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

Final Report

August 2011

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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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Project meeting with Government of Viet Nam and Bien Hoa officials, November, 2010

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[1] 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^3 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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[1] 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[2]:

- 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

[2] 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[3] 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.

[3] Health Canada consumption guideline for edible fish tissue is 20 pg/g TEQ wet weight.

Dioxins and furans in human blood and breast milk:[4]

- 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, α=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 2nd 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.

[4] 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.

Sampling at Bien Hoa Airbase, November, 2010

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^3 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.


Bien Hoa Airbase, October, 1972
(the US pulled out in 1973)

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.

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. Schecter *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. Schecter *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) Schecter 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^2, 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^2, 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)** – ZI 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^2;

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.

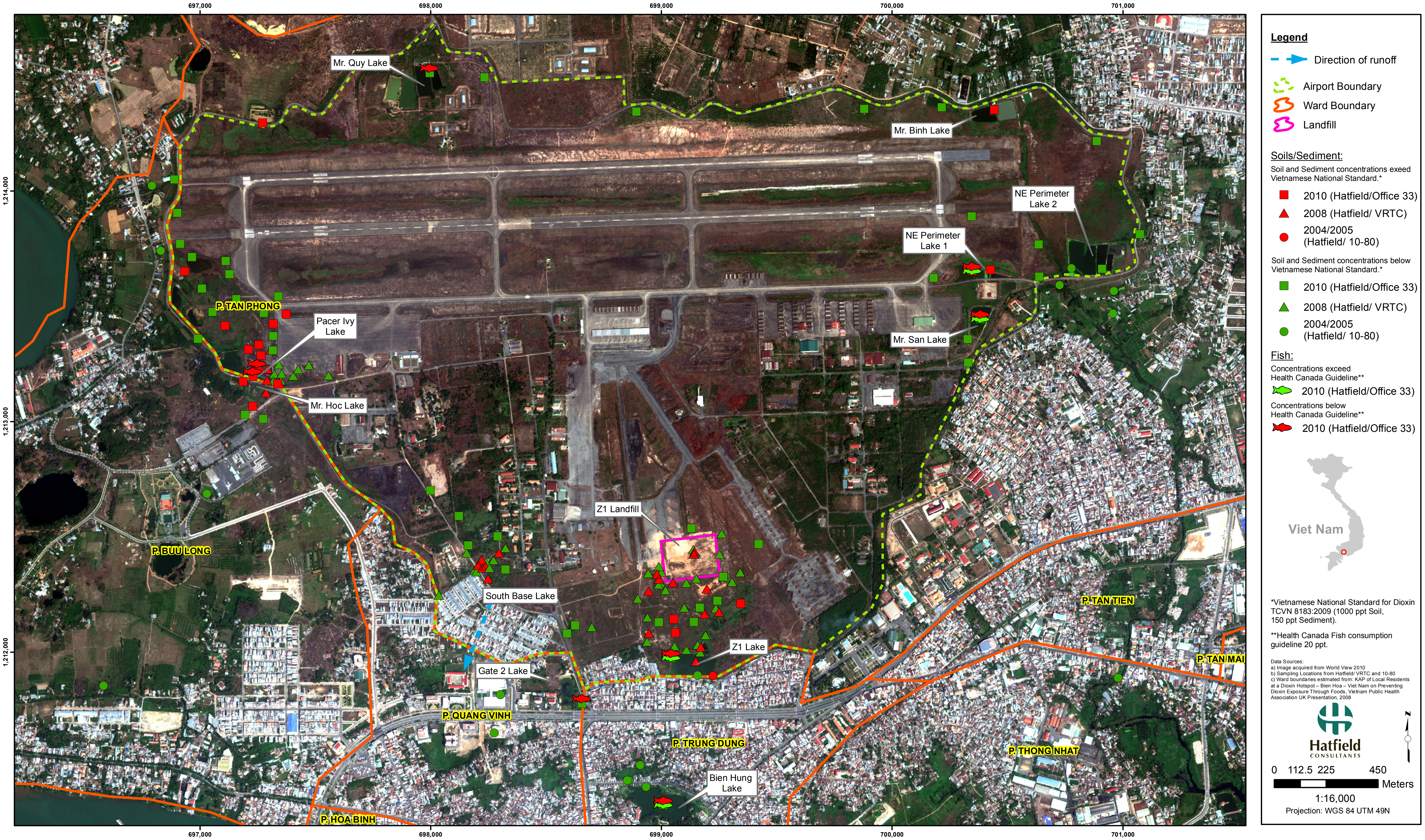

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Figure 1.2 Historical sampling locations, outside the Bien Hoa Airbase, Viet Nam, 2004 to 2005 (Hatfield/10-80 2006).

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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)
Southwest Corner of Airbase					
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
Pacer Ivy Storage and Re-drumming Area					
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
Z1 Area					
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
Perimeter of the Z1 Area					
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)
Perimeter of the Z1 Area (cont'd.)					
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
Ponds and Lakes Downstream of Z1 Area					
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).

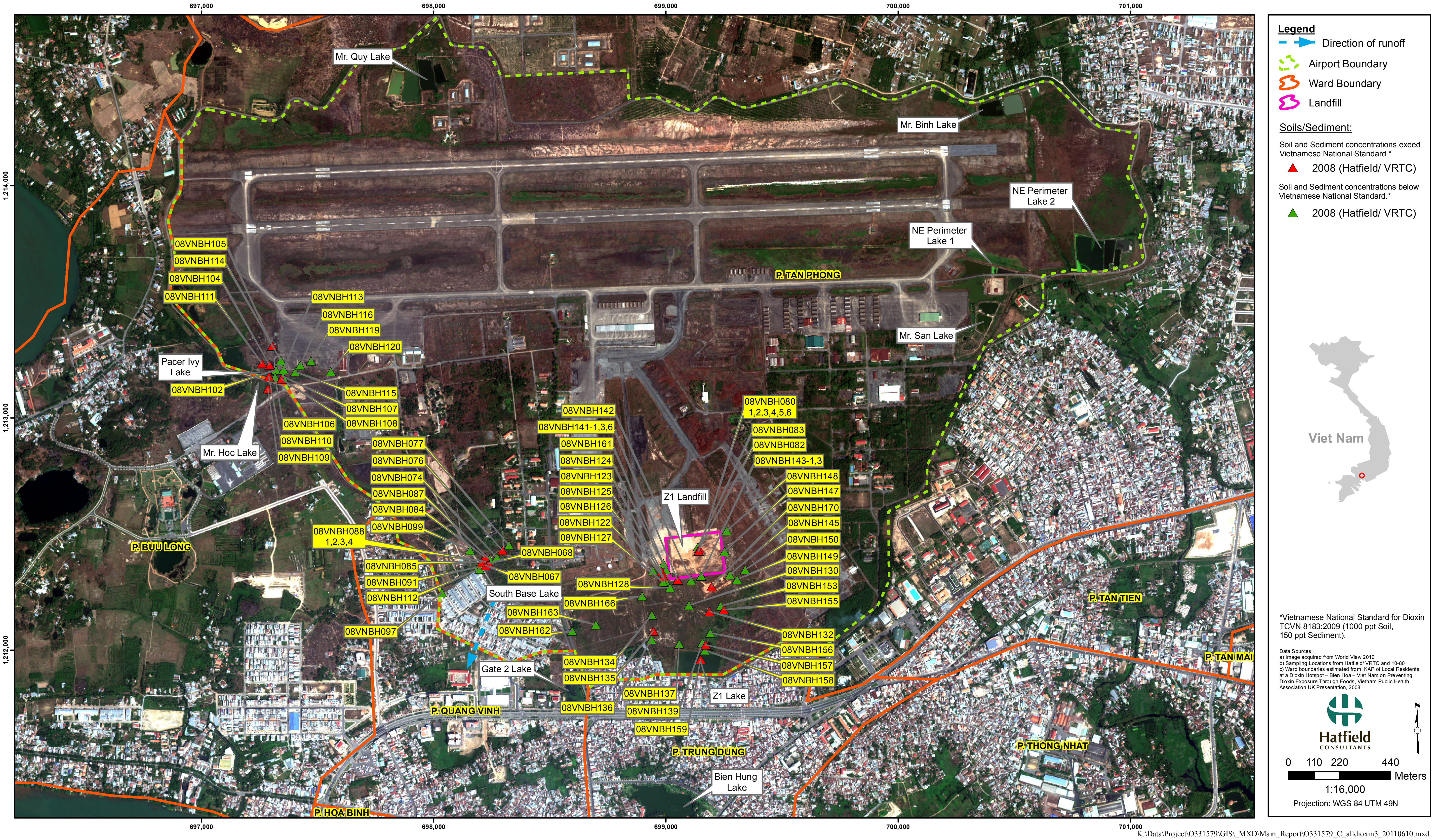
ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

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).



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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 9.6×10^9 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 Viswanthan *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[1]	1,000 pg/g TEQ	Dioxin heavily contaminated sites (soils)
Germany[2,3]	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[3]	250 pg/g TEQ	If exceeded, research studies required
	1,000 pg/g TEQ	If exceeded, removal required
British Columbia, Canada[4] (Provincial)	10 pg/g TEQ	Agricultural – human health protection
	350 pg/g TEQ	Residential – human health protection
Alberta, Canada[5] (Provincial)	250 pg/g TEQ	Natural area remediation guideline
	4 pg/g TEQ	Agricultural, residential/parkland, commercial, industrial remediation guideline
Canada (Federal)[6]	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)[6]	10 pg/g TEQ	Agricultural soils
	1,000 pg/g TEQ	Residential/park land soils
Czech Republic[7]	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[7]	<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)[3]	1,000 pg/g TEQ	Residential
*USEPA (Regional)[8]	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[9]	11 pg/g	PCDD soil guideline level
	38.6pg/g	PCDF soil guideline level
California [10]	50 pg/g TEQ	Residential
	200-1,000 pg/g TEQ	Commercial/ Industrial
	<40 pg/g TEQ	Agricultural
New Zealand Interim Accepted Criteria [7]	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
	21 pg/g TEQ	Maintenance
ATSDR[11]	≤50 pg/g TEQ	Screening level
	>50 - <1,000 pg/g TEQ	Evaluation level
	≥1,000 pg/g TEQ	Action level
Sweden[3]	10 pg/g TEQ	Residential soils
	250 pg/g TEQ	Industrial soils
Netherlands[3]	10 pg/g TEQ	Dairy farming and land with sensitive use
	1,000 pg/g TEQ	Residential and agricultural
Finland[2,3]	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).

1 Viet Nam National Standard TCVN 8183:2009.
2 AEA 1999.
3 NZMOE 2002.
4 BC- Queen's Printer 2009.
5 Alberta Environment 1994, 2009.
6 CCME 2001.
7 IPEN 2009.
8 USEPA 2009.
9 USEPA 2003.
10 HHRA 2009.
11 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 ≥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[1]	150 pg/g TEQ	Dioxin heavily contaminated sites (sediments)
USEPA, Region 10[2]	4 pg/g TEQ	Protection of human and ecological receptors
USEPA, Region 3[3]	0.85 pg/g TEQ	Freshwater Sediment Screening Benchmarks
USEPA, Region 5[4]	1.2 pg/g TEQ	Sediment ecological screening levels
New York State Dept. of Environmental Conservation[2]	10-100 pg/g TEQ	Protection of human and ecological receptors
Wisconsin Dept. of Natural Resources[2]	1 pg/g TEQ	Protection of human receptors
Int. Joint Comm., Great Lakes Science Advisory Board[2]	10 pg/g TEQ	Protection of human and ecological receptors
Canada[5]	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[2]	10 pg/g TEQ	Protection of ecological receptors
British Columbia, Canada[6]	130 pg/g TEQ 260 pg/g TEQ	Criteria at sensitive sites Criteria at typical sites
Germany – Hamburg Dept. of Environment[2]	5-10 pg/g TEQ	Protection of human receptors
Netherlands[2]	100 pg/g TEQ	Protection of human receptors (threshold for remediation)

1 Viet Nam National Standard TCVN 8183:2009.
2 AEA 1999.
3 USEPA Region III BTAG Freshwater Sediment Screening Benchmarks. 8/2006.
4 USEPA 2003.
5 CCME 2001. PEL= Probable Effect Level; ISQG= Interim Sediment Quality Guidelines.
6 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.

Tilapia sampled from Bien Hoa Airbase, November 2010

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 *et al.* 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 *et al.*	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 Schecter *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; Schecter *et al.* 1991; Park *et al.* 2009).

Fish sampling in Pacer Ivy Lake, Bien Hoa Airbase, November 2010

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[1]	1998	Tolerable Daily Intake	1-4 pg/kg/d	10 – 30 ppt
JECFA[2]	2001	Provisional Tolerable Monthly Intake (PTMI) 70 pg/kg/mo	2.3 pg/kg/d	40 – 70 ppt
ECSCF[2]	2001	Tolerable Weekly Intake (TWI) 14 pg/kg/wk	2 pg/kg/d	42 – 74 ppt
UKCOT[2]	2001	Tolerable Daily Intake (TDI)	2 pg/kg/d	31 – 55 ppt
ATSDR[2]	1999	Minimal Risk Level (MRL) 1 pg/kg/d	1 pg/kg/d	15 ppt

1 Adapted from American Chemistry Council (ACC) 2003.

2 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 break 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).

Sediment sampling, Bien Hoa Airbase, November 2010

Source: Hatfield Consultants

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

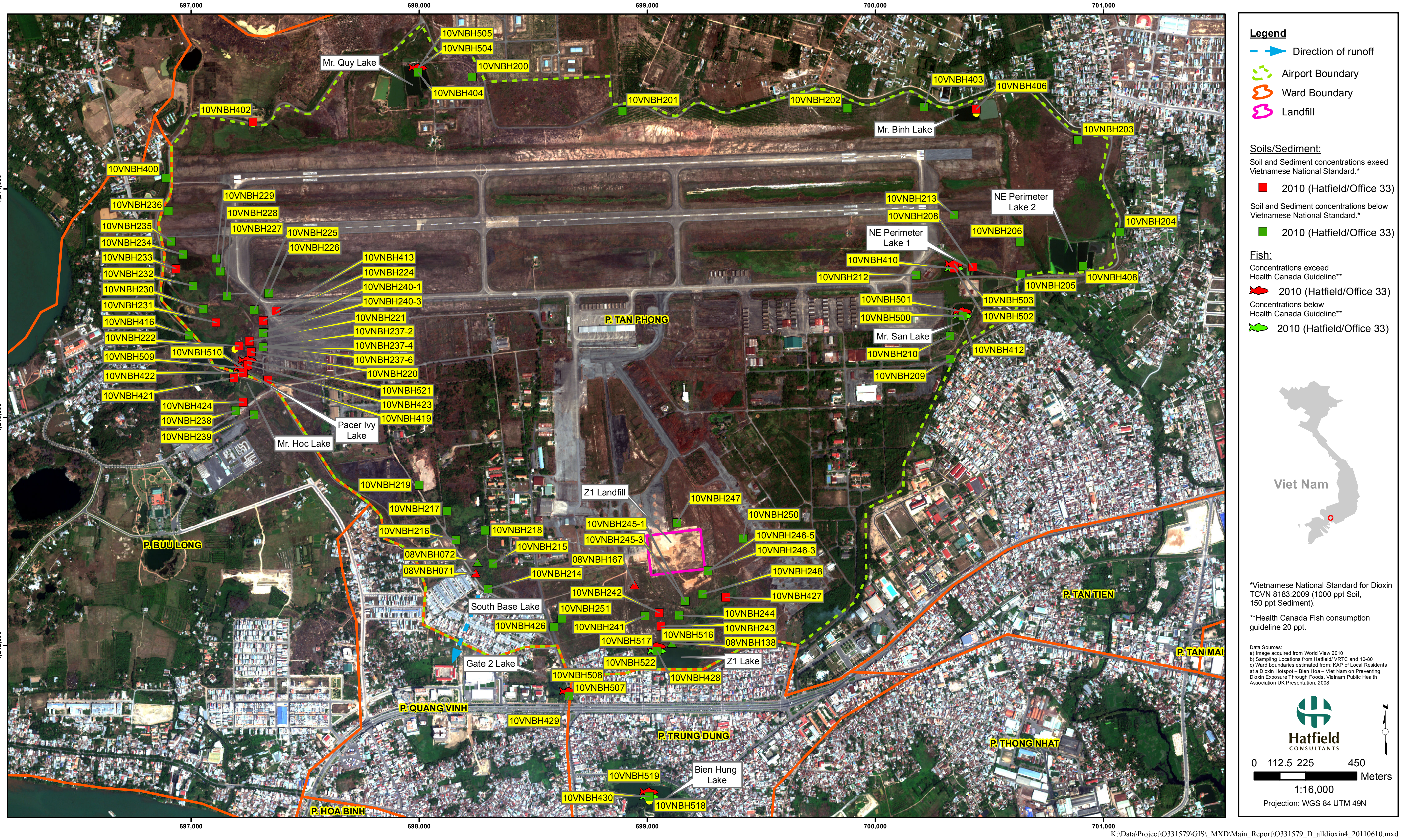

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Table 2.1 Soil and sediment samples analyzed for dioxins and furans, Bien Hoa, Viet Nam, November 2010.

Sample ID	Date	Location	Media	Depth	Coordinates		Analysis
					Easting	Northing	PCDD/F
Northern Perimeter							
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	
Bien Hoa City (Southern Perimeter)							
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
Northeastern Perimeter							
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
SW Airbase							
08VNBH071[1]	1-Nov-08	SW Airbase	Soil	0-10	698247	1212318	X
08VNBH072[1]	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
Pacer Ivy							
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
					Easting	Northing	PCDD/F
Pacer Ivy (Cont'd.)							
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	
Z1 Area							
08VNBH138[1]	1-Nov-08	Z1 Area	Soil	0-10	699116	1212011	X
08VNBH167[1]	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

[1] 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, calibers, 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).

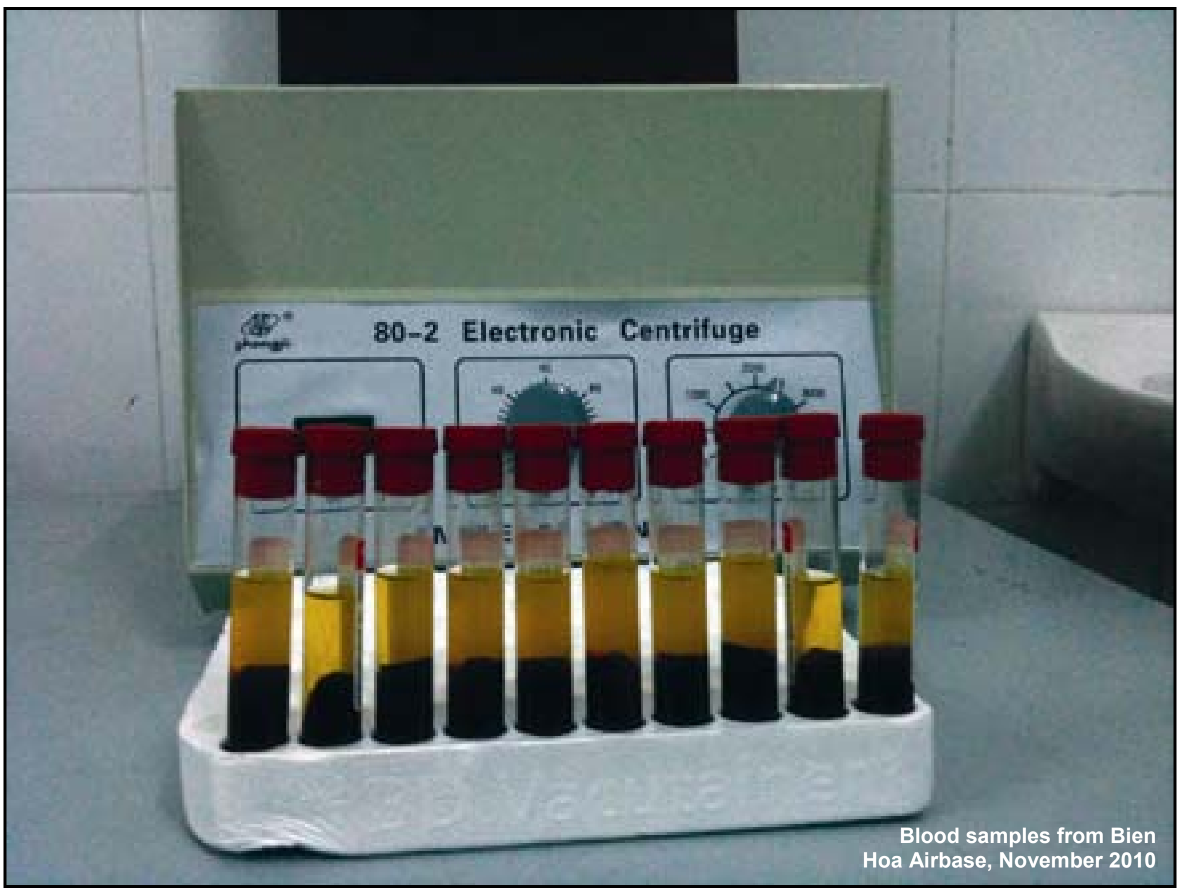
2.5.4 Human Blood Sampling Protocol

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.



Blood samples from Bien Hoa Airbase, November 2010

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.

Matrix	Sample Size (per analysis)	Sample Container	Condition Upon Receipt	Storage Conditions
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.

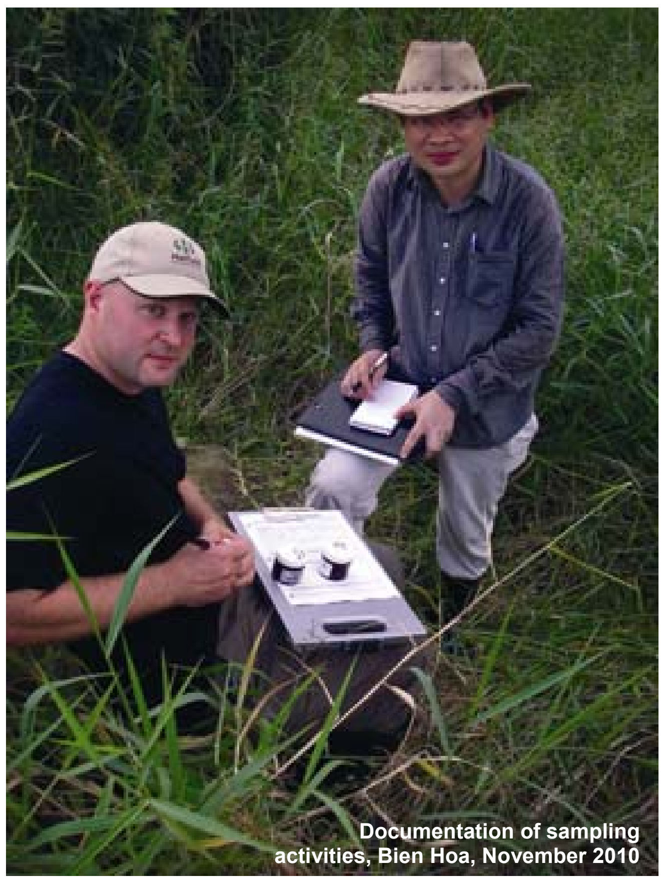
Demining personnel from MND accompanied Hatfield staff to all sites and screened all sampling sites for UXO prior to collection of soils/sediments on the Bien Hoa Airbase.

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 α (*"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 α level to determine significance. If the p-value is less than the α level, the test is significant, and if it is equal or greater, the test is not significant.


Documentation of sampling activities, Bien Hoa, November 2010

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^2, 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.

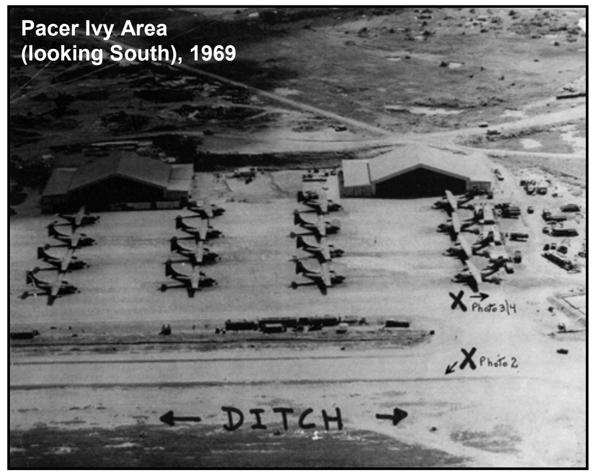
NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

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.

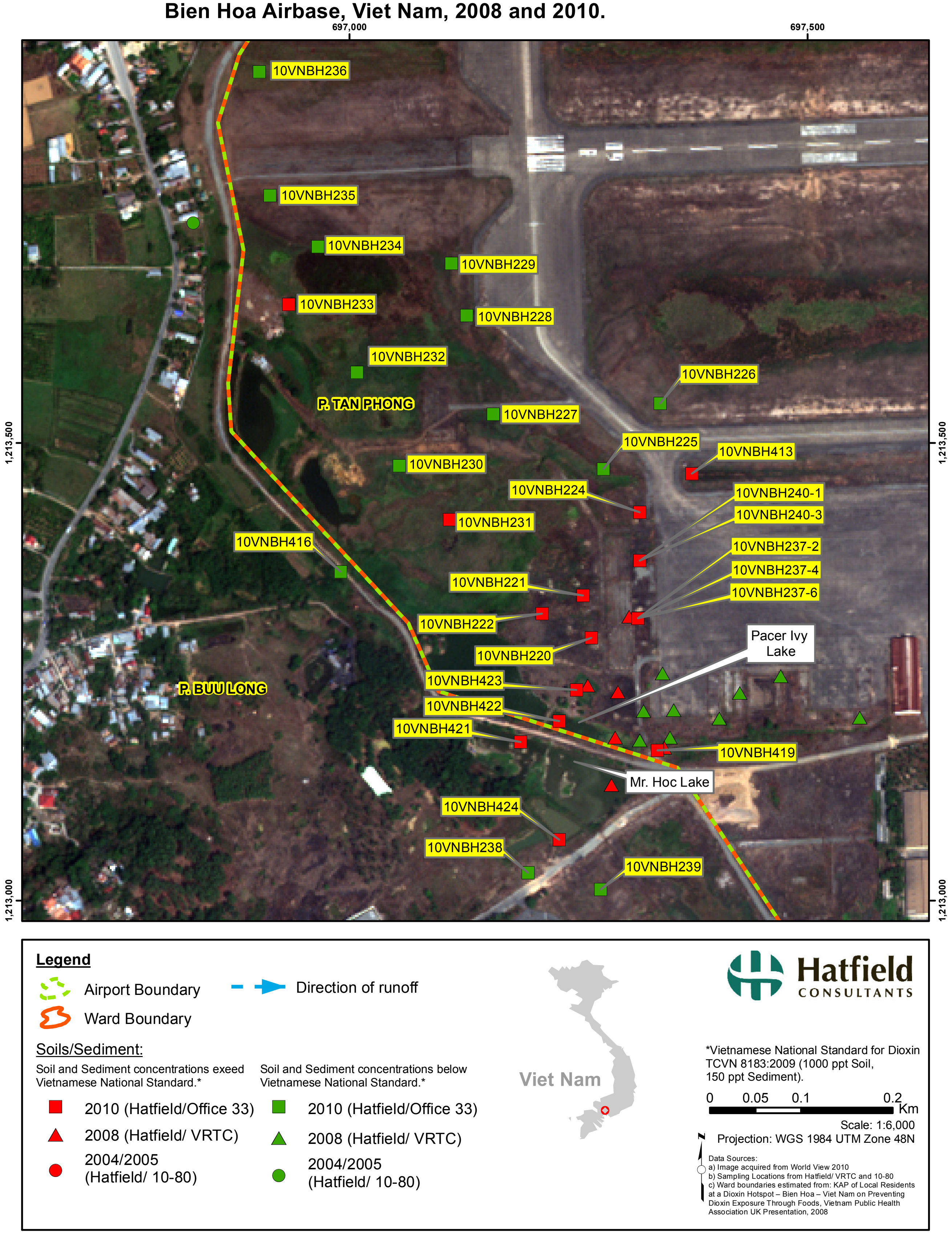


Source: National Archives and Records Administration, Washington, DC

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.

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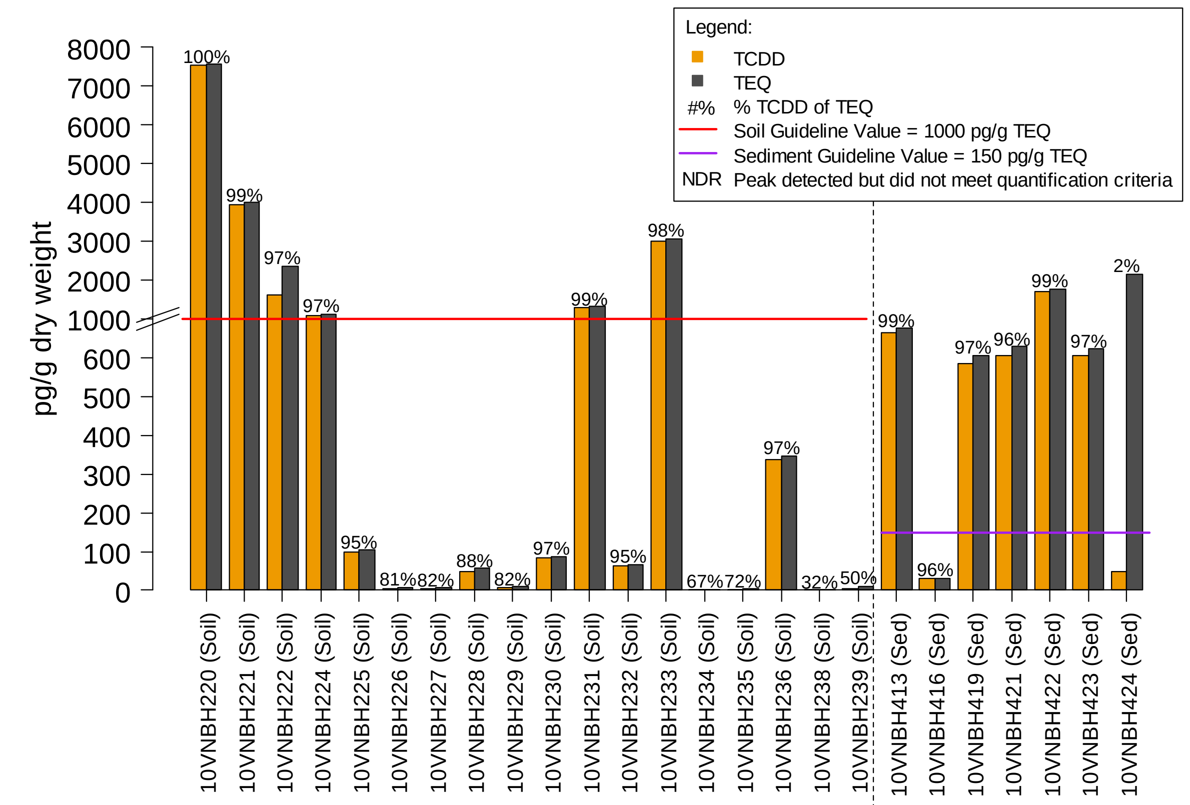
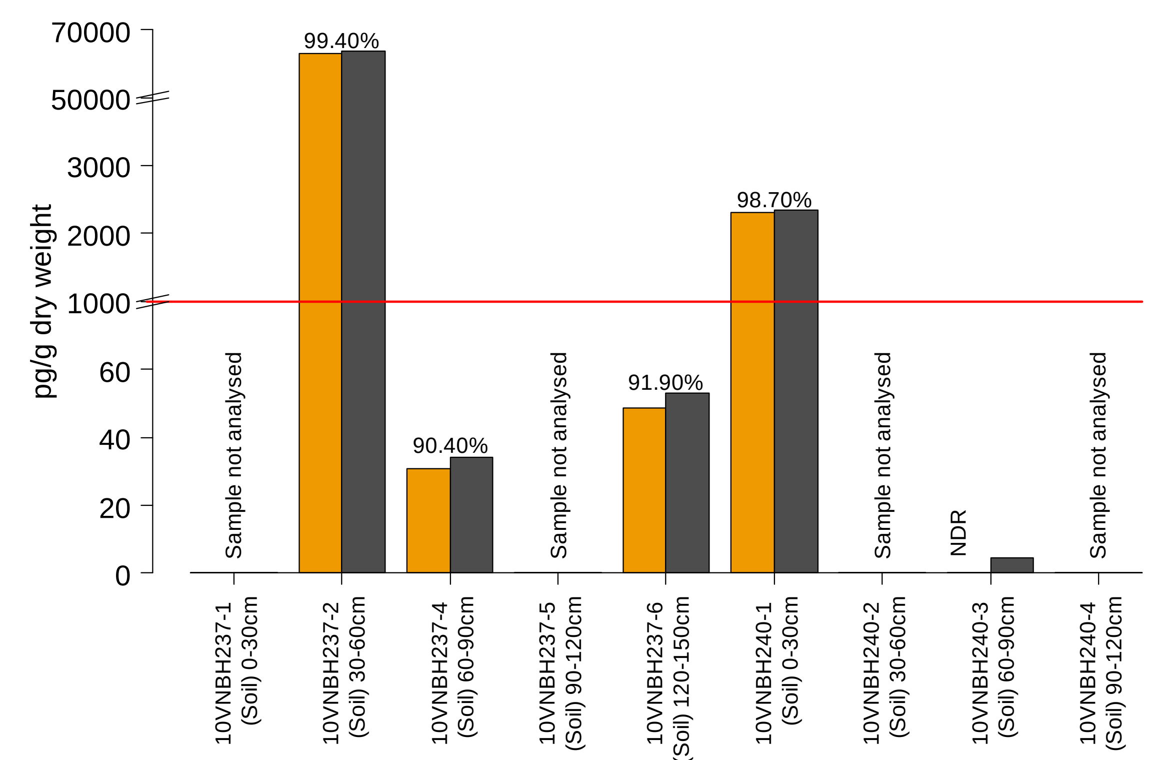
TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from the Pacer Ivy Area, Bien Hoa Airbase, Viet Nam, November 2010.



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^2, 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.