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Preliminary Ecological Risk Assessment for Nitrogen at Pearl Harbor Naval Shipyard

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ADMINISTRATIVE INFORMATION

The work described in this report was performed for Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, Code 106.3 by the SSC San Diego Marine Environmental Quality Branch (D362).

EXECUTIVE SUMMARY

Pearl Harbor Naval Shipyard (PHNSY) dry dock operations are regulated under the National Pollutant Discharge Elimination System (NPDES), which mandates specific discharge restrictions for several contaminants. Since the last NPDES permit in October 1992, the Shipyard has frequently exceeded State requirements for dry dock nutrient discharge in the form of total nitrogen (TN), nitrate-nitrite (NO_x), or ammonia (NH_3).

Nitrogen is an essential nutrient for biological health and marine ecosystem integrity. The role nitrogen plays as a "pollutant" is related to eutrophication when present in excess amounts beyond the natural capacity of a given system to assimilate or flush the excess. Eutrophication is simply the process of over stimulated algae growth due to water enrichment from inorganic plant nutrients, primarily nitrogen, and phosphorus. Secondary effects of eutrophication include loss of submerged aquatic vegetation, nuisance/toxic algal blooms, and low dissolved oxygen values, which may, in turn, impact the health and vitality of fish, shellfish, and other marine organisms. While eutrophication represents a natural process, the occurrence of accelerated and above average eutrophication rates has been attributed to human impacts on the surrounding watersheds (Bricker et al., 1999).

The 1992 NPDES permit, which expired in 1994, has been administratively extended during the renewal process (author's post-report note: the Shipyard applied again in 2000 and the permit was once again extended and not yet reissued as of fall 2001). The State of Hawaii disallowed a Shipyard request to remove nutrient monitoring from any new permit, and then began discussions of proposed Notice of Violations (NOVs) for nutrient water quality violations. The Shipyard has maintained that dry dock operations do not contribute substantial nutrient loading to the discharge, but that inputs from sources outside the Shipyard are possible contributors to the high nutrient levels. In April 2000, the Shipyard submitted an application for a new permit.

In the fall of 1999, the Marine Environmental Quality Branch (D362), Space and Naval Warfare Systems Center, San Diego (SSC San Diego) was tasked with analyzing Pearl Harbor ambient and discharge nutrient data in support of the Shipyard's permit renewal process. The purpose of this analysis was to define the likely causes of elevated nitrogen discharges and provide a preliminary ecological risk assessment (ERA) as to possible impacts upon the local marine ecosystems from the ambient nutrient levels in Pearl Harbor.

There are several sources of nitrogen in Pearl Harbor. However, effluents are routinely monitored at only the Shipyard and the Waste Water Treatment Facility at Fort Kamehameha (WWTFFK). Nitrogen concentrations in these effluent data and at several ambient monitoring locations indicate that the Shipyard and the treatment facility represent two distinct nitrogen sources. However, other important sources of nitrogen in Pearl Harbor that have not been well-characterized include streams and springs that drain much of the surrounding non-Navy lands, as well as groundwater, which may be seeping onto Navy land already contaminated with excess nitrogen. Since the Shipyard effluent is regulated at Water Quality Standards (WQS) levels, it is being singled out by the State as a major source. The arithmetic means of all forms of nitrogen frequently have exceeded their corresponding limits, ranging from just over the limit for TN, and nearly 3 times the limit for NO_x, to over 7 times the limit for NH_3. Nitrogen concentrations in Shipyard effluent and in precursor source inputs to the Shipyard indicate that groundwater seepage and possibly potable water are potentially the cause of elevated nitrogen. However, small sample sizes, limited temporal distribution, and insufficient source/loading characterization all serve to limit the scientific assessment. In comparisons of ambient or effluent data against the respective WQS for the different forms of nitrogen (NO_x, NH_3, and TN), the form that most frequently violated its limit was ammonia, which appears to be responsible for most WQS violations of total nitrogen.

While the effluent concentration data indicates the Shipyard is a distinct nitrogen loading source to Pearl Harbor, a comprehensive mass loading assessment indicates that the Shipyard introduces a relatively small nitrogen load compared to other sources. The best available estimates for nitrogen loading to Pearl Harbor, admittedly rough, indicate that the Shipyard contributes between 0.7 to 2% of total nitrogen, less than 1% of nitrate-nitrite, and 6 to 25% of ammonia. Sources that contribute potentially much greater loads are streams (55% of NO_x, 86% of NH_3), springs (24% of NO_x), and the WWTFFK (15% of NO_x). It appears that during the 1990s, both nitrogen input from the Shipyard and ambient nitrogen concentrations in the harbor have gradually increased. However, nitrogen loads are not increasing ambient concentrations over short periods of time (i.e., days to months). Speculation about dispersion based on limited mixing and flushing characteristics of Pearl Harbor, when combined with ambient nitrogen concentration data, support a general hypothetical explanation for this apparent steady state condition (i.e., resistance to increasing ambient levels).

A preliminary risk assessment was performed to answer the following question: "Do elevated nitrogen levels pose a potential eutrophication risk to designated beneficial uses or to the ecological receptors of Pearl Harbor?" Studies and qualitative observations to date have not revealed the presence of any standard indicators for eutrophication discussed in this report. A technical approach was implemented based on a national assessment of eutrophication in U.S. harbors and estuaries by the National Oceanographic and Atmospheric Administration (NOAA). The approach involves calculating theoretical ambient concentrations using Dissolved Concentration Potentials (DCP) and Particle Retention Efficiencies (PRE) to rank eutrophication risk, relative to the existing data set, which compares urban estuaries and harbors of the United States. The DCP estimates ambient concentrations based on nitrogen loads, combined with total estuary volume and freshwater turnover (USEPA, 1999b). The PRE is the ability of a waterbody to trap suspended particles and the pollutants adhered to those particles. A final refinement of these eutrophication estimates based on DCP and PRE was performed to incorporate harbor-specific loading and ambient nutrient data presented in this report.

Three terms are used in this report to describe different aspects of the eutrophication assessment for Pearl Harbor. The first, "*susceptibility,*" relates directly to NOAA's use of the DCP to determine the relative susceptibility of our nation's estuaries to eutrophication, based on a standard 10,000 ton load per year for every water body assessed. The second, "*status,*" refers to NOAA's incorporation of actual loadings into the DCP model to predict site-specific ambient concentrations. The third, "*risk,*" is used by SSC San Diego authors in this report as the final overarching evaluation of eutrophication after combining the NOAA hypothetical evaluation with the actual ambient data presented previously in this report.

The following findings are explained in the report:

- Without consideration of nitrogen loads, Pearl Harbor has a medium DCP and a medium PRE when compared to other estuaries, which indicates only an *average susceptibility for eutrophication*.
- When adding to the DCP the best available nitrogen loading estimates, *the wet and dry season data yield two of the lowest concentration statuses*, relative to other harbors in the U.S.
- Incorporation of measured ambient nitrogen concentrations confirms, in this assessment, that *Pearl Harbor has a medium eutrophication risk*.

Finally, in the conclusions and results section, recommendations are made in the following areas:

1. Monitoring ambient conditions
2. Assessment of sources and mass loads
3. Modeling nutrient fate and effects
4. Management response to eutrophication concerns

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1. INTRODUCTION

Pearl Harbor Naval Shipyard (PHNSY) dry dock operations are regulated under the National Pollutant Discharge Elimination System (NPDES), which mandates specific discharge restrictions for several contaminants. Since the last NPDES permit in October 1992, the Shipyard has frequently exceeded State requirements for dry dock nutrient discharge in the form of total nitrogen, nitrate-nitrite, or ammonia.

The 1992 NPDES permit, which expired in 1994, has been administratively extended during the renewal process. The State of Hawaii disallowed a Shipyard request to remove nutrient monitoring from any new permit, and then began discussions of proposed Notices of Violation (NOV) for nutrient water quality violations. The Shipyard has maintained that dry dock operations do not contribute substantial nutrient loading to the discharge, but that inputs from sources outside the Shipyard are possible contributors to the high nutrient levels.

The Marine Environmental Quality Branch (D362), Space and Naval Warfare Systems Center, San Diego (SSC San Diego) was tasked with analyzing Pearl Harbor ambient and discharge nutrient data in support of the Shipyard's permit renewal process. The purpose of this analysis is to scientifically define not only the likely causes of high nutrient discharges, but also provide a preliminary ecological risk assessment as to possible impacts upon the local marine ecosystems from high ambient nutrient levels in Pearl Harbor.

2. METHODS

This section is organized into the following sections:

- Data Resources and Statistical Calculations
- Summary Listing of All Resources
- Description of Resources and Statistical Calculations for Effluent-Ambient Comparisons
- Description of Resources and Statistical Calculations for Effluent-Source Comparisons
- Nutrient Trend Analysis

2.1. DATA RESOURCES AND STATISTICAL CALCULATIONS

2.1.1. Summary Listing of All Resources

Chemical analytical data for total nitrogen, nitrate-nitrite, and ammonia are analyzed from the resources listed in Table 1. Facility and station locations are shown in Figures 1 and 2.

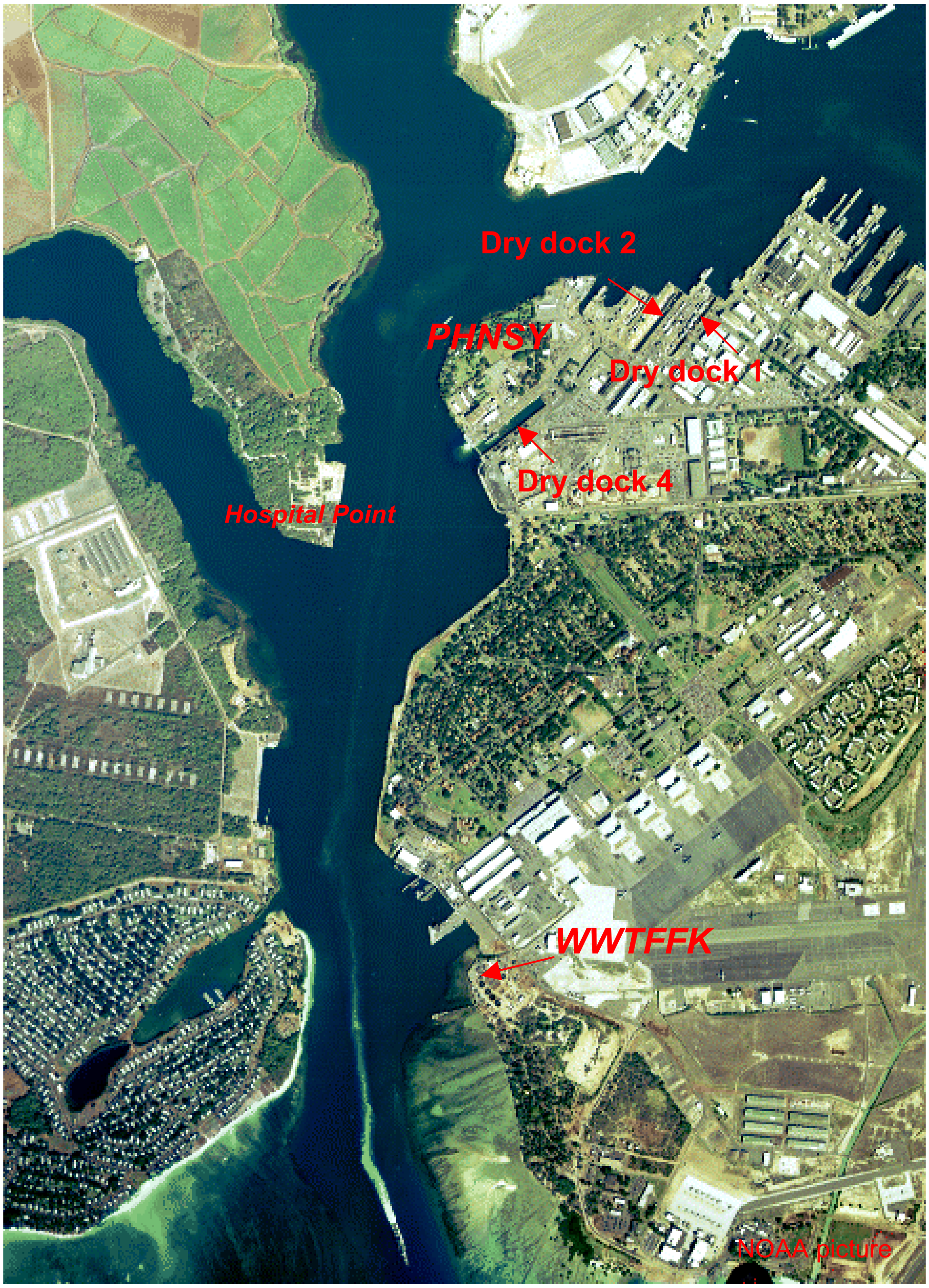

Figure 1. Aerial photograph of Pearl Harbor entrance channel, South Channel, and Pearl Harbor Naval Shipyard.

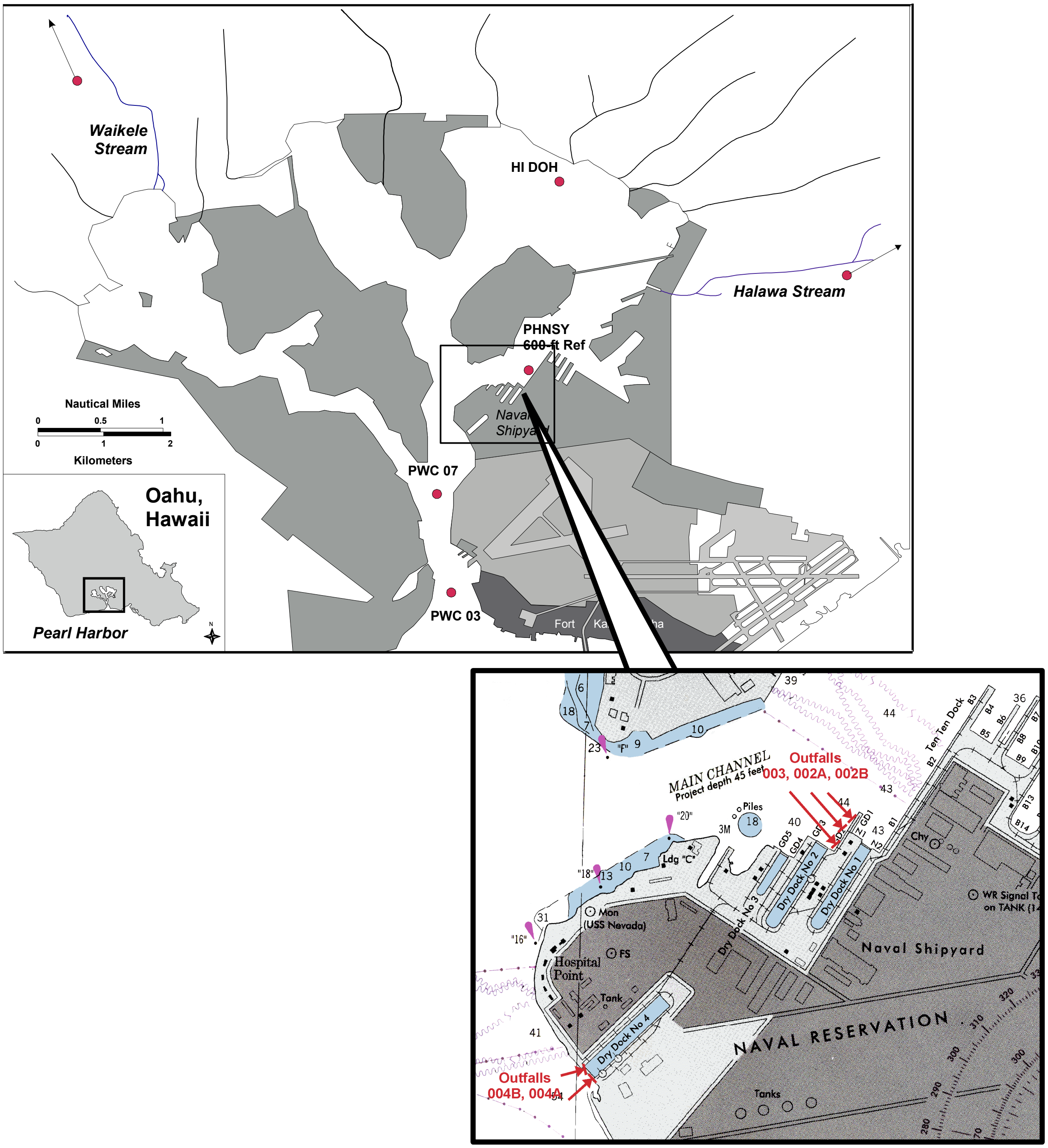

Figure 2. Discharge and monitoring station locations for Pearl Harbor nutrient data analysis.

Table 1. Data resources used for SSC San Diego nutrient analysis.

Type	*Resource*
Effluent data (Dry Docks 1, 2, and 4)	Pearl Harbor Naval Shipyard (PHNSY)
Dry Dock groundwater seepage	Pearl Harbor Naval Shipyard (PHNSY)
WWTFFK effluents	Public Works Center (PWC), Pearl Harbor
Ambient water quality station - Ref 600 ft	Pearl Harbor Naval Shipyard (PHNSY)
Ambient water quality stations (part of WWTFFK permit)	Public Works Center (PWC), Pearl Harbor
Ambient water quality station - Blaisdell Park	Department of Health, State of Hawaii
Ambient stream monitoring (Halawa and Waikele)	United States Geological Survey
Potable water wells monitoring (for wells supplying Pearl Harbor region)	Board of Water Supply, City and County of Honolulu

2.1.2. Description of Resources and Statistical Calculations for Effluent-Ambient Comparisons

AMBIENT NITROGEN COMPARISONS: Shipyard Effluents and Ambient Water

Nutrient data used in the comparison of Shipyard effluents to ambient water monitoring came from three primary sources: PHNSY discharge and reference data; Public Works Center (PWC), Navy Region Hawaii; and Department of Health, State of Hawaii.

PHNSY Dry Dock discharge

PHNSY samples dry dock discharge on a monthly basis from designated outlets 002A, 002B, 003, 004A, and 004B. Data is available for total nitrogen, nitrate-nitrite, and ammonia from January 1993 to May 1999. There is a data gap (i.e., no discharge sample reported) from March 1994 to June 1994, and another from November 1997 to March 1998.

In order to characterize the overall Shipyard nutrient contributions, a geometric mean from all dry dock discharge was calculated for each sampled month and used as the "PHNSY Dry Dock" trend analysis.

PHNSY reference 600 feet

PHNSY has designated an ambient reference site located approximately 600 feet northwest of Dry Dock 1. Data is available from July 1994 to May 1999. Data gaps are more frequent earlier than March 1997 and for the November 1997 to March 1998 time frame.

PWC monitoring stations

PWC continually monitors several ambient water quality stations near the Pearl Harbor entrance channel located north to just south of Hospital Point on Waipio Peninsula. This effort is in support of the WWTFFK NPDES compliance. Six surface and six corresponding sub-surface (3-meter depth) stations represent spatial monitoring away from the sewage treatment plants (STP) outfall in both directions (harborside and oceanside). Data is available monthly from April 1995 to March 1999.

A geometric mean, including all PWC station data by month, was calculated to compare to the PHNSY geometric mean discharge. Additionally, Station RW07 closest to the Shipyard (just south of Hospital Point) and RW03 (in the vicinity of the STP outfall) are also used to compare a far-field and near-field region to Shipyard nutrient levels.

HI DOH monitoring station

The State of Hawaii Department of Health (HI DOH) conducted limited nutrient monitoring for a site in East Loch between Ford Island and Blaisdell Park. Data was obtained from the U.S. Environmental Protection Agency (USEPA) STORET database and directly from the Hawaii Department of Health, which contained slightly more amplifying information. Episodic monitoring was conducted between January 1993 and May 1997. The apparently high method detection limit (100 μg/L or ppb for total nitrogen, 10 μg/L for nitrate-nitrite, and 50 μg/L for ammonia) limit the data's usefulness in determining low level ambient conditions for East Loch (note that μg/L and ppb are equivalent and used interchangeably in this report).

NOSC

The Naval Ocean Systems Center (NOSC), the former name for SSC San Diego, conducted a series of water quality measurements of ambient Pearl Harbor conditions at nine stations in May 1990 (Figure 3). Although not as applicable from a time trend perspective, the data does provide a useful snapshot of nutrient concentrations from the southern portion of East Loch to the Entrance Channel.

2.1.3. Description of Resources and Statistical Calculations for Effluent-Source Comparisons

SOURCE NITROGEN COMPARISONS: Shipyard Discharge, Potable Water, and Groundwater Seepage

Time series and T-test comparisons can be made between PHNSY discharge and a smaller set of measurements made by the Shipyard to screen possible non-operational/industrial nutrient inputs to the discharge.

Potable water

PHNSY conducted a small series of nutrient measurements from potable water supplied to naval vessels while within the dry docks. Unused potable water is routed to the dry dock floor and forms a component of the dry dock discharge to Pearl Harbor. Data is available from November 1997 to March 1998 (n = 5).

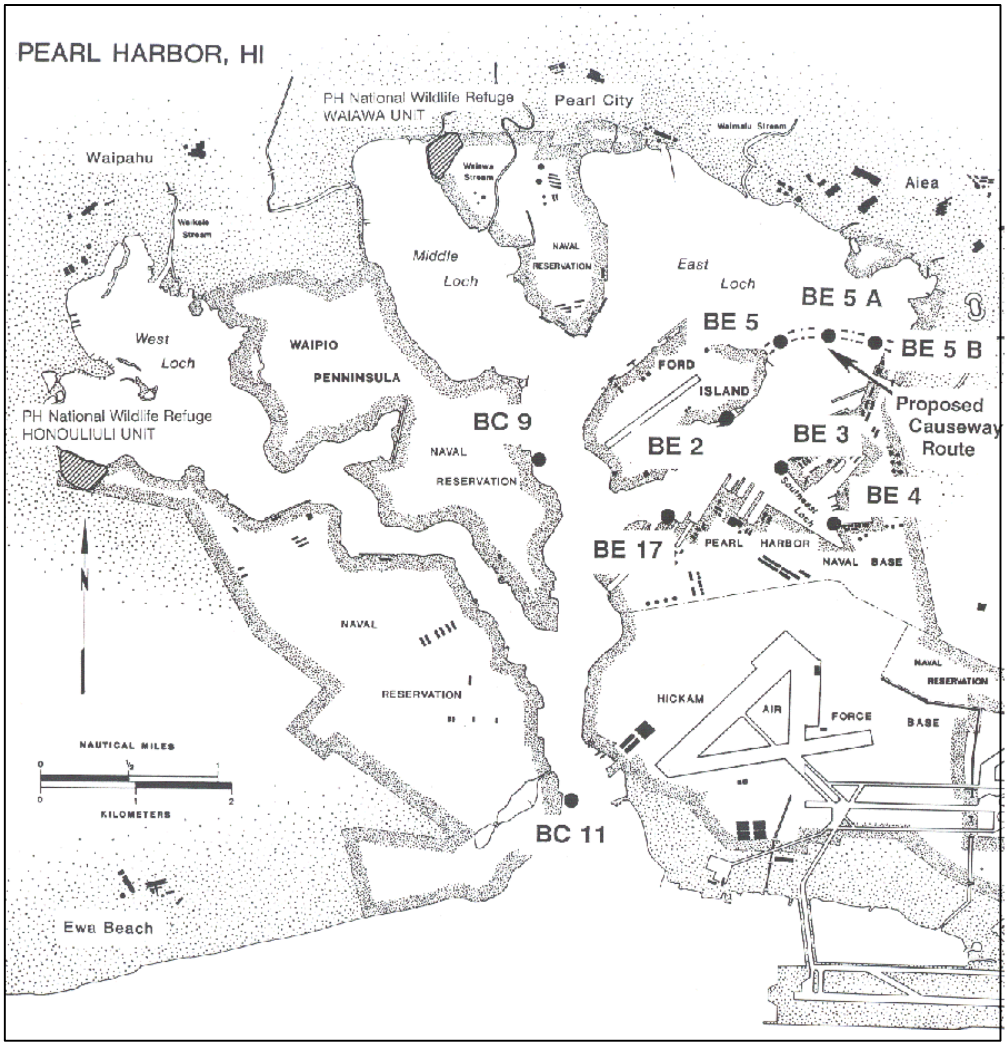

Figure 3. Station locations for Pearl Harbor ambient monitoring study May 1990 (source: Grovhoug, 1992).

Harbor water intake

PHNSY conducted a small series of nutrient measurements from harbor water following intake into the land-side pump station. Data available is the same as for potable water (n = 5).

Dry Dock seepage

PHNSY measured nutrient content for 2 non-consecutive months groundwater seepage into Dry Dock 1, 2, and 4. Data is available for February and April 1999 (n = 6). For Shipyard wide nutrient trend analysis, the geometric mean from all dry docks was calculated for each month.

2.2. NUTRIENT TREND ANALYSIS

For both effluent-ambient and effluent-source comparisons, the following graphical presentations were used to evaluate the data sets:

- Student's T-test (for two samples assuming unequal variances). The T-test is typically used to detect differences in two data sets, each of which represents a collection of values obtained in the same manner for the same parameter. The basic question being answered in this test is "Are the two data sets different?" By answering this question, we can first see which data sets may be close enough to be considered to be associated with the same source. However, it should be noted that with a high variability in either of the data sets, especially when the magnitude ranges overlap, a finding of "no difference" must be treated with some caution. Specifically, high variability (statistically expressed as variance in the test) can cause the test to show no difference when in fact this high variance may be due to one or two single spikes that are far from the mean and not representative of the data set. Consequently, the T-test is better at detecting true differences between data sets than similarities.
- Bar graphs. To assess spatial trends for the different nitrogen forms among the various locations for both the effluent-ambient and effluent-source comparisons, bar graphs were created to display the nitrogen mean values relative to a north-south transect within Pearl Harbor. Since the T-tests can only compare one data set against another, the bar graphs also provide a way to show how all the data sets compare among one another in a single view.
- Time series plots. In order to graphically illustrate potential trends over long time periods (2 years and more) in nutrient concentrations for the Pearl Harbor region, time series graphs comparing PHNSY geometric mean discharge to both the (1) ambient monitoring and (2) source monitoring geometric means are presented for each nutrient parameter. Additionally, when the T-test yields confusing results, the time series plots are useful in examining the problem. And since the bar graphs also depict only the means, these time series plots permit us to look deeper into the time-varying characteristics of each data set.

3. RESULTS

First, in order to place nitrogen concentration values in perspective, it is useful to review the regulatory standards imposed by the State of Hawaii on Pearl Harbor and the Naval Shipyard. For Pearl Harbor, the State WQS for total nitrogen (TN), nitrate/nitrite (NO_x), and ammonia (NH_3) are 300 µg/L, 15 µg/L, and 10 µg/L, respectively (Title 11 Chapter 54 Hawaii, Revised Water Quality Standards). These values are adopted directly, with no allowance for dilution, as the Shipyard's effluent limits.

3.1. AMBIENT NITROGEN COMPARISONS: SHIPYARD EFFLUENTS AND AMBIENT WATER

Significant findings from a Student's T-test analysis of PHNSY discharge versus the ambient monitoring data are presented in Table 2 by nutrient parameter. Since most of the DOH data was from January 1993 to May 1997, the 1993 to 1997 PHNSY data are used for comparison with DOH. Other comparisons were for the periods 1997 to 1999.

Table 2. T-test results for PHNSY effluent discharge and various ambient monitoring stations.

PHNSY Effluent vs.	PWC 03	PWC 07	Ref 600 ft	DOH *
Total nitrogen	ND	-	-	-
Nitrate-nitrite	-	-	-	-
Ammonia	-	-	-	ND

Remarks:
ND = not statistically different
- = statistically different
* most of DOH data only available from Jan 1993 to May 1997; therefore, used PHNSY data from 1993 to 1997 for this comparison.

At first glance, the T-test results show that the Shipyard effluent could be related, from a statistical perspective, to the near-field PWC site (03) for TN, and to the DOH station for ambient NH_3. However, the high variability found within these data sets limits the usefulness of these T-test comparisons. For instance, inclusion of more recent PHNSY effluent data in the PHNSY-DOH station comparison would lead to a finding of "statistically different." It should be noted that the DOH station is probably the weakest data set with which to make T-test comparisons because of its high detection limit of 50 µg/L for ammonia. This results in a less accurate depiction of ambient conditions in northern East Loch.

To assess whether long-term monitoring has shown a historical improvement or degradation of effluent and ambient water quality, mean nitrogen concentrations are presented in Table 3 comparing a recent time period (1997 to 1999) with an older one (1993 to 1996). The disturbing trend is that mean ammonia and total nitrogen concentration increase over time for the combined Shipyard dry dock discharge, while ambient stations remain the same or decrease. The large standard deviations relative to the means is one way to show the extremely high variability among the data at any given station, regardless of the data set size (i.e., number of samples). Total nitrogen trends show a non-statistically significant decline at all monitoring stations with the exception of PWC 03, which essentially showed no change. Although the Shipyard total nitrogen shows an upward trend indicating a possible degradation of effluent quality, it can be argued that the mean change is again not significant because of the high variability measured by the large standard deviations and overlapping data sets.

Table 3. Nutrient geometric mean concentrations by source.

Location	Total Nitrogen 1997–1999	Total Nitrogen 1993–1996	Nitrate-nitrite 1997–1999	Nitrate-nitrite 1993–1996	Ammonia 1997–1999	Ammonia 1993–1996
	Geometric mean concentration (µg/L)					
Monitoring station						
PWC Station 03	274 ±113 (n=27)	273±196 (n=9)	62±58 (n=27)	52±112 (n=21)	37±64 (n=27)	68±63 (n=21)
PWC Station 07	176±83 (n=27)	204±177 (n=9)	5±7 (n=27)	5±48 (n=21)	28±27 (n=27)	34±24 (n=21)
PHNSY Ref 600 ft	192± 121 (n=25)	236±66 (n=5)	13±10 (n=25)	8±4 (n=5)	38±35 (n=25)*	17±13 (n=7)
DOH Blaisdell Park	100±0 (n=2)	153±86 (n=24)	10±0 (n=2)	12±9 (n=24)	50±0 (n=2)	53±14 (n=23)
Discharge station						
PHNSY Discharge	307±173 (n=27)	234±107 (n=45)	42±29 (n=27)	41±21 (n=47)	77±56 (n=27)	60±25 (n=47)

Remarks:
* significantly different from 1993 to 1996 time period
± = standard deviation
n= = number of data points

To provide another perspective for comparing the sites among each other, mean nitrogen concentrations for the two time periods are presented in Figure 4 using bar graphs and error bars to represent the standard deviations. This view at first appears to support the T-test in showing some similarity in total nitrogen measurements between Shipyard effluent and PWC 03. However, these two monitoring stations geographically bound Station PWC 07, which has a much lower mean. Further, with the exception of total nitrogen, all PWC stations were shown to be statistically different from the effluent station via the T-test (Table 2). Consequently, it is more likely that the similarity between these two stations are the result of two distinct sources of total nitrogen producing similar ambient concentrations close to their respective points of discharge. To provide additional insight into the somewhat confusing T-test results, Figures 5 through 7 contain time series graphs of PHNSY dry dock effluent and ambient monitoring data from 1997 to 1999 (the time series from 1993 to 1999 are contained in Appendix A). In these graphs, one can see that there is large variability in the reference site data for NO_x and NH_3. The time series plot is useful for indicating any potential relationships among the various data sources over time, which may be missed by the standard T-test or central tendency value (i.e., mean) comparisons.

Figure 5, for instance, is useful for evaluating overall water quality with respect to nitrogen. Only the near-field PWC 03 monitoring station consistently violates the 300 µg/L WQS for total nitrogen. The other ambient stations are about one-half of this level or lower. For NO_x and NH_3, the situation is more problematic. For NO_x, the Ref 600 ft site routinely violates WQS (15 µg/L), while the DOH site is close to the limit (10 µg/L, compared to 15 µg/L) (Figure 6). For NH_3, there is even greater concern since all ambient stations exceed the 10 µg/L limit by 2 to 5 times (Figure 7). Since the Shipyard effluent is regulated at the same WQS levels, it is being singled out by the State as a major source. The means of all forms of nitrogen violate their corresponding limits, ranging from just over the limit for TN, and nearly 3 times the limit for NO_x, and to over 7 times the limit for NH_3.

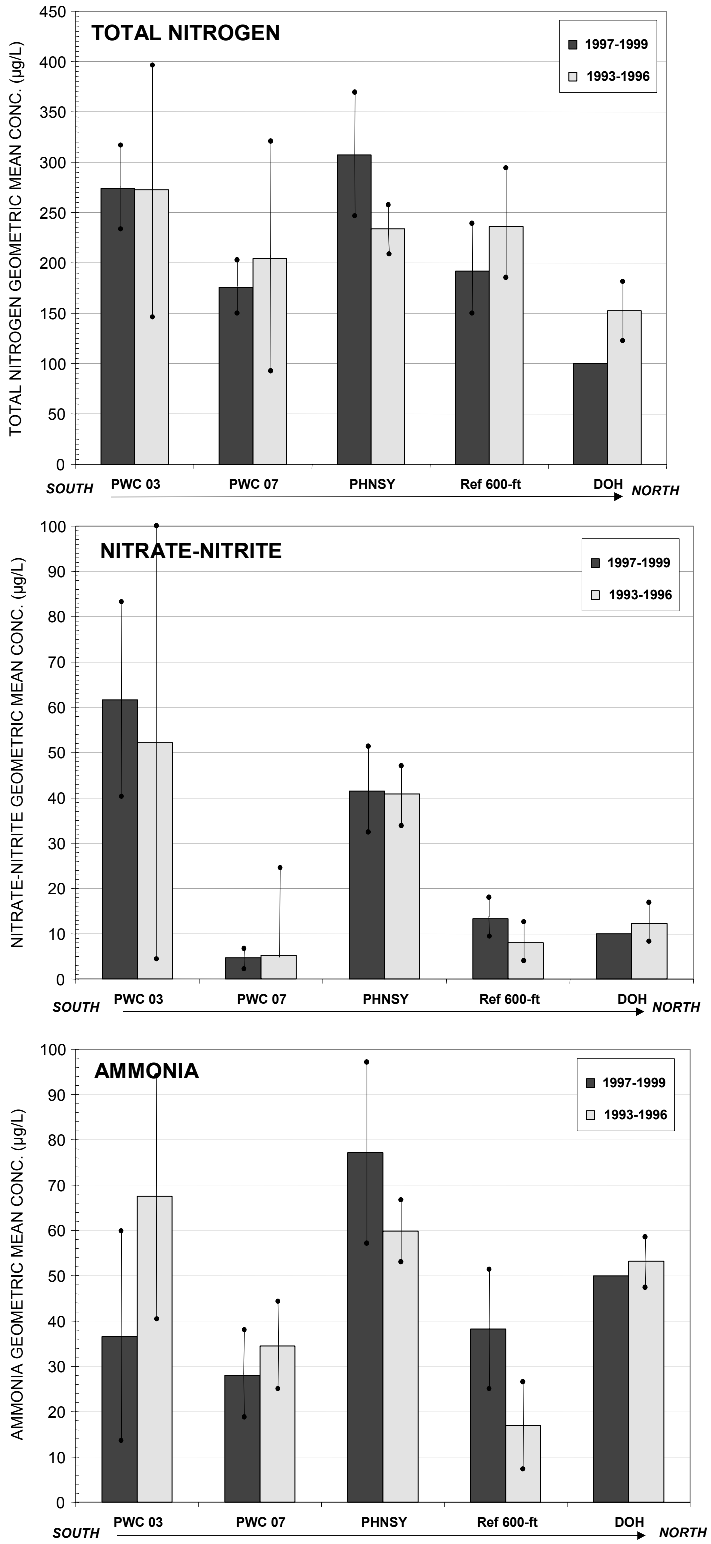

Figure 4. Nutrient geometric mean total nitrogen, nitrate-nitrite, and ammonia concentration by station from south-to-north. (Notes: (1) Bars indicate 95% Confidence Limits. (2) PHNSY is unique in this figure as an effluent, not an ambient station.)

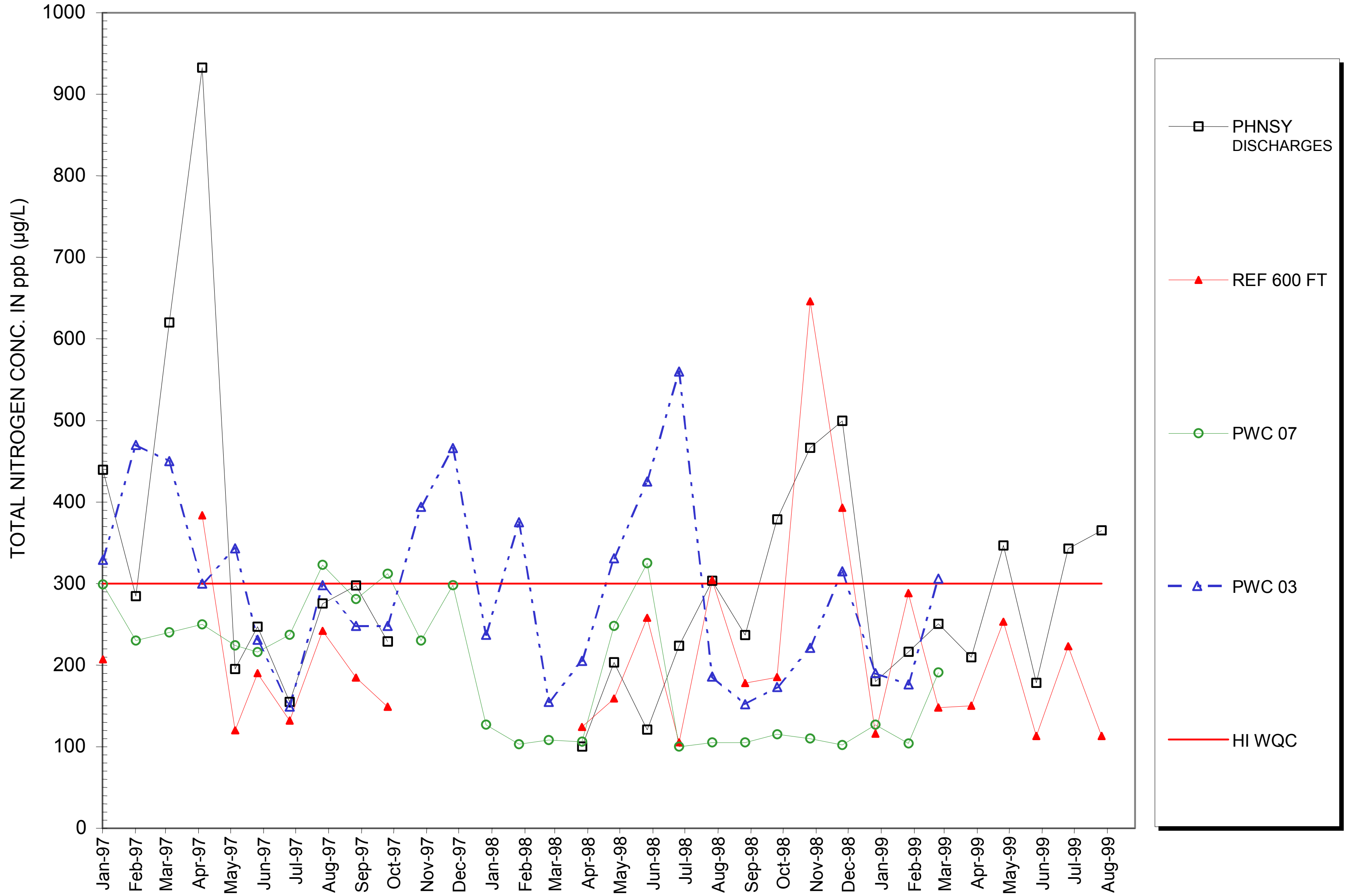

Figure 5. Total nitrogen concentrations from PHNSY discharges and ambient monitoring data (1997 to 1999).

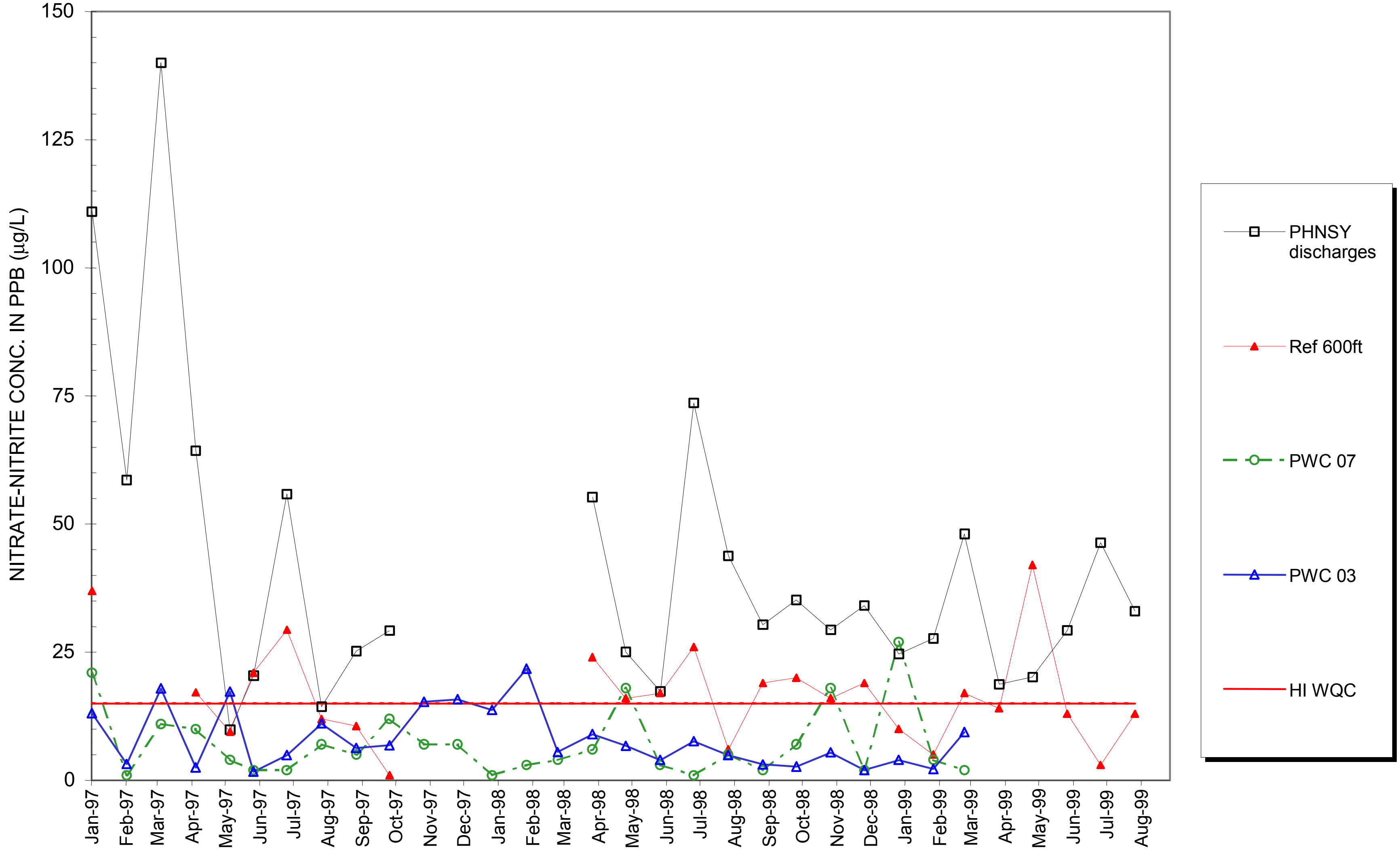

Figure 6. Nitrate-nitrite concentrations from PHNSY dry dock discharge and ambient monitoring data (1997 to 1999).

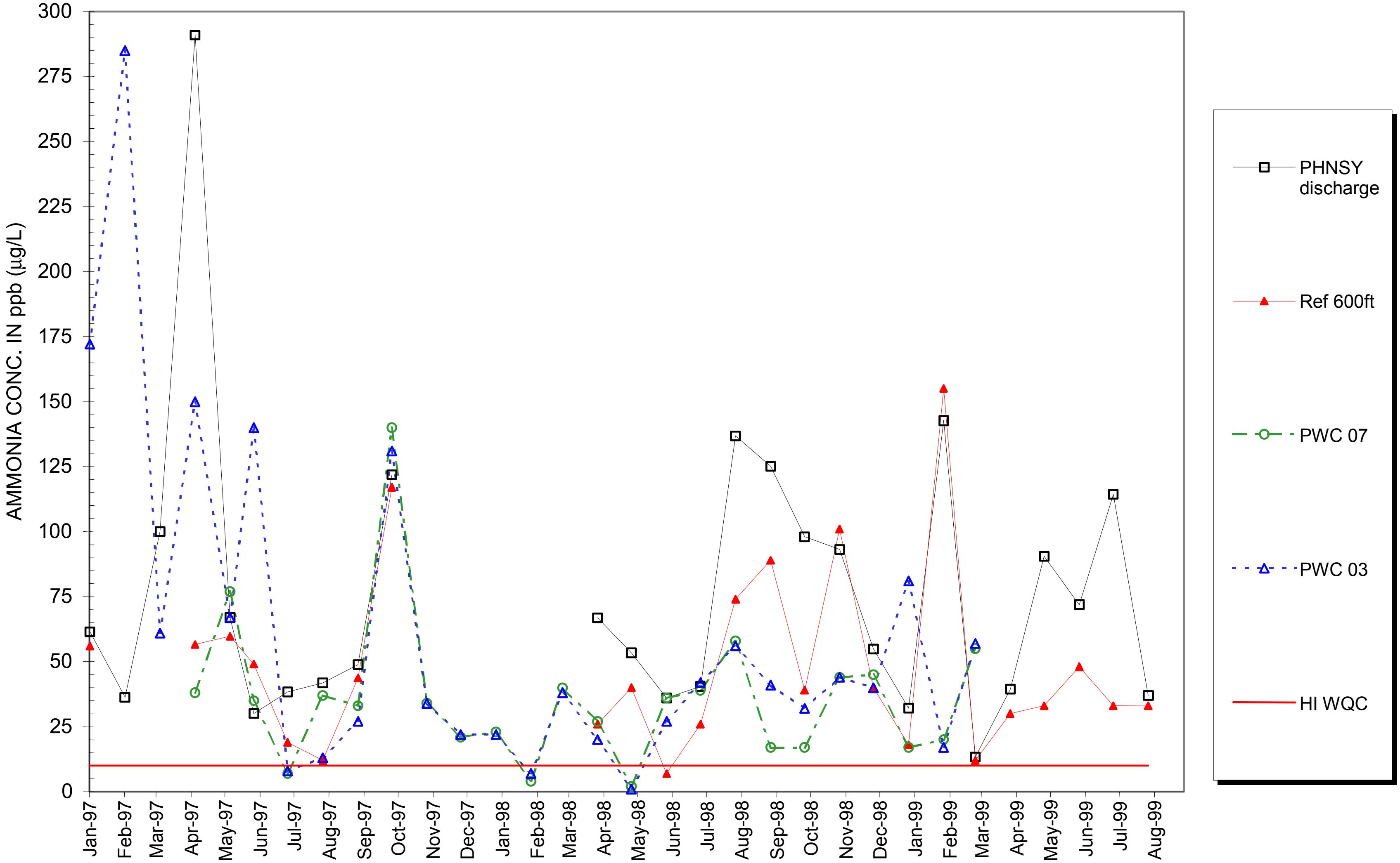

Figure 7. Ammonia concentrations from PHNSY dry dock discharge and ambient monitoring data (1997 to 1999).

The time series plot also supports the conclusion that any similarity between Shipyard effluent and PWC 03 is only that they represent two distinct and significant sources of nitrogen. There is no apparent temporal relationship between the month-to-month data from these two stations. However, in some cases, temporal comparisons of trends across all data sets indicate some similarities among different locations, suggesting that nitrogen pulses in Pearl Harbor might be caused by regional increases in loading due to widespread changes in environmental input or cycling. Some examples might include rainfall events that could increase nitrogen loads due to stream inputs, surface runoff, and atmospheric deposition. Nevertheless, these associations are not strong or consistent across the data sets. Additionally, it is known that sampling is not coordinated among the various locations; they are taken at different times, and with each data point represented by a single grab sample.

Finally, Figure 8 depicts ambient concentrations for total nitrogen and ammonia that were collected by NOSC during a May 1990 study (Grovhoug, 1992). It is useful for providing a historical snapshot of ambient conditions that were assessed for several different stations by a single assessor. Consequently, one would expect to have greater confidence in the consistency of the chemical analyses. The results for total nitrogen show fairly homogeneous concentrations across the nine stations, but showed a possible layering effect at station BC-11 that was not present elsewhere. Considering the large volumes of lighter fresh water discharged close to BC-11 by the WWTFFK, this vertical stratification might be expected. However, the results for ammonia are more confusing, with a high spike and surface layer effect at a location close to the Shipyard. This potential ammonia concern at the Shipyard will be discussed later. The most important observation to glean from this historical snapshot in Figure 8 is that nitrogen levels appeared to be lower at the beginning of the decade. Most of the stations in 1990 had TN concentrations of between 100 to 125 µg/L, lower than the 168 to 274 µg/L means measured from 1993 to 1999 at three of four ambient stations in Figure 4. Only the DOH station, with its recent 100 µg/L TN mean, appears to be unaffected by this water quality degradation. Values for NH_3 show a similar trend, with all but one (the spike at the Shipyard, mentioned above) of the nine stations measured in 1990 below the 10 µg/L limit.

3.2. SOURCE NITROGEN COMPARISONS: SHIPYARD DISCHARGE, POTABLE WATER, AND GROUNDWATER SEEPAGE

Significant findings from a Student's T-test analysis of PHNSY effluent nitrogen verses the nitrogen levels from several different potential sources are presented in Table 4.

Table 4. T-test results for PHNSY effluent discharge and various non-operational sources.

PHNSY Effluent vs.	Seepage	Potable Water	Harbor Water In-take
Total nitrogen	ND	-	ND
Nitrate-nitrite	ND	-	ND
Ammonia	ND	-	ND

Remarks:
ND = not statistically different
- = statistically different

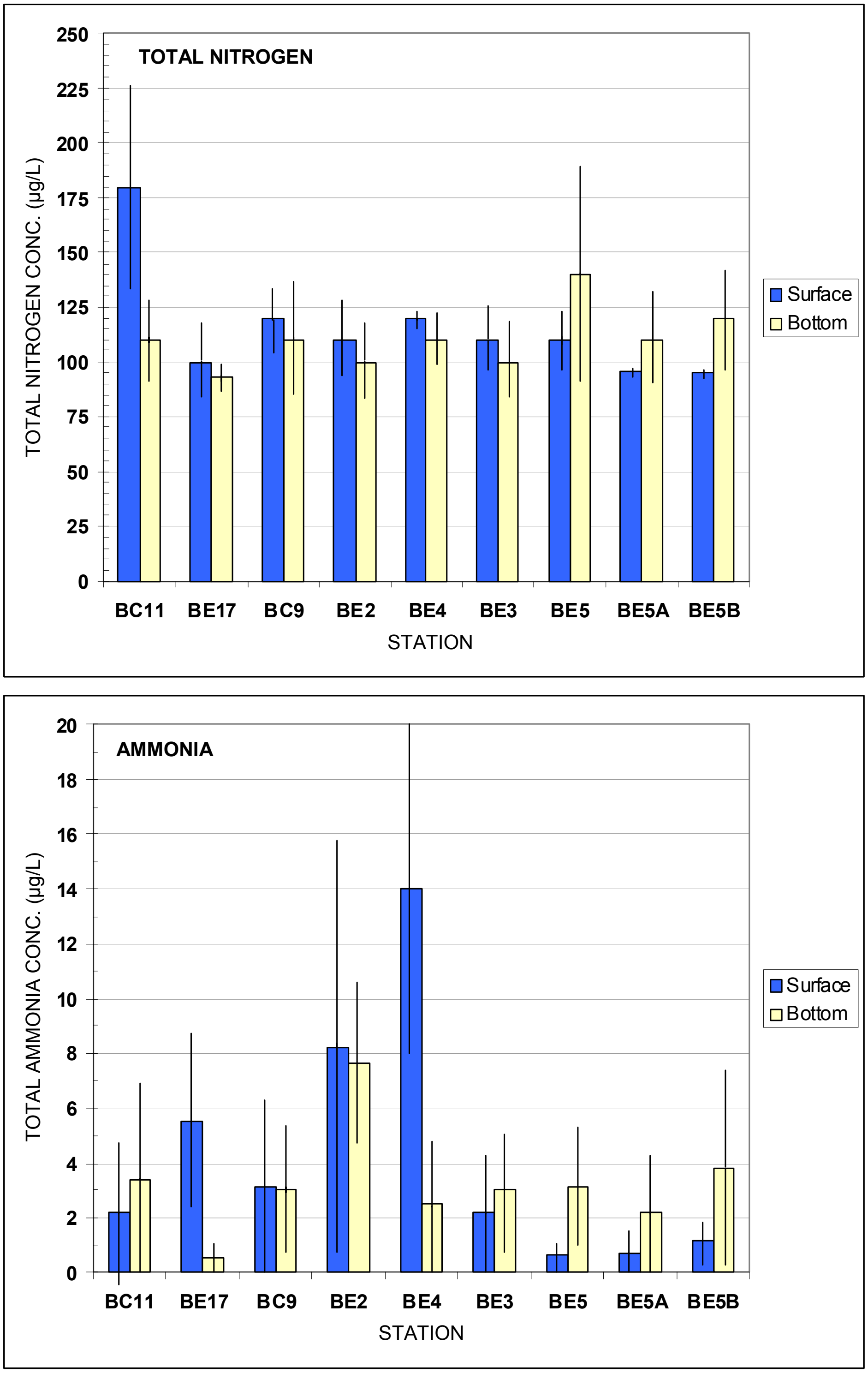

Figure 8. Nutrient concentration and associated one standard deviation error bars from south-to-north (*left-to-right*) collected for Pearl Harbor ambient conditions May 1990 (source: Grovhoug, 1992).

At first glance, Figure 8 results indicate that Shipyard effluent is different from only one of all these potential sources – potable water. However, data variability is large and again limits useful comparisons.

As done previously for the effluent-ambient comparisons, Figure 9 compares all of the site means. This view is interesting since it introduces two new sets of monitoring data that indicate potential nitrogen sources for the high levels measured in Shipyard effluents. Specifically, the potable water means for both TN and NO_x are each considerably higher than the corresponding Shipyard mean, by more than 3 times and 22 times, respectively. Acknowledging that Figure 10 shows one lone spike over 900 µg/L, measured in April 1997, about two-thirds of the Shipyard effluent values for TN from 1997 to 1999 are under the 300 µg/L limit, while all of the TN potable water values are about 800 µg/L or higher. Figure 11 is similar in showing that all of the Shipyard NO_x means are below 150 µg/L, whereas all the potable water means are above 600 µg/L. In sum, Figures 9 through 11, as well as Table 4, all support the finding that potable water represents a much more concentrated source of total nitrogen than the Shipyard effluent. The observation that NH_3 for potable water is low (in fact the T-test showed it to be the only data set that was different from Shipyard effluent because it was lower rather than higher, averaging only 4 µg/L) is consistent with expectations that potable water supplies would be treated to remove this aesthetically unpleasant contaminant. Furthermore, there is some data external to Pearl Harbor that shows potable water supplies in Hawaii having substantial levels of nitrogen in the form of nitrates. This issue will be discussed in the next section.

The most important question relative to the issue of potable water as a potential source of nitrogen to the Shipyard is: "Does the Shipyard use and discharge large quantities of potable water?" Unfortunately, there is little hard data to quantitatively answer this question. With our somewhat limited knowledge of operations at PHNSY, we might expect the high use and subsequent discharge of potable water by Shipyard workers during normal working operations on a large Naval vessel. However, Shipyard environmental managers indicate that large quantities of potable water (at 300,000 gallons per day [GPD]) are discharged only infrequently during special operations related to cooling water discharges from high-pressure air compressors. The other significant sources of potable water (rinses and hydroblast water) have been collected since January 1998 (Atta, personal communication, 1999). If potable water is truly a significant source with respect to TN concentrations, it does not appear to be responsible for the high levels of nitrogen measured in Shipyard effluent. Nevertheless, it makes sense for the Shipyard to conduct some systematic monitoring to quantitatively assess the contribution of potable water use and discharge to the harbor from the dry docks.

Meanwhile, Figure 9 shows another potential source of nitrogen to Shipyard effluent: groundwater seepage. It is important to note right away that seepage measurements represent the smallest data set reviewed, with only a total of six samples, two from each dry dock during one 2-month period. Consequently, the T-test results and trend analysis are automatically suspect data. However, since the Shipyard estimates that groundwater accumulates at a rate of about 500,000 GPD, every day, this is a source that must be considered. For the moment, we will make the assumption that the small data set is representative of data that would be collected over a period similar to all of the other data sets evaluated. The small size of this data set may explain why the T-test results displayed above do not show any difference between the nitrogen in effluent and nitrogen in seepage water. Figure 9 shows a TN mean for seepage that is 44% higher than the corresponding PHNSY effluent mean, while the NH_3 mean is 23% higher. However, the small data set size limits the usefulness of Figures 10 through 12. In view of the suggested results from the limited data and the inadequacy of the current data set size, the Shipyard should continue to collect nitrogen data from seepage measurements in conjunction with all other monitoring events.

If the seepage data is eventually shown to be representative, one might expect groundwater to be higher in NO_x due to infiltration by agricultural fertilizers, a phenomenon known to be occurring in the uplands of Oahu. However, Figure 9 does not show this to be the case. To explain a possible reason for this disparity, it is important to first explain that the cycling of nitrogen among its different forms is very much related to the presence of oxygen. In high oxygen environments, there tends to be more NO_x than NH_3, and the reverse is true for low oxygen environments. Therefore, this disparity in trends between effluent and seepage may be explained by a hypothesis that much of the nitrogen in seepage remains in the NH_3 or reduced form due to the lower levels of oxygen present underground. On the other hand, seepage water that enters the dry dock and is exposed to atmospheric oxygen can be oxidized from NH_3 to NO_x.

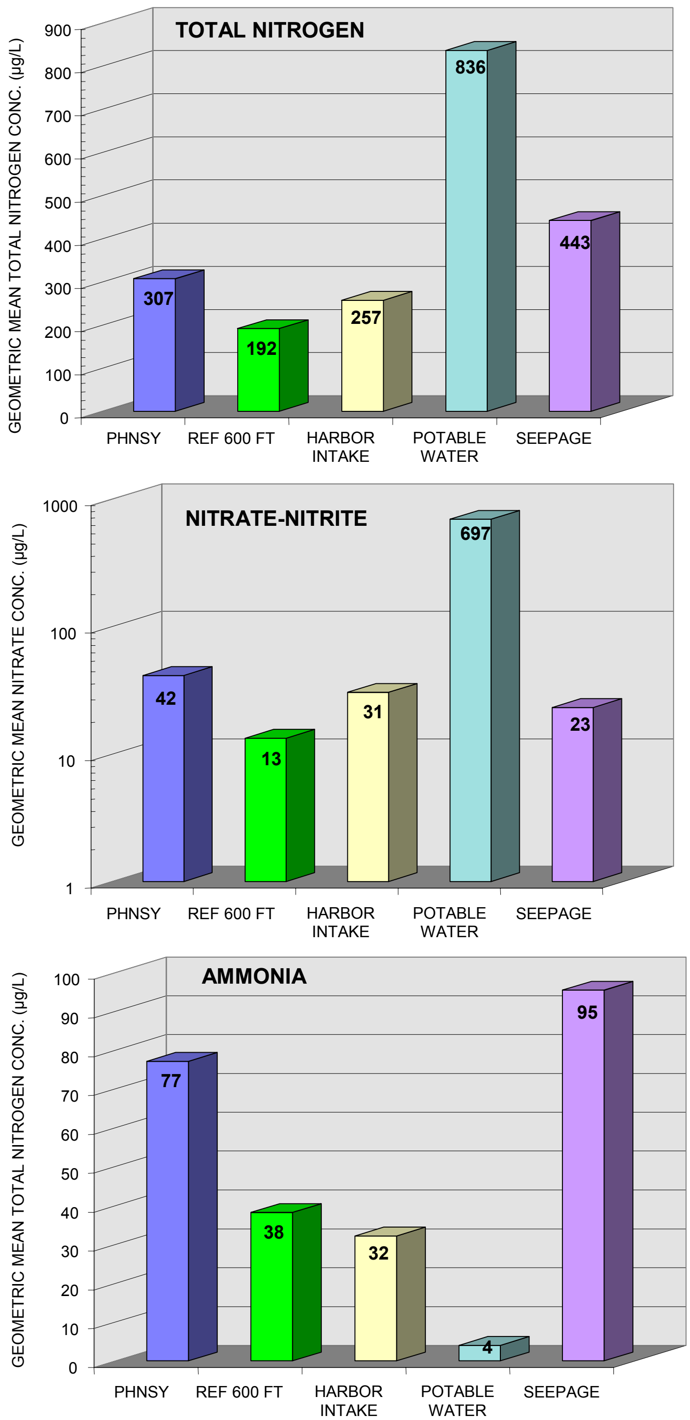

Figure 9. Geometric mean nutrient concentration for PHNSY source stations (1997 to 1999).

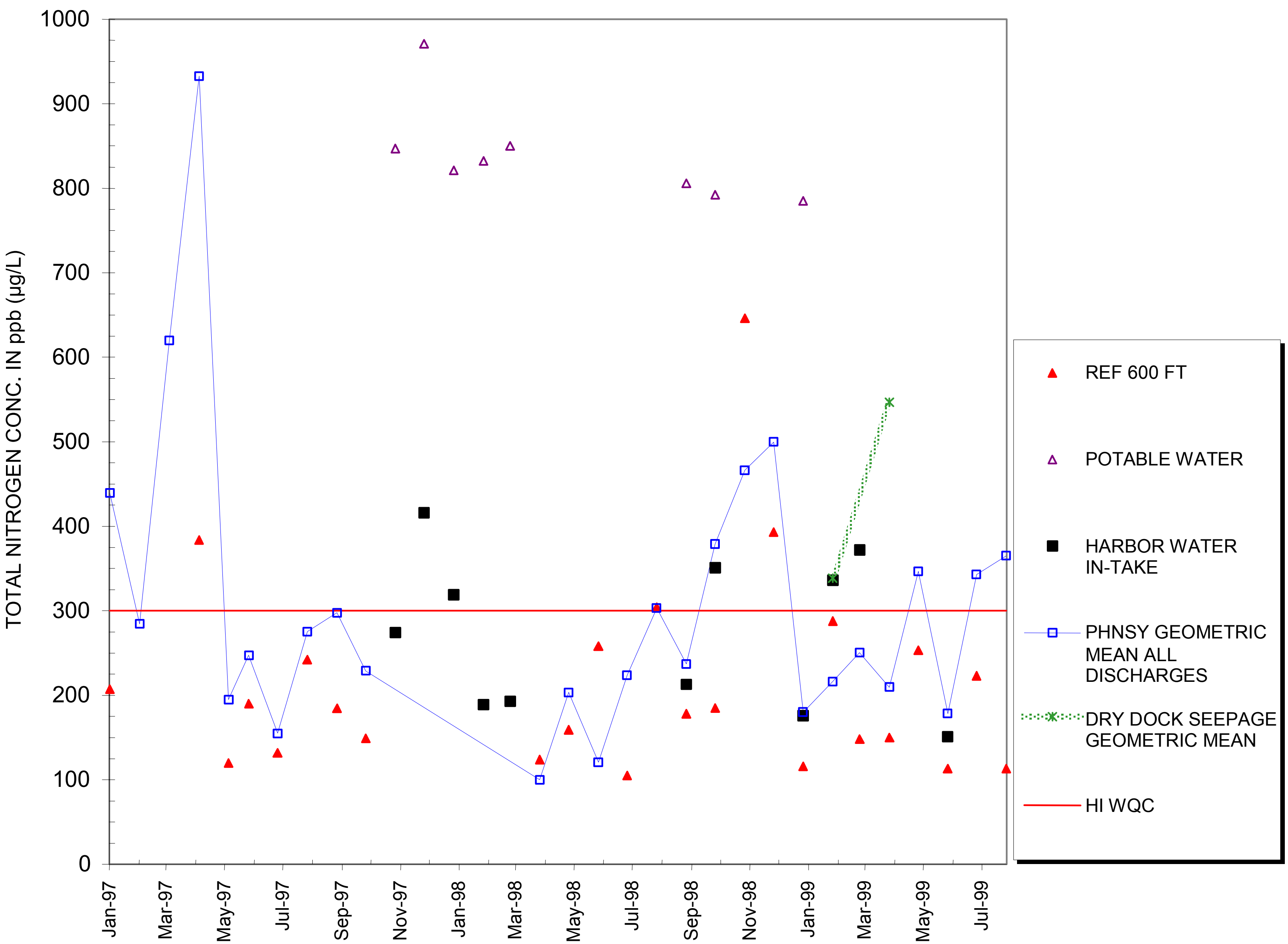

Figure 10. Total nitrogen trend lines for PHNSY source monitoring data (1997 to 1999).

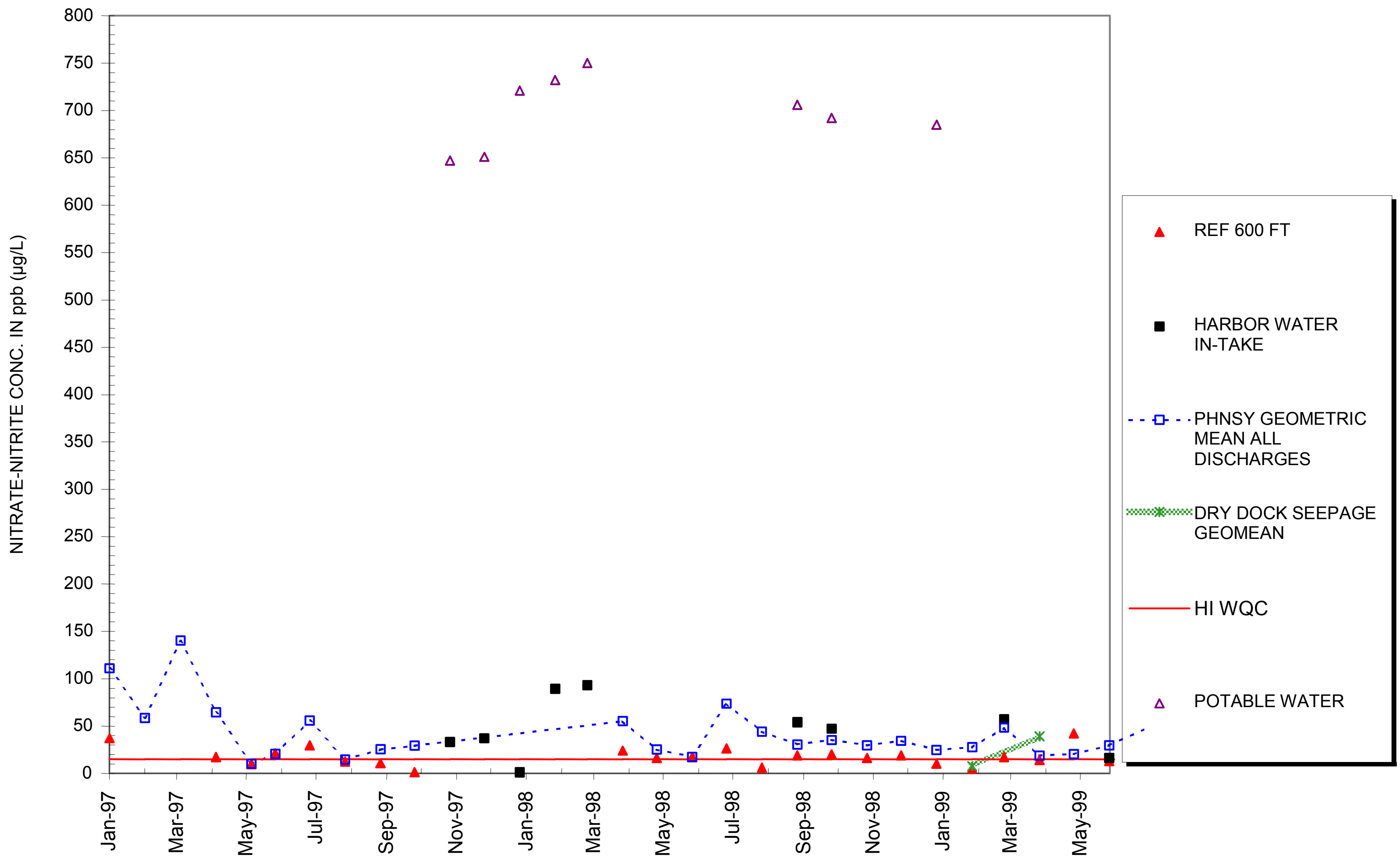

Figure 11. Nitrate-nitrite trend lines for PHNSY source monitoring data (1997 to 1999).

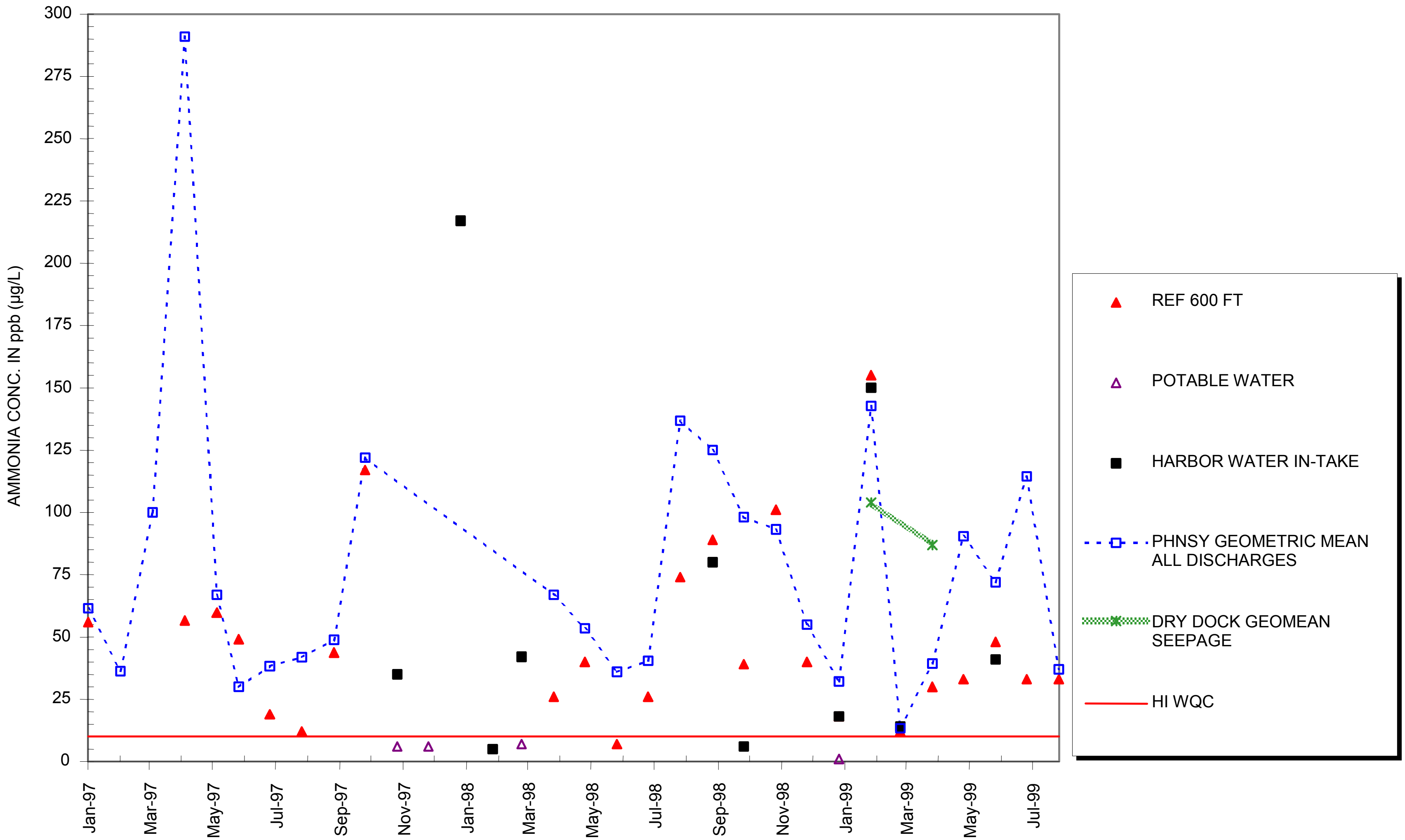

Figure 12. Ammonia trend lines for PHNSY source monitoring data (1997 to 1999)

4. DISCUSSION AND LOADING SUMMARY

4.1. AMBIENT-EFFLUENT COMPARISONS

It is important to note a couple of key concepts when effluent concentrations are compared to ambient water concentrations. First, the comparison between Shipyard effluents and ambient water quality is a comparison of two dissimilar measurements. However, note that the higher concentrations for Shipyard effluents are displayed along with the lower concentrations measured at ambient monitoring stations not for the purpose of direct comparison; rather, they are displayed together to examine the possibility of concentration gradients originating from the Shipyard. This hypothetical visualization technique facilitates the investigation of source identification for the purpose of establishing cause (sources) and effect (elevated ambient levels).

Second, for typical scenarios in which an effluent serves as a source of contaminant into a water body, one would expect that some dilution will occur in the near-field environment unless ambient water concentrations are equal to or greater than effluent concentrations. Consequently, we should not expect to find ambient-level concentrations in effluents if we know that the effluent is a source for contaminants entering the ambient waters.

To summarize the results, the ambient-effluent comparisons pointed to both the WWTFFK and the Shipyard as being two distinct sources of nitrogen loading to Pearl Harbor. Mean ambient levels are close to the 300 μg/L WQS at the near-field PWC (03) station, whereas the far-field PWC (07) station and Shipyard Ref 600 ft station are similar, each with a mean of about 170 μg/L. The northernmost station (DOH) showed the lowest levels of about 100 μg/L, but as mentioned previously, 100 ppb represents the minimum detection limit. Note that this observation must be tempered by the fact that there are other sources of nitrogen from non-Navy origins (e.g., streams, springs, and groundwater seeps) that have not been subject to any monitoring. These comparisons are only for the two sets of effluent data that were available.

4.2. SOURCE-EFFLUENT COMPARISONS

It is unfortunate that the data sets for both potable water ($n = 8$) and seepage water ($n = 2$) are very small, and may or may not be indicative of long term trends. This limits the robustness of analysis and any resulting conclusions when analyzing these potential sources, especially considering that the nitrogen levels in both appear to be significantly higher than those of the Shipyard effluent. Shipyard managers have indicated that mass loading of potable water is insignificant since it is done so infrequently. However, in view of the much higher concentrations of nitrogen in potable and seepage water, the Shipyard should implement systematic monitoring programs to measure nitrogen concentration and flow in both of these potential sources at their respective entrance points onto Shipyard property.

4.3. GROUNDWATER AS A SOURCE AND ITS RELATIONSHIP TO BOTH POTABLE WATER AND SURFACE RUNOFF

Unfortunately, groundwater contaminant loading, transfer, and flux are not clearly understood at this time and difficult to quantify without detailed hydrological information concerning groundwater potential within the Shipyard.

Due to nutrient enrichment and associated algal blooms, the University of Hawaii and the State of Hawaii Department of Health have been studying groundwater seeps and their associated nitrogen sources on the islands of Maui (USEPA, 1998) and Hawaii (Dollar et al., 1992.) The USEPA recently published an electronic newsletter detailing some of these findings from Maui that are detailed in the text box. The relevant observations from this article are (1) the relative importance of underground pathways as opposed to surface pathways, (2) the phenomenon of tidal pumping, which introduces groundwater contaminants directly into tidal waters, and (3) the fact that Maui's groundwater has been determined to be loaded with nitrates originating from agricultural practices.

Since the Hawaiian Islands have the same geological origin and similar influences from agriculture, it is reasonable to expect that these observations would also be seen (to some extent) on Oahu.

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July/August 1998

"News from the States"

Ground-water seeps, areas where fresh water enters the ocean from an underground source, are found along the entire shoreline of Maui. Ground water from higher elevations carries pollutants to underground "rivers" that eventually exit though cracks in the ocean floor. In coastal areas, seawater seeps into the cracks at high tide and mixes with the freshwater; then the mixture flows back to the ocean at low tide. Tidal pumping, as this process is called, has been studied in detail at the University of South Carolina. Scientists there found that as many as eight billion gallons of ground water flow into the ocean along South Carolina's coast each day — about half as much fresh water as South Carolina's rivers discharge to the ocean.

In 1996, scientists found that approximately 87 percent of the nitrate in Maui's ground water comes from fertilizers applied to crops. Yet studies show that surface runoff and streamflow, common culprits when it comes to nutrient pollution, have not been important sources of nutrients along Maui's shore. The annual nutrient input from ground water is 4 to 16 times greater than the total annual input from streams.

Dr. Edward Laws, professor of oceanography at the University of Hawaii at Manoa, believes that further studies are needed before surface runoff and streamflow can be let off the hook completely. Virtually all streams in the watershed are diverted for irrigation, Laws says. Nearly all are dry at lower elevations during most times of the year and discharge to the ocean only during times of heavy rainfall. "Therefore, during a dry year, [such as the years in which these studies were conducted], groundwater seepage is by default the only significant source of freshwater entering the ocean. Nutrient inputs from stream runoff may be quite significant during rainy periods." (USEPA, 1999a)

An indirect measurement of groundwater nutrient content on Oahu can be obtained from drinking water well monitoring reports. The 1999 water quality reports, obtained from the Board of Water Supply, City and County of Honolulu, detail high nitrate levels found in Oahu groundwater and well water (Table 5). Average 1999 nitrate concentrations from these six wells were 339 to 793 µg/L while maximum concentrations were 360 to 910 µg/L.

Well monitoring for total nitrogen and ammonia are not required under current Federal regulation, so there is no data on levels of these contaminants in potable water. Since these wells are the major supply to Pearl Harbor facilities and also indicative of background groundwater contamination, elevated nitrates would be expected in any potable water or groundwater seepage released to the dry docks.

Table 5. Drinking water nitrate levels in wells drawing from the Pearl Harbor aquifer.

Source	Highest Average Nitrate Conc. (µg/L)	Maximum (µg/L)	Minimum (µg/L)
Punanani Well	419	520	0
Pearl City Well II	440	530	330
Pearl City Shaft	733	910	550
Newtown Wells	339	370	320
Kaonohi Wells I	340	360	290
Aiea Wells	793	870	470

"Highest Average" is a term used by the Honolulu Water Board and these numbers represent the highest of the monthly averages for calendar year 1999 in order to derive the most conservative (i.e., highest or worst-case) loading estimates. Note that the NO_x levels in these wells that supply potable water to the Shipyard are an order of magnitude higher than either the ambient or the source data reviewed for Pearl Harbor and the Shipyard. In addition, these concentrations are in the same range as the potable water measurements taken at PHNSY (Figure 11), thus serving to increase confidence in this limited data set. The Shipyard should consider monitoring groundwater at a geographic point where it first enters the Shipyard property to assess the relative contribution of this potential source of nitrogen over which the Shipyard has no control. It should also be mentioned that SSC San Diego has developed tools and methods for examining groundwater seepage between coastal lands and adjacent water bodies that could be applied to study the tidal pumping phenomenon.

Finally, it is worth mentioning that surface runoff from lands used for agricultural purposes typically contains elevated levels of nitrogen. Runoff can enter the Shipyard in two ways: by infiltrating the ground and adding to the groundwater, and by directly migrating onto the Shipyard property on the surface of the ground. The following section discusses this potential source in more detail. In parallel, surface runoff can enter Pearl Harbor via three pathways outside the Shipyard: by groundwater migration, surface migration, and through the streams that empty the large agriculturally-influenced watersheds upland from the Shipyard.

4.4. SURFACE WATER RUNOFF

Another possible contributor of apparently high nitrogen values to Pearl Harbor may be direct surface water runoff. Surface runoff can be defined as rainwater or freshwater that does not percolate into the ground (to add to the groundwater below), but rather pools and migrates over ground and eventually enters a receiving water body via stream or river flow and sheet runoff. The concern with surface runoff is that it can carry pollutants that are present in the original water source (e.g., rain or freshwater), ultimately depositing them in the water body.

Although Pearl Harbor typically receives about 71 cm (28 in) of rain per year, the eastern Koolau Range and western Waianae Range, which feed the watershed draining into Pearl Harbor, can receive up to 305 cm (120 in) of annual rainfall. High nitrate and ammonia concentrations (e.g., the larger Waikele Stream) have been reported and reflect the impacts of natural nitrogen cycling, agricultural practices, and urbanization impacts (Table 6). Data from the National Stream Water Quality Monitoring Program, as run by the United States Geological Survey (USGS), is currently available for only two Pearl Harbor streams. The USGS fixed-site gaging stations provide an indication of the elevated nutrient levels and the high variability of inputs to Oahu streams, and ultimately to Pearl Harbor. Although the gaged station data represents only two of seven streams draining to the harbor, the nitrate levels appear to be significantly elevated in comparison with national background levels (Table 7).

In March 1999, the USGS began a 2-year program of renewed sampling for Waikele Stream as part of the Oahu National Water Quality Assessment Program. Surface water sampling including nutrients, flow characteristics, bed sediment and tissue, aquatic ecology, and groundwater studies are planned (USGS, 1999a). This program may provide better characterization of stream loading in the future.

Table 6. Nutrient levels reported in Oahu streams (source: USGS, 1997).

Stream	Parameter	Dates	Geometric Mean (μg/L)	Range (μg/L)	n = / SD
Waikele Stream, *at Waipahu*	Total nitrogen	1971–1995	2,390	35 – 9,600	148/1,580
	Nitrate	1971–1995	1,826	130 – 5,400	124/1,220
	Ammonia	1971–1995	93	20 – 3,300	96/420
North Halawa Stream, *near Honolulu*	Nitrate	1983–1997	101	50 – 130	27/176
	Ammonia	1983–1997	14	10 – 30	10/8

Table 7. Background nutrient concentrations derived from USGS national stream monitoring programs (source: USGS, 1999b).

Nutrient	Background Conc. (μg/L)
Total nitrogen in streams	1,000
Nitrate in streams	600
Ammonia in streams	100
Nitrate in shallow ground water	200

Note that the mean nitrate value for Waikele Stream during a monitoring period of 24 years is 2 orders of magnitude higher than the values that have been reviewed in this report thus far. As with groundwater, the Shipyard could make measurements of surface runoff (or “run-on”) as it enters Shipyard property.

4.5. THE WASTE WATER TREATMENT FACILITY AT FORT KAMEHAMEHA AS A POTENTIAL SOURCE

The WWTFFK discharges treated effluent near the entrance channel to Pearl Harbor. Although near the mouth of the harbor, there should be some consideration as to WWTFFK’s potential influence upon high nitrogen levels within Pearl Harbor. The STP was upgraded in December 1997 to a maximum effluent flow of 13 million gallons per day (MGD). The PWC, Navy Region Hawaii, indicates that the plant still typically operates at a lower flow of about 6 to 7 MGD (Joanne Higuchi, e-mail). PWC provided effluent discharge data (1997 to 1999) for nitrogen prior to ambient mixing, and these data are presented in Figure 13.

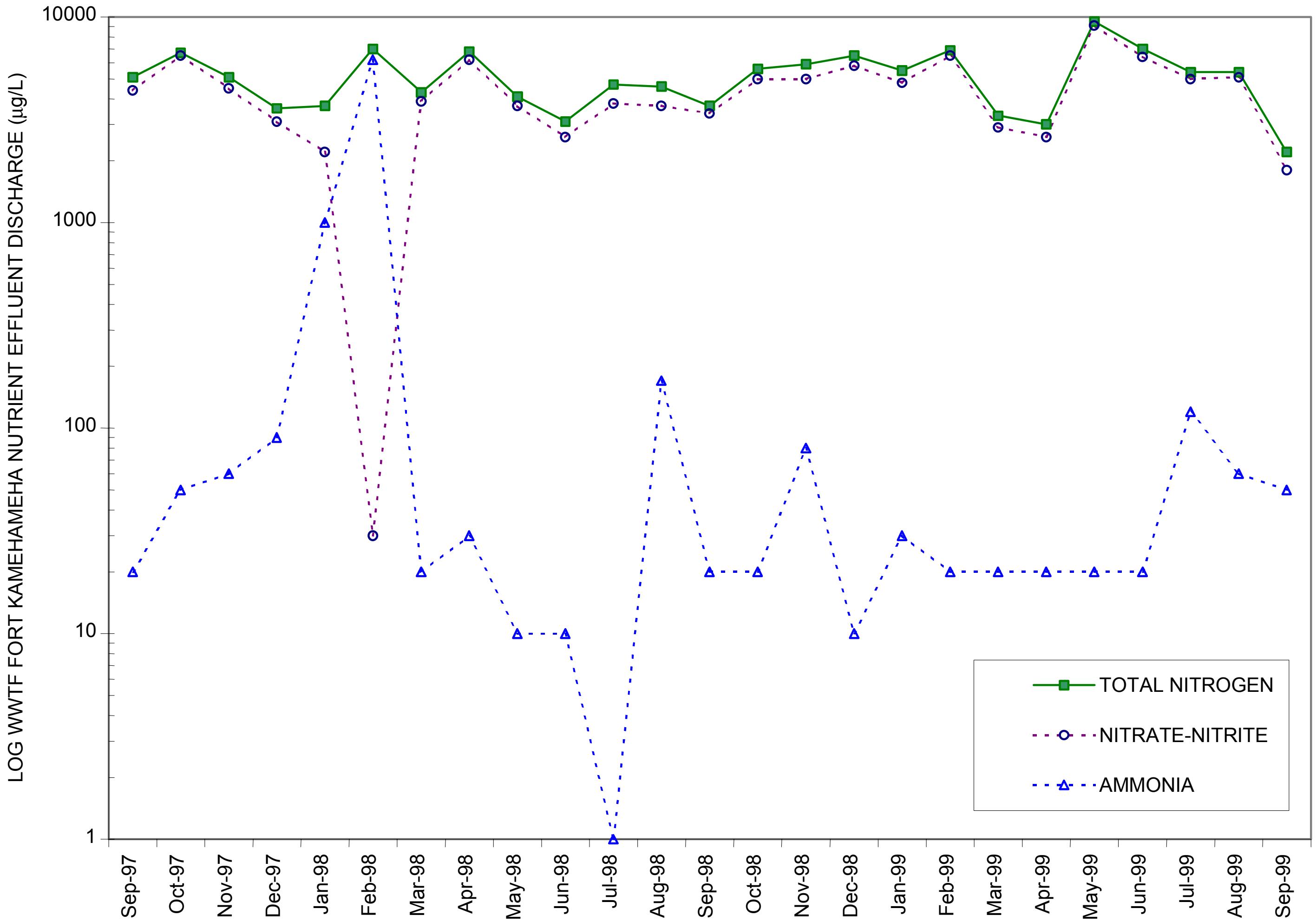

Figure 13. Waste Water Treatment Facility at Fort Kamehameha nutrient effluent discharge (Sep 1997 to Sep 1999).

Although only one near-field and one far-field station were included in the previous results and discussions to represent a worst-case (i.e., near-field and highest concentration) and best-case (i.e., far-field and lowest concentration) station respectively, PWC also monitors several other ambient stations between the entrance channel and a point just south of Hospital Point on Waipio Peninsula. Figure 14 shows the six surface and six corresponding sub-surface (3 meters below surface) harbor stations representing a spatial sampling distribution away from the STP outfall in both directions (towards inner harbor and towards harbor entrance).

Total nitrogen in the STP effluent is an order of magnitude above the HI WQC (2,000 to 9,500 μg/L vs. HI WQC of 300 μg/L), and NO_x is the major component, with levels nearly as high as those for TN. Since the STP processes a tremendous amount of potable wastewater, it would be expected that the STP would be a significant source of both TN and NO_x (the NH_3 is typically reduced in the STP treatment processes). Nevertheless, the effluent discharge from the WWTFFK does not appear to cause excessively high ambient concentrations near the Shipyard. Furthermore, the WWTFFK NPDES permit includes a zone of mixing for nutrients and the facility meets the conditions of its permit. There are decreasing gradients of nitrogen in the ambient monitoring stations away from the STP outfall (Figure 14), but for both NO_x and NH_3, these gradients reach a low at PWC 07 (the far-field station) and then increase again at the near-field 600-ft Shipyard reference site. While the TN values between PWC 07 and Ref 600 are essentially the same, this spatial trend supports the conclusion made earlier that the Shipyard and WWTFFK represent two distinct sources of nitrogen. Once again, it is important to note that other important sources, such as streams, springs, and groundwater seeps, have not been measured. They also probably represent distinct sources of nitrogen to Pearl Harbor.

4.6. POTENTIAL PEARL HARBOR NUTRIENT LOADING

There are some issues to investigate relative to the high NH_3 concentrations measured as Shipyard effluent and as seepage water. Depending on the location of the sampling points, elevated NH_3 (and potentially NO_x and TN) in Shipyard discharges could be related to the decay of marine fouling organisms and other biological material (e.g., algae) trapped in the dry dock sumps/pumps. If sampling for dry dock water takes place in a sump where organisms get trapped and there is insufficient flushing, ammonia can accumulate. Associated high NO_x and TN values could mean that some of the NH_3 is undergoing oxidation to these other forms in the presence of oxygen. As explained earlier, the main difference in the relative amounts of the two partial (i.e., other than total) nitrogen measurements is that nitrate-nitrite is found in oxygenated environments, while ammonia is found in reducing or anaerobic environments.

If this is thought to be a reasonable hypothesis, then the Shipyard should run a series of additional monitoring surveys to investigate this possibility.

Nitrogen loading has been shown to be highly variable on a watershed-by-watershed basis, with no single non-point source dominant in each region (Puckett, 1994). In a review of 107 watersheds in the National Water Quality Assessment Program, the USGS listed major nitrogen sources:

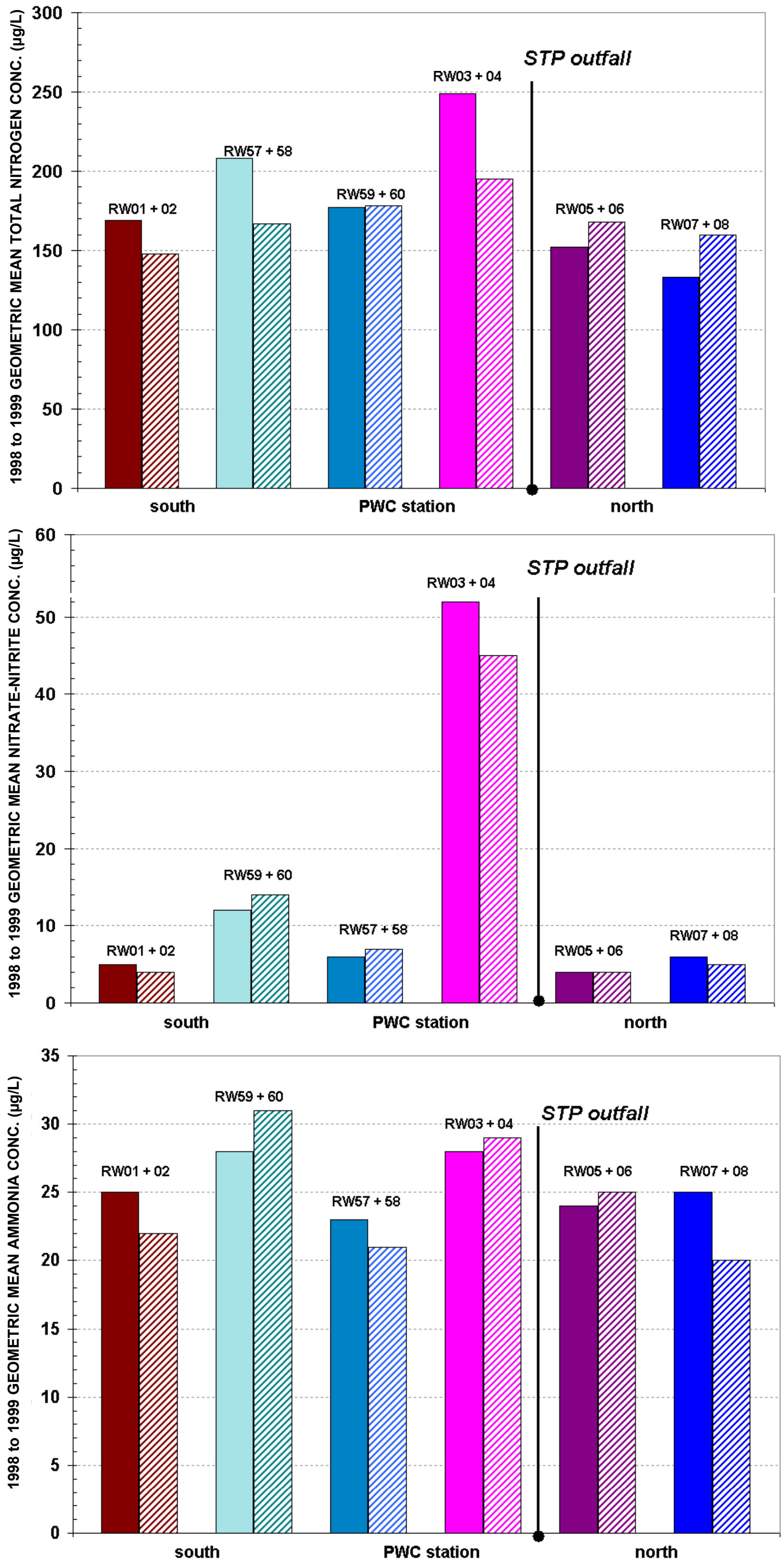

Figure 14. The March 1998 to March 1999 mean total nitrogen concentration for surface (solid bar) and sub-surface locations at PWC south-to-north ambient monitoring station.

- fertilizer application with atmospheric ammonia gas release or nitrate ground/surface water runoff;
- animal manure leachate into ground and surface waters;
- atmospheric deposition from utility operation, industrial facilities, and automotive exhaust (approximately 38% of nitrogen emissions);
- point source input from waste-water treatment plants and industrial activity (Puckett, 1994).

In general, non-point sources can account for 0 to100% (highly developed to highly undeveloped) of the total nitrogen load, depending on site-specific watershed characteristics. The more industrialized a watershed is, the greater the role point sources have in contributing to overall nitrogen loading.

Based on some of the simple assumptions presented below, a preliminary Pearl Harbor watershed loading budget for total nitrogen, nitrate-nitrite, and ammonia can be estimated (Tables 8, 9, and 10, and Figure 15). Further studies are necessary to better characterize these sources. Given the inherent uncertainty in these loading estimates, they should be considered tentative, as they represent only the best information available.

4.6.1. Total Nitrogen Loading

Determination of total nitrogen loading is presented in Table 8 and predicated on the assumptions described below.

Table 8. Estimated total nitrogen load to Pearl Harbor, HI.

Source	WET season load (kg/yr)	DRY season load (kg/yr)
PHNSY dry dock discharge	2,164	2,164
WWTFFK effluent discharge	53,996	53,996
Combined stream input	184,923	
Natural springs input	61,425	21,887
Well input	5,648	3,530
Shallow aquifer input	7,060	4,236
Atmospheric deposition - background	894	894
Atmospheric deposition - anthropogenic		
Total (kg/yr)	316,111	113,125
Total (tons/yr)	348	125

PHNSY: calculated from geometric mean concentration of all discharges from 1993 to 1999 and average daily flow as reported by ENSR (1996).

WWTFFK: calculated from geometric mean concentration of effluent discharge from 1997 to 1999 and average daily flow of 8 MGD.

Combined streams: Grovhoug (1992) listed wet and dry weather annual stream flows to Pearl Harbor. The geometric mean concentration for Waikele Stream (Table 6) was used to represent

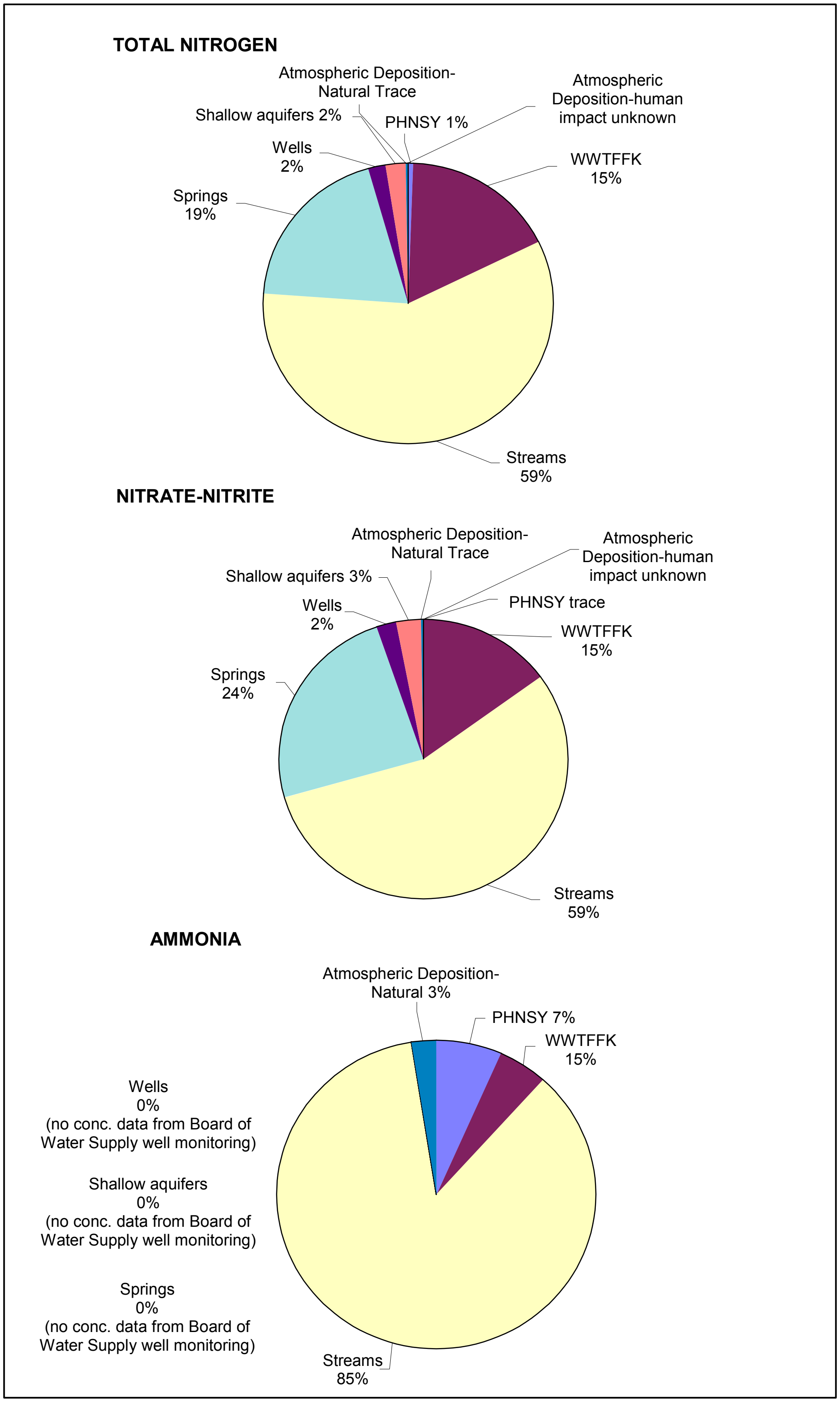

Figure 15. Estimated annual nitrate-nitrite and ammonia loading to Pearl Harbor, HI, during wet season flow conditions.

all stream concentrations and the total Pearl Harbor stream flow was taken from Grovhoug (1992). Although each stream is likely to have varying nutrient enrichment depending on associated land use, Waikele is estimated to represent from 46 to 76% of the annual stream flow to Pearl Harbor. Another broad assumption incorporated into this estimate is that stream flow captures all urban stormwater runoff. While stormwater runoff certainly feeds into the surrounding streams that drain into the harbor, there remains an unquantified portion of stormwater that enters the harbor via sheet runoff.

Springs/wells/aquifer: Natural springs and wells are treated as separate input sources for the purposes of this estimate. Grovhoug (1992) provides wet and dry weather annual flows for these sources. The only available data for estimating aquifer concentrations was the well water testing provided by the Board of Water Supply. An overall mean groundwater nitrate-nitrite concentration was calculated from the highest average concentrations for all wells listed in Table 5. There is no ammonia concentration data available from the Board of Water Supply data set. Since total nitrogen includes nitrate-nitrite and ammonia, the NOx concentration is conservatively used as a surrogate for TN in the absence of that concentration. The true TN concentration would probably not be too much higher, since NH_3 is typically removed from drinking water sources.

Atmospheric deposition: Atmospheric deposition is currently the focus of significant regulatory and field research, particularly along the United States east coast. To date, we have not found deposition studies specific to Oahu. However, there is data available from the Island of Hawaii through the National Atmospheric Deposition Program (NADP), a collaboration of Federal, State, and academic research agencies. Precipitation-weighted annual mean concentrations for nitrate NO_3 and ammonia deposition in mg/L (1980 to 1993) are available from the NADP Internet site (Bowersox, 1999). The geometric overall mean of the reported annual concentrations for the Island of Hawaii was used to simulate deposition to the water surface of Pearl Harbor. The volume of rainwater used for calculating annual nutrient loads from the rainfall concentration values is the product of Pearl Harbor's water surface area and annual rainfall, as detailed below. Total nitrogen air deposition in Table 8 is the sum of nitrate and ammonia. Deposition to land was assumed to impact stormwater and/or stream runoff and therefore not reflected in the "water-only" calculation below.

Mean Nitrogen Concentration in Rainwater	Annual Rainwater Volume	Annual Nitrogen Load (kg)
Nitrate Conc (mg/L)		
0.067	10,668,000,000	715
Ammonia (mg/L)		
0.016	10,668,000,000	179

Calculated as a product of water surface area (21,000,000 m^2) and annual rainfall of 20 inches/year.

$= [(20 \text{ in} \times 2.54 \text{ cm/in}) / 100 \text{ cm/m}] \times 21{,}000{,}000 \text{ m}^2 \times 1{,}000 \text{ L/m}^3$

where:

2.54 cm = 1 in
1 m = 100 cm
1,000 L = 1 m^3

The resulting atmospheric load term is based on both man-made and natural background-levels for the Island of Hawaii. However, anthropogenic sources such as NO_x emission (power plant air emissions, automotive exhaust, ship exhaust, and lawn equipment exhaust) and agricultural/landscape emissions (fertilizer application and air leaching) (USEPA, 1997) are anticipated to be more pronounced on Oahu. Unfortunately, no monitoring data exists to quantify this additional enrichment.

4.6.2. Nitrate-nitrite Loading

Determination of nitrate-nitrite loading is presented in Table 9.

Table 9. Estimated nitrate-nitrite load to Pearl Harbor, HI.

Source	WET season load (kg/yr)	DRY season load (kg/yr)
PHNSY dry dock discharge	323	323
WWTFFK effluent discharge	38,068	38,068
Combined stream input	141,285	20,184
Natural springs input	61,425	21,887
Well input	5,648	3,530
Shallow aquifer input	7,060	4,236
Atmospheric deposition - background	715	715
Atmospheric deposition - anthropogenic	unknown	unknown
Total (kg/yr)	254,524	88,943
Total (tons/yr	281	98

4.6.3. Ammonia Loading

Determination of ammonia loading is presented in Table 10 and also predicated on most of the assumptions listed above. The one exception is the lack of ammonia in springs, wells, or aquifers. Consistent with speculation made earlier in this report, this absence of NH_3 from this Board of Water Supply data may reflect that ammonia is not present in significant quantities in Oahu groundwater.

Table 10. Estimated ammonia load to Pearl Harbor, HI.

Source	WET season load (kg/yr)	DRY season load (kg/yr)
PHNSY dry dock discharge	547	547
WWTFFK effluent discharge	423	423
Combined stream input	7,196	1,028
Natural springs input	0	
Well input	0	
Shallow aquifer input	0	
Atmospheric deposition - background	179	179
Atmospheric deposition - anthropogenic	unknown	unknown
Total (kg/yr)	8,345	2,178
Total (tons/yr)	9	2

Given only the loading terms identified to date, the most obvious finding in this initial analysis for total nitrogen, nitrate-nitrite, and ammonia is the relatively significant amount of the total load accounted for by stream inputs in both wet or dry scenarios. Depending on the nutrient and wet vs. dry year analysis, streams may contribute between 22% (dry season) to 86% (wet season) of the total loads. The WWTFFK effluent really becomes significant to the total nitrate load (15 to 43%) while the Shipyard dry dock effluent represents less than 1% of the potential nitrate-nitrite load.

4.7. ANALYSIS AND LOADING SUMMARY

The sum of the information from the wet weather scenarios (worst-case for loading) in the two loading tables, shown in Figure 15, depicts a mass loading model for nitrogen that differs substantially from the conceptual model available from assessment of concentration data only. Rather than showing the WWTFFK and the Shipyard as the two primary sources, this more comprehensive assessment of potential loading sources to Pearl Harbor reveals that the Shipyard influence is probably minimal. Rough estimates based on the best available data indicate that the Shipyard contributes between 0.7 to 2% of total nitrogen, less than 1% of the nitrate-nitrite, and 6 to 25% of the ammonia. Sources contributing much greater loads are streams (55% of NO_x, 86% of NH_3), springs (24% of NO_x), and the WWTFFK (15% of NO_x).

At this point, it makes sense to check whether these loading estimates appear to be reasonable, given what we know about the ambient nitrogen data reviewed earlier, and what we can infer from our somewhat limited knowledge about Pearl Harbor's flushing characteristics. First, Figures 16 through 18 give some insight into the dynamic mixing processes of Pearl Harbor. Figure 16 shows the influence that the prevailing northeast trade winds have on inducing surface currents that may move in a direction opposite to a flooding tidal current. Figure 17 shows the difference in residence times for various points throughout the harbor, indicating that the vertical gradient is more important than the spatial gradient. Specifically, the surface layer flushes in a matter of hours, 36 at the northernmost region, while the bottom layer throughout most of the harbor flushes in about 4 to 6 days. These two figures are also consistent with PWC's nitrogen data, in Figure 14, showing surface concentrations that are different from the layer measured only 3 meters below. Although the discharge of effluent from the WWTFFK is on the bottom of the harbor, it too represents a large mass of mostly fresh water that is much less dense than seawater. Figure 18 shows a conceptual model of the rapid rise to the surface of such freshwater effluent plumes.

Given this rapid rise, in conjunction with the geographical position of the outfall at the entrance to the harbor and the strong influence of a northeastern wind, one can speculate that much of this input may be blown out of the harbor before it ever has any chance to be driven inwards on a flooding tide. The presence of the strong northeastern wind-induced currents may also explain why high mass loading from the streams do not cause higher ambient concentrations at the north of the harbor. In fact, the ambient concentrations at the DOH station are significantly lower than stations to the south, also supporting the hypothesis that southerly moving surface currents may carry the nitrogen loads in fresh water surface layers quickly towards the mouth of the harbor.

In summary, the mixing and flushing of surface currents that occur in Pearl Harbor may explain why ambient concentrations of nitrogen are not rapidly rising due to large mass inputs into the water body. The monitoring data obtained and examined thus far shows that ambient total nitrogen is averaging about 100 to 200 μg/L throughout Pearl Harbor.

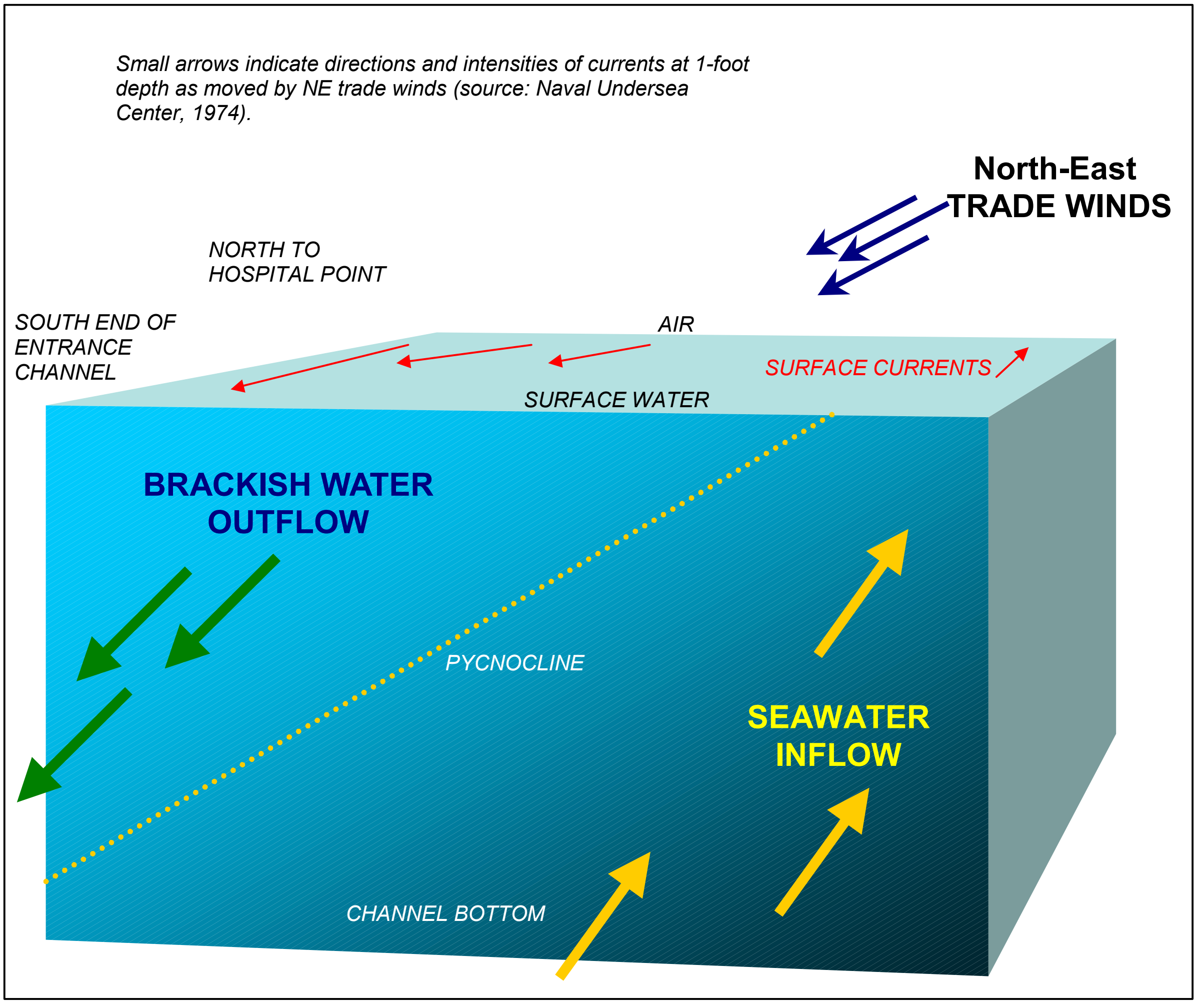

Figure 16. Conceptual model of water circulation pattern within the Pearl Harbor entrance channel looking south to north.

It is important to realize that these calculations are only rough estimates, and there are no historical or ongoing dispersion studies to validate them. However, the technical capability exists at SSC San Diego to perform this kind of work as a follow-on to this preliminary assessment, should Shipyard management deem it necessary.

The following observations summarize the assessment of nitrogen loading and ambient conditions in Pearl Harbor:

- Comparison of nitrogen concentrations in Shipyard effluent and nitrogen at several ambient monitoring locations show that both the Shipyard and the WWTFFK represent two distinct sources.
- Comparison of nitrogen concentrations in Shipyard effluent and nitrogen from potential source inputs to the Shipyard indicate that groundwater seepage and potable water are more highly contaminated with nitrogen than the effluent. However, small sample sizes, limited temporal distribution, and unquantified input amounts (i.e., flow) limit the scientific conclusions that can be drawn.

- In all cases of comparisons of ambient or effluent data against the respective WQS for the different forms of nitrogen (NO_x, NH_3, and TN), the one form that most frequently violated its limit was ammonia, and appeared to be responsible for most exceedences of TN.
- Loading estimates for Pearl Harbor indicate that the Shipyard provides minimum loading quantities when compared to other sources.
- It appears that both nitrogen input from the Shipyard and ambient nitrogen concentrations in the harbor have increased from 1990 to the mid- to late 1990s.
- Nitrogen loads are not increasing ambient levels over short periods of time (days to months). Speculation about dispersion based on limited mixing and flushing characteristics of Pearl Harbor, when combined with ambient nitrogen concentration data, supports a general hypothetical explanation for this steady state characteristic.

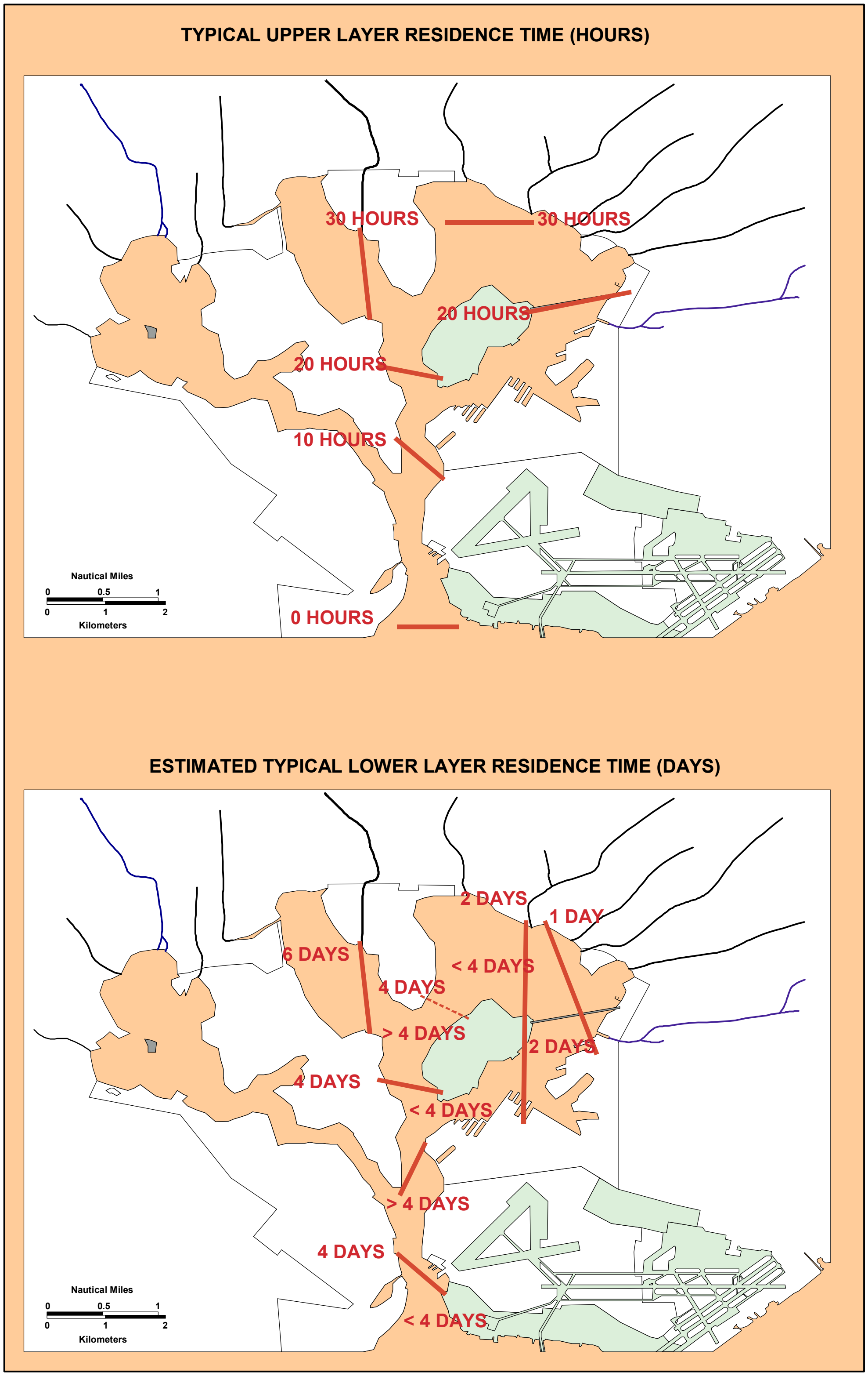

Figure 17. Typical surface and estimated typical sub-surface water residence time for Pearl Harbor, HI (source: Evans III, 1974).

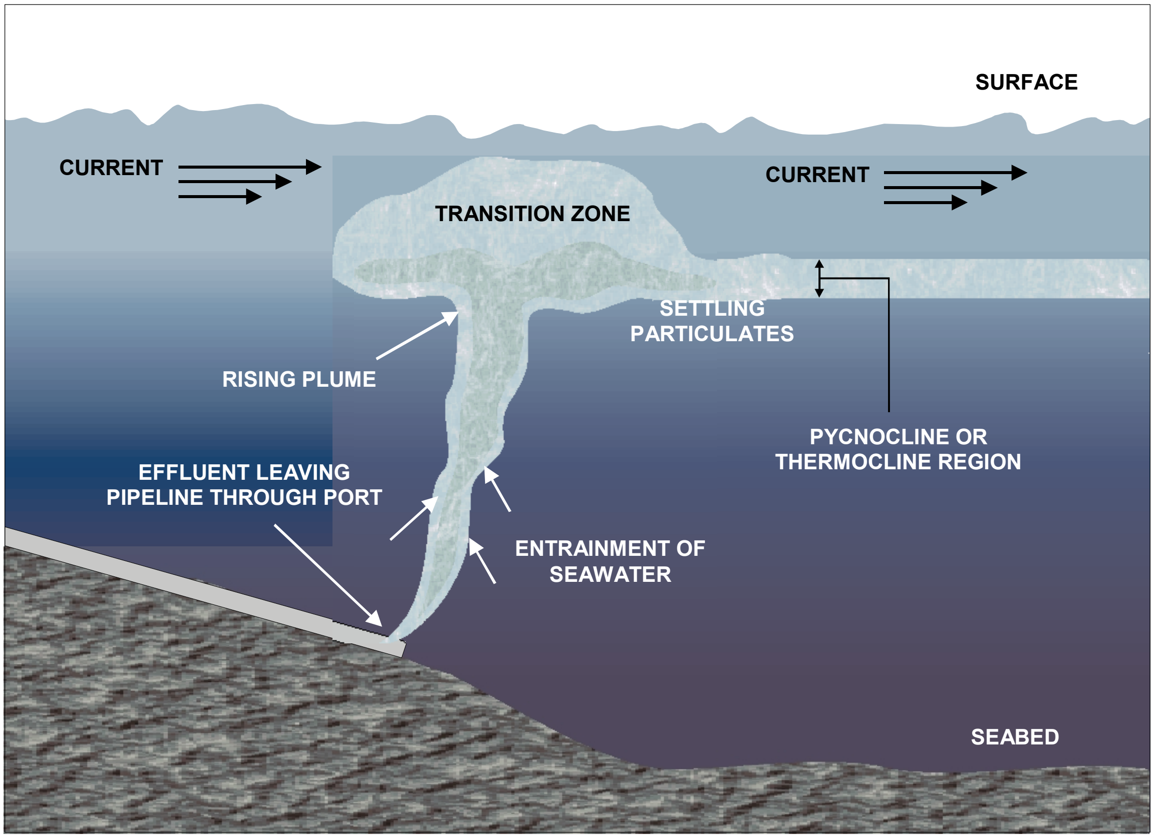

Figure 18. Effluent fate in marine waters (source: Office of Technology Assessment, 1987).

5. ECOLOGICAL RISK ASSESSMENT FROM ELEVATED NUTRIENTS

This section presents a preliminary ecological risk assessment from potentially elevated water-column nutrient levels within Pearl Harbor. Pacific Division, Naval Facilities Engineering Command, has performed a more extensive ecological risk assessment for Pearl Harbor sediments under the Navy's Installation Restoration Program. However, the goal of that assessment was to determine the influence of historic and ongoing Navy activities upon levels of industrial pollutants (primarily organic chemicals and metals) and their resulting contamination of nearby sediments and potential impacts on ecological receptors. That study did not consider non-Navy loading sources, the effects of elevated water column nutrients, or the longer-term possibility of eutrophication within the harbor. To the best of our determination, there has been no previous assessment of nutrients as contaminants or toxicants, or as indicators of eutrophication in Pearl Harbor.

Data presented earlier in this report indicates that total nitrogen averages between 100 to 200 µg/L throughout the harbor with significant point source inputs from streams, the WWTFFK, and the Shipyard. These total nitrogen averages are just slightly higher than one-half the State WQS, while ambient levels for ammonia and nitrate-nitrite appear to be much higher, relative to their respective standards: Average concentrations for NO_x range from 5 to 15 µg/L (compared to a WQS of 15 µg/L); and NH_3 ranges from 27 to 50 µg/L (compared to a WQS of 10 µg/L). Ammonia and nitrate-nitrite also show a possible gradient from the harbor head towards the mouth, a gradient opposite to that of TN, and thus could reflect the significance of surface runoff inputs from the streams.

The most important question to answer, given that there appears to be elevated nitrogen levels in the harbor relative to the State of Hawaii WQS, is:

> **"Do elevated nitrogen levels pose a potential risk to designated beneficial uses of Pearl Harbor, or to the ecological receptors within the harbor?"**

5.1. TECHNICAL APPROACHES FOR ASSESSING ECOLOGICAL RISK AS EUTROPHICATION POTENTIAL

In most ecological risk assessments, the stressors of concern are contaminants introduced naturally or anthropogenically which elicit adverse effects through acute or chronic toxicity. Nutrients, on the other hand, are not typically considered to be contaminants, since by definition, these substances are essential for maintaining and promoting ecological life, habitat, and health. The adverse effects associated with excessive levels of nutrients are best summarized by secondary symptoms and the potential effects/use impairments described in Figure 19, a simple conceptual model for eutrophication.

There are many different means for assessing potential for undergoing eutrophication. Several agencies have performed evaluations with a variety of tools and methods, notably the USEPA and NOAA. Most of the assessments have focused on estuaries and rank the study areas relative to one another in order to determine management priorities and allocation of resources.

NOAA, for instance, has completed several studies all focused on the severity and extent of eutrophication throughout the United States. The *National Estuarine Eutrophication Assessment* is an evaluation of 138 estuaries encompassing over 90% of estuarine surfaces throughout the continental United States (Bricker et al., 1999). This study is based on 5 years of comprehensive surveys and evaluations by leading researchers for each region. Figure 19, taken from that report, illustrates the symptomatology of eutrophication and can serve as a useful framework in quantifying the relative degree of eutrophication within an estuary. Primary symptoms include decreased light availability, algal dominance changes, and increased organic matter production. Secondary symptoms include loss of submerged aquatic vegetation, nuisance/toxic algal blooms, and low dissolved oxygen. A detailed method is provided (Appendix A in Bricker et al, 1999) for developing an overall assessment of eutrophication, based on a mixture of qualitative observations and quantitative measurements. In addition to the factors described in Figure 19, this method also considered the reliability of data used, and results from a series of surveys, interviews, and regional consensus-forming workshops among technical experts. These were all integrated to form a synoptic characterization of each estuary.

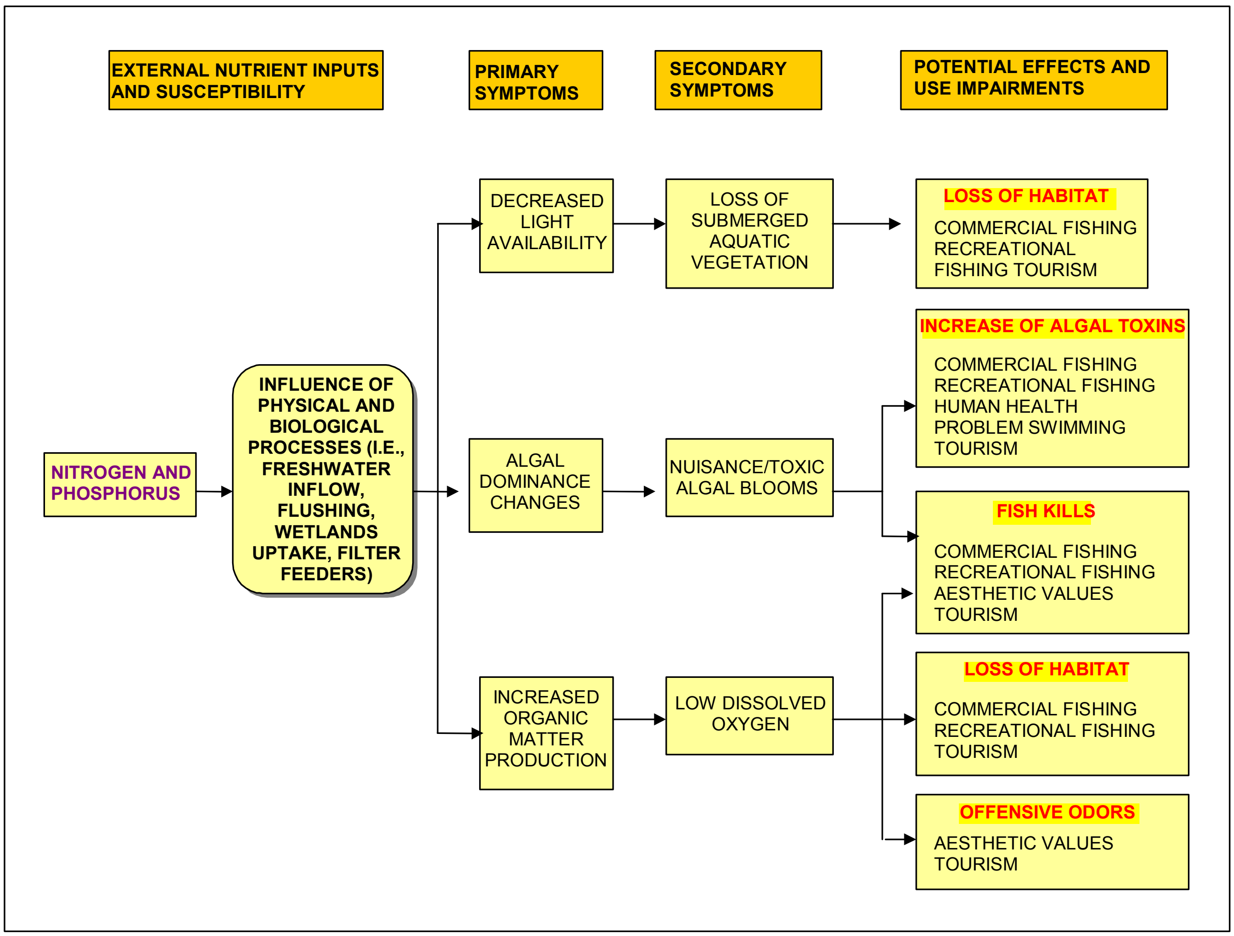

Figure 19. Eutrophication model (from Bricker et al., 1999).

Of note is the fact that “nutrient concentration in the water column is not included as a primary symptom because elevated nutrient concentrations do not necessarily indicate eutrophic symptoms nor do low concentrations necessarily indicate eutrophication is not present.” (Bricker et al., 1999). A case in point is during peak phytoplankton production when these organisms assimilate dissolved nutrients from the water column. Of 44 estuaries determined by NOAA to have high eutrophic conditions, only six (14%) had correspondingly high nitrogen levels.

NOAA also published the earlier *Strategic Assessments of Near Coastal Waters* which estimated the relative susceptibility of estuaries with respect to nutrient-related pollution (NOAA/USEPA, 1989). Susceptibility was determined for each estuary based on the ability to concentrate dissolved and particulate pollutants. Note that NOAA's assessment approach was focused on dilution and flushing which does not account for biological processes that may serve to remove nitrogen from the water, such as filter feeding organisms, and nutrient use within wetlands.

Finally, the USEPA has published reports on the variety of endpoints and assessment tools that are available for evaluating nutrient overenrichment (USEPA, 1995, 1999b, 1999c). In general agreement with NOAA's factors described in Figure 19, this other report describes several endpoints that can be used for evaluations. These endpoints are commonly used in eutrophication and nutrient studies.

Following is a summary of the endpoints and description of their relationships to eutrophication:

- Light Transmission. High nutrient concentrations promote plankton growth and reduce light transmission through the water column, causing a reduction in benthic primary production. Populations of algae and plants die off, as well as fish, causing hypoxia/anoxia and organic accumulation in the sediments.
- Dissolved Oxygen (DO) Concentrations. Nutrient enrichment is often signaled by excessive oxygen production in surface waters, leading to supersaturation in some cases, and by hypoxia (DO = <2 mg/L) or anoxia (DO = 0 mg/L) in deep waters caused by the biological decay process.
- Submerged Aquatic Vegetation (SAV). SAV is sensitive to the available underwater light which is directly related to water clarity and nutrient loads. Because of this sensitive relationship, SAV is a good indicator of habitat quality.
- Trophic Alterations/Monospecific Algal Blooms. Nutrient enrichment can cause alterations in primary production or the consumption of that production in a waterbody. These alterations cause changes in the food web structure and increase the potential for monospecific algal blooms.
- Dissolved Concentration Potential (DCP). NOAA's application of DCP in assessing eutrophication uses a nominal nutrient-loading factor (10 K tons/yr) weighted for total volume and freshwater turnover in order to estimate contaminant concentrations in the water column.
- Nitrogen/Phosphorous Ratio. Phytoplankton use an approximate atomic ratio of nitrogen to phosphorous of 16:1 for optimal growth. Since there are site-specific and species-specific factors that determine the exact optimal ratio for any water body, the practical working range of optimal ratios is 10:1 to 20:1. The nutrient with the lesser atomic proportion relative to the specific optimal ratio is considered the limiting nutrient (i.e., limits phytoplankton growth) (NOAA/USEPA, 1999).
- Biological Indicators. Long term analysis of changes in benthic fauna biomass and composition, larval fish abundance, and algal and zooplankton species composition can provide information on the condition of an estuary. These indicators are directly linked to water and habitat quality.
- Algal Growth Potential Test. The use of specific algae in a growth assay can determine which nutrient in a system is limited, and give maximum potential growth rates. This test has the advantage of being cost-effective, but the disadvantage of not being able to apply the results to any site-specific conditions.

- Enzyme Assays. Specific enzyme assays have been used to assess phosphorous limitation. This area of investigation is relatively new and requires more scientific investigation and a larger database in relation to changes in nutrient enrichment status of any given waterbody.
- Historical Trends. Long-term records of biotic and physical conditions within estuarine and coastal waters place nutrient enrichment processes in context with natural long term trends and weather cycles. This information is useful for calibrating simulation models and management scenarios.
- Watershed Loading Models. Modeling tools for watershed nutrient loading, hydrodynamic interactions, and atmospheric deposition can be applied to estuarine systems to refine the understanding of a specific environment.

Given wide variability in the types of marine and estuarine waterbodies affected by nutrient over-enrichment, in addition to climatological differences, it is generally accepted that endpoints are regional in nature, as opposed to nationwide. The same level of water quality may not be obtained with national endpoints because of the wide variety of uses (USEPA, 1995).

Nutrient endpoints might require site-specific adjustment or development within the context of a total maximum daily load (TMDL). A balance is necessary in choosing endpoints that reflect specific ecoregion conditions, and choosing those that allow practical implementation (USEPA, 1995). Although the USEPA has published guidance for the development of nutrient TMDLs (USEPA, 1999c), the primary focus of this protocol has been on lakes and rivers. Specific guidance on developing nutrient TMDLs in estuarine waters has not been promulgated. However, the document does refer to a general principle that applies to all systems:

…the availability of data influences the types of methods that developers can use. Ideally, extensive monitoring data are available to establish baseline water quality conditions, pollutant source loading, and waterbody system dynamics. However, without long-term monitoring data, the developer will have to use a combination of monitoring, analytical tools (including models), and qualitative assessments to collect information, assess system processes and responses, and make decisions. The degree of complexity in the methods used within individual TMDL components also may vary (USEPA, 1995).

5.2. SELECTING AN APPROACH FOR PEARL HARBOR

An extensive literature search has not identified specific eutrophication concerns within Pearl Harbor. However, Pearl Harbor has historically been primarily controlled and occupied by the U.S. Navy. It is reasonable to conjecture that the Navy's dominant presence has limited the number of ecological studies in Pearl Harbor due to the water body's limited number of beneficial and/or designated uses. Information on studies and observations that are relevant are mostly qualitative. Based on SSC San Diego's experience over the decades in studying, working, and observing this water body, visible eutrophication was apparent in Pearl Harbor only when vessels and STPs discharged primary and untreated effluents into the harbor during the 1950s through 1970s. These discharges were primarily into Middle Loch, Southeast Loch, and at the entrance channel near Iroquois Point. STP effluents were finally diverted out of the harbor during the early to mid-1980s (Grovhoug and Fransham, 1997, personal communication). This visible eutrophication was documented in 1974 during an extensive biological survey of Pearl Harbor. "The occurrence of red tides in Pearl Harbor appears to be a relatively recent phenomena, documented only within the past several years." (Evans et al., 1974).

Currently, observations of impaired water clarity have been related to sediment loading from ephemeral rain events, and suspension/resuspension in the water column (Grovhoug and Fransham, 1997, personal communication). However, it does not appear that the water clarity problems are associated with algal blooms, which would be an indicator of excessive nutrient loading into the system.

With respect to overall aquatic ecosystem health, a more recent study concluded "…based on comparison of biodiversity studies conducted in the early 1970s and recently, marine environmental conditions are of higher quality than in the past when silt runoff, sedimentation, and water contamination once precluded establishment of viable coral reef assemblages within Pearl Harbor. Coral species have been reported colonizing hard substrata in the entrance channel and other locations within the harbor" (Coles et al., 1997).

There is enough data to perform some preliminary eutrophication evaluations for Pearl Harbor and to make some comparisons with national trends. Since very few measurement data or even qualitative observations were made in Pearl Harbor to support use of NOAA's 1999 technical approach (Bricker et. al., 1999), the SSC San Diego authors decided to employ NOAA's simpler technical approach from 1989. An evaluation of the DCP was performed so that the results could be compared to those associated with NOAA's Strategic Assessment of near Coastal Waters (NOAA /USEPA, 1989) that has been completed for all regions of the continental United States. By applying a widely used DCP approach to the loading and ambient nutrient data presented previously in this report, a qualitative ranking of eutrophication risk can be determined, relative to an existing data set of many urban estuaries and harbors throughout the U.S.

A DCP is a hypothetical ambient water column concentration (derived from a hypothetical 10,000-ton load) that is used to compare the relative abilities of waterbodies in their assimilation of introduced pollutants. "The DCP characterizes the effect of flushing and estuarine dilution on a load of a dissolved pollutant to an estuary, assuming average concentration throughout the estuary and steady-state conditions. The DCP is a relative measure of overall potential and does not reflect site-specific conditions within an estuary. A high DCP value suggests that an estuary is likely to retain or concentrate a load of dissolved pollutant. A low DCP suggests that an estuary has significant dilution ability (due to large estuarine volume) and/or rapid flushing ability (due to rapid volume replacement)" (NOAA, 1989).

With loading information presented earlier, a DCP can be calculated for Pearl Harbor and used to derive estimated water column concentrations. DCP estimates can be compared to mainland estuaries to allow classification relative to nutrient load, and included in a qualitative relative ranking of eutrophication risk. There are limitations to DCP use:

1) The DCP method assumes a vertically homogenous well-mixed system (which increases in accuracy as mixing increases).

2) DCP assumes a recognizable freshwater inflow component to infer pollutant distribution.

3) The method does not take into consideration the effects of biological uptake, recycling, and regeneration (NOAA, 1989).

5.3. PEARL HARBOR EUTROPHICATION RISK

There are four terms used in this section to describe different aspects of the eutrophication assessment for Pearl Harbor. Although there is obvious overlap among the four in their generic uses, there are very specific uses applied in this report. The first term, "s*usceptibility,*" relates directly to NOAA's use of this term in combining the DCP and Particle Retention Efficiency (PRE) (explained below) in a determination of relative susceptibility of our nation's estuaries to eutrophication. The second term, "*potential*," is used in two different ways. The first use is with NOAA's "DCP" in which "*potential*" defines hypothetical concentrations of water bodies under nominal 10,000-ton annual loadings. The other use of "*potential*," when not specifically associated with DCPs, is its use as a synonym for "likelihood" or "possibility." The third term, "*status,*" refers to NOAA's incorporation of actual loadings into the DCP/PRE equation to predict site-specific ambient concentrations. Finally, the fourth term, "*risk,*" is used in this report as the final overarching evaluation of eutrophication, resulting from the combination of the NOAA hypothetical evaluation with the actual ambient data presented previously in this report.

5.3.1. The Dissolved Concentration Potential (DCP) for Determining Eutrophication Susceptibility, Status, and Risk

Data from the NOAA Strategic Assessment Branch was combined with data obtained from Evans (1974), as well as calculations contained in this review. This information is useful in assessing the eutrophication potential of Pearl Harbor and its relative relationship to other harbors throughout the United States.

NOAA uses the DCP as one of its standard waterbody evaluation tools (Equation 1). The DCP approach is a means to predict ambient concentrations of any conserved (i.e., no transformation, degradation, etc.) chemical or pollutant by estimating flushing and dilution based on waterbody volumes and freshwater turnover volumes. In the assessment of overall eutrophication potential, NOAA applies the DCP in a two-stepped process.

The first step allows an evaluation of the eutrophication "*susceptibility*" of an estuary relative to other estuaries throughout the United States by comparing both the waterbody's DCP and PRE. The PRE is the ability of a waterbody to trap suspended particles and the pollutants adhered to those particles (Equation 2). This assumes that the relative ability of an estuary to trap sediments correlates to its ability to retain any associated toxic pollutant (NOAA/USEPA, 1989). In general, higher DCP and PRE values indicate that an estuary will be more likely to retain or concentrate a dissolved pollutant. Lower DCP and PRE values indicate that an estuary has significant dilution and flushing abilities due to a larger overall volume and/or a rapid volume replacement. Since the purpose is to compare flushing/retention capabilities across a spectrum of waterbodies without respect to site-specific loadings, a nominal annual 10,000-ton load of nutrient (e.g., nitrogen, phosphorous, etc.) is used in this first step.

Equation 1: Dissolved Concentration Potential Calculation (DCP)

$$DCP = L \bullet (V_{fw} / i_{fw}) \bullet (1/V_{tot})$$

<u>Where:</u>

L = loading rate

V_{fw} = estuarine freshwater volume

i_{fw} = freshwater inflow

V_{tot} = total estuarine volume

The second step incorporates site-specific loadings of specific nutrients into the DCP equation above to assess waterbody "*status.*" These loads are plotted against the 10,000-ton DCP value in order to predict an ambient concentration. This characterization estimates the concentration of a specific pollutant in the water column by substituting a site-specific loading value (*"L"* in Equation 1) for the nominal 10,000 ton/year loading rate.

NOAA had previously established three concentration ranges for estimating relative *eutrophication status* based on empirical data:

- low concentration = below 0.1 mg/L
- medium concentration = between 0.1 and 1.0 mg/L
- high concentration = above 1.0 mg/L

These effects-based levels are based on observed estuarine characteristics at different nutrient levels and are adopted directly from the Chesapeake Environmental Quality Classification Scheme (NOAA/USEPA, 1989). High nutrient concentrations are associated with high chlorophyll levels, low species diversity, and occasional red tides, while low nutrient concentrations are associated with high diversity of aquatic life (NOAA/USEPA, 1989). This report on Pearl Harbor takes the classification scheme a step further by adopting these concentration "status" ranges as relative risk boundaries, based on NOAA's correlation of nutrient concentrations with eutrophication effects.

Equation 2: Particle Retention Efficiency (PRE)

$$PRE = C / I$$

Where:

C = estuarine volume

I = annual freshwater inflow

We have introduced a third and final step in SSC San Diego's effort to evaluate eutrophication "*risk*" in Pearl Harbor by comparing ambient data for Pearl Harbor with other harbors using an empirical national assessment of DCP data. Since the purpose of the DCP is to estimate ambient concentrations based on waterbody volumes and flushing/turnover rates, then any available long-term consistent data set of ambient nutrient concentrations should be considered for use in place of the calculated ambient values. Such a data set is available for Pearl Harbor, as discussed in depth previously in this report.

5.3.2. Estimating Relative Susceptibility to Eutrophication with PRE and DCP

As described for Step 1 in the previous section, the DCP and the PRE are calculated for Pearl Harbor using a standard pollution-loading rate of 10,000 tons/year, as specified by NOAA in the following calculations:

Calculation 1: DCP for Pearl Harbor with Standard Loading Rate

$$DCP = L \bullet (V_{fw} / i_{fw}) \bullet (1/V_{tot})$$

Where:

L = 10,000 tons/ year (constant value used)

V_{fw} = 2,500,000 m^3 (Evans, 1974, p3.3-73)

i_{fw} = 9 m^3/ *second* (Evans, 1974, p3.3-46)

V_{tot} = 144,000,000 m^3 (Evans, 1974 p3.3-73)

With the following unit conversions:

1 m^3 = 1,000 L

1 year = 31,536,000 seconds

1 ton = 907,184,740 mg

DCP = 10,000 tons/year • (2,500,000 m^3/9 m^3/sec) • (1/144,000,000 m^3) • (1 m^3/1,000 L) • (1 year/31,449,600 sec) • (907,184,740 mg/1 ton)

DCP = 0.56 mg/L

Calculation of PRE for Pearl Harbor

$$PRE = C / I$$

Where:

C =144,000,000 m^3

I = 9 m^3/ *second*

With the following unit conversions:

1 year = 31,536,000 seconds

PRE = (144,000,000 m^3 / 9 m^3/sec) • (1 year / 31,449,600 sec)

PRE = 0.51

Based on the these results, Pearl Harbor has a medium DCP and a medium PRE (Figure 20) when compared to other estuaries, which indicates an average susceptibility for eutrophication.

It should be remembered, however, that this *susceptibility* rating is just an indicator of the potential for eutrophication and does not consider specific nutrient loads or concentrations in Pearl Harbor.

5.3.3. Estimating Pearl Harbor Eutrophication Status Using DCP and Actual Loadings

A hypothetical concentration of a contaminant in a waterbody can be estimated by replacing the 10,000 tons/year standard loading rate in the DCP equation (Equation 1) with a waterbody specific loading rate (Equation 3). Using the estimated nitrogen loading rates for Pearl Harbor previously calculated in section 4.6.1 of 347 to 124 tons/year (wet season/dry season) yields a predicted total nitrogen concentration in Pearl Harbor of 0.013 to 0.0193 mg/L (or 19.3 to 6.9 µg/L).

Equation 3: Estimated Wet and Dry Season Concentration of Pearl Harbor Nitrogen

$$DCP = L \bullet (V_{fw} / i_{fw}) \bullet (1/V_{tot})$$

Where:

L = 347 tons/year (wet season loading) and 124 tons/year (dry season loading)

V_{fw} = 2,500,000 m^3 (Evans, 1974, p3.3-73)

i_{fw} = 9 m^3/ *second* (Evans, 1974, p3.3-46)

V_{tot} = 144,000,000 m^3 (Evans, 1974 p3.3-73)

With the following unit conversions:

1 m^3 = 1,000 L

1 year = 31,536,000 seconds

1 ton = 907,184,740 mg

DCP = 347 tons/year • (2,500,000 m^3/9 m^3/sec) • (1/144,000,000 m^3) • (1 m^3/1,000 L) • (1 year/31,449,600 sec) • (907,184,740 mg/1 ton)

DCP = 124 tons/year • (2,500,000 m^3/9 m^3/sec) • (1/144,000,000 m^3) • (1 m^3/1,000 L) • (1 year/31,449,600 sec) • (907,184,740 mg/1 ton)

TN conc $_{(PH\ wet)}$ = .0193 mg/L (ppm) or 19.3 µg/L (ppb)

TN conc $_{(PH\ dry)}$ = .0069 mg/L (ppm) or 6.9 µg/L (ppb)

The results from equation 3 are combined with NOAA (NOAA/USEPA, 1989) estimates from the *Strategic Assessments of Near Coastal Waters* and are presented in Figure 21 to compare potential for eutrophication with respect to nitrogen loading. In Figure 21, DCP and annual nitrogen load are two variables that yield the predicted ambient concentrations (wet and dry season, based on DCP estimates). The estimated concentrations, along with the mean measured ambient concentration (0.17 mg/L), the Hawaii WQS (0.3 mg/L), and the "boundary" concentrations separating low/medium risk (0.1 mg/L) and medium/high risk (1.0 mg/L) are all plotted as isoconcentration lines. Recall that previously, when considering just PRE and the DCP in Step 1, Pearl Harbor had a *medium susceptibility* for eutrophication relative to all other estuarine locations (Figure 20). *Now, when adding the best available loading estimates, the wet and dry season data yield two of the lowest "estimated" concentrations, relative to other harbors in the U.S. (*Figure 21*).*

5.3.4. Estimating Pearl Harbor Eutrophication Risk Based on Ambient Data and Empirical Criteria from National DCP Studies

In summary, the first two steps of the NOAA DCP approach in estimating eutrophication relative *susceptibility* and *status* can be very useful when ambient data on nutrients is lacking for a water body. In proceeding to a third assessment step in which the large data set of historical ambient nitrogen concentrations are incorporated, the actual ambient nitrogen concentrations are higher than predicted above by Equation 2. In Figure 21, the 0.17 mg/L isoconcentration is based on the geometric total nitrogen mean of the ambient station means shown in Figure 4 (RW-03, RW-07, Ref 600, DOH). Consistent with the results of Equation 1, the isoconcentration line of 0.17 mg/L indicates a *medium eutrophication risk*, relative to all other U.S. "estimated" ambient concentrations (Figure 22). Harbors plotting above 1.0 ppm are considered to have high eutrophication risk, while those falling below 0.1 ppm have low eutrophication risk.

For Pearl Harbor, however, the "*medium risk*" assessment from Equation 3 is more scientifically valid than Equation 2, since it is based on actual ambient data - the isoconcentration line of 0.17 mg/L. More accurate characterization of nutrient loading and flushing would probably serve to bring the two (wet and dry season) estimated isoconcentration lines closer to the true ambient conditions. Recognizing that the hypothetical DCP ("calculated generic DCP" of 0.56 mg/L in Figure 21, marked by vertical dashed line) and/or estimated nitrogen load could be inaccurate, there are many ways to arrive at the ambient isoconcentration of 0.17 mg/L. Three points are plotted on the line to demonstrate that a spectrum of possibilities exist, by which DCP and load estimates can intersect at the ambient isoconcentration line. If Point #1 reflected the truth, the DCP would have been closely approximated and our nitrogen loading estimate of 124 to 347 tons/year would have been low by 2 orders of magnitude. Point #2 would reflect a correctly estimated loading value combined with a DCP that is actually much greater than the calculated one, indicating a more poorly flushed water body. Finally, Point #3 reflects the other end of the spectrum from Point #2, an actual DCP that is much lower than calculated (i.e., better flushing than predicted) coupled with a nitrogen load that is much higher than was estimated (by 4 orders of magnitude). It would be futile to speculate on a definitive reason for the low predicted concentrations without further data, but the following discussion highlights some possible causes.

Several potentially significant loading sources remain unquantified due to lack of information. For instance, nutrient-contaminated groundwater is a likely source of loading, as discussed previously in this report, yet little is known about its contribution via underground seepage. Another unknown nitrogen loading source is localized atmospheric deposition of both anthropogenic (i.e., man-made emission sources such as automotive and power plant exhaust, and volatilization of ammonia during fertilizer application) and natural (volcanically-derived) nitrogen (Health and Huebert, 1999). The DCP method is best used to characterize estuaries that are vertically homogenous and well mixed (NOAA/USEPA, 1989). As conditions deviate from these ideal characteristics, the DCP characterization will be less reliable. Pearl Harbor can be generally described as a two-layer flow estuary with some vertical mixing (Evans et al., 1974). The vertical mixing is not considered strong, and it is noteworthy that one of the most important factors contributing to mixing was considered to be ship traffic (Evans et al., 1974). In summary, the DCP calculation could have over-estimated flushing, suggesting that if the DCP formula had contained a term for expressing the small degree of vertical mixing, then the calculated DCP could have been higher, approaching the Point #2 scenario.

Notably absent from the DCP formula is any consideration of nutrient assimilation by the ecosystem and corresponding loss of nitrogen from the water column. If this uptake is more important than any reduced flushing phenomenon (i.e., yielding a greater mass loss of nitrogen from the water column), then the DCP would have been over-estimated. Such a lower DCP, plotted to the left of the one shown in Figure 21, could combine with a highly under-estimated nitrogen load to intersect the isoconcentration line between Points #1 and #3. On the other hand, if the loads missed in our calculations are not too large and the reduced flushing is more important than nitrogen assimilation, then a DCP to the right would intersect the ambient concentration line between Points #1 and #2. It should be noted that for the known nitrogen sources, conservative estimates (i.e., assuming worst-case) for mass loads are always used. For example, the geometric mean concentration for nitrogen in the Waikele stream (a massive water source) was used to be representative of all tributary input to Pearl Harbor, and Waikele drains a watershed region with expected higher nitrogen loads.

Only more accurate characterization of nitrogen loading and dispersion will give us additional insight on the particulars of the disparity between predicted and ambient nitrogen values. *However, the presence of a long-term data set of ambient values renders the differences almost moot beyond stimulating academic discussion, since ambient data from this report indicates that Pearl Harbor has medium eutrophication risk.*

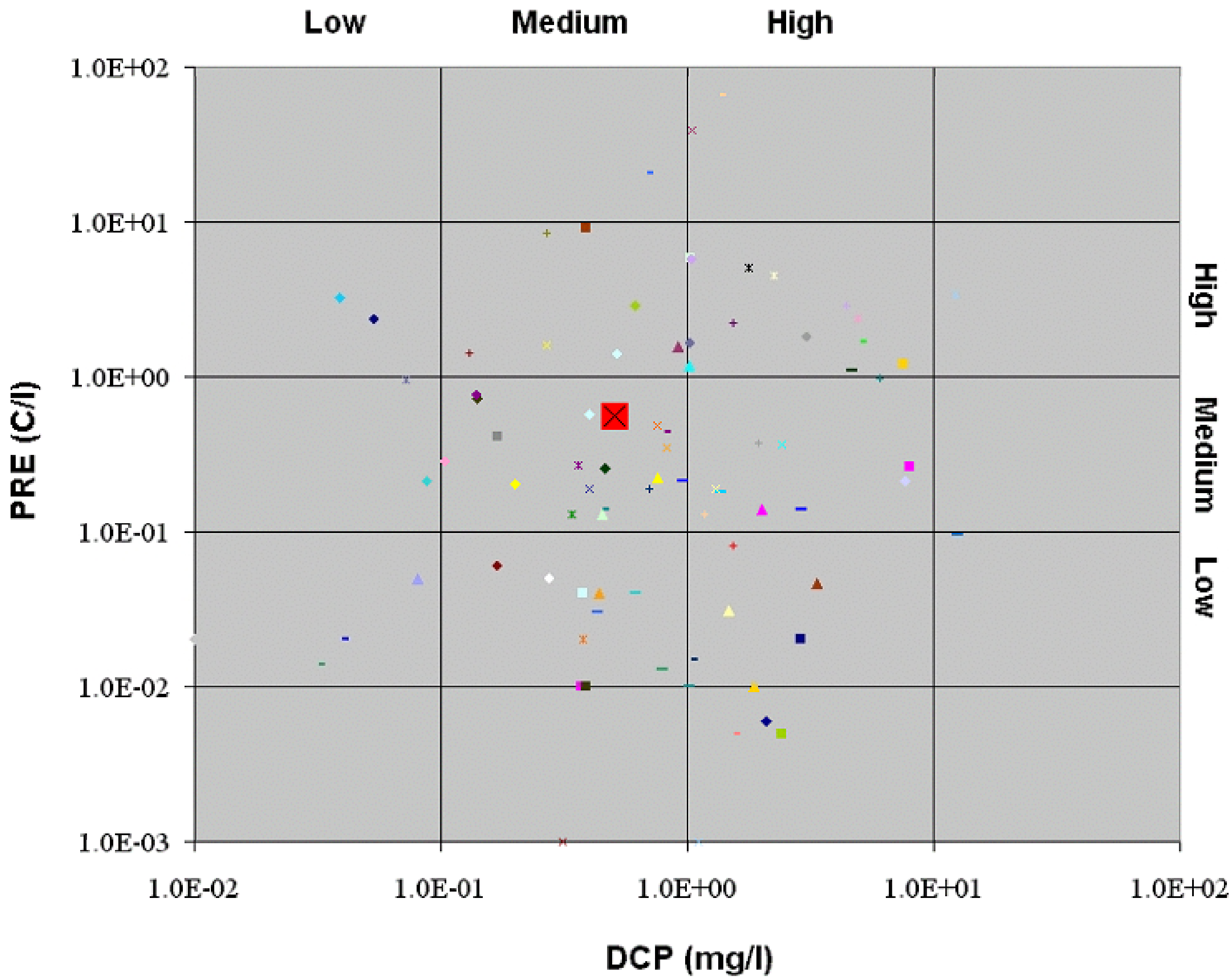

Figure 20. Relative susceptibility classification for estuaries including Pearl Harbor.

Figure 20 Legend

Alsea River Estuary, OR	Altamaha River, GA	Andrew Bay, FL
Andrew/ St. Simons Sound, GA	Apalachee Bay, FL	Apalachicola Bay, FL
Aransas Bay, TX	Atchafaya and Vermilion Bays, LA	Barnegat Bay, NJ
Biscayne Bay, FL	Blue Hill Bay, ME	Bogue Sound, NC
Brazos River, TX	Broad River, SC	Buzzards Bay, MA
Calcasieu Lake, LA	Cape Cod Bay, MA	Cape Fear River, NC
Casco Bay, ME	Catherines/ Sapelo Sound, GA	Charleston Harbor, SC
Charlotte Harbor, FL	Chesapeake Bay, VA	Chincoteague Bay, MD
Choctawhatchee Bay, FL	Columbia River, WA, OR	Corpus Christi Bay, TX
Delaware Bay, DE	Eel River Estuary, CA	Englishman Bay, ME
Galveston Bay, TX	Gardiners Bay, NY	Grays Harbor, WA
Great Bay, NH	Great South Bay, NY	Helena Sound, SC
Hudson River/ Raritan Bay, NY	Humboldt Bay, CA	Indian River, FL
Klamath River Estuary, OR	Laguna Madre, TX	Long Island Sound, NY
Massachusetts Bay, MA	Matagorda Bay, TX	Merrimack River, NH
Mississippi River, LA	Mississippi Sound, LA	Mobile Bay, AL
Montery Bay, CA	Muscongus Bay, ME	Narragansett Bay, MA
Narraguagus Bay, ME	Nehalem River Estuary, OR	Netarts Bay, OR
New River, NC	North and South Santee Rivers, SC	Ossabaw Sound, GA
Passamaquoddy Bay, ME	Pearl Harbor Predicted Wet	Albemarle/Pamlico Sound, NC
Penobscot Bay, ME	Pensacola Bay, FL	Perdido Bay, FL
Puget Sound, WA	Sabine Lake, LA	Saco Bay, ME
San Antonio Bay, Tx	San Diego Bay, CA	San Francisco Bay, CA
San Pedro Bay, CA	Santa Monica Bay, CA	Savannah River, SC
Sheepscot Bay, ME	Siletz Bay, OR	Siuslaw River Estuary, OR
St. Johns River, FL	Suwannee River, FL	Tampa Bay, FL
Ten Thousand Islands, FL	Tillamook Bay, OR	Umpqua River Estuary, OR
Willapa Bay, WA	Winyah Bay, SC	Yaquina Bay, OR

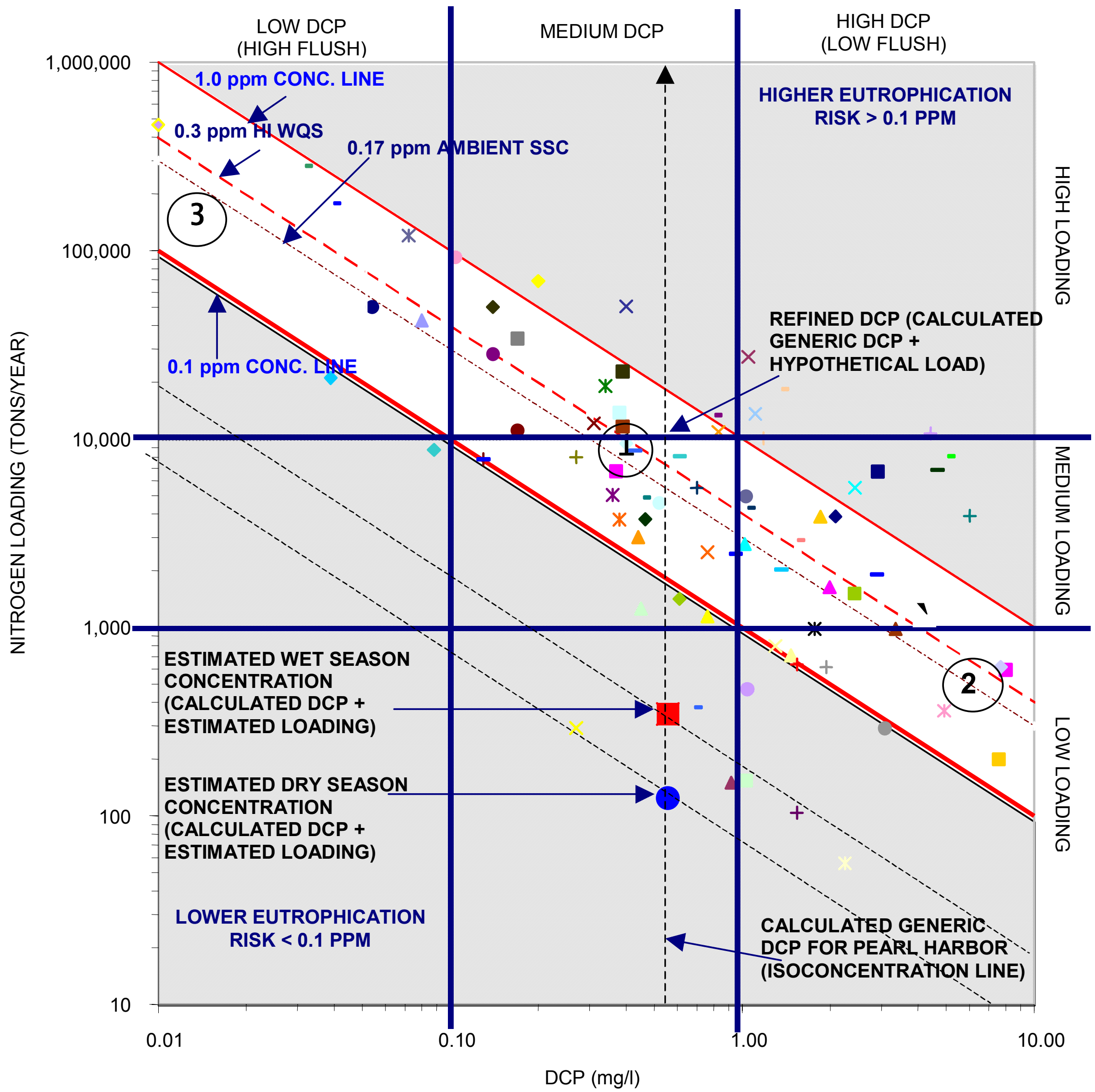

Figure 21. Relative risk of eutrophication with respect to nitrogen.

Figure 21 Legend

Alsea River Estuary, OR	Altamaha River, GA	Andrew Bay, FL
Andrew/ St. Simons Sound, GA	Apalachee Bay, FL	Apalachicola Bay, FL
Aransas Bay, TX	Atchafaya and Vermilion Bays, LA	Barnegat Bay, NJ
Biscayne Bay, FL	Blue Hill Bay, ME	Bogue Sound, NC
Brazos River, TX	Broad River, SC	Buzzards Bay, MA
Calcasieu Lake, LA	Cape Cod Bay, MA	Cape Fear River, NC
Casco Bay, ME	Catherines/ Sapelo Sound, GA	Charleston Harbor, SC
Charlotte Harbor, FL	Chesapeake Bay, VA	Chincoteague Bay, MD
Choctawhatchee Bay, FL	Columbia River, WA, OR	Corpus Christi Bay, TX
Delaware Bay, DE	Eel River Estuary, CA	Englishman Bay, ME
Galveston Bay, TX	Gardiners Bay, NY	Grays Harbor, WA
Great Bay, NH	Great South Bay, NY	Helena Sound, SC
Hudson River/ Raritan Bay, NY	Humboldt Bay, CA	Indian River, FL
Klamath River Estuary, OR	Laguna Madre, TX	Long Island Sound, NY
Massachusetts Bay, MA	Matagorda Bay, TX	Merrimack River, NH
Mississippi River, LA	Mississippi Sound, LA	Mobile Bay, AL
Montery Bay, CA	Muscongus Bay, ME	Narragansett Bay, MA
Narraguagus Bay, ME	Nehalem River Estuary, OR	Netarts Bay, OR
New River, NC	North and South Santee Rivers, SC	Ossabaw Sound, GA
Passamaquoddy Bay, ME	Albemarle/Pamlico Sound, NC	Penobscot Bay, ME
Pensacola Bay, FL	Perdido Bay, FL	Puget Sound, WA
Sabine Lake, LA	Saco Bay, ME	San Antonio Bay, Tx
San Diego Bay, CA	San Francisco Bay, CA	San Pedro Bay, CA
Santa Monica Bay, CA	Savannah River, SC	Sheepscot Bay, ME
Siletz Bay, OR	Siuslaw River Estuary, OR	St. Johns River, FL
Suwannee River, FL	Tampa Bay, FL	Ten Thousand Islands, FL
Tillamook Bay, OR	Willapa Bay, WA	Winyah Bay, SC
Yaquina Bay, OR	Pearl Harbor Predicted Dry	Pearl Harbor Predicted Wet
1.0 ppm conc. line	0.1 ppm conc. line	0.3 ppm conc. line
0.2 ppm conc. line		

5.3.5. Controlling Nutrients When Eutrophication is Indicated

Regardless of the qualitative ranking determined in Figure 21, regulators may still insist that it is necessary to control the input of nutrients to the system. The standard approach for determining which nutrient is limiting (nitrogen or phosphorous) is to examine their concentration ratios in the water column.

While nitrogen is the subject of this report, the SSC San Diego authors performed some preliminary calculations (Appendix A, p. A-18) to get a better understanding of the influence that phosphorous imparts on the Pearl Harbor eutrophication issue. Based on estimated loading and nutrient levels, the N:P ratio for Pearl Harbor appears to range from 5:1 (dry season) to 7:1 (wet season). As described in Section 5.1, a ratio under 10:1 (N is in lesser proportion relative to optimal atomic ratio) points to a more cost-effective management solution in reducing nitrogen loading (USEPA, 1999b). Note that from a mass loading perspective, the more significant problem is with the nutrient that is in excess (phosporous in this case). However, since the objective is to prevent maximum productivity rates (achieved by nitrogen and phosporous together with sunlight and optimal temperature ranges), it is easier to target the nutrient that is at the lower levels relative to the optimal atomic ratio. Consequently, the regulatory focus on nitrogen in Pearl Harbor would be warranted if eutrophication indicators were present. The issue is whether or not these indicators are present. Based on this study, no obvious eutrophication indicators are present; however, it appears that focused efforts have not been made to examine the potential problem (i.e., no information was available related to the many symptoms of eutrophication presented earlier in Figure 21).

Recommended monitoring strategies and management options applicable to all estuaries impacted by nutrient loading, including Pearl Harbor, are shown by Figure 22 (Bricker et al., 1999*). Pearl Harbor is best represented in the first assessment condition "Estuaries with No or Low Symptoms." Considering the medium risk (step 3) calculated in this report, "preventive measures" may be warranted. However, given the relative absence of eutrophication indicators, "early warning monitoring" may be more appropriate.*

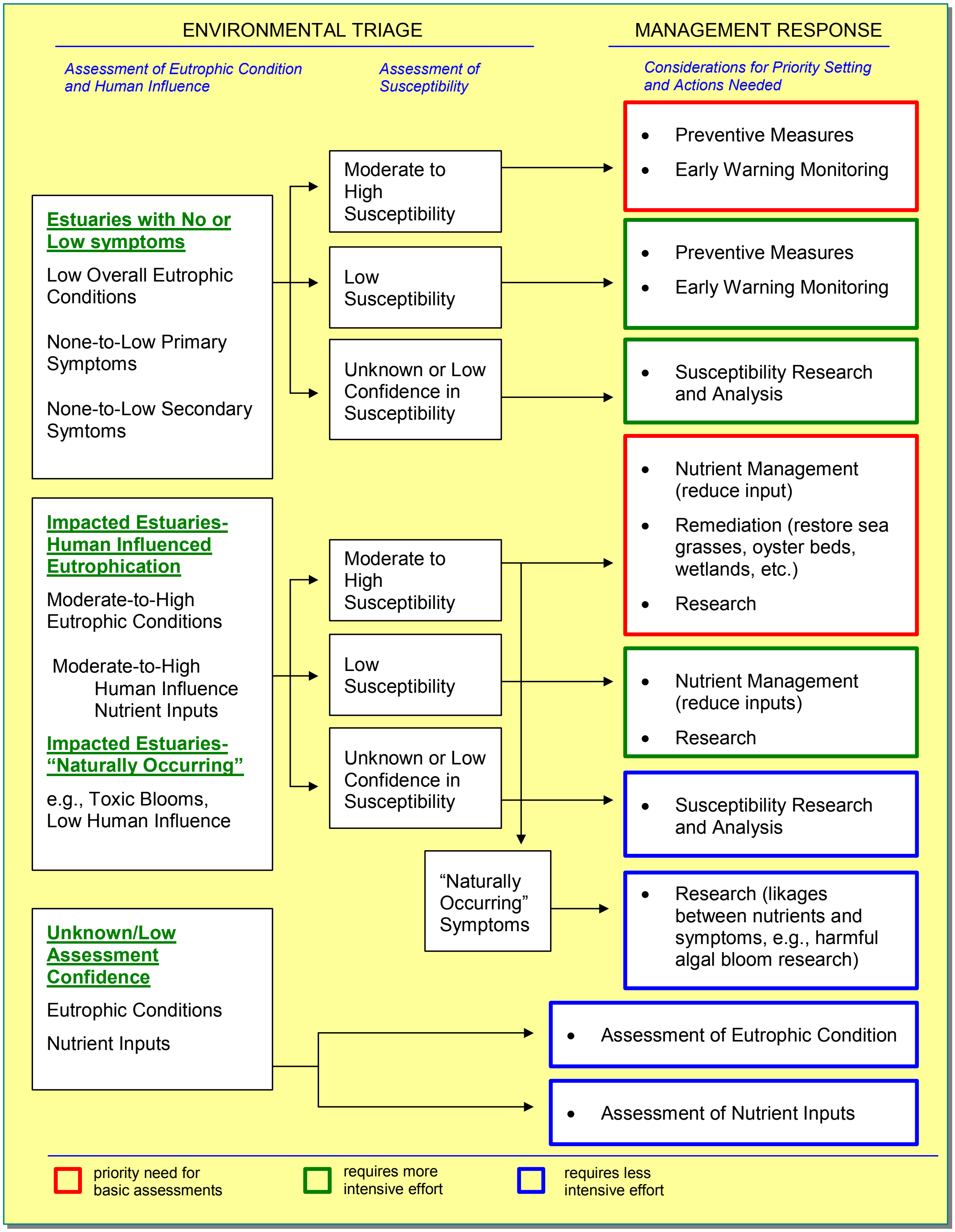

Figure 22. Framework for developing a national strategy (from Bricker et al., 1999).

6. CONCLUSIONS AND RECOMMENDATIONS

Four main issues and associated recommendations can be gleaned from the results of this nutrient assessment.

1. <u>Monitoring Ambient Conditions</u>

The monitoring data reviewed in this report was assumed to be representative of typical or average ambient conditions. However, there are two major problems with this assumption: the actual data may not be temporally or spatially representative. The data that is paired temporally (i.e., month by month) are in fact compiled from distinct sample collection events that may not have had any association among one another. Specifically, monitoring data for a given month from the various stations may have been taken on different days of the month that may have reflected totally different environmental or operational conditions. This is true even for the collections from the various dry docks. Likewise, the data that represents different ambient monitoring stations are collected by different agencies at different times using different methods. Furthermore, a grid of so few stations may not be sufficient to characterize the entire area of Pearl Harbor. If personnel are to be deployed to collect data in the harbor, it seems that it would be cost-effective in the long run to have them collect data from many stations that together represent a more extensive and systematic sampling design of the harbor, with broader spatial coverage.

2. <u>Assessment of Sources and Mass Loads</u>

Ammonia appears to be the form of nitrogen that violates the Shipyard permit limits most frequently, but it is closely followed by the other two forms. Comparison of nitrogen concentrations in Shipyard effluent and nitrogen potential source inputs to the Shipyard indicate that groundwater seepage and potable water have higher concentrations of nitrogen than the effluent. However, small sample sizes, limited temporal distribution, and unquantified input amounts (i.e., flow) limit the scientific conclusions that can be drawn. In the future, in order to truly understand the characteristics of the effluent's effect, monitoring should be conducted to obtain time-series data during various operational regimes, from the times of minimal discharge to the times of maximum discharge. For example, this data could be collected in 1-hour segments over periods lasting 1 or more days. SSC San Diego has developed tools and methods for examining groundwater seepage between coastal lands and adjacent water bodies, which could be applied to study the tidal pumping phenomenon (i.e., is groundwater contaminating surface waters or vice versa?).

For the effluent and influent measurements, the Shipyard should ensure that the sampling is not confounded by other variables, such as sampling points that introduce contaminants that are not representative of the effluent. One example is the sampling of effluent in atypically anoxic conditions caused by the cycling of nitrogen from its oxidized to reduced forms (i.e., from NO_x to NH_3). Another example might be the sampling of sumps where trapped organisms have decayed in a stagnant pool of effluent.

The Shipyard should conduct systematic monitoring on its property to find sources of nitrogen entering from non-Shipyard locations that are causing high nitrogen levels in Shipyard effluents. Additional monitoring could be conducted to track the flow and concentrations of nitrogen, nitrate-nitrite, and ammonia from groundwater and potable water from their respective points of entry to the Shipyard to their eventual discharge through the dry dock outlets.

Finally, attempts should be made to further refine the nitrogen loading sources and quantities, including the effect of elevated nitrogen in groundwater discharge to Pearl Harbor, the degree of localized atmospheric nitrogen deposition, and the magnitude of stormwater contributions.

3. Modeling Nutrient Fate and Effects

As indicated from the comparison of DCP-predicted concentrations with actual ambient data, mixing and flushing characteristics of Pearl Harbor may require better characterization. It is possible that wind-induced currents produce more dynamic flushing than is predicted by the DCP. Two complementary technological approaches for evaluating hydrodynamic characteristics have been implemented in other Navy harbor locations (e.g., San Diego Bay, Sinclair Inlet) by SSC San Diego.

First, the real-time environmental mapping capability of SSC San Diego's Marine Environmental Survey Capability (MESC) could be employed cost-effectively to assess nitrogen sources, gradients, and dispersion in the harbor during an intensive survey period of 1 to 2 weeks. MESC has been used to map many water quality contaminants and other parameters in Navy harbors (Chadwick et al., 1999; Katz, 1998; Katz et al., 1999).

Second, the data collected with MESC could also be used in conjunction with SSC San Diego's hydrodynamic modeling capabilities to develop a fate and transport model for nitrogen that could predict dispersion scenarios under myriad loading and environmental conditions that are not observable during the survey periods. SSC San Diego has experience in tailoring standard hydrodynamic models for use in Navy harbors (Wang and Richter 1999; Wang, 1998; Wang et al., 1998), and for specific use in evaluating nutrient processes (Wang et al., 1999) that are not addressed in this preliminary assessment. Because of the evidence supporting a vertically-stratified system with at least a surface layer and a bottom layer, a 3-dimensional modeling capability should be considered.

4. Management Response to Eutrophication Concerns

In the larger context (e.g., waterbody and watershed scales), PHNSY plays a relatively small role as a nutrient loading source. Loading estimates for Pearl Harbor indicate that the Shipyard may provide less than 7% of the overall nitrogen loading, compared to far more significant loads contributed by other identified sources such as streams (e.g., 88% of the ammonia).

Focusing specifically on nitrogen concentrations in Shipyard effluents, there are levels approaching and sometimes surpassing State WQS, which are obviously a concern to the local regulatory authorities. However, the question arising from this assessment is "Are these levels of nitrogen causing any eutrophication symptoms in Pearl Harbor?"

The assessment in this report, which used a national NOAA program to rank a multitude of U.S. harbors and estuaries with respect to eutrophication potential/risk, determined that Pearl Harbor had a medium risk. Furthermore, studies and qualitative observations to date have not yielded any of the classic eutrophication symptoms discussed in a NOAA comprehensive assessment of nutrient enrichment in the nation's estuaries.

Based on this report's assessment and the acknowledgement that regulatory scrutiny continues, it is recommended that future monitoring be focused on the eutrophication concerns. Since several national programs have determined that there are specific "indicators" which are useful in monitoring efforts to provide early detection of eutrophication problems, it is highly recommended that the Shipyard propose to substitute other monitoring activities (e.g., frequent chemical-specific measurement of effluents, since years of such data already exist) with this more relevant eutrophication-focused monitoring in the receiving waters. Such monitoring activities may provide long-term data that could support a conclusion that current eutrophication concerns are not valid. Finally, if eutrophication symptoms are observed, such monitoring would permit more focused management response.

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APPENDIX A. NUTRIENT RISK ASSESSMENT: PEARL HARBOR NAVAL SHIPYARD

PHNSY AND MONITORING DATA FOR TOTAL NITROGEN

TOTAL NITROGEN	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	Seepage Geomean	HI DOH Blaisdell	PWC Monitoring	PWC Station RW 07	PWC Station RW 03
Jan-93		216		**216**	182	182	**182**	198								120			
Feb-93		95		**95**	95	95	**95**	95								100			
Mar-93		178		**178**	124	124	**124**	149											
Apr-93		174		**174**	143	143	**143**	158								100			
May-93		101		**101**	106	106	**106**	103								100			
Jun-93		225		**225**	136	136	**136**	175								100			
Jul-93		30		**30**	145	145	**145**	66								100			
Aug-93	**265**	0			125	125	**125**									100			
Sep-93		108		**108**	146	146	**146**	126								100			
Oct-93	**158**	193		**193**	386	386	**386**	245								100			
Nov-93	**125**	195		**195**	272	272	**272**	204								300			
Dec-93		163		**163**	355	355	**355**	241											
Jan-94	**179**	170		**170**	279	279	**279**	209								220			
Feb-94	**200**	153		**153**	270	270	**270**	203								100			
Mar-94	**188**	174		**174**	241	241	**241**	201											
Apr-94		208		**208**	146	146	**146**	174											
May-94		208		**208**	232	232	**232**	220											
Jun-94		374		**374**	288	288	**288**	328											
Jul-94		160		**160**	190	190	**190**	174	277							200			
Aug-94		225		**225**	221	221	**221**	223								100			
Sep-94	**1660**	255		**255**	622	622	**622**	530								200			
Oct-94		173		**173**	232	232	**232**	200								340			
Nov-94		210		**210**	488	488	**488**	320	277							210			
Dec-94		283		**283**	323	323	**323**	302											
Jan-95		249		**249**	280	280	**280**	264											
Feb-95	**183**	253		**253**	353	353	**353**	271								310			
Mar-95																			
Apr-95	**270**	242		**242**	253	253	**253**	252	265							300			
May-95	**589**	138		**138**	222	222	**222**	223								100			
Jun-95		139		**139**	167	167	**167**	152											
Jul-95	**187**	134		**134**															
Aug-95		277		**277**	177	177	**177**	221											
Sep-95		255		**255**	269	269	**269**	262											
Oct-95		214		**214**	161	161	**161**	186											
Nov-95		105		**105**	90	90	**90**	97								300			

TOTAL NITROGEN	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	Seepage Geomean	HI DOH Blaisdell	PWC Monitoring	PWC Station RW 07	PWC Station RW 03
Dec-95	**140**	170		**170**	130	130	**130**	147											
Jan-96	**130**	240		**240**	110	110	**110**	155											
Feb-96	**334**	210		**210**	213	213	**213**	232								100			
Mar-96		241		**241**	139	139	**139**	183	129										
Apr-96		130		**130**	210	210	**210**	165									130		320
May-96	**341**	232	275	**253**	266	227	**246**	249								200	295		100
Jun-96	**154**	386	1320	**714**	331	331	**331**	453									158		284
Jul-96		218	377	**287**	439	802	**593**	339	279								278		316
Aug-96		532	690	**606**	574		**574**	595								200	278		142
Sep-96	**315**		309	**309**	405		**405**	354									300		274
Oct-96	**228**	144	161	**152**	135		**135**	177									164		204
Nov-96	**958**	313	329	**321**	510		**510**	331									271		492
Dec-96		380	179	**261**	302		**302**	375									215		741
Jan-97		561	344	**439**				439	207								341		329
Feb-97		308	263	**285**				285								100	221		470
Mar-97			620	**620**				620									229		450
Apr-97	**450**	1000	870	**933**				933	384								241	250	300
May-97	**210**	110	150	**128**				195	120							100	202	224	343
Jun-97		333	216	**268**				247	190								173	216	231
Jul-97	**285**	150	160	**155**				155	132								151	237	149
Aug-97		271	249	**260**	281	294	**287**	276	242								187	323	298
Sep-97	**197**	340	254	**294**		305	**305**	298	185								212	281	248
Oct-97		189	225	**206**	328		**328**	229	149								242	312	248
Nov-97										847	274						311	230	394
Dec-97										971	416						321	298	466
Jan-98										821	319						147	127	237
Feb-98										832	189						177	103	375
Mar-98										850	193						138	108	155
Apr-98		100	100	**100**	100	100	**100**	100	124								163	106	205
May-98		212	228	**220**	202	175	**188**	203	159								253	248	331
Jun-98	**298**	143	121	**132**	110	112	**111**	121	258								385	325	425
Jul-98		138	147	**142**	388	239	**305**	224	105								244	100	560
Aug-98			333	**333**	276		**276**	303	304								128	105	186
Sep-98			215	**215**	237	261	**249**	237	178	806	213						132	105	152
Oct-98			387	**387**	538	261	**375**	379	185	792	351						139	115	173
Nov-98			570	**570**	469	379	**422**	466	646								123	110	221
Dec-98			418	**418**	699	427	**546**	500	393								184	102	315
Jan-99			166	**166**	234	150	**187**	180	116	785	176						126	127	190
Feb-99			243	**243**	165	252	**204**	216	288		336	619	187	335	338		126	104	176
Mar-99			239	**239**	294	224	**257**	251	148		372						223	191	306
Apr-99			171	**171**	200	269	**232**	210	150			965	261	649	547				

TOTAL NITROGEN	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	Seepage Geomean	HI DOH Blaisdell	PWC Monitoring	PWC Station RW 07	PWC Station RW 03
May-99			328	**328**	346	367	**356**	347	253										
Jun-99			203	**203**	151	185	**167**	178	113		151								
Jul-99			353	**353**	333		**333**	343	223										
Aug-99					365		**365**	365	113										

PHNSY AND MONITORING DATA FOR NITRATE-NITRITE

NITRATE-NITRITE	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	HI DOH Blaisdell	PWC Monitoring	PWC Station RW 07	PWC Station RW 03
Jan-93		92		**92**	28	28	**28**	42							20			
Feb-93		25		**25**	10	10	**10**	14							10			
Mar-93		36		**36**	8	8	**8**	13										
Apr-93		18		**18**	21	21	**21**	20							10			
May-93		15		**15**	19	19	**19**	18							10			
Jun-93		125		**125**	42	42	**42**	60							10			
Jul-93		50		**50**	21	21	**21**	28							10			
Aug-93	**34**	25		**25**	10	10	**10**	17							10			
Sep-93		22		**22**	13	13	**13**	15							10			
Oct-93	**50**	44		**44**	142	142	**142**	82							10			
Nov-93	**23**	36		**36**	45	45	**45**	36							10			
Dec-93		27		**27**	23	23	**23**	24										
Jan-94	**29**	34		**34**	47	47	**47**	38							20			
Feb-94	**61**	32		**32**	44	44	**44**	44							10			
Mar-94	**49**	28		**28**	42	42	**42**	39										
Apr-94		62		**62**	40	40	**40**	46										
May-94		68		**68**	40	40	**40**	48										
Jun-94		173		**173**	44	44	**44**	69										
Jul-94		218		**218**	67	67	**67**	99	6						10			
Aug-94		65		**65**	51	51	**51**	55							10			
Sep-94	**279**	47		**47**	58	58	**58**	81							10			
Oct-94		38		**38**	45	45	**45**	43							40			
Nov-94		13		**13**	1.1	1.1	**1**	3							10			
Dec-94		23		**23**	23	23	**23**	23										
Jan-95		65		**65**	65	65	**65**	65										
Feb-95	**8.12**	34.5		**35**	40.9	40.9	**41**	26							10			
Mar-95																		
Apr-95	**43.9**	33.9		**34**	38.9	38.9	**39**	39	14.2						10	5.5		8.2
May-95	**104**	22.1		**22**	37.1	37.1	**37**	42							20	2.1		0.1
Jun-95		39		**39**	42	42	**42**	41								13.3		8.4
Jul-95	**67**	34		**34**				48								6.9		11.6
Aug-95		60		**60**	15	15	**15**	24								8.4		10.3
Sep-95		45		**45**	29	29	**29**	34								8.1		15.4
Oct-95		54.5		**55**	21.1	21.1	**21**	29	3.6							8.1		1.6
Nov-95		53		**53**	33	33	**33**	39							10	21.4		20.1

NITRATE-NITRITE	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	HI DOH Blaisdell	PWC Monitoring	PWC Station RW 07	PWC Station RW 03
Dec-95	**28**	45		**45**	29	29	**29**	32								18.0		44.2
Jan-96	**25**	30		**30**	6	6	**6**	13								18.0		14.9
Feb-96	**54**	60		**60**	43	43	**43**	49							40	11.4		24
Mar-96		84		**84**	39	39	**39**	50	9							6.1		31
Apr-96		27		**27**	36	36	**36**	33								6.7		10
May-96	**23**	58	59	**58**	32	29	**30**	37							10	2.4		0.3
Jun-96	**37**	49	51	**50**	25	28	**26**	36								3.2		0.6
Jul-96		37	37	**37**	29	28	**28**	32	11.83							6.4		1.2
Aug-96		56	166	**96**	74		**74**	88							10	14.3		2.1
Sep-96	**27**		50	**50**	53		**53**	42								10.4		10.1
Oct-96	**28**	44	61	**52**	35		**35**	40								4.5		0.9
Nov-96	**168**	73	69	**71**	30		**30**	71								122.4		122
Dec-96		49	41	**45**	65		**65**	51								25.6		115
Jan-97		131	94	**111**				111	37							20.8		131
Feb-97		70	49	**59**				59							10	5.4		32
Mar-97			140	**140**				140								13.9		179
Apr-97	**22**	110	110	**110**				64	17.15							15.3	10	25
May-97	**12**	9	9	**9**				10	9.49						10	7.8	4	173
Jun-97		38	11	**20**				20	21							5.3	2	17
Jul-97	**58**	50	60	**55**				56	29.39							11.3	2	49
Aug-97		28	21	**24**	8	9	**8**	14	12							10.7	7	111
Sep-97	**8**	50	48	**49**		21	**21**	25	10.58							9.1	5	63
Oct-97		11	36	**20**	63		**63**	29	1							13.1	12	68
Nov-97										647	33					16.8	7	153
Dec-97										651	37					13.2	7	158
Jan-98										721	1					7.4	1	137
Feb-98										732	89					7.9	3	218
Mar-98										750	93					9.4	4	55
Apr-98		52	49	**50**	54	68	**61**	55	24							9.8	6	105
May-98		27	43	**34**	17	20	**18**	25	16							9.8	18	81
Jun-98	**27**	23	21	**22**	10	12	**11**	17	17							5.2	3	19
Jul-98		41	44	**42**	209	78	**128**	74	26							9.0	1	106
Aug-98			64	**64**	30		**30**	44	6							8.4	5	86
Sep-98			21	**21**	31	43	**37**	30	19	706	54					8.4	2	43
Oct-98			49	**49**	33	27	**30**	35	20	692	47					9.9	7	36
Nov-98			35	**35**	22	33	**27**	29	16							16.7	18	121
Dec-98			44	**44**	30	30	**30**	34	19							4.9	2	2

NITRATE-NITRITE	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	HI DOH Blaisdell	PWC Monitoring	PWC Station RW 07	PWC Station RW 03
Jan-99			31	**31**	23	21	**22**	25	10	685						13.2	27	90
Feb-99			37	**37**	25	23	**24**	28	5			38	4	3		6.4	4	76
Mar-99			66	**66**	33	51	**41**	48	17		57					8.0	2	11
Apr-99			23	**23**	22	13	**17**	19	14			12	71	69				
May-99			10	**10**	22	37	**29**	20	42									
Jun-99			26	**26**	22	44	**31**	29	13		16							
Jul-99			86	**86**	25		**25**	46	3									
Aug-99					33		**33**	33	13									

PHNSY AND MONITORING DATA FOR AMMONIA

AMMONIA	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	Dry dock geomean seepage	HI DOH Blaisdell	PWC monitoring	PWC RW 07	PWC RW 03
Jan-93		7		**7**	25	25	**25**	16								50			
Feb-93		21		**21**	35	35	**35**	30								50			
Mar-93		9		**9**	62	62	**62**	33											
Apr-93		4		**4**	61	61	**61**	25								50			
May-93		6		**6**	40	40	**40**	21								50			
Jun-93		36		**36**	50	50	**50**	45								50			
Jul-93		10		**10**	90	90	**90**	43								50			
Aug-93	**14**	0			77	77	**77**	44								80			
Sep-93		12		**12**	92	92	**92**	47								50			
Oct-93	**20**	38		**38**	131	131	**131**	60								50			
Nov-93	**11**	24		**24**	143	143	**143**	48								50			
Dec-93		15		**15**	104	104	**104**	55											
Jan-94	**21**	13		**13**	132	132	**132**	47								50			
Feb-94	**23**	27		**27**	141	141	**141**	59								50			
Mar-94	**17**	24		**24**	113	113	**113**	48											
Apr-94		35		**35**	146	146	**146**	91											
May-94		19		**19**	108	108	**108**	61											
Jun-94		31		**31**	149	149	**149**	88											
Jul-94		43		**43**	110	110	**110**	80	10							50			
Aug-94		19		**19**	55	55	**55**	39								50			
Sep-94	**83**	19		**19**	173	173	**173**	83								50			
Oct-94		24		**24**	159	159	**159**	85								50			
Nov-94		30		**30**	17	17	**17**	21	25							50			
Dec-94		42		**42**	170	170	**170**	107											
Jan-95		11		**11**	131	131	**131**	57											
Feb-95	**45.4**	75.1		**75**	152	152	**152**	94								50			
Mar-95																50			
Apr-95	**31.5**	37.1		**37**	147	147	**147**	71	32.9								35.2		48
May-95	**99.1**	50.7		**51**	195	195	**195**	118								50	61.7		84
Jun-95		43		**43**	111	111	**111**	81									53.3		71
Jul-95	**54**	85		**85**				68									62.3		74
Aug-95		20		**20**	51	51	**51**	37									18.4		39
Sep-95		72		**72**	140	140	**140**	112									92.4		106
Oct-95		26.7		**27**	58.2	58.2	**58**	45	5.4								51.7		83
Nov-95		30		**30**	37	37	**37**	35									62.5		120
Dec-95	**34**	39		**39**	58	58	**58**	46									40.8		59

AMMONIA	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	Dry dock geomean seepage	HI DOH Blaisdell	PWC monitoring	PWC RW 07	PWC RW 03
Jan-96	**24**	69		**69**	25	25	**25**	32									26.8		24
Feb-96	**170**	17		**17**	60	60	**60**	57								110	29.1		38
Mar-96		68		**68**	76	76	**76**	73	42								23.3		29
Apr-96		35		**35**	82	82	**82**	62									29.7		27
May-96	**21**	38	38	**38**	118	71	**92**	48								60	24.5		44
Jun-96	**32**	26	832	**147**	37	75	**53**	72	20								27.6		246
Jul-96		16	17	**16**	319	723	**480**	89	11								56.0		253
Aug-96		23	68	**40**	314		**314**	79								50	31.3		66
Sep-96	**35**		82	**82**	269		**269**	92									25.9		51
Oct-96	**24**	68	74	**71**	143		**143**	64									42.7		141
Nov-96	**53**	37	36	**36**	98		**98**	51									68.3		69
Dec-96		38	42	**40**	123		**123**	58									91.3		80
Jan-97		70	54	**61**				61	56								66.4		172
Feb-97		40	33	**36**				36								50	58.5		285
Mar-97			100	**100**				100								50	45.1		61
Apr-97	**70**	690	510	**593**				291	56.53								61.2	38	150
May-97	**71**	63	67	**65**				67	59.74								67.7	77	67
Jun-97		31	29	**30**				30	49								53.8	35	140
Jul-97	**36**	29	54	**40**				38	19								13.2	7	8
Aug-97		17	16	**16**	101	112	**106**	42	12								18.3	37	13
Sep-97	**42**	29	31	**30**		150	**150**	49	43.68								26.0	33	27
Oct-97		129	120	**124**	117		**117**	122	117								133.5	140	131
Nov-97										6	35						32.2	34	34
Dec-97										6							17.4	21	22
Jan-98											217						24.8	23	22
Feb-98											5						3.9	4	7
Mar-98										7	42						40.1	40	38
Apr-98		41	36	**38**	129	105	**116**	67	26								23.9	27	20
May-98		43	43	**43**	72	61	**66**	53	40								2.0	2	1
Jun-98	**10**	45	40	**42**	60	56	**58**	36	7								27.9	36	27
Jul-98		26	44	**34**	41	57	**48**	40	26								34.2	39	42
Aug-98			96	**96**	195		**195**	137	74								57.8	58	56
Sep-98			97	**97**	142	142	**142**	125	89		80						22.2	17	41
Oct-98			36	**36**	234	112	**162**	98	39		6						19.3	17	32
Nov-98			62	**62**	102	128	**114**	93	101								43.3	44	44
Dec-98			25	**25**	92	72	**81**	55	40								43.4	45	40
Jan-99			20	**20**	46	36	**41**	32	18	1	18						29.6	17	81

AMMONIA	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Date	**Dry Dock 001**	Dry Dock 002A	Dry Dock 002B	**Geomean 002A and B**	Dry Dock 004A	Dry Dock 004B	**Geomean 004A and B**	Geomean ALL PHNSY	Ref 600-ft	Potable Water	Harbor Water in-take	Dry Dock 1 Seepage	Dry Dock 2 Seepage	Dry Dock 4 Seepage	Dry dock geomean seepage	HI DOH Blaisdell	PWC monitoring	PWC RW 07	PWC RW 03
Feb-99			138	**138**	130	162	**145**	143	155		150	184	139	44	104		16.9	20	17
Mar-99			13	**13**	13	14	**13**	13	12		14						57.1	55	57
Apr-99			25	**25**	47	52	**49**	39	30			52	43	293	87				
May-99			26	**26**	159	179	**169**	90	33										
Jun-99			47	**47**	74	107	**89**	72	48		41								
Jul-99			60	**60**	218		**218**	114	33										
Aug-99					37		**37**	37	33										

PWC WASTE WATER TREATMENT FACILITY AT FORT KAMEHAMEHA MONITORING DATA

PWC, Navy Region Hawaii, as part of the WWTFFK NPDES support, monitors six surface and six corresponding sub-surface (3 m below surface station) harbor stations along the entrance channel to Pearl Harbor.

Figures A-1 through A-3 represent the April 1998 to March 1999 monitoring period and show temporal trends for each station. The data series are listed in approximate south-to-north order where RW01 is the furthermost toward sea, RW59 and RW03 bracket the STP outfall, and RW07 is just south of Hospital Point.

Total Nitrogen. Total nitrogen is elevated at most stations with several instances above the State of Hawaii WQS of 300 μg/L. As would be expected, those stations nearest the STP outfall exhibit the highest total nitrogen concentrations. Station RW07 is the closest to the Shipyard and most concentrations are below the WQS except for June 1998.

Nitrate-nitrite. Station differences are more pronounced regarding nitrate-nitrite concentrations. As was the case with total nitrogen, those stations nearest the STP outfall are elevated, especially RW03 which is often 3 to 5 times higher than the WQS of 15 μg/L.

Ammonia. Ammonia concentrations are high for most stations compared to the WQS of 10 μg/L. The variation between stations is much less pronounced than was the case for total nitrogen and nitrate-nitrite, indicating an overall elevated ambient ammonia level.

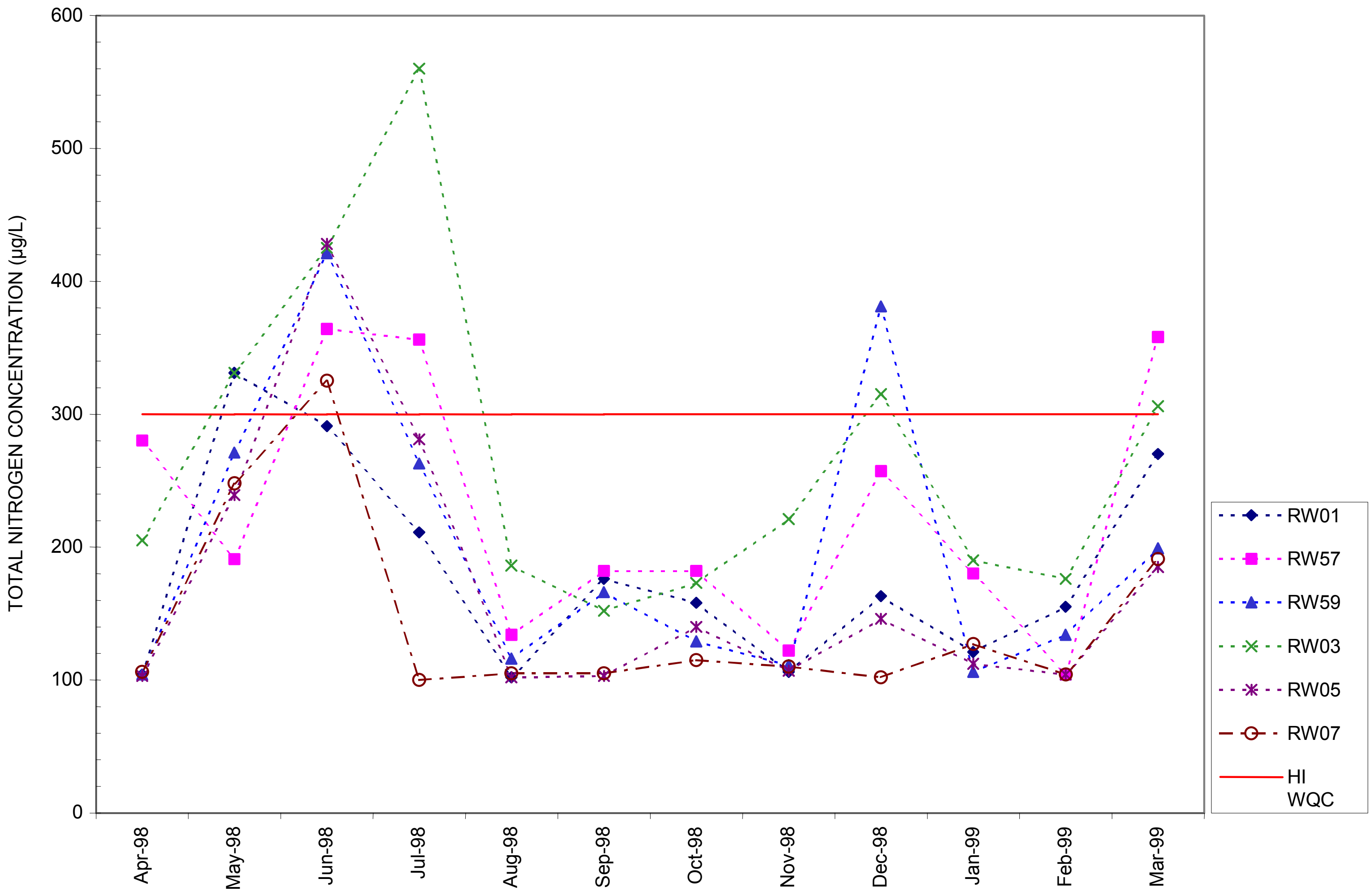

Figure A-1. Total nitrogen concentration from PWC ambient monitoring stations (1998 to 1999).

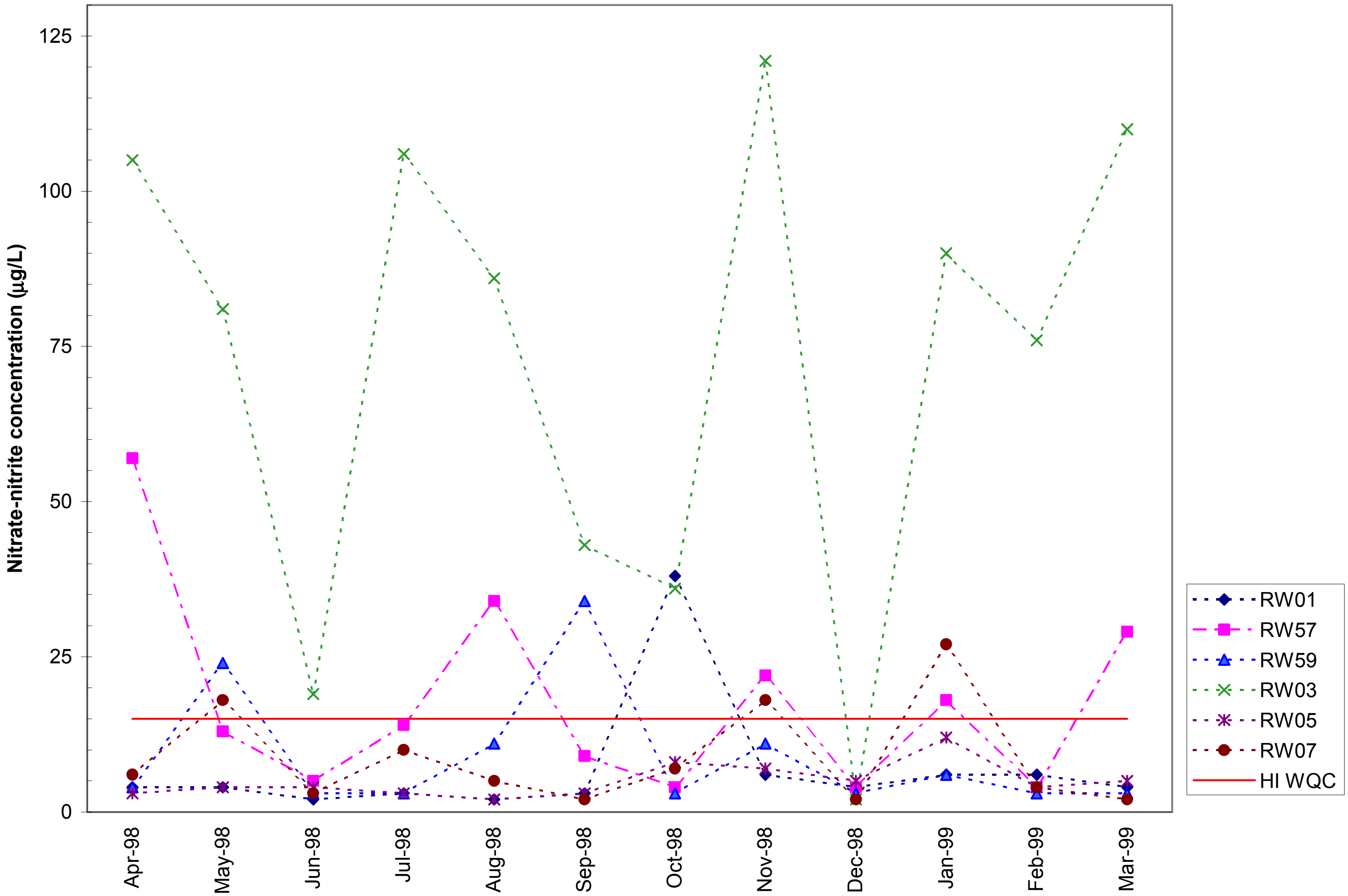

Figure A-2. Nitrate-nitrite concentration from PWC ambient monitoring stations (1998 to 1999).

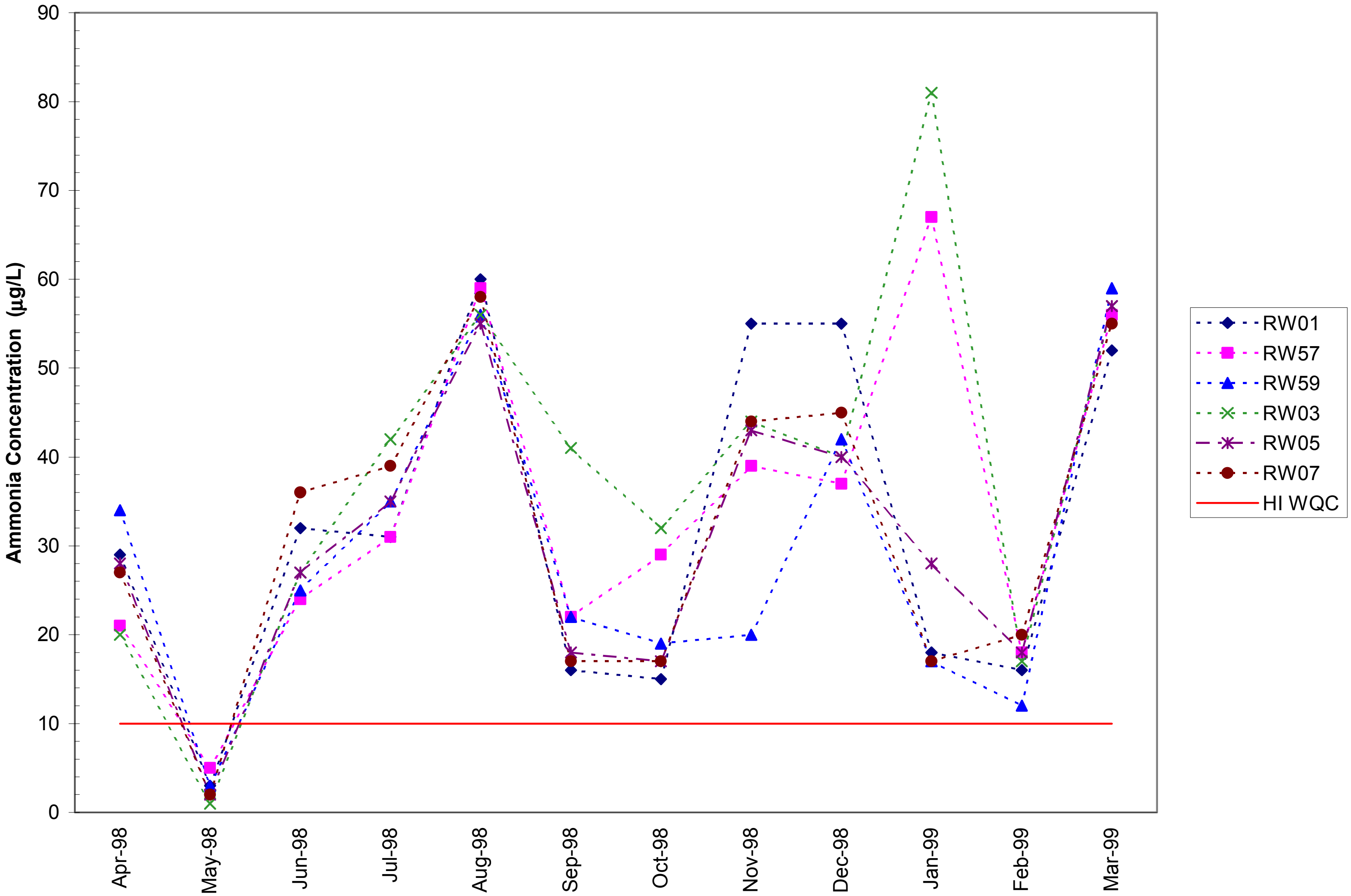

Figure A-3. Ammonia concentration from PWC ambient monitoring stations (1998 to 1999).

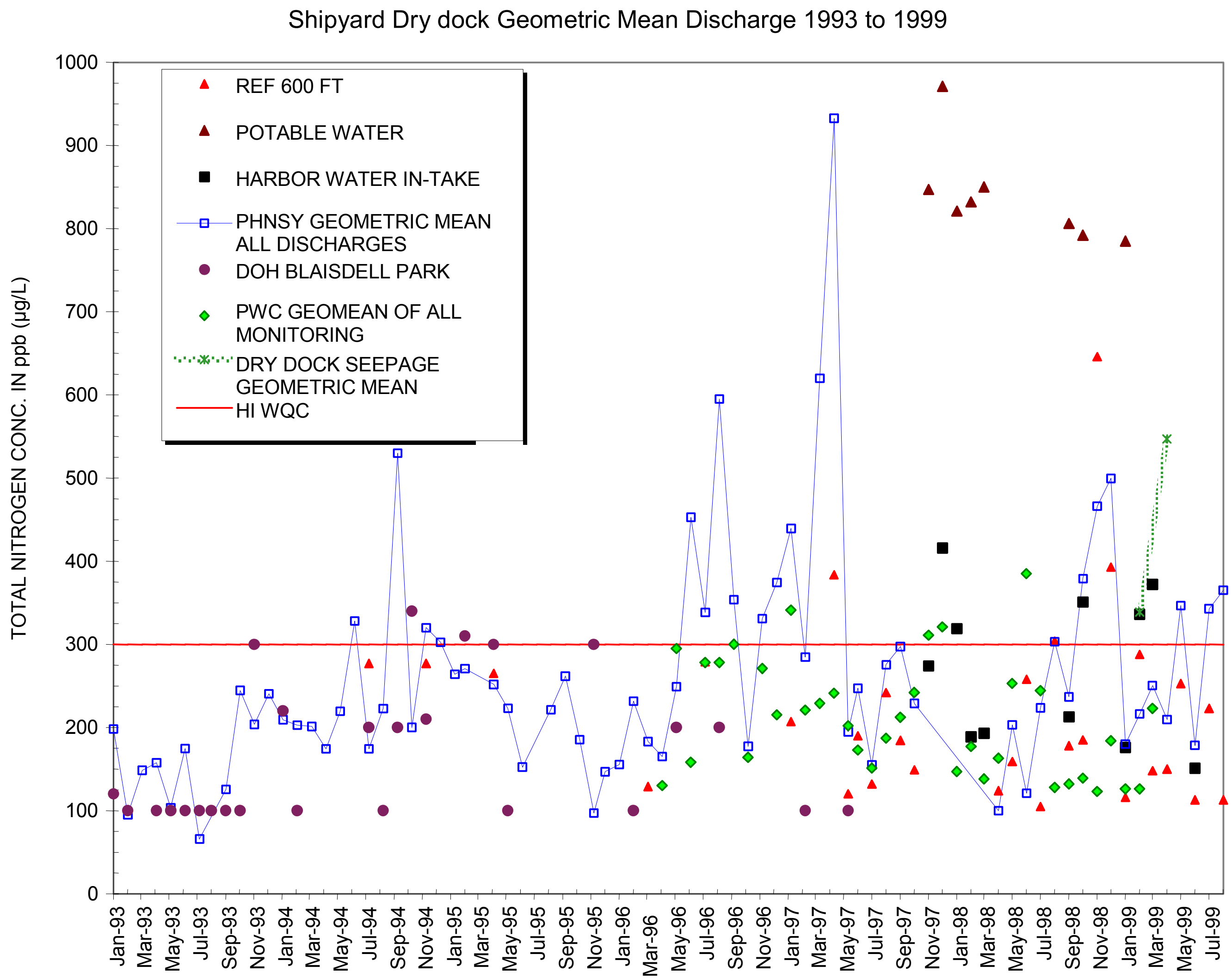

Figure A-4. PHNSY dry dock total nitrogen trend data from 1993 to 1999.

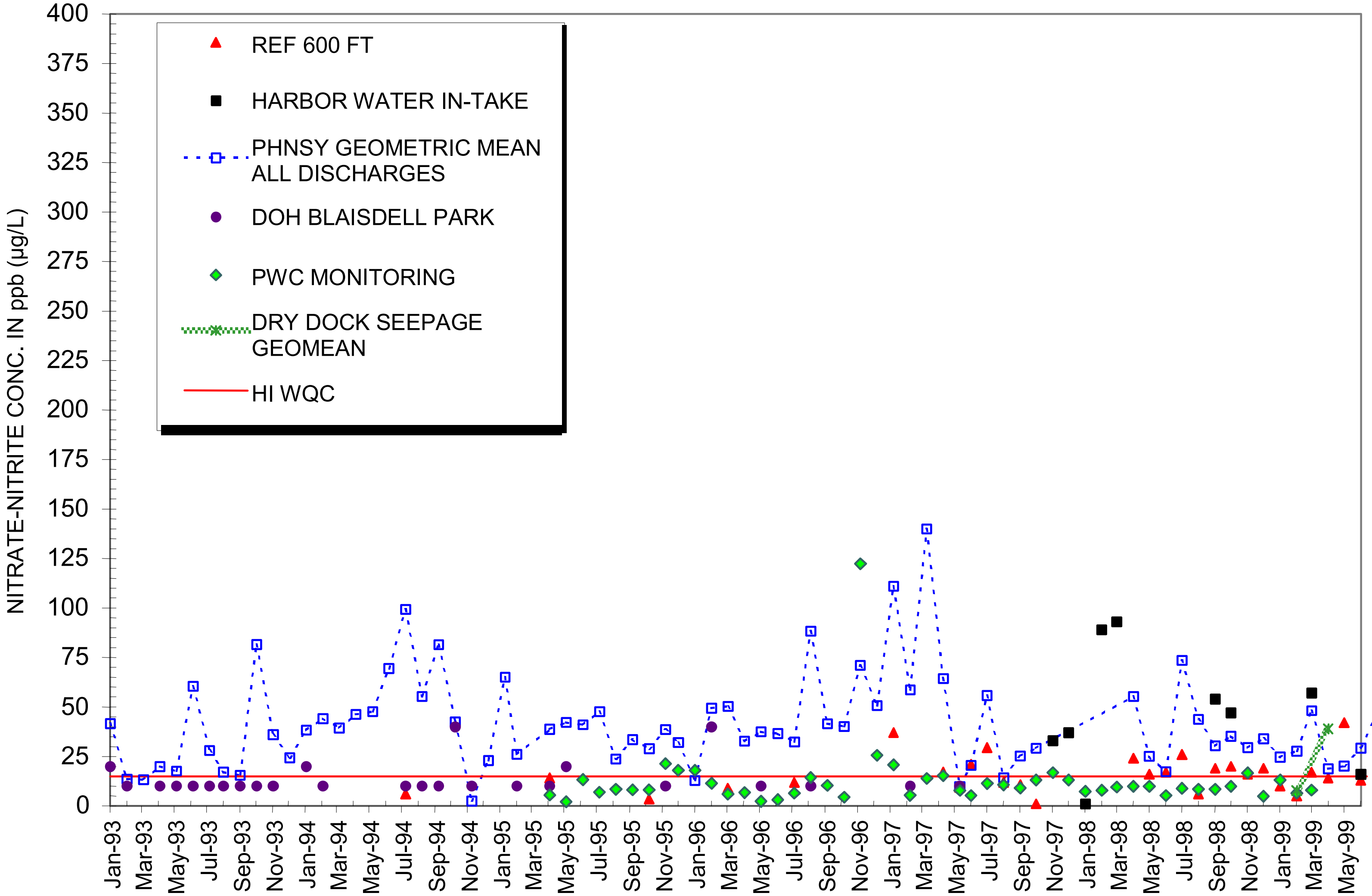

Figure A-5. PHNSY dry dock nitrate-nitrite trend data from 1993 to 1999.

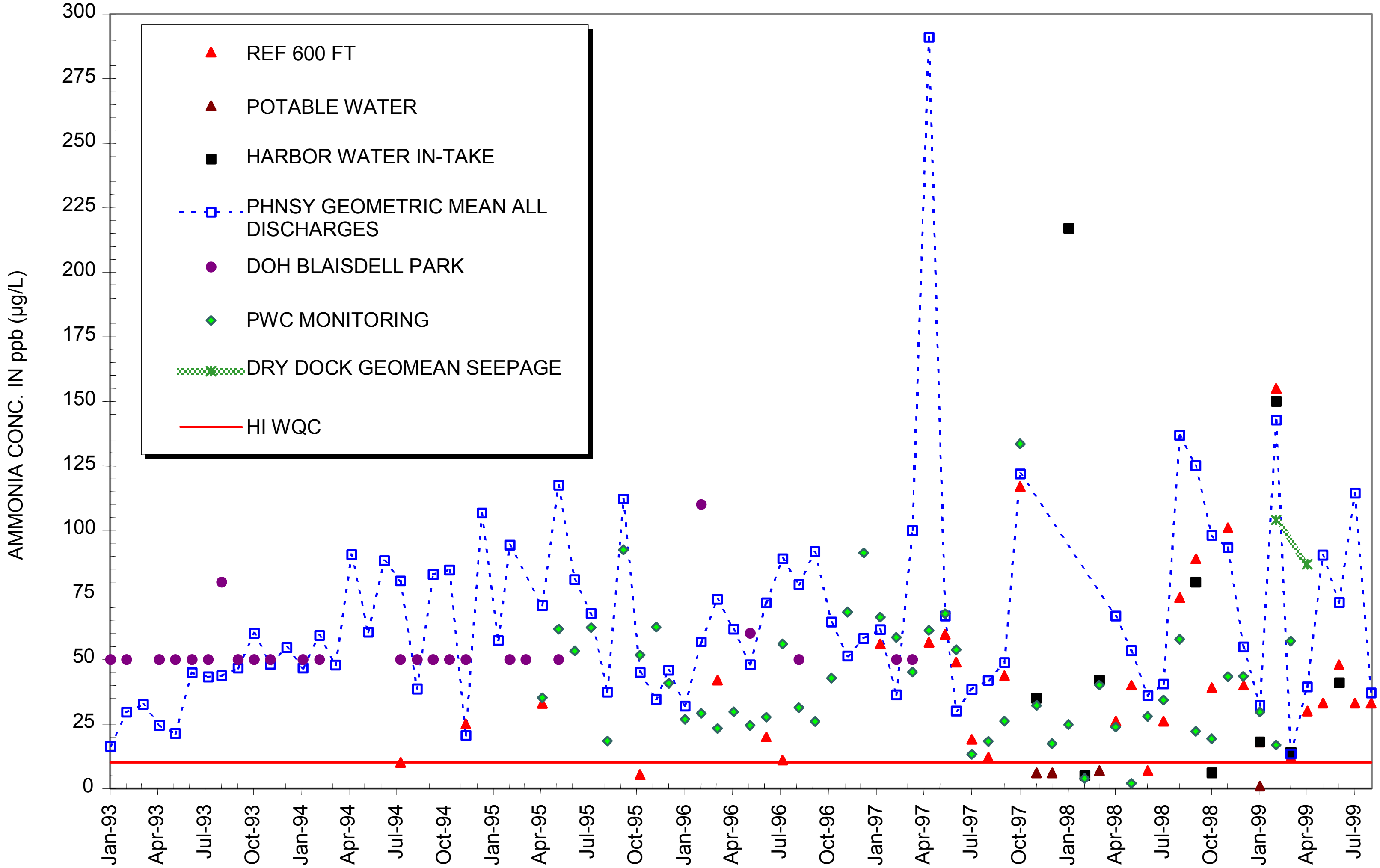

Figure A-6. PHNSY dry dock ammonia trend analysis from 1993 to 1999.

T-TEST STATISTICAL DATA – TOTAL NITROGEN COMPARISONS

t-test ALL PHNSY Total Nitrogen discharge (geometric mean) 94-99 vs Ref 600-ft 94-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Ref 600*
Mean	219.71	286.00
Variance	12801.31	21683.27
Observations	30.00	55.00
Hypothesized Mean Difference	0.00	
df	74.00	
t Stat	**2.31**	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.02	
t Critical two-tail	**1.99**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Total Nitrogen (geomean) 97-99 vs REF 600 (97-99)

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Ref 600*
Mean	308.81	104.01
Variance	33052.95	32313.52
Observations	24.00	24.00
Hypothesized Mea	0.00	
df	46.00	
t Stat	**3.92**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.01**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Total Nutrient discharge (geometric mean) 93-97 vs DOH Blaisdel Park Station 93-97

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY 93-97	*DOH 93-97*
Mean	260.0	165.4
Variance	23537.8	7097.8
Observations	50.0	26.0
Hypothesized Mean Difference	0.0	
df	74.0	
t Stat	**3.47**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.00	
t Critical two-tail	**1.99**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Total Nitrogen (geometric) 93-99 vs combined PW 93-99

t-Test: Two-Sample Assuming Unequal Variances

	Geomean ALL PHNSY	*PWC Monitoring*
Mean	260.0	211.3
Variance	19876.5	4957.9
Observations	69	36
Hypothesized Mean Difference	0	
df	103	
t Stat	**2.36**	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.02	
t Critical two-tail	1.98	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Total Nitrogen (geometric) 97-99 vs combined PWC 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*PWC combined*
Mean	308.8	204.4
Variance	33052.9	5123.4
Observations	24	27
Hypothesized Mean Difference	0	
df	29	
t Stat	**2.64**	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.70	
P(T<=t) two-tail	0.01	
t Critical two-tail	**2.05**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Total Nitrogen (geometric) 97-99 vs PWC 07 only 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY geomean	*PWC 07*
Mean	308.8	185.3
Variance	33052.9	7035.6
Observations	24.0	24.0
Hypothesized Mean Difference	0.0	
df	32.0	
t Stat	**3.02**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.04**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Total Nitrogen (geometric) 97-99 vs PWC 03 only 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY geomean	*PWC 03*
Mean	309	294
Variance	33053	12741
Observations	24	27
Hypothesized Mean Difference	0	
df	38	
t Stat	**0.35**	
P(T<=t) one-tail	0.36	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.73	
t Critical two-tail	**2.02**	

t-stat < t-crit two-tail; accept Ho (no difference)

PHNSY ALL (geomean) 97-99 verses Seepage Geomean

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY ALL geomean	*Seepage geomean*
Mean	309	443
Variance	33053	21693
Observations	24	2
Hypothesized Mean Difference	0	
df	1	
t Stat	**-1.21**	
P(T<=t) one-tail	0.22	
t Critical one-tail	6.31	
P(T<=t) two-tail	0.44	
t Critical two-tail	**12.71**	

t-stat < t-crit two-tail; accept Ho (no difference)

PHNSY ALL (geomean) 97-99 verses Potable water

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Potable H20*
Mean	307.3184731	838
Variance	30057.69508	3455.42857
Observations	27	8
Hypothesized Mean Difference	0	
df	32	
t Stat	**-13.50**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.04**	

t-stat < t-crit two-tail; accept Ho (no difference)

PHNSY ALL (geomean) 97-99 verses Harbor water in-take

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*HARBOR WATER INTAKE*
Mean	307.3184731	271.8181818
Variance	30057.69508	8375.363636
Observations	27	11
Hypothesized Mean Difference	0	
df	33	
t Stat	**0.82**	

T-TEST STATISTICAL DATA – NITRATE-NITRITE COMPARISONS

t-test ALL PHNSY Nitate-Nitrite (geometric) 93-99 vs Ref 600-ft 93-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Ref 600*
Mean	42.61	15.41
Variance	636.80	89.53
Observations	56.00	30.00
Hypothesized Mean Difference	0.00	
df	78.00	
t Stat	**7.18**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.00	
t Critical two-tail	**1.99**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Nitate-Nitrite (geometric) 97-99 vs Ref 600-ft 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Ref-600*
Mean	41.52	16.70
Variance	858.72	94.63
Observations	27.00	25.00
Hypothesized Mean Difference	0.00	
df	32.00	
t Stat	**4.16**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.04**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY NITRATE-NITRITE (geometric) 93-97 vs DOH Station 93-97

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY 93-97	*DOH 93-97*
Mean	44.3	13.5
Variance	704.5	71.5
Observations	52.0	26.0
Hypothesized Mean Difference	0.0	
df	68.0	
t Stat	**7.64**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.00**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY NITRATE-NITRITE (geometric) 93-99 vs combined PWC 93-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*PWC Monitoring*
Mean	41.3	12.5
Variance	601.1	288.4
Observations	71	48
Hypothesized Mean Difference	0	
df	117	
t Stat	**7.57**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.00	
t Critical two-tail	**1.98**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY NITRATE-NITRITE (geometric) 97-99 vs combined PWC 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*PWC combined*
Mean	42.2	10.3
Variance	959.6	15.9
Observations	24	27
Hypothesized Mean Difference	0	
df	24	
t Stat	**5.01**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.71	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.06**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY NITRATE-NITRITE (geometric) 97-99 vs PWC 07 only 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY all geomea	*PWC 07*
Mean	42	7
Variance	960	41
Observations	24	24
Hypothesized Mean Difference	0	
df	25	
t Stat	**5.51**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.71	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.06**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY NITRATE-NITRITE (geometric) 97-99 vs PWC 03 only 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*PWC 03*
Mean	44.25	86.85
Variance	997.17	3337.44
Observations	22.00	27.00
Hypothesized	0.00	
df	42.00	
t Stat	**3.28**	
P(T<=t) one-t	0.00	
t Critical one-t	1.68	
P(T<=t) two-t	0.00	
t Critical two-t	**2.02**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY NITRATE-NITRITE (geometric) 97-99 vs Seepage

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Seepage*
Mean	41.5	23.3
Variance	858.7	486.3
Observations	27	2
Hypothesized Mean Difference	0	
df	1	
t Stat	**1.10**	
P(T<=t) one-tail	0.23	
t Critical one-tail	6.31	
P(T<=t) two-tail	0.47	
t Critical two-tail	12.71	

t-stat < t-crit two-tail; accept Ho (no difference)

t-test ALL PHNSY NITRATE-NITRITE (geometric) 97-99 vs Potable water

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Potable water*
Mean	41.5178579	698
Variance	858.723034	1352.5714
Observations	27	8
Hypothesized Mean Difference	0	
df	10	
t Stat	**-46.32**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.81	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.23**	

t-stat < t-crit two-tail; accept Ho (no difference)

t-test ALL PHNSY NITRATE-NITRITE (geometric) 97-99 vs Harbor water in-take

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Harbor intake*
Mean	41.5	47.4
Variance	858.7	925.0
Observations	27	9
Hypothesized Mean Difference	0	
df	13	
t Stat	**-0.51**	

T-TEST STATISTICAL DATA – AMMONIA COMPARISONS

t-test ALL PHNSY Ammonia 94-99 (geometric) vs Ref 600-ft 1994-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Ref 600-ft*
Mean	65.8	43.1
Variance	1599.9	1246.9
Observations	71	29
Hypothesized Mean Difference	0	
df	59	
t Stat	**2.81**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.01	
t Critical two-tail	**2.00**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Ammonia (geometric) 97-99 vs Ref 600-ft (97-99)

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Ref 600*
Mean	77.13	48.68
Variance	3146.94	1243.70
Observations	27.00	25.00
Hypothesized	0.00	
df	44.00	
t Stat	**2.21**	
P(T<=t) one-t	0.02	
t Critical one-t	1.68	
P(T<=t) two-t	0.03	
t Critical two-t	**2.02**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test PHNSY Ammonia (geometric) 93-97 vs DOH Blaisdel Park Station 1993-1997

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY 93-97	*DOH 93-97*
Mean	64.8	54.0
Variance	1620.2	175.0
Observations	52.0	25.0
Hypothesized Mean Difference	0.0	
df	69.0	
t Stat	**1.75**	
P(T<=t) one-tail	0.04	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.09	
t Critical two-tail	**1.99**	

t-stat < t-crit two-tail; accept Ho (no difference)

t-test ALL PHNSY Ammonia discharge (geometric) 93-99 vs combined PWC 93-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*PWC monitoring*
Mean	65.8	41.6
Variance	1599.9	607.6
Observations	71	48
Hypothesized Mean Difference	0	
df	116	
t Stat	**4.09**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.00	
t Critical two-tail	**1.98**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Ammonia discharge (geometric) 97-99 vs combined PWC 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*PWC Combined*
Mean	77.5	38.5
Variance	3425.8	713.4
Observations	24	27
Hypothesized Mean Difference	0	
df	31	
t Stat	**3.00**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.70	
P(T<=t) two-tail	0.01	
t Critical two-tail	**2.04**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Ammonia (geometric) 97-99 vs PWC 07 only 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY all geome	*PWC 07*
Mean	77	36
Variance	3426	799
Observations	24	24
Hypothesized Mean Difference	0	
df	33	
t Stat	**3.12**	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.00	
t Critical two-tail	**2.03**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Ammonia (geometric) 97-99 vs PWC 03 only 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY all geome	*PWC 03*
Mean	77	61
Variance	3426	4085
Observations	24	27
Hypothesized Mean Difference	0	
df	49	
t Stat	**0.99**	
P(T<=t) one-tail	0.16	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.33	
t Critical two-tail	**2.01**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Ammonia discharge (geometric) 97-99 vs Seepage

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Seepage*
Mean	77.1	95.4
Variance	3146.9	147.3
Observations	27	2
Hypothesized Mean Difference	0	
df	6	
t Stat	**-1.33**	
P(T<=t) one-tail	0.12	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.23	
t Critical two-tail	**2.45**	

t-stat < t-crit two-tail; accept Ho (no difference)

t-test ALL PHNSY Ammonia discharge (geometric) 97-99 vs Potable water

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Potable water*
Mean	77.1	5.0
Variance	3146.9	7.3
Observations	27	4
Hypothesized	0	
df	27	
t Stat	**6.63**	
P(T<=t) one-t	0.00	
t Critical one-t	1.70	
P(T<=t) two-t	0.00	
t Critical two-t	**2.05**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test ALL PHNSY Ammonia discharge (geometric) 97-99 vs Harbor water in-take

t-Test: Two-Sample Assuming Unequal Variances

	PHNSY	*Harbor intake*
Mean	77.1	60.8
Variance	3146.9	4919.3
Observations	27	10
Hypothesized Mean Difference	0	
df	14	
t Stat	**0.66**	
P(T<=t) one-tail	0.26	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.52	
t Critical two-tail	**2.14**	

t-stat < t-crit two-tail; accept Ho (no difference)

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t-test for PHNSY Ref 600 Ammonia discharge 93-96 vs Ref 600 97-99

t-Test: Two-Sample Assuming Unequal Variances

	Ref 600 93-9	*Ref 600 97-99*
Mean	20.9	48.67806
Variance	177.3167	1243.698
Observations	7	25
Hypothesized Mean Differe	0	
df	27	
t Stat	**-3.205849**	
P(T<=t) one-tail	0.001724	
t Critical one-tail	1.703288	
P(T<=t) two-tail	0.003449	
t Critical two-tail	**2.051829**	

t-stat > t-crit two-tail; reject Ho (no difference) and accept null Ho that they are different

t-test for PWC 03 Ammonia discharge 93-96 vs Ref 600 97-99

t-Test: Two-Sample Assuming Unequal Variances

	PWC 03 97-99	*PWC 03 93-96*
Mean	60.55556	83.42857
Variance	4085.41	3964.357
Observatio	27	21
Hypothesiz	0	
df	43	
t Stat	**-1.240299**	
P(T<=t) on	0.110795	
t Critical or	1.681071	
P(T<=t) tw	0.22159	
t Critical tw	**2.016691**	

t-stat < t-crit two-tail; accept Ho (no difference)

NOSC TR1502 AMBIENT NUTRIENT DATA (MAY 1990)

Total Nitrogen

station	surface Total N	SD (n=3)	bottom Total N	SD (n=3)
BC11	180	56	110	17
BE17	100	15	93	7.1
BC9	120	13	110	24
BE2	110	18	100	12
BE4	120	2	110	10
BE3	110	13	100	16
BE5	110	12	140	48
BE5A	96	1.5	110	20
BE5B	95	1.5	120	26

Ammonia

station	surface NH4	SD (n=3)	bottom NH4	SD (n=3)
BC11	2.2	2.5	3.4	3.6
BE17	5.5	3.6	0.54	0.51
BC9	3.1	3.7	3	2.3
BE2	8.2	7.2	7.6	2.8
BE4	14	5.7	2.5	2.4
BE3	2.2	2.3	3	2.5
BE5	0.66	0.55	3.1	2.3
BE5A	0.72	0.94	2.2	2.6
BE5B	1.2	1.2	3.8	3.9

NUTRIENT LOADING CALCULATIONS

Nutrient Loading to Pearl Harbor

Discharge Breakdown by type (kg/yr)

		WET	DRY			
		total nitrogen	**total nitrogen**		***wet***	***dry***
	source	load (kg/yr)	load (kg/yr)		%	%
	PHNSY	**2,164**	**2,164**		0.7%	1.9%
	Fort Kam STP	**53,996**	**53,996**		17.1%	47.7%
assume impacted by stormwater runoff	Streams	**184,923**	**26,418**		58.5%	23.3%
assume impacted by stormwater runoff	Springs	**61,425**	**21,887**		19.4%	19.3%
assume impacted by stormwater runoff	Wells	**5,648**	**3,530**		1.8%	3.1%
assume impacted by stormwater runoff	Shallow aquifers	**7,060**	**4,236**		2.2%	3.7%
	Atmospheric Deposition-natural	**960**	**960**		0.3%	0.8%
impacted by HECO, automotive exhaust	Atmospheric Deposition-human impact				0.0%	0.0%
	sum ALL loads::	**316,177**	**113,191**	kg/year		
		349	125	tons/year		

		WET	DRY			
		nitrate-nitrite	**nitrate-nitrite**		***wet***	***dry***
		load (kg/yr)	load (kg/yr)		%	%
	PHNSY	**323**	**323**		0.1%	0.4%
	Fort Kam STP	**38,068**	**38,068**		15.0%	42.8%
	Streams	**141,285**	**20,184**		55.5%	22.7%
	Springs	**61,425**	**21,887**		24.1%	24.6%
	Wells	**5,648**	**3,530**		2.2%	4.0%
	Shallow aquifers	**7,060**	**4,236**		2.8%	4.8%
	Atmospheric Deposition-natural	**747**	**747**		0.3%	0.8%
	Atmospheric Deposition-human impact				0.0%	0.0%
1 kg = 0.001102311 tons		**254,556**	**88,975**	kg/year		
		281	98	tons/year		

		WET	DRY			
		ammonia	**ammonia**		***wet***	***dry***
		load (kg/yr)	load (kg/yr)		%	%
	PHNSY	**547**	**547**		6.5%	24.7%
	Fort Kam STP	**423**	**423**		5.1%	19.1%
	Streams	**7,196**	**1,028**		85.9%	46.5%
	Springs	**0**	**0**		0.0%	0.0%
	Wells	**0**	**0**		0.0%	0.0%
	Shallow aquifers	**0**	**0**		0.0%	0.0%
	Atmospheric Deposition-natural	**213**	**213**		2.5%	2.5%
	Atmospheric Deposition-human impact				0.0%	0.0%
	sum ALL loads::	**8,380**	**2,212**	kg/year		
		9	2	tons/year		

Phosphorus

Discharge Breakdown by type (kg/yr)

		total phosphorus	**total phosphorus**		***wet***
	source	load (kg/yr)	load (kg/yr)		%
	PHNSY	**402**	**402**		1.7%
	Fort Kam STP	**13,623**	**13,623**		57.2%
assume impacted by stormwater runoff	Streams	**10,948**	**1,564**		6.6%
assume impacted by stormwater runoff	Springs	**17,009**	**6,061**		25.5%
assume impacted by stormwater runoff	Wells	**1,564**	**978**		4.1%
assume impacted by stormwater runoff	Shallow aquifers	**1,955**	**1,173**		4.9%
	Atmospheric Deposition-natural			unknown	0.0%
impacted by HECO, automotive exhaust	Atmospheric Deposition-human impact			unknown	0.0%
	sum ALL loads::	**45,502**	**23,801**		
		WET	**DRY**		

CALCULATION OF NUTRIENT LOADING BY STREAM INPUT

source	dry year flow (MGD)	wet year flow (MGD)
Streams	8	56
Springs	31	87
Wells	5	8
Shallow aquifers	6	10

source: Table 2c. Grovhoug 1992 (TR1502)

		Est Max flow (MGD)		Est Min flow (MGD)	
Waikele	West Loch	26	46.4%	6	75.0%
Walawa	Middle Loch	16	28.6%	2	25.0%
Waimalu	East Loch	5	8.9%	0	0.0%
Kalauao	East Loch	1	1.8%	0	0.0%
Halawa	East Loch	8	14.3%	0	0.0%
		56	100.0%	8	100.0%

source: Table 2a. Grovhoug 1992 (TR1502)

Nitrate-nitrite

DRY	MGD	% of total	GD	Liters/day	L/year	nitrate-nitrite conc (ug/L)	Load (ug/year)	Load (kg/yr)
Streams	8	16%	8,000,000	30,283,294	11,053,402,409	1826	20,183,512,799,277	20,184
Springs	31	62%	31,000,000	117,347,765	42,831,934,336	511	21,887,118,445,602	21,887
Wells	5	10%	5,000,000	18,927,059	6,908,376,506	511	3,530,180,394,452	3,530
Shallow aquifers	6	12%	6,000,000	22,712,471	8,290,051,807	511	4,236,216,473,342	4,236
total	50	100%	50,000,000	189,270,589	69,083,765,058			**49,837**

WET	MGD	% of total	GD	Liters/day	L/year	nitrate-nitrite conc (ug/L)	Load (ug/year)	Load (kg/yr)
Streams	56	34.8%	56,000,000	211,983,060	77,373,816,865	1826	141,284,589,594,939	141,285
Springs	87	54.0%	87,000,000	329,330,825	120,205,751,201	511	61,425,138,863,462	61,425
Wells	8	5.0%	8,000,000	30,283,294	11,053,402,409	511	5,648,288,631,123	5,648
Shallow aquifers	10	6.2%	10,000,000	37,854,118	13,816,753,012	511	7,060,360,788,904	7,060
total	161	100.0%	161,000,000	609,451,297	222,449,723,486			**215,418**

1 GAL = 3.78541178 Liters

Ammonia

DRY	MGD	% of total	GD	Liters/day	L/year	nitrate-nitrite conc (ug/L)	Load (ug/year)	Load (kg/yr)
Streams	8	16%	8,000,000	30,283,294	11,053,402,409	93	1,027,966,424,060	1,028
Springs	31	62%	31,000,000	117,347,765	42,831,934,336	0	0	0
Wells	5	10%	5,000,000	18,927,059	6,908,376,506	0	0	0
Shallow aquifers	6	12%	6,000,000	22,712,471	8,290,051,807	0	0	0
total	50	100%	50,000,000	189,270,589	69,083,765,058			**1,028**

WET	MGD	% of total	GD	Liters/day	L/year	nitrate-nitrite conc (ug/L)	Load (ug/year)	Load (kg/yr)
Streams	56	34.8%	56,000,000	211,983,060	77,373,816,865	93	7,195,764,968,417	7,196
Springs	87	54.0%	87,000,000	329,330,825	120,205,751,201	0	0	0
Wells	8	5.0%	8,000,000	30,283,294	11,053,402,409	0	0	0
Shallow aquifers	10	6.2%	10,000,000	37,854,118	13,816,753,012	0	0	0
total	161	100.0%	161,000,000	609,451,297	222,449,723,486			**7,196**

1 GAL = 3.78541178 Liters

Total Nitrogen

DRY	MGD	% of total	GD	Liters/day	L/year	nitrogen conc (ug/L)	Load (ug/year)	Load (kg/yr)
Streams	8	16%	8,000,000	30,283,294	11,053,402,409	2390	26,417,631,758,090	26,418
Springs	31	62%	31,000,000	117,347,765	42,831,934,336	511	21,887,118,445,602	21,887
Wells	5	10%	5,000,000	18,927,059	6,908,376,506	511	3,530,180,394,452	3,530
Shallow aquifers	6	12%	6,000,000	22,712,471	8,290,051,807	511	4,236,216,473,342	4,236
total	50	100%	50,000,000	189,270,589	69,083,765,058			**56,071**

WET	MGD	% of total	GD	Liters/day	L/year	nitrogen conc (ug/L)	Load (ug/year)	Load (kg/yr)
Streams	56	34.8%	56,000,000	211,983,060	77,373,816,865	2390	184,923,422,306,629	184,923
Springs	87	54.0%	87,000,000	329,330,825	120,205,751,201	511	61,425,138,863,462	61,425
Wells	8	5.0%	8,000,000	30,283,294	11,053,402,409	511	5,648,288,631,123	5,648
Shallow aquifers	10	6.2%	10,000,000	37,854,118	13,816,753,012	511	7,060,360,788,904	7,060
total	161	100.0%	161,000,000	609,451,297	222,449,723,486			**259,057**

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