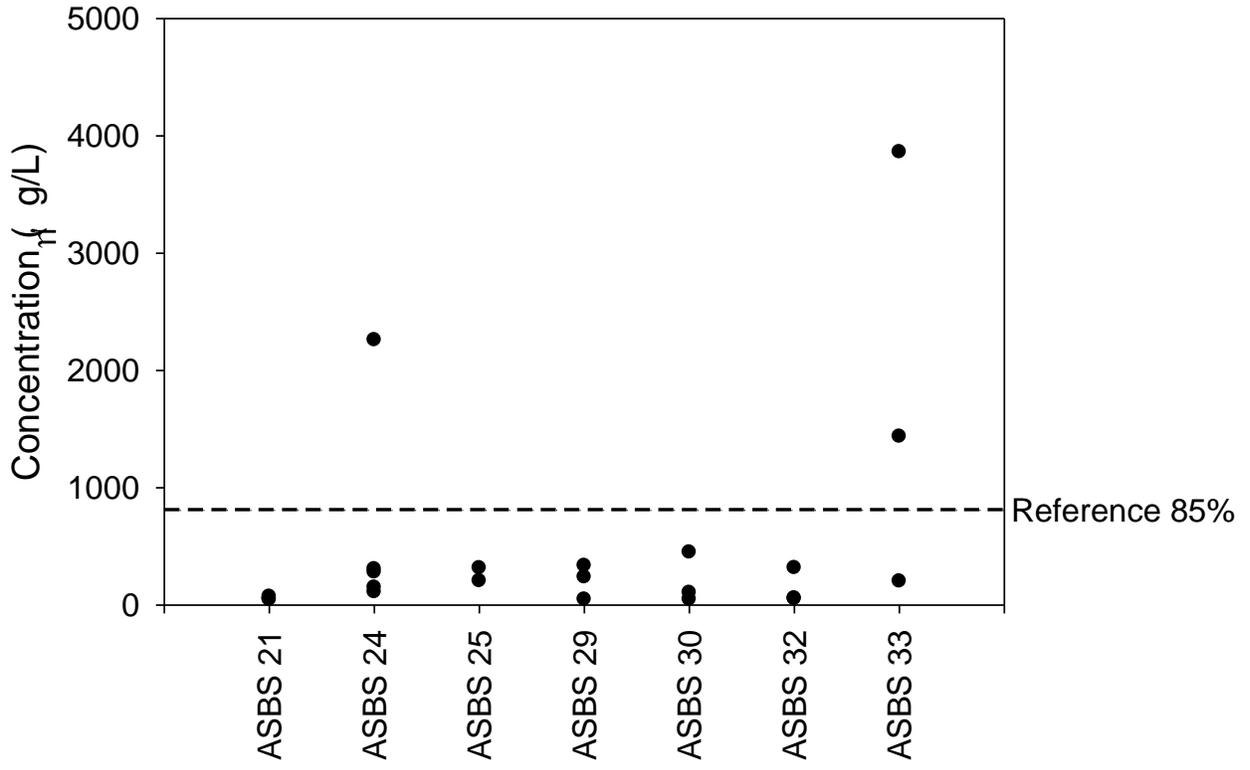
Copper - Total



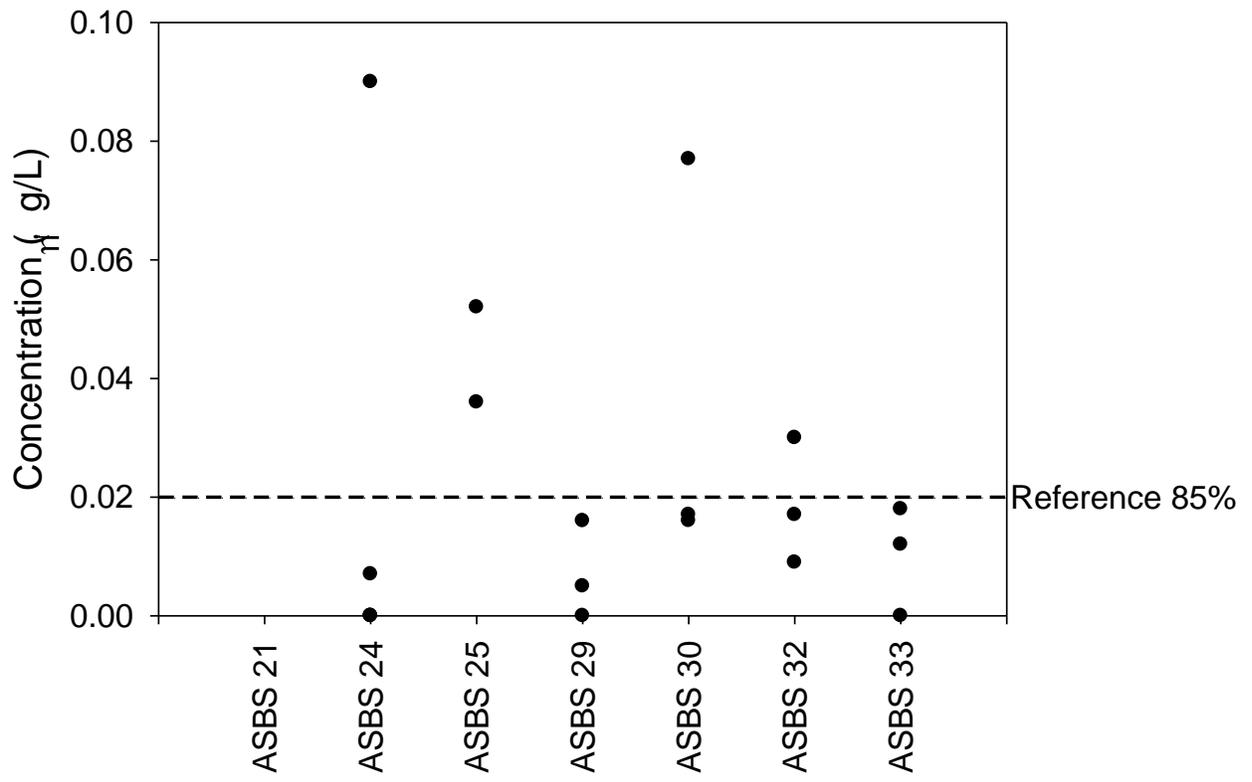
Iron - Dissolved



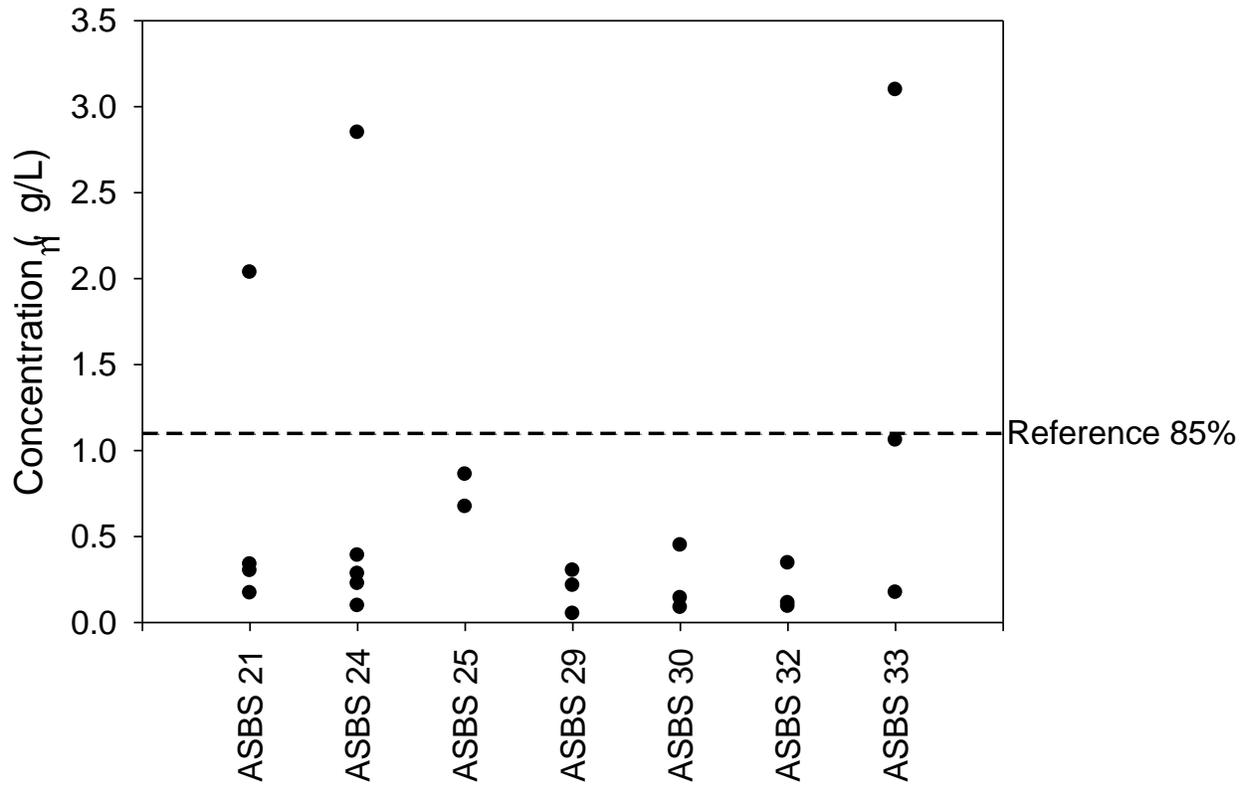
Iron - Total



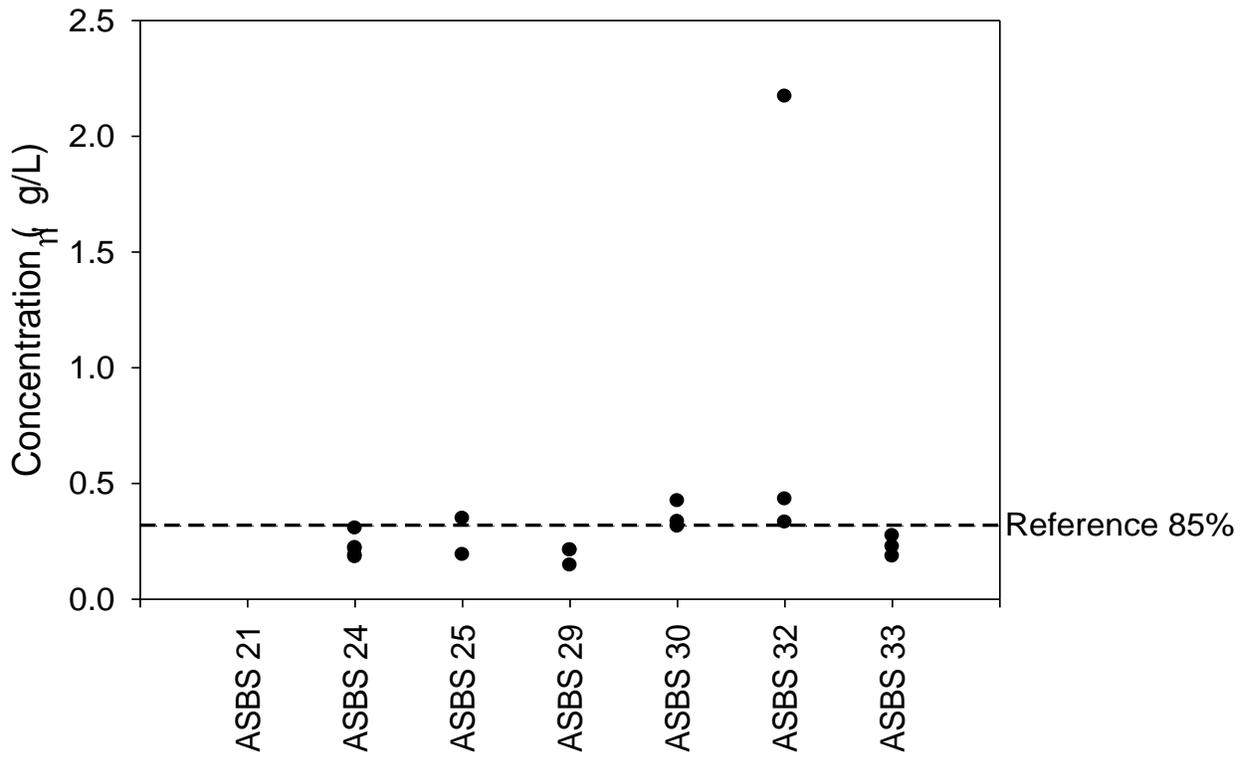
Lead - Dissolved



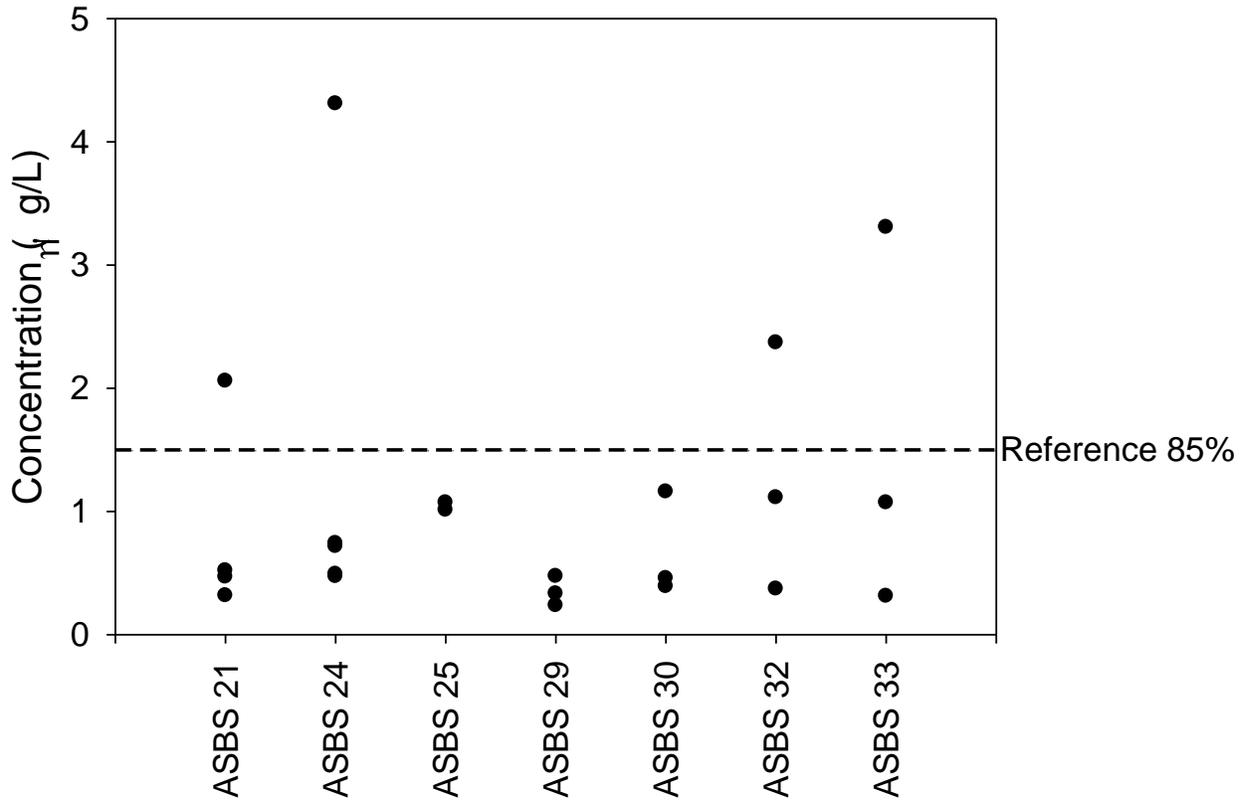
Lead - Total



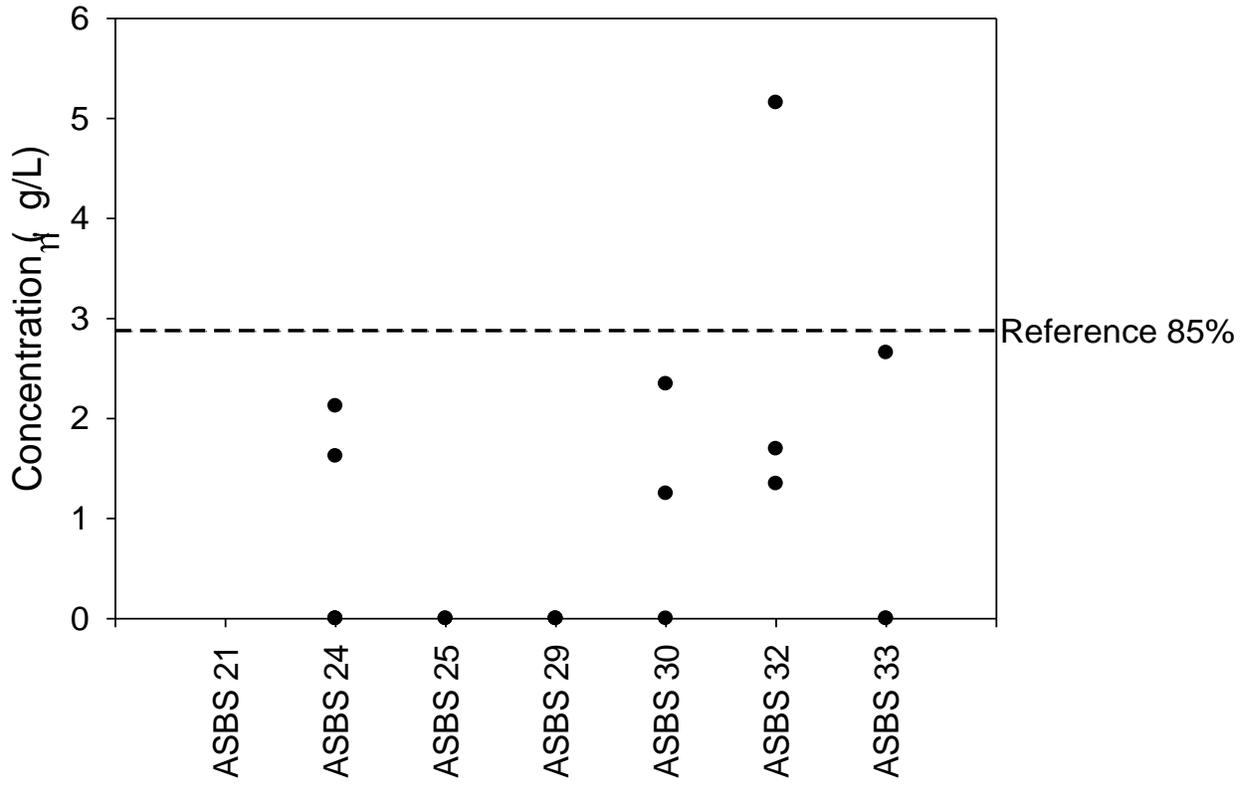
Nickel - Dissolved



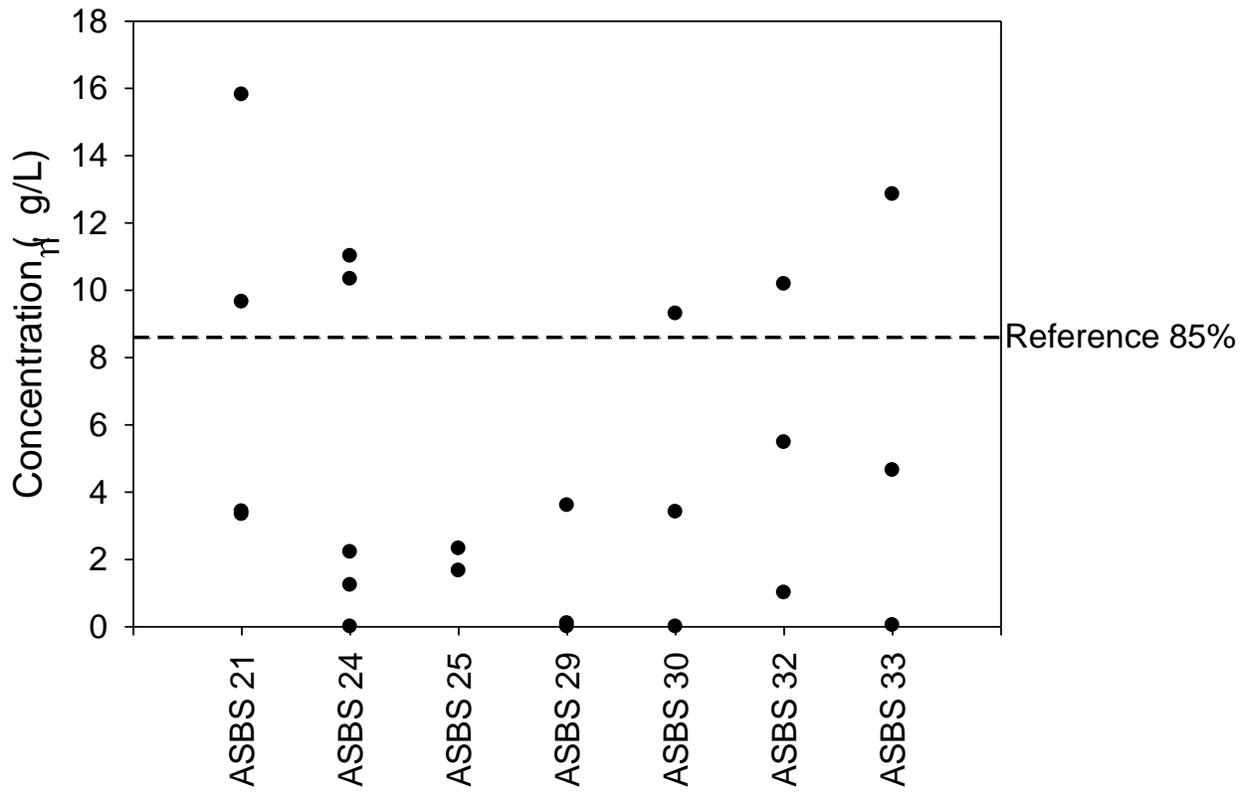
Nickel - Total



Zinc - Dissolved



Zinc - Total



Total PAH

