



# Environmental and Human Health Assessment of Dioxin Contamination at Bien Hoa Airbase, Viet Nam

## *Final Report*

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*Prepared by:*

**Office of the National Steering Committee 33, MONRE**  
Ha Noi, Viet Nam

*and*

**Hatfield Consultants**  
North Vancouver, British Columbia, Canada

*Funded by:*

**Ford Foundation Special Initiative on Agent Orange/Dioxin**  
New York, USA

#200 - 850 Harbourside Drive, North Vancouver, British Columbia, Canada V7P 0A3 • Tel: 1.604.926.3261 • Fax: 1.604.926.5389 • [www.hatfieldgroup.com](http://www.hatfieldgroup.com)





# ENVIRONMENTAL AND HUMAN HEALTH ASSESSMENT OF DIOXIN CONTAMINATION AT BIEN HOA AIRBASE, VIET NAM

*Prepared by:*

**OFFICE OF THE NATIONAL STEERING COMMITTEE 33  
MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT  
83 NGUYEN CHI THANH STR.  
DONG DA DISTRICT  
HA NOI, VIET NAM**

*and*

**HATFIELD CONSULTANTS  
SUITE 200 - 850 HARBOURSIDE DRIVE  
NORTH VANCOUVER, BC  
CANADA**

*Funded by:*

**FORD FOUNDATION SPECIAL INITIATIVE  
ON AGENT ORANGE/DIOXIN  
320 EAST 43RD STREET  
NEW YORK, NY 10017 USA**

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Source: Hatfield Consultants

## SUMMARY OF FINDINGS

This report presents the results, conclusions, and recommendations of three recent studies conducted by Hatfield Consultants and the Government of Viet Nam (GVN) to determine the extent and level of dioxin contamination in the environment and the exposed human populations in and around the Bien Hoa Airbase, Viet Nam. The 10-80 Division of Viet Nam's Ministry of Health led the first of these studies in 2004-2005, while the second (in 2008) was conducted under the direction of the Viet Nam-Russia Tropical Centre (VRTC) of the Ministry of National Defence (MND). The Office of the National Steering Committee 33 (Office 33) was responsible for implementation of the current study; Hatfield Consultants (North Vancouver, Canada) collaborated closely with the Vietnamese agencies on all three studies. The current (2010) study, and the 2004-2005 investigations, were funded by the Ford Foundation Special Initiative on Agent Orange Dioxin, while the 2008 study was funded by the United Nations Development Program (UNDP).

Bien Hoa was the largest U.S. Department of Defence (DOD) Operation Ranch Hand site in Viet Nam, in terms of the number of C-123 aircraft sorties and volume of herbicides stored and used. Dioxin contamination at Bien Hoa Airbase is the result of the storage, loading, spillage, and handling of Agent Orange and other toxic herbicides during the US-Viet Nam war, especially between 1965 and 1971.

A total of 97 environmental samples (including 57 soil, 20 sediment, and 20 fish tissues), and 64 human blood serum and breast milk were collected and analyzed for dioxin<sup>1</sup> and furan concentrations over the course of the three Hatfield/10-80/VRTC/Office 33 studies. Human tissue sampling was performed on a volunteer basis and followed internationally-accepted protocols to ensure consent of donors. All samples were analyzed at AXYS Analytical Laboratories (Sidney, BC, Canada), a WHO-accredited independent laboratory for dioxin and furan analyses. The 2005 data, consisting of soil and sediment samples, were part of a larger reconnaissance survey of former US military bases and suspected Agent Orange dioxin hotspots in southern Viet Nam. The 2008 sampling focused on soils/sediments from the most highly contaminated areas in Bien Hoa and Phu Cat Airbases. These earlier studies, and the work of other Vietnamese and international scientists, confirmed Bien Hoa Airbase to be a significant dioxin hotspot.

Interim mitigation measures are currently being implemented at Bien Hoa to protect the local population from continued exposure to dioxins from the Airbase. Remediation measures implemented with funding provided by GVN include soil excavation and construction of a passive landfill at the Z1 Area (former herbicide storage area) on the Airbase. Approximately 43,000 m<sup>3</sup> of contaminated soils have been excavated and placed in a secure landfill, completed in 2009. Soils throughout the Z1 Area at Bien Hoa Airbase are now heavily disturbed due to these remediation efforts. Rapid urban development in Bien Hoa City has also significantly changed the urban landscape in recent years, including local topography, hydrological patterns, and potential dioxin exposure pathways.

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<sup>1</sup> In this report, dioxin or TCDD refers specifically to 2,3,7,8-tetrachlorodibenzo-p-dioxin; TEQ is based on 2005 WHO TCDD Toxic Equivalent factors (using one-half of the detection limit). PCDD and PCDF are general terms for all dioxin or furan congeners, respectively. Note that "ppt" is the same as "pg/g".



The 2010 environmental and human population studies at Bien Hoa Airbase and Bien Hoa City have provided a more complete picture of the overall dioxin contamination issue in Bien Hoa. As a result, a clearer understanding of dioxin contaminated areas has emerged, including exposure pathways, and affected populations in Bien Hoa. These data will help facilitate ongoing and future remediation efforts for Bien Hoa Airbase, and reduce or eliminate risk to public health. Results are presented below, as well as in the attached figures.

#### Dioxins in soils and sediments<sup>2</sup>:

- There are clearly a number of distinct dioxin hotspots at Bien Hoa Airport, apart from the historical herbicide storage area (Z1 Area), and landfill area. Elevated dioxin concentrations were measured at several locations in the western, southern, and eastern areas of the Airbase. Samples collected from the northern area of the Airbase had lower levels of dioxin contamination, although some lake sediments require remediation.
- Remediation efforts undertaken by the GVN and MND in the Z1 Area appear to have significantly reduced dioxin concentrations in soils in the south central area of the Airbase. However, other dioxin hotspots at the Airbase will require remediation, particularly in the Pacer Ivy Area in the western section of the Airbase.
- Significant quantities of TCDD, the dioxin contaminant in Agent Orange, were detected in soil samples analyzed from the Pacer Ivy Area on Bien Hoa Airbase in January 2008, and again in November 2010. Dioxin levels at this location exceed Vietnamese and international standards and guidelines for these chemicals. TCDD concentrations ranged from non-detectable levels to 61,400 pg/g dry weight in samples collected from the Pacer Ivy Area in 2010.
- Dioxin concentrations in sediments collected from lakes and ponds located at and around the Pacer Ivy Area exceeded the Vietnamese guideline of 150 pg/g TEQ; TEQs from 2008 and 2010 sediment samples from the Pacer Ivy sites ranged from 30.9 to 5,970 pg/g dry weight.
- Dioxin congener profiles confirmed that the main source of dioxin contamination at Bien Hoa Airbase was Agent Orange and other dioxin-containing herbicides. TCDD contributed over 80% of the TEQ (TCDD toxic equivalents) in most soil and sediment samples analyzed from the Airbase.
- High TEQ levels were measured in some soil samples collected from the Z1 Area (outside the landfill) in the southern area of the Airbase in November 2010. Three (3) samples exhibited TEQ concentrations exceeding the Vietnamese guideline of 1,000 pg/g, while TEQ levels in other samples remained low (ranging from 1.46 to 237 pg/g dry weight). Highest levels of contamination in soils from Bien Hoa were found in the Z1 Area in 2008 prior to completion of the

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<sup>2</sup> Vietnamese TEQ guidelines are 1,000 pg/g for soils and 150 pg/g for sediments (Viet Nam National Standard TCVN 8183:2009).

landfill, at a depth of 60-90 cm (262,000 ppt; 99% TCDD). All samples collected at different depths at this sampling point exhibited >26,400 ppt TEQ. These highly contaminated soils were subsequently contained in the new landfill.

- High TCDD levels were also recorded in a small area at the southwest corner of the Bien Hoa Airbase during the January 2008 program. In November 2010, additional samples were collected from areas surrounding the identified hotspot. All samples collected in 2010 exhibited low concentrations (between 7.84 and 124 ppt TCDD), suggesting that dioxin contamination is limited to a small area in the southwestern portion of the Airbase.
- Soil samples collected from the northern perimeter of the Airbase exhibited low TCDD concentrations, ranging between 8.47 to 425 pg/g; none exceeded the Vietnamese guideline of 1,000 pg/g. However, sediments sampled from two lakes in this area exhibited elevated TCDD values (372 pg/g and 268 pg/g).
- Generally low TEQ concentrations were recorded in soil and sediment samples collected from the northeastern perimeter of the Airbase in 2010. One soil sample (1,040 pg/g) and one sediment sample (633 pg/g) from this area exceeded the Vietnamese guidelines.
- Sediment samples were collected from Bien Hung Lake and 'Gate 2 Lake', located in Bien Hoa City (south of the Airbase). None of the samples exceeded the Vietnamese sediment dioxin guideline; however, elevated TEQ concentrations were recorded at Bien Hung Lake (95.6 pg/g). Sediment samples collected from this lake during the 2005 sampling program (Hatfield/10-80 2006) exhibited TEQ values ranging from 36 to 131 pg/g dry weight.
- The present study and previous work by Hatfield/10-80 Division/Office 33/VRTC demonstrated that the highest concentrations of dioxins are generally in the top 10 cm layer; however, migration of dioxins to deeper layers of soil was observed in the Hatfield/VRTC (2009) study (Z1 Area), where high concentrations of herbicides were stored and used.
- Other contaminants are likely present in the environment of Bien Hoa, which contribute to total PCDD/PCDF load (including polychlorinated biphenyls, organochlorine pesticides, and hydrocarbons). These other contaminants were not investigated in the current study, but have been identified at Da Nang Airbase (another former Ranch Hand site).
- This study and previous investigations confirm high contaminations of dioxins in soils and sediments at a number of locations on Bien Hoa Airbase, and that Bien Hoa Airbase is a significant dioxin hotspot. The samples collected from the northern and eastern areas of the Airbase exhibit lower dioxin contamination than samples collected from the southern, and western areas.

### Dioxins in fish tissues<sup>3</sup> and dioxin exposure pathways:

- The evidence indicates that dioxin moves from the former Agent Orange storage and washing/loading area (Z1 Area), and the Pacer Ivy Area into surrounding drainage ditches, small creeks, ponds and lakes, and ultimately into humans (via ingestion of contaminated fish, ducks and molluscs, direct dermal contact with soils and sediments, and likely via inhalation of dust), and is directly linked to historical Agent Orange use on the Bien Hoa Airbase. The most contaminated soils from the Z1 Area have recently (2009) been contained in a secure landfill by the MND, and public access has been restricted to reduce the risk of dioxin exposure to local populations. However, there is extensive aquaculture pond development and agricultural activities being conducted on the Airbase itself, which poses a significant risk to the population of Bien Hoa City.
- Tilapia, the most common fish captured and raised in aquaculture ponds on the Bien Hoa Airbase property, exhibited TEQ concentrations ranging from 4.54 to 4,040 pg/g wet weight in fat tissues; the median TEQ value in fat tissues was 1,440 pg/g.
- The maximum TEQ concentration recorded in Tilapia fat from 'Mr. Hoc Lake' in the Pacer Ivy Area in 2010 (4,040 pg/g wet weight basis) is more than 200 times the acceptable level established by Health Canada. Tilapia fat tissue samples from 'Mr. Quy Lake' (2,460 pg/g), 'NE Perimeter Lake' (1,680 pg/g), 'Gate 2 Lake' (1,520 pg/g), and 'Z1 Lake' (1,440 pg/g) all exceed this guideline by more than 70 times.
- Muscle samples analyzed from Tilapia and other fish species from lakes inside and outside the Bien Hoa Airbase property in 2010 generally exhibited lower dioxin levels, ranging from 0.0782 to 33.5 pg/g TEQ wet weight, and were below the Health Canada guideline.
- Dioxin levels recorded in whole-fish tissues of small Tilapia composites collected from 'Pacer Ivy Lake' and 'Z1 Lake' in 2010 also exhibited high TEQ concentrations (622 pg/g and 96.5 pg/g, respectively), well above the Health Canada guideline.
- Tilapia muscle and fat tissues sampled from Bien Hoa Market and Gate 2 Market, where fish raised from inside the Airbase are occasionally sold, exhibited low TEQ concentrations (5.9 pg/g and 4.54 pg/g dry weight, respectively). These levels are below the Health Canada guideline. The fish sampled from the markets in the current study, however, likely originated from aquaculture cages in the Dong Nai River.

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<sup>3</sup> Health Canada consumption guideline for edible fish tissue is 20 pg/g TEQ wet weight.

#### Dioxins and furans in human blood and breast milk:<sup>4</sup>

- TCDD concentrations in human blood serum collected from Airbase workers exhibited elevated TCDD and TEQ levels; TEQ concentrations ranged from 19.3 to 2,020 pg/g lipid basis. Given the high percentage of TCDD in the TEQ (range from 56.4% to 98.3%) in human blood serum analyzed, it is clear that dioxin levels recorded are related to exposure to historical Agent Orange use at the Airbase.
- Dioxin/furan levels in human serum lipid were compared to exposure standards calculated based on the WHO's Tolerable Daily Intakes (1998). A chronic intake of 4 pg/kg bw/day corresponds to 30 pg/g TEQ; all but one serum sample analyzed exceeded this guideline.
- Extremely high dioxin/furan levels (1,080 - 2,020 pg/g TEQ) were found in blood serum of three (3) individuals who actively harvest fish and other aquatic animals (e.g., ducks) from the Bien Hoa Airbase. TCDD accounted for more than 96% of the TEQ in these workers. TEQ concentrations in these three samples were more than 35 times greater than the WHO 1998 standard (30 pg/g).
- Individuals who consumed fish caught exclusively inside the Airbase exhibited higher average serum TCDD and TEQ concentrations (at a statistically significant level,  $\alpha=0.01$ ) compared to those who caught fish from lakes and ponds both inside and outside the Airbase, and compared to those who fish exclusively outside the Airbase. No significant gender- and age-related effects on serum dioxin levels were discovered.
- Dioxins and furans were recorded in all breast milk samples analyzed in 2010 (N=22). Maximum levels were detected in a mother (age 29) who was breastfeeding her 2<sup>nd</sup> child (30.3 pg/g TCDD lipid basis), and who previously consumed fish from 'Z1 Lake' and 'Gate 2 Lake'. Average Daily Intake of breast milk per infant was calculated based on WHO/Euro (1989); Total TEQ ingested by infants ranged from 5 to 172 pg TEQ/kg bw/d.
- All breast milk samples analyzed exhibited TEQs exceeding the WHO Tolerable Daily Intake guideline of 4 pg TEQ/kg bw/d. High dioxin and furan levels in breast milk are cause for concern, and emphasize the need for raising awareness of potential contaminated food items originating from Bien Hoa Airbase.
- Comparison of Bien Hoa (2010) breast milk data to those recorded in Hatfield/Office 33 (2007, 2009) studies at Da Nang Airport indicates that TEQ levels observed in Bien Hoa are generally lower; Average Daily Intakes in breast milk samples collected from in and around Da Nang Airport ranged from 23.4 to 2,320 pg TEQ/kg bw/d.

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<sup>4</sup> The typical range of TCDD in the general population of industrialized countries has been reported as 3 to 7 pg/g (lipid-based) (ATSDR 1998). ATSDR also indicated that TCDD in human blood rarely exceeds 10 pg/g and that typically, lower levels of this contaminant are recorded in less industrialized countries.

## Recommendations:

- Planning and implementation of remediation measures, and clean-up of Bien Hoa Airbase, is urgently required to ensure protection of the local population from future exposure to dioxins from historical Agent Orange use at the site.
- Final remediation and clean-up efforts should focus on mitigating dioxin and furan contamination downstream of the Z1 Area and at the Pacer Ivy Area. Current remediation efforts have focused on the construction of drainage ditches and a secure onsite landfill in the Z1 Area. Final destruction of dioxin contaminated soils in the Z1 landfill will also be required in the future.
- Cultivation of Tilapia, other fish species and aquatic animals (e.g., ducks, molluscs, etc.) should be halted immediately. Investigation of potential dioxin contamination related to other agricultural activities (e.g., raising livestock) should be conducted.
- Other potential dioxin and furan contamination sources, particularly uncontrolled combustion and industrial emissions, should be identified, as well as other potential contaminated materials which may be present at the Airbase.
- Awareness raising of dioxin exposure pathways (eating contaminated fish and other food items raised on Bien Hoa Airbase, exposure to contaminated soil and sediment, uncontrolled combustion, etc.) is required to help reduce dioxin loads in local Bien Hoa residents, especially nursing mothers.
- Other major dioxin hotspots in Viet Nam, particularly Da Nang and Phu Cat, also require remediation and clean-up, to protect the local populations from continued exposure to Agent Orange and other herbicides used over 40 years ago during the US-Viet Nam war. Lessons learned from ongoing cleanup activities at Da Nang Airport (funded by the US and Vietnamese governments) will be invaluable for the future remediation of Bien Hoa and Phu Cat Airbases, and at other dioxin hotspots in Viet Nam.



Source: Hatfield Consultants

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## 1.0 INTRODUCTION AND BACKGROUND

This report summarizes work completed during investigations conducted in November 2010 for the project entitled *Environmental and Human Health Assessment of Dioxin Contamination at Bien Hoa Airbase, Viet Nam* (hereafter referred to as the *Bien Hoa 2010 Study*). The report was prepared by Hatfield Consultants (hereafter referred to as “Hatfield”) and the Office of the National Steering Committee 33 (hereafter referred to as “Office 33”), and was funded through a grant from the Ford Foundation Special Initiative on Agent Orange Dioxin.

Results of environmental investigations on the Agent Orange dioxin issue at Bien Hoa are presented from field sampling conducted at the Bien Hoa Airbase (hereafter referred to as the “Airbase”) and its vicinity in November 2010. Historical environmental sampling conducted from 2004/2005 and 2008 (Hatfield/10-80 2006; Hatfield/VRTC 2009) are included in this report to provide a complete picture of the status of dioxin contamination at Bien Hoa Airbase.

Previous reports investigating the Agent Orange dioxin issue in and around the Bien Hoa Airbase were prepared by Hatfield, in association with 10-80 Division of the Ministry of Health and the Viet Nam-Russia Tropical Centre in 2006 and 2009 (Hatfield/10-80 2006; Hatfield/VRTC 2009). Soil and sediment surveys were undertaken from areas around the Airbase in 2004 and 2005 to identify potentially contaminated sites (hotspots) that may pose an unacceptable risk to human health, and to develop mitigation strategies for those sites (Hatfield/10-80 2006). A second field program conducted in January 2008 by Hatfield and VRTC (2009) analyzed additional soil and sediment samples to gain a better understanding of the level and extent of contamination in Bien Hoa, and to assess potential impacts of dioxin on the environment and people residing in the vicinity of the hotspots (Hatfield/VRTC 2009).

In June 2007, a workshop was organized in Ha Noi by the Viet Nam Ministry of National Defence (MND) and the US Department of Defence (DOD) to discuss dioxin contamination and, additionally, the “Pacer Ivy” mission. In logistics operations, the word “Pacer” refers to the movement of material, and the word “Ivy” is a short-form of “Inventory” (Young 2007). On April 17, 1970 all uses of Agent Orange were halted in the Republic of Viet Nam and all remaining materials were put into storage. The Pacer Ivy mission was launched on September 15, 1971 to consolidate, re-drum and ship all remaining Agent Orange material in South Viet Nam to Johnston Island in the Central Pacific Ocean.

Consolidation of contaminated herbicide barrels and other materials occurred at Bien Hoa Airbase, Tuy Hoa Airbase and Da Nang Airport. On December 23, 1971 clean-up, re-labeling and re-packaging of Agent Orange for shipment began at Da Nang Airport. The ARVN Commander was responsible for designating sites for the operations area and storage area, as well as the transportation routes to the port of Da Nang (Young 2009). About half of the 8,220 drums of Agent Orange were re-drummed, and on March 7, 1972 drums were loaded onto the M/T Trans Pacific ship in Da Nang Harbor. The ship travelled to Cam Rhan Bay where 6,000 drums from Tuy Hoa were loaded, and then on to the Port of Saigon

where a further 11,000 drums were added from Bien Hoa before heading to Johnston Island. Final inspection of the Agent Orange storage areas was completed by April 3, 1972.

Because of the war-time conditions, clean-up of former Ranch Hand sites (including Bien Hoa) was not always undertaken with consideration of human and environmental health; there are concerns that herbicides and waste water used for cleaning was dumped directly to the ground or possibly into groundwater wells.

From 2006-2009, MND constructed a landfill at Bien Hoa Airbase to contain 43,000 m<sup>3</sup> of contaminated soils from the main contaminated site (Z1 Area). Sampling conducted in 2008 by Hatfield and VRTC (2009) included investigations of soil and sediment contamination prior to construction of the landfill. The current study was undertaken following completion of the landfill.

Work of the 2010 study focused on identifying the pathways in which dioxin may be entering the local population, in order to protect the health of the human population of Bien Hoa from future dioxin contamination. The primary focus was on the collection of soil and sediment samples from various locations on the Airbase, to gain a better understanding of the extent of contamination. Additional soil samples were taken from the Pacer Ivy Area, Z1 Area, and the Southwest Corner of Airbase as extension to sampling conducted during the 2008 study (Hatfield/VRTC 2009). Samples were also taken from the northern perimeter of the Airbase, which had not been previously sampled.

Blood and breast milk samples were collected from members of the population deemed at high risk (i.e., Airbase workers, people who consume fish/aquatic organisms from lakes and ponds, etc.), and included people who reside inside and outside of the Airbase. Fish tissue samples were collected from lakes and ponds in and around the Airbase in order to present baseline contaminant concentrations and assess potential risks to human health through fish consumption.



Bien Hoa Airbase, October, 1970

Source: National Archives and Records Administration, Washington, DC



## 1.1 PROJECT OBJECTIVES

The main objectives of the Bien Hoa 2010 study were to:

1. Provide a comprehensive understanding of dioxin contamination in the environment and in the vicinity of Bien Hoa Airbase;
2. Assess the levels of dioxins and furans in soil, sediment and fish in areas not previously sampled within and in the vicinity of Bien Hoa Airbase;
3. Better understand bio-accumulation pathways of dioxin in the local food chain and human populations;
4. Assist with the protection of human health and development of mitigation measures for the contaminated areas; and
5. Enhance public awareness, strengthen governmental management at central and local levels, and increase scientific knowledge exchange to improve prevention and protection of people from dioxin exposure.

The primary focus of previous Hatfield/10-80/Office 33/VRTC studies was to identify dioxin exposure pathways to protect the human population of Bien Hoa (and other hotspots such as Da Nang and Phu Cat) from future dioxin contamination (i.e., “positive human health outcomes”). Protection of local people from current and future dioxin exposure in Bien Hoa City is the ultimate objective of this study.

Primary project activities included determining the linkage between potential dioxin contamination in soils and sediments in Bien Hoa Airbase and their movement into aquatic ecosystems, and into the human food chain. The identification and assessment of potential dioxin pathways into the human population allows recommendations to be made for immediate and longer-term mitigation measures to protect people working on the Airbase, as well as local communities downstream of the Airbase.

Important issues considered in the assessment of dioxin contamination at the Bien Hoa Airbase included the following:

1. Numerous dioxin hotspots with contamination levels exceeding Vietnamese and international standards and guidelines were identified on the Airbase during 2004/2005 and 2008 studies (Hatfield/10-80 2006; Hatfield/VRTC 2009). The hotspot in the southwest area of the Airbase (Pacer Ivy Area) was only confirmed following completion of the 2008 study. Therefore, the potential for additional hotspots in other areas of the Airbase was deemed high;
2. As of January 2010, people were continuing to earn livelihoods from harvesting fish, ducks and other aquatic animals from various lakes and ponds within the Airbase. There is also extensive agriculture throughout the Airbase, especially on the northwest, northeast and

northern perimeter. Based on our field observations, some city residents enter the Airbase perimeter to harvest fish, other edible plants and aquatic organisms from Z1 Lake for subsistence use. There are also a number of commercial aquaculture facilities operating on the Airbase. Therefore, it was necessary to identify exact dioxin exposure pathways to the human food chain, in order to determine dioxin containment measures for contaminated areas;

3. Given the likelihood that dioxin continues to enter the food web and human population through consumption of fish, aquatic animals and possibly vegetation and livestock, or from direct exposure to highly-contaminated soil and sediments, the implementation of mitigation measures to protect the human population is of high priority. Based on field surveys conducted in 2008, recommendations were made for sampling of fish tissues to determine if there were potential health risks associated with consumption of fish originating from the Airbase (Hatfield/VRTC 2009);
4. Human exposure to contamination outside the Airbase along the north, east, south, and west perimeters was suspected given the historical use of herbicides at the site, but unknown prior to the human surveys conducted under this study in November 2010. Blood and breast milk analyses were used to determine to what extent dioxins are bioaccumulating in the human food chain; and
5. For the current study, all samples were analyzed at AXYS Analytical Laboratories (AXYS, Sidney BC, Canada), an internationally accredited independent laboratory, which has analyzed all samples collected in previous Hatfield/10-80/Office 33/VRTC Viet Nam Agent Orange dioxin studies.



Source: National Archives and Records Administration, Washington, DC

## 1.2 BACKGROUND ON AGENT ORANGE AND BIEN HOA AIRBASE

During the US-Viet Nam war, the American and the ARVN military forces initiated the use of herbicides in Viet Nam through a program codenamed Operation Ranch Hand (Young 2009). The operation, which extended from 1961 to 1971, released over 80 million litres of herbicides into the environment of southern Viet Nam. Application of herbicides was primarily conducted through cargo aircraft (C-123s), and ground mechanisms (i.e., trucks, backpack sprayers, and river boats); helicopters were also used in certain areas of the country. Sixty-one percent (61%) of the herbicides used in Viet Nam was Agent Orange, intended to destroy forest cover and food crops. Vietnamese were exposed to these chemicals during the actual spraying and on a regular basis for the past 40+ years, primarily through contact with media such as soils, sediments, dust and food products near former US military bases.

Military installations throughout Viet Nam (e.g., Bien Hoa, Da Nang, Nha Trang, and Phu Cat) served as bulk storage and supply facilities for Agent Orange (US Army documents 1969; Cecil 1986). These storage sites experienced significant contamination due to the spillage of herbicides and improper disposal of empty barrels (Dwernychuk *et al.* 2002). In the past decade, several studies have been undertaken by Vietnamese and international scientists to verify the extent of dioxin contamination at a number of US bases in southern Viet Nam. The military history and present environmental conditions related to dioxin contamination have been recorded at key hotspots in Viet Nam, including Da Nang, Bien Hoa, Phu Cat, Pleiku, Nha Trang, Can Tho, and Tan Son Nhut (Dwernychuk *et al.* 2002; Hatfield/10-80 2006). Installations at Bien Hoa, Da Nang and Phu Cat have been identified as the most contaminated of the Airbases studied, and previous studies recommended to initiate remediation of soils as soon as possible (Hatfield/Office 33 2009).

Bien Hoa Airfield (Dong Nai Province) was the main location for Ranch Hand activities in southern Viet Nam. Previous residual herbicide studies in the Bien Hoa area suggest very high dioxin contamination (Schechter *et al.* 2001, 2002; Hatfield/10-80 2007). Runoff from the airfield is suspected to have contaminated the wards and communes downstream of the base. With a relatively high population density, the Bien Hoa area is placed very high on the priority list for human health risk due to dioxin contamination.

Since the US-Viet Nam war, Vietnamese living in the vicinity of key former Ranch Hand sites have been exposed to contaminated soils, sediments and foods; these contaminated areas are often referred to as dioxin 'hotspots' (Dwernychuk *et al.* 2002). Herbicide applications ceased in 1971. However, due to the chemical stability of dioxins, contaminated lands have the potential to expose the general population to dioxin for many decades, well beyond initial aerial applications and spillages during wartime Ranch Hand operations.



Herbicide barrels including Agent Orange, at Johnston Island, South Pacific in the early 1970s

Source: National Archives and Records Administration, Washington, DC

### 1.3 AGENT ORANGE USE AT BIEN HOA AND HOTSPOTS

Bien Hoa Airbase, located approximately 1.5 km drive northeast of Ho Chi Minh City (HCMC) was the primary Airbase for Ranch Hand operations in southern Viet Nam. Data provided by the US military to the Government of Viet Nam indicates that over 98,000 45-gallon barrels of Agent Orange, 45,000 barrels of Agent White, and 16,000 barrels of Agent Blue were stored/used at Bien Hoa (US DOD 2007). Over 11,000 barrels of herbicides were transferred from Bien Hoa under Operation Pacer Ivy in 1970.

Previous sampling programs primarily focused on the assessment and mitigation of dioxin impacts in the south-west and south-central portions of the Airbase, as well as in downstream lakes (i.e. South Base Lake, Bien Hung Lake, 'Gate 2 Lake'). A number of soil and sediment samples were analysed by VRTC at Bien Hoa Airbase, under previous MND studies. Confirmation of key hotspot areas at Bien Hoa was made by Hatfield and VRTC (2009). Additional information on dioxin/furan concentrations in perimeter areas outside of Bien Hoa Airbase in Bien Hoa City was provided by Hatfield/10-80 (2006).

According to US military data provided in 2007, the southwest corner of the Airbase served as the main storage area for Agent Orange and other herbicides at Bien Hoa. This location was sampled for the first time in 2008 during the Hatfield/VRTC (2009) study. This study also found extremely high dioxin concentrations, well exceeding the Vietnamese standards of 1,000 pg/g in soil and 150 pg/g in sediment in the former Pacer Ivy Storage and Redrumming Area and in the Z1 Storage Area.

Bien Hoa is densely populated outside the Airbase, with approximately 1 million people living in the city. Trung Dung and Tan Phong Wards are located next to the Airbase and have been recognized as the 'most severe dioxin hotspot' in Viet Nam (Tran *et al.* 2010). Soils throughout the Z1 Area at Bien Hoa Airbase are now heavily disturbed due to remediation efforts completed to date at the

Airbase (including landfill construction), and through rapid urban development immediately south of the Airbase in the City of Bien Hoa.

A number of dioxin sampling programs have been undertaken in Bien Hoa to assess the status of historical and current contamination. Schechter *et al.* (2001) sampled soil, sediment and human blood samples near the Bien Hoa Airbase, and measured extremely high levels of TCDD in both soil and blood. Schechter *et al.* (2001) reported a soil TCDD level of >1million pg/g, although the exact origin of this sample is not known by the senior author (pers. comm.). Soil and sediment sampling and dioxin analysis was undertaken by Hatfield/10-80 (2006) for suspected hotspots outside the Airbase, including the eastern end of the runway, South Base Lake, Bien Hung Lake and vicinities (summarized in Table 1.1). In 2008, Hatfield/VRTC (2009) conducted a more extensive assessment of soils and sediments the Southwest Corner of the Airbase, Pacer Ivy Area (southwest corner of the runway), and the Z1 area and its perimeter.

**Table 1.1 Bien Hoa dioxin data analyses completed between 1995 and 2010.**

Agency	Year	Number of Samples Analysed	Sample Type	Analytical Technique	Laboratory
1) Ministry of National Defence	1995 to 1996	84	Soil	GCMS (low resolution)	Vietnam (VRTC)
2) Schechter et. al. 2001	1999	35	Soil, Sediment & Blood	GCMS (high resolution)	Viet Nam and Japan (ERGO Laboratory)
4) Hatfield/10-80	2004 to 2005	36	Soil & Sediment	GCMS (high resolution)	Canada (AXYS)
5) Hatfield/ VRTC	2008	125	Soil & Sediment	GCMS (high resolution)	Canada (AXYS) Viet Nam (VRTC)
6) Hatfield/ Office 33 (current study)	2010	161	Soil, Sediment, Fish/Blood and Breast Milk	GCMS (high resolution)	Canada (AXYS)

Historical sampling was conducted in various locations inside and outside the Bien Hoa Airbase by Hatfield/10-80/VRTC (2006; 2009) (Figure 1.1). During the Hatfield/10-80 (2006) study, samples were taken from areas around the Airbase (South Base Lake, Bien Hung Lake, and eastern end of the runway), due to restricted access to Airbase property for all sampling personnel (Figure 1.2; Table 1.2). Sampled sites included areas that receive direct drainage from the base, areas of high human/environmental contact, and areas that were subject to repeated hand/truck spray around the base perimeter. Sampling by Hatfield/VRTC (2009) focused on the following hotspot locations (Figure 1.3):

1. **Southwest Airbase Corner** - Located on the southwest end of the runway, and covering an area of 2,000 m<sup>2</sup>, with an even and flat terrain, slightly sloping to the west. Run-off water (rainwater) carries dioxin from contaminated sites through the runway and residential areas to adjacent rice fields. Analysis of soil samples from this area demonstrated the historical use of Agent Orange at this site;



2. **Pacer Ivy area (western corner of Airbase)** – Recommended by the US DOD for further investigation, given its historical use as a herbicide storage and re-drumming location. The area is located on the western corner of the Airbase, close to the current runway. Sampling sites covered an area of 150,000 m<sup>2</sup>, including a concrete yard. Southwest of the concrete yard is a buffer zone sloping to surrounding drainage ditches, small creeks, and ponds. Fish and ducks are raised and harvested in man-made ponds in this area;
3. **Site Z1 (main hotspot area)** – Z1 was the main storage area for Agent Orange, Blue and White herbicides at Bien Hoa, and is highly contaminated with dioxin. During the US-Viet Nam war, large herbicide storage tanks were present at this location, and the area surrounding the Z1 Site was subjected to significant spillage. At least four times between December 1969 and March 1970, major spills occurred in the environment in this area; approximately 25,000 litres of Agent Orange and 2,500 litres of Agent White were released to the environment (US DOD 2007). This site has recently been remediated, including construction of drainage ditches and containment of contaminated soils; the MND remediation program covers an area of approximately 43,000 m<sup>2</sup>;
4. **Perimeter (south) of Z1 Area** – downstream of the Z1 area receives drainage from the hotspot site, and there are a number of ponds and lakes used for aquaculture; and
5. **Ponds and Lakes Downstream of the Z1 Area** – a number of ponds, lakes and other aquatic habitats are located approximately 300 m south of the Z1 Area at the southern border of the Airbase. At present, these ponds and lakes are used for fish and vegetable cultivation. Prior to remediation efforts, rainwater carried residual herbicides from the Z1 Area, and subsequently dioxins, into these ponds and lakes, including Bien Hung Lake outside of Bien Hoa Airbase.

For potential health risks to be present, a contaminated site must exhibit at least three conditions or risk factors:

- Chemical Hazard – one or more chemical contaminants at concentrations capable of causing human or ecological health impacts;
- Receptors – humans, animals or plants at the site; and
- Exposure Pathway – a way for chemical contaminants to reach the receptors.

Given all scientific evidence from previous studies concerning the Bien Hoa Airbase (Hatfield/10-80 2006; Hatfield/VRTC 2009), it is evident that all of these potential risk factors co-exist as a result of historic handling, storage, and disposal activities of Agent Orange and other herbicides. Although various contaminants have been identified at the site, the focus is on polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) as the chemical hazards of interest.

A summary of dioxin/furan analyses completed in Bien Hoa Airbase and Bien Hoa City in previous studies (Hatfield/10-80 2006; Hatfield/VRTC 2009), and in the current study, is presented in Table 1.1; sampling locations are presented in Figure 1.1. In the Hatfield/10-80 (2006) study, the highest soil dioxin levels were recorded east of the Airbase (05VN089: 392 pg/g with a resulting TEQ of 424 pg/g, 92% TCDD of TEQ); highest sediment dioxin value was recorded at South Base Lake (05VH078: 797 pg/g TCDD, 833 pg/g TEQ, and 96% TCDD of TEQ), suggesting extensive contamination outside the Bien Hoa Airbase (Table 1.2; Figure 1.2).

In the Hatfield/VRTC (2009) study, it was found that several areas exhibited dioxin levels above internationally accepted standard of 1,000 pg/g TCDD in soils, including the southwest corner of the Airbase, Pacer Ivy Area, and the Z1 Area and its vicinity. The maximum soil TEQ concentration recorded was 262,000 ppt from a sample collected at a depth of 60-90 cm from the Z1 Area; this is >250 times greater than the Vietnamese and international recommended guidelines (Table 1.3, Figure 1.3).

Drainage patterns from the Bien Hoa Airbase into the city of Da Nang were determined based on field investigations by Hatfield. The Dong Nai River flows to the west and south of the Airbase, and is regarded as one of the main recipients of drainage from the Bien Hoa Airbase.

The current study included a detailed investigation of soil and sediment dioxin levels in areas previously not sampled on the Bien Hoa Airbase, to gain a better understanding of the extent of contamination. Fish tissue from lakes and ponds within and outside the Airbase, and human serum and breast milk samples from people working inside and residing near the Airbase were analyzed in order to assess possible impacts to local residents from dioxin exposure.



Ranch Hand C-123s, and spillage at Bien Hoa Airbase, March 1969

Source: National Archives and Records Administration, Washington, DC

**Table 1.2 2,3,7,8-TCDD (pg/g dry weight), TEQ (pg/g), and percent TCDD of the TEQ concentration for soil and sediment samples from Bien Hoa Airbase, Viet Nam, 2005 (Hatfield/10-80 2006).**

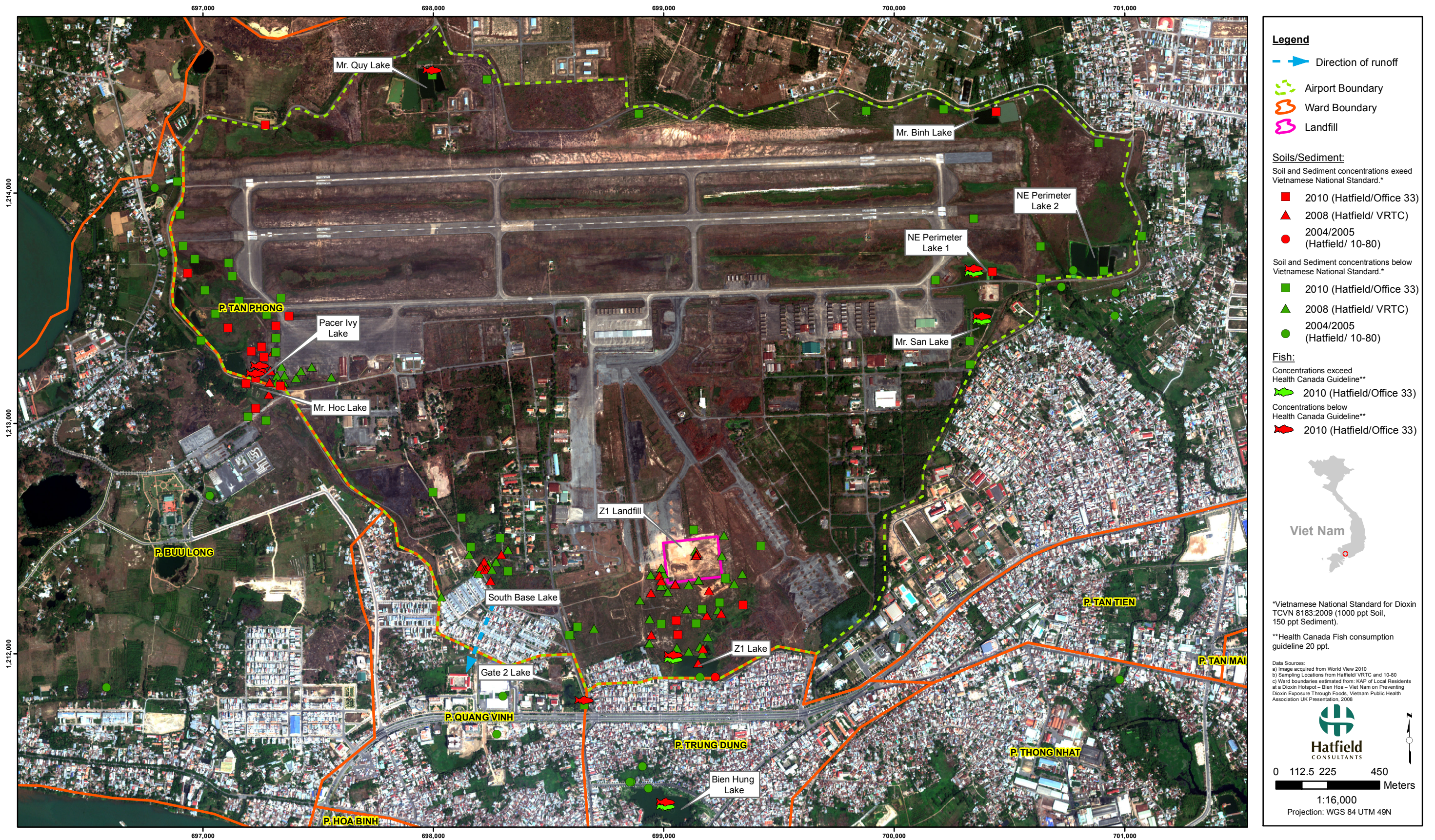
Sample ID	Sample Type	Location	2,3,7,8-TCDD	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
05VN087	soil	NE Perimeter	257	267	96.3
05VN089	soil	NE Perimeter	392	424	92.5
05VN080	soil	Z1 Area	284	294	96.6
05VN074	soil	Outside Airbase - SW	279	287	97.2
05VN077	soil	Outside Airbase - SW	27.1	39.4	68.8
05VN096	soil	Outside Airbase - SW	0.596	2.76	21.6
04VN013	soil	Outside Airbase - NW	12.2	14.3	85.3
05VN073	soil	Outside Airbase - NW	18.8	22.6	83.2
05VN095	soil	Outside Airbase - S	208	224	92.9
05VN085	sediment	NE Perimeter	41.5	48.3	85.9
05VN086	sediment	NE Perimeter	40.6	48.7	83.4
05VN088	sediment	NE Perimeter	82.8	101	82.0
05VN078	sediment	Z1 Area	797	833	95.7
05VN079	sediment	Z1 Area	224	234	95.7
05VN081	sediment	Z1 Area	76.9	80.3	95.8
04VN014	sediment	Bien Hung Lake	96.7	106	91.2
05VN102	sediment	Bien Hung Lake	96	131	73.3
05VN103	sediment	Bien Hung Lake	31.1	36	86.4
04VN011	sediment	Outside Airbase - W	0.304	1.19	25.5
05VN094	sediment	Outside Airbase - SE	5.22	8.24	63.3
05VN097	sediment	Outside Airbase - SE	3.73	14.8	25.2
05VN098	sediment	Outside Airbase - SE	0.969	3.26	29.7
05VN101	sediment	Dong Nai River	2.72	9.03	30.1
05VB101 (Duplicate)	sediment	Dong Nai River	2.73	8.81	31.0

Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).



Figure 1.1 Overview of all dioxin sampling locations in Bien Hoa, Viet Nam by Hatfield/10-80 Division/VRTC/Office 33, 2004 to 2010.





**Figure 1.2 Historical sampling locations, outside the Bien Hoa Airbase, Viet Nam, 2004 to 2005 (Hatfield/10-80 2006).**



**Legend**

- Airport Boundary
- Ward Boundary
- Landfill
- Direction of runoff

**Soils/Sediment:**

Soil and Sediment concentrations exceed Vietnamese National Standard.\*

- 2004/2005 (Hatfield/ 10-80)

Soil and Sediment concentrations below Vietnamese National Standard.\*

- 2004/2005 (Hatfield/ 10-80)

\*Vietnamese National Standard for Dioxin TCVN 8183:2009 (1000 ppt Soil, 150 ppt Sediment).

0 0.2 0.4 0.8 Km

Scale: 1:26,000

Projection: WGS 1984 UTM Zone 48N

Data Sources:  
a) Image acquired from World View 2010  
b) Sampling Locations from Hatfield/VRTC and 10-80  
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot – Bien Hoa – Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008

Viet Nam

**Table 1.3 2,3,7,8-TCDD (pg/g dry weight), TEQ (pg/g), and percent TCDD of the TEQ concentration of soil and sediment samples from Bien Hoa Airbase, Viet Nam, 2008 (Hatfield/VRTC 2009).**

Sample ID	Sample Type	Depth	2,3,7,8-TCDD	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
<i>Southwest Corner of Airbase</i>					
08VNBH067*	Soil	0-10	1890	1920	98.4
08VNBH068	Soil	0-10	1380	1400	98.6
08VNBH074	Soil	0-10	439	449	97.8
08VNBH076	Soil	0-10	1530	1540	99.4
08VNBH077	Soil	0-10	71	74	95.3
08 VNBH084*	Soil	0-10	65400	65500	99.8
08VNBH085	Soil	0-10	1980	2000	99.0
08VNBH087	Soil	0-10	428	440	97.3
08VNBH088	Soil	0-10	72	78	91.3
08VNBH088-2	Soil	30-Oct	16	19	83.7
08 VNBH088-3*	Soil	30-60	NDR 12.6	4	NC
08VNBH088-4	Soil	60-90	3	5	63.0
08VNBH091	Soil	0-10	214	245	87.3
08VNBH097	Soil	0-10	10	13	74.2
08VNBH099	Soil	0-10	132	140	94.3
08VNBH112	Soil	0-10	30	43	71.0
<i>Pacer Ivy Storage and Re-drumming Area</i>					
08VNBH102	Soil	0-10	29	80	36.4
08VNBH104	Soil	0-10	2000	2040	98.0
08VNBH105	Soil	0-10	22300	22800	97.8
08VNBH106	Soil	0-10	140	147	95.2
08VNBH107	Soil	0-10	489	556	87.9
08VNBH113	Soil	0-10	69	93	74.0
08VNBH114	Soil	0-10	467	516	90.5
08VNBH115	Soil	0-10	1	780	0.1
08 VNBH116*	Soil	0-10	844	894	94.4
08VNBH119	Soil	0-10	70	217	32.3
08 VNBH120*	Soil	0-10	221	289	76.5
08VNBH108	Sediment	0-10	1030	1090	94.5
08 VNBH109*	Sediment	0-10	2650	2780	95.3
08VNBH110	Sediment	0-10	1400	1500	93.3
08 VNBH111*	Sediment	0-10	5810	5970	97.3
<i>Z1 Area</i>					
08VNBH080	Soil	0-30	36800	37500	98.1
08VNBH080-2	Soil	30-60	144000	146000	98.6
08VNBH080-3	Soil	60-90	259000	262000	98.9
08VNBH080-4	Soil	90-120	215000	217000	99.1
08VNBH080-5	Soil	120-150	26200	26400	99.2
08VNBH082	Soil	0-10	48600	49100	99.0
08VNBH083	Soil	0-10	100	109	91.5
<i>Perimeter of the Z1 Area</i>					
08VNBH122	Soil	0-10	194	223	87.0
08 VNBH123*	Soil	0-10	1310	1330	98.5
08 VNBH124*	Soil	0-10	387	395	98.0



**Table 1.3 (Cont'd.)**

Sample ID	Sample Type	Depth	2,3,7,8-TCDD	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
<i>Perimeter of the Z1 Area (cont'd.)</i>					
08VNBH125	Soil	0-10	2010	2090	96.2
08 VNBH126*	Soil	0-10	71	74	95.7
08VNBH127	Soil	0-10	66	70	93.5
08 VNBH128*	Soil	0-10	850	879	96.7
08VNBH130	Soil	0-10	566	589	96.1
08VNBH134	Soil	0-10	41	48	85.1
08 VNBH135*	Soil	0-10	2620	2670	98.1
08VNBH136	Soil	0-10	67	73	92.5
08VNBH137	Soil	0-10	396	411	96.4
08VNBH139	Soil	0-10	20	26	76.0
08VNBH141	Soil	0-10	742	753	98.5
08VNBH141-3	Soil	30-60	8240	8310	99.2
08VNBH141-6	Soil	120-150	12	22	53.2
08VNBH142	Soil	0-10	31	41	76.9
08 VNBH143*	Soil	0-10	84	113	74.4
08VNBH143-3	Soil	30-60	4	6	61.8
08VNBH145	Soil	0-10	82	94	86.7
08VNBH147	Soil	0-10	236	259	91.1
08VNBH 148*	Soil	0-10	30	32	93.7
08VNBH149	Soil	0-10	94	106	89.0
08VNBH150*	Soil	0-10	20	23	86.7
08VNBH153	Soil	0-10	738	757	97.5
08VNBH161	Soil	0-10	311	323	96.3
08VNBH162*	Soil	0-10	393	442	88.9
08VNBH163	Soil	0-10	17	25	68.8
08VNBH166	Soil	0-10	81	98	82.6
08VNBH170	Soil	0-10	12400	13300	93.2
08 VNBH132*	Sediment	0-10	405	413	98.1
<i>Ponds and Lakes Downstream of Z1 Area</i>					
08VNBH155*	Sediment	0-10	2200	2240	98.2
08VNBH156	Sediment	0-10	15.2	20.9	72.7
08 VNBH157*	Sediment	0-10	1740	1790	97.2
08VNBH158	Sediment	0-10	18	22.0	81.8
08VNBH159	Sediment	0-10	727	756	96.2

\* Samples analyzed by AXYS.

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

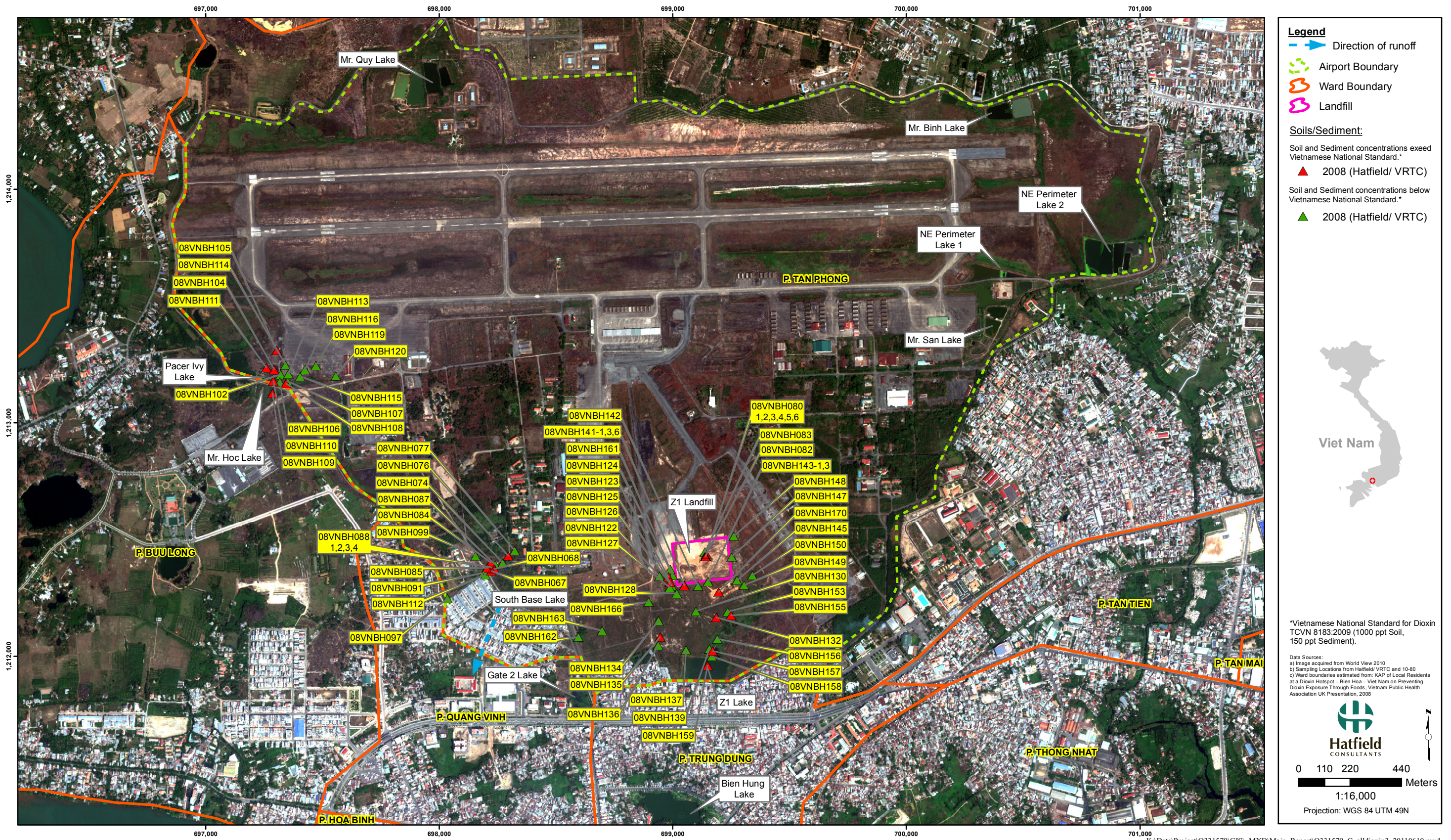
NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).



Figure 1.3 Historical sampling locations, Bien Hoa Airbase, Viet Nam, January 2008 (Hatfield/VRTC 2009).





## 1.4 DIOXIN GUIDELINES TO LIMIT HUMAN EXPOSURE

Polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), biphenyls (PCBs) and related compounds, collectively known as dioxins, are unintentional byproducts of combustion processes, metallurgical processes, chemicals manufacturing and pulp and paper processing (AEA 1999). There are 210 congeners of PCDD/Fs, 17 of which have chlorine substitutions in the 2,3,7,8 positions, making them toxic, stable, and persistent in the environment. 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) is the most toxic of all of the congeners and is classified as a carcinogen by the WHO (Abad *et al.* 2000; Srogi 2008). Each individual congener is assigned a toxic equivalency factor (TEF) to define their level of toxicity as it relates to 2,3,7,8-TCDD.

This report uses a WHO endorsed TCDD Toxic Equivalent (WHO-TEQ) to assess contamination. WHO-TEQ is determined by multiplying the concentration of each individual congener in its mixture by its TEF (Srogi 2008). International Toxic Equivalent (I-TEQ) preceded the WHO-TEF and WHO-TEQ, and generated a value about 10% higher than the WHO-TEQ. I-TEQ have been referred to in various past reports; however, in this report, 2005 WHO-TEQ is the most commonly referenced TEQ.

Characteristics exhibited by dioxins include low water solubility, attraction to organic materials, and lipophilic properties (a tendency to combine with lipids). Considered as Persistent Organic Pollutants (POPs), dioxins are relatively immobile; but over time, they may migrate from their source of origin through media such as air, water, and soil.

PCDD/Fs' presence in many parts of the world today has been a result of intentional and unintentional introduction of PCDD/Fs into our environment in the past. In Japan, pesticide use accounted for 460 kg TEQ released into the environment between 1950 and 1998 (Masunaga *et al.* 2001; Seike *et al.* 2003; Weber and Masunaga 2005; Weber *et al.* 2008). During the US-Viet Nam war, an estimated 366 - 600 kg of TEQ was released to the environment of Viet Nam in the form of herbicides (Allen 2004; Stellman *et al.* 2003; Young 2006, Young *et al.* 2008; Weber *et al.* 2008). In Hamburg, 378 kg TEQ was released from a single factory producing hexachlorocyclohexane (HCH) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) (University of Bayreuth 1995; Weber *et al.* 2008). From a study of 55 countries, contemporary releases of dioxins were set at 20 kg TEQ/year (Fiedler 2007; Weber *et al.* 2008).

Regulatory agencies addressing human health protection have employed various protocols to address the issue of dioxin contamination, and to limit their presence and spread in the environment. Guidelines have been established for the protection of environment and human health in various media such as soils, sediments, and fish.

### 1.4.1 PCDD/F in Soils

Dioxins in general, and TCDD in particular, in soils from industrialized countries are detected in varying concentrations. Historically, soils near specific industries and certain material treatment plants have a high probability of containing dioxins, particularly if chlorine is involved in the processes (e.g., bleaching of pulp and paper with elemental chlorine, incineration of chemical waste, hospital waste and sewage sludge, processing of certain metals) (Webster and Commoner 1994).

In EU Member Countries, PCDD/F concentrations detected in soil generally range between <1 and 100 ng I-TEQ/kg of dry matter, with a maximum recorded concentration of 100,000 pg I-TEQ/g (AEA 1999). The Agency for Toxic Substance and Disease Registry ATSDR (ATSDR 1998) reports that in the United States, TCDD levels in soil from industrialized regions typically range from 1.0 pg/g to 10 pg/g, while they are generally not detected in rural soils.

The International Agency for Research on Cancer (IARC 1997) provided a detailed summary of 42 studies conducted in 18 industrialized countries, which presented over 150 TCDD data points. TCDD concentrations presented in this overview ranged from non-detected (ND) to  $9.6 \times 10^9$  pg/g; the highest concentrations recorded in the IARC (1997) summary were found in highly contaminated soils from Missouri (a horse arena and farm soil, Kimbrough *et al.* 1997 and Viswanathan *et al.* 1995, both *cited in* IARC 1997). Other very high TCDD levels (i.e., >1,000 pg/g) were recorded in soils collected from heavily industrialized sites; these sites included manufacturing plants for tetrachlorophenol, pentachlorophenol, chlorophenolics, and herbicides (e.g., 2,4,5-T) and incineration facilities.

In Canada, soils affected by pulp and paper mills exhibited PCDD/F WHO-TEQ levels of 255pg/g. At the site of a warehouse fire in the province of Quebec, a PCDD/F WHO-TEQ level of 1,124 pg/g was measured in soils (Environment Canada 2004).

Dioxins in soil can pose a lingering threat to human health. Paustenbach *et al.* (1992) has indicated that the half-life of dioxins in subsurface soils can extend to 100 years. Therefore, any substantial disturbance of the integrity of soil layers has the potential of re-mobilizing dioxin, and ultimately may lead to its integration into the human food chain.

A number of industrialized countries have established TEQ guidelines for soils contaminated with polychlorinated dioxins and furans (PCDD and PCDF), which if exceeded, would designate the site as a "contaminated site". WHO-TEQ guidelines (and I-TEQ for older guidelines) for dioxin contamination in soil vary with target soil use: a range of 4 to 40 pg/g TEQ for agricultural use and approximately 1,000 pg/g TEQ for residential/recreational areas. Higher dioxin concentrations (up to 10,000 pg/g TEQ) are generally tolerated in industrial areas. The rationale for the difference in TEQ relates to the issues of bioaccumulation and biomagnification. More stringent standards have been

designated for agricultural areas, as they are used for raising food (crops and livestock) that is ultimately consumed by humans, therefore, directly facilitating the transfer of dioxins to humans. Given that residential and recreational park areas are not major food producing sites, ecological health standards are greater. Table 1.4 summarizes the various soil dioxin criteria over numerous jurisdictions around the world.

In Viet Nam, the dioxin thresholds for contaminated soils are defined in the National Standard TCVN 8183:2009. A dioxin threshold of 1,000 pg/g TEQ for soil has been set in “dioxin heavily contaminated sites”. This level provides a base for restricting site access and treating dioxin in sites that are heavily contaminated by dioxin. The guideline value 1,000 pg/g TEQ is used in this report.

**Table 1.4 Summary of dioxin (TCDD and TEQ) criteria for soil (dry weight basis).**

Country/Jurisdiction	Guideline	Comments
Viet Nam <sup>1</sup>	1,000 pg/g TEQ	Dioxin heavily contaminated sites (soils)
Germany <sup>2,3</sup>	5-40 pg/g TEQ	Agricultural soils – target concentration
	100 pg/g TEQ	Playground soils
	1,000 pg/g TEQ	Residential soils
	10,000pg/g TEQ	Industrial soils
Japan <sup>3</sup>	250 pg/g TEQ	If exceeded, research studies required
	1,000 pg/g TEQ	If exceeded, removal required
British Columbia, Canada <sup>4</sup> (Provincial)	10 pg/g TEQ	Agricultural – human health protection
	350 pg/g TEQ	Residential – human health protection
Alberta, Canada <sup>5</sup> (Provincial)	250 pg/g TEQ	Natural area remediation guideline
	4 pg/g TEQ	Agricultural, residential/parkland, commercial, industrial remediation guideline
Canada (Federal) <sup>6</sup>	4 pg/g TEQ	Agricultural (provisional Soil Quality Guideline) Residential/Parkland (provisional Soil Quality Guideline) Commercial (Soil Quality Guideline) Industrial (provisional Soil Quality Guideline)
Canada (Interim soil quality criterion) <sup>6</sup>	10 pg/g TEQ	Agricultural soils
	1,000 pg/g TEQ	Residential/park land soils
Czech Republic <sup>7</sup>	1 pg/g TEQ	Background
	100 pg/g TEQ	Pollution Limit
	500 pg/g TEQ	Action limit- living area
	1,000 pg/g TEQ	Action limit- recreational area
	10,000 pg/g TEQ	Action limit- industrial
Denmark <sup>7</sup>	<5 pg/g TEQ	Target concentration soil used for agricultural purpose
	>100 pg/g TEQ	Soil exchange on children’s playgrounds
	>1,000 pg/g TEQ	Soil exchange in residential areas
	>10,000 pg/g TEQ	Soil exchange independent of the location
USEPA (Federal) <sup>3</sup>	1,000 pg/g TEQ	Residential
*USEPA (Regional) <sup>8</sup>	4.5 pg/g TCDD	Residential soils, if exceeded, risk assessment required
	18.0 pg/g TCDD	Industrial soils, if exceeded, risk assessment required



**Table 1.4 (Cont'd.)**

Country/Jurisdiction	Guideline	Comments
USEPA Region 5 <sup>9</sup>	11 pg/g	PCDD soil guideline level
	38.6pg/g	PCDF soil guideline level
California <sup>10</sup>	50 pg/g TEQ	Residential
	200-1,000 pg/g TEQ	Commercial/ Industrial
	<40 pg/g TEQ	Agricultural
New Zealand Interim Accepted Criteria <sup>7</sup>	10 pg/g TEQ	Agricultural
	1,500 pg/g TEQ	Residential
	18,000 pg/g TEQ	Industrial
	90,000 pg/g TEQ	Industrial – Paved, with a management plan
ATSDR <sup>11</sup>	21 pg/g TEQ	Maintenance
	≤50 pg/g TEQ	Screening level
	>50 - <1,000 pg/g TEQ	Evaluation level
Sweden <sup>3</sup>	≥1,000 pg/g TEQ	Action level
	10 pg/g TEQ	Residential soils
Netherlands <sup>3</sup>	250 pg/g TEQ	Industrial soils
	10 pg/g TEQ	Dairy farming and land with sensitive use
Finland <sup>2,3</sup>	1,000 pg/g TEQ	Residential and agricultural
	2 pg/g TEQ	Protection of humans
	500 pg/g TEQ	Limit for contaminated soils

\* In May of 2009 the USEPA released the Regional Screening table to replace the previous RBC table for Region 3, the Region 6 Screening Level table and the Region 9 PRG table. Region 4 also recommends the use of this table for screening in certain projects (USEPA 2009).

<sup>1</sup> Viet Nam National Standard TCVN 8183:2009.

<sup>2</sup> AEA 1999.

<sup>3</sup> NZMOE 2002.

<sup>4</sup> BC- Queen's Printer 2009.

<sup>5</sup> Alberta Environment 1994, 2009.

<sup>6</sup> CCME 2001.

<sup>7</sup> IPEN 2009.

<sup>8</sup> USEPA 2009.

<sup>9</sup> USEPA 2003.

<sup>10</sup> HHRA 2009.

<sup>11</sup> ATSDR 1997, 2006.



Soil sampling on Bien Hoa Airbase, November 2010

Source: Hatfield Consultants

These guidelines are only one method of protecting the environment and human health from dioxin contamination. The ATSDR (1997) guideline recommends that an area with a soil concentration of >50 pg/g to <1,000 pg/g T-TEQ should be evaluated further based on the following criteria:

- Bioavailability;
- Ingestion rates;
- Pathway analyses;
- Soil cover;
- Climate;
- Other contaminants;
- Community concerns;
- Demographics; and
- Background exposures.

ATSDR (1997) also recommends that if soil levels are  $\geq 1000$  pg/g T-TEQ, public health actions should be considered, such as:

- Surveillance;
- Research;
- Health studies;
- Community;
- Education, and
- Exposure investigations.

Essentially, health assessors should obtain a sufficiently detailed database to enable a judgment regarding assessment of the site as a public health hazard, thereby facilitating implementation of public health recommendations to prevent human exposure, which includes clean-up of the contaminated site.

#### **1.4.2 PCDD/F in Sediments**

Dioxins are characterized by their low water solubility and their tendency to be strongly absorbed onto the surface of particulate matter (Srogi 2008). In aquatic systems, PCDD/Fs accumulate in suspended sediments, the organic-rich fraction of the bed, and with lipid-rich tissues of aquatic organisms (CCME 2001).

Sediments are soils found in freshwater and marine environments, and act as sinks and secondary sources for dioxins and other POPs (Weber *et al.* 2008). Historically deposited POPs can be buried in sediments, making them not bio-available. These contaminated sediments can be exposed and released into the food chain through dredging, floods, and construction activities.

Dioxins in sediments can be detected in varying concentrations in industrialized countries. In Canada, sediment analyzed from sites downstream of pulp mills exhibited PCDD/F levels to 158 pg/g TEQ (dry weight), while sites upstream exhibited non-detectable levels (Environment Canada 2009). In EU countries,

sediment concentrations typically ranged from <1 to 200 pg /g I-TEQ with a maximum concentration of 80,000 pg/g I-TEQ at contaminated sites (AEA 1999). In a study by Mai *et al.* (2007), sediment samples were taken from Bien Hung Lake in Bien Hoa at different layers. The study found that the highest concentrations of PCDD/F were observed in the first 30 cm, where organic debris had settled, facilitating dioxin absorption. This observation was also confirmed in a Hatfield study from a core sample from Sen Lake at Da Nang Airport (Hatfield/ Office 33 2007).

Table 1.5 summarizes proposed dioxin guidelines in sediments designed for the protection of human health and ecological receptors in various industrialized countries.

In Viet Nam, the dioxin thresholds for contaminated sediments are defined in the National Standard TCVN 8183:2009. A dioxin threshold of 150 pg/g TEQ for sediment has been set in “dioxin heavily contaminated sites”. This level provides a base for restricting site access and treating dioxin in sites that are heavily contaminated by dioxin. The guideline value 150 pg/g TEQ is used in this report.

**Table 1.5 Proposed dioxin guidelines (TCDD TEQ) in sediments (dry weight basis).**

Country/Jurisdiction	Guideline	Comments
Viet Nam <sup>1</sup>	150 pg/g TEQ	Dioxin heavily contaminated sites (sediments)
USEPA, Region 10 <sup>2</sup>	4 pg/g TEQ	Protection of human and ecological receptors
USEPA, Region 3 <sup>3</sup>	0.85 pg/g TEQ	Freshwater Sediment Screening Benchmarks
USEPA, Region 5 <sup>4</sup>	1.2 pg/g TEQ	Sediment ecological screening levels
New York State Dept. of Environmental Conservation <sup>2</sup>	10-100 pg/g TEQ	Protection of human and ecological receptors
Wisconsin Dept. of Natural Resources <sup>2</sup>	1 pg/g TEQ	Protection of human receptors
Int. Joint Comm., Great Lakes Science Advisory Board <sup>2</sup>	10 pg/g TEQ	Protection of human and ecological receptors
Canada <sup>5</sup>	21.5 pg/g TEQ (PEL) 0.85 pg/g TEQ (ISQG)	Provisional maximum expressed on a toxic equivalency basis using toxic equivalent factors for fish
Environment Canada, Pacific Yukon Region <sup>2</sup>	10 pg/g TEQ	Protection of ecological receptors
British Columbia, Canada <sup>6</sup>	130 pg/g TEQ 260 pg/g TEQ	Criteria at sensitive sites Criteria at typical sites
Germany – Hamburg Dept. of Environment <sup>2</sup>	5-10 pg/g TEQ	Protection of human receptors
Netherlands <sup>2</sup>	100 pg/g TEQ	Protection of human receptors (threshold for remediation)

<sup>1</sup> Viet Nam National Standard TCVN 8183:2009.

<sup>2</sup> AEA 1999.

<sup>3</sup> USEPA Region III BTAG Freshwater Sediment Screening Benchmarks. 8/2006.

<sup>4</sup> USEPA 2003.

<sup>5</sup> CCME 2001. PEL= Probable Effect Level; ISQG= Interim Sediment Quality Guidelines.

<sup>6</sup> MacDonald 2003.

### 1.4.3 PCDD/F in Food Sources and Tolerable Daily Intakes

PCDD/Fs tend to bioaccumulate up the food chains, and are found in the tissues of humans and other higher trophic level organisms (Michell 1997; Schecter *et al.* 2006; Park *et al.* 2009). According to AEA (1999) and Srogi (2008), food consumption contributes to more than 90% of the human exposure to dioxins in the general population. A dietary exposure assessment of EU Member States revealed that the average total human exposure was up to 210 pg I-TEQ/day in Spain (AEA 1999). Assuming an average body weight of 70 kg, this translates to an average of 3.0 pg I-TEQ per kg of body weight per day. Because this amount of PCDD/Fs and dioxin-like PCBs is only assumed to contribute about 50% of the total dietary TEQ, many individuals are likely to exceed the WHO-recommended daily value (Tolerable Daily Intake) of 1 to 4 pg TEQ per kg of body weight per day (pg TEQ/kg bw/d).

Background concentrations for foodstuffs in the EU revealed that fruits and vegetables generally have the lowest concentrations of dioxins (I-TEQ of 0.01 to 0.2 pg /g fresh weight) while fish fat has the highest concentration (I-TEQ of 2.4 to 214.3 pg/g wet weight) (AEA 1999). A study of 228 food items collected from a market in Finland revealed that fish had the highest dioxin and PCB concentrations. The contribution of fish to the intake of PCDD/F and PCBs by the general population in Finland was estimated to be between 72% and 94% (Kiviranta *et al.* 2004; Srogi 2008).

In Western Canada, PCDD/F levels in the fat-rich hepatopancreas (digestive gland) of Dungeness crab are good indicators of contamination. Because of their sedentary nature and preference for sandy substrates, crabs are susceptible to contaminant build-up and bioconcentrate contaminants at a higher level than finfish and many other shellfish (Environment Canada 2009). In 2007, the Canadian closure threshold for the crab fishery was reduced from 30 pg/g TEQ to 22.5 pg TEQ/g wet weight in crab hepatopancreas. Health Canada (1990) uses a maximum allowable concentration (wet weight) of 20 pg/g TEQ for edible portions of fish.



Source: Hatfield Consultants

**Table 1.6 Maximum allowable PCDD/F concentration in fish.**

Country/ Jurisdiction	Maximum allowable concentration – wet weight (pg/g)	Reference
EU	4 pg/g TEQ	Bellona 2009
Canada	20 pg/g TEQ in fish (edible portions) 22.5 pg/g TEQ in crab hepatopancreas	Health Canada 1990 Environment Canada 2007
Ontario, Canada	2.7 pg/g TEQ – consumption restriction	Queen's Printer Ontario 2009
	21.6 pg/g TEQ – total restriction	Queen's Printer Ontario 2009
US FDA	50 pg/g TEQ	The Food and Drug Administration (FDA) (ATSDR 2008)
WHO (JECFA)	5 pg/g TEQ	Government of Canada- website accessed 2009

The toxicity of PCDDs and PCDFs in general, and TCDD in particular, has promoted organizations such as the World Health Organizations (WHO) and various countries to develop and adopt tolerable daily intakes (TDI) for PCDDs and PCDFs in foods, based on international toxic equivalents of TCDD. TDI values have been established to ensure that human populations are not exposed to dioxin levels that could result in adverse health effects (AEA 1999; Smith and Lopipero 2001). A TDI value of 10 pg/kg bw/d was originally recommended by the WHO (WHO/EURO 1991) based on liver toxicity, reproductive effects, immunological effects, and on information on kinetics in humans and experimental animals.

In 1998, the WHO European Centre for Environment and Health and the International Programme on Chemical Safety conducted a detailed assessment of health risks associated with dioxin-like compounds. Based on this assessment, the TDI value was revised to a range of 1–4 pg/kg bw/day (WHO/EURO 1998a,b), considering recent epidemiological and toxicological data, particularly information focusing on neurodevelopment and endocrinological effects. The WHO has stressed that the upper value of the range (4 pg/kg bw/d) should be considered the maximum TDI, and that “*the ultimate goal is to reduce human intake levels below 1 pg TEQ/kg bw/d*”.

The new levels recommended by WHO are considerably lower than the TDIs currently in use by several countries. They are comparable to the Netherlands limits, which is 1-3 pg TEQ/kg bw/d (Birnbaum and Slezak 1999, Patandin *et al.* 1999), and are not nearly as low as those of the US Environmental Protection Agency (USEPA), which has proposed a virtually safe dose of 0.0064 pg TEQ/kg bw/d (Mclachlan 1993, Patandin *et al.* 1999).

The ATSDR has established a minimal risk level (MRL) for oral exposure as opposed to a TDI. The acute level is 200 pg TEQ/kg bw/d, the intermediate level is 20 pg/kg bw/d and the chronic level is 1 pg TEQ/kg bw/d.

**Table 1.7 International tolerable daily intake PCDD/F exposure guidelines.**

Country / Agency	Year	Guideline (pg-TEQ/kg-bw/day)	Derivation	Reference
USEPA	2003	*RfD = 0.001	Range of effects from biochemical to adverse.	USEPA 2003
European Commission	2001	TDI = 2 (day)	Extrapolated from a 14 pg-TEQ/kg-bw/week. The Tolerable weekly intake was derived using the lowest-observed-adverse-effect levels from a study showing developmental effects in male rat offspring following repeated subcutaneous administration of TCDD; applied uncertainty factor of 9.6.	European Commission 2001
WHO	1998	TDI = 1-4	Human daily intakes corresponding with body burdens similar to those associated with reproductive and developmental toxicity in animals estimated in the range of 14-37 pg/kg-bw/day. A composite uncertainty factor of 10 was recommended to achieve the TDI.	van Leeuwen <i>et al.</i> 2000
JECFA	2001	TDI = 2.3	Based on developmental and reproductive effects in rodents and monkeys (4 studies), and endometriosis in monkeys; applied uncertainty factor of 9.6	JECFA 2001
Health Canada	2005	TDI = 2.3	Based on JECFA/WHO TDI	Health Canada 2005
Japan	1999	TDI = 4	Based on WHO TDI	Japan Environmental Health Committee of the Central Environmental Council 1999
United Kingdom	2000	TDI = 2	Based on European Commission TDI	UK Committee on Toxicity 2000
Australia	2002	TDI = 2.3	Based on JECFA/WHO TDI	Australian NHMRC 2002
Nordic countries	2000	TDI = 5		Johansson and Hanberg 2000; IARC 1997; IOM 2003
Netherlands		TDI = 1		IARC 1997; IOM 2003
Sweden		TDI = 5		IARC 1997; IOM 2003
AEA Technology	1999	TDI = 1-4		IOM 2003
Fiedler <i>et al.</i>	2000	TDI = 1-4		IOM 2003

\* The USEPA has not established a reference dose for dioxin, but predicts that it would be 100-1,000 times lower than current background exposure levels. That theoretical reference dose is represented here as 0.001 pg-TEQ/kg-bw/day.

Uncertainty factors are applied when accounting for inter- and intra-species variations.

Adapted from: ARCC 2009.



#### 1.4.4 PCDD/F Levels in Human Blood and Breast Milk

Concentrations of PCDD/Fs in human tissue are on average higher in industrialized countries (~15 pg/g TEQ lipid) than in non-industrialized countries (below 10 pg/g TEQ lipid).

A study by Schechter *et al.* (2006) compared human tissue concentrations and toxic equivalents of dioxins and dibenzofurans from different countries and exposure scenarios; the following is a summary of key findings. In the US, fat tissues from the general population had an average TEQ of 22.8 pg/g, with TCDD contributions of 3.6 pg/g to the TEQ. People exposed to pentachlorophenol in the US exhibited higher TEQ levels (609 pg/g), mostly comprised of Penta-CDD, Hexa-CDDs and PCDFs. A pooled sample of human blood tested in Viet Nam revealed a TEQ of 13 pg/g (2.2 pg/g TCDD). The TEQ from people exposed to Agent Orange in Viet Nam was higher (111 pg/g) with TCDD contributing to a significant portion of the TEQ (101 pg/g). In Japan, the general population exhibited TEQ levels of 24.6 pg/g in blood with TCDD contributions of 2.6 pg/g to the TEQ. Incinerator workers in Japan had higher TEQ levels, averaging 1,467 pg/g and TCDD levels of 6.4 pg/g. PCDFs contributed to a majority of the TEQ (1,365 pg/g). In Austria, men with no or low occupational exposure to 2,3,7,8-TCDD had blood concentrations of <5 to 23 pg/g (IARC 1997). It is evident from these studies that occupational or accidental exposure can result in PCDD/F concentrations in humans above normal or background levels (Domingo *et al.* 2001; Hansson *et al.* 1995, 1997; Iida *et al.* 1999; Papke *et al.* 1992; Schechter *et al.* 1991; Park *et al.* 2009).



Source: Hatfield Consultants

The American Chemistry Council (ACC) (2003) calculated an acceptable exposure guideline for blood serum (lipid) based on the WHO's Tolerable Daily Intake guidelines. The serum lipid level corresponding to a chronic intake of 4 pg TEQ/kg bw/d (upper limit of WHO 1998 standard) is approximately 30 ppt, assuming a 25% body fat level and an absorption rate of 60% (ACC 2003). Aylward *et al.* (2008) provides health based exposure guidance values for 2,3,7,8-TCDD and related compounds from a variety of agencies, including WHO Joint Expert Committee on Food Additives (JECFA), the European Commission Scientific Committee on Food (ECSCF), the United Kingdom Committee on Toxicology (UKCOT), and the U.S. Agency for Toxic Substances and Disease Registry (ATSDR). They estimate the Biomonitoring Equivalent (BE) values (the concentration of toxins in serum lipid) that are consistent with existing health-based exposure guidelines (Table 1.8).

**Table 1.8 Biomonitoring Equivalent (BE) concentrations of human serum (lipid) based on existing health-based dioxin exposure guidelines from various agencies.**

Organization	Year	Criterion	Guideline TDI Equivalent Pg/kg/d	BE Concentration of Serum Lipid
WHO <sup>1</sup>	1998	Tolerable Daily Intake	1-4 pg/kg/d	10 – 30 ppt
JECFA <sup>2</sup>	2001	Provisional Tolerable Monthly Intake (PTMI) 70 pg/kg/mo	2.3 pg/kg/d	40 – 70 ppt
ECSCF <sup>2</sup>	2001	Tolerable Weekly Intake (TWI) 14 pg/kg/wk	2 pg/kg/d	42 – 74 ppt
UKCOT <sup>2</sup>	2001	Tolerable Daily Intake (TDI)	2 pg/kg/d	31 – 55 ppt
ATSDR <sup>2</sup>	1999	Minimal Risk Level (MRL) 1 pg/kg/d	1 pg/kg/d	15 ppt

<sup>1</sup> Adapted from American Chemistry Council (ACC) 2003.

<sup>2</sup> Adapted from Aylward et al. 2003.

For blood serum sample analysis presented in this report, the WHO 1998 upper limit value (30 ppt) is used to indicate exceedances.

2,3,7,8-TCDD in human tissue is estimated to have a half life of 7 to 11 years, with a wide individual variation (IARC 1997; Srogi 2008). If the source of dioxin is removed from the exposure pathway, dioxin concentrations decrease over time. Blood samples taken in Germany showed that PCDD/Fs dropped from an average of (lipid-based) 45,800 pg/g to 16,100 pg I-TEQ/kg from 1989 to 1996 (IARC 1997). The rate of decrease was slightly higher in rural areas than industrial areas.

The daily dioxin intake of breastfed babies are generally 1 to 2 orders of magnitude higher than adults (Jodicke *et al.* 1992; McLachlan 1993; Srogi 2008). Dioxin intake levels are generally higher in industrialized countries (10-35 pg



I-TEQ/g milk fat) than in developing countries (<10 pg I-TEQ/g milk fat), and in industrial areas than in rural areas. The intake levels in 2 month-old breast feeding infants was 106 pg I-TEQ/kg/day in rural areas and 144 pg I-TEQ/kg/day in industrial areas.

PCDD/Fs tend to be stored within fatty tissues, and as a result, the chemicals build up in breast tissue and milk during lactation (Jensen 1991; Srogi 2008). Breast feeding is predicted to contribute to a higher body burden of dioxin early in life, but not to an increased steady-state body burden when compared to the ingestion of 10 pg/kg bw/d from birth (Srogi 2008). The levels of PCDD/Fs in breast milk are lower when a mother is nursing her second child than when nursing the first child (Fürst *et al.* 1989; Kiviranta *et al.* 1998; Srogi 2008).

Studies have found a significant negative correlation between smoking and PCDD/F levels. Mothers who smoke actively or even passively have lower PCDD/F levels in their breast milk than mothers who do not smoke (Fürst *et al.* 1992; Srogi 2008). Therefore, age, smoking history, dietary habits and other factors must be accounted for when drawing conclusions about the influence of smoking on PCDD/F levels in breast milk (Uehara *et al.* 2006). Smoking is a source of carcinogens in its own right and therefore causes alternative health risks.



Interviewing a breast milk sample donor, Trung Dung, Bien Hoa, November 2010

Source: Hatfield Consultants

## **2.0 MATERIALS AND METHODS**

### **2.1 GENERAL**

All sampling activities conducted in the Bien Hoa 2010 study were undertaken in close collaboration with Office 33 and other Vietnamese authorities. Office 33 and local Bien Hoa authorities played critical roles in all aspects of project implementation, including data collection and overseeing the sampling program with Hatfield.

Sampling activities at Bien Hoa Airbase in 2010 were conducted under direct supervision of MND, who provided assistance to Hatfield with sampling program design, sample collection, demining, and security clearance. Hatfield followed instructions of MND personnel at all stages of the sampling program, and provided technical training on-site to build capacity of Office 33 and MND to conduct future dioxin sampling and mitigation activities. All field sampling activities, both at Bien Hoa Airbase and in the general Bien Hoa City population outside of the Airbase, were conducted in November 2010.

Health and Safety (H&S) of the Hatfield/Office 33/MND and other personnel working on the project was a critical component of all sampling activities, given the expected high levels of dioxin contamination and potential for unexploded ordnance (UXO) and landmines in the area. A deminer (from MND) pre-screened all sampling areas on land and aquatic ecosystems (e.g., Bien Hung Lake) for UXO and landmines prior to sample collection. Precautionary measures were taken to protect sampling personnel from exposure to highly contaminated soils and sediments present on the base. Protective clothing and gloves were worn during sampling to avoid direct skin contact with contaminated soil and sediment, and respirators were used as needed.

All sampling equipment were transported from Canada, including sampling jars, soil coring devices used for collecting samples, and the Ekman dredge; the only exception was acetone and hexane and stainless steel pans, which were acquired in Viet Nam. All soil and sediment samples collected in Bien Hoa were split into two batches: one set of samples was taken to Canada for analysis at AXYS Laboratory, and the other was left in Viet Nam for Office 33/MND. All fish tissue, blood, and breast milk samples were exported to Canada, due to the small volumes collected.

Soil and sediment sampling on the Bien Hoa Airbase focused on three main suspected hotspots: i) Pacer Ivy Area; ii) Southwest Corner of Airbase; and, iii) Z1 Area. Samples were also collected from northeastern, northern and southern perimeters of the Airbase, in order to gain a better understanding of general levels of contamination throughout the area. Fish samples were taken from lakes/ponds on and around the Airbase. Blood and breast milk sampling focused on members of the population at high risk, including Airbase workers and people deriving livelihoods and consuming fish from local lakes and aquaculture ponds.

In general, sampling procedures followed those previously developed and applied by Hatfield for Agent Orange dioxin assessment projects in Viet Nam (Hatfield/10-80 1998, 2000, 2006; Hatfield/Office 33 2007, 2009; and Hatfield/VRTC 2009). Standard operating procedures for all Hatfield field sampling programs were applied.

## **2.2 NUMBER AND TYPES OF ANALYSES PERFORMED**

Summaries of samples analyzed are presented in Table 2.1 to Table 2.3 inclusive. All soil and sediment samples collected were split into two batches at the time of collection, one for archiving in Viet Nam, and one for transport to Canada for analyses and archiving. A complete list of all samples is presented in Appendix A1. All samples were analyzed by AXYS in Canada, using analytical methods provided in Appendix A1.5.

Soil, sediment, fish, and human blood and breast milk samples (all samples) were analyzed for dioxins/furans using High Resolution Gas Chromatography/Mass Spectrometry (HR-GCMS). One soil sample (10VNBH701) and one sediment sample (10VNBH428) were analyzed for total organic carbon and particle size. Percent lipid (tissue samples) was analysed for fish, human blood and breast milk.

## **2.3 SAMPLING SITE SELECTION**

The location of 2010 Bien Hoa sampling sites is presented in Figure 2.1, Table 2.1 and Table 2.2.

Soil and sediment sampling locations were determined during a pre-field desktop review of existing topographic maps and remote sensing information available for the study area, in conjunction with historical sampling results from areas within and surrounding the Bien Hoa Airbase, and information provided by the US-DOD and VN-MND.

Environmental sampling density was highest in suspected key hotspot areas to provide sufficient data to allow dioxin concentration mapping of surface conditions. Dioxin concentration mapping was based on final environmental sample distribution and post-processing of analytical results, with sampling focus placed in the following order:

- Pacer Ivy Area (Southwest Corner of Runway);
- Z1 Area;
- Northeastern Perimeter;
- Southwest Corner of Airbase; and
- Northern and Southern Perimeter and Outside Airbase.

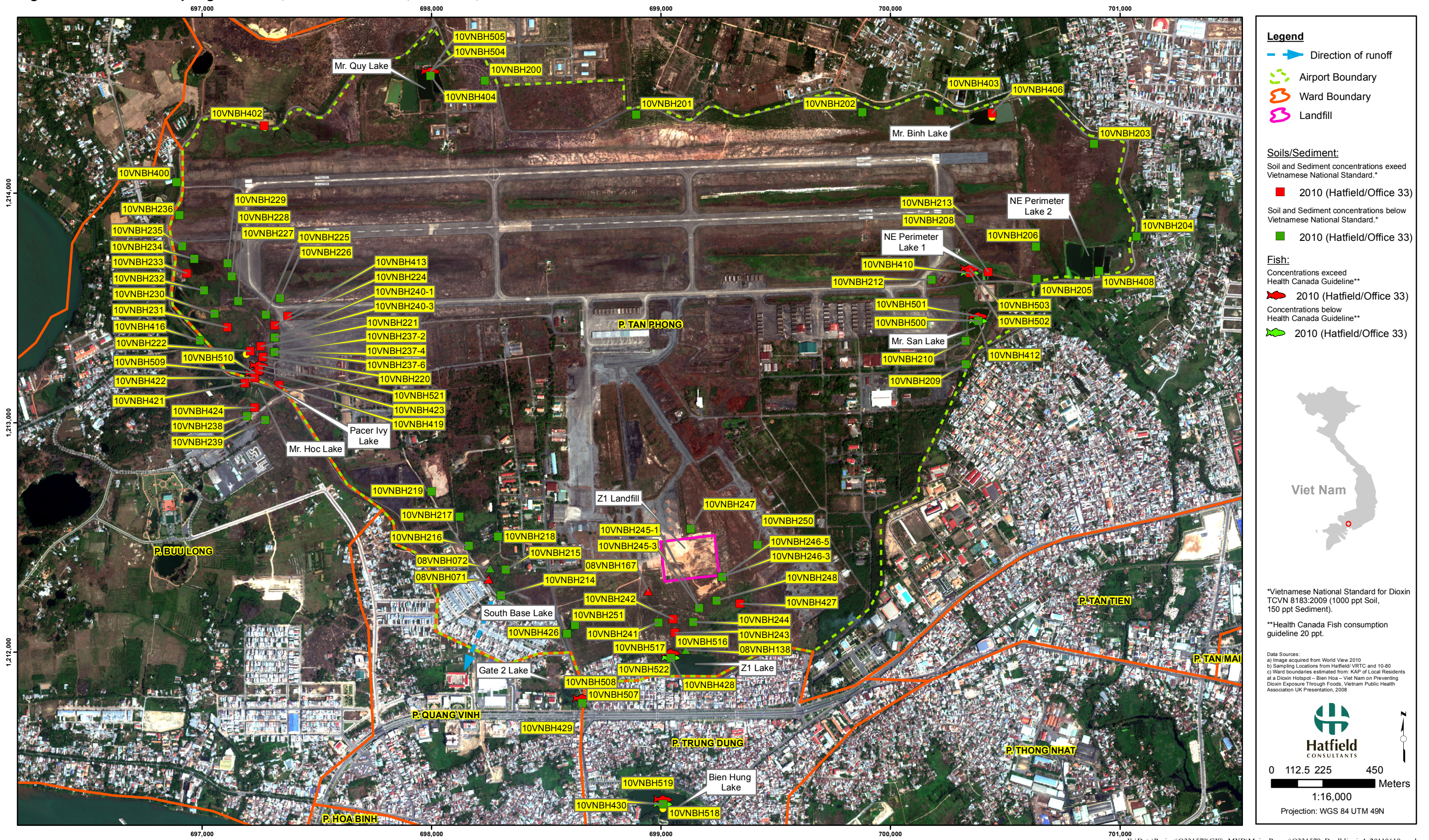
The study design included sampling sequentially on the Airbase from the least contaminated area (perimeter areas) to the most contaminated sites (Z1 area), to minimize potential of cross contamination. Onsite conditions were evaluated prior to the initiation of field sampling to ensure physical habitat variables were similar between sample sites. For sediment sampling, special consideration was given to water depth (primary) and substrate composition. Where possible, stations corresponded with historical dioxin/furan sampling locations (Hatfield/10-80 2006, Hatfield/VRTC 2009 and other Vietnamese MND studies).



Source: Hatfield Consultants



Figure 2.1 Dioxin sampling locations, Bien Hoa Airbase, Viet Nam, November 2010.



\*Vietnamese National Standard for Dioxin TCVN 8183:2009 (1000 ppt Soil, 150 ppt Sediment).  
\*\*Health Canada Fish consumption guideline 20 ppt.

Data Sources:  
a) Image acquired from World View 2010  
b) Sampling Locations from Hatfield VRTIC and 10-80  
c) Ward boundaries estimated from KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008





**Table 2.1 Soil and sediment samples analyzed for dioxins and furans, Bien Hoa, Viet Nam, November 2010.**

Sample ID	Date	Location	Media	Depth	Coordinates		Analysis PCDD/F
					Easting	Northing	
<i>Northern Perimeter</i>							
10VNBH200	2-Nov-10	N. Perimeter	Soil	0-15	698233	1214492	X
10VNBH201	2-Nov-10	N. Perimeter	Soil	0-15	698891	1214344	X
10VNBH202	2-Nov-10	N. Perimeter	Soil	0-20	699878	1214355	X
10VNBH203	2-Nov-10	N. Perimeter	Soil	0-20	700887	1214216	X
10VNBH400	2-Nov-10	N. Perimeter	Sediment	0-10	696889	1214049	X
10VNBH402	2-Nov-10	N. Perimeter	Sediment	0-50	697271	1214295	X
10VNBH403	2-Nov-10	N. Perimeter	Sediment	0-130	700214	1214362	X
10VNBH404	2-Nov-10	N. Perimeter	Sediment	0-50	697996	1214512	X
10VNBH406	2-Nov-10	N. Perimeter	Sediment	0-200	700442	1214351	X
10VNBH407	2-Nov-10	N. Perimeter	Sediment	0-10	700335	1214359	
<i>Bien Hoa City (Southern Perimeter)</i>							
10VNBH429	6-Nov-10	Gate 2 Lake	Sediment	0-20	698656	1211778	X
10VNBH430	6-Nov-10	Bien Hung Lake	Sediment	0-100	699009	1211337	X
<i>Northeastern Perimeter</i>							
10VNBH204	2-Nov-10	NE Perimeter	Soil	0-15	701073	1213812	X
10VNBH205	2-Nov-10	NE Perimeter	Soil	0-20	700637	1213628	X
10VNBH206	3-Nov-10	NE Perimeter	Soil	0-20	700634	1213768	X
10VNBH207	3-Nov-10	NE Perimeter	Soil	0-20	700574	1213752	
10VNBH208	3-Nov-10	NE Perimeter	Soil	0-10	700426	1213658	X
10VNBH209	3-Nov-10	NE Perimeter	Soil	0-20	700328	1213255	X
10VNBH210	3-Nov-10	NE Perimeter	Soil	0-20	700327	1213357	X
10VNBH211	3-Nov-10	NE Perimeter	Soil	0-20	700204	1213581	
10VNBH212	3-Nov-10	NE Perimeter	Soil	0-20	700179	1213623	X
10VNBH213	3-Nov-10	NE Perimeter	Soil	0-20	700345	1213889	X
10VNBH401	3-Nov-10	NE Perimeter	Sediment	0-2	696995	1214284	
10VNBH405	2-Nov-10	NE Perimeter	Sediment	0-150	697873	1214435	
10VNBH408	2-Nov-10	NE Perimeter	Sediment	0-20	700910	1213662	X
10VNBH409	2-Nov-10	NE Perimeter	Sediment	0-40	700839	1213761	
10VNBH410	3-Nov-10	NE Perimeter	Sediment	0-5	700347	1213652	X
10VNBH411	3-Nov-10	NE Perimeter	Sediment	0-30	700540	1213588	
10VNBH412	3-Nov-10	NE Perimeter	Sediment	0-120	700383	1213444	X
<i>SW Airbase</i>							
08VNBH071 <sup>1</sup>	1-Nov-08	SW Airbase	Soil	0-10	698247	1212318	X
08VNBH072 <sup>1</sup>	1-Nov-08	SW Airbase	Soil	0-10	698255	1212365	X
10VNBH214	3-Nov-10	SW Airbase	Soil	0-20	698303	1212248	X
10VNBH215	3-Nov-10	SW Airbase	Soil	0-10	698324	1212359	X
10VNBH216	3-Nov-10	SW Airbase	Soil	0-20	698162	1212463	X
10VNBH217	3-Nov-10	SW Airbase	Soil	0-10	698121	1212590	X
10VNBH218	3-Nov-10	SW Airbase	Soil	0-15	698290	1212503	X
10VNBH219	3-Nov-10	SW Airbase	Soil	0-15	697999	1212702	X
<i>Pacer Ivy</i>							
10VNBH220	4-Nov-10	Pacer Ivy	Soil	0-10	697264	1213287	X
10VNBH221	4-Nov-10	Pacer Ivy	Soil	0-10	697255	1213333	X
10VNBH222	4-Nov-10	Pacer Ivy	Soil	0-10	697210	1213313	X
10VNBH223	4-Nov-10	Pacer Ivy	Soil	5-10	697314	1213355	
10VNBH224	4-Nov-10	Pacer Ivy	Soil	0-10	697317	1213424	X
10VNBH225	4-Nov-10	Pacer Ivy	Soil	0-10	697277	1213471	X
10VNBH226	4-Nov-10	Pacer Ivy	Soil	0-15	697339	1213543	X
10VNBH227	4-Nov-10	Pacer Ivy	Soil	0-10	697157	1213531	X
10VNBH228	4-Nov-10	Pacer Ivy	Soil	0-10	697128	1213639	X
10VNBH229	4-Nov-10	Pacer Ivy	Soil	0-10	697111	1213696	X
10VNBH230	4-Nov-10	Pacer Ivy	Soil	0-15	697054	1213475	X
10VNBH231	4-Nov-10	Pacer Ivy	Soil	0-15	697109	1213416	X
10VNBH232	4-Nov-10	Pacer Ivy	Soil	0-10	697008	1213577	X

**Table 2.1 (Cont'd.)**

Sample ID	Date	Location	Media	Depth	Coordinates		Analysis PCDD/F
					Easting	Northing	
<i>Pacer Ivy (Cont'd.)</i>							
10VNBH233	4-Nov-10	Pacer Ivy	Soil	0-10	696933	1213651	X
10VNBH234	4-Nov-10	Pacer Ivy	Soil	0-15	696965	1213714	X
10VNBH235	4-Nov-10	Pacer Ivy	Soil	0-10	696913	1213770	X
10VNBH236	4-Nov-10	Pacer Ivy	Soil	0-10	696901	1213905	X
10VNBH237-1	4-Nov-10	Pacer Ivy	Soil	0-30	697315	1213308	
10VNBH237-2	4-Nov-10	Pacer Ivy	Soil	30-60	697315	1213308	X
10VNBH237-3	4-Nov-10	Pacer Ivy	Soil	60-70	697315	1213308	
10VNBH237-4	5-Nov-10	Pacer Ivy	Soil	60-90	697315	1213308	X
10VNBH237-5	5-Nov-10	Pacer Ivy	Soil	90-120	697315	1213308	
10VNBH237-6	5-Nov-10	Pacer Ivy	Soil	120-150	697315	1213308	X
10VNBH238	5-Nov-10	Pacer Ivy	Soil	0-10	697195	1213030	X
10VNBH239	5-Nov-10	Pacer Ivy	Soil	0-10	697274	1213012	X
10VNBH240-1	5-Nov-10	Pacer Ivy	Soil	0-30	697317	1213371	X
10VNBH240-2	5-Nov-10	Pacer Ivy	Soil	30-60	697317	1213371	
10VNBH240-3	5-Nov-10	Pacer Ivy	Soil	60-90	697317	1213371	X
10VNBH240-4	5-Nov-10	Pacer Ivy	Soil	90-120	697317	1213371	
10VNBH413	4-Nov-10	Pacer Ivy	Sediment	0-10	697374	1213466	X
10VNBH414	4-Nov-10	Pacer Ivy	Sediment	0-5	696945	1213599	
10VNBH415	4-Nov-10	Pacer Ivy	Sediment	0-50	696883	1213486	
10VNBH416	4-Nov-10	Pacer Ivy	Sediment	0-5	696990	1213359	X
10VNBH417	5-Nov-10	Pacer Ivy	Sediment	0-10	697552	1213182	
10VNBH418	5-Nov-10	Pacer Ivy	Sediment	0-5	697455	1213169	
10VNBH419	5-Nov-10	Pacer Ivy	Sediment	0-5	697336	1213164	X
10VNBH420	5-Nov-10	Pacer Ivy	Sediment	0-10	697245	1213146	
10VNBH421	5-Nov-10	Pacer Ivy	Sediment	0-10	697187	1213173	X
10VNBH422	5-Nov-10	Pacer Ivy	Sediment	0-10	697229	1213196	X
10VNBH423	5-Nov-10	Pacer Ivy	Sediment	0-10	697248	1213230	X
10VNBH424	5-Nov-10	Pacer Ivy	Sediment	0-20	697229	1213066	X
10VNBH425	5-Nov-10	Pacer Ivy	Sediment	0-10	697304	1212966	
<i>Z1 Area</i>							
08VNBH138 <sup>1</sup>	1-Nov-08	Z1 Area	Soil	0-10	699116	1212011	X
08VNBH167 <sup>1</sup>	1-Nov-08	Z1 Area	Soil	0-10	698937	1212266	X
10VNBH241	5-Nov-10	Z1 Area	Soil	0-15	698989	1212130	X
10VNBH242	5-Nov-10	Z1 Area	Soil	0-15	699053	1212143	X
10VNBH243	5-Nov-10	Z1 Area	Soil	0-15	699060	1212084	X
10VNBH244	5-Nov-10	Z1 Area	Soil	0-15	699140	1212131	X
10VNBH245-1	5-Nov-10	Z1 Area	Soil	0-30	699166	1212194	X
10VNBH245-2	5-Nov-10	Z1 Area	Soil	30-60	699166	1212194	
10VNBH245-3	5-Nov-10	Z1 Area	Soil	60-90	699166	1212194	X
10VNBH245-4	5-Nov-10	Z1 Area	Soil	90-120	699166	1212194	
10VNBH246-1	6-Nov-10	Z1 Area	Soil	0-30	699267	1212327	
10VNBH246-2	6-Nov-10	Z1 Area	Soil	30-60	699267	1212327	
10VNBH246-3	6-Nov-10	Z1 Area	Soil	60-90	699267	1212327	X
10VNBH246-4	6-Nov-10	Z1 Area	Soil	90-120	699267	1212327	
10VNBH246-5	6-Nov-10	Z1 Area	Soil	120-150	699267	1212327	X
10VNBH247	6-Nov-10	Z1 Area	Soil	0-10	699130	1212537	X
10VNBH248	6-Nov-10	Z1 Area	Soil	0-10	699242	1212224	X
10VNBH249	6-Nov-10	Z1 Area	Soil	0-10	699044	1212287	
10VNBH250	6-Nov-10	Z1 Area	Soil	0-10	699421	1212468	X
10VNBH251	6-Nov-10	Z1 Area	Soil	0-10	698625	1212117	X
10VNBH426	6-Nov-10	Z1 Area	Sediment	0-5	698590	1212081	X
10VNBH427	6-Nov-10	Z1 Area	Sediment	0-5	699344	1212211	X
10VNBH428	6-Nov-10	Z1 Lake	Sediment	0-20	699043	1211975	X

<sup>1</sup> Archived historical samples from 2008 analyzed during this program.

**Table 2.2 Fish tissue samples analyzed for dioxins and furans, Bien Hoa, Viet Nam, November 2010.**

Sample ID	Location	Date	Species*	Tissue Type (for fish)	Composite (n)	Sample weight (g)	Average Length of Fish (cm)	Standard Deviation	Average Weight of Fish (g)	Standard Deviation	Coordinates		Analysis	
											Easting	Northing	PCDD/F	Lipid
10VNBH 500	Mr. San Lake	3-Nov-10	Tilapia	Muscle	6	50	22.1	3.3	254.7	103.5	700383	1213444	X	X
10VNBH 501	Mr. San Lake	3-Nov-10	Tilapia	Fat	6	7	22.1	3.3	254.7	103.5	700383	1213444	X	X
10VNBH 502	NE Perimeter Lake	3-Nov-10	Tilapia	Muscle	6	43	20.4	1.5	181.5	32.1	700347	1213652	X	X
10VNBH 503	NE Perimeter Lake	3-Nov-10	Tilapia	Fat	6	6	20.4	1.5	181.5	32.1	700347	1213652	X	X
10VNBH 504	Mr. Quy Lake	4-Nov-10	Tilapia	Muscle	3	42	24.2	2.0	304.0	95.0	697996	1214512	X	X
10VNBH 505	Mr. Quy Lake	4-Nov-10	Tilapia	Fat	3	5	24.2	2.0	304.0	95.0	697996	1214512	X	X
10VNBH 506	Mr. Binh Lake	3-Nov-10	Butterfish	Muscle	6	37	23.5	2.6	280.3	68.0	700442	1214351		
10VNBH 507	Gate 2 Lake	4-Nov-10	Tilapia	Muscle	5	5	23.5	2.6	280.3	68.0	698656	1211778	X	X
10VNBH 508	Gate 2 Lake	4-Nov-10	Tilapia	Fat	5	237.0	9.0	0.5	15.8	1.7	698656	1211778	X	X
10VNBH 509	Mr. Hoc Lake	4-Nov-10	Tilapia	Muscle	3	36	13.9	0.9	59.6	12.1	697229	1213196	X	X
10VNBH 510	Mr. Hoc Lake	4-Nov-10	Tilapia	Fat	3	3	13.9	0.9	59.6	12.1	697229	1213196	X	X
10VNBH 511	Mr. Hoc Lake	4-Nov-10	Tilapia	Eggs	3	199.0	10.6	1.6	24.9	9.4	697229	1213196		
10VNBH 512	Gate 2 Market	5-Nov-10	Tilapia	Muscle	3	35	17.1	5.4	117.0	119.8	*	*	X	X
10VNBH 513	Gate 2 Market	5-Nov-10	Tilapia	Fat	3	7	17.1	5.4	117.0	119.8	*	*	X	X
10VNBH 514	Bien Hoa Market	5-Nov-10	Tilapia	Muscle	2	52	32.2	1.2	899.3	73.4	*	*	X	X
10VNBH 515	Bien Hoa Market	5-Nov-10	Tilapia	Fat	2	60	32.2	1.2	899.3	73.4	*	*	X	X
10VNBH 516	Z1 Lake	5-Nov-10	Tilapia	Muscle	13	38	30.3	1.8	557.0	28.3	699043	1211975	X	X
10VNBH 517	Z1 Lake	5-Nov-10	Tilapia	Fat	13	41	30.3	1.8	557.0	28.3	699043	1211975	X	X
10VNBH 518	Bien Hung Lake	6-Nov-10	Tilapia	Muscle	2	43	32.3	0.4	638.0	8.5	699009	1211337	X	X
10VNBH 519	Bien Hung Lake	6-Nov-10	Tilapia	Fat	2	1	32.3	0.4	638.0	8.5	699009	1211337	X	X
10VNBH 520	Bien Hung Lake	6-Nov-10	Tilapia	Eggs	2						699009	1211337		
10VNBH 521	Pacer Ivy Lake	4-Nov-10	Tilapia	Whole Fish	15						697248	1213230	X	X
10VNBH 522	Z1 Lake	4-Nov-10	Tilapia	Whole Fish	8						699043	1211975	X	X

\* Samples collected from local markets; original source unknown.



## 2.4 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Quality assurance sample collections were undertaken at a generally accepted rate of 10% of total samples. Three water rinseate samples consisted of analyte-free water passed through/over a pre-cleaned, decontaminated sampling device; these samples provided information of potential cross-contamination related to field sampling equipment, and are representative of the procedure used for the decontamination between all samples (Table 2.3).

**Table 2.3 Additional analyses (rinseate water) collected for analysis, Bien Hoa, Viet Nam, November 2010.**

Sample ID	Comments	Media	Analysis PCDD/F
10VNBH703	Taken at the start of the program	Water	
10VNBH706	Taken at the middle of the program	Water	X
10VNBH712	Taken after completion of sampling on the Airbase	Water	X

Field duplicates were collected from the same sampling location as the original sample, collected consecutively, and using identical procedures. Three (3) soil field duplicates and 1 sediment field duplicate were collected during the November 2010 sampling event. The field duplicates are intended to measure the “total system” variability from both the environment and laboratory, including the variability component resulting from the inherent environmental heterogeneity. Laboratory duplicates (1 fish tissue sample and 5 soil samples) were selected randomly from the sample batch to provide information on method precision and sample heterogeneity.

Two trip blanks of laboratory-provided clean sand were shipped to and from Viet Nam in the coolers with the samples, without being opened during the sampling event. Trip blanks are used to assess cross-contamination of target analytes within the coolers during shipment.

To ensure samples are not contaminated during the collection process, a number of sampling procedures were incorporated:

- Disposable latex gloves were used to handle all samples and specimens; gloves were changed between samples and specimens;
- All sampling equipment that comes in direct contact with samples was constructed of stainless steel;
- All stainless steel equipment (dissection trays, scalpels, forceps, calipers, etc.) was rinsed in ambient water, triple rinsed with reagent grade hexane and triple rinsed with reagent grade acetone, before each use and between sample collections (see equipment decontamination below);

- All dioxin samples were placed in 60 mL heat treated, wide-mouth jars provided to AXYS and transported to Viet Nam by Hatfield;
- Sample jars were pre-labelled, cross-referenced to field sheets, stored in a cool/dark area, and where feasible, transported to freezer facilities within two hours of collection (cold storage was limited to biological media);
- Any tools or gloved areas that came in direct contact with skin or external organs of sampled animals were not permitted to touch internal tissues; any tissue suspected of being contaminated in this manner was discarded;
- Duplicate soil and sediment samples were collected at all sampling stations; duplicates were provided to Office 33. Given the volume restrictions, only one blood and breast milk sample per person, and one batch of fish tissue samples were to be collected and exported to Canada - duplicates were not collected;
- The location of each sampling station was recorded using a hand-held GPS and still photography to ensure repeatability in future sampling programs;
- Detailed records of the name of the owners of local farms, fields, fish ponds, and animals sampled were collected where possible. This information was collected through interviews with local residents; and
- Smoking was not permitted in the vicinity of sampling activities.

## **2.5 SAMPLING METHODOLOGY**

All soil and sediment sampling was conducted in a similar manner to previous Hatfield programs in Viet Nam (Hatfield/10-80 1998, 2000, 2003, 2006; Hatfield/Office 33 2007, 2009; Hatfield/VRTC 2009; Dwernychuk *et al.* 2002). All soil and sediment sampling sites were screened for UXO in advance of samples being collected.

A permit from the Canadian Food Inspection Agency was required for importing samples to Canada; a permit was also required to export samples from Viet Nam (see Appendix A2).

### **2.5.1 Surface Sediment Sampling Protocol**

Surface sediment samples were collected using a 6x6" stainless steel Ekman grab or from near-shore using a stainless steel spoon. Each sample consisted of a single grab. The top 5-10 cm of sediments were collected at each site. Photos were taken at each station to record sampling procedure, sediments and shoreline.

### Detailed Ekman sample collection procedure:

1. Clean sampling equipment using techniques outlined Section 2.4;
2. Collect sample;
3. Bring sampler grab up and set in the cleaned stainless steel sampling tray (or scoop sediments directly into tray);
4. Lift lids to reveal top of sample;
5. Drain excess overlying water in dredge;
6. Spoon top layer (5-10 cm) into stainless pan and set aside;
7. Discard remainder of grab;
8. Complete soil observations + photograph sample;
9. Thoroughly mix sample in stainless steel pan;
10. Spoon sample directly from Ekman to sample containers;
11. Fill appropriate sample jars (dioxin); and
12. Fill out station details on sediment data sheet (Appendix A2).

### 2.5.2 Soil Sampling Protocol

All soil sampling was conducted in a similar manner to previous Hatfield programs in Viet Nam (e.g., Hatfield/Office 33 2009). Soil sampling at a depth of 0-10 cm below ground surface (bgs) was conducted with the exception of four depth profiles (Samples 10VNBH237, 10VNBH240, 10VNBH245, and 10VNBH246), which were conducted to a maximum depth of 180 cm.

Soil sampling protocols were similar to the sediment sampling methodology with one exception – each soil sample consists of a composite of 10-subsamples. Soil samples were collected using a stainless steel soil corer in softer ground, and stainless steel digging instruments (e.g., spade, chisel) in harder ground.

Each soil sample utilized a standardized area coverage and spacing system, as follows:

- 5 x 5 m square plot; and
- 10 evenly-spaced sampling points within the plot identified to be UXO free by the VN-MND.

All ten sub-samples from each plot were transferred to a clean stainless steel tray, homogenized with a clean stainless steel spoon, and transferred to a laboratory-supplied sample jar. The soil data sheet was filled in with details about the site (Appendix A2).

In order to conduct soil sampling at different depths, personnel from MND carried out pit excavations. The sample collection personnel then entered the pits, and exposed an undisturbed area on the face of the pit from which the final

sample was collected. Depth of each sample was measured from the surface at uncapped sites, and from the bottom of concrete at sample sites located on the concrete tarmac. Six samples were collected from each pit, at the following intervals: (1) 0-30cm, (2) 30-60 cm, (3) 60-90 cm, (4) 90-120 cm, (5) 120-150 cm, and, (6) 150-180 cm.

### **2.5.3 Fish Tissue Sampling Protocol**

Nile Tilapia (*Oreochromis niloticus niloticus*; cà rô phi) were sampled from Bien Hung Lake, Z1 Lake, and other privately-owned lakes and ponds inside and outside the Airbase. Fish sampling was also conducted in Bien Hoa Market and Gate 2 Market, as these are the key locations where fish are purchased by the local population of Bien Hoa City. It is likely that fish purchased from the market originated from Dong Nai River aquaculture ponds, but the exact location is unknown.

Only fish visually certified as being captured in target water bodies on Bien Hoa Airbase and City lakes were collected and analyzed (with the exception of market fish). Fish were captured by local residents using traditional fishing techniques (i.e., netting or hook and line). Captured fish were dissected on-site within two hours of capture; fish were kept cool on ice packs or frozen in cases when dissection took place more than 6 hours after capture.

Muscle tissues (skin removed) were collected from the left side of each fish, above the lateral line, and between the dorsal and caudal fins. Liver tissue samples (entire livers removed from each specimen), fish fat (collected from the viscera), and on occasion fish roe (eggs) were collected. Tissue samples were placed in individual jars for each type of tissue, and frozen immediately after dissections were completed.

A fish sampling field data sheet was filled out for each specimen. This record documented fork length (mm), whole weight (g), sex (visual inspection of gonads), internal and external fish health, and organ (liver and gonad) weight (g) (Appendix A2).

### **2.5.4 Human Blood Sampling Protocol**

Human blood and breast milk sampling was undertaken according to protocols employed in previous Hatfield/10-80 Division/Office 33 investigations in Viet Nam (Hatfield/10-80 1998, 2000, 2003, 2006; Hatfield/Office 33 2007, 2009). Hatfield personnel supervised all sample collections, and followed internationally-accepted protocols to ensure consent of donors in advance (see Section 2.5.6).

Prior to the blood sampling, a detailed questionnaire survey of each potential donor was conducted to ensure they were eligible donors (Appendix A3). Information included age, sex, family history, general health, work history, smoking habits, food consumption patterns and awareness on the dioxin issue.

A total of 42 blood samples were collected, and serum was analyzed from all eligible donors. A number of individuals refused to provide a sample, or did not appear at the medical clinic to provide samples on the date prescribed. Three (3) volunteer donors were not sampled, as they were suffering from Hepatitis B and/or anaemia at the time of sampling. Trained medical staff from the Medical Clinics in Bien Hoa Airbase, National Psychiatric 2 Hospital Training Center, and Family Medical Clinics collected individual blood samples using a syringe and 10-mL glass vacutainers, and was supervised by Thomas Boivin of Hatfield. A target volume of 80 mL (10 vacutainers) were collected from each person. All blood collection equipment was imported from Canada.

Whole blood samples were kept cool on ice packs during the sampling procedure. After collection, blood was allowed to clot at room temperature for a period of 30 minutes to 2 hours, and centrifuged for 15 minutes at 2400 rpm to separate the clear serum from red blood cells. The clear serum was separated from red cells through centrifugation, and transferred to two 40 mL glass bottles using a pipette. The bottles were stored in freezers until they were shipped to AXYS Laboratory in Canada.



Source: Hatfield Consultants

Blood samples were collected from males (N = 37) and females (N = 5) who are currently working within Bien Hoa Airbase premises or had worked there in the past. They engage in a range of livelihoods, including working for MND, raising animals, fishing and aquaculture, growing vegetables, and serving as airport workers. All of the sampled donors currently reside in Tan Phong Ward or Trung Dung Ward. Most of the sampled donors reside in Tan Phong Ward located inside the Airbase perimeter. Population density in this ward was lower compared to outside of the Airbase. The inhabitants are concentrated to the west of the Pacer Ivy area, the southwestern perimeter, and near the southeastern end of the runway. Trung Dung Ward is located outside the Airbase, to the south of the highly contaminated Z1 Area. The area is densely populated, and a number of ponds, lakes and other aquatic habitats are located in this area. At present, these ponds and lakes are used for fish and vegetable cultivation. Prior to the implementation of remediation efforts at the Airbase, rainwater carried residual herbicides stored or spilled from the Z1 Area, including dioxins, into these ponds and lakes; contaminated water eventually flowed into the Bien Hung Lake located within Trung Dung Ward.

### **2.5.5 Human Breast Milk Sampling Protocol**

Twenty-two (22) breast milk samples were collected from volunteer donors: 18 from Trung Dung Ward, 2 from Tan Phong Ward, 1 from Tan Tien Ward, and 1 from Hoa An Ward. Volunteer patients were asked to donate 15 to 50 cc of breast milk; milk was manually extruded by each individual mother, with assistance of a medical professional (if needed), directly into the sample jar. Sampling was conducted at the Trung Dung Medical Clinic, Bien Hoa City.

### **2.5.6 Questionnaire and Consent Form Protocol**

Human tissue sampling was performed on a volunteer basis and followed internationally-accepted protocols to ensure consent of donors. Prior to human tissue sampling, a detailed survey of each potential donor was conducted. All donors signed consent forms in advance of completing detailed questionnaires (Appendix A3); both consent forms and questionnaires were translated into Vietnamese language, and were presented through Vietnamese translators.

Socioeconomic data collection, completion of questionnaire surveys, and human donor screening was conducted by Office 33 and Hatfield in November 2010.

Questionnaire design was adapted from the format used for the University of Michigan Dioxin Study; pre-approval for Hatfield to use the Michigan questionnaire as a model was previously provided by Dr. Alfred Fransblau. Extensive information was collected from each patient in advance of blood/milk sampling, including age, sex, family history, general health, work history, smoking habits, food consumption patterns, and awareness on the dioxin issue. Each volunteer donor was interviewed by the Hatfield/Office 33/MOH/Bien Hoa Health Department staff to determine name, age and personal medical history.

## 2.6 LABORATORY HANDLING REQUIREMENTS

Table 2.4 provides a summary of laboratory sample requirements for the Bien Hoa dioxin sampling program.

**Table 2.4 Typical sample sizes, sample storage, and sample receipt requirements for PCDD/F analysis.**

<b>Matrix</b>	<b>Sample Size (per analysis)</b>	<b>Sample Container</b>	<b>Condition Upon Receipt</b>	<b>Storage Conditions</b>
Solid (Sed/Soil)	10 g dry	Glass	<4°C, dark	<-10°C, dark
Fish (& Crab Tissue)	10 g wet	Glass or foil wrapped	<4°C, dark	<-10°C, dark
Aqueous (water)	1 L	Amber Glass	0 - 4°C	0 - 4°C, dark
Blood	80 mL	Glass	<4°C	<-10°C, dark
Milk	50 – 80 mL	Glass	<4°C	<-10°C, dark

Source: AXYS.

All samples were kept cool (4°C), or frozen (for sediments, sufficient airspace was left in the jars to prevent breakage upon freezing). Samples were exported to Canada immediately after completion of the field program. Canadian and international shipping/handling protocols for samples were employed. Hatfield personnel transported the samples back to Canada with them upon departure from Ho Chi Minh City. This was essential to ensure QA/QC and proper chain-of-custody of the samples. Samples were transferred immediately to freezer facilities at Hatfield upon arrival in Vancouver, and then shipped to AXYS Analytical Laboratories in Sidney (British Columbia), within 48 hours of arrival in Canada. Laboratory analytical methods used in this study are provided in Appendix A1.5.

## 2.7 HEALTH AND SAFETY

Health, safety, and security of Hatfield and Vietnamese personnel working on the project were top priorities. Extensive measures were taken to protect project workers from exposure to toxic contamination, landmines and UXO, and to ensure safety in all day-to-day fieldwork activities.

Demining personnel from MND accompanied Hatfield staff to all sites and screened all sampling sites for UXO prior to collection of soils/sediments on the Bien Hoa Airbase.

Utmost caution was taken to protect sampling personnel from direct exposure to highly contaminated soils present on the base. Protective clothing, gloves, soap, and water were kept on hand to limit direct skin contact with sediment and soil.

## 2.8 STATISTICAL METHODS

Several statistical techniques were used to test for patterns in dioxin concentrations and life history traits. Data were first assessed visually to

determine potential relationships and check for outliers and data entry errors. Data were then checked for normality both graphically and using the Shapiro-Wilks test for normality. The  $\alpha$  (“alpha”, or significance) level was set at 0.01 for all statistical tests. If the data were found to be not normal, they were log-transformed and re-assessed. If data were not normal following transformation, the equivalent nonparametric statistical tests were used. Some statistical tests also required that the variances of groups being compared must not be statistically different. The Bartlett’s test was applied in these cases in order to ensure the data met the assumptions of the test.

Three types of comparisons were used in this study. First, when the dioxin concentrations of two groups were being compared (for example, comparing dioxins between males and females) a t-test was used. When the data were not normal, the equivalent Mann-Whitney U test was employed. Secondly, an ANOVA (or equivalent nonparametric Kruskal-Wallis test) was used to compare dioxin concentrations of more than two groups. A correlation test (or equivalent nonparametric Spearman’s correlation test) was used to compare relationships between variables, for example serum dioxin concentrations and the number of years individuals worked on the Airbase. This test produces a correlation coefficient that may or may not be significant. If it is significant, this correlation coefficient describes the strength of the correlation. A coefficient of 1 indicates that the variables co-vary, a coefficient of 0 indicates no covariance, and -1 indicates the variables vary in directly opposite directions. These three tests (t-test, ANOVA and correlation) produce a p-value that is compared with the  $\alpha$  level to determine significance. If the p-value is less than the  $\alpha$  level, the test is significant, and if it is equal or greater, the test is not significant.



Source: Hatfield Consultants



## **3.0 RESULTS AND DISCUSSION**

### **3.1 SOIL AND SEDIMENT**

Soil and sediment samples were screened against the Vietnamese Dioxin Threshold in Soil and Sediment (National Standard TCVN 8183:2009). The guideline for soil in “dioxin heavily contaminated sites” is 1,000 pg/g TEQ; the sediment guideline is 150 pg/g TEQ. Soil and sediments samples collected from all areas of the Airbase exhibited TCDD and TEQ concentrations exceeding the Vietnamese acceptable standards. Soil and sediment samples analyzed from the 2010 sampling locations in the Pacer Ivy Area generally exhibited higher levels of dioxin contamination than those collected from other areas of the Airbase.

#### **3.1.1 Pacer Ivy Area**

Investigation of the Pacer Ivy area was recommended by the US DOD (2007), given its historical use as herbicide storage and redrumming location. This area, located to the south-west of the Bien Hoa Airbase, close to the present runway (Figure 3.1), was first sampled during 2008 (Hatfield/VRTC 2009). The current study was the second sampling program conducted in this area of the Bien Hoa Airbase. Sampling sites covered an area of 150,000 m<sup>2</sup>, including a concrete yard; southwest of the concrete yard is a buffer zone, sloping to surrounding drainage ditches, small creeks and ponds. Fish and ducks are raised and harvested in man-made ponds in this area.

At the Pacer Ivy site, 42 soil and sediment samples were collected in 2010 and 30 (23 soil; 7 sediment) samples were analysed by AXYS, including 2 duplicate samples for QA/QC. Analytical results from AXYS are presented in Table 3.1.

Analyses indicated that eight (8) of the 23 soil samples exhibited TCDD and TEQ concentrations exceeding the Vietnamese standard for soil dioxin (1000 ppt). The highest dioxin concentration was recorded in sample 10VNBH237-2 taken immediately west of the concrete yard, at a depth of 30 to 60 cm below the surface; the sample exhibited a TCDD concentration of 61,400 ppt and a TEQ of 61,800 ppt. TCDD accounted for 99.4% of the TEQ, indicating Agent Orange as the source of contamination at this site. Soil samples taken at different depths at the same site exhibited lower TEQ concentrations (34.2 ppt at 60-90cm and 52.9 at 120-150 ppt cm below surface). The highest dioxin level recorded in soil at the Pacer Ivy area during the sampling program in 2008 (Hatfield/VRTC 2009) was also found in a surface soil sample (08VNBH105) collected very close to the 10VNBH237-2 sample; this 2008 sample had 22,300 ppt TCDD, 22,800 ppt TEQ, and 97.8% TCDD of TEQ (Hatfield/VRTC 2009).

The second highest dioxin concentration was recorded in sample 10VNBH220, collected to the west of the concrete yard. This sample exhibited 7,530 ppt TCDD, 7,550 ppt TEQ, and 99.7% TCDD of TEQ. Six (6) other soil samples collected from the Pacer Ivy Area also exceeded the Vietnamese soil dioxin standard, and ranged from 1,120 to 3,990 ppt TEQ. Proportions of TCDD in TEQ in these samples were all greater than 97%, clearly indicating significant Agent Orange contamination in this area. The remaining 15 soil samples collected from this area exhibited lower levels of contamination, ranging between 0.836 ppt TEQ (10VNBH238) and 346 ppt TEQ (10VNBH236).

**Table 3.1 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in the Pacer Ivy Area soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa Airbase, Viet Nam, November 2010.**

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2 DL	TEQ (WHO 2005) ND=1/2 DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
10VNBH220	4-Nov-10	Soil	0-10	7530	7900	150	363	270	829	78.1	863	865	119	22.8	28.7	7550	7550	99.7
10VNBH221	4-Nov-10	Soil	0-10	3940	4180	172	250	373	1830	211	950	757	85.4	42.3	30.7	3990	3990	98.7
10VNBH222	4-Nov-10	Soil	0-10	2620	2870	259	291	467	1870	153	1090	1200	87.6	55.1	35	2700	2700	97.0
10VNBH224	4-Nov-10	Soil	0-10	1090	1220	247	412	542	1930	112	389	419	13.2	24.5	58	1120	1120	97.3
10VNBH225	4-Nov-10	Soil	0-10	99.1	106	6.56	21.8	64	274	8.66	41	46.1	8.25	4.08	NDR 7.37	104	104	95.3
10VNBH226	4-Nov-10	Soil	0-15	5.81	5.81	< 0.928	3.77	28.3	170	1.39	1.69	2.41	< 0.928	< 0.928	NDR 5.85	7.2	7.13	81.5
10VNBH227	4-Nov-10	Soil	0-10	5.5	5.5	< 0.975	< 0.975	26.8	145	< 1.02	< 0.975	< 0.975	< 0.975	< 0.975	NDR 4.63	6.8	6.73	81.7
10VNBH228	4-Nov-10	Soil	0-10	49.4	49.4	10.4	94.7	517	2690	8.09	23	6.76	18.9	39.2	43.2	56.1	56.4	87.6
10VNBH229	4-Nov-10	Soil	0-10	7.97	7.97	< 0.794	19.6	112	513	1.27	2.27	0.938	1.51	10.6	14.2	9.67	9.69	82.2
10VNBH230	4-Nov-10	Soil	0-15	83.9	83.9	1.53	31.9	70.2	326	11.7	26.8	26.8	3.68	< 0.975	NDR 23.7	86.9	86.7	96.8
10VNBH231	4-Nov-10	Soil	0-15	1300	1440	41.2	41.1	33	141	44.7	307	178	23.9	3.51	2.68	1310	1310	99.2
10VNBH232	4-Nov-10	Soil	0-10	62.4	80.9	16.3	22.3	28.7	196	2.48	15.9	15.7	3.7	3.32	4.22	65.8	65.8	94.8
10VNBH233	4-Nov-10	Soil	0-10	3000	3250	200	243	242	1170	213	646	642	115	78.2	60.4	3070	3070	97.7
10VNBH234	4-Nov-10	Soil	0-15	1.87	2.63	1.43	7.45	57.4	255	NDR 0.157	1.86	1.09	0.154	2.7	2.12	2.75	2.79	67.0
10VNBH235	4-Nov-10	Soil	0-10	2.76	4.16	1.78	10.5	42.7	247	0.334	12.7	2.82	3.2	5.2	6.76	3.86	3.86	71.5
10VNBH236	4-Nov-10	Soil	0-10	336	349	78.8	< 4.91	< 5.16	544	32.7	121	132	7.96	12.2	NDR 27.9	346	346	97.1
10VNBH237-2	4-Nov-10	Soil	30-60	61400	64800	1730	1840	1030	1910	798	8300	6000	962	157	53.7	61800	61800	99.4
10VNBH237-4	5-Nov-10	Soil	60-90	30.9	30.9	< 3.03	< 2.32	< 2.30	NDR 23.4	< 2.59	2.82	< 2.88	< 3.78	< 3.31	< 4.26	34.5	34.2	90.4
10VNBH237-6	5-Nov-10	Soil	120-150	48.6	48.6	< 4.13	< 4.18	< 2.86	NDR 22.1	< 3.16	< 3.16	< 3.69	< 4.14	< 2.91	NDR 5.67	53.3	52.9	91.9
10VNBH238	5-Nov-10	Soil	0-10	0.264	0.536	0.343	6.12	25	172	0.168	4.63	2.58	2.98	4.36	4.14	0.874	0.836	31.6
10VNBH239	5-Nov-10	Soil	0-10	5.83	8.68	7.99	61.1	366	1980	1.38	28.5	17.8	27.2	39.1	35.1	11.6	11.7	49.8
10VNBH240-1	5-Nov-10	Soil	0-30	2310	2440	128	202	307	533	206	508	486	33.4	< 3.44	NDR 12.0	2340	2340	98.7
10VNBH240-3	5-Nov-10	Soil	60-90	< 2.20	< 2.20	< 2.96	< 2.30	< 3.27	NDR 9.17	< 2.18	< 2.18	< 3.06	< 4.03	< 3.71	< 3.14	4.74	4.4	NC
10VNBH413	4-Nov-10	Sediment	0-10	665	721	58.8	153	297	969	29.3	123	126	40.9	35.2	20.7	676	675	98.5
10VNBH416	4-Nov-10	Sediment	0-5	30.9	33.1	5.95	4.36	26.5	73.8	< 1.23	1.97	6.38	< 0.401	< 1.48	NDR 2.59	32.2	32.1	96.3
10VNBH419	5-Nov-10	Sediment	0-5	586	638	50	244	879	4370	29.4	223	232	110	165	141	605	605	96.9
10VNBH421	5-Nov-10	Sediment	0-10	605	643	33.9	209	872	4160	97.1	274	202	95.8	61.2	118	627	628	96.3
10VNBH422	5-Nov-10	Sediment	0-10	1710	1780	98.4	415	1560	7200	89.4	541	428	191	274	226	1770	1770	96.6
10VNBH423	5-Nov-10	Sediment	0-10	605	639	11.3	46.2	208	428	NDR 50.4	126	151	8.83	< 3.70	< 4.05	622	622	97.3
10VNBH424	5-Nov-10	Sediment	0-20	50	3490	4400	5930	4660	3500	598	28900	32600	26800	14400	2730	2490	2020	2.5

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

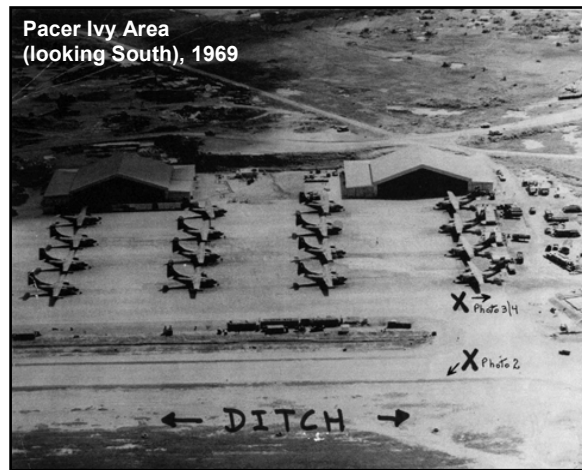
The soil depth profile samples indicated higher TCDD levels in the surface layers (2,310 ppt at 0-30 cm in 10VNBH240-1; 61,400 ppt at 30-60 cm in 10VNBH237-2), but much lower contamination at >60 cm depth (Figure 3.1). Samples immediately west of the concrete yard exhibited higher TCDD concentrations, while samples west of the runway had lower concentrations.

Sediment samples collected from various lakes and ponds in the Pacer Ivy area also indicated high levels of contamination. Six (6) of the seven (7) sediment samples collected had TEQ concentrations exceeding the Vietnamese standard for sediments (150 ppt). The highest dioxin level was recorded in a sediment sample (10VNBH424) collected from a lake located just outside the Airbase boundary (2,020 ppt TEQ). TCDD (50 ppt) only accounted for 2.5% of the TEQ in this sample; other contaminants (particularly 2,3,4,7,8-PCDF and 1,2,3,7,8-PCDD) also contributed to the total TEQ in this sample.

High dioxin levels were also detected in sediment sample 10VNBH422 collected near the Airbase boundary (1,710 ppt TCDD, 1,770 ppt TEQ; 96.6% TCDD of TEQ). Four (4) sediment samples collected from sites around the concrete yard

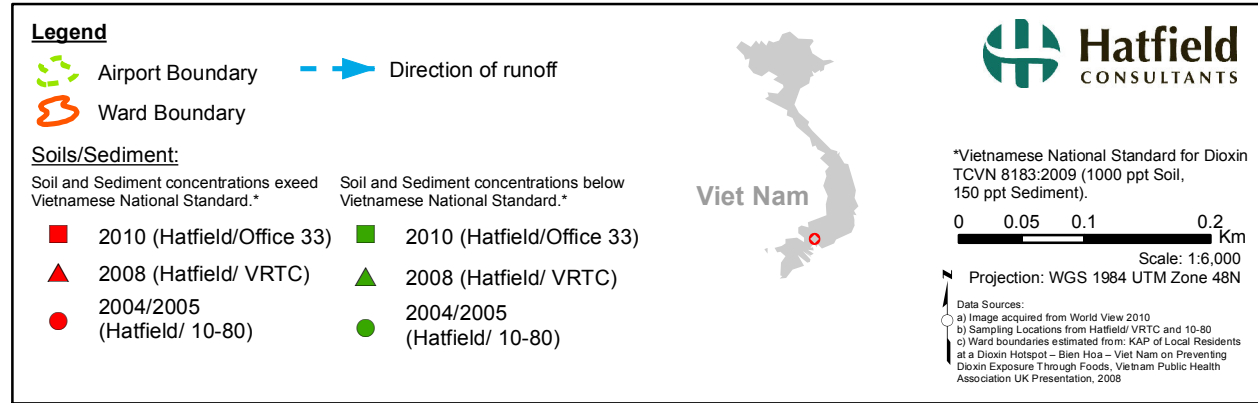
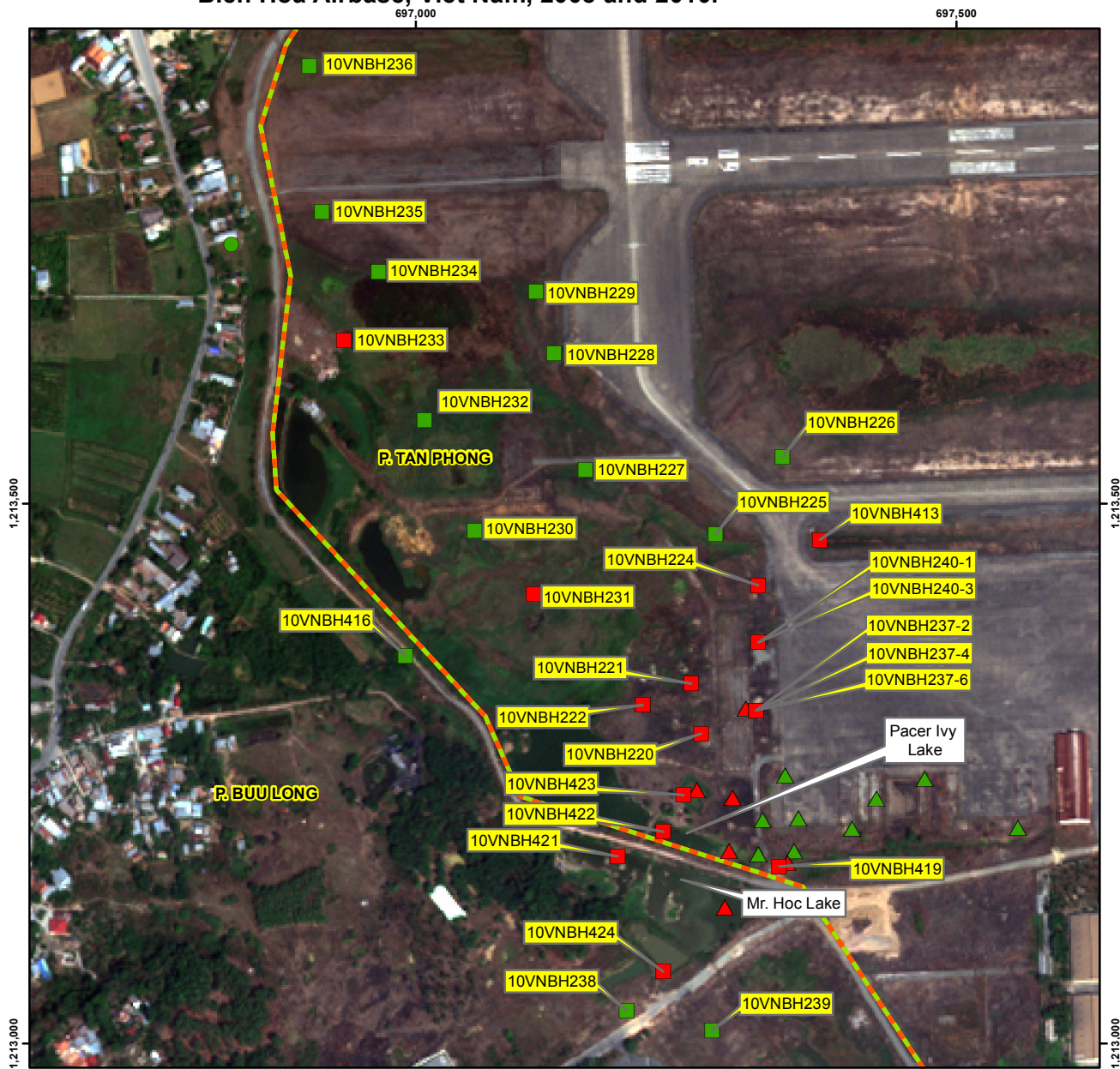
exhibited TCDD concentrations ranging between 605 ppt and 675 ppt. One sediment sample (10VNBH416) collected from outside the Airbase perimeter adjacent to the Pacer Ivy Area indicated a lower level of contamination (30.9 ppt TCDD and 32.1 ppt TEQ). All sediment samples (except 10VNBH424) exhibited above 96% TCDD to TEQ proportions, indicating Agent Orange as the source of contamination.

Overall, high levels of contamination were detected in soil and sediment samples collected from the Pacer Ivy Area. The proportion of TCDD to total TEQ concentration in 2010 sampling data was greater than 80% in most of the soil and sediment samples analysed, indicating Agent Orange as the primary contaminant contributing to the TEQ. Significant dioxin contamination was also reported by Hatfield/VRTC (2009), and confirmed by the current study. Therefore, there is a high potential for dioxin to enter aquatic food systems, and pose risks to human health from ingestion of contaminated fish and other animals. Given the significant amount of aquaculture and agriculture undertaken in this area, measures need to be taken immediately to reduce potential exposure.



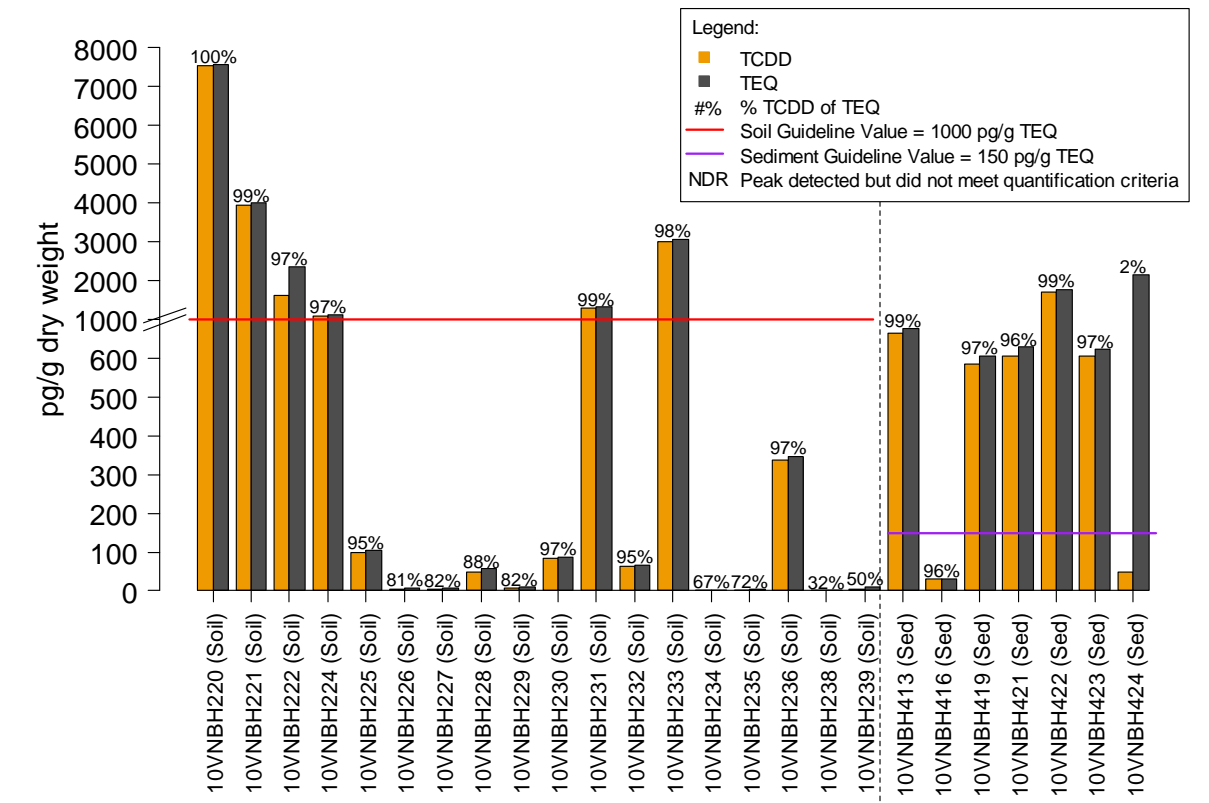
Source: National Archives and Records Administration, Washington, DC

**Figure 3.1** Soil and sediment sampling locations in the Pacer Ivy Area, Bien Hoa Airbase, Viet Nam, 2008 and 2010.

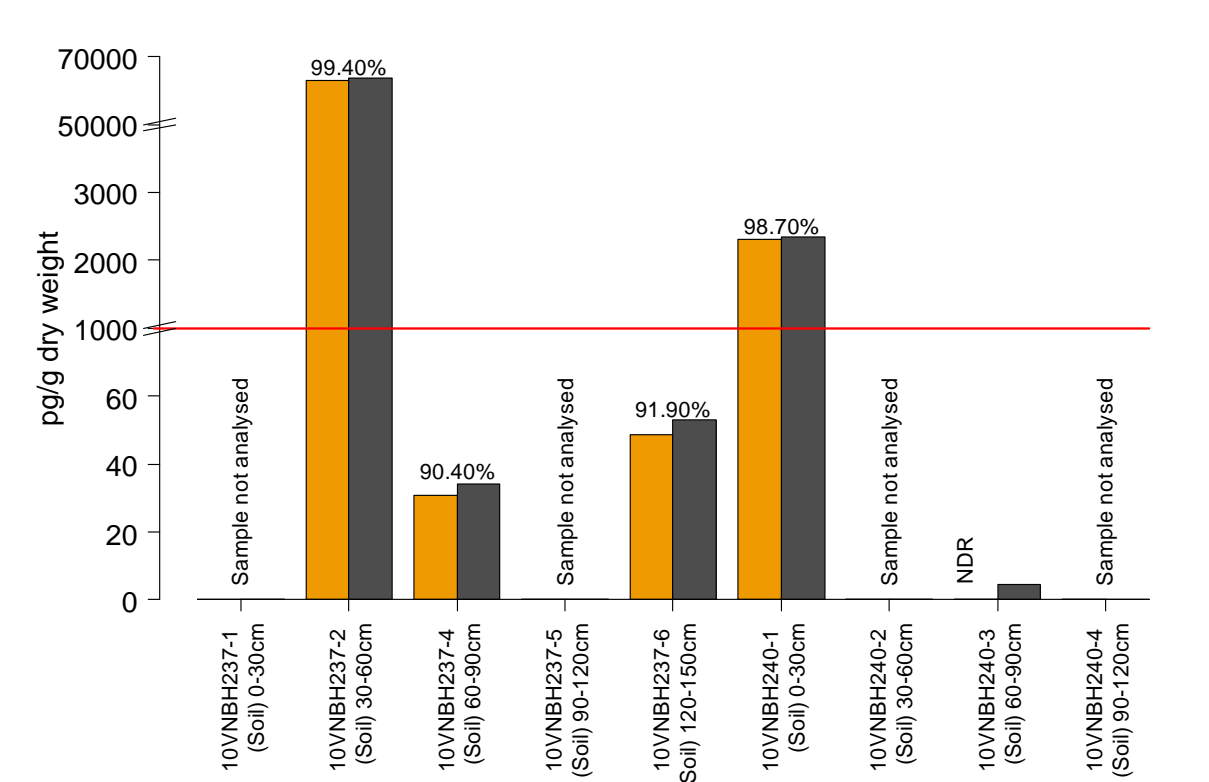


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**TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from the Pacer Ivy Area, Bien Hoa Airbase, Viet Nam, November 2010.**



**TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil samples collected from a depth profile at Pacer Ivy Area, Bien Hoa Airbase, Viet Nam, November 2010.**





### 3.1.2 Southwest Corner of Airbase

The Southwest Area of the Airbase (hereafter referred to as 'SW Airbase') was first sampled during the Hatfield/VRTC (2009) program in 2008, as a result of new information provided to VRTC from US DOD (2007) regarding potential dioxin contamination from historical use of Agent Orange in the area. Covering an area of 2,000 m<sup>2</sup>, the dioxin contaminated southwest corner of the Airbase is an even and flat terrain, slightly sloping to the west (Figure 3.2). Run-off water (rainwater) carries dioxin from contaminated sites through the runway and residential areas to adjacent rice fields.

The Hatfield/VRTC (2009) study discovered high levels of dioxin contamination in some soil samples collected from the SW Airbase during the 2008 sampling program (maximum 3,640 ppt TCDD). Five samples from this site exhibited high TEQ concentrations with TCDD to TEQ proportions of over 98%. The 2008 study found that contamination appeared to be restricted to a small area. As a result, the 2010 program was designed to further investigate the areal extent of contamination at this site by sampling around the previously identified hotspot. Analytical results from the current (2010) study are presented in Table 3.2.

Six (6) soil samples collected in 2010 and two (2) soil samples archived from the 2008 sampling program were analysed by AXYS from the SW Airbase in 2010. One archived sample from the 2008 program analysed in 2010 (08VNBH71) exhibited a TEQ concentration greater than 1,000 ppt TEQ; the sample had a TCDD concentration of 3,640 ppt and TEQ of 5,150 ppt. TCDD comprised 70% of the TEQ. The other archived (2008) sample exhibited a TCDD concentration of 57.2 ppt, a TEQ of 56.2 ppt, and 91% TCDD of TEQ.

The remaining samples exhibited relatively lower levels of contamination, with TCDD levels ranging between 7.84 ppt (10VNBH215) and 124 ppt (10VNBH216). TCDD contributed more than 82% of the TEQ in four (4) samples, indicating that dioxin in the SW Airbase likely originated from historical use of Agent Orange at the site.

Samples collected during the November 2010 program from the SW Airbase did not exhibit high levels of dioxin contamination. These results support the Hatfield/VRTC (2009) finding that contamination in the SW Airbase is limited to a specific area, and that the suspected hotspot covers a relatively small area. However, additional analysis is required to further investigate the potential transport of dioxins to surrounding agricultural and residential lands.

**Table 3.2 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in southwest corner of Airbase soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa, Viet Nam, January 2008 and November 2010.**

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
08VNBH071 <sup>1</sup>	16-Jan-08	Soil	0-10	3640	6030	1900	1020	1410	3720	7400	52000	32300	748	152	119	5180	5150	70.7
08VNBH072 <sup>1</sup>	16-Jan-08	Soil	0-10	51.2	65.8	2.36	58.6	261	1170	4.03	47.2	21.2	14.7	52.5	47	56.1	56.2	91.1
10VNBH214	3-Nov-10	Soil	0-20	62.7	87.6	66.2	412	3790	12500	5.58	76.3	50.1	102	256	212	107	110	57.0
10VNBH215	3-Nov-10	Soil	0-10	7.84	13.1	0.376	12.9	102	443	0.682	12.5	49.5	36.3	21.2	NDR 12.1	9.21	9.22	85.0
10VNBH216	3-Nov-10	Soil	0-20	124	136	14.7	70.6	515	2760	2.4	18.2	20.5	22.8	60.9	56.5	130	131	94.7
10VNBH217	3-Nov-10	Soil	0-10	33.8	41.6	12.6	39.6	351	1370	2.23	15.3	20.4	30.9	75.5	80.9	40.9	41.1	82.2
10VNBH218	3-Nov-10	Soil	0-15	25.8	32.4	3.52	35.1	120	489	1.86	25.3	17	9.39	19.6	13.7	30.2	30	86.0
10VNBH219	3-Nov-10	Soil	0-15	21.5	22.6	15.9	208	1520	8150	2.31	20.5	46.1	175	356	341	45.8	47.4	45.4

<sup>1</sup> Archived historical samples from 2008 analyzed during the 2010 program.

<sup>2</sup> Laboratory QA/QC for 10VNBH219 did not meet accepted criteria for 1,2,3,4,6,7,8-HPCDF. Given that the contribution of this congener to Total TEQ concentration is minimal (TEF = 0.01), results of this analysis were used.

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

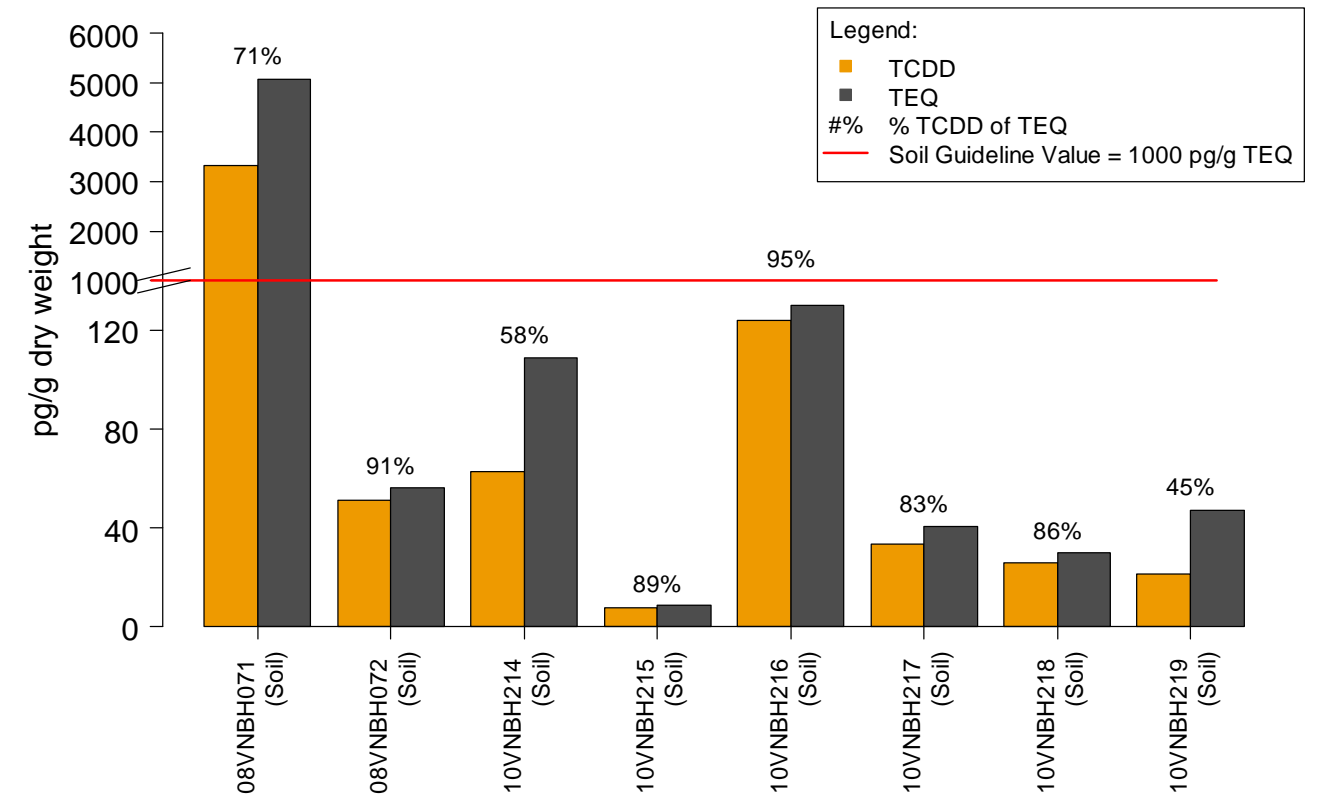
NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

**Figure 3.2** Soil and sediment sampling locations in the southwest corner of Bien Hoa Airbase, Viet Nam, 2008 and 2010.



**TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil samples collected from the southwest corner of Airbase, Bien Hoa, Viet Nam, January 2008 and November 2010.**



**Legend**

- Airport Boundary
- Ward Boundary
- Direction of runoff

**Soils/Sediment:**

2010 (Hatfield/Office 33)	2010 (Hatfield/Office 33)
2008 (Hatfield/VRTC)	2008 (Hatfield/VRTC)

**Viet Nam**

**Hatfield CONSULTANTS**

\*Vietnamese National Standard for Dioxin TCVN 8183:2009 (1000 ppt Soil, 150 ppt Sediment).

0 0.04 0.08 0.16 Km

Scale: 1:50,198.501

Projection: GCS WGS 1984

**Data Sources:**

- a) Image acquired from World View 2010
- b) Sampling Locations from Hatfield/VRTC and 10-80
- c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008



### 3.1.3 Z1 Area

Located in the south-central area of Bien Hoa Airbase, the Z1 Area is highly contaminated with dioxin, given that it was the main storage area for Agent Orange, Blue and White herbicides at Bien Hoa during Operation Ranch Hand. During the US - Viet Nam war, large herbicide storage tanks were present at this site, and the area surrounding the Z1 Area was subject to significant spillage. Major spills occurred in the environment in this area at least four times between December 1969 and March 1970; approximately 25,000 litres of Agent Orange and 2,500 Agent White were released to the Environment (US DOD 2007).

This site has recently been remediated by MND, including construction of drainage ditches and containment of contaminated soils in a secure landfill; the remediation program covers an area of approximately 43,000 m<sup>2</sup>. Downstream canals from the Ranch Hand herbicide storage tank area receive drainage from the hotspot site, and there are a number of ponds and lakes used by local fishermen (including Z1 Lake). The area has changed significantly since the implementation of remediation efforts. Rainwater from the storage area now flows to the Dong Nai River via newly constructed drainage canals, instead of Bien Hung Lake and other lakes inside the Airbase.

A number of soil samples were collected from the north and south of the Z1 containment area to identify any potential contaminant pathways leading to the general population in Bien Hoa City. Two (2) archived samples from the 2008 sampling program were also analysed by AXYS in 2010. Sampling results are presented in Table 3.3.

Most soil samples collected at the Z1 Area in 2010 had low TEQ concentrations ranging from 1.46 ppt to 212 ppt. Two samples exhibited high TCDD and TEQ concentrations; sample 10VNBH242 had 3,130 ppt TCDD and 3,210 ppt TEQ; 10VNBH243 contained 2,540 ppt TCDD and 2,650 TEQ. Sample 08VNBH167 (collected in 2008) also had elevated TCDD (985 ppt) and TEQ (1,000 ppt) concentrations. Proportions of TCDD to the TEQ concentration in all three samples were above 95%, indicating residual Agent Orange contamination at these sites.

Core samples were collected from the Z1 Area at two locations in 30 cm increments to a depth of 150 cm. Core sample 10VNBH245 and 10VNBH246 were collected to the south and southeast of the landfill area. Results of sample 10VNBH245 demonstrate that TCDD concentrations generally decreased with depth: the TCDD concentration was 7.66 ppt in the 0-30 cm fraction; and non-detectable at 60-90 cm. Non-detectable TCDD concentrations were also observed in soil samples analysed at 60-90 cm and 120-150 cm layers at site 10VNBH246. Results of the core samples remain inconclusive, as samples from several consecutive layers were not analyzed in 2010.

**Table 3.3 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in Z1 Area soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa Airbase, Viet Nam, January 2008 and November 2010.**

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2 DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
08VNBH138 <sup>1</sup>	18-Jan-08	Soil	0-10	19.6	19.6	1.61	9.44	51.5	477	1.62	2	7.25	< 0.971	6.33	10.7	22.4	22.4	87.5
08VNBH167 <sup>1</sup>	19-Jan-08	Soil	0-10	985	1050	65.6	128	242	921	33.9	212	199	49.1	39	24.4	1000	1000	98.5
10VNBH241	5-Nov-10	Soil	0-15	196	221	37.1	135	582	2060	10.1	61	94	66.9	75.3	37.2	212	212	92.5
10VNBH242	5-Nov-10	Soil	0-15	3130	3380	221	152	62	215	125	765	758	78.3	9.55	NDR 10.8	3210	3210	97.5
10VNBH243	5-Nov-10	Soil	0-15	2540	2870	298	188	110	450	133	901	745	45.2	25.4	19	2660	2650	95.8
10VNBH244	5-Nov-10	Soil	0-15	74.9	100	29.2	36.7	30.6	133	9.29	61.7	42.2	4.59	2.34	4.21	88.1	88	85.1
10VNBH245-1	5-Nov-10	Soil	0-30	7.66	10.8	2.86	7.02	18.3	67.4	<0.929	7.75	3.69	< 0.929	1.45	1.96	9.83	9.75	78.6
10VNBH245-3	5-Nov-10	Soil	60-90	< 0.921	< 0.921	< 0.921	< 0.921	< 0.921	10.9	< 0.921	< 0.921	< 0.921	< 0.921	< 0.921	< 0.921	1.56	1.46	NC
10VNBH246-3	6-Nov-10	Soil	60-90	NDR 1.69	< 0.963	< 0.963	< 0.963	2.38	17.8	< 0.963	3.28	< 0.963	< 0.963	< 0.963	< 0.963	1.63	1.53	NC
10VNBH246-5	6-Nov-10	Soil	120-150	< 0.986	< 0.986	< 0.986	< 0.986	< 0.986	14.9	< 0.986	3.8	2.23	< 0.986	< 0.986	< 0.986	1.67	1.56	NC
10VNBH247	6-Nov-10	Soil	0-10	93.7	100	21.1	126	858	4340	3.25	18.9	34.4	93.3	261	247	112	113	82.9
10VNBH248	6-Nov-10	Soil	0-10	4.83	5.8	< 0.923	2.67	30.2	162	<0.923	< 0.923	1.86	1.14	< 0.923	6.17	6.31	6.24	77.4
10VNBH250	6-Nov-10	Soil	0-10	28.3	38.8	5.94	81.9	306	1490	2.22	40.9	30.5	45.8	69.9	50.1	34.9	34.8	81.3
10VNBH251	6-Nov-10	Soil	0-10	225	241	26.9	78.8	482	2010	5.51	48.9	33.6	45.5	61.8	42.2	237	237	94.9
10VNBH426	6-Nov-10	Sediment	0-5	111	116	16.2	136	896	3470	5.19	49	24.8	45.3	82.4	58.7	124	125	88.8
10VNBH427	6-Nov-10	Sediment	0-5	212	224	12.9	66.2	393	1770	6.88	35.1	50.8	22.9	44.4	80.1	219	219	96.8
10VNBH428	6-Nov-10	Sediment	0-20	33.9	33.9	5.35	14.2	82.3	342	2.92	6.02	< 2.54	13.4	9.48	14.4	40	39.8	85.2

<sup>1</sup> Archived historical samples from 2008 analyzed during the 2010 program.

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

Sediment samples were collected from a canal that drains the South Base Lake, a wetland situated to the southeast of the landfill, and Z1 Lake. The sediment sample collected from the wetland area (10VNBH427) south of the Z1 Area had a high TCDD concentration of 212 ppt and TEQ concentration of 219 ppt (96.8% TCDD of TEQ), and exceeded the sediment guideline of 150 ppt TEQ. The sample collected from the canal draining South Base Lake (10VNBH426) also exhibited elevated dioxin levels (111 ppt TCDD; 125 ppt TEQ; 88.8% TCDD of TEQ). The Z1 Lake sediment sample contained relatively low TCDD (33.9 ppt) and TEQ (39.8 ppt) concentrations.

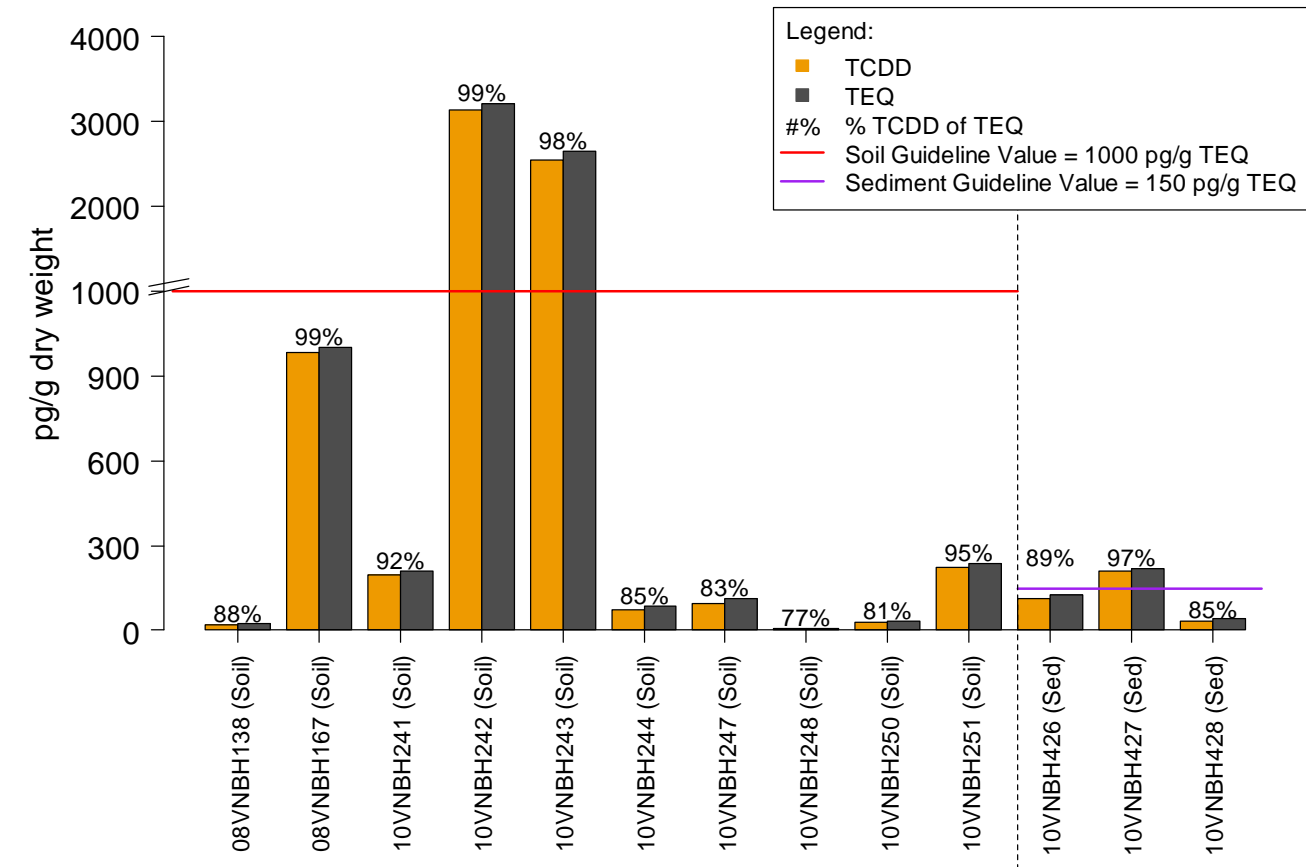
In general, the Hatfield/VRTC (2009) study found that samples collected from the area to the south and southwest of the Z1-contaminated area had higher levels of dioxin than samples collected from the area east and north of the landfill (Figure 3.3). This observation held true for the results of the 2010 study as well.

Construction of the landfill appears to have been effective in significantly reducing the soil dioxin levels in the Z1 Area. However, high levels detected in some soil and sediment samples collected downstream of the Z1 Area in 2010 emphasize the need for periodic monitoring of dioxin levels to confirm the effectiveness of treatment mechanisms, and to prevent the spread of toxic chemicals into the receiving environment (i.e., to fish ponds downstream of the Z1 Area).

**Figure 3.3 Soil and sediment sampling locations in the Z1 Area, Bien Hoa Airbase, Viet Nam, 2004 to 2010.**



**TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from the Z1 Area, Bien Hoa Airbase, Viet Nam, January 2008 and November 2010.**



**Legend**

- Airport Boundary
- Ward Boundary
- Landfill
- Direction of runoff

**Soils/Sediment:**

Soil and Sediment concentrations exceed Vietnamese National Standard.\*

- 2010 (Hatfield/Office 33)
- 2008 (Hatfield/ VRTC)
- 2004/2005 (Hatfield/ 10-80)

Soil and Sediment concentrations below Vietnamese National Standard.\*

- 2010 (Hatfield/Office 33)
- 2008 (Hatfield/ VRTC)
- 2004/2005 (Hatfield/ 10-80)

**Viet Nam**

**Hatfield CONSULTANTS**

\*Vietnamese National Standard for Dioxin TCVN 8183:2009 (1000 ppt Soil, 150 ppt Sediment).

Scale: 1:5,500  
Projection: WGS 1984 UTM Zone 48N

Data Sources:  
a) Image acquired from World View 2010  
b) Sampling Locations from Hatfield/ VRTC and 10-80  
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008



### 3.1.4 Northeastern Perimeter

The northeastern perimeter of the Airbase was sampled in 2010 as a result of slightly elevated dioxin levels (425 ppt TEQ in soil) discovered outside the Airbase during the Hatfield/10-80 (2006) study. During the 2004-2005 sampling program, soil and sediment samples were collected from outside the northeastern perimeter, suggesting potential contamination in the eastern region of the Airbase. This area was not sampled during the Hatfield/VRTC (2009) program. In 2010, the project team sampled this area for the first time, inside the eastern Airbase perimeter, to identify potential contamination sources inside the Airbase.

Eight soil samples and three sediment samples were analyzed in the northeastern part of the Airbase, along the southeastern and eastern sides of the runway, in November 2010. Analytical results are presented in Table 3.4.

One surface soil sample (10VNBH208) collected from a low-lying grass field near the 'NE Perimeter Lake 1' (Figure 3.4) exhibited a TCDD concentration of 996 ppt and a TEQ of 1,040 ppt, slightly exceeding the Vietnamese soil dioxin guideline (1,000 ppt). Another sample collected from the perimeter (10VNBH204) also exhibited slightly elevated TCDD (333 ppt) and TEQ (347 ppt) concentrations. In both of these samples, TCDD contributed to over 95% of the TEQ, indicating Agent Orange as the source of contamination. Dioxin concentrations were lower in the remaining soil samples collected from this area; TCDD concentrations ranged from 3.4 to 47.9 ppt, and TEQ concentrations ranged from 12.1 to 56.1 ppt.

Three (3) sediment samples were collected from an aquaculture pond ('Mr. San Lake'), and 'NE Perimeter Lake 1 and 2' located near the southeastern end of the runway. The sample collected from 'NE Perimeter Lake 1' (10VNBH410) exhibited a TCDD concentration of 600 ppt and a TEQ of 633 ppt, exceeding the Vietnamese sediment dioxin guideline of 150 ppt TEQ. In the remaining two samples, TCDD concentrations were very low (5.11 ppt in 'Mr. San Lake' and 11.6 ppt in 'NE Perimeter Lake 2'), as were TEQs (6 ppt in 'Mr. San Lake' and 12.3 ppt in 'NE Perimeter Lake 2'). Dioxin levels are likely not a significant concern in these latter 2 lakes.

Soil and sediment samples were collected from outside the northeastern Airbase perimeter during the Hatfield/10-80 2004-2005 study (Hatfield/10-80 2006) (Table 1.2). Both soil and sediment samples showed elevated TCDD and TEQ concentrations, but none exceeded the current Vietnamese guidelines for dioxins in soil and sediment. The highest soil TCDD concentration was recorded at 05VN089 (392 ppt), with a resulting TEQ of 424 ppt (92% TCDD of TEQ). The highest sediment dioxin value was recorded in 05VN088 (82.8 ppt TCDD and 101 ppt TEQ). In all the historic samples collected from this area, over 82% of the TEQ was TCDD, indicating Agent Orange as the likely source of contamination.

**Table 3.4 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in northeastern Airbase perimeter soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa Airbase, Viet Nam, November 2010.**

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
10VNBH204	2-Nov-10	Soil	0-15	333	376	38.1	69	360	2600	13.8	109	107	43.2	63	91.4	347	347	96.0
10VNBH205	2-Nov-10	Soil	0-20	39.2	71.6	23.2	64.1	286	1500	2.71	43.5	39	49.7	55	56.2	48.4	48.5	80.8
10VNBH206	3-Nov-10	Soil	0-20	32.7	40.3	11.9	48.3	219	926	1.59	14.8	17.7	30.3	46.8	37.2	36.6	36.6	89.3
10VNBH208	3-Nov-10	Soil	0-10	996	1190	136	132	256	1010	85.3	481	474	111	65.5	48.3	1040	1040	95.8
10VNBH209	3-Nov-10	Soil	0-20	17	17.8	3.71	21.9	101	600	0.668	7.27	8.13	10.3	14.5	12.4	19	19.1	89.0
10VNBH210	3-Nov-10	Soil	0-20	3.4	10.2	11.6	73.6	403	2340	0.558	13.6	29.4	95.8	75.6	55.7	11.6	12.1	28.1
10VNBH212	3-Nov-10	Soil	0-20	47.9	56.5	19.2	68.7	294	1240	9.49	33.3	34.1	35.8	54	44.4	56.1	56.1	85.4
10VNBH213	3-Nov-10	Soil	0-20	17.8	20.6	3.74	7.73	21.6	112	1.1	10.5	5.28	2.64	2.8	2.75	18.7	18.7	95.2
10VNBH408	2-Nov-10	Sediment	0-20	11.6	13.2	2.23	1.29	5.65	34.4	1.04	6.71	3.91	1.12	0.506	0.989	12.3	12.3	94.3
10VNBH410	3-Nov-10	Sediment	0-5	600	709	92.1	147	411	1930	96.6	357	289	83	64.8	56.8	634	633	94.8
10VNBH412	3-Nov-10	Sediment	0-120	5.11	7.67	2.17	5.83	49.8	315	0.558	5.29	3.77	5.32	8.94	6.64	5.94	6	85.2

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

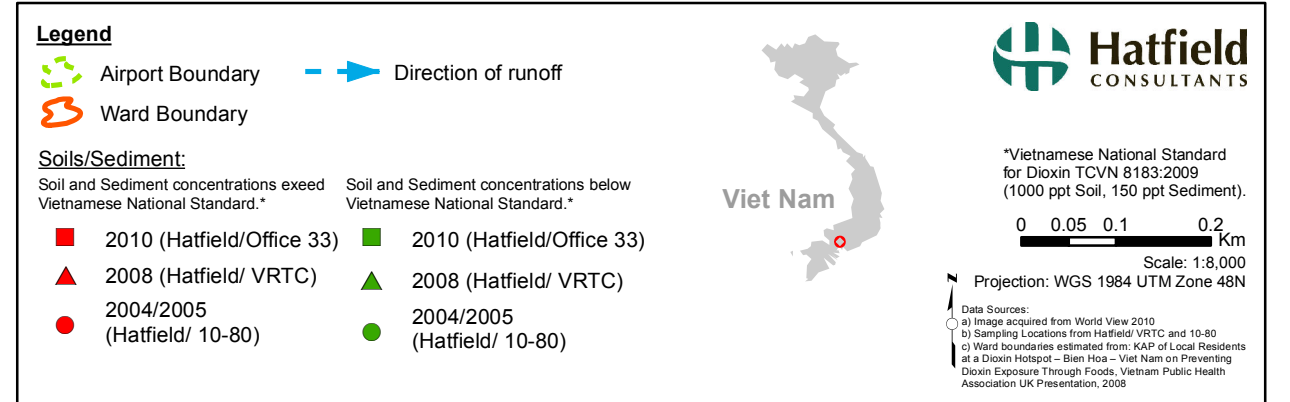
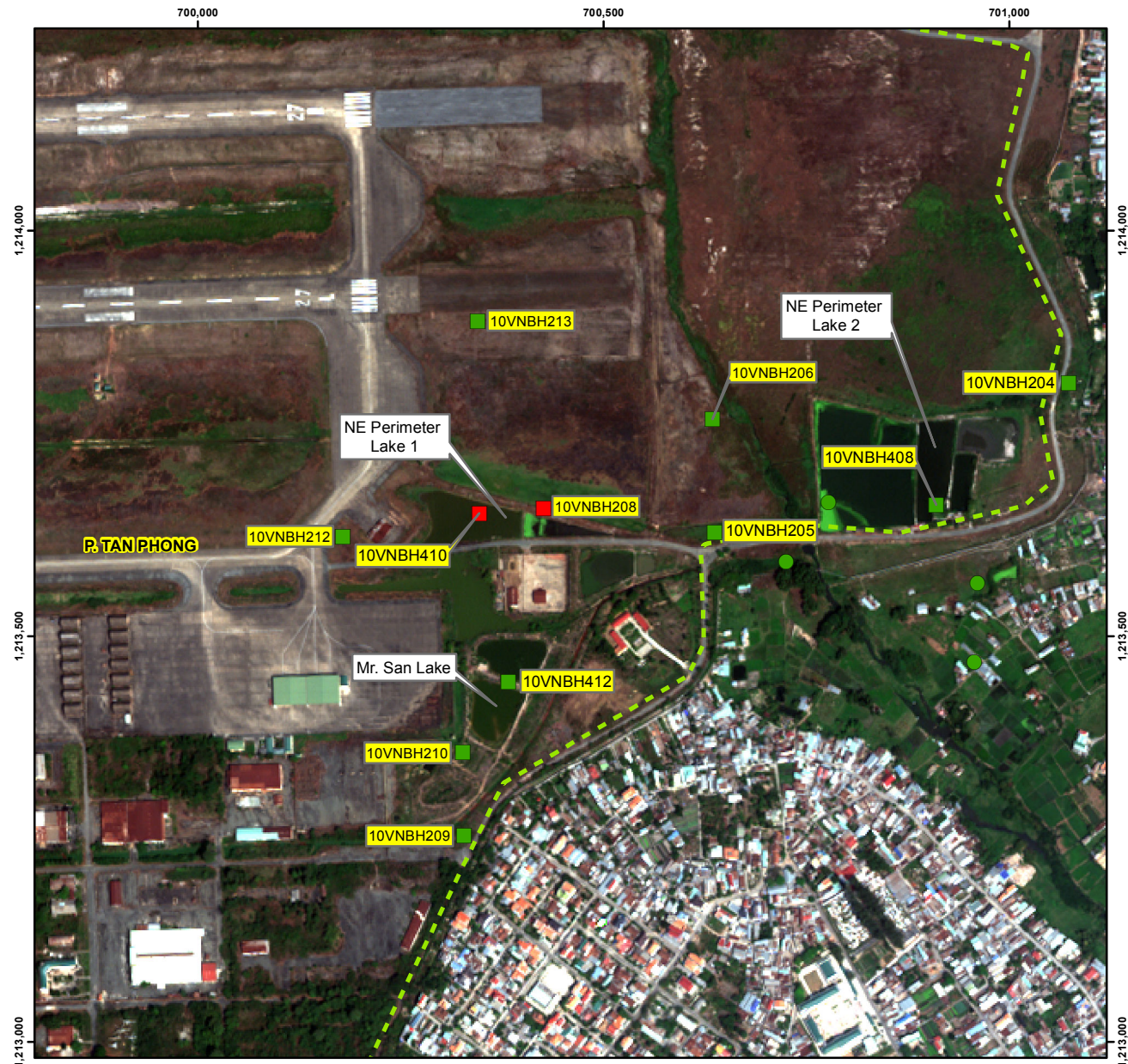
ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

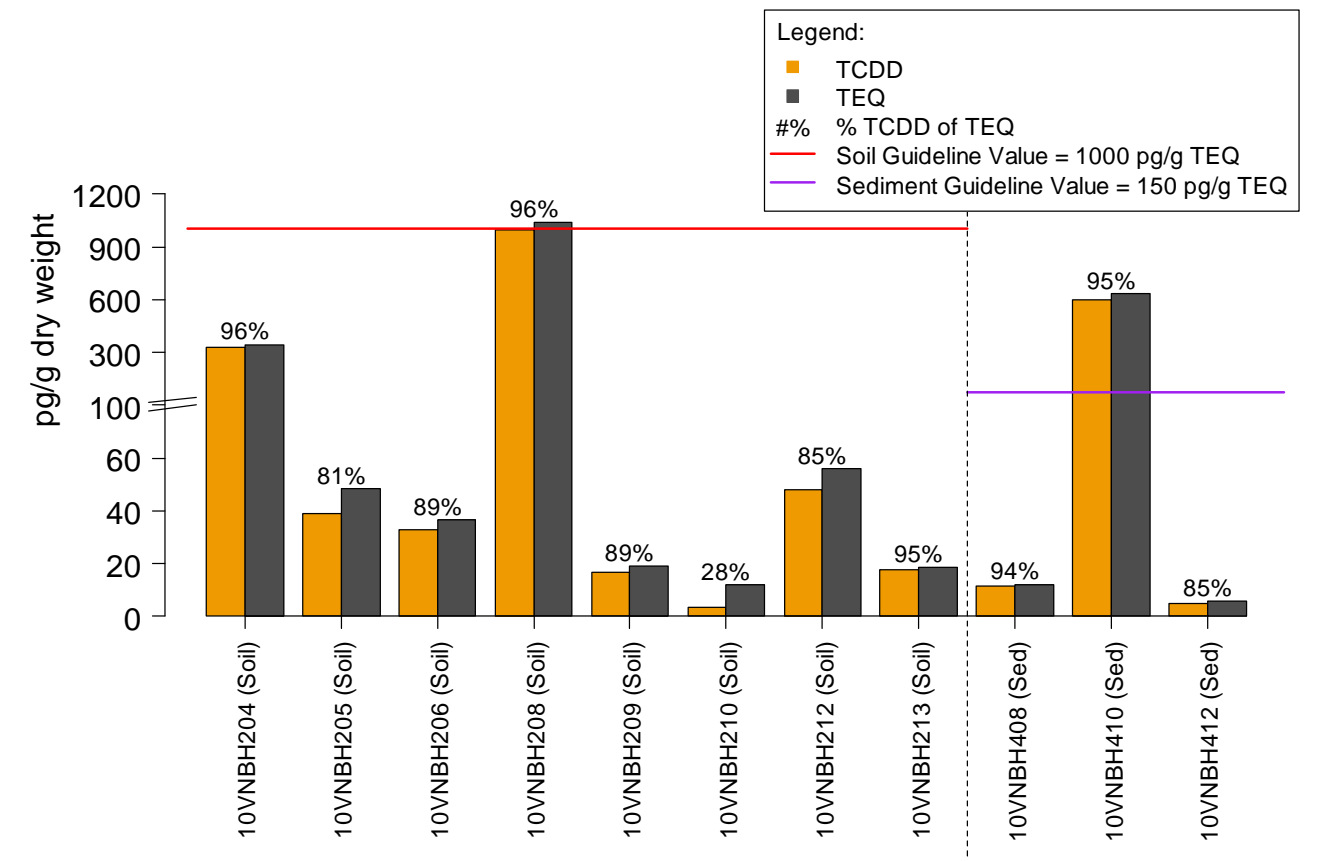
Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

**Figure 3.4 Soil and sediment sampling locations in the northeastern perimeter of Bien Hoa Airbase, Viet Nam, 2004 to 2010.**



**TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from northeastern perimeter of Airbase, Bien Hoa, Viet Nam, November 2010.**



### 3.1.5 Northern Perimeter and Bien Hoa City (Southern Perimeter)

Four (4) soil and five (5) sediment samples were collected in November 2010 from the northern perimeter of Bien Hoa Airbase, and two (2) sediment samples were collected from outside the southern perimeter, in Bien Hoa City. The northern perimeter was not sampled during previous Hatfield/10-80/VRTC field programs.

Soil samples collected from the north Airbase exhibited low dioxin concentrations; none exceeded the Vietnamese guideline value for dioxins in soil (1000 ppt TEQ). One sample exhibited elevated levels (425 ppt TCDD; 459 ppt TEQ; and 92.6% TCDD of TEQ). In the remaining three samples, TEQ concentrations ranged from 8.47 to 17.1 ppt.

Sediment samples were collected from five (5) sites along the northern perimeter. Two samples exhibited TEQ concentrations exceeding the Vietnamese guideline value for dioxins in sediment (150 ppt TEQ). A sample collected from a small pond on the northwestern perimeter of the Airbase (10VNBH402) exhibited a sediment TCDD concentration of 362 ppt and a TEQ of 372 ppt; this was the highest value recorded in this area. TCDD contributed 97.3% of the TEQ, indicating Agent Orange as the source of contamination. Another sediment sample taken from 'Mr. Binh Lake' (10VNBH406) on the eastern side of the Airbase perimeter also exhibited a high dioxin concentration (257 ppt TCDD; 268 ppt TEQ; 95.9% TCDD of TEQ).

A sediment sample (10VNBH400) collected from a small pond on the northwestern perimeter of the Airbase exhibited slightly elevated dioxin levels (62.8 ppt TCDD; 68.5 ppt TEQ; 91.7% TCDD of TEQ). Elevated dioxin levels observed in this sample, as well as sample 10VNBH402 discussed above, may be attributed to their proximity to the highly contaminated Pacer Ivy Area, the site of former herbicide storage and re-drumming (see Section 3.1.1).

Sediment samples collected from a small pond to the west of 'Mr. Binh Lake' (10VNBH403) and 'Mr. Quy Lake' (10VNBH404) exhibited relatively low TCDD and TEQ concentrations (38.2 ppt TEQ and 5.66 ppt TEQ, respectively).

Two sediment samples were collected from 'Gate 2 Lake' and Bien Hung Lake, located to the south of the Airbase in Bien Hoa City. The sample collected from 'Gate 2 Lake' (10VNBH429) had a relatively low dioxin concentration (24.3 ppt TCDD; 26.9 ppt TEQ; and 90.3% TCDD of TEQ). Elevated dioxin levels were observed in Bien Hung Lake (10VNBH430); the TCDD concentration was 79.1 ppt and TEQ was 95.6 ppt (82.7% TCDD of TEQ).

Bien Hung Lake was sampled at several locations during the 2004-2005 Hatfield/10-80 (2006) field program as well. The historic samples also exhibited elevated dioxin levels (Table 1.2; Figure 1.2). The TEQ levels in sediments from this lake ranged from 36 ppt (86% TCDD to TEQ) to 131 ppt (73% TCDD to TEQ). All the samples analysed thus far from Bien Hung Lake, however, remained below the Vietnamese guideline for sediment dioxins (150 ppt TEQ). Schecter et al. (2001) also reported sediment dioxin in Bien Hung Lake 1 and Bien Hung Lake 2; 177 ppt TCDD was reported as the highest value from both lakes. There is no information in their publication as to the exact location of these lakes or of the samples collected.



**Table 3.5 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in northern perimeter of Airbase and Bien Hoa City soil and sediment samples (pg/g [ppt] dry weight), Viet Nam, November 2010.**

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
<i>Northern Perimeter</i>																		
10VNBH200	2-Nov-10	Soil	0-15	10.8	11.4	1.13	7.33	24.4	146	0.373	2.46	1.67	2.14	4.05	4	11.5	11.6	93.1
10VNBH201	2-Nov-10	Soil	0-15	5.33	8.13	5.72	26.7	126	654	0.573	6.02	6.54	12.9	16.2	14.4	8.43	8.47	62.9
10VNBH202	2-Nov-10	Soil	0-20	425	645	293	346	286	933	26.2	220	202	57	38.3	27.4	460	459	92.6
10VNBH203	2-Nov-10	Soil	0-20	15.4	17.1	4.55	10.9	18	86.2	1.24	3.99	5.44	1.63	1.47	2.71	17.1	17.1	90.1
10VNBH400	2-Nov-10	Sediment	0-10	62.8	77.1	19.2	74.1	294	1430	2.73	20.3	21.7	18.1	18.6	19.4	68.3	68.5	91.7
10VNBH402	2-Nov-10	Sediment	0-50	362	394	27.8	63	118	517	38.1	108	92.4	30.4	18.3	11.8	372	372	97.3
10VNBH403	2-Nov-10	Sediment	0-130	37.4	42.2	2.17	9.95	42.2	216	1.34	10.4	8	5.97	8.95	7.24	38.2	38.2	97.9
10VNBH404	2-Nov-10	Sediment	0-50	4.9	7.63	1.18	3.61	19.9	86.2	0.463	10.5	0.625	1.77	3.08	3.4	5.67	5.66	86.6
10VNBH406	2-Nov-10	Sediment	0-200	257	316	39.8	34.8	49.5	319	38.1	152	73.9	12.5	7.93	9.64	268	268	95.9
<i>Southern Perimeter (Bien Hoa City)</i>																		
10VNBH429	6-Nov-10	Sediment	0-20	24.3	24.3	< 2.22	6.66	31	393	< 2.23	< 2.23	5.27	3.92	< 1.46	14.9	27.1	26.9	90.3
10VNBH430	6-Nov-10	Sediment	0-100	79.1	106	3.23	208	745	5010	29.3	98.3	52.8	40.7	170	213	95.5	95.6	82.7

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

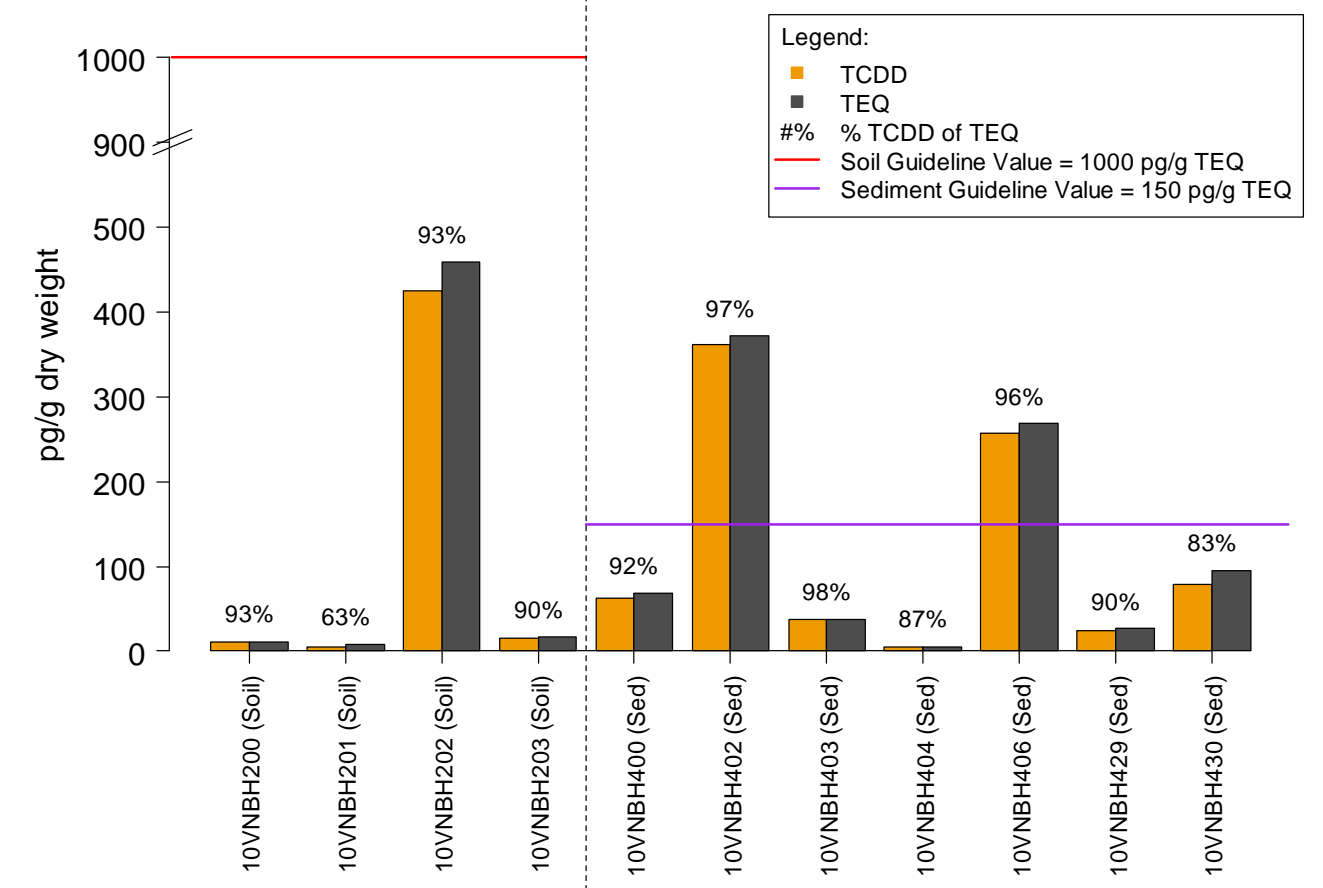
Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

**Figure 3.5 Soil and sediment sampling locations on the perimeter of Bien Hoa Airbase and Bien Hoa City, Viet Nam, 2004 to 2010.**



**TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from the perimeters of Bien Hoa Airbase, Viet Nam, November 2010.**



**Legend**

- Airport Boundary
- Ward Boundary
- Landfill
- Direction of runoff

**Soils/Sediment:**

■ 2010 (Hatfield/Office 33)	■ 2010 (Hatfield/Office 33)
▲ 2008 (Hatfield/VRTC)	▲ 2008 (Hatfield/VRTC)
● 2004/2005 (Hatfield/10-80)	● 2004/2005 (Hatfield/10-80)

\*Vietnamese National Standard for Dioxin  
TCVN 8183:2009 (1000 ppt Soil,  
150 ppt Sediment).

0 0.2 0.4 0.8 Km  
Scale: 1:25,000  
Projection: WGS 1984 UTM Zone 48N

Data Sources:  
a) Image acquired from World View 2010  
b) Sampling Locations from Hatfield/VRTC and 10-80  
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008



### 3.1.6 Other Soil and Sediment Analyses

One soil sample (10VNBH701) and one sediment sample (10VNBH428) were analysed by the ALS Laboratory Group, Saskatoon, SK, Canada for Total Organic Carbon (TOC) and particle size (Table 3.6).

#### 3.1.6.1 Total Organic Carbon (TOC)

Levels of TOC should be considered when reviewing contaminant levels in soils and sediments, as many contaminants preferentially partition into, or bind onto, organic material. Sample 10VNBH701 (a duplicate of sample 10VNBH210 collected from the northeast perimeter of the Airbase) exhibited a TOC level of 0.8%, consistent with the generally sandy nature of soils on the Airbase. The sediment sample had an intermediate TOC level of 2.71%.

#### 3.1.6.2 Particle Size Analysis (PSA)

PSA analyses were completed for selected soil and sediment samples (10VNBH701 and 10VNBH428, respectively). The percentage of gravel (>2 mm), sand (2 mm – 0.063mm), silt (0.063 mm – 4 µm), and clay (>4 µm) can impact contaminant levels in soils and sediments. In general, soils with high gravel and sand content retain lower levels of contaminants than soils predominantly composed of silt and clay. Sand dominated the PSA profiles of the samples analysed (88.7% in 10VNBH701, and 62.8% in 10VNBH428). As expected, the sediment sample contained higher silt (18.7%) and clay (13.3%) content.

**Table 3.6 Particle size and carbon content in selected soil and sediment samples, Bien Hoa, Viet Nam, November 2010.**

Sample ID	Location	Matrix	Particle Size				Total Organic Carbon (%)
			% Gravel (>2 mm)	% Sand (2.0 mm to 0.063 mm)	% Silt (0.063mm to 4 µm)	% Clay (<4 µm)	
10VNBH701	NE Perimeter	Soil	1.71	88.7	8.20	1.39	0.80
10VNBH428	Z1 Area	Sediment	5.18	62.8	18.7	13.3	2.71

### 3.1.7 Comparison with Da Nang and Phu Cat Airbase Results

Review of dioxin concentrations at other known Ranch Hand sites in Viet Nam provides useful information for comparative purposes. Significant quantities of TCDD were detected in soil samples analysed from Da Nang Airport in December 2006 and January 2009 (Hatfield/Office 33 2007, 2009), and from Phu Cat Airbase in 2004 and 2005 (Hatfield/10-80 2006) and January 2008 (Hatfield/VRTC 2009). Comparison of results from the three airbases is presented in Table 3.7.

**Table 3.7 Highest recorded concentrations of polychlorinated dibenzo-*p*-dioxins in Da Nang, Phu Cat and Bien Hoa airbases, Viet Nam.**

	Da Nang	Phu Cat	Bien Hoa
Highest Recorded Dioxin Concentration in Soil	361,000 ppt TCDD	236,000 ppt TCDD	259,000 ppt TCDD
	365,000 ppt TEQ	238,000 ppt TEQ	262,000 ppt TEQ
	99% TCDD of TEQ	99% TCDD of TEQ	99% TCDD of TEQ
	Former Mixing and Loading Area (Hatfield/Office 33 2007)	Former Storage Area (Hatfield/VRTC 2009)	Z1 Area (Hatfield/VRTC 2009)
Highest Recorded Dioxin Concentration in Sediment	8,390 ppt TCDD	194 ppt TCDD	5,810 ppt TCDD
	8,580 ppt TEQ	201 ppt TEQ	5,970 ppt TEQ
	98% TCDD of TEQ	96% TCDD of TEQ	97% TCDD of TEQ
	Drainage ditch d/s of Storage Area (Hatfield/Office 33 2009)	East of the Runway (Hatfield/10-80 2006)	Pacer Ivy Area (Hatfield/VRTC 2009)

Soil and sediment samples analysed from the Former Mixing and Loading and Former Storage Areas in northern Da Nang Airport exhibited the highest TCDD levels of all sites sampled by Hatfield to date in Viet Nam. The maximum soil TEQ concentration recorded in 2006 was 365,000 ppt from samples collected at the Former Mixing and Loading Area; this is 365 times the Vietnamese and globally acceptable maximum standard of 1,000 ppt. Three soil samples were >100,000 ppt; seventeen (17) of the 23 soil samples (74%) analysed from Da Nang Airport were >1,000 ppt. TCDD levels measured in 2009 in the central and southern Da Nang Airport areas were significantly lower than contaminant levels detected in the north; TCDD concentrations ranged between 0.388 ppt and 145 ppt, with the exception of the Pacer Ivy Storage Area, where one soil sample exhibited 13,400 ppt TCDD and 20,600 ppt TEQ (65% TCDD of TEQ). Dioxin concentrations in sediments of Sen Lake and North Airport drainage ditches exceeded the Vietnamese guideline of 150 ppt TEQ; TEQs from 2006 and 2009 sediment samples from the North Airport sites ranged from 674 to 8,580 ppt.

At Phu Cat Airbase, the highest dioxin concentrations were detected in the Storage Area (236,000 ppt TCDD; 238,000 TEQ; 99.2% TCDD of TEQ) during the Hatfield/VRTC (2009) study. Most samples collected from this area exhibited dioxin levels exceeding 1,000 ppt. TCDD represented over 95% of TEQ in all samples analyzed, verifying the source as being Agent Orange. Dioxin concentrations at Phu Cat Airbase are comparable to those found at Bien Hoa and Da Nang. Highest sediment TCDD level was recorded to the east of the runway (194 ppt), at a location downstream of the suspected Ranch Hand operational area, which was established as a dioxin mitigation site by Vietnamese authorities. Run-off from this site ultimately flows into the South Lake, which is used for irrigation purposes, exposing villagers to dioxins during work in paddies, consumption of fish, and perhaps other food items.

The highest soil dioxin concentrations at Bien Hoa Airbase were recorded during the Hatfield/VRTC (2009) study. A sample collected from a depth of 60-90 cm in Z1 Area (main site for herbicide storage) exhibited a TEQ concentration



of 262,000 ppt (259,000 ppt TCDD; 99% TCDD of TEQ). High concentrations (>26,000 ppt TEQ) were detected at all depths sampled at this site. Previous VRTC studies, however, found several samples >1 million ppt at Bien Hoa prior to construction of the landfill (N.X. Truong, pers. comm). Contaminated soils in the Z1 Area have now been contained in a secure landfill, and dioxin levels in and around this area have been reduced significantly as a result. Highest sediment dioxin levels were recorded in samples collected from the Pacer Ivy Area in 2008 (5,970 ppt TEQ; Hatfield/VRTC 2009) and 2010 (2,020 ppt TEQ).

Overall, Da Nang, Phu Cat and Bien Hoa airbases have exhibited comparable soil dioxin concentrations. As former Ranch Hand operation sites, these three airbases are confirmed as the most significant dioxin hotspots in the country. Highest sediment TEQ concentrations recorded were lower at the Phu Cat Airbase relative to the other airbases; however, they remained above the Vietnamese standard (150 ppt TEQ). As of 2010, dioxin continues to enter the aquatic ecosystem, the general environment and the food chain in and around Da Nang, Phu Cat and Bien Hoa airbases. Dioxin levels recorded in soil and sediment samples at all three airbases continue to exceed all international standards and guidelines for these toxic chemicals. Remediation activities at Bien Hoa in the Z1 Area have helped significantly reduce dioxin levels in the main hotspot area, but it is clear that other hotspots exist on the Airbase, which need to be treated. Lessons learned from ongoing cleanup activities at Da Nang Airport (funded by the US Government) will be invaluable for the future remediation of Bien Hoa and Phu Cat Airbases.

### **3.1.8 Summary Discussion – Soil and Sediment**

Soil and sediment samples analyzed in 2010 at and around Bien Hoa Airbase (i.e., Z1 Area, southwest corner of Airbase, northeastern perimeter, northern perimeter and Bien Hoa City) generally exhibited lower levels of dioxin contamination than those collected from the Pacer Ivy Area. Eight (8) soil samples and six (6) sediment samples from the Pacer Ivy Area exceeded the TEQ guidelines of 1,000 ppt for soil and 150 ppt for sediment. Soil and sediment samples with high TEQ concentrations exceeding these guidelines were also recorded in all other areas sampled.

In the Hatfield/VRTC (2009) study of dioxin concentrations in Bien Hoa Airbase, the highest concentration of TCDD in soil was recorded at site 08VNBH080-3 (depth of 60-90 cm) in the Z1 Area (259,000 ppt TCDD and 262,000 ppt TEQ). Samples taken at a depth profile at this same site all exhibited extremely high TEQ concentrations (>26,400 ppt). The highest TCDD concentration in sediment was recorded during the Hatfield/VRTC (2009) study in a sample collected from the Pacer Ivy Area. Sample 08VNBH111 exhibited a TCDD concentration of 5,810 ppt, TEQ of 5,970 ppt and 97.3% TCDD of TEQ. All 2010 samples analysed from inside and outside the Airbase had TCDD concentrations lower than historical samples from 2009.

Agent Orange continues to contribute to the high concentrations of TCDD in soil and sediment samples in the Pacer Ivy Area of Bien Hoa Airbase (Table 3.1 and Figure 3.1). Soil and sediment samples analyzed to the west of the concrete yard

exhibited extremely high TCDD levels in 2010. Site 10VNBH237-2 (at a depth of 30-60cm) exhibited the highest recorded soil TEQ concentrations in Bien Hoa in 2010 (61,800 ppt); a soil sample taken very close to this site (08VNBH105) during the 2008 sampling program (Hatfield/VRTC 2009) also exhibited extremely high levels of contamination (22,300 ppt TCDD, 22,800 ppt TEQ, and 97.8% TCDD of TEQ). Sediment samples taken from the Pacer Ivy Area also exhibited high dioxin levels, exceeding the TEQ guideline of 150 ppt. The highest sediment TEQ concentration recorded in 2010 was in sample 10VNBH424 (2,020 ppt). Dioxin levels at the Pacer Ivy Area exceeds Vietnamese and international guidelines by significant margins. Guideline levels set in Canada, the US EPA and Finland are the most conservative and were exceeded by the greatest margin.

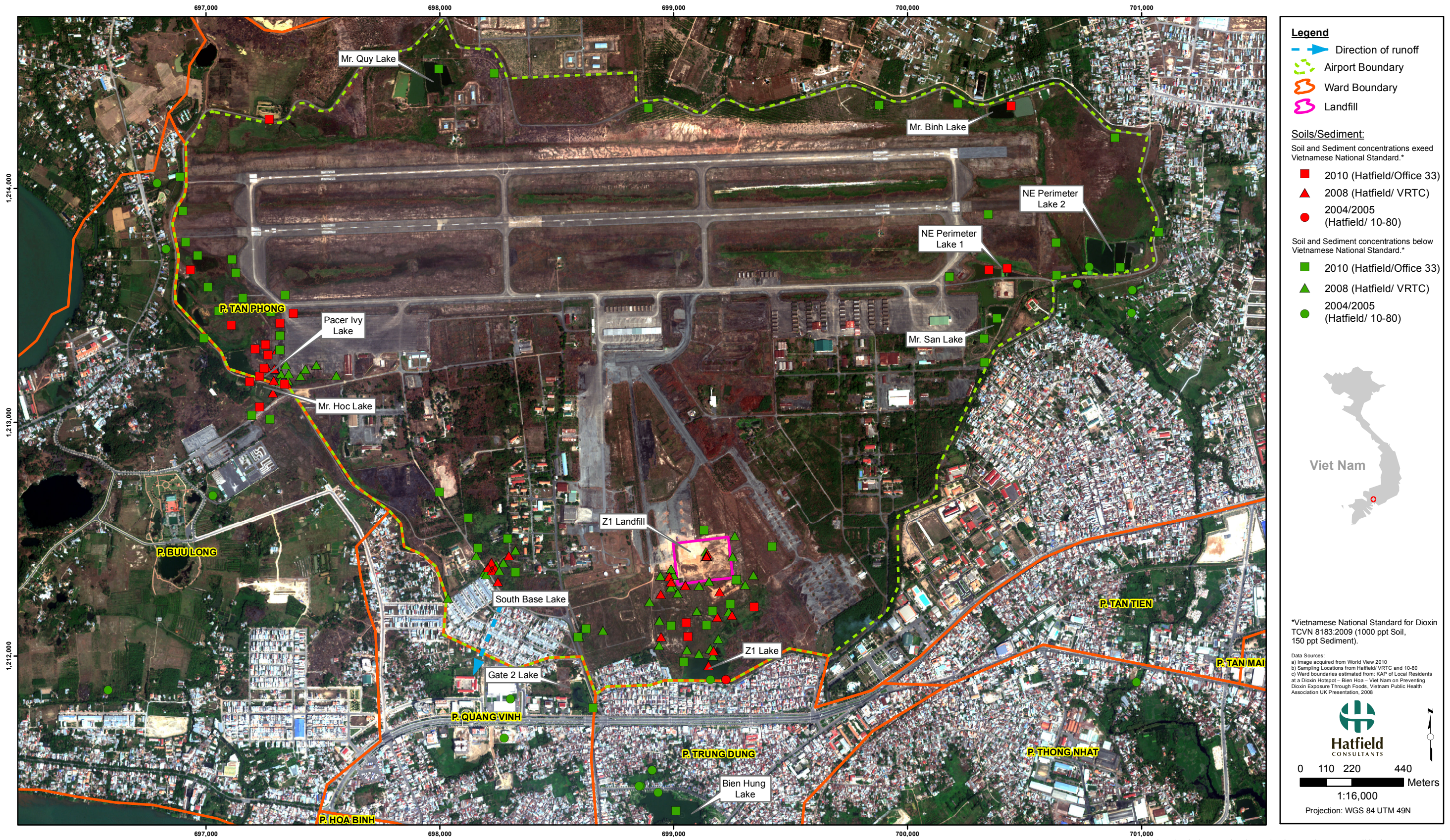
Hatfield/VRTC/Office 33 (2009 and 2010) studies found that soil and sediment samples collected from the area to the south and southwest of the Z1 contaminated area had higher levels of dioxins than samples collected from the area east and north of the landfill. The highest soil TEQ concentration in the Z1 Area during the 2010 study was recorded in sample 10VNBH242 (3,210 ppt) located to the south of the landfill.

Soil and sediment samples exceeding the Vietnamese TEQ guidelines were also observed in the northeastern perimeter of the Airbase. One soil sample taken from this area had a TEQ value of 1,040 ppt; a sediment sample analyzed from 'NE Perimeter Lake 2' also exhibited a high TEQ of 633 ppt (Table 3.4 and Figure 3.4)

A soil sample collected from SW Airbase also exhibited high levels of TCDD (3,640 ppt) and TEQ (5,150 ppt TEQ); the sample was archived from the 2008 program (08VNBH071). TCDD concentrations in all samples collected in 2010 from the SW Airbase were relatively low (ranged between 7.84 ppt and 124 ppt). These concentrations were significantly lower than 2008 concentrations (65,400 ppt TCDD; Hatfield/VRTC 2009). The TEQ concentrations in soil samples collected from the northern perimeter of the Airbase were also low (8.47 to 459 ppt); however, sediment samples exceeding the TEQ guideline (150 ppt) were recorded in several lakes and ponds.



Figure 3.6 Summary of TEQ values (pg/g dry weight) for soil and sediment samples analyzed in Bien Hoa, Viet Nam, 2004 to 2010.





## 3.2 FISH

Dioxin/furan concentrations in fish tissues were determined from several lakes (N = 11) on Bien Hoa Airbase and Bien Hoa City. At least one of the fish tissue samples analyzed from each of the lakes and ponds in 2010 from the Bien Hoa Airbase and its vicinity were above Health Canada consumption guidelines (20 ppt for edible fish tissue). Fish tissues sampled from market places outside the Airbase (Gate 2 Market and Bien Hoa Market) did not exceed Health Canada consumption guidelines. Results from the 2010 sampling program are provided in Table 3.8, and discussed the following sections.

### 3.2.1 Z1 Area

In November 2010, Tilapia were collected from Z1 Lake, located south of the main hotspot, on the southern perimeter of the Airbase. Muscle tissue from a composite of 13 small Tilapia from the Z1 Lake had a TEQ concentration of 18.9 ppt (wet weight), which was below the Health Canada consumption guideline. Fat tissue taken from the same Tilapia composite had an extremely high TEQ concentration (1,440 ppt; 97.9% TCDD), indicating Agent Orange as the source of the contamination. Whole fish tissue (full body composite analysis) taken from a composite of 8 small Tilapia from Z1 Lake also had a very high TEQ of 96.5 ppt (TCDD 98.1% of the TEQ).



Source: Hatfield Consultants



**Table 3.8 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in fish tissue samples (pg/g [ppt] wet weight), Bien Hoa, Viet Nam, November 2010.**

Sample ID	Location	Fish Species (Common Name)	Tissue Type	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
<i>NE Perimeter</i>																		
10VNBH500	Mr. San Lake	Tilapia	Muscle	1.4	1.4	<0.0499	<0.0499	<0.0499	NDR 0.105	0.253	0.4	0.0574	<0.0499	<0.0499	<0.0499	1.5	1.49	94.0
10VNBH501	Mr. San Lake	Tilapia	Fat	73.3	76.9	<0.494	3.6	9.59	40.1	15.7	24.4	3.49	<0.494	0.854	1.46	76.3	76	96.4
10VNBH502	NE Perimeter	Tilapia	Muscle	14.4	14.4	<0.0501	<0.0501	<0.0501	0.0945	3.41	3.8	0.0696	<0.0501	<0.0501	<0.0501	14.8	14.8	97.3
10VNBH503	NE Perimeter	Tilapia	Fat	1620	1630	17.2	3.09	2.63	3.63	487	472	18.3	0.512	<0.460	<0.460	1680	1680	96.4
<i>Northern Perimeter</i>																		
10VNBH504	Mr. Quy Lake	Tilapia	Muscle	25.4	25.5	0.187	0.053	0.105	0.504	2.53	3.02	<0.0455	<0.0455	<0.0455	<0.0455	25.9	25.9	98.1
10VNBH505	Mr. Quy Lake	Tilapia	Fat	2410	2410	27.7	10.7	15.4	25.4	306	310	21.5	1.25	<0.497	0.776	2460	2460	98.0
<i>Pacer Ivy Area</i>																		
10VNBH509	Mr. Hoc Lake	Tilapia	Muscle	31.2	31.2	0.072	<0.0485	<0.0485	0.0886	2.21	2.85	0.0517	<0.0485	<0.0564	<0.0485	31.5	31.5	99.0
10VNBH510	Mr. Hoc Lake	Tilapia	Fat	3990	4000	14.4	7.74	3.65	8.48	339	334	10.7	<0.461	<0.461	<0.461	4040	4040	98.8
10VNBH521	Pacer Ivy Lake	Tilapia	Whole Fish	618	618	4.07	6.92	5.14	8.69	2.81	4.54	0.323	0.1	0.285	0.333	622	622	99.4
<i>Z1 Area</i>																		
10VNBH516	Z1 Lake	Tilapia	Muscle	18.6	18.6	0.123	<0.0487	0.069	0.0852	1.65	1.91	<0.0487	<0.0487	<0.0487	<0.0487	18.9	18.9	98.4
10VNBH517	Z1 Lake	Tilapia	Fat	1410	1420	16.4	3.93	3.19	10.4	158	183	17	1.03	<0.494	<0.494	1440	1440	97.9
10VNBH522	Z1 Lake	Tilapia	Whole Fish	94.7	95.8	2.08	3.52	11.6	57.9	7.64	11.7	4.06	1.5	1.82	1.96	96.5	96.5	98.1
<i>Outside Airbase</i>																		
10VNBH507	Gate 2 Lake	Tilapia	Muscle	32.7	32.7	0.233	0.081	0.08	0.226	2.76	3.75	0.129	<0.0496	<0.0496	<0.0496	33.2	33.2	98.5
10VNBH508	Gate 2 Lake	Tilapia	Fat	1490	1490	13.8	5.82	3.56	3.73	162	189	5.69	0.807	<0.393	<0.393	1520	1520	98.0
10VNBH512	Gate 2 Market	Tilapia	Muscle	NDR	<0.0499	<0.0499	<0.0499	0.059	0.123	NDR	0.066	<0.0499	<0.0499	<0.0499	<0.0499	0.0837	0.0782	NC
10VNBH513	Gate 2 Market	Tilapia	Fat	0.0862	4.66	1.17	1.56	1.93	2.69	0.0530	2.01	6.95	1.78	<0.492	<0.492	4.78	4.54	55.3
10VNBH514	Bien Hoa Market	Tilapia	Muscle	NDR	<0.0500	<0.0500	0.05	<0.0500	0.0899	0.065	0.114	<0.0500	<0.0500	<0.0525	<0.0500	0.0911	0.0856	NC
10VNBH515	Bien Hoa Market	Tilapia	Fat	0.117	3.29	5.49	1.55	1.57	1.5	3.55	2.85	5.75	4.64	<0.481	<0.481	6.21	5.9	55.8
10VNBH518	Bien Hung Lake	Tilapia	Muscle	1.25	1.25	<0.0500	<0.0500	<0.0500	0.0622	0.526	0.603	<0.0500	<0.0500	<0.0596	<0.0500	1.36	1.35	92.6
10VNBH519	Bien Hung Lake	Tilapia	Fat	86.7	86.7	<0.468	<0.468	2.32	39.2	44.8	53.6	1.44	<0.468	1.07	1.13	91.9	91.8	94.4

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Large comp. = A composite sample of the 6 largest Tilapia collected.

Small comp. = A composite sample of the 6 smallest Tilapia collected.

■ Red shading indicates value exceeds Health Canada consumption guideline 2009 - 20 pg/g TEQ in edible fish.

### **3.2.2 Pacer Ivy Area**

In 2010, fish muscle, fat and whole fish tissues were sampled from 'Mr. Hoc Lake' and 'Pacer Ivy Lake' in the Pacer Ivy Area. All fish tissue samples analysed from this area exceeded Health Canada consumption guideline of 20 ppt. In 'Mr. Hoc Lake', a composite of Tilapia (n=3) were analyzed for dioxins in muscle and fat tissues. The muscle sample had a TEQ concentration of 31.5 ppt (99% TCDD), while the fat tissue sample exhibited an extremely high TEQ of 4,040 ppt (98.8% TCDD). A composite of 15 Tilapia sampled from the small pond north of 'Mr. Hoc Lake' also had a high TEQ (622 ppt), with TCDD making up 99.4% of the TEQ. Given that all samples exhibited a TCDD to TEQ proportion of 98% or greater indicates that Agent Orange is the source of contamination.

### **3.2.3 Northeastern Perimeter**

Fish muscle and fat tissues were sampled from 'Mr. San Lake' and the 'NE Perimeter Lake 1' in the northeastern Airbase in 2010. A composite of 6 Tilapia were sampled from each lake. The muscle tissue sample analysed from 'Mr. San Lake' had a low TEQ concentration (1.49 ppt). The fat tissue had a higher TEQ (76 ppt), and a proportion of TCDD to the TEQ concentration of 96.4%, indicating Agent Orange as the source of contamination. In 'NE Perimeter Lake 1', the TEQ concentration in the fat tissue was extremely high (1,680 ppt). TCDD comprised 96.4% of the TEQ concentration in the fat tissue, again indicating that Agent Orange is the source of contamination.

### **3.2.4 Northern Perimeter**

In 2010, fish samples were collected from 'Mr. Quy Lake' near the northern perimeter of the Bien Hoa Airbase. Muscle and fat tissues sampled from a composite of 3 Tilapia from this lake exceeded Health Canada consumption guidelines of 20 ppt for dioxins. Muscle tissue of the Tilapia composite exhibited a TEQ concentration of 25.9 ppt, while the fat tissue was extremely high (2,460 ppt TEQ). The proportion of TCDD in the TEQ of muscle and fat tissues were 98.1% and 98%, respectively, clearly indicating Agent Orange as the source of contamination in this lake.

### **3.2.5 Bien Hoa City (Lakes and Markets)**

Tilapia were sampled from 'Gate 2 Lake', Bien Hung Lake, Gate 2 Market, and Bien Hoa Market, located outside the Airbase in Bien Hoa City. Muscle and fat tissue samples collected from a composite of 5 Tilapia from 'Gate 2 Lake' (outside the southern perimeter of the Airbase) exhibited TEQ concentrations well above Health Canada consumption guideline of 20 ppt. Muscle tissue had a TEQ concentration of 33.2 ppt (98.5% TCDD), and the fat tissue had a TEQ of 1,520 ppt (98% TCDD). In Bien Hung Lake, the Tilapia composite (n=2) sample exhibited a low TEQ concentration in muscle tissue (1.35 ppt), but a high concentration in fat tissue (91.8 ppt). TCDD comprised 92.6% of the TEQ in muscle tissue and 94.4% in the fat tissue, indicating Agent Orange as the contaminant source.

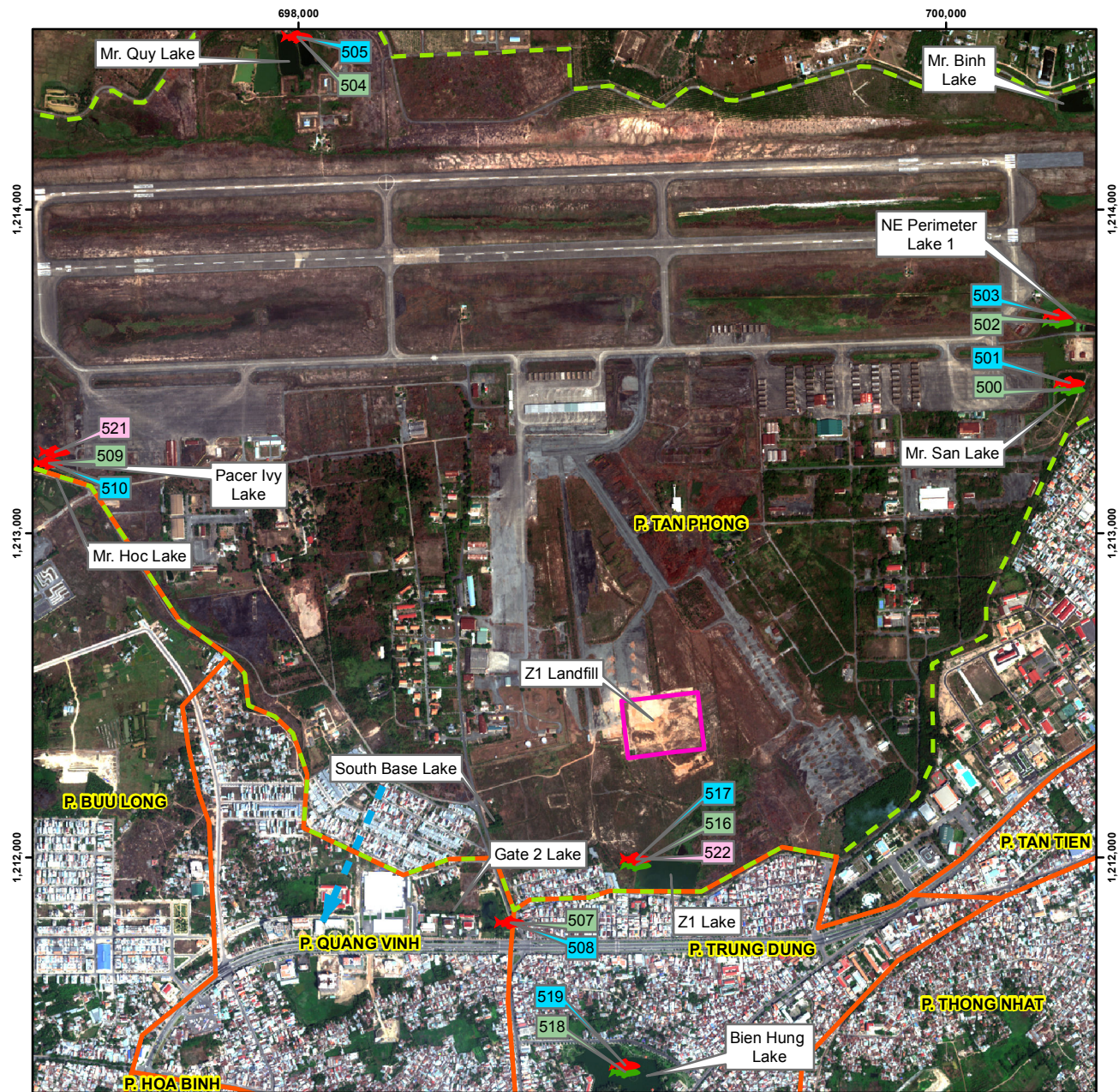
Fish sampled in Gate 2 Market and Bien Hoa Market exhibited low TEQ concentrations. Muscle tissues sampled from both markets had very low TEQ concentrations (NDR 0.0782 ppt from Gate 2 Market and NDR 0.0856 ppt from Bien Hoa Market). Fat tissues sampled had slightly higher TEQ concentrations: 4.54 ppt (55.3% TCDD) from Gate 2 Market and 5.9 ppt (55.8% TCDD) in Bien Hoa Market. These concentrations are lower than Health Canada guidelines. It is likely that these fish, sampled from the markets, originated from aquaculture ponds in the Don't Nai River (according to interviews with the market sellers). However, considering that Tilapia sampled inside the Bien Hoa Airbase exhibited extremely high TEQ concentrations, and fish caught inside the Airbase are sold in outside markets, the cultivation and sale of fish from the Airbase should be prohibited immediately.



Source: Hatfield Consultants



**Figure 3.7 Fish sampling locations, Bien Hoa Airbase and Bien Hoa City, Viet Nam, November 2010.**



**Legend**

- Direction of runoff
- Airport Boundary
- Ward Boundary
- Landfill
- 502 Fat Tissue Samples
- 503 Muscle Tissue Samples
- 504 Whole Fish Samples

**Fish:**

- Concentrations exceed Health Canada Guideline\*\*
- Concentrations below Health Canada Guideline\*\*
- 2010 (Hatfield/Office 33)

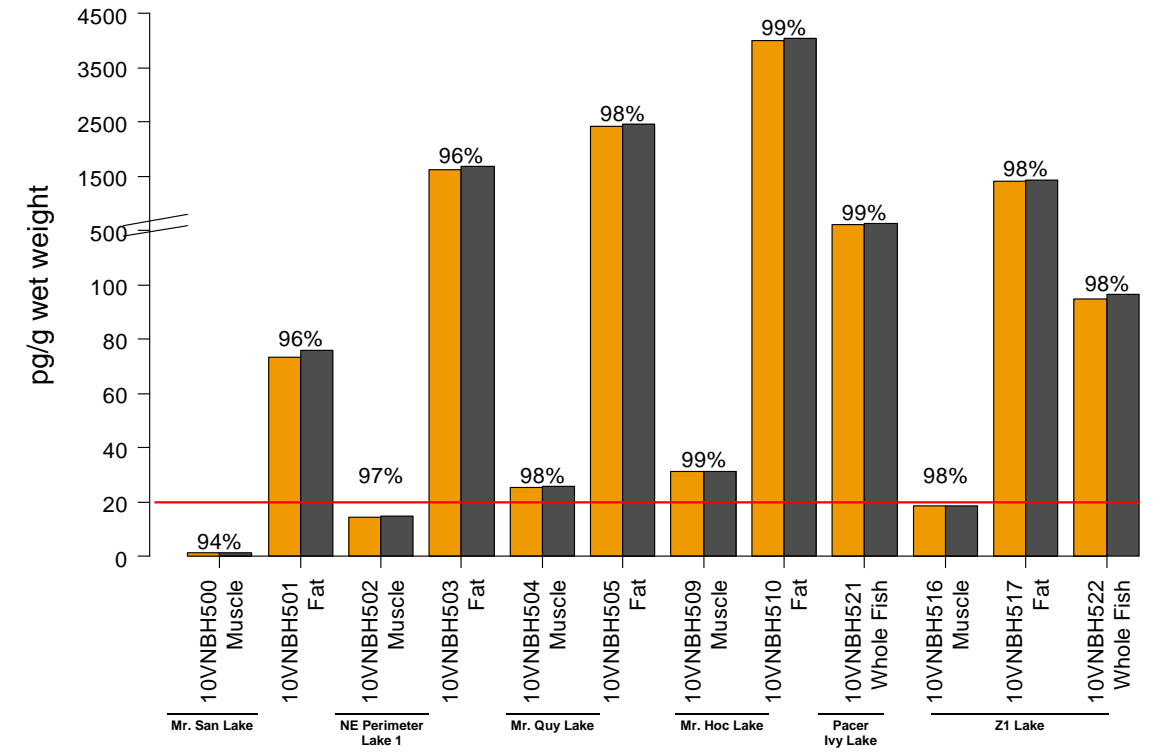
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Scale: 1:20,000  
Projection: WGS 1984 UTM Zone 48N

**Hatfield CONSULTANTS**

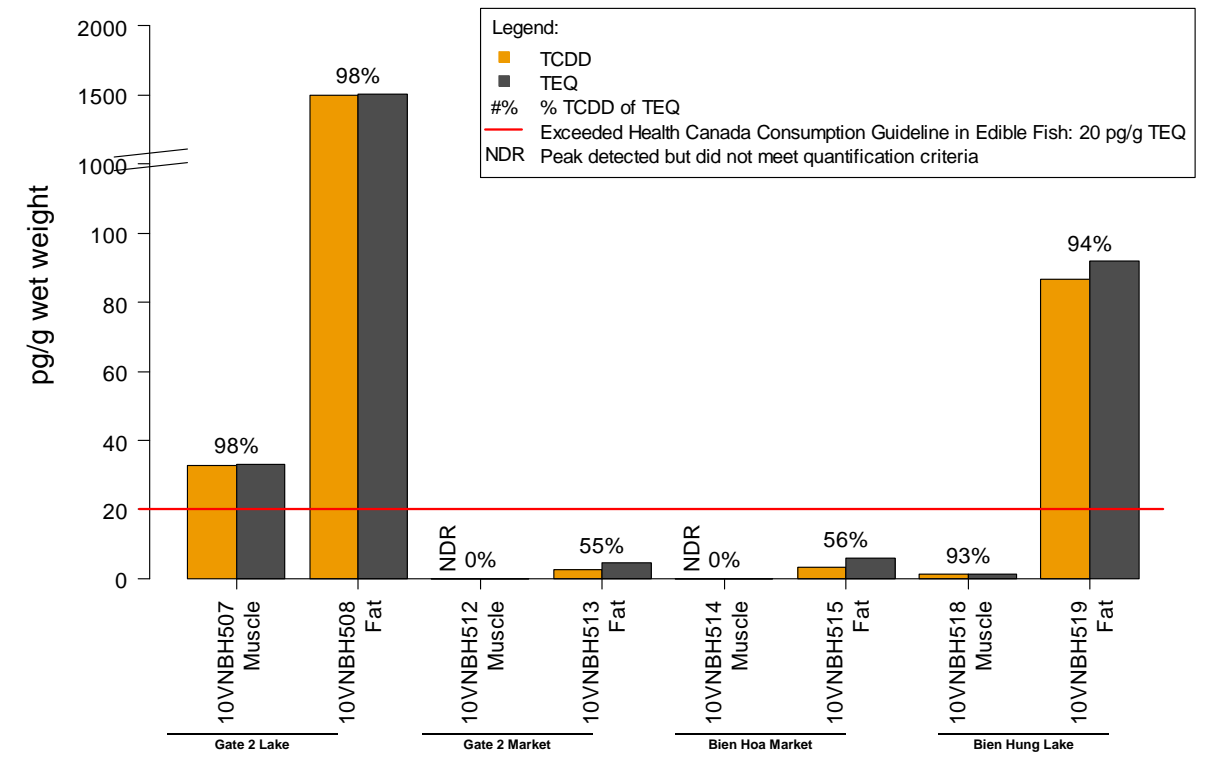
**Viet Nam**

Data Sources:  
a) Image acquired from World View 2010  
b) Sampling Locations from Hatfield/VRTC and 10-80  
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008

**TCDD (pg/g wet weight, TEQ (pg/g) and percent TCDD of TEQ in talapia fish samples collected inside the Bien Hoa Airbase, Viet Nam, November 2010.**



**TCDD (pg/g wet weight, TEQ (pg/g) and percent TCDD of TEQ in talapia fish samples collected from Bien Hoa City, Viet Nam, November 2010.**





### 3.2.6 Comparison with Da Nang Results (2006 and 2009)

Studies conducted by Hatfield/Office 33 in Da Nang in 2006 and 2009 (Hatfield/Office 33 2007, 2009) found that Sen Lake A, located in the northern part of the Da Nang Airport, downstream of the main dioxin hotspot areas, exhibited the highest recorded total TEQ in fish fat in Viet Nam to date. In 2009, Tilapia fat taken from a composite of 6 large Tilapia (average weight 439.8 g) exhibited contaminant concentrations as high as 8,350 ppt TEQ and 7,920 ppt TCDD. Muscle (88.2 ppt TEQ), egg (1,290 ppt TEQ), and liver (1,540 ppt TEQ) tissues analysed from the composite of large Tilapia in Sen Lake all exceeded Health Canada guidelines. In 2006, Tilapia fat tissues analysed from the north Airport also exhibited very high TEQ values (3,120 ppt). Fish sampled from the rest of the lakes and ponds inside the airport generally remained below the Health Canada guideline.

In Bien Hoa, Tilapia sampled from all lakes and ponds inside and outside the Airbase exhibited very high contaminant concentrations in fat tissue, well exceeding the designated Health Canada guideline. In 2010, the highest recorded fish TEQ level in Bien Hoa was found in fat tissue of a Tilapia composite (n=3) in 'Mr. Hoc Lake', Pacer Ivy Area (4,040 ppt TEQ; 3,990 ppt TCDD). Muscle samples from 'Mr. Quy Lake' (25.9 ppt TEQ), 'Mr. Hoc Lake' (31.5 ppt TEQ) and 'Gate 2 Lake' (33.2 ppt TEQ) exhibited TEQ values exceeding Health Canada consumption guidelines. In the 2010 samples collected from lakes inside and outside the Airbase (market places excluded), over 90% of the TEQ was attributed to TCDD. Only the fish sampled from Gate 2 Market and Bien Hoa Market exhibited contaminant concentrations below the Health Canada guideline.

Fish sampling results from Da Nang Airport (Hatfield/Office 33 2007, 2009) and the 2010 Bien Hoa Study are comparable. Dioxin concentrations in Tilapia fat tissue sampled from Sen Lake A (8,350 ppt TEQ and 7,920 ppt TCDD) in Da Nang Airport remains the highest recorded in Viet Nam to date; Tilapia fat tissue sampled from 'Mr. Hoc Lake' in Bien Hoa Airbase (2010) recorded the second highest TEQ value (4,040 ppt). Dioxin contamination in fish from the Da Nang Airport appears to be concentrated in the northern part of the airport, in Sen Lake A and other surrounding lakes located near former hotspot areas. In Bien Hoa, very high dioxin levels are detected in fish sampled from lakes and ponds throughout the Airbase and its vicinity, indicating more widespread contamination.

### 3.2.7 Summary of Fish Data

The Pacer Ivy Area had the highest level of dioxin contamination in bottom sediments of all water bodies sampled, both inside and outside of Bien Hoa Airbase. Consequently, fish captured in 'Mr. Hoc Lake' from this area contained the highest level of TCDD recorded in biological tissues (4,040 ppt in fat; Table 3.8). This value exceeds the Health Canada guideline by >200 times. Extremely high levels of dioxins were also recorded in fish fat from lakes in the northern perimeter, northeastern perimeter, Z1 Area, and Bien Hoa City. Fish

muscle from three of the six lakes sampled ('Mr. Quy Lake', 'Mr. Hoc Lake' and 'Gate 2 Lake') exhibited TEQ values exceeding the Health Canada guideline. Fish sampled from marketplaces outside the Airbase in Bien Hoa City had comparatively low TEQ concentrations in 2010 (NDR 0.0856 ppt for muscle and 5.9 ppt for fat).

In the northern perimeter of the Airbase, fish samples taken from 'Mr. Quy Lake' indicate high contaminant exposure. The TEQ in fish fat was 2,460 ppt, which is >120 times greater than the Health Canada guideline, while the TEQ in muscle (25.9 ppt) also exceeds this guideline. In the Z1 Area (Z1 Lake), the TEQ values in sampled fish fat tissue were 72 times greater than the guideline, while the whole fish tissue exceeded the guideline by 4.8 fold. Fat tissue sampled from the northeastern perimeter of the Airbase also exhibited high TEQ concentrations: 76 ppt in 'Mr. San Lake' (3.8 times greater than guideline) and 1,680 ppt in 'NE Perimeter Lake 1' (84 times greater than guideline).

Given that the Bien Hoa Airbase has a general south sloping topography, dioxins are likely carried through runoff to lakes and ponds located in the south and southeast of the Airbase. As expected, fish sampled from 'Gate 2 Lake' exhibited high TEQ concentrations in both fat and muscle tissues. Fish from Bien Hung Lake also exhibited a high TEQ in fat tissue.

Dai *et al.* (1994b) and Cau *et al.* (1994) reported that by 1998, dioxins had decreased significantly in southern Viet Nam and levels in foodstuffs were considered comparable to those for other nations. However, both authors offered the generalization that residual dioxin contamination in specific locations nonetheless remained a threat to human health in Viet Nam. Hatfield and 10-80 (2000) also confirmed high TCDD levels in fish fat from Aluoi District, in former bomb craters used as aquaculture ponds.

An estimated 25 tons of fish are harvested from lakes and ponds inside the Bien Hoa Airbase every year (Appendix A3.3). Our data confirm extremely elevated levels of TCDD for fish from all lakes and ponds sampled inside the Bien Hoa Airbase and in Bien Hoa City. Health Canada has specific guidelines for consumable tissues. If, for example, fat tissue exceeds 20 ppt TEQ, an assessment of consumption and probable restrictions on intake would be determined for the species of fish involved. Given the fish data presented above, it is suggested that all of the lakes and ponds sampled on Bien Hoa Airbase and immediate vicinities be assigned total fishing/consumption bans.

### **3.3 HUMAN BLOOD SERUM**

#### **3.3.1 Results and Discussion**

In 2010, dioxins and furans were analyzed in blood serum from a total of 42 residents of Bien Hoa. Blood donors were sampled from Tan Phong Ward inside the Airbase and Trung Dung Ward to the south of the Airbase in Bien Hoa City. All of the sampled residents (or families of residents) were involved in various occupations inside the Airbase, including working for MND, airport workers, fishermen and farmers. Blood data were collected from 37 male workers

and 5 female workers. Table 3.9 and Figure 3.8 summarize dioxin/furan concentrations in human serum samples collected from workers inside the Bien Hoa Airbase. All serum data are presented on a lipid basis.

Human serum data were collected and analysed for the first time in Bien Hoa under the current study. Schecter *et al.* (2001) collected and analysed 20 whole-blood samples from individuals residing in Bien Hoa City, near the potentially contaminated Bien Hung Lake. Whole-blood samples were also analysed in and around the Da Nang Airport by Hatfield/Office 33 (2007, 2009).

Dioxin and furan data in serum samples were analysed against the WHO's Acceptable Exposure Guidelines calculated based on 1998 Tolerable Daily Intake (see Section 1.4.4). A guideline value of 30 ppt in human serum lipid corresponds to a chronic intake of 4 pg/kg/day. This guideline is used to determine TEQ concentration exceedances.

Among the 42 serum samples analysed from Bien Hoa residents in 2010, three (3) samples recorded extremely high TCDD concentrations. The highest contamination was recorded in serum sample 10VNBH633 (1,970 ppt TCDD; 2,020 ppt TEQ) belonging to an Airbase worker (male) involved in aquaculture and fishing near the Pacer Ivy Area, Bien Hung Lake, South Base Lake and Z1 Lake, and wetlands. His spouse (10VNBH637) recorded the second highest TCDD concentration of 1,130 ppt (1,150 ppt TEQ). A serum sample from another Airbase worker (10VNBH604) also exhibited a high dioxin concentration (1,040 ppt TCDD and 1,080 ppt TEQ). TEQ concentrations in these three samples are more than 35 times the WHO 1998 standard (30 ppt). TCDD comprised over 96% of the TEQ in all three serum samples, indicating Agent Orange as the source of contamination.

An additional 38 serum samples (34 males and 4 females), excluding those discussed above, exhibited serum TEQ concentrations exceeding the WHO 1998 acceptable standard; their TEQ concentrations ranged from 31.2 to 347 ppt. Only one sample (10VNBH610) recorded a TEQ value below the WHO 1998 guideline (19.3 ppt).

The percent TCDD of the TEQ ranged from 56.4% to 98.3%. Workers with lower concentrations of TCDD generally exhibited a lower percent TCDD of TEQ. Other dioxin congeners were present in all serum samples analysed in 2010. However, percent TCDD of TEQ remained relatively high for all Airbase workers (TCDD  $\geq$  56% of TEQ), indicating that Agent Orange exposure remains the likely primary source of contamination for these individuals.



**Table 3.9 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in human blood serum (pg/g [ppt], lipid basis) from workers at Bien Hoa Airbase, November 2010.**

Sample ID	Sex	Age	PCDD (pg/g lipid basis)					PCDF (pg/g lipid basis)					% Lipid	TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)		
			2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF					Total H7CDF	Total O8CDF
10VNBH600	M	45	27.8	27.8	5.87	28.4	62.1	402	< 0.709	< 0.709	6.78	19	16.7	NDR 0.732	0.86	42.7	41.5	67.0
10VNBH601	F	46	58	58	10.7	32	25.6	282	1.52	1.52	8.15	18.9	10.5	< 0.720	0.86	78	76.6	75.7
10VNBH602	M	48	42.1	42.1	8.33	28.8	17.2	225	0.978	0.978	9.29	22.3	11.3	< 0.595	0.94	60.7	58.8	71.6
10VNBH603	M	47	137	137	< 0.701	27.6	29.3	319	NDR 1.40	< 0.701	7.49	17.5	12.1	NDR 0.724	0.87	146	145	94.5
10VNBH604	M	42	1040	1040	25.1	46.7	39.4	275	1.57	1.57	14.1	17.4	23.6	NDR 0.902	0.81	1080	1080	96.3
10VNBH605	M	47	37.7	37.7	5.05	18.5	25.7	346	NDR 1.21	< 0.564	5.88	20	15	< 0.564	1.1	50.1	49	76.9
10VNBH606	M	50	92.8	92.8	9.81	33.3	29.4	249	NDR 1.32	< 0.752	9.93	22.1	17.7	NDR 1.80	0.89	113	111	83.6
10VNBH607	M	47	40.9	40.9	6.21	17.9	11.6	105	1.34	1.34	< 0.564	13.1	6.3	< 0.564	1.1	50.7	50.7	80.7
10VNBH608	M	48	29.9	29.9	4.22	7.27	18.6	109	NDR 0.867	< 0.667	4.71	11.8	7.12	< 0.667	0.9	38.8	37.9	78.9
10VNBH609	M	48	17.6	17.6	7.45	20.7	< 1.12	280	1.55	1.55	6.56	16.3	9.82	< 1.12	0.78	32.5	31.2	56.4
10VNBH610	M	46	13.7	13.7	< 1.09	12.9	25	212	NDR 1.60	< 1.09	5.56	14	11.4	< 1.09	0.63	20.3	19.3	71.0
10VNBH611	M	45	56.5	56.5	6.53	25.5	33.4	214	NDR 1.27	< 0.670	7.24	18.9	13	< 0.670	0.82	71.7	70.2	80.5
10VNBH612	M	47	79	79	11.8	50.8	72.6	596	1.8	1.8	12.8	30.6	22.2	< 0.688	0.9	106	104	76.0
10VNBH613	M	48	53.3	53.3	9.52	47.2	21.6	370	0.526	0.526	9.99	22.3	12.5	NDR 0.666	1.5	75	73.2	72.8
10VNBH614	M	43	327	327	9.04	29.5	72.1	596	3.05	3.05	10.3	35.4	23.4	1.22	0.9	349	347	94.2
10VNBH615	M	46	42.8	42.8	9.82	36.9	42.5	377	2.36	3.11	12.2	28.8	17.1	< 0.610	1	66.2	63.9	67.0
10VNBH616	M	48	45.9	45.9	8.55	33.6	66.2	558	NDR 1.12	< 0.754	< 0.754	23.3	12.9	< 0.754	1.1	61.3	61.3	74.9
10VNBH617	M	47	322	322	12.1	43.2	61.4	547	NDR 1.24	< 0.903	9.81	8.58	29.6	< 0.903	0.71	345	343	93.9
10VNBH618	M	45	67.8	67.8	8.37	25.2	42.4	331	1.53	1.53	8.62	10.5	15.6	< 0.654	0.98	84.9	83.3	81.4
10VNBH619	M	46	38.9	38.9	5.19	18.8	17.5	223	NDR 1.01	< 0.711	5.75	14.6	13.1	< 0.711	0.8	50.8	49.7	78.3
10VNBH620	M	48	32.4	32.4	7.26	22.7	20.4	202	< 0.913	1.1	6	14.1	11.3	< 0.913	0.7	46.8	45.7	70.9
10VNBH621	M	45	95.8	95.8	7.66	22.2	28.6	237	1.01	1.59	6.61	14.4	7.68	0.791	1.2	111	110	87.1
10VNBH622	M	48	274	274	14.9	57.9	77.8	663	NDR 2.64	< 1.04	14	35.5	35	NDR 1.73	0.71	306	303	90.4
10VNBH623	M	47	67.7	67.7	7.6	23.9	14.1	211	1.4	1.4	8.15	18.8	1.01	< 0.719	0.89	84	82.4	82.2
10VNBH624	M	45	72.1	72.1	8.8	36	45	314	NDR 1.47	1.25	< 1.09	22.8	23	< 1.09	0.64	87.9	87.8	82.1
10VNBH625	M	46	44.1	44.1	6.62	22.3	27.4	208	2.29	2.29	7.35	18	< 0.500	0.55	1.2	59	57.5	76.7
10VNBH626	F	46	31.9	31.9	< 0.989	17.5	15.2	261	1.91	3.26	< 0.989	7.5	10.1	< 0.989	0.76	35.8	35.8	89.1
10VNBH627	M	48	71	71	8	31.5	28.8	330	1.98	1.98	10.5	28	19	< 1.44	0.52	91.1	89	79.8
10VNBH628	M	53	159	159	9.43	33.2	33.9	295	4.09	4.09	< 1.02	< 1.02	< 1.04	< 1.02	0.73	173	173	91.9
10VNBH629	F	61	160	160	11.8	31.6	34	260	4.66	4.66	7.02	8.96	8.21	< 0.781	1.1	180	179	89.4
10VNBH630	M	45	85.4	85.4	< 1.49	24.7	28.2	240	NDR 1.99	< 0.864	< 0.864	14.8	14.1	< 1.13	0.8	90.9	90.8	94.1
10VNBH631	M	50	49.5	49.5	4.57	16.9	15.8	182	1.07	1.07	7.26	17.2	8.8	< 0.692	1.1	61.1	59.9	82.6
10VNBH632	M	48	211	211	10.7	30	35.4	311	1.75	1.75	9.07	19.2	10.1	< 0.527	1.5	232	230	91.7
10VNBH633	M	49	1970	1970	34.2	61.4	21.6	163	1.51	1.51	11.4	14.2	8.57	NDR 0.763	0.89	2020	2020	97.5
10VNBH634	M	45	87	87	< 0.970	13.5	24.1	158	1.8	1.8	6.52	16.1	11.8	< 0.970	0.64	94.4	93.1	93.4
10VNBH635	M	47	67.1	67.1	4.75	12.4	12.8	131	2.38	2.38	< 0.536	9.83	5.09	< 0.536	1.7	74.7	74.7	89.8
10VNBH636	M	48	161	161	13.4	44	54.3	449	2.76	2.76	< 0.969	28.3	14.5	< 0.969	0.67	183	183	88.0
10VNBH637	F	38	1130	1130	17.6	44.3	32.8	332	3.24	4.88	< 1.20	10.7	17.6	NDR 1.41	0.51	1150	1150	98.3
10VNBH638	M	48	28.1	28.1	6.79	26.3	36.2	392	NDR 1.03	< 0.989	9.11	29.9	18.5	1.03	0.8	45.8	44.1	63.7
10VNBH639	F	47	102	102	9.54	38.2	60.8	802	1.13	1.13	6.99	19	17.3	1.31	0.77	122	121	84.3
10VNBH640	M	48	34.4	34.4	5.98	22.8	33.3	339	1.78	1.78	6.43	12.3	20.6	< 0.892	0.73	48	46.7	73.7
10VNBH641	M	48	119	119	8.52	38.1	44.3	486	1.13	1.13	8.5	31	22.9	NDR 0.978	0.85	140	138	86.2

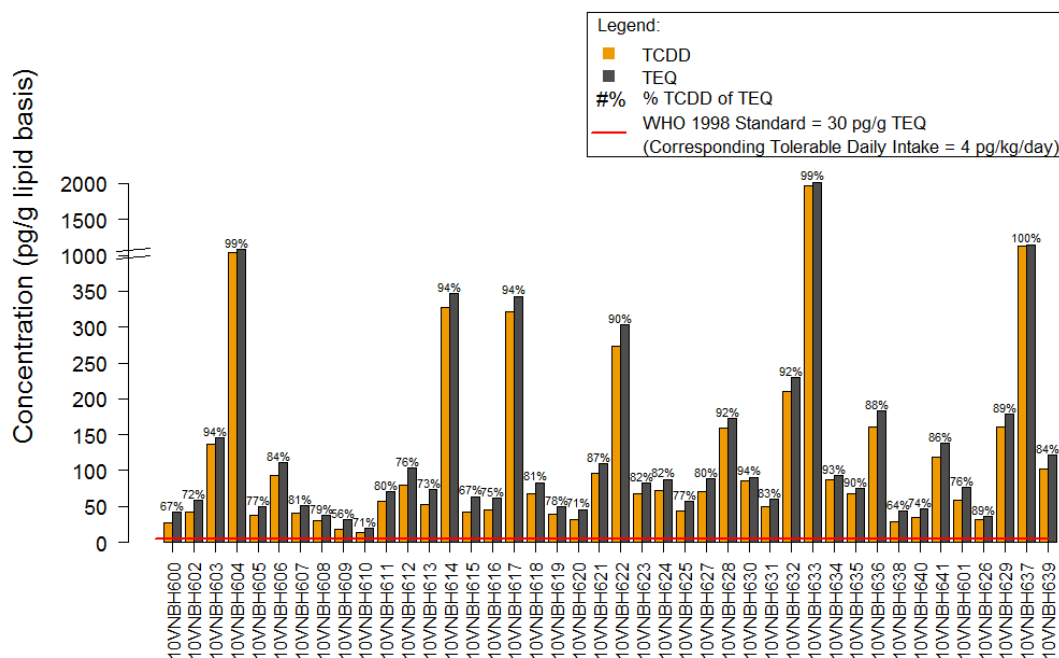
ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

Lipid calculations based on "independent" or "factored" analysis (see Appendix A1).

■ Red shading indicates value exceeds the World Health Organization Acceptable Exposure Guidelines (1998) for TCDD in Serum Lipid - 30 ppt corresponding to a chronic intake of 4 pg/kg/day (upper limit).

**Figure 3.8 TCDD and total TEQ (pg/g [ppt], lipid basis) for human blood serum, Bien Hoa, Viet Nam, November 2010.**



### 3.3.2 Statistical Analyses of Blood Data

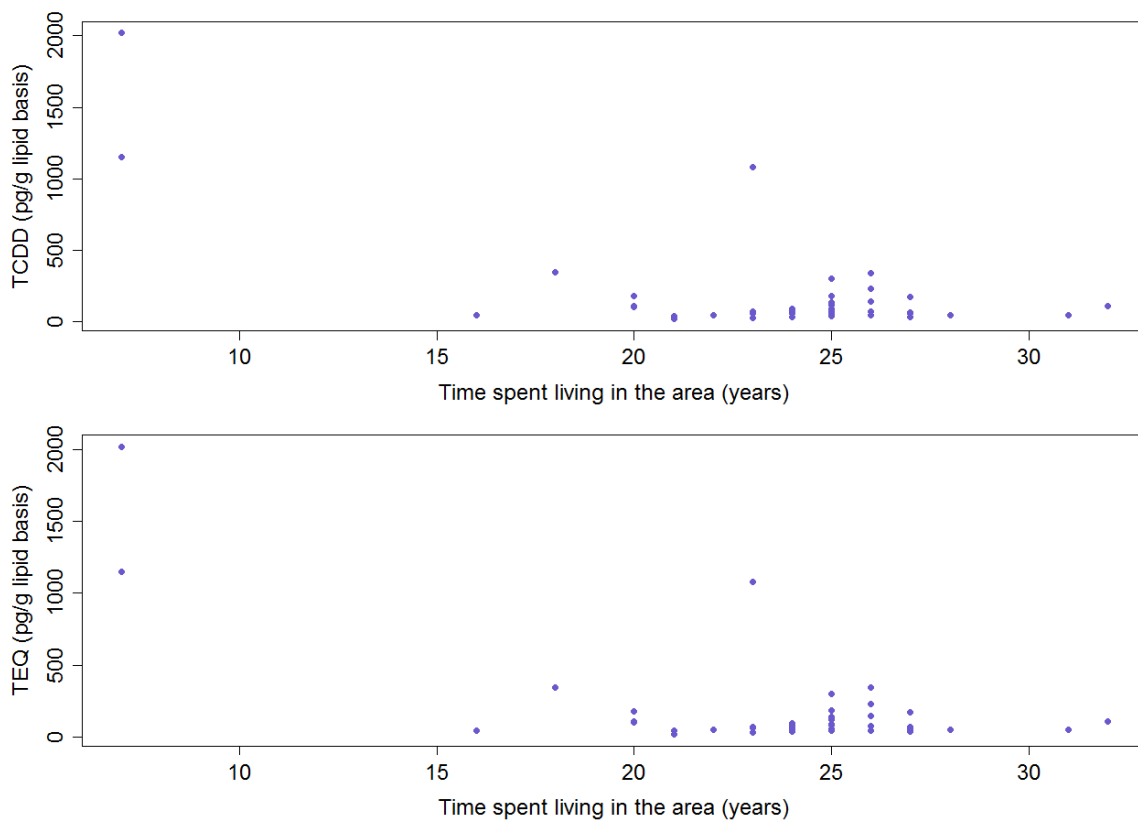
#### 3.3.2.1 Sex-related effects

Differences in the blood dioxin levels of males and females were tested using a Mann-Whitney U test. The results indicated no statistically significant difference in either serum TCDD or serum TEQ between males and females ( $p_{TCDD} = 0.4043$ ;  $p_{TEQ} = 0.4489$ ; data not shown).

#### 3.3.2.2 Effect of the Length of Stay in Bien Hoa Airbase and its Vicinity

The length of time an individual lived inside the Airbase or its vicinity may determine the length of exposure to dioxins. A Spearman's correlation test was carried out to identify a possible relationship between the length of stay in the Bien Hoa area and TCDD and TEQ concentrations in blood serum. A statistically significant correlation was not observed among the two variables ( $p_{TCDD} = 0.6406$ ;  $p_{TEQ} = 0.5631$ ). These results indicate that the length of residence at Bien Hoa Airbase and its vicinity does not affect the dioxin levels in blood serum (Figure 3.9).

**Figure 3.9 Relationship between the length of stay at the Bien Hoa Airbase and its vicinity and blood serum TCDD and TEQ (pg/g [ppt], lipid basis) of individuals in Bien Hoa, November 2010.**



Source: Hatfield Consultants

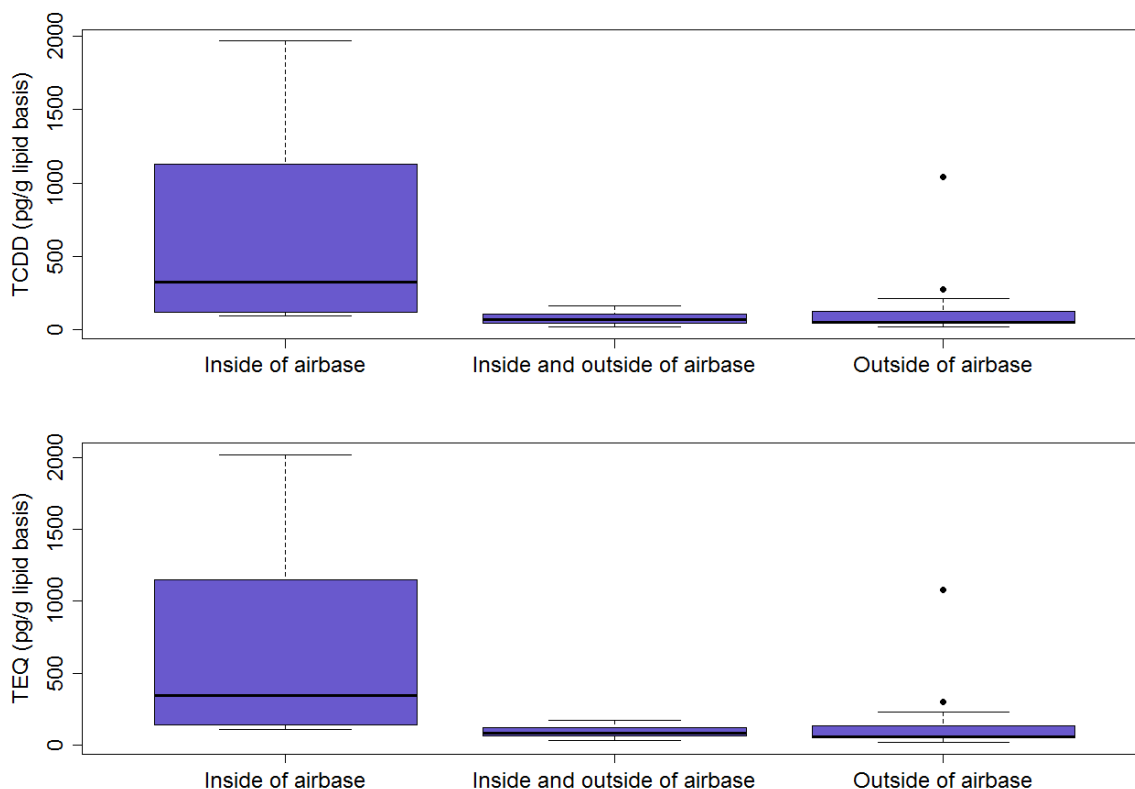
### 3.3.2.3 Effect of the Length of Employment on the Airbase

A potential relationship between the serum dioxin concentrations of individuals and the number of years they have worked on the Airbase were analysed through Spearman's correlation test. No significant correlation was found between the number of years working in the Airbase and the blood serum TCDD or TEQ values ( $p_{TCDD}= 0.4209$ ;  $p_{TEQ}= 0.4386$ ).

### 3.3.2.4 Effects of Fishing Location

The present study found high levels of dioxin contamination in Tilapia fat tissues sampled from lakes inside and immediately to the south of the Airbase (see Section 3.2). A Kruskal Wallis Test was carried out to identify a difference in TCDD and TEQ concentrations in individuals fishing in various locations inside and outside the Airbase. A statistically significant difference was found in both TCDD and TEQ concentrations in individuals fishing in lakes inside the Airbase, both inside and outside the Airbase, and only outside the Airbase ( $p_{TCDD}= 0.0098$ ;  $p_{TEQ}= 0.0093$ ). Figure 3.10 shows that individuals fishing exclusively inside the Airbase exhibit higher average TCDD and TEQ concentrations, compared to those who fish both inside and outside the Airbase, and only outside the Airbase.

**Figure 3.10** Locations of fishing sources and blood serum TCDD and TEQ (pg/g [ppt], lipid basis) of individuals in Bien Hoa, November 2010.

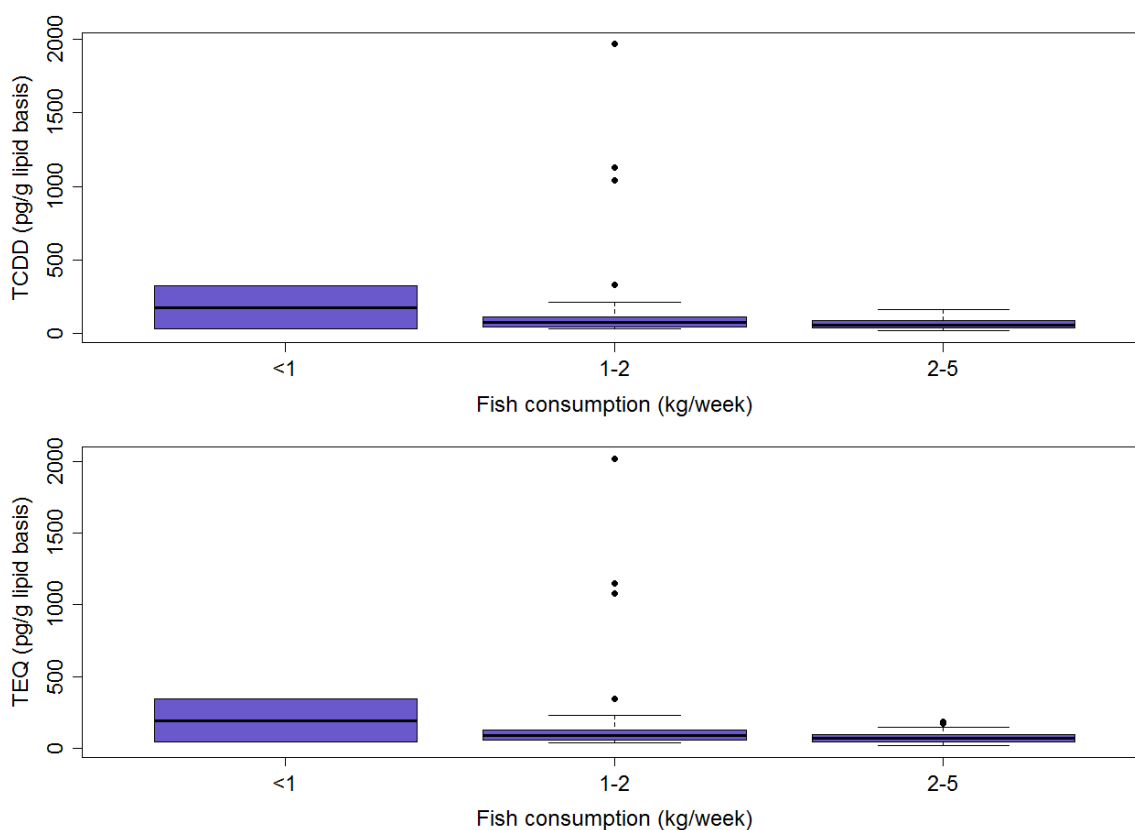




### 3.3.2.5 The Effect of the Amount of Fish Consumed

Serum dioxin levels were expected to be higher in individuals consuming greater amounts of fish from the Bien Hoa Airbase and its vicinities. A Kruskal Wallis test was carried out to compare TCDD and TEQ concentrations in serum samples between individuals consuming less than 1 kg of fish per week, 1 to 2 kg/week, and 2-5 kg/week (Figure 3.11). No statistically significant difference in TCDD and TEQ concentrations was found between individuals consuming different amounts of fish ( $p= 0.3350$ ). A similar result was observed when TEQ levels were tested ( $p= 0.3602$ ).

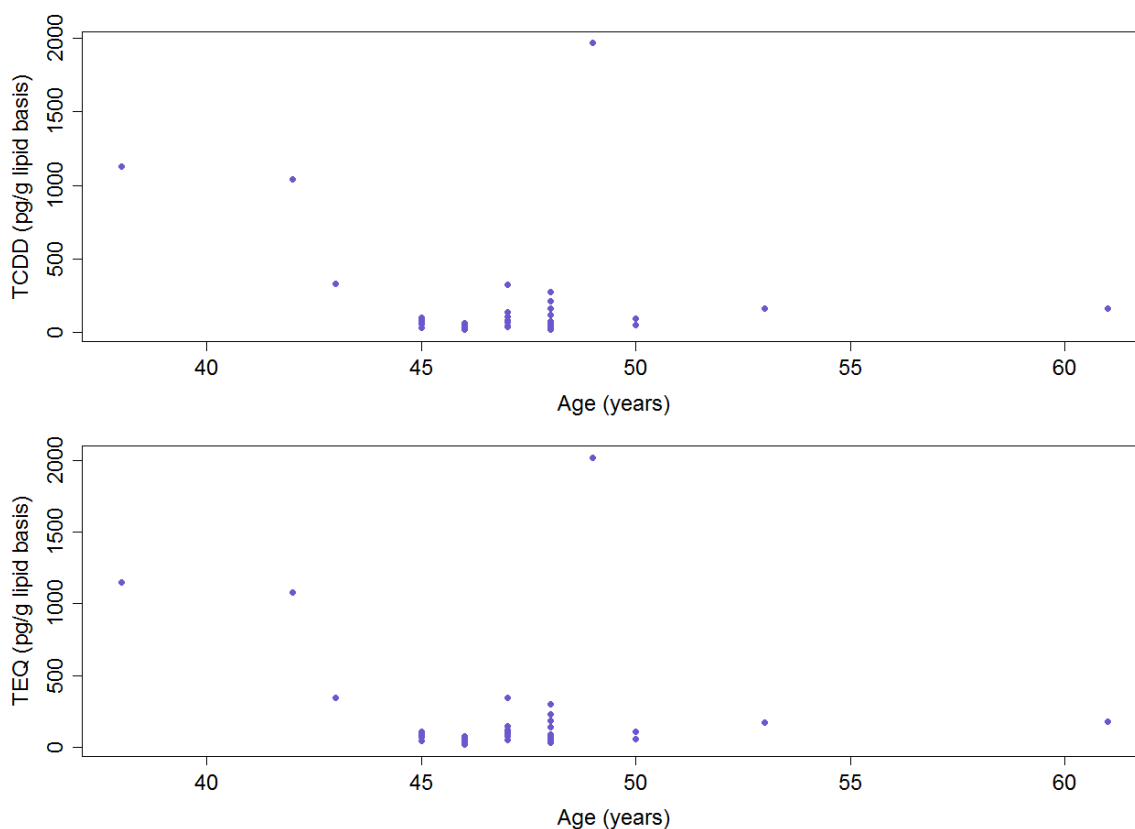
**Figure 3.11** The amount of fish consumed per week and blood serum TCDD and TEQ (pg/g [ppt], lipid basis) in individuals from Bien Hoa, November 2010.



### 3.3.2.6 Age-related Effects

If the source of dioxin is removed from the exposure pathway, concentrations decrease over time. On the other hand, continued consumption of dioxin contaminated food may result in an increase in concentrations over time. A Spearman's correlation test was carried out to test if TCDD and TEQ concentrations vary with age for individuals sampled in Bien Hoa in 2010. A statistically significant correlation was not observed between age of an individual and their serum TCDD or serum TEQ concentration ( $p_{TCDD} = 0.8652$ ;  $p_{TEQ} = 0.9232$ ) (Figure 3.12).

**Figure 3.12 Age versus blood serum TCDD and TEQ (pg/g [ppt], lipid basis) in individuals from Bien Hoa, November 2010.**



### 3.3.3 Summary of Blood Data

The typical range of TCDD in the general population of industrialized countries has been reported as 3 to 7 pg/g (lipid basis) (ATSDR 1998). ATSDR also indicated that TCDD in human blood rarely exceeds 10 pg/g and that typically, lower levels of this contaminant are recorded in less industrialized countries. In serum samples analysed at Bien Hoa Airbase, TCDD concentrations were all higher than 10 pg/g. The minimum TCDD concentration recorded in Bien Hoa (2010) is 13.7 pg/g; the maximum is 1,970 pg/g; and the median is 67.8 pg/g. All but one serum sample exceeded the WHO 1998 standard of 30 ppt, clearly indicating the penetration of Agent Orange dioxin into the aquatic ecosystem and food chain.

Potential predictors of high serum dioxin content were tested through a series of statistical tests. The results indicated a statistically significant difference between serum dioxin levels and the location of fishing activities. Individuals who consume fish caught exclusively inside the Bien Hoa Airbase exhibited higher average TCDD and TEQ values compared to those who consume fish caught from both inside and outside the Airbase, and compared to those who fish exclusively outside the Airbase. Statistically significant gender- and age-related effects on serum dioxin levels were not discovered. The amount of fish consumed per week, the length of employment in the Airbase, and the length of residence in the Bien Hoa area also did not affect serum dioxin levels.

This study reports the percent TCDD present in the TEQ as the marker for Agent Orange exposure given that it is the only dioxin/furan congener that was a contaminant in Agent Orange. TCDD is considered the most toxic dioxin/furan congener, and has a multiplier of "1" when calculating WHO 2005 TEQs.

Where the percentage of TCDD in the TEQ is low, there are several other dioxin and furan congeners that are primary contributors to TEQ calculations for human blood samples in this study. These include 1,2,3,7,8-PCDD (TEF = 1), 2,3,4,7,8-PCDF (TEF = 0.3), 2,3,7,8-TCDF and all hexa-dioxins and furans (TEF = 0.1). Note that although OCDD concentrations are quite high, the TEF is very low (0.0003), and the contribution of OCDD to TEQ is consequently low.

In samples where penta- and hexa-dioxins and furans contribute more to TEQ, sources of contamination may include biphenyls, PCBs, pesticides, or incineration. Polychlorinated dibenzo-P-dioxins and furans (PCDDs and PCDFs) are mainly the by-products of industrial processes (such as metallurgical processing, bleaching of paper pulp, and the manufacturing of some herbicides and pesticides), but they can also result from natural processes like volcanic eruptions and forest fires (Srogi 2008). Waste incineration, particularly if combustion is incomplete, is among the largest contributors to the release of PCDDs and PCDFs into the environment. Consumption of food is considered as the major source of non-occupational human exposure to PCDD/Fs with foodstuffs from animal origin accounting for more than 90% of the human body burden, with meat, dairy and fish products being the main contributors (Srogi 2008). Other potential dioxin sources in Bien Hoa need to be determined and quantified in order to verify the total dioxin load to the environment and human population.

## 3.4 BREAST MILK

### 3.4.1 Results and Discussion

Dioxins and furans were analyzed in human breast milk collected from a total of 22 female donors in Bien Hoa in 2010. A majority of the women (n=18) were from the Trung Dung Commune, located to the south of the Airbase; others were from Tan Phong (n=2), Tan Tien (n=1), and Hoa An (n=1). Breast milk samples were not collected and analyzed during previous Hatfield/10-80/VRTC field programs in Bien Hoa. All milk TCDD/TEQ data are provided on a lipid-normalized basis.

Of the 22 breast milk donors, twelve were breastfeeding their first infant (primiparous females), eight were feeding their 2<sup>nd</sup> infant, and two were with their 3<sup>rd</sup> infant (Table 3.11).

A milk sample (10VNBH803) collected from a mother in Tan Phong Ward (inside the Airbase) exhibited elevated TCDD (30.3 ppt) and TEQ (39.6 ppt) levels relative to all other samples collected in 2010. TCDD contributed 76.5% of TEQ, indicating Agent Orange as the likely main contributor to dioxin loading. This donor is known to have consumed fish from 'Gate 2 Lake' and 'Z1 Lake' on numerous occasions in the past, where high dioxin concentrations were recorded in Tilapia sampled in 2010.

Milk samples collected from two donors in Trung Dung Ward to the south of the Airbase also showed elevated dioxin concentrations. Sample 10VNBH804 exhibited a high TCDD of 22.5 ppt and a TEQ of 28.6 ppt; TCDD accounted for a large proportion (78.7%) of the contamination. Sample 10VNBH814 exhibited a TCDD level of 13.8 ppt and TEQ of 31.8 ppt. TCDD comprised 43.4% of the TEQ, indicating that other sources of dioxins contribute to overall contamination of this sample.

Fifteen (15) breast milk samples collected during the 2010 sampling program exhibited TCDD concentrations below 4 pg/g. Proportions of TCDD to the TEQ concentration in these samples were all below 50% (except 10VNBH808). Sample 10VNBH821 collected from Trung Dung Ward had a low proportion of TCDD in the TEQ concentration (12.2%). These results indicate that Agent Orange is not the sole source of dioxin contamination in breast milk sampled from this area. Other dioxin congeners also contribute to total TEQ values.



**Table 3.10 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in human breast milk from districts near the Bien Hoa Airbase (pg/g [ppt], lipid basis), Viet Nam, November, 2010.**

Sample ID	Age	PCDD (pg/g lipid basis)						PCDF (pg/g lipid basis)						% Lipid	TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
		2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF				
10VNBH800	34	8.21	8.21	2	6.17	7.12	44.7	0.584	0.699	3.79	8.95	4.03	0.146	9.61	13.4	12.8	64.1
10VNBH801	27	2.39	2.39	1.74	7.39	10	113	NDR 0.456	0.765	3.89	13.9	8.79	<0.306	6.14	8.22	7.54	31.7
10VNBH802	30	1.48	1.48	2.01	7.17	7.82	44.7	0.564	0.722	4.02	10.4	5.09	0.229	5.7	7.24	6.53	22.7
10VNBH804	21	22.5	22.5	2.7	6.53	14.1	106	NDR 0.917	13.4	3.74	13.3	1.32	<0.479	4.25	29.3	28.6	78.7
10VNBH805 <sup>1</sup>	39	< 12.3	NC	NC	NC	NC	70.3	< 6.74	NC	NC	NC	NC	<0.22	3.68	14.3	13.7	NC
10VNBH806 <sup>1</sup>	21	< 0.246	NC	NC	NC	NC	48.3	< 2.33	NC	NC	NC	NC	<0.246	3.58	1.86	1.55	NC
10VNBH807	28	2.94	2.94	5.07	16.3	17.3	153	< 0.787	0.812	5.99	11.6	8.88	<0.482	1.97	14.2	13	22.6
10VNBH808	28	3.11	3.11	< 0.434	2.87	8.17	54.2	NDR 0.837	0.518	3.39	7.61	< 0.558	0.398	2.51	6.25	5.58	55.7
10VNBH809	25	2.45	2.45	2.27	2.52	6.89	49.2	0.732	< 0.252	3.91	9.79	5.78	<0.252	3.96	8.16	7.39	33.2
10VNBH810	29	9.85	9.85	2.4	6.43	6.03	35.2	NDR 1.17	< 0.705	< 0.705	7.91	1.02	<0.705	1.96	14.1	14	70.4
10VNBH811	24	NDR 1.64	< 0.359	1.14	6.94	20.5	77.5	NDR 0.629	0.729	2.02	6.54	< 0.325	0.431	6.04	3.88	3.49	NC
10VNBH814	27	13.8	13.8	13.1	29.8	10.4	116	1.01	0.781	< 0.344	15.7	4.91	0.781	3.46	31.8	31.8	43.4
10VNBH816 <sup>1</sup>	23	1.37	NC	NC	NC	NC	35.4	< 5.38	NC	NC	NC	NC	<0.417	3.64	6.58	5.86	23.4
10VNBH817 <sup>1</sup>	27	< 0.815	NC	NC	NC	NC	47.5	< 8.71	NC	NC	NC	NC	<1.51	1.24	3.23	2.99	NC
10VNBH818	34	10.2	10.2	1.74	3.94	5.61	30	NDR 0.744	0.992	1.86	5.09	2.18	<0.263	4.03	13.9	13.5	75.6
10VNBH819	38	1.72	1.72	2.21	5.76	7.48	60.8	NDR 0.592	< 0.425	2.74	7	4.14	<0.425	1.86	6.79	6.25	27.5
10VNBH820	25	3.2	3.2	1.17	6.22	12.9	111	0.361	0.509	2.55	8.68	6.96	<0.168	4.7	7.19	6.78	47.2
10VNBH821	24	0.773	0.773	1.87	11.2	18.2	94.9	0.244	0.378	3.12	13.9	6.09	0.218	11.9	6.92	6.32	12.2
10VNBH803	29	30.3	30.3	4.25	28.7	113	182	NDR 0.437	0.714	4.84	9.88	0.873	<0.314	2.52	40.4	39.6	76.5
10VNBH812	26	8.99	8.99	1.67	5.72	7.88	63.2	NDR 0.818	1.04	3.08	5.87	3.57	<0.312	2.69	13.1	12.7	70.8
10VNBH813	34	2.27	2.27	1.46	5.51	6.68	58.4	0.859	0.978	2.81	6.34	4.84	<0.274	4.19	6.33	5.87	38.7
10VNBH815	28	2.31	2.31	3.11	10.1	23	104	NDR 0.854	0.552	5.22	14.8	8.14	<0.397	1.99	10.9	9.83	23.5

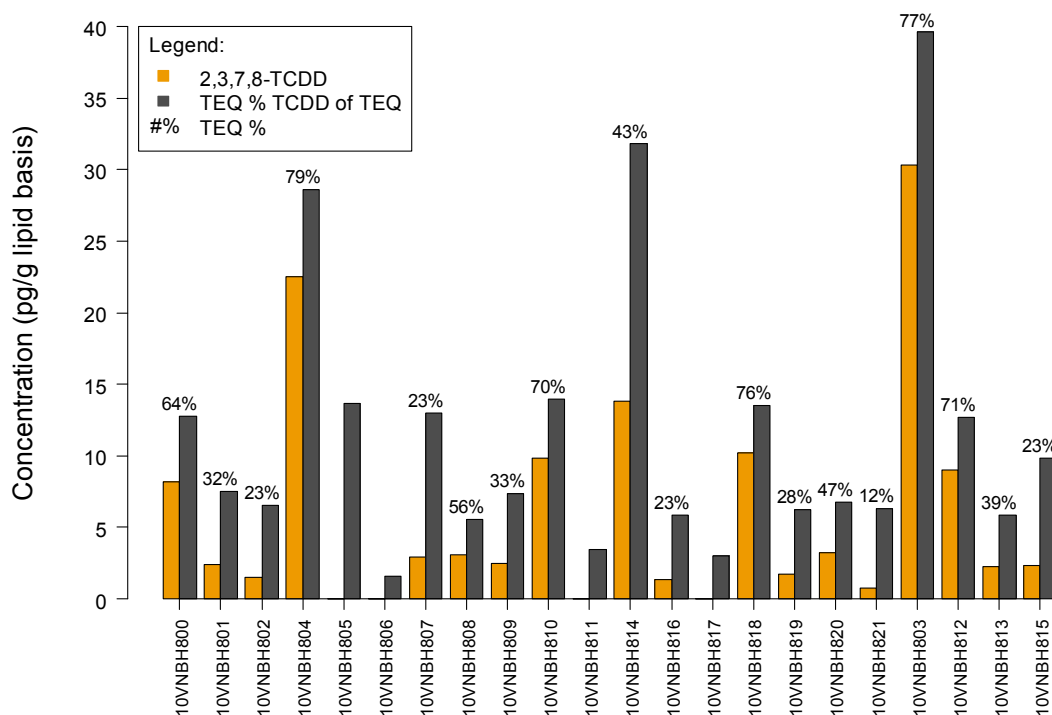
<sup>1</sup> Additional clean up was not successful; therefore, only the 2,3,7,8-TCDD and -TCDF values were reported with confidence. As the reported congeners have non-zero TEFs, the TEQ for each sample remains unaffected.

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

NC = Not calculated.

**Figure 3.13 TCDD and Total TEQ (pg/g [ppt], lipid basis) in human breast milk for Bien Hoa Airbase and Bien Hoa City, November 2010.**

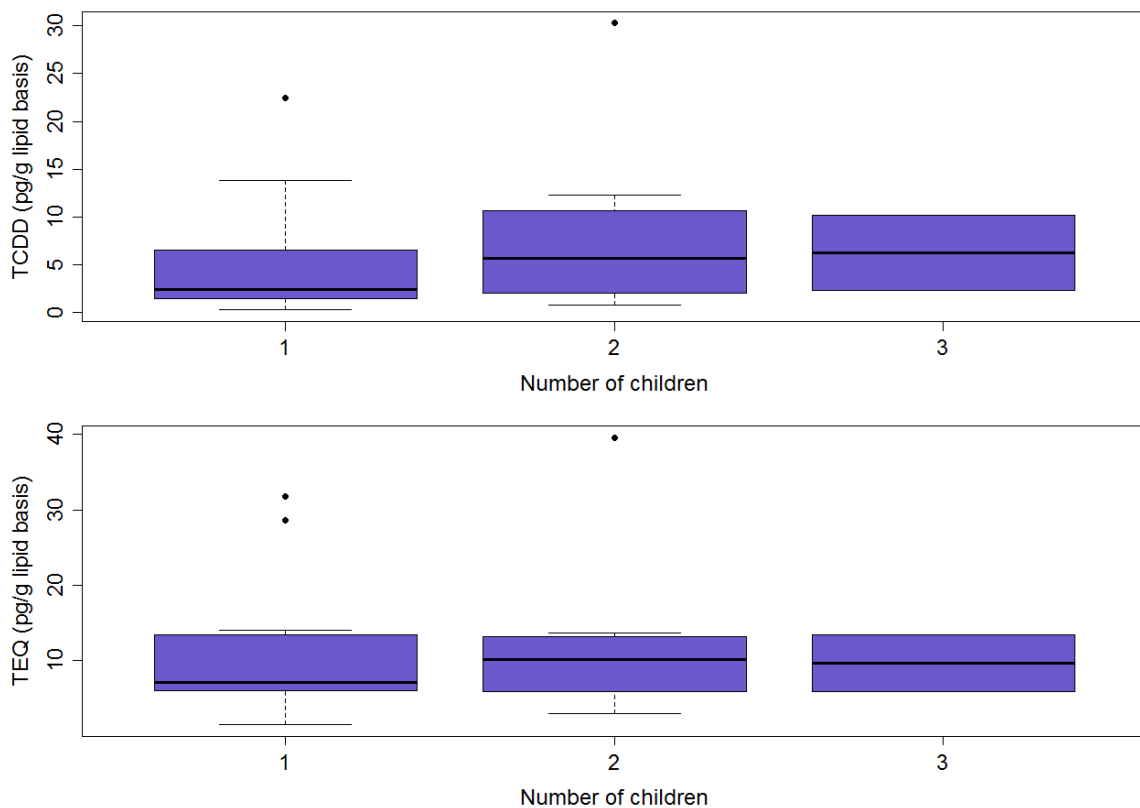


### 3.4.2 Statistical Analysis of Breast Milk Data

#### 3.4.2.1 The Effect of Multiple Child Births

There is evidence that the first child is exposed to higher concentrations of PCDDs/Fs than second and later children (Fürst *et al.* 1989). Whether the number of children affects the mother's TCDD and TEQ concentrations (pg/g lipid basis) was statistically tested. No significant differences in the TCDD and TEQ were found between mothers who were nursing their first, second, and third child in Bien Hoa area ( $p_{TCDD} = 0.5182$ ;  $p_{TEQ} = 0.929$ ) (Figure 3.14)

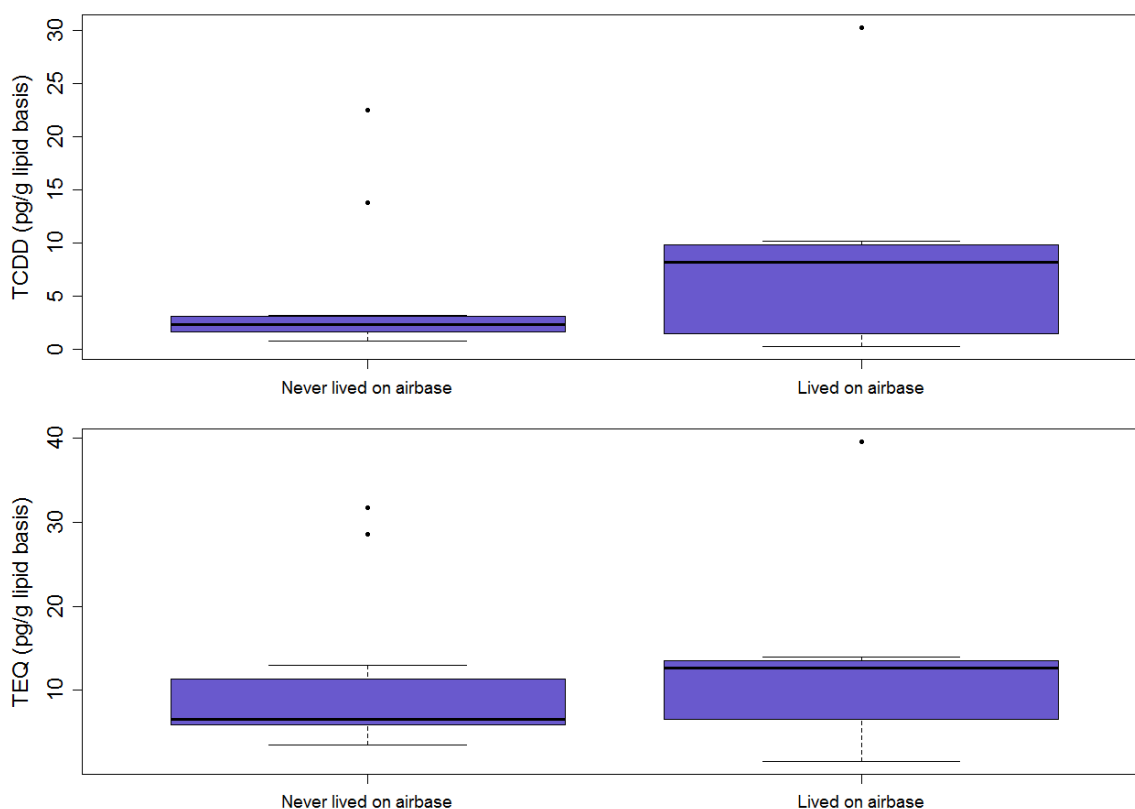
**Figure 3.14 Breast milk TCDD and TEQ (pg/g [ppt], lipid basis) for mothers nursing their first, second and third infant in Bien Hoa, November 2010.**



### 3.4.2.2 The Effect of Residing Inside the Airbase

Given the high dioxin concentrations observed inside the Bien Hoa Airbase, it is assumed that women who have lived inside the Airbase exhibit higher TEQ concentrations than women who have not, because they would likely be eating more fish from the lakes on the Airbase. Breast milk TCDD and TEQ concentrations were compared between women who have lived on the Airbase and those who have not (Figure 3.15). No statistically significant difference in TCDD and TEQ were found between the two groups ( $p_{TCDD} = 0.6242$ ;  $p_{TEQ} = 0.9700$ ).

**Figure 3.15 Breast milk TCDD and TEQ (pg/g [ppt], lipid basis) for mothers who have resided inside the Bien Hoa Airbase and those who have not, November 2010.**

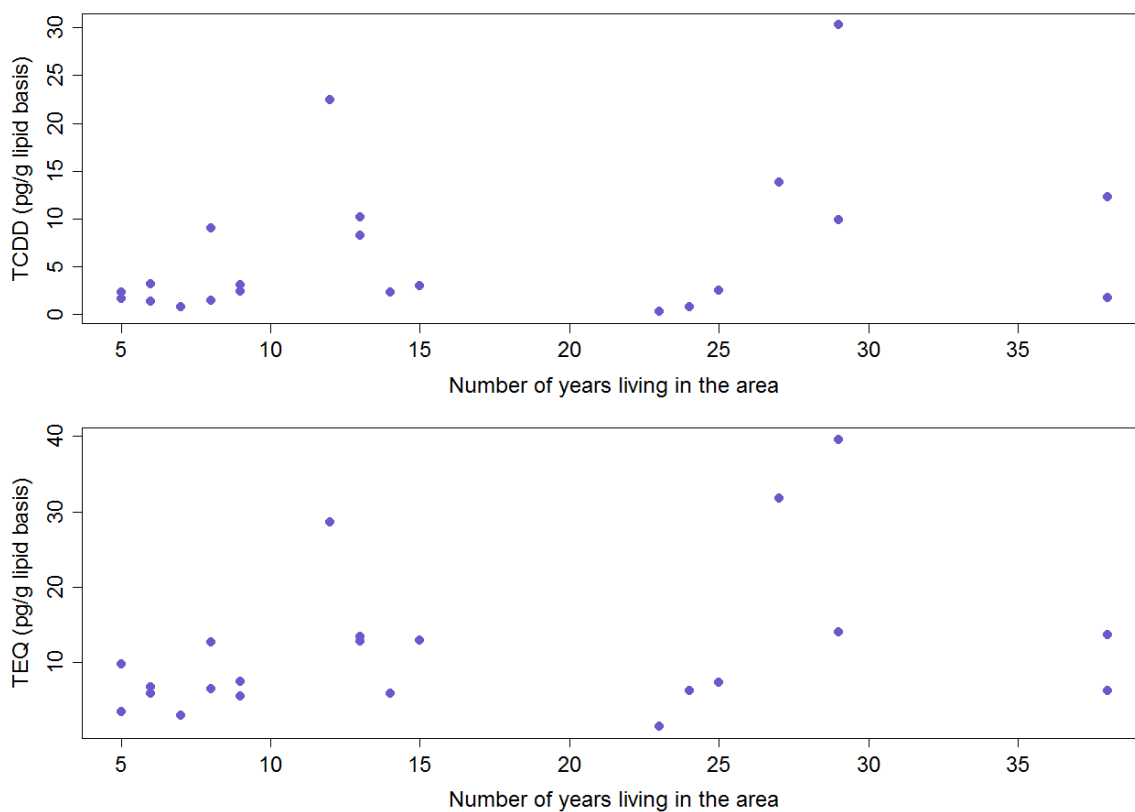




### 3.4.2.3 The Effect of the Length of Stay in the Bien Hoa Airbase and Its Vicinity

A statistical test was carried out to identify a possible correlation between the length of stay in the Bien Hoa area and the TCDD and TEQ concentration in breast milk (Figure 3.16). No statistically significant correlation was observed among the two variables for TCDD ( $p=0.3044$ ) and TEQ concentrations ( $p=0.2099$ ) and the length of stay, indicating that the length of residence at Bien Hoa Airbase and its vicinity does not affect dioxin levels in breast milk.

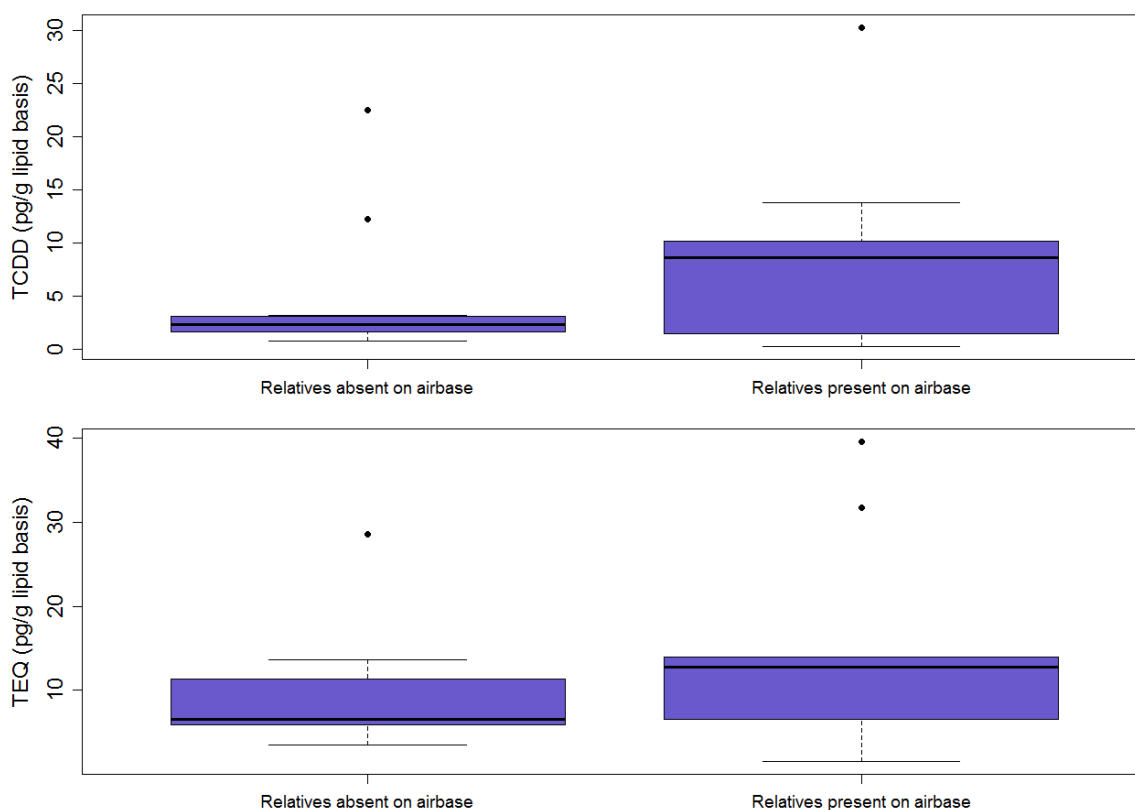
**Figure 3.16 Relationship between the length of stay at the Bien Hoa Airbase and its vicinity and breast milk TCDD and TEQ (pg/g [ppt], lipid basis), November 2010.**



### 3.4.2.4 Effect of Relatives on the Airbase

Higher breast milk dioxin levels are expected in women who have relatives living inside the Airbase, compared to those who do not, as they may receive fish, vegetables, and other aquatic plants/animals cultivated inside the Airbase, which may be contaminated with dioxins. Breast milk TCDD and TEQ concentrations were statistically tested for differences between women who have relatives living inside the Airbase and women who do not. No significant differences were found in TCDD or TEQ concentrations ( $p_{TCDD}=0.4424$  and  $p_{TEQ}=0.5286$ ) between the two groups (Figure 3.17).

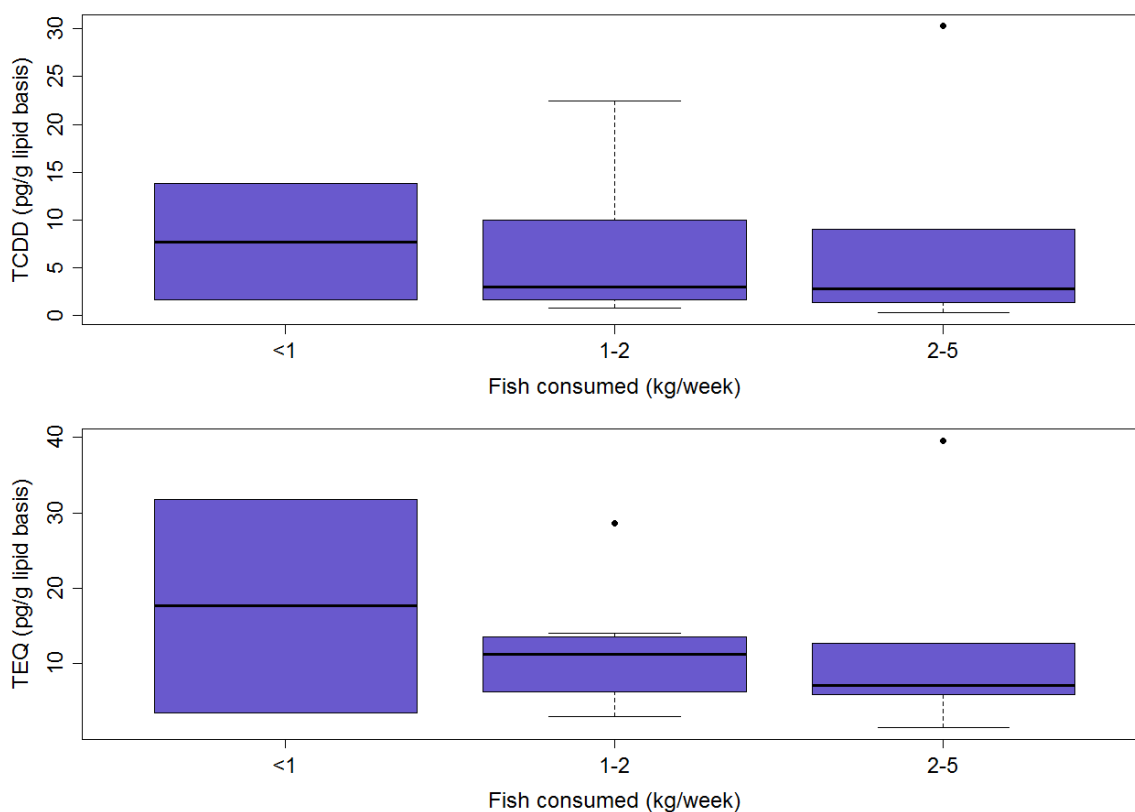
**Figure 3.17 Breast milk TCDD and TEQ (pg/g [ppt], lipid basis) in women with and without relatives living inside the Bien Hoa Airbase, November 2010.**



### 3.4.2.5 The Effect of the Amount of Fish Consumed

The present study found extremely high dioxin concentrations in Tilapia sampled from inside the Bien Hoa Airbase, and in lakes and ponds immediately to the south of the Airbase (see Section 3.2). An ANOVA test was carried out to compare TCDD and TEQ concentrations in breast milk samples between women who consume less than 1 kg of fish per week, 1 to 2 kg/week, and 2-5 kg/week (Figure 3.18). A statistically significant difference was not found in TCDD concentrations and the amount of fish consumed ( $p=0.8949$ ). A similar result was observed when TEQ levels were tested ( $p=0.8726$ ).

**Figure 3.18** The amount of fish consumed per week and breast milk TCDD and TEQ (pg/g [ppt], lipid basis) in women in Bien Hoa, November 2010.



### 3.4.3 Summary of Bien Hoa Breast Milk Data

The WHO acceptable standards (1 to 4 pg TEQ/kg bw/day) cover the range of established Tolerable Daily Intake PCDD/F exposures for several countries (as presented in Table 1.7). In Canada, the TDI has been reduced to 2.3 pg TEQ/kg bw/d (Health Canada 2005) from 10 pg TEQ/kg bw/d. The most highly exposed part of the population is breastfed infants, where exposure to PCDDs and PCDFs via ingestion can be higher, on a body weight basis, than during other periods in a person's life (Lakind 2007).

To assess the TEQ levels in breast milk recorded during the Bien Hoa 2010 Study, the Average Daily Intake (ADI) was calculated based on recommended parameters established by the WHO (WHO/EURO 1989). These parameters assume an infant weight of 5 kg, milk consumption by the infant of 700 ml/d, and a percent milk fat of 3.5%. Table 3.11 presents these calculations and the ADI based on actual milk fat (lipid) percentages by donor.

Utilizing the WHO parameters, all individual ADI values from the Bien Hoa study exceeded the 4 pg TEQ/kg bw/d WHO standard. The ADI was lowest with sample 10VNBH817, a mother from Trung Dung Ward, who was feeding her second child. The ADI was 5 pg TEQ/kg bw/d based on the actual lipid percent, and 14.7 pg TEQ/kg bw/d when the 3.5% WHO parameter was used. As reported in Section 1.4.4, breastfed babies often have a daily dioxin intake 1- to 2- times greater than adults, and can be as high as 35 pg I-TEQ/g milk fat in industrialized countries. The Tan Tien sample (10VNBH813) and samples 10VNBH809, 10VNBH816 and 10VNBH820 from Trung Dung Ward fall within this exposure level.

The ADI calculated with actual milk fat (lipid) for a mother from Trung Dung (10VNBH800) is the highest of those sampled in Bien Hoa in 2010 (172 pg TEQ/kg bw/d), followed by a sample from a young mother feeding her first child residing in the same ward (10VNBH804: 170 pg TEQ/kg bw/d). ADIs greater than 100 pg TEQ/kg bw/d were also observed for two other residents of Trung Dung and another from Tan Phong.

A series of statistical analyses were carried out to identify possible relationships between breast milk TCDD and TEQ concentrations, and historical, locational and consumption characteristics of sampled women. The analyses did not reveal statistically significant (at  $\alpha=0.01$ ) determinations of milk dioxin levels. An increase in sample size may yield different results.

Lakind (2007) reports that there appears to be a decline in global levels of PCDDs/Fs in human milk from the 1970s to 2005. However, the question of whether the presence of PCDDs/Fs in milk is from the lifetime accumulation of PCDDs/Fs in adipose tissue or current diet (or a combination of both) remains unanswered. There is evidence that the first child is exposed to higher concentrations of PCDDs/Fs than second and later children (Fürst *et al.* 1989).



**Table 3.11 Average daily intake<sup>1</sup> (pg TEQ/kg bw/d) of TCDD and Total-TEQ by infants consuming human breast milk<sup>2</sup> collected from females (first, second or third child), Bien Hoa 2010.**

Sample ID	Age	Infant # Currently Breast- feeding	% Lipid	2,3,7,8- TCDD	TEQ (WHO 2005) ND=1/2DL	Average Daily Intake			
						TCDD (actual lipid)	T-TEQ (actual lipid)	TCDD (3.5% lipid)	T-TEQ (3.5% lipid)
10VNBH800	34	2nd	9.61	8.21	12.8	110.5	172	40.2	62.7
10VNBH801	27	2nd	6.14	2.39	7.54	20.5	64.8	11.7	36.9
10VNBH802	30	1st	5.7	1.48	6.53	11.8	52	7.3	32.0
10VNBH804	21	1st	4.25	22.5	28.6	133.9	170	110.3	140.1
10VNBH805	38	2nd	3.68	< 12.3	13.7	NC	71	NC	67.1
10VNBH806	23	1st	3.58	< 0.246	1.55	NC	8	NC	7.6
10VNBH807	28	1st	1.97	2.94	13	8.1	36	14.4	63.7
10VNBH808	28	2nd	2.51	3.11	5.58	10.9	20	15.2	27.3
10VNBH809	25	1st	3.96	2.45	7.39	13.6	41	12.0	36.2
10VNBH810	29	1st	1.96	9.85	14	27.0	38	48.3	68.6
10VNBH811	24	1st	6.04	NDR 1.64	3.49	NC	30	NC	17.1
10VNBH814	27	1st	3.46	13.8	31.8	66.8	154	67.6	155.8
10VNBH816	23	1st	3.64	1.37	5.86	7.0	30	6.7	28.7
10VNBH817	27	2nd	1.24	< 0.815	2.99	NC	5	NC	14.7
10VNBH818	34	3rd	4.03	10.2	13.5	57.5	76	50.0	66.2
10VNBH819	38	2nd	1.86	1.72	6.25	4.5	16	8.4	30.6
10VNBH820	25	1st	4.7	3.2	6.78	21.1	45	15.7	33.2
10VNBH821	24	1st	11.9	0.773	6.32	12.9	105	3.8	31.0
10VNBH803	29	2nd	2.52	30.3	39.6	106.9	140	148.5	194.0
10VNBH812	26	2nd	2.69	8.99	12.7	33.9	48	44.1	62.2
10VNBH813	34	3rd	4.19	2.27	5.87	13.3	34	11.1	28.8
10VNBH815	28	1st	1.99	2.31	9.83	6.4	27	11.3	48.2

<sup>1</sup> Average daily intake = (volume of milk per day in ml)x(% lipid in milk/100)x(concentration of chemical in pg/g)/(infant weight in kg).

<sup>2</sup> Average daily intake via human milk based on an infant body weight of 5 kg and consuming 700 ml of milk per day (WHO/EURO 1989).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

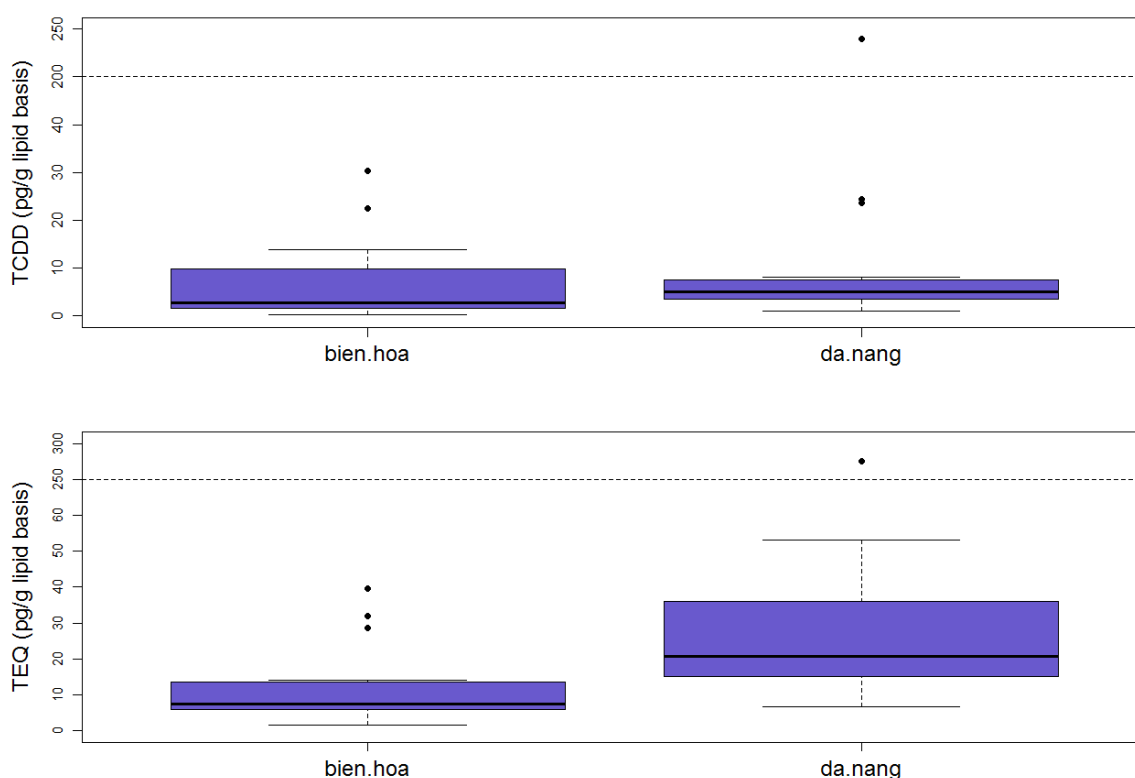
NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

NC = Not calculated.

### 3.4.4 Comparison with Da Nang Results (2007 and 2009)

Dioxins and furans were analysed in human breast milk collected from a total of 14 female donors in Da Nang during the Hatfield/Office 33 (2009) study. On average, the TCDD concentrations in breast milk samples collected in Da Nang were higher than samples analysed in Bien Hoa (2010); samples from Bien Hoa exhibited a mean TCDD concentration of 6.49 ppt with a standard deviation of 7.71 ppt, while samples from Da Nang exhibited a mean TCDD of 22.24 ppt with a standard deviation of 58.46 ppt. Distribution of TCDD and TEQ concentrations in Da Nang and Bien Hoa breast milk samples are shown in Figure 3.19.

**Figure 3.19** Box plot of breast milk TCDD and TEQ (pg/g [ppt], lipid basis) in Bien Hoa (2010) and Da Nang (2007 and 2009).



A milk sample collected from a relocated Sen Lake Worker from Da Nang exhibited very high TCDD (232 ppt) and TEQ (263 ppt) values; the highest TCDD and TEQ values observed in Bien Hoa are 30.3 ppt and 39.6 ppt, respectively. The ADI values calculated based on actual milk fat (lipid) percentages of donors exceeded the WHO acceptable standard (1-4 pg TEQ/kg bw/d) for all donors from the Da Nang 2009 Study (Hatfield/Office 33 2009) and the Bien Hoa 2010 Study. Five donors from Bien Hoa had ADI values exceeding 100 pg TEQ/kg bw/d, the highest recorded being 172 pg TEQ/kg bw/d. In Da Nang, nine (9) of the 15 breast milk samples analyzed exhibited ADI values exceeding 100 pg TEQ/kg bw/d, and the highest average daily intake was as high as 2,320 pg TEQ/kg bw/d for the same relocated Sen Lake worker.

### 3.5 QA/QC

#### 3.5.1 Environmental Samples

##### *Lab QA/QC*

AXYS performed a number of duplicate and replicate dioxin and furan analyses as part of the QA/QC for this project (Table 3.12). In most cases, soil, sediment and fish tissue duplicate samples were in close agreement, and were within acceptable levels of variability. A relatively high variability in TCDD (RPD=20.5%) observed in sample 08VNBH167 may be attributed to a slight variation in substrate composition of the soil sample.

##### *Field QA/QC*

QA/QC replicate samples were collected by Hatfield throughout the Airbase. Soil replicates were collected at the Pacer Ivy Area, Z1 Area, and the northeast perimeter; sediment replicates were collected from Z1 Area; and fish tissue replicates were collected for Tilapia whole fish sampled in Pacer Ivy Lake. The difference between replicates was calculated as a relative percent difference (RPD). RPDs calculated for TCDD were greater than 20% for soil collected at the Pacer Ivy Area (10VNBH230) and Z1 Area (10VNBH428). A high variability in TCDD in these two samples could be attributed to soil heterogeneity. All other replicates had RPDs below 20% for both TCDD and TEQ indicating good homogenization of samples, and a high level of confidence in lab analysis.

#### 3.5.2 Rinseate Water

Two samples were analyzed from rinseate water used to clean sampling equipment used in this study (Table 3.12). One sample, collected at the middle of the November 2010 Airbase sampling program (10VNBH706) did not have detectable levels of dioxins and furans. The second sample, collected at the end of the sampling program (10VNBH712), had similar results indicating no cross-contamination between sites.



Source: Hatfield Consultants

**Table 3.12 AXYS Lab and Hatfield Consultants QA/QC for dioxin and furan analyses, Bien Hoa, Viet Nam, November 2010.**

Sample ID	Location	Media	Depth (bgs) <sup>7</sup>	2,3,7,8-	1,2,3,7,8-	1,2,3,4,7,	1,2,3,6,7,	1,2,3,7,8,	1,2,3,4,6,7	OCDD	2,3,7,8-	2,3,7,8-	1,2,3,7,8-	2,3,4,7,8-	1,2,3,4,7,	1,2,3,6,7,	1,2,3,7,8,	2,3,4,6,7,	1,2,3,4,6,7	1,2,3,4,7,8,	OCDF
				TCDD	PeCDD	8-HxCDD	8-HxCDD	9-HxCDD	,8-HpCDD		TCDF	TCDF (C) <sup>8</sup>	PeCDF	PeCDF	8-HxCDF	8-HxCDF	9-HxCDF	8-HxCDF	,8-HpCDF	9-HpCDF	
<b>Field Duplicates</b>																					
10VNBH704	Pacer Ivv Area	Soil	0-15	61.9	< 2.96	< 4.33	NDR 4.52	< 4.33	NDR 25.3	168	9.89	NDR 8.30	< 3.85	< 3.85	< 4.41	< 4.41	< 4.41	< 4.41	< 2.98	< 2.98	NDR 4.17
10VNBH230				83.9	NDR 1.99	NDR 1.71	NDR 3.74	NDR 3.09	34	326	13.4	11.7	< 0.975	1.17	< 0.975	< 0.975	< 0.975	< 0.975	NDR 7.78	< 0.975	NDR 23.7
<b>RPD (%)<sup>1,2</sup></b>				<b>30.2</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>64.0</b>	<b>30.1</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>
10VNBH705	Pacer Ivv Area	Soil	30-60	54700	240	24.7	199	102	547	1390	1790	912	NDR 16.7	21.2	NDR 21.5	NDR 6.02	< 4.02	NDR 10.9	88.6	NDR 4.35	58.1
10VNBH237-2				61400	252	NDR 21.8	176	92	557	1910	1530	798	NDR 22.7	NDR 21.6	NDR 18.0	7.88	< 5.30	6.46	77.5	< 4.79	53.7
<b>RPD (%)<sup>1,2</sup></b>				<b>11.5</b>	<b>4.9</b>	<b>NC</b>	<b>12.3</b>	<b>10.3</b>	<b>1.8</b>	<b>31.5</b>	<b>15.7</b>	<b>13.3</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>13.4</b>	<b>NC</b>	<b>7.9</b>
10VNBH708	Z1 Area	Sediment	0-20	26.1	< 4.31	< 5.20	< 5.20	< 5.20	NDR 21.1	265	NDR 5.38	< 5.58	< 4.27	< 4.27	< 3.36	< 3.36	< 3.36	< 3.36	8.45	< 3.90	10.5
10VNBH428				33.9	NDR 7.77	10.3	NDR 11.2	NDR 8.47	38.3	342	6.02	2.92	NDR 2.92	NDR 4.61	6.96	6.48	< 3.35	NDR 8.80	6.17	NDR 5.87	14.4
<b>RPD (%)<sup>1,2</sup></b>				<b>26.0</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>31.2</b>	<b>NC</b>	<b>31.3</b>
<b>Trip Blanks</b>																					
10VNBH710	Trip Blank	Sand		NDR 0.0718	< 0.0495	< 0.0495	< 0.0495	< 0.0495	0.234	2.89	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	0.0668	< 0.0495	NDR
<b>Laboratory Duplicates</b>																					
08VNBH167	Z1 Area	Soil	0-10	985	11.1	2.59	19	NDR 11.9	126	921	48.3	33.9	< 2.17	< 2.17	NDR 2.11	1.08	< 0.898	NDR 1.00	19.1	NDR 1.26	24.4
08VNBH167 (Duplicate)				1210	15.1	4.94	20.5	12.7	156	1130	53.7	37.1	1.14	NDR 2.05	2.53	1.45	< 0.994	1.47	21.8	NDR 1.37	34.2
<b>RPD (%)<sup>1,2</sup></b>				<b>20.5</b>	<b>30.5</b>	<b>62.4</b>	<b>7.6</b>	<b>NC</b>	<b>21.3</b>	<b>20.4</b>	<b>10.6</b>	<b>9.0</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>29.2</b>	<b>NC</b>	<b>NC</b>	<b>13.2</b>	<b>NC</b>	<b>33.4</b>
08VNBH144	Z1 Area	Soil	0-10	34	3.91	< 4.04	7.29	< 4.04	NDR 84.1	1140	< 3.83	< 3.83	< 2.43	2.69	4.35	< 2.94	< 2.94	< 2.94	NDR 18.6	4.77	57.1
08VNBH144 (Duplicate)				29.1	< 2.95	NDR 2.72	NDR 4.49	< 2.19	90.3	1260	< 2.43	< 2.43	< 3.05	< 3.05	< 3.99	< 3.99	< 3.99	< 3.99	NDR 14.9	< 3.15	66.1
<b>RPD (%)<sup>1,2</sup></b>				<b>15.5</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>10.0</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>14.6</b>
10VNBH426	Z1 Area	Soil	0-10	111	3.3	5.95	15.6	14	416	3470	10.8	5.19	1.24	NDR 1.90	4.91	2.78	NDR 0.384	2.78	32.6	2.18	58.7
10VNBH426 (Duplicate)				114	3.43	6	17.7	14.8	482	3860	6.84	4.54	1.49	2.33	4.63	2.87	NDR 0.400	3.04	36.9	2.73	67.1
<b>RPD (%)<sup>1,2</sup></b>				<b>2.7</b>	<b>3.9</b>	<b>0.8</b>	<b>12.6</b>	<b>5.6</b>	<b>14.7</b>	<b>10.6</b>	<b>44.9</b>	<b>13.4</b>	<b>18.3</b>	<b>NC</b>	<b>5.9</b>	<b>3.2</b>	<b>NC</b>	<b>8.9</b>	<b>12.4</b>	<b>22.4</b>	<b>13.4</b>
10VNBH229	Pacer Ivv Area	Soil	0-10	7.97	< 0.794	NDR 1.52	NDR 2.82	NDR 3.01	57.8	513	1.41	1.27	< 0.794	< 0.794	< 0.794	< 0.794	< 0.794	< 0.794	4.52	< 0.794	14.2
10VNBH229 (Duplicate)				NDR 5.16	< 0.873	NDR 1.33	2.47	< 0.897	55.3	469	< 3.12	< 14.4	< 4.01	< 4.01	< 1.40	< 1.40	< 1.40	< 1.40	< 4.86	< 4.86	NDR 6.20
<b>RPD (%)<sup>1,2</sup></b>				<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>4.4</b>	<b>9.0</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>
10VNBH235	Pacer Ivv Area	Soil	0-10	2.76	0.382	NDR 0.559	0.971	1.25	20.7	247	0.677	0.334	0.192	0.233	0.384	NDR 0.212	0.138	0.212	2.41	NDR 0.189	6.76
10VNBH235 (Duplicate)				2.98	0.425	0.471	1.1	1.45	20.1	261	0.827	0.352	0.186	0.267	0.339	0.315	< 0.0873	NDR 0.355	2.81	0.234	7.58
<b>RPD (%)<sup>1,2</sup></b>				<b>7.7</b>	<b>10.7</b>	<b>NC</b>	<b>12.5</b>	<b>14.8</b>	<b>2.9</b>	<b>5.5</b>	<b>19.9</b>	<b>5.2</b>	<b>3.2</b>	<b>13.6</b>	<b>12.4</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>15.3</b>	<b>NC</b>	<b>11.4</b>
10VNBH521	Pacer Ivv Lake	Fish	Whole Fish	618	3.22	0.803	3.15	1.2	3.68	8.69	3.76	< 0.0547	0.323	NDR 0.108	< 0.0867	< 0.0867	< 0.0867	0.285	< 0.160	0.333	2.81
10VNBH521 (Duplicate)				621	3.11	0.727	3.27	1.06	3.77	8.64	3.86	NDR 0.121	0.278	0.0869	< 0.0819	< 0.0819	< 0.0819	0.217	< 0.0865	0.318	2.91
<b>RPD (%)<sup>1,2</sup></b>				<b>0.5</b>	<b>3.5</b>	<b>9.9</b>	<b>3.7</b>	<b>12.4</b>	<b>2.4</b>	<b>0.6</b>	<b>2.6</b>	<b>NC</b>	<b>15.0</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>NC</b>	<b>27.1</b>	<b>NC</b>	<b>4.6</b>	<b>3.5</b>
10VNBH208	Northeast Perimeter	Soil	0-10	996	25.6	3.47	11.3	8.86	131	1010	130	85.3	3.27	3.86	4	1.87	0.512	1.43	29.4	1.9	48.3
10VNBH208 (Duplicate)				1110	27.9	3.94	12.6	10.5	151	1170	145	99.7	3.61	4.44	4.72	2.08	0.511	1.79	36	1.98	61.8
<b>RPD (%)<sup>1,2</sup></b>				<b>10.8</b>	<b>8.6</b>	<b>12.7</b>	<b>10.9</b>	<b>16.9</b>	<b>14.2</b>	<b>14.7</b>	<b>10.9</b>	<b>15.6</b>	<b>9.9</b>	<b>14.0</b>	<b>16.5</b>	<b>10.6</b>	<b>0.2</b>	<b>22.4</b>	<b>20.2</b>	<b>4.1</b>	<b>24.5</b>
<b>Equipment Rinseates<sup>3</sup></b>																					
Sample ID	Location	Media	Depth (bgs)	PCDD (pg/L)							PCDF (pg/L)							TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)	
				2,3,7,8-TCDD	Total T4CDD	Total T5CDD	Total T6CDD	Total T7CDD	OCDD	2,3,7,8-TCDF	Total T4CDF	Total T5CDF	Total T6CDF	Total T7CDF	OCDF						
10VNBH706	Mid program rinseate	Water	-	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	3.63	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	1.63	1.52	NC
10VNBH712	End of program rinseate	Water	-	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	5.12	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	1.61	1.51	NC

<sup>1</sup> RPD = Relative Percent Difference.

<sup>2</sup> The RPDs which exceed the Project criteria (> 20%) are considered acceptable due to the low level concentrations and sample heterogeneity in the matrix.

<sup>3</sup> 10VNBH706 and 10VNBH712 (equipment rinsates) are aqueous samples (pg/L). The concentrations in the equipment rinsate should be considered in analyzing the final results.

<sup>4</sup> "<" = less than the detection limit; number following this symbol represents the detection limit.

<sup>5</sup> NDR = peak detected but did not meet quantification criteria; number following this flag represents the estimated maximum possible concentration.

<sup>6</sup> NC = Not calculated when NDR values of TCDD are considered "0" or concentrations are less than detection for RPDs.

<sup>7</sup> bgs = below ground surface.

<sup>8</sup> If 2,3,7,8 TCDF is detected on the primary column, the result must be confirmed on a second column. The 2,3,7,8 TCDF isomer cannot be uniquely resolved from its neighbouring isomers (i.e. 1249-, 2348-, and 2346-TCDF) if they are present; all four compounds appear as a single peak on the primary column. The 2,3,7,8 TCDF (C) confirmatory column only includes the 2,3,7,8 TCDF isomer. Only 2,3,7,8 TCDF (C) is considered herein to meet QA/QC limits.



## 4.0 CONCLUSIONS AND RECOMMENDATIONS

The 2010 environmental and human studies at Bien Hoa Airbase and in surrounding communities have provided significant new information on the overall dioxin contamination issue in the Bien Hoa area. When combined with data collected in 2004-2005 and 2008 from the most highly contaminated areas in the Airbase (Hatfield/10-80 2006; Hatfield/VRTC 2009), we now have a better understanding of dioxin-contaminated areas, exposure pathways, and affected populations. A total of 258 environmental samples have been analyzed for dioxin/furan concentrations from Bien Hoa Airbase and Bien Hoa City since 2005, under studies conducted by Hatfield, Office 33, 10-80 Division and VRTC (Hatfield/10-80 2006; Hatfield/VRTC 2009). These data will help facilitate planned remediation efforts for Bien Hoa Airbase, which are currently being discussed between the Governments of Viet Nam, the United States, and the international community.

Dioxin (particularly 2,3,7,8-tetrachlorodibenzo-*p*-dioxin; also referred to as 2,3,7,8-TCDD or TCDD), a known component of the Agent Orange mixture, is known to cause an increased risk of cancers, immunodeficiencies, reproductive and developmental changes, nervous system, and other health problems. Dioxins in soil can pose a lingering threat to human health. Paustenbach *et al.* (1992) has indicated that the half-life of dioxins in subsurface soils can extend to 100 years. Once in the human body, the half-life is estimated at approximately 7 to 11 years.

Many western jurisdictions have taken a “standards/guideline” approach to protect human health from dioxin exposure. Numerical standards and guidelines addressing TCDD contamination have been established by many reputable organizations and scientists (e.g., WHO/EURO 1988, 1989, 1991, 1998a, 1998b, 2001, Agency for Toxic Substances and Disease Registry 1997, 1998; International Agency for Research on Cancer [a division of the World Health Organization] 1997). Standards have also recently been released for Viet Nam (National Standard TCVN 8183:2009). Mitigation action is recommended and/or enforced when these contamination guidelines are exceeded in soils, sediments, or human food.

Despite the fact that environmental and human impacts of dioxins have been known for a long time, it has only been in the recent years that adequate measures have been taken to properly assess the extent and impact of contamination around known hotspots in Viet Nam, especially in Bien Hoa, Da Nang, and Phu Cat. Protection of human health in the vicinity of these dioxin hotspots is of key concern, and Bien Hoa is a priority area for intervention, given its historical significance as the largest Ranch Hand site in Viet Nam. Clean up efforts are currently underway at Da Nang Airport, with US Government funding.

Primary conclusions from studies conducted at Bien Hoa Airbase and its vicinities between 2008 and 2010 are as follows:

- Elevated TCDD levels, a contaminant in Agent Orange, were detected in samples analyzed from the perimeters of the Bien Hoa Airbase in 2004 and 2005 (Hatfield/10-80 2006). The study identified two dioxin “hot” zones in Bien Hoa City at South Base Lake, Bien Hung Lake and vicinities, and near the eastern end of the runway. The maximum soil TEQ concentration recorded in 2006 was 425 ppt, from a sample collected southeast of the Airbase. The highest sediment dioxin was recorded at South Base Lake (797 ppt TCDD and 833 ppt TEQ); this sample exceeded the Vietnamese standard (150 ppt TEQ) by more than five (5) times. TCDD was over 92% of the TEQ in both samples, clearly indicating Agent Orange contamination.
- The Hatfield/VRTC (2009) study found several areas inside Bien Hoa Airbase which had dioxin levels above the internationally accepted standard of 1,000 ppt TCDD in soils; this included the Southwest Corner of the Airbase, Pacer Ivy Area near the runway, and Z1 Area and its vicinity. The maximum soil dioxin level was observed in a sample collected at a depth of 60-90 cm in the Z1 Area, which exhibited extremely high TEQ (262,000 ppt) and TCDD (259,000 ppt) concentrations. Samples collected from different depths at the same site all exhibited TEQ concentrations  $\geq 26,400$  ppt (with over 91% TCDD). Highest sediment TEQ was detected in a lake sampled from the Pacer Ivy Area (5,870 ppt TCDD; 5,970 ppt TEQ).
- Building on previous studies, the current study extensively sampled areas inside and outside the Bien Hoa Airbase, including the Pacer Ivy Area, southwest corner of Airbase, Z1 Area, northeastern perimeter, northern perimeter and Bien Hoa City (south). The analytical chemistry undertaken at AXYS, a WHO-tested and approved dioxin laboratory, indicated elevated TCDD levels in all areas sampled on the Airbase. Highest contaminant levels were recorded in the Pacer Ivy Area; the maximum soil TCDD concentration was 61,400 ppt, with a resultant TEQ of 61,800 ppt. The most contaminated lake bottom sediments were also found in the Pacer Ivy area, with TEQ concentrations ranging from 32.1 to 2,020 ppt.
- As of 2010, dioxin continues to enter the aquatic ecosystem, the general environment, and the food chain. To this day, dioxin levels recorded in the Bien Hoa Airbase continue to exceed all international standards and guidelines for these toxic chemicals.
- Dioxin congener profiles confirm that the main source of dioxin contamination in the Bien Hoa Airbase area was Agent Orange and other dioxin-containing herbicides. TCDD contributed over 90% of the TEQ in soil and sediment samples collected from all areas inside the Airbase and outside in Bien Hoa City. A more detailed account of past site investigations and contaminant distributions is available in Hatfield/10-80 (2006) and Hatfield/VRTC (2009).

- Other contaminants (particularly 2,3,4,7,8-PCDF and 1,2,3,7,8-PCDD) also contribute to the total PCDD/PCDF load in some samples analyzed. Contaminants such as polychlorinated biphenyls, organochlorine pesticides and hydrocarbons are also likely present in the environment, both inside and outside the perimeter of Bien Hoa Airport. Other potential dioxin sources in Bien Hoa need to be determined and quantified in order to verify the total dioxin load to the environment and human population.
- The present study (and previous work by Hatfield/10-80/Office 33/VRTC [1998, 2000, 2003, 2006, 2007, 2009]) has verified that the highest concentrations of Agent Orange dioxin in soils/sediments in Viet Nam are found in the top 10 cm layer; some contamination is found in deeper strata (e.g., >60 cm) in Bien Hoa, but only limited to the former storage area in the Z1 Area (Hatfield/VRTC 2009). In this study, the depth profiles at Pacer Ivy Area indicated elevated TEQ levels in the 0-30 and 30-60 cm depths.
- The maximum TEQ value in Tilapia fat, 4,040 ppt (wet weight basis), was recorded in 'Mr. Hoc Lake' in the Pacer Ivy Area, which is more than 200 times the acceptable level established by Health Canada. Tilapia fat levels in 'Mr. Quy Lake' were 2,460 ppt TEQ (wet weight basis), which is more than 120 times the acceptable fish consumption level. High concentrations (more than 70 times the guideline) were also found in 'NE Perimeter Lake', 'Gate 2 Lake' and 'Z1 Lake'. It is likely other aquatic biota in these lakes (such as frogs, snails, ducks, etc.) are also contaminated.
- Tilapia fat tissues sampled from Bien Hoa Market and Gate 2 Market, where fishermen inside the Airbase sell their aquaculture products, exhibited low TEQ concentrations.
- Collectively, the concentrations of total dioxins and furans indicate extremely high contamination, and confirm the south, southwest and western parts of the Bien Hoa Airbase as significant PCDD/PCDF hotspots. The northern and eastern parts of the Airbase exhibit significantly lower dioxin contamination.
- The evidence indicates dioxin moves from the former storage sites in Pacer Ivy and Z1 Areas and into nearby watercourses, and ultimately into humans (via ingestion of contaminated fish and direct contact with soils and sediments), and is directly linked to historical Agent Orange use on the Airport.
- Soils throughout the Z1 Area have been placed in a contained landfill (43,000 m<sup>3</sup>) as a part of MND and GVN remediation efforts ongoing at the Airbase. GVN and MND's efforts have resulted in a reduction in dioxin contamination at the main hotspot area, but other hotspots remain on the Airbase.

- People who may regularly come into close contact with contaminated soils derived from the site may ingest small amounts of the soil through incidental hand-to-mouth activity. Given the notably high PCDD concentrations in soil, even small amounts of incidental soil ingestion can potentially cause significant exposure.
- Dermal absorption of PCDD may occur where certain people come into contact with contaminated soil or sediment during activities such as working on site, or wading into sediments while fishing, harvesting vegetation, etc. Soil or sediment contacting the skin for prolonged periods may result in small amounts of contaminants adhering and absorbing into the skin.
- Because contamination is generally found in surficial soil, finer contaminated particulates may on occasion become suspended in the air due to wind erosion or disturbance by cars and trucks. Airborne particulates carrying PCDDs may be inhaled and absorbed across the respiratory pathway. Although no airborne particulate data are presented in this report, inhalation of such particulates is likely a significant dioxin exposure pathway under periodic conditions.
- Given the high environmental levels of dioxin recorded in the southern and southwestern Airbase area, the human population of Bien Hoa City likely continues to be exposed to dioxin from contaminated food (especially fish), and also absorbs dioxin through the skin and lungs as a result of direct exposure to contaminated soils, sediments, and dust from the Airbase.
- The people most affected by direct exposure to dioxins from the Bien Hoa Airbase hotspots are those who fish and conduct aquaculture and agriculture from Z1 Lake, Pacer Ivy Lakes and other privately owned lakes and ponds inside the Airbase (and their extended families). Others may also be affected by eating fish and other aquatic animals harvested from the Airport lakes, although exact numbers are presently unknown.
- Human blood serum samples were collected and analysed for the first time in Bien Hoa during present study. Serum dioxin levels recorded in the 2010 study (n=42 blood donors sampled) for Bien Hoa Airbase workers ranged from 19.3 to 2,020 pg/g lipid basis. TEQ concentrations in all but one participant exceeded the WHO (1998) standard of 30 pg/g (equivalent to chronic intake of 4 pg/kg bw/d). Extremely high TEQ concentrations (1,080 - 2,020 pg/g TEQ) were found in three (3) individuals who actively harvest fish and plants from the Bien Hoa Airbase. Their dioxin levels were more than 35 times globally acceptable levels. These results support the contention that various people (either present on site or at peripheral locations), activities, and conditions coexist to create operative exposure pathways and potential for health risks.



- In analysing all individuals sampled for factors that could explain their blood dioxin levels, location of fishing was deemed a significant factor. A high variability in serum lipid values were discovered among individuals who consumed fish caught exclusively from inside the Airbase, and those who caught fish from both inside and outside the Airbase and solely from outside. No significant gender- and age-related effects on serum dioxin levels were identified.
- The typical range of TCDD in the general population of industrialized countries has been reported as 3 to 7 pg/g (lipid-based) (ATSDR 1998). ATSDR also indicated that TCDD in human blood rarely exceeds 10 pg/g and that typically, lower levels of this contaminant are recorded in less industrialized countries. All Bien Hoa Airbase workers sampled during the 2010 programs exhibited TCDD concentrations in blood greater than 10 pg/g. These include residents from Tan Phong Ward, inside the Airbase, and Trung Dung Ward (Bien Hoa City).
- Dioxins and furans were recorded in all breast milk samples analyzed in 2010 (N=22). Maximum levels were detected in a mother (age 29) breastfeeding her 2<sup>nd</sup> child (30.3 pg/g lipid basis TCDD), who previously consumed fish from Z1 Lake and 'Gate 2 Lake'. Average Daily Intake of breast milk per infant was calculated based on WHO/Euro (1989); Total TEQ ingested by infants ranged from 5 to 172 pg TEQ/kg bw/d.
- All breast milk samples analyzed exhibited TEQs exceeding the WHO Tolerable Daily Intake guideline of 4 pg TEQ/kg bw/d. High dioxin and furan levels in breast milk are cause for concern, and emphasize the need for raising awareness of potential contaminated food items originating from Bien Hoa Airbase.
- Comparison of Bien Hoa (2010) breast milk data to those recorded in Hatfield/Office 33 (2007, 2009) studies at Da Nang Airport indicate levels observed in Bien Hoa are generally lower than in Da Nang; ADIs in breast milk samples collected from in and around Da Nang Airport ranged from 23.4 to 2,320 pg TEQ/kg bw/d.

#### Recommendations:

- Planning and implementation of remediation measures, and clean-up of Bien Hoa Airbase, is urgently required to ensure protection of the local population from future exposure to dioxins from historical Agent Orange use at the site.
- Final remediation and clean-up efforts should focus on mitigating dioxin and furan contamination downstream of the Z1 Area and at the Pacer Ivy Area. Current remediation efforts have focused on the construction of drainage ditches and a secure onsite landfill in the Z1 Area. Final destruction of dioxin contaminated soils in the Z1 landfill will also be required in the future.

- Cultivation of Tilapia, other fish species and aquatic animals (e.g., ducks, molluscs, etc.) should be halted immediately. Investigation of potential dioxin contamination related to other agricultural activities (e.g., raising livestock) should be conducted.
- Other potential dioxin and furan contamination sources, particularly uncontrolled combustion and industrial emissions, should be identified, as well as potential contaminated materials which may be present at the Airbase.
- Awareness raising of dioxin exposure pathways (eating contaminated fish and other food items raised on Bien Hoa Airbase, exposure to contaminated soil and sediment, uncontrolled combustion, etc.) is required to help reduce dioxin loads in local Bien Hoa residents, especially nursing mothers.
- Other major dioxin hotspots in Viet Nam, particularly Da Nang and Phu Cat, also require remediation and clean-up, to protect local populations from continued exposure to Agent Orange and other herbicides used over 40 years ago during the US-Viet Nam war. Lessons learned from ongoing cleanup activities at Da Nang Airport (funded by the US and Vietnamese governments) will be invaluable for the future remediation of Bien Hoa and Phu Cat Airbases, and at other dioxin hotspots in Viet Nam.



Source: Hatfield Consultants

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