

Saigon River Valley: A Navigation, Trade, Mitigation, Invasion, Liberation, and Unification Pathway

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Abstract

The Saigon River is located in southern Vietnam with headwaters starting in southeastern Cambodia. The river flows southeast for about 225 km to the South China Sea. Most readers of Vietnam's history know about the American-Vietnam War (1965-1973). However, centuries before that time, Vietnam fought with the Chinese, the Khmers, the Chams and the Mongols. The history of Vietnam begins in the Red River Delta, where farmers first cultivated rice. A millenia of struggle against the Chinese then followed. The Saigon River Valley was the pathway used by the North Vietnamese Army (NVA) to get from the Ho Chi Minh Trail in Cambodia to Saigon during the 1968 Tet Offensive. The NVA dug Cu Chi and Iron Triangle soil tunnels near Cu Chi in the Old Alluvium terrace to hide from American Forces and Air Force bombers. In 1962, the Tan Son Nhut Air Force base on the northern edge of Saigon received the first shipments of Agent Blue, the arsenic based herbicide, used to destroy the rice crop. The most dioxin TCDD and arsenic contaminated site in Vietnam was Bien Hoa Air Force base on the Saigon River just 30 km northeast east of Ho Chi Minh City. The adjacent Bien Hoa City has a population of over 800,000. The Port of Ho Chi Minh City is the most significant river port in Vietnam and Southeast Asia. The river is navigable by ships which draft up to 9 m. Vietnam only became a united country in the 19th century. Its independence was soon affected by French colonialism and then the destructive American intervention in the Vietnam War. The Vietnam War Archive no. 2 in Ho Chi Minh City houses residual correspondence between the Republic of Vietnam (RV) President Diem's administration and US President Kennedy's administration related to the Khai Huang program (hamlet strategy). In addition, the archive contains some of the tactical herbicide spray records of the RV military for the Mekong Delta.

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The primary objective this study is to document the role that the Saigon River Valley played, in modern warfare. The Saigon River Valley was used as a navigation, trade, invasion, liberation and unification pathway. The Vietnamese people have survived centuries of stormy, troubled times and their power of character has served them well.

Keywords

Saigon River, Ho Chi Minh City, Port of Saigon, Cu Chi Soil Tunnels, Iron Triangle Soil Tunnel, Khai Huang, Bien Hoa, Cu Chi, Nha Be Base

1. Introduction

The Saigon River, known in Vietnamese as *Sông Sài Gòn*, is a river located in southern Vietnam. It starts in southeast Cambodia, near Phum Daung, and flows southwest for 225 km before emptying into the Soài Rạp. The river discharges into the South China Sea approximately 20 km northeast of the Mekong Delta and the mouth of the Mekong River. The Saigon River is joined by the Dong Nai River 29 km northeast of Ho Chi Minh City. The Saigon River flows through Bien Hoa and Ho Chi Minh City, formerly known as Saigon (**Figure 1**). The Ben Cat River joins just above the Ho Chi Minh City. At Cho Lon, the former Chinese southern sector of Ho Chi Minh City, the Saigon River connects to two ship channels, the Kinh Te and the Kinh Tau Hu.

Saigon River is important to Ho Chi Minh City as its main water supply in addition to being the host of Saigon Port (**Figure 2**), with a total cargo volume loaded and out loaded of more than 35 million metric tons in 2006. Tactical herbicides including Agent Blue, the arsenic based rice killer, were shipped via the Saigon River to Tan Son Nhut Air Force base (**Figure 3**) on the edge of Saigon from 1962 to 1965 and later transported to Bien Hoa Air Base (**Figure 4**) from 1965 to 1971 for distribution to other US military bases in Southern Vietnam. In 1972, the remaining stockpiles of the tactical herbicides at the US military bases in Vietnam were transported back to Bien Hoa Air Base, re-barreled and shipped to Johnston Island (**Figure 5**) in the Pacific for disposal by incineration in 1977 [1].

For centuries traversing the Saigon River required boats. Eventually, the Saigon River was crossed by the Thu Thiem Bridge, Thu Thiem 2 Bridge (**Figure 6**), and Phu My Bridge [2]. The Bình Quới Tourist Village is located on the Thanh Da peninsula on the Saigon River, in the Bình Thạnh District of Ho Chi Minh City. Thiem Tunnel (**Figure 7**) (**Figure 8**), an underwater tunnel passing below the Saigon River, was opened to traffic on November 20, 2011. Since its completion, it has been the longest cross-river tunnel in Southeast Asia [3]. The Saigon Waterbus service (**Figure 9**) launched in 2017, connected District 1 with Thu Duc District [4].

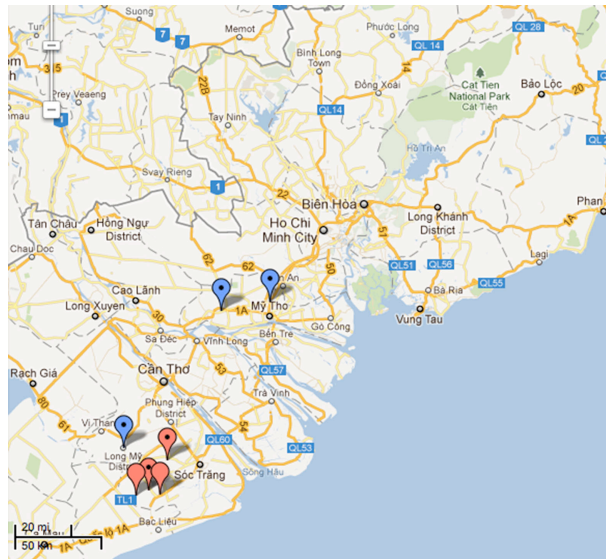


Figure 1. Saigon River map in the Bien Hoa (with a black border line) and Ho Chi Minh areas.



Figure 2. Port of Saigon. Ships being off-loaded.



Figure 3. Tan Son Nhut Air Force base museum in Ho Chi Minh City.



Figure 4. The front gate at Bien Hoa Air Force base.



Figure 5. Approximately 20,000 tactical herbicide barrels stored on Johnston Island beach in the Pacific Ocean from 1972 to 1977.

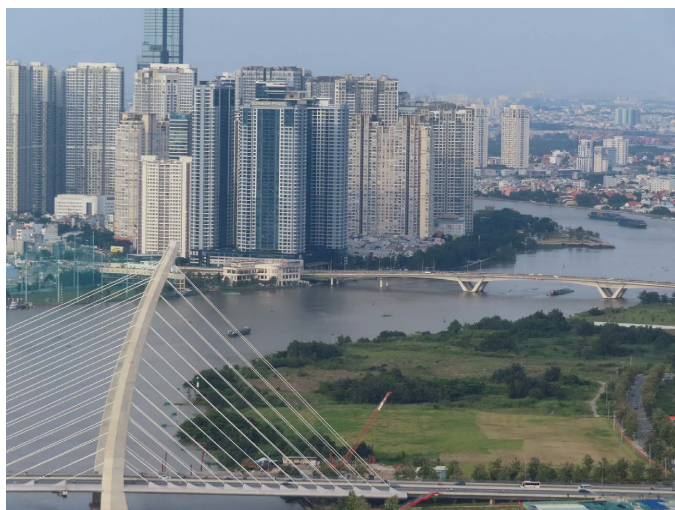


Figure 6. Two bridges over the Saigon River including the Thu Thiem 2 bridge.



Figure 7. Thiem Tunnel entrance near a tributary of the Saigon River. The six lane road disappears under a green tree line in the center of the photograph.



Figure 8. Thiem Tunnel exit east of the Saigon River in Ho Chi Minh. The six lane road re-surfaces just past trees and just before the overhead bridge.



Figure 9. Water bus service terminal with two boats docked.

Approximately 16 km south of Ho Chi Minh City is the oil harbor of Nha Be (**Figure 10**) which was used as a Navy base during the American-Vietnam War. The Saigon River Valley was the pathway used by the North Vietnamese Army (NVA) to get from the Ho Chi Minh Trail in Cambodia to Saigon. The NVA dug Cu Chi and Iron Triangle soil tunnels near Cu Chi in the Old Alluvium terrace to hide from American Forces and US Air Force bombers. The Saigon River forms an estuary at Ganh Rai Bay (**Figure 11**) an outlying part of the Mekong Delta. The Saigon River then flows into the South China Sea.

The primary objective of this paper is to document the use of the Saigon River Valley as a modern warfare, navigation, trade, invasion, liberation and unification pathway. The Saigon River Valley was also the gateway for military and environmental chemical weapons, including Agent Blue the arsenic based herbicide used to destroy rice, introduced and used by the RV and US military during the Vietnam War (1962 to 1971).

2. Background

2.1. Ancient History

Ancient Vietnam was situated on the southeast edge of Asia with a combination of high rainfall, humidity, heat, favorable winds, and fertile soil. These natural sources combined to generate an unusually prolific growth of rice, other plants and wildlife. This region's ancient agricultural villages held well over 90 percent of the ancient Vietnam population. The high volume of rainy season water required villagers to concentrate their labor in managing floods, transplanting rice, and harvesting. These activities produced a cohesive village life with a religion in which one of the primary values was the desire to live in harmony with other people and nature [4]. The way of life, centered in harmony, featured many enjoyable aspects that the people valued. Examples included people not needing many material things, enjoyment of music and poetry, and living in harmony with nature [5] [6].



Figure 10. Nha Be Navy base in the Saigon River.

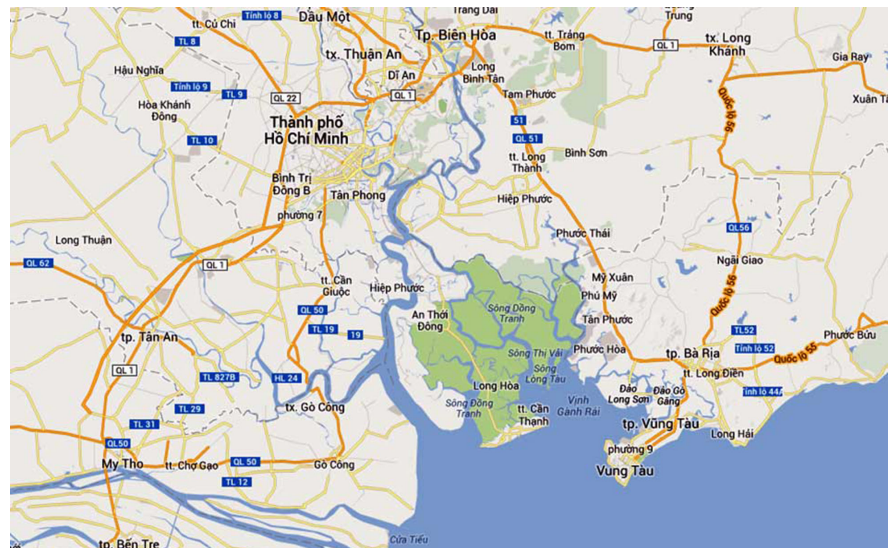


Figure 11. A map of Ganh Rai Bay wetland Saigon River delta.

About 2000 years ago people in Northern Vietnam began growing rice in the Red River Valley. To irrigate their crops, they built dikes and dug canals. They were forced to work together and consequently an organized kingdom emerged called Van Lang [6]. In the 2nd century B.C., the Chinese conquered the area. The Chinese ruled northern Vietnam for more than 1000 years and Chinese civilization had a great impact on the Vietnamese. In Southern Vietnam was under the influence of the Indian culture.

From the 1st century to the 6th century A.D. the southernmost part of Vietnam was part of a state called Funan. In the middle of Vietnam, an Indian-influenced state called Champa arose in the 2nd century AD. In Northern Vietnam, the people resented Chinese rule and in 40 A.D. the Trung sisters led a rebellion. However, in 43 A.D. the Chinese crushed the rebellion and the sisters killed themselves. The Chinese continued to rule North Vietnam until the 10th century A.D. Finally, in 938 A.D. a leader named Ngo Quyen defeated the Chinese at the battle of Bach Dang River and Northern Vietnam became an independent state.

In the 13th century, the Mongols invaded Vietnam three times. In 1257 A.D. and 1284 A.D. they captured the capital but each time they soon withdrew [5]. Then in 1288 A.D. the Vietnamese leader Tran Hung Dao routed the Mongols at the Bach Dang River.

However, in the early 15th century, China tried to regain control of Northern Vietnam. In 1407 A.D. they occupied the country but their rule was resisted. In 1418 Le Loi began the Lam Son Uprising. By 1428 A.D. the Chinese were driven out and Le Loi became Emperor Le Thai To. Under his successors, the central Vietnamese state of Champa became a vassal state of Northern Vietnam [5]. Meanwhile the Portuguese reached Vietnam by sea in 1516 A.D. In their wake came missionaries, first Dominicans then Jesuits, and the Roman Catholic Church made some headway in Vietnam.

In the early 16th century, the power of the Le dynasty declined. During the 17th and 18th centuries, two rival families effectively held power, the Trinh in the north and the Nguyen in the south. The Nguyen family conquered the Mekong Delta from the Khmer Empire. In the 1770s a rebellion began in the town of Tay Son. Three brothers called Nguyen led it. Gradually they took territory from the Nguyen lords in the south and the Trinh lords in the north. By 1786, they were in control of the whole of Vietnam and one brother, Nguyen Hue made himself Emperor Quang Trung. In 1788, the Chinese intervened in Vietnam but the Vietnamese routed them at Dong Da. However, a Nguyen lord named Nguyen Anh escaped. He raised an army and from 1789 on he pushed back the rebels. Nguyen Anh took Hanoi in 1802 and made himself Emperor Gia Long. Under him, Vietnam became a strong united kingdom [6].

2.2. French History in Vietnam

In the late 19th century, Vietnam became a French colony. However, the French took over Vietnam in stages. The French colonial empire was heavily involved in Vietnam in the 19th century. French intervention was undertaken in order to protect the work of Paris Foreign Missions Society in Vietnam [4]. As a result of many Catholic missionary incidents, Napoleon III of France order 14 French gunships to attack the port of Da Nang in 1858. The attack caused damage but French failed to gain a foothold. The French gunships moved south along the coast and then entered the Saigon River from the South China Sea (an early invasion pathway from the south) and captured the poorly defended city of Gia Dinh (later named Saigon) located on an Old Alluvial terrace approximately 80 km north of the mouth of the Saigon River. The city later became Saigon and then Ho Chi Minh City. In 1859 the French troops captured Saigon and then expanded their control over all six provinces of the Mekong delta to form a colony known as Cochinchina.

Finally in 1883, North and Central Vietnam was forced to become a French protectorate. The French built infrastructure in Vietnam such as the Saigon to Hanoi railway. They also built roads and bridges. However, the building was funded by heavy taxation of the Vietnamese populace. Naturally, the Vietnamese

wanted independence. The Communists spearheaded the struggle for independence. Ho Chi Minh founded the Revolutionary Youth League from the safety of China in 1925. In 1930, it became the Vietnamese Communist Party [5].

In 1940, the Germans defeated France. Japan decided to take advantage of French weakness and they forced the French government to allow Japanese troops to occupy French Indo-China, although they left the French administration in place [5]. The Vietnamese Communists or Viet Minh fought the Japanese and by 1945 they controlled parts of North Vietnam. Meanwhile, in March 1945, the Japanese took control of the administration of Vietnam and when Japan surrendered on 15 August 1945 they left a power vacuum.

Ho Chi Minh moved quickly to fill the vacuum. He called for an uprising called the August Revolution and the Viet Minh took control of most of Vietnam. On 2 September 1945, Ho Chi Minh declared Vietnam independent. However, the great powers of the world ignored the Vietnamese demand for independence. Under the terms of the Potsdam Conference Japanese troops south of the 16th parallel surrendered to the British. Those to the north surrendered to the Nationalist Chinese [5].

However, the French army soon arrived in the south to take control from the British. In the north, Chinese troops moved in. Ho Chi Minh soon decided that the French were the lesser of two evils and he signed a treaty, which said that French troops should replace Chinese troops in North Vietnam for five years. In return, the French promised to recognize Vietnam as a “free state”. However, it soon became clear the French had no intention of giving up power in Vietnam and fighting broke out between the French and the Viet Minh [6]. For eight years the Viet Minh fought a guerrilla war against the French.

Finally, in 1954, the Viet Minh surrounded a French army at Dien Bien Phu. After a siege lasting 57 days, the French were forced to surrender. By then it was clear that the French could not win the war and both sides met at the Geneva Conference to end the war. They agreed that Vietnam would be “temporarily” divided at the 17th parallel and elections would be held by 20 July 1956. However, no elections were held and the division of Vietnam became permanent.

2.3. Modern Vietnam History

In the north, Ho Chi Minh introduced a Communist regime while in the south Ngo Dinh Diem became ruler. However, in the early 1960s, South Vietnam was rocked by demonstrations and in 1963 Diem was ousted in a coup. Meanwhile, in 1959, the North Vietnamese began a long guerrilla war to reunite Vietnam under Communist rule. The Northern Guerrillas were known as the Viet Cong (VC). They were essentially a communist revolutionary organization. Later in the Vietnam War, they were incorporated into the North Vietnamese Army (NVA) [7] [8].

Gradually, the USA became involved in the Vietnam War. As early as 1950, the US sent military advisers to South Vietnam. Financially they supported the French and later the South Vietnamese government. Then in 1964, two US Navy

ships were supposedly subject to “unprovoked” attacks by the North Vietnamese. First, the Maddox was attacked with minor damage. Two days later the Maddox and a ship called the C Turner Joy claim they were going to be attacked based on wrongly interpreted communications. This event became known as the Gulf of Tonkin Incident.

The Americans then bombed the north and Congress passed the Tonkin Gulf Resolution allowing the president to take “all necessary measures” to prevent “further aggression”. As a result, by December 1965, there were 183,000 US soldiers in Vietnam and by the end of 1967, there were nearly half a million soldiers. However, the NVA continued their guerrilla war.

In January 1968, the NVA launched the Tet offensive in towns and cities across South Vietnam. They suffered heavy losses but afterward the Americans gradually withdrew from Vietnam. In January 1973, they signed a ceasefire and the remaining American troops withdrew. The South Vietnamese continued to fight the NVA alone. However, in the early months of 1975 Southern Vietnamese resistance collapsed on 30 April 1975, the Northern Vietnamese captured Saigon. Vietnam was re-united under Communist rule.

Then, in late 1970s, the Khmer Rouge made attacks on Vietnam via the Mekong River and Saigon River pathways. During 1978, the Vietnamese occupied most of Cambodia. They stayed until 1989. In the meanwhile, in 1986 the Vietnamese government introduced market reforms. As a result, the Vietnamese economy began to grow rapidly. In 1994, the USA lifted an economic embargo on Vietnam and in 1995 diplomatic relations were restored.

Ho Chi Minh City retains the faded look of a European city, its many Western-style buildings, including the Majestic Saigon Hotel, dating back (1925) to the French colonial rule. Most of the bars and restaurants that thrived in Saigon during the Vietnam War have closed their doors. The elegant Cercle Sportif, a focal point of social life for Westerners, after it was founded in 1912, is now a people’s museum. The old opera house, for 20 years the National Assembly Building, was converted to a national theatre. The University of Saigon was reorganized to form the University of Ho Chi Minh City. Tan Son Nhut Airport has regularly scheduled flights by Air Vietnam to other domestic urban centers and by Air France to Paris [5].

Today the Vietnamese economy is booming. Vietnam is becoming more and more prosperous. Tourism is an important industry in Vietnam. Furthermore, a stock exchange opened in Vietnam in 2000. Vietnam launched its first satellite in 2008. In 2020, the population of Vietnam had grown to 97 million from 28 million in 65 years.

3. Findings

3.1. National Academy of Sciences (NAS) 1974 Assessment of the Impacts of Agent Blue Spraying in Southern Vietnam on the Food Supply, Environment and Human Health

National Academy of Sciences (NAS) PL 91-441. A NAS study was authorized

by an Act of Congress, Public Law 91-441, Fiscal Year 1971 Military Procurement Authorization Act Section 506-9c. Secretary of Defense was required to make arrangements with the NAS to do a comprehensive study and investigate: (1) physiological and ecological dangers in inherent use of defoliation program by Department of Defense in South Vietnam, the NAS [9] study started in September 1971 to September 1973. NAS scientists spent 1500 scientist days working in Vietnam during the Vietnam War and found it an impossible to determine whether arsenic found in the rice paddy soils was from the herbicide spraying of Agent Blue, from other anthropic sources, or was present naturally in the soil prior to the spraying [1].

The NAS over flight on January 27, 1972 of the Song-Re Valley, Quang-Nyai Province of an area sprayed with Agent Blue on August 9, 1970 found that rice fields and vegetable plots appeared normal from the low flying aircraft. NAS [9] analyses of small number of samples of fish, rice, shellfish, worms, soils and water collected near a community in Rung Sat, which had Agent Blue spray missions between 1964 and 1969, found the arsenic levels within the normal ranges.

NAS scientists studied the effects of Agent Blue on settlements by interviewing the villagers and reported their findings, in a report entitled “Effects of Herbicides on Humans” to NAS [9]. Human reactions to military spraying of tactical herbicides were documented. Herbicide spraying, including Agent Blue, resulted in the displacement of people from their rural homes into government sponsored villages as part of President Diem government’s “strategic hamlet” policy or urbanization as a result of the rural Vietnamese movement into the slums of Saigon and other larger cities. Only one of 18 rural areas increased in population and settlement during the 1960s. After spraying of tactical herbicides and subsequent burning of crops, individuals interviewed in every community reported on who became ill or died after the spraying, or as a result of consuming herbicide-treated food plants or drinking contaminated water. The NAS [9] report was translated into Vietnamese for the locals to read. Vietnamese had to live with the consequences and had to undertake remedial action. Financial and technical support was from the U.S. (funds, and training for Vietnamese workers, lent professional and technical personnel and supplied equipment).

U.S. and Vietnam public concerns:

1) Did the extensive use of tactical herbicides, including Agent Blue, modify the environment of Vietnam beyond the point of recovery? Agent Blue did not raise the arsenic levels in the groundwater above the 1970s drinking water standards [9]. However, during the next 50 years, hotspots found in areas sprayed with herbicides containing dioxin (TCDD) (all of the tactical herbicides except Agent Blue and Agent White contained dioxin or TCDD) did not recover naturally and DOD cleanup was required at Da Nang, Bien Hoa Air Force bases and other dioxin hotspots in South Vietnam. 2) Damage to crops and forest caused a major economic loss. Was there evidence of a correlation between exposure to herbicides and congenital malformations, human reproductive failures, and genetic damage? There were many spikes in the arsenic levels (above WHO stan-

dard) in the Mekong Delta groundwater. Arsenic was bio-accumulated in the Vietnamese as a result of elevated arsenic levels in the drinking water and food supply. Medical evidence collected from U.S. veterans and Vietnamese and their offspring during the next 50 years suggests there was significant genetic damage. Meanwhile, the effects of herbicide damage were: 1) the loss of potential food crop production at a stage before maturity and when it became economically valuable, and 2) the loss of commercial products such as grain, timber, fruit, seedlings and seeds required to maintain food production.

For the last 46 years, the NAS [9] Part A: Summary and Conclusion report appears to have been the “*final word*” on the fate of Agent Blue and its active component cacodylic acid. Cacodylic acid breaks down to arsenic in the soil and thought to bind tightly as arsenate (+5) to soil compounds. Olson and Cihacek [1] explained that the arsenic exists in four forms including two water soluble forms arsenite (+3) and arsenate (+5). These two water soluble arsenic salts, and much of the water soluble arsenic were not tightly bound and leached from the rice paddy and root zone into the Mekong Delta or Central Highland groundwater potentially contaminating the groundwater. The arsenic rich groundwater (from natural and anthropic sources) after 1975 pumped back to the surface by hundreds of thousands of tube wells. The water was used for rice paddies, shrimp ponds and to meet the drinking water and household water needs of 15 million Vietnamese living on the Mekong Delta and in the Central Highlands [1].

The National Academy of Sciences Part A: Summary and Conclusions report [9] states: “*Cacodylic acid, the active component in Agent Blue, is a non-selective herbicide killing a wide variety of herbaceous plants. It is a non-volatile, highly soluble organic compound which is broken down in soil, mostly to inorganic arsenate bound as insoluble compounds which also exist naturally in the soil.*”

“*Acute and chronic toxicity studies in a variety of animals indicates a low to medium toxicity rating. No teratological studies, nor toxicity studies in man seem to have been reported.*”

While the Merry Band of Retirees research and writing team and the author have great respect for the National Academy of Sciences and their field work and research in South Vietnam, its scope was limited. The NAS study (1971-1972) was conducted after President Nixon ordered the stop of herbicide spraying and completed just before he ordered, in January, 1973, the withdrawal of soldiers from the American Vietnam War. Furthermore, the study was conducted mostly from the air due to the unstable political environment on the ground. This gave little chance for scientist boots on the ground. It is now time for a fresh look. Olson and Cihacek [1] findings and a re-assessment of the fate of Agent Blue, cacodylic acid, and arsenic including both water soluble and inorganic arsenate and arsenite makes this clear. In addition, there has been recent research [10] studying the effects of feeding chickens organic arsenic (non-toxic) supplements and their ability to convert it into inorganic arsenic (toxic Group-A carcinogen). As a result of these findings the use of organic rich chicken feed was banned in

the United States. The feed had been used to make chickens more marketable (plumper, redder and prevent certain chicken diseases). Arsenic is a heavy metal and thought to be a carcinogen and dangerous.

3.2. Saigon River Pathway between the Ho Chi Minh Trail in Cambodia and Saigon

The North Vietnamese Army (NVA) utilized the Ho Chi Minh Trail and Saigon River Valley to launch attacks on Saigon. Supplies and forces came through from the end of the trail in Cambodia via the Saigon River Valley to staging areas on the edge of Saigon. The headwaters of the Saigon River near Phum Daung, Cambodia were close to the southern section of the Ho Chi Minh Trail and the upland topography and relief was relatively flat which made it easier to traverse the watershed boundary and ridge between the Mekong and Saigon watersheds. Thus the Saigon River Valley was a natural pathway into Saigon. Because the US forces controlled the Saigon River it was not used to transport NVA soldiers. However, the river and the city of Saigon were vulnerable to attack from both sides of the Saigon River Valley (invasion pathways). The wood lots located on the river's floodplain soils provided considerable tropical forest, a natural cover, along the river banks. In addition, protection by the extensive network of soil tunnels enabled the NVA to successfully advance to staging areas to attack Saigon.

3.3. Boi Loi Woods

One of the most secure NVA and VC, the guerilla military branch of the National Liberation Front, base areas, in late 1964, was Boi Loi Woods located 60 km northwest of Saigon. The Woods were located on both the west and east sides of the Saigon River approximately 10 km north of Ho Bo Woods (**Figure 12**). Before the Republic of Vietnam (RV) could defeat the NVA and VC base areas (**Figure 13**) had to be cleared. However, the RV soldiers were either unwilling or unable to undertake the long and costly job of clearing and holding Boi Loi Woods by mounting a conventional ground operation. The US military sought to substitute a technological solution for manpower. The Operation code name was "Sherwood Forest" [11]. Defoliants were used, probably Agent Orange or Agent Purple, to remove the leaves from the trees and later the forest was burned to deny the NVA and VC its use as a hiding place. In the past, such defoliation requests were denied by Military Assistance Compound Vietnam (MACV). However, with the US militaries expanding involvement and armed with a new tactical herbicide weapon, Agent Orange, the December 3, 1964 RV request was approved by MACV. The 7400 ha Boi Loi Woods was thought to be home to a NVA regiment, two village guerrilla units and about 40 ha of food crops. The RV had abandoned its last outpost in the Boi Loi Woods in October of 1964. The RV military tried to get the Vietnamese to leave the NVA controlled area by dropping leaflets and using loudspeakers. The Boi Loi Woods had 6000 Vietnamese living in the targeted area. About 4000 Vietnamese lived in three hamlets and

2000 lived scattered throughout the forest. These Vietnamese lead a difficult life of farming, land clearing for cultivation and cutting of firewood.

U.S. General Westmoreland, MACV Commander, directed his staff to conduct a feasibility study on burning Boi Loi Woods. He received conflicting advice. Some advisors claimed that the forest consisting of non-coniferous broad-leaf evergreens, unlike pines, contained low levels of oleoresin. They concluded without the oil-held resins, the trees would not support a self-sustaining forest fire and any attempt would probably end in failure. Later a revised defoliation request for the Boi Loi Woods area burn was approved. The final operations plan called for preparatory bombings before Ranch Hand flew its defoliation sorties. From January 18-20th (1965) the US and RV Air Forces dropped over 395

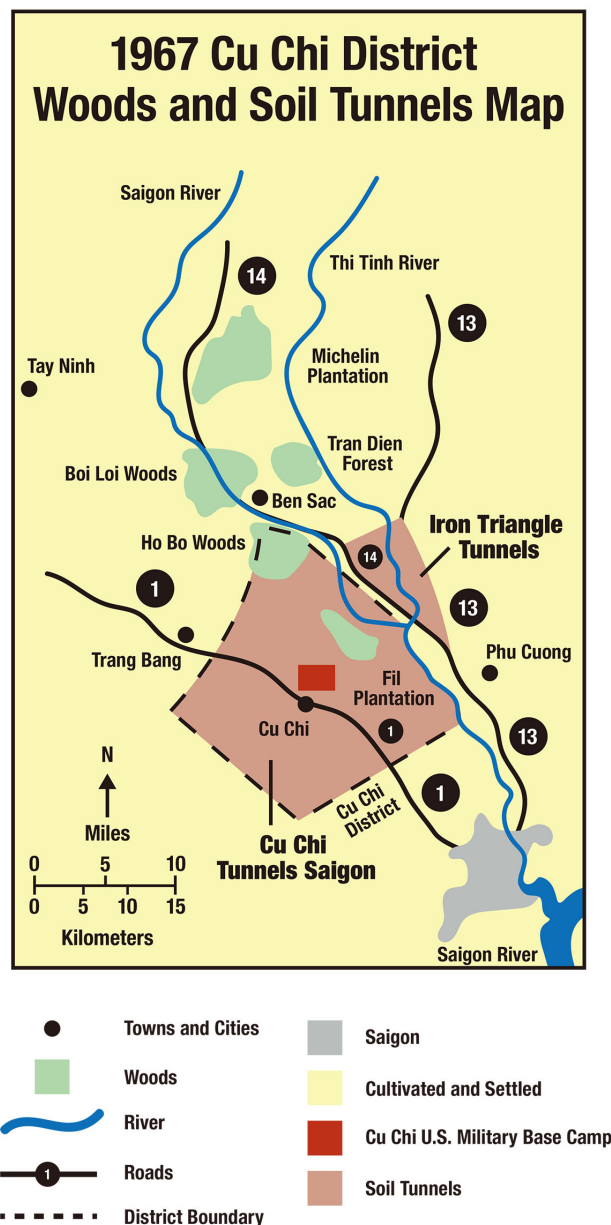


Figure 12. New Bo Ho Woods and Boi Loi Woods maps.

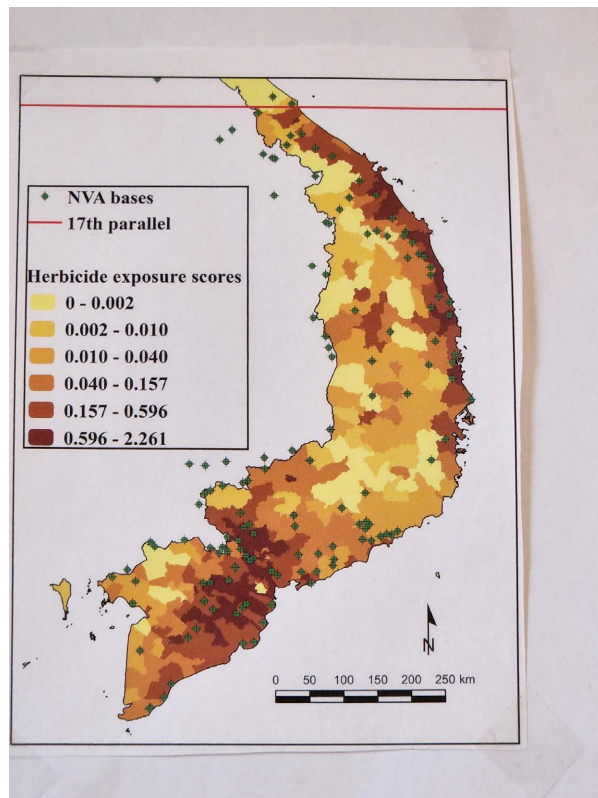


Figure 13. Distribution of herbicide exposure scores and location of North Vietnamese Army bases in Southern Vietnam. The modified figure shows the distribution of herbicide exposure scores and locations of NVA bases.

tons of bombs on enemy units stationed in the Woods. Riot gas was dropped on the hamlets and in the defoliation target area to add to the occupant's incentive to leave the NVA and VC controlled area. From January 22 through February 18, Operation Rand Hand aircraft delivered 314,000 liters of tactical herbicides, mostly Agent Orange for defoliation and Agent Blue to destroy the food crops. The 2nd Air Division attempted to resurrect the idea of burning the defoliated forest on March 12, 1965 [11]. This time the plan was approved and the operation took place on March 31, 1965. Ignition did occur as a result of the use of flares, napalm, white phosphorus, diesel fuel (in drums) and incendiaries. However, on April 1, 1965, the start of the monsoon season, thunderstorms moved through the area and extinguished the fires. In spite of the extensive effort to start a self-sustaining forest fire, the military's attempt to burn the Boi Loi Woods was judged a failure.

3.4. Ho Bo Woods

Ho Bo woods (Figure 12) are located 50 km northwest of Ho Chi Minh City in Binh Duong Providence approximately 12 km northwest of Vietnam War Soil Tunnels and Memorial Park at Cu Chi. The Ho Bo Woods is 20 km north of village of Cu Chi and 4 km to the west of the Saigon River and the Iron Triangle

soil tunnel area. The Woods consist of rubber plantations, sparse woods, and open rice paddies with some large dikes up to 2 m high. The forests were used by the NVA and VC as a base camp during the Vietnam War. The effectiveness for the NVA and VC of the cover and protection provided by the improvements in the wood was demonstrated in one engagement of numerous fought in valley. During Operation Circle Pines, 29 March to 5 April 1966, the 1st Battalion, 5th Infantry Regiment attacked the woods. They discovered that the NVA and VC had built extensive bunkers and tunnels systems, some soil tunnels were three or four levels deep (Figure 14) [12]. On 19 July 1966 the 1st Platoon, Company A, 1st Battalion of the 27th Infantry Regiment 25th Infantry was dropped into a landing zone in the woods and were met by sniper fire. Two additional platoons were dropped into the landing zone in the Ho Bo Woods and a nearby landing zone. They too were engaged by NVA and VC fire. Eventually, the 1st Platoon was extracted under fire. The U.S. Army losses were 25 killed and 24 wounded. The next day, the 1st Battalion, 5th Mechanized Infantry was sent from Cu Chi Base Camp to recover the bodies of 15 US soldiers that had been left behind in the previous day's battle. The bodies were found neatly lined up but without their weapons and equipment [13]. On 10 June, 2013, the 1/27th Infantry would be awarded a Presidential Unit Citation for its actions on 19 July 1966 [14] [15].

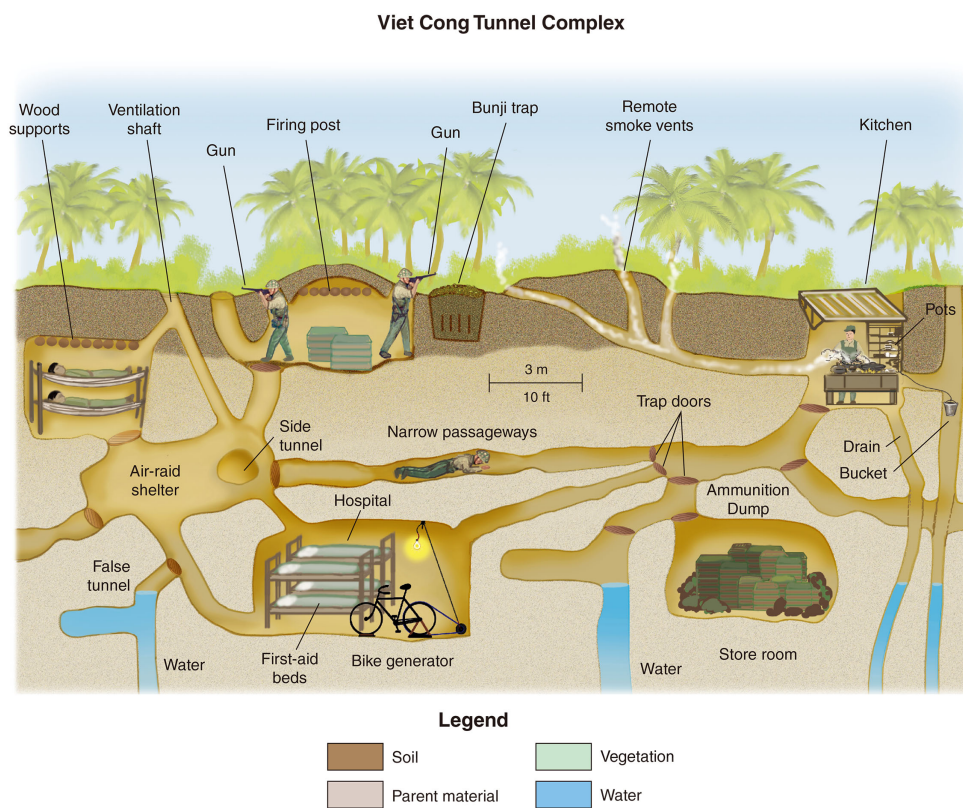


Figure 14. This diagram illustrates a multi-level North Vietnamese Army headquarters at Cu Chi soil tunnel complex used for living quarters and fighting. Diagram was based on displays at Vietnam Memorial at Ben Dinh near Ho Chi Minh City. Reprinted with the permission of the Managing Editor of Open Journal of Soil Science.

After the cease fire in 1973, the Ho Bo area (**Figure 12**) was silent, a flat, almost featureless terrain. “Laced with trenches and tunnels, deeply pocked with ragged lines of bomb craters left by numberless waves of B-52s. Its shattered plantations were over grown with head-high weeds and dense brush. Nearly 10 years of battle littered the defaced Ho Bo Woods and the adjacent countryside” [15]. The tangle of tank-tread marks gave it the appearance of an abandoned armored training ground. Hidden beneath its jungle reclaimed landscape were the bunkers and fighting positions of NVA 101st Regiment and supporting VC (local) battalions, the main force units and principal occupants who had first entered the southern battlefield in 1966 via the Ho Chi Minh Trail (**Figure 16**) from North Vietnam and had been a more or less constant resident of the Tây Ninh-Hậu-Saigon corridor for seven years [15].

3.5. Cu Chi Soil and Iron Triangle Soil Tunnels

The soil tunnels in the Iron Triangle, on the east side of the Saigon River, was used to attack Saigon from the north and the soil tunnels at Cu Chi were used to attack Saigon from the west via the Saigon River Valley. The NVA Tet Offensive plan was not to capture Saigon. The plan was to attack six major targets in Saigon and hold for 48 hours until re-enforcement arrived [6]. Re-enforcements never arrived.

The Cu Chi and Iron Triangle tunnel systems (**Figure 14**) are northwest of Ho Chi Minh City (Saigon) and both tunnel systems were used by NVA and VC to move from Ho Chi Minh Trail (**Figure 16**) at the Vietnam-Cambodian border to Saigon. These adjacent tunnel systems served as a stronghold of NVA and VC (**Figure 15**) during Vietnam War. US soldiers and their vehicles could move easily in this upland area during the monsoon seasons (May to October) [16] so it

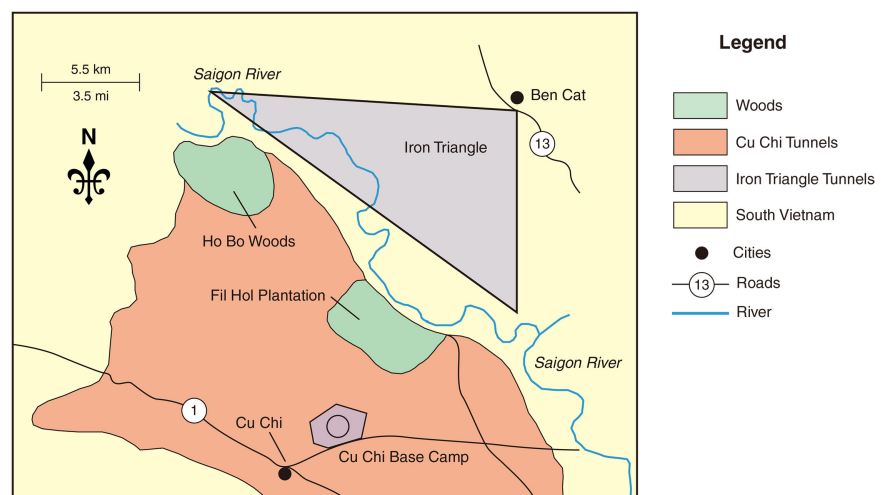


Figure 15. The Cu Chi and Iron Triangle tunnel areas and the Cu Chi US Military base camp located near the Saigon River about 80 km northwest of Saigon (Ho Chi Minh City), Vietnam. The Cu Chi and Iron Triangle tunnels were constructed in Old Alluvium soils which had high concentrations of ferric oxides and clays. Map by Mic Greenberg. Reprinted with permission from Editor of the Open Journal of Soil Science.

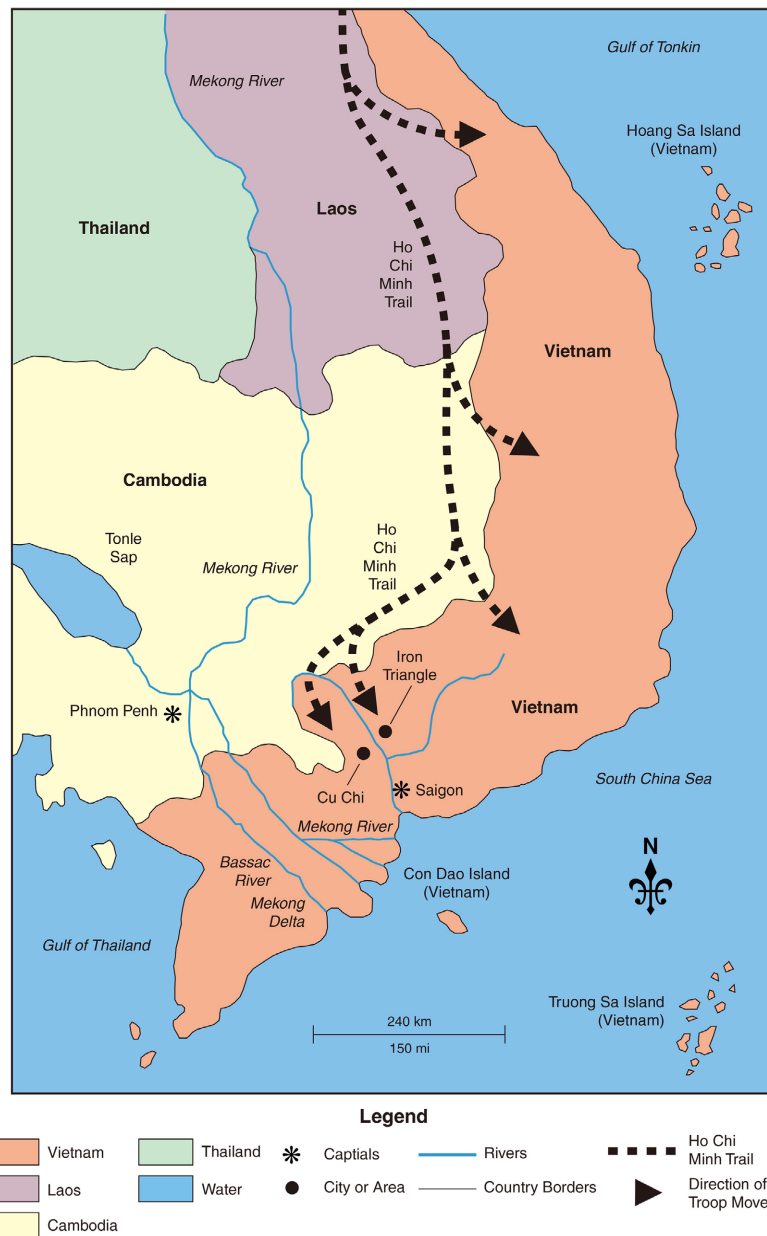


Figure 16. The Ho Chi Minh pathway from North Vietnam, to Laos to Cambodia and into South Vietnam. Map by Mic Greenberg. Reprinted with permission from Editor of the Open Journal of Soil Science.

became a good staging area for the Cu Chi base camp. This was an important clue as to where tunnels could be built; but it took a while before the American forces realized the significance of the link between trafficability, tunnel construction, and soil characteristics [17]. The reason for ease of movement of vehicles relates to the nature and properties of the soils (Ultisols and Oxisols) (Figure 17) on the Old Alluvium terraces [18] [19] [20] [21]. The Old Alluvium terraces were of strategic significance since the tunnels linked to the mainland and the NVA to transport supplies and troops from North Vietnam into Southern Vietnam via the Ho Chi Minh Trail could use the Saigon River. The districts of Cu Chi

and Iron Triangle (**Figure 15**) became the most bombed and defoliated areas in war history [12]. Soils were stripped of their protective vegetative cover (**Figure 18**) and became degraded, disturbed, polluted and eroded [19] [20] was [17] [18]. Detached sediments were transported by rain events into the Saigon River (**Figure 19**), which also became degraded and polluted. The Cu Chi and Iron Triangle tunnels were located in III Corps Tactical Zone (**Figure 15**). The NVA and VC moved underground in response to US artillery, aircraft, bombs, and chemical warfare. The Iron Triangle was 103 km² of jungle and thick undergrowth covering an intricate network of tunnels and bunkers approximately 80 km northwest of Saigon and on the north side of the Saigon River. The Cu Chi area was 40 km northwest of Saigon and on the south side of the Saigon River and about 51 km² in size. The tunnels were between 1.5 m and 20 m deep in the Old Alluvium parent material (**Figure 14**) where the water table was low [18] [21].



Figure 17. The Ho Chi Minh Trail through the mountains and jungles of Vietnam, Laos and Cambodia was a system of trails and paths controlled by the Democratic Republic of Vietnam (1959-1975) used for transporting food, military equipment and North Vietnamese Army soldiers into southern Vietnam during the Vietnam War.



Figure 18. Agent Orange and other color-coded herbicides were sprayed by low flying aircraft over the Vietnam jungle and rural landscapes. Most these herbicides had short-half lives of hours, days and a few weeks; and vegetation regrowth required additional applications. Picture taken by US Army Flight Operations Specialist 4 John Crivello in 1969. Reprinted with permission from Editor of Open Journal of Soil Science.



Figure 19. With the loss of stream bank vegetation in 2016, bank erosion looks similar to the soil erosion that occurred in the 1960s after stream bank defoliation.

At the peak of the Vietnam War, the network of tunnels in the Iron Triangle and Cu Chi linked NVA support bases over a distance of some 150 km, from the Ho Chi Minh Trail and Cambodian border to the outskirts Saigon [22]. In the early 1960s, the United States escalated its military presence in Vietnam in support of RV, a non-Communist regime in South Vietnam. The NVA gradually expanded the tunnels [22]. Tunnels frequently were dug by hand in Old Alluvium terraces [19] (Figure 20), and only a short distance at a time. Four major efforts were made by the US Army to locate and destroy these tunnels. These included Operation Crimp, a search and destroy mission, which began in 1966, and a geological and soil survey approach was used to detect NVA and VC tunnels. Later in 1967, U S Army General William Westmoreland tried launching a larger assault on Cu Chi and the Iron Triangle areas (Figure 15). The operation called Operation Cedar Falls was an expanded version of Operation Crimp. Finally, in 1969, B-52s started bombing the Cu Chi and Iron Triangle areas and destroyed many of the tunnels. However, not before the tunnels had proven very effective in 1960s at hiding and protecting the RVA during US occupation and bombing of the area. The nature and properties of the Old Alluvium soils were key to the soil tunnels being so resilient.

3.6. Port of Ho Chi Minh City

Ho Chi Minh City (Figure 21) port (port code: VNsgn), also known as Saigon Port (Figure 2), is the largest port in the southern of Vietnam. Located in Ho Chi Minh City (Figure 22) on the west bank of Song Sai Gon, it is accessed via two channels of the Saigon and Soi-Rap Rivers [4]. The Saigon River is navigable by vessels up to LOA 220 m, draught 11.0 m, and deadweight 36,000 tn, while the Soi-Rap Rivers is limited to vessels with a maximum draught of 6.7 m. This port handles approximately 12,000,000 tn of cargo and 1,200,000 TEU annually.

3.7. Bien Hoa Air Force Base

The fate of dioxin in the environment can best be determined by studying the movement of dioxin at hot spots including Thailand (Figure 23) and Vietnam (Figure 24) Air Force bases beyond the perimeter fences. The most contaminated site appears to be Bien Hoa Air Force base just 30 km northeast east of Ho Chi Minh City with a population of over 800,000 living in an adjacent Bien Hoa City.



Figure 20. As the Mekong and Bassac rivers flow south through the Mekong Delta they water a diverse landscape bringing freshwater to the lowlands around the flooded mountains; to saltwater river regions in the wet season; and sediment loads that replenish the fertility of rice fields. Coastal dunes along the South China Seas are high points in the landscape. Farmers in the uplands of Vietnam grow coffee, rubber, fruit and nut trees. Map by Mic Greenberg. Reprinted with permission from Editor of the Open Journal of Environmental Protection.



Figure 21. A view of the Ho Chi Minh City skyline with the Vietnam government building and the Saigon River in the background.



Figure 22. Thu Thiem tunnel in Ho Chi Minh City east of the Saigon River.

The 10 US Air Force bases of Vietnam were the primary hotspots (**Figure 24**). A 870-page report was funded by US AID in 2014 or approximately 41 years after the Vietnam War ending and 43 years after the stock pile of Agent Orange was removed from Vietnam. The tactical herbicides were shipped to Johnston Island for incineration (**Figure 5**) 43 years before the study. The title of the 2016 report was “Environmental Assessment of Dioxin Contamination at Bien Hoa Air Force Base” [23]. USAID contracted with CDM International and Hatfield Consultants to address the Requirements of Title 22 of US Code of CFR, Part 216.

The scope of the work included addressing potential adverse health related environmental and social issues [24] [25] [26] associated with implementing remediation activities of dioxin contaminated soil and sediment to Government of

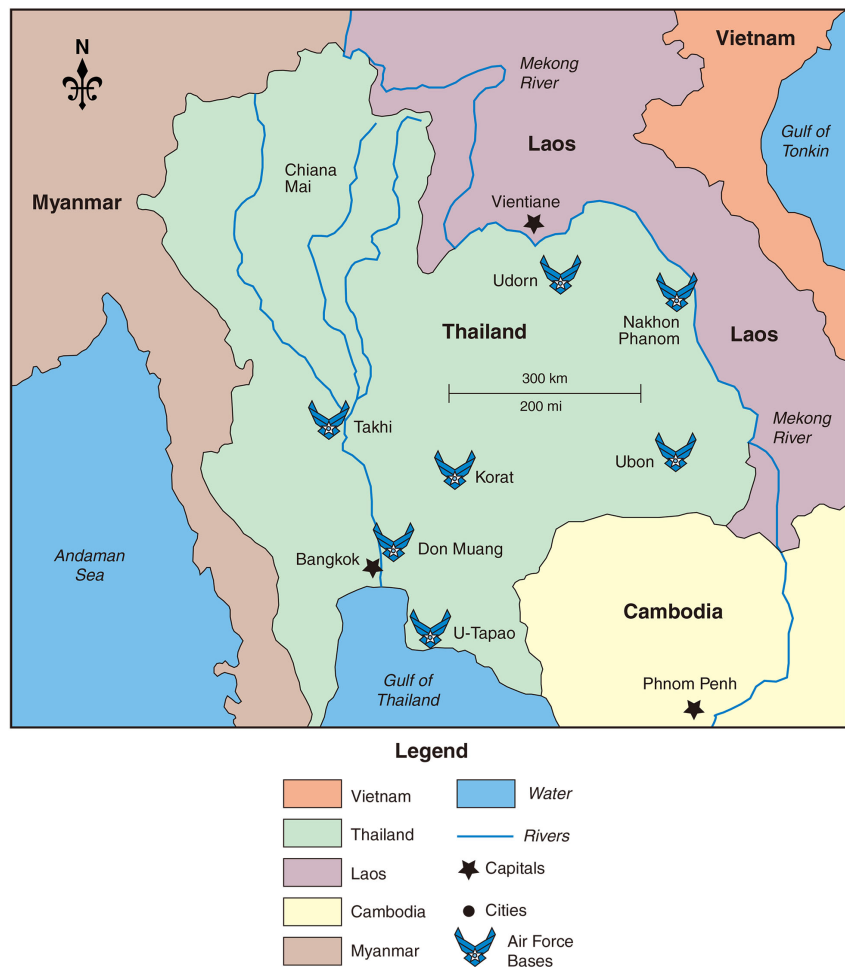


Figure 23. There are seven hotspot airbases in Thailand with dioxin-contaminated soils where the dioxin contaminated herbicides were stored and handled. Agent Orange was sealed in 208 liter barrels that were shipped to Vietnam airbases for use by C-123 aircraft during the Vietnam War. Map by Mic Greenberg. Reprinted with permission from Editor of Open Journal of Soil Science.

Vietnam (GVN) standards for remediation. Supplemental investigations, sampling and analysis, the site conceptual model, and evaluation of remediation alternatives, reported environmental consequences of implementing remediation, consequences to social resources if they are indirectly affected through changes in physical and natural environment from implementing remediation approaches for environmental mitigation and monitoring and resettlement.

3.8. Mega Hotspot: Bien Hoa Air Force Base Dioxin TCDD Contamination

Bien Hoa Air Force base is well-known as the dioxin mega-hotspot in Vietnam (Figures 24-26). There were 11 previous studies characterizing the dioxin contamination at Bien Hoa Air Force base between 1990 and 2015. The USAID [23] funded study was the 12th and the most comprehensive final report. The study found multiple areas of contamination on the Air Force base and outside the pe-

rimeter fence. After examination the historical soil and sediment sampling efforts it was evident that dioxin contaminated soil and sediment still existed after 45 years as a result of storage, handling, leakage, spills and disposal of Agent Orange and other tactical herbicides. When released, these ionic materials, which combined with water molecules (hydrolysis), which were attached to the organic fractions of Air Force base soils and sediments, go in solution [27]. Contaminated surface soils and sediments have spread from the original sites by spills, transport and release mechanisms including water and wind erosion, runoff, transport, deposition erosion, excavation and movement of the contaminated soil materials.



Figure 24. There are 10 Agent Orange hotspot airbases in Vietnam with dioxin-contaminated soils and sediments. These US airbases handled most of the Agent Orange coming into Vietnam and were the collection sites for shipping of Agent Orange for at-sea incineration. Map by Mic Greenberg. Reprinted with permission from Editor of Open Journal of Soil Science.



Figure 25. A cement perimeter fence at the Bien Hoa Air Force base. The jungle vegetation was similar to the vegetation surrounding all the Vietnam Air Force bases in the 1960s, were sprayed with tactical herbicides.



Figure 26. A side gate at the Bien Hoa Air Force base near the Saigon River.

Soil samples were collected from 76 different Bien Hoa Air Force base and surrounding areas during field sampling in 2014 and 2015, almost 45 years after Agent Orange use in Vietnam. There were 1300 composited soil and sediment samples for potential dioxin analysis and 100 samples for soil, sediment, ground water and biota for various chemical and physical property testing. The USAID funded project was the largest dioxin sampling program undertaken in Vietnam.

Approximately 550 of 1300 composite dioxin soil and sediment samples were compared to Ministry of National Defense standards and were within range based on currently and likely future lands use. However, the other 750 soil and sediment samples suggest areas that were still contaminated, both known and unknown, and between 408,500 and 495,300 m³ of contaminated soils (75%) and

sediment (25%) were found both on and off the Bien Hoa Air Force base.

Dioxin contaminated soil and sediment on and off Bien Hoa airbase was used to identify the main food supply pathways which were the consumption of fish and other aquatic organisms. The raising, harvesting and transport of contaminated fish and other aquatic animals both inside and outside the Airbase resulted in high potential for dioxin contamination even after 45 years [28]. All but one of the fish, tested for dioxin, were contaminated. Banning the sale of fish have not been ineffective. Controlling the raising, harvesting and transport of contaminated fish and other aquatic animals have been also been ineffective. Some water samples contained arsenic at above 10 parts per quadrillion (ppq) standard. The only other soil or sediment contaminant found was arsenic [29]. The only other soil or sediment contaminant found was arsenic. Drinking water samples and off site samples were found tested and found to be safe.

3.9. Bien Hoa Air Force Base

The most dioxin and arsenic contaminated site on the Saigon River is Bien Hoa Air Force base just 30 km northeast of Ho Chi Minh City. The adjacent Bien Hoa City has a population of over 800,000. Tactical herbicides including Agent Blue was shipped via the Saigon River to Tan Son Nhut Air Force base (**Figure 3**) on the edge of Saigon from 1962 to 1965 and later transported to Bien Hoa Air Base (**Figure 4**) from 1965 to 1971 for distribution to other US military bases in Southern Vietnam. In 1972 the remaining stockpiles of the tactical herbicides at the US military bases in Vietnam were transported back to Bien Hoa Air Base, re-barreled and shipped to Johnston Island (**Figure 5**) in the Pacific for disposal by incineration [1].

Hatfield Consultants collected 3000 biological and soil samples at Bien Hoa Air Force base. Many samples were tested in 2014 and 2015 for dioxin. These test results still remained high after 50 years. Hatfield Consultants prepared an 870-page report for US AID [23] which was used by DOD to provide 330 million dollars to the Vietnam government for clean-up of Bien Hoa Air Force base.

Hatfield Consults were apparently not aware that Bien Hoa Air Force base was also the primary distribution point for all the Agent Blue (in liquid form) shipped to South Vietnam after the US joined the American-Vietnam War in 1965. After President Nixon stopped the spraying of all tactical herbicides in 1971, Bien Hoa Air Force base become the primary collection point for residual tactical herbicides including Agent Blue. Agent Blue barrels were transported from the other US military bases back to Bien Hoa for repackaging and shipped to Johnston Island in the Pacific Ocean. The 3000 biological and soil samples collected at Bien Hoa Air Force base should have been test for arsenic in addition to dioxin.

Hatfield Consultants were contacted to see if they had any residual samples remaining and if they still existed could they be tested for arsenic. The Hatfield Consultants did a lot baseline soil sampling and testing at the start of a major

environmental sampling project. The EPA standard for arsenic in soils is 0.39 mg/kg (ppm). The published base line data [23] for 22 soil samples and all the soil samples were collected in 2014-2015, and before dioxin TCDD cleanup disturbed the site, exceeded the EPA standard. The arsenic content ranged from 3.1 to 63 mg/kg (ppm) or 9 to 161 times above the EPA standard. If Hatfield Consults have sufficient residual soil samples left, these samples could be test to verify the previous arsenic baseline findings.

The impact of incineration of Bien Hoa soil samples, to dispose of the dioxin, was effective in treating the As rich Bien Hoa Air Force base soils. The literature suggests that the arsenic would not be released as arsine (AsH_3) gas (toxic) but As or would be concentrated in the incinerator bottom ash as arsenate which could be reduced under aerobic conditions to arsenite. The arsenic would be oxidized to most likely As^{+5} in a well oxidized system and fall to the bottom in the ash as some combined compound. However, As metal can sublime at 615°C (boiling point) into a vapor form (but this is not arsine gas, it is a metallic vapor) so it can be emitted to the atmosphere. But it generally further oxidized to As^{+3} or As^{+5} . Burying the bottom ash with clean soil will help keep it out of the immediate environment but the As compounds in the ash would still be subject to leaching during the monsoon season. Since most of the ash from the incinerator was returned to the Bien Hoa Air Force base original contaminated sites and covered with “clean soil”, this raises an important question. If the arsenic is concentrated in the bottom ash as water-soluble arsenite or arsenate, could it be leached back into the groundwater during the monsoon season? The answer appears to be a yes unless a water impermeable barrier was placed below the buried ash.

3.10. Tan Son Nhut AFB

Tan Son Nhut Airport was built by the French in 1930s when the French Colonial government of Indochina constructed a small unpaved airport, known as Tan Son Nhut Airfield, in the village of Tan Son Nhut near the city of Saigon and served as Saigon’s commercial airport. Tan Son Nhut Air Base (1955-1975) was a Republic of Vietnam Air Force Base (RVNAF). The United States used it as a major base during the Vietnam War (1959-1975). The US Army, Navy and Marine units were stationed there. Following the Fall of Saigon, it was taken over as a Vietnam Peoples’ Air Force (VPAF) facility and is no longer in use [6]. It is a Vietnam War Museum (Figure 27) and (Figure 28) with the lawn covered with aircraft and the museum dedicated to Ho Chi Minh with no information related to the Tan Son Nhut airport use from 1930 to 1975. The fate of the RV and US military records is unclear but they may have been transferred to the Vietnam War archive no. 2 in Ho Chi Minh City. The Tan Son Nhat International Airport is located a few km’s away from the original site and is now a major Vietnamese civil airport for domestic flights. Between 1968 and 1974, Tan Son Nhut Airport was one of the busiest military airbases in the world.



Figure 27. Tan Son Nhut Air Force base museum yard with a Vietnam War fight plane.



Figure 28. Tan Son Nhut Air Force base museum yard with a Vietnam War helicopter.

The first recorded use of Agent Blue by the US Air Force was in November of 1962 [1]. Approximately 3.2 million liters of Agent Blue (468,008 kg As) previously sprayed or dumped by the RV military, with the support of the US military, during the Khai Huang Program [27] [28]. In addition, during the next nine years 4.6 million liters (664,392 kg of As) were sprayed during Operation Ranch Hand missions [1]. The Institute of Medicine [25] estimated a total of 7.8 million liters (1,132,400 kg As) of Agent Blue was applied to southern Vietnam from 1961 to 1971. This total includes both the Agent Blue used in US Air Force Operation Ranch Hand and the Agent Blue used in the RV Khai Huang program [27] [28] which was assisted by the US Air Force, Army and Navy. New studies of US military flight logs suggest an even greater use of Agent Blue; however, the Agent Blue application total of 7.8 million liters (1,132,400 kg As) applied to southern Vietnam, from 1961 to 1971, is the best available documented As total at this time [27] [28].

Agent Blue was first delivered to Port Saigon and transported Tan Son Nhut Air Force Base near Saigon River and used in southern Vietnam in early 1962.

There are records that 42% [1] of all tactical herbicides used before 1965 was the arsenic-based Agent Blue herbicide. The RV government and military with the support of the US Army, US Navy and CIA did not document their spraying and make them available to the media and public [27] [28]. The Mekong Delta region is complex water network. Its wetlands, forest vegetated stream banks, small streams and natural river distributaries of the Mekong River as well as intricate human engineering canals, dykes, and ditches used to produce paddy rice creates a potential environmental sink to trap pollutants.

These drainage systems crossed the entire Mekong Delta region. These drainage waterways were used as a navigation network (Figure 20) and were accessible by non-motorized and motorized boats and floating platoons that were used by locals and militaries. To access and destroy the NVA and VC base camps in the Mekong Delta (Figure 13) and destroy rice food supply would have required the skills of water and land-based military forces including the US Army and US Navy [27]. Because there are not many US Army and US Navy records of Agent Blue spraying in much of the Delta region, it is now impossible to distinguish natural from anthropogenic arsenic spikes in the Delta groundwater. However, Vietnam War Archive no. 2 in Ho Chi Minh City may have copies of the RV herbicide spray records and the Vietnam War historians and scholars need to read these documents and publish their findings. One could surmise that arsenic based Agent Blue herbicide was one of the vegetation management tools available to the RV military, US Army and US Navy and that its use throughout the delta increased the concentration of arsenic in the Mekong Delta groundwater.

During the Vietnam War (1962-1971), herbicides were sprayed by RV and US military forces at an order of magnitude greater than amounts used for domestic weed control [27] [28]. The herbicides were stored and shipped in 208-liter barrels, and named after the colored band painted on each barrel [28]. They were mostly sprayed by RV military, with the support of the US military, over the forests of southern Vietnam to kill crops in order to deprive the NVA troops of food, and to remove the vegetation cover used for concealment [11], making ambushes more difficult [24]. RV and US Army soldiers used mortars and grenades in an attempted to destroy rice paddies and rice stocks, but rice grains were very durable and not easily destroyed [11] [29]. Soon, the “rice-killing operations” became more sophisticated. Rubber or plastic bladders were dropped directly into rice paddies, bursting on impact and releasing toxic herbicides including Agent Blue, and barrels of herbicides were also dropped into the water irrigating rice paddies, polluting rivers and poisoning the soil and Vietnamese for many years [27] [28]. Agent Blue was used as a contact herbicide in Southern Vietnam for rapid defoliation, grassy plant control and rice destruction. Agent Blue was the agent of choice for the destruction of rice crops by the RV military with the support of the US Army and Navy [11] [29].

More than 4.6 million liters of Agent Blue (also known as Phytar 560-G), were dispensed in the DOD herbicide program, according to US Air Force Operation Ranch Hand herbicide records [27] and 3.2 million liters of Agent Blue was

sprayed as part of Khai Huang program [28]. Agent Blue, applied by the RV military, US Navy and US Army worked rapidly to defoliate or desiccate a wide variety of plant species of grasses and grains. It works by uncoupling phosphorylation in plants. It was used in situations requiring rapid defoliation, causing browning or discoloration within one day, with maximum desiccation and leaf fall occurring within two to four weeks [28]. By starving rice plants of moisture, the enemy and millions of rice-growing villagers could be denied their most basic food source. This formed an essential part of the RV and U.S. government's "rice-killing operations". The term "Blue" was first applied to cacodylic acid in powder form that was mixed with water. Cacodylic acid is a highly soluble organic arsenic compound that readily breaks down in soil [27]. It is considered to have very low direct toxicity for mammals.

The original commercial liquid form of Agent Blue was so common and so profitable that it was among 10 toxic insecticides, fungicides and herbicides partially deregulated by the US Environmental Protection Agency (EPA) in February 2004, and specific limits on toxic residues in meat, milk, poultry and eggs were removed [1] [27] [28]. However, in 2009, the U.S. Environmental Protection Agency issued a cancellation order to eliminate and phase-out the use of organic arsenical pesticides by 2013, with one exception – monosodium methanearsonate (MSMA), a broadleaf weed herbicide for use in defoliation of cotton. Small amounts of cacodylic acid (or disodium methanearsonate) were historically applied as herbicides in cotton fields, golf courses, backyards and other areas, but its use is now prohibited under the USEPA 2009 organic arsenical product cancellation. Other organic arsenicals (e.g. roxarsone, arsanilic acid and its derivatives) were used as feed additives for poultry and swine to increase the rate of weight gain, improve feed efficiencies, pigmentation, and to treat and prevent disease.

The highest exposure in herbicide manufacturing was usually found at the mixing, screening, drying, bagging, and drum-filling operations (Figure 29). During these operations, reported arsenic concentrations in air ranged from 0.5 - 45 mg/m³. The World Health Organization (WHO) guideline for the safety limit of arsenic is 10 µg/L in drinking water [28]. In Vietnam, the legal arsenic concentration limit is five times higher than in the WHO guidelines. The problems were caused largely by the "tube wells", which draw water from depths of between approximately 10 and 40 m. The wells, designed to provide safe drinking water by avoiding polluted surface waters, inadvertently tapped into arsenic laden underground aquifers [27]. The use of Agent Blue during the Vietnam War and other industrial developments caused the levels of bio-available arsenicals to spike dangerously [27]. The arsenic contamination levels varied from 1 - 3050 µg/L, with an average arsenic concentration of 159 µg/L in rural groundwater samples from private small-scale tube wells. In a highly affected rural area, the groundwater used directly as drinking water had an average concentration of 430 µg/L [27] [28]. Analysis of raw groundwater pumped from the lower aquifer for the Hanoi water supply yielded arsenic levels of 240 - 320 µg/L in three of eight water treatment plants and 37 - 82 µg/L in another five plants. Aeration and sand filtration

applied in the treatment plants to remove iron lowered the As concentrations to 25 - 91 $\mu\text{g/L}$, but 50% remained above the Vietnamese standard of 50 $\mu\text{g/L}$.

Agent Blue affects plants by causing them to dry out (**Figure 30**). Because rice is highly dependent on water to live, using Agent Blue on these paddies can destroy an entire field and leave it unsuitable for further planting. This is why Agent Blue was also used where food was not a factor, but the foliage was. The Communist insurgents (NVA and VC) had an advantage while fighting in southern Vietnam because they were used to the abundance of plant life on the battlefield. The U.S. found themselves at a disadvantage and based on the precedent set by the British in Malaya [23] decided that the best retaliation would be to take the enemy's advantage away from them by removing their cover. Along roads, canals, railroads, and other transportation networks, Ranch Hand cleared several hundred meters using the herbicides to make ambushes more difficult for their enemies. In Laos, the herbicide removed the jungle canopy from the roads and trails (**Figure 18**) used for infiltrating men and supplies, making them more vulnerable to attack from the air.



Figure 29. Repacking herbicide barrels and recovering buried barrels leaking into the ground. Reprinted with permission from Editor of the Open Journal of Soil Science.



Figure 30. Rice residue in dried out fields similar to the rice paddies sprayed with Agent Blue in the 1960s and 1970s. Reprinted with permission from Editor of the Open Journal of Soil Science.

Although the acute and chronic effects of organic arsenicals are not as severe as those of inorganic arsenicals, organic arsenicals still have a significant impact on human health because they degrade to inorganic species in the environment. Additional studies may uncover more currently unproven or unknown health effects. The present public health concern to human exposure to arsenic was linked with the consumption of arsenic-rich drinking water. This is a result of the alluvial sediments on the floodplains being rich in arsenic [1] [27] [28]. Current epidemiological and experimental studies have attempted to elucidate the specific mechanism of arsenic carcinogenicity. This has led to the question of whether it is an epigenetic carcinogen. Due to the complexity of the mechanism of toxicity on the molecular level, and because of genetic polymorphism in the human population, both options continue to remain plausible [1]. However, recent studies show that the trivalent organic arsenicals that are metabolic products of inorganic arsenic could possibly be more toxic than the parent compound [27] [28]. The mechanism of arsenic includes inhibition and oxidative stress, as well as immune, endocrine, and epigenetic effects.

Analytical determination of arsenic poisoning may be made by examining arsenic levels in human urine, hair and toenails. Kapaj and Pederson [30] found communities and individuals relying, on groundwater sources for drinking water, need to measure arsenic levels to ensure their water supplies are safe. Communities with arsenic levels greater than 5 ug/L in drinking water should consider a program to document arsenic levels [31].

Since arsenic poisoning of humans can occur by gradual accumulation of small doses until lethal levels are reached, the use of Agent Blue (during the Vietnam War) and other organic arsenicals pose a long-term danger [31]. Neurological symptoms are usually more frequent than gastrointestinal effects over prolonged exposure of organic arsenicals. Cacodylic acid may cause paresthesia and/or weakness in the hands and feet [32]. Repeated skin contact may cause hyper pigmentation and keratosis. Malnourished people are more susceptible to arsenic-related skin lesions [32] [33].

3.11. Vietnam War Archive No. 2—Ho Chi Minh City

The RV official government records are all stored at the Vietnam War archive number 2 in Ho Chi Minh City (**Figure 31**). The Archive no. 2 staff have indexed and stored these documents in loose-leaf binders. Unfortunately, these documents have not been scanned and stored in electronic files. These records include personal and government correspondence between the President Diem and President Kennedy administrations. This could easily prove that we sent Agent Blue to Southern Vietnam (Tan Son Nhut AFB between 1962 and 1965) at the request of the RV government. The powder was mixed water and then sprayed on the rice crops in the Mekong Delta to eliminate the food supply including rice. In addition, RV and US military sometimes sprayed an area and then burnt the rice crop residue and the smoke adversely affected the villages



Figure 31. The Republic of Vietnam and United States printed correspondence is kept at Vietnam War Archive number 2 in Ho Chi Minh City.

nearby and there are reports in the Vietnam War Archive no. 2 files of when and what happened. Apparently, the US DOD has never had access to these Vietnam War Archive no. 2 files. They could be used to show that Agent Blue was sprayed by the RV military with the assistance of the US military in the Mekong Delta. This could support the Olson and Cihacek calculated number of more than 1 million kg of pure arsenic [1] [27] [28] was applied to southern Vietnam where US military has almost no flight records. Apparently the US military did not want to document flight records or if documented did not want to retain them.

The Vietnamese archive staffs have agreed to accept and preserve the 12 to 16 referred journal articles (Figure 31), four radio podcasts of Mack Payne on Agent Blue, and four Olson lectures on both Agent Orange and Agent Blue, with 360 ppt slides. The Olson exhibit, with almost 500 journal pages to date will be available for future researchers and scholars. While the Olson slide talks and Payne radio podcasts are very important, the Merry Band of Retirees team's refereed journal articles are the mother lode of important information which will be made available to future Vietnamese scholars and historians. The radio podcasts and power point talks are designed to educate the current Vietnamese public including students.

4. Summary and Conclusions

In 1962, the Tan Son Nhut Air Force base on the northern edge of Saigon received the first shipments of Agent Blue, the arsenic based herbicide used to destroy the rice crop. The Tan Son Nhut Air Force base was buried or covered by urbanization and the only building left is the Tan Son Nhut Air Force base museum and horticultural garden and lawn with many aircraft on display in potentially arsenic rich soil.

The most dioxin and arsenic contaminated site on the Saigon River appears to be Bien Hoa Air Force base just 30 km northeast of Ho Chi Minh City with a

population of over 800,000 living in an adjacent Bien Hoa City. The Port of Ho Chi Minh City is the most important river port in Vietnam and Southeast Asia. The river is navigable by ships which draft up to 9 m. Vietnam only became a united country in the 19th century, but was soon affected by French colonialism, internal strife, and then the destruction by American intervention and miscalculation in the Vietnam War. The Vietnam War Archive no. 2 in Ho Chi Minh City houses the correspondence between the RV and the US government related to the Khai Huang program as well as the RV Agent Blue spraying flight records in the Mekong Delta. The Saigon River pathway played a role in modern warfare. The Saigon River Valley was used as a tactical herbicide, invasion, liberation and unification pathway. The Vietnamese nation has survived stormy, troubled times, but their power of character has served well.

5. Recommendations

An effort has been underway, by the Merry Band of Retirees, for more than two years to obtain spray records from the US DOD for all the Agent Blue sprayed on the Mekong Delta to destroy the rice crop during the Vietnam War. DOD has consistently suggested the Agent Blue spraying in the Mekong Delta never happened so there were no records or very few Agent Blue spray records available for the entire 10-year time period (1962-1971) to be found. It is a known fact that the goal was to eliminate the NVA and VC food supply and to implement the Hamlet strategy. Most of the rice was produced in the Mekong Delta, not the central highlands, which does have Operation Ranch Hand Agent Blue spray records. The US government and military records were either not kept or not maintained. The additional RV spray program, from 1962 to 1965, was quite possible. This finding is supported by the mass migration from rural South Vietnam to hamlets or to Saigon slums. However, Vietnam War Archive no. 2 in Ho Chi Minh City may have the spray records of the RV military, assisted by the US Navy, US Army and CIA to implement the hamlet strategy and these records need to be electronically preserved. Vietnamese correspondence between President Diem's administration and the President Kennedy administration is shelved in loose-leaf binders at the Vietnam War Archive number 2 in Ho Chi Minh City (personal observation). Since the binders only have a paper table of contents it will take considerable time and effort to find the key documents. My recommendation is that these documents be electronically scanned to preserve and store the unique correspondence. These include herbicide spray decisions and location applications throughout the Mekong Delta. An international foundation needs to step (such as the Ford Foundation) and fund this project before the spray records are lost for a variety of reasons. After meeting with the archive staff at Vietnam War archive no. 2 -Ho Chi Ming City in October of 2022, I believe the staff there could do this proposed project if appropriately funded. In the meantime, it is rather important that these Republic of Vietnam printed documents be protected, since most of the US spray records for the Mekong Delta,

except for the US Air Force Operation Ranch Hand records, were either not recorded or if recorded not maintained.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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